

Light and Life: The Relationship between Light and Life in the Natural World (PLBio 1130)

Tuesdays and Thursdays 8:40-9:55, 114 Plant Sciences Bldg.

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Office hours: Friday 1 PM- 3 PM

Syllabus (Fall 2026)

Light and Vision: There is more than meets the Eye

August 25. Light, the eye and the mind: Historical introduction to the elements of vision.

August 27

September 1. Geometrical optics and image formation

September 3. Development, anatomy, and physiology of the eye

September 8. Eye color and its inheritance

September 10. Color and color vision

September 15. Animal eyes and the Darwinian theory of the evolution of the human eye

September 17

September 22. Charles Darwin, Samuel Wilberforce, and how we see the color of ants

Light and Energy

September 24. First light: Big bang cosmology

September 29. Production of sunlight and chemical spectroscopy

October 1. Photosynthesis I: Converting radiant energy into chemical energy

October 6. Photosynthesis II: Converting radiant energy into chemical energy

October 8. Chemical History of the Candle: Converting hydrocarbons into light

FALL BREAK October 10-13

October 13. Cellular Respiration: Converting carbohydrate into chemical energy without emitting visible light

Living Light

October 15. Luminescence: Production of light by living organisms

Using Light to Keep Track of Time and Determine Orientation in Space

October 20. Photomorphogenesis in plants

October 22. Melanopsin, circadian rhythms, and wellness in humans

Seeing the Invisible: The Photon

October 27. Ultraviolet light and wellness, ozone layer, vitamins, DNA repair, fluorescence

October 29. Trip to Rare and Manuscript Collection in Kroch Library

November 3. Trip to Rare and Manuscript Collection in Kroch Library

November 5. Plant and animal coloration: Pigments, attraction, camouflage and mimicry

November 10. Plant and animal colorations: Iridescence, sexual attraction and the wave nature of light

November 12. Using the properties of light and pigments to make microscopic organisms, including germs, visible

November 17. Polarized light and bee vision

November 19. Red, blue and purple dyes

November 24. What is light and what is life?

November 1. What is light and what is life? (Calendar due)

Thanksgiving Break November 25-29

December 3. [Braver College Debate](#)

December 7. [Braver College Debate](#)

Final Paper due at scheduled final exam time (???????) Plant Science Building 114

Light and Life Sponsored Events that Promote Free Speech and Critical Thinking

Lecture Notes

My lecture notes are available on Canvas. Scan over them before each lecture—to get a sense of the material that will be covered, the main ideas of the lecture, and the evidence for the main ideas. Read the lecture notes carefully immediately after the lecture to ensure that you understand the main ideas and the evidence for them.

Expectations and Grading:

Calendar: (200 pts). You must pass in a hard copy and an electronic version (pdf).

You can make your calendar using any program you choose. You must take a minimum of 12 photographs (with your cell phone camera) that document various aspects of light and life. You must attach a written description, one paragraph to one page long for each photograph that describes how each photograph documents an important aspect of light and life. Save the calendar and the accompanying documentation as a pdf. You can have your calendar printed on cardstock and bound at the Cornell Print Services (<https://printservices.cornell.edu/>). I want you to have your own hard copy so that you can look at the material for another year. You can turn in a bound hard copy or a collated printed version on normal paper. In either case, you will get it back. I will post the pdfs of your calendar on a class website.

I will make time at the beginning of each class period for people to present and describe a picture that relates to the last lecture. Please email it to me at row1@cornell.edu by 10 PM the night before the lecture.

Dinner Conversations (360 pts). Choose the person who is most interesting to you in each set of lecture notes. For each set of lecture notes, write a one-page script of a dinner conversation between you and that person where you discuss the issue that is most meaningful to you and ask a question. Like any conversation, it may be deep, witty, funny, argumentative, as well as informative. The Socratic dialogues can serve as a model. The Socratic dialogue is a method to stimulate critical thinking through asking and answering questions that test any underlying assumptions. You must pass in **18 conversations** (20 pts each). Each conversation is due at 8 AM in the morning—just before the lecture. These are human conversations and must show your natural intelligence, so do not use ChatGPT or any other AI program to write these conversations. If you do, you will get 0/360 for the dinner conversations.

Pop Quizzes (40 pts). There will also be **2 pop quizzes** (20 pts each) to ensure that you understand and can answer quantitative questions.

Final Paper: (200 pts). This is a creative writing project (approximately 10 pages long or perhaps a music video) in which you use your scientific knowledge and creative writing skills to

communicate to a lay audience the beauty and importance of light and life. For full credit, you must present your project to the class at the time of the scheduled final exam.

Class participation: (200 pts). You will be expected to:

- attend each class and show up on time.
- do the readings (posted on Canvas).
- participate in class discussions, and if you like, draw and present concept maps (<http://cmap.ihmc.us/>).
- solve problems on the board.
- participate in the demonstrations and experiments. You will **not** be required to perform a dissection of a cow eye.
- *send me a jpeg of a photograph attached to an email by 10 pm the night before each lecture.*

Teaching Philosophy

I will unapologetically defend Western Civilization which has made the freedom to do science possible. My teaching philosophy is in line with that used in the Freedom Schools of Mississippi. [“Notes on Teaching in Mississippi”](#) written by The Student Nonviolent Coordinating Committee (SNCC), began with, *“This is the situation: You will be teaching young people who lived in Mississippi all their lives. That means that they have been deprived of a decent education from the first grade through high school. It means that they have been denied free expression and free thought. Most of all—it means that they have been denied the right to question. The purpose of the Freedom Schools is to help them begin to question.”*

“The purpose of the Freedom Schools is to help them begin to question.”

In their 1915 *Declaration of Principles*, the American Association of University Professors put it this way: *“he should cause his students to become familiar with the best published expressions of the great historic types of doctrine upon the questions at issue; and he should, above all, remember that **his business is not to provide his students with ready-made conclusions, but to train them to think for themselves, and to provide them access to those materials which they need if they are to think intelligently.**”*

Put another way:

Do not believe anything I say!

My job is to help you begin or continue to question. I will provide you with enough firsthand experience and primary texts so that you will have access to the available facts and the interpretations of those facts. I want you to develop a relationship with the facts, question the interpretations of those facts, and make up your own mind on important issues. I will encourage you to use the knowledge you learn in this class to be able to explain the line of reasoning that

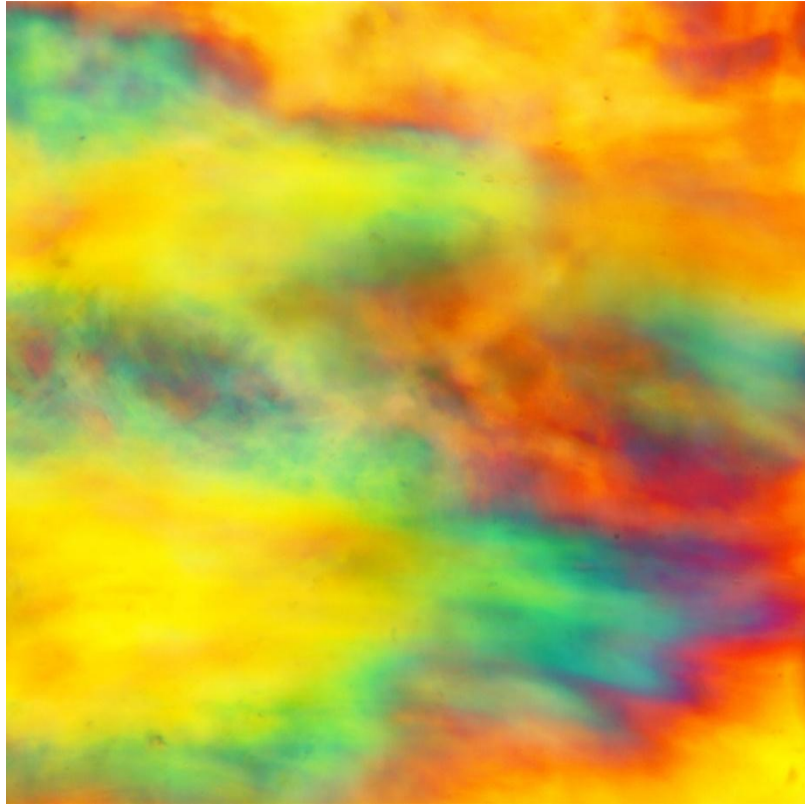
brought you to your answers with conditional certainty. It is possible for each person to answer exam questions differently and still get full credit. I will not “encowardice” you to be mental slaves and merely spit back interpretations that you do not believe to be true.

Academic Integrity

College is a time for you to find and develop your character, interests and skills. DO NOT wait for a gap year to do this! I expect that you will be described as someone who is honest, who sees the light, who reflects on the past and who envisions a bright future. The Cornell University Code of Academic Integrity states that, *“Absolute integrity is expected of every Cornell student in all academic undertakings. Integrity entails a firm adherence to a set of values, and the values most essential to an academic community are grounded on the concept of honesty with respect to the intellectual efforts of oneself and others. Academic integrity is expected not only in formal coursework situations, but in all University relationships and interactions connected to the educational process, including the use of University resources. While both students and faculty of Cornell assume the responsibility of maintaining and furthering these values, this document is concerned specifically with the conduct of students.*

A Cornell student's submission of work for academic credit indicates that the work is the student's own. All outside assistance should be acknowledged, and the student's academic position truthfully reported at all times. In addition, Cornell students have a right to expect academic integrity from each of their peers.”

Specific examples of code violations can be found at:
<http://cuinfo.cornell.edu/Academic/AIC.html>.



DNA viewed with a polarized light microscope

Light and Vision: There is more than meets the eye—an historical introduction to the elements of vision



Science is a way of looking at the world around us in order to make sense of who we are, where we come from, and to help us understand and plan where we are going. Erwin Schrödinger stated that the value of natural science “*is the command of the Delphic deity...get to know yourself.*”

We study humans to help understand who we are. We study plants, animals, microorganisms, rocks, stars, air, and water to understand the biotic and physico-chemical world we live in and our relationship to that world. We gather **data** using our five **senses** and even more data that are **invisible** to our senses by using technology based on past scientific advances. We use these data to construct **models** of the world, in an **analogous** way to how our minds create models of the world using the visual information captured by our eyes. When many minds agree on the validity of the model, we call that model a **theory** or a **law of nature**. The laws of nature include the physical, chemical, and biological world as well as human nature. The laws of nature are **valuable** in helping us understand and appreciate the world around us and understand our place in the universe. There are also **limitations** in the observational and experimental evidence that contribute to the natural laws.



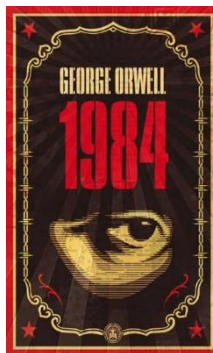
There is also a metaphysical limitation. As C.S. Lewis wrote in an essay entitled, [The Laws of Nature](#), “*the Laws of Nature explain everything except the source of events.*”

As scientists we should realize that the laws are limited and provisional. Each of us must make a personal choice about how reliable and applicable they are. For example, I think that the laws of thermodynamics are more reliable, applicable, and fundamental than Einstein’s Theory of Relativity and the Uncertainty Principle of Quantum Mechanics. As we will see later, James Joule presented the first law of thermodynamics right back to the Creator.

There is currently a national trend to teach only the **value** of current scientific theories and not their **limitations**. The National Center for Science Education (<http://ncse.com/creationism/general/academic-freedom-legislation>; <https://house.mo.gov/billtracking/bills141/biltxt/intro/HB1587I.htm>; <https://ncse.ngo/fermi-missouri>) is fighting “academic freedom bills” that ask teachers to teach "the full range of scientific views regarding biological and chemical evolution," and to help students develop "critical thinking skills" on "controversial issues" by permitting teachers to discuss "the scientific strengths and scientific weaknesses of existing scientific theories."

While there is a movement to teach “*the state of the scientific consensus on the issues*” remember what Eric Blair a.k.a. George Orwell wrote in his book, *1984*:

“Being in a minority, even a minority of one, did not make you mad. There was truth and there was untruth, and if you clung to the truth even against the whole world, you were not mad. A yellow beam from the sinking sun slanted in through the window and fell across the pillow. He shut his eyes. The sun



on his face and the girl's smooth body touching his own gave him a strong, sleepy, confident feeling. He was safe, everything was all right. He fell asleep murmuring 'Sanity is not statistical,' with the feeling that this remark contained in it a profound wisdom."

...and remember that **re-member** even more than **re-collect**, means to put ourselves back together.

I love science and the ability of the scientific method for helping us to question, understand, and appreciate the world around us. According to Karl Popper (1962), *"the secret of intellectual excellence is the spirit of criticism; it is intellectual independence. And this leads to difficulties which must prove insurmountable for any kind of authoritarianism. The authoritarian will in general select those who obey, who believe, who respond to his influence. But in doing so, he is bound to select mediocrities. Nothing is less true, as far as intellectual initiative is concerned, than the idea that those who are good in obeying will also be good in commanding... the whole secret of scientific method is a readiness to learn from mistakes."* I am a staunch supporter of questioning any and all authority in order to help us understand and appreciate the world around us. On that note, I will try to provide you with as much personal experience as possible concerning light and life so that you do not have to believe a single thing I say but have enough experience or **original participation** to trust your knowledge while understanding both the **value and limitations** of what you and others know. I want you to be able to say, "I understand" before you say, "I agree," "I disagree," or "I suspend judgement" on any scientific issue.



Trust the evidence of your own senses. Remember Plato's story, as told in [Theaetetus](#), of the philosopher whose mind is so separated from his senses that he does not even know what he does not know:



Socrates: *And all these things the philosopher does not even know that he does not know; for he does not keep aloof from them for the sake of gaining reputation, but really it is only his body that has its place and home in the city; his mind, considering all these things petty and of no account, disdains them and is borne in all directions, as Pindar says, 'both below the earth,' and measuring the surface of the earth, and 'above the sky,' studying the stars, and investigating the universal nature of every thing that is, each in its entirety, never lowering itself to anything close at hand.*

Theodorus: *What do you mean by this, Socrates?*

Socrates: *Why, take the case of Thales, Theodorus. While he was studying the stars and looking upwards, he fell into a pit, and a neat, witty Thracian servant girl jeered at him, they say, because he was so eager to know the things in the sky that he could not see what was there before him at his very feet. The same jest applies to all who pass their lives in philosophy.*

Trust the information gained by your own senses. Keep your eyes on the sky and your feet on the ground!



Johann Wolfgang von Goethe coined the phrase *Thatige Skepsis*, which according to Thomas H. Huxley means, “*An Active Skepticism is that which unceasingly strives to overcome itself and by well directed research to attain to a kind of conditional certainty*” or “*A state of doubt which so loves truth that it neither dares rest in doubting, nor extinguish itself by unjustified belief.*”

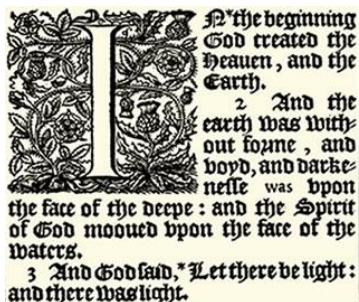
We all are equals in the search for truth. When I was in high school, there was a poster on the door that had a quote:

Don't walk in front of me...I may not follow.

Don't walk behind me, I may not lead.

Walk beside me...just be my friend.

The quote was attributed to Albert Camus, who I had never heard of, and so I thought Camus, which I pronounced Kā-mus, must be a child. Then I learned who Camus was, and I also learned that there was no evidence that he had anything to do with the quote. Indeed, the quote may have come from a friend of [Dr. William F. Knox](#). Knox used the quote in a column in the December 2, 1971 issue of the *Quincy Sun*, entitled, [Just Be My Friend](#).



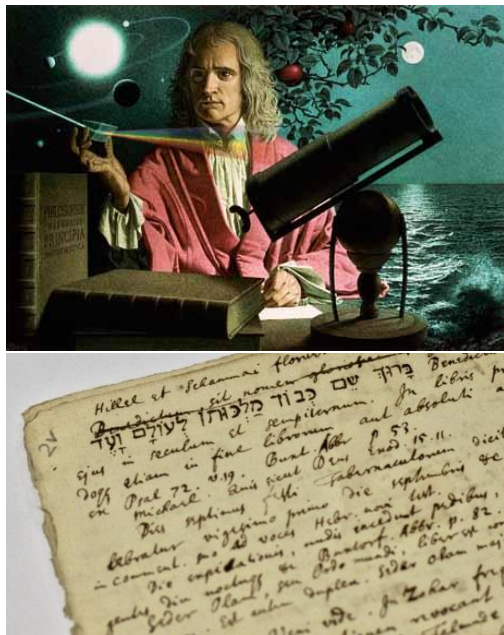
Let's begin talking about light from the beginning. In the Old Testament, Moses (ca. 1500 BC) wrote, **God Said**, “***Let there be light,***” and ***there was light*** (Genesis 1:3), or as it says in the Wycliffe Bible (ca. 1384), *And God seide, Liyt be maad, and liyt was maad.*

According to the Turin papyrus (ca. 1300 BC), for those who lived in Heliopolis in the New Kingdom of Egypt, light was the Sun God Ra seeing: “*I am he who opens*

his eyes and there is light, who shuts his eyes and there is darkness.” For Zoroaster (ca. 500 BC), God was Ahura Mazda, whose name literally means light wisdom.

Robert Grosseteste (1175-1253), the Bishop of Lincoln, wrote in *De Luce* that God was the **uncreated light** from which **created light** and eventually **life** arose. Grosseteste is known as the founder of modern scientific thought. He realized that by looking at specific phenomena, it is possible to arrive at universal laws of nature. He also realized that it was possible to make predictions, such as scammony (*Convolvulus scammonia*) causes the discharge of red bile, that could be verified through a [controlled experiment](#).

Historically, and in many cultures, light has been associated with God and good, and with truth and knowledge. The ancient Hindu festival of lights, known as Diwali, celebrates the victory of light over darkness, good over evil, knowledge over ignorance.



Historically, much of science has been derived from a religious quest to understand the wisdom of God and promote a virtuous world.

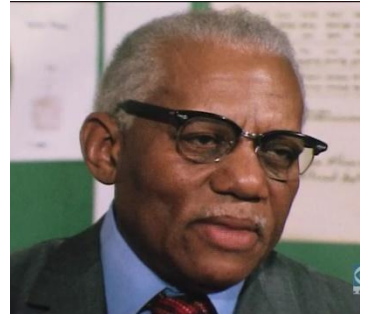
[Isaac Newton](#), for example, did not make a clear distinction between science and faith. For Newton, light, both particulate and real and symbolic and divine, held a central place in science and theology. In [The First Book](#) concerning the *Language of the Prophets*, Newton wrote, “*Light—for the glory, truth and*

knowledge wherewith great and good men shine and illuminate others.” What

kind of knowledge did Newton illuminate? Newton (1687) wrote in the General Scholium of his [*Principia*](#), “*This most beautiful system of the sun, planets, and comets, could only proceed from the counsel and dominion of an intelligent and powerful being...and from his true dominion it follows that God is a living, intelligent, and powerful being.*”

This does not sound like the same Isaac Newton described by scientists today. For example, Johnjoe McFadden (2008) wrote in an article entitled, [Survival of the Wisest](#), published on the 150th anniversary of the *Origin of Species*, “*Quite simply, Darwin and Wallace destroyed the strongest evidence left in the 19th century for the existence of a deity. Two centuries earlier, Newton had banished God from the clockwork heavens. Darwin and Wallace made the deity equally redundant on the surface of the earth.*” Had McFadden not read Newton? Darwin or Wallace did not see the deity as being absolutely redundant. Not able to see evidence of a material solution to origins, Charles Darwin (1958) wrote that “*The mystery of the beginning of all things is insoluble by us: and I for one must be content to remain an Agnostic*” and Alfred Wallace (1871) not seeing the application of natural selection to mankind wrote that the “*faculties which enable us to transcend time and space..., or which give us an intense yearning for abstract truth..., are utterly inconceivable as having been produced through the action of a law which looks only, and can look only, to the immediate material welfare of the individual or the race.*”

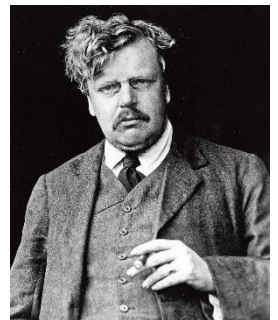
On November 28, 1944, [Robert Thornton](#), a young physicist was beginning a new job and wrote a letter to Albert Einstein asking his opinion on his plan to introduce as much of the philosophy of science as possible into the modern physics course. On December 7, 1944, Einstein responded:



*“I fully agree with you about the significance and educational value of methodology as well as history and philosophy of science. So many people today—and even professional scientists—seem to me like somebody who has seen thousands of trees but has never seen a forest. A knowledge of the historic and philosophical background gives that kind of independence from prejudices of his generation from which most scientists are suffering. **This independence created by philosophical insight is—in my opinion—the mark of distinction between a mere artisan or specialist and a real seeker after truth.**”*

We will begin with an historical account of light and life that is not exclusively **materialistic**, does not marginalize the theological component, and emphasizes the importance of questioning authority, no matter who the authority is (including me).

G. K. Chesterton (1905) eloquently wrote in [Heretics](#) that a materialistic view of nature may not be natural: *Take away the supernatural, and what remains is the unnatural*. In an essay entitled [seeing the supernatural](#), **Andrew Klavan** uses Charles Dickens’ *A Christmas Carol* to illustrate this point.



According to one Greek legend, **Prometheus** formed men out of clay and Athena gave the clay figures life by putting a fire within their clay bodies.



Ovid (43 BC-18 AD) wrote that Prometheus “*gave human beings an upturned aspect, commanding them to look towards the skies.*” Prometheus then brought to men the gift of fire from Mount Olympus so that they could warm themselves and illuminate the darkness. The Olympic torch lighting ceremony at the Temple of Hera is a reminder of Prometheus’ gift of fire.



While fire can warm and illuminate the darkness, it also casts **shadows** of things. In the *Allegory of the Cave*, Plato tells us of men imprisoned in a cave and chained to a wall so that they cannot see the fire behind them. They also do not know that there is a puppeteer behind them that is casting shadows of puppets and other things on the opposite wall. The prisoners can only see the shadows and they imagine that the sounds they hear come from the shadows themselves. The prisoners only have reason to believe that the shadows are the real and only entities of the world. One prisoner escaped from the cave and while he was above ground, he found truth and enlightenment in the heavens. He saw shadows of real objects

and realized that what he had seen in the cave were only shadows of real objects. Then he realized that the position of the life-sustaining sun, which changed throughout the day and throughout the year, influenced the nature of the shadows. And he came to know the relation between what we see and reality and understood from his path of knowledge, the idea of good and inferred that there is an author of good.



When he returned to the cave to tell his fellow prisoners about his newfound knowledge, they laughed at him as though he had gone mad. Indeed, in the meantime, they had set up contests, where the person who could predict the actions of the shadows would win a prize. Plato tells us that we all live in a cave, and it is incumbent on us to learn the laws of optics so that we will be able to understand the relationship between what we see and the true and real object.

The ancient Greeks realized that in order to see an object, there must be some kind of **contact** between the eye doing the seeing and the object being seen.

They developed several theories of light and vision to explain the nature of the contact. These theories can be reduced into two main opposing classes:

-**Extramission** theories, championed by [Empedocles](#), Euclid and [Ptolemy](#), state that vision results from the emission of visual rays from the eye to the object being viewed.

-**Intromission** theories, [championed by Lucretius and Democritus](#), state that vision results from light in the form of a minute replica (eidola) or a thin film (simulacra) of atoms that is emitted from the object and enters the eye.

Both theories relate the sense of vision to the sense of **touch**.

However, the extramission theory is analogous to the act of **touching**, while the intromission theory is analogous to the act of **being touched**.

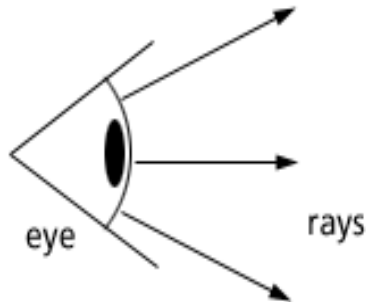
We can also say that seeing involves both the **seer** and the **seen**, or the **perceiver** and the **perceived**. In *Saving the Appearances: A Study in*

Idolatry, **Owen Barfield** (left) reminds us of the difference between sensation and perception, where touch is the sense that comes closest to sensation without perception and sight is the sense that comes closest to perception without sensation.



Extramission theory is based in part on the belief that the gods endowed us with the “**fire in the eye**.” However, the extramission theory was robust enough to explain why we see “stars” when someone strikes our head, why we see light or phosphenes when we rub our closed eyes, why we see images when we sleep in the dark, why we “feel” it when someone stares at us, why we see only the surface of objects, and why more than one person can see the same object at the same time.

The intromission theory, by contrast, could only explain why we cannot see in the dark.



Euclid (300 BC) **mathematized** the extramission theory to explain why distant objects appear to be smaller than nearer objects. Euclid used the **geometry of straight lines and angles** to describe how we see the world.

To use geometry to explain vision, Euclid demands (or postulates) that we accept certain assumptions. Euclid's postulates can be summarized like so:

- Infinite straight lines, known as visual rays, proceed from the eye, forming a cone such that the vertex is at the eye and the base is at the surfaces of the objects being seen.
- Objects touched by the visual rays are visible; those untouched by the visual rays are not seen.
- Objects seen through a larger angle appear larger, those seen under a smaller angle appear smaller, and those seen under equal angles appear equal.

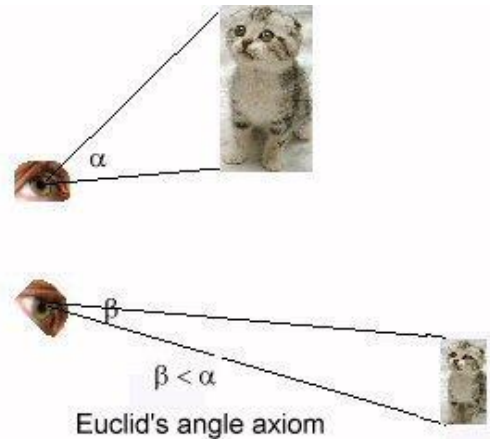
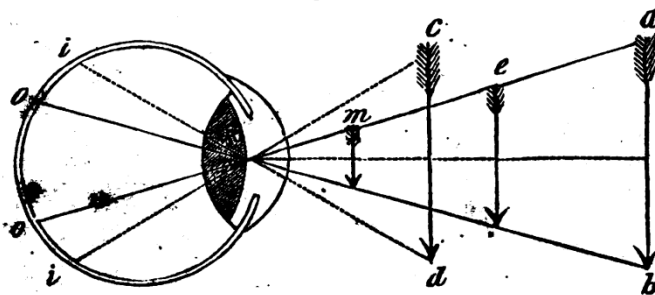


Fig. 183.





Note that the visual angle cannot tell us whether an object is naturally small or naturally large but far away. We are fooled by forced perspective photography to see large objects that are really farther away to be as close as the near object, but smaller.

-Objects touched by visual rays coming from more angles, or a greater angle, are seen more clearly.

The visual rays cease to travel in straight lines when they encounter an **opaque** object, which stops them. Euclid's geometrical optics is also useful in describing the shadows and images produced in these cases.

Visual rays also cease to travel in a straight line when they strike a shiny object such as a **mirror** that reflects them. Hero of Alexandria used Euclid's geometry to describe the images formed by reflection and stated that the position of the image can be determined by using the Law of Reflection, where the angle of reflection equals the angle of incidence. The image is formed by the convergence of apparently straight visual rays.

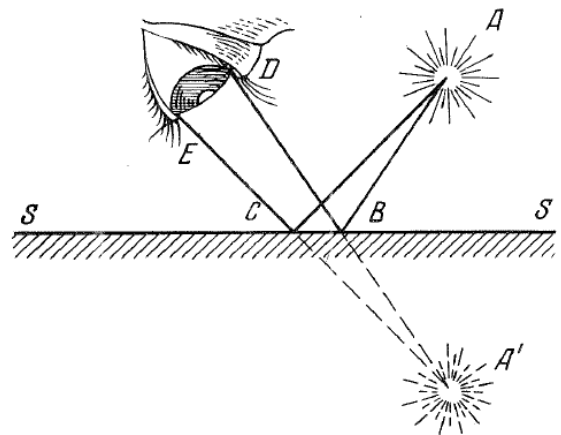
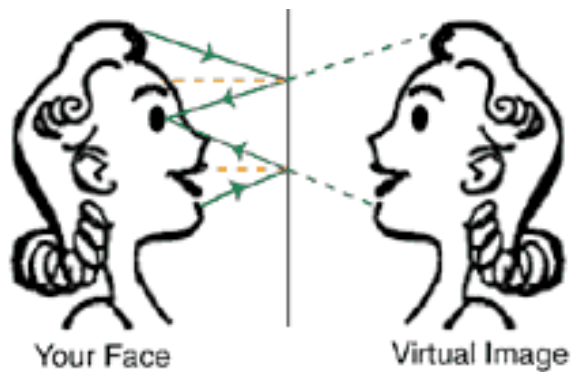


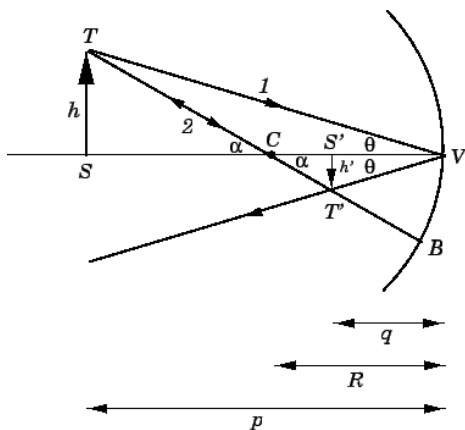
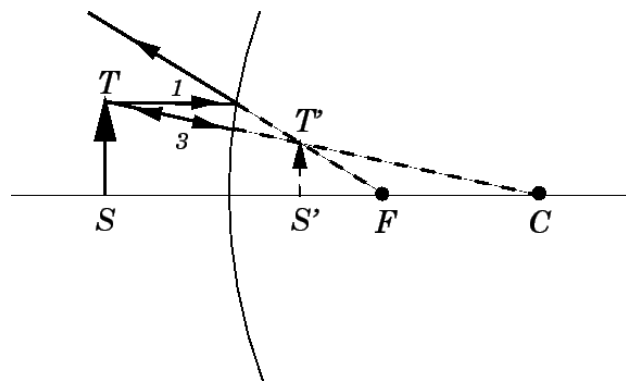
FIG. 3. Observing the reflection of a luminous point in a mirror.



Note one of the shortest poems *Me. We* was created by [Muhammad Ali after giving his Harvard Commencement Speech on June 4, 1975](#). Another two syllable poem entitled, [One Question](#) is *I — Why?* by Eli Siegel.

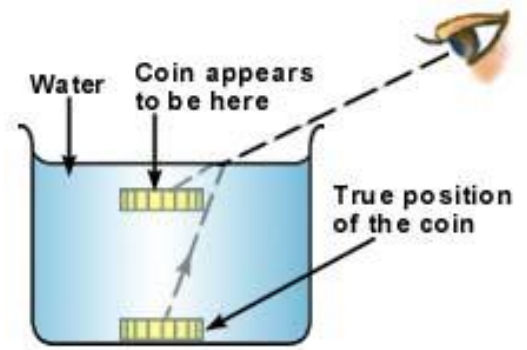


The Law of Reflection can also be used to find the image in concave and convex mirrors. We will go into the geometrical laws of image formation in the next lecture.



Visual rays also cease to travel in a straight line when they pass through a **transparent** medium such as water or the atmosphere that bends them.

Euclid knew that *“If something is placed into a vessel and a distance is so taken that it may no longer be seen, with the distance held constant if water is poured, the thing that has been placed will be seen again.”* Ptolemy used Euclid’s geometry to explain the position of an image that is refracted or bent by a transparent medium.



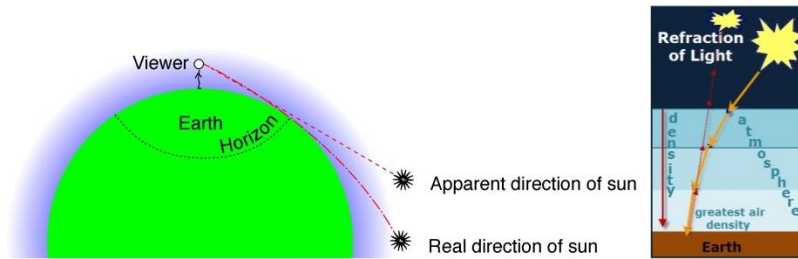
Ptolemy (90-168 AD) realized that the position of light had a powerful effect on the bending of plants. In the days when astrology and astronomy were not differentiated, he realized that the **actual** position of the stars at the time of one’s birth, and not their **apparent** position, would be important for constructing accurate horoscopes. He incorporated the concept of refraction of starlight by the earth’s atmosphere to determine the true positions of stars at the time of one’s birth in order to construct accurate horoscopes and the true positions of the heavenly bodies which allowed accurate navigation.



Ptolemy knew that when a visual ray passed from a less dense medium to a denser medium, it did not travel in a straight line but was bent toward the perpendicular (e.g., looking at a coin in water) and as it passed from a denser medium to a less dense medium (e.g., seeing a star in the heavens), it bent away from the perpendicular. Ptolemy realized that this meant that we see a star higher in the sky than it really is because



our **mind's eye** assumes that the visual rays travel in straight lines. Based on the same assumption, we think that the sun is setting long after it has already set.



Ptolemy did not figure out the ratio of the angles, even though he knew trigonometry. The effect is roughly proportional to the obliquity of the visual rays and the difference in the densities of the media. Next class, we will see that the ratio of the sine of the angles of the incident and transmitted light is equal to a constant.



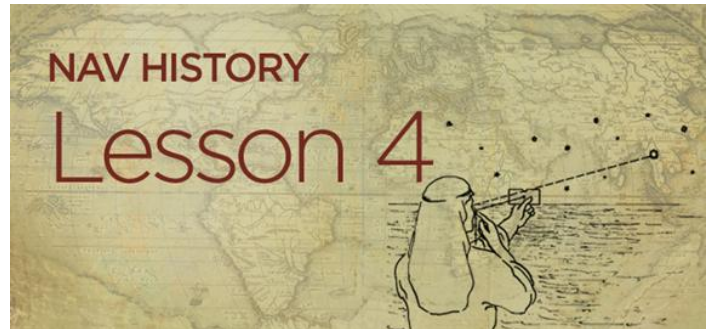
Demonstration: Make a table of the relationship between the angle of incidence and the angle of transmission. Check out these two formulaic models:

$$(\text{angle } i)/(\text{angle } t) = n$$

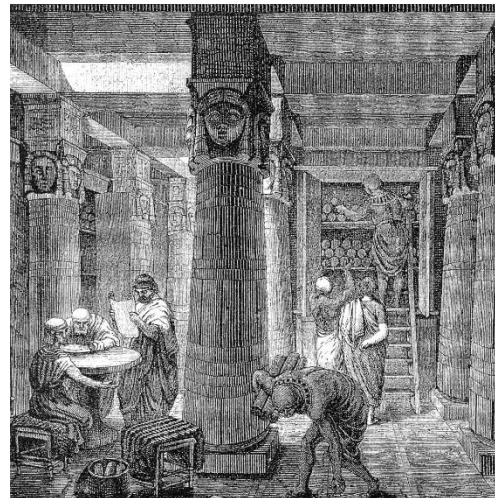
$$(\sin \text{ angle } i)/(\sin \text{ angle } t) = n$$

Which formula seems to be correct and why does it seem to you to be correct?

While Euclid's and Ptolemy's assumption of the reality of visual rays may seem **reasonable** to little children who cover their eyes when playing hide and seek or peek-a-boo, they seem absurd to us. Nevertheless Euclid's geometry, which was based on his theory of vision, became very successful when extended to distant objects like the sun and moon because it made **navigation** to distant places possible. There seemed to be no reason to consider further the **limitations** of the extramission theory, such as why can't we see in the dark, especially at a time when Greek science was in jeopardy.



In 391, under the rule of Emperor Theodosius I, who made Christianity the official religion of the Roman Empire and made pagan thought illegal, Pope Theophilus of Alexandria (385-412) ordered the burning of the last vestige of the great library in Alexandria, which had existed for almost seven centuries and which contained Euclid's texts.



Thankfully this was not the end of Greek Scholarship since the Greek scholars who were displaced from the centers of learning found sanctuary in Persia and Constantinople. They brought their manuscripts with them, and [Greek cultural thought persisted](#).

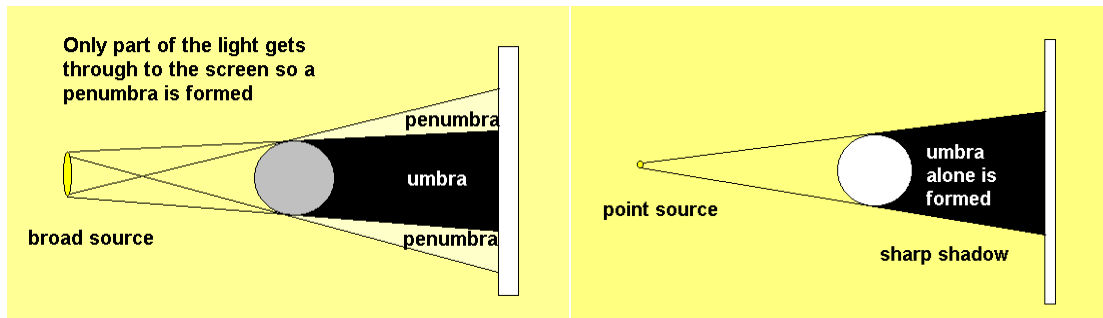
Unfortunately, Greek scholarship suffered again in 529 when Justinian I (482-565), the Byzantium Emperor who also outlawed pagan thought, shut down

the Platonic Academy in Athens. At the margins of the Roman Empire, including Sicily, Greek culture also survived because the scholars were left alone.

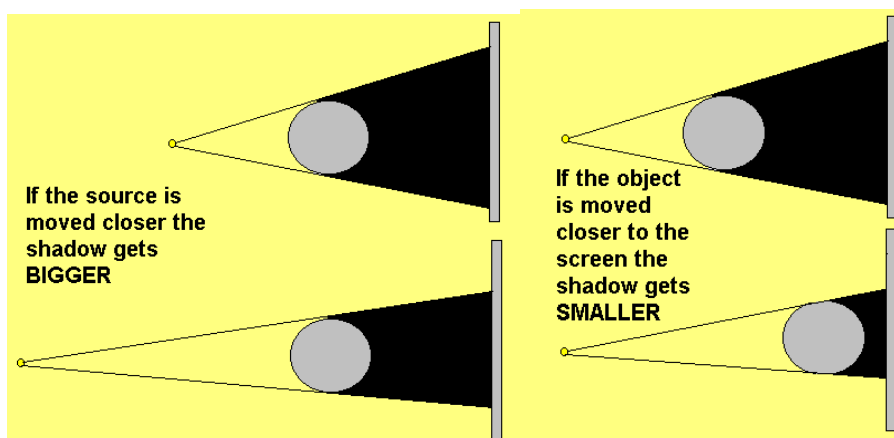
Sicily, a center of Greek science, was conquered by the Muslims from North Africa in 965, and Euclidean texts became available to Ibn Ishak al-Kindi, Abdullah ibn Sina (Avicenna) and Ibn al-Haytham (Alhazen), who sought to assimilate and further develop Greek Science. **Alhazen** (965-1040), who lived in Cairo, began to study Euclid's theory of light and vision under the Caliph Al Hakim. Alhazen, perhaps a little too full of himself, figured that he could solve any problem with mathematics and so the Caliph ordered Alhazen to stop the Nile from flooding. Unable to carry out the Caliph's request, Alhazen was thrown in prison. Sitting in the dark in prison, Alhazen began to question Euclid's assumption that we could see because light emanated by the eye. Alhazen realized that he could only see when the sunlight entered the dark prison cell. He also wondered, if light emanated from his eye, why would looking at the sun cause pain? Alhazen resuscitated the intromission theory and concluded that we see not because visual rays extend from our eyes in straight lines but because light from **luminous** objects or light reflected from **nonluminous** objects follow **straight lines into the eyes**.



What evidence do we have that light travels in straight lines? The shape and size of shadows produced by **opaque** objects tells us that light travels in straight lines. To make the geometry simple, consider the source to be a point source.



The size of the shadow depends on the relative distance between the object, the light source, and the screen.

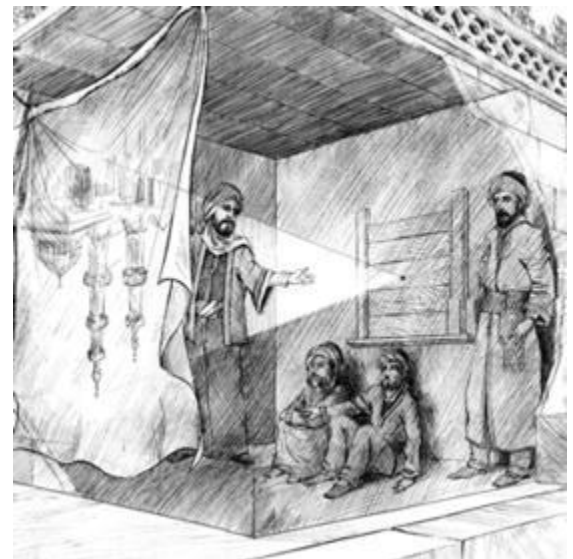


The fact that light travels in straight lines is used by the Pilobolus Dance Troupe to create their [shadow dance](#).



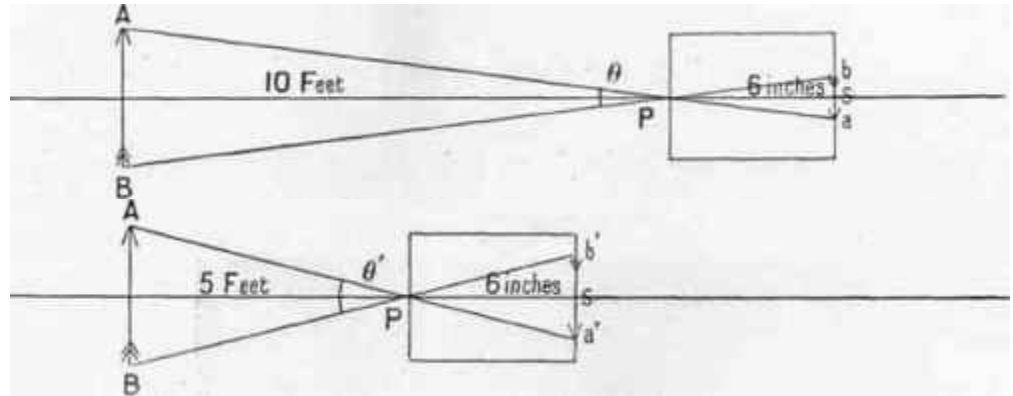
After 12 years in prison, the Caliph died, and Alhazen was freed. Alhazen continued making observations and performing experiments and then published a text on optics. In his *Optics*, Alhazen wrote, “*Light emanates in every direction from any luminous body, however it is illuminated. Thus, when the eye faces any visible object that shines with some sort of illumination, light from that visible object will shine on the eyes’ surface. And it was shown that it is a property of light to affect sight, while it is the nature of sight to be affected by light. It is therefore fitting to say that sight senses the luminosity of a visible object only through light that shines from it upon the eye.*”

Alhazen used **analogy** (degree of similarity; relevance of similarity) to suggest that the eye formed an image the same way that a **camera obscura** (dark room) or pinhole camera formed an image. Alhazen pierced a tiny hole in the wall of a dark room and placed three lamps outside the room and saw that three light spots appeared on the wall across from the pinhole. By placing an obstacle in front of a lamp, he saw that the image of that lamp disappeared and reappeared when he removed the obstacle. The image of a given lamp was always aligned with a straight line from the object to the image. Moreover, obscuring one lamp had no effect on the images of the others. Alhazen described vision, not as the complete transfer of the surface of an object, but as the **transfer of light rays emitted in all directions from individual points on the external surface to the crystalline humor of the eye**. Only the rays that stuck perpendicular to the crystalline humor in the eye were powerful enough to form an image. Thus if image formation by eyes is



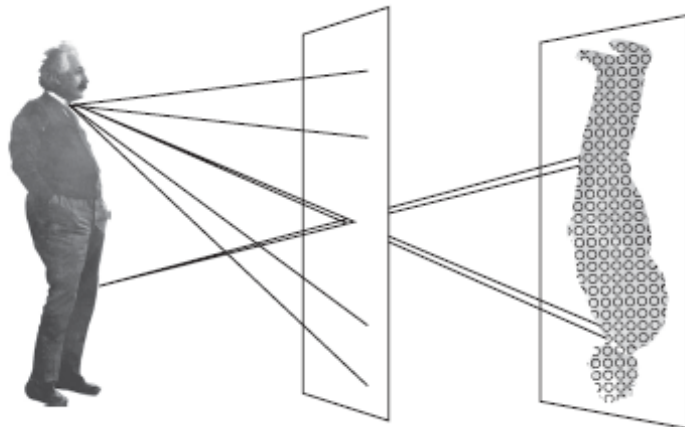
analogous to image formation by pinholes, **the image on the crystalline humor would be a point-by-point representation of the surface of the object.**

By eliminating the visual rays, Alhazen nullified the foundation of geometrical optics, which has been so successful in understanding vision and



so useful for navigation. Consequently, he reformulated geometrical optics to account **for light rays radiating in straight lines from the object to the eyes** instead of visual rays extending out to the objects.

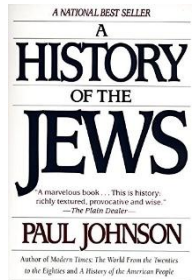
Demonstration: Turn room into camera obscura. See the effect of aperture size on the image. See the **tradeoff** between brightness and resolution. See how a lens affects this tradeoff and introduces a plane of best



focus for an object at a given distance. See that for a pinhole, some information is more valuable than all information. See that **image formation can be explained only if light travels in straight lines.** This valuable truth that light travels in straight lines will find its **limitations** when we study the interaction of light with **small microscopic objects.**

Around 1100, Muslim-ruled Sicily and Toledo, Spain became Christian-ruled and scholars of every religion lived side-by-side peacefully in these linguistic borderlands that became multicultural cities. One of the Toledo translators, known as Gerard of Cremona (1114-1187), translated Alhazen's *Optics* into Latin.

Aside: The multiculturalism lasted until the Spanish Inquisition that began in 1478 under King Ferdinand II and Queen Isabella I, which resulted in the expulsion of the Jews in 1492 and the Muslims in 1502.



Roger Bacon (1214-1294), a Franciscan monk, who was inspired by Robert Grosseteste's way of mixing science and faith, studied the works of the Islamic scholars such as Alhazen which had recently been translated into Latin. He realized how useful this knowledge was and like Augustine of Hippo (354-400), wanted to reclaim scientific knowledge for the service of the Christian faith. Roger Bacon asserted that the science of vision (**perspectiva**), which had been neglected by the Latins, was the noblest of the sciences and invaluable for biblical exegesis in the pursuit of wisdom since it offered “**sure experiences** of all that is in the heavens and on earth.” After all, light, color, vision, and mirrors were frequently referenced in the Scriptures. For example, In John 8:12 it is written, *When Jesus spoke again to the people, he said, “I am the light of the world. Whoever follows me will never walk in darkness, but will have the light of life”* and in I Corinthians 13:12 it is written, *“For now we see through a glass, darkly; but then face to face: now I know in part; but then shall I know even as also I am known”* or *“For now we see in a mirror dimly, but then face to face. Now I know in part; then I shall know fully, even as I have been fully known.”*

Bacon felt that the **truth** given by the Bible could be grasped though the development of **reason**, made precise by **mathematics**, and confirmed by

experience. He thought that an understanding of the natural world would lead to knowledge of its Creator. According to Roger Bacon, “*in the things of the world, as regards to their efficient and generating causes, nothing can be known without the power of geometry*” and that “*it is necessary to verify the matter of the world by demonstrations set forth in geometrical lines.*” As it says in Isaiah 1:18, “Yes, Come now, and let us reason together.”

Geometric optics tells us that as objects become more distant, their visual angle decreases and this is why they appear smaller to us. This is why the distance between two parallel railroad rails seems to vanish at the vanishing point. It is sometimes useful to think of the vanishing point, not only as the limit of objects of constant size seen at greater distances, but in terms of binocular vision, where the vanishing point is the intersection of visual rays from each eye. By studying geometrical optics or perspective as it was known, Roger Bacon could use **lenses**, from the Latin word for lentil, to increase the **visual angle**.



Fig. 173.

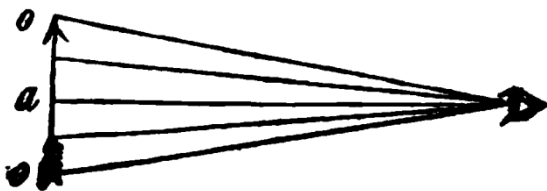
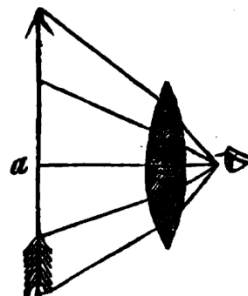


Fig. 174.



To build his knowledge of geometrical optics, Roger Bacon took a new look at **burning glasses**, which had been used since ancient times to light fires.



Aristophanes documents the use of burning glasses in *The Clouds* (423 BC):

Strepsiades. “I say, haven’t you seen in druggists’ shops That stone, that splendidly transparent stone, By which they kindle fire?”

Socrates. “The burning glass?”

Strepsiades. “That’s it: well then, I’d get me one of these, And as the clerk was entering down my case, I’d stand, like this, some distance towards the sun, And burn out every line.”



Clear glass was also developed to drink and appreciate wine.

Aristophanes documents this too. He wrote in *The Acharnians* (425 BC):

“And then they feasted us, and would insist all That we should drink from cups of gold and crystal Their strong sweet wine.” It seems likely that happy and playful wine drinkers would have looked through the glass, that was geometrically similar to burning glasses, and seen small objects magnified.

Roger Bacon studied **refraction** or bending of light and thought that lenses that bent or refracted light might be useful for helping old men read the Bible. Roger Bacon wrote, *“If the letters of a book or any minute objects be viewed through a lesser segment of a sphere of glass or crystal, whose plane base is laid upon them, they will appear far better and larger...And therefore this instrument is useful to old men and to those that have weak eyes. For they may see the smallest letters sufficiently magnified... also that the most remote objects may appear just at hand....”*

For Roger Bacon, light also became a way to dramatize the teachings of the church. The churches and cathedrals were illuminated with candlelight and stained glass windows that illustrated bible stories for the illiterate and were sermons that “*reached the heart through the eyes instead of entering at the ears.*”



Roger Bacon saw knowledge such as the study of optics as a **handmaiden to theology** and not valuable for its own sake. He wrote that “*For every investigation of man that is not directed toward salvation is totally blind and leads finally to the darkness of hell.*” However, [Roger Bacon](#) also emphasized the importance of questioning and experimental science in searching for truth. He began his *Opus maius* by discussing **four obstacles to realizing the truth**; obstacles that Moses and Jesus also faced when presenting their message to pharaoh and to the Pharisees, respectively. [Bacon also pointed out that, men such as Jerome, who were originally thought of as heretics, were later shown to be right and were made saints.](#)

According to Roger Bacon, **the first obstacle is adherence to flawed and unworthy authority. The second obstacle is the persistence of custom, which often favors the false over the true. The third obstacle is popular prejudice, which produces obstinacy and confirms men in their error. The fourth and most serious obstacle error is the tendency to cloak ignorance in a show of wisdom.** Roger Bacon stated that “*Although argument does not suffice for the certification of truth, authority suffices far less....Therefore this [experimental] science wishes to teach that nothing is to be examined by argument or authority*

unless there is some [confirming] experience.” I want to provide you with experience and want you to learn to question authority (including me).

Knowledge of **perspective**, as geometric optics was called, allowed later painters, such as Andrea Pozzo (1642-1709), to mathematize the intuitive techniques of *trompe-l'oeil* (using optical illusion to depict objects as three dimensional) or *di sotto in sù* (seen from below), and include architectural elements to develop the technique known as *quadratura* (opening up walls through visual illusion), which creates an imaginary focal point to paint ceilings in churches that appeared to extend to the heavens.



On the right is a beautiful *Trompe l'oeil* of a violin and a bow hanging on a door in Chatsworth painted by Jan van der Vaart (1653-1727). We will hear more about Chatsworth and its gardener Joseph Paxton later in the semester.

On the right is a *Trompe l'oeil* entitled ***Dipper Missing*** by [Darius Cobb](#) (1834-1919). It shows his canteen, battered cap, and knapsack from the Civil War hanging from a door. There is a note nailed to the wall that says “dipper missing” with a picture of a cup on it.

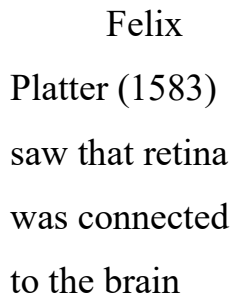
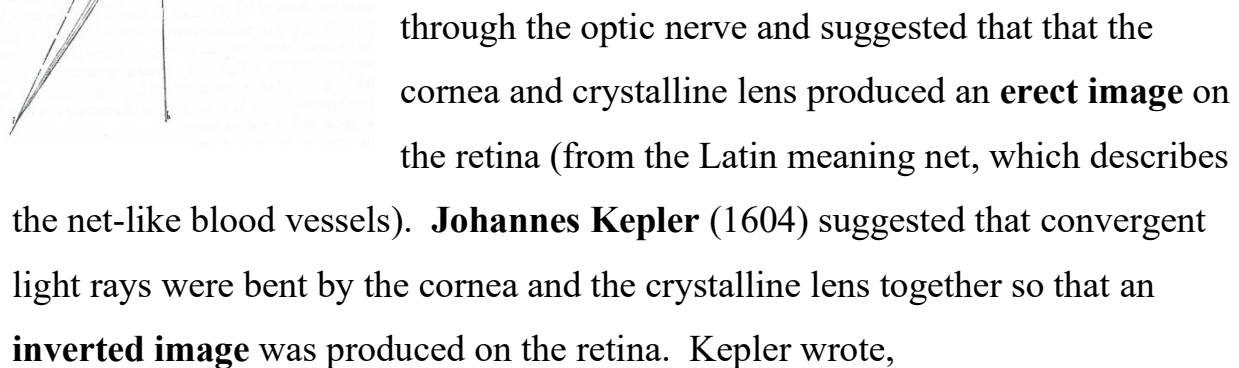


According to Aristotle (De Anima Book II 1: 412b), seeing is to the eye what the soul is to the animal. Aristotle wrote,

Suppose that the eye were an animal-sight would have been its soul, for sight is the substance or essence of the eye which corresponds to the formula, the eye being merely the matter of seeing; when seeing is removed the eye is no longer an eye, except in name -- it is no more a real eye than the eye of a statue or of a painted figure. We must now extend our consideration from the 'parts' to the whole living body; for what the departmental sense is to the bodily part which is its organ, that the whole faculty of sense is to the whole sensitive body as such.



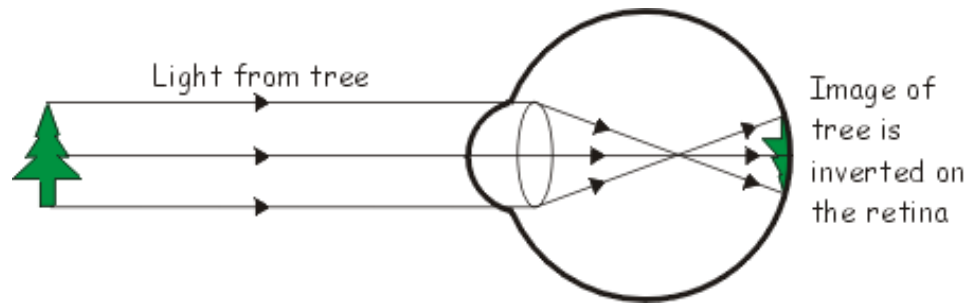
Following works by Alhazen, Leonardo da Vinci (ca. 1500), and others, Giovanni Batitista della Porta (1535-1615), in his book *Natural Magic*, promoted the comparison between the eye and a *camera obscura*. He also popularized the addition of a converging lens to the *camera obscura* in order to maximize the brightness and resolution of the image. This made the *camera obscura* more useful. Johannes Kepler (who actually coined the term *camera obscura*) used the *camera obscura* to survey land and to observe the sun.



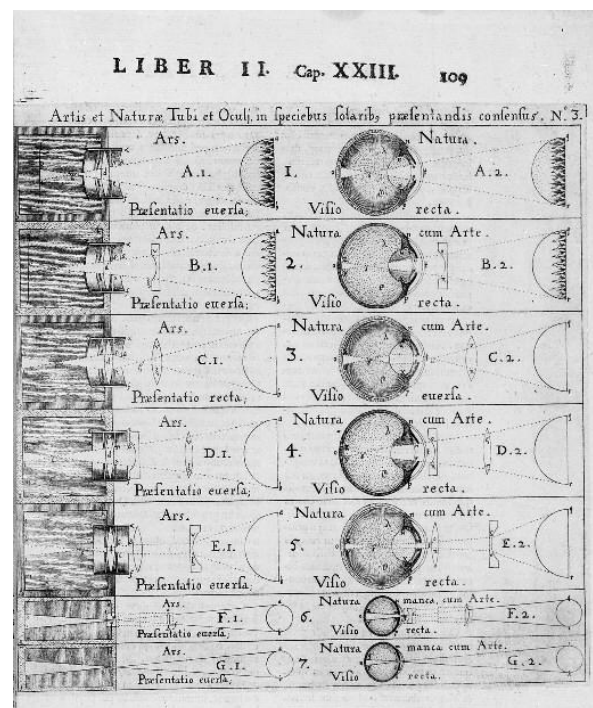
*“Vision takes place by a painting of the visible object on the white and concave wall of the retina; the leftward objects are the right side of the wall, the rightward on the left side, the upward on the lower side, the downward on the upper side; green is painted with the same green color, and in a general manner every object is painted with its original color; so that if this painting on the retina could be exposed to daylight by removing the interposed parts of the eye that serve to form it, and **if there were a man with sufficient visual acuity**, he could recognize the identical figure of the hemisphere [of vision] on the tiny inside of the retina.*

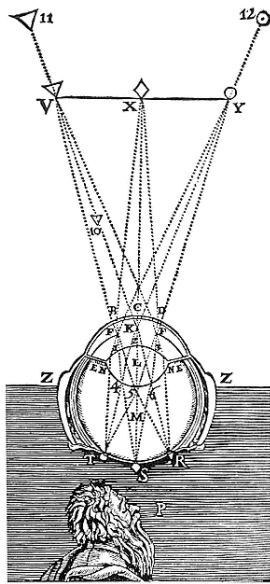
Proportions are indeed conserved: the angle under which lines drawn from a given point of the visible object would reach a certain point within the eye is about equal to the angle under which these points are depicted; even the smallest points are not omitted; the sharper is a man's vision, the subtler is this painting in the eye."

About the inverted image painted on the retina, Johannes Kepler wrote, “I leave it to the natural philosophers to discuss the way in which this image or picture is put together by the spiritual principles of vision residing in the retina and in the nerves, and whether it is made to appear before the soul or tribunal of the faculty of vision by a spirit with the cerebral cavities, or the faculty of vision, like a magistrate sent by the soul, goes out from the council chamber of the brain to meet this image in the optic nerves and retina, as it were descending to a lower court.”



Christoph Scheiner (*Rosa ursina*; 1630) tested Kepler’s theory by placing the eye of an ox and many other animals, including cows, sheep, goats and pigs in which the **sclera** and **choroid** covering the back of the retina had been removed, in the aperture of a *camera obscura*, and saw that an inverted image was formed on the retina the same way it was formed on the wall opposite the pinhole and lens by the *camera obscura* itself. He suggested that the human eye worked the same way.





Rene Descartes (1637) repeated Scheiner's experiment and illustrated it in his Optics book taking into consideration the Snel-Descartes Law of refraction when drawing the light rays. Considering that the image on the retina was inverted, the **mind** must interpret the image and invert it again, indicating that **image formation requires more than optics. It requires the mind.** Descartes wrote, "*...we should consider that there are many things besides pictures which can stimulate our thought, such as, for example, signs and words, which do not in any way resemble the things which they signify....It is only a question of knowing how the images can enable the mind to perceive all the different qualities of the object to which they refer; not how they hold their resemblance.*"



Bishop **George Berkeley** agreed that vision was not solely the result of angles and lines. Indeed the **mind**, with all its experiences, was involved in making judgments about the nature of the image projected on the retina. He suggested that the inverted image on the retina was

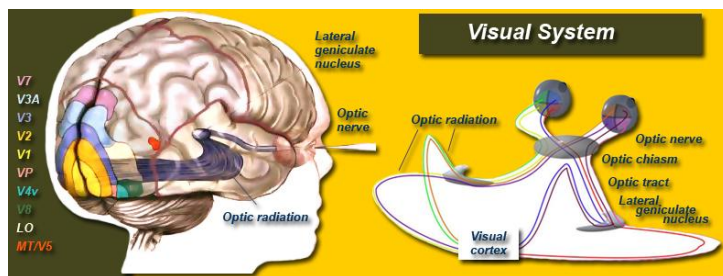
judged by the mind to be an erect object, consistent with one's experience with touching the object. According to Berkeley, even the size and distance of objects were not seen directly using lines and angles but judged by the mind. He came to this conclusion after considering the **moon illusion**. That is, even though the moon has a constant size and distance from the earth, it seems larger when it is on the horizon than when it is at its zenith. Berkeley suggested that, just like a word does

not have the same significance in our mind when heard in different contexts, an object placed in different contexts will not produce the same image in our mind and an object placed on high will seem smaller than an object placed at an equal distance at eye level. Berkeley showed that an object placed on the top of a one-hundred-foot-high steeple seemed smaller than the same object placed the same distance at eye level. In *An Essay Towards a New Theory of Vision*, Berkeley (1709) concluded that it was the orientation of the head and eyes that determined the apparent size of the object. Bishop Berkeley emphasized that there is a difference between the optical processes of **seeing** in the eye and the final process of **perceiving** or seeing with the mind's eye. Consequently, vision cannot be left to the simplifications of the mathematicians but must take into consideration the complications of the mind.

The mind has the ability to correct the image formed on the retina in order to bring it in alignment with reality. In the late 19th century, George Stratton showed that the mind could also learn not to invert an erect image projected on the retina. Stratton wore inverting glasses that produced an erect image on his retina. For four days he saw the world as **upside down** but by the fifth day, his mind brought the visual information in alignment with the tactile information, and he began to see the world **right-side up** again. The role of the mind in mediating competing sensory information is known as **perceptual adaptation**.



The parts of the brain involved with vision were discovered **serendipitously** as a result of wartime **brain injuries**. People with brain injuries can be blind even though their eyes are perfectly healthy. Following the Russo-Japanese War (1904-1905), Tatsuji Inouye created a map of the visual cortex by correlating **visual field deficits** with regions of the **occipital lobe** of the brain that were damaged by bullets. Gordon Holmes and William Lister (1916) studied the relationship between visual field deficit and regions of the brain that were damaged by bullet wounds in World War I. The spatial resolution of their map compared with Inouye's map was improved because they used X-rays to localize

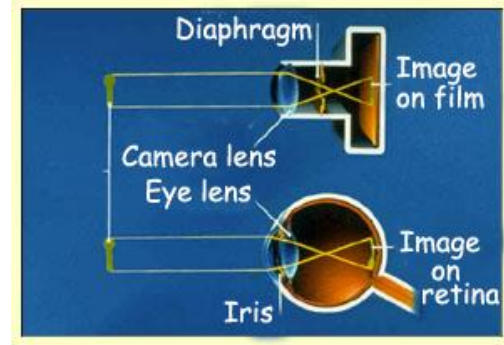


the bullets and the damage was more localized as a result of rifles with greater muzzle velocity and bullets that were smaller and less deformable.

Holmes and Lister studied over 2000 soldiers because the WWI British Brodie helmet (as well as the USMC Doughboy helmet) unlike the German (Stahlhelm) helmets did not protect the occipital lobe and the cerebellum.

During WWI, George Riddoch noticed that some soldiers could still perceive **motion** even though they were blind as a result of bullet injury to the visual cortex meant that other regions of the brain were involved in vision. We now know that loss of color vision can occur when there is a lesion outside the visual cortex. We now know that more than [50% of the brain cortex](#) is involved in vision, and a [stroke can result in loss of various aspects of vision](#).

The eye itself can be considered to be an image-capturing, mechanical device **analogous** to a modern-day camera. The cornea is the major factor in image formation because of the great difference in the refractive index of the air ($n = 1$) and the cornea ($n = 1.376$). The



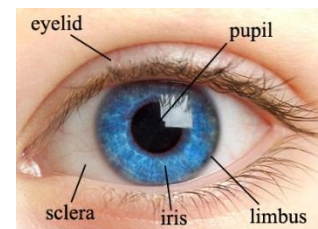
cornea has its own lens cap and lens cleaning system too. The eyelid shuts to protect the cornea; the eyebrows and eyelashes keep out sweat and dust, respectively, and the tears wash the cornea. The light rays are refracted toward the perpendicular by the cornea are slightly refracted away from the perpendicular by the aqueous humor ($n = 1.336$) on the way to the crystalline lens ($n = 1.386$ - 1.406).

The crystalline lens is composed of over 2000 microscopically thin layers. The crystalline lens, with the help of the ciliary muscle, fine focuses the image first made by the cornea. In a human, the distance between the crystalline lens and the retina is fixed, and the crystalline lens, which is elastic, focuses on nearby objects by increasing its curvature and decreasing its focal length. This process is known as **accommodation**. The inability to accommodate is known as **presbyopia** and can be corrected with reading glasses. In a camera, focusing of nearby objects to take a close-up is effected by moving the lens farther from the CCD (charged coupled device) or CMOS (complementary metal–oxide–semiconductor) chip or film plane.

The color of the eye is determined by the color of the **iris**, named after Iris, the goddess of the rainbow. In a later lecture, we will



discuss the **inheritance of eye color**. The muscles of the iris control the opening of the pupil. This allows the amount of



light that enters the eye to vary much like the **aperture diaphragm** of a camera lens varies the amount of light that reaches the film. The f-number (focal length/diameter of aperture) of the eye varies from f/8.3 to f/2.1. That is, the diameter of the aperture = focal length/f number. A larger aperture favors a brighter image with greater **spatial resolution** and less **depth-of-field**, while a smaller aperture favors a dimmer image, with less **aberration** and more depth-of-field. Squinting accomplishes the same results consciously.

The excitation of **photoreceptor cells** captures the image on the **retina** much like a **CCD chip** in a camera captures the image in a camera. In bright light, the retina is analogous to a high-resolution color CCD chip or film, while under low light conditions, the retina is analogous to a monochromatic, black and bluish-white CCD chip or film. We will talk more about the development, anatomy, and physiology of the eye and color vision over the next two weeks.

The **photoreceptors** that capture the image on the retina of the eye are proteins known as **opsins**. The photoreceptor proteins are determined by genes and we will discuss them in terms of **sex-linked inheritance**. When the **chromophores** of the photoreceptors are excited by light, a signal transduction chain is stimulated so that the **radiant energy is transformed into electrical energy** that travels as nerve impulses through the **optic nerve** to the **brain**. The image we perceive however depends on the **mind**, which does the **image processing**. The images captured by digital cameras can also be processed.

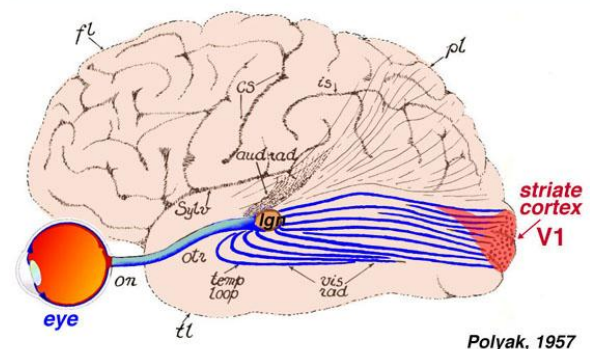


Figure 8. Visual input to the brain goes from eye to LGN and then to primary visual cortex, or area V1, which is located in the posterior of the occipital lobe. Adapted from Polyak (1957).

Our two eyes, which give us **binocular or stereoscopic vision**, are analogous to a stereo camera, which produces two images observed at slightly different angles that the mind processes into a three-dimensional image in the mind's eye. By taking into consideration the positions of the eyeballs that are creating the visual image, the mind helps us to **judge distance**.



Animals that have two eyes will only have stereoscopic vision that allows them to judge distances if the two eyes are in the same plane so that the two visual fields overlap. This is important for **predatory animals** such as cats and wolves. Primates have stereoscopic vision that allows them to use their hands and to jump from branch to branch. Flounder, which have two eyes in a single plane, also have stereoscopic vision. This helps these bottom-dwelling predators to catch their prey. Squirrels have eyes that are intermediate between being on the same frontal plane and on opposite sides of their head. There is sufficient overlap of the two visual fields to produce stereoscopic vision which allows depth perception to catch branches and use their hands and also keep a wide angle of surveillance. Small birds that flit through shrubbery have similar eye geometry. Most birds, including the chicken and pigeon, have eyes on the sides of their heads to give them a wide angle for surveillance but must judge distance by moving their heads and focusing with each eye independently. Owls, which are predatory birds, have both eyes in the frontal plane. This gives them stereoscopic vision and the depth perception they need to capture their prey. **Browsing animals** have their two eyes on the sides of their head because surveillance with an all-

around view is more important than depth perception. They can see in all directions without moving their head.

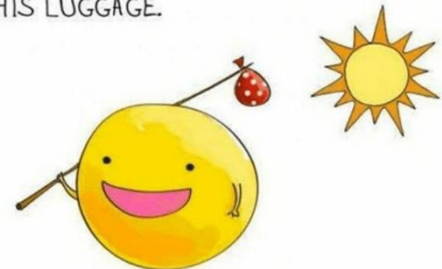
While most animals have two eyes, other animals, like *Cyclops* (a Copepod) have one eye while spiders may have eight.



Light, in the form of **photons**, carries **information** about the external world to our retina.

The photoreceptors in the retina absorb the photons and transform the spatial information into electrical signals that are encoded by the neural cells of the retina, which include the bipolar cells and the ganglion cells. The electrical signal is then transmitted along the optic nerve and it is further processed by various regions of the brain ultimately forming our **perception**, an image in the mind's eye.

A PHOTON CHECKS INTO A HOTEL AND IS ASKED IF HE NEEDS ANY HELP WITH HIS LUGGAGE.

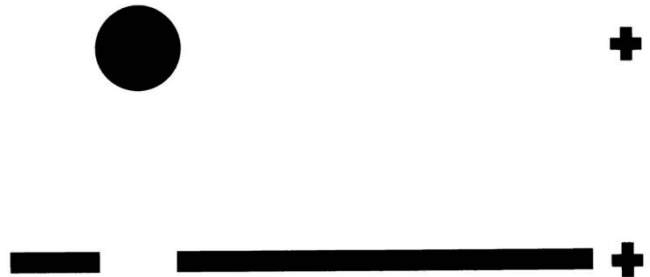


"NO, I'M TRAVELLING LIGHT."

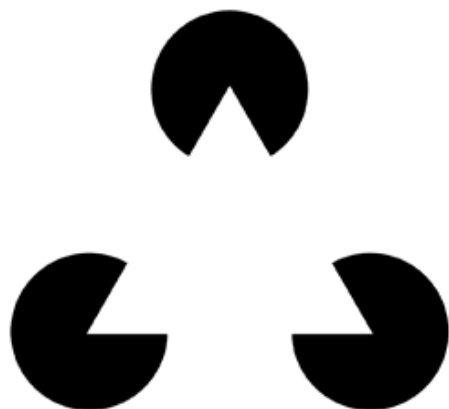
Perception is not determined solely by the physical distribution of light energy in space, but by our mind that searches for the best interpretation of the distribution of light energy in space. That is, our mind combines the sensory information with our knowledge of the world to make the best possible interpretation of the world within a reasonable time. *Thus we do not perceive the world directly since what we perceive goes beyond the sensory experience of what we see.*

This is clearly demonstrated by the **blind spot test**, in which the mind “**completes**” the missing information. As we will see next week, the retina has a region devoid of photoreceptor cells where the optic nerve enters the nasal side of the eye, resulting in a blind spot.

Find your blind spot! Using the diagram below, fixate on the cross, close your right eye and hold the figure about 1.5 feet from your face. When the filled circle disappears, its image is on your blind spot. Fixate on the lower cross. Note how the line appears continuous.



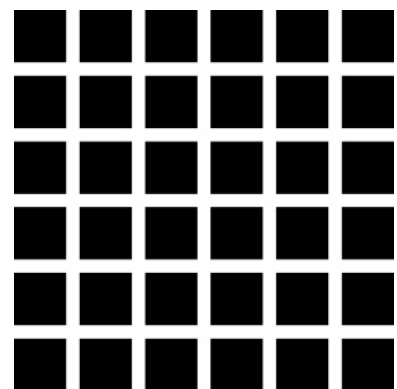
Demonstration: Close your right eye and hold the test pattern 18 inches in front of your eyes. Focus your left eye on the plus sign and move your eye back or forth until the dot disappears.



Usually, our perceptions are correct in the way they illustrate the natural world to our mind’s eye, but **optical illusions** remind us that this is not always the case. Do you **see** the photons that make up a triangle? Do you **perceive** a triangle? Is a triangle there in reality? What we **perceive** with our mind’s eye is not the **real world** but is a **testable hypothesis that can be confirmed by**

experience. Are we any different from the prisoners in **Plato’s cave**?

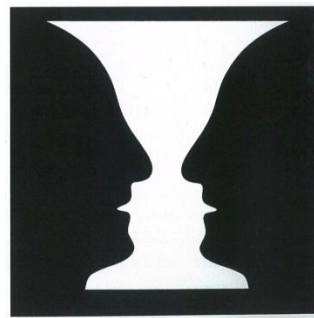
When we look at the Hermann grid, we see the invisible phantom dots at the intersections that are not really there. Again, are we any different from the prisoners in **Plato’s cave**?





When we see an **ambiguous image**, which consists of two separately valid images, each of which conforms to a realistic picture of the world, our mind makes a choice between the two **interpretations**. We typically cannot see the two interpretations simultaneously, although one can learn how. Do you see a woman sitting at a vanity or a skull in Charles Gilbert's (1920) "*All is Vanity*"?

Do you see a goblet or two faces in Edgar Rubin's (1915) "*Hidden Faces and Goblet*"?

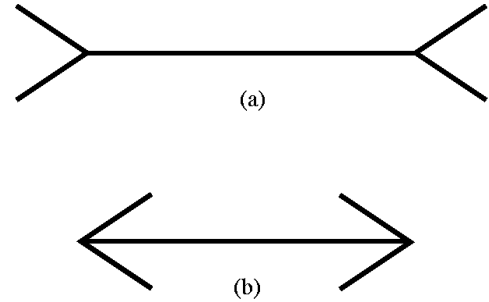


Do you see a young woman or an old woman in this picture on an old German postcard from 1880?

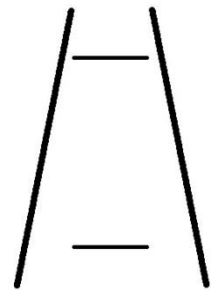


We will use optical illusions to document that we do not perceive the real objective world directly as a camera does because the mind processes visual images. The mind makes certain logical and reasonable assumptions such as the influence of distance on size and that there is only one source of light illuminating the object. In everyday life, the processing gives a rapid and realistic view of the world with a modest number of photoreceptors and neurons. We can confirm the limitations of the mind's image processing capability when we study objects that we do not realize are optical illusions until we investigate the image using rulers, light meters, or touch.

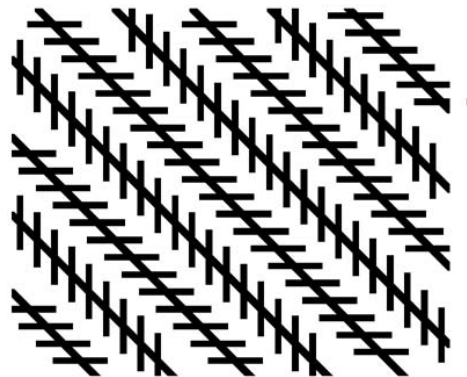
In the Müller-Lyer illusion, the lengths of the horizontal lines in figures (a) and (b) are the same, yet our minds trick us in seeing the line in (a) longer than the line in (b). Even after we measure the lengths of both lines, we still see the line in (a) longer than the line in (b). Why can't our minds fix the illusion in the same manner it erects the inverted image on the retina, to give us the right answer?



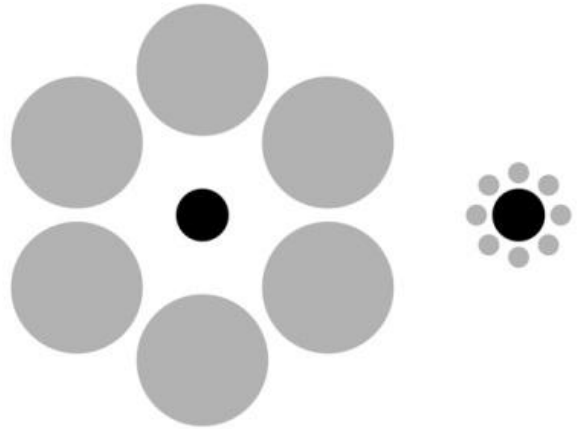
In the Ponzo illusion, the lengths of the two horizontal lines are the same, yet our minds trick us in seeing the upper line as longer than the lower line. Again, even after we measure the lengths of both lines, we still see the upper line as longer than the lower line. Why can't our minds fix the illusion and give us the right answer?



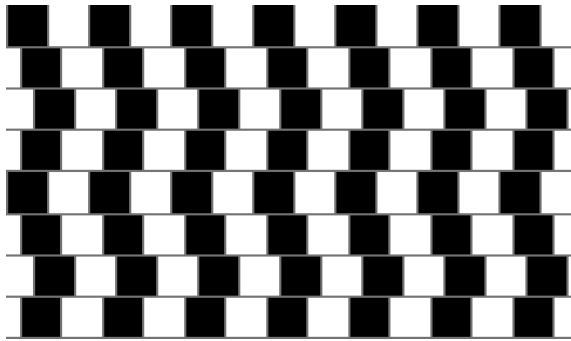
In the Zöllner illusion, parallel lines appear to diverge or converge when the lines are crossed by short lines that appear to be a part of an arrowhead or a barb, respectively. Why can't our minds fix the illusion to give us the right answer?



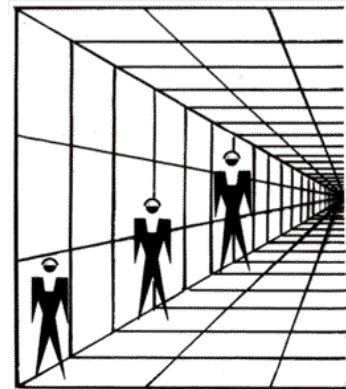
In the Ebbinghouse illusion the central spots are the same size even though the one on the right looks larger. Why can't our minds fix the illusion and give us the right answer?



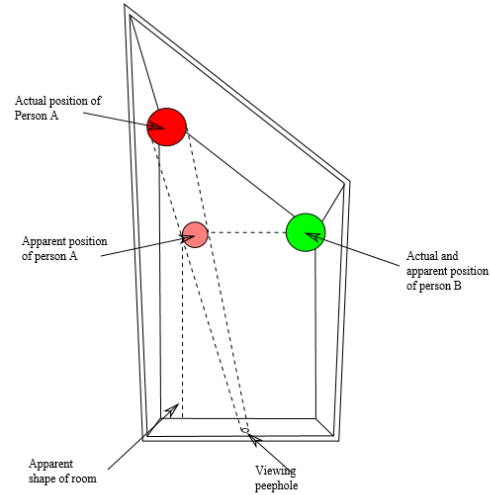
The mind cannot make the horizontal lines in the figure below straight,



nor perceive the people in the figure on the right to have the same height.



In the **Ames Room illusion**, which is an architectural illusion, we **think** that the room is a cube, even though, in **reality**, it is trapezoidal. Consequently, we **perceive** that a person standing at position A is tiny and a person standing at position B is a giant. A single person walking between position A and position B seems to grow and shrink. Are we any different from the prisoners in **Plato's cave**? What if the cave were trapezoidal shaped?



We discussed **spatial information** that contributes to optical illusions. What about **temporal information**? **When** do we see? Light takes time to travel from an object to our eye, but more importantly now, it takes time to process the visual information. Under low light conditions, it takes more time before a neural cell is sufficiently stimulated to fire. The dimmer the light, the more time it takes to process the image.

Demonstration of the Pulfrich

Pendulum Effect: Look at the apple pendulum swinging back and forth in a straight line. When you look with both eyes at the pendulum swinging perpendicular to your line of sight, it appears to move in a straight line. When you look with both eyes at the pendulum swinging perpendicular to your line of sight, it appears to move in a straight line. When you put a neutral density filter in front of your left eye, the apple will appear to move clockwise in an ellipse and when you put the neutral density filter in front of your right eye, the apple appears

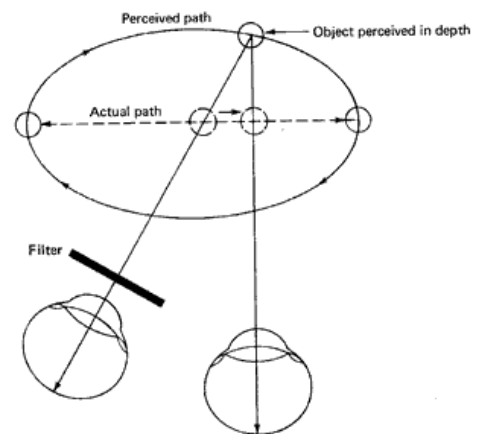
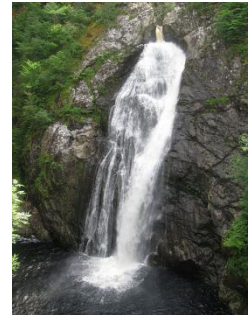


Fig. 13.7. The Pulfrich phenomenon. The attenuated eye perceives the pendulum ball as lagging behind the position as seen by the unattenuated eye. This is consistent with the ball actually traveling in an elliptical path, as shown.

to move counterclockwise in an ellipse. **Try this at home** using sunglasses that only cover one eye at a time.

The **waterfall illusion** observed by Robert Addams (1834) at the Falls of Foyers in Scotland is another **temporal** optical illusion. You can observe the waterfall illusion at Taughannock Falls. When one stares at a waterfall for a period of time and then looks to the side; the stationary rock face beside the waterfall appears to move up. Also, after stopping a video of a waterfall, it looks like the water goes up!

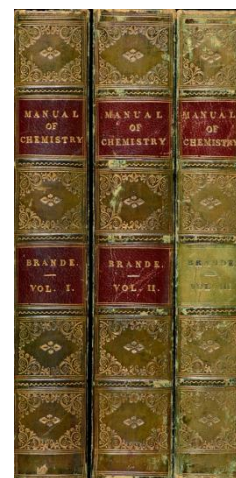


Solomon Asch was a social psychologist who showed that our ability to have the courage of our convictions and speak publicly as a minority of one could be influenced by peer pressure. He was also a mentor of **Stanley Milgram**. Asch conducted his conformity experiment using college students who were told that they would be part of an experiment in **visual discrimination**. Each subject was part of a group with confederates who knew the true aims of the experiment. The group was shown a card with a line on it. On the right was another card with 3 lines on it labeled 1, 2, and 3. The participants were asked which line matched in length the line on the card on the left. The real subject answered last. For the first two trials, the subject would feel at ease in the experiment because the others gave the obvious and correct answer. However, after this, the confederates responded with the clearly wrong answer. The participant could either trust his eyes (the subjects were all white males) and ignore the majority or ignore his own senses and go along with the majority. Asch found that the majority of subjects ignored their own eyes and went along with the consensus. He also found that if



one other person gave the obvious and correct answer, the subject was more likely to announce his correct answer in spite of the consensus. Asch (1955) wrote, *“Life in society requires consensus as an indispensable condition. But consensus, to be productive, requires that each individual contribute independently out of his experience and insight. When consensus comes under the dominance of conformity, the social process is polluted and the individual at the same time surrenders the powers on which his functioning as a feeling and thinking being depends. That we have found the tendency to conformity in our society so strong that reasonably intelligent and well-meaning young people are willing to call white black is a matter of concern. It raises questions about our ways of education and about the values that guide our conduct. Yet anyone inclined to draw too pessimistic conclusions from this report would do well to remind himself that the capacities for independence are not to be underestimated. He may also draw some consolation from a further observation: those who participated in this challenging experiment agreed nearly without exception that **independence was preferable to conformity.**”*

Every generation must be reminded of the danger of not being responsible for thinking for oneself. William Thomas Brande (1848) wrote in *A Manual of Chemistry*, *“It may seem trite to quote Lord [Francis] Bacon; but, as experience is constantly showing the neglect of the invaluable doctrines inculcated in his works, and as students, especially, are too apt to throw off the burden and responsibility of thinking for themselves, by adopting the notions of others, without duly weighing their merit or appreciating their correctness, and often only because they are new, I shall call their attention to one of the many relevant passages of this author:—*



*‘He who would come duly prepared, and fitted to the business of interpretation, **must neither be a follower of novelty, custom, not antiquity; nor indulge himself in a liberty of contradicting; nor servilely follow authority.** He must neither be hasty in affirming, nor loose and skeptical in doubting; but raise up particulars to the places assigned them by their degree of evidence and proof. His hope must **encourage him to labor**, and not to rest; he must **not judge of things by their uncommon nature, their difficulty, or their high character**; but by their just weight and use. He must, in his own particular, carry on his view with concealment, and yet have due regard for posterity. He must **prudently observe the first entrance of errors into truths, and of truths into errors, without despising or admiring anything.** He must understand his own talents and abilities, or the advantages of his own nature. He must comply with the nature of others. He must, as with one eye, survey the natures of things, and have the other turned towards human uses. **He must distinctly understand the mixed nature of words, which is extremely capable both of prejudicing and assisting.** He must lay it down to himself, that the art of discovering will grow up, and improve, along with discoveries themselves. He must not be vain either in delivering or concealing the knowledge he has acquired, but ingenuous and prudent, and communicate his inventions without pride or ill-nature: and this in a strong and lively manner, well defended against the injuries of time, and fit for the propagation of knowledge, without occasioning errors; and, which is the principle thing of all, it must be such as may select and choose for itself a prepared and suitable reader.’”*

Hannah Arendt (1971) wrote in *The Life of the Mind—Thinking*,
“*There are no dangerous thoughts; **thinking itself is dangerous**...[b]ut that danger does not arise out of the Socratic conviction that an unexamined life is not worth living, but, on the contrary, out of the desire to find results that would make further thinking unnecessary...However, non-thinking, which seems so recommendable a state for political and moral affairs, also has its perils...the readiest to obey will be those who were the most respectable pillars of society, the least likely to indulge in thoughts, dangerous or otherwise....”*



To think for oneself requires courage. Cornel West (2008) wrote, *“To be human requires the courage to think, hope, love, and fight for justice and freedom in the face of catastrophe.”*



get lifted

“The three pillars of deep spirituality are faith, hope and love—yet it is courage that enables all three.”

Hope on a Tightrope

When times are toughest, says CORNEL WEST, that is the moment to turn away from fear

We travel through life with two inescapable companions—change and choice. When an aggressive cancer nearly became a death sentence, I was told that I might have only a few months to live. My first thought? Deep and overwhelming gratitude for being allowed to sit at the banquet of life for nearly 50 years, enfolded by the indescribable love of family and friends that sustained me on each step of my journey. I didn't know whether or not I was going to die then. But I refused to let death come in like a thief in the night and steal the joy I had already given and received. I was so grateful that God had allowed me to pursue my spiritual vocation of promoting unarmed truth and unconditional love. To be human means choosing the courage to think, love, hope and fight for justice and freedom in the face of catastrophe. Death could come, because I had made my choice.

Deep and mature spirituality is rooted in a wrestling with catastrophe. Black spirituality has been the antidote to the vicious attempts to render us so intimidated and hapless that we give up, cave in, or sell out to an unjust status quo. Our unimagined victories in the face of catastrophic conditions are majestic evidence of a rich spiritual tradition. The question is never whether catastrophes will come but rather, when they come, what choices will we make?

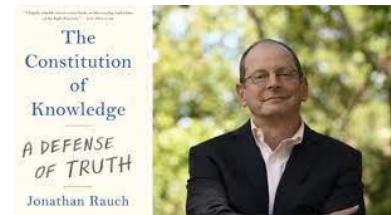
Spirituality gives us armor to cope with disaster. The three pillars of deep spirituality are faith, hope and love—yet it is courage that enables all three. Faith enables us to face the future—including inescapable catastrophes—with humility and generosity. Yet there is no faith without the courage to be humble. Hope empowers us to stay on the tightrope despite the winds and storms of catastrophes. Yet there is no hope without the courage to fight despair. Love ennobles us to maintain a steadfast commitment to the well-being of someone or some cause greater than our own petty ego. Yet there is no love without the courage to surrender to something more priceless than yourself.

The profoundly spiritual dimension that we all face in this historic election season is whether we will choose to counter excessive greed, hatred and fear with courageous fairness, compassion and hope. Let us pray, push and pull for this election to transform decaying school systems, dilapidated housing, unavailable health care and child care, the many jobs without a living wage, gun violence run amok and mean-spirited policies here and abroad.

Brother Barack Obama's trek to the White House represents a democratic awakening of the American people. But we know that a mere Black face in a high place does not by itself yield humane results—each of us must be accountable for those who suffer. Let us hope on our tightropes that we will have the vision, courage and determination to keep our spiritual focus on the catastrophic circumstances of our society and world. Together with faith, hope and love, we can choose to plant the indestructible seeds of change. □

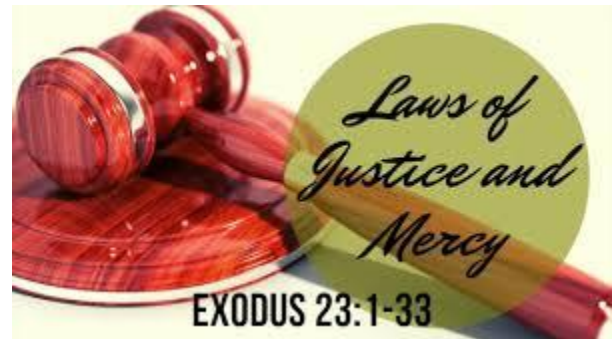
New York Times best-selling author **Cornel West's** latest book, *Hope on a Tightrope: Words and Wisdom* (SmileyBooks), will be released this month.

In the “**Allegory of the Cave**,” **Plato** warned us of the discrepancy between perception and reality and presented an example of how one man learned the difference. Later, **Roger Bacon** warned us not to blindly accept any authority’s view of reality. It is unlikely that we will ever see true reality, but we can do our best to understand it, and the laws of nature can help us with this. If you are interested in the question, what is knowledge as opposed to which answer will get me the most test points, I recommend that you read Jonathan Rauch’s book [*The Constitution of Knowledge: A Defense of Truth*](#). The truth in this book will set you free!



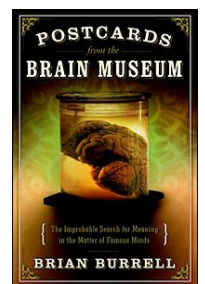
Interestingly, when discussing the laws of justice and mercy and the roles of judges, the Bible suggests that blindness can be caused by bribery:

Exodus 23:8 *Do not accept a bribe, for a bribe blinds those who see and twists the words of the innocent.*

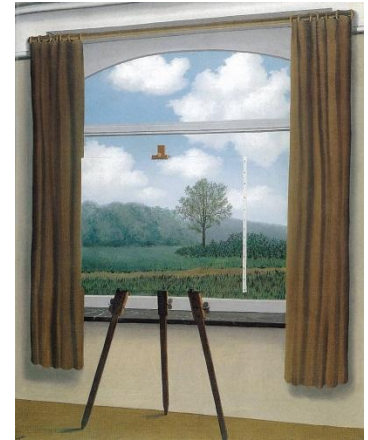


Deuteronomy 16:19: *Do not pervert justice or show partiality. Do not accept a bribe, for a bribe blinds the eyes of the wise and twists the words of the innocent.*

All too often we take the world around us for granted as we quickly and effectively go from all the point A’s in our life to all the point B’s. The reason we are able to take the world around us for granted is because our visual system, composed of our eyes and mind, is so effective in creating a seamless and accurate representation of the world in our mind’s eye. The mind usually creates seamless and accurate perceptions in real time because most of the assumptions, upon which the image processing takes place, are justified.

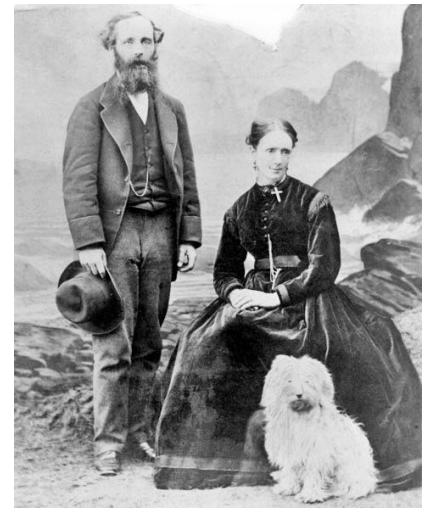


However, our creative mind is also **playful** and plays tricks on us. This can be joyful and fun, especially when looking at optical illusions. The playfulness may be a design feature or an evolutionary adaptation to remind us not to take ourselves too seriously. But if we really want to know something about the **natural, real, and objective world** around us, and this applies especially to natural scientists (Tolansky, 1964), we have to get to know the value and limitations of our **assumptions** and how we use our minds to construct our personal hypotheses about the natural world, and how these personal hypotheses can be **generalized** into **laws of nature**. It is the human condition (Magritte, 1933) that we have an amazing ability to distill out the **laws of nature**, which is a shared image of the world, from the paintings on our retinas and the images created immediately by our mind's eye.



What are the advantages of knowing the laws of nature?

In his inaugural lecture at Aberdeen, James Clerk Maxwell (1856) said, *“Now I would begin to answer this question by directing your attention to the method of teaching in a University. The same set of students meet at stated hours during the whole session with scarcely a day's intermission. Does not this seem as if we had some one thing to do requiring steady resolution and repeated efforts. And is not that one thing to learn something of the first principles of the works of nature, the rudiments of the creation so that we may no longer be oppressed with the multitude of wonders, but rather confident that as we have recognized the operation of general principles in some instances, so in due time we shall discover*



more and more that the whole system of nature is disposed according to a wonderful order.

Indeed the very fact that these general principles are to be found shows that it is needless to bewilder our minds with an accumulation of detached facts for in the light of the great laws of nature these facts are no longer detached and bewildering, but necessary consequences of principles which they illustrate. When we have once made our minds familiar with one or two great physical laws we begin to look upon the Universe as a realization of the highest principles of Order and Beauty and we are prepared to see in Nature not a mere assemblage of wonders to excite our curiosity but a systematic museum designed to introduce us step by step into the fundamental principles which are displayed in the works of Creation.”

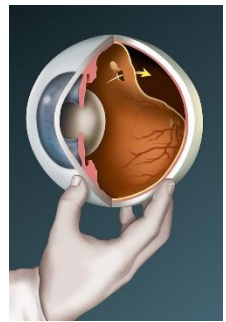
The mind is a *sine qua non* for seeing the world in a meaningful way. **Do you see what I mean?** The image in our mind’s eye of reality is much like a scientific theory used to describe and explain reality. Both must be considered provisional, and both must be tested by experience. According to Joseph Priestley (1787), “*The great superiority of man over brutes consists in the greater comprehensiveness of his mind, by means he is, as it is commonly expressed, capable of reflection....*” In *The Everlasting Gospel*, William Blake wrote about the importance of the mind/soul in seeing:

*This life's five windows of the soul
Distorts the heavens from pole to pole
And leads you to believe a lie
When you see with, not through, the eye.*

People with **anorexia nervosa** give us another example of the discrepancy between what we see and what is real. Anorexia is a life-threatening eating disorder that can affect anyone. It causes people to starve themselves and become emaciated. However, when they look in the mirror, they do not see an emaciated body but an image of an obese body.



[Phoebe Gloeckner](#), a graphic illustration, illustrated the relationship of the eye and the mind like so:



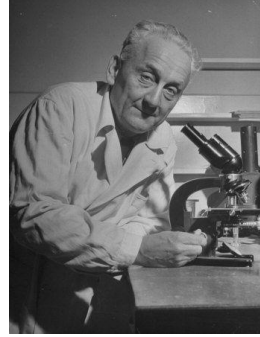
Iain McGilchrist (2025), the Chancellor of [Ralston College](#), writes, “[p]eople often ask me what they should do to redress the balance between the brain hemispheres. The first step to recovering anything is to be aware of how much you are missing by your way of being in the world. So the first question to ask yourself should be: what does my particular take on reality exclude from my vision?”



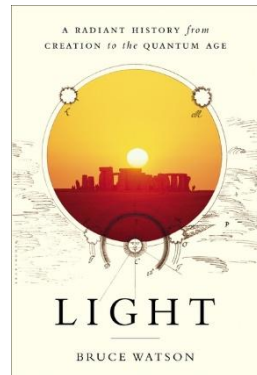
After realizing that she had heard two opposing stories about the circumstances of her birth, one that she was born on a bed of roses and the other that her mother was hemorrhaging as she was born, **Ruth Wisse** (2021) wrote in her autobiography *Free as a Jew*, “My later attraction to **literature over other forms of knowing** had something in common with this realization that **truth was not reducible to any single interpretation of the known facts.**” Let’s not from the beginning exclude “other forms of knowing” in our search for truth.



Albert Szent-Györgyi (1985) described the relationship of the eye and the mind like so: “*Discovery consists of looking at the same thing as everyone else and thinking something different.*”



Bruce Watson wrote an excellent book on light from creation to the quantum age.

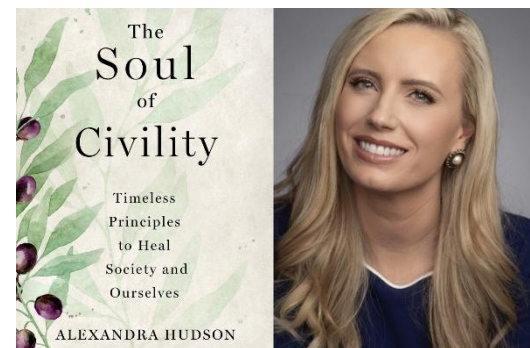


I will not teach and test you on my own conclusions but will teach you to come up with your own conclusions by reflecting on the things that I present to you and by turning the knowledge presented in this class into your own ideas, your own perspective, your own wisdom. ***Remember, do not believe anything I say.*** I will not try to convince you of anything but will give you the resources to stoke your inner fire of passion, logic, and reason so that you can come to your own well-conceived and well-thought-out conclusions and convictions. What is right for one person may not be right for someone else and it follows that there may be many different yet correct answers to test questions. As [Socrates](#) said, “*For it is not from any sureness in myself that I cause others to doubt: it is from being in more doubt than anyone else that I cause doubt in others.*” Throughout this semester, we will do experiments and make observations that will assist you in developing your own conclusions. That is, to make a judgement with *logos*—a reasoned argument based on first principles or what Socrates called in [Theaetetus](#), the elements. I will

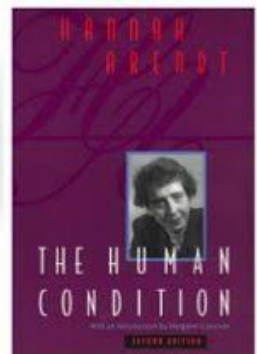
teach at a level that, in the words of Arthur C. Clarke (1974), “*all the fundamental problems and their solutions can be understood even by anyone who is terrified at the thought of [changing a burned-out lamp-bulb](#).*” I want to teach you to make up your own mind, and to make arguments, not based on **talking points** that have become the foundation of groupthink but based on having a **line of reasoning** that seems to be closest to the truth. Knowledge obtained in this way will not only develop **strong minds** but also **tough skins**. That is, **character**.



On that note, Alexandra Hudson (2023) reminds us in *The Soul of Civility*, “*The Greek word logos overlaps both ‘reason’ and ‘speech,’ two attributes that only humans possess. Our communication today undermines the historical connection between speech and reason: new technologies often deploy communication to inflame passions instead of nurturing our reason.*”



Hannah Arendt (1958) wrote in [The Human Condition](#) about the influence of science in undermining meaningful communication. Arendt wrote, “*While such possibilities still may lie in a distant future, the first boomerang effects of science's great triumphs have made themselves felt in a crisis within the natural sciences themselves. The trouble concerns the fact that **the ‘truths’ of the modern scientific world view, though they can be demonstrated in mathematical formulas and proved technologically, will no longer lend themselves to normal expression in speech and thought.** The moment these ‘truths’ are spoken of conceptually and coherently, the resulting statements will be ‘not perhaps as meaningless as a ‘triangular circle,’ but much more so than a ‘winged lion’*” (Erwin Schrodinger). *We do not yet know whether this situation is final. But it could be that we, who are earth-bound creatures and have begun to act as though we were dwellers of the universe, **will forever be unable to understand, that is, to think and speak about the things** which nevertheless we are able to do.*



In this case, it would be as though our brain, which constitutes the physical, material condition of our thoughts, were unable to follow what we do, so that from now on we would indeed need artificial machines to do our thinking and speaking. If it should turn out to be true that knowledge (in the modern sense of know-how) and thought have parted company for good, then we would indeed become the helpless slaves, not so much of our machines as of our know-how, thoughtless creatures at the mercy of every gadget which is technically possible, no matter how murderous it is.

*However, even apart from these last and yet uncertain consequences, the situation created by the sciences is of great political significance. **Wherever the relevance of speech is at stake, matters become political by definition, for speech is what makes man a political being.** If we would follow the advice, so frequently urged upon us, to adjust our cultural attitudes to the present status of scientific achievement, we would in all earnest **adopt a way of life in which speech is no longer meaningful.** For the sciences today have been forced to adopt a ‘language’ of mathematical symbols which, though it was originally meant only as an abbreviation for spoken statements, now contains statements that in no way can be translated back into speech. The reason why it may be wise to distrust the political judgment of scientists qua scientists is not primarily their lack of ‘character’—that they did not refuse to develop atomic weapons—or their naivete—that they did not understand that once these weapons were developed they would be the last to be consulted about their use—but precisely the fact that **they move in a world where speech has lost its power. And whatever men do or know or experience can make sense only to the extent that it can be spoken about.** There may be truths beyond speech, and they may be of great relevance to man in the singular, that is, to man in so far as he is not a political being, whatever else he may be. **Men in the plural, that is, men in so far as they live and move and act in this world, can experience meaningfulness only because they can talk with and make sense to each other and to themselves.**”*

According to Emily Dickinson, our brain has a boundless capacity:

The Brain — is wider than the Sky

by Emily Dickinson

The Brain — is wider than the Sky —

For — put them side by side —

*The one the other will contain
With ease — and You — beside —*

*The Brain is deeper than the sea —
For — hold them — Blue to Blue —
The one the other will absorb —
As Sponges — Buckets — do —*

*The Brain is just the weight of God —
For — Heft them — Pound for Pound —
And they will differ — if they do —
As Syllable from Sound —*

And when we are in love, we can see the world through our lover's eyes. [Graham Nash](#), of [Crosby, Still and Nash](#), wrote [Lady of the Island](#) about Joni Mitchell:

*Holding you close undisturbed before a fire
The pressure in my chest when you breathe in my ear
We both knew this would happen when you first appeared
My lady of the island*

*The brownness of your body in the fire glow
Except the places where the sun refused to go
Our bodies were a perfect fit in afterglow we lay
My lady of the island*



Letting myself wander through the world inside your eyes

You know I'd like to stay here until every tear runs dry

Do, do, do, do, do, do, do

My lady of the island

Wrapped around each other in the peeping sun

Beams of sunshine light the stage the red light's on

I never want to finish what I've just begun with you

My lady of the island

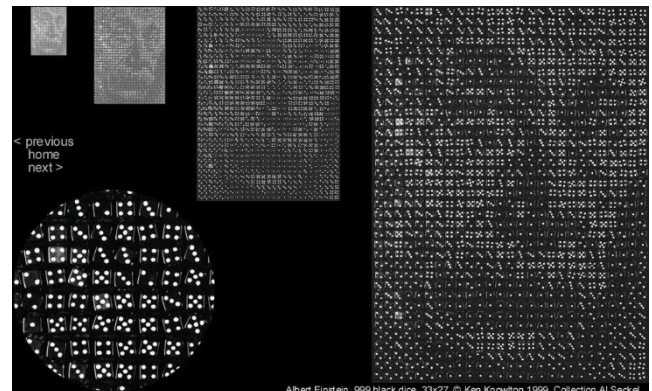
Do, do, do, do, do, do, do

I'll end with a reference to divinity. Ken Knowlton (1999)

(<http://www.knowltonmosaics.com/pages/AEdice.htm>) created a mosaic out of dice called, “**God Does Not Play Dice with the Universe**” that is now in the collection of Al Seckel

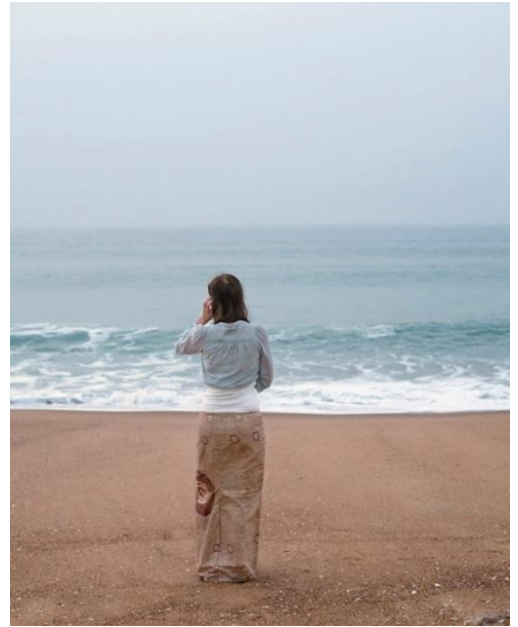
(http://www.ted.com/talks/al_seckel_says_our_brains_are_mis_wired.html) .

When you stand back from the mosaic, Albert Einstein's face appears. In contrast to many of his contemporaries and almost all current scientists, Einstein did not believe that the Uncertainty Principle of Quantum Mechanics was fundamental.



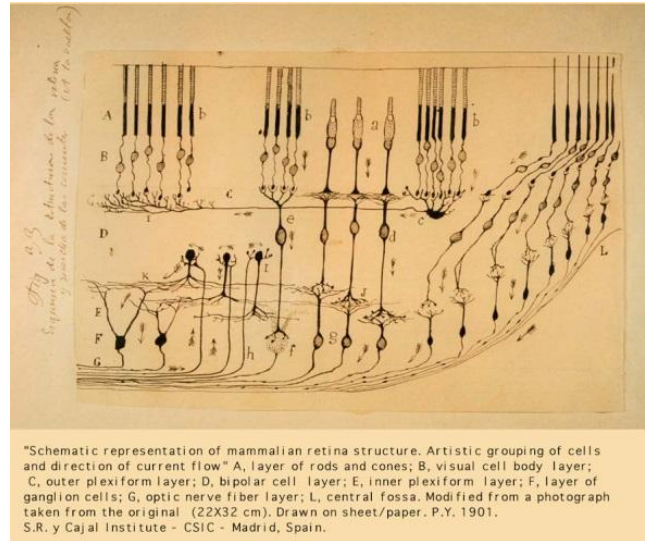
Light and Life: Geometrical Optics and Image Formation

As Plato advised us in the “*Allegory of the Cave*,” we can discover and learn the **rules** that relate our perception of reality to reality itself. Today we will talk about the mathematical or geometrical rules known as the **laws of reflection and refraction** that relate the perceived image to the real object. But before we do, I want to remind you of two illusions that demonstrate that the rules that relate perception to reality are not limited to those that are mathematical or geometrical. As Bishop Berkeley predicted, there are also higher-order and “wholistic” rules than cannot be **reduced** currently if ever to geometry.

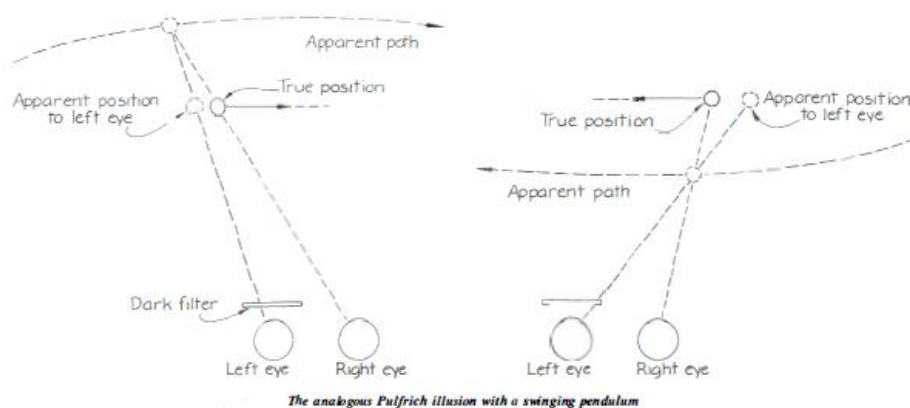


Last class we experienced the **Pulfrich pendulum effect**, which taught us that our **perception** of an object is *not* determined solely by the physical distribution of **light energy** at a given point in **space** at a given instant in **time**. Is this illusion an evolutionary maladaptation and/or a deficiency in the design of the visual system or a consequence of evolutionary adaption and/or good design? The eye that we cover with a neutral density filter while observing the Pulfrich pendulum illusion becomes dark-adapted, and the rods become the primary photoreceptors (**skotopic vision**). Rods are sensitive to minute levels of light, but the high sensitivity of the rods can result in their occasional “misfiring” in the dark. In order to prevent the perception of would-be annoying twinkling noise from this misfiring, several rods are connected to a single bipolar cell in the retina. Together, the neural cells in the retina **integrate spatially and temporally** the output from several rods so that the ganglion cell only transmits a signal to the brain when the

inputs from the rods surpass a threshold. This integration increases the signal-to-noise ratio by pooling weak signals in the dark-adapted eye before sending an impulse to the brain and withholding from the brain any isolated signal that would most likely represent would-be annoying twinkling noise.



As a result of the **neural integration**, the dark-adapted eye sends a delayed impulse to the brain that reports on the past position of the apple while the light-adapted eye (**photopic vision**), which relies on the **cones** of the **fovea**, sends an immediate impulse to the brain that reports the nearly present position of the apple. At any instant, the brain receives two messages—one from the light-adapted eye that gives the nearly-present position of the apple and one from the dark-adapted eye that gives the past position of the apple. The mind combines the two images seen at two times into one image. Consequently, we interpret the two messages to mean that the apple is farther away when it moves from the covered eye towards the uncovered eye and closer when the apple moves from the uncovered eye towards the covered eye.



The Pulfrich pendulum effect is not necessarily a maladaptation or a design flaw, but a happy consequence of the adaptive and well-designed ability of the neural cells to “**rule**” over the rods they are connected to in order to minimize distracting twinkling. This rule increases the signal-to-noise level in dim light by performing an integration, which is similar to **freshman-level calculus**. Perhaps it is possible, as Richard Dawkins (1987) wrote in “*The Blind Watchmaker*,” “*to understand [a complex process such as vision] in terms of simpler parts that we do already understand.*” Taking his hierarchical reductionism to the limit, Dawkins **believes** that complex objects and processes will be “*ultimately explained in terms of the smallest of fundamental particles.*”

When we see the **waterfall illusion**, it is because the neurons in the brain (at least in a cat’s brain in which the electrophysiological experiments have been done) “**rule**” over what we (or the cat) perceive. When we look at a constantly moving object, such as a waterfall, the mind seems to consider it “status quo and safe” and the neurons in the brain that are involved in sensing motion adapt. Consequently, when we change the input to these neurons by looking away or stopping the motion, we temporarily perceive stationary objects as objects moving in the opposite direction. The illusion seems to be a consequence of our mind reducing the priority of constant velocity and increasing the priority of acceleration (= change in velocity). This seems reasonable to anyone who may be considered to be someone else’s dinner.



Our fovea focuses on one small area of the real world and the image that falls on the rest of the retina may not make it into our consciousness. In this video,

[Dan Simons](#) asks people to count how many times the white team passes the ball. Almost everyone gives the correct answer: 15. But when he asks them if they saw the gorilla, they say no. This means we have selective attention. When I watched the [video](#) of the white and black teams passing the ball, I counted the number of passes by the white team, but I did not see the gorilla—even when I already knew that a gorilla would be in the video. I definitely have selective attention—for the good and bad.

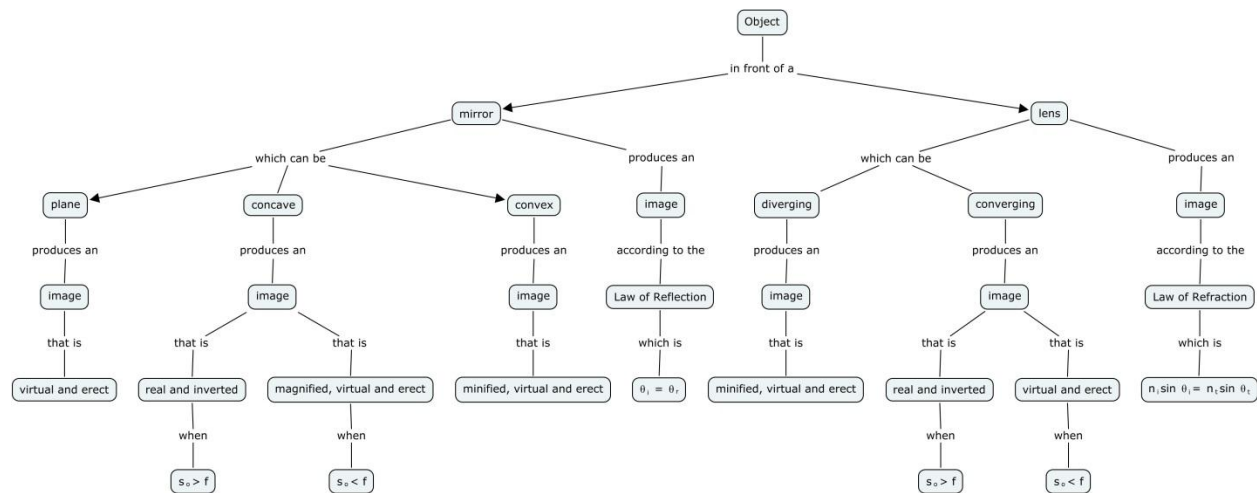


It is generally true that a given **cause** has more than one **effect**. The Pulfrich pendulum effect leads us to the insight that higher-level rules ensure that the sensitivity of dark-adapted vision is good **enough** but not maximal, since maximal sensitivity would cause us to see annoying twinkling. The waterfall illusion leads us to the insight that everything cannot be the highest priority and higher-level rules ensure that **the mind sets priorities** in terms of perceiving movement. The **tradeoff** that occurs when a **part** of the mind cedes its ability to sense constant movement is that the **whole** mind can be more aware of potentially dangerous movement. Likewise, the selective attention experiment shows us that the mind prioritizes what we aim the fovea at to see. By studying nature, we see the universal truth that **too much of a good thing may not be a good thing** and that **everything has values and limitations**.

This truth is concisely demonstrated by the **camera obscura**. We saw that when a piece of translucent vellum is put up to a window it does not produce an image even though it captures most of the image-forming light rays that originate

from each point on the objects outside the window. However, when the number of image-forming rays originating from each given point on the object is limited by a pinhole, *mirable dictu*, an image is formed. In fact, the more the aperture reduces the number of image-forming rays, the sharper the image is. Thus, we see, literally and figuratively, that more of a good thing is not always better. There are tradeoffs here too, since the smaller the aperture, the dimmer the image is, and we see that less of a good thing is not always better either.

While we are talking about the mind, I want to remind you of, or introduce you to, **concept maps**, which were developed by Joe Novak at Cornell University to help students learn science in a meaningful way. A concept map is a concise representation of ideas that answers a specific **focus question**, such as: What is the relation between the object and the image according to geometrical optics? The very act of constructing a concept map develops logical thinking and a deeper understanding of the concepts because a well-constructed concept map reveals hierarchical connections between concepts and tests your understanding of how the parts relate to the whole. **Cmap Tools** is software that can facilitate your use of concept maps and is available to you at no cost at <http://cmap.ihmc.us/>. Here is a concept map that I just drew for the focus question: What is the relation between the object and the image according to geometrical optics?

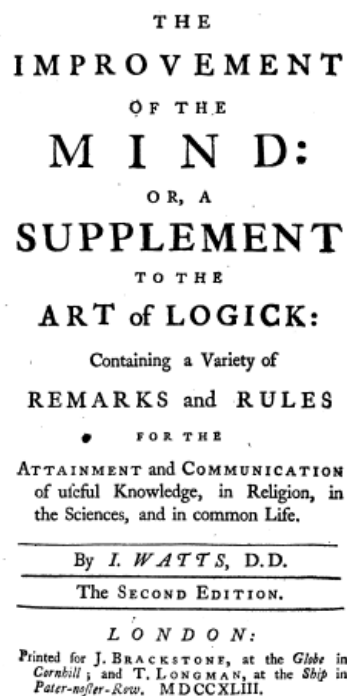


Concept maps are created by first choosing a **provisional focus question**, which is to be answered by the concept map. It is often the case that the focus question gets revised as you construct the concept map as a result of your understanding becoming more refined. The second step in forming a concept map is to think of the **concepts** that are related to the focus question. Then you do triage on the list to glean the most important concepts. In the above case, important concepts included object, image, law of reflection, mirror, law of refraction, lens, real, virtual, inverted, erect, magnified, minified, the object position (s_o) and the focal length (f). The third step is to choose **explicit linking words** that make **meaningful connections**, known as **propositions**, between the concepts. As you develop the propositions in the map, you create a **hierarchy**, through trial and error, that most clearly and completely answer your focus question.

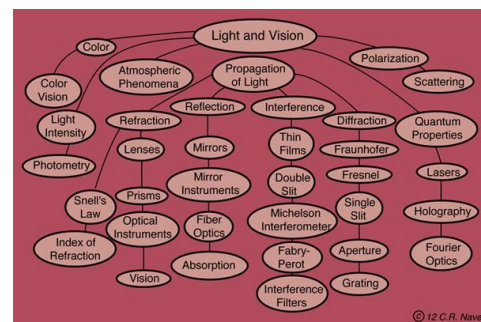
Notice that this concept map does not even mention the eye or the mind. You can create a different concept map that relates the object to the image on the retina by including concepts such as cornea, aqueous humor, pupil, iris, crystalline lens, vitreous humor, and retina. You can also create a concept map that relates the object to the image perceived by the mind's eye. Cmap Tools will allow you to link related concept maps. It will also allow you to build concept maps with other students in the class. Cmap Tools allow you to attach pictures to the concept, which is a great way of using the photographs that you take for your calendar to help you study.

You may be interested in reading the chapter on determining a question in **Isaac Watts' *The Improvement of the Mind***

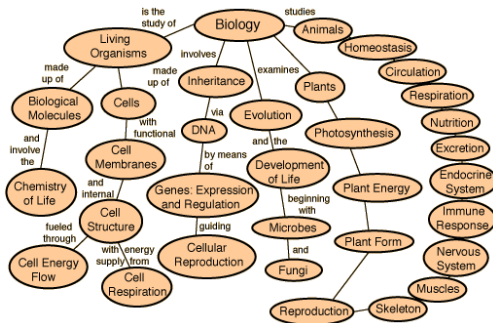
*XII. IN determining a question, especially when it is a Matter of Difficulty and Importance, do not take up with partial Examination, but turn your Thoughts on all sides to gather in all the **Light** you can toward the Solution of it. Take **Time**, and use all the Helps that are to be attain'd before you fully determine, except only where present Necessity of Action calls for speedy Determination.* Aside: Isaac Watts wrote the lyrics to “Joy to the World,” based on [Psalm 98](#).



The HyperPhysics website, (<http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html>) makes use of concept maps to explain many concepts in physics, including concepts related to light and vision (<http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html>).



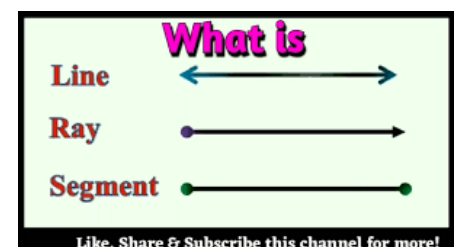
The HyperPhysics website also includes biology concepts
<http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html>):



The size and form of the **shadows** cast by opaque objects such as camels lit by sunlight in the desert, trees lit by moonlight, silhouette images (named after the penny-pinching Étienne de Silhouette), and the Pilobolus dancers lit by stage light can be most clearly and **parsimoniously described and explained** if **light travels in straight lines**. Likewise, the **images** formed in the **camera obscura** can be most clearly and **parsimoniously described and explained** if **light travels in straight lines**.



Geometrically speaking, since light travels in straight lines in a given direction, it is more accurate to state that light travels as a **ray**, which is defined as a line with a single point of origin that extends infinitely in any given direction.

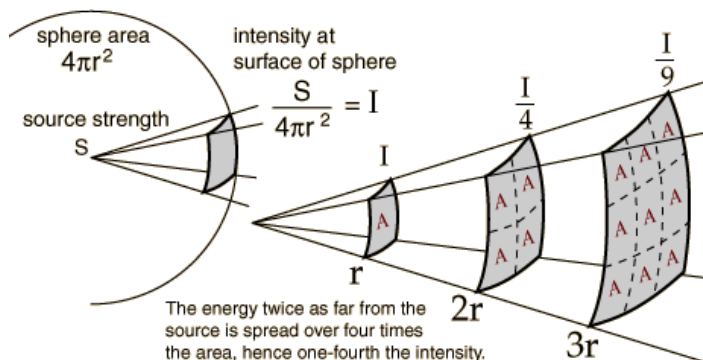
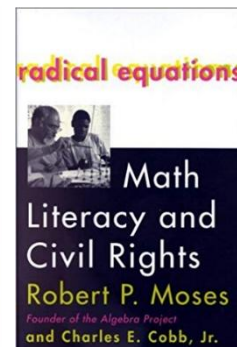


If light rays radiated in straight lines from a point source of light in all directions, the intensity of the light would decrease by the inverse square of the distance. This is because the radiant power (= energy per unit time) from the source would be spread out over a

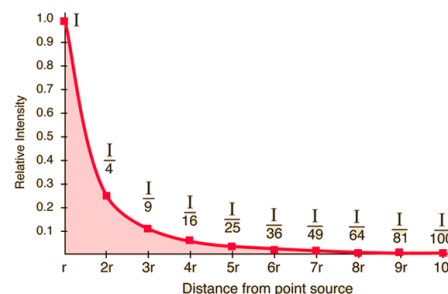
surface whose **area** is proportional to the square of the **distance** from the source. Since the surface area of a spherical surface is given by ($4\pi r^2$) and the distance is given by the radius (r), the intensity (I_r) of

the light striking a constant area at distance (r) from the source is proportional to the radiant power of the source (S_{source}) and inversely proportional to the square of the radial distance. Let's test the **inverse square law**.

$$I_r = \frac{S_{source}}{4\pi r^2}$$

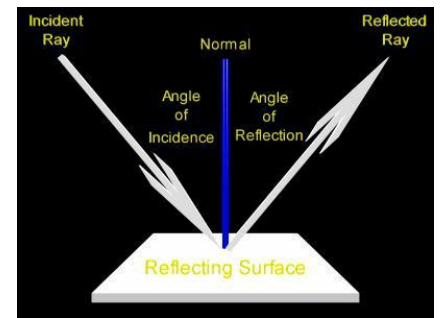


Demonstration: Use a beeswax candle from Monticello as an approximation of a point source of light and measure the intensity at successive distances with a quantum radiometer. Sketch your results and observe the shape of the curve. Are your results described by the **inverse square law**? The quantum radiometer is calibrated in $\mu\text{mol photons m}^{-2} \text{s}^{-1}$ ($= 6.02 \times 10^{17} \text{ photons m}^{-2} \text{s}^{-1}$). We will assume that **corpuscles** of light, which Einstein called *lichtquanten*, and are now universally known as **photons**, are moving out from the source along each **ray**.



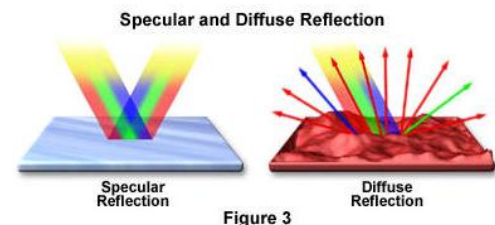
Now we will talk about the influence of **reflection** on **image formation**. We now have sufficient empirical evidence to believe that **light travels in straight lines**. However, as was known by the ancient Greek philosophers, when a light ray strikes a mirror it **changes direction** and travels as a different straight line as described by the **law of reflection**. While the mathematical law of reflection had been known for centuries, Dante Alighieri (1265-1321) poetically described the law of reflection in *Purgatorio* Canto XV of *The Divine Comedy*:

*As when from off the water, or a mirror,
The sunbeam leaps unto the opposite side,
Ascending upwards in the self-same measure
That it descends, and deviates as far
From falling of a stone in line direct,
(As demonstrate experiment and art) . . .*



...or more succinctly, $\theta_r = \theta_i$, **the angle of reflection (θ_r) is equal to the angle of incidence (θ_i)**.

Sunlight is reflected from a shiny metal mirror in such a way that a beam of sunlight, composed of parallel rays is reflected at the same angle relative to the normal as the incident beam that strikes the mirror. The reflected light



leaves the surface as a beam, and this is known as **specular reflection**. However, if the surface that the sunlight strikes is not smooth and shiny, but coarse and rough, the rays that compose the beam strike the surface at many angles and the rays of

light are reflected at those many angles,



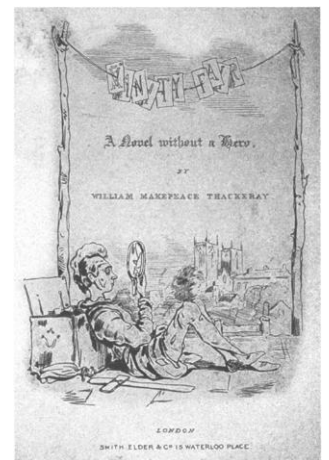
each of which obeys the law of reflection. The reflected light forms a cone, and this is known as **diffuse reflection**. In ancient times, the reflection from polished obsidian (6000 BC), a volcanic stone, or metal (copper or bronze) mirrors was probably more diffuse than and not as specular as the reflection from mirrors we use today made of flat metal-coated glass. I guess that vanity (from the Latin *vanus*, which means empty) is at least 8000 years old and part of human nature.

<http://www.ucl.ac.uk/museums-static/digitalegypt/metal/mirrors.html>

Imagine being lighter than emptiness? **John Bunyan** (1679) wrote in *The Pilgrim's Progress*, “Then I saw in my Dream, that when they were got out of the Wilderness, they presently saw a Town before them, and the name of that Town is *Vanity*; and at the Town there is a *Fair* kept, called *Vanity-Fair*: It is kept all the Year long, it beareth the name of *Vanity-Fair*, because the Town where tis kept, is *lighter then Vanity*; and also, because all that is there sold, or that cometh thither, is *Vanity*. As is the saying of the wise, *All that cometh is vanity*.”

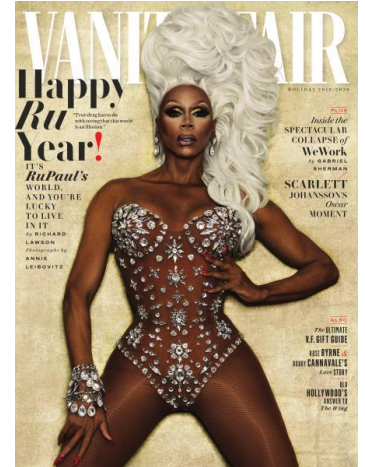


In *Vanity Fair*, **William Makepeace Thackeray** (1848) wrote, *The world is a looking-glass, and gives back to every man the reflection of his own face. Frown at it, and it will in turn look sourly upon you; laugh at it and with it, and it is a jolly kind companion; and so let all young persons take their choice.*



Most of us know *Vanity Fair* as a magazine that reflects the times:

Primitive blown glass mirrors coated with metal were developed in Sidon in Phoenicia in 1 AD. Since blown glass is not as flat as plate glass, these mirrors were small and not very planar. Metal-coated glass mirrors improved. In his encyclopedic book, written in the 13th century entitled, *Speculum Majus* (which is Latin for Large Mirror) that “contains that [which] is worth admiring or imitating among the things that have been done or said, in the world visible and invisible,” **Vincent of Beauvais** (1190-1264) extolled the virtues of tin-coated glass mirrors over polished metal mirrors. By the 16th century, reflective and flat mercury-coated **plate glass** mirrors were produced by Venetian glassmakers. The secret process used to make the excellent mirrors became known throughout Europe as a result of industrial espionage. The toxic mercury was finally replaced with silver, tin, and/or aluminum.



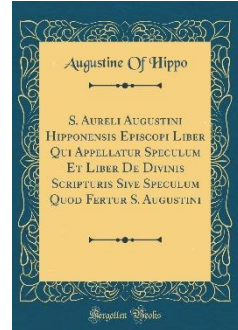
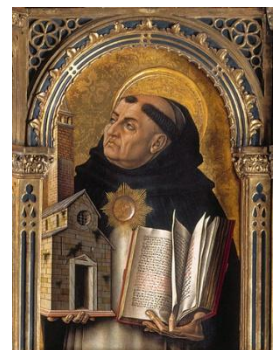
At the time the New Testament was written, the images produced by mirrors (*specula* in Latin) were probably not very sharp. Moreover, the mirrored surfaces were probably made of metal and not glass. Consequently, “*For now we see only a reflection as in a mirror*” was probably anachronistically translated in the 17th century as “*For now we see through a glass, darkly (Videmus nunc per speculum in aenigmate)*” (1 Corinthians 13:12).

As **Roger Bacon** (1214-1292) realized, the Bible makes use of many optical analogies involving reflections. It is written in Proverbs (27:19), “As water *reflects* the face, so one’s life *reflects* the heart.” The apostle James (James 1:23-24) wrote,

“Anyone who listens to the word but does not do what it says is like someone who looks at his face in a mirror and, after looking at himself, goes away and immediately forgets what he looks like.” The importance of the Bible as a mirror became part of Christian thought. **Augustine of Hippo** (427)

extracted the divine precepts from the Old and New Testaments into a single volume that he entitled *Speculum*, for those, who were not great readers, so that they could *reflect* on their obedience to God. **Pope Gregory the Great** (ca. 600) wrote, “*The Holy Bible is like a mirror before our mind's eye. In it we see our inner face. From the Scriptures we can learn our spiritual deformities and beauties. And there too we discover the progress we are making and how far we are from perfection.*”

The word speculation is related to speculum. To **Thomas Aquinas**, speculation meant a consideration of the relationship between two subjects that could be modeled by the relationship between the object and the image produced by a mirror and described by the law of reflection. Thomas Aquinas (ca. 1250) wrote “*To see something by means of a mirror is to see a cause in its effect wherein its likeness is reflected. From this we see that ‘speculation’ leads back to meditation.*”



The church was not always supportive of optical knowledge. In the 13th century there was a movement to protect religious orthodoxy and eliminate heresy—“*any provocative belief or theory that is strongly at variance with established beliefs or customs.*”



The word heresy comes from the Greek word *haireisthai* meaning to choose. **Robert Grosseteste** (1175-1253), a bishop and a scientist, whose optical research (*De Luce*) inspired Roger Bacon, defined heresy as “*an opinion chosen by human perception, created by human reason, founded on the Scriptures, contrary to the teachings of the Church, publicly avowed, and obstinately defended.*” The movement to prevent questioning the orthodoxy was ironically known as the *inquisition*—which means a period of prolonged and intensive questioning (*inquisitio* is Latin for inquiry). During the inquisition, one of the questions in the *Summa de officio inquisitionis* of 1270 was aimed at finding those who practiced divination using reflective objects (catoptromancy, from the Greek word for mirror κάτοπτρον (*kátoptron*), “*Have you conducted experiments with mirrors, swords, fingernails, spheres or ivory handles?*”

The mirror was a very powerful symbol—being capable of reflecting the truth and of producing illusions. The German folk legend of **Till Eulenspiegel** (*eulen* and *spiegel* are the German words for owl and mirror, respectively) describes a trickster born around 1300 who carried a mirror and an owl as he traveled through the countryside exposing injustice, lunacy, and hypocrisy. Richard Strauss put Till Eulenspiegel’s story to music. In the beginning of *Til Eulenspiegel’s*

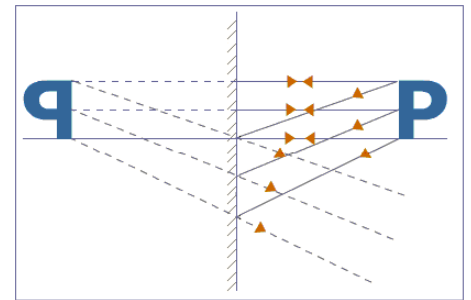


Merry Pranks, the music tells of his trips through the countryside poking fun at and mocking the establishment. The end tells us of his capture by the authorities, his death sentence for blasphemy, and his execution by hanging. After his death, the playful initial musical theme reappears, suggesting that Till Eulenspiegel's message will live forever. <https://www.youtube.com/watch?v=S7O9Oa22nsQ>

Even today, various mirrors tell us about ourselves and the world around us. In analogy to silvered glass mirrors, we ask, do these newspapers and magazines reflect the truth or produce illusion?

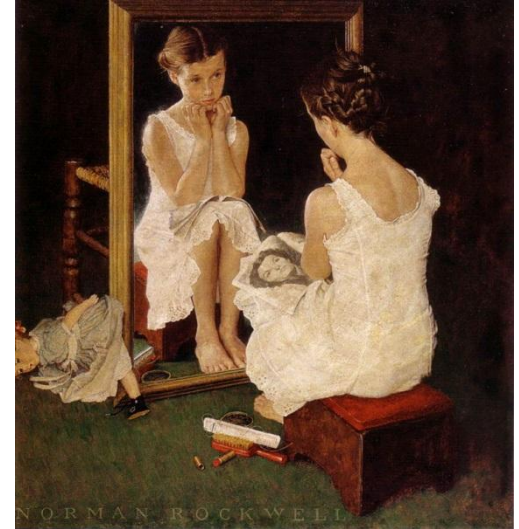


We can determine the position, orientation, and size of an image formed by a **plane mirror** by drawing light rays radiating from at least two different points on the object to the mirror. Then we assume that rays that strike the mirror are reflected in such a way that the angle of reflection equals the angle of incidence. Practically, we find a given image point by drawing two of the infinite number of rays that radiate from a given point on the object. We draw these rays, which are known as **characteristic rays**, using the following rules:

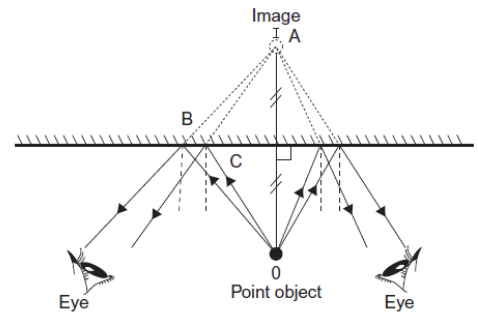


1. From a given point on the object, draw a line perpendicular to the mirror. Because $\theta_i = 0$ then $\theta_r = 0$. Draw the reflected ray and then extend the reflected ray backwards behind the mirror.

2. From the same point on the object, draw another line to any other point on the mirror. Draw the normal to the mirror at this point and then draw the reflected ray using the rule $\theta_r = \theta_i$. Extend the reflected rays backwards behind the mirror, to the other extended reflected ray originating from the same point on the object. The point of **intersection** of the extensions of the reflected rays originating from the same object point is the position of the image of that object point. If the reflected rays **converged** in front of the mirror, which they do not do when they strike a plane mirror, a **real image** would have been formed. A real image is an image that can be projected on a piece of translucent vellum. A real image is composed of radiant energy, and the light intensities of the points that make up a real image can be measured with a light meter. However, since the reflected rays **diverge** from a plane mirror, we extend the rays backwards from where they appear to be diverging. While an image appears in the place from which the rays appear to diverge, a piece of translucent vellum would **not** display an image. The image is **virtual**. The cornea and lens in our eyes collect the rays that seem to diverge from each point in the virtual image and form a real image on the retina. The virtual image appears **only** in our mind's eye.



Oddly enough, we can resurrect the **extramission theory** to help us understand the placement of the virtual image. The mind's eye assumes that the diverging rays originate from a single point behind the mirror. This is exactly where the **visual rays** issuing *from* the eye would converge. Of course, there are no visual rays, and in fact, light from the object actually enters our eyes after it bounces off the mirror. However, the mind knows where it sees the virtual image because of the **neural signals** that travel between our **neck, head,** and **eye muscles**, and our **brain** to let our mind know the direction the eyes are looking in order to see the virtual image.



There is a story told in many cultures about a man who, in ancient times, when mirrors were rare, brought home a mirror as a present for his wife. She looked into the mirror and saw another woman who she immediately assumed was her husband's lover and started yelling at her husband. He looked into the mirror not knowing what his wife was talking about and saw another man who he assumed was his wife's lover. A huge ruckus commenced. Learning the laws of geometrical optics may be good for your relationship!



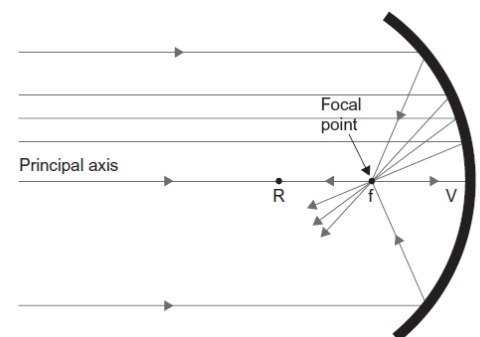
Not all mirrors are planar. We will look at images produced by **concave** and **convex mirrors**.

Demonstration: Place a short candle 40-50 cm from the **convex** mirror and slowly move it toward the mirror and away from you. Describe what happens to the image of the candle as its distance to the convex mirror decreases. Place the candle 40-50 cm from the **concave** mirror and



slowly move it toward the mirror and away from you. Describe what happens to the image of the candle as its distance to the concave mirror decreases. Compare the images made by the concave and the convex mirrors. Place the candle approximately 30 cm from the concave mirror. Find the image with the translucent vellum. Move the candle towards the mirror. Find the image with the translucent vellum. Move the candle away from the mirror. Find the image with the translucent vellum. How does the image formed by the concave mirror on the translucent vellum change with the position of the object?

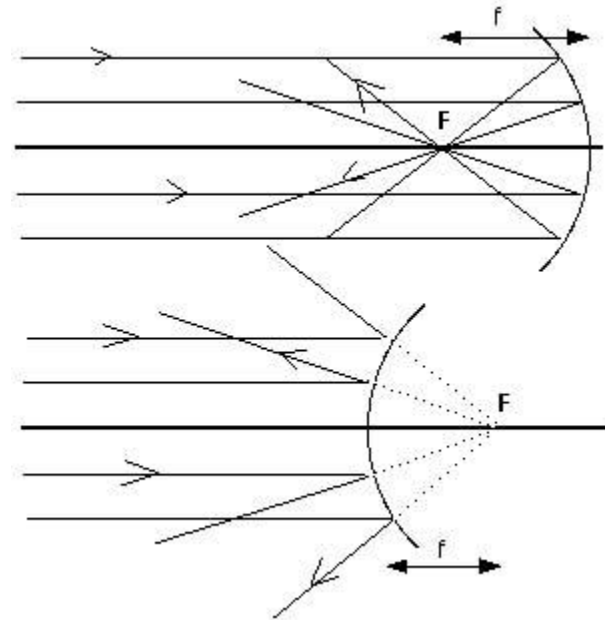
The **center of curvature** of a mirror is defined as the center of the imaginary sphere of which the curved mirror would be a part. The distance between the center of curvature (C) and the mirror itself is known as the radius of curvature (R). For a concave mirror, the radius of curvature is on the object side of the mirror and for a convex mirror, the radius of curvature is on the image side.



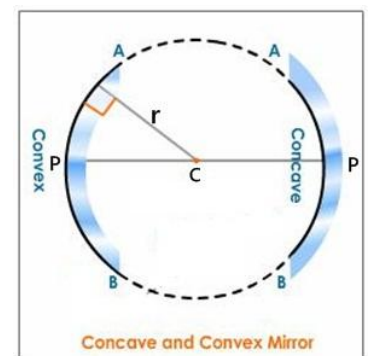
The line connecting the midpoint of the mirror with the center of curvature is called the **principal axis** of the mirror. The **vertex** V represents the intersection of the mirror and the principal axis. The **focus**, which is **positive** for a **concave**

mirror, is on the principal axis midway between the mirror and the center of curvature. The **focal length** of a mirror is the distance between the focus and the vertex.

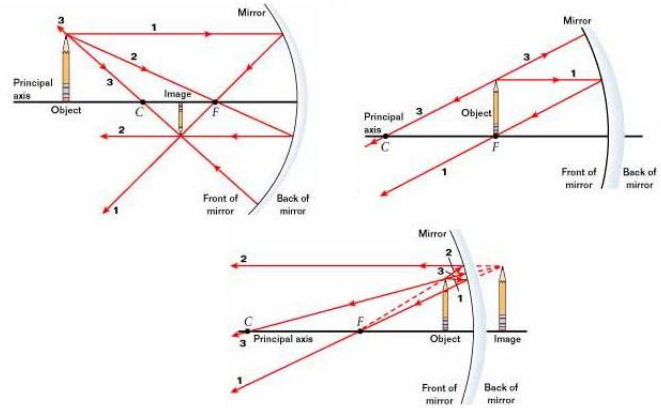
Consider a beam of light that strikes a concave (convex) mirror **parallel to the principal axis**. When a ray of light in this beam moves along the principal axis and strikes the mirror, it is reflected back on itself. When a ray of light in this beam strikes the mirror slightly above or below the principal axis, the ray makes a small angle with the normal and consequently the reflected ray is bent slightly toward (or away from) the principal axis. If the incident ray strikes the mirror farther away from the principal axis, the reflected ray is bent toward (away from) the principal axis with a greater angle. With a concave mirror, in all cases, the reflected rays from every part of the mirror converge toward the **focus**. With a convex mirror, in all cases, the reflected rays from every part of the mirror appear to diverge from the **focus**.



Moreover, a line drawn between the center of curvature and the point on the mirror where a ray parallel to the principal axis strikes, bisects the angle that subtends the incident and reflected rays. Since the line that comes from the center of curvature is radial, it is perpendicular to the surface of the mirror and in all cases, $\theta_r = \theta_i$ and the law of reflection holds.



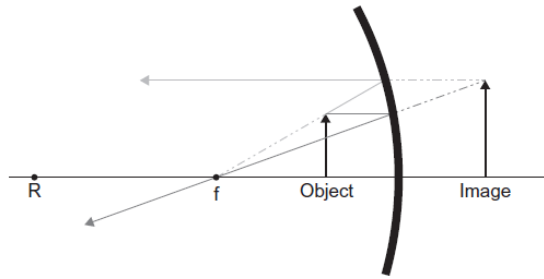
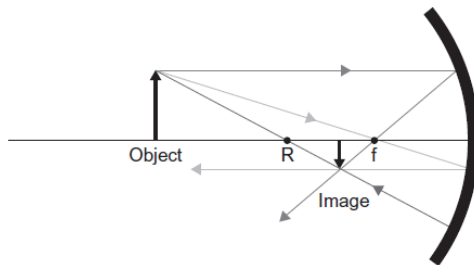
While the position, orientation, and size of the image formed by a **concave mirror** can be determined by any two of the infinite number of rays that radiate from each object point, they are most easily determined by drawing two or three **characteristic rays** that are based on the law of reflection from at least two points on the object (the point on the principal axis is a giveaway):



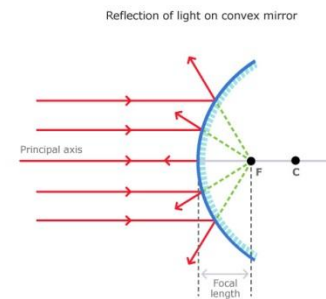
1. A ray traveling parallel to the principal axis passes through the focus (f) after striking a concave mirror.
2. A ray that travels through the focus on the way to the concave mirror or appears to come from the focus, if the object is between the focus and the mirror, travels backwards parallel to the principal axis after striking the mirror.
3. A ray that passes through the center of curvature (R) is reflected back through the center of curvature.

A **real image** of an **object point** is formed at the point where the rays **converge**. If the rays do not converge at a point, a **virtual image** may be formed. To find the virtual image of an object point, one must trace back the **reflected** rays to the point from which the extensions of each reflected ray seem to **diverge**. Tracing the reflected rays backward is geometrically equivalent to tracing the visual rays forward.

Here are examples of image formation by a concave mirror when the object distance is less than or greater than the focal length, respectively.

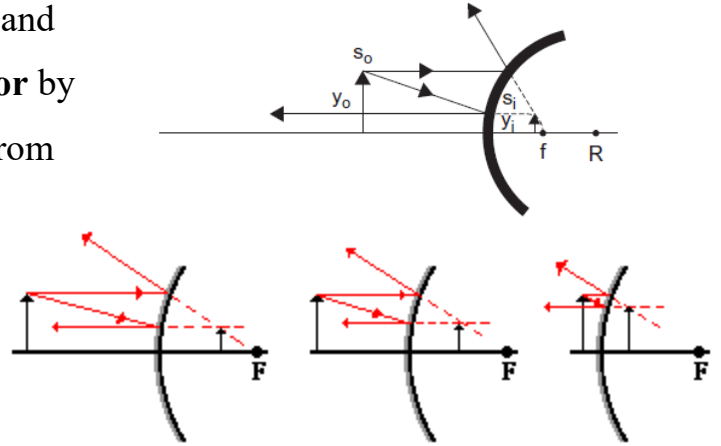


Convex mirrors, by convention, have a positive radius of curvature. When a beam of light parallel to the principal axis strikes a convex mirror, the rays are reflected away from the principal axis and therefore **diverge**. If we follow the reflected rays backward, they appear to originate from a point behind the mirror, known as the **focus**. Since the focus is behind the mirror, f and the focal length are **negative**. We can draw a line between the center of curvature and the point on the mirror where a ray parallel to the principal axis strikes. This line, which is perpendicular to the surface of the mirror, bisects the angle that subtends the incident and reflected rays so that in all cases, $\theta_r = \theta_i$, and the law of reflection holds.



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We can determine the position, orientation, and size of the image formed by a **convex mirror** by drawing two or three **characteristic rays**, from any two points on the object, that are based on the law of reflection (the point on the principal axis is a giveaway):



1. A ray traveling parallel to the principal axis is reflected from the convex mirror as if it originated from the focus (f).
2. A ray that travels toward the focus on the way to the mirror is reflected back parallel to the principal axis after striking the mirror.
3. A ray that strikes the mirror as it was heading toward the center of curvature (R) is reflected back along the same path.

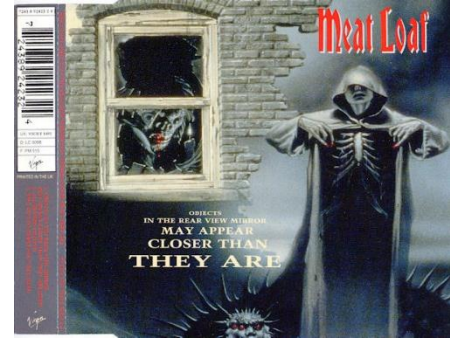
A real image of an object point is **never** formed by a convex mirror. If we trace back the reflected rays to a point from where the extensions of each reflected ray seem to **diverge**, we will find the **virtual image** of the object point. The virtual image is erect and **minified**. The minified image makes us think that the objects are farther than they would appear to be if the mirror were planar, but really, as it says in the convex side view mirror: “*objects in the mirror are closer than they appear.*”



The image formed by a convex mirror can be used as a metaphor. Sometimes events that happened in our past may appear closer than they are:

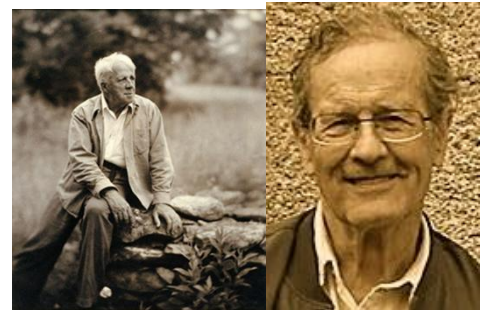
Objects in the Rear View Mirror May Appear Closer Than They Are—[Meat Loaf](#)

*The skies were pure and the fields were green
And the sun was brighter than it's ever been
When I grew up with my best friend Kenny
We were close as any brothers than you ever knew
It was always summer and the future called
We were ready for adventures and we wanted them all
And there was so much left to dream and so much time to make it real
But I can still recall the sting of all the tears when he was gone
They said he crashed and burned
I know I'll never learn why any boy should die so young
We were racing, we were soldiers of fortune
We got in trouble but we sure got around
There are times I think I see him peeling out of the dark
I think he's right behind me now and he's gaining ground
But it was long ago and it was far away, oh God it seems so very far
And if life is just a highway, then the soul is just a car
And objects in the rear view mirror may appear closer than they are
And objects in the rear view mirror may appear closer than they are
And objects in the rear view mirror may appear closer than they are
And objects in the rear view mirror may appear closer than they are.*



Thanks, Robert Frost, by David Ray

*Do you have hope for the future?
someone asked Robert Frost, toward the end.
Yes, and even for the past, he replied,
that it will turn out to have been all right
for what it was, something we can accept,
mistakes made by the selves we had to be,
not able to be, perhaps, what we wished,
or what looking back half the time it seems
we could so easily have been, or ought...
The future, yes, and even for the past,
that it will become something we can bear.
And I too, and my children, so I hope,
will recall as not too heavy the tug
of those albatrosses I sadly placed
upon their tender necks. Hope for the past,
yes, old Frost, your words provide that courage,
and it brings strange peace that itself passes
into past, easier to bear because
you said it, rather casually, as snow
went on falling in Vermont years ago.*



Henri Poincaré (1901): *“To doubt everything or to believe everything are two equally convenient solutions; both dispense with the necessity of reflection.”*



As an alternative to drawing characteristic rays known as **ray tracing**, we can determine **analytically** with the aid of algebra, where the reflected rays originating from a luminous or nonluminous object will converge (or seem to diverge) to form an image. The formula we use is known as the **Gaussian lens equation**:

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}$$

where s_o is the distance from the object to the mirror (in m), s_i is the distance between the image and the mirror (in m), and f is the focal length of the mirror (in m). The magnification (m_T) is defined as $(\frac{y_i}{y_o})$, where y_i and y_o are linear dimensions (in m) of the image and object, respectively, is given by the following formula:

$$m_T = \frac{y_i}{y_o} = -\frac{s_i}{s_o}$$

When using these formulae for concave and convex mirrors, which will be discussed below, the following sign conventions must be observed: s_o , s_i , and f are positive when they are in front of the vertex (V) of the mirror and negative

when behind; and y_i and y_o are positive when they are above the principal axis and negative when below.

When s_i is **positive**, the image formed by a concave mirror is **real**. When s_i is **negative**, the image formed by a concave mirror is **virtual**. The image is erect when m_T is positive and inverted when m_T is negative. The degree of magnification or minification is given by the absolute value of m_T . Let's have a little practice in using the preceding formulae for **concave mirrors**:

Example 1: When an object is placed at infinity ($s_o = \infty$), $\frac{1}{s_o}$ equals zero, and thus $\frac{1}{s_i} = \frac{1}{f}$ and $s_i = f$. In other words, when an object is placed at an infinite distance from the mirror, the image is formed at the focal point and the magnification ($-\frac{s_i}{s_o}$) is equal to zero.

Example 2: When an object is placed at the focus ($s_o = f$), $\frac{1}{f} + \frac{1}{s_i} = \frac{1}{f}$. Thus $\frac{1}{s_i}$ must equal zero and s_i must be equal to infinity. In other words, when an object is placed at the focus, the image is formed at infinity, and the magnification ($-\frac{s_i}{s_o}$) is almost infinite.

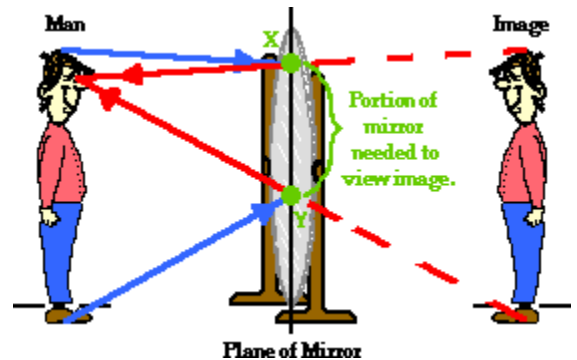
Example 3: When an object is placed at the center of curvature ($s_o = 2f$), then $\frac{1}{2f} + \frac{1}{s_i} = \frac{1}{f}$ and $\frac{1}{s_i} = \frac{1}{2f}$ (remember $\frac{1}{2} - \frac{1}{4} = \frac{1}{4}$). Thus $s_i = 2f$, and the image is real and the same distance from the mirror as the object is. The magnification ($-\frac{s_i}{s_o}$) is minus one, and the image is inverted.

Example 4: When an object is placed at a distance equal to $\frac{1}{2}f$, which is between the focus and the mirror, then $\frac{2}{f} + \frac{1}{s_i} = \frac{1}{f}$. Thus $\frac{1}{s_i} = \frac{1}{f} - \frac{2}{f}$ and $\frac{1}{s_i} = -\frac{1}{f}$, and $s_i =$

$-f$. Since s_i is a negative number, the image is behind the mirror and virtual. Since $-\frac{s_i}{s_o}$ equals +2, the image is erect and twice the height as the object.

The **Gaussian lens equation** can also be used to determine the nature of images produced by **convex mirrors**. For convex mirrors, the focal length is **negative**. To form any image in a convex mirror where f is always negative, s_o must be positive. According to the Gaussian lens equation, $\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}$, s_i will always be negative and the image will always be behind the mirror and virtual. Since $-\frac{s_i}{s_o}$ will always be positive, the image will always be erect.

The **Gaussian lens equation** can also be used to determine the characteristics of an image formed by a **plane mirror** analytically. When light rays parallel to the normal strike the mirror, they are reflected back along the normal and remain parallel. That is, they never converge and the focal length of a plane mirror is equal to infinity, and $\frac{1}{f} = 0$. Thus $\frac{1}{s_o} = -\frac{1}{s_i}$ and $-\frac{s_i}{s_o}$ will always be positive and equal to one. This describes the image in a plane mirror as being erect, the same size as the object, and virtual.

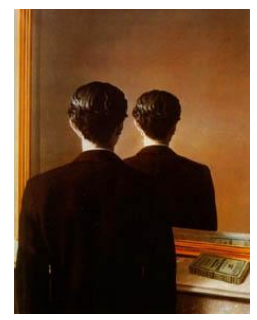


The following table summarizes the nature of the images formed by concave and convex mirrors:

TABLE 2.1 Nature of Images Formed by Curved Mirrors

Location	Type	Location	Orientation	Relative Size
Object		Image in a Concave Mirror		
$\infty > s_o > 2f$	Real	$f < s_i < 2f$	Inverted	Minified
$s_o = 2f$	Real	$s_i = 2f$	Inverted	Same size
$f < s_o < 2f$	Real	$\infty > s_i > 2f$	Inverted	Magnified
$s_o = f$		∞		
$s_o < f$	Virtual	$ s_i > s_o$	Erect	Magnified
Object		Image in a Convex Mirror		
Anywhere	Virtual	$ s_i < f $	Erect	Minified

For fun, which kind of mirror is depicted in each of the following paintings: *John Arnolfini and His Wife* by Jan Van Eyck, *Venus and Cupid* by Diego Rodriguez de Silva y Velázquez, *Self Portrait* by Parmigianino and *La Reproduction Interdite* by René Magritte?



Roy Lichtenstein's *Girl in Mirror* (1964):



John Ashbery (1974) wrote a poem *Self-portrait in a convex* (<http://www.poetryfoundation.org/poetrymagazine/browse/124/5#!/20596528/0> <https://www.youtube.com/watch?v=zrvXX9QVAT8>). Other paintings that depict mirrors include, *Vanity* by Hans Memling; *The Moneychanger and his Wife* by Quentin Metsys; *The Bar at the Folies Bergères* by Edouard Manet; *Joking Couple*

by Hans von Aachen; *Venus in Front of the Mirror* by Peter Paul Rubens; *Venus in Front of the Mirror* by Titian; *Nude Standing before a Mirror* by Henri Toulouse Lautrec; and *Triple Self Portrait* by Norman Rockwell. See <http://larsdatter.com/mirrors.htm>.

Leonardo daVinci wrote, “*Those men who are inventors and interpreters between Nature and Man, as compared with boasters and declaimers of the works of others, must be regarded and not otherwise esteemed than as the object in front of a mirror, when compared with its image seen in the mirror. For the first is something in itself, and the other nothingness. — Folks little indebted to Nature, since it is only by chance that they wear the human form and without it I might class them with the herds of beasts.*”

The set in Christopher Wheeldon's performance of [Stravinsky's *Scènes de Ballet*](#) is a Russian ballet studio bisected by a barre and an imaginary mirror. Sixty-two dancers are divided between “real” dancers and their “reflections.”



How many “real” dancers are in this freestyle dance video called *Mirror Story*? <https://www.youtube.com/watch?v=HzZ1K-IRxA4>



Lucille Ball and Harpo Marx in *I Love Lucy* performing the best [mirror routine](#) in comedy:

B & W: <https://www.youtube.com/watch?v=79EnDc-Ucv8>

Color: <https://www.youtube.com/watch?v=TFLFrHBeu3I>



As long as we consider only the rays that emanate from a given point of an object and strike close to the midpoint of a **spherical** mirror, we will find that these rays converge at a point. However, when the incident rays hit a **spherical** mirror far from the midpoint, they will not be bent sharply enough and will not converge at the same point as the rays that strike close to the midpoint of the mirror. Thus, even though all rays obey the law of reflection, a **spherical** zone of confusion instead of a luminous point results. The **inflation of a point into a sphere** by a spherical mirror results in **spherical aberration**, from the Latin word *aberrans*, which means wandering. While spherical mirrors are abundant since they are easy and cheap to make, Descartes found that the correct shape of a mirror that leads to a perfect focus

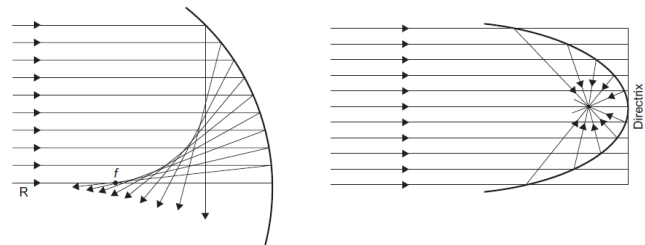


FIGURE 2.11 Because of the law of reflection, where the angle of reflection equals the angle of incidence, a spherical mirror does not focus parallel rays

is **parabolic**. **Chromatic aberration** occurs when parallel rays of light of different colors are not focused to the same point. While spherical aberration occurs in spherical mirrors, chromatic aberration does **not** occur in any mirrors.

Ever wonder why somethings like blackboards, pants, or tree bark are darker when wet? Professor Michael Dorf (1988; Cornell Law) did. It is because the wet layer has a greater refractive index than air so that the wide-angle rays that would have been reflected by the surface in the absence of a wet layer undergo **total internal reflection** at the liquid-air interface and become absorbed by the interface between the surface and the liquid.



Michael C. Dorf

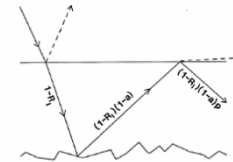


Fig. 1. Liquid layer over a rough surface. The coefficients represent the fraction of the incident light intensity which is transmitted along each path.



Now we will talk about the influence of **refraction** on **image formation**. **Light travels in straight lines** as long as it remains in a single **homogeneous medium**, however, when a light ray traveling through air strikes a **denser medium** (e.g., water or glass) at an **oblique angle** (θ_i) with respect to the normal, the ray is bent toward the normal in the denser medium. The angle that the light ray makes in the denser medium, relative to the normal, is known as the angle of transmission (θ_t). Ptolemy found that the angle of transmission is always smaller than the angle of incidence but never discovered the true relationship.

The true mathematical relationship between the angle of incidence and the angle of transmission was first worked out by Willebrord Snel van Royen in 1621. Snel, also known as Snellius did not publish his work. René Descartes, who independently worked out the relationship, published the relationship in 1637. The law of refraction, which is known as the **Snel-Descartes Law**, states that when light passes from air to a denser medium, the ratio of the sine of the angle of

incidence to the sine of the angle of transmission is equal to a constant, called the **refractive index**. The Snel-Descartes Law can be expressed by the following equation:

$$\frac{\sin \theta_i}{\sin \theta_t} = \frac{n_t}{n_i} = n_t \text{ (when } n_i = 1 \text{)}$$

where n_t is the refractive index of the denser medium and n_i is the refractive index of air ($n_i = 1$). The Snel-Descartes Law can be written more generally as:

$$n_i \sin \theta_i = n_t \sin \theta_t$$

Demonstration: Make a table of the relationship between the angle of incidence and the angle of transmission through water. Check out these two formulaic models:

$$\frac{\theta_i}{\theta_t} = n_t$$

$$\frac{\sin \theta_i}{\sin \theta_t} = n_t$$



Which formula seems to be correct and why does it seem to you to be correct?

Demonstration: In general, the denser a transparent medium, the greater is its refractive index. We can observe this by measuring the refractive indices of 0%, 5%, and 10% (w/v) sucrose solutions with a hand-held refractometer. The solution in the hand-held refractometer bends light in a manner that depends on the refractive index of the solution. The hand-held refractometer is useful to beer and wine makers and is often

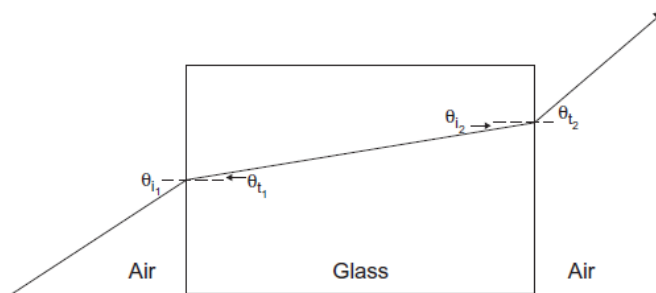


calibrated in degrees Brix instead of refractive index. Degrees Brix is equivalent to the percent sugar (S). The refractive index of the solution = $1.3333 + (0.0018)(S)$.

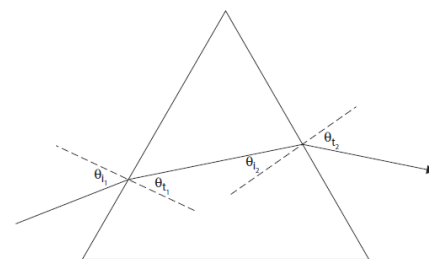
Demonstration: A piece of Pyrex glass becomes invisible when it is placed in a solution of Wesson (soybean) oil, but not in air or water. Can you guess why?



When a light ray passes from **air** through a piece of glass with **parallel edges** and returns to the **air**, the refraction at the far edge **reverses** the refraction at the near edge and the ray **emerges parallel** to the incident ray, although slightly **displaced**. The amount of displacement depends on two things: the **refractive index of the glass** and the **distance the beam travels in the glass**.

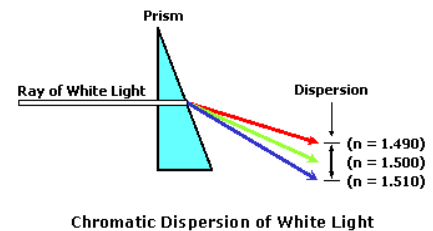


However, when the edges are **not parallel**, the refraction at the far edge will **not reverse** the effect of the refraction at the near edge. In this case, the light ray will not emerge parallel to the incident light ray but will be **bent** in a manner that depends on the shape of the edges. Consider a ray of light passing through a **prism** oriented with its apex upward. If the ray of light hits the normal at an angle from below, it crosses into the glass above the normal and bends towards the normal making a smaller angle with respect to the normal since the glass has a

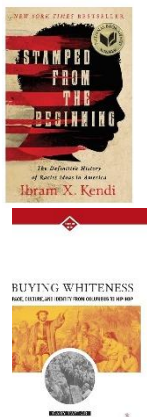


higher refractive index than the air. When the ray of light reaches the glass-air interface at the far side of the prism, it makes an angle with a new normal. As it emerges into the air it bends away from the normal making a larger angle with respect to the normal since the refractive index of air is less than the refractive index of glass. The result is the ray of **light is bent twice in the same direction**.

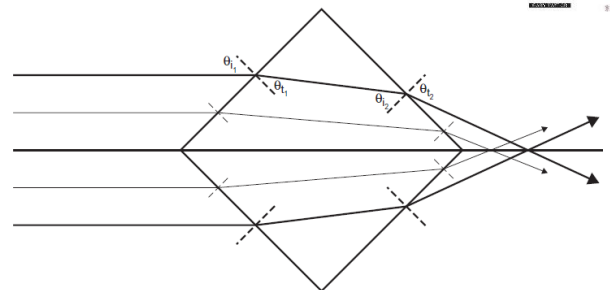
Aside: The refractive index of glass, or the amount it bends light, is not a constant but varies with the color of light. For this reason, as Isaac Newton discovered, a prism splits or **disperses** white light into its constituent colors in the form of a **spectrum**.



In *Stamped from the Beginning*, Ibram X Kendi (2016) states that Newton was a racist since he “*imaged perfect whiteness*,” and wrote that colored light was “*positioned in relation to their ‘distance from whiteness.’*” Kendi’s reference is not from the original work but from Gary Taylor’s (2005) book entitled, “*Buying Whiteness: Race, Culture, and Identity from Columbus to Hip-hop.*”



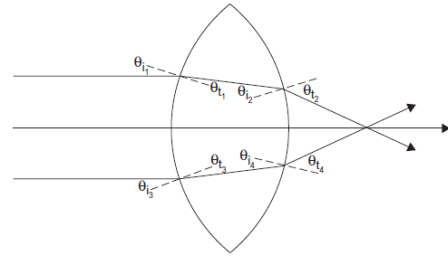
What would happen to a parallel beam of incident light rays that strike two prisms whose bases are cemented together? The light that strikes the upper prism will be **bent downward** toward its base and the light that strikes the lower prism will be **bent upward** toward its base. The



two halves of the beam of light will **converge** and cross on the other side. However, the beam emerging from this double prism will not come to a focus since the rays that strike the two corresponding prisms farther and **farther from the principal axis** all strike at the same angles but travel through **less and less glass**

and thus will converge at greater and greater distances from the double prism. Is there a particular shape of glass that will bring parallel rays to converge at a **focus**?

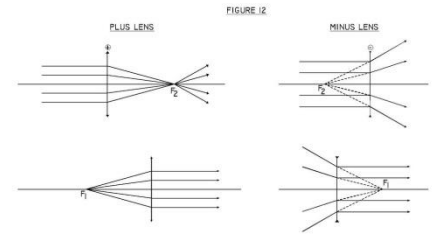
A “**lentil-shaped**” transparent object will cause parallel rays to converge at a focus according to the Snel-Descartes Law and consequently, a **lens** got its name from the Latin word for lentil. Everything is botany!!!!



The ability of a lens to bend or refract light rays is characterized by its **focal length**; the shorter the focal length, the greater the ability of the lens to bend light. A lens with a long focal length is relatively flat and a lens with a short focal length is more curved. The power of a lens to bend light is known as the **dioptric power** (D). It is given by the reciprocal of the focal length in meters:

$$D = \frac{1}{f}$$

Lenses have two **focal points**—an **object focal point** and an **image focal point**. The two focal points, which lie on the principal axis, can be found in this way: The image focal point of a **converging lens** is the place where parallel rays passing through the lens converge. The object focal point of a **converging lens** is where you place a point source of light so that the light that passes through the lens comes out as parallel rays. **Converging lenses have positive focal lengths.**



The image focal point of a **diverging lens** is the place where rays diverging from the lens appear to have diverged from. **The object focal point is where a virtual point source of light seems to be when parallel rays of light emerge from the lens. Diverging lenses have negative focal lengths.**

Demonstration: Place the bayberry candle from Monticello at one end of the desk. Look at it close-up through the 0.5 m (2 D) and then the 1 m (1 D) focal length double convex converging lenses. Describe the images formed by the two lenses. Are the images real or virtual? Erect or inverted? Which one forms the larger image? Then place the 0.5 m and 1 m focal length converging lenses side by side about 2 m away from the candle. Find the images behind the lenses by moving the translucent vellum backwards starting at the back of the lenses. Describe and compare the images that are formed by the two lenses. Are the images real or virtual? Erect or inverted? Which one forms the larger image? Place a -1 m (-1 D) focal length double concave diverging lens immediately behind the 0.5 m (2 D) double convex converging lens. Find the image with the

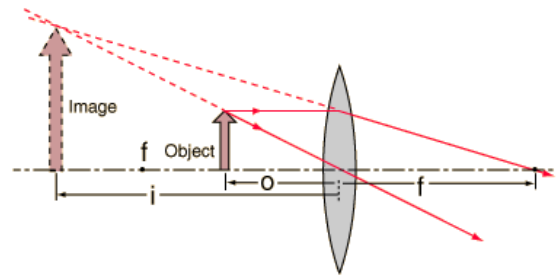


translucent vellum. What happens to the image? Compare it to the images formed by the 0.5 m and the 1m focal length converging lenses.

Bayberry (*Myrica pensylvanica*) grows on the patio of the Plant Sciences Bldg. Why might the berries be coated with wax? Why are plants in general, whether they live in the desert or the tropics, coated with wax?

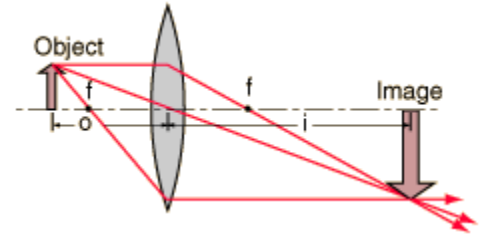


We can characterize the type, location, orientation, and relative size of images formed by converging and diverging lenses using the ray tracing method just as we characterized the images formed by mirrors. We must draw two or three **characteristic rays** from at **least two points** that obey the Snel-Descartes Law (a point on the principal axis is a giveaway):



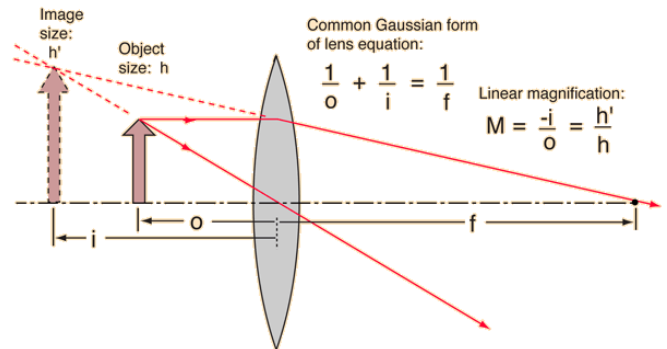
1. A ray that strikes a converging lens parallel to the principal axis goes through the image focus (f_i).
2. A ray that strikes a diverging lens parallel to the principal axis appears to have come from the image focus (f_i).
3. A ray that strikes a converging lens after it passes through the object focus (f_o) emerges parallel to the principal axis.
4. A ray that strikes a diverging lens on its way to the object focus (f_o) emerges parallel to the principal axis.
5. A ray that passes through the vertex (V) of a converging or diverging lens passes through undeviated.

Draw three characteristic rays from each point on the object when the object is **farther than the object focal length** of a **converging lens**. The rays converge and the image is real, magnified, and inverted. As the object moves farther away from the focus, the image goes from magnified to same size to minified.

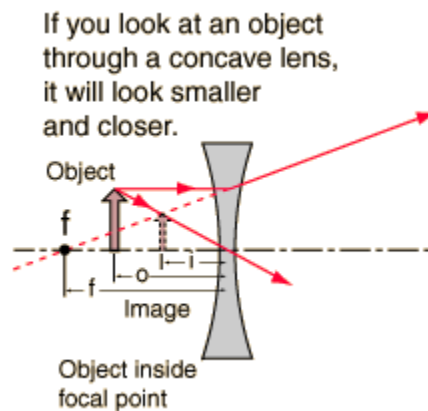
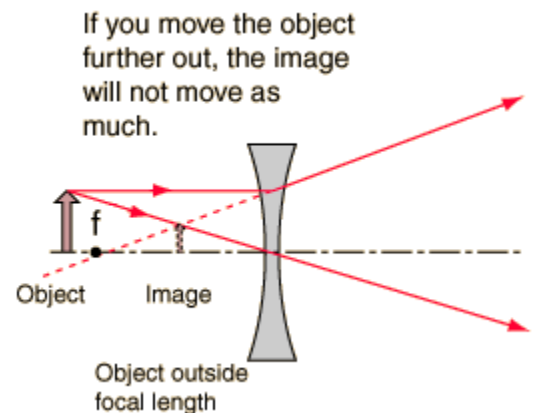


Draw three characteristic rays from each point on the object when the object is **closer than the object focal length** of a converging lens.

Since the rays do not converge, we have to trace them back and see where they appear to diverge from (or where our visual rays seem to converge). The image is erect, virtual, and magnified. As the object moves toward the focus, the magnification increases.



Draw three characteristic rays from each point on the object when the object is anywhere relative to the image focal point of a **diverging lens**. Since the rays do not converge, we have to trace them back and see where they appear to diverge from (or where our visual rays seem to converge). The image is virtual, erect, and minified. As the object is moved farther from the lens, the image will be more and more minified.



As an **alternative to drawing** characteristic rays, we can determine **analytically** with the aid of algebra, where the refracted rays originating from a luminous or nonluminous object will converge to form an image. We use the same **Gaussian lens equation** we used for finding the images formed by mirrors:

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}$$

where s_o is the distance from the object to the lens (in m), s_i is the distance between the image and the lens (in m), and f is the focal length of the lens (in m). A **converging lens** has a **positive focal length (f)** and a **diverging lens** has a **negative focal length (f)**. s_o is positive for a real object in front of the lens. s_i is positive for a real image behind the lens and is negative for a virtual image in front of the lens. The magnification (m_T) is defined by ($\frac{y_i}{y_o}$), where y_i and y_o are linear dimensions (in m) of the image and object, respectively. The magnification is given by the following formula:

$$m_T \equiv \frac{y_i}{y_o} = -\frac{s_i}{s_o}$$

y_i and y_o are positive when they are above the principal axis and negative when they are below the principal axis. When $m_T > 0$, the image is virtual and erect and when $m_T < 0$, the image is real and inverted.

Example 1: When an object is placed at infinity ($s_o = \infty$) in front of a converging lens, $1/s_o$ equals zero, and thus $\frac{1}{s_i} = \frac{1}{f}$ and $s_i = f$. In other words, when an object is

placed at an infinite distance from a converging lens, the image is formed at the focal point and the magnification ($-\frac{s_i}{s_o}$) is equal to zero.

Example 2: When an object is placed at the focus ($s_o = f$) of a converging lens, $\frac{1}{f} + \frac{1}{s_i} = \frac{1}{f}$. Thus $\frac{1}{s_i}$ must equal zero and s_i must be equal to infinity. In other words, when an object is placed at the focus of a converging lens, the image is formed at infinity, and the magnification ($-\frac{s_i}{s_o}$) is almost infinite.

Example 3: When an object is placed at the center of curvature of a converging lens ($s_o = 2f$), then $\frac{1}{2f} + \frac{1}{s_i} = \frac{1}{f}$ and $\frac{1}{s_i} = \frac{1}{2f}$ (remember $\frac{1}{4} + \frac{1}{4} = \frac{1}{2}$). Thus $s_i = 2f$, and the image is real and the same distance from the lens as the object is. The magnification ($-\frac{s_i}{s_o}$) is minus one, and the image is inverted.

Example 4: When an object is placed at a distance equal to $\frac{1}{2}f$ in front of a converging lens, which is between the focus and the lens, then $\frac{2}{f} + \frac{1}{s_i} = \frac{1}{f}$. Thus $\frac{1}{s_i} = \frac{1}{f} - \frac{2}{f}$ and $\frac{1}{s_i} = -\frac{1}{f}$, and $s_i = -f$. Since s_i is a negative number, the image is on the same side of the lens as the object, and it is virtual. Since $-\frac{s_i}{s_o}$ equals $+2$, the image is erect and twice the height as the object.

Example 5: When an object is placed at a positive distance equal to $-\frac{1}{2}f$ (remember that f is negative) in front of a diverging lens, which is between the focus and the lens, then $-\frac{2}{f} + \frac{1}{s_i} = \frac{1}{f}$. Thus $\frac{1}{s_i} = \frac{1}{f} - \frac{-2}{f}$ and $\frac{1}{s_i} = \frac{3}{f}$, and $s_i = \frac{f}{3}$. Since s_i is a negative number, the image is on the same side of the lens as the object, and it is virtual. Since $-\frac{s_i}{s_o}$ equals $+\frac{2}{3}$, the image is erect and two-thirds the height as the object.

The following table summarizes the nature of the images formed by converging and diverging lenses.

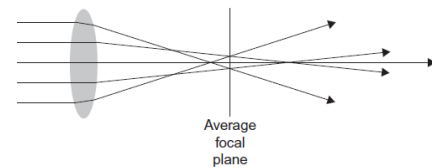
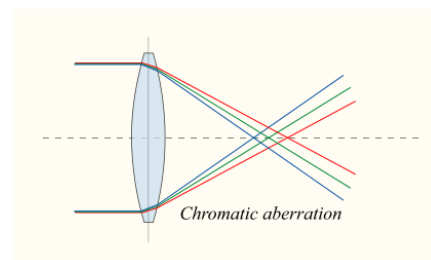
TABLE 2.5 Nature of Images Formed by Lenses				
Location	Type	Location	Orientation	Relative Size
Object		Image Formed by a Converging Lens		
$\infty > s_o > 2f$	Real	$f < s_i < 2f$	Inverted	Minified
$s_o = 2f$	Real	$s_i = 2f$	Inverted	Same size
$f < s_o < 2f$	Real	$\infty > s_i > 2f$	Inverted	Magnified
$s_o = f$		∞		
$s_o < f$	Virtual	$ s_i > s_o$	Erect	Magnified
Object		Image Formed by a Diverging Lens		
Anywhere	Virtual	$ s_i < f $	Erect	Minified

Unlike reflecting mirrors, refracting lenses can have both spherical and chromatic aberrations.

Spherical aberration occurs because the rays from any given object point that hit a lens with

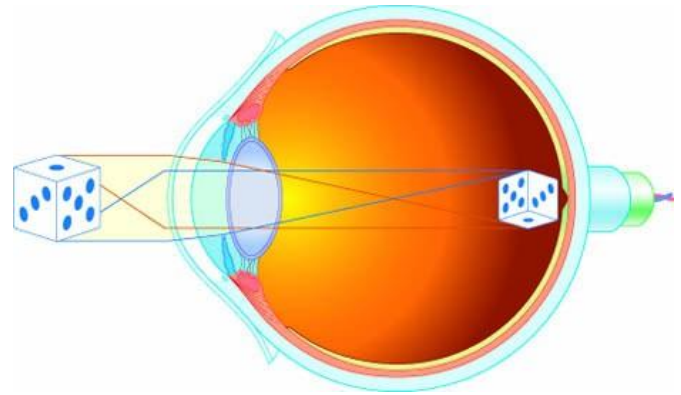
spherical surfaces far from the principal axis are refracted too strongly, resulting in the inflation of a point into a sphere. Spherical aberration can be reduced by molding or grinding the lens so that it has aspherical surfaces or using only the part of the lens close to the principal axis. **Chromatic**

aberration occurs because the refractive index of refracting materials is color dependent. This results in the violet-blue rays being more strongly refracted by glass than the orange-red rays and the image has colored halos.



The **eye** too has some spherical and chromatic aberrations, but it is not noticeable to us. Perhaps a small pupil minimizes these aberrations. Children have larger pupils than adults, indicating that the aberrations may get worse with age.

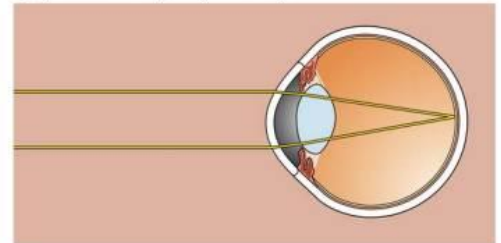
Together, the cornea and the crystalline lens act as a converging lens that produces a real reliable minified image on the retina (**emmetropia**).



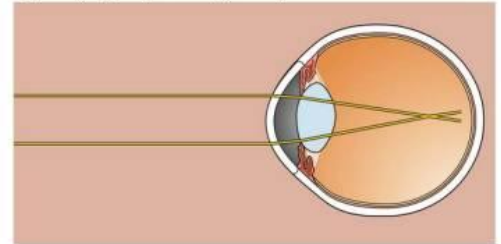
If the focal length of an eye is **too short**, and the dioptric power is too high because the cornea is **too convex** (or the eyeball **too long**), the image will be formed in front of the retina and vision will be nearsighted (**myopia**). Myopia can be corrected by using spectacles with diverging lenses with negative focal lengths and negative dioptric powers. Myopia can also be corrected with Lasik surgery that makes the cornea less convex.

If the focal length of an eye is **too long**, and the dioptric power is too low because the cornea is not convex enough (or the eyeball **too short**), the image will be formed behind the retina and vision will be farsighted (**hyperopia**). Hyperopia can be corrected by using spectacles with converging lenses with positive focal lengths and positive dioptric powers. Hyperopia can also be corrected with Lasik surgery that makes the cornea rounder.

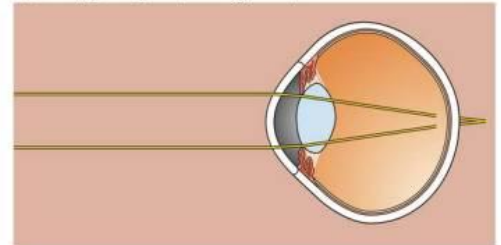
(A) Emmetropia (normal)

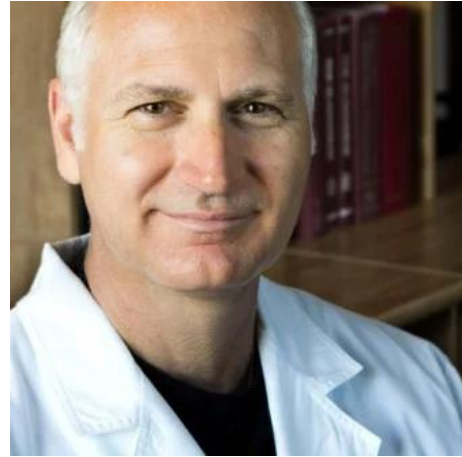


(B) Myopia (nearsighted)

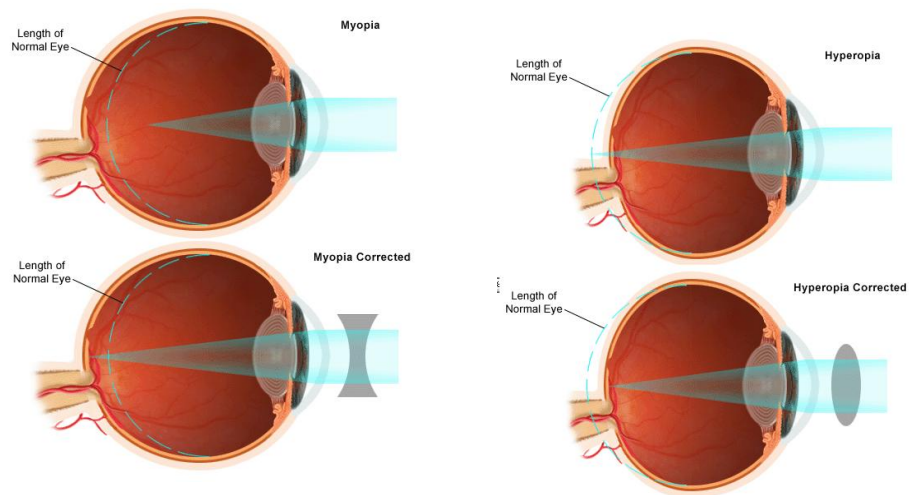


(C) Hyperopia (farsighted)





The effect of spectacles on myopia (nearsightedness) and hyperopia (farsightedness).

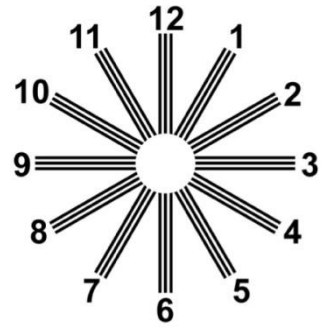


Take an online vision test: <https://www.personaleyeyes.com.au/online-eye-test/index.php> that tests the refraction of your eyes using the Snellen eye chart:

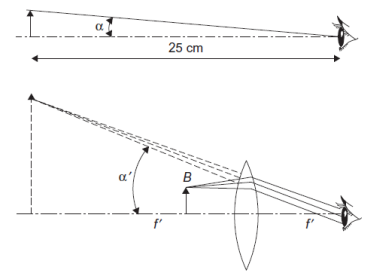
E	1	20/200
F P	2	20/100
T O Z	3	20/70
L P E D	4	20/50
P E C F D	5	20/40
E D F C Z P	6	20/30
F E L O P Z D	7	20/25
D E F P O T E C	8	20/20
L E F O D P C T	9	
F D P L T C E O	10	
P E Z O L C F T D	11	

Note that this is a vision test and not an eye exam performed by an eye doctor which exams eye health as well as vision (<https://www.aoa.org/online-eye-test>; <https://www.cnn.com/2017/03/15/health/online-eye-exam-telemedicine-explainer/index.html>).

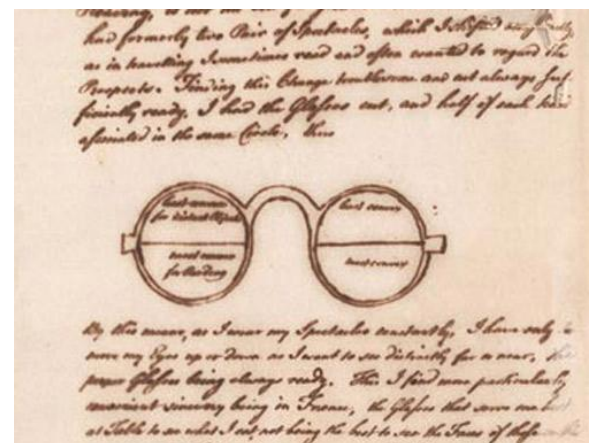
The cornea of some eyes are not symmetrical and the focal length in one radial direction is greater than the focal length in another radial direction. For example in the **astigmatism** test on the right, the lines marked with a 3 may be in focus but the lines marked with a 12 are not. Astigmatism can be corrected with **cylindrical lenses** or with Lasik surgery.



The **cornea** is fixed and can only focus distant objects on the **retina**. The **crystalline lens** is elastic and can change its shape to focus near and far objects on the retina. The ciliary **muscles** contract (**accommodate**) to focus on near objects and relax to focus on distant objects. As one ages, the crystalline lens loses its elasticity and the ability to accommodate decreases. This is called **presbyopia** and it is corrected with reading glasses made with converging lenses. As Roger Bacon realized, a converging lens used as a magnifying glass increases the angle of the light rays that reach the eye for old men!!!



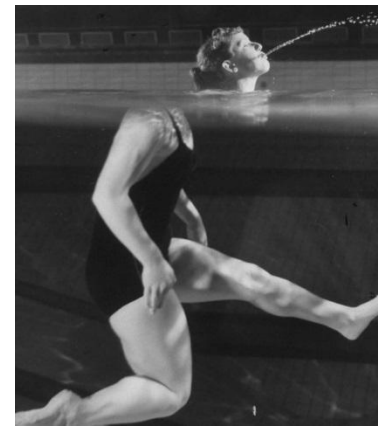
Bifocals are spectacles that contain lenses with two **focal lengths**. Bifocals were invented by **Benjamin Franklin** and are useful for people with **presbyopia** and either near- or far-sightedness.



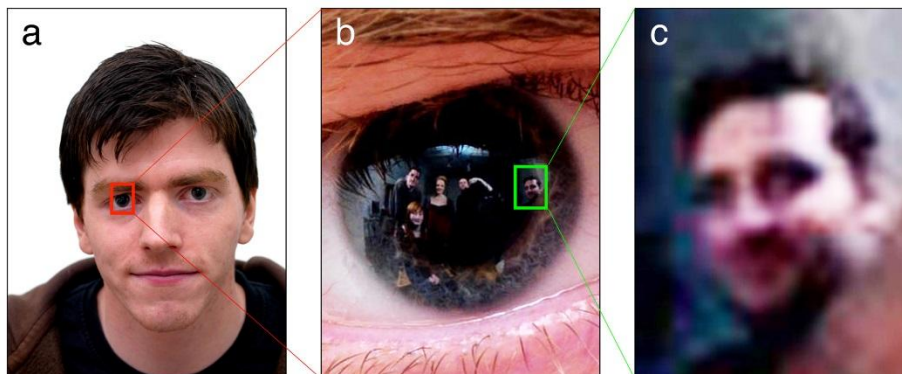
Speaking of two prescriptions, *Anableps* is the four-eyed fish that lives on the surface of the water. It needs one kind of lens to look for food in the air ($n=1$) and another kind of lens to watch for predators in the water ($n = 1.333$) below.



Anyone who gets new glasses knows that the **disagreeable distortions and aberrations** that you first see quickly disappear, not from any change in the glasses themselves, but from a change in the perceiving mind. **The mind knows how to align the perceived image so that it conforms to reality.** Our brain is quite good when it comes to vision, but it still can't fix this:

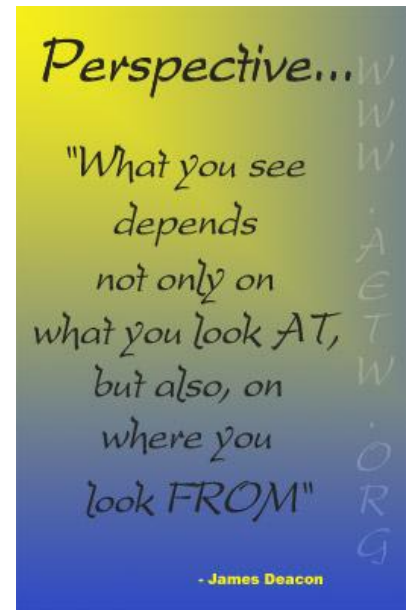


Next lecture we will study the lenses of the eye—but don't forget that the shiny surface of the eye can act as a mirror and reflect the scenery. In fact, as megapixel cameras become more prevalent, zooming in on reflected images in a person's eye may help solve crimes.



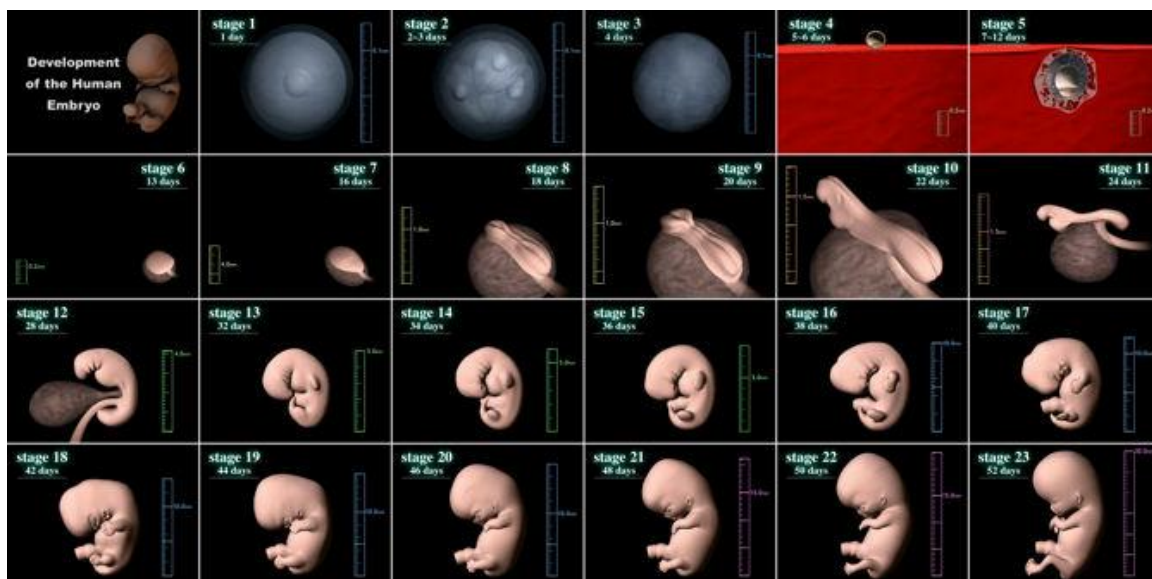
Development, Anatomy, and Physiology of the Eye

The word **perspective** comes from the Latin *per-* “through” and *specere* “look at”. Last week we discussed vision from a **historical perspective** in order to understand how Johannes Kepler, René Descartes, and Bishop Berkeley discovered the importance of the mind in effecting vision. Next, we discussed image formation from a **geometrical and analytical perspective** in order to understand how Euclid, Ptolemy, Alhazen, Kepler, Snel, and Descartes discovered how images were formed by reflecting and refracting elements, including metallic mirrors, glass lenses, and the proteinaceous cornea and crystalline lens of our eye. Today we will talk about the eye and its connections with the brain from the perspective of development, anatomy, and physiology.



Our eyes develop to a large extent while we are in the womb from the fourth to the tenth week (28-70 days) following conception:

(https://embryology.med.unsw.edu.au/embryology/index.php/Carnegie_stage_13).



Following conception, which is when a sperm from the male fertilizes an egg produced by the female, the fertilized egg divides to form tissues that will connect the embryo to the mother, yolk cells that will give rise to the germ cells, and stem cells. The **embryonic stem cells** give rise to the three embryonic tissues.

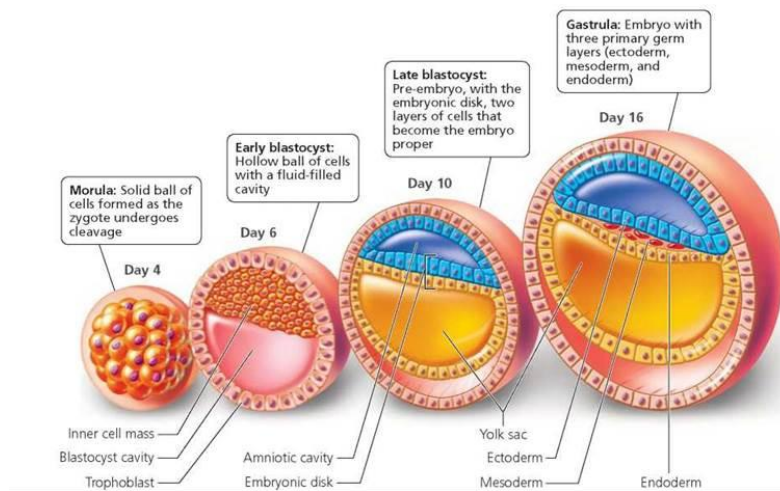
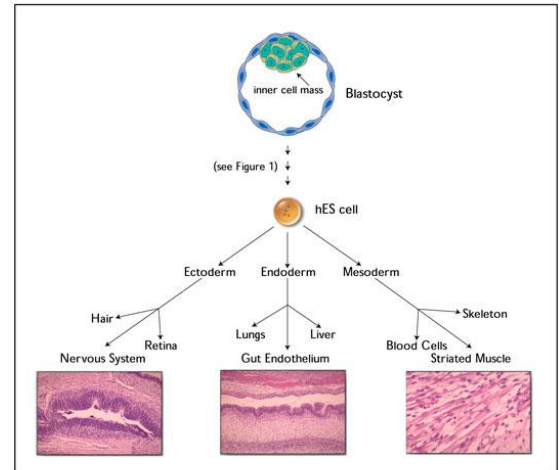
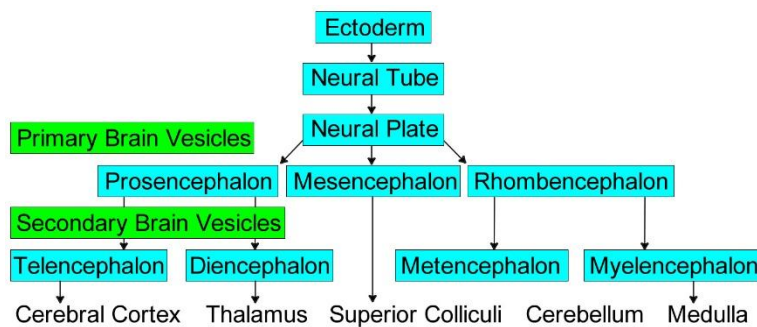
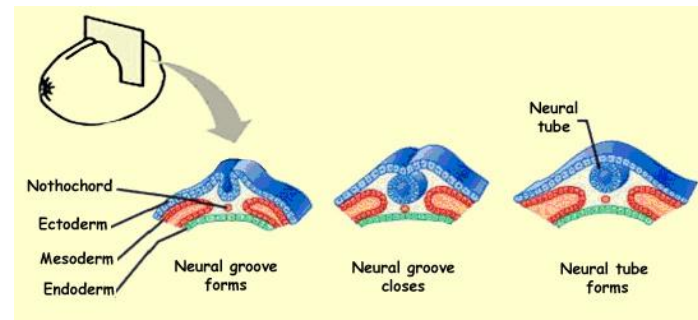
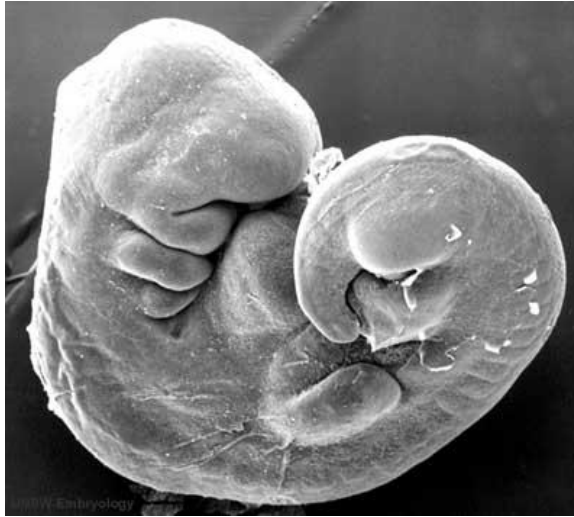
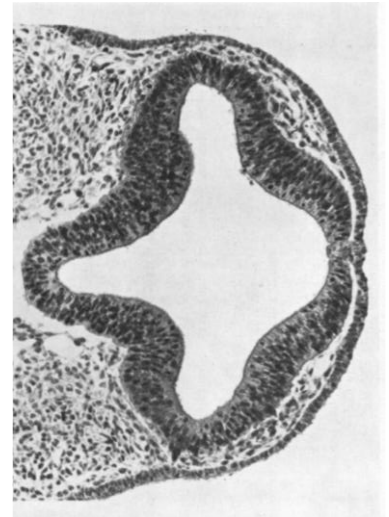


Figure 2: Differentiation of hES Cells into Three Germ Layers

Our eyes have their origin in these embryonic tissues: the lens and the cornea as well as the optic nerve, the retina and the epithelial layers of the iris and ciliary body are derived from the **ectoderm**, while the rest is derived from the **mesoderm**.

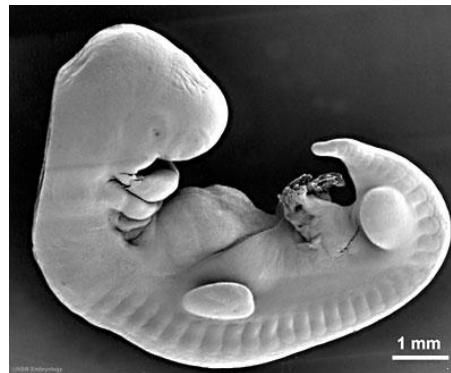
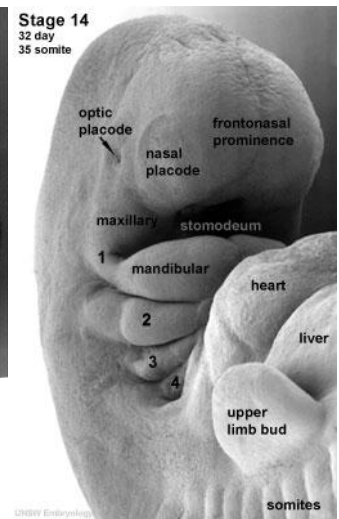


Approximately **four weeks** (28 days) after conception, the **forebrain**, which is derived from the **ectoderm** and from which the optic nerve, the retina, and the epithelia of the ciliary body develop, pushes its way into the

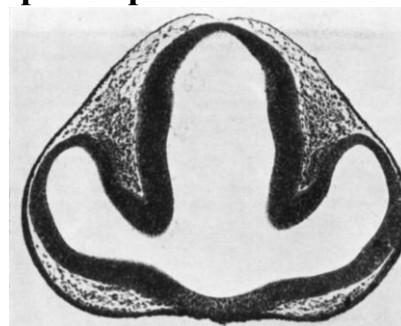


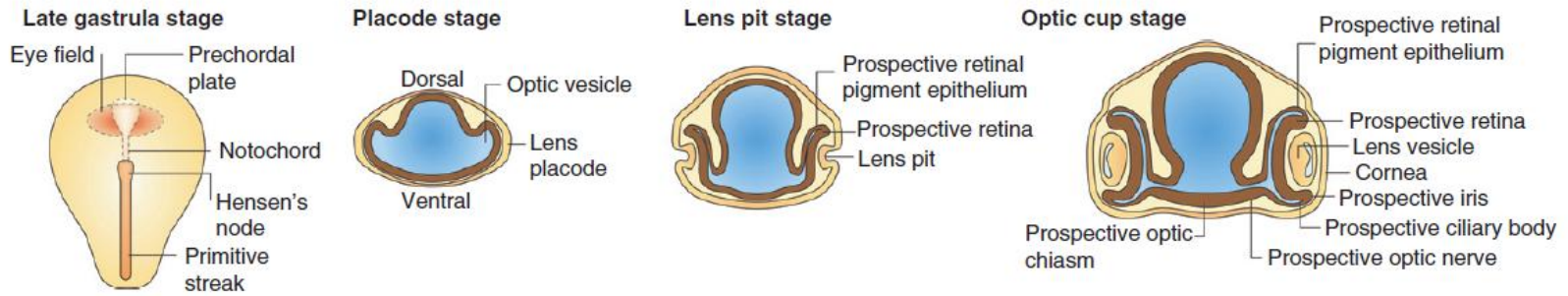
surrounding loosely-associated cells known as the **mesenchyme**, which is derived from the **mesoderm**, to form the **optic vesicles**.

During the **fifth week** (35 days), as each optic vesicle grows, it makes contact with the thickened surface of the **ectoderm** known as the **lens placode** causing it to

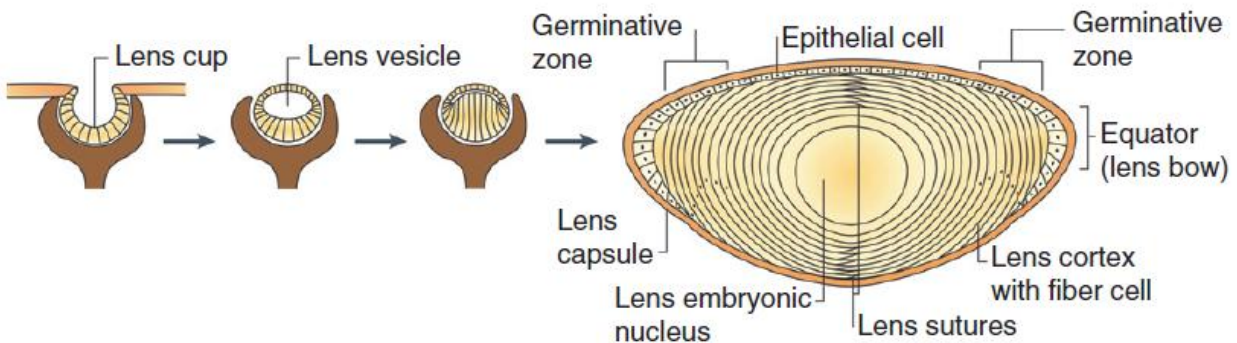


differentiate into the **crystalline lens** of the eye instead of skin epidermal cells. The contact is also accompanied by invagination of the **optic vesicle** into an **optic cup** where the lumen of the optic vesicle is reduced to a slit. The **inner layer** of the optic cup develops into the **neural retina** and the **outer layer** develops into the **retinal pigmented epithelium**.





By the **sixth week** (42 days), the **crystalline lens** breaks free within the optic cup where it will continue to develop.



By the **seventh week** (49 days), the **outer layer of the cornea** differentiates from the ectoderm. The mesenchyme surrounding the optic cup differentiates into the **stroma of the cornea**, the **sclera**, and the **choroid**.



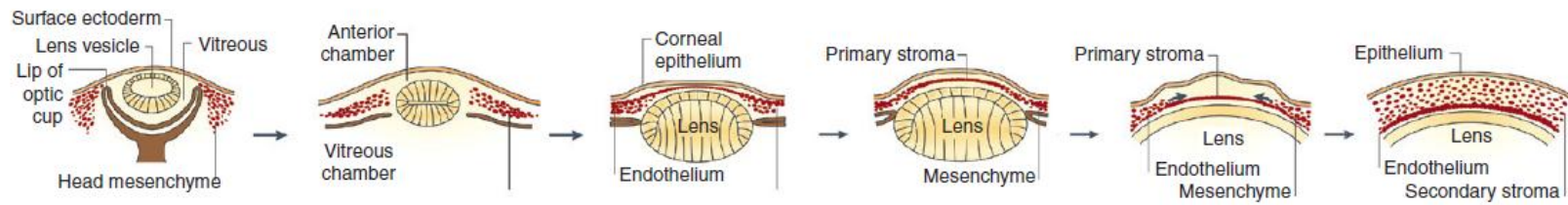
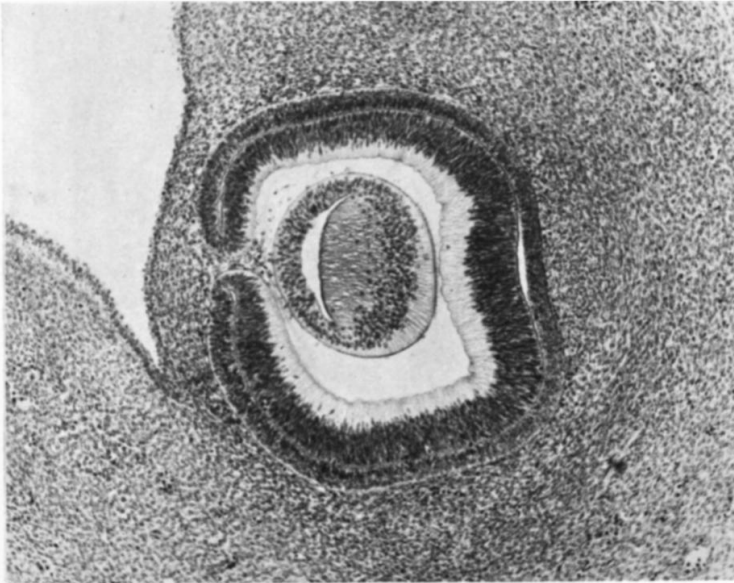
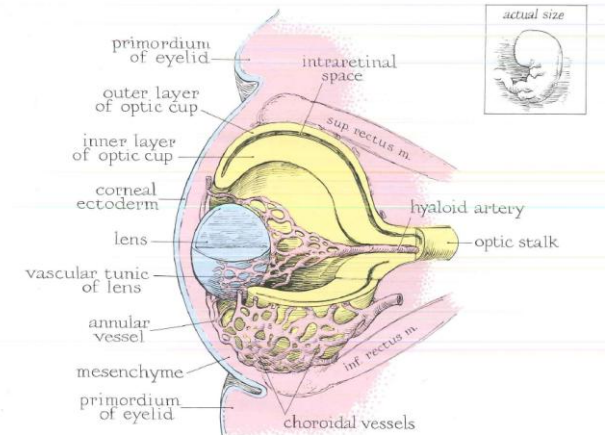
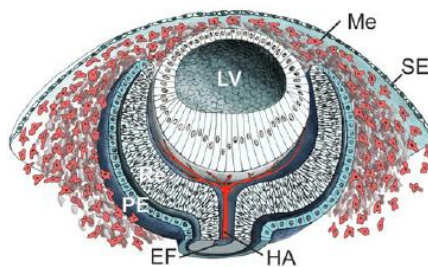
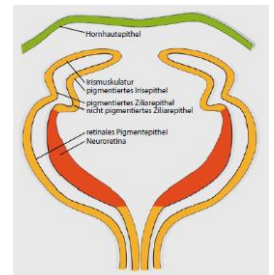
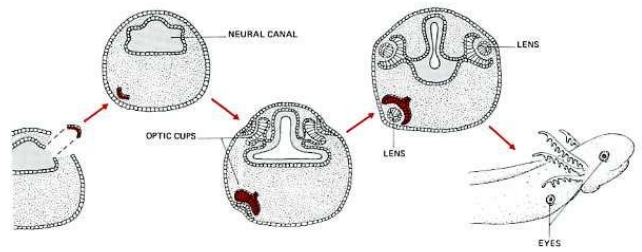
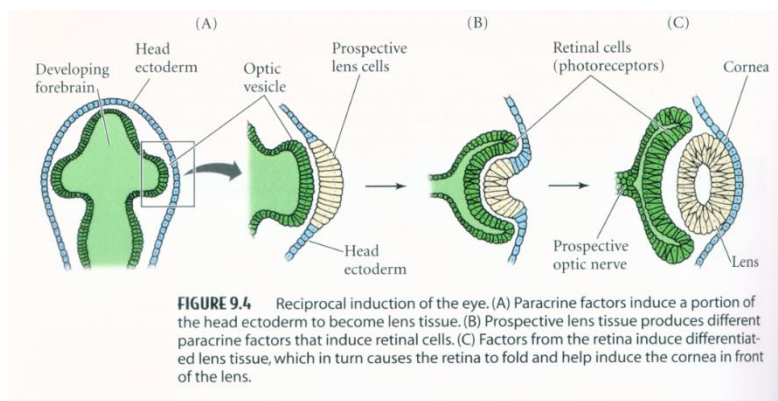


Figure 102. Stage 19
16–18 mm 48 days 7th week
(172, 175, 176, 177, 223)
Section of the eye

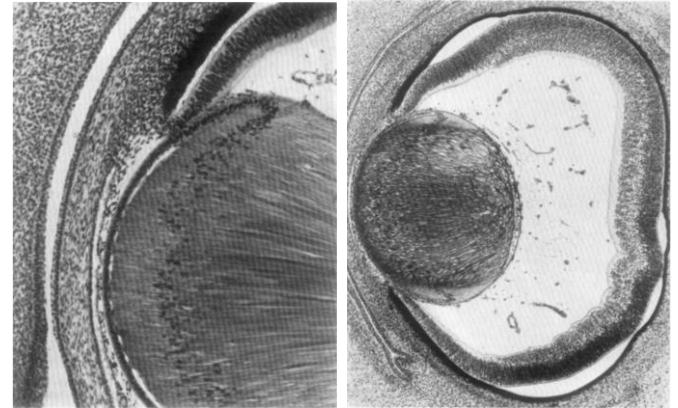
While the inner layer of the optic cup develops into the **neural retina**, the leading edge of the optic cup participates in the formation of the epithelial portion of the **iris** and the **ciliary body**. While most of the neural retina will differentiate into a layer of **rods and cones**, it will also differentiate into a layer of **bipolar cells** and a layer of **ganglion cells**. Some of the ganglion cells will extend towards the brain and differentiate into the **optic nerve**. We will talk about the retina in detail next week when we talk about color vision.



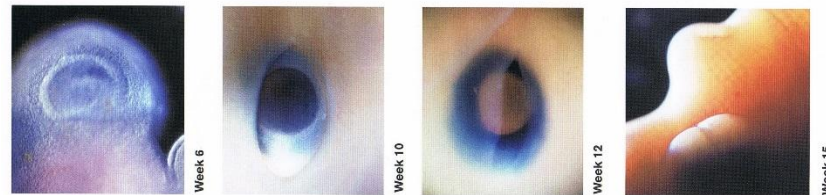
Hans Spemann (1924) studied eye development and hypothesized that the optic cup acts as an “*organizer of the lens*.” He proved the existence of “organizers” by doing tissue transplants and inducing tissues to develop into other tissues. Spemann won the Nobel Prize in 1935 for his work (http://www.nobelprize.org/nobel_prizes/medicine/laureates/1935/press.html). Below is a proposed model of the role of organizers, which are now known as **localized inducing molecules** or **paracrine factors** that may cause the differentiation of the crystalline lens, the retina, and the cornea.



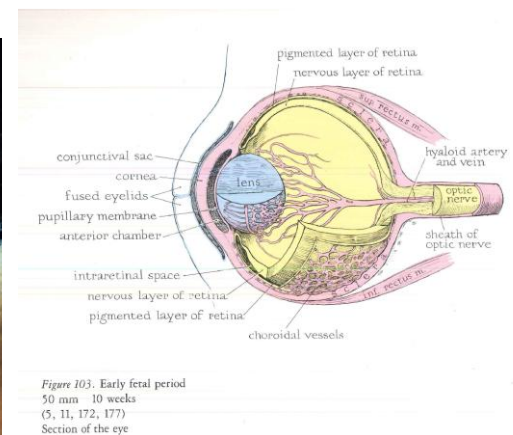
During the **eighth week** (56 days), the **stroma of the iris** differentiates from mesenchyme as the anterior and posterior spaces on either side of the iris fill with **aqueous humor**. We will talk about the iris in detail next class when we talk about eye color. The **vitreous humor** develops in the space between the crystalline lens and the neural retina. At this stage, the **retinal pigmented epithelium** causes the eyes to be seen as small dark holes on either side of the head.



By the **ninth week** (63 days), the **eyelids** are developed. The eyelids will stay closed from the third month until the seventh month (26 weeks).



By the **tenth week** (70 days), although still developing, the eye looks very much like an adult eye.



Ultrasound at 10 weeks: <https://www.youtube.com/watch?v=SdXfTqBS-9E>

[Finger Lakes Pregnancy Care](#) does ultrasounds locally.



During the **sixteenth week** (4 months), the retina and the neural connections to the brain are still developing. At **six and one-half months**, the eyes are still sealed-shut.

The scientific evidence I presented to you can be taken into consideration in any debate regarding reproductive rights bills.

On January 22, 2019, on the 46th anniversary of Roe v. Wade, New York Governor **Andrew M. Cuomo** signed legislation that allowed him to proclaim, *“Today we are taking a giant step forward in the hard-fought battle to ensure a woman's right to make her own decisions about her own personal health, including the ability to access an abortion.”*

<https://www.governor.ny.gov/news/governor-cuomo-signs-legislation-protecting-womens-reproductive-rights>

Those who do not support this legislation ask, does a women’s fundamental right to control their own body involve the fundamental right to abort a baby right up until [the day](#) it would have been born or [after](#).

The Abortion Talks (also streamed as *The Basement Talks*) is a movie made by Josh Sabey and Sarah Perkins, describes how pro-choice and pro-life advocates learned to **talk** with and even love each other despite their opposing views on abortion.





Bernard Nathanson, as a Cornell undergraduate, a founder of NARAL, the director of the Center of Reproductive and Sexual Health, and later a pro-life advocate has an interesting though controversial perspective. He made a movie called “[The Silent Scream](#)” describing his changing thoughts on abortion. In 2022, the U.S. Supreme Court [overturned](#) Roe v Wade, making abortion laws [dependent on the states](#) rather than the federal government.



African American, Hispanic, and Asian babies are usually, although not always, born with brown eyes while Caucasian babies are usually born with blue eyes. Babies do not always come out the way parents expect: Richie Lopez was born without eyes. His parents hope that he will get an eye transplant or eyes grown



from stem cells. <http://www.cnn.com/videos/tv/2015/01/27/dnt-az-baby-born-without-eyes.ktvk>

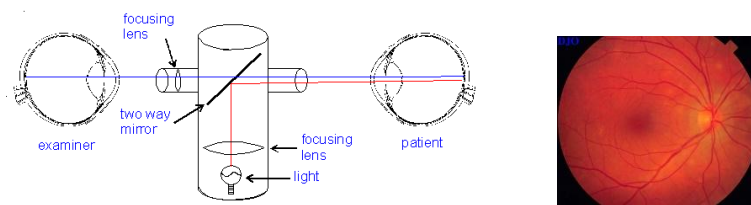
Richie currently has prosthetic eyes:

<http://www.beeherald.com/news/richie%E2%80%99s-new-look-sight-sore-eyes>

When a baby is born the **rods** are fully developed and the baby has low light **black and white scotopic vision**. Approximately three months later, the **cones** form and the baby also has **photopic color vision**.

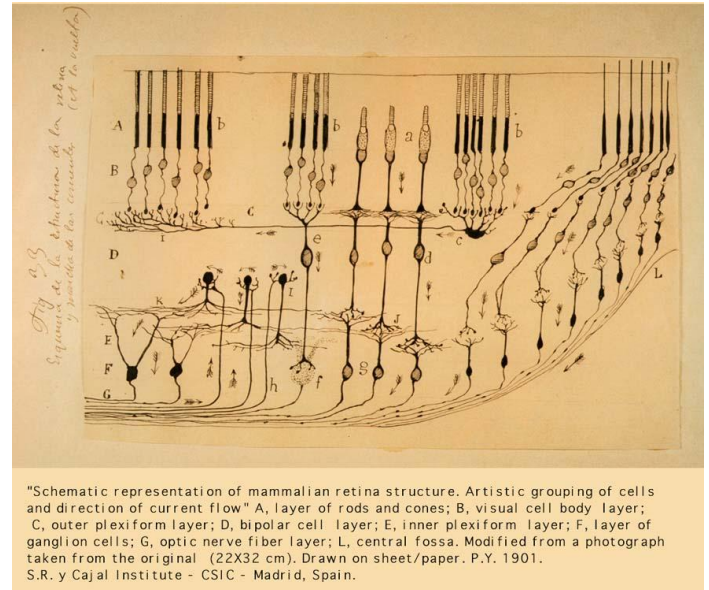
Cicero (46 BC) wrote in the *Orator, ut imago est animi voltus sic indices oculi*, which means for *if the countenance is the image of the mind, the eyes are it's interpreters* (<http://www.gutenberg.org/cache/epub/9776/pg9776-images.html>).

The **retina** is derived from the optic cup and some consider the retina to be a part of the brain, having been sequestered but not isolated from it early in development. Interestingly, **the retina is only part of brain that is readily visible to us**. It can be viewed with an **ophthalmoscope**.

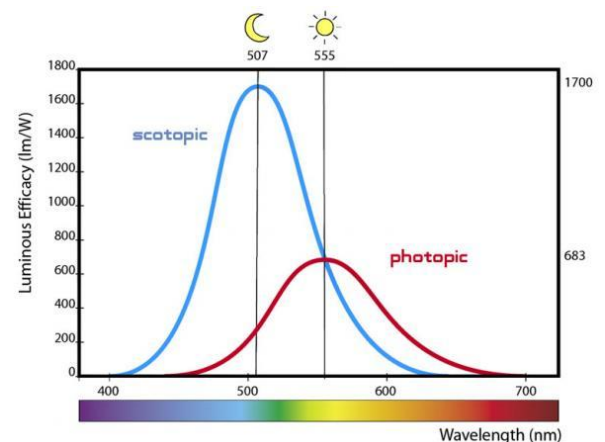


Demonstration: View your classmate's retina with an ophthalmoscope.

The **neural retina** contains the light-sensitive photoreceptor cells, known as **rods** and **cones**. The rods and cones are modified cilia. The rods and cones are on the neural retinal layer closest to the **retinal pigmented layer** and farthest from the external world. The rods are very light sensitive and are involved in dark (**scotopic**) vision while the cones are less light sensitive and are involved in normal color (**photopic**) vision.



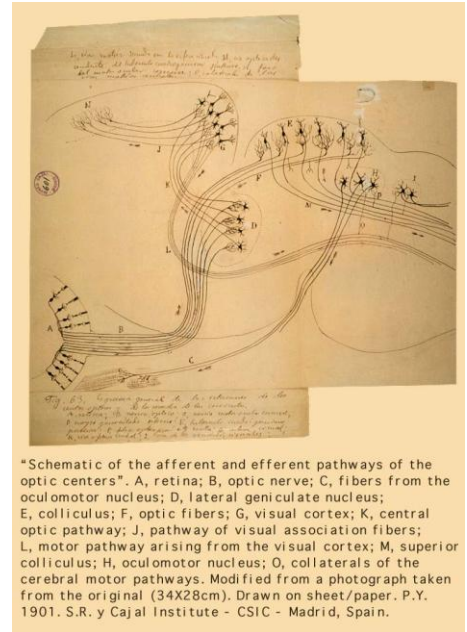
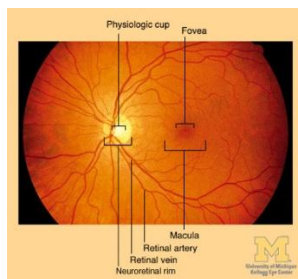
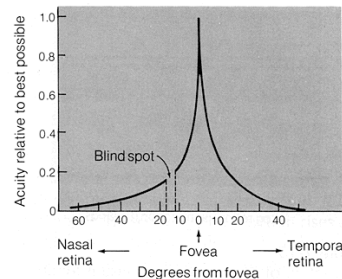
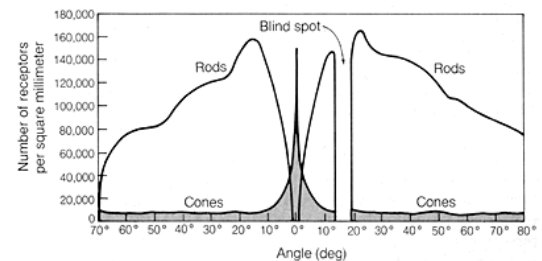
Scotopic vision, effected by the rods, is more **efficient** in utilizing light at low light intensities than **photopic vision**, effected by cones. Moreover, the range of spectral colors utilized by the rods is blue-shifted relative to the range of spectral colors utilized by the cones. Perhaps this is why objects illuminated by moonlight look black and bluish-white.



Remember from the Pulfrich pendulum effect, that when we use our scotopic vision, we see things “**in the past.**” Night lights in baseball stadiums allow players to play with their photopic vision, so they see, and catch or hit the ball “**in the present.**”



The **cones** and **rods** are connected to the **bipolar cells** which in turn are connected to **retinal ganglion cells**. The retinal ganglion cells are in the layer of the retina closest to the external world. The axons of the retinal ganglia pass through the retina at the **optic disc** to connect with the optic nerve. Since two cells cannot be in the same place at the same time, this precludes the photoreceptor cells from being in the **optic disc**, thus creating a **blind spot** on the nasal side of the retina.



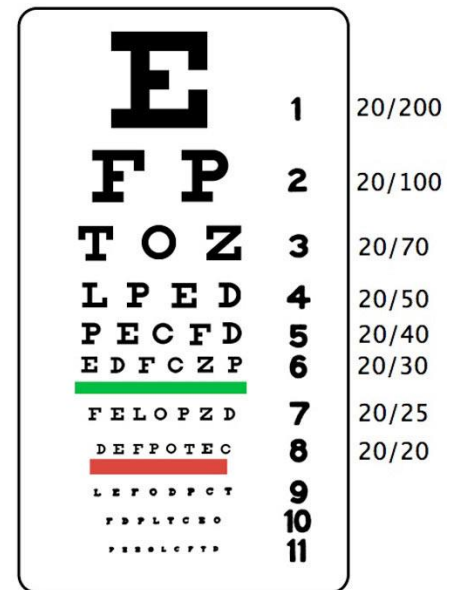
The **rods**, which are used for **scotopic vision**, are located around the periphery of the retina. The most peripheral rods are capable of sensing motion but are not able to produce an image of what is moving. You can tell this by having a friend wave an object such as a **fork or a spoon** at the very edge of your visual field near your ear. You will be able to tell something is moving, and in which direction, but you will have no idea what is moving!

The **cones** that are involved in **photopic color vision** are enriched in the center of the retina known as the **macula**, which is 2.5-3 mm in diameter. The macula is a region of the retina that is rich in retinal ganglion cells as well as cones. The **fovea** is in the center of the **macula**. Just as the **optic disc** excludes the

photoreceptor cells, the **fovea** is a depressed area of the retina, about 0.3 mm in diameter, that excludes the bipolar cells and the retinal ganglion cells so that **light travels directly and unhindered through the rest of the neural retina layer to the cones**. Consequently, this region of the retina gives us the greatest **visual acuity**.

Light is hindered from reaching the rods and cones outside the fovea by the bipolar cells and retinal ganglion cells since the rods and cones outside the **fovea** face the retinal pigmented layer instead of the outside world. The rods and cones may face “**backwards**” so that old discs from the photoreceptor cells are **sloughed off to the back** of the retina so that they do not accumulate in the vitreous humor. It has been suggested that the melanin-containing cells are adjacent to the rods and cones to help them chemically restore the light-sensitive visual pigment in the receptors after it has been bleached by light.

Visual acuity is measured with a **Snellen eye chart**, developed by Hermann Snellen in 1862. To measure visual acuity, a person stands 20 feet away from the chart, covers one eye, and reads the letters starting at the top until they get to the line where they can no longer make out the letters. The last line that they can clearly read, gives their visual acuity. A “**standard**” person has a visual acuity of 20/20. Others have better or worse vision. If someone has a visual acuity of 20/200, it means that he or she can see as clearly at 20 feet as a “standard” person can see at 200 feet. Someone with 20/200 vision is legally blind. If someone has a visual acuity of 20/10, it means that he or she can see clearly at 20 feet what a “standard” person can see at 10 feet.



In angular terms, 20/20 vision is the ability to distinguish between objects that are separated by one minute of arc. The letters on the 20/20 line on the chart are 0.34 inches tall, which at twenty feet (240 inches) subtend 1.42×10^{-3} radians, which equals 0.08 degrees, which equals 4.9 minutes of arc. That means that the limbs of each letter subtend about one minute of arc. (Note: 2π radians = 360° and $1^\circ = 60$ minutes of arc).

While human visual acuity is excellent, it is not as good as that found in raptors, such as the Bald Eagle.

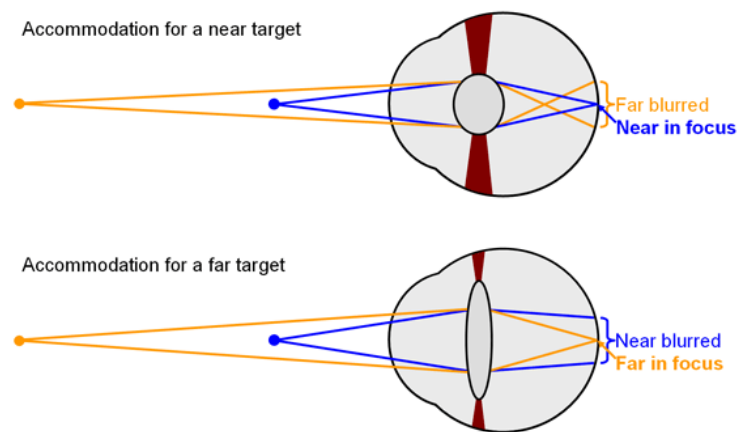


Image formation by the human eye depends on **two refracting elements**, the **cornea** and the **crystalline lens** that act together to make a **converging lens** with a **variable focal length** and a dioptric power that ranges from 40-53 diopters ($D = \frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$; $s_o = 0.025 \text{ m} - \infty \text{ m}$) in order to project an **in-focus, inverted, real, minified, image** of the outside world on the **retina** (the optical distance between the crystalline lens and the retina is $s_i = 0.025 \text{ m}$). Remember only real images have the **radiant energy** necessary to activate the photoreceptor cells on the retina. The transparent **cornea**, which is the **window of the eye**, is the main refractive element of the eye since there is a great difference in the refractive index between the **cornea** ($n = 1.376$) and air. This cornea is a powerful lens with a dioptric power of about 40 diopters.

The cornea does not have a blood supply because the choroid does not extend into the anterior of the eye. The cornea is nourished by the aqueous humor, which is refilled every 4 hours. Interestingly, the absence of a blood supply means that **antibodies** made by the immune system of the body **do not** reach the cornea. The absence of any rejection response by the immune system has made **corneal transplants** successful since as early as 1905.

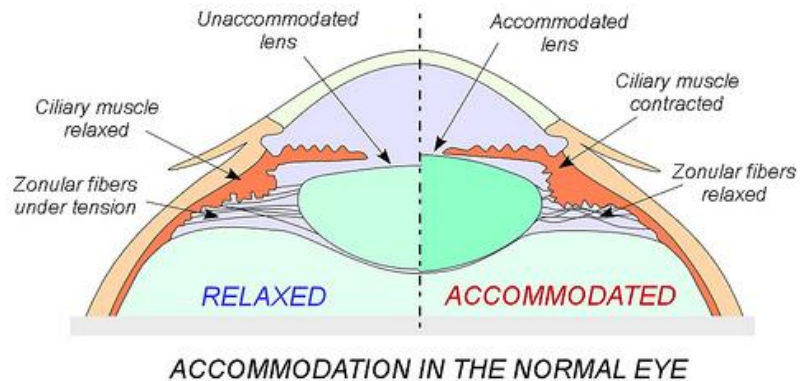
The **crystalline lens** ($n = 1.386\text{--}1.406$) is the second refracting element of the eye. When we are young, the crystalline lens can increase the dioptric power of the eye by an additional 13 diopters, giving a total dioptric power of about 53 diopters. The reason that the dioptric power of the crystalline lens, with a refractive index of 1.386–1.406, is less than the dioptric power of the cornea with a smaller refractive index of 1.376, is that the crystalline lens is surrounded by the **aqueous** and **vitreous humors** that have refractive indices 1.336 and 1.337, respectively. The small difference in refractive index, like that of Pyrex glass in Wesson oil, does not allow for much light bending or coarse focusing—only fine focusing.

The crystalline lens is held in place by the **ciliary body** which contains muscles that **contract** in order to increase the curvature of the crystalline lens, which decreases its focal length and increases its dioptric power. The increased dioptric power and decreased focal length allows us to focus near objects on the retina. When the muscles of the ciliary body **relax**, the crystalline lens becomes flatter, the dioptric power decreases, the focal length increases, and we can focus distant objects on the retina.



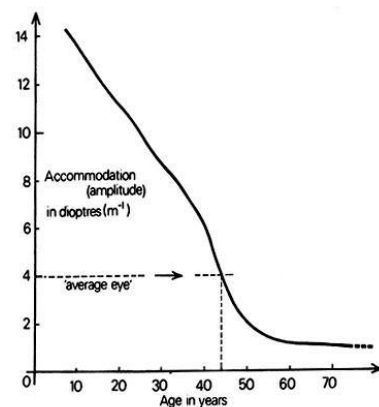
The ciliary muscles act on the crystalline lens through the **zonular fibers** that make up the **suspensory ligament**. The crystalline lens and zonular fibers are both elastic. When the eye is observing **distant objects**, the ciliary muscles are **relaxed**, the zonular fibers are under tension, and the elastic **crystalline lens is maximally flat**. This results in minimal dioptric power and maximal focal length.

However, when the eye is observing nearby objects, the ciliary muscle **contracts** and pulls itself forward, releasing the tension on the zonular fibers. This causes the **crystalline lens to become more curved**, and the dioptric power to increase and the focal length to decrease. Note that a camera lens fine-focuses nearby objects by moving the lens closer to the object and farther from the CCD, instead of changing the shape of the lens.



As one ages, the ability to accommodate decreases and the near point moves toward infinity, making it harder and harder to read small print close up (ask your parents).

Demonstration: Keep your glasses on if you wear them. Block one eye. Have someone hold a book and measure the farthest distance between the book and your eye where you can still read the book ($s_o \approx 1$ m). Take the reciprocal of the distance of the far point and add it to the reciprocal of the optical distance between the crystalline lens and the retina ($D = \frac{1}{f} = \frac{1}{s_o} + \frac{1}{0.025}$) to get the dioptric power of the eye. As an example, if $s_o = 1$ m, the dioptric



power of the eye is $1 + \frac{1}{0.025} = 41$ diopters, where $\frac{1}{0.025} = 40$. Move the book closer to you until the words get blurry and measure the closest distance ($s_o \approx 0.08$ m) between the book and your eye where you can still read the book. Take the reciprocal of the distance of the near point and add it to the reciprocal of the optical distance between the crystalline lens and the retina ($D = \frac{1}{f} = \frac{1}{s_o} + \frac{1}{0.025}$) to get the dioptric power of the eye. As an example, if $s_o = 0.08$ m, the dioptric power of the eye is 52.5 diopters. Accommodation range is given by (near point in diopters) – (far point in diopters). In the example, it is 11.5 diopters.



As the crystalline lens of a human ages, the crystalline lens proteins, known as alpha **crystallins** **fall out of solution** or **precipitate**, the lens becomes cloudy, and **cataracts** are formed. The crystalline precipitates scatter blue light out of the eye so that objects appear more yellowish. At this point the crystalline lens can be replaced with a synthetic intraocular plastic lens.

In 1940, Harold Ridley noticed that when Fighter Lt. Gordon “mouse” Cleaver was shot down in his Hurricane in combat, his eyes were filled with slivers of Perspex (Poly(methyl methacrylate)) that were not rejected by the body’s immune system. Ridley realized that the body’s tolerance to Perspex, as well as its mechanical and optical qualities, would make Perspex a good artificial intraocular lens material. The medical establishment thought that such an operation was too risky, so in 1949, Harold Ridley performed the first lens transplant in secret. Currently intraocular lens are made of softer material such as silicone and acrylic, making it possible to insert the intraocular lens through a tiny incision.



The **iris** is the colored part of the eye and we will talk about its color next week. The **iris** contains **circularly arranged sphincter and radially-arranged dilator muscles**. Contraction of the sphincter muscle, which is a striated muscle, **closes the pupil** in response to stimulation by the parasympathetic nervous system, which is active when the body is in the **rest and digest state**. Contraction of the dilator muscle, which is a smooth muscle, **opens the pupil** in response to stimulation by the sympathetic nervous system, which is active when the body is in the **fight or flight state (or according to Robert Sapolsky, the 4 Fs—fight, flight, fear, and sex)**.

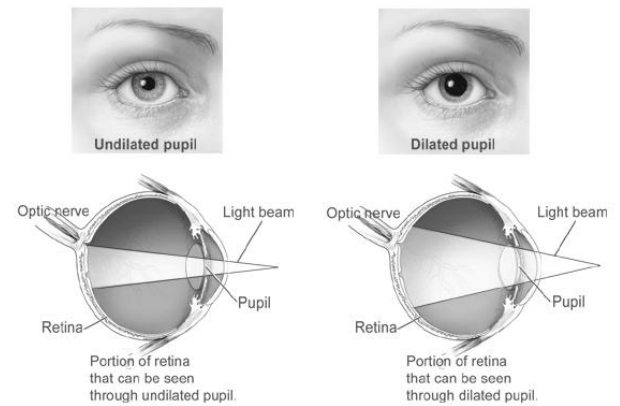
Oxytocin, which is produced by the human body during sexual arousal, also causes pupils to dilate. Eckhard Hess discovered the role of pupil size in communicating attitude. The size of the pupil lets people know our emotional state.

We can mimic emotional states in terms of pupil size with drugs, such as **atropine (belladonna)**, hysocamine, and scopolamine that cause dilation of the pupils known as mydriasis by inhibiting the parasympathetic nervous system. **Opiates** mimic the rest and digest state by inhibiting the sympathetic nervous system and causing an extreme contraction of the pupils known as miosis.

Typically, the adult human pupil is about 2-3 mm in diameter and children have larger pupils than adults. The adult human pupil varies from 2 mm in bright light to 8 mm in dim light.

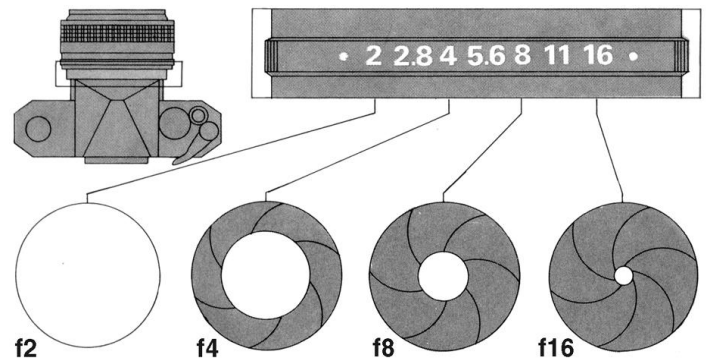
Demonstration: Perform the flashlight test to see your classmate's pupils contract in bright light and dilate in dim light. Both pupils respond the same way, even if you only illuminate one. This **consensual response** indicates that there is higher-level control of pupil size. Also notice that the pupils constrict when your

classmate's pupils go from looking at a distant object to looking at a near object. Did you also notice that your classmate's eyes turn in when going from looking at a distant object to looking at a near object? **Accommodation** is a **global process** that is always accompanied by constriction of the pupils and converging of the eyes. Note that a dilated pupil at night will allow the light of a distant star to hit more rods!

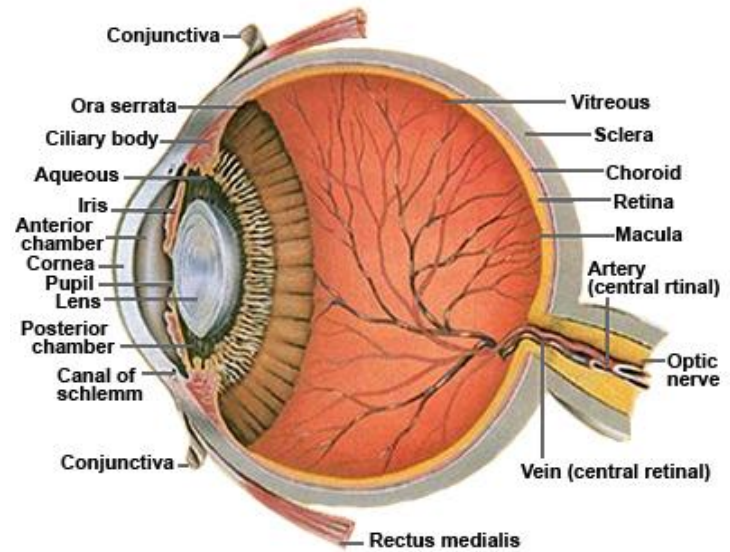


The closing of the human pupil is probably not important in reducing the intensity of light that enters the eye since the area of the pupil varies over a ratio of 16:1 while the eye works efficiently over an intensity ratio of 100,000:1. The closing of the pupil probably functions to limit the rays of light to the central part of the lens, which is the optically best part of the lens that gives maximal acuity, except under low light conditions when the full aperture is needed for maximal light sensitivity (Land and Nilsson, 2012).

The **iris** and **pupil** allow the amount of light that enters the eye to vary much like the **aperture diaphragm of a camera** lens varies the amount of light that reaches the film. The **f-stop** of the eye varies from f/8.3 to f/2.1. A larger aperture favors a brighter image with greater spatial resolution, more aberration and less depth-of-field, while a smaller aperture favors a dimmer image, with less aberration and a greater depth-of-field. Perhaps children have larger pupils because their young refracting elements have fewer aberrations.



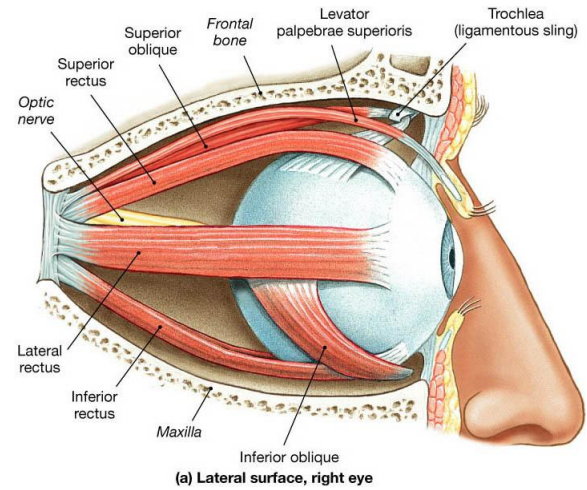
The human eye is a sphere approximately **one inch** in diameter. Most of the eye is surrounded by the **sclera**, which is about 1 mm thick. The word **sclera** is derived from the Greek word for “hard.” The tough and hard sclera protects the eye. It is the body part that was immortalized at the Battle of Bunker Hill when Israel Putnam or William Prescott yelled, “*Don’t fire till you see the whites of their eyes,*” reminding the soldiers not to waste gunpowder when the enemy was not close enough.



The white part of the eye (sclera) and the inner surface of the eyelid are covered by a membrane, known as the **conjunctiva** that contains blood vessels. Infection of the conjunctiva results in conjunctivitis, commonly known as **pinkeye** (left). Blood can also accumulate in the region between the conjunctiva and the sclera (right). This is known as a subconjunctival hemorrhage and can also be caused by high blood pressure, chemicals, or trauma.

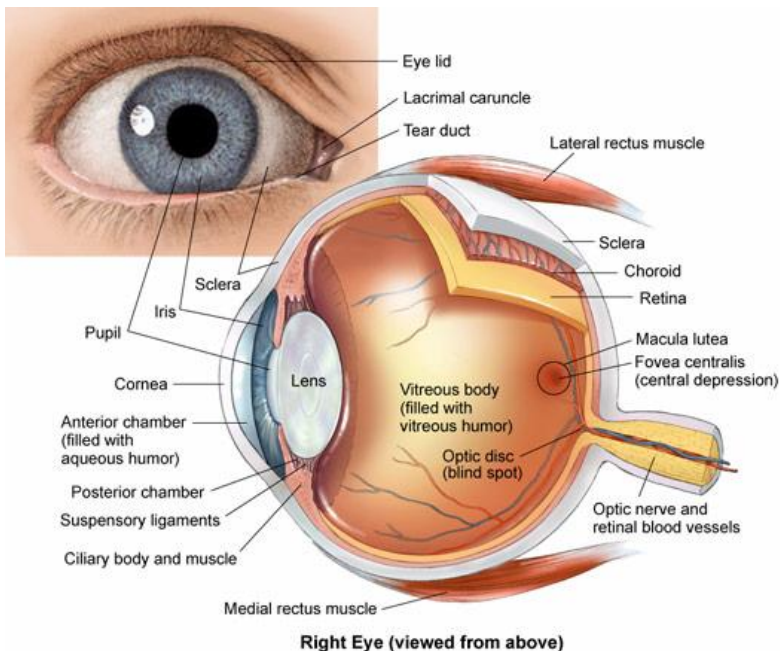
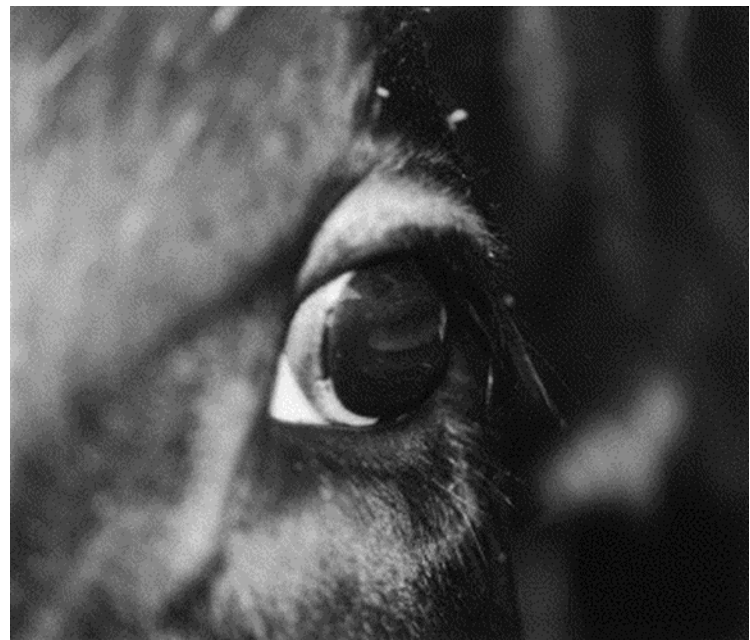


The sclera is covered with **fatty tissue** that insulates the eye from mechanical shock. The sclera also is connected to three pairs of **extraocular muscles** that move the eye up and down, side to side, and to rotate the eyes to counteract head movement. Cows only have four muscles that move the eyes up and down and side to side. **Nerves** innervate these muscles to tell the brain which direction each eye is looking. Information is passed to the brain concerning the **convergence angle** described as the angle each eye turns to look at the same object when the image in each eye is projected on the **fovea** of the **retina** in each eye.



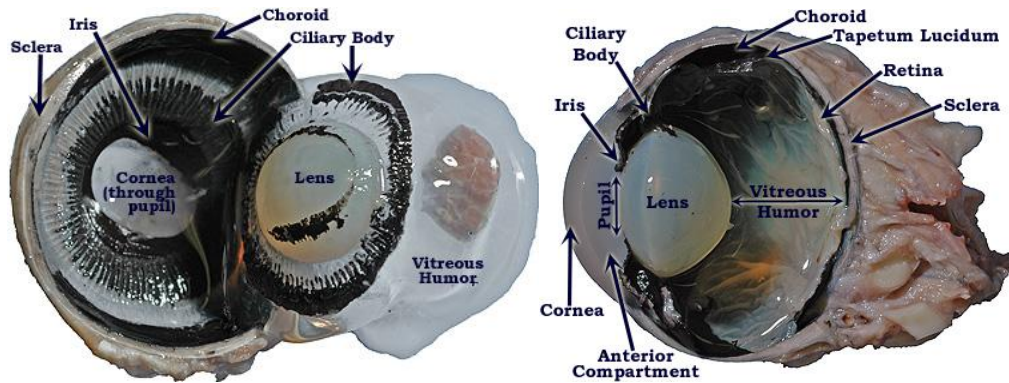
The **choroid** is the layer inside the sclera that contains blood vessels that nourish most of the tissues of the eye and remove wastes.

We will dissect a cow or pig eye to understand the anatomy of a human eye:



Dissection of cow eye

The parts of the eye we will see are labelled below:

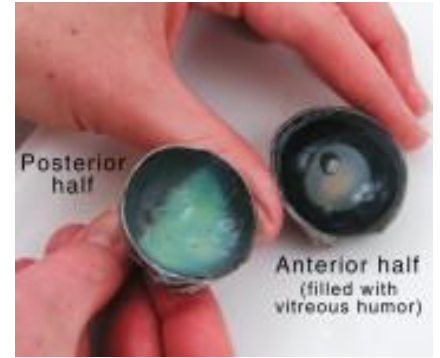
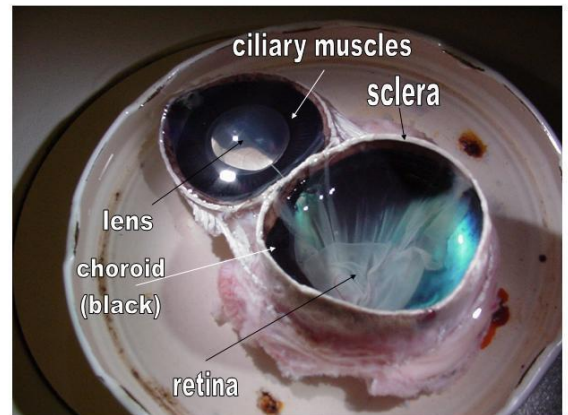


Put on gloves that fit, and get a scalpel, scissors, a tray and an eye. If necessary, remove with the scissors, the fat and the muscles that are attached to the sclera. In the back of the eye, you should see the optic nerve that transmits the visual information to the brain.

Use the scalpel to cut through the sclera at the middle of the eye. Then use the scissors to cut all around so that the eye separates into the anterior and the posterior halves. Hopefully you will have disturbed neither the ciliary body nor the retina. You will see the **crystalline lens**, the **ciliary body**, the **iris**, the **pupil** and the **cornea** in the front half and the **retina** and the **tapetum** in the back half. The vitreous humor fills the cavity. Bits of cellular debris in the vitreous humor, known as floaters, are the cause of faint shadows on the retina.

Hold the front part of the eye and look through it to get a **cow's eye view of the world**.

Turn the front half of the eye so that the back of the **crystalline lens** is facing up. (The picture is of the top facing up). The crystalline lens is held in place by the **ciliary body** which contains muscles that contract in order to increase the dioptric power of the crystalline lens and we can see nearby objects in focus. When the muscles of the ciliary body relax, the crystalline lens becomes flatter, which decreases the dioptric power of the crystalline lens and we can see distant objects in focus.



Remove the crystalline lens from the ciliary body. Is the crystalline lens converging or diverging? Is the image real or virtual? How can you tell?



Look through the crystalline lens. The lens is a double convex converging lens that produces an inverted, real image of an object that is more distant than its focal length. The crystalline lens produces an erect, virtual image when the object is closer than the focal point. The elastic properties of the crystalline lens cause it to round up and take the form of an accommodated lens when it is separated from the zonal fibers and the ciliary body. Feel how elastic the crystalline lens is.

Demonstration: Cut a sliver from the crystalline lens and carefully place it on the pin of the **Leeuwenhoek microscope replica**. As you are looking through the pinhole in the window or at the clear blue sky, adjust the specimen height so that the top edge of the specimen is in the middle of the lens and then adjust the distance of the specimen from the lens until the specimen is in focus. Can you see the **fibrous layers of the crystalline lens** like Leeuwenhoek did? Is the lens in the Leeuwenhoek microscope replica converging or diverging? Is the

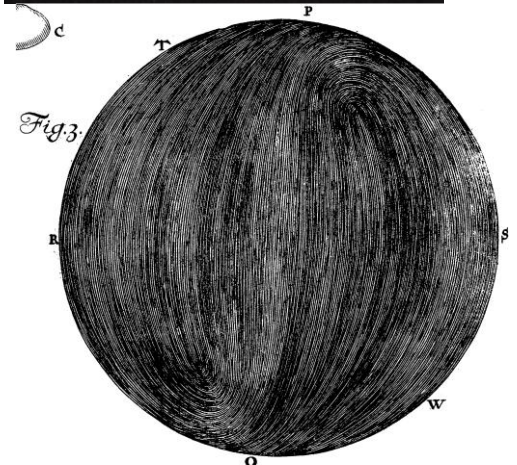


image formed by the microscope real or virtual? How do you know?



Push back the ciliary body and find the **black elastic iris** and the **oblong pupil** whose major axis is horizontal. The pupil regulates the amount of light that enters the eye. When the pupil contracts, it reduces the amount of light, reduces the amount of aberrations, increases the depth of field, and reduces the resolution, just like the iris diaphragm in the pinhole camera. Grazing animals, like the cow, tend to have horizontal pupils. Since the pupil of the cow is greater in the horizontal direction, the cow can resolve horizontal details more sharply than it can resolve vertical details. Humans, with a round iris, see details equally sharply, independent of their orientation. Remove the iris and look at the **cornea**. The cornea is relatively thin; neither delicate nor tough. Imagine doing Lasik surgery on it!

Now look at the back half of the eye. The retina is a very soft tissue, typical of neural tissue.



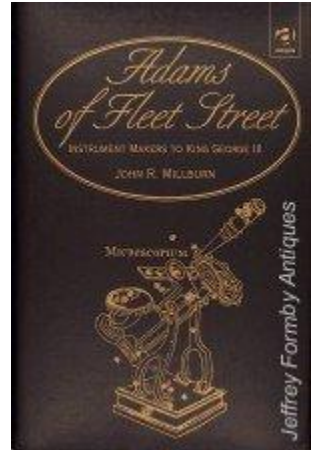
The retina is somewhat gooey. The retinal ganglion cells pass through the **optic disc** to connect to the optic nerve. The **optic nerve** is very shiny because of the high lipid content of the **myelin sheath** that surrounds the neurons.

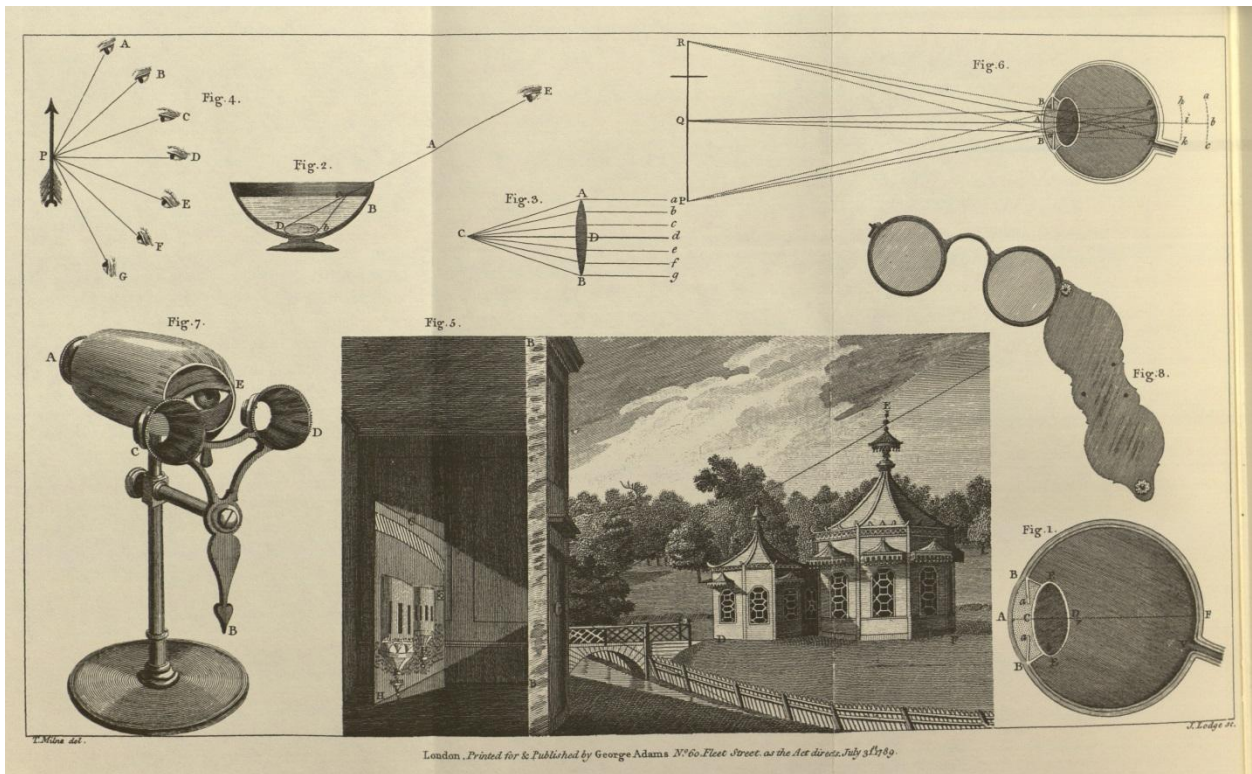
Humans have a melanin containing pigmented layer in the back of the eye to absorb any photons that are not absorbed by the photoreceptor pigments in order to **minimize any glare** that would come from stray light. On the other hand, it is hard for us to see at night because humans do not have a mirror-like **tapetum lucidum**. Animals including, cows, pigs, raccoon, dogs, cats, alligators, and



sharks have a mirror-like tapetum lucidum that reflects light that was not absorbed the first time back to the retina so that they can see better in the dark. Although the tapetum lucidum enhances the ability to see in the dark it makes the image less sharp since the light from a single object point is reflected to nearby photoreceptor cells. The reflection of light from the tapetum lucidum is responsible for the glowing eyes of animals seen in dim light.

The eye is a simple and elegant instrument. **George Adams** (1789, 1792), the instrument maker to King George III, wrote in his *An Essay on Vision*, “*In the structure of the eye we find the most evident manifestations of exquisite art and design, every part elegantly framed, nicely adjusted, and commodiously placed, to answer in the most perfect manner every possible good purpose, and thus evince that it is the work of unerring wisdom, prompted to action by infinite love. So manifold are the blessings we derive from this organ....To it we are indebted for that delightful sensations that arise from the proportion and variety of forms, the harmonious mixture of colours, and the graces of beauty. It enables us to seek, to see, and to chuse our food; to go here and there, as the calls of friendship, or the occasions of business, require; to traverse the ocean, ransack the bowels of the earth, visit distant regions, accumulate wealth, and multiply knowledge. Assisted by it, we become acquainted with the works of the Creator, and can trace his wisdom, his power, and his goodness, in the texture of plants, the mechanism of animals, and the glories of the heavens.*”



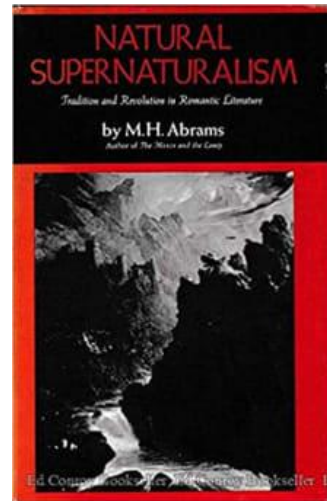


Percy Shelley wrote in his *Hymn of Apollo*:

*I am the eye with which the Universe
Beholds itself, and knows it is divine;
All harmony of instrument or verse,
All prophecy, all medicine, is mine,
All light of art or nature; - to my song
Victory and praise in its own right belong.*



In *Natural Supernaturalism: Tradition and Revolution in Romantic Literature*, M. H. Abrams (1973; Cornell) gives many examples where the romantic poets speak of the **physical eye** and the **spiritual eye** when describing a nature that transcends the physical.



Eye Color and its Inheritance

Color generally provides a **readily visible and reliable attribute, characteristic, trait, or quality to easily differentiate or distinguish one individual or group from another**. We often describe people by the color of their eyes, skin, and hair, although it is important to remember not only the **value** but the **limitations** of this description as the Reverend Martin Luther King, who was born Michael King Jr, pointed out on the steps of the Lincoln Memorial on August 28, 1963, when he professed the sentiment described the Book of Samuel¹: *“I have a dream that my four little children will one day live in a nation where they will not be judged by the color of their skin but by the content of their character.”* Out of the seven traits **Gregor Mendel** chose with intention to observe in culinary peas (*Pisum sativum*), three had to do with color. (Two traits had to do with shape, one had to do with length, and one had to do with position).



The [Pro-Human Foundation](#) has launched a, initiative named [Renewing the Dream](#) to replace the worn-out marker on the steps of the Lincoln Memorial where MLK gave the ***I Have a Dream*** speech.

¹ 1 Samuel 16:7. But the LORD said to Samuel, “Do not consider his appearance or his height, for I have rejected him. The LORD does not look at the things people look at. People look at the outward appearance, but the LORD looks at the heart.” The ‘I have a Dream’ speech, or sermon if you will, was given extemporaneously in [Washington D.C.](#) on [August 28, 1963](#), after [Mahaila Jackson](#), who sang, ‘[I Been 'Buked and I Been Scorned](#)’, shouted to MLK, ‘[\[t\]ell them about your dream, Martin! Tell them about the dream!](#)’ Encouraged by the audience, MLK put down his prepared remarks and continued speaking. The improvised part of the speech became the landmark statement of the civil rights movement—the dream of all people, of all races and colors and backgrounds, sharing in the freedom of America. The [Pro-Human Foundation](#) has launched a, initiative named [Renewing the Dream](#) to replace the worn out marker on the steps of the Lincoln Memorial where MLK gave the I have a dream speech.

Gregor Mendel was born Johann Mendel but changed his name to Gregor Mendel on October 9, 1843, after he joined the Order of Saint Augustine to become an Augustinian monk. The monastery in Brunn (Brno, Czech Republic) that Mendel joined was run by an Abbot and scientist named Cyrill Napp, who had a great interest in breeding fruit trees and understanding the scientific basis of inheritance. In fact, many of the monks in the Monastery were also scientists.



Mendel read a book by **Carl von Gärtner** entitled, *Versuche und Beobachtungen über die Bastarderzeugung im Pflanzenreiche* (Research and Observations on the Production of Hybrids in the Vegetable Kingdom). The book documented the results of thousands of **hybridization** or **artificial fertilization** experiments that he performed on useful and ornamental plants. Gärtner (1849) showed that sometimes the progeny looked more or less like one parent while other times the progeny looked like intermediates between the two parents. The results did not seem to be generalizable, but that was okay since and Gärtner was concerned with documenting the proposition that **plants were sexual organisms** whose parts could be differentiated into male and female and that pollen was absolutely necessary for the formation of seeds. Mendel, on the other hand, was interested in using artificial fertilization to find a **law of nature** that **explained inheritance**.



In 1865, after eight years of experimentation, Mendel presented his results and his interpretations of his work at a meeting of the Brünn Natural History Society. He began by stating “*Experience of artificial fertilisation, such as is effected with ornamental plants in order to obtain new variations in colour, has led to the experiments which will here be discussed.*”



Mendel went on to say, “among all the numerous experiments made [by others], not one has been carried out to such an extent and in such a way as to make it possible to determine the **number of different forms** under which the offspring of hybrids appear, or to arrange these forms with certainty according to their separate generations, or definitely to ascertain their **statistical relations**. It requires indeed some **courage** to undertake a labour of such far-reaching extent; this appears, however, to be the only right way by which we can finally reach the solution of a question the importance of which cannot be overestimated in connection with the history of the evolution of organic forms.”

Knowing the importance of the question was only the beginning. Mendel had to find the right experimental material to answer the question. Mendel went on to say, “**The value and utility of any experiment are determined by the fitness of the material to the purpose for which it is used**, and thus in the case before us it cannot be immaterial what plants are subjected to experiment and in what manner such experiments are conducted. The selection of the plant group which shall serve for experiments of this kind must be made with all possible care if it be desired to avoid from the outset every risk of questionable results. The experimental plants must necessarily — 1. Possess **constant differentiating characters**....”

Color was a **constant differentiating character**. Mendel performed his experiments using hybrids of peas that varied in **one or two constant differentiating characters**. Because of the shape of the pea flowers, in the absence of bees, pistils of the hybrids were naturally pollinated by pollen from the anthers of the same flower—allowing Mendel to know, with near certainty, who the parents were.



According to Mendel, “*The object of the experiment was to **observe these variations** in the case of **each pair of differentiating characters**, and to **deduce the law** according to which they appear in the successive generations.*”

Mendel chose the “*difference in the colour of the seed cotyledons*” to be the constant differentiating character.

“*The cotyledon of the ripe seeds is either pale yellow, bright yellow and orange coloured, or it possesses a more or less intense green tint. This difference of colour is easily seen in the seeds....*”



Mendel noted that for each of the seven traits he selected to study, “*the hybrid-character resembles that of one of the parental forms so closely that the other either escapes observation completely or cannot be detected with certainty. This circumstance is of great importance in the determination and classification of the forms under which the offspring of the hybrids appear. Henceforth in this paper those **characters which are transmitted entire, or almost unchanged** in the hybridisation, and therefore in themselves constitute the characters of the hybrid, are termed the **dominant**, and those which become **latent** in the process **recessive**.*”

Mendel then presented his results:

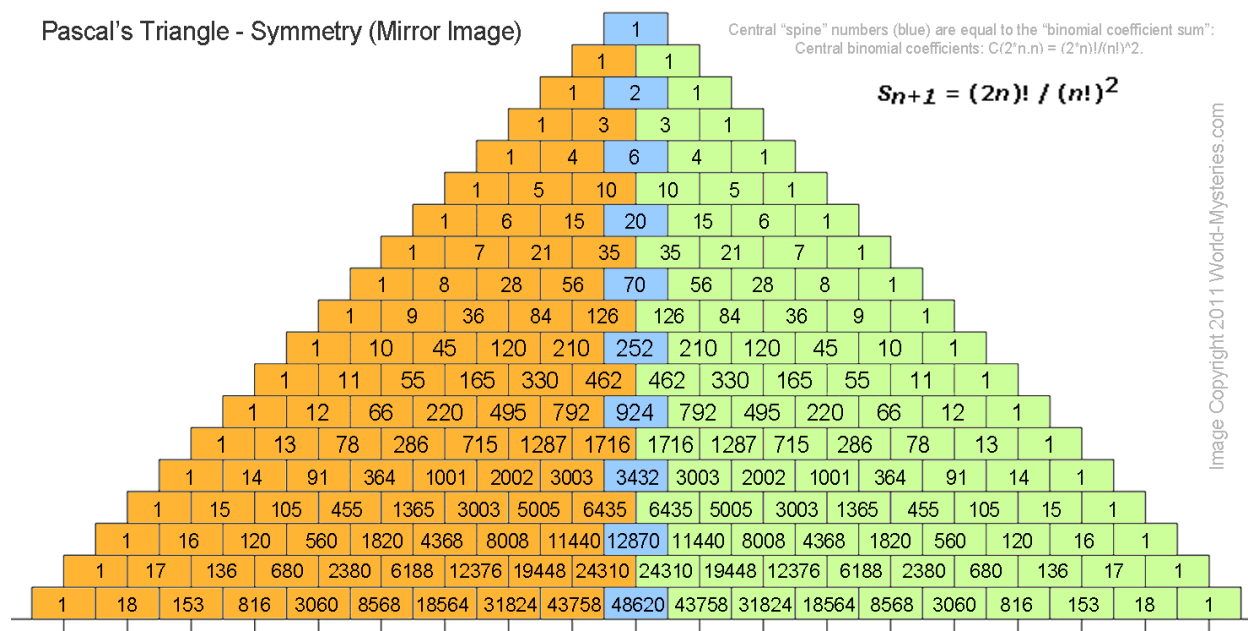
Colour of cotyledon. — 258 plants yielded 8,023 seeds, 6,022 yellow, and 2,001 green; their ratio, therefore, is as 3.01 to 1.”

Mendel then **averaged** and **rounded off** to the nearest integer the results from the various experiments to find the essence of the data: *“If now the results of the whole of the experiments be brought together, there is found, as between the number of forms with the dominant and recessive characters, an average ratio of 2.98 to 1 or 3 to 1.”*

Mendel then found a way to **reduce the characters to letters** and then **deduce the algebraic model that describes and explains the results**: *“If A be taken as denoting one of the two constant characters, for instance the dominant, a , the recessive, and Aa the hybrid form in which both are conjoined, the expression $A + 2Aa + a$ shows the terms in the series for the progeny of the hybrids of two differentiating characters.”*

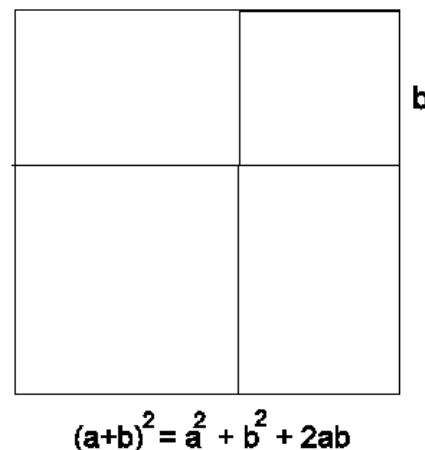
Mendel was good at numbers. We will also get familiar with the power of numbers. Note that $1A + 2Aa + 1a$ looks like the third row of the triangle created by polymaths such as Omar Khayyám (1070) and Blaise Pascal (1653) to visualize the relationships between numbers—especially the numbers involved in a binomial distribution (where there are two possible outcomes like heads or tails; and bi means 2).

Pascal's Triangle - Symmetry (Mirror Image)

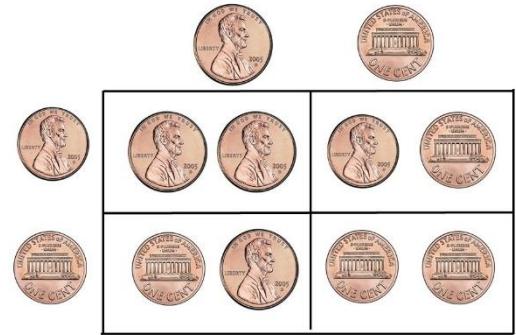


Pascal's triangle is amazing! The rows (0, 1, 2, 3...n) give the coefficients of the binomial expansion, the sum of the values in a row give the value of 2^n , and the powers of 11 can be read off directly from each row. The Binomial Theorem, which relates the parts to the whole, goes back to **Euclid** (Elements II:4) who wrote "*if a straight line be cut at random, the square on the whole is equal to the squares on the segments and twice the rectangle of the segments.*" This can be stated algebraically like so:

$$(a + b)^2 = 1a^2 + 2ab + 1b^2$$

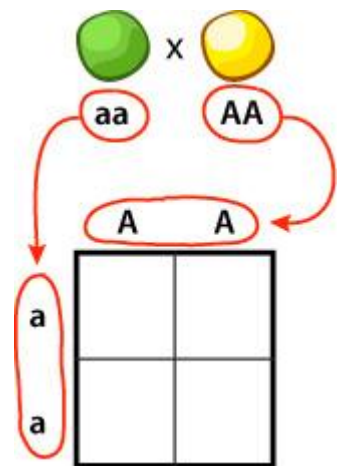


Pascal's triangle gives the coefficients of the binomial expansion. Imagine that we were flipping two coins ($n = 2$) and that a is heads and b is tails and there is equal probability of each coin landing on heads or tails. This is known as a Bernoulli trial. Out of the $2^n = 4$ possible combinations, there is one way to get two heads (a^2), one way to get two tails (b^2) and two ways of getting one head and one tail (ab).



Now imagine along with Mendel that the coins are color genes that come from the egg-producing female and the sperm-producing male (which makes $n = 2$). The gene from the female can land head up (A) or tail up (a) and the gene from the male can land head up (A) or tail up (a). Again, there are $2^n = 4$ possible combinations with one way to get AA , one way to get aa , and two ways to get Aa . This made sense mathematically, but how did Mendel make sense of it biologically?

Building on Gärtner's conclusions, Mendel assumed that [sex was binary](#) (which is signified by the 2 in 2^n) and that the anthers produce **sperm-containing pollen** just like male animals produce sperm and the pistils produce **egg-containing ovules** just like female animals produce eggs. (The fusion of egg and sperm in plants was finally observed by Eduard Strasburger in 1884). If this were true and the sperm and egg both carried the hereditary information to make the zygote, the sperm and egg would each have to have half the information contained in the zygote. Otherwise, the amount of information would double at each generation. Mendel assumed that the **gametes** had only one form of each gene.

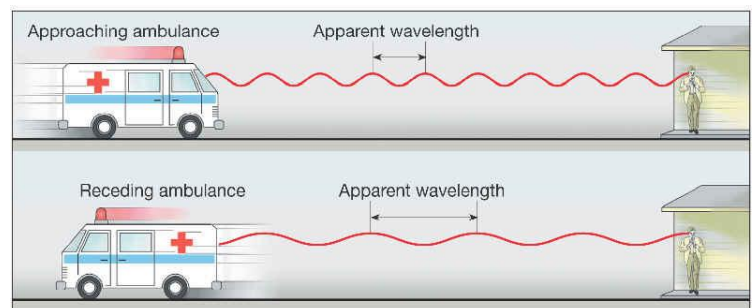


If the **characters** transmitted from one generation to the next by the sperm and egg were **particulate and elastic** (see **demonstration**), they would be transmitted unchanged from one generation to the next. According to Mendel's **Law of Segregation**, during the formation of gametes, the two factors (e.g., A and a) that coexist in the parent plant, would **segregate**, each gamete getting only one (e.g., A or a). Reginald Punnett devised a method, known as the **Punnett Square**, to keep track of the segregated factors in the gametes and the predicted characters in the offspring. Assuming that a pea plant of type Aa produced pollen that had either A or a and ovules that had either A or a , then the ratio of progeny would be 3:1. The **dominant character** would be that one that appears in 75% of the progeny and the **recessive character** would be that one that appears in 25%. In today's parlance, the **phenotype** or outward appearance of the progeny is explained by the **genotype** or internal content of genes.



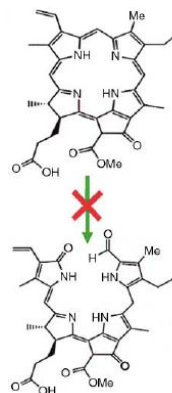
	A	a
A	AA	Aa
a	Aa	aa

Mendel made so much progress, in part, because he complemented good **experimental design** with **mathematical modeling** and **analysis** in order to understand the **nature of inheritance**. (Somewhat earlier, mathematical modeling and analysis that related **the parts to the whole** was used by James Clerk Maxwell (1855,1860) to understand the nature of color vision in humans). Mendel had learned the power of numbers and the importance of mathematical modeling from his physics teacher, **Christian Doppler**, the man who mathematically modeled and predicted the change in the color of light emitted by moving bodies.



Interestingly, Mendel's work lay buried until it was rediscovered by three botanists in 1900. Perhaps Mendel's work was not taken seriously until 1900; because his **laws of inheritance** emphasized atomistic, **discrete**, or “digital” traits and neglected the vast number of **continuous** or “analog” phenotypic differences that clearly exist between individuals and could easily be explained by **blending**. In 1900, the atomistic, discrete, **quantum of energy**, which would later be known as the **photon**, was discovered by **Max Planck**. The onset of the twentieth century was a time for appreciating the possibility that **continuous** appearances can result from summing many small **discrete** events. That is, the biologists and physicists arrived at the conclusion that was already well-known to chemists who build up molecules, both on paper and in test tubes from atomic parts. Chemists were the rock stars of the time as a result of the dye and drug industry that could transform black coal tar to mauve, perfume, aspirin, and heroin.

Just over a century after the rediscovery of Mendel, Armstead et al. (2006,2007) and Sato et al. (2007) found the gene itself that causes the seeds to remain **green** instead of turning yellow. The dominant version of the gene codes for an **enzyme** involved in the breakdown (**catabolism**) of **chlorophyll**. The seeds with the **dominant** character are **yellow** because the chlorophyll, which is green, is broken down before the seed dries. The **breakdown of chlorophyll** allows for the **mobilization** of the nitrogen that was originally part of the chlorophyll to the developing seedling where it can be used to make nitrogen-rich amino acids and proteins. In the **green** seeds that exhibit the **recessive** trait, the enzyme does not function, chlorophyll is not broken down, and the nitrogen of chlorophyll is not mobilized to the developing seedling.



A

	mature seeds	non-senescent leaflet	senescent leaflet
J12775 (ii)			
J14 (II)			

F o r m u l a r.

Schule (Volksschule, Gymnasium u. s. w.) zu

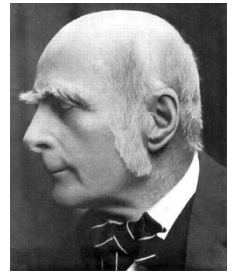
Zahl der Schüler: . . , darunter Juden . .

Davon haben:

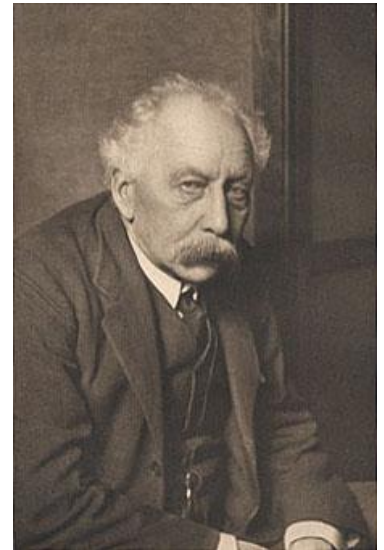
	Gesamt- zahl	darunter Juden
1) blaue Augen, blonde Haare, weisse Haut		
2) " " braune " " " "		
3) " " braune " braune " "		
4) graue Augen, blonde Haare, weisse Haut		
5) " " braune " " " "		
6) " " braune " braune " "		
7) " " schwarze " " " "		
8) braune Augen, blonde Haare, weisse Haut		
9) " " braune " " " "		
10) " " braune " braune " "		
11) " " schwarze " " " "		

Durchschnittliches Alter der besichtigten Schüler:

Francis Galton (1889), a cousin of Charles Darwin, stated in his book, *Natural Inheritance*, that eye-color was **non-blending** but inherited as an **either-or trait**, blue or brown.



In 1902, **William Bateson** wrote in his “*Mendel’s Principles of Heredity. A Defence*”, “*Soon every science that deals with animals and plants will be teeming with discovery, made possible by Mendel’s work. The breeder, whether of plants or of animals, no longer trudging in the old paths of tradition, will be second only to the **chemist** in resource and in foresight. Each conception of life in which heredity bears a part—and which of them is exempt?—must change before the coming rush of facts.*” Could Mendel’s Laws apply to cabbages and kings, animals and humans?



In 1907, following the rediscovery of Mendel, **Charles Hurst** examined the **eye colors** of 139 pairs of parents and their 383 offspring in Burbage, Leicestershire, England, where he owned a plant nursery, and determined that mating of **blue-eyed** (simplex) parents resulted in **blue-eyed** children and the mating of **brown-eyed** (duplex) parents resulted in **brown-eyed** and **blue-eyed** children in a **ratio of 3:1**. Consequently Hurst concluded that eye color was a **Mendelian trait** where **brown eyes** are **dominant** and **blue eyes** are **recessive**.



In America, also in 1907, **Gertrude and Charles Davenport** published a paper entitled, *Heredity of eye-color in man*. The Davenports wondered, “*Is human*

eye-color inherited in Mendelian fashion? The importance of knowing whether it is depends on the fact that, if Mendelian, the result of any combination of eye-colors of the parents upon the eye-color of the offspring can be, within certain limits, predicted.” The Davenports passed out survey cards asking about the eye colors of grandparents, parents, and children. They passed out 132 survey cards to principals of schools and friends. They tallied the results and concluded, “*The practical applications of these results to human marriage are as follows: Two blue-eyed parents will have only blue-eyed children....*”



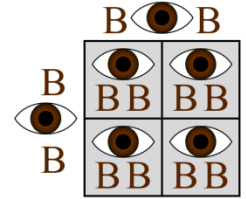
Charles Davenport (1911) tabulated the various studies of eye color in his book entitled, *Heredity in Relation to Eugenics*.

THE INHERITANCE OF FAMILY TRAITS 31											
TABLE IV											
		HURST		DAVEN- PORT		HOLMES & LOOMIS		TOTAL		P'ORTION	
One Parent	Other Parent	Blue	Pig't	Blue	Pig't	Blue	Pig't	Blue	Pig't	Blue	Pig't
pure blue	pure blue	101	0	77	0 ¹	51	1	229	1	99.5	0.5
pigmented (Pp)	blue	137	121	428	506	89	85	654	712	48.0	52.0
pigmented (PP)	blue	0	66	0	70			0	136	0	100
pigmented (Pp)	pigmented (Pp)	18	45	98 ²	169	5	34	121	248	33	67
pigmented (PP)	pigmented (Pp)	0	195	0	99			0	294	0	100

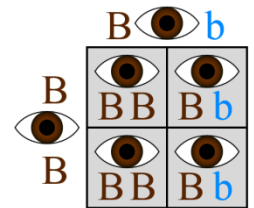
Assume people with brown eyes that have two dominant factors are BB , people with brown eyes that have one dominant factor are Bb or bB , and people with blue eyes that have no dominant factors are bb . People with **two identical factors** (BB or bb) are **homozygous** for the character and people with **two different factors** (Bb or bB) are **heterozygous**. The following **Punnett Squares**

describe the predicted proportion of each eye color in children of various parents **if only one gene**, with **dichotomous** forms, is involved in eye color.

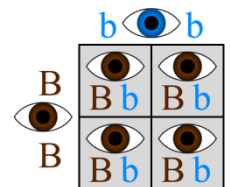
If only one gene is involved in eye color, when two homozygous, brown-eyed parents mate, all the children will be homozygous and will have brown eyes. The ratio of the phenotypes and genotypes will be 4:0 and 4:0:0, respectively.



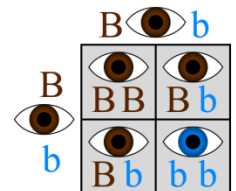
If only one gene is involved in eye color, when one homozygous and one heterozygous, brown-eyed parents mate, all the children will have brown eyes, but two will be homozygous and two will be heterozygous. The ratio of the phenotypes and genotypes will be 4:0 and 2:2:0, respectively.



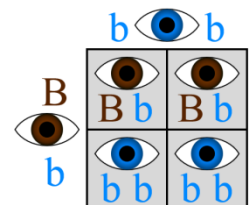
If only one gene is involved in eye color, when one homozygous, brown-eyed parent and one homozygous blue-eyed parent mates, all the children will be heterozygous and will have brown eyes. The ratio of the phenotypes and genotypes will be 4:0 and 0:4:0, respectively.



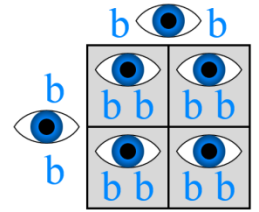
If only one gene is involved in eye color, when two heterozygous, brown-eyed parents mate, the ratio of the phenotypes of brown eyes to blue eyes will be 3:1. The genotypes will be 1:2:1.



If only one gene is involved in eye color, when one heterozygous, brown-eyed parent mates with a homozygous blue-eyed parent, the ratio of the phenotypes and genotypes will be 1:1 and 0:2:2, respectively.

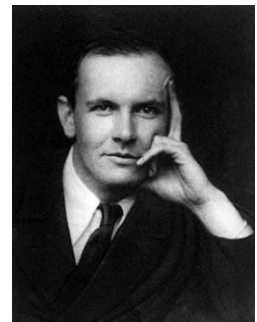


If only one gene is involved in eye color, when two homozygous, blue-eyed parents mate, all the children will be homozygous and will have blue eyes. The ratio of the phenotypes and genotypes will be 0:4 and 0:0:4, respectively.



Davenport (1911) analyzed the data in the table: “*When both parents have pure blue eyes all of the children will have pure blue eyes (the discordant case is probably due to an error),*” and he added, “*We have heard of two blue-eyed parents regretting that they had no brown-eyed children. They wished for the impossible.*”

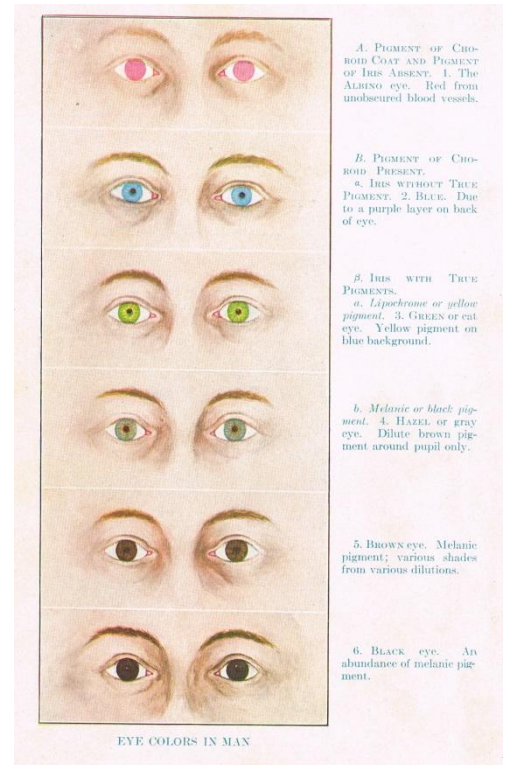
Likewise, **Arthur Darbishire** (1912) wrote in *Breeding and the Mendelian Discovery*, “*The offspring of the union of two persons with simplex [blue] eyes, whatever their ancestry is, will never have brown eyes. At any rate, no exceptions to this rule have yet been observed and recorded.*”



Reginald Punnett (1911) wrote in *Mendelism*, “*...no individuals of the brown class are to be looked for among the offspring of blues mated together.*”



There you have it, **eye color in humans**, at least as far as the **experts** were concerned, could be **reduced to a single gene** where **brown was the dominant form** and **blue was the recessive form** of the gene. That was the story, and they were sticking to it. The geneticists abstracted out of the data that one single gene was important for eye color but what about that one brown-eyed child of two blue-eyed parents? Could it be possible that there was no error in the data, that the wife was not unfaithful, that the milkman was not to blame for the **outlier**? Could it be that the outlier was meaningful and the geneticists who tended towards **reductionism** simplified the story too much? There is a difference between **simple** and **simplistic** (too simple).



Helene Boas, an anthropologist wrote in 1919, “*These conclusions are not convincing because the investigator has been forced to substitute a hypothetical eye-color for the color actually recorded or to “doubt whether the term is used with precision” in order that his results may conform to the Mendelian formula.*” Indeed, Boas found, that “*there are here among the children of two blue-eyed parents 12 per cent with brown eyes.*” But what does a female anthropologist, who crosses disciplinary lines and contradicts the experts, know about Mendel?



Let's look at the pictures of eyes that you took this week. Is eye color a simple, brown v blue, **discrete**, digital, and dichotomous trait? If not, is it likely that more than one gene is involved? Is eye color so **continuous** that **many** genes may be involved, or **relatively discrete** so that only a **few** genes would be involved? What if some of the factors have **incomplete dominance** and there is more of a **blending effect**, like Carl Gärtner saw in many of his horticultural hybrids?



Eye Colors
Strum and Frudakis (2004) Trends in Genetics 20:327

How many Mendelian genes with alternative, dichotomous, dominant, or recessive characters might you guess have a major effect on eye color?

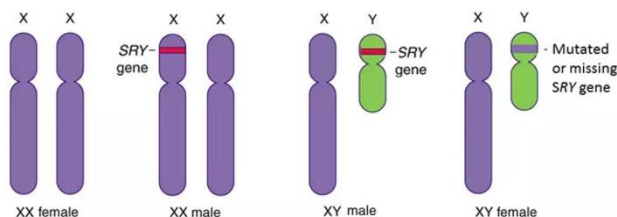
Number of Mendelian dichotomous Genes	Number of Phenotypes
1	$2^1 = 2$
2	$2^2 = 4$
3	$2^3 = 8$
4	$2^4 = 16$
n	2^n

How is reality best described? Are eyes **either** brown or blue? Is there a **continuous variation** in color? Are there a **few or several distinct categories** of color? Scientists must consider more than one version of reality simultaneously: The reductionist and the wholistic—otherwise the assumption may incorrectly give the expected conclusion. Remember having an **equation** means that the left side **equals** the right side, or stated differently, the assumptions **equal** the conclusion.

We can **assume** that only one gene is involved in eye color and then we consider brown-eyed children of blue-eyed parents as **outliers** and **conclude** that

eye color is a one gene dichotomous trait. This has been the **textbook version**. We can also say that in general, one gene for blue eyes explains the great majority of the variation in eye color, but there are other factors, yet unknown. In part, our position will depend on the **value** we put on the **individual** or the **mathematics** as the **fundamental reality**. Which version of reality is truer? Is it unreasonable or reasonable to be a dualist where reality may be characterized in two ways?

Other examples of the **dual nature of reality** exist. Most people can be described as males with XY chromosomes or females with XX chromosomes; however, 0.005% of males and females have XX and XY chromosomes, respectively. Does this mean that male/female is not a valid dichotomy, and that male/female and XY/XX is not a one-to-one correlation; or does it mean that in general the male/female classification is a good categorization, but we must leave room for individual differences that do not fit into a dichotomous classification system?



Paula Scanlan, [Jennifer Sey](#), and Riley Gaines.

Remember, just because there are sporks does not mean forks and spoons are not good categories.

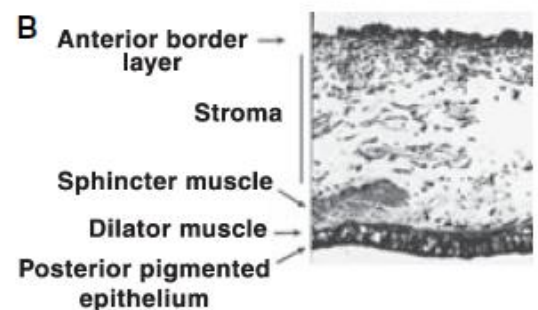
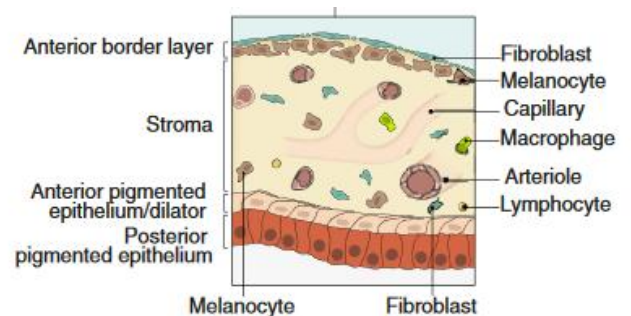
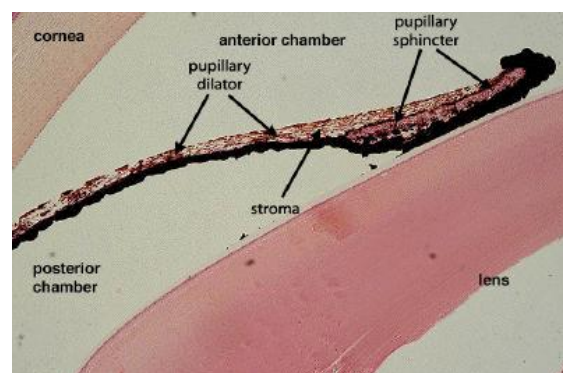


If gender depends on self-identification, should [Enes Kanter Freedom](#) be allowed to play in the WNBA (where W stands for Women's)? Notice the “W” Sophie Cunningham is making with her body.

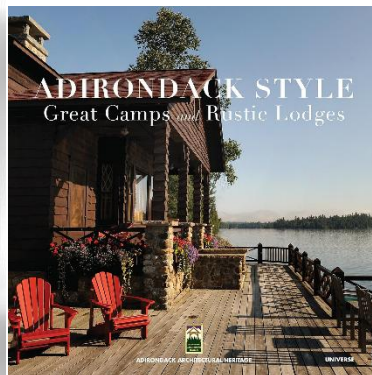
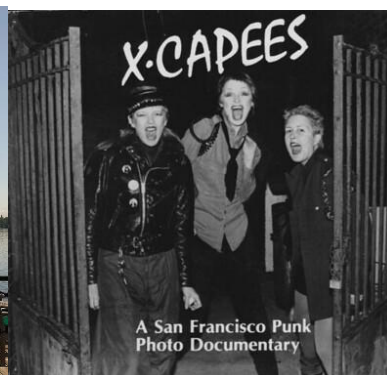
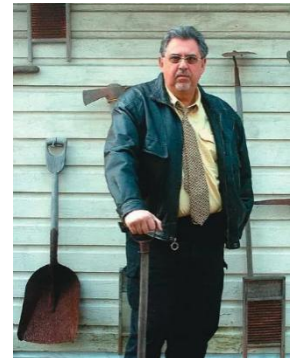


Before we look at the genetic cause of eye color, let's look at the **anatomy of the iris**. The iris is composed of **three layers** that influence eye color. From front to back, they are called, the **anterior layer of the pigmented stroma** (from mesoderm), the internal tissue of the **stroma** (from mesoderm), and the **posterior layer of the iris pigmented epithelium (IPE)** (from ectoderm).

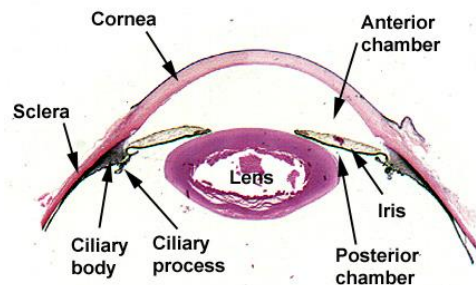
Contraction of the sphincter muscle causes pupil constriction. It is a striated muscle controlled by the parasympathetic nervous system and inhibited by atropine (belladonna). Contraction of the dilator muscle causes pupil dilation. It is a smooth muscle controlled by the sympathetic nervous system and inhibited by opiates.



Aside: The iris acts like the aperture of a camera where the size of the opening is characterized by its f-stop. [f-stop Fitzgerald](#) is a photographer who has produced beautiful books about the early Punk Rock scene entitled *Xcapees* and [Adirondack Style: Great Camps and Rustic Lodges](#), respectively.



Now back to the iris:



Layer of Iris	Pink eye	Blue eye (simplex)	Brown eye (duplex)
Anterior layer of stroma (absorption):	--	--	melanin
Internal tissue of stroma (scatter/absorption):	collagen	collagen	collagen melanin
Posterior layers of IPE (absorption): (two cell layers thick)	--	eumelanin	eumelanin

People with no melanin in the stroma **but** with melanin in the posterior layer of the iris pigmented epithelium have blue eyes:



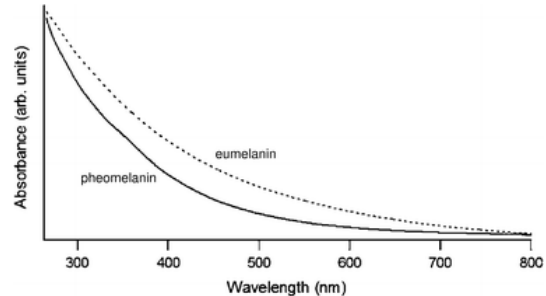
A person with melanin **neither** in the stroma **nor** in the posterior layer of the iris pigmented epithelium will have pink eyes. The additional light that bounces around the eye causes **photosensitivity** and leads to **glare** or multiple reflections, which reduces visual acuity.



People with melanin in the stroma **and** in the posterior layer of the iris pigmented epithelium have brown eyes:



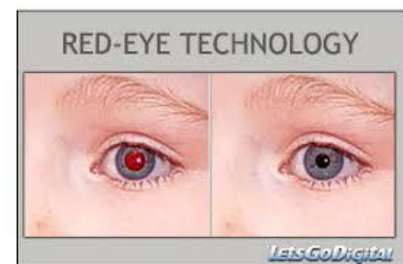
In **brown eyes**, the anterior layer of the pigmented stroma contains a **pigment**, known as **melanin**, that **absorbs** the majority of the incoming light. The **melanin** may be either **eumelanin**, which absorbs nearly all colors of light and reflects back little light and thus appears black or brown, or **phaeomelanin** that absorbs nearly all the colors of light but reflects back a little more reddish-pink light than eumelanin does. The more melanin in this layer, the less light is transmitted through the colored part of the iris to the internal layer of the stroma. Blue-eyed and pink-eyed people do not have any melanin in the anterior layer, so all the incoming light is transmitted to the internal tissue of the stroma. Eumelanin and pheomelanin may also occur in the internal tissue of the stroma, providing even more variety in eye color. (Both eumelanin and pheomelanin absorb UV light that may otherwise cause retinal cancer).



An eye of any color will appear red (**red eye**) if it is illuminated with so much light (i.e., from a flash) that the light is not absorbed by the melanin in the pigmented layer in the retina so that the light is reflected from the blood vessels (choroid) in the eye and travel back out through the pupil.

Cameras reduce red eye by using a pre-flash just before the main flash. The pre-flash causes the pupils to constrict. This reduces the reflection of light from the blood in the choroid.

The internal tissue of the **stroma** is composed of transparent **fibers** made of the **protein collagen**. Some of the **collagen fibers** circle the pupil and some radiate from it. The **collagen fibers** are



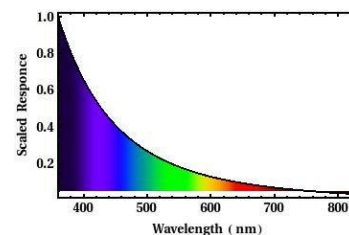
connected to the sphincter and dilator muscles, the contraction of which close or dilate the pupil, respectively. The collagen fiber is much smaller than the **wavelength of a photon** or perhaps the **photon** itself (my research). Consequently, when white light strikes the collagen molecules, it gets **scattered** in a manner such that the intensity I of light of that color that is scattered is inversely proportional to the fourth power of the wavelength (or inversely proportional to the square of the cross-sectional area $(\frac{\lambda^2}{4\pi})$ of the photon):

$$I \propto \frac{1}{\lambda^4}$$

The light is **scattered** by the collagen fibers in all directions, which includes the direction that the light came in. When we look at someone with blue eyes, we see the light that is scattered back out of the eye.

Blue light has a wavelength of about 400 nm, green light has a wavelength of about 500 nm and red light has a wavelength of about 600 nm:

Color	Amount Scattered	Relative Amount Scattered
Blue	3.9×10^{-11}	4.9
Green	1.6×10^{-11}	2
Red	0.8×10^{-11}	1



The **blue light** component of the light is **scattered** almost 5 times more than the **red-light** component is. That is, the red-light component of the light goes right by the collagen molecules into the posterior layer of the iris pigmented epithelium, where it is absorbed, almost five times better than the blue light component does. The green light component acts intermediately.

Demonstration: Shine the light from a penlight on and through the colorless glass “sunset egg” that is embedded with microscopic particles of cobalt oxide. Observe the opalescence—that is the blue light scattered from the egg when light shines on the egg and the yellow light scattered from the egg when light shines through the egg.



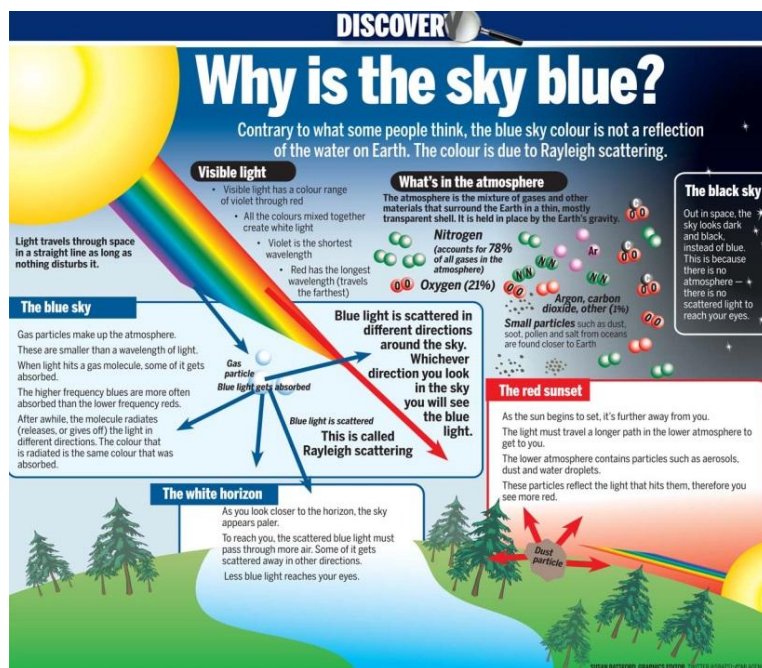
J. M. W. Turner was famous for painting sunsets, and it is rumored that his last words were, “*The sun is God.*” In describing the difference between nature and art, **Oscar Wilde** (1889) wrote in *The Decay of Lying: An Observation*, “*Art creates an incomparable and unique effect, and, having done so, passes on to other things. Nature, upon the other hand, forgetting that imitation can be made the sincerest form of insult, keeps on repeating this effect until we all become absolutely wearied of it. Nobody of any real culture, for instance, ever talks nowadays about the beauty of a sunset. Sunsets are quite old-fashioned. They belong to the time when **Turner** was the last note in art. To admire them is a distinct sign of provincialism of temperament. Upon the other hand they go on.*”



G. K. Chesterton (1913) wrote in *Orthodoxy*, “*Oscar Wilde said that sunsets were not valued because we could not pay for sunsets. But Oscar Wilde was wrong; we can pay for sunsets. We can pay for them by not being Oscar Wilde.*”



The scattering of light from molecules smaller than the wavelength of light is called **Rayleigh scattering**, after Lord Rayleigh, who wanted to describe and explain **why the sky is blue**. Eyes are blue because the incoming light is scattered back out from the eye of the observed person to the eye of the beholder.



Aside: A **mirror** (1 cm) **reflects** all the colors (violet, indigo, blue, green, yellow, orange and red; or ROYGBIV) without discrimination. Imagine making a mirror smaller and smaller until it is as small as a gas molecule (about 0.3 nm) like N₂ or O₂ that scatters sunlight to make the sky blue. **Collagen fibers**, which are 300-300 nm in diameter, are smaller than a mirror and larger than gas molecules. Perhaps light eyes such as **violet** and **gray** eyes result from collagen fibers that are smaller or larger than those in blue eyes. Perhaps violet-eyed people have the smallest collagen molecules and scatter violet light; blue-eyed people have intermediate-sized collagen molecules and scatter violet and blue light; and gray-eyed people have the largest collagen fibers and scatter violet, blue, green, and red light. The following color simulation allows you to



construct gray from blue, green, and red.

<http://phet.colorado.edu/en/simulation/color-vision>



In **blue eyes** and **brown eyes**, the **innermost or posterior layer of the iris pigment epithelium** contains eumelanin. The eumelanin absorbs almost all of the light that reaches it. People with **pink eyes** ***do not*** have eumelanin in this layer, so the light is transmitted all the way to the blood vessels in the choroid and red light is reflected out from the eye. The combination of red reflected from the blood vessels and blue scattered from the stroma, makes magenta.

The **pupil** is a **hole in the iris** that contains neither melanin nor collagen, so all the light that enters the pupil is transmitted to the retina. The pigment in the stroma of the iris is produced in cells called **melanocytes**. The color of the iris is determined, not by the number of

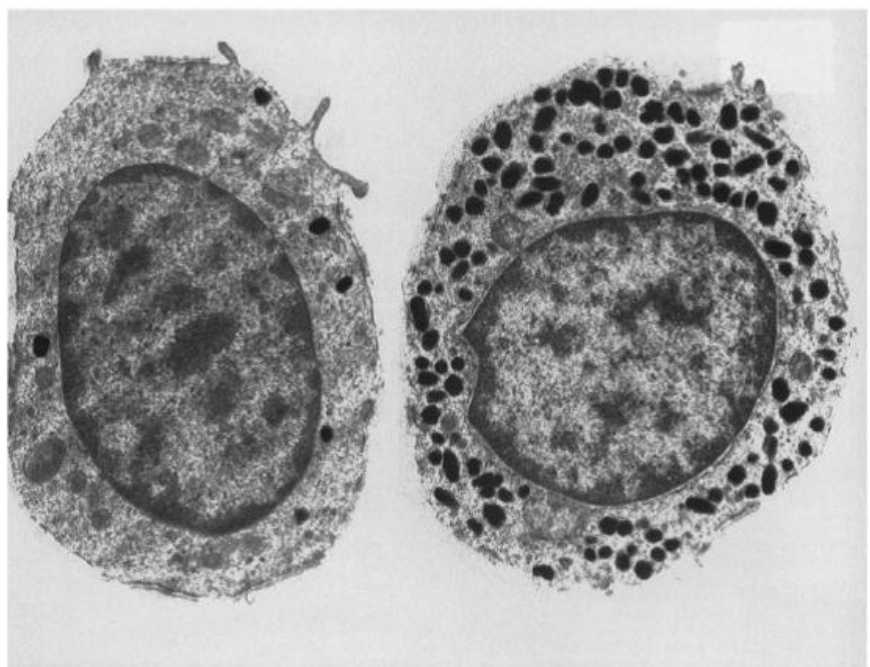


Fig. 2. Electron microscopic photograph at 4000 $\times$ of a superficial stromal iris melanocyte containing only a few melanin granules from an eye with a blue iris on the left and an example of melanocyte from a brown eye on the right.

melanocytes, but by the number of the melanin-containing bodies or **melanosomes** in the melanocytes in the stroma of the eye (Imesch et al., 1997). Brown eyes have more melanin in the anterior layer of the iris than do blue eyes.

Brown eyes can vary from black to amber. The type of melanin, **eumelanin** and **pheomelanin** in the melanosomes determines the shade of brown (Prota et al., 1998). Eumelanin produces **darker brown eyes** and pheomelanin produces **lighter brown eyes**. Note, both eumelanin and pheomelanin **absorb ultraviolet light** very well. As we will

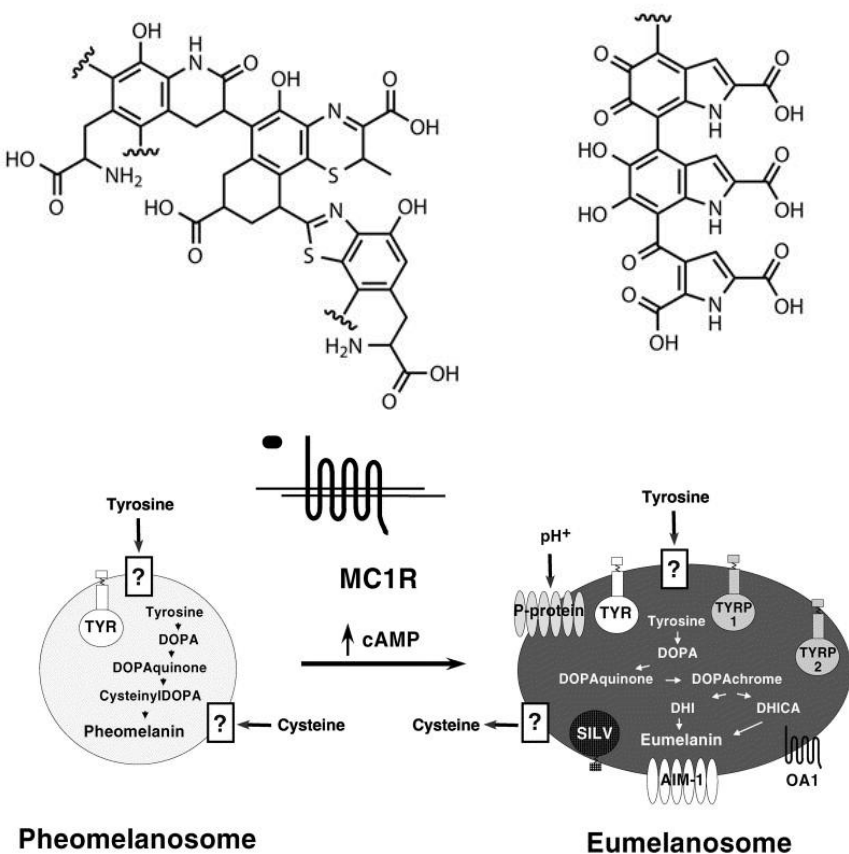


discuss later in the semester, while ultraviolet light is required to make vitamin D, too much ultraviolet light can do damage to cells.

Melanin is formed in the melanosomes of the melanocytes from the amino acid tyrosine in a pathway that involves **several enzymes**, each of which is encoded by a **gene**.

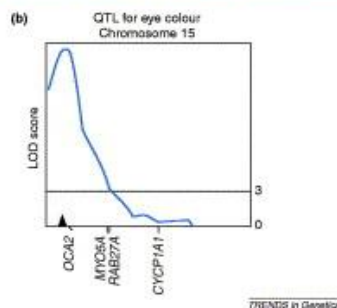
Oculocutaneous albinism is the lack or reduction of melanin pigment in the eyes and skin. A

variation in the oculocutaneous albinism gene that codes for tyrosinase (OCA1), the enzyme that initiates the transformation of tyrosine to melanin, results in the

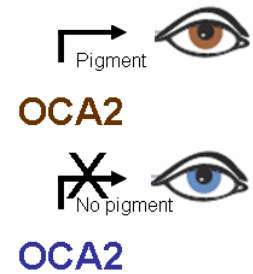


complete lack of production of melanin. A person with this form of the gene will be an albino with blue or pink eyes.

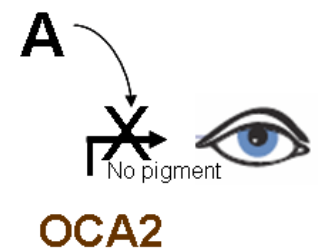
A variation in another **ocularcutaneous albinism** gene (**OCA2**) is correlated with fair skin, light hair, and blue eyes.



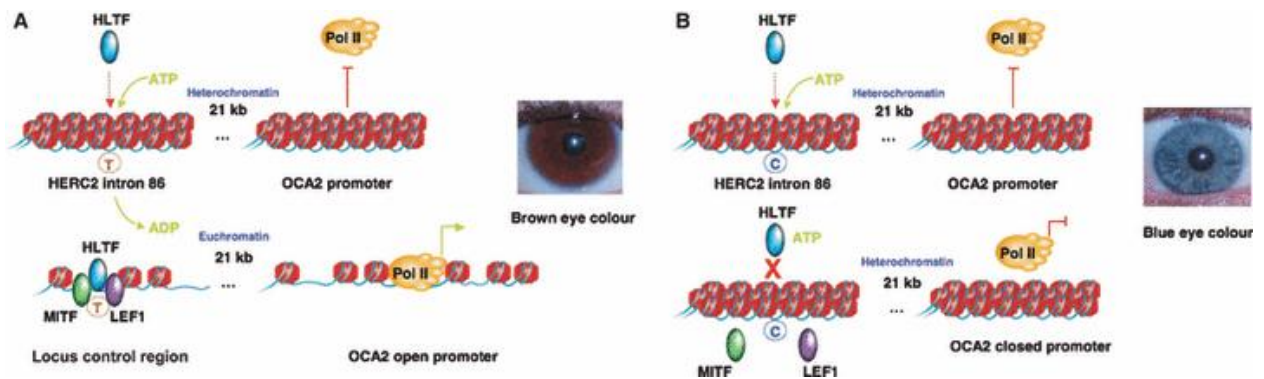
Three of the **variations** or **single nucleotide polymorphisms** (SNPs) in the DNA of the OCA2 gene are statistically **correlated** with blue eye color. LOD stands for Logarithm of the Odds. Thus, some versions of the OCA2 gene lead to brown eyes and others lead to blue eyes. There is no direct causal chain between OCA2 and eye color since the function of the OCA2 gene is unknown. However it is **believed** to be an integral membrane protein involved in the **transport of tyrosine** into the **melanosome** where it can act as a precursor for melanin synthesis.



There is another gene called **HERC2** that is adjacent to **OCA2**. One version of the HERC2 gene DNA sequence (TGACA(T/C)TTAAT) where there is a base change from T to C is highly **correlated** with blue eyes. The following **model** has been proposed by Sturm and Larsson (2009) to explain the interaction of the two genes: The T form of the HERC2 gene binds a helicase-like transcription factor (HLTF) that opens up the OCA2 gene so that RNA polymerase II can bind to OCA2 and the OCA2 gene **can be expressed**. Consequently, the protein for tyrosine transport into the melanosomes is produced. The variation of HERC2 that is correlated with blue eyes (C) prevents the binding of a helicase-like transcription



factor (HLTF) and consequently, RNA polymerase II never binds to OCA2 and the OCA2 gene is **never expressed**.



Assume that the form of OCA2 that would lead to brown eyes if only one gene is involved is dominant and is given by B, and the recessive form of OCA2 that would lead to blue eyes if only one gene was involved is given by b. Assume that the form of HERC2 that would allow the expression of OCA2 and would lead to brown eyes is dominant and given by A and the form of HERC2 that would prevent the expression of OCA2 and would lead to blue eyes is recessive and given by a.

If blue eyes were determined by these two genes, there are many possible ways of having blue eyes: AAbb, Aabb, aabb, aaBB, and aaBb. For example, a person with the blue-eyed version of HERC2 (aa) and the brown-eyed version of OCA2 (BB or Bb), would have blue eyes. Here are a few examples:

Aabb x aabb

ab

Ab **Aabb** (blue)

ab **aabb** (blue)

AAbb x aaBB

aB

Ab **AaBb** (brown)

aaBb x Aabb

Ab

ab

aB **AaBb** (brown) **aaBb** (blue)

ab **Aabb** (blue) **aabb** (blue)

etc.

Since there are a number of variations in each gene and the proportion of each variation is unknown, we cannot determine the exact probability that two blue-eyed parents can have a brown-eyed child. **Experience tells us that it is rare; our analysis of the inheritance of two interacting genes tells us that it is not impossible.** Studies of the irises of identical twins show that approximately 58-78% of the iris characters have a genetic basis.

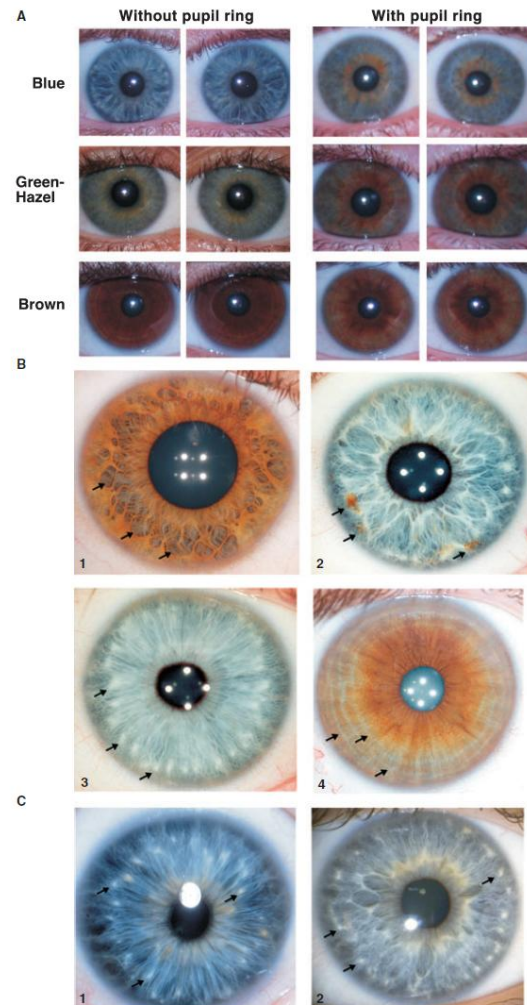
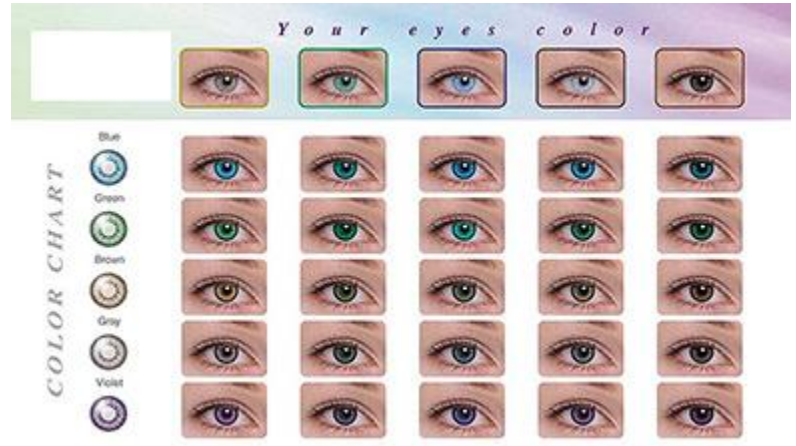


Figure 2. Human iris colour classification and patterns. (A) Three major classes of eye colour are shown as Blue, Green-Hazel, Brown with and without a brown peripupillary ring. (B) Patterns found within the iris highlighted by arrows: 1. Fuchs' Crypts, mild stroma atrophy; 2. Nevus, dots of accumulated melanin; 3. Wolfflin nodules, dots of accumulated collagen fibrils; 4. Contraction Furrows, fold marks in thicker irises due to iris contraction and dilation. (C) Patterns found within the iris highlighted by arrows: 1. Brushfield spots, observed in Down's syndrome; 2. Wolfflin nodules, observed in normal controls.

The human iris shows as many as 240 different features that can contribute to our individuality. In this respect, it is no surprise that the **Iris Recognition Immigration System (IRIS)** is used for individual identification.



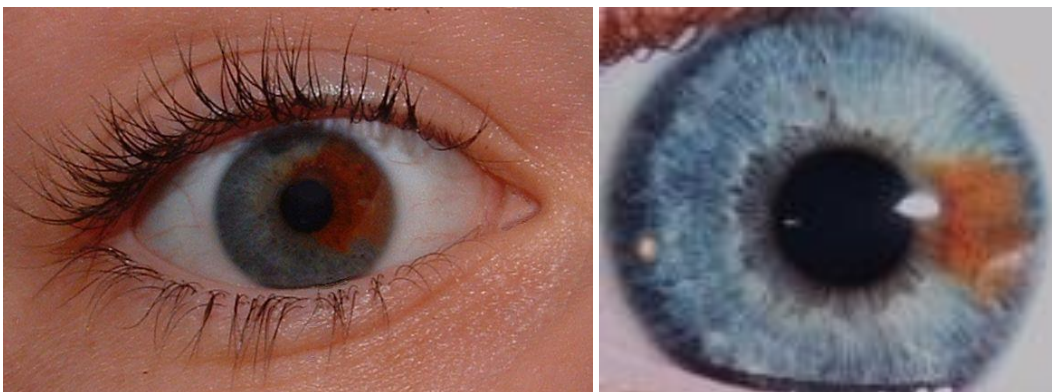
Is it possible that the environment has an effect on eye color? The only datum I have that the environment affects eye color is the existence of color contact lenses. A **phenocopy** is someone who has a certain genotype but looks like he or she has a different one.



Because the detailed development of the iris depends on initial conditions in the embryonic mesoderm and ectoderm from which it develops, the phenotypic expression of the two irises possessed by one individual can



be different. This is known as **heterochromia**. Heterochromia can also exist in one iris.



Mendelian genetics was used as a basis of paternity tests. While blue eyes were considered to a simple Mendelian character, one must remember that blue-eyed babies may become brown-eyed children due to the developmental control of melanin production in Caucasian children (Beckman et al., 1960). Note that not many traits are inherited in a simple Mendelian fashion.

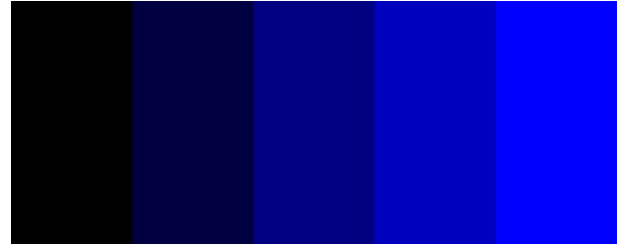
TABLE 32. *Qualitative characters. Summary of the results of the analysis of the family data.*

Character	Nothing contradicts simple inheritance	Inherited though not in a simple way	Sex variation	Age variation	Bilateral variation
Eye color	+		—	+	
Hair color	—	+	—	+	
„ form	—	+	—	+	
„ whorl	+		—	—	
Frontal hair	—	+	+	+	
Hair between the eyebrows	—	+	+	+	
Mid-digital hair	—	+	—	+	—
DARWIN's tubercle	—	—	—	—	—
Ear lobes	—	+	+	+	—
Tongue-rolling	+		—	—	
Chin groove	—	+	+	+	
Eye openings	—	+	—	+	
Folds on the upper eyelids	—	+	—	+	—
Extensibility of the proximal thumb joint	—	+	—	+	+
BONNEVE's fingerprint formulae	—	—	—	—	
Length of the second toe	—	+	—	+	—
Tasting	+		—	—	

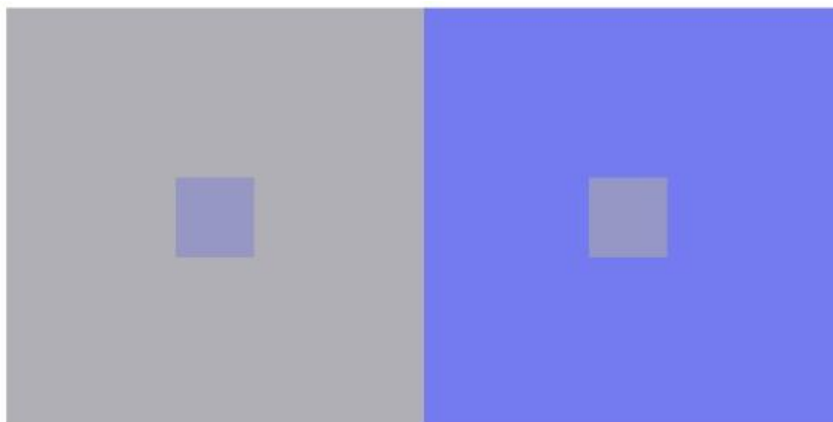
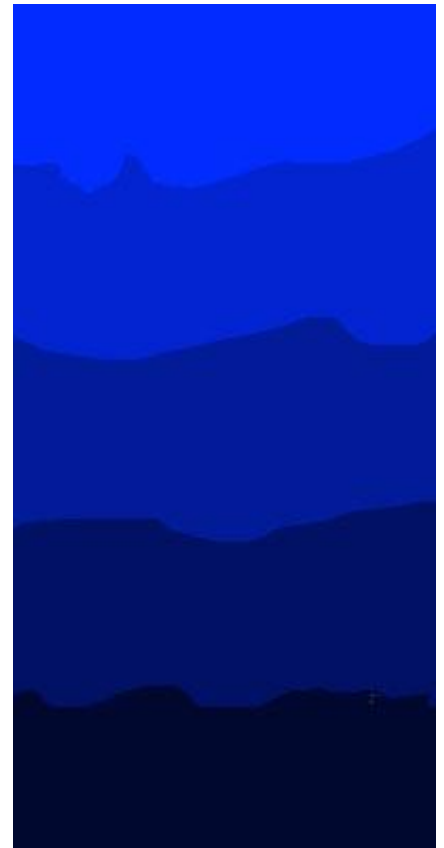
Because our brain judges colors relative to the surrounding or nearby color, the distribution of melanin in an iris may have a great effect on the perceived color of the iris.



Look at the **Chevreul illusion**. Each rectangle is a homogenous, yet the part next to the lighter rectangle looks darker. The Chevreul illusion works for uneven shapes too, as long as the color family is the same.



This color saturation illusion shows you that nearby colors influence your perception of a given color. While two small squares appear to be different colors, they are the same color. In his book, *Theory of Colors*, Johann Wolfgang von Goethe (1810) emphasized that our perception of the color of something depended on the context!

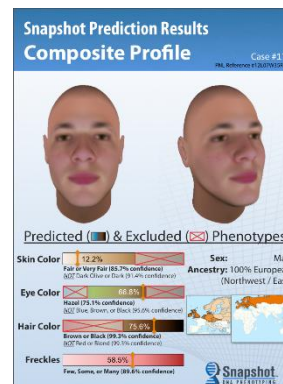
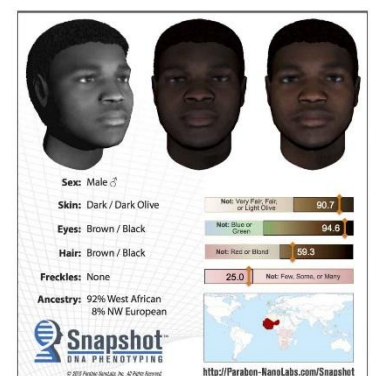


Both irises in the figure below are the same shade of gray, but the red color surrounding the iris makes the iris on the left look blue. But after masking the iris on the left, it looks like the same shade of gray as the one on the right.

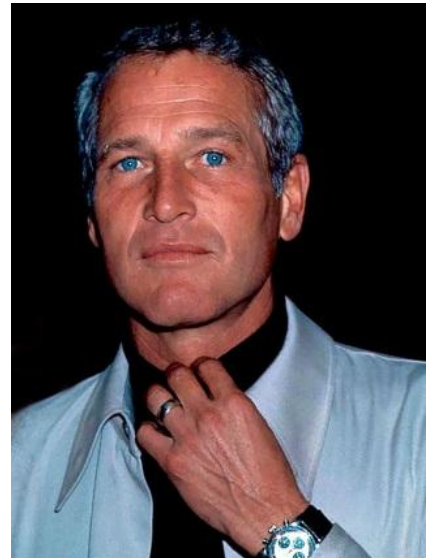


We have found that **eye color is not absolutely a single Mendelian trait**, but a **polygenetic trait**. Indeed, there are even more than two genes that are correlated with eye color. You may expect this for two reasons: One, that there are more than two categories of blue-brown eye color; and two, that there are a number of enzymes that are involved in melanin synthesis. **Each enzyme is encoded by a gene and each gene may be regulated by other genes**, like the OCA2 gene is regulated by the HERC2 gene. Moreover, **any gene may exhibit incomplete dominance**. In addition, since only 58-78% of iris characteristics can be explained genetically in identical twins, **the environment or chance related to the position of iris cells derived from different cell populations in the embryo** may contribute to iris color.

Law enforcement is interested in predicting the eye color of the person who left behind DNA at a crime scene. Currently it is possible to predict the eye color of an individual with greater than 90% accuracy for brown and blue using six single nucleotide polymorphisms (SNPs). <http://snapshot.parabon-nanolabs.com/>



Melanin production in the iris begins during gestation in African American, Hispanic, and Asian babies. Melanin production is usually delayed up to a year after birth in the irises of Caucasian infants so Caucasian babies are usually born with blue eyes. Within a year melanin production begins if the final color of the eye is going to be brown. Melanin production begins earlier in Caucasian girls than Caucasian boys. Some, like Paul Newman, keep their baby blue eyes.



Aside: Speaking of children, not all kids are so lucky. According to Dr. Abraham C., Nazi physician **Josef Mengele** noticed that a few seven-year old boys in Auschwitz “*had one odd characteristic: they were blond and had brown eyes, so Mengele was trying to find a way to color their eyes blue.*” Mengele tried to find a way to change their eye color and **injected**



their eyes with methylene blue. While the treatment caused severe pain and inflammation, *“their eyes of course did not change.”* Robert Jay Lifton (1986) wrote in his book *The Nazi Doctor*, *“But the methylene blue injections are of a different order, not in their cruelty (which was usual) but in their extraordinary scientific naïveté—or, one might more accurately say, their scientific corruption.”*

Mengele shared the eyes he obtained from the *“inferior human material”* at Auschwitz with Karin Magnussen, a scientist who worked on eye pigmentation at the Kaiser Wilhelm Institute (KWI) for Anthropology, Human Genetics, and Eugenics, which was directed by Mengele’s mentor Otmar von Verschuer. Lifton wrote that Verschuer spoke of the *“enormously interesting specimens”* of different-colored eyes Mengele had sent him and seemed *“surprised and upset”* when he was told they had come from Gypsies that Mengele had ordered killed because of this abnormality. *“In Verschuer’s attitude we encounter a hypocritical academic accessory to Mengele’s characteristic pattern of killing for science.”*

Eva Kor, a twin in Mengele’s experiments, found the power to forgive the doctors. Her son Alex carries on her message of forgiveness.



Race-based progressive science played roles in a wide variety of social policies. **Paul Popenoe** (1934), of the Human Betterment Foundation wrote, *“Germany’s eugenic sterilization law, which went into effect on January 1, 1934, is no hasty improvisation of the Nazi regime. It has been taking shape gradually during many years, in the discussions of eugenicists. From one point of view, it is merely an accident that it happened to be the Hitler administration which was ready to put into effect the recommendations of specialists.”*



“But Hitler himself—though a bachelor—has long been a convinced advocate of race betterment through eugenic measures. Probably his earlier thinking was colored by Nietzsche, but he studied the subject more thoroughly during his years in prison, following the abortive revolutionary movement of 1923. Here, it is said, he came into possession of the two volume text on heredity and eugenics, by E. Baur, E. Fischer, and F. Lenz, which is the best-known statement of eugenics in the German language, and evidently studied it to good purpose. In his book, Mein Kampf, most of which was written during these prison years, and which outlines most of the policies since adopted by the Nazis as a political party, he bases his hopes of national regeneration solidly on the application of biological principles to human society.”

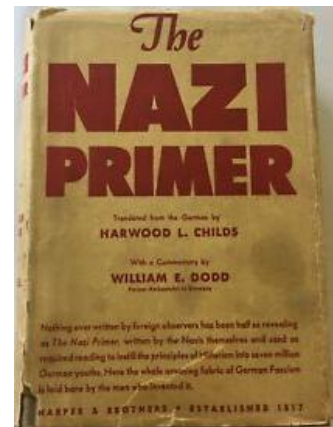
“The policy of the present German government is therefore to gather about it the recognized leaders of the eugenics movement, and to depend largely on their counsel in framing a policy which will direct the destinies of the German people, as Hitler remarks in Mein Kampf, “for the next thousand years.” Whether this policy will be carried through successfully, of course remains to be seen. At best,

mistakes will be inevitable. But the Nazis seem, as this scientific leadership becomes more and more prominent in their councils, to be avoiding the misplaced emphasis of their earlier pronouncements on questions of race, and to be proceeding toward a policy that will accord with the best thought of eugenicists in all civilized countries."

"In any case, the present German government has given the first example in modern times of an administration based frankly and determinedly on the principles of eugenics. It has thus posed the question in a way that no other people can ignore."

[Eugenic Archives: "The German Sterilization Law," by Paul Popenoe, <i>Journal of Heredity</i> \(vol. 25\) \(eugenicsarchive.org\)](http://eugenicsarchive.org/eugenix/essay/30/german-sterilization-law)

Using science to justify policy has its limits. According to [*The Nazi Primer: The Official Handbook for Schooling the Hitler Youth*](#), written by Fritz Brennecke (1938), who described Mendel's laws and characterized races in terms of eye color, *"Even in our day the fact is shown many times that certain men have no feeling for race honor or race shame...Even those occupying the highest places in government during the 'System Time' consciously closed their eyes to the facts of race... We, however, shape the life of our people and our legislation according to the verdicts of the teachings of genetics."*



Nazis gained the hearts of 20,000 Americans who filled Madison Square Garden on February 20, 1939 for a [rally](#). [Isadore Greenbaum](#), a 26-year-old plumber's helper from Brooklyn, charged the stage yelling “*Down with Hitler*” and was beaten up and arrested. Greenbaum told the judge, “I went down to the Garden without any *intention of interrupting, but being that they talked so much against my religion and there was so much persecution I lost my head and I felt it was my duty to talk.*” The judge asked him, “*Don't you realize that innocent people might have been killed?*” And Isadore Greenbaum answered, “*Don't you realize that plenty of Jewish people might be killed with their persecution up there?*” Isadore was one of the first Americans to fight Nazi terror.



Greenbaum: Rabin. Foto: which Hit Kohn



[Joseph Goebbels](#) described one of his first meetings with [Adolf Hitler](#) like so: “*Shakes my hand. Like an old friend. And those big blue eyes. Like stars. He is glad to see me. I am in heaven. That man has everything to be king.*”



Interested in eye color, Reginald Punnett (1911) wrote, “*A discussion of eye-colour suggests reflections of another kind. It is difficult to believe that the markedly different states of pigmentation which occur in the same species are not associated with deep-seated chemical differences influencing the character and bent of the individual. May not differences in pigmentation be coupled with and so become in some measure a guide to mental and temperamental characteristics? In the National Portrait Gallery in London the pictures of celebrated men and women are*



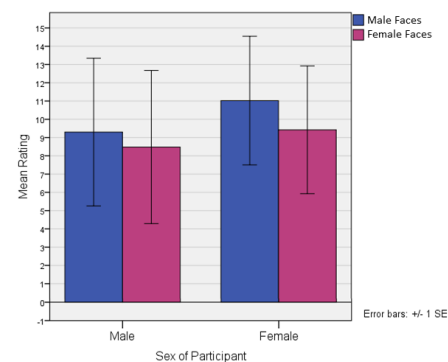
*largely grouped according to the vocations in which they have succeeded. The observant will probably have noticed that there is a tendency for a given type of eye-colour to predominate in some of the larger groups. It is rare to find anything but a blue among the soldiers and sailors, while among the actors, preachers, and orators the dark eye is prominent, although for the population as a whole it is far scarcer than the light. **The facts are suggestive, and it is not impossible that future research may reveal an intimate connection between peculiarities of pigmentation and peculiarities of the mind.***”

Unbelievably to me, this kind of speculation has not stopped. Today there are many studies done by psychologists to understand how “*early expressing genes in the iris, are linked to brain development, and thereby potentially can contribute to identify networks of genes that influences different behavioural tendencies (Larsson et al., 2007).*” Some titles of published papers include, Eye color predicts alcohol use in two archival samples (Personality and Individual Differences 31 (2001) 535-539); Associations between iris characteristics and personality in adulthood (Biological Psychology 75 (2007) 165-175); and Eye color predicts but does not directly influence perceived dominance in men (Personality and Individual Differences 49 (2010) 59-64). Another study asks, why do blue-eyed men prefer women with the same eye color (Behav Ecol Sociobiol 61 (2007) 371-384)?

Others ask about the evolutionary advantage of blue eyes in Northern climates where they are more common. According to Sturm and Larsson (2009), the ability to overcome seasonal affective disorder (SAD) is linked to lighter eye color. “*Perhaps those with blue eyes may have been able to withstand the dark,*

depressing days of the Neolithic European winters better than those with brown eye colour.”

The **limbal ring** is the colored annulus at the border of the iris and the sclera. The thickness of the limbal ring decreases as a function of age and health. This led Peshek et al. (Evolutionary Psychology 9(2): 137-146; 2011) to ask, “*Are judgements of facial attractiveness shaped to use the information within the limbal ring in a potentially adaptive way?*” To answer this question, they showed observers photographs of two faces, which were identical except that one face had dark limbal ring and the other had none. Observers thought that the faces with limbal rings were more attractive. The authors conclude that “*Male and female participants rated faces with clearly visible limbal rings as more attractive, suggesting that both sexes have been shaped by natural selection to use the limbal ring as a probabilistic indicator of reproductive fitness....The results could have practical application: Colored contact lenses are now commercially available that mimic the appearance of a limbal ring.*” Note: Positive values indicate preference for faces with a dark limbal ring.



Prosthetic iris replacements made of colored silicone (a polymer made up of siloxane ($-R_2Si-O-SiR_2-$, where R is an organic group) are now available in the United States



(<http://www.brightocular.com/>) and laser surgery to convert brown eyes to blue is being developed (<http://www.stromamedical.com>).

I think that there is something nice about keeping the eye color we were born with!

Songs about Eyes

Green Eyes: Cold Play <https://www.youtube.com/watch?v=whqebes2EFo>

Green-Eyed Lady: Sugarloaf

https://www.youtube.com/watch?v=c_DydKnpDsk&list=PLhvjr2FOINky0ZtMLza8CNVINxsZK5uSO&index=12

Lying Eyes: Eagles <https://www.youtube.com/watch?v=r5KtEToyWrI>

Sad Eyes: Robert John <https://www.youtube.com/watch?v=l5grdfnGUss>

Hungry Eyes: Eric Carmen

<https://www.youtube.com/watch?v=2ssCL292DQA>

Behind These Hazel Eyes: Kelly Clarkson

https://www.youtube.com/watch?v=c_DydKnpDsk&list=PLhvjr2FOINky0ZtMLza8CNVINxsZK5uSO&index=12

Eyes Off You: Prettymuch

https://www.youtube.com/watch?v=NWA_1lXzGnU

In Your Eyes: The Weeknd

<https://www.youtube.com/watch?v=dqRZDebPIGs>

Ocean Eyes: Billie Eilish https://www.youtube.com/watch?v=viimfQi_pUw

Brown Eyed Girl: Van Morrison

https://www.youtube.com/watch?v=TWoFl_0UtiQ

I Only Have Eyes for You: The Flamingos

<https://www.youtube.com/watch?v=FvzNeh4Mql0>

My Eyes Adored You: Frankie Valle:

<https://www.youtube.com/watch?v=CcJDSLg-0uU>

Can't Take My Eyes off of You: Frankie Valle

<https://www.youtube.com/watch?v=NGFToiLtXro>

Blue Eyes Crying in the Rain: Willie Nelson
<https://www.youtube.com/watch?v=JA644rSZX1A>

Blue Eyes Crying in the Rain: Elvis Presley
https://www.youtube.com/watch?v=SRs3uPMK_Dk

Blue Eyes Crying in the Rain: Vince Gill
<https://www.youtube.com/watch?v=Tk5rQmGzrvk>

Blue Eyes Crying in the Rain: Willie Nelson and Shania Twain
<https://www.youtube.com/watch?v=N6wBxQVBozI>

Blue Eyes Crying in the Rain: Dwight Yoakam
<https://www.youtube.com/watch?v=CFs5JvxibmM>

Blue Eyes Crying in the Rain: Roy Acuff
https://www.youtube.com/watch?v=POTHIP_GjY8

Blue Eyes Crying in the Rain: Hank Williams Sr.
<https://www.youtube.com/watch?v=o3fYZ6oFBxM>

Brown Eyed Girl: Bruce Springsteen
<https://www.youtube.com/watch?v=dLFKEdHKeaw>

Brown-Eyed Women (Live at Barton Hall, Cornell University, Ithaca, NY
5/8/77): Grateful Dead

<https://www.youtube.com/watch?v=gdvY6BiPPhE>

Brown-Eyed Women: Grateful Dead
https://www.youtube.com/watch?v=-Aa-_WqVq-8

Blue Eyes: Elton John <https://www.youtube.com/watch?v=JA644rSZX1A>

Pale Blue Eyes: Velvet Underground
<https://www.youtube.com/watch?v=S23VK1v9dB8>

Behind Blue Eyes: The Who
<https://www.youtube.com/watch?v=BfuWXRZe9yA>

Behind Blue Eyes: Limp Bizkit
<https://www.youtube.com/watch?v=8IEQpfA528M>

Behind Blue Eyes: Cheryl Crow
<https://www.youtube.com/watch?v=ILdAjfa70TY>

Suite Judy Blue Eyes: Crosby Still & Nash (written about Judy Collins)
<https://www.youtube.com/watch?v=kVUwriwKrl>

Don't It Make My Brown Eyes Blue: Crystal Gayle
https://www.youtube.com/watch?v=C9lz_yzrGZw

In Your Eyes: Peter Gabriel
<https://www.youtube.com/watch?v=evN6DIGPIJM>

Betty Davis Eyes: Kim Carnes
<https://www.youtube.com/watch?v=EPOIS5taqA8>

My Eyes Have Seen You: The Doors
<https://www.youtube.com/watch?v=Yq3jxRV2kWI>

Eyes of Silver: Doobie Brothers
https://www.youtube.com/watch?v=wY4_5kl7B_o

My Father's Eyes: Eric Clapton
https://www.youtube.com/watch?v=wY4_5kl7B_o

Angry Eyes: Loggins & Messina:
<https://www.youtube.com/watch?v=w9iTjVfh558>

Dark Eyes: Bob Dylan and Patti Smith
<https://www.youtube.com/watch?v=w9iTjVfh558>

Being a monk, and after Cyrill Napp's death an abbot, Gregor Mendel gave sermons. Here is an excerpt from his [*Sermon on Easter*](#), in which he talks about a gardener who *plants seedlings in prepared soil*.

Jesus appeared to the disciples after the resurrection in various forms. He appeared to Mary Magdalene so that they might take him for a gardener. Very ingeniously these manifestation of Jesus is to our minds difficult to penetrate. (He appears) as a gardener. The gardener plants seedlings in prepared soil. The soil must exert a physical and chemical influence so that the seed of the plant can grow. Yet this is not sufficient. The warmth and light of the sun must be added, together with rain, in order that growth may result.

The seed of supernatural life, of sanctifying grace, cleanses from sin, so preparing the soul of man, and man must seek to preserve this life by his good works. He still needs the supernatural food, the body of the Lord, which received continually, develops and brings to completion of the life. So natural and supernatural must unite to the realization of the holiness to the people. Man must contribute his minimum work of toil, and God gives the growth. Truly, the seed, the talent, the grace of God is there, and man has simply to work, take the seeds to bring them to the bankers. So that we "may have life, and abundantly"...

Three sacraments that contribute to life, baptism, confession, communion, have been used at Easter time. (Eucharist connects completely faith and baptism, God and man incompletely) Triumph: As expected of pious Christians, the joy of victory is heard in the midst of an unjust world; victory and not disparagement, insult, persecution. With the day of the victory of Christ, the Easter, the bonds are broken, the death and sin laid (?), and the Redeemer of mankind rises strongly the human race from night time and fetters, in blessed heights, heavenly gates!)...

The [Mendel Medal Award](#) is given by Villanova University to recognize the scientific accomplishments and religious conviction of outstanding scientists.

Perspective: Railroad track going to Auschwitz

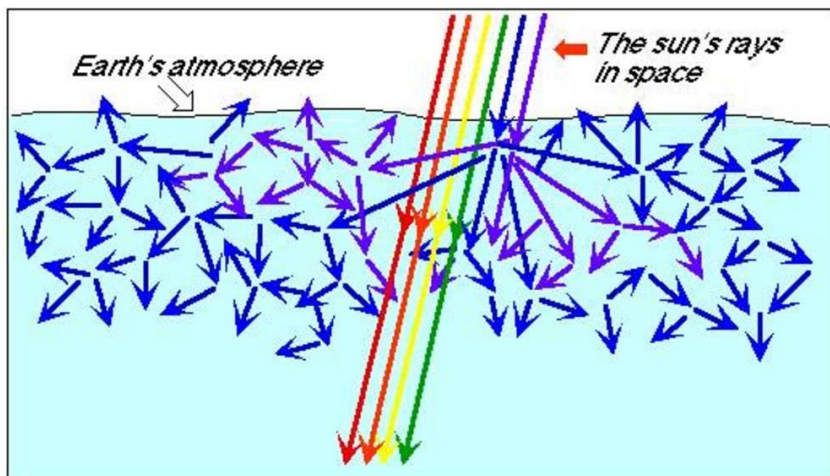
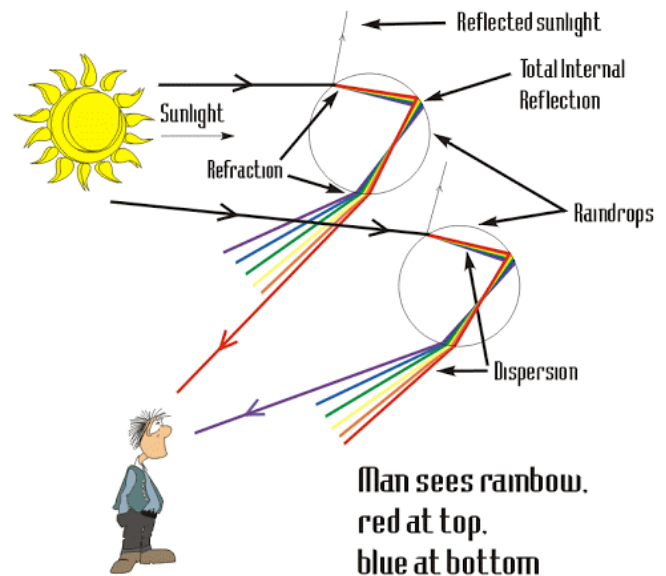


Aside: The 1600-year old [Lycurgus Cup](#), which is in the British Museum, appears jade green under normal lighting and ruby red when lit from behind as a result of scattering by [gold and silver particles](#) embedded in the glass.



Color and Color Vision

We live in a happy and joyous world of color. As Lord Rayleigh discovered, sunlight before it even reaches the earth is **scattered** by small gas molecules in the atmosphere to give rise to the blue sky as well as warm sunrises and sunsets. As Roger Bacon discovered, sunlight **reflected** and **refracted** through water droplets gives rise to rainbows.



[George Washington](#) (1790) wrote to the Hebrew Congregation in Newport, Rhode Island: “*May the father of all mercies **scatter light and not darkness** in our paths, and make us all in our several vocations useful here, and in his own due time and way everlastingly happy.*”

It says in the apocryphal book of Ecclesiasticus (43:11-12), “*Look upon the rainbow, and praise him that made it; very beautiful it is in the brightness thereof. It compasseth the heaven about with a glorious circle, and the hands of the most High have bended it.*” In Ephesians (5:13) it says, “*But everything exposed by the light becomes visible—and everything that is illuminated becomes a light.*”

Q: How much does a rainbow weigh?

A: Not much, they're actually pretty light.

Sunlight falling on **pigment**-containing rock formations in the rainbow mountains in Danxia China is differentially reflected from the rocks in a manner that depends on the mineral content of the sandstone and conglomerates that make up the rock formations. http://www.huffingtonpost.com/2013/07/31/rainbow-mountains-china-danxia-landform_n_3683840.html



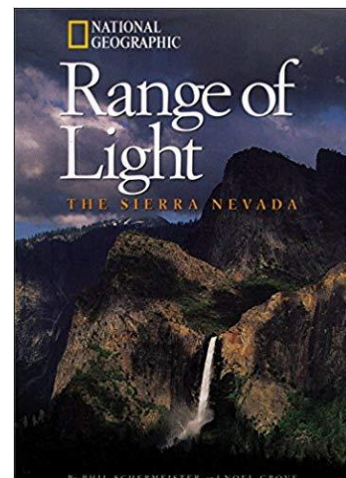
Similar reflected colors are seen in the salt domes and glaciers in the [Zagros Mountains of Iran](#).



John Muir (1890) wrote in *The Treasures of Yosemite*, “One shining morning, at the head of the Pacheco Pass, a landscape was displayed that after all my wanderings still appears as the most divinely beautiful and sublime I have ever beheld.

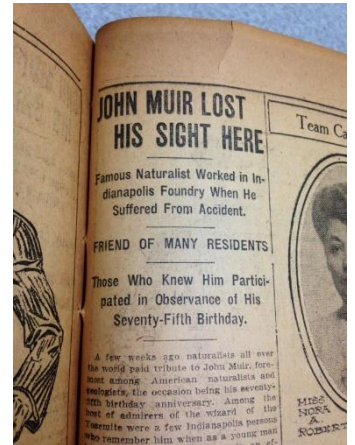


There at my feet lay the great central plain of California, level as a lake thirty or forty miles wide, four hundred long, one rich furred bed of golden *Compositae*. And along the eastern shore of this lake of gold rose the mighty Sierra, miles in height, in massive, tranquil grandeur, **so gloriously colored and so radiant that it seemed not clothed with light, but wholly composed of it**, like the wall of some celestial city. Along the top, and extending a good way down, was a rich pearl-gray belt of snow; then a belt of blue and dark purple, marking the extension of the forests; and stretching along the base of the range a broad belt of rose-purple, where lay the miners' gold and the open foothill gardens — all the colors smoothly blending, **making a wall of light clear as crystal** and ineffably fine, yet firm as adamant. Then it seemed to me the Sierra should be called, not the Nevada or Snowy Range, but the **Range of Light**. And after ten years in the midst



of it, rejoicing and wondering, seeing the glorious floods of light that fill it, — the sunbursts of morning among the mountain-peaks, the broad noonday radiance on the crystal rocks, the flush of the alpenglow, and the thousand dashing waterfalls with their marvelous abundance of irised spray, — it still seems to me a range of light.”

John Muir really appreciated the power of light and vision since he was [temporarily-blinded](#) by an awl which was flung into his right eye in an industrial accident. Muir called out “*My right eye is gone—closed forever on all God’s beauty.*” The uninjured left eye became sympathetically blind. A few months later, his vision returned.



Sunlight falling on **pigment**-containing flowers, fruits, and autumn leaves is transmitted through and reflected from plants creating a spectrum of living color.



Leigh Hunt (1840) wrote in *The Seer; or Common-Places Refreshed*, that “Colours are the **smiles of nature**. When they are extremely smiling and break forth into other beauty besides, they are her laughs; as in the flowers.” Edwin Matzke (1942) wrote in an article on autumn colors entitled, “The Finest Show on Earth,” that “Perhaps this [autumn colors] is the **botanical expression of ‘art for art’s sake’.**”

Sunlight falling on pigment-containing bird feathers is reflected to produce reds. The red color results from the **carotenoid pigments** in the food the birds eat.



The blue in the plumage of birds and the wings of butterflies is not due to pigments. The blue is due to the laminated structure that makes up the feathers or wings. We will talk about structural colors, which is known as **iridescence** later in the semester.



Human beings mimic the colors of nature by creating natural and synthetic **dyes**, such as tekhelet, cochineal, madder, indigo, and mauveine to further color our world. We will learn about the histories (natural and otherwise) of the production of dyes later this semester.



Popularity by Robert Browning (1812-1889)

*Who has not heard how Tyrian shells
Enclosed the blue, that dye of dyes
Whereof one drop worked miracles,
And coloured like Astarte's eyes
Raw silk the merchant sells?*



I can find no historical evidence that Astarte, the goddess of fertility, had blue eyes. It appears that Lord Byron (1788-1824), and poets, writers, painters (Dante Gabriel Rossetti (Jane Morris as Astarte)), and anime creators after him, gave her blue eyes. Starbucks put her on their logo.

Color inspires wonder. Giovanni Dondi dell'Orologio (ca. 1382) wrote, “*To whatever object the eye first turns, the same is a wonder and full of wonder, if only we examine it a little.*”

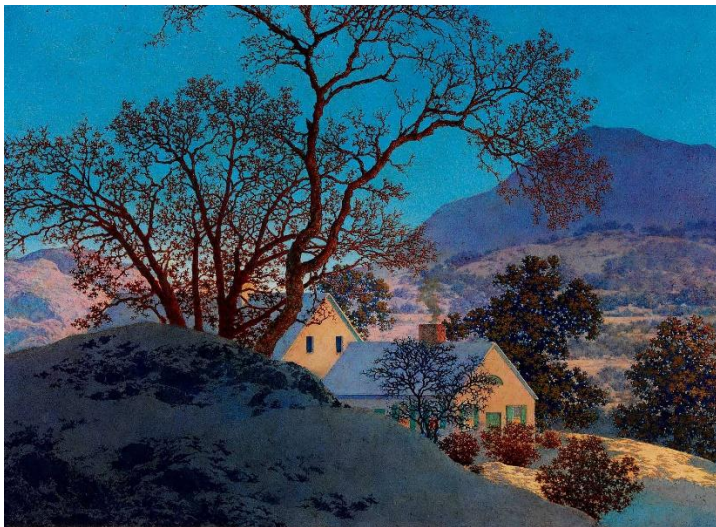
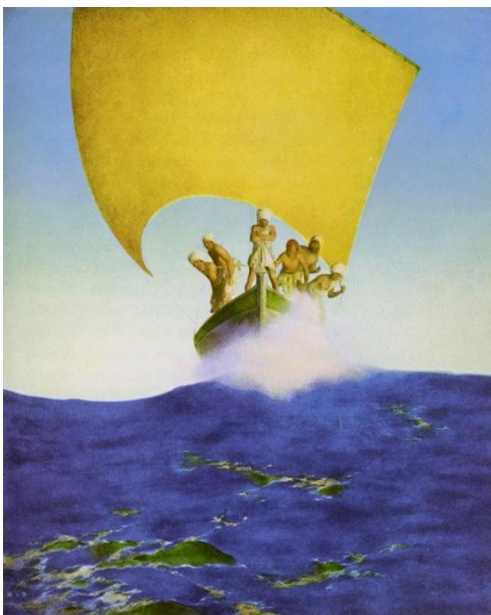
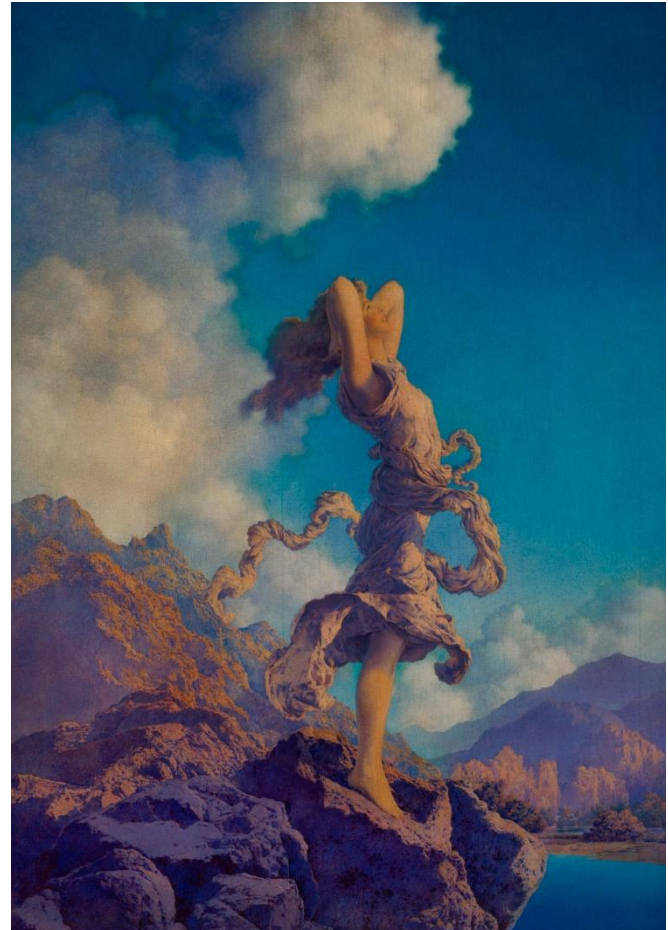
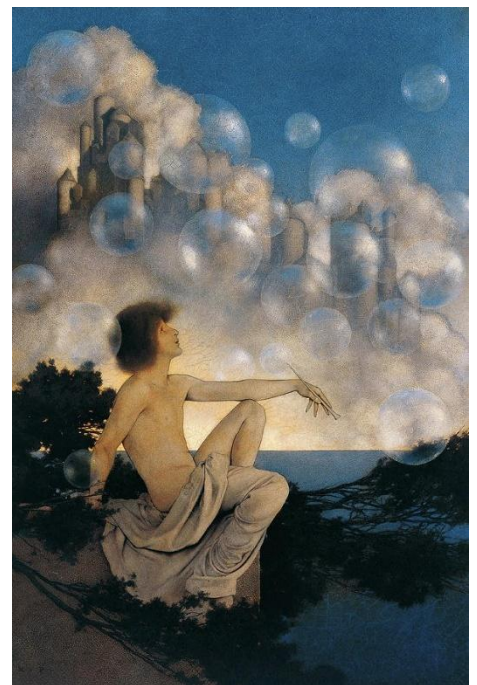


Painters have captured the colors of nature using pigments made from ground-up rocks, minerals, twigs, roots, leaves, animal exudates, and bugs. Tyrian purple comes from an exudate of a snail, Ultramarine and Klein blue came from the ground gemstone, lapis lazuli, indigo from the *Indigofera* plant, Prussian blue from iron ferrocyanide, cobalt blue from cobalt salts, green vertigris from arsenic, Indian Yellow from the urine of cows that had been fed mango leaves, Cadmium yellow from ground cadmium, Chrome yellow from acidified chromium, Chrome orange from alkaline chromium, and cochineal from ground scale insects.

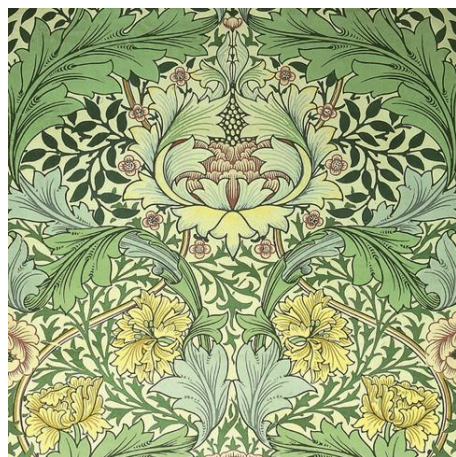
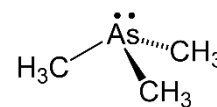




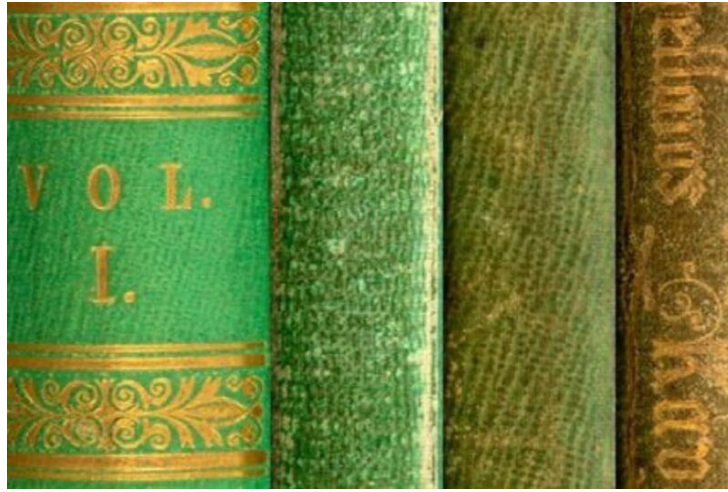
Maxfield Parrish (1870-1966) specialized in blues.



A sepia-toned studio portrait of a man with a thick, dark beard and mustache. He is wearing a dark, textured suit jacket over a dark vest and a white shirt with a dark cravat. He is seated, holding a dark hat with both hands in his lap. The background is a plain, light-colored studio backdrop.



In Victorian times, arsenic, in the form of copper acetoarsenite was used to make beautiful green book covers. Unfortunately, they are [toxic](#).



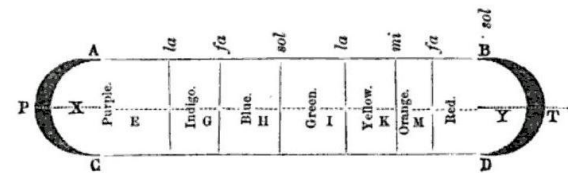
David Hockney has come full circle creating paintings with light itself using a program called Brushes on his iPad.



Demonstration: Look at the colors in the photographs you sent me.



Isaac Newton (1675) discovered that sunlight carried the colors of the rainbow, of the sky, and of the sunrises and sunsets within itself. Newton found this out by showing that sunlight streaming through a **pinhole** in the window can be resolved with a glass prism into a **spectrum** of **seven colors**. At the December 9, 1675 meeting of the Royal Society, Newton explained that a prism separated white light into light of “*unequal bignesses...the largest beget a sensation of a red colour; the least, or shortest, of a deep violet; and the intermediate ones, of intermediate colours; much after the manner that bodies... which according to those bignesses, make several tones in sound... colours, like sounds, being various, according to the various bigness of the pulses.*” He went on to say that “...colour may be distinguished into its principal degrees, red, orange, yellow, green, blue, indigo, and deep violet, on the same ground, that sound within an eighth is graduated into **tones**.”¹



Demonstration: Observe light coming through pinhole and candlelight with large water-filled prism.

Newton added, “*Now for the cause of these and such colours made by refraction, the biggest or strongest rays must penetrate the refracting superficies more freely and easily than the weaker, and so be less turned awry by it, that is, less refracted; which is as much as to say, the rays, which make red, are least*

¹In his book, *Stamped from the Beginning*, Ibram X. Kendi (2016) describes Newton’s work like so, “Isaac Newton took it upon himself to substantiate Boyle’s color law: light is white is standard. In 1704, a year after he assumed the presidency of the Royal Society, Newton released one of the most eminent books of the modern era, *Opticks*. “Whiteness is produced by the Convention of all Colors,” he wrote. Newton created a color wheel to illustrate his thesis. “The center” was “white of the first order,” and all the other colors were positioned in relation to their “distance from Whiteness.” In one of the foundational books of the upcoming European intellectual renaissance, Newton imagined “perfect whiteness.”

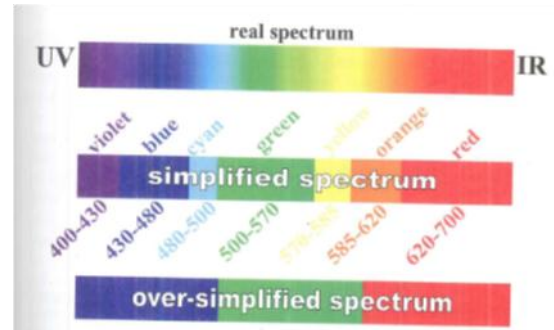
refrangible, those which make blue and violet, most refrangible, and others otherwise refrangible according to their colour: whence, if the rays, which come promiscuously from the sun, be refracted by a prism, as in the aforesaid experiment, these of several sorts being variously refracted, must go to several places on an opposite paper or wall, and so parted, exhibit every one their own colours, which they could not do while blended together. And, because refraction only severs them, and changes not the bigness or strength of the ray, thence it is, that after they are once severed, refraction cannot make any further changes in their colour.”

Are there really **seven discrete** colors or do colors vary **continuously**? Mendel chose to look at **seven** discrete characteristics of peas. Why **seven**? Could it be that in the Bible, seven symbolizes completeness or perfection? Some examples include: “By the **seventh** day God had finished the work he had been doing; so on the **seventh** day he rested from all his work. Then God blessed the **seventh** day and made it holy, because on it he rested from all the work of creating that he had done” (Genesis 2:2-3); “But in the days when the seventh angel is about to sound his trumpet, the mystery of God will be accomplished, just as he announced to his servants the prophets” (Revelation 10:7); and “I saw in heaven another great and marvelous sign: seven angels with the seven last plagues—last, because with them God’s wrath is completed” (Revelation 15:1); and “The seventh angel poured out his bowl into the air, and out of the temple came a loud voice from the throne, saying, “It is done!” (Revelation 16:17). Likewise, seven is the number of perfection in the Quran: “Allah is the One Who created seven heavens ‘in layers’, and likewise for the



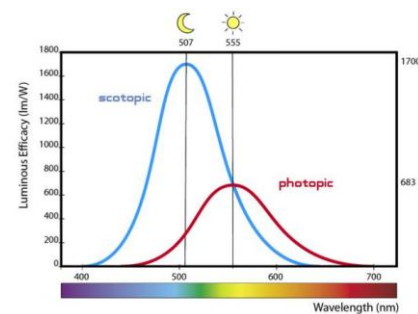
earth. The 'divine' command descends between them so you may know that Allah is Most Capable of everything and that Allah certainly encompasses all things in 'His' knowledge."

While there may be no *scientific* reason to divide the **infinite array of spectral colors** into **seven artificial colors**, there is a natural reason to divide the infinite array into **three primary colors**.

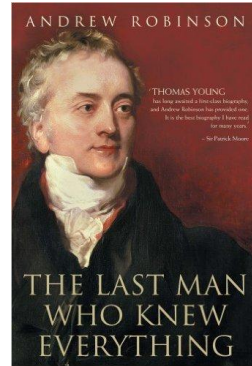


Demonstration: Look at the sky through your **spectroscope**, which uses a diffraction grating to separate the differently-colored light rays. Describe the spectrum of sunlight. Is it **continuous**, **discrete** or **both**?

Demonstration: Look at colorful items in the room when the curtains are open and the lights are on. Describe the colors you see when you use your **photopic vision**. Now dim the lights and close the curtains. Describe the colors you see when you use your **scotopic vision**.

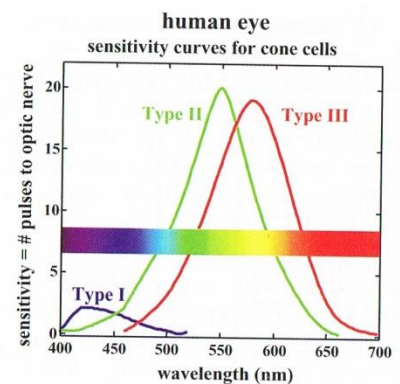


Since the **three primary colors** are capable of mixing all the other colors, **Thomas Young** (1802), *The Last Man Who Knew Everything*, guessed that there must be **three color receptors** in the retina: one red sensitive, one yellow sensitive, and one blue sensitive. We now know that there are three types of **cones**, with different **spectral sensitivities** where one type is **red** sensitive, one is **green** sensitive, and one is **blue** sensitive cones.



Color vision depends on the **cones**. There are three types of cones in the **retina**:

Short (S or Type I) wavelength cones, most sensitive to short wavelengths and bluish (B) colors; mid (M or Type II) wavelength cones, most sensitive to mid wavelengths and greenish (G) colors; and long (L or Type III) wavelength cones, most sensitive to long wavelengths and reddish (R) colors. Here is the original data from George Wald (1964).



Note that the sensitivity of the blue cones is less than the

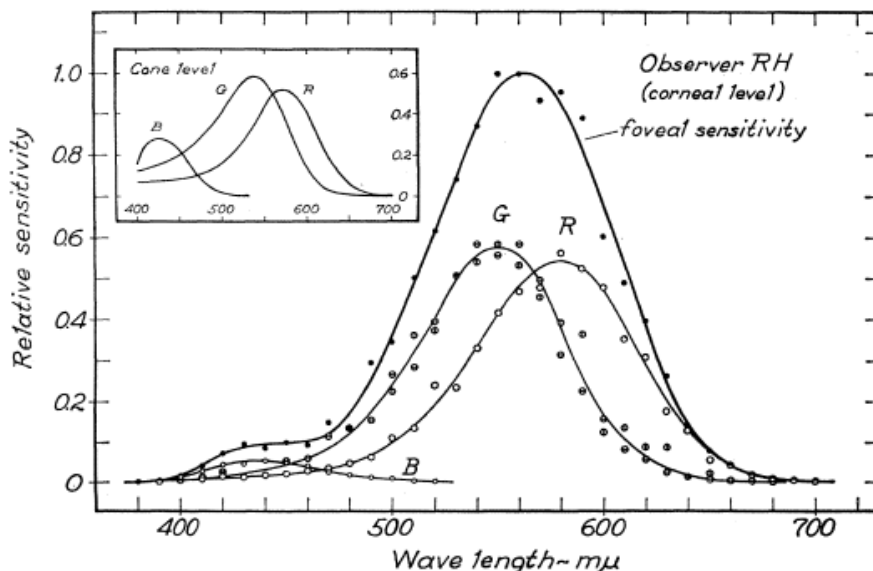


Fig. 8. Contributions of the individual color-receptor mechanisms to the total foveal sensitivity of R.H. The main graph shows measurements at the corneal level, the inset, corresponding curves at the level of the cones. In this particularly blue-sensitive observer, when the total foveal sensitivity is given a maximal height of 1.0, the heights of the B, G, and R curves are as 0.053 : 0.575 : 0.542 at the corneal level, and 0.28 : 0.59 : 0.52 at the level of the cones. In the average observer the blue-component is only about one-third as high.

sensitivity of the green and red cones. The sensitivity to blue in the subject (R.H. = Ruth Hubbard, his wife) shown was about three times greater than that of the average observer. Again, I believe that there is only one reality, but individually, we picture it differently in our mind's eye, in part due to having a

greater or fewer number of a given type of cone. Speaking of blues, Elijah Wald, son of George Wald and Ruth Hubbard, plays the blues guitar.

<https://www.youtube.com/watch?v=yt5iQen4aBQ;>

<https://www.youtube.com/watch?v=gU3W5Gx9PJU>

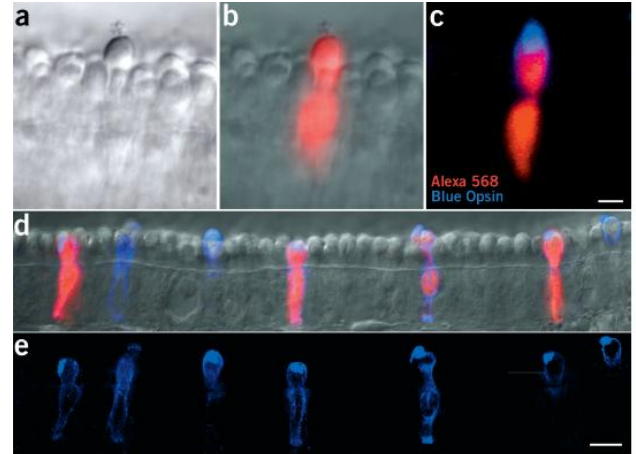
Are the antique teal-colored barbershop sinks in the picture below **bluish** or **greenish**?



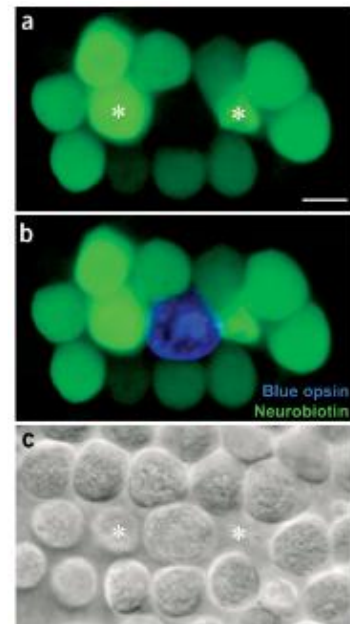
How the absorption of light by the cones results in our perception of color is still a mystery. However, we understand more as a result of studying vision in various animals. For example, the ground squirrel (*Spermophilis tridecemlineatus*) is one animal where color vision is studied because it has a **cone-dominated retina** that resembles the **fovea** of humans. The ground squirrel retina differs from the human retina in that it only has only two cone types, one that is blue sensitive and one that is green sensitive.



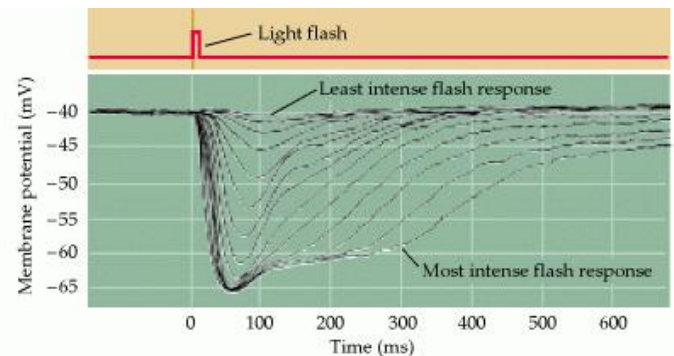
Here is a **tissue slice** of a ground squirrel **retina** showing many **cones**. The **cones** that are most sensitive to blue light are stained with an antibody that fluoresces blue. When the blue light-sensitive cones are injected with a red fluorescent dye, the dye stays in the injected cones, showing that each **blue-sensitive cone is isolated** from the other cones.



On the other hand, when a fluorescent green dye (neurobiotin) is injected into one green-sensitive cone, it diffuses into nearby green-sensitive cones, but not the blue-sensitive cones showing that the **green-sensitive cones are isolated from blue sensitive cones but interconnected to other green sensitive cones**. The coupling of similar cells increases the **signal-to-noise ratio** when light is limiting but also causes **blurring**, resulting in a decrease in **visual acuity**.

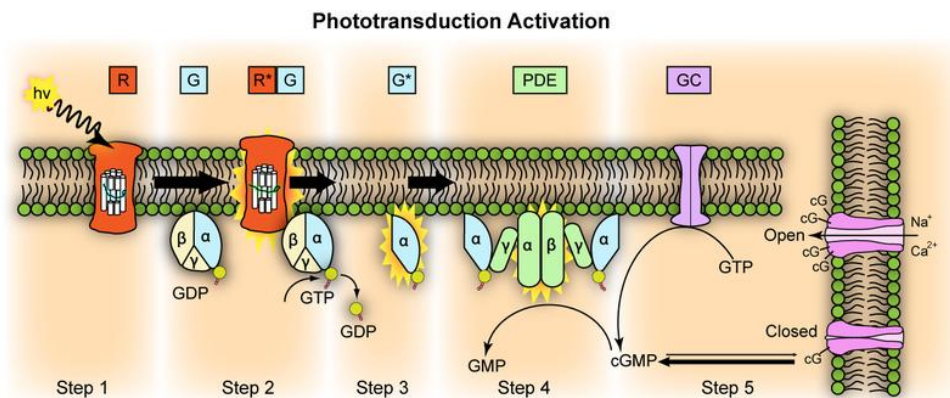


The neural processing of the outputs of the Type I, Type II, and Type III cones of humans must be considered as a **black box** in terms of the connections and functions of the various neurons that connect the cones to the visual cortex. The initial effect of light on the cone is to make the electrical potential of the plasma membrane more negative (**hyperpolarized**).



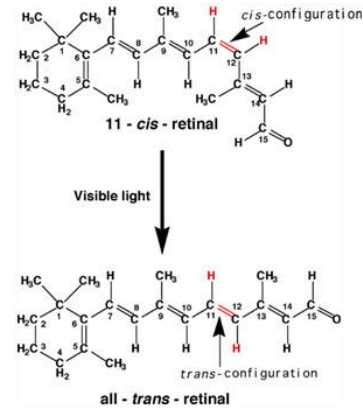
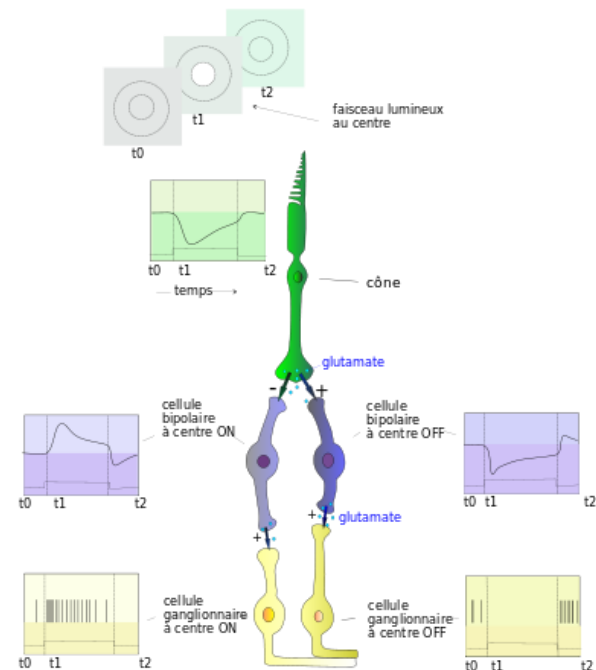
In a cone cell in the **dark**, the **sodium channels** in the plasma membrane are **open**. Sodium ions, with a positive charge, enter the cell along their concentration

gradient which causes the plasma membrane of the cone to stay **depolarized**. When the membrane is depolarized, **glutamate** is released. The glutamate is a **neurotransmitter** and the released glutamate causes the plasma membrane of some neurons to depolarize and the plasma membrane of other neurons to hyperpolarize.

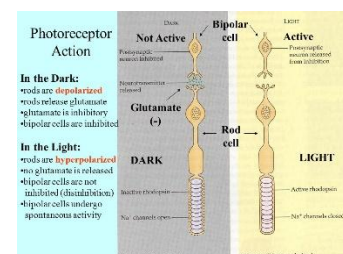


When light is **absorbed** by a **photopsin photoreceptor pigment** in the cone, the pigment becomes active. **Photopsin** is composed of a **chromophore**, known as **11-cis retinal**, which is a derivative of **vitamin A** and the protein **opsin**. The Type I, Type II, and Type III cones in humans have the same retinal chromophore, but the amino acid sequence of the **opsin** protein in each type of photoreceptor cell is different enough to cause the three different spectral sensitivities. In humans, Type I cones are sensitive to violet, blue, and green light; Type II cones are sensitive to blue, green, yellow, orange, and red light; and Type III cones are sensitive to green, yellow, orange, and red light.

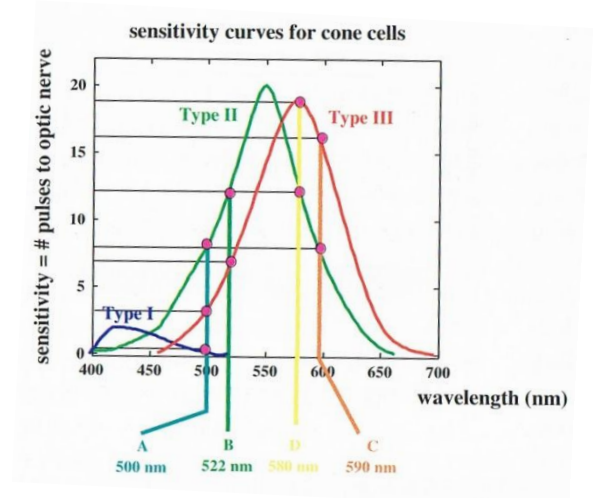
When photopsin absorbs light, the **11-cis retinal** is converted into **all-trans retinal**. The all-trans retinal form of photopsin activates a **G protein** known as **transducin** that *eventually* causes the sodium channels to **close**. The inhibition of the movement of positively charged sodium ions into the cell causes the plasma membrane to hyperpolarize, and the hyperpolarization inhibits the release of glutamate. The inhibition of glutamate release results in a change in the neural activity of the nearby ganglion cells and a message that light was absorbed by a particular cone is sent to the **brain**. The neural message carried by the ganglion cell encodes the brightness of the light that hits a cone that is sensitive to a given color region, and the mind sees the neural message as a color at the point. It takes the neural messages of *three different cone types* for the mind's eye to see white. **The mind can see a million different colors in a given point by reconstructing the neural signals that come from three nearby cones with different spectral sensitivities.**



Aside: The **rods** do not play a role in color vision, but I will mention them here for completeness. The rods, like the cones, secrete glutamate in the dark and stop secreting glutamate in the light. Since the bipolar cells are inhibited by glutamate, they do not send a message to the brain when the rod is dark, but they do send a message to the brain when the rod is light.

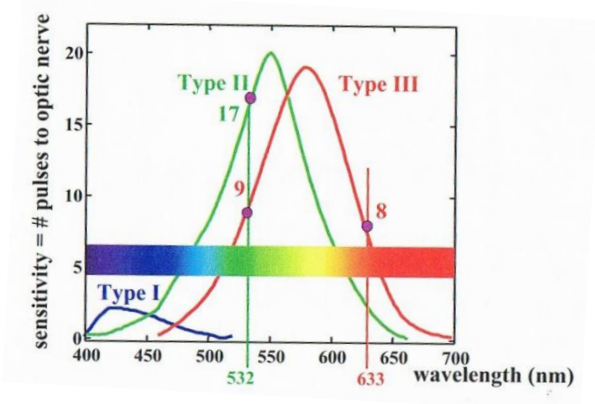


Let's look at the **response of a Type II** cone to four particular wavelengths: 500 nm (cyan), 522 nm (green), 580 nm (yellow) and 590 nm (orange). The Type II cone has the same response to equal intensities of 500 nm and 590 nm light. It also responds identically to equal intensities of 522 nm and 580 nm light. If we only had Type II cones, we could not distinguish cyan from orange or green from yellow.



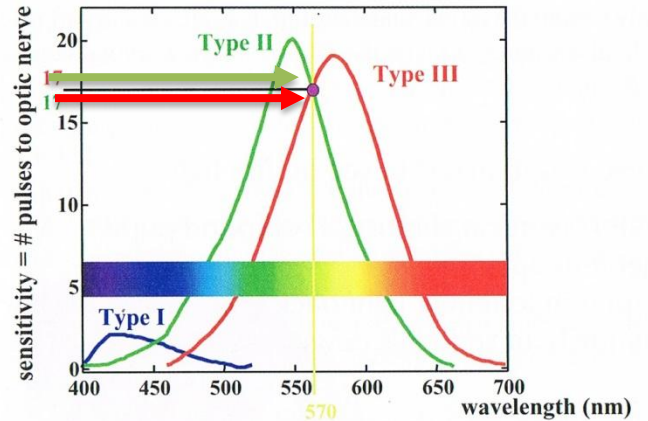
However, by having **three types of cones**, each with a different spectral response, we can differentiate approximately a million colors. Now you can see how: green (500 nm) and orange (590 nm) generate a response of 8 on Type II cones, but green generates a response of 3 on Type III cones while orange generates a response of 17. Green generates a tiny response on Type I cones while orange generates no response on Type I cones. The three types of cones send three messages, encoded into neural pulses, to the brain. The set of three messages define a wavelength: The complete message for 500 nm light is (0.1, 8, 3) and for 590 nm light it is (0, 8, 17).

Demonstration: Look at the spots made by the red and green lights. The peak of the green spot is about 532 nm and the peak of the red spot is about 633 nm. The green spot generates a response of 17 in the Type II cone and a response of 9 in the Type III cone. The red spot generates a response of 2 in the Type II cone and a response of 8 in the Type



III cone. The message for the 532 nm light is (0, 17, 9) and for the 633 nm light, it is (0, 2, 8).

When the green and red spots overlap, they will generate yellow and the total number of neural responses will be 0 from the Type I cone, 19 from the Type II cone, and 17 from the Type III cone. This neural response (0,19,17) is similar to the neural response that would be generated by a single wavelength of yellow light between 560 and 570 nm. Thus

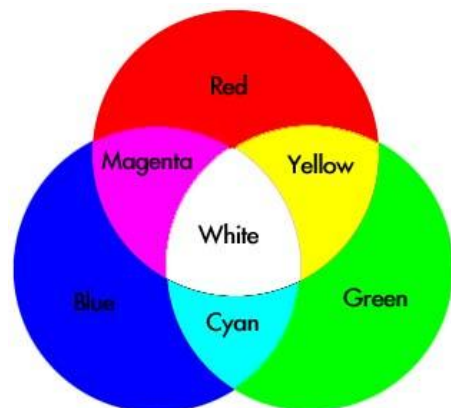


the neural signal that is sent to the brain and decoded into color is the same whether a **pure spectral color** is observed or two or more pure colors that give the **exact same neural response** are **mixed**. This is why we cannot tell the difference between a pure spectral color and a mixed color. Some humans may have four types of cones (**tetrachromats**) instead of three types of cones (**trichromats**). Tetrachromats can differentiate between pure and mixed colors even better than trichromats.

Demonstration: Use the color Addition Spotlights

to see the three primary colors and how they add.

What color do you get when you add red and green? Blue and green? Red and Blue? A color and its complementary color make white. Which pairs are complementary colors?



Demonstration: The color of an object not only depends on the chemical composition of its surface, but on the spectral quality of the illumination. What color is the red or green apple when it is placed in each color zone?

COLOR OF PIGMENT	COLOR OF LIGHT							
	Violet	Blue	Blue-green	Green	Yellow	Orange	Red	Purple
Violet	Deep violet	Dark violet	Dark violet	Violet	Dark brown	Dark brown	Dark gray	Dark violet
Blue	Light blue	Deep blue	Light bluish gray	Light blue	Dark bluish gray	Black	Gray	Blue
Blue-green	Dark blue	Very dark blue	Dark bluish gray	Dark green	Greenish blue	Dark greenish brown	Black	Dark blue
Green	Bluish brown	Light olive green	Light greenish gray	Intense green	Bright green	Dark green	Dark gray	Dark greenish brown
Yellow	Scarlet	Greenish yellow	Greenish yellow	Greenish yellow	Intense yellow	Yellow-orange	Red	Orange
Orange	Scarlet	Light brown	Light brown	Light brown	Orange	Intense orange	Intense orange-red	Scarlet
Red	Scarlet	Purplish black	Dark maroon	Maroon	Bright red	Orange red	Intense red	Red
Purple	Reddish purple	Dark violet	Maroon	Purplish violet	Light brown	Maroon	Reddish brown	Deep purple

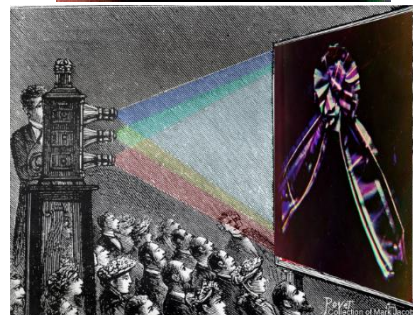
Demonstration: Arrange the three lights so that they make one big white spot. Use your hand to make a shadow by blocking one of the colored lights at a time. The shadow will be the color of the two colors that were not blocked.



Adding equal intensities of the **three primary colors**, red, blue, and green results in white. A primary color cannot be matched by any mixture of the other two primaries. Adding red and blue produces **magenta**, adding red and green produces **yellow** and adding blue and green produces **cyan**. A **complementary color** is defined as the color that when added to another color produces white. Magenta is the complementary color of green, yellow is the complementary color of blue, and cyan is the complementary color of red.



Red, green and blue light can be added together in various proportions to make any color. [James Clerk Maxwell](#) and photographer Thomas Sutton used this idea in 1861 to create the



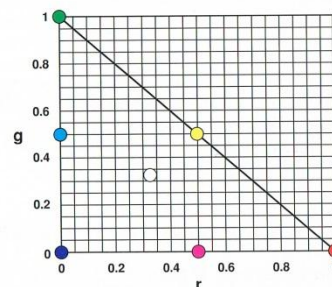
first color photograph of a tartan. The creation of any color from the three primary colors can be clearly seen with the color vision program from PhET Interactive Simulations: <http://phet.colorado.edu/en/simulation/color-vision>. The color (C) formed is described by the following equation:

$$C = aR + bG + cB$$

where a , b , and c are the intensities of **R**ed, **G**reen and **B**lue light, respectively.

The fraction of the light that is red is given by $r = \frac{a}{a+b+c}$, and the fraction of the light that is green is given by $g = \frac{b}{a+b+c}$. Since all the colors can be made by R, G, and B, then r , g , and b must add up to 1 and $b = 1 - r - g$. Therefore we do not have to calculate b directly and we can characterize any color spot with r and g . The total intensity of the spot is given by $I = a + b + c$.

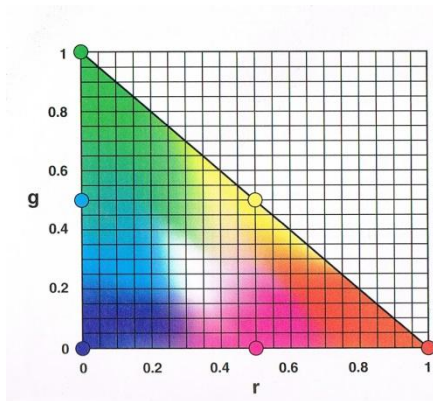
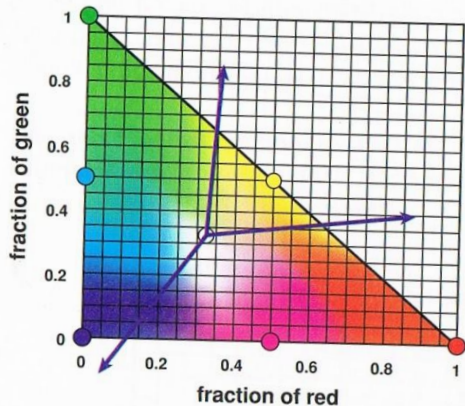
We can use a **color triangle** to characterize most of the colors that a human can see. To use the **color triangle**, plot the value (r, g) for each color to be added. Then draw a line between them. The resulting color is the middle of the line. Magenta is the midpoint between $(0,0)$ and $(1,0)$; yellow is the midpoint between $(0,1)$ and $(1,0)$; Cyan is the midpoint between $(0,0)$ and $(0,1)$. White is the point $(0.33, 0.33)$.



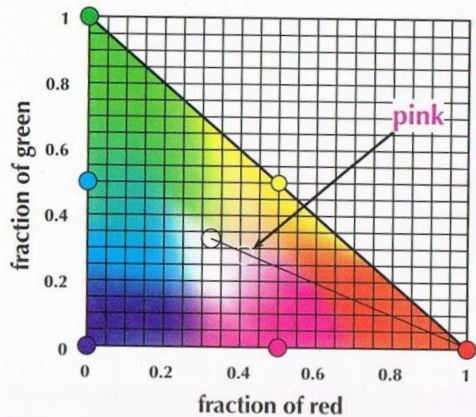
Any mixed color can be considered to be the **sum of any spectral color or hue plus white**. A **high-saturation** color contains no white whereas a **lower-**

saturation or pastel color contains more white.

One can draw a line *from* the white spot *to* any of the spots representing the primary or secondary colors. Along the line, the **hue (or spectral color)** stays the same, but the **saturation** increases. A **hue or spectral color** is defined by a single wavelength.



A line drawn from the white spot to any pure spectral color represents a single **hue** with increasing **saturation**.

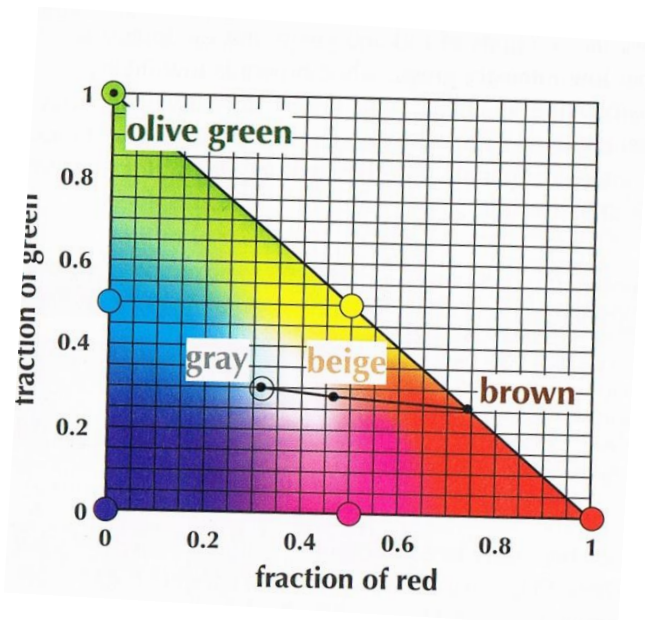


Pink is a very low-saturation red and falls on the line between white and red.

The **color triangle** can be used to predict the color made by mixing any two colors

of light. In order to predict the outcome of the mixture, we must find the position of the colored light that will be mixed on the color triangle. If we want to mix equal parts of high-saturation green and high-saturation orange, we draw a line between the two colors and find the midpoint, which is yellow. If we want to mix 2 parts of high-saturation green with 1 part high-saturation orange, we find the point on the line that is one-third of the way from green and two-thirds of the way from orange. The resulting color is lime green.

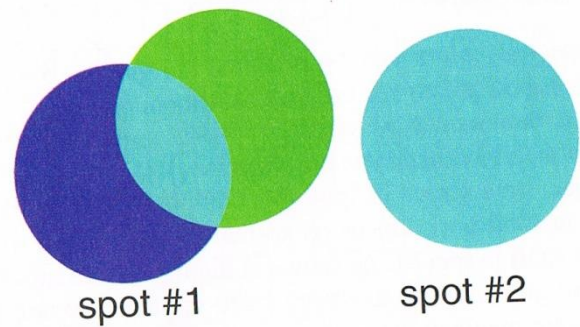
Likewise, gray is low-intensity white and brown is low-intensity orange, and beige is low-saturation brown or low-saturation and low-intensity orange.



Unfortunately, this simple color triangle does not show every color. For example, it does not show olive green, which is just a low-intensity green. Check this with the color vision program:

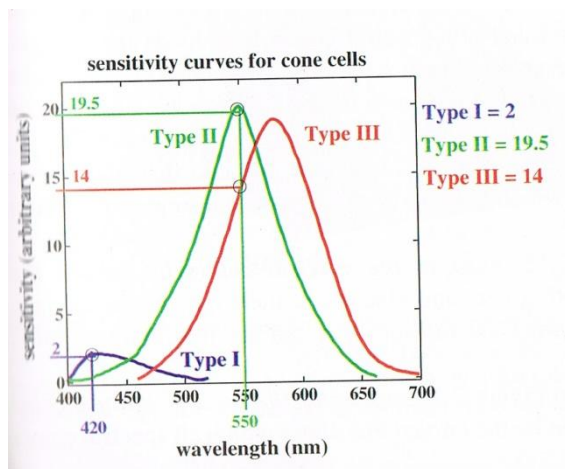
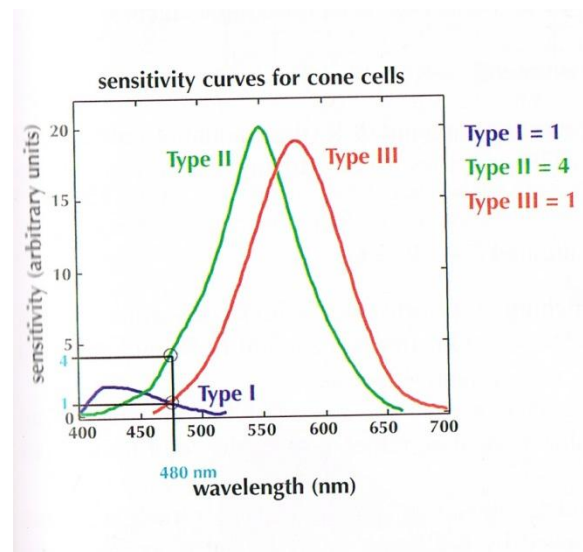
<http://phet.colorado.edu/en/simulation/color-vision>.

Let's consider the two ways to make cyan. One is with a 480 nm spectral color (spot 2) and the other is to use a combination of RGB (spot 1). The two colors are matched when our visual system with our eyes and brain tell us that they are matched. Spot 2 sends a neural message produced by 480 nm light with the code (1, 4, 1). Spot 1 sends a neural message produced by a mix of 420 nm and 550 nm light with the code (2, 19.5, 14). Clearly, they are not matched!

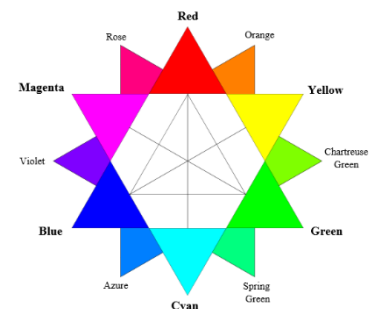


Spot #1

Spot #2



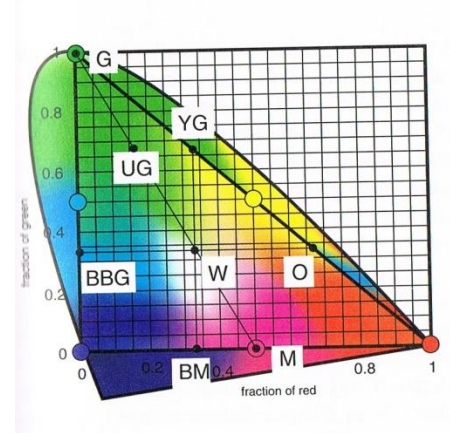
We could get the two neural signals to match if we added red light to spot 2. Since **red is the complement of cyan**, this is equivalent to desaturating the cyan. Adding red to the cyan in spot 2 is mathematically equivalent to adding **negative red** to the violet and green that makes spot 1. Adding negative red will “saturate” the unsaturated cyan to make spectral cyan.



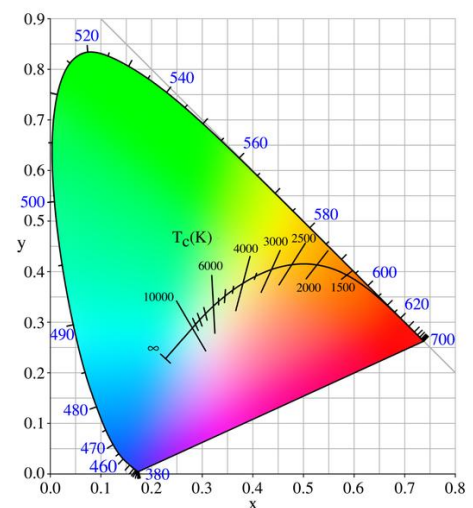
$$\text{Spectral Cyan} + xR = G + B$$

$$\text{Spectral Cyan} = G + B - xR$$

We can represent the addition of negative red by using the area *outside* the color triangle as shown in this **CIE Chromaticity Diagram**. (CIE stands for International Commission on Illumination). The horseshoe shaped area is the area of human vision. The spectral colors that we can see and mix with RGB are inside the color triangle. The spectral colors that we *can* see but cannot mix with just positive values of **RGB** are outside the triangle. I like talking about the RGB system because it matches the color sensitivities of our cones, but there are other systems of combining colors such as the Cyan-Magenta-Yellow-Black (CMYK) used in many printers. CMYK is a subtractive process, which means that when a given color is injected, additional light is absorbed to create a unique color tending towards black. By contrast, RGB is an additive process, which means that when a given color is added, the image becomes whiter. It is used for screens.



The **CIE Chromaticity Diagram** can be rescaled so that all the values are positive. The rescaled (0-0.8) **CIE Chromaticity Diagram** can be used to describe the spectral qualities of various sources of illumination with different **color temperatures (from 1500 K to 10,000 K)**.



The CIE Chromacity Diagram was derived from [James Clerk Maxwell's](#) (1855) experiments on the perception of color by the human eye using the [color wheel](#) where the observer would match any given color with the proportion of the three primary colors (vermillion, ultramarine, and Emerald green) needed to produce that color.



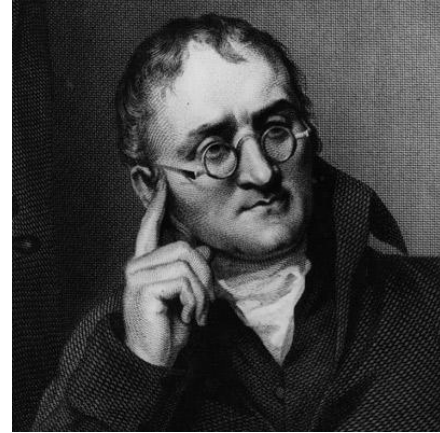
Cerulean (RGB: 152, 180, 212), mazarine (RGB: 39, 60, 118), and navy (RGB: 64,63,111) were some of the blues used for Victorian fashion. Cerulean blue was made from a mixture of cobalt and tin. Mazarine blue was made from cobalt. Navy blue was made from indigo.



The Pantone color of the year (2026) is: Cloud Dancer.



Under the same illumination, not everyone sees an object as having the same color. [John Dalton](#), the founder of the **atomic theory**, noticed this in 1794. Dalton wrote, *“It has been observed that our ideas of colours, sounds, tastes, &c. excited by the same object may be very different in themselves, without our being aware of it; and that we may nevertheless converse intelligibly concerning such objects, as if we were certain the impressions made by them on our minds were exactly similar. All, indeed, that is required for this purpose, is, that the same object should uniformly make the same impression on each mind; and that objects which appear different to one should be equally so to others. It will, however, scarcely be supposed, that any two objects, which are every day before us, should appear hardly distinguishable to one person, and very different to another, without the circumstance immediately suggesting a difference in their faculties of vision; yet such is the fact, not only with regard to myself, but to many others also, as will appear in the following account.”*



“I was of the opinion, though I might not often mention it, that several colours were injudiciously named. The term pink, in reference to the flower of that name, seemed proper enough, but when the term red was substituted for pink, I thought it highly improper; it should have been blue, in my apprehension, as pink and blue appear to me very nearly allied; whilst pink and red have scarcely any relation.”

*“In the course of my application to the sciences, that of optics necessarily claimed attention; and I became pretty well acquainted with the theory of light and colours before I was apprized of any peculiarity in my vision. I had not, however, attended much to the practical discrimination of colours, owing, in some degree, to what I conceived to be a perplexity in their nomenclature. Since the year 1790, the occasional study of **botany** obliged me to attend to colours more than before. With respect to colours that were white, yellow, or green, I readily assented to the appropriate term. Blue, purple, pink, and crimson appeared rather less distinguishable; being according to my idea, all referable to blue. I have often seriously asked a person whether a flower was blue or pink, but was generally considered to be in jest. Notwithstanding this, I was never convinced of a peculiarity in my vision, til I accidentally observed the colour of the flower on the *Geranium zonale* by candle-light, in the autumn of 1792. The flower was pink, but it appeared to me almost an exact sky-blue by day; in candle-light, however, it was astonishingly changed, not having then any blue in it, but being what I called red, a colour which forms a striking contrast to blue. Not then doubting but that the change in colour would be equal to all, I requested some of my friends to observe the phenomenon; when I was surprised to find they all agreed, that the colour was not materially different from what it was by day-light, except my [brother](#), who saw it in the same light as myself. This observation clearly proved, that my vision was not like that of other persons; and, at the same time, that the difference between day-light and*



candle-light, on some colours, was indefinitely more perceptible to me than to others."

Dalton guessed that the difference between his and his brother's color vision and the color vision of others was a result that the vitreous humor in his and his brother's eyes must be bluish and if so, would imitate the effect of looking at the world through a blue filter.

Demonstration: Look at the world through a blue filter.



Dalton asked that his eyes would be dissected after his death in order to test his hypothesis. Dalton died on July 27, 1844, when he was 78. On the next day, Joseph Ransome performed an autopsy. Ramsome found that both the **aqueous** and **vitreous humors** of the eye were **clear** and **transparent**, although the crystalline lens was yellowish, like anyone's of his age. Luckily Ransome saved and preserved the remains of the two eyes.



John Dalton's older brother [Jonathan Dalton wrote](#): *"Once, on our mother's birthday, John bought her some very special stockings. This was to be a treat for she always wore homespun stockings. Mother exclaimed to John, "Why did you buy me scarlet stockings?" John had thought they were blue and turned to me to verify their suitable color. Since we both saw blue instead of scarlet, Mother took the stockings out to some of the other women. So at the age of twenty -six, John discovered that we were both color-blind. John experimented and wrote about this*

phenomenon in his first important scientific paper. Many years later when John had an audience with the King, he refused to wear the customary dress which included a sword. In a compromise, he agreed to wear his Oxford honorary doctoral robe. John thought the robe was grey, but in reality it was red, which at that time was not an appropriate color for a Quaker. The condition of color-blindness came to be known as Daltonism in France.”

Now we know that color blindness usually arises from the lack of one of the three types of cones in the retina. **Deuteranopia** results from the lack of a functional mid wavelength sensitive Type II photoreceptor and **protanopia** results from the lack of a functional long wavelength sensitive Type III photoreceptor. Deuteranopia and protanopia are forms of **red-green colorblindness**.

Since the three photoreceptors are a result of three different versions of the opsin protein, the genes that code for Dalton’s cones could be determined from his preserved eye. Dalton was a deuteranope, who was missing the mid wavelength sensitive Type II photoreceptor.

Without a Type II photoreceptor, the world would be to Dalton a mixture of blue and red (left). Without a

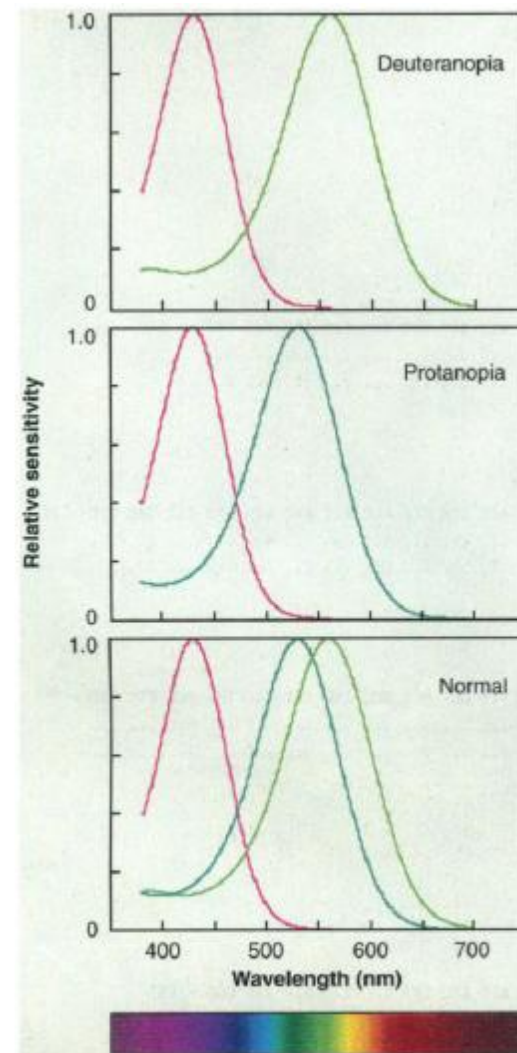
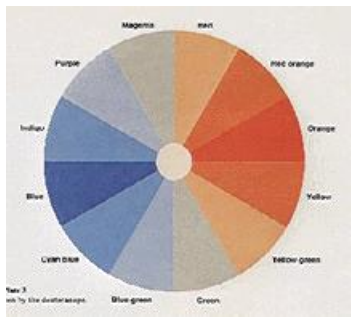
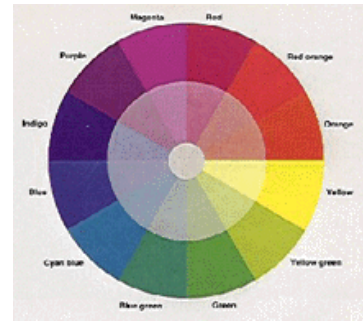


Fig. 3. The spectral sensitivities of the three type of cone photoreceptors in the normal eye (bottom panel), protanopia (middle panel), and deuteranopia (top panel).

Type III photoreceptor, the world would be a mixture of blue and yellow (middle).

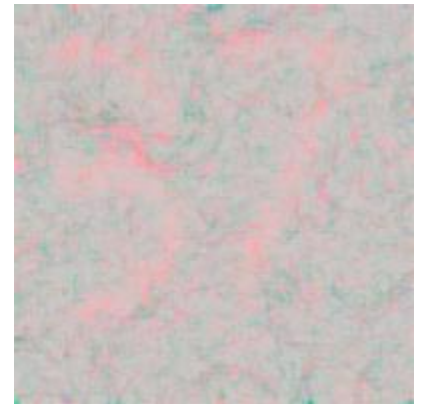
The



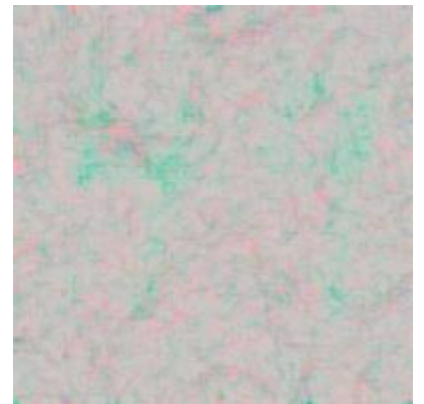
world of a trichromat is

shown on the right.

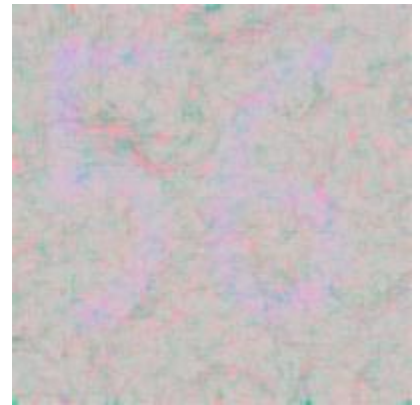
Do you see the number 37? If not, you may be missing Type III cones and have protanopia.



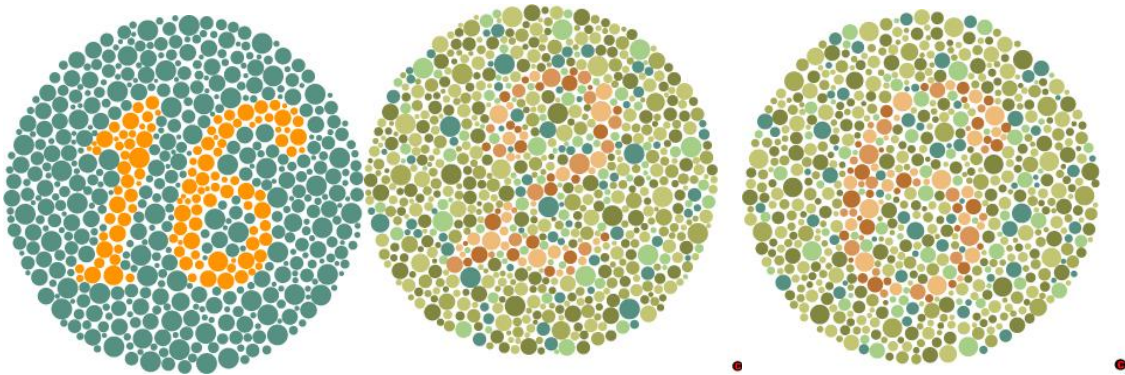
Do you see the number 49? If not, you may be missing Type II cones and have deuteranopia.

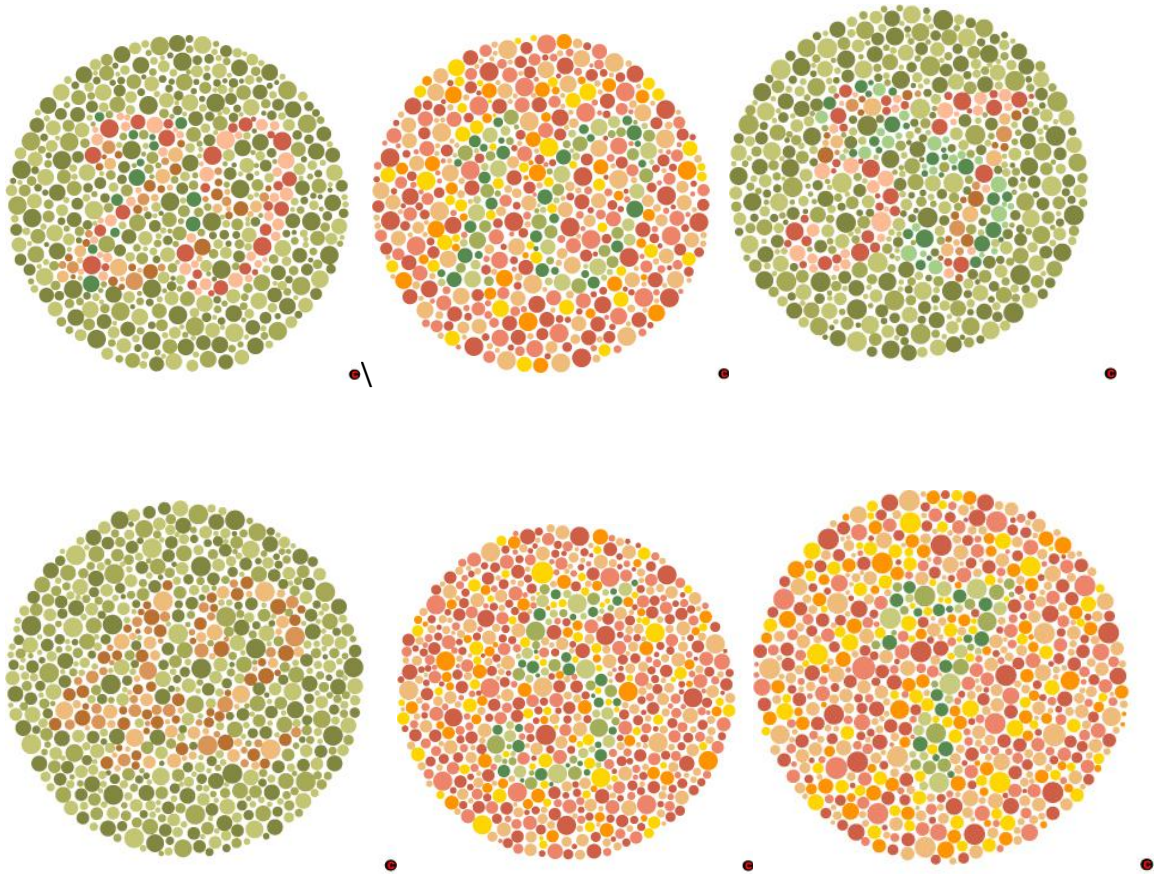


Do you see the 56? If not, you may be missing Type I comes and have tritanopia.

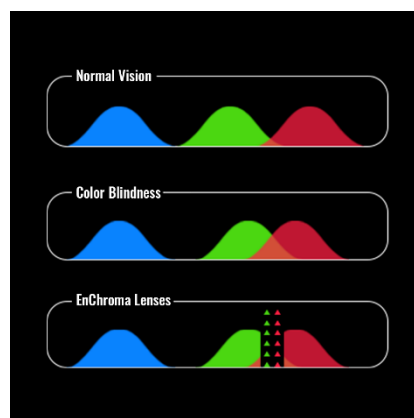


Take the Ishihara Color Vision Test. What numbers do you see?

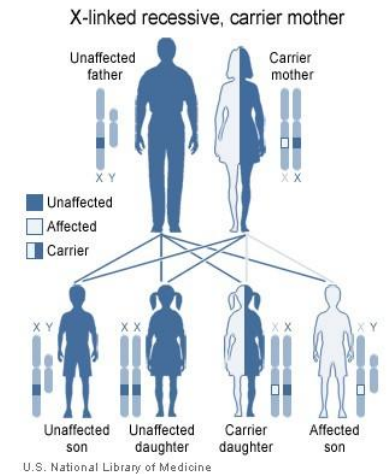




[EnChroma](#) makes glasses for people with red/green colorblindness. They work by selectively filtering out wavelengths of light where the red/green confusion occurs.



Dalton and his brother both were colorblind; suggesting that color blindness is a **genetic trait**. The Human Genome Project tells us that **fifty-six different genes** on 19 different chromosomes affect colorblindness. Because the major and common (red-green protanopia and deuteranopia) colorblind genes are on the **X-chromosome**, color blindness is often a **sex-linked trait** that is more common in men than in women since women; with two X chromosomes often have one normal copy of the gene that will cover for (or is **dominant** over) the colorblind version of the gene (which is **recessive**). Of course, if men and women are considered to be [social constructs](#) rather than biological groups, then the last sentence is ridiculous.



Color vision requires photopic vision. **Jan Purkinje** noticed that with scotopic vision, blue flowers appeared brighter than red flowers but as the dawn progressed, the red flowers appeared brighter than the blue as photopic vision was used. He wrote, *“Objectively, the degree of illumination has a great influence on the intensity of color quality. In order to prove this most vividly, take some colors before daybreak, when it begins slowly to get lighter. Initially one sees only black and grey. Particularly the brightest colors, red and green, appear darkest. Yellow cannot be distinguished from a rosy red. Blue became noticeable to me first. Nuances of red, which otherwise burn brightest in daylight, namely carmine, cinnabar and orange, show themselves as darkest for quite a*



while, in contrast to their average brightness. Green appears more bluish to me, and its yellow tint develops with increasing daylight only.”

During a full moon, the light is too bright for **scotopic** vision and too dim for **photopic** vision. Could this **mesopic** vision be involved in **lunacy**? Just asking!



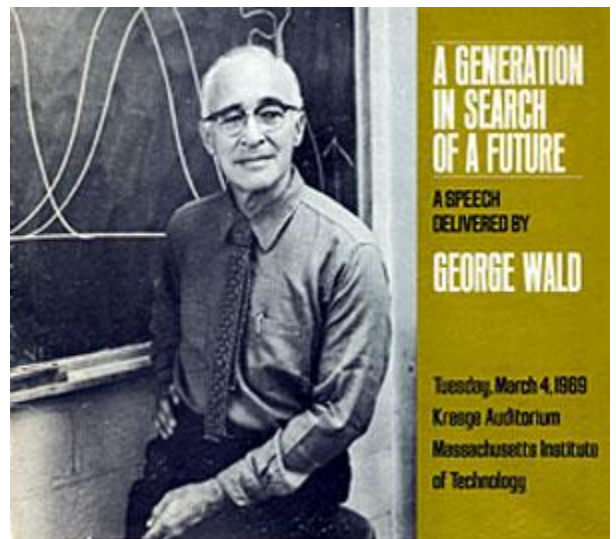
The name of colors and the color itself is processed by our brain differently, and that is what makes the **Stroop Test** so fun. Say the name of the color the word is printed in, not what the word represents.

Stroop Effect

YELLOW BLUE ORANGE
BLACK RED GREEN
PURPLE YELLOW RED
ORANGE GREEN BLUE
BLUE RED PURPLE
YELLOW RED GREEN

George Wald discovered that vitamin A was necessary for making the visual pigments in the rods and cones. Here is the speech he gave at the banquet when he received the Nobel Prize in Stockholm, December 10, 1967.

Your Majesty, Royal Highnesses, Excellencies, Ladies, Gentlemen, and fellow students:



A scientist should be the happiest of men. Not that science isn't serious; but as everyone knows, being serious is one way of being happy, just as being gay is one way of being unhappy.

A scientist lives with all reality. There is nothing better. To know reality is to accept it, and eventually to love it.

I tell my students to try early in life to find an unattainable objective. The trouble with most of the things that people want is that they get them. No scientist needs to worry on that score. For him there is always the further horizon. Science goes from question to question; big questions, and little, tentative answers. The questions as they age grow ever broader, the answers are seen to be more limited.

A scientist is in a sense a learned small boy. There is something of the scientist in every small boy. Others must outgrow it. Scientists can stay that way all their lives.

I have lived much of my life among molecules. They are good company. I tell my students to try to know molecules, so well that when they have some question involving molecules, they can ask themselves, What would I do if I were that molecule? I tell them, Try to feel like a molecule; and if you work hard, who knows? Some day you may get to feel like a big molecule!

So we have much to be thankful for. With this great honor you cast a radiance upon our science. We who work in vision are happy to have it made so visible.

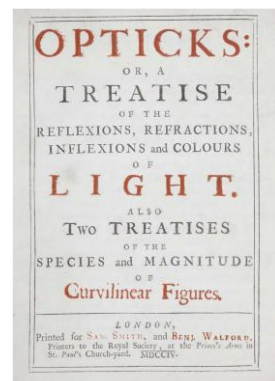
I am glad to be able to bring this offering to the memory of my teacher, Selig Hecht, whose widow Gelia is here with us tonight; to my wife, who is also my closest co-worker; and to my co-workers at home, particularly Paul Brown, who for twenty years has done so much himself, and with us all.

But there is something more. The grocer, the butcher, the taxi man, all seem delighted to share in our pleasure. The Nobel Prize is an honor unique in the world in having found its way into the hearts and minds of simple people everywhere. It casts a light of peace and reason upon us all; and for that I am especially grateful.

Aside: All else being equal, the color of an object affects its temperature. There is a relationship between color of a material and its ability to reflect visible light, or to **absorb visible light and radiate heat**.

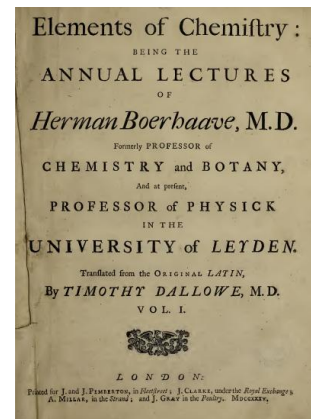
Robert Boyle (1664) noticed that an egg that had been painted black and exposed to the sun cooked faster than a white egg. He wrote in *Experiments and Considerations Touching Colours*, “*SIXTHLY, I remember, that acquainting one day a Virtuoso of unsuspected credit, that had visited hot countries, with part of what I have here delivered concerning blackness, he related to me, by way of confirmation of it, a very notable experiment, which he had both seen others make, and made himself in a warm climate; namely, that having carefully blacked over eggs, and exposed them to the hot sun, they were thereby in no very long time well roasted; to which effect I conceive the heat of the climate must have concurred with the disposition of the black surface to reflect the sun-beams inward: for I remember, that having made that among other trials in England, though in summer-time, the eggs I exposed acquired indeed a considerable degree of heat, but yet not so intense a one, as proved sufficient to roast them.*”

Isaac Newton (1704) asked in Query 6 of his *Opticks*, “*Do not black Bodies conceive heat more easily from Light than those of other Colours*



do, by reason that the Light falling on them is not reflected outwards, but enters the Bodies, and is often reflected and refracted within them, until it be stifled and lost?”

Herman Boerhaave (1735) wrote in *A New Method of Chemistry* (Experiment XIII), “If this Fire, thus determined by the Sun, falls upon Bodies that are exceedingly black, its Heat will be retained there a considerable time. On this account, therefore, such Bodies grow sooner hot, and acquire a greater degree of Heat from the same Fire, grow dry in a shorter time when they have been wetted with Water, and burn much more readily than any other. We need go no farther for the proof of these assertions, than daily Observation. Take a piece of cloth died a very deep black; another piece of the same cloth, but white; a third, scarlet; and others of different Colours; and hang them up in the Air, and Sun, and you’ll find that the black will grow warmest, and much sooner than any of the rest. And of the others of different dyes, those always acquire Heat slowest, whose Colours are most vivid, and affect the eyes most strongly: for the white, and scarlet are longest growing warm; and the rest so much sooner as their Colours are less bright, as we see evidently in the weaker Green. And this, those people that live in the hottest countries are well acquainted with; for they find, that if their outward garment is white, it best secures them from the Heat of the scorching Sun, whereas if it is black, it suffocates the Heat, and makes it more troublesome. And it is a common Observation of the manufacturers of Woollen-cloth, that if a parcel of wet cloths are hung up at the same time, and are equally exposed to the Sun, the black will presently grow warm, reek, and dry, the white will retain its wet a long time; and the others will dry so much slower, as their Colour is brigh[t]er. Hence, again,



white garments, when they are exposed to Heat retain their dampness much longer than others, and thus too keep the Body cool.

It has, yet farther, been observed that black Bodies take fire, flame, and burn, much easier with the same Fire than Bodies of any other Colour. Shavings, for instance, of very white wood will scarcely receive a spark struck upon them, so as to keep it in; but if you burn them to a black coal, the powder of this will easily support it, and be soon kindled all over by one single one. In the same manner a spark won't keep a-light any considerable time in a piece of very clean white linen; whereas, if it falls upon the same when it is reduced to tinder, which is a sort of exceeding thin black coal, it will spread itself all over it. Nor would even Gunpowder itself, so soon take fire, where it not for its blackness; as we see evidently in the powder of very white Nitre rubbed with Sulphur. The Gardeners too have long observed to their disadvantage, that white Earth will hardly grow hot, except just on the surface; whilst the black conceives so great a heat, as to burn the very roots of their Plants. The Chemists, likewise, long ago informed us, that black Bodies committed to digestion, or reduced to it by Art, grow warm with the same Fire easier than others; different degrees of Heat being required in the head of a Crow, the neck of a Swan, and the tail of a Peacock. And lastly, the Philosophers have confirmed the same by ocular demonstration. If you hold a piece of very white paper in the Focus of a burning Glass, it will be a considerable time before it grows hot, and much longer before it takes fire; and when it is just going to kindle, it first loses its whiteness, grows brown, then black, and afterwards flames in an instant.”

Joseph Breintnal (January 25, 1736), a friend of **Benjamin Franklin**, performed the following experiment testing the effect of color of a fabric on its

ability to melt snow. Interestingly, he found that clear window glass was as effective as black cloth in melting snow.

*“Experiments with Colours of various Sorts, to shew which imbibe, and which repel (or do not readily admit) the Sun's Rays; made with placing on the level Snow, Bitts of Linnen, Silks, Leather, Paper, Woollen Cloth, Feathers, and other Materials - exemplify'd by six Degrees of melting down or sinking in the Snow. By which it was observable that the different Weights or Kinds of the Subjects made no Alteration; All the Variety of Effects being owing only to Difference of Colours, except the **Piece of Glass**, and except the Circumstances of Cloth being closely or loosely wove—*

1st Degree. Shallowest_____ White.

*2. Less shallow_____ Light Red. Red & White striped.
Light Yellow. Light Azure.*

*3. Least shallow, meaning next above deep_____ Lively Blood Red.
Reddish Brown, or bright Cinnamon.*

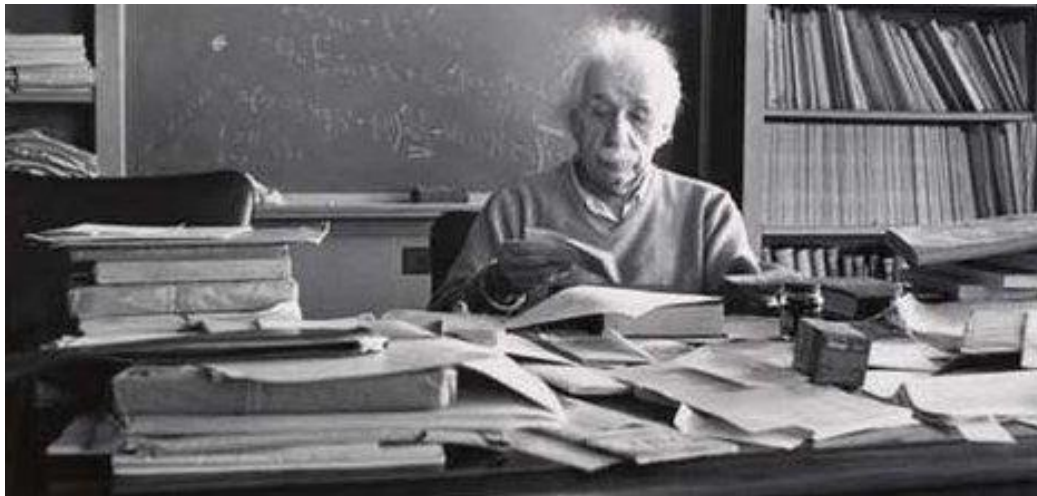
*4. Deep Deep_____ Grass Green. Yellow Brown, or
dirty Yellow.*

*5. Deeper_____ Deep Blue. Gloomy Red. Dark
Olive, or Dark Brown.*

*6. Deepest_____ Black. Also a piece of **Window Glass**.”*

How does window glass melt the snow? The window glass allows the visible light to pass through it. Since we can see the snow through the glass, some of the visible rays reflect off the snow and pass back through the glass to our eyes. However, the rest of the visible rays are converted into heat rays which cannot pass back through the glass. The heat rays build up under the glass and thus melt the snow beneath the glass.

In his advice to youth, Albert Einstein said: *“The important thing is not to stop questioning. Curiosity has its own reason for existence. One cannot help but be in awe when he contemplates the mysteries of the eternity, of life, of the marvelous structure of reality. It is enough if one tries to comprehend a little of this mystery each day. Never lose a holy curiosity. Try not to become a man of success but rather try to become a man of value.”* (Life Magazine, May 2, 1955)



True Colors; Cyndi Lauper

<https://www.youtube.com/watch?v=LpN0KF1bqX8>

Colours: Donovan https://www.youtube.com/watch?v=hoEle04qu_U

Colours of My Life: The Seekers

<https://www.youtube.com/watch?v=DQioqPLvG3s>

CAN LIGHT BE GOLDEN?
By Owen Barfield



*Can light be golden? That can never be,
The well-informed assure us, because light
Is what we see by, never what we see.*

*But are the well-informed, I wonder, right?
Those painters of the old Italian school
Seem almost to condense it into sight.*

*I doubt if Cimabue was a fool,
Or faked the background, or the aureole.
Perhaps they worked to some more secret rule*

*That light observes—not light through Newton's hole
(The force we see by when we are not blind),
But light inbreathed by man's adoring soul.*

*Can light be golden? Now recall to mind
That seeding whereof Perseus was the flower:
How sad Acrisius' daughter was confined*

*In Argos long ago—the brazen tower—
Then Zeus, the Light of Day, with godlike stride
Descending on it in a Golden Shower,*

*Breaching its walls to glorify the bride.
Can light be golden? Now the truth comes clear:
It is, when wonder meets it open-eyed—*

*As I am to the light that streams from her,
When she at last is near, and these old walls
Invading, overwhelms their prisoner:*

*The light that, condescending, disentralls!
For now the pagan myth's inverted: she
(Look up, and see how smilingly it falls!)
The Shower of Gold; I, wondering Danäe.*

The Pale Blue Dot

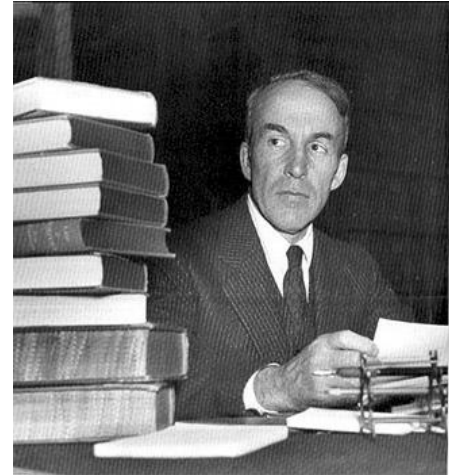
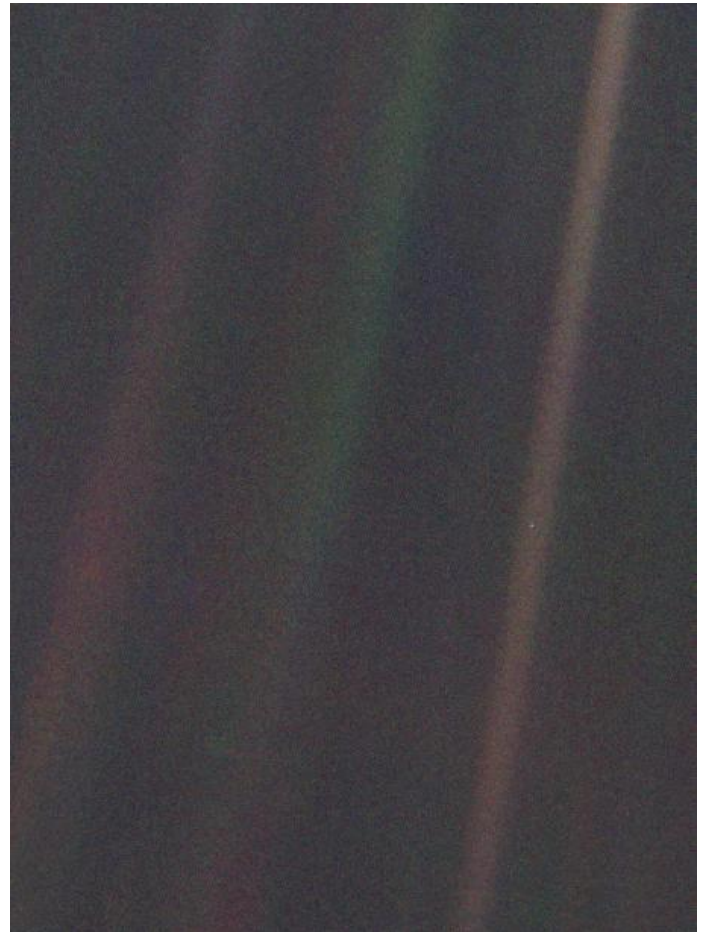
On Christmas 1968, **Archibald MacLeish** wrote *Riders on Earth Together, Brothers in Eternal Cold*, in which he described the earth.

*To see the earth as it truly is, small and **blue** and beautiful in that eternal silence where it floats, is to see ourselves as riders on the earth together, brothers on that bright loveliness in the eternal cold—brothers who know now they are truly brothers.—The New York Times, December 25, 1968, p. 1.*

<https://archive.nytimes.com/www.nytimes.com/library/national/science/nasa/122568sci-nasa-macleish.html?scp=1&sq=%252522medieval%252520notion%252520of%252520the%252520earth%252520put%252520man%252522&st=cse>

Carl Sagan (1994) wrote a book entitled, **Pale Blue Dot** that was inspired by an image taken, at Sagan's request, by Voyager 1 on February 14, 1990. As the spacecraft was leaving our planetary neighborhood for the fringes of the solar system, it turned it around for one last look at its home planet.

Sagan wrote, “Look again at that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child,



inventor and explorer, every teacher of morals, every corrupt politician, every “superstar,” every “supreme leader,” every saint and sinner in the history of our species lived there—on a mote of dust suspended in a sunbeam.

The Earth is a very small stage in a vast cosmic arena. Think of the rivers of blood spilled by all those generals and emperors so that, in glory and triumph, they could become the momentary masters of a fraction of a dot. Think of the endless cruelties visited by the inhabitants of one corner of this pixel on the scarcely distinguishable inhabitants of some other corner, how frequent their misunderstandings, how eager they are to kill one another, how fervent their hatreds.

Our posturings, our imagined self-importance, the delusion that we have some privileged position in the Universe, are challenged by this point of pale light. Our planet is a lonely speck in the great enveloping cosmic dark. In our obscurity, in all this vastness, there is no hint that help will come from elsewhere to save us from ourselves.

The Earth is the only world known so far to harbor life. There is nowhere else, at least in the near future, to which our species could migrate. Visit, yes. Settle, not yet. Like it or not, for the moment the Earth is where we make our stand.

It has been said that astronomy is a humbling and character-building experience. There is perhaps no better demonstration of the folly of human conceits than this distant image of our tiny world. To me, it underscores our responsibility to deal more kindly with one another, and to preserve and cherish the pale blue dot, the only home we've ever known.”

Animal Eyes

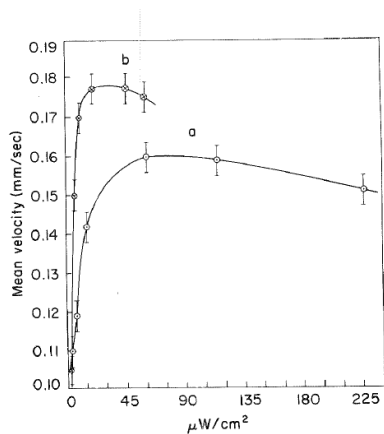
We can learn a lot from the wonder of, and the wonder in, animal eyes. **Aldo Leopold** a pioneer in the conservation movement, did. He wrote in *Thinking like a Mountain*, “We reached the old wolf in time to watch a fierce **green fire** dying in her eyes. I realized then, and have known ever since, that there was something new to me in those eyes – something known only to her and to the mountain. I was young then, and full of trigger-itch; I thought that because fewer wolves meant more deer, that no wolves would mean hunters’ paradise. But after seeing the **green fire** die, I sensed that neither the wolf nor the mountain agreed with such a view.” For Aldo Leopold, the green fire in the wolf’s eyes symbolized a new way of **seeing** our place in the world, and with his new **insight**, he provided a new **ethical perspective** for the environmental movement. <http://vimeo.com/8669977>



Light contains information about the environment, and animals without eyes can make use of the information provided by environmental light without forming an image. *Euglena*, a single-celled organism that did not fit nicely into **Carl Linnaeus’** two kingdom system of classification, quite clearly responds to light. Its plant-like nature responds to light by **photosynthesizing** and its animal-like nature responds to light by **moving** to and staying in the light. Light causes an increase in the swimming speed, a response known as



photokinesis. Light also causes another response in *Euglena*, known as an accumulation response (**phototaxis**). The light sensitive *Euglena* cells sense the direction of light, swim quickly towards the light, and stay in the light. The *Euglena* cell can be described as a **light meter**, not unlike the one that we used to test the **inverse square law**. [Jerome Wolken](#) (1995) describes *Euglena* as a **photo-neurosensory** cell. *Euglena* can also be considered a [sensorimotor cell](#), in which the stimulus sensing and the motile response occur in the same cell—a simple precursor to our nervous system, where the brain mediates the message.



Demonstration: See how the *Euglena* cells/organisms accumulate in the light.



Light-induced movements in *Euglena* have been studied by **Jerome Wolken**, the father of Jonathan Wolken, a founding member of the Pilobolus Dance Company, who performs Shadowland. The dance company was named after *Pilobolus*, a light-sensitive fungus growing in Wolken's lab that shoots its spores towards the light. Here is a drawing of *Pilobolus* on the night of November 3, 1911, showing its ability to sense and grow towards the direction of light.

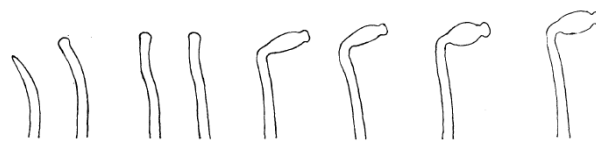
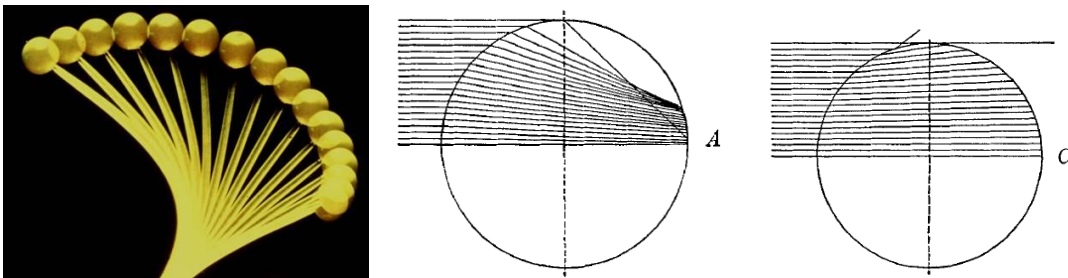
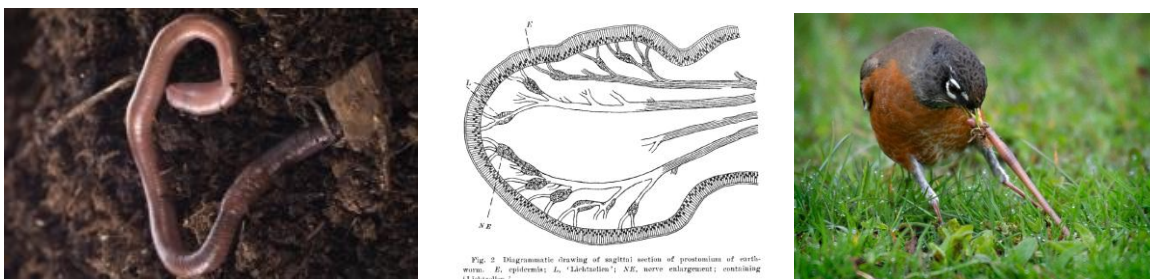


FIG. 12

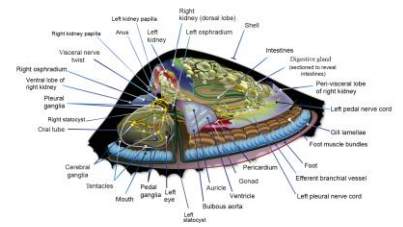
The single-celled sporangiophore of *Phycomyces*, a fungus similar to *Pilobolus* acts like a light meter/converging lens that, when in air, focuses the light on the back side (A). When *Phycomyces* is grown in a medium that has the same refractive index as the cell, the light is not focused (C) and the sporangiophore does not bend (Castle, 1933)!



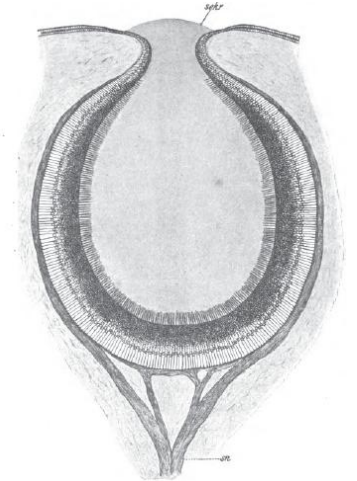
Earthworms are also capable of sensing light *without* eyes as reported by Charles Darwin (1881) in his book, *The Formation of Vegetable Mould, through the Action of Worms, with Observations of their Habits*. Earthworms have **light-sensitive photoreceptor cells in and under the skin** throughout their body although they are concentrated in the anterior portion (Hess, 1925). The earthworms are **photophobic** and move away from the light and towards the dark. At dawn, they crawl into their dark holes and stay there until dusk. I wonder if the birds know their schedule.



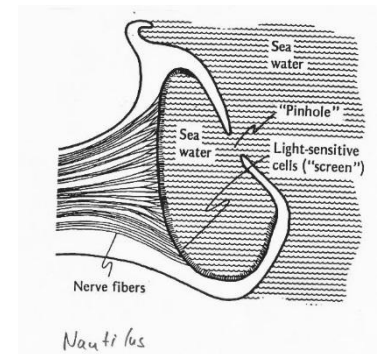
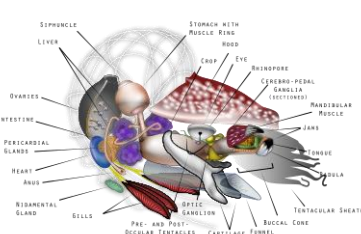
A photograph showing a rocky shoreline where numerous white, oval-shaped eggs are scattered across the dark, wet rocks and in the shallow, rippling water. The eggs are densely packed in some areas, particularly on the larger, flatter rock surfaces. The water is a deep blue-grey color, and the sky is not visible in this frame.



The geometry of the eye of the **iridescent mollusk**, *Haliotis* or abalone is more like a **pinhole camera**. The smaller **aperture** and more spherical retina would result in a relatively sharp image and relatively good **visual acuity**. The **tradeoff** of the smaller aperture is that the image will be **dimmer**.



The geometry of the eye of the **cephalopod mollusk**, *Nautilus*, is even more like a **pinhole camera**. The smaller **aperture** and more spherical retina would result in a relatively sharp image and relatively good **visual acuity**. The **tradeoff** of the smaller aperture is that the image will be **dimmer**.

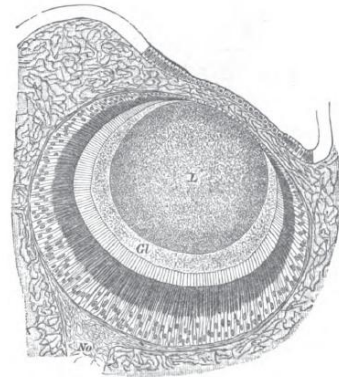


The **pinhole camera eye** of *Nautilus*, trades off dimness for visual acuity. Dimness can be overcome by the addition of a converging lens to make a **camera-like eye**, just as the *camera obscura* was improved by adding a converging lens.



The gelatinous lenses of *Murex* and *Helix* that I will describe below do not have the refracting or dioptric power to produce a focused image on the retina.

Murex is a mollusk that lives in the intertidal zone. We will talk about *Murex* later in the semester when I talk about the dyes **Tyrian** (royal) **purple** and **Tekhelet**. *Murex* has a camera-like eye where the optic cup-like retina is filled with a gelatinous lens that captures a lot of light compared with a pinhole but it probably underfocuses and is not very effective in image formation. *Murex* does have a cornea that interfaces with salt water ($n = 1.33$ - 1.34) at times and air ($n = 1$) at other times, but because the cornea is so flat it does not have much refractive or dioptric power and does not participate much in image formation.

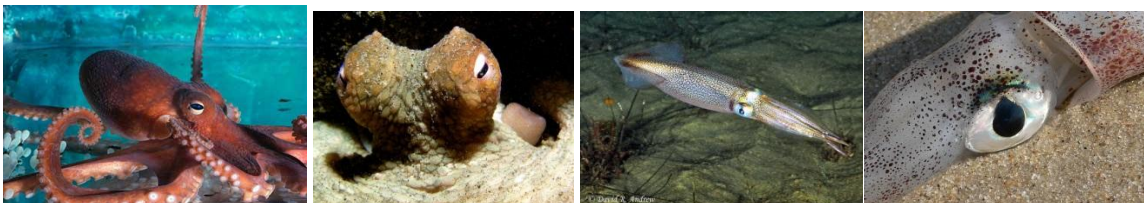




Other mollusks, such as land snail, *Helix*, have an eye like that of *Murex* that captures a lot of light but is also probably not very effective in image formation.

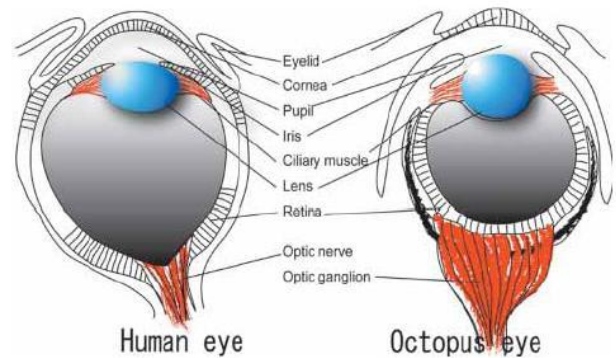


Going back to aquatic animals, some **predatory** animals, such as squid and octopus that live **in the sea** where **light may be limiting** have eyes with the ability to both capture light and to produce a focused image on the retina. A lens that has the ability of **accommodate** mitigates the tradeoff between brightness and visual acuity, although it does introduce aberrations.

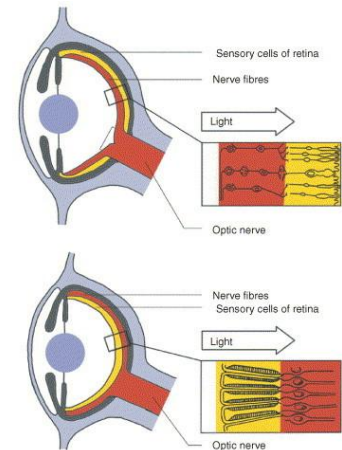


The eye of a **squid** or an **octopus** is similar to the human eye in that it has a **cornea** and a **crystalline lens** to refract light, an **iris** that surrounds a **pupil** that opens in dim light, a **retina**, and an **optic nerve**. The visual system is also similar

in that a large part of the **brain** is involved in visual processing. The octopus and squid eyes differ in that the human eye **accommodates** by changing the shape of the **crystalline lens**, becoming more convex when focusing nearby objects whereas the octopus and squid eyes, like a camera, **accommodate** by moving the crystalline lens closer to the object when focusing nearby objects.



There is also a difference in the organization of the **retina** in the human and octopus eye. In the human retina, except at the fovea, the photoreceptor cells are at the far side of the incoming light and the neural cells are on the near side. This by necessity results in a blind spot. In the octopus, the photoreceptor cells are at the near side of the incoming light and the neural cells are on the far side. Consequently, there is no blind spot.



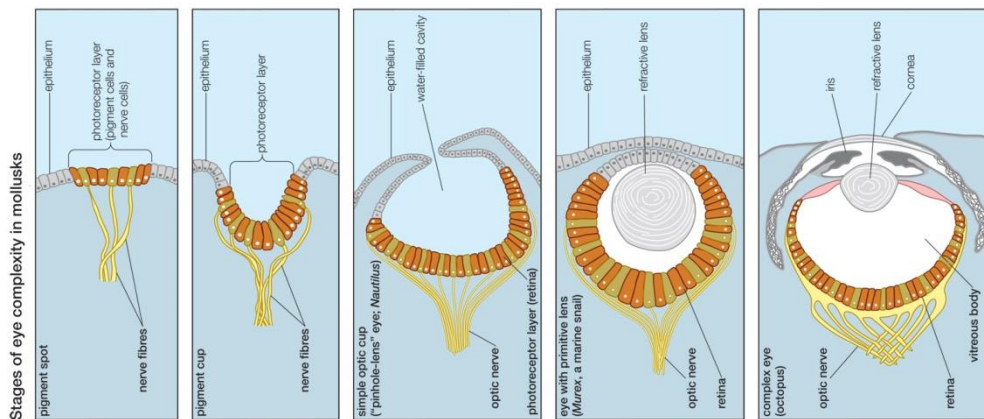
The giant or colossal squid is about 4.2 meters long and lives 1000 meters beneath the sea. The large soccer ball-sized eye, orange-sized lens, and its 8-9 cm in diameter pupil, results in a large light gathering capacity that helps the giant squid see in deep waters. Humans can only see in waters 500-600 meters down. The giant squid eye also has **photophores** that contain **bioluminescent bacteria**

help the giant squid to see in deep waters.

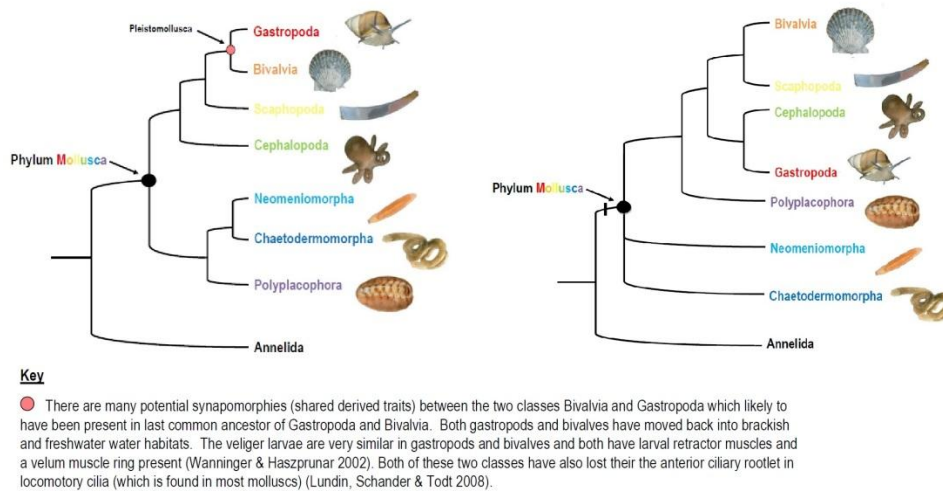
<http://squid.tepapa.govt.nz/anatomy/article/the-eye-of-the-colossal-squid>



The levels of complexity of the molluscan eye from a **light-meter eye**, through a **pinhole camera eye** to a **camera eye** are summarized in the figure below.



Potential evolutionary relationships between these organisms are given below:

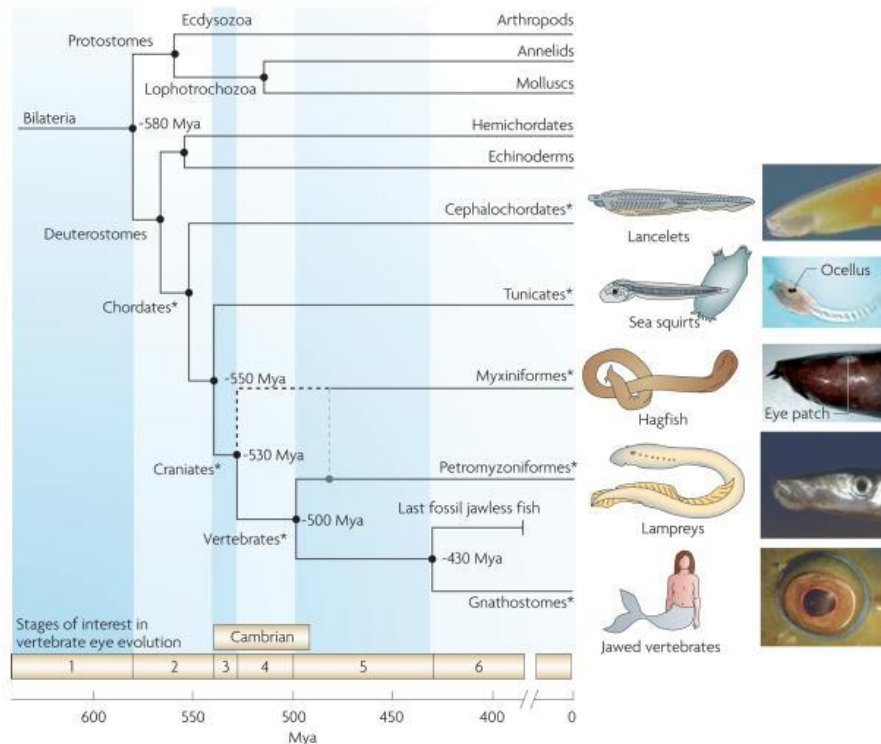


Let's look at the eyes of **chordates** (a phylum), including hagfish, lampreys and other vertebrates (a subphylum), the ancestors of which existed at the time of the **Cambrian explosion** about 543 million years ago. Chordates are bilaterally symmetrical and possess a notochord, which is a support structure that develops into the backbone in vertebrates. During the Cambrian, diversification does not appear **gradual** as Darwinian theory assumes but **rapid**. A deep insight into the mystery of the Cambrian explosion can be obtained by reading *Darwin's Doubt* by Stephen C. Meyer (2014).

I am considering **time to be real and unidirectional**. This is not a common belief nowadays. To quote an anonymous reviewer of one of my recent papers (2/7/15): "*I'm worried that the author is addressing a non-problem. Even if time's arrow is not real, there still may be local time asymmetries – in the same way as organisms constitute local violations of the law of increasing entropy.*"



In *In the Blink of an Eye: How Vision Sparked the Big Bang of Evolution* and *Seven Deadly Colours: The Genius of Nature's Palette and How it Eluded Darwin*, Andrew Parker suggests that the rapid diversification of animals that took place in the Cambrian was a result to the evolution of eyes which led to intense predation and the ability to escape it.



The **hagfish** is a slime secreting, jawless eel-like living fossil that has a notochord but lacks vertebrae. It may be more primitive than lampreys or may have degenerated from lampreys (Lamb et al, 2007). The hagfish eye is **small and buried behind a patch of translucent skin**. It cannot

form an image since it lacks a cornea, an iris, a pupil (or pinhole), and a crystalline lens. Moreover, the photoreceptors in the retina do not connect to bipolar cells but connect directly to ganglion cells, which go the suprachiasmatic nucleus (SCN) in

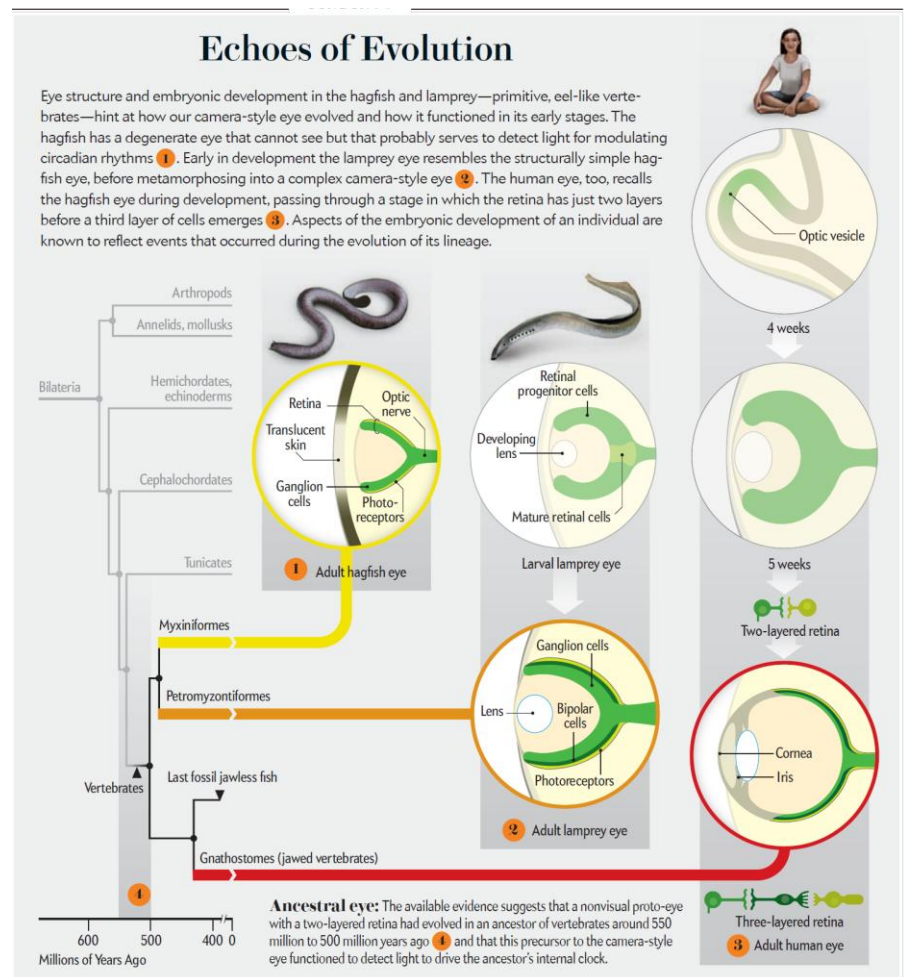


the anterior portion of the hypothalamus, a part of the brain that is in part involved with circadian rhythms.

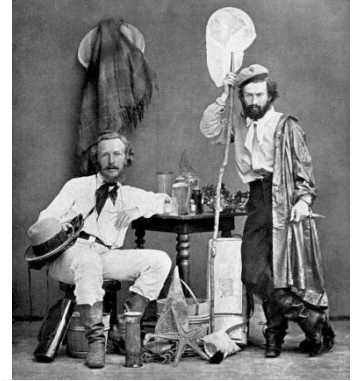
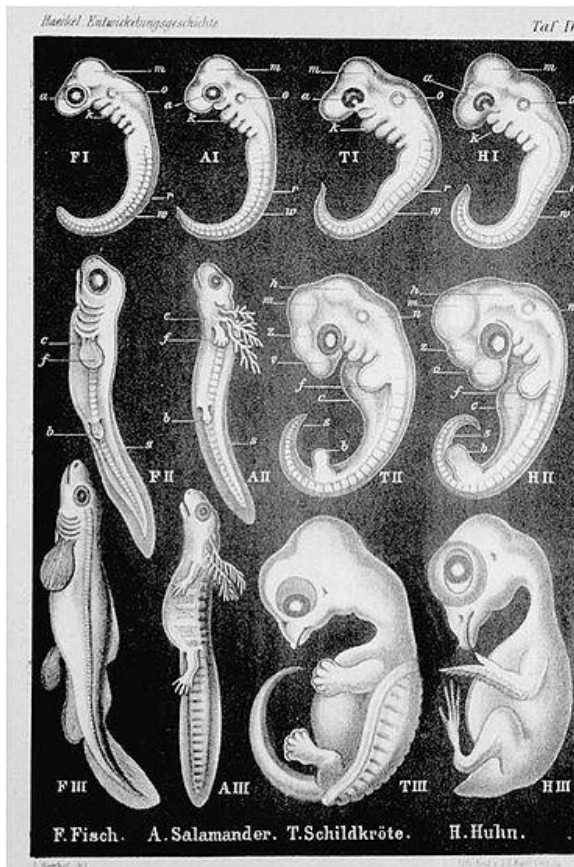
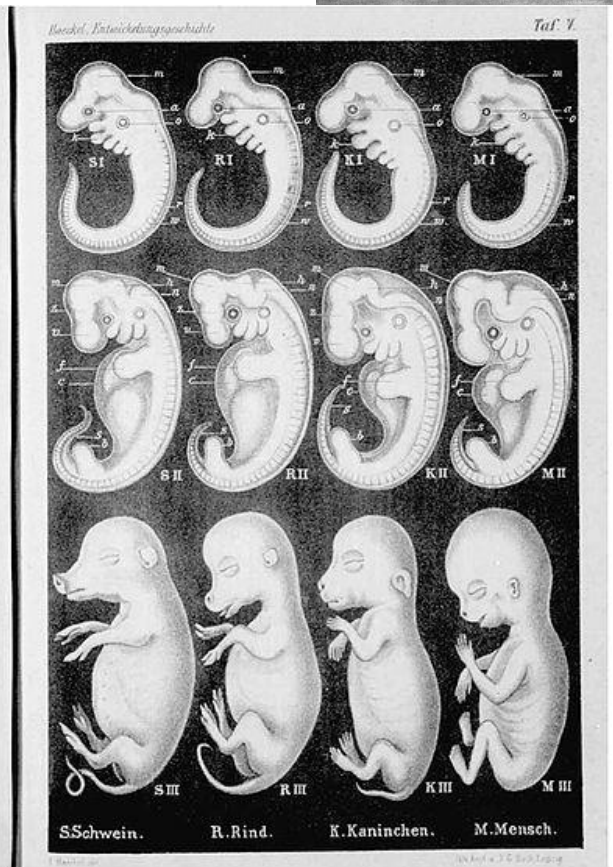
The **lamprey** is also an eel-like jawless fish that has a notochord and has cartilaginous rather than bone vertebrae. Unlike the hagfish, the lamprey has large eyes. The **eyes** of the adult lamprey are similar to human eyes, while the eyes of the larvae are reminiscent of the hagfish eye,



which is unable to produce an image. **Karl Von Baer** suggested that the **developmental stages** through which the embryo passes might reflect the **evolutionary history** of that organism. Even though natural selection could act on any stage of embryo development, it would be more life-threatening to change an earlier process than to add on a process later in development. Similar embryology may be a reflection of **common descent**.



See the illustration from **Ernst Haeckel's** (1) (1874) book *Anthropogenie* showing very early, somewhat later, and still later stages of embryos of fish (F), salamander (A), turtle (T), chick (H), pig (S), cow (R), rabbit (K), and human (M)

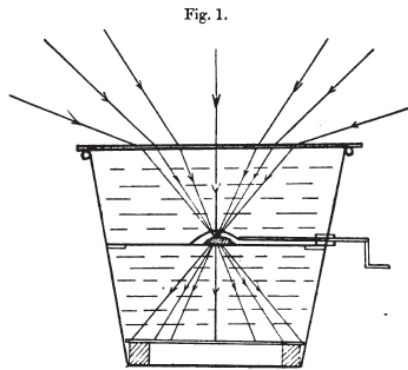


Fish are aquatic vertebrates whose eyes differ from eyes of terrestrial organisms because the **refractive index** of water differs from the refractive index of air. Compared to terrestrial vertebrates, fish lenses are denser and more **spherical**. This is because the refractive index of water is



close to the refractive index of the cornea, and consequently, the cornea has little refracting or dioptric power and the **crystalline lens provides the majority of the dioptric power of a fish eye**. Unlike human eyes, the crystalline lens in the eyes of fish is typically **spherical** with a **short focal length that focuses near objects on the retina when the muscles are relaxed**. When the inelastic, rigid fish eye **accommodates** it does *not* change shape. The crystalline lens moves toward the retina so that distant objects become focused. The **size of the pupil** of a fish's eye is **fixed**.

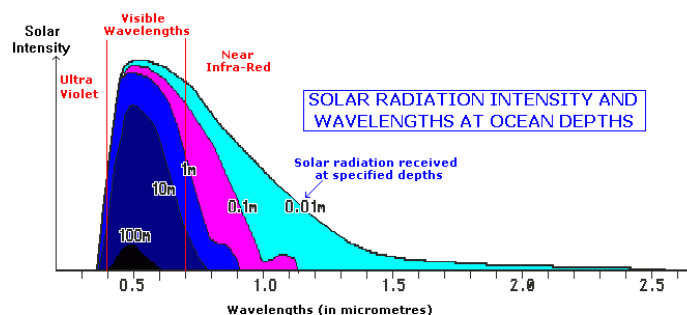
James Clerk Maxwell (1854) contemplated the way the world would look to a fish based on the geometry of a fish's very short focal length crystalline lens and Robert Wood (1906) "*interested to ascertain how the external world looks to the fish*", created the first **fish-eye camera** by putting a camera underwater (middle figure). He then created a horizontal water camera (figure on right) that "*gives us a good idea of how the visitors at an aquarium look to the fishes*." Lenses that capture rays coming from **ultra-wide angles** are known as fisheye lenses.



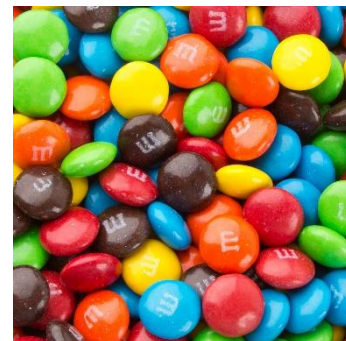
Fish-eye lenses are available for smart phones for less than ten dollars.



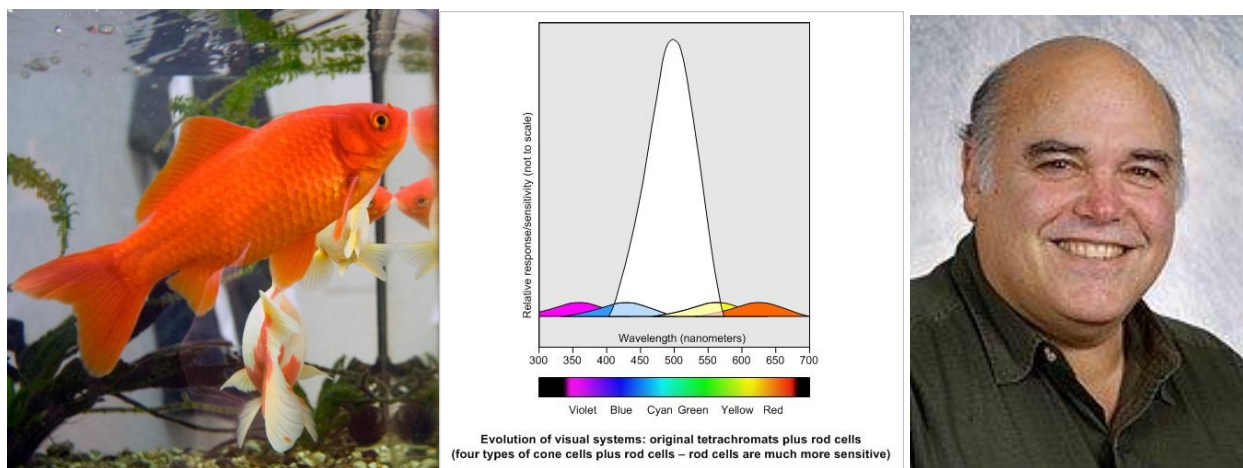
Sunlight traveling into water becomes bluer with depth since the longer (redder) wavelengths get **absorbed** by the water. Since water absorbs the redder wavelengths and scatters and reflects the shorter wavelengths, it appears blue. You can test this by throwing M&M's off the side of a boat into water and see which ones disappear first.



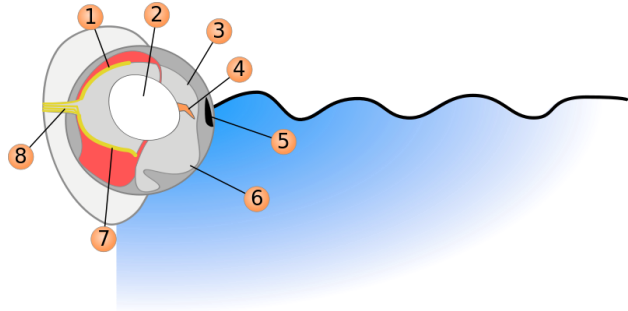
The solar radiation 'envelope' penetrates the ocean to 100 metres at visible wavelengths but to much shallower depths as wavelength increases. Back radiation in the far infra-red from the Greenhouse Effect occurs at wavelengths centred around 10 micrometres, well off the scale of this chart, and cannot penetrate the ocean beyond the surface 'skin'.



Consequently, while fish living in shallow water have **retinas** with mostly **cones** that give **photopic** color vision, fish living in deeper water have **retinas** with mostly **rods** that give **scotopic** vision. The retinas of fish living in shallow waters are also sensitive to **ultraviolet light**. **Goldfish** are **tetrachromats** with four different types of cones, including ultraviolet, blue, green, and red. Goldfish are able to see colors ranging from infrared through the visible range to the ultraviolet. Ellis Loew (Cornell) studies vision in fish.

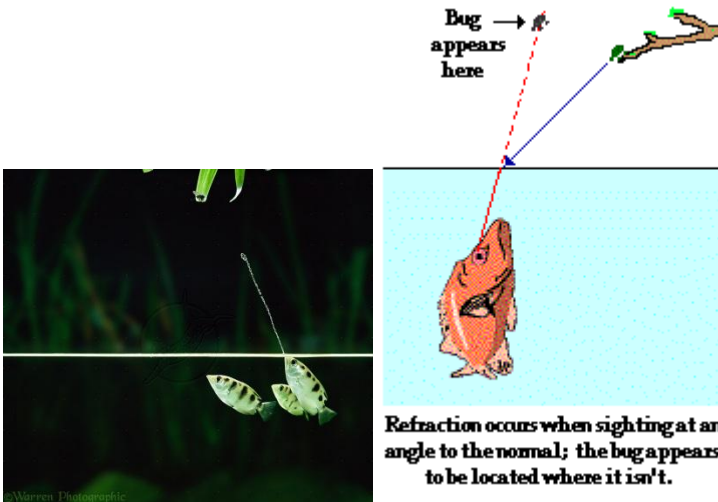


The **four-eyed fish** (*Anableps*) are visionaries among fish. They have eyes on each side of their head that are divided into two parts that can be used simultaneously. The top part of the eye is good for catching insects in the **air** to eat. The bottom part of the eye is good for looking for predators under **water**. A part of the retina is used for water vision (1) and another part is used for air vision (7). The curvature of the crystalline lens (2) is greater for light coming through the water pupil (6) than it is for the light coming through the air pupil (3) as a result of the need for greater refracting or dioptric power for focusing light rays coming from water ($n = 1.333$) compared with light rays coming from air ($n = 1$).

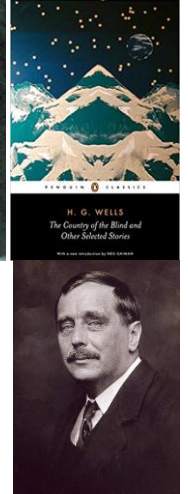


<http://www.youtube.com/watch?v=ZPR7aqzvHtA>

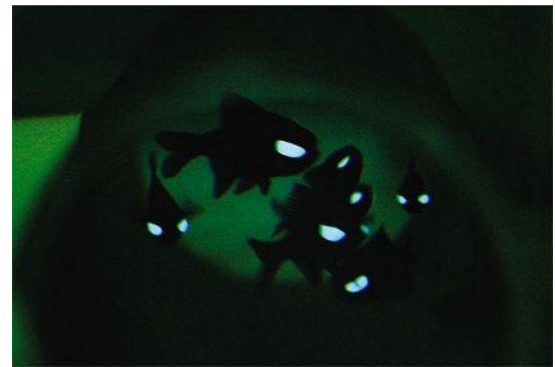
The **archerfish** (*Toxotes*) are the sharpshooters among fish. They are able to spit at insects up to three meters above the surface of the water and knock them into the water so they can eat them. This means that the archerfish is able to compensate for the bending of light that occurs at the air water interface and is described by the **Snel-Descartes Law**. The archerfish's brain fixes the refraction illusion unlike ours when we see a broken pencil at a water air interface! Unlike the archerfish, we are hard-wired to think that light travels in straight lines!



Cave fish (*Amblyopsis*) live in the dark and have no need for eyes. Some are completely blind, and some can only detect the difference between light and dark. (Remember, “*In the Country of the Blind, the one-eyed man is king.*”—a short story written by **H. G. Wells** in which Nuñez would rather see anywhere else than be king in the country of the blind.) Here is a radio play with Sir Laurence Olivier: https://www.youtube.com/watch?v=2Dy_qldjLJ4) It will remind you of **Plato’s Allegory of the Cave**.



The eyes of **flashlight fish** light up as a result of symbiotic **bioluminescent bacteria** that are contained in **photophores** below each eye. The light is produced constantly but the fish flashes the light two to three times a minute by rotating the photophore in the eye socket. We will talk about deep ocean-dwelling fish that make use of bioluminescent bacteria for **camouflage**, communication, and for catching prey later this semester.



Frogs are **amphibians** that begin their life as tadpoles swimming with their **eyes underwater** and then spend most of their life with their **eyes above water**. During the metamorphosis, the **cornea** becomes **smoother** and **rounder** and **eyelids** and **tear ducts**, which keep the cornea clean and moist, form. These are features that **do not** occur in fish eyes that are surrounded by water. The crystalline lens of frogs, like that of fish is rigid, and accommodation results from the back-and-forth movement of the lens and not from a change in its shape. During the metamorphosis, the eyes are positioned near the top of the head where they provide the **stereo vision necessary for catching food** as well as **peripheral vision necessary for seeing predators**.



The red-eyed tree frog (*Agalychnis callidryas*) has a spectacular iris color. Red eyes also occur in albino frogs that lack pigmentation in the iris.



Aside: While we are talking about frogs, here is a poem by **Emily Dickinson**:

I'm Nobody! Who are you?

*I'm Nobody! Who are you?
Are you - Nobody - too?
Then there's a pair of us!
Dont tell! they'd banish us - you know!*

*How dreary - to be - Somebody!
How public - like a Frog -
To tell your name - the livelong June -
To an admiring Bog!*



Reptiles, unlike fishes and amphibians have a retina with a **fovea** that allows them to **resolve fine details**. Reptilian eyes accommodate as a result of changing the shape of the crystalline lens. Unlike other animals, the **crystalline lens** of chameleons at rest is a **diverging lens** that reduces the



refracting or dioptric power of the eye given by the **converging lens cornea** when a distant object is focused on the retina. Chameleon eyes are mounted on **turrets** on both sides of the head. The two eyes turn independently, allowing chameleons to see in two different directions at once. Diurnal reptiles that are active during the day have **cone-rich retinas** for **photopic color vision**, while nocturnal and burrowing reptiles have **rod-rich retinas** for **scotopic vision**.

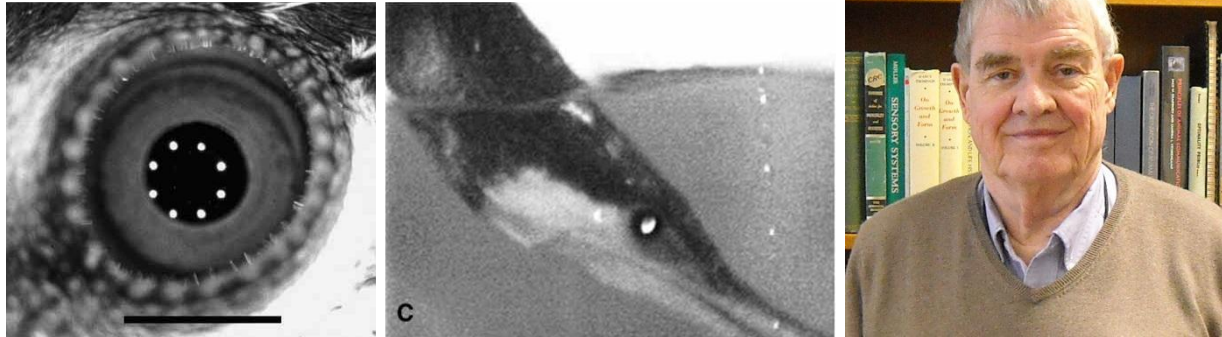
Birds have a variety of eyes that let them see with great acuity. The ostrich has the second largest (2 inches in diameter) eye among animals, second only to the giant squid. While a large eye is useful to a squid for its **light collecting ability** in dimly-lit habitats, the large eye is useful to an ostrich for the **better visual acuity** it provides.



Birds that need good vision when in air, with a refractive index of 1 and water with a refractive index of 1.33-1.34 have the ability to change the curvature of **both** their **cornea** and their **crystalline lens** when they **accommodate**. **Cormorants** (*Phalacrocorax carbo sinensis*) and **gannets** (*Morus serrator*) **accommodate** with their **corneas above water**



where the refractive index of air is one and **accommodate** with their **crystalline lens** when they are **underwater** ($n = 1.33-1.34$) and the cornea no longer has much refractive or dioptric power. Howard Howland (Cornell) studied bird eyes.



Diurnal birds have cone-dominated retinas and excellent **photopic color vision** while **nocturnal birds**, such as **owls** have **rod-dominated retinas** and **scotopic vision**. In fact, the fovea of owls is also rod-dominated. Owls also have large eyes with good light-capturing ability for hunting at night. They also have a **tapetum lucidum** for reflecting back to the photoreceptor pigments any light that had not been captured on the first pass. The two forward-facing eyes give them good stereo vision. Owls cannot move their eyes in their sockets, but they can see in many directions by turning their neck 270 degrees in either direction.



Raptors are birds of prey that can have a piercing stare as a result of the large eyebrow above their eye that shields the eye from the direct rays of the sun. **Raptors** also have great visual acuity compared with humans. Their greater visual acuity results from **cones** in the **fovea** that are **thinner** and **more numerous** than the cones of humans. In fact, raptors have two highly developed foveae in each retina. When a **bifoveate** raptor initially sees its prey, it does not fly directly towards the prey, but spirals towards it, with its head straight relative to the body but at an angle to its prey. The position of the head reduces air resistance and puts the central fovea of one eye (**monocular vision**) in the line of sight. As the raptor approaches its prey, the flight path becomes more direct and the temporal fovea are used in order to enhance the **stereo vision** necessary for precision aim.

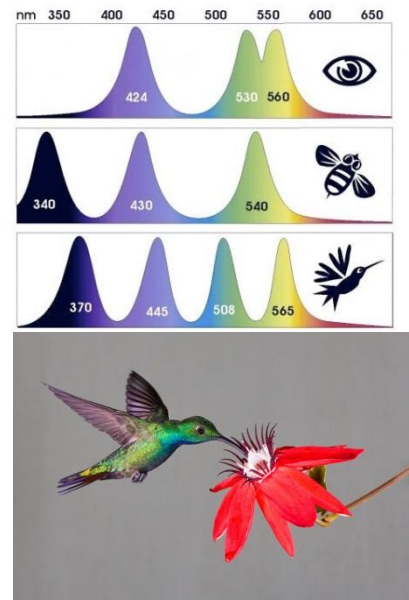


Predatory birds, such as the **peregrine falcon**, tend to have large forward-facing eyes with a small field of view but **stereo vision** with good depth perception, while **prey species**, such as **pigeons**, have **small, flat, laterally-placed** eyes that are capable of **surveying a wide area**, but with monocular vision and little or no depth perception.



Birds that pollinate flowers are typically **tetrachromats** and have ultraviolet, blue, green, and red cones. These birds also have carotenoid pigment-containing oil droplets that act like filters in front of the cones, perhaps creating even more types of cones. Some birds may be **pentachromatic** as a result of the differential filtering of the oil droplets over the four types of opsin photoreceptors. While the ability to **discriminate colors** may be an advantage, the downside is reduced visual acuity. Do you know why?

The **visual spectrum of diurnal bird pollinators** is enhanced in the **red** compared with the visual spectrum of bees. Consequently, red and orange flowers are more likely to be pollinated by birds than by bees. (Some **butterflies** are tetrachromatic and also see in the red). We will talk about flower color and pollinator vision later in the semester.



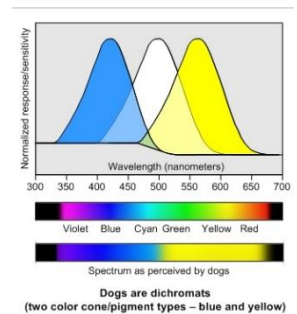
Predatory mammals, including **cheetahs**, **dogs** and **cats** have their camera eyes placed in the front of their head to give **binocular vision** with good **depth perception**. Predatory mammals also have retinas with **foveae** that give good **visual acuity**. **Accommodation** of mammalian eyes results from a change in the shape and a **decrease in the focal length** of the crystalline lens when viewing nearby objects.



Grazing animals, such as a **horse** or antelope that might serve as a meal for predators, have camera eyes placed on the side of their heads to give a **wide field of view** (350°, 65 ° of binocular vision and 285 ° of monocular vision) with little depth perception. Horses have little power of accommodation.

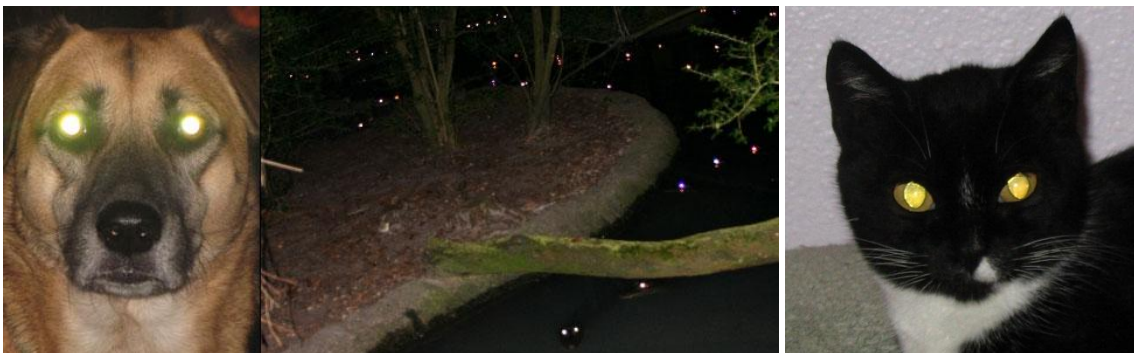


Most terrestrial **mammals**, including **dogs**, **cats**, and **bulls** are **dichromats** and have poor color vision. Exceptions include monkeys, apes, and humans, which are all **trichromats**.



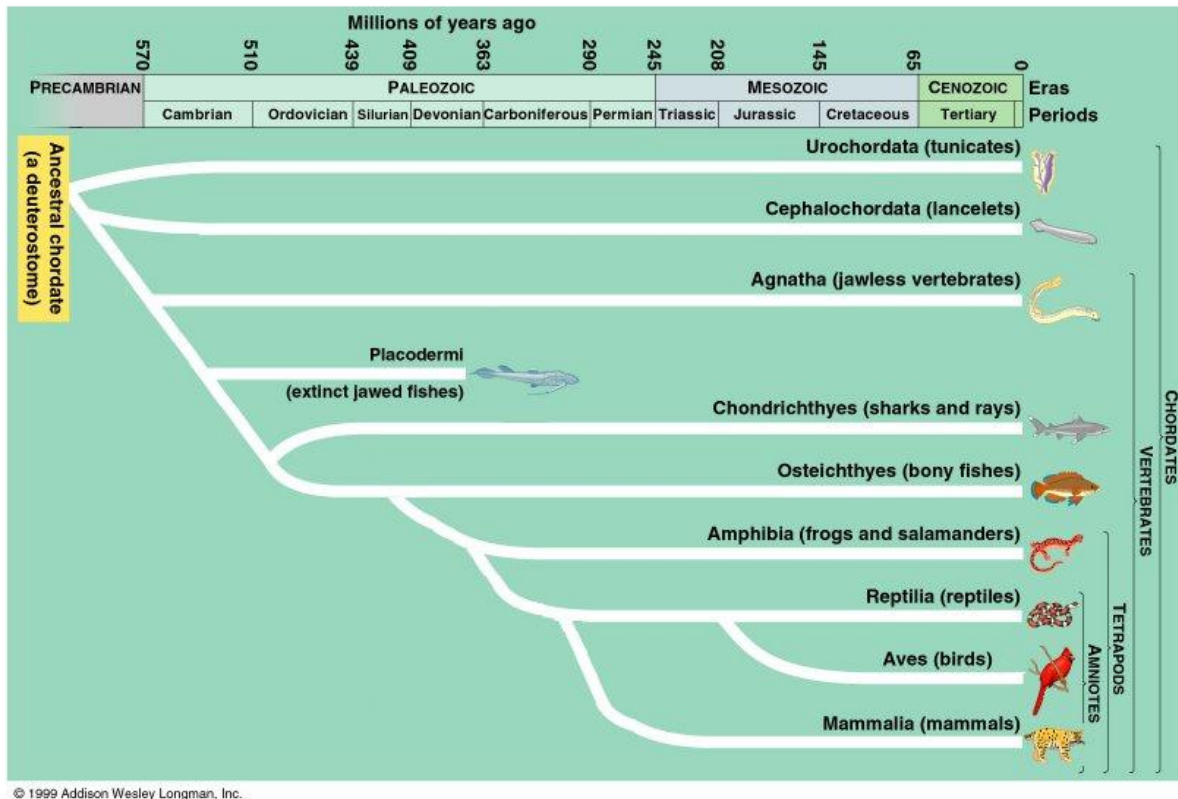


Nocturnal mammals have rod-rich retinas for scotopic vision and a **tapetum lucidum** to help them see in the dark. **Reflection** of light from the **tapetum lucidum** is the cause of **eyeshine** (in dogs, cats, and alligators).

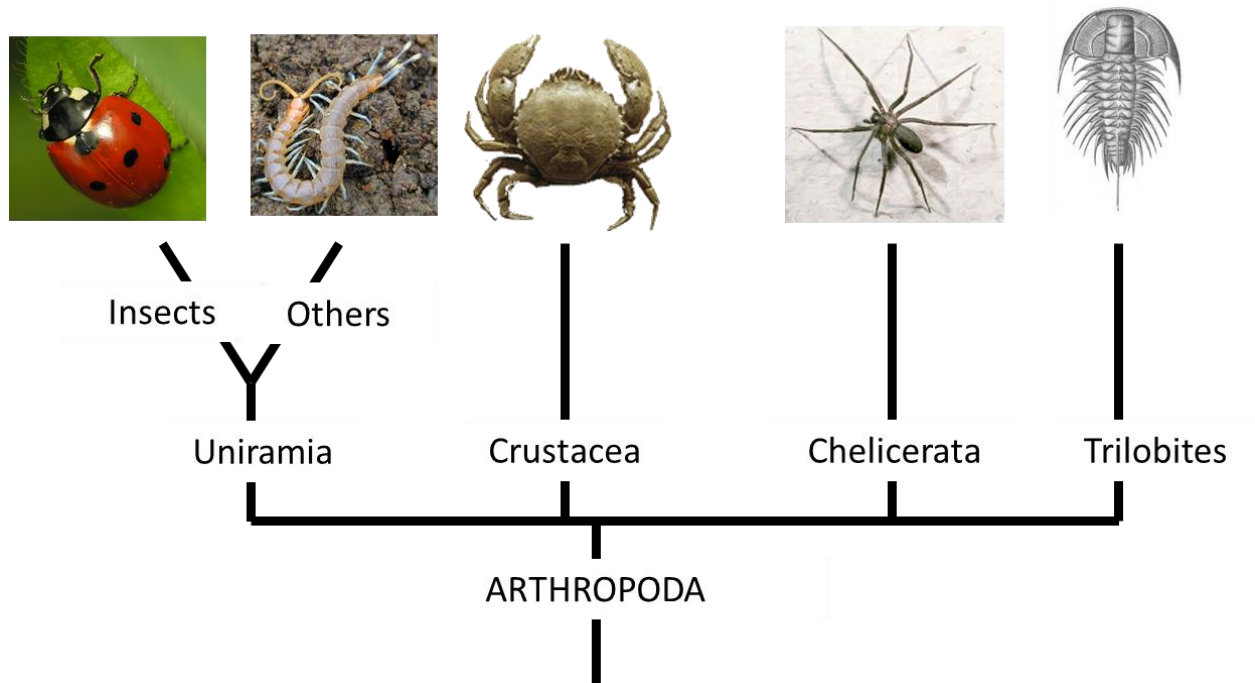


We see the **variation** in the placement of the eyes, the size of the eyes, the proportion of focusing that is due to the cornea and crystalline lens, the mechanism of accommodation, the ability of the pupil to contract and dilate, the ratio of rods

(scotopic vision) to cones (photopic color vision) in the retina, and the spectral sensitivity of the cones. We can see that the eyes of fish, amphibians, reptiles, birds, and mammals have evolutionary adaptations and/or designs that **suit the life style of the beholder**. What are the **causes** of the diversity seen in the vertebrate eye?



Before answering that question, let's look at the **eyes** of the **arthropods** , which include the Trilobites, the Arachnids, the Crustaceans, and the Insects.



Five hundred and forty million years ago, in the **Cambrian**, the **trilobites** may have been the first animals to see the world. They had **compound eyes** like their relatives, the insects and crustaceans.

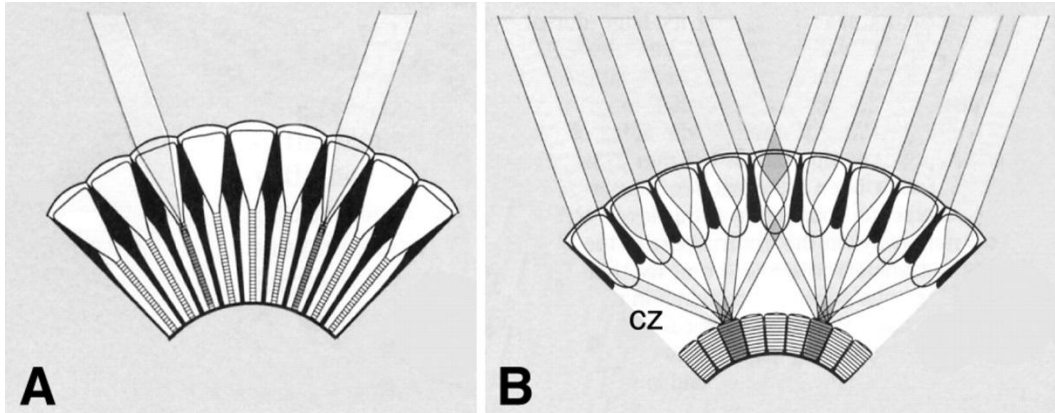


Compound eyes are made out of many units called **ommatidia**. They function to give a **wide field** and **rapid** responses, which is why it is hard to swat a fly. A compound eye typical of **diurnal insects** such as **houseflies**, **dragonflies**, and **butterflies** is of the **apposition type (A)** where **light reaches the photoreceptors exclusively from the small corneal lens located directly above**.

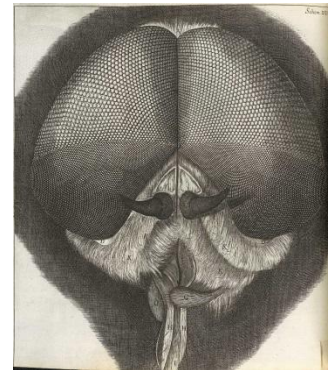


Generally speaking, each cornea forms an inverted image of the object, but the photoreceptors at the base of each **ommatidium** measure only the brightness of the small region of space collected by the cornea. The erect image seen by the insect is a mosaic of the individual brightness levels of each field of view.

Nocturnal insects such as cockroaches and moths that live in limiting light conditions have a **superposition type (B)** of compound eye. The sensitivity to light is increased by having hundreds to thousands of corneal facets that collect and focus the light on single photoreceptors in the retina.



Robert Hooke (1665) published his observation of the compound eyes of a grey drone fly and the eyes of other insects in his *Micrographia*. We will see the *Micrographia* when we go to Kroch Library later this semester.



Demonstration: Observe a house fly's apposition type compound eye under the dissecting microscope.



Crustaceans, such as **lobsters**, shrimp, and crayfish also have **superposition type compound eyes**. However, in their case, the light is directed down the **ommatidium** according to the **law of reflection**, not the law of refraction.

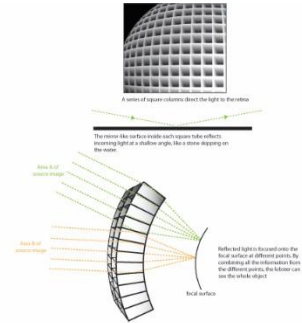
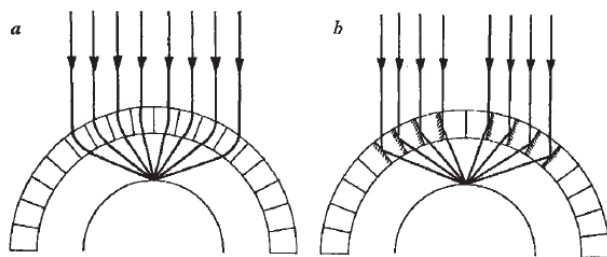
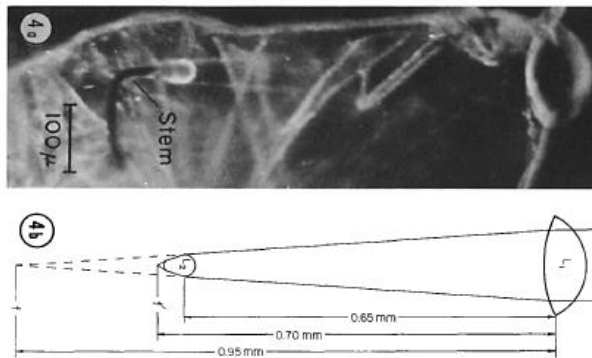
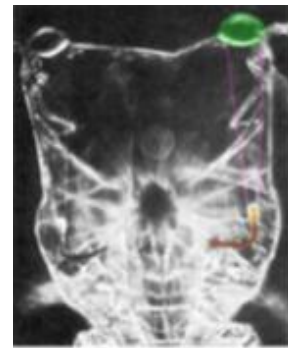


Fig. 1 Superposition image formation (a) by refraction (modified from Exner) and (b) by reflection.



Some **copepods**, which are also crustaceans, can have eyes that can only be described as **telescopes**!

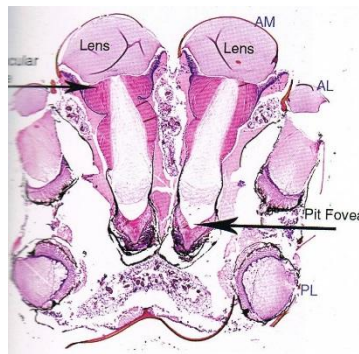
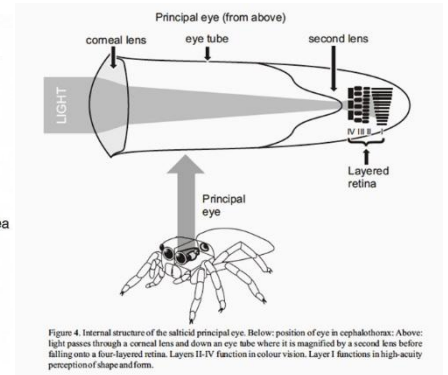


Spiders are **arthropods** that typically have eight simple eyes. Some of the eyes look forward, the rest scan the peripheries. As in other land animals, the

EYE ARRANGEMENTS OF THREE COMMON SPIDER FAMILIES



cornea is the main refracting system in spider eyes and the optical system is reminiscent of a **refracting telescope**.



The **jumping spider** (*Portia fimbriata*), which can jump twenty body lengths, and the **ogre-faced net-casting spider** (*Dinopis subrufa*) have very high-



resolution eyes with a limiting resolution only 2.4 arc minutes that allows them to hunt and successfully capture their prey. Some spiders are diurnal and others are nocturnal hunters. <https://www.youtube.com/watch?v=Wt4LpZa3iFs>

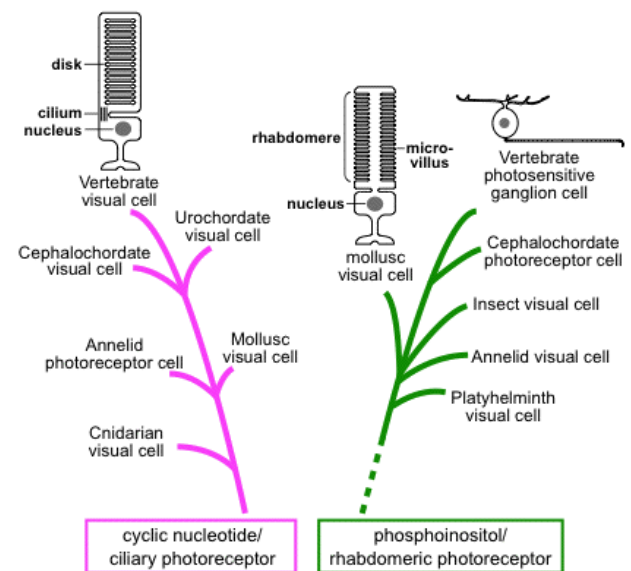
Nocturnal spiders have relatively large eyes and well developed tapeta to allow them to hunt at dusk and in moonlight. Here is a picture of eyeshine from a **wolf spider**.



Web-spinning spiders whose food comes to them, have eyes with low resolving power.



There is diversity in the type of cells that act as photoreceptors in animals. In the vertebrate line, the rods and cones are modified **cilia**. In all other animals, the photoreceptor cells can be either modified cilia or modified **microvilli**. Later in the semester we will talk about **melanopsin**, a pigment that is in the human eye that does not participate in image formation, but in sensing the light-dark cycle involved in our sleep-wake cycle. While the rod (**rhodopsin**) and cone (**photopsin**) pigments in humans are found in **ciliary**-like cells, the **melanopsin** is found in **microvilli**-like cells.



As we see there is a great diversity in eyes in the animal world and each form is suited to the life style of the beholder. Optically speaking, there are as many ways that animal eyes use light to form images as there are optical instruments. Animals use **pinholes**, **converging** and **diverging lenses**, and **mirrors** to produce images of the external world. We have discussed the eyes of diurnal and nocturnal animals as well as the eyes of aquatic and terrestrial animals and the design constraints. Amazed by the design of eyes, **William Paley**

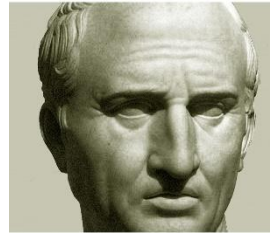


(1802) wrote in *Natural Theology*, “every indication of contrivance, every manifestation of design, which existed in the watch, exists in the works of nature; with the difference, on the side of nature, of being greater and more, and that in a degree which exceeds all computation. I mean that the contrivances of nature surpass the contrivances of art, in the complexity, subtilty, and curiosity of the mechanism; and still more, if possible, do they go beyond them in number and variety; yet, in a multitude of cases, are not less evidently mechanical, not less evidently contrivances, not less evidently accommodated to their end, or suited to their office, than are the most perfect productions of human ingenuity.

I know no better method of introducing so large a subject, than that of comparing a single thing with a single thing; an eye, for example, with a telescope. As far as the examination of the instrument goes, there is precisely the same proof that the eye was made for vision, as there is that the telescope was made for assisting it. They are made upon the same principles; both being adjusted to the laws by which the transmission and refraction of rays of light are regulated. I speak not of the origin of the laws themselves; but such laws being fixed, the construction, in both cases, is adapted to them. For instance; these laws require, in order to produce the same effect, that the rays of light, in passing from water into the eye, should be refracted by a more convex surface, than when it passes out of air into the eye. Accordingly we find that the eye of a fish, in that part of it called the crystalline lens, is much rounder than the eye of terrestrial animals. What plainer manifestation of design can there be than this difference? What could a mathematical-instrument-maker have done more, to show his knowledge of his principle, his application of that knowledge, his suiting of his means to his end; I will not say to display the compass or excellence of his skill and art, for in these all comparison is indecorous, but to testify counsel, choice, consideration, purpose?”

Paley's argument from design was a restatement of what Cicero (45 BC) wrote in [*De Natura Deorum*](#):

De natura deorum
Marco Tullius Cicero



 The Perfect Library

Now of all the things which are administered by nature the universe is, so to speak, the originator, begetter, parent, rearer, and supporter, and it cherishes and contains them as members and parts of itself. But if the parts of the universe are administered by nature, the same must be the case with the universe itself; at any rate there is nothing in the administration of it which can be found fault with, for the best that could have been produced from the elements which there were has been produced. If that is denied, then let some one show that better could have been produced. But no one ever will show this, and whoever wishes to amend anything will either make it worse, or will be regretting the absence of that which could not have been attained. But if all the parts of the universe have been so ordered that they could not have been better adapted for use, or more beautiful as regards appearance, let us see whether they are the work of chance, or whether their arrangement is one in which they could not possibly have been combined except by the guidance of consciousness and the divine providence. If, then, the things achieved by nature are more excellent than those achieved by art, and if art produces nothing without making use of intelligence, nature also ought not to be considered destitute of intelligence. If at the sight of a statue or painted picture you know that art has been employed, and from the distant view of the course of a ship feel sure that it is made to move by art and intelligence, and if you understand on looking at a horologe [Sundial], whether one marked out with lines, or working by means of water [water-clock], that the hours are indicated by art and not by chance, with what possible consistency can you suppose that the universe which contains these same products of art, and their constructors, and all things, is destitute of forethought and intelligence?

Charles Darwin (1859) in *The Origin of Species* proposed that the eye did not need a creator but evolved by natural selection. *“To suppose that the eye, with all its inimitable contrivances for adjusting the focus to different distances, for admitting different amounts of light, and for the correction of spherical and chromatic aberration, could have been formed by natural selection, seems, I freely confess, absurd in the highest possible degree.*



Yet reason tells me, that if numerous gradations from a perfect and complex eye to one very imperfect and simple, each grade being useful to its possessor, can be shown to exist; if further, the eye does vary ever so slightly, and the variations be inherited, which is certainly the case; and if any variation or modification in the organ be ever useful to an animal under changing conditions of life, then the difficulty of believing that a perfect and complex eye could be formed by natural selection, though insuperable by our imagination, can hardly be considered real. How a nerve comes to be sensitive to light, hardly concerns us more than how life itself first originated; but I may remark that several facts make me suspect that any sensitive nerve may be rendered sensitive to light, and likewise to those coarser vibrations of the air which produce sound.

In looking for the gradations by which an organ in any species has been perfected, we ought to look exclusively to its lineal ancestors; but this is scarcely ever possible, and we are forced in each case to look to species of the same group, that is to the collateral descendants from the same original parent-form, in order to see what gradations are possible, and for the chance of some gradations having been transmitted from the earlier stages of descent, in an unaltered or little altered condition. Amongst existing Vertebrata, we find but a small amount of gradation in the structure of the eye, and from fossil species we

can learn nothing on this head. In this great class we should probably have to descend far beneath the lowest known fossiliferous stratum to discover the earlier stages, by which the eye has been perfected.

*In the Articulata we can commence a series with **an optic nerve merely coated with pigment**, and without any other mechanism; and from this low stage, numerous gradations of structure, branching off in two fundamentally different lines, can be shown to exist, until we reach a moderately high stage of perfection. In certain crustaceans, for instance, there is a double cornea, the inner one divided into facets, within each of which there is a lens-shaped swelling. In other crustaceans the transparent cones which are coated by pigment, and which properly act only by excluding lateral pencils of light, are convex at their upper ends and must act by convergence; and at their lower ends there seems to be an imperfect vitreous substance. With these facts, here far too briefly and imperfectly given, which show that **there is much graduated diversity in the eyes of living crustaceans**, and bearing in mind how small the number of living animals is in proportion to those which have become extinct, I can see no very great difficulty (not more than in the case of many other structures) in believing that natural selection has converted the simple apparatus of an optic nerve merely coated with pigment and invested by transparent membrane, into an optical instrument as perfect as is possessed by any member of the great Articulate class.*

He who will go thus far, if he find on finishing this treatise that large bodies of facts, otherwise inexplicable, can be explained by the theory of descent, ought not to hesitate to go further, and to admit that a structure even as perfect as the eye of an eagle might be formed by natural selection, although in this case he does not know any of the transitional grades. His reason ought to conquer his imagination;

though I have felt the difficulty far too keenly to be surprised at any degree of hesitation in extending the principle of natural selection to such startling lengths.

*It is scarcely possible to avoid comparing the eye to a telescope. We know that this instrument has been perfected by the long-continued efforts of the highest human intellects; and we naturally infer that the eye has been formed by a somewhat analogous process. But may not this inference be presumptuous? Have we any right to assume that the Creator works by intellectual powers like those of man? If we must compare the eye to an optical instrument, we ought in imagination to take a thick layer of transparent tissue, with a nerve sensitive to light beneath, and then suppose every part of this layer to be continually changing slowly in density, so as to separate into layers of different densities and thicknesses, placed at different distances from each other, and with the surfaces of each layer slowly changing in form. Further we must suppose that there is a power always intently watching each slight accidental alteration in the transparent layers; and carefully selecting each alteration which, under varied circumstances, may in any way, or in any degree, tend to produce a distincter image. **We must suppose each new state of the instrument to be multiplied by the million; and each to be preserved till a better be produced, and then the old ones to be destroyed. In living bodies, variation will cause the slight alterations, generation will multiply them almost infinitely, and natural selection will pick out with unerring skill each improvement. Let this process go on for millions on millions of years; and during each year on millions of individuals of many kinds; and may we not believe that a living optical instrument might thus be formed as superior to one of glass, as the works of the Creator are to those of man?***

If it could be demonstrated that any complex organ existed, which could not possibly have been formed by numerous, successive, slight modifications, my

theory would absolutely break down. But I can find out no such case. No doubt many organs exist of which we do not know the transitional grades, more especially if we look to much-isolated species, round which, according to my theory, there has been much extinction. Or again, if we look to an organ common to all the members of a large class, for in this latter case the organ must have been first formed at an extremely remote period, since which all the many members of the class have been developed; and in order to discover the early transitional grades through which the organ has passed, we should have to look to very ancient ancestral forms, long since become extinct.”

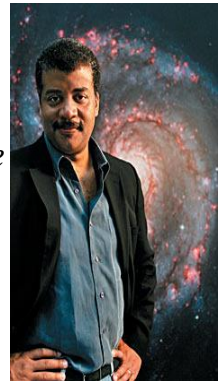
In the *Blind Watchmaker*, Richard Dawkins (1986) discounted Paley and supported Darwin, “*Paley’s argument is made with passionate sincerity and is informed by the best biological scholarship of his day, but it is wrong, gloriously and utterly wrong. The analogy between telescope and eye, between watch and living organism, is false. All appearances to the contrary, the only watchmaker in nature is the **blind forces of physics**, albeit deployed in a very special way. A true watchmaker has **foresight**: he designs his cogs and springs, and plans their interconnections, with a future purpose in his **mind’s eye**. Natural selection, the blind, unconscious, automatic process which Darwin discovered, and which we now know is the explanation for the existence and apparently purposeful form of all life, has no purpose in mind. It has no mind and **no mind’s eye**. It does not plan for the future. It has **no vision, no foresight, no sight at all**. If it can be said to play the role of the watchmaker in nature, it is the **blind** watchmaker.*” Dawkins wrote in the *New York Times* (April 9, 1989), “*It is absolutely safe to say that if you meet somebody who claims not to believe in evolution, that person is ignorant, stupid or insane (or wicked, but I’d rather not*



consider that).” Richard Dawkins demonstrates the evolution of the eye in this short video: <http://www.youtube.com/watch?v=Nwew5gHoh3E>

How will technology be involved in the evolution of the eye? Go to this website <http://www.space-between.org/> and ask David Brewer, Senior Extension Associate at the K. Lisa Yang and Hock E. Tan Institute on Employment and Disability ILR School, 201 Dolgen Hall Cornell University.

Today, scientists are emphasizing the ***un-intelligent design*** of the eye as evidence for evolution by natural selection. Neil deGrasse Tyson (2009) wrote in *The Perimeter of Ignorance*, “The eye is often held up as a marvel of biological engineering. To the astrophysicist, though, ***it's only a soso detector***. A better one would be much more sensitive to dark things in the sky, and to all the invisible parts of the spectrum. How much more breathtaking sunsets would be if we could see ultraviolet and infrared. How useful it would be if, at a glance, we could see every source of microwaves' in the environment, or know which radio station transmitters were active. How helpful it would be if we could spot police radar detectors at night.



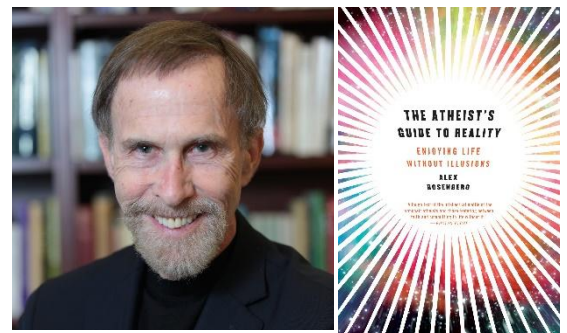
To deny or erase the rich, colorful **history** of scientists and other thinkers who have invoked divinity in their work would be intellectually dishonest. Surely there's an appropriate place for intelligent design to live in the academic landscape. How about the **history** of religion? How about philosophy or psychology? The one place it doesn't belong is the science classroom.”

Trevor Lamb (2011) wrote in *The Evolution of the Eye*, “For all the ingenious features evolution built into the vertebrate eye, there are a number of decidedly inelegant traits. For instance, the retina is inside out, so light has to pass through the whole thickness of the retina—through the intervening nerve fibers and cell bodies that scatter the light and degrade image quality—before reaching the light-sensitive photoreceptors. Blood vessels also line the inner surface of the retina, casting unwanted shadows onto the photoreceptor layer. The retina has a blind spot where the nerve fibers that run across its surface congregate before tunneling out through the retina to emerge behind it as the optic nerve. The list goes on and on.



*These defects are by no means inevitable features of a camera-style eye because octopuses and squid independently evolved camera-style eyes that do not suffer these deficiencies. Indeed, if engineers were to build an eye with the flaws of our own, they would probably be fired. **Considering the vertebrate eye in an evolutionary framework reveals these seemingly absurd shortcomings as consequences of an ancient sequence of steps, each of which provided benefit to our long-ago vertebrate ancestors even before they could see. The design of our eye is not intelligent—but it makes perfect sense when viewed in the bright light of evolution.***

Alex Rosenberg (2011) states in *The Atheist's Guide to Reality Enjoying Life Without Illusions*, that our sense of vision is so bad, as evidenced by our being deceived by **optical illusions** that you should “Never Let Your Conscious Be Your Guide.” He



writes, “Ultimately, science and scientism are going to make us give up as illusionary the very thing conscious experience screams out at us loudest and longest: the notion that when we think, our thoughts are about anything at all, inside or outside of our minds...Thinking about things is an overwhelmingly powerful illusion. Once we learn how this profound illusion is produced, we’ll understand why it’s hard to cast the illusions of consciousness aside for the real answers to the relentless questions about the self, mind, soul, free will, and the meaning of life.”

Here are some of Alex Rosenberg’s answers to the relentless questions:

Is there a God? No.

What is the nature of reality? What physics says it is.

What is the purpose of the universe? There is none.

What is the meaning of life? Ditto.

Why am I here? Just dumb luck.

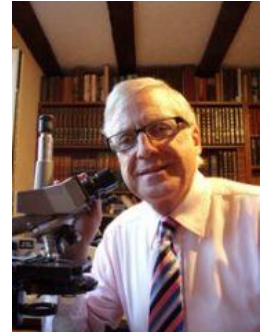
Does prayer work? Of course not.

Is there a soul? Is it immortal? Are you Kidding?

What is the difference between right and wrong, good and evil? There is no moral difference between them.

“If you still can’t sleep at night, even after accepting science’s answers to the persistent questions, you probably just need one more little thing besides Epicurean detachment. Take a Prozac or your favorite serotonin reuptake inhibitor, and keep taking them till they kick in.”

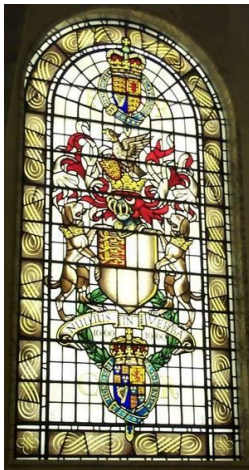
More recently, Brian Ford (2013) wrote in *Debunking the Myth of Intelligent Design*, “The structure of the eye is widely cited as an example of intelligent design because, say the proponents, until an eye has been fully formed it simply cannot function. Thus, evolution vaguely in the direction of a fully developed eye could not have taken place unless there were a designer at work, who envisaged what the final result might be. This does not stand scrutiny. First, there are eyes of every type in differing animals. Some are simple (like those of spiders) whereas others are complex (like those of flies). Some eyes (including ours) have lenses, whereas others, like those of a squid [sic], work wonderfully with no lens at all. Any designer, having worked out a perfect organ of sight, would install it in everything that needed an eye. Running countless different types of eyes in parallel is the height of inefficiency.



*It is the mammalian eye that provides unambiguous evidence. No designer could have made such a curious mistake than in contriving our eyes, They're assembled backwards, and afflict us all with inferior vision.... This all reveals to us that humans were not designed by some supreme being. As a product of design we are excruciating inefficient, metabolically muddled, functionally futile and conceptually confused. **It would take a designer of unimaginable and perverse stupidity to make so many obvious mistakes. God is portrayed in many ways by world religions, but not one of them insists that their deity is an idiot....So we can see that the design of humans is idiotic and riddled with problems that make people suffer. If you wish to seek intelligence in the way living systems work, then there is no point in seeking inspiration from God.***”

What do **you think**? Natural selection? Godly design?

The motto of the Royal Society of London is *Nullius in Verba*, which roughly translates as “*take no one’s word for it.*” The motto expresses the Society’s belief in the importance of **seeing for oneself** and **not bowing to external authority.**



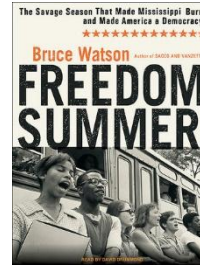
The Royal Society's motto 'Nullius in verba' roughly translates as 'take nobody's word for it'. It is an expression of the determination of Fellows to withstand the domination of authority and to verify all statements by an appeal to facts determined by experiment.



Russell Seitz wrote in a piece called [*Nullius in Verba*](#) in the Wall Street Journal,

*The Royal Society's view of the conflict between authority and evidence is made clear by its motto. Nullius in Verba is Latin shorthand for what Harry Truman meant when he said "I'm from Missouri. Show me." **It's a notion the full quote from Horace -- Nullius addictus judicare in verba magistri -- expands into the gold standard of objectivity: "Not compelled to swear to any master's words."***

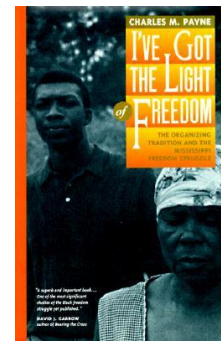
What are our eyes for? Jacob Helen Campbell (1892), author of *Darkness and Daylight*, and Jacob Riis (1890,1902,1903), author of *How the Other Half Lives* and *The Battle with the Slum*, used their eyes to see injustice.



<http://www.authentichistory.com/1898-1913/2-progressivism/2-riis/index.html> They shared their sight with us by way of flashlight-lit photographic images that showed the **dark side** of affluent society. **Marilyn Van Derbur** told the story of being an incest survivor in *Darkness to Light* (<https://www.youtube.com/watch?v=ALEfE3rNCqI>).

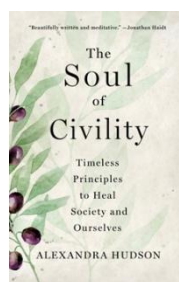


Likewise, people in the civil rights movement illuminated what was wrong with America with the light of freedom, and made it better. Hear Fannie Lou Hamer sing *This Little Light of Mine*: <https://www.youtube.com/watch?v=zAjSlf3BDP8> and see a short documentary about her entitled, *This Little Light of Mine*:



<https://www.youtube.com/watch?v=ZITvXzxloCs>

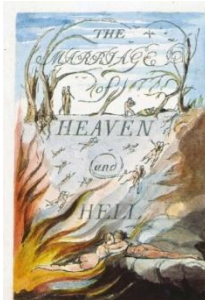
Alexandra Hudson (2023) reminds us in *The Soul of Civility* that “[t]he word ‘respect’ comes from the Latin word ‘specere,’ which means ‘to look at.’ Respect calls us to ‘re-inspect others, to see them as they really are, as being with innate dignity, and to treat them with the decency and civility they deserve as members of the human community.’”



What do we learn about being human from studying eyes and vision?

William Blake (ca. 1790) wrote in *The Marriage of Heaven and Hell*:

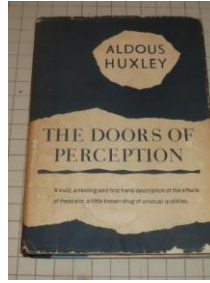
“If the **doors of perception** were cleansed everything would appear to man as it is, infinite.



For man has closed himself up. Till he sees all things thro' narrow chinks of his cavern.”

Remind you of **Plato’s Allegory of the Cave**?

Aside: Aldous Huxley (1954) used *The Doors of Perception* as a title for a book about his experiences with mescaline.



Viktor Frankl (1955) wrote in *The Doctor and the Soul*:

“If we present man with a concept of man which is not true, we may well corrupt him. When we present him as an automation of reflexes, as a mind-machine, as a bundle of instincts, as a pawn of drives and reactions, as a mere product of instincts, heredity, and environment, we feed the despair to which man is, in any case, already prone. I became acquainted with the last stages of corruption in my second concentration camp in Auschwitz. The gas chambers of Auschwitz were the ultimate consequence of the theory that man is nothing but the product of heredity and environment—or, as the Nazis liked to say, of ‘Blood and Soil.’ I am absolutely convinced that the gas chambers of Auschwitz, Treblinka, and Maidanek were ultimately prepared not in some Ministry or other in Berlin, but rather at the desks and in the lecture halls of nihilistic scientists and philosophers.”



http://www.ted.com/talks/viktor_frankl_youth_in_search_of_meaning

In *12 Rules for Life: An Antidote to Chaos*, Jordan B. Peterson (2012) tells us: ***It is our responsibility to see what is before our eyes***, courageously, and to learn from it, even if it seems horrible—even if the horror of seeing it damages our consciousness, and half-blinds us. The act of seeing is particularly important when it challenges what we know and rely on, upsetting and destabilizing us. It is



the act of seeing that informs the individual and updates the state. It was for this reason that Nietzsche said that a man's worth was determined by how much truth he could tolerate. You are by no means only what you already know. You are also all that which you could know, if you only would. Thus, you should never sacrifice what you could be for what you are. You should never give up the better that resides within for the security you already have—and certainly not when you have already caught a glimpse, an undeniable glimpse, of something beyond.

Blowin in the Wind

by Bob Dylan (1962)

*How many roads must a man walk down
Before you call him a man?
Yes, 'n' how many seas must a white dove sail
Before she sleeps in the sand?
Yes, 'n' how many times must the cannonballs fly
Before they're forever banned?
The answer, my friend, is blowin' in the wind
The answer is blowin' in the wind*

*How many years can a mountain exist
Before it's washed to the sea?
Yes, 'n' how many years can some people exist
Before they're allowed to be free?
**Yes, 'n' how many times can a man turn his head
Pretending he just doesn't see?**
The answer, my friend, is blowin' in the wind
The answer is blowin' in the wind*

***How many times must a man look up
Before he can see the sky?**
Yes, 'n' how many ears must one man have
Before he can hear people cry?
Yes, 'n' how many deaths will it take till he knows*



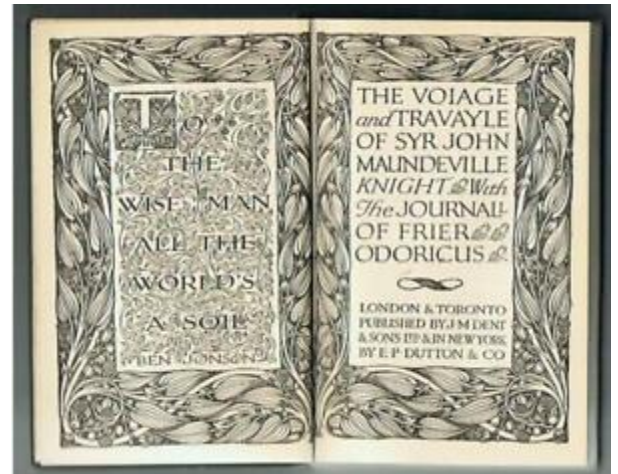
*That too many people have died?
The answer, my friend, is blowin' in the wind
The answer is blowin' in the wind*

Bob Dylan won the 2016 Nobel Prize in Literature:

https://www.nobelprize.org/nobel_prizes/literature/laureates/2016/dylan-speech.html

https://www.nobelprize.org/nobel_prizes/literature/laureates/2016/dylan-lecture.html

What about crocodile tears? In a book written around 1400 and entitled [*The Voyage and Travel of Sir John Mandeville*](#), a description is given of the tears shed by crocodiles as they consume their prey. *“In that country and by all Ind be great plenty of cockodrills, that is a manner of a long serpent, as I have said before. And in the night they dwell in the water, and on the day upon the land, in rocks and in caves. And they eat no meat in all the winter, but they lie as in a dream, as do the serpents. These serpents slay men, and they eat them weeping; and when they eat they move the over jaw, and not the nether jaw, and they have no tongue.”*



The idea that crocodiles shed tears while they eat their prey gave rise to the idea of “crocodile tears”—tears that are shed without remorse or sympathy.

George Johnson (1927) studied crocodiles but found that crocodile tears were a myth. He wrote:

“I made the experiment of squeezing the juice of an onion mixed with common salt into the eyes of four species in order to ascertain whether this irritating solution would excite any flow of tears, but it had no effect in increasing the moisture beyond the slight normal secretion. To my mind this is conclusive that the popular notion of Crocodiles shedding tears is entirely a myth.”

However, Malcolm Shaner and Kent Vliet (2007) took movies of alligators eating and showed that they do cry when they eat—perhaps because their tear ducts are activated serendipitously by the eating processes.

I would like to introduce you to a polymath named **Jerry Lettvin** who taught us about “what the frog’s eye tells the frog’s brain.” This work demonstrated that signal processing goes on in the neurons of the frog’s eye as well as in the brain. **The real reason I am introducing you to Jerry Lettvin is because his lectures were so good that students brought dates to watch him lecture.** Here is a writeup about [Jerry Lettvin](#):



Figure 1. Bubbles in the eyes of “Bomber,” a 4.1-meter-long male American alligator. Bubbles formed as researchers approached the alligator with food. The photo was taken 2.75 minutes after the first feeding in the trial. Photograph: Kent A. Vliet.



“When MIT materials science professor Robert Rose entered Jerome Lettvin’s office in the basement of Building 20 on a fall day in 1968, he immediately heard a problem. “I heard this screeching noise that sounded exactly like a bearing about to fail,” he recalls. “And I knew something was wrong, so I said, ‘Professor Lettvin, you may have a fire!’” As Rose peered around the room looking for the source of the sound, Lettvin seemed unfazed. When he lifted up the lid of a 50-gallon trash bin, the noise became deafening. “There was a cricket colony in there. One million crickets!” says Rose. “ ‘Professor Lettvin,’ I asked, ‘why do you have a cricket colony in your office?’ And he said, ‘To feed my frogs.’”

By then Lettvin, a professor of electrical and bioengineering and of communications physiology, was famous for his research on frogs. “What the Frog’s Eye Tells the Frog’s Brain,” which he’d published a decade earlier, was “viewed as a seminal paper in cognitive science,” according to his longtime colleague Joel Moses, Institute Professor of electrical engineering and computer science. It became one of the most cited scientific papers of all time and laid the groundwork for advances in neuroscience, physiology, and cognition research. But at MIT, where Lettvin had arrived as a researcher in 1951, he was known as much for his outsize personality, his love of language, and his thirst for debate as he was for his groundbreaking research. Although he died in 2011 at age 91, and his last graduate student earned his PhD in 1989, countless stories about him live on.

Lettvin’s MIT legacy is especially remarkable because his was a career that almost wasn’t. Trained initially as a doctor in his native Chicago, he had wanted to be a poet. In school, one of his mentors took him aside and said, “Look, do you really want to go to medical school? Why don’t you go out and become a writer? Doctors are a dime a dozen but the writers are not.”

Lettvin would pen [poetry](#) throughout his career, publishing poems and essays in literary journals; when he was elected to the American Academy of Arts & Sciences for his scientific achievements, he was one of a select few who lived up to its full name. But his mother had matter-of-factly stated, “No medical school, no support,” so he stuck with medicine, earning his MD in 1943 from the University of Illinois. After an internship at Boston City Hospital and several years practicing psychiatry in the Army, he concluded that psychiatry was not as fascinating as the anatomy and physiology behind what makes us think. When the war ended, he spent the next several years working furiously to reinvent himself.

In 1946, Lettvin returned to Boston as a full-time neurologist at the Veterans Administration, auditing physics and higher mathematics classes at MIT and conducting research on the side. Following a motion sickness project at the University of Rochester, he went back to Illinois and lived a double life as a psychiatrist and the head of his own physiology lab at a now-defunct state hospital. In 1951, after half a decade of hectic work (he would later speak of getting three to four hours of sleep per night for much of that time), he landed a full-time entry-level position at MIT’s new Research Laboratory of Electronics.



Lettvin (with collaborator Walter Pitts) plays with one of his research subjects.

At MIT, Lettvin set out “to devise new approaches to problems in neurophysiology, and to define these problems more and more clearly,” he wrote in a 1958 CV. Two years earlier, he’d gotten interested in vision and, as he put it, “decided to play with frogs.” The choice was hardly capricious: he could inject frogs with tubocurare to temporarily paralyze them without affecting the sensory systems he wanted to study—and without killing them. Although tubocurare is lethal to mammals (arrows laced with it quickly shut down their lungs), it doesn’t harm frogs, which breathe through their skin.

Before Lettvin’s frog studies, the retina was viewed as a receptor of light that merely sent signals to the brain for interpretation. “The assumption has always been that the eye mainly senses light, whose local distribution is transmitted to the brain in a kind of copy by a mosaic of impulses,” he wrote. Instead of accepting that assumption, he attached electrodes to the frog’s optic nerve so he could eavesdrop on the signals it sent. He then positioned an aluminum hemisphere around the frog’s eye and moved objects attached to small magnets along the inner surface of the sphere by moving a large magnet on its outer side. By analyzing the signals the optic nerve produced when viewing the objects, Lettvin and his collaborators demonstrated the concept of “feature detectors”—neurons that respond to specific features of a visual stimulus, such as edges, movement, and changes in light levels. They even identified what they called “bug detectors,” or cells in a frog’s retina that are predisposed to respond when small, dark objects enter the visual field, stop, and then move intermittently. In short, Lettvin’s group discovered that a lot of what was thought to happen in the brain actually happened in the eye itself. “The eye speaks to the brain in a language already highly organized and interpreted, instead of transmitting some more or less accurate copy of the distribution of light on the receptors,” he concluded.



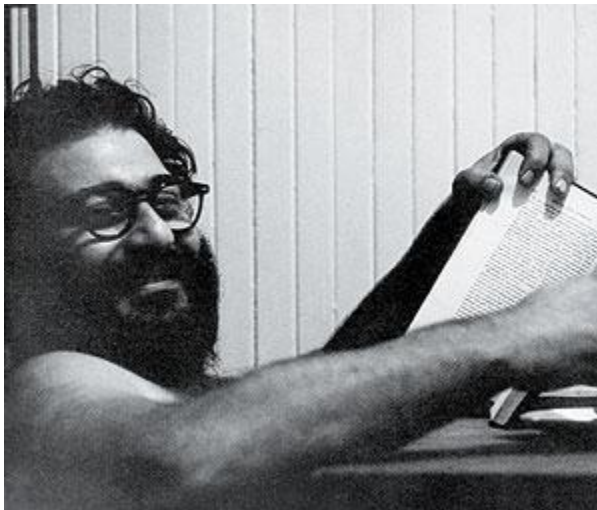
Never without an opinion, Lettvin “was wildly alive,” his wife says.

These important results were initially dismissed. “We had the utmost trouble. We were laughed off the stage, literally, at the American Physiology Society in Atlantic City, where we tried to present it,” Lettvin told his collaborator Luis Amador in 1986. The NIH even threatened to withdraw his grant if he didn’t “start behaving,” he recalled. Then he got his break. “IRE [the Institute of Radio Engineers] was after me to write a paper on electrodes,” he told Amador. “I made a trade with them—I’d write the paper on

electrodes if they would publish the paper on the frog's eye." The editor's response? "All right, but we want a good paper on electrodes."

Even after the paper was published in 1959, the findings met with considerable skepticism. One disgruntled scientist—fellow MIT researcher Walter Rosenblith—"felt we were ... liars, held a meeting on perception, visual perception, and didn't invite us," Lettvin told Amador. Another colleague circumvented the snub by taking conference attendees on an unannounced visit to his lab so they could see for themselves how the experiment was done. The visiting audience was convinced, and Rosenblith soon apologized. "And that," Lettvin concluded, "was the time that we began to be taken seriously."

He himself was hardly serious all the time, though. As a university student, he studied in a Chicago strip club. He wrote poetry on toilet paper during the Battle of the Bulge. And he proposed after three dates, saying, "Most people get to know each other and then get married. How about we do it the other way around?" says Maggie, his wife of 64 years. "He told outrageous stories," Rose says, but "he led a fairly outrageous life, so you never knew which one was true." A skilled debater, Lettvin "loved to argue" says Moses, and "knew so much about so many things." He could conjure up well-articulated positions on the fly, delivering them with eloquence—and often with colorful language. ("His favorite word," Maggie says, "was 'bullshit.'") His crowning performance was a nationally televised 1967 debate about LSD with the former Harvard psychologist Timothy Leary, an advocate of psychedelic drugs. When Leary's original opponent backed out and organizers asked Lettvin to fill in at the last minute, he was "up to his shirtsleeves in an experiment, but he walked right over and did it," his son Jonathan recalled in 2011. After Leary extolled the benefits of LSD, Lettvin responded with an engaging 17-minute lecture. "The kick is cheap. The ecstasy is cheap. And you are settling for a permanent second-rate world by the complete abrogation of the intellect," he told a packed audience in Kresge.



Lettvin routinely spent "hours and hours" reading in the bathtub.

In the classroom, Lettvin put on an equally good show. Maggie, who lived in Bexley Hall when she and her husband served as housemasters in the late 1960s and early '70s, would overhear students talking about a history of science class that he took over to help an ailing colleague get his pension: they'd say

"Come and bring your lunch, bring your girlfriends. Lettvin is teaching," she says. "Classes would last three or four hours." But Lettvin was perhaps at his best holding forth at the giant table in his Building 20 office, where, Rose says, colleagues loved "schmoozing and arguing and calling each other names." That environment, Rose says, served as "a model of what academia ought to be." The opening stanza of - Lettvin's poem "Elegy for Building 20" captures it well: "Place of work is part of mind/Memories imprint the wall/Shabby artifacts recall/Crystal concepts, well-defined."

When friends and colleagues paid tribute to Lettvin on his 60th birthday, a former student sent a telling telegram: "Friend to students, friend to janitors, friend to the elite and friend to the strays, friend to man and especially friend to girls, you are the enemy only of complacent dogma (and, of course, frogs)."



Fisheye Lens

Charles Darwin, Samuel Wilberforce, and How We See the Color of Ants

"We are not afraid to entrust the American people with unpleasant facts, foreign ideas, alien philosophies, and competitive values. For a nation that is afraid to let its people judge the truth and falsehood in an open market is a nation that is afraid of its people."

From "Remarks on the 20th Anniversary of the Voice of America,"
John F. Kennedy (2/26/62) <http://www.jfklibrary.org/Asset-Viewer/Archives/JFKWHA-075-005.aspx>



Likewise, in our personal struggle to keep what is good, bring in what is better, remove the bad, and keep out the worst, we should not be afraid to entrust students, including science students, with unpleasant facts, foreign ideas, alien philosophies, and competitive values in their own personal **search for truth**. After all, while I believe that truth exists, and that the truth will set you free (John 8:32), I also believe that none of us (including me) has a monopoly on the truth. Pilate asked (John 18:38) “*What is truth?*” More recently, Johnny Cash asked *What is Truth* and sang (<https://www.youtube.com/watch?v=qO5z2xUNUpU>; <https://www.youtube.com/watch?v=pjBrbZ52544>)

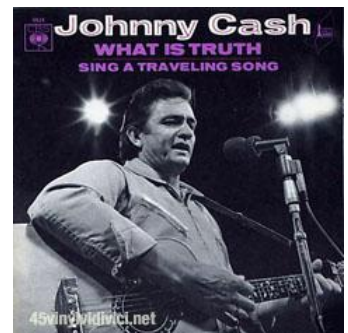


You better help the voice of youth find

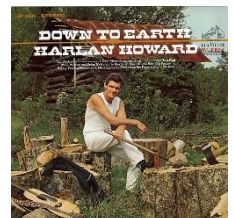
"What is truth"

And the lonely voice of youth cries

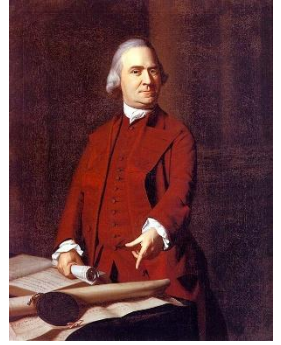
"What is truth?"



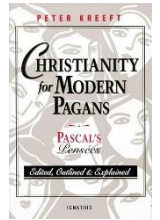
According to Harlan Howard, “*Country music is three chords and the truth.*”



Samuel Adams said on August 2, 1776 at the Second Continental Congress, “*Truth loves an appeal to the common-sense of mankind. Your unperverted understandings can best determine on subjects of a practical nature. The positions and plans which are said to be above the comprehension of the multitude may be always suspected to be visionary and fruitless. He who made all men hath made the truths necessary to human happiness obvious to all.*”



Blaise Pascal (1623-1662) wrote in *Pensée* 739, “*Truth is so obscured nowadays and lies so well established that unless we love the truth we shall never recognize it.*”

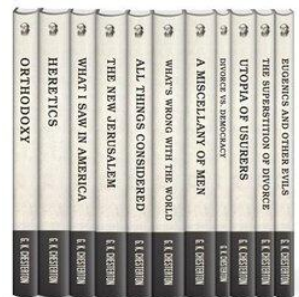


In *A Few Good Men* Tom Cruise said, “*I want the truth.*”

<https://www.youtube.com/watch?v=9FnO3igOkOk> We should all ask, in everything we study and do, *What is truth?*

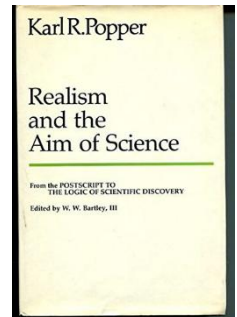


Unfortunately, our educational system does not instill in us the love of truth, the importance of knowing how to seek the whole truth, or even that there is a whole and objective truth. G. K. Chesterton (1915) wrote in *All Things Considered*, “*the thing we never teach at all is the general duty of telling the truth, of giving a complete and fair picture of anything we are talking about, of not misrepresenting, not evading, not suppressing, not using plausible arguments that we know to be unfair, not selecting unscrupulously to prove an ex parte case, not telling all the nice stories about the Scotch, and all the nasty stories about the Irish, not pretending to be disinterested when you are really angry, not pretending to be angry when you are really only avaricious. The one thing that is never taught by any chance in*



the atmosphere of public schools is exactly that--that there is a whole truth of things, and that in knowing it and speaking it we are happy.”

Karl Popper (1983), in *Realism and the Aim of Science*, considers the central problem in the philosophy of knowledge to be: “*How can we adjudicate or evaluate the far-reaching claims of competing theories and beliefs?*” Popper goes on to say, “*This problem has led, historically, to a second problem: How can we justify our theories or beliefs? And this second problem is, in turn, bound up with a number of other questions: What does a justification consist of? And, more especially: Is it possible to justify our theories or beliefs **rationally**: that is to say, by giving reasons—‘positive reasons’ (as I shall call them), such as an appeal to observation; reasons, that is, for holding them to be true, or to be at least ‘probable’ (in the sense of the probability calculus)?*” Popper then introduces a third problem to consider. “*This third problem is the problem of whether one theory is **preferable** to another—and, if so, why. (I am speaking of a theory’s being preferable in the sense that we think or conjecture that it is **a closer approximation to the truth**, and that we may even have reasons to think or to conjecture that it is so.)*”



The [*Report of the Committee on Freedom of Expression at Yale*](#) (Woodward Report; 1974) stated:

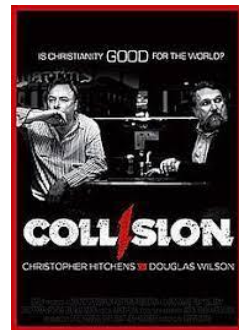
*The history of intellectual growth and discovery clearly demonstrates the need for unfettered freedom, the right to **think the unthinkable, discuss the unmentionable, and challenge the unchallengeable**. To curtail free expression strikes twice at intellectual freedom, for whoever deprives another of the right to state unpopular views necessarily also deprives others of the right to listen to those views.*

On [March 14, 2017](#), Professors Robert George, a conservative, and Cornel West, a radical, wrote, “[t]he pursuit of knowledge and the maintenance of a free and democratic society require the cultivation and practice of *the virtues of intellectual humility,*

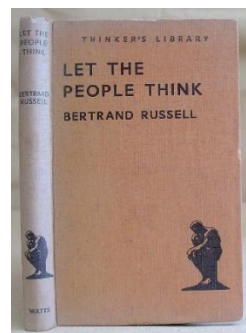


openness of mind, and, above all, love of truth...Our willingness to listen to and respectfully engage those with whom we disagree (especially about matters of profound importance) contributes vitally to the maintenance of a milieu in which people feel free to speak their minds, consider unpopular positions, and explore lines of argument that may undercut established ways of thinking. Such an ethos protects us against dogmatism and groupthink, both of which are toxic to the health of academic communities and to the functioning of democracies.”

[Collision](#) documents a civil debate on whether the **source of truth** is our evolutionary history or God. The debate is between Christopher Hitchens, an anti-theist, and Douglas Wilson, a theist.



Bertrand Russell (1941) states in *Let the People Think*, that one’s philosophy has practical consequences for politics. He says that **relativism**, the idea that there is no such thing as objective truth, and **pragmatism**, the idea that what is useful is true, are closely linked with fascism. In *Conjectures and Refutations*, Karl Popper (1965) extends this sentiment to all authoritarian and totalitarian ideologies.



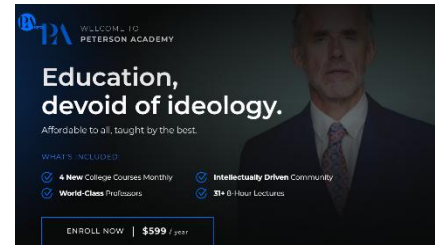
Pano Kanelos (November 8, 2021), president of the newly established [University of Austin](#) wrote in an article entitled, [We Can't Wait for Universities to Fix Themselves](#), “I left my post as president of St. John’s College in Annapolis to build a new university dedicated to the fearless pursuit of truth...Much is broken in

America. But higher education might be the most fractured institution of all. There is a gaping chasm between the promise and the reality of higher education. Yale's motto is Lux et Veritas, light and truth. Harvard proclaims: Veritas. Young men and women of Stanford are told Die Luft der Freiheit weht: The wind of freedom blows. These are soaring words. But in these top schools, and in so many others, can we actually claim that the pursuit of truth—once the central purpose of a university—remains the highest virtue? Do we honestly believe that the crucial means to that end—freedom of inquiry and civil discourse—prevail when illiberalism has become a pervasive feature of campus life?...This core purpose—the intrepid pursuit of truth—has been at the heart of education since Plato founded his Academy in 387 B.C. Reviving it would produce a resilient (or “antifragile”) cohort with exceptional capacity to think fearlessly, nimbly, and inventively. Such graduates will be the future leaders best prepared to address humanity's challenges.” Pano Kanelos, who is now Chancellor of the University of Austin, received the [2025 Courage in Education Award](#) from the Steamboat Institute.

[Ralston College](#) is another newly founded college whose telos is the [search for truth](#). Students at Ralston College [e]ncounter the richest and most challenging works of art and intellect from an uncensored past. Exercise free and independent thinking to answer the challenges of our own time and culture. Question openly, in a community dedicated to freedom of thought and speech: to seeking truth, no matter where it leads, and in fellowship with others.



Peterson Academy is a newly founded online university that provides as education devoid of ideology, affordable for all, and with courses taught by the best teachers.



Leonhard Euler discussed the nature of truth and its discovery “*from our own experience, from reasoning, or from the report of others.*” These are the “*sources laid open by the Creator for the discovery of truth*” in his *Letters to a German Princess, On Different Subjects in Physics and Philosophy* written to Princesses Charlotte and Louise from 1760-1762. These letters also address many of the aspects of optics, light, and colors we discuss in this class.



Vol I: <https://archive.org/details/letterseulertoa00eulegoog>

Vol II: <https://archive.org/details/letterseulerond07brewgoog>

In Peter Kreeft’s (1982) book *Between Heaven & Hell: A Dialog Somewhere Beyond Death*, John F. Kennedy, C. S. Lewis, and Aldous Huxley, who all died on November 22, 1963, discuss the nature and importance of **exoteric** (external), as opposed to **esoteric** (within), truth.

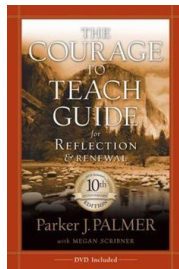
Lewis: *Because the one thing necessary for all true liberation is often very painful.*

Kennedy: *What’s that?*

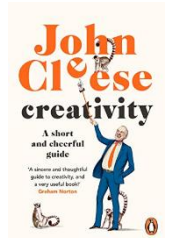
Lewis: *Truth.*

Kennedy: *But truth is a primary human need.*

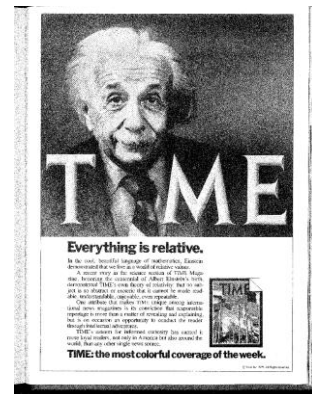
In *The Courage to Teach*, Parker J. Palmer (2007) notes that “*A mode of knowing arises from the way we answer two questions at the heart of the educational mission: **How do we know what we know? And by what warrant can we call our knowledge true?***”



John Cleese (2020) wrote about the truth in *Creativity: A Short and Cheerful Guide*, “*The trouble is that most people want to **be** right. The very best people, however, want to know **if** they’re right. That’s the great thing about working in comedy. If the audience doesn’t laugh, you know you’ve got it wrong.*”



Or is **everything relative** in our **post-modern** world and there no such thing as absolute truth? *Time* magazine reported in 1979 (when they misrepresented Einstein’s belief in absolutes), “*In the cool, beautiful language of mathematics, Einstein demonstrated that we live in a world of **relative values.***”



According to **Noam Chomsky** (1967), “*It is the responsibility of intellectuals to speak the truth and to expose liesIf it is the responsibility of the intellectual to insist upon the truth, it is also his duty to see events in their historical perspective.*” It is our responsibility to ask the intellectuals to state the **assumptions, evidence, and line of reasoning** that led them to the truth. To ensure clarity of communication, it is also important for each of us to define the words we are using to make or refute our arguments.



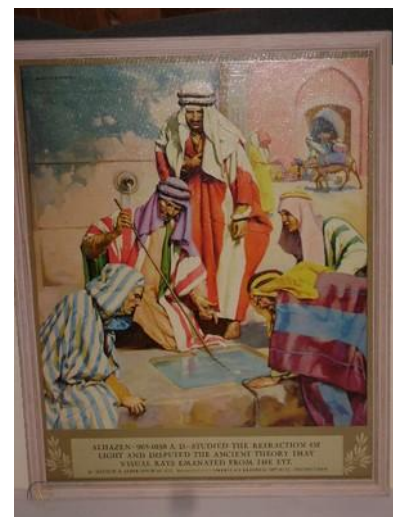
According to **Karl Niklas**, *“The only thing that stands in the way of communication is language.”*

Abdelhamid I. Sabra (2003) tells us that **Alhazen** wrote in his book, *Aporias against Ptolemy*: ***“Truth is sought for itself” but “the truths,” he warns, “are immersed in uncertainties” and the scientific authorities (such as Ptolemy, whom he greatly respected) are “not immune from error....” Nor, he said, is human nature itself: “Therefore, the seeker after the truth is not one who studies the writings of the ancients and, following his natural disposition, puts his trust in them, but rather the one who suspects his faith in them and questions what he gathers from them, the one who submits to argument and demonstration, and not to the sayings of a human being whose nature is fraught with all kinds of imperfection and deficiency. Thus the duty of the man who investigates the writings of scientists, if learning the truth is his goal, is to make himself an enemy of all that he reads, and, applying his mind to the core and margins of its content, attack it from every side. He should also suspect himself as he performs his critical examination of it, so that he may avoid falling into either prejudice or leniency.”***

<https://www.harvardmagazine.com/2003/09/ibn-al-haytham-html>

I realize that the claim, *“There is a Truth”* is not provable but the claim *“There is no Truth”* is self-defeating.

THE
THERE
ARE
TWO
SIDES
TO
EVERY
STORY



In this lecture it is my aim to stimulate, not to satisfy, curiosity, and it is no part of my object to save my students the labor of observation or of thought. For labor is life. These sentiments, and the words themselves come from **George P. Marsh's** *Man and Nature; or, Physical Geography as Modified by Human Action* (1865) and *The Earth as Modified by Human Action* (1907):



In these pages it is my aim to stimulate, not to satisfy, curiosity, and it is no part of my object to save my readers the labor of observation or of thought. For labor is life, and

*Death lives where power lives unused.**

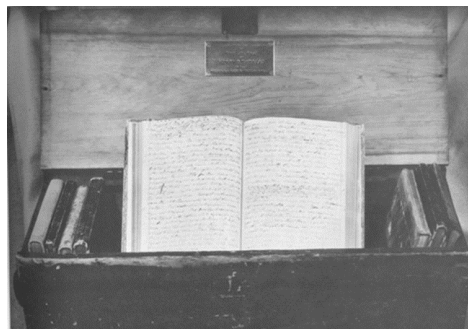
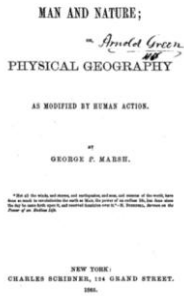
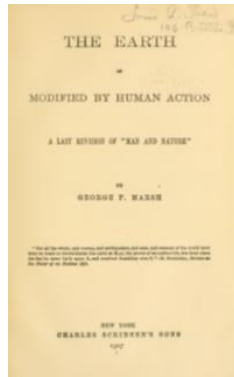
*Self is the schoolmaster whose lessons are best worth his wages; and since the subject I am considering has not yet become a branch of formal instruction, those whom it may interest can, fortunately, have no pedagogue but themselves. To the natural philosopher, the descriptive poet, the painter, the sculptor, and indeed every earnest observer, the power most important to cultivate, and, at the same time, hardest to acquire, is that of seeing what is before him. **Sight is a faculty; seeing, an art.** The eye is a physical but not a self-acting apparatus, and in general it sees only what it seeks. Like a mirror, it reflects objects presented to it; but it may be as insensible as a mirror, and not consciously perceive what it reflects.*

It has been maintained by high authority, that the natural acuteness of our sensuous faculties can not be heightened by use, and hence, that the minutest details of the image formed on the retina are as perfect in the most untrained as in the most thoroughly disciplined organ. This may be questioned, and it is agreed on all hands that the power of multifarious perception and rapid discrimination may be immensely increased by well-directed practice. This exercise of the eye I desire to promote, and, next to moral and religious doctrine, I know no more important practical lessons in this earthly life of ours—which, to the wise man, is a school from the cradle to the grave—than those relating to the employment of the sense of vision in the study of nature.

Marsh quoted and translated Frederik Paludam Müller:

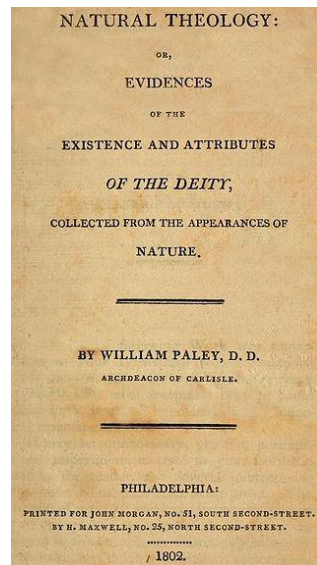
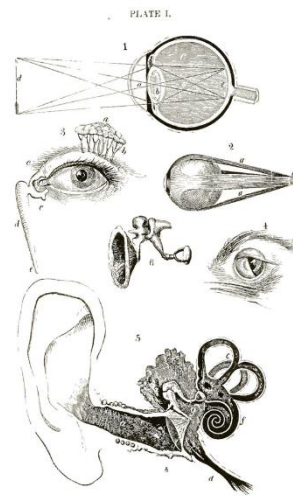
***In the material eye, you think, sight lodgeth!
The eye is but an organ. Seeing streameth
From the soul's inmost depths. The fine perceptive
Nerve springeth from the brain's mysterious workshop.***

On August 5, 1851, Henry David Thoreau wrote in his journal, “*The question is not what you look at, but what you see.*” <https://www.walden.org/wp-content/uploads/2016/02/Journal-2-Chapter-7.pdf>



In the last lecture I talked about **eyes**, both human and animal, and the conditions and compromises that are necessary for seeing in **water and/or air**, seeing during **daytime and/or during the night**, and seeing for **predators and their prey**.

Looking at the eye, **William Paley** concluded that the Creator must be good. Paley (1802) wrote, “*The proof of the divine goodness rests upon two propositions; each, as we contend, capable of being made out by observations drawn from the appearances of nature. The first is, ‘that, in a vast plurality of instances in which contrivance is perceived, the design of the contrivance is beneficial.’ The second, ‘that the Deity has superadded pleasure to animal sensations, beyond what was necessary for any other purpose, or when the purpose, so far as it was necessary, might have been effected by the operation of pain.’*”



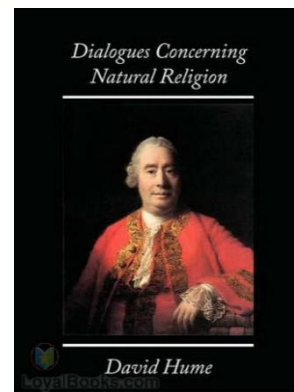
Nature is not simple and there are difficult questions for everyone to ask and answer. Paley saw nature in terms of evidence of the goodness of God. However, others, such as Augustin Pyramus de Candolle (1820) saw nature as war-like:

*“All the plants of a given country, all those of a given place, are **at war one with another**. The first which establish themselves by chance in a particular spot, tend, by the mere occupancy of space, to exclude other species—the **greater choke the smaller**, the longest livers replace those which last for a shorter period, the more prolific gradually make themselves **masters** of the ground, which species multiplying more slowly would otherwise fill.”*



De Candolle's thinking about nature as a battlefield coincided with Hume's (1779) philosophy as expressed in *Dialogues Concerning Natural Religion*, in which he wrote:

*And why should man, added he, pretend to an exemption from the lot of all other animals? The whole earth, believe me, PHILO, is cursed and polluted. **A perpetual war is kindled amongst all living creatures.** Necessity, hunger, want, stimulate the strong and courageous: Fear, anxiety, terror, agitate the weak and infirm. The first entrance into life gives anguish to the new-born infant and to its wretched parent: Weakness, impotence, distress, attend each stage of that life: and 'tis at last finished in agony and horror.*



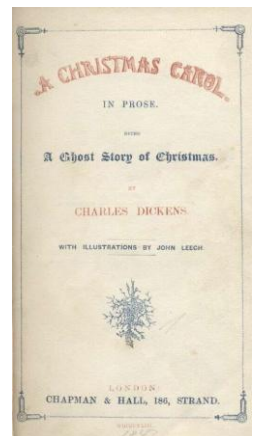
Observe too, says PHILO, the curious artifices of Nature, in order to imbitter the life of every living being. The stronger prey upon the weaker, and keep them in perpetual terror and anxiety. The weaker too, in their turn, often prey upon the stronger, and vex and molest them without relaxation. Consider that innumerable race of insects, which either are bred on the body of each animal, or flying about infix their stings in him. These insects have others still less than themselves, which torment them. And thus on each hand, before and behind, above and below, every

animal is surrounded with **enemies**, which incessantly seek his misery and destruction.

This coincided with **Thomas Malthus'** (1798) thinking that there will not be enough food for a growing population of humans as he expressed in *An Essay on the Principle of Population*. Malthus wrote, *"The power of population is so superior to the power in the earth to produce subsistence for man, that premature death must in some shape or other visit the human race. The vices of mankind are active and able ministers of depopulation. They are the precursors in the great army of destruction; and often finish the dreadful work themselves. But should they fail in this **war of extermination**, sickly seasons, epidemics, pestilence, and plague, advance in terrific array, and sweep off their thousands and ten thousands. Should success be still incomplete, gigantic inevitable famine stalks in the rear, and with **one mighty blow levels the population with the food of the world.**"* That is, the mighty blow decreases the surplus population. Malthus' thinking was known in artistic circles.



Scrooge in **Charles Dickens'** (1843; Rare Books PR4572 .C55 1843b; <https://www.npr.org/2004/12/13/4225458/jonathan-winters-a-christmas-carol>) *A Christmas Carol* put it this way: *"I wish to be left alone," said Scrooge. "Since you ask me what I wish, gentlemen, that is my answer. I don't make merry myself at Christmas and I can't afford to make idle people merry. I help to support the establishments I have mentioned—they cost enough; and those who are badly off must go there."*



"Many can't go there; and many would rather die."

*"If they would rather die," said Scrooge, "they had better do it, and **decrease the surplus population.** Besides—excuse me—I don't know that."*

“But you might know it,” observed the gentleman.

“It’s not my business,” Scrooge returned. “It’s enough for a man to understand his own business, and not to interfere with other people’s. Mine occupies me constantly. Good afternoon, gentlemen!”

Scrooge was reminded of his words in a conversation with The Ghost of Christmas Present: *“Spirit,” said Scrooge, with an interest he had never felt before, “tell me if Tiny Tim will live.”*

“I see a vacant seat,” replied the Ghost, “in the poor chimney-corner, and a crutch without an owner, carefully preserved. If these shadows remain unaltered by the Future, the child will die.”

“No, no,” said Scrooge. “Oh, no, kind Spirit! say he will be spared.”

*“If these shadows remain unaltered by the Future, none other of my race,” returned the Ghost, “will find him here. What then? If he be like to die, he had better do it, and **decrease the surplus population.**”*

Scrooge hung his head to hear his own words quoted by the Spirit, and was overcome with penitence and grief.

“Man,” said the Ghost, “if man you be in heart, not adamant, forbear that wicked cant until you have discovered What the surplus is, and Where it is. Will you decide what men shall live, what men shall die? It may be, that in the sight of Heaven, you are more worthless and less fit to live than millions like this poor man’s child. Oh God! to hear the Insect on the leaf pronouncing on the too much life among his hungry brothers in the dust!”

Scrooge’s partner, Jacob Marley, died the day before Christmas Eve, the same day as Thomas Malthus (December 23, 1834).

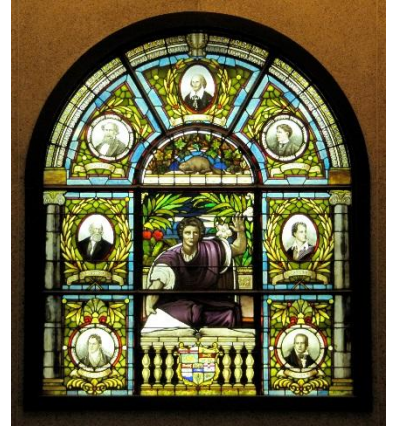


The poet, **Alfred, Lord Tennyson** (1849) wrote in *In Memoriam A.H.H.*, a poem about hope after great loss that took seventeen years to write:

<http://www.online-literature.com/tennyson/718/>

*Are God and Nature then at strife,
That Nature lends such evil dreams?
So careful of the type she seems,
So careless of the single life;*

*Who trusted God was love indeed
And love Creation's final law
Tho' Nature, red in tooth and claw
With ravine, shriek'd against his creed*

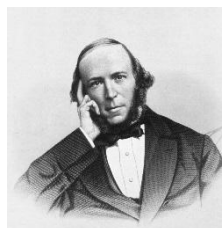


And the theme *red in tooth and claw* was taken up by Sting in *I was Brought to My Senses*

(<https://www.youtube.com/watch?v=QrLF4HymAs4>)



De Candolle 's thinking was considered by scientists such as the geologist **Charles Lyell** (1832), the botanist **William Jackson Hooker** (1834), and the polymath **Herbert Spencer** (1852). Spencer wrote “*On contemplating its general circumstances, we perceive that any race of organisms is subject to two sets of conflicting influences. On the one hand by natural death, by enemies, by lack of food, by atmospheric changes, &c., it is constantly being destroyed. On the other hand, partly by the strength, swiftness, and sagacity of its members, and partly by their fertility, it is constantly being maintained.*” Spencer then uses physical analogy.

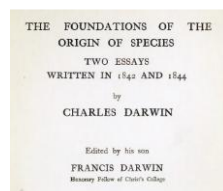
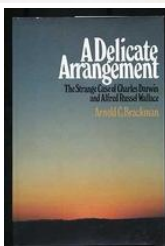


$$F_{\text{preservative}} - F_{\text{destructive}} = \frac{dp}{dt}$$

where $\frac{dp}{dt}$ is the change in population (rather than momentum) over time.

*“These conflicting sets of influences may be conveniently generalized as—the **forces destructive** of race, and the **forces preservative** of race. Whilst any race continues to exist, the forces destructive of it and the forces preservative of it must perpetually tend towards **equilibrium**. If the forces destructive of it decrease, the race must gradually become more numerous, until, either from lack of food or from increase of enemies, the destroying forces again balance the preserving forces. If, reversely, the forces destructive of it increase, then the race must diminish, until, either from its food becoming relatively more abundant, or from its enemies dying of hunger, the destroying forces sink to the level of the preserving forces. Should the destroying forces be of a kind that cannot be thus met (as great change of climate), the race, by becoming extinct, is removed out of the category. Hence this is necessarily the law of maintenance of all races; seeing that when they cease to conform to it they cease to be.”*

Charles Darwin also saw nature in terms of war and warfare. In June 1858, upon receiving a manuscript on evolution by natural selection written by Alfred Russel Wallace, Darwin stitched together unpublished essays he wrote in 1842 and 1844 and wrote a manuscript to **combat** Wallace’s claims to the theory of evolution by natural selection (Brackman, 1980; Wolfe, 2016). In a “delicate arrangement,” the two manuscripts were presented in alphabetical order (D before W) at the Linnean Society meeting on July 1, 1858, giving Darwin priority. Darwin began: *“De Candolle, in an eloquent passage, has declared that **all nature is at war**, one organism with another, or with external nature. **Seeing***



*the contented face of nature, this may at first well be doubted; but **reflection** will inevitably prove it to be true.”*

Charles Darwin went on to say that the war exists, in part, because each species has the ability to produce an exponentially increasing number of offspring: *“Nature may be compared to a surface on which rest ten thousand sharp wedges touching each other and driven inwards by incessant blows. Fully to realize these views much **reflection** is requisite. **Malthus on man** should be studied; and all such cases as the mice in La Plata, or of the cattle and horses when first turned out in South America, of the birds by our calculation, &c., should be well considered. **Reflect on the enormous multiplying power inherent** and annually in action in all animals; **reflect on the countless seeds scattered by a hundred ingenious contrivances, year after year, over the whole face of the land;”***

Darwin built on Malthus’ (1798), de Candolle’s (1820), and Spencer’s (1852) thinking. Darwin realized that even though species have the potential to increase exponentially, the number of individuals in that species tends to stay constant because there is a struggle for the limited amount of food: *“and yet we have every reason to suppose that the **average percentage of each of the inhabitants of a country usually remains constant**. Finally, let it be borne in mind that this average number of individuals (the external conditions remaining the same) in each country is kept up by **recurrent struggles** against other species or against external nature (as on borders of the Arctic regions, where the cold checks life), and that ordinarily **each individual of every species holds its place**, either by its **own struggle** and capacity of acquiring nourishment in some period of its life, from the egg upwards; or by the **struggle of its parents** (in short-lived organisms, when the main check occurs at longer intervals) **with other individuals of the same or different species.**”*

$$F_{\text{preservative}} - F_{\text{destructive}} = \frac{dp}{dt} = 0$$

Darwin goes on to say that if conditions change and a certain variation in an individual gives it an advantage in the struggle for existence under the new conditions, and, if the adaptive trait is inherited, then the offspring that inherit the advantageous variation would have an advantage in the struggle for existence: *“Now, can it be doubted, from the struggle each individual has to obtain subsistence, that any minute variation in structure, habits, or instincts, adapting that individual better to the new conditions, would tell upon its vigour and health? In the struggle it would have a better chance of surviving; and those of its offspring which inherited the variation, be it ever so slight, would also have a better chance.”*



How much of a difference in the advantage of a variation would determine the life or death of an individual? According to Darwin, *“Yearly more are bred than can survive; the smallest grain in the balance, in the long run, must tell on which death shall fall, and which shall survive.”*

The greater the advantage, the shorter the time it should take for the individuals that inherited the advantageous variation to replace the individuals that do not have the advantageous variation. If a variation had such a small selective advantage, how long would it take to produce a new species that had the advantageous variation and for the old species that did not have the advantageous variation to die out? According to Darwin, *“Let the work of selection on the one hand, and death on the other, go on for a thousand generations, who will pretend to affirm that it would produce no effect, when we remember what, in a few years,*



[Robert] Bakewell effected in cattle, and Western in [Ancon] sheep, by this identical principle of selection?”

<https://www.ans.iastate.edu/about/history/people/robert-bakewell>



In 1859, Darwin put his theory more succinctly in *On the Origin of Species*, “If during the long course of ages and under varying conditions of life, **organic beings vary at all in the several parts of their organisation**, and I think this cannot be disputed; if there be, owing to the **high geometrical powers of increase of each species**, at some age, season, or year, **a severe struggle for life**, and this certainly cannot be disputed; then, considering the infinite complexity of the relations of all organic beings to each other and to their conditions of existence, causing an infinite diversity in structure, constitution, and habits, to be advantageous to them, I think it would be a most extraordinary fact if no variation ever had occurred useful to each being's own welfare, in the same way as so many variations have occurred useful to man. **But, if variations useful to any organic being do occur, assuredly individuals thus characterised will have the best chance of being preserved in the struggle for life**; and from the strong principle of inheritance they will tend to produce offspring similarly characterised. This principle of preservation, I have called, for the sake of brevity, Natural Selection.”



Darwin (1859) ended the *Origin of Species*, like so: “**In the distant future I see open fields for far more important researches. Psychology will be securely based on a new foundation, that of the necessary acquirement of each mental power and capacity of gradation. Light will be thrown on the origin of man and his history.**”

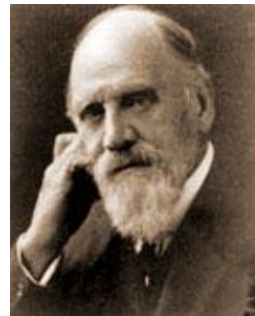
We will discuss Darwinian evolutionary theory in detail when we discuss the coloration of the peppered moth later this semester. For now, we will set the way-back machine to Oxford, England on the thirtieth of June in the year 1860 when there was a meeting of the British Association for the Advancement of Science (BAAS). This was the first meeting of the BAAS since the November 24, 1859 publication of Charles' Darwin's *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*.



Legend has it that at this meeting, the young **Thomas Henry Huxley** debated the seasoned Bishop of Oxford, **Samuel Wilberforce** who had been elected to the **Royal Society of London** on December 18, 1845 and was vice president of the **British Association for Advancement of Science**, although the legend leaves out his scientific credentials. (The photograph of Samuel Wilberforce was taken by his friend, Charles Lutwidge Dodgson, who is better known as Lewis Carroll).



Accounts of the meeting were given in the *Athenaeum* and the *Oxford Chronicle and Berks and Bucks Gazette* of July 21, 1860 <https://paulbraterman.wordpress.com/2017/11/06/tl-dr-wilberforce-huxley-encounter-oxford-chronicle-and-athenaeum-accounts/>, but there was no mention of a debate. The first mention of the debate was given twenty-seven years later by **Francis Darwin** (1887) when he put the following description in volume II (pp. 321-323) of *The Life and Letters of Charles Darwin, including an Autobiographical Chapter*:



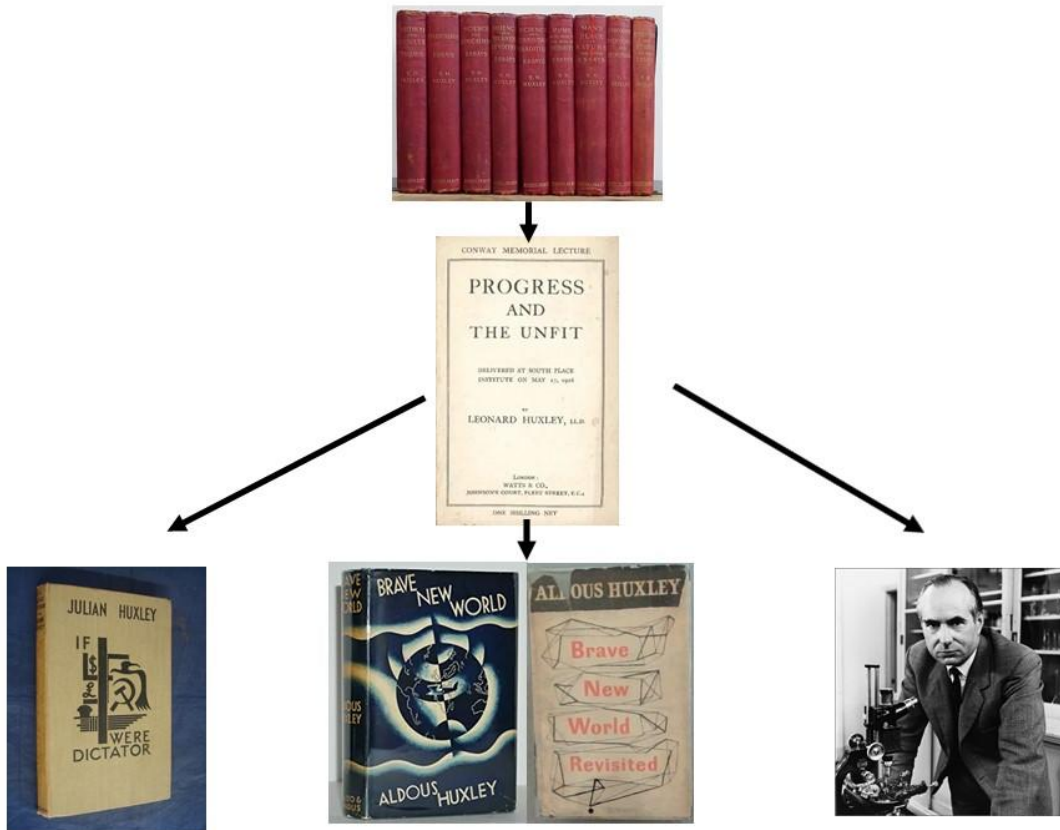
"The excitement was tremendous. The Lecture-room, in which it had been arranged that the discussion should be held, proved far too small for the audience, and the meeting adjourned to the Library of the Museum, which was crammed to

suffocation long before the champions entered the lists. The numbers were estimated at from 700 to 1000. Had it been term-time, or had the general public been admitted, it would have been impossible to have accommodated the rush to hear the oratory of the bold Bishop. Professor Henslow, the President of Section D, occupied the chair, and wisely announced in limine that none who had not valid arguments to bring forward on one side or the other, would be allowed to address the meeting: a caution that proved necessary, for no fewer than four combatants had their utterances burked by him, because of their indulgence in vague declamation.

"The Bishop was up to time, and spoke for full half-an-hour with inimitable spirit, emptiness and unfairness. It was evident from his handling of the subject that he had been 'crammed' up to the throat, and that he knew nothing at first hand; in fact, he used no argument not to be found in his 'Quarterly' article (that was finished on May 20, 1860). He ridiculed Darwin badly, and Huxley savagely, but all in such dulcet tones, so persuasive a manner, and in such well-turned periods, that I who had been inclined to blame the President for allowing a discussion that could serve no scientific purpose, now forgave him from the bottom of my heart. Unfortunately the Bishop, hurried along on the current of his own eloquence, so far forgot himself as to push his attempted advantage to the verge of personality in a telling passage in which he turned round and addressed Huxley: I forget the precise words, and quote from Lyell. 'The Bishop asked whether Huxley was related by this grandfather's or grandmother's side to an ape.'* Huxley replied to the scientific argument of his opponent with force

and eloquence, and to the personal allusion with a self-restraint, that gave dignity to his crushing rejoinder."

The legend of the Oxford Debate was also presented by **Leonard Huxley**, (1900) a writer, the son of T. H. Huxley, and the father of Julian Huxley, Andrew



Fielding Huxley, and Aldous Huxley in *The Life and Letters of Thomas Henry Huxley* Volume 1 (pp. 192-204). Here is an excerpt:

"[The famous Oxford Meeting of 1860 was of no small importance in Huxley's career. It was not merely that he helped to save a great cause from being stifled under misrepresentation and ridicule—that he helped to extort for it a fair hearing; it was now that he first made himself known in popular estimation as a dangerous adversary in debate—a personal force in the world of



science which could not be neglected. From this moment he entered the front fighting line in the most exposed quarter of the field....

Then there were calls for the Bishop, but he rose and said he understood his friend Professor Beale had something to say first. Beale, who was an excellent histologist, spoke to the effect that the new theory ought to meet with fair discussion, but added, with great modesty, that he himself had not sufficient knowledge to discuss the subject adequately. Then the Bishop spoke the speech that you know, and the question about his mother being an ape, or his grandmother.

From the scientific point of view, the speech was of small value. It was evident from his mode of handling the subject that he had been "crammed up to the throat," and knew nothing at first hand; he used no argument beyond those to be found in his "Quarterly" article, which appeared a few days later, and is now admitted to have been inspired by Owen. "He ridiculed Darwin badly and Huxley savagely; but," confesses one of his strongest opponents, "all in such dulcet tones, so persuasive a manner, and in such well turned periods, that I who had been inclined to blame the President for allowing a discussion that could serve no scientific purpose, now forgave him from the bottom of my heart."

The Bishop spoke thus "for full half an hour with inimitable spirit, emptiness and unfairness." "In a light, scoffing tone, florid and fluent, he assured us there was nothing in the idea of evolution; rock-pigeons were what rock-pigeons had always been. Then, turning to his antagonist with a smiling insolence, he begged to know, was it through his grandfather or his grandmother that he claimed his descent from a monkey?" ("Reminiscences of a Grandmother," [sic] "Macmillan's Magazine," October 1898. Professor Farrar thinks this version of what the Bishop said is slightly inaccurate. His impression is that the words actually used seemed

at the moment flippant and unscientific rather than insolent, vulgar, or personal. The Bishop, he writes, "had been talking of the perpetuity of species of Birds; and then, denying a fortiori the derivation of the species Man from Ape, he rhetorically invoked the aid of FEELING, and said, 'If any one were to be willing to trace his descent through an ape as his **GRANDFATHER**, would he be willing to trace his descent similarly on the side of his **GRANDMOTHER**?' His false humour was an attempt to arouse the antipathy about degrading **WOMAN** to the **quadrumana**. Your father's reply showed there was vulgarity as well as folly in the Bishop's words; and the impression distinctly was, that the Bishop's party, as they left the room, felt abashed, and recognised the Bishop had forgotten to behave like a perfect gentleman.")

This was the fatal mistake of his speech. Huxley instantly grasped the tactical advantage which the descent to personalities gave him. He turned to Sir Benjamin Brodie, who was sitting beside him, and emphatically striking his hand upon his knee, exclaimed,] "The Lord hath delivered him into mine hands." [The bearing of the exclamation did not dawn upon Sir Benjamin until after Huxley had completed his "forcible and eloquent" answer to the scientific part of the Bishop's argument, and proceeded to make his famous retort. (The "**Athenaeum**" reports him as saying that Darwin's theory was an explanation of phenomena in Natural History, as the undulatory theory was of the phenomena of light. No one objected to that theory because an undulation of light had never been arrested and measured. Darwin's theory was an explanation of facts, and his book was full of new facts, all bearing on his theory. Without asserting that every part of that theory had been confirmed, he maintained that it was the best explanation of the origin of species which had yet been offered. With regard to the psychological distinction between men and animals, man himself was once a

monad—a mere atom, and nobody could say at what moment in the history of his development he became consciously intelligent. The question was not so much one of a transmutation or transition of species, as of the production of forms which became permanent.

Thus the short-legged sheep of America was not produced gradually, but originated in the birth of an original parent of the whole stock, which had been kept up by a rigid system of artificial selection.)

Reminiscences of a Grandmother was actually entitled, A Grandmother's Tales, which states: "I was happy enough to be present on the incredible occasion at Oxford when Mr. Huxley bearded Bishop Wilberforce. There were so many of us that were eager to hear that we had to adjourn to the great library of the Museum. I can still hear the American accents of Dr. Draper's opening address, when he asked, "Are we a fortuitous concourse of atoms?" and his discourse I seem to remember as somewhat dry. Then the Bishop rose, and in a light scoffing tone, florid and fluent, he assured us there was nothing in the idea of evolution; rock-pigeons were what rock-pigeons had always been. Then, turning to his antagonist with a smiling insolence, he begged to know, was it through his grandfather or his grandmother that he claimed his descent from a monkey? On this Mr. Huxley slowly and deliberately arose. A slight tall figure stern and pale, very quiet and very grave, he stood before us, and spoke those tremendous words,—words which no one seems sure of now, nor I think, could remember just after they were spoken, for their meaning took away our breath, though it left us in no doubt as to what it was. He was not ashamed to have a monkey for his ancestor; but he would be ashamed to be connected with a man who used great gifts to obscure the truth. No one doubted his meaning and the effect was tremendous. One lady fainted and had to be carried out: I, for one, jumped out of my seat; and when in the evening we

met at Dr. Dubeney's, every one was eager to congratulate the hero of the day. I remember that some naïve person wished 'it could come over again:' and Mr. Huxley, with the look on his face of the victor who feels the cost of victory, put us aside saying, 'Once in a life-time is enough, if not too much.'"

Leonard Huxley ended his account by saying ***The importance of the Oxford meeting lay in the open resistance that was made to authority, at a moment when even a drawn battle was hardly less effectual than acknowledged victory. Instead of being crushed under ridicule, the new theories secured a hearing, all the wider, indeed, for the startling nature of their defence.]***"

Leonard Huxley's account of the so-called Oxford debate between Wilberforce and Huxley became standard reading for many as a result of its inclusion in *The Norton Anthology of English Literature*, edited by M. H. Abrams (Cornell), as an example of Victorian literature. A similar account presented by William Irvine (1955, 1963) in his book, *Apes, Angels, & Victorians* was endorsed by Julian Huxley, and the tradition continues in Ruth Moore's (1955) *Charles Darwin: A Great Life in Brief* and Ian Hesketh's (2009), *Of Apes and Ancestors: Evolution, Christianity, and the Oxford Debate*.

Reginald G. Wilberforce (1881), Samuel's son, wrote in the *Life of the Right Reverend Samuel Wilberforce, D. D.*, "the Bishop...made an eloquent speech condemning Mr. Darwin's theory as unphilosophical and as founded on fancy, and he denied that any one instance had been produced by Mr. Darwin which showed that the alleged change from one species to another had ever taken place. In the course of this speech, which made a great impression, **the Bishop said, that whatever certain people might believe, he would not look at the monkeys in the Zoological as connected with his ancestors, a remark that drew from a certain**

learned professor the retort, ‘I would rather we descended from an ape than a bishop.’”

Huxley’s account became the standard story about Samuel Wilberforce. As Randy Moore and Mark Decker (2009) wrote, in *More than Darwin: The People and Places of the Evolution-Creationism Controversy*, “The ‘Huxley—Wilberforce debate’ has become legendary, aided by the lack of a transcript of the proceedings... Whether these statements were actually said, and who ‘won’ the debate is unclear.... Although the ‘debate’ accomplished little for either science or religion, the event was significant because it was a public refusal by the scientific community to allow the Church to dictate matters of science.”



FIGURE 1.20. Vanity Fair magazine caricatures of Bishop Wilberforce (left), Thomas Henry Huxley (middle), and Charles Darwin (right). Wilberforce attacked Darwin’s ideas at an 1860 British Association meeting, and Huxley—“Darwin’s bulldog”—defended Darwin at this debate.

1.20, reprinted from Drawings by Ape from Vanity Fair (left) July 24, 1869, (center) January 28, 1871, (right) Sept. 30, 1871

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Unfortunately, it is the only story that most scientists know; which reminds me of a few lines from *Waiting for Godot* by Samuel Beckett:

ESTRAGON:

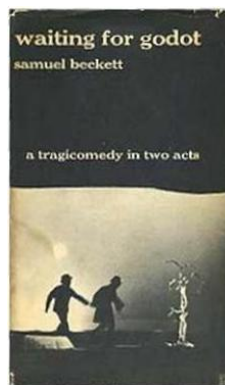
Who believes him?

VLADIMIR:

Everybody. It's the only version they know.

ESTRAGON:

People are bloody ignorant apes.



Speaking of ignorance, according to the *Oxford Chronicle* of July 21, 1860, Professor HUXLEY, being

called upon by the chairman, declined entering into the subject, alleging the undesirability of contesting a scientific subject involving nice shades of idea before a general audience, who could not be supposed to judge upon its merits.

*The BISHOP of OXFORD again rose and was received with cheers and laughter...He ridiculed Professor Huxley's **appeal to authority** in connection with his remarks on amateurs in science. On which side lay the **authority**. Sir B. Brodie, Professor Owen, and other eminent men were opposed to it, and how the Professor could talk as he had done about **authority** he did not know. (Laughter and cheers.) The Bishop then noticed the Professor's concluding remarks, denying the cogency of the illustrations, and after experiencing some interruptions in his scientific dicta, sat down amid loud cheers.*

Professor HUXLEY rose in answer to calls for him, and said he was sure the Bishop could have no desire to mislead, but

Professor HUXLEY, being called upon by the chairman, declined entering into the subject, alleging the undesirability of contesting a scientific subject involving nice shades of idea before a general audience, who could not be supposed to

The BISHOP of OXFORD, on rising, was warmly received. Having briefly noticed Professor Draper's arguments, and ridiculed his comparison of the marble and table, he proceeded to say he had given the theory advanced by Mr Darwin his most careful and anxious consideration. The conclusion he had come to was, that when tried by the principles of inductive science, philosophy, or logic, it entirely broke down. (Cheers.) And to come to facts, he maintained that those brought forward utterly failed to prove his theory. The permanence of specific forms was a fact confirmed by all observation, the few exceptions that existed being confined to a few cases in certain species of plants. Take, for instance, the remains of animals, plants, and men, found in those earliest records of the human race—the Egyptian catacombs. Now, anatomists tell us that even in mummies, 4,000 years old, there is not the slightest physiological difference as compared with the race now—(hear, hear)—and so it was with animals and plants. All spoke of their identity with existing forms, and of the irresistible tendency of organized beings to assume an unalterable character. (Applause.) Glancing at Professor Huxley's remarks, on the previous day, in a discussion with Professor Owen, the Bishop facetiously asked if he had any particular predilection for a monkey ancestry, and, if so, on which side—whether he would prefer an ape for his grandfather, and a woman for his grandmother. (Much laughter.) But to treat the subject seriously. (Hear, hear.) The line between man and the lower animals was distinct. There was no tendency on the part of the lower animals to become the self-conscious intelligent being, man; or, in man, to degenerate and lose the high characteristics of mind and intelligence. All experiments failed to show any tendency in one animal to assume the form of the other. Even in the great case of the pigeons, quoted by Mr. Darwin, he admitted that no sooner were these animals set free, than they returned to their primitive type. (Hear, hear.) Everywhere sterility attended hybridism, as was seen in the closely allied forms of the horse and the ass. Viewing the matter in another aspect, he did consider it a most degrading assumption—(hear, hear)—that man, who, in many respects, partook of the highest attributes of God—(hear, hear)—was a mere development of the lowest forms of creation. (Applause.) He could scarcely trust himself to speak upon the subject, so indignant did he feel at the idea. He did not desire animosity in scientific investigation. (Hear, hear.) Religion had nothing to fear. (Hear, hear.) But what he did protest against was the hasty adoption of unsound hypotheses and unproved assertions for the weighty realities of scientific truth. (Applause.) He did not believe that science and revelation were inimical to each other, but that what appeared irreconcilable in the present state of scientific knowledge would in the fulness of time be made manifest, and redound to the triumph of both. (Prolonged cheering.)

Professor HUXLEY followed. In reply to the Bishop's query he said that if the alternative were given him of being descended from a man conspicuous for his talents and eloquence, but who misused his gifts to ridicule the laborious investigators of science and obscure the light of scientific truth, or from the humble origin alluded to, he would far rather choose the latter than the former. (Oh, oh, and laughter and cheering.) He then defended Mr. Darwin's theory from the charge of being a mere hypothesis, and said it was an explanation of phenomena in natural history holding the same relation as the undulating theory to the phenomena of light. Did any one object to that theory because an undulation of light had

he thought he had misapprehended his remarks upon **authority**. What he had deprecated was **authority** like the Bishop's, authority derived from a reputation acquired in another sphere. (Hear, hear, and laughter.)

Indeed, according to **Tom Wolfe** (2016), "*Subscribing to Darwinism showed that one was part of a bright, enlightened minority who shone far above the mooing herd below.*"



The debate that never happened continues in Crispin Whittell's 2003 play, *Darwin in Malibu*.



never been arrested and measured? His charge against Mr. Darwin's opponents was that they did not attempt to bring forward any important fact against his theory. That theory was an explanation of facts the result of laborious research, and abounded in new facts bearing upon it. Without asserting that every part of the theory had been confirmed, he maintained that it was the best explanation of the origin of species which had yet been offered—(hear, hear)—and he did protest against this subject being dealt with by amateurs in science, and made the occasion of appeals to passion and feeling. (Applause.) With regard to the psychological distinction between man and animals, it must be remembered man himself was once a nomad—a mere atom of matter—and who could say at what moment of his development he became consciously intelligent. (Hear, hear.) The question was not so much one of a transmutation or transition of species as of the production of forms which became permanent. In the course of an argument to support this position, he instanced the short-legged sheep of America, which were not produced gradually, but originated in the birth of an original parent of the whole stock, which had been kept up by a rigid system of artificial selection. (The Professor, on resuming his seat, was loudly applauded.)

The BISHOP OF OXFORD again rose and was received with cheers and laughter. He said he regretted that Professor Huxley had taken umbrage at what he had said. He did not know that he had said anything which could possibly give offence to Mr. Darwin's greatest friends, and as for his query to Professor Huxley he had been tempted to it by the merriment of the audience, and it was merely a passing allusion. He ridiculed Professor Huxley's appeal to authority in connection with his remarks on amateurs in science. On which side lay the authority. Sir B. Brodie, Professor Owen, and other eminent men were opposed to it, and how the Professor could talk as he had done about authority he did not know. (Laughter and cheers.) The Bishop then noticed the Professor's concluding remarks, denying the cogency of the illustrations, and after experiencing some interruptions in his scientific dicta sat down amid loud cheers.

Professor HUXLEY rose in answer to call for him, and said he was sure the Bishop could have no desire to mislead, but he thought he had misapprehended his remarks upon authority. What he had deprecated was authority like the Bishop's, authority derived from a reputation acquired in another sphere. (Hear, hear, and laughter).

Aside: As a graduate student in the 1980s, studying how plant cells respond to light, I could see how the truly great natural laws, derived from physics, chemistry, and biology applied at every level to the world around us and I saw a logic and beauty in this design and it inspired in me a sense of wonder and gratitude and love for its creator.

Because of my love of science and how useful it was for understanding the world I lived in, I wrote a book entitled, *Plant Cell Biology: From Astronomy to Zoology* for Princeton University Press. As the title suggests, I include all disciplines to emphasize the unity of nature and the intricacy of the design at all levels, as I describe and explain cells and how they make life possible. The book had several working titles, including *Molecular Theology of the Cell*.

In the 400 pages of text and 140 pages of references, I put in a section entitled, The Mechanistic Viewpoint and God. I wrote, *“In general, there seems to be a war between science and religion, but this does not need to occur. In studying mechanisms, one must deconstruct the whole into its parts and determine the relationships between the parts as well as the relationships between the parts and the whole. Each community has words to describe ‘the whole’. Throughout civilization, Homo sapiens have strived to live up to our specific epithet by struggling to understand the relationship between the parts and the whole in terms of understanding, among other things, our place in the universe, our relation to other people, our relationship to other species, and our relationship to the environment. Science and religion have been our guides throughout this struggle to understand. Science and religion may be two sides of the same coin of understanding, each with a measure of truth, and each complementing the other....It is often thought that a mechanistic viewpoint excludes God. ...In this book, I will not base any mechanisms on the existence of God, and at the same time, I will not conclude that the discovery of a mechanism precludes the existence of a God.”*

While it was not OK to include God in a science book, it seemed like it was OK to dismiss God in a science book. In *DNA: The Secret of Life*, James Watson (2009) wrote: *Does life have some magical, mystical essence, or is it, like any chemical reaction carried out in a science class, the product of normal physical and chemical processes? Is there something divine at the heart of a cell that brings it to life? The double helix answered that question with a definitive No.*” I did not think the question of whether there was something divine at the heart of a cell was definitively solved.

My editor, Emily Wilkinson retired and Sam Elworthy, who became editor at Princeton University Press, told me that **God had no place in a science textbook**. I explained to him why it was important for *scientific completeness* in explaining the relationships between the parts and the whole. He wanted it out, and I said no and we canceled the contract for that book and another one that I wrote on Light Microscopy that begins with, *And God said, Let there be light: and there was light*.

I had worked hard for almost 20 years on those books, and it wasn't for the money since the royalties had already been promised to the Profiles-in-Courage Award given by the JFK Library and to Habitat for Humanity. But I knew it was the right decision. A year or two later I got a call from Elsevier asking me whether they should publish a certain book. I raved about the book, saying that it was among the top three books written since the field of plant physiology was initiated 150 years ago, and definitely would be worth publishing...but it would not be a money maker because the perspective of the book was not fashionable enough and too few teachers would put in the work necessary to teach the material—even though the book was original, scholarly, and important. Good they said, since that is the kind of book they wanted to publish! They liked my way of looking at science. And they asked, “by the way do you have any books you’d like us to publish!” I said yes, and they published them.

I was surprised at the difference in perspectives between the nonprofit academic publisher, who should be my peeps, and the capitalist publisher. I started to wonder if we in academia are giving you the whole story.

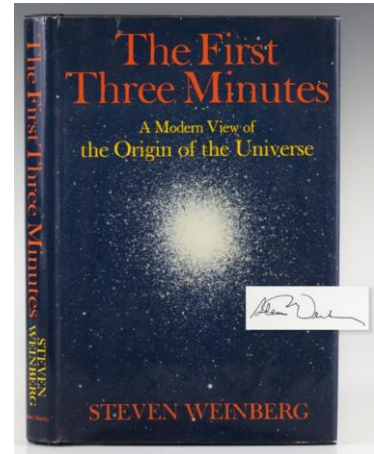
My story is not unique:

<https://www.thegoodbook.com/blog/interestingthoughts/2019/01/09/the-time-john-lennox-was-pressured-to-give-up-his-/>

Steven Weinberg (1993) wrote in *The First Three Minutes*, “*The more the universe seems comprehensible, the more it also seems pointless...The effort to understand the universe is one of the very few things that lifts human life a little above the level of farce, and gives it some of the grace of tragedy.*”

The New York Times reported that at a conference entitled, “*Beyond Belief: Science, Religion, Reason and Survival*,” Steven Weinberg said, “*Anything that we scientists can do to weaken the hold of religion should be done and may in the end be our greatest contribution to civilization.*”

<https://www.nytimes.com/2006/11/21/science/21belief.html>



Now let's discuss Samuel Wilberforce's **Review of Origin of Species**.

Samuel Wilberforce began his review by saying, “*Any contribution to our Natural History literature from the pen of Mr. C. Darwin is certain to command attention. **His scientific attainments, his insight and carefulness as an observer, blended with no scanty measure of imaginative sagacity, and his clear and lively style, make all his writings unusually attractive.***”

*The essay is full of Mr. Darwin's characteristic excellences. It is a most readable book; full of facts in natural history, old and new, of his collecting and of his observing; and all of these are told in his own perspicuous language, and all thrown into **picturesque** combinations, and all sparkle with the **colours** of fancy and the **lights** of imagination. It assumes, too, the grave proportions of a sustained argument upon **a matter of the deepest interest, not to naturalists only, or even to***

men of science exclusively, but to every one who is interested in the history of man and of the relations of nature around him to the history and plan of creation. (pp. 52-53).

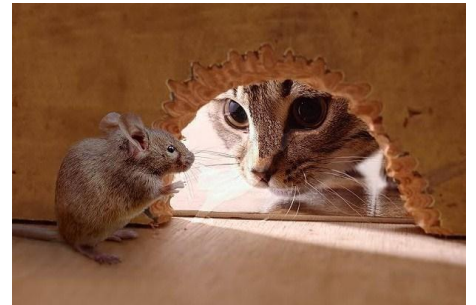
With Mr. Darwin's 'argument' we may say in the outset that we shall have much and grave fault to find. But this does not make us the less disposed to admire the singular excellences of his work; and we will seek in limine to give our readers a few examples of these. Here, for instance, is a beautiful illustration of the wonderful interdependence of nature—of the golden chain of unsuspected relations which bind together all the mighty web which stretches from end to end of this full and most diversified earth. Who, as he listened to the musical hum of the great humble-bees¹, or marked their ponderous flight from flower to flower, and watched the unpacking of their trunks for their work of suction, would have supposed that the multiplication or diminution of their race, or the fruitfulness and sterility of the red clover, depend as directly on the vigilance of our cats as do those of our well-guarded game-preserves on the watching of our keepers? Yet this Mr. Darwin has discovered to be literally the case:—

From experiments which I have lately tried, I have found that the visits of bees are necessary for the fertilisation of some kinds of clover; but humble-bees alone visit the red clover (*Trifolium pratense*), as other "bees cannot reach the nectar. Hence I have very little doubt, that if the whole genus of humble-bees became extinct or very rare in



¹ Humble bees, who were named after their hum, became known as bumble bees in Beatrix Potter's (1910) book *The Tale of Mrs. Tittlemouse*, in which she wrote, "Suddenly round a corner, she met Babbitty Bumble--"Zizz, Bizz, Bizz!" said the bumblebee." Listen to a bumblebee inside a flower. The sound of their buzzing changes. When they are performing buzz pollination, the bees unhinge their wings from their wing muscles and vibrate their bodies, making that buzzing sound of middle C. The sound of the vibration causes the flower to explosively release pollen.

England, the heartsease and red clover would become very rare or wholly disappear. The number of humble-bees in any district depends in a great degree on the number of field-mice, which destroy their combs and nests; and Mr. H. Newman, who has long attended to the habits of humble-bees, believes that "more than two-thirds of them are thus destroyed all over England." Now the number of mice is largely dependent, as every one knows, on the number of cats; and Mr. Newman says, "near villages and small towns I have found the nests of humble-bees more numerous than elsewhere, which I attribute to the number of cats that destroy the mice." Hence, it is quite credible that the presence of a feline animal in large numbers in a district might determine, through the intervention, first of mice, and then of bees, the frequency of certain flowers in that district. (pp. 73-74).



Again, how beautiful are the experiments recorded by him concerning that wonderful relation of the ants to the aphides, which would almost warrant us in giving to the aphids the name of Vacca formicaria:—

One of the strongest instances of an animal apparently performing an action for the sole good of another with which I am acquainted is that of aphides voluntarily yielding their sweet excretion to ants. That they do so voluntarily the



following facts will show. I removed all the ants from a group of about a dozen aphides on a dock plant, and prevented their attendance during several hours. After this interval, I



felt sure that the aphides would want to excrete. I watched them for some time through a lens, but not one of them excreted. I then tickled and stroked them with a hair in the same manner, as well as I could, as the ants do with their antennae, but not one excreted. Afterwards I allowed an ant to visit them, and it immediately seemed, by its eager way of running about, to be well aware what a rich flock it had discovered. It then began to play with, its antennae on the abdomen first of one aphis and then of another, and each aphis, as soon as it felt the antennae, immediately lifted up its abdomen and excreted a limpid drop of sweet juice, which was eagerly devoured by the ant. Even the quite young aphides behaved in this manner, showing that the action was instinctive, and not the result of experience. (pp. 210-211).

*Or take the following admirable specimen of the union of which we have spoken, of the employment of the observations of others with what he has observed himself, in that which is almost the most marvelous of facts—the **slave-making instinct** of certain ants. We say nothing at present of the place assigned to these facts in Mr. Darwin's argument, but are merely referring to the collection, observation, and statement of the facts themselves:*

Slave-making Instinct.—This remarkable instinct was first discovered in the *Formica (Polyerges) rufescens* by Pierre Huber, a better observer even than his celebrated father. This ant is absolutely dependent on its **slaves**; without their aid the species would certainly become extinct in a single year. The males and fertile females do no work.

The workers or sterile females, though most energetic and courageous in capturing slaves, do no other work. They are incapable of making their own nests or of



feeding their own larvae. When the old nest is found inconvenient, and they have to migrate, it is the slaves which determine the migration, and actually carry their masters in their jaws. So utterly helpless are the masters, that when Huber shut up thirty of them without a **slave**, but with plenty of the food, which they like best, and with their larvae and pupæ to stimulate them to work, they did nothing; they could not even feed themselves, and many perished of hunger. Huber then introduced a single slave (*F. fusca*), and she instantly set to work, fed and saved the survivors, made some cells and tended the larvae, and put all to rights. What can be more extraordinary than these well-ascertained facts? If we had not known of any other slave-making ant, it would have been, hopeless to have speculated **how so wonderful an instinct could have been perfected**. Another species (*Formica sanguinea*) was likewise first discovered by P. Huber to be a **slave-making ant**. This species is found in the southern parts of England, and its habits have been attended to by Mr. F. Smith, of the British Museum, to whom I am much indebted for information on this and other subjects,— Although fully trusting to the statements of Huber and Mr. Smith, **I tried to approach the subject in a sceptical frame of mind, as any one may well be excused for doubting the truth of so extraordinary and odious an instinct as that of making slaves**. Hence I give the observations which I have myself made in some little detail. I opened fourteen nests of *F. sanguinea*, and found a few slaves in each. Males and fertile females of the slave-species (*F. fusca*) are found only in their own proper communities, and have never been observed in the nests of *F. sanguinea*. **The slaves are black**, and not above half the size of their **red masters**, so that **the contrast in their appearance is very great**. When the nest is slightly disturbed, the slaves



occasionally come out, and, like their masters, are much agitated, and defend the nest. When the nest is much disturbed, and the larvae and pupae are exposed, the slaves work energetically with their masters in carrying them away to a place of safety. Hence it is clear that the slaves feel quite at home. During the months of June and July, in three successive years, I have watched for many hours several nests in Surrey and Sussex, and never saw a slave either leave or enter a nest. As, during these months, the slaves are very few in number, I thought that they might behave differently when more numerous, but Mr. Smith informs me that he has watched nests at various hours during May, June, and August both in Surrey and Hampshire, and has never seen the slaves, though present in large numbers in August, either leave or enter the nest. Hence he considers them as **strictly household slaves**. The masters, on the other hand, may be constantly seen bringing in materials for the nest and food of all kinds. During the present year, however, in the month of July, I came across a community with an unusually large stock of slaves, and I observed a few slaves mingled with their masters leaving the nest, and marching along the same road to a large Scotch fir-tree, twenty-five yards distant, which they ascended together, probably in search of aphides or cocci. According to Huber, who had ample opportunities for observation, in Switzerland the slaves habitually work with their masters in making the nest, and they alone open and close the doors in the morning and evening; and, as Huber expressly states, their principal office is to search for aphides. This difference in the usual habits of the masters and slaves in the two countries probably depends merely on the slaves being captured in greater numbers in Switzerland than in England.



One day I fortunately witnessed a migration of *F. sanguinea* from one nest to another, and it was a most interesting spectacle to behold the masters carefully carrying (instead of being carried by, as in the case of *F. rufescens*) their slaves in their jaws.



Another day my attention was struck by about a score of the slave-makers haunting the same spot, and evidently not in search of food: they approached, and were vigorously repulsed by an independent community of the slave species (*F. fusca*), sometimes as many as three of these ants clinging to the legs of the slave-making *F. sanguinea*. The latter ruthlessly killed their small opponents, and carried their dead bodies as food to their nest, twenty-nine yards distant, but they were prevented from getting any pupæ to rear as slaves. I then dug up a small parcel of pupæ of *F. fusca* from another nest, and put them down on a bare spot near the place of combat; they were eagerly seized and carried off by the tyrants, who perhaps fancied that, after all, they had been victorious in their late combat....

Now I was curious to ascertain whether *F. sanguinea* could distinguish the pupæ of *F. fusca*, which they habitually make into slaves, from those of the little and furious *F. flava*, which they rarely capture, and it was evident that they did at once distinguish them, for we have seen that they eagerly and instantly seized the pupæ of *F. fusca*, whereas they were much terrified when they came across the pupæ or even the earth from the nest of *F. flava*, and quickly ran away; but in about a quarter of an hour, shortly after all the little yellow ants had crawled away, they took heart and carried off the pupæ.



One evening I visited another community of *F. sanguinea*, and found a number of these ants entering their nest, carrying the dead bodies of *F. fusca* (showing that it was not a migration) and numerous pupæ. I traced the returning file burthened with booty, for about forty yards, to a very thick clump of heath, whence I saw the last individual of *F. sanguinea* emerge, carrying a pupa; but I was not able to find the desolated nest in the thick heath. The nest, however, must have been close at hand, for two or three individuals of *F. fusca* were rushing about in the greatest agitation, and one was perched motionless with its own pupa in its mouth on the top of a spray of heath over its ravaged home. (pp. 219-223).

We can perhaps best convey to our readers a clear view of Mr. Darwin's chain of reasoning, and of our objections to it, if we set before them, first, the conclusion to which he seeks to bring them; next, the leading propositions which he must establish in order to make good his final inference; and then the mode by which he endeavours to support his proposition. Here is "the theory which really pervades the whole volume." (p. 57).

Analogy would lead me one step further, namely, to the belief that all animals and plants have descended from some one prototype. But analogy may be a deceitful guide. Nevertheless all living things have much in common, in their chemical composition, their germinal vesicles, their cellular structure, and their laws of growth and reproduction....Therefore I should infer from analogy that probably all the organic beings which have ever lived on this earth have descended from some one primordial form, into which life was first breathed [by the Creator]. (p. 484).

But we are too loyal pupils of inductive philosophy to start back from any conclusion by reason of its strangeness. Newton's patient philosophy taught him

*to find in the falling apple the law which governs the silent movements of the stars in their courses; and if Mr. Darwin can with the same correctness of reasoning demonstrate to us our fungular descent, we shall dismiss our pride, and avow, with the characteristic humility of philosophy, our unsuspected cousinship with the mushrooms.... Now, the main propositions by which Mr. Darwin's conclusion is attained are these:- 1. That observed and admitted variations spring up in the course of descents from a common progenitor. 2. That many of these variations tend to an improvement of the parent stock. 3. That, by a continued selection of these improved specimens as the progenitors of future stock, **its improvement may be unlimitedly increased**. 4. And, lastly, that there is in nature a power continually and universally working out this selection, and so fixing and augmenting these improvements. (pp. 57-58).*

What do you think is the strength of each of these propositions? Wilberforce concedes that *"The facts are all gathered from a true observation of nature, and from a patiently obtained comprehension of their undoubted and unquestionable relative significance. That such a struggle for life then actually exists, and that it tends continually to lead the strong to exterminate the weak, we readily admit...But before we can go a step further, and argue from its operation in favour of a perpetual improvement in natural types, we must be shown first that this law of competition has in nature to deal with such favourable variations in the individuals of any species, as truly to exalt those individuals above the highest type of perfection to which their least imperfect predecessors attained...and then, next, we must be shown that there is actively at work in nature, co-ordinate with the law of competition and with the existence of such favourable variations, a power of accumulating such favourable variation through successive descents. (pp. 61-62).*

Wilberforce admits that variation exists in a species and so does selection for superior traits. He wonders however, is there proof that nature has the power to fix this variation into a new and improved species? That is, why don't we see old species turn into new and improved species?

Wilberforce points out that in the past 4000 years of history, domestic pigeons, which are a race eminently subject to **variation** and have been **selected** to produce any given feather, beak, or head, all have identical major structures (e.g., **skeletal**) and all **interbreed**. Moreover, there is reversion of hybrids to the parental type. Consequently, there is more of a tendency for **variations to vanish** and for the hybrids to return or relapse to the parental type than for variations to **become fixed** and form new species. Consequently, Wilberforce considers all domestic pigeons one species. Are they **one diverse species with well-marked varieties** as Wilberforce suggests or are they **each incipient species** as Darwin asserts?





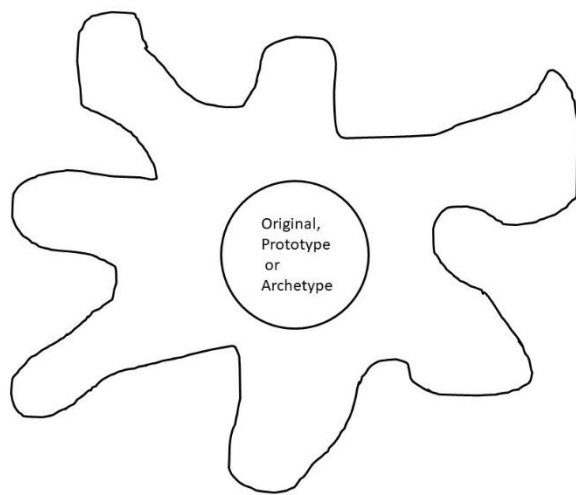
Wilberforce points out that the same is true of the hog, horse, ass, sheep, goat, cow, dog, cat, and chicken: when breeding is relaxed, they tend back to the **original type** without a **SPECIFIC change**. In fact, ever since the wandering Ulysses returned to Ithaca with his dog, **there has not been a SPECIFIC change in dogs** (e.g., no major difference in the skeletal structure or in the ability to breed). Consequently, according to Wilberforce, dogs are **one diverse species with well-marked varieties**. That is, there is an archetypical or Platonic dog with many varied representations.



Cats were embalmed in Egypt 4000 years ago and, while there is a lot of variation, there appears to be no **SPECIFIC change** in cats in the past 4000 years and all cats are of **one diverse species with well-marked varieties**. That is, there is an archetypical or platonic cat with many varied representations.



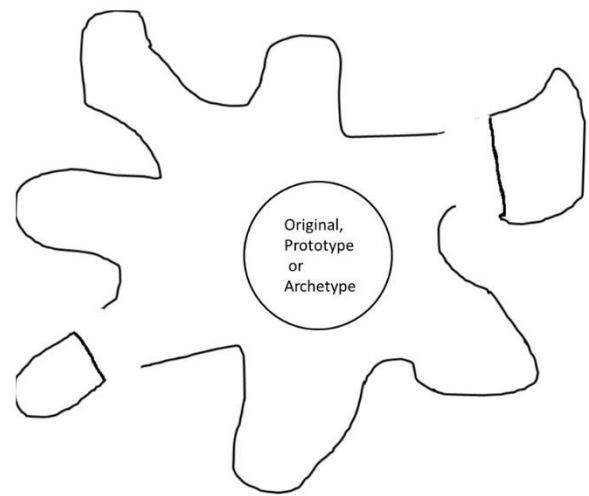
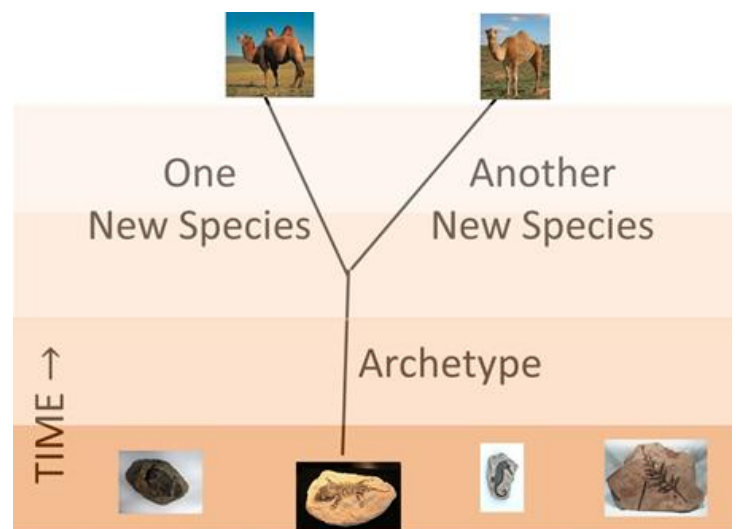
Darwin argues that **nature is a more powerful and continuous selector, working over vast expanses of time**, and can do more than man in selecting varieties...that is ...can cause *specific* or *species-inducing* changes...(p. 67).



One Newly Evolved Species



Another Newly Evolved Species

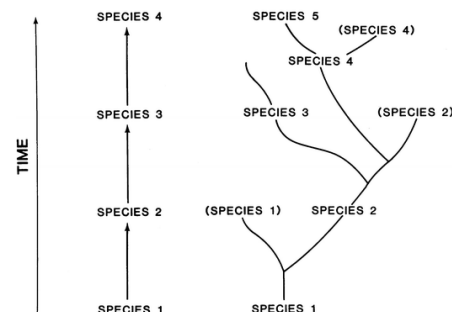


Wilberforce argues that man can only **select one part at the expense of another**...this is a LAW! The **bulldog gains in strength but loses in swiftness**... **the greyhound gains in swiftness but loses in strength**... Man's variations do not IMPROVE the character of an animal because something is lost and something is gained. **Nature tends to kill the monster and stabilize the type**. There is no evidence for accumulating and fixing **specific** variations. (p. 68).

Wilberforce asks, if new species were occurring **shouldn't we see at least one**? He also wonders why the closest microscopic observation has never detected the faintest tendency in the highest of the Algae to improve into the very lowest Zoophyte. (pp. 69-70).

Wilberforce concludes that there is **no** evidence for **speciation going on**. What about evidence from the fossil record?

Why then is not every geological formation and every stratum full of such intermediate links? Geology assuredly does not reveal any such finely graduated organic chain; and this, perhaps, is the most obvious and gravest objection which can be urged against my theory. The explanation lies, as I believe, in the extreme imperfection of the geological record. (p. 280).



Now Wilberforce asks, “*On what then is the new theory based? We say it with unfeigned regret, in dealing with such a man as Mr. Darwin, on the merest hypothesis, supported by the most unbounded assumptions. These are strong words, but we will give a few instances to prove their truth:--*” (p. 81).

All physiologists admit that the swim-bladder [in boney fish] is homologous or "ideally similar " in position and structure with the lungs of the higher vertebrate

animals; hence there **seems to me to be no great difficulty in believing** that natural selection has actually converted a swim-bladder into a lung, or organ used exclusively for respiration. (p. 191).

I can indeed hardly doubt that all vertebrate animals having true lungs have descended by ordinary generation from the ancient prototype, of which we know nothing, furnished with a floating apparatus or swim-bladder. (p. 191).

I see no difficulty in supposing that such links formerly existed, and that each had been formed by the same steps as in the case of the less perfectly gliding squirrels, and that each grade of structure was useful to its possessor. Nor **can I see any insuperable difficulty in further believing** it possible that the membrane-connected fingers and forearm of the galeopithecus [flying lemur] might be greatly lengthened by natural selection, and this, as far as the organs of flight are concerned, would convert it into a bat. (p. 181).

Wilberforce protests against the frequent occurrence of statements such as “*I can conceive*”... “*It is not incredible*”... “*I do not doubt*” ... “*It is conceivable*” Wilberforce adds, “*In the name of all true philosophy we protest against such a mode of dealing with nature, as utterly dishonourable to all natural science, as reducing it from its present lofty level of being one of the noblest trainers of man’s intellect and instructors of his mind, to being a mere idle play of the fancy, without the basis of fact or the discipline of observation.*” (pp. 83-84). Is Wilberforce being fair here? Why and/or why not?

Why might someone have a hard time believing what Darwin asks us to believe? Darwin answers,

...the chief cause of our natural unwillingness to admit that one species has given birth to other and distinct species is that we are always slow in admitting any great change of which we do not see the intermediate steps. (p. 481).

But what is **belief** and what is **analysis**? What is **faith** and what is **reason**?

Wilberforce answers, '*Analysis*,' says Professor Sedgwick, 'consists in making experiments and observations, and in drawing general conclusions from them by induction, and admitting of no objections against the conclusions but such as are taken from experiments or other certain truths; for hypotheses are not to be regarded in experimental philosophy.' [*A Discourse on the Studies of the University*, by A. Sedgwick, p. 102].

Wilberforce also rejects Darwin's use of **time**. According to Wilberforce, *The other solvent which Mr. Darwin most freely and, we think, unphilosophically employs to get rid of difficulties, is his use of time. This he shortens or prolongs at will by the mere wave of his magician's rod. Thus the duration of whole epochs, during which certain forms of animal life prevailed, is gathered up into a point, whilst an unlimited expanse of years, impressing his mind with a sense of eternity, is suddenly interposed between that and the next series, though geology proclaims the transition to have been one of gentle and, it may be, swift accomplishment. All this too is made the more startling because it is used to meet the objections drawn from facts. 'We see none of your works,' says the observer of nature; 'we see no beginnings of the portentous change; we see plainly beings of another order in creation, but we find amongst them no tendencies to these altered organisms.'* True says the great magician, with a calmness no difficulty derived from the obstinacy of facts can disturb; 'true, but remember the effect of time. Throw in a few hundreds of millions of years more or less, and why should not all these

changes be possible, and, if possible, why may I not assume them to be real? (pp. 84-85).

Now I think we come to the crux of the matter. Wilberforce writes, “*There are no parts of Mr. Darwin's ingenious book in which he gives the reins more completely to his fancy than where he deals with **the improvement of instinct by his principle of natural selection**. We need but instance his assumption, without a fact on which to build it, that the marvelous skill of the honey-bee in constructing its cells is thus obtained, and the **slave-making habits of the Formica Polyerges** thus formed. There seems to be no limit here to the exuberance of his fancy, and we cannot but think that we detect one of those hints by which Mr. Darwin indicates the application of his system from the lower animals to man himself, **when he dwells so pointedly upon the fact that it is always the black ant which is enslaved by his other coloured and more fortunate brethren. 'The slaves are black!'** We believe that, if we had Mr. Darwin in the witness-box, and could subject him to a moderate cross-examination, we should find that he believed that the tendency of the lighter-coloured races of mankind to prosecute the negro slave-trade was really a remains, in their more favoured condition, of the 'extraordinary and odious instinct ' which had possessed them before they had been ' improved by natural selection ' from Formica Polyerges into Homo.*” (pp. 88-89).

Samuel Wilberforce, who obtained a first class degree in mathematics at Oxford, was a member of the Royal Society of London, and was vice president of the BAAS then states, “*Our readers will not have failed to notice that we have objected to the views with which **we have been dealing solely on scientific grounds**. We have done so from our fixed conviction that it is thus that the truth or falsehood of such arguments should be tried. **We have no sympathy with those who object to any facts or alleged facts in nature, or to any inference logically***

deduced from them, because they believe them to contradict what it appears to them is taught by Revelation. We think that all such objections savour of a timidity which is really inconsistent with a firm and well-instructed faith:—

'Let us for a moment,' profoundly remarks Professor Sedgwick, 'suppose that there are some religious difficulties in the conclusions of geology. How, then, are we to solve them? Not by making a world after a pattern of our own—not by shifting and shuffling the solid strata of the earth, and then dealing them out in such a way as to play the game of an ignorant or dishonest hypothesis—not by shutting our eyes to facts, or denying the evidence of our senses—but by patient investigation, carried on in the sincere love of truth, and by learning to reject every consequence not warranted by physical evidence' [Wilberforce's note: 'A Discourse on the Studies of the University, p. 149].

*He who is as sure as he is of his own existence that the **God of Truth is at once the God of Nature and the God of Revelation**, cannot believe it to be possible that His voice in either, rightly understood, can differ, or deceive His creatures. To oppose facts in the natural world because they seem to oppose Revelation, or to humour them so as to compel them to speak its voice, is, he knows, but another form of the ever-ready feeble-minded dishonesty of lying for God, and trying by fraud or falsehood to do the work of the God of truth. It is with another and a nobler spirit that the true believer walks amongst the works of nature. The words graven on the everlasting rocks are the words of God, and they are graven by His hand. No more can they contradict His Word written in His book, than could the words of the old covenant graven by His hand on the stony tables contradict the writings of His hand in the volume of the new dispensation. There may be to man difficulty in reconciling all the utterances of the two voices.*

But what of that? He has learned already that here he knows only in part, and that the day of reconciling all apparent contradictions between what must agree is nigh at hand. He rests his mind in perfect quietness on this assurance, and rejoices in the gift of light without a misgiving as to what it may discover:—” (pp. 92-93).

Darwin wrote to J. D. Hooker on July 20, 1860

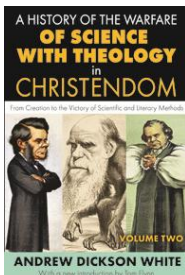
P.S. I have just read Quarterly R. **It is uncommonly clever; picks out with skill all the most conjectural parts, & brings forwards well all difficulties.** It quizzes me quite splendidly by quoting the Anti-Jacobin versus my grandfather. You are not alluded to; nor, strange to say, Huxley, & I can plainly see here & there Owen’s hand. The concluding pages will make Lyell shake in his shoes. By Jove if he sticks to us he will be a real Hero.

Good night—your well-quizzed, but not sorrowful & affectionate friend. C.D.

I can see there has been some queer tampering with the Review—for a page has been cut out & reprinted.

Harvard University was founded in 1636 and was affiliated with Calvinism. Yale University was founded in 1701 and was affiliated with Calvinism. The University of Pennsylvania was founded in 1740 and was nonsectarian. Princeton University was founded in 1746 and was nonsectarian. Columbia University was founded in 1754 and was affiliated with the Church of England. Brown University was founded in 1754 and was affiliated with Baptists. Dartmouth College was founded in 1769 and was affiliated with Calvinists and Cornell University was founded in 1865 and was nonsectarian. Cornell was the first Ivy League university founded in America. The earlier ones were founded in British colonies.

Andrew Dickson White (1896), the first president of the nonsectarian Cornell University and a historian, wrote about Wilberforce’s review of Darwin’s *Origin of Species* and the Oxford debate in his *History of the Warfare of Science with Theology in Christendom* (pp. 70-86):



*“Darwin's **Origin of Species** had come into the theological world like a **plough into an ant-hill**. Everywhere those thus rudely awakened from their old comfort and repose had swarmed forth angry and confused. Reviews, sermons, books light and heavy, came flying at the new thinker from all sides.*



*The keynote was struck at once in the **Quarterly Review** by Wilberforce, Bishop of Oxford. He declared that Darwin was guilty of "a tendency to limit God's glory in creation"; that "the principle of natural selection is absolutely incompatible with the word of God"; that it "contradicts the revealed relations of creation to its Creator"; that it is "inconsistent with the fulness of his glory"; that it is "a dishonouring view of Nature"; and that there is "a simpler explanation of the presence of these strange forms among the works of God": that explanation being—"the fall of Adam." Nor did the bishop's efforts end here; at **the meeting of the British Association for the Advancement of Science** he again disported himself in the tide of popular applause. Referring to the ideas of Darwin, who was absent on account of illness, he congratulated himself in a public speech that he was not descended from a monkey. The reply came from Huxley, who said in substance: "If I had to choose, I would prefer to be a descendant of a humble monkey rather than of a man who employs his knowledge and eloquence in misrepresenting those who are wearing out their lives in the search for truth."*

This shot reverberated through England, and indeed through other countries.

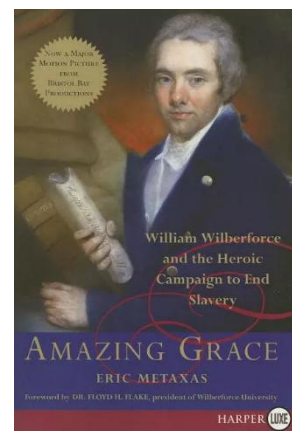
*Whatever additional factors may be added to natural selection—and Darwin himself fully admitted that there might be others—the theory of an evolution process in the formation of the universe and of animated nature is established, and the old theory of direct creation is gone forever. In place of it **science** has given us*

*conceptions far more noble, and opened the way to an argument for design infinitely more beautiful than any ever developed by **theology**.*”

A. D. White, Francis Darwin, and Leonard Huxley never mentioned Wilberforce’s scientific criticisms. **Were A. D. White, Francis Darwin, and Leonard Huxley promoting the questioning of authority as long as no one questioned their view of scientific authority?** I personally wonder if the way the scientific establishment, who became a “Darwinist mob,” chose to argue or not argue the merits of the case between Wilberforce and Huxley set up the model for the **unquestioning authority of scientism**, the use of *ad hominin* remarks to the “deniers” and “contrarians,” and the eventual marginalization of the unfit in the name of **eugenics**. Eugenics is a term that was coined by Darwin’s cousin, Francis Galton (<http://galton.org/eugenicist.html>).

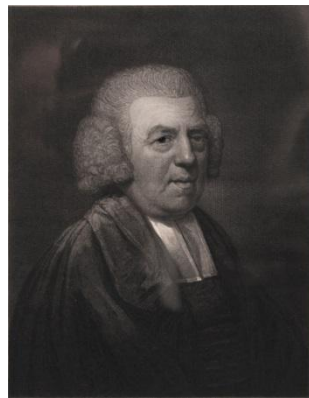
Why was Samuel Wilberforce so concerned about the slave-making instinct of ants and that this instinct may be inherited by humans? Samuel Wilberforce’s father was **William Wilberforce**. William was influenced by his friend named **John Newton** (1788), the author of *Thoughts upon the African Slave Trade* and the hymn **Amazing Grace**. The autobiographical hymn is about Newton, who was a slave trader and realized that he was lost. **Newton** wrote, “*I can see no reason why the Lord singled me out for mercy, but this, " that so it seemed good to him;" unless it was to show, by one astonishing instance, that " with him nothing is impossible."*” He got William Wilberforce to become an abolitionist, and Wilberforce spent the rest of his life to end the slave trade in the British Empire.

<http://www.amazinggracemovie.com/>



Newton wrote *Amazing Grace* for a sermon he was giving on January 1, 1773 based on 1 Chronicles 17: 16-17. Then King David went in and sat before the Lord, and he said: *“Who am I, Lord God, and what is my family, that you have brought me this far? And as if this were not enough in your sight, my God, you have spoken about the future of the house of your servant. You, Lord God, have looked on me as though I were the most exalted of men.”*

William Wilberforce was well-known in the nineteenth century. He was mentioned by Harriet Beecher Stowe in *Uncle Tom’s Cabin* published in 1852, by Frederick Douglass in a speech given on [July 5th 1852](#), and by Abraham Lincoln during a debate in 1858.

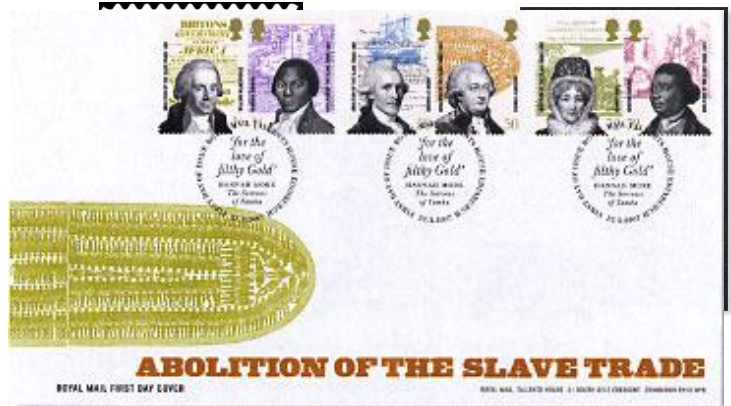


81 **Amazing Grace.**
John Newton. McIntosh. C. M. Arr. by E. O. Excell.

1. A - maz - ing grace! how sweet the sound, That saved a wretch like me! I
2. 'Twas grace that taught my heart to fear, And grace my fears re-lieved; How
3. Thro' man - y dan-gers, toils and snares, I have al - read - y come; 'Tis
4. When we've been there ten thousand years, Bright shin-ing as the sun, We've

once was lost, but now am found, Was blind, but now I see.
pre - cious did that grace ap - pear The hour I first be-lieved!
grace hath bro't me safe thus far, And grace will lead me home.
no less days to sing God's praise Than when we first be - gun. A - MEN.

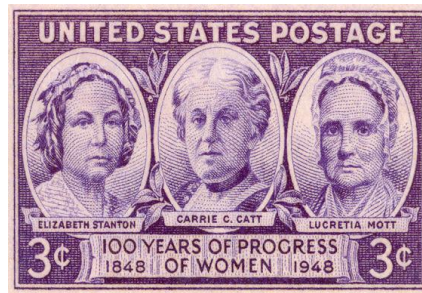
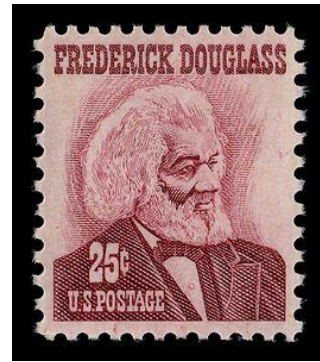
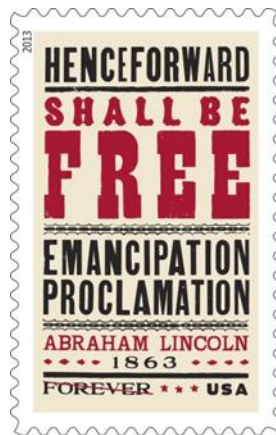
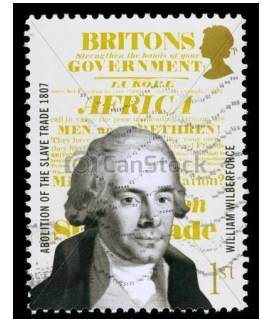
Do any of you know the name of William Wilberforce? If not, I bet you know the names of other freedom fighters such as Abraham Lincoln, Martin Luther King, Cesar Chavez, Mahatmas Gandhi, Frederick Douglass, Elizabeth Cady



Stanton, Susan B. Anthony, and Nelson Mandela. William Wilberforce belongs to this group. Martin Luther King Jr. (1957) used the example of William

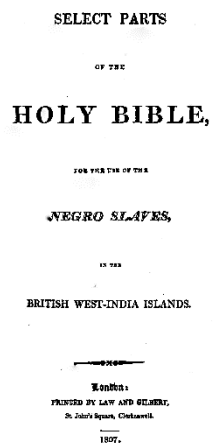
Wilberforce as a way of “Conquering Self-centeredness” in a sermon delivered at Dexter Avenue Baptist Church: *“And the way to solve this problem is not to drown out the ego but to find your sense of importance in something outside of the self. And you are then able to live because you have given your life to something outside and something that is meaningful, objectified. You rise above this self-absorption to something outside. We look through history. We see that biography is a running commentary of this. We see a Wilberforce. We see him somehow satisfying his desire by absorbing his life in the slave trade, those who are victims of the slave trade. ...And then we can even find Jesus totally objectifying himself when he cries out, ‘Ye have done it unto the least of these my brethren, ye have done it unto me.’”*





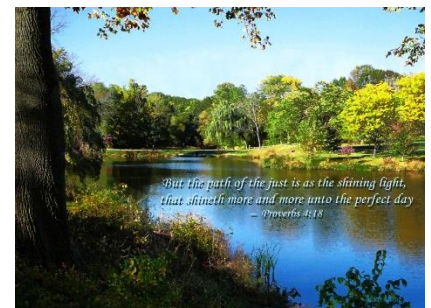
During the time William Wilberforce was working to end the slave trade and slavery, the Society for the Conversion of Negro Slaves (1807) had a Bible printed that could be used in the British West-India Islands. It was entitled, “*Select Parts of the Holy Bible for the use of the Negro Slaves in the British West-India Islands.*” Exodus begins at Chapter 19. Passages such as “*There is neither Jew nor Greek, there is neither **bond nor free**, there is neither male nor female: for ye are all one in Christ Jesus*” (Galatians 3:28) were omitted while passages such as “*Servants, be obedient to them that are your masters according to the flesh, with fear and trembling, in singleness of your heart, as unto Christ*” (Ephesians 6:5) were kept. That is, passages that could incite rebellion were removed while those that promoted submission to authority were retained.

https://books.google.com/books/about/Select_parts_of_the_holy_Bible_for_the_u.html?id=e9gHAAAAQAAJ)



Samuel Wilberforce (1868) wrote a book about his father's life entitled, *Life of William Wilberforce*. He ended the book like so: *"A number of those who had been indebted to his kindness met after his funeral, 'with feelings almost as disconsolate as those of the bereaved apostles, to lament his loss.' 'Great part of our coloured population, who form here an important body,' writes a dignified clergyman from the West Indies, 'went into mourning at the news of his death.' The same honour was paid him by this class of persons at New York, where also an eulogium (since printed) was pronounced upon him by a person publicly selected for the task, and their brethren throughout the United States were called upon to pay the marks of external respect to the memory of their benefactor. For departed kings there are appointed honours, and the wealthy have their gorgeous obsequies: it was his nobler portion to clothe a people with spontaneous mourning, and go down to the grave amid the benedictions of the poor."*

"It is impossible to conclude this history without noting the truth of the inspired words: 'Godliness has the promise of the life that now is, as well as that which is yet to come.' If ever any man drew the lot of a happy life, he did so who has been described. Yet his Christian faith was from first to last the talisman of his happiness. Without it the buoyancy of his youthful spirits led to a frivolous and unsatisfying waste of life. With it came lofty conceptions—an energy which triumphed over sickness and languor, over the coldness of friends and the violence of enemies—a calmness not to be provoked—a perseverance which repulse could not baffle. To these virtues was owing the happiness of his active days. Through the power of the same sustaining principle, his affection towards his fellow-creatures was not dulled by the intercourse with the world, nor his sweetness of temper impaired by the irritability of age. A firm trust in God,

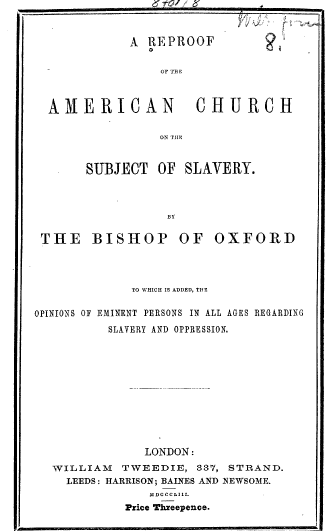


*an undeviating submission to His will, an overflowing thankfulness—these maintained in him to the last that cheerfulness which this world could neither give nor take away. They poured even upon his earthly pilgrimage the anticipated radiance of that brighter region, to which the servants of God are admitted, For ‘the path of the just is like the **shining light**, which **shineth** more and more unto the perfect day.’ ”*

There was still more work to be done in ending slavery throughout the world. His Royal Highness Prince Albert presided over the Meeting of the **Society for the Extinction of the Slave Trade, & for the Civilization of Africa** on June 1, 1840. Hundreds of British and 50 Americans attended. Prince Albert said, *“I have been induced to preside at the Meeting of this Society, from a conviction of its paramount importance to the great interests of humanity and justice. I deeply regret that the benevolent and persevering exertions of England to abolish that atrocious traffic in human beings (at once the desolation of Africa and the blackest stain upon civilized Europe) have not as yet led to any satisfactory conclusion. But I sincerely trust that this great country will not relax in its efforts until it has finally, and for ever, put an end to a state of things so repugnant to the spirit of Christianity, and **the best feelings of our nature**. Let us therefore trust that Providence will prosper our exertions in so holy a cause, and that (under the auspices of our Queen and Her Government) we may at no distant period be rewarded by the accomplishment of the great and humane object for the promotion of which we have this day met.”*



After his father William Wilberforce brought a successful end to the slave trade and slavery in the British Empire, Samuel Wilberforce (1844,1853) fought to end slavery in America. *“Of the twenty-six states, thirteen are slave states; admitting, that is, within their own borders, the institution of Slavery as a part of their institutions; and of these, five—Maryland, Virginia, Kentucky, Missouri, and in part, Tennessee—are **slave-selling**, whilst those south of them are **slave-buying** states....Accordingly, the master-evil of the South is, that the slaves are not treated as having souls.... ‘Let no man from henceforth,’ said the Christian Council of London, in 1102, ‘presume to carry on that wicked traffic, by which men in England have been hitherto sold like brute animals.’ This must be the Church’s rule on the banks of the Mississippi, as it was on those of the Thames.”*



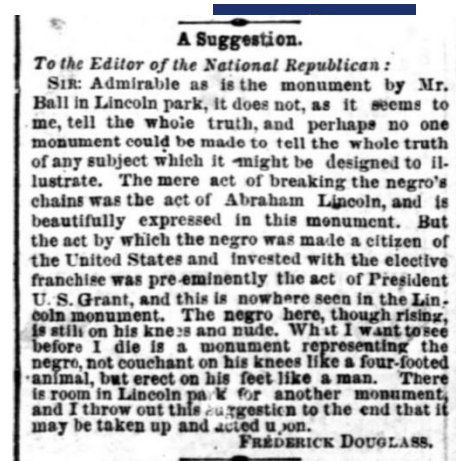
On April 14, 1876, Frederick Douglass gave a speech at the unveiling of the [Freedmen's Monument in Memory of Abraham Lincoln](#), in Lincoln Park, Washington, D.C., where he said, *“Few facts could better illustrate the vast and wonderful change which has taken place in our condition as a people than the fact of our assembling here for the purpose we have today. Harmless, beautiful, proper, and praiseworthy as this demonstration is, I cannot forget that no such demonstration would have been tolerated here twenty years ago. The spirit of slavery and barbarism, which still lingers to blight and destroy in some dark and distant parts of our country, would have made our assembling here the signal and excuse for opening upon us all the flood-gates of wrath and violence. **That we are here in peace today is a compliment and a credit to American civilization, and a prophecy of still greater national enlightenment***



and progress in the future. I refer to the past not in malice, for this is no day for malice; but simply to place more distinctly in front the gratifying and glorious change which has come both to our white fellow-citizens and ourselves, and to congratulate all upon the contrast between now and then; the new dispensation of freedom with its thousand blessings to both races, and the old dispensation of slavery with its ten thousand evils to both races—white and black. In view, then, of the past, the present, and the future, with the long and dark history of our bondage behind us, and with liberty, progress, and enlightenment before us, I again congratulate you upon this auspicious day and hour.” It was not Douglass’ way to not tell the **whole truth**. He went on to say, *“It must be admitted, truth compels me to admit, even here in the presence of the monument we have erected to his memory, Abraham Lincoln was not, in the fullest sense of the word, either our man or our model. In his interests, in his associations, in his habits of thought, and in his prejudices, he was a white man. He was preeminently the white man’s President, entirely devoted to the welfare of white men.”* Douglass also knew how to observe and analyze the evidence: *“Despite the mist and haze that surrounded him; despite the tumult, the hurry, and confusion of the hour, we were able to take a comprehensive view of Abraham Lincoln, and to make reasonable allowance for the circumstances of his position. We saw him, measured him, and estimated him; not by stray utterances to injudicious and tedious delegations, who often tried his patience; not by isolated facts torn from their connection; not by any partial and imperfect glimpses, caught at inopportune moments; but by a broad survey, in the light of the stern logic of great events, and in view of that divinity which shapes our ends, rough hew them how we will, we came to the conclusion that the hour and the man of our redemption had somehow met in the person of Abraham Lincoln. It mattered little to us what language he might employ on special occasions; it mattered little to us, when we fully knew him, whether he was swift or slow in his*

movements; it was enough for us that Abraham Lincoln was at the head of a great movement, and was in living and earnest sympathy with that movement, which, in the nature of things, must go on until slavery should be utterly and forever abolished in the United States.” This monument, which depicts Abraham Lincoln holding the Emancipation Proclamation and an ex-slave with broken shackles, on one knee, about to stand up. Douglass knew that there was more to be done to overcome the legacy of slavery. On [April 19, 1876](#), he wrote in a letter to the editor of the National Republican, “*Admirable as is the monument by Mr. Ball in Lincoln park, it does not, as it seems to me, tell the whole truth, and perhaps no one monument could be made to tell the whole truth of any subject which it might be designed to illustrate. The mere act of breaking the Negro's chains was the act of Abraham Lincoln, and is beautifully expressed in this monument. But the act by which the negro was made a citizen of the United States and invested with the elective franchise was pre-eminently the act of President U.S. Grant, and this is nowhere seen in the Lincoln monument. The negro here, though rising, is still on his knees and nude. What I want to see before I die is a monument representing the negro, not couchant on his knees like a four-footed animal, but erect on his feet like a man. There is room in Lincoln park for another monument, and I throw out this suggestion to the end that it may be taken up and acted upon.*”

As described by Hannah Arendt (1976), in *The Origins of Totalitarianism*, in the 19th century, racism combined with bureaucracy allowed the seemingly endless expansion of the British Empire throughout the world. The *Great Game* of expansion for expansion’s sake, is well characterized by Cecil Rhodes, who said, “*The world is nearly all parcelled out, and what there is left of it is being divided up, conquered and*



colonised. To think of these stars that you see overhead at night, these vast worlds which we can never reach. I would annex the planets if I could; I often think of that. It makes me sad to see them so clear and yet so far.”

Wilberforce University, named after William Wilberforce, was the first predominantly African-American Private University in the United States. It was founded in 1856 by members of the Methodist Episcopalian Church. **The Wilberforce School** in Princeton, NJ, was also named after him.



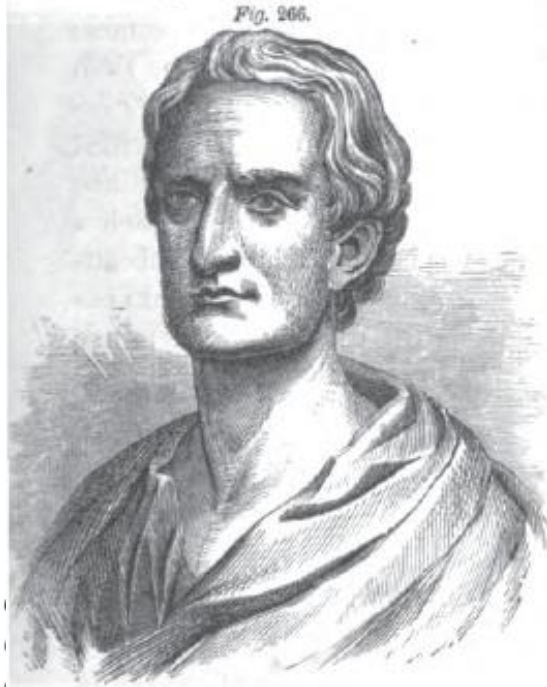
In May 1860, just a month before the meeting of the BAAS at Oxford, Samuel Wilberforce gave speeches on behalf of the Oxford and Cambridge Mission to Central Africa. He said, “*The Gospel must be brought from without from those who had now the **lamp of truth**, and who had it in order that they might **enlighten** others as well as themselves. The grounds which should induce us to make some great and hearty efforts to carry God’s truth among His people were, that they need it greatly, that they are ready to receive it, that we are specially called to impart it from close connection with them, and because **as the children of slave traders we had to cut off the entail of curses by reversing the inheritance of wrong which the slave trade had inflicted upon Africa.***”

I think that Samuel Wilberforce, like Thomas Jefferson, believed “**We hold these truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable Rights, that among these are Life, Liberty and the pursuit of Happiness.**” I think that Wilberforce would have accepted Darwinian Theory if the **evidence** from the **fossil record** was strong enough and if someone could show that a **new and improved species was differentiated from a pre-existing and less improved species**. That is **macroevolution** (which he rejected) as opposed to **microevolution** (which he accepted). But in the absence of that data, he would not accept the theory because the theory could serve as a **natural law justification** for a **slave-making instinct in humans** at a time when England was looking for **new colonies** to replace the lost American colonies. Science is often used to provide a natural law for justifying political, social, and economic policy. For example, **John Draper** (1861) wrote in *History of the Intellectual Development of Europe* that the “*Social advancement is as completely under the control of natural law as is bodily growth.*” The page below is from Draper’s book on *Human Physiology*, the same John Draper who was the keynote speaker in June 1860 at the BAAS meeting in Oxford.



THERE are great differences in the aspect of men.

The portrait of Newton is from the frontispiece of his immortal Prin-



Sir Isaac Newton.

cipia. "Does he eat, and drink, and sleep, like other people?" ask-

Differences in form, color, and dispositions of men.



Australian.

ed the Marquis de l'Hôpital, himself a great contemporary French math-
 ematician. This man lives in a hollow tree, which he has in
 part excavated by fire, and obtains a precarious support from shell-fish,
 or bruised ants and grass. He can make a hook of a piece of oyster,

There was no "consensus" among great scientists regarding the value and the limitations of Darwin's theory of evolution by natural selection. Charles Darwin sent a copy of his book to John Herschel. After not hearing back from Herschel directly, Darwin wrote to Charles Lyell on [December 10, 1859](#), "*I have heard by round about channel that Herschel says my Book "is the law of higgledy-pigglety".—What this exactly means I do not know, but it is evidently very contemptuous.—If true this is great blow & discouragement.*" Asa Gray (1860) and Louis Agassiz (1874), two Harvard scientists, reviewed the *Origin of Species* in the *Atlantic Monthly*:

Louis Agassiz's review, like Wilberforce's, was critical:

https://books.google.com/books/about/Evolution_and_Permanence_of_Type.html?id=wQVbAAAAQAAJ, writing, "*Darwin has placed the subject on a different basis from that of all his predecessors, and has brought to the discussion a vast amount of well-arranged, information, a convincing cogency of argument, and a captivating charm of presentation. His doctrine appealed the more powerfully to the scientific world because he maintained it at first not upon metaphysical ground but upon observation. Indeed it might be said that he treated his subject according to the best scientific methods, had he not frequently overstepped the boundaries of actual knowledge and allowed his imagination to supply the links which science does not furnish.*"

In the book *Leading Men of Science* edited by David Starr Jordan (1910; Cornell), Charles Frederick Holder, a co-founder of the **Tournament of Roses Parade**, compared the views of Agassiz and Darwin: "*Agassiz was essentially an idealist. All of his investigations were to him not studies of animals or plants as such, but of the divine plans of which their structures are the expression. 'That earthly form was the cover of spirit was to him a truth at once fundamental and self-evident. The work of the student was to search out the thoughts of God, and as well as may be to think them over again. To Agassiz, these divine thoughts were especially embodied in the relations of animals to each other. The species was the thought-mind at the moment of the creation of the first one of the series which represents the species. The marvel of the affinity of structure, of unity of plan in creatures widely diverse in habits and outward appearances, was to him a result of the association of ideas in the divine mind, an illustration of*



divine many-sidedness. To Darwin these relations would illustrate the force of heredity acting under different conditions of environment.

*Agassiz had no sympathy with the prejudices worked upon by weak and foolish men in opposition to Darwinism. He believed in the absolute freedom of science; that no power on earth can give answers beforehand to the questions which men of science endeavor to solve. Of this I can give no better evidence than the fact that every one of the men specially trained by him has joined the ranks of the evolutionists. **He would teach them to think for themselves not to think as he did.**"*

Asa Gray's review was more accepting:

<https://www.theatlantic.com/magazine/archive/1860/07/darwin-on-the-origin-of-species/304152/>

When species, like individuals, were found to die out one by one, and apparently to come in one by one, a theory for what Owen sonorously calls "the continuous operation of the ordained becoming of living things" could not be far off... That all such theories should take the form of a derivation of the new from the old seems to be inevitable, perhaps from our inability to conceive of any other line of secondary causes, in this connection. Owen himself is apparently in travail with some [non gradual] transmutation theory of his own conceiving, which may yet see the light, although Darwin's came first to the birth. Different as the two theories will probably be in particulars, they cannot fail to exhibit that fundamental resemblance in this respect which betokens a community of origin, a common foundation on the general facts and the obvious suggestions of modern science. Indeed,- to turn the point of a taking simile directed against Darwin,— the difference between the Darwinian and the Owenian hypotheses may, after all, be

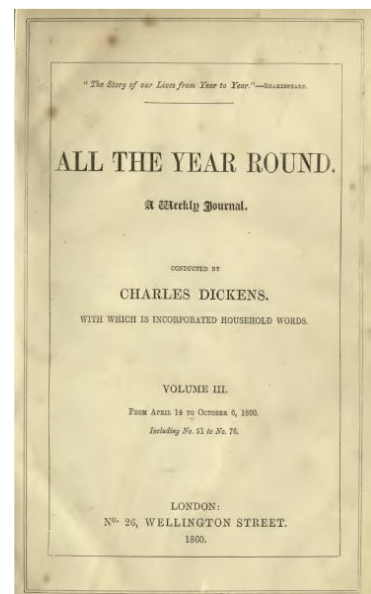
only that between homoeopathic and heroic doses of the same drug. We will discuss Owen's theory in a later lecture.

Today, the Green New Deal is justified in the name of "Science" but what are the values and limitations of the evidence supporting the Green New Deal?

<https://ocasio-cortez.house.gov/sites/ocasio-cortez.house.gov/files/Resolution%20on%20a%20Green%20New%20Deal.pdf>.

Charles Dickens (1842), who wrote ardently against slavery in *American Notes for General Circulation*, weighed in on Charles Darwin's *Origin of Species* in what may be called **A Tale of Two C.D.s**:

In an article entitled *Natural Selection*, published in Dickens' magazine *All the Year Round* (3, 293-299; <https://archive.org/details/allyearround03dick/page/n7>), Dickens (1860) wrote about Darwin's theory of natural selection as applied to the evolution of structures and the evolution of instincts: *It is well for Mr. Charles Darwin, and a comfort to his friends, that he is living now, instead of having lived in the sixteenth century; it is even well that he is a British subject, and not a native of Austria, Naples, or Rome. Men have been kept for long years in durance, and even put to the rack and the stake, for the commission of offences minor to the publication of ideas less in opposition to the notions held by the powers that be.*



But we have come upon more tolerant times. If a man can calmly support his heresy by reasons, the heresy will be listened to; and, in the end, will be either received or refuted, or simply neglected and forgotten. Mr. Darwin also enjoys the benefit of the bygone heresies of previous heretics; one heresy prepares the way for, and weakens the shock occasioned by, another. Astronomical and geological innovations render possible the acceptance of doctrines that would have made people's hair stand on end three centuries ago. This is an enormous progress; for what are three or four centuries in the history of the human race? What, in the history of the world? Truth is a bugbear which is fast losing its terrors: we are getting

more and more accustomed to it, and are less and less afraid to look it in the face. But then comes the old question, "**What is Truth?**" Mr. Darwin believes he knows, or is on the way to know.

Charles Darwin comes of a family renowned for close observation, intellectual ability, and boldness of speculation; he is gifted with clear and passionless judgment, and with an amiable and gentlemanly disposition; it is doubtful whether he have an enemy in the world; it is certain that he has, and deserves to have, many friends. He is blessed with a sufficiency of worldly riches, and has not strong health — the very combination to make a student. He is sincerity itself, thoroughly believing all he states, and daring to state what he believes. No mental reservation is employed to dissemble the tendency of his scientific views. He has circumnavigated the globe, and beheld the manners of many men, savage and civilised; of many birds, beasts, reptiles, and fishes. He has compared living forms with those which existed on the same spot of land ages and ages ago. In his Voyage with the Beagle he has delighted his readers with the simplicity and the clearness with which he has explained geological changes. For more than twenty years he has been patiently accumulating and reflecting on all sorts of facts which could possibly have any bearing on the origin of living things as we now behold them existing; regardless of expense and labour, he has long searched for the truth respecting this question. He believes he has found it, and he enunciates his creed in a book which is an abstract of a larger work that will take two or three more years to complete.

But, as the tolerant spirit of the age allows him to state and to hold his belief unmolested, it also allows dissenters from his novel doctrines to declare their unbelief of them, and to manifest the hardness of their hearts by utter deafness to Mr. Darwin's most persuasive attempts at conversion. The world in general is quite unprepared to hear his unaccustomed views propounded. The propositions are so unfamiliar, that, be they false or be they true, they are almost sure to meet with a flat denial. The dominant and fundamental idea may be grand, clear, and decided. **As a theory, it is complete and harmonious in all its parts, regarded merely as a theory; but, as a history of the past, and as a statement of present and future facts, its authority must entirely rest on the reader's judgment whether the proofs and the reasoning are conclusive to his mind or not. It is a question of the interpretation to be given to certain appearances and occurrences; it is a matter of circumstantial evidence.** Mr. Darwin is already

supported by a small party of disciples and fellow-labourers, who put faith in his inspiration; while the great majority shrink back in alarm at the boldness of his conclusions, and at the illimitable lapse of time which it unfolds before their wondering and bewildered gaze. He will hardly be surprised himself—nor will the reader—to find that the mass of his audience have ears but hear not, and eyes but see not—as he sees and understands the works of nature. **Before accepting such a theory, we, the multitude, must think twice. Well, let us think twice; thinking twice never does harm.**

The creed to which it is proposed to convert the world is as follows: Although much remains obscure, and will long remain obscure, Mr. Darwin entertains no doubt that the view which most naturalists entertain, and which he formerly entertained himself—namely, that each species has been independently created—is erroneous. **He is fully convinced that species are not immutable;*** [* See "Species," in *All the Year Round*, No. 58, p. 174.] **but that those belonging to what are called the same genera are lineal descendants of some other and generally extinct species.**

The modifications which species have undergone are mainly, but not exclusively, he believes, the result of a process called Natural Selection. He cannot doubt that **the theory of descent, with modification**, embraces all the members of the same class. He believes that animals have descended from at most only four or five progenitors, and plants from an equal or lesser number. Analogy would lead him one step further; namely, to the belief that, in the beginning, there arose some single, primitive, rudimentary, organised cell, or elementary being, which was the first parent of every living creature—that all animals and plants have descended from some one prototype. But **analogy**, he owns, may be a deceitful guide. Nevertheless, **all living things have much in common in their chemical composition, their germinal vesicles, their cellular structure, and their laws of growth and reproduction.** We see this even in so trifling a circumstance as that the same poison often similarly affects plants and animals; or that the poison secreted by the gall-fly produces monstrous growths on the wild rose or oak-tree. Therefore, Mr. Darwin would **infer from analogy** that, probably, all the organic beings which have ever lived on this earth have descended from some one primordial form, into which life was first breathed by the Creator.

*Is it too much to say that, in the good old times, opinions like these would have been strongly redolent of **fagot and flame**?*

Our philosophical reformer adduces numerous facts which he holds to be inexplicable on the theory of independent acts of creation. By the supposition of a migration, with subsequent modification, we can see why oceanic islands should be inhabited by few species, but, of these, that many should be peculiar. We can clearly see why those animals which cannot cross wide spaces of ocean, as frogs and terrestrial mammals, should not inhabit oceanic islands; and why, on the other hand, new and peculiar species of bats, which can traverse the ocean, should so often be found on islands far distant from any continent. The grand facts respecting the grouping of all organic beings on certain areas of the earth's surface — such as a predominance of monkeys with prehensile tails in one country, of ant-eaters and toothless animals in another, of pouched animals in another, of a peculiar modification of leaves in Australian shrubs, of peculiar aloes or agaves in America — are inexplicable on the theory of creation.

*Glancing at instincts, marvellous as some are, they offer, it appears, no greater difficulty than does corporeal structure, on the theory of the Natural Selection of successive, slight, but profitable, modifications. We can thus understand why nature moves by graduated steps in endowing different animals of the same class with their several instincts. On the view of all the species of the same genus having descended from a common parent, and having inherited much in common, we can understand how it is that allied species, when placed under considerably different conditions of life, yet should follow nearly the same instincts; why the male wrens of North America, for instance, build "cock-nests" to roost in, like the males of our distinct kitty-wrens — a habit wholly unlike that of any other known bird. **On the view of instincts having been slowly acquired through Natural Selection**, we need not marvel at some instincts being apparently not perfect, but liable to mistakes, as when blow-flies lay their eggs in the carrion-scented flowers of stapelias; **nor at many instincts causing other animals to suffer, as when ants make slaves of their fellow-ants**, when the larvae of ichneumon flies feed within the live bodies of caterpillars, and when the nestling cuckoo ungratefully ejects his legitimate foster-brethren out of the family nest.*

*Instincts are as important as bodily structure for the welfare of each species, under the conditions of life by which it happens to be surrounded. Under changed circumstances, it is possible that slight modifications of instinct might be profitable to a species; and if it can be shown that instincts do vary ever so little, then Mr. Darwin sees no difficulty in Natural Selection preserving and continually accumulating variations of instinct to any extent that may be profitable. His line of argument — **and the whole volume is one long argument** — **may be summed up in this: give him an inch, and he takes an ell.** Instincts certainly do vary — for instance, the migratory instinct varies, both in extent and direction, and in its total loss. So it is with the nests of birds, which vary partly in dependence on the situations chosen and on the nature and temperature of the country inhabited, but often from causes wholly unknown to us. It is thus, he believes, that all the most complex and wonderful instincts have originated; although no complex instinct can possibly be produced except by the slow and gradual accumulation of numerous slight, yet profitable, variations, requiring ages upon ages, and tens of thousands, perhaps hundreds of millions, of generations to work them out. For Mr. Darwin assumes such an inconceivably vast period of lapsed time for the accomplishment of his theory, that it is simply not eternity, because it had beginning.*

***Variations of instinct, thus acquired, become, in races, habitual and hereditary.** Habit and the selection of so-called accidental variations, have played important parts in modifying the mental qualities of our domestic animals. It cannot be doubted that young pointers will sometimes point, and even back other dogs, the very first time that they are taken out; retrieving is certainly in some degree inherited by retrievers; as is a tendency to run round, instead of at, a flock of sheep by shepherds' dogs. These actions do not differ essentially from true instincts; for the young pointer can no more know that he points to aid his master, than the white butterfly knows why she lays her eggs on the leaf of the cabbage. How strongly these habits and dispositions are inherited, and how curiously they become mingled, is well shown when different breeds of dogs are crossed. A cross with the greyhound has given to a whole family of shepherds' dogs, the lurchers, a tendency to hunt hares, rendering them invaluable to poachers. Le Roy describes a dog whose great-grandfather was a wolf, and this dog showed a trace of its wild parentage only in one way — by not coming in a straight line to his master when called.*

To understand how instincts in a state of nature have become modified by Natural Selection, let us consider the case of the cuckoo. It is commonly admitted that the more immediate and final cause of the cuckoo's instinct is that she lays her eggs, not daily, but at intervals of two or three days; so that, if she were to make her own nest and sit on her own eggs, those first laid would have to be left for some time unincubated, or there would be eggs, and young birds of different ages in the same nest; which would make the process of laying, hatching, and rearing the young, inconveniently long and troublesome. The American cuckoo makes her own nest, and has eggs and young successively hatched, all at the same time.

Now, instances can be given of various birds which have been known occasionally to lay their eggs in other birds' nests. Let us suppose that the ancient progenitor of our European cuckoo had the habits of the American cuckoo, but that she occasionally laid an egg in another bird's nest by way of experiment. If the old bird profited by this occasional habit, or if the young were made more vigorous by the mistaken maternal instinct of another bird than by their own mother's care, encumbered as she can hardly fail to be by having eggs and young of different ages at the same time, then the old birds, or the fostered young, would gain an advantage. And analogy leads Mr. Darwin to believe that the young thus reared would be apt to follow, by inheritance, the occasional and aberrant habit of their mother, and in their turn would possibly lay their eggs in other birds' nests, and thus be successful in rearing their young. By a continued process of this nature, he believes that the strange instinct of our cuckoo could be, and has been, generated.

*To Mr. Darwin, this explanation appears conclusive; other persons, less under the influence of a fixed idea, may observe that, **with the help of an "if" and a "suppose," there is little difficulty in explaining anything.***

The occasional habit of birds laying their eggs in other birds' nests, either of the same or of a distinct species, is not very uncommon with the Gallinaceae; it is frequent with domestic hens; and this, perhaps, explains the origin of a singular instinct in the allied group of ostriches, for several hen ostriches, at least in the case of the American species, unite and lay, first a few eggs in one nest, and then the rest in another, and these are hatched by the males. This instinct may probably be accounted for by the fact of the hens laying a large number of eggs, but, as in

the case of the cuckoo, at intervals of two or three days. The instinct, however, of the American ostrich has not as yet been perfected; for a surprising number of eggs lie strewed over the plains, so that in one day's hunting Mr. Darwin himself picked up no less than twenty lost and wasted eggs.

Many bees are parasitic, and always lay their eggs in the nests of bees of other kinds. This case is more remarkable than that of the cuckoo, for these bees have not only their instincts, but their structure also, modified in accordance with their parasitic habits: they do not possess the pollen-collecting apparatus which would be necessary if they had to store food for their own young. Some species likewise of Sphegidae (wasp-like insects) are parasitic on other species; and M. Fabre has lately shown good reason for believing that although the Tachytes nigra generally makes its own burrow and stores it with paralysed prey for its own larvae to feed on, yet that when this insect finds a burrow already made and stored by another spheg, it takes advantage of the prize, and becomes, for the occasion, parasitic. In this case, as with the supposed case of the cuckoo, Mr. Darwin can see no difficulty in Natural Selection making an occasional habit permanent, if, advantage to the species, and if the insect whose nest and stored food are thus feloniously appropriated, be not thus exterminated.

Such ideas are opposed to the belief of philosophers who hold that the various species of plants and animals have been independently created, and have been purposely fitted and adapted to the place in creation which they were intended to occupy by an Overruling Intelligence; for it is maintained that the more complex organs and instincts have been perfected, not at once in the first-created individual, by the Hand of the Maker, but by the accumulation of innumerable slight variations, each good for the individual possessor for the time being, during an exceedingly long succession of individuals from generation to generation.

*The result is asserted to have been effected in this way: **there can be no doubt that species give rise to minor varieties**; for no two individuals are exactly alike, but may be easily distinguished one from the other. A shepherd knows every sheep in his flock, a huntsman every hound in his pack, calling it by name; a busy-body knows every face in his village and its neighbourhood; probably a bee knows every bee belonging to its hive. **Variations are often***

hereditary; red-haired parents will probably have a red-haired family. Varieties of talent and bodily strength are hereditary; diseases and defects are hereditary, as is every day seen with consumption and deafness. If any animal or plant in a state of nature be highly useful to man, or from any cause closely attract his attention, varieties of it will almost universally be found recorded. Now, individual differences are considered by Mr. Darwin as the first step towards such slight varieties as are barely thought worth mentioning in works on natural history: varieties which are in any degree more distinct and permanent, are steps leading to more strongly marked and more permanent varieties; and these latter lead to sub-species, and to species. In short, all organised and animated forms are in a state of passage from one stage of difference to another; all nature is moving insensibly forwards up the slope of one vast sliding scale; the world is a never-ceasing workshop for the process of manufacturing new species of plants and animals.

Mr. Darwin believes that any well-marked variety may be called an incipient species; and herein lies the whole turning-point, the cornerstone, perhaps the stumbling-block, of his System of Nature; grant him that, and nothing can stop the career of his theory; give him that inch, and he may take, not an ell, but a hundred thousand miles of philosophical territory. Conscious of the importance of his postulate, he candidly observes: "Whether this belief" (that varieties are incipient species)" be justifiable, must be judged of by the general weight of the several facts and views given throughout this work." Achilles is a mighty man, but unfortunately he is afflicted with a vulnerable heel. Elsewhere he says: "It has often been asserted, but the assertion is quite incapable of proof, that the amount of variation under nature is a strictly limited quantity." But there's the rub. A mathematical demonstration may be impossible; but certain observers and experimenters say that their experiments and observations strongly tend to the belief that varieties do not vary beyond certain limits; that is the impression which their minds receive from what they see; just as Mr. Darwin's observations strongly tend to make him view all existing beings, not as special creations, but as the lineal descendants of some few beings which lived long before the first bed of the Silurian system was deposited, and to conclude thence that (as all the living forms of life are the lineal descendants of those which lived long before the Silurian epoch) we may feel certain that the ordinary succession by

generation has never once been broken, that no cataclysm has desolated the whole world, and that we may look with some confidence to a secure future of equally inappreciable length.

But no human intellect, unaided by revelation, is at present able to make such conclusions as these matters either of positive proof or of positive refutation. They must remain a question of opinion, a balancing of probabilities, in which each man judges according to his lights, the tone of his mind, and the inferences which his previous notions lead him to draw from the premises before him. Two men may arrive at contrary opinions, both reasoning with perfect sincerity of heart and desire for truth, For instance, while Mr. Darwin holds that the world has been desolated by no past cataclysm and need apprehend no future one (which is contrary to the universal tradition and belief of civilised nations), M. Boutigny, a savant, of high rank in his own country, asserts, with specious and plausible argument, not only that the moon was shot out by a convulsive explosion from the earth, but that our planet may any day be seized with the throes of a universal earthquake which shall end in the expulsion of a second satellite; in which case, every living thing must be destroyed by fire. No cataclysm! Why Messieurs Adhémar and Lehon, distinguished men of science, believe that they have proved that a grand deluge must inevitably devastate the globe every ten thousand five hundred years* [* See All the Year Round, No. 52, p. 40.]; that such deluges have regularly occurred during all previous time, and that such will recur again at their stated epochs; and that, although these grand deluges may not be so universal as to desolate the whole world, they are cataclysms sufficiently terrific to exterminate the great majority of existing creatures, and to render a fresh act of creation an event at least desirable and called for by circumstances.

To return to the theory by which independent creations are obviated. Nature is most prodigal in conferring life. ***More individuals of every kind, both plants and animals, are produced than can possibly survive, and there must in every case be a contest for life; either between individuals of the same species, or between the individuals of distinct species. It is Malthus's doctrine applied to the whole animal and vegetable kingdoms, with increased force; for, in this case, there can be no artificial increase of food, and no prudential restraint from marriage. Although some species may be now increasing more or less rapidly in numbers, all cannot so increase, for the world would not hold them. There is no exception to the rule that every organic being naturally increases at so high a rate, that, if not destroyed, the earth would***

soon be covered by the progeny of a single pair. Even slow-breeding man has doubled in twenty-five years; and at this rate, in a few thousand years there would literally not be standing-room for his progeny. Linnaeus has calculated that if an annual plant produced only two seeds — and there is no plant so unproductive as this — and their seedlings next year produced two, and so on, then, in twenty years, there would be a million of plants.

As a consequence, the weakest goes to the wall; it is a race for life, with the deuce taking the hindmost. A grain in the balance will determine which individual shall live and which shall die: which variety or species shall increase in number, and which shall decrease, or finally become extinct. The slightest advantage in one being, at any age or during any season, over those with which it comes into competition, or any better adaptation in however slight a degree to the surrounding physical conditions, will tend to the preservation of that individual, and will generally be inherited by its offspring. The offspring, also, will thus have a better chance of surviving, for, of the many individuals of any species which are periodically born, but a small number can survive. This is Natural Selection — a power which acts during long ages, rigidly scrutinising the whole constitution, structure, and habits of each creature — favouring the good and rejecting the bad. Though nature grants vast periods of time for the work of natural selection, she does not grant an indefinite period; for as all organic beings are striving, it may be said, to seize on each place in the economy of nature, if any one species does not become modified and improved in a corresponding degree with its competitors, it will soon be exterminated.

Cases of adaptation which have hitherto been attributed to design and contrivance are by this theory regarded as the result of natural selection only. When we see leaf-eating insects green, and bark-feeders mottled grey, the Alpine ptarmigan white in winter, the red grouse the colour of heather, and the black grouse that of peaty earth, we must believe that those tints are of service to these birds and insects in preserving them from danger. Grouse, if not destroyed at some period of their lives, would increase in countless numbers — they are known to suffer largely from birds of prey; and hawks are guided by eyesight to their prey — so much so, that on parts of the Continent persons are warned not to keep white pigeons, as being the most liable to destruction. Hence Mr. Darwin can see no reason to doubt that Natural Selection might be

effective in giving the proper colour to each kind of grouse, and in keeping that colour, when once acquired, true and constant.

To make it clear how Natural Selection acts, an imaginary illustration is given. Let us take the case of a wolf, which preys on various animals, securing some by craft, some by strength, and some by fleetness; and let us suppose that the fleetest prey, a deer, for instance, had from any change in the country increased in numbers, or that other prey had decreased in numbers, during that season of the year when the wolf is hardest pressed for food. Under such circumstances, there is no reason to doubt that the swiftest and slimmest wolves would have the best chance of surviving, and so be preserved or selected — provided always that they retained strength to master their prey at this or some other period of the year, when they might be compelled to prey on other animals. There seems no more reason to doubt this, than that man can improve the fleetness of his greyhounds by methodical selection, or by that unconscious selection which results from each man trying to keep the best dogs without any thought of modifying the breed.

Even, without any change in the proportional numbers of the animals on which our wolf preyed, a cub might be born with an innate tendency to pursue certain kinds of prey. Nor can this be thought very improbable; for we often observe great differences in the natural tendencies of our domestic animals; one cat, for instance, taking to catching rats, another mice; one cat, according to Mr. St. John, bringing home winged game, another hares, or rabbits, and another hunting on marshy ground and almost nightly catching woodcocks or snipes. The tendency to catch rats rather than mice is known to be inherited. Now, if any slight innate change of habit or of structure benefited an individual wolf, it would have the best chance of surviving and of leaving offspring. Some of its young would probably inherit the same habits or structure, and by the repetition of this process, a new variety might be formed which would either supplant or coexist with the parent form of wolf. Or, again, the wolves inhabiting a mountainous district, and those frequenting the lowlands, would naturally be forced to hunt different prey; and from the continued preservation of the individuals best fitted for the two sites, two varieties might be slowly formed. According to Mr. Pierce, there are two varieties of the wolf inhabiting the Catskill Mountains in the United States; one with a light greyhound-like form, which pursues

deer, and the other more bulky, with shorter legs, which more frequently attacks the shepherds' flocks.

The use and the disuse of particular organs combine their effects with those of natural selection, in the modification of species; use strengthens and enlarges certain parts, and disuse diminishes them. Such modifications are inherited. Many animals have structures which can be explained by the effects of disuse. As Professor Owen has remarked, there is no greater anomaly in nature than a bird that cannot fly; yet there are several in this state. Since the larger ground-feeding birds seldom take flight except to escape danger, Mr. Darwin believes that the nearly wingless condition of several birds, which now inhabit or have lately inhabited several oceanic islands, tenanted by no beast of prey, has been caused by disuse. The ostrich, indeed, inhabits continents, and is exposed to danger from which it cannot escape by flight; but by kicking it can defend itself from its enemies, as well as any of the smaller quadrupeds. We may imagine that the early progenitor of the ostrich had habits like those of a bustard, and that as Natural Selection increased in successive generations the size and weight of its body, its legs were used more, and its wings less, until they became incapable of flight.

The eyes of moles and of some burrowing rodents are rudimentary in size, and in some cases are quite covered up by skin and fur. This state of the eyes is probably due to gradual reduction from disuse, but aided, perhaps, by Natural Selection. In South America, a burrowing rodent, the tuco-tuco, is even more subterranean in its habits than the mole; and the Spaniards, who often catch them, assert that they are frequently blind. One, which Mr. Darwin kept alive, was certainly in this condition, the cause, as appeared on dissection, having been inflammation of the nictitating membrane. As frequent inflammation of the eyes must be injurious to any animal, and as eyes are certainly not indispensable to animals with subterranean habits, a reduction in their size, with the adhesion of the eyelids and growth of fur over them, might, in such case, be an advantage; and if so, Natural Selection would constantly aid the effects of disuse. It is well known that several animals, belonging to the most different classes, which inhabit the caves of Styria and of Kentucky, are blind. In some of the crabs, the foot-stalk for the eye remains, though the eye is gone; the stand for the telescope is there, though the telescope with its glasses has been lost. As it is difficult to imagine that eyes, though useless, could be in any way injurious to animals living in darkness, Mr. Darwin attributes their loss wholly to

disuse. Not a single domestic animal can be named which has not, in some country, drooping ears; and the view suggested by some authors, that the drooping is due to the disuse of the muscles of the ear from the animals not being much alarmed by danger, is accepted as probable.

Mr. Wollaston has discovered the remarkable fact that two hundred kinds of beetles, out of the five hundred and fifty inhabiting Madeira, cannot fly; and that of the twenty-nine endemic genera, no less than twenty-three genera have all their species in this condition. Several facts, namely, that beetles, in many parts of the world, are frequently blown to sea and perish; that the beetles in Madeira, as observed by Mr. Wollaston, lie much concealed until the wind lulls and the sun shines; that the proportion of wingless beetles is larger on the exposed Desertas than in Madeira itself; and especially the extraordinary fact, so strongly insisted on by Mr. Wollaston, of the almost entire absence of certain large groups of beetles, elsewhere excessively numerous, and which groups have habits of life almost necessitating frequent flight;—these several considerations have made Mr. Darwin believe that the wingless condition of so many Madeira beetles is due mainly to the action of natural selection, but combined probably with disuse. For, during thousands of successive generations, each individual beetle which flew least, either from its wings having been ever so little less perfectly developed, or from indolent habit, will have had the best chance of surviving from not being blown out to sea; and, on the other hand, those beetles which most readily took to flight would oftenest have been blown to sea and thus have been destroyed. As with mariners shipwrecked near a coast, it would have been better for the good swimmers if they had been able to swim still further, whereas it would have been better for the bad swimmers if they had not been able to swim at all, and had stuck to the wreck.

The theory, of which a brief sample has been given, entails the vastest consequences. We are no longer to look at an organic being as a savage looks at a ship — as at something wholly beyond his comprehension; we are to regard every production of nature as one which has had a history; we are to contemplate every complex structure and instinct as the summing up of many contrivances, each useful to the possessor, nearly in the same way as when we look at any great mechanical invention as the summing up of the labour, the experience, the reason, and even the blunders, of numerous workmen. The natural system of classification becomes a genealogical arrangement, in which we have to discover the lines of descent by the most permanent characters, however slight their vital importance may be; because the real

affinities of all organic beings are due to inheritance or community of descent. Natural Selection can only act through and for the good of each being; acting by competition, it adapts the inhabitants of each country only in relation to the degree of perfection of their associates; so that we need feel no surprise at the inhabitants of any one country (although on the ordinary view supposed to have been specially created and adapted for that country) being beaten and supplanted by the naturalised productions from another land. Nor ought we to marvel if all the contrivances in nature be not, as far as we can judge, absolutely perfect; and if some of them be abhorrent to our ideas of fitness. We need not marvel at the sting of the bee causing the bee's own death; at the instinctive hatred of the queen bee for her own fertile daughters; and at other such cases.

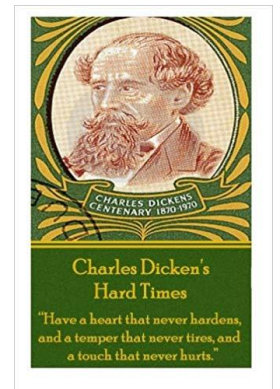
*Judging from the past, we are to infer that not one living species will transmit its unaltered likeness to a distant futurity. And, of the species now living, very few will transmit progeny of any kind to a far-distant futurity; for the manner in which all organic beings are grouped, shows that the greater number of species of each genus, and all the species of many genera, have left no descendants, but have become utterly extinct. We can so far take a prophetic glance into futurity as to foretell that it will be the common and widely-spread species, belonging to the larger and dominant groups, which will ultimately prevail and procreate new and dominant species. **And as Natural Selection works solely by and for the good of each being, all corporeal and mental endowments will tend to progress towards perfection. Thus, from the war of nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows.***

*Timid persons, who purposely cultivate a certain inertia of mind, and who love to cling to their preconceived ideas, fearing to look at such a mighty subject from an unauthorised and unwonted point of view, may be reassured by the reflection that, **for theories, as for organised beings, there is also a Natural Selection and a Struggle for Life.** The world has seen all sorts of theories rise, have their day, and fall into neglect. **Those theories only survive which are based on truth, as far as our intellectual faculties can at present ascertain;** such as the Newtonian theory of universal gravitation. **If Mr. Darwin's theory be true, nothing can prevent its ultimate and general reception, however much it may pain and shock those to whom it is propounded for the first time. If it be merely a clever hypothesis, an ingenious hallucination, to which a***

*very industrious and able man has devoted the greater and the best part of his life, its failure will be nothing new in the history of science. It will be a **Penelope's web**, which, though woven with great skill and art, will be ruthlessly unwoven, leaving to some more competent artist the task of putting together a more solid and enduring fabric.*

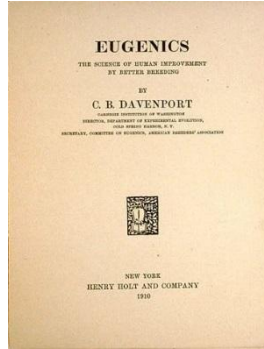
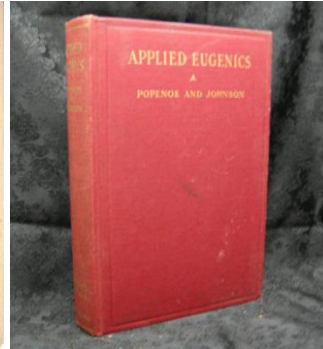
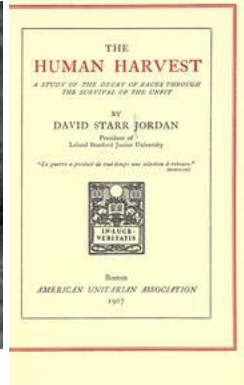


This article, like the others that appeared in *All the Year Round*, was written to be discussed around the breakfast table. Dickens' personal experiences and observations of instinct and human nature expressed in Victorian England, where technology, based on the steam engine driven by burning coal, rapidly transformed a rural agrarian society into an urban industrial society provided the foundational evidence for his novels. According to Tom Wolfe (1989), in Dickens' novels, the city of London was “*always in the foreground, exerting its relentless pressure on the souls of its inhabitants.*” Had Dickens been a strict Darwinian when it came to materialism and the instincts of humans, in *A Christmas Carol*, there would have been no Christmas ghosts and **the Scrooge at the beginning of the story would have represented the survival of the fittest.** It may be no surprise to learn that the intelligentsia in Victorian England, according to Tom Wolfe (1989) and Arnold Hauser (1951), regarded Dickens as “*the author of the uneducated, indiscriminating public.*”



Many scientists, including **David Starr Jordan**, a Cornell graduate and first president of Stanford University, Paul Popenoe, Luther Burbank, Charles Davenport, William Castle, and others began looking at human beings as

predominantly a product of their genes and built up the **progressive science of eugenics**, the science of the improvement of the human race by better breeding. As **Charles B. Davenport** (1911), who we



discussed in terms of eye color, wrote, “*The eugenical standpoint is that of the agriculturalist who, while recognizing the value of culture, believes that permanent advance is to be made only by securing the best ‘blood.’ Man is an organism—an animal; and the laws of improvement of corn and of race horses hold for him also. Unless people accept this simple truth and let it influence marriage selection human progress will cease.*”

William E. Castle (1921) wrote in *Genetics and Eugenics*: “*No one can deny that our country’s population is increasing fast enough, the only danger is that the biologically poorest elements in the population may increase faster than any other. The declining birth rate is not itself serious, but the differential character of its decline is serious. The most intellectual and cultured elements in the population breed slowest. Professor Cattell says that a Harvard graduate has on the average three-fourths of a son and a Vassar graduate one-half of a daughter. If this continues college graduates may look forward to the early extinction of their line as an element of the American population.*”

See the movie, *The Black Stork*, made in 1917 about Doctor **Harry J. Haiselden** and his quest to use his scientific and medical knowledge for human progress. <https://www.youtube.com/watch?v=9m6OCT8YmfU> Tomorrow’s

Children is another movie made in 1934 with the same theme.

<https://www.youtube.com/watch?v=yXQNU4IeO6Y>

C. S. Lewis (1952) wrote in *Mere Christianity*, “*We all want progress. But progress means getting nearer to the place where you want to be. And if you have taken a wrong turning, then to go forward does not get you any nearer. If you are on the wrong road, progress means doing an about-turn and walking back to the right road; in that case the man who turns back soonest is the most progressive man.*”



Scientist at Work | Edward O. Wilson

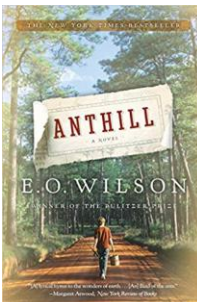
Taking a Cue From Ants on Evolution of Humans (<https://www.nytimes.com/2008/07/15/science/15wils.html>)

Edward O. Wilson is an expert in the study of ants and the author of *Anthill*, and ***Sociobiology: The New Synthesis***.

The New Synthesis (with “The” with a capital T) is based on his knowledge of the social behavior of ants, as well as genetics and evolution. Wilson (1975) states, “*the humanities and social sciences shrink to specialized branches of*



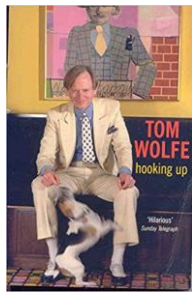
biology...,” that “*Scientists and humanists should consider together the possibility that the time has come for ethics to be removed temporarily from the hands of the philosophers and biologicized*” and that “*It seems that our autocatalytic social evolution has locked us onto a particular course which the early hominids still within us may not welcome. To maintain the species indefinitely we are compelled to drive toward total knowledge, right down to the levels of the neuron and gene. When we have progressed enough to explain ourselves in*



these mechanistic terms, and the social sciences come to full flower, the result might be hard to accept.”

Are we merely products of natural selection and everything we do or think genetically determined? Is the soul dead? Is there no such thing as self-control and free will? Can we really explain ourselves or a man like Wilberforce in these materialistic and mechanistic terms? Some biologists, including Walter Gilbert who shared the 1980 Nobel Prize in Chemistry, think that once we know a person's genome, a computer with sufficient analytical power could predict the course of that person's life.

Tom Wolfe (2000) has written about E.O. Wilson, who he calls Darwin II in *Digibabble*, *Fairy Dust*, and *the Human Anthill* and *Sorry, but Your Soul Just Died*—two essays in the book, *Hooking Up*.



Viktor Frankl (1962), a survivor of Auschwitz, wrote in the *Doctor and the Soul*, “Three factors characterize human existence as such: man's spirituality, his freedom, his responsibility.” Is it likely that these three factors arose by natural selection and that these three factors will be enhanced through a breeding program?

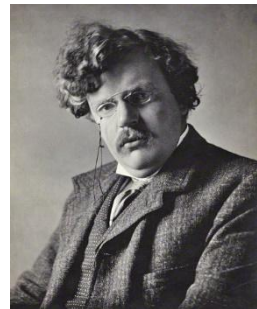
William Jennings Bryan (1925) began to question the value of the Darwinian war-like philosophy. At the Scopes Trial, he said, “*Let us, then, hear the conclusion of the whole matter. Science is a magnificent material force, but it is not a teacher of morals. It can perfect machinery, but it adds no moral restraints to protect society from the misuse of the machine. It can also build gigantic intellectual ships, but it constructs no moral rudders or the control of storm-tossed human vessels. It not only fails to supply the spiritual*



element needed, but some of its unproven hypotheses rob the ship of its compass and thus endanger its cargo.

In war, science has proven itself an evil genius; it has made war more terrible than it ever was before. Man used to be content to slaughter his fellowmen on a single plain - the earth's surface. Science has taught him to go down into the water and shoot up from below and to go up into the clouds and shoot down from above, thus making the battlefield three times as bloody as it was before. But science does not teach brotherly love. Science has made war so hellish that civilization was about to commit suicide; and now we are told that newly discovered instruments of destruction will make the cruelty of the late war seem trivial in comparison with the cruelties of wars that may come in the future. If civilization is to be saved from the wreckage threatened by intelligence not consecrated by love, it must be saved by the moral code of the meek and lowly Nazarene. His teachings, and His teachings alone, can solve the problems that vex the heart and perplex the world."

We hear all the time "Science says," but science does not say anything, scientists do. And scientists must make their case stating a **line of reasoning** rather than a **talking point** as much as anyone else. In seeing the gradual change from science as a method of inquiry to **scientism**, where the authority of science becomes unquestioned, **G. K. Chesterton** (1932) wrote in, *On the Intellect of Yesterday* "Or take another test from another type of inquiry. When all the drawing-rooms began to buzz suddenly with the name of Einstein, some of us were enabled to guess that they must once have buzzed quite as abruptly with the name of Darwin. **Some of us are inclined to guess that Darwinism became a fashion long before anybody really thought it was a fact.** Doubtless any number of society ladies went about saying that Professor Darwin was really too wonderful, just as they afterwards went about saying that Professor Einstein was really too wonderful. But, when all is said, there is no comparison



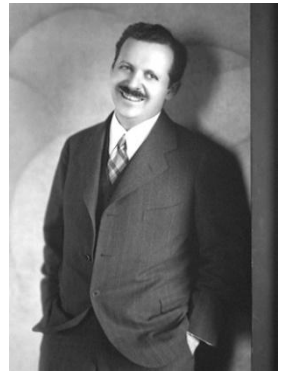
between the two cases. Any number of people did really attack the study of biology, in order to agree or disagree with Darwin. Hardly one person in a thousand thought of attacking the higher mathematics in order to agree with Einstein. People did talk about Darwinism as well as about Darwin. Most of those who talk about Einstein talk about Einstein. They know nothing but the name and the notion that something very important has happened in connexion with the name. The talk about Darwin may have been popular science, but it was science, and it was popular. The talk about Einstein may rather be called **popular nescience**. He has not made astronomy really popular, as the other made biology really popular. And **I believe that the reason is a certain increased laziness of the intellect**; that fewer people are ready for a long, sustained logical demonstration, quite apart from whether we think that the demonstration really demonstrates. In my boyhood there were any number of funny little atheists running about ready and eager to prove what they had learned from the work of Darwin. So there were any number of fanatical little Free-Traders eager to prove what they had learned from the speeches of Cobden. **I do not find men now so eager to prove things; but, at the most, to assure me that they have been proved.**

One way of putting it is that this is a psychological age, which is the opposite of an intellectual age. It is not a question of persuading men, but of suggesting how they are persuaded. It is an age of Suggestion; that is, of appeal to the irrational part of man. Men discussed whether Free Trade was false or true; they do not so much discuss whether Empire Free Trade is false or true, as whether it is booming or slumping; whether it is based on an understanding of Mass Psychology, or whether its opponents or supporters have what Americans call Personality. It is all great fun, and there is doubtless a truth in it, as in other things. But, whatever else it is, it is not a mark of stronger mentality, and any old Scotch Calvinist farmer, who

could follow his minister's desolate and appalling sermon to Seventeenthly and Lastly, had an immeasurably better brain."

In his essay, *Is Darwin Dead?*, Chesterton made very weak scientific arguments against Darwinism where he questioned "*the survival value of features in their unfinished state.*" While his scientific critique is weak and flawed, his **critique of scientism** is strong and accurate.

Sigmund Freud's nephew, **Edward Bernays** (1928), who graduated from Cornell University in 1912, wrote in his book, *Propaganda*, "*Universal literacy was supposed to educate the common man to control his environment. Once he could read and write he would have a mind fit to rule. So ran the democratic doctrine. But instead of a mind, **universal literacy has given him rubber stamps, rubber stamps inked with advertising slogans, with editorials, with published scientific data, with the trivialities of the tabloids and the platitudes of history, but quite innocent of original thought.** Each man's rubber stamps are the duplicates of millions of others, so that when those millions are exposed to the same stimuli, all receive identical imprints. It may seem an exaggeration to say that the American public gets most of its ideas in this wholesale fashion. The mechanism by which ideas are disseminated on a large scale is propaganda, in the broad sense of an organized effort to spread a particular belief or doctrine...."*



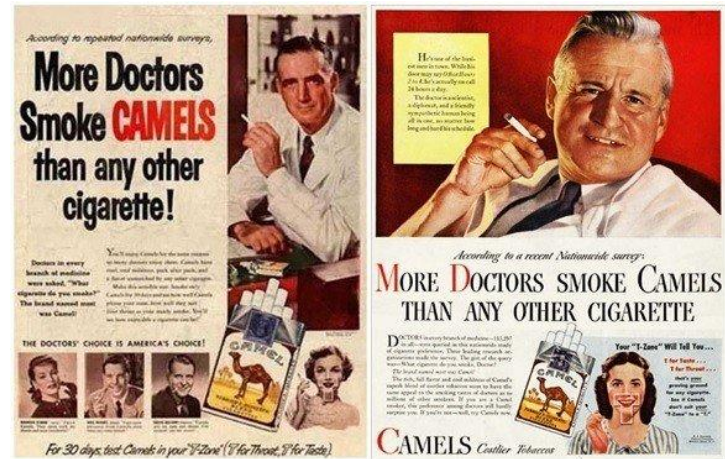
"Trotter and Le Bon concluded that the **group mind** does not think in the strict sense of the word. **In place of thoughts it has impulses, habits and emotions.** In making up its mind its first impulse is usually to follow the example of a trusted leader [or to know what answer will result in an "A"]. This is one of the most firmly established principles of mass psychology. It operates in establishing

the rising or diminishing prestige of a summer resort, in causing a run on a bank, or a panic on the stock exchange, in creating a best seller, or a box-office success [or what is considered right or wrong on a test].”

“But when the example of the leader is not at hand and the herd must think for itself, it does so by means of cliches, pat words or images which stand for a whole group of ideas or experiences. Not many years ago, it was only necessary to tag a political candidate with the word interests to stampede millions of people into voting against him, because anything associated with "the interests" seemed necessarily corrupt. Recently the word Bolshevik has performed a similar service for persons who wished to frighten the public away from a line of action.”

*“The old propagandist based his work on the mechanistic reaction psychology then in vogue in our colleges. This assumed that the human mind was merely an individual machine, a system of nerves and nerve centers, **reacting with mechanical regularity to stimuli, like a helpless, will-less automaton**. It was the special pleader's function to provide the **stimulus** which would cause the desired **reaction** in the individual purchaser. It was one of the doctrines of the reaction psychology that a certain stimulus often repeated would create a habit, or that the mere reiteration of an idea would create a conviction. Suppose the old type of salesmanship, acting for a meat packer, was seeking to increase the sale of bacon. It would reiterate innumerable times in full-page advertisements: ‘Eat more bacon. Eat bacon because it is cheap, because it is good, because it gives you reserve energy.’”*

“The newer salesmanship, understanding the group structure of society and the principles of mass psychology, would first ask: “Who is it that influences the eating habits of the public?” The answer, obviously, is: “The physicians.” The new salesman will then suggest to physicians to say publicly that it is wholesome to eat bacon. He knows as a mathematical certainty, that large numbers of persons will follow the advice of their doctors, because he understands the psychological relation of dependence of men upon their physicians.”



Edward Bernays (1937) wrote in *The Minority Rules*, “Thomas Jefferson said that the world was made, not for Caesar, but for the common man. The contemporary common man, however, shows no sign of giving three whoops in East New York whether it was made for him or

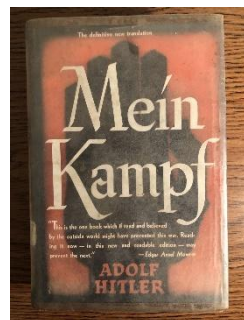


Public relations pioneer Edward Bernays, shown (L to R) from the late 1920s to early '30s, the mid-to-late '40s and 1990. *The Museum of Public Relations*

not. Caesar leads him along by the nose. Universal literacy was supposed to educate the common mortal into control of his environment. Once he could read and write he would have a mind fit to rule. So ran the democratic doctrine. But instead of a mind, universal literacy has given him a rubber stamp, a rubber stamp inked with advertising slogans, with editorials, with published scientific data, with the trivialities of the tabloids and the profundities of history, but quite innocent of original thought. Each man's rubber stamp is the twin of millions of

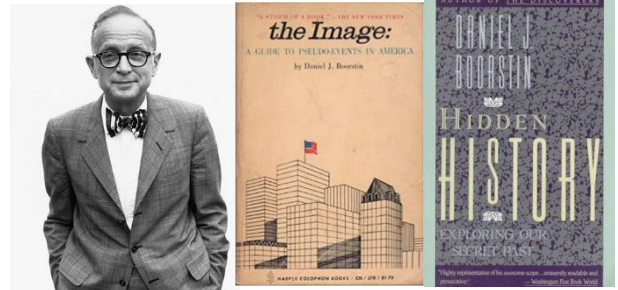
others, so that when these millions are exposed to the same stimuli, all receive identical imprints. It may seem a wild exaggeration to say that the American public gets most of its ideas in this wholesale fashion. But to say so is merely to state a fact that is as real as it is unrecognized. The mechanism by which it is done is propaganda—propaganda, that is, in its broad sense of an organized effort to spread a particular belief or opinion.” In his book entitled *Crystalizing Public Opinion*, Bernays (1923) wrote, **“The only difference between “propaganda” and “education,” really, is in the point of view. The advocacy of what we believe in is education. The advocacy of what we don’t believe in is propaganda. Each of these nouns carries with it social and moral implications. Education is valuable, commendable, enlightening, instructive. Propaganda is insidious, dishonest, underhand, misleading.”**

Adolf Hitler (1924) wrote in [Mein Kampf](#), **“The function of propaganda is, for example, *not to weigh and ponder* the rights of different people, but exclusively to emphasize the one right which it has set out to argue for. *Its task is not to make an objective study of the truth*, in so far as it favors the enemy, and then set it before the masses with academic fairness; its task is to serve our own right, always and unflinchingly. ...**But the most brilliant propagandist technique will yield no success unless one fundamental principle is borne in mind constantly and with unflagging attention. It must confine itself to a few points and repeat them over and over.** Here, as so often in this world, persistence is the first and most important requirement for success.”** Ironically, this quote is often [misattributed](#) to Joseph Goebbels.



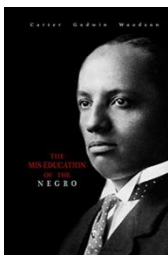
According to **Daniel Boorstin** (1961, 1987),
“*propaganda substitutes opinion for facts.*”

Is science ever presented as propaganda?



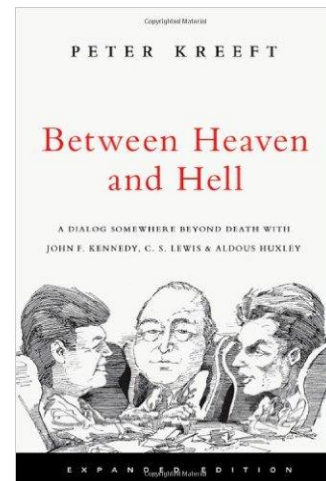
The National Center for Science Education (<https://ncse.ngo/why-teach-evolution-0>), staffed by experts in science education, states that “*Biological evolution is a **scientifically settled theory**. Among scientists, this means that its fundamental principle —the shared ancestry of living organisms —has overcome all scientific challenges. However, the general public is uncomfortable with evolution because of what some people perceive as the moral, or cultural implications of evolution. The NCSE” is concerned with critical thinking about evolution: “Critical thinking is an important component of a good education. Critical thinking about evolution must start with a solid understanding of what evolution is and how contemporary scientists understand it. ‘Critical thinking’ materials recently offered to school boards consist of misinterpretations of scientific research about biological evolution. They confuse an active discussion among scientists over the details of evolution with a disagreement about whether evolution has occurred. This is not critical thinking, but hucksterism.*” In teaching you about Wilberforce, have I misrepresented anything to you?

Mental slavery results when one cannot differentiate between education and indoctrination. **Carter Goodwin Woodson** (1933) wrote in ***The Mis-Education of the Negro***, “*When you control a man’s thinking you do not have to worry about his actions. You do not have to tell him to stand here or go yonder. He will find his ‘proper place’ and will stay in it.*”

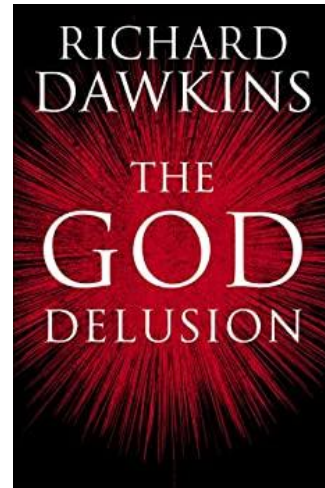
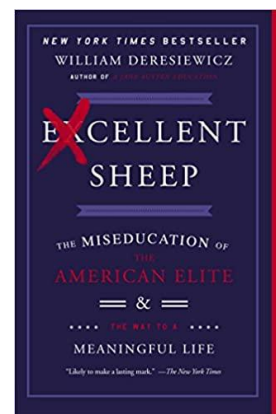


Viktor Frankl (1986) wrote in *The Doctor and the Soul*, “If we present a man with a concept of man which is not true, we may well corrupt him. When we present man as automaton of reflexes, as a mind-machine, as a bundle of instincts, as a pawn of drives and reactions, as a mere product of instinct, heredity and environment, we feed the nihilism to which modern man is, in any case, prone. I became acquainted with the last stage of that corruption in my second concentration camp, Auschwitz. The gas chambers of Auschwitz were the ultimate consequence of the theory that man is nothing but the product of heredity and environment – or, as the Nazi liked to say, of 'Blood and Soil.' **I am absolutely convinced that the gas chambers of Auschwitz, Treblinka, and Maidanek were ultimately prepared not in some Ministry or other in Berlin, but rather at the desks and in the lecture halls of nihilistic scientists and philosophers.**”

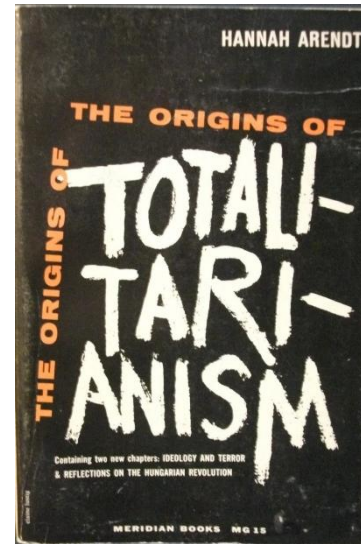
Professors and science books can also be salesmen...which is why I say—Think for yourself, observe and experiment, and use logic and reason—and do not believe anything I write or say! I do not want to teach you what I know, but I want to teach you how to learn to know so that you don't just accept the *cliches, pat words or images* at a time as Kreeft describes, when we do get “*respect and acceptance by others...not by being different but by being the same.*”



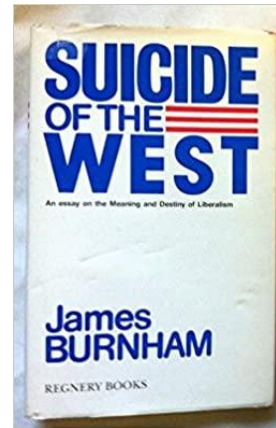
Richard Dawkins (2006) wrote in *The God Delusion*, “A study in the leading journal *Nature* by Larson and Witham in 1998 showed that of those American scientists considered eminent enough by their peers to have been elected to the National Academy of Sciences...only about 7 per cent believe in a personal God. This overwhelming preponderance of atheists is almost the exact opposite of the profile of the American population at large, of whom more than 90 per cent are believers in some sort of supernatural being. The figure for less eminent scientists, not elected to the National Academy, is intermediate. As with the more distinguished sample, religious believers are in a minority, but a less dramatic minority of about 40 per cent. It is completely as I would expect that American scientists are less religious than the American public generally, and that the most distinguished scientists are the least religious of all. What is remarkable is the polar opposition between the religiosity of the American public at large and the atheism of *the intellectual elite*.” At an Ivy League University, do you feel any pressure to be part of the intellectual elite rather than the American public at large? Does the pressure lead in any way to becoming what **William Dereshwicz** calls, an excellent sheep?



Aside: In *The Origins of Totalitarianism*, Hannah Arendt (1976) describes the role of elites historically as functionaries in totalitarian movements based upon “*the [organizational] principle that whoever is not included is excluded, whoever is not with me is against me, [such that] the world at large loses all the nuances, differentiations, and pluralistic aspects*”. Arendt writes, “*The total responsibility for everything done by the movement and this total identification with every one of its functionaries have the very practical consequence that nobody ever experiences a situation in which he has to be responsible for his own actions or can explain the reasons for them.*” How does the inability for the elites to explain their reasons even when calling for or implementing mandates come about? Arendt writes, “*The machine that generates, organizes, and spreads the monstrous falsehoods of totalitarian movements depends again upon the position of the Leader. To the propaganda assertion that all happenings are **scientifically predictable according to the laws of nature or economics**, totalitarian organization adds the position of one man who has monopolized this knowledge and whose principal quality is that he ‘was always right and will always be right.’ To a member of a totalitarian movement this knowledge has nothing to do with truth and this being right nothing to do with the objective truthfulness of the Leader’s statements which cannot be disproved by facts but only by future success or failure. The Leader is always right in his actions and since these are planned for centuries to come, the ultimate test of what he does has been removed beyond the experience of his contemporaries.*” How much trust should we put in our leaders and how much trust should we put in ourselves?



When I say, think for yourself, I am not suggesting that reality and truth are relative and that you should be a **post-modernist** who thinks that reality and truth are esoteric, relative concepts that are constructed by each individual. I am not a **post-modernist**. I am a dualist—a mixture of a **pre-modernist** and a **modernist**—perhaps what James Burnham (1964) in *Suicide of the West*, would call a conservative *and* a liberal.



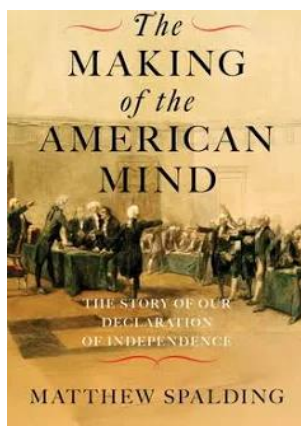
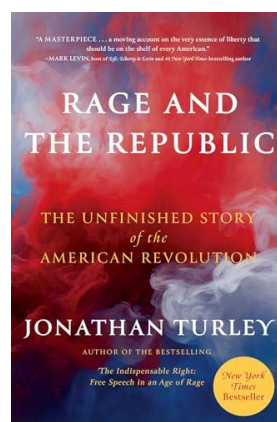
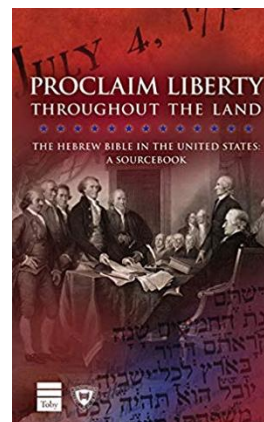
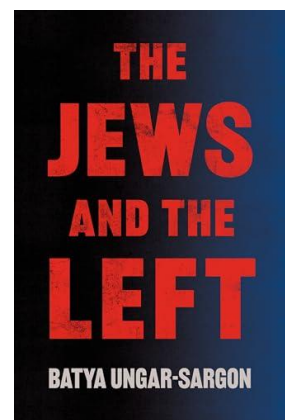
PREMODERNISM	MODERNISM	POSTMODERNISM
Objective Ultimate Truth	Objective Ultimate Truth	Objective Ultimate Truth is Unknowable
Supernatural	Anti-Supernatural	Mystical
Authority from God (or gods)	Authority from Science & Human Reason	No Ultimate Authority

The founding document of the United States of America is the **Declaration of Independence**. It states that individual liberty is God-given and thus each person is free to choose his or her own philosophy and worldview. The first amendment of the Constitution states that *Congress shall make no law respecting an establishment of religion [worldview], or prohibiting the free exercise thereof*. That is final. **Calvin Coolidge** spoke on the 150th Anniversary of the Declaration of Independence, “*It is often asserted that the world has made a great deal of progress since 1776, that we have had new thoughts and new experiences which have given us a great advance over the people of that day, and that we may therefore very well discard their conclusions for something more modern. But that reasoning can not be applied to this great charter. **If all men are created equal, that is final. If they are endowed with inalienable rights, that is final. If governments derive their just powers from the consent of the governed, that is***

final. No advance, no progress can be made beyond these propositions. If anyone wishes to deny their truth or their soundness, the only direction in which he can proceed historically is not forward, but backward toward the time when there was no equality, no rights of the individual, no rule of the people. Those who wish to proceed in that direction can not lay claim to progress. They are reactionary. Their ideas are not more modern, but more ancient, than those of the Revolutionary fathers.”

What do we believe to be true? What do we know to be true? Whose authority do we accept and whose ideas do we believe and why? The [1619 Project](#) and [1776 Report](#) offer diametrically opposed views on freedom and slavery in America. [Parents](#) and [educators](#) also seem to have diametrically opposed views.

Many of the discussions related to the historical truth about America require knowledge about the Judeo-Christian and Enlightenment foundations.

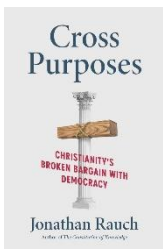


Some people believe that talking about the Judeo-Christian foundations of America go against the “[wall of separation between church and state](#)” that they interpret to be in the first Amendment which states that *Congress shall make no law respecting an establishment of religion.*

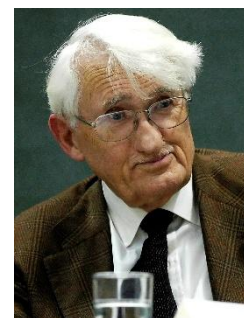
John Adams wrote in a [letter](#) to the poet, playwright, and human rights activist [Mercy Otis Warren](#) on April 16, 1775 “*The Form of Government, which you admire, when its Principles are pure, is admirable indeed. It is productive of every Thing, which is great and excellent among Men. But its Principles are as easily destroyed, as human Nature is corrupted. **Such a Government is only to be supported by pure Religion, or Austere Morals. Public Virtue cannot exist in a Nation without private, and public Virtue is the only Foundation of Republics.***” Adams [wrote](#) to the Massachusetts Militia on October 11, 1798, “*Our Constitution was made only for a moral and religious people. It is wholly inadequate to the government of any other.*”



Today, some atheists, including Jonathan Rauch, Marcello Pera, Luc Ferry, and Chris Berg, and former atheists including Ayaan Hirsi Ali are speaking up about the importance of religious values and small r-republican virtues in maintaining a democracy.



Jürgen Habermas (2006) reminds us in *A Conversation about God and the World*, in *Time of Transitions* that you don't have to believe in God to see the value of the Judeo-Christian legacy. Habermas wrote, “*Universalistic egalitarianism, from which sprang the ideals of freedom and a collective life in solidarity, the autonomous conduct of life and*



*emancipation, the individual morality of conscience, human rights and democracy, is the direct legacy of the Judaic ethic of justice and the Christian ethic of love. This legacy, substantially unchanged, has been the object of continual critical appropriation and reinterpretation. To this day, there is no alternative to it. And in light of the current challenges of a postnational constellation, we continue to draw on the substance of this heritage. **Everything else is just idle postmodern talk.***”

I think William and Samuel Wilberforce could be described as men who after learning from the slave trader John Newton that “*God created mankind in his own image*” (Genesis 1:27), followed the words of the prophet Micah (6:8) “*to do justice, to love kindness, And to walk humbly with your God.*”

Anecdote of the late Rev. John Newton.

Two or three years before the death of this eminent servant of Christ, when his sight was become so dim, that he was no longer able to read, an aged friend and brother in the ministry, now living, called on him to breakfast. Family prayer succeeding, the portion of scripture for the day was read to him. It was taken out of Bogatsky's Golden Treasury:

*‘By the grace of God, I am what I am.’ It was the pious man's custom on these occasions, to make a short familiar exposition of the passage read. After the reading of this text, he paused for some moments, and then uttered the following affecting soliloquy:- ‘I am not what I ought to be ! Ah! how imperfect and deficient! -I am not what I wish to be! I ‘abhor what is evil’ and I would cleave to what is good!’-I am not what I hope to be!-Soon, soon, I shall put off mortality: and with mortality all sin and imperfection! **Yet, though I am not what I ought to be, nor what I wish to be, nor what I hope to be, I can truly say, I am not what I once***

was a slave to sin and Satan; and I can heartily join with the Apostle, and acknowledge; By the grace of God, I am what I am! Let us pray!"

If you think that God is “arguably the most unpleasant character in all fiction: jealous and proud of it; a petty, unjust, unforgiving control-freak; a vindictive, bloodthirsty ethnic cleanser; a misogynistic, homophobic, racist infanticidal, genocidal, filicidal, pestilential, megalomaniacal, sadomasochistic, capriciously malevolent bully” as Richard Dawkins wrote in *The God Delusion*, it makes no sense to give voice to William and Samuel Wilberforce and John Newton, who were motivated by both faith in God and reason. According to Robert Fitch (1959), who wrote *The Obsolescence of Ethics*: “Ours is an age where ethics has become obsolete. It is superseded by science, deleted by philosophy and dismissed as emotive by psychology.”

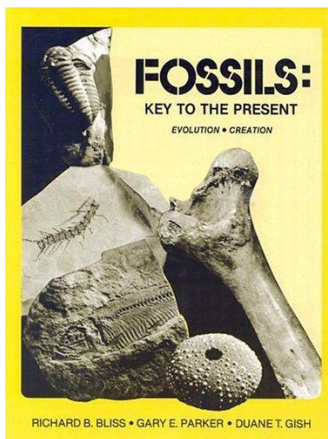
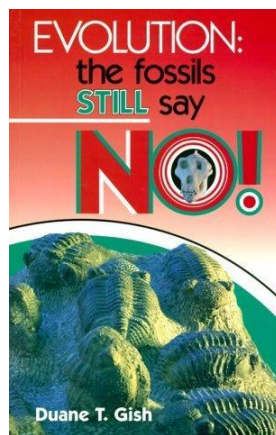
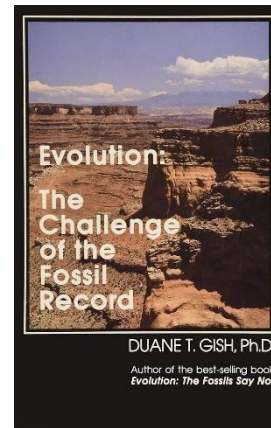
According to music and pop culture journalist **Steve Turner**, Darwin is part of the trinity *Marxfreudanddarwin* that is so important in today’s culture. Turner wrote in *Creed*,

***This is the creed I have written on behalf of all us.
We believe in Marxfreudanddarwin...***

***We believe that there is no absolute truth
excepting the truth that there is no absolute truth.***

There are books written by **Duane T. Gish**, a creationist, who looks at the fossil record from the point of view of creation theory and evolutionary theory. When people are given two perspectives and asked to make their own decision about the evidence and the values and limitations of each theory, they can really develop their intellect, a word that comes from the Latin *inter* and *legere*—which

means to choose between. If we don't give students two sides to choose between, they will not be able to develop their intellect. We cannot have intellectual diversity without having a diversity of intellectuals, each of whom can discern between fact and fiction, and true and false.



[Genesis Impact](#) has short movies that question the assumptions upon which the science is based. I found the movie on [deep time](#) particularly interesting.

I want to emphasize that while Samuel Wilberforce, William Wilberforce, and John Newton were abolitionists because of their religion, being pro- or anti-slavery depends on the individual and not on one's affiliation with any particular group. **Frederick Douglass** (1845) states this clearly in [Narrative of the Life of Frederick Douglass, an American Slave](#): ***“I should regard being the slave of a religious master the greatest calamity that could befall me. For of all slaveholders with whom I have ever met, religious slaveholders are the worst. I have ever found them the meanest and basest, the most cruel and cowardly, of all others. It was my unhappy lot not only to belong to a religious slaveholder, but to live in a community of such***



religionists. Very near Mr. Freeland lived the Rev. Daniel Weeden, and in the same neighborhood lived the Rev. Rigby Hopkins. These were members and ministers in the Reformed Methodist Church. Mr. Weeden owned, among others, a woman slave, whose name I have forgotten. This woman's back, for weeks, was kept literally raw, made so by the lash of this merciless, religious wretch. He used to hire hands. His maxim was, Behave well or behave ill, it is the duty of a master occasionally to whip a slave, to remind him of his master's authority. Such was his theory, and such his practice.

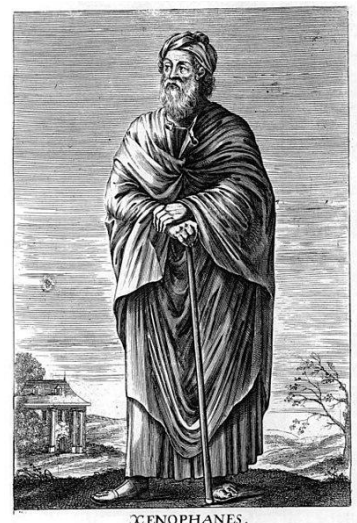
Mr. Hopkins was even worse than Mr. Weeden. His chief boast was his ability to manage slaves. The peculiar, feature of his government was that of whipping slaves in advance of deserving it. He always managed to have one or more of his slaves to whip every Monday morning. He did this to alarm their fears, and strike terror into those who escaped. His plan was to whip for the smallest offences, to prevent the commission of large ones. Mr. Hopkins could always find some excuse for whipping a slave. It would astonish one, unaccustomed to a slaveholding life, to see with what wonderful ease a slaveholder can find things, of which to make occasion to whip a slave.

A mere look, word, or motion,—a mistake, accident, or want of power,—are all matters for which a slave may be whipped at any time. Does a slave look dissatisfied? It is said, he has the devil in him, and it must be whipped out. Does he speak loudly when spoken to by his master? Then he is getting high-minded, and should be taken down a button-hole lower. Does he forget to pull off his hat at the approach of a white person? Then he is wanting in reverence, and should be whipped for it. Does he ever venture to vindicate his conduct, when censured for

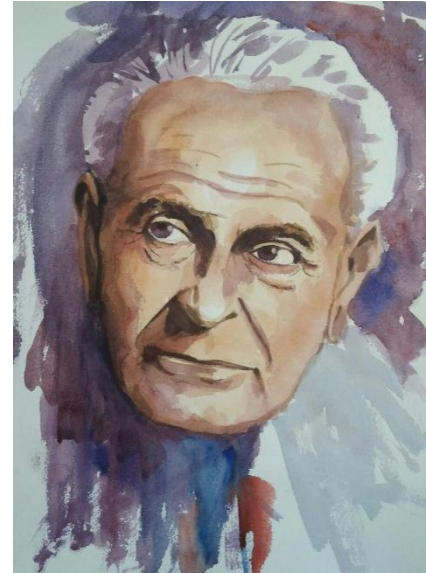
*it? Then he is guilty of impudence,—one of the greatest crimes of which a slave can be guilty. Does he ever venture to suggest a different mode of doing things from that pointed out by his master? He is indeed presumptuous, and getting above himself; and nothing less than a flogging will do for him. Does he, while ploughing, break a plough,—or, while hoeing, break a hoe? It is owing to his carelessness, and for it a slave must always be whipped. Mr. Hopkins could always find something of this sort to justify the use of the lash, and he seldom failed to embrace such opportunities. There was not a man in the whole county, with whom the slaves who had the getting their own home, would not prefer to live, rather than with this Rev. Mr. Hopkins. **And yet there was not a man any where round, who, made higher professions of religion, or was more active in revivals, —more attentive to the class, love-feast, prayer and preaching meetings, or more devotional in his family,—that prayed earlier, later, louder, and longer,—than this same reverend slave-driver, Rigby Hopkins.***”

Xenophanes (570-478 BC) believed that there is an ultimate Truth, but no person has ever nor will ever know it. In fact, even if a person spoke the ultimate Truth, he would not even recognize it. Karl Popper (1963) quoted Xenophanes in *Realism and the Aim of Science*:

*But as for certain truth, no man has known it,
Nor will he know it; neither of the gods
Nor yet of all the things of which I speak.
And even if by chance he were to utter
The perfect truth, he would himself not know it;
For all is but a woven web of guesses.*



Guesses that Popper defined as **working hypotheses** in the search for truth. Popper wrote, *“I then suggested that the whole trouble was due to the mistaken belief that scientific knowledge was an especially strict or certain or august kind of knowledge. This statement met with the same reception as the first. I concluded with an attempt to explain that, in the usual sense of 'know', whenever I know that it is raining, it must be true that it is raining; for if it is not true, then I simply cannot know that it is raining, however sincerely I may believe that I know it. In this sense of the word, 'knowledge' always means 'true and certain knowledge'; and 'to know' means, in addition, to be in possession of sufficient reason for holding that our knowledge is true and certain. But, I said, there was no such thing as scientific knowledge in this sense. If, nonetheless, we chose to label the results of our scientific endeavours with the customary name 'scientific knowledge', then we ought to be clear that scientific knowledge was not a species of knowledge; least of all, a species distinguished by a high degree of solidity or certainty. On the contrary, measured by the high standards of scientific criticism, 'scientific knowledge' always remained sheer guesswork—although guesswork controlled by criticism and experiment...Admittedly, I had attacked, by implication, Science with a capital 'S', and those of its devotees who were ready to take its pronouncements as gospel truth.”*

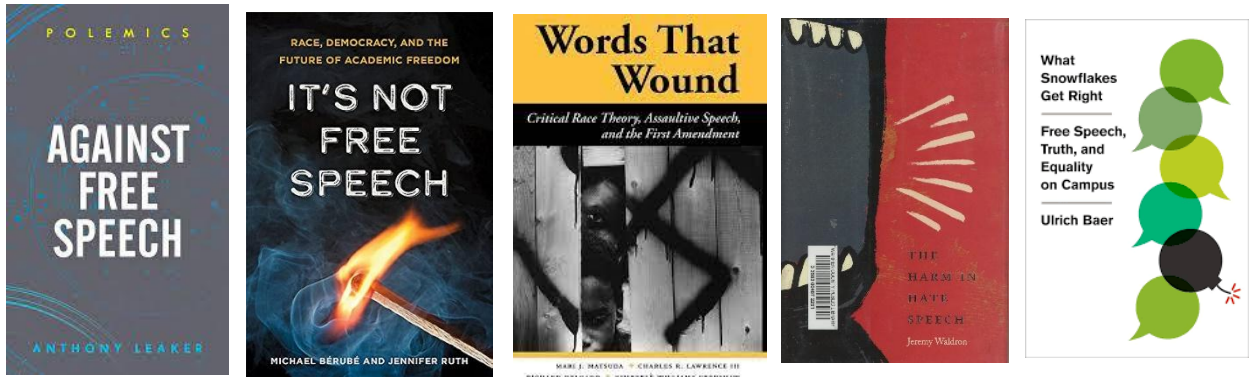


In today's cancel culture, those who believe that they know the truths of science use it to cancel others. Herbert Marcuse (1969) wrote in [Repressive Tolerance](#), *“Such indiscriminate tolerance is justified in harmless debates, in conversation, in academic discussion; it is indispensable in the scientific enterprise, in private religion. But society cannot be indiscriminate where the pacification of existence, where freedom and happiness themselves are at stake: here, certain things cannot be said, certain ideas cannot be expressed, certain policies cannot be proposed, certain behavior cannot be permitted without making tolerance an instrument for the continuation of servitude.”* And, in today's cancel culture, when the happiness of some is at stake, tolerance in the scientific enterprise is no longer warranted.



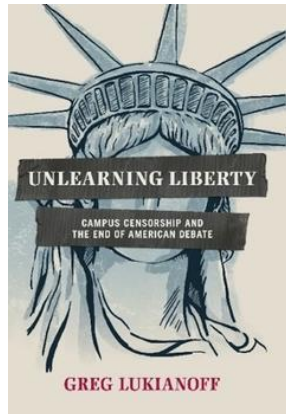
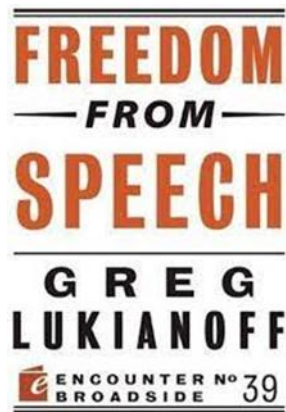
Marcuse goes on to say, *“This pure toleration of sense and nonsense is justified by the democratic argument that nobody, neither group nor individual, is in possession of the truth and capable of defining what is right and wrong, good and bad. Therefore, all contesting opinions must be submitted to 'the people' for its deliberation and choice. But I have already suggested that the democratic argument implies a necessary condition, namely, that the people must be capable of deliberating and choosing on the basis of knowledge, that they must have access to authentic information, and that, on this basis, their evaluation must be the result of autonomous thought.”* This tolerance is not practiced by those who think that they are uniquely intelligent and in possession of authentic information, whereas the unwashed masses, the commonfolk, and the *hoi paloi*, are neither intelligent nor in possession of authentic information.

Many people today agree with Marcuse's idea of speech for me but not for thee:



Greg Lukianoff, the CEO of the Foundation for Individual Rights and Expression disagrees. He testified to Congress on February 6, 2024: *“I’ve dedicated my life to defending freedom of speech because it is an essential human right. However, free speech is more than that; it’s nothing less than essential to our ability to understand the world. A giant step for human progress was the realization that, despite what our senses tell us, knowledge is hard to attain. It’s a never-ending, arduous, necessarily de-centralized process of testing and retesting, of chipping away at falsity to edge a bit closer to truth. It’s not just about the proverbial “marketplace of ideas”; it’s about allowing information — independent of idea or argument — to flow freely so that we can hope to know the world as it really is. This means seeing value in expression even when it appears to be wrongheaded or useless.*





I think that the erasure of Wilberforce's name in academia is a modern instance of **cancel culture**, which is **not unlike** the example set by Theodosius I in 391, when he made pagan thought illegal and not unlike the example set by Pope Theophilus of Alexandria, when he ordered the burning of the last vestige of the great library in Alexandria.



Questioning Darwin is not allowed in academia.

Samuel Wilberforce questioned Darwinian evolution and instead of responding with reason, the response was to use *ad hominem* attacks and then to ostracize **Samuel Wilberforce** and his whole family, including William Wilberforce. Yes, academia can be red in tooth and claw. In terms of what goes around comes around, T. H. Huxley's name was just removed from the **Huxley College of the Environment** at Western Washington University.



HUXLEY

COLLEGE OF THE ENVIRONMENT

ON THE PENINSULAS

We have come a long way, although I would not say progressed, since September 14, 1859, when Prince Albert served as the President at the meeting of the [British Association for the Advancement of Science](#), where he said, “*To return to ourselves, however: one part of the functions of the Association can receive no personal representation, no incarnation: I mean the very fact of meetings like that which we are at present inaugurating. **This is not the thoughtful direction of one mind over acquired knowledge, but the production of new thought by the contact of many minds, as the spark is produced by the friction of flint and steel; it is not the action of the monarchy of a paternal Government, but the republican activity of the Roman Forum.** These meetings draw forth the philosopher from the hidden recesses of his study, call in the wanderer over the field of science to meet his brethren, to lay before them the results of his labours, to set forth the deductions at which he has arrived, to ask for their examination, to maintain in the combat of debate the truth of his positions and the accuracy of his observations. These meetings, unlike those of any other Society, throw open the arena to the cultivators of all sciences, to their mutual advantage: the geologist learns from the chemist that there are problems for which he had no clue, but which that science can solve for him; the geographer receives light from the naturalist, the astronomer from the physicist and engineer, and so on. And all find a field upon which to meet the public at large,—invite them*



*to listen to their reports and even to take part in their discussions,—show to them that philosophers are not vain theorists, but essentially men of practice—**not conceited pedants, wrapped up in their own mysterious importance, but humble inquirers after truth**, proud only of what they may have achieved or won for the general use of man. Neither are they daring and presumptuous unbelievers—a character which ignorance has sometimes affixed to them—who would, like the Titans, storm heaven by placing mountain upon mountain, till hurled down from the height attained, by the terrible thunders of outraged Jove; but rather the pious pilgrims to the Holy Land, who toil on in search of the sacred shrine, in search of truth—God’s truth—God’s laws as manifested in His works, in His creation.”*

The Prayer of Agassiz

By John Greenleaf Whittier (1807–1892)

ON the isle of Penikese,

*Ringed about by sapphire seas,
Fanned by breezes salt and cool,
Stood the Master with his school.
Over sails that not in vain
Wooed the west-wind's steady strain,
Line of coast that low and far
Stretched its undulating bar,
Wings aslant along the rim
Of the waves they stooped to skim,
Rock and isle and glistening bay,
Fell the beautiful white day.*

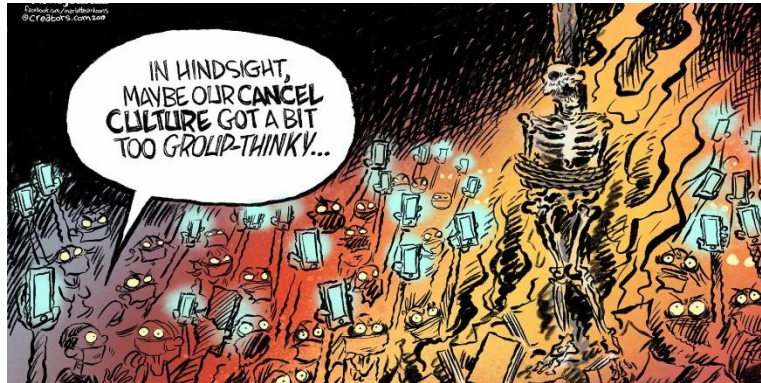
Said the Master to the youth:
"We have come in search of truth,
Trying with uncertain key 15
Door by door of mystery;
We are reaching, through His laws,

*To the garment-hem of Cause,
 Him, the endless, unbegun,
 The Unnameable, the One, 20
 Light of all our light the Source,
 Life of life, and Force of force.
 As with fingers of the blind,
 We are groping here to find
 What the hieroglyphics mean 25
 Of the Unseen in the seen,
 What the Thought which underlies
 Nature's masking and disguise,
 What it is that hides beneath
 Blight and bloom and birth and death. 30
 By past efforts unavailing,
 Doubt and error, loss and failing,
 Of our weakness made aware,
 On the threshold of our task
 Let us light and guidance ask, 35
 Let us pause in silent prayer!"*

*Then the Master in his place
 Bowed his head a little space,
 And the leaves by soft airs stirred,
 Lapse of wave and cry of bird, 40
 Left the solemn hush unbroken
 Of that wordless prayer unspoken,
 While its wish, on earth unsaid,
 Rose to heaven interpreted.
 As in life's best hours we hear 45
 By the spirit's finer ear
 His low voice within us, thus
 The All-Father heareth us;
 And his holy ear we pain
 With our noisy words and vain. 50
 Not for him our violence,
 Storming at the gates of sense;
 His the primal language, his
 The eternal silences!
 Even the careless heart was moved, 55
 And the doubting gave assent,*

*With a gesture reverent,
 To the Master well-beloved.
 As thin mists are glorified
 By the light they cannot hide, 60
 All who gazed upon him saw,
 Through its veil of tender awe,
 How his face was still uplit
 By the old sweet look of it,
 Hopeful, trustful, full of cheer, 65
 And the love that casts out fear.
 Who the secret may declare
 Of that brief, unuttered prayer?
 Did the shade before him come
 Of the inevitable doom, 70
 Of the end of earth so near,
 And Eternity's new year?
 In the lap of sheltering seas
 Rests the isle of Penikese;
 But the lord of the domain 75
 Comes not to his own again:
 Where the eyes that follow fail,
 On a vaster sea his sail
 Drifts beyond our beck and hail!
 Other lips within its bound 80
 Shall the laws of life expound;
 Other eyes from rock and shell
 Read the world's old riddles well;
 But when breezes light and bland
 Blow from Summer's blossomed land, 85
 When the air is glad with wings,
 And the blithe song-sparrow sings,
 Many an eye with his still face
 Shall the living ones displace,
 Many an ear the word shall seek 90
 He alone could fitly speak.
 And one name forevermore
 Shall be uttered o'er and o'er
 By the waves that kiss the shore,
 By the curlew's whistle, sent 95
 Down the cool, sea-scented air;*

*In all voices known to her
 Nature own her worshipper,
 Half in triumph, half lament.
 Thither love shall tearful turn, 100
 Friendship pause uncovered there,
 And the wisest reverence learn
 From the Master's silent prayer.*



The Marquis de Sade (1791) wrote about nature in *Justine*:

"The question is about the thing itself. Surely if you are not stronger than your nature and like to enjoy according to your principles, will you not take to killing?"

"So be it! By tastes bestowed by nature for her own use, who works out her creations through destructions, I shall carry out her own designs. Oh, Therese, is that a crime, to serve nature? And has man the power of committing crimes? And when, preferring his own happiness to that of others, he overthrows and destroys all he finds in his way, has he done anything but serve nature, whose first and surest inspirations prompt him to make himself happy, no matter at whose expense? The system of love for one's neighbor is a fantastic illusion we owe to

Christianity, not to nature. Most followers of early religions were weak, plagued and oppressed; of course they needed toleration very badly, and were forced by their very weakness to cry out for humanity. It meant their salvation to establish this fabulous relation of one being to another, and their preservation depended upon its success. But the philosopher doesn't admit these relationships. Considering but himself alone, only to himself does he account for everything; and prevails by his own strength. He has recourse to those fine systems of humanity and beneficence only at times for policy's sake."

"Such a man is a monster!" Justine said.

"Such a man is a man of nature."

First Light: Big Bang Cosmology and the Origin of Life

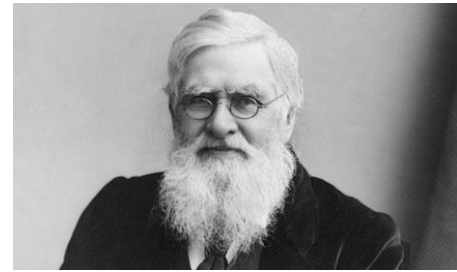
Last time we discussed Samuel Wilberforce's (1860) scientific and critical review of Charles Darwin's *On the Origin of Species by Means of Natural Selection: or The Preservation of Favoured Races in the Struggle for Life*. I also presented what I think was the unfair way Wilberforce was marginalized and forgotten by many in the scientific and academic communities. The marginalization of the whole Wilberforce family name may be a result of Samuel Wilberforce's rigorous criticism of the *Origin of Species*. Indeed, it is even possible that there is, according to Leon Wieseltier, a "scientific tyranny in American intellectual life." Wieseltier realizes that "The problem of the limits of science is not a scientific problem. It is also pertinent to note that the history of science is a history of mistakes, and so the dogmatism of scientists is especially rich." <https://newrepublic.com/article/112481/darwinist-mob-goes-after-serious-philosopher> There is no reason why a free human being has to follow the consensus or authority mindlessly. *Emancipate yourself from mental slavery!*

While **Frederick Douglass** was a slave, he was not a mental slave! Douglass (1845) wrote in *Narrative of the Life of Frederick Douglass, an American Slave*, "I may be deemed superstitious, and even egotistical, in regarding this event as a special interposition of divine Providence in my favor. **But I should be false to the earliest sentiments of my soul, if I suppressed the opinion. I prefer to be true to myself, even at the hazard of incurring the ridicule of others, rather than to be false, and incur my own abhorrence. From my earliest recollection, I date the entertainment of a deep conviction that slavery would not**



always be able to hold me within its foul embrace; and in the darkest hours of my career in slavery, this living word of faith and spirit of hope departed not from me, but remained like ministering angels to cheer me through the gloom. This good spirit was from God, and to him I offer thanksgiving and praise.”

I gave voice to Wilberforce in the last lecture because he has a lot to teach us, yet he has no voice in the modern world. We do hear about **Alfred Russel Wallace**, but only in terms of where he and Darwin agreed. Beyond that, biologists don't often give him a listen either. Wallace differed with Charles Darwin on the influence of natural selection on qualities in humans that in all honesty probably do not have a selective advantage in terms of producing more progeny.



For example, Wallace (1913) did not think that there was a slave making instinct. He wrote in *Social Environment and Moral Progress*, “*The belief was once prevalent, and is still held by many persons, that a knowledge of right and wrong is inherent or instinctive in everyone, and that the immoral person may be justly punished for such wrongdoing as he commits. But that this cannot be wholly, if at all, true is shown by the fact that in different societies and at different periods the standard of right and wrong changes considerably. That which at one time and place is held to be right and proper is, at another time or place, considered to be not only wrong, but one of the greatest of crimes. The most striking example of this change of opinion is that of **slavery**, which was held to be quite justifiable by the most highly civilized people of antiquity, and hardly less so by ourselves within the memory of persons still living.*”



In a review of Lyell's books *Principles of Geology*, tenth edition and *Elements of Geology*, sixth edition, published in the *Quarterly Review* (April

1869), Wallace wrote, “*This subject is a vast one, and would require volumes for its proper elucidation, but enough, we think, has now been said, to indicate the possibility of a new stand-point for those who cannot accept the theory of evolution as expressing the **whole truth** in regard to the origin of man. While admitting to the full extent the agency of the same great laws of organic development in the origin of the human race as in the origin of all organized beings, **there yet seems to be evidence of a Power which has guided the action of those laws in definite directions and for special ends. And so far from this view being out of harmony with the teachings of science, it has a striking analogy with what is now taking place in the world, and is thus strictly uniformitarian in character.** Man himself guides and modifies nature for special ends. The laws of evolution alone would perhaps never have produced a grain so well adapted to his uses as wheat; such fruits as the seedless banana, and the bread-fruit; such animals as the Guernsey milch-cow, or the London dray-horse. Yet these so closely resemble the unaided productions of nature, that we may well imagine a being who had mastered the laws of development of organic forms through past ages, refusing to believe that any new power had been concerned in their production, and scornfully rejecting the theory that in these few cases a distinct intelligence had directed the action of the laws of variation, multiplication, and survival, for his own purposes. We know, however, that this has been done; and we must therefore admit the possibility, that in the development of the human race, a Higher Intelligence has guided the same laws for nobler ends.*

Such, we believe, is the direction in which we shall find the true reconciliation of Science with Theology on this most momentous problem. Let us fearlessly admit that the mind of man (itself the living proof of a supreme mind) is able to trace, and to a considerable extent has traced, the laws by means of which

the organic no less than the inorganic world has been developed. But let us not shut our eyes to the evidence that an Overruling Intelligence has watched over the action of those laws, so directing variations and so determining their accumulation, as finally to produce an organization sufficiently perfect to admit of, and even to aid in, the indefinite advancement of our mental and moral nature.”

Wallace had the same opinion in the twentieth century. In an interview with W. B. Northrop, Wallace (1913) said, *“I maintain that the theory of evolution does not account for many of the mental attributes of man. It does not account for our wonderful mathematical, musical, or artistic faculties. Who can claim that man has received these endowments from some lower animal which never possessed an inkling of them? Many of the lower animals, it is true, display a much finer physical and muscular development than man does. They are gifted with greater agility and endurance, and undoubtedly we have derived from them many of our physical attributes. But who can reasonably say that we are indebted to any of the lower animals for our high intellectual faculties? The gulf which separates the ant from Newton, the ape from Shakespeare, the parrot from Isaiah, cannot be bridged by the struggle for existence. To call the spiritual nature of man a 'by-product,' developed by us in our struggle for existence, is a joke too big for this little world. **It was on this very point that I differed from Darwin, and it is on these points that I cannot meet the modern materialists who say that man is merely an animal and there is nothing for him beyond the grave.** It is very well for us to try to account for the material on a mere material basis, and it may be very satisfactory to some people who do not seriously consider the subject; but, if the soul has come into being from what is popularly termed 'the struggle for existence,' how is it that in this very struggle for existence we meet daily with people who are making self-sacrifices, exhibiting wonderful heroism and disinterested affection—live men and*

women of the day who are actually spending their existence for the sake of others? If every one were merely engaged in the desperate struggle for existence, why should any member of the human family try to help along or support anybody else?

"Evolution can account well enough for the land-grabber, the company promoter, the trust, and the sweater, but it fails to account for Raphael and Wagner, Swedenborg, Newton, Florence Nightingale, or others of this character. The world has been moved far more by spiritual forces than by material and selfish ones. Neither Darwin nor Moses has yet conquered mankind. Life, with its mysteries of consciousness and personality, is still the dumping-ground of theories and dreams. Until science has demonstrated the existence of the soul man approaches death with an open mind. I hold that the existence of the soul and the presence of consciousness beyond the grave have been already proved. It is because the scientific investigation of psychical matters has become confused in the popular mind with the imposture of charlatans that indiscriminating people regard Spiritualism as a fake. An honest and unbiased examination of all the facts gathered by modern psychologists would certainly open the eyes of even the most doubtful of all the Thomases. Truth is born into this world only with pangs and tribulations, and every fresh truth is received unwillingly. To expect the world to receive a new truth, or even an old truth, without challenging it, is to look for one of those miracles which do not occur."

T. H. Huxley began to see the limits of the theory of evolution by natural selection when it came to the **ethical behavior of human beings**. In his Romanes Lecture of 1893, eleven years after Charles Darwin died, he said, "*The science of ethics professes to furnish us with a reasoned rule of life; to tell us **what is right action** and **why it is so**. Whatever differences of opinion may exist among experts, there is a*



general consensus that the ape and tiger methods of the struggle for existence are not reconcilable with sound ethical principles ... As I have already urged, the practice of that which is ethically best—what we call goodness or virtue—involves a course of conduct which, in all respects, is opposed to that which leads to success in the cosmic struggle for existence. In place of ruthless self-assertion it demands self-restraint; in place of thrusting aside, or treading down, all competitors, it requires that the individual shall not merely respect, but shall help his fellows; its influence is directed, not so much to the survival of the fittest, as to the fitting of as many as possible to survive. It repudiates the gladiatorial theory of existence. It demands that each man who enters into the enjoyment of the advantages of a polity shall be mindful of his debt to those who have laboriously constructed it; and shall take heed that no act of his weakens the fabric in which he has been permitted to live. Laws and moral precepts are directed to the end of curbing the cosmic process and reminding the individual of his duty to the community, to the protection and influence of which he owes, if not existence itself, at least the life of something better than a brutal savage.”

T.H. Huxley went on to say, *“Let us understand, once for all, that the ethical progress of society depends, not on imitating the cosmic process, still less in running away from it, but in combating it. It may seem an audacious proposal thus to pit the microcosm against the macrocosm and to set man to subdue nature to his higher ends; but I venture to think that the great intellectual difference between the ancient times with which we have been occupied and our day, lies in the solid foundation we have acquired for the hope that such an enterprise may meet with a certain measure of success.”*

In the third edition of *Darwinism* by Alfred Russel Wallace (1912), he wrote, *“I am glad to be able to quote the opinion of the late Professor Huxley in support of*

one of the more important arguments adduced in this chapter as to certain human faculties being such as could not have been developed by the agency of natural selection. Mr. Wilfred [sic Wilfrid] Ward (in the Nineteenth Century of August 1896) states, that Huxley once said to him: ‘One thing which weighs with me against pessimism, and tells for a benevolent Author of the Universe, is, my enjoyment of scenery and music. I do not see how they can have helped in the struggle for existence. They are gratuitous gifts.’”

<https://mathcs.clarku.edu/huxley/comm/Books/Ward.html>

<https://books.google.com/books?id=k29JAAAAYAAJ&pg>

In *The Nature of Government*, Ayn Rand (1966) points out something that separates human beings from animals: “[m]an is the only species that can transmit and expand his store of knowledge from generation to generation.”



Rand wrote, “[s]ince man’s mind is his basic tool of survival, his means of gaining knowledge to guide his actions—the basic condition he requires is the freedom to think and to act according to his rational judgment. This does not mean that a man must live alone and that a desert island is the environment best suited to his needs. Men can derive enormous benefits from dealing with one another. A social environment is most conducive to their successful survival—but only on certain conditions.

“The two great values to be gained from social existence are: knowledge and trade. Man is the only species that can transmit and expand his store of knowledge from generation to generation; the knowledge potentially available to man is greater than any one man could begin to acquire in his own lifespan; every man

gains an incalculable benefit from the knowledge discovered by others. The second great benefit is the division of labor: it enables a man to devote his effort to a particular field of work and to trade with others who specialize in other fields. This form of cooperation allows all men who take part in it to achieve a greater knowledge, skill and productive return on their effort than they could achieve if each had to produce everything he needs, on a desert island or on a self-sustaining farm.

*“But these very benefits indicate, delimit and define what kind of men can be of value to one another and in what kind of society: only rational, productive, independent men in a rational, productive, free society.” (“The Objectivist Ethics,” *The Virtue of Selfishness*)*

A society that robs an individual of the product of his effort, or enslaves him, or attempts to limit the freedom of his mind, or compels him to act against his own rational judgment—a society that sets up a conflict between its edicts and the requirements of man’s nature—is not, strictly speaking, a society, but a mob held together by institutionalized gang-rule.”

Thomas Jefferson wrote to Peter Carr on August 10, 1787: “Moral philosophy. ... man was destined for society. his morality therefore was to be formed to this object. he was endowed with **a sense of right & wrong** merely relative to this. **this sense is as much a part of his nature as the sense of hearing, seeing, feeling ... the moral sense, or conscience, is as much a part of man as his leg or arm.**”

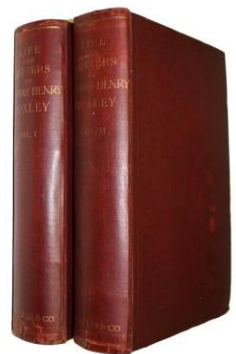
Scientists typically ask what makes humans like apes; but we also must ask **what makes us different?** What is the origin of our conscience, our sense of right and wrong, good and evil? Jonathan Haidt, Paul Bloom, and others ask such questions.



Charles Darwin disagreed with Wallace, writing to him, on March 27, 1869: *“I hope you have not murdered too completely your own & my child.”* The editors (2007) of *Nature* identify with Darwin, writing *“the idea that human minds are the product of evolution is not atheistic theology. It is unassailable fact.”* <https://www.nature.com/articles/447753a>

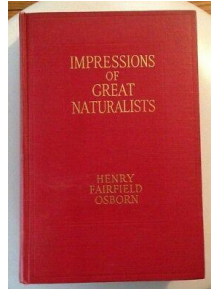


Aside: T. H. Huxley was not such a **“bulldog”** as his reputation suggests. In fact, he was never called Darwin’s bulldog during his lifetime. The oft-repeated idea that he was Darwin’s bulldog came about like so: In a lecture given in 1895, shortly after Huxley’s death, **Henry Fairfield Osborn** described a day in 1879 when Darwin visited Huxley’s anatomy class where Osborn was a student. According to Osborn, *“They came in together, Huxley leading slowly down the long, narrow room, pointing out the especial methods of teaching, which he had originated and which are now universally adopted in England and in this country. Darwin was instantly recognized by the class as he entered and sent a thrill of curiosity down the room, for no one present had ever seen him before. There was the widest possible contrast in the two faces. Darwin’s grayish-white hair and bushy eyebrows overshadowed the pair of deeply set blue eyes, which seemed to image his wonderfully calm and deep vision of nature, and at the same time to emit benevolence. Huxley’s piercing black eyes and determined and resolute face were full of admiration and at the same time protection of his older friend. He said afterwards: ‘You know I have to take care of him—in fact, I*

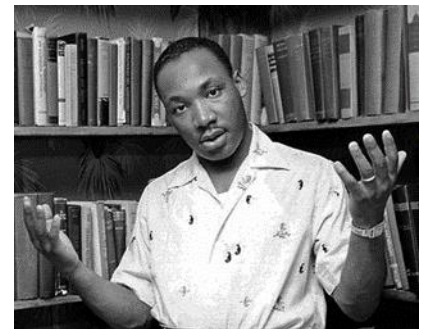


have always been Darwin's bull-dog,' and this exactly expressed one of the many relations which existed so long between the two men."

In *Life and Letters of Thomas Henry Huxley* (v. 1, p. 363), Leonard Huxley (1900), T. H. Huxley's son and PR man, changed Osborn's recollection to a direct quote having to do with the so-called Huxley-Wilberforce debate: *"I am Darwin's bull-dog,' he once said, and the Quarterly Reviewer's treatment of Darwin, 'alike unjust and unbecoming,' provoked him into immediate action."* Since then, Huxley's image as being a bull-dog stuck (<https://www.linnean.org/news/2019/07/01/1st-july-2019-why-there-was-no-darwins-bulldog>). Even Osborn eventually came to ape Leonard Huxley's misrepresentation of Osborn's earlier writing, changing "once" to "often." Osborn (1924) wrote that Huxley *"often alluded to himself as "Darwin's bull dog."* This is how scientific reputations are made. Science is not immune from the use of propaganda.



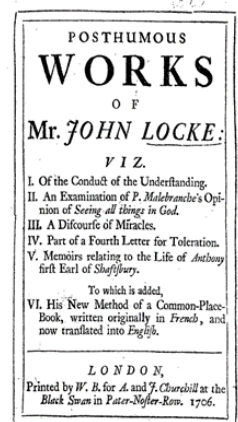
Martin Luther King (1947) wrote in "The Purpose of Education:" *"To think incisively and to think for one's self is very difficult. We are prone to let our mental life become invaded by legions of half truths, prejudices, and propaganda.... To save man from the morass of propaganda, in my opinion, is one of the chief aims of education. Education must enable one to sift and weigh evidence, to discern the true from the false, the real from the unreal, and the facts from the fiction."*



To be able to sift and weigh evidence at a university, a university must be what Justice **William O. Douglas** called, a “*marketplace of ideas*” where there must be, in Justice **Oliver Wendell Holmes** (1919)’ words, a “*free trade in ideas.*” Holmes went on to say, “*The best test of truth is the power of the thought to get itself accepted in the competition of the market.*” But this test is only valid when opposing evidence is freely available. As William Bragg (1933) wrote, “*From religion comes man’s purpose; from science, his power to achieve it. Sometimes people ask if religion and science are not opposed to one another. They are: in the sense that the thumb and fingers on my hand are opposed to one another. It is an opposition by means of which anything can be grasped.*”



John Locke (1706) in *Of the Conduct of the Understanding*, wrote “*Every man carries about him a touchstone, if he will make use of it, to distinguish substantial gold from superficial glitterings, truth from appearances. And indeed the use and benefit of this touchstone, which is natural reason, is spoiled and lost only by assumed prejudices, overweening presumption, and narrowing our minds.*”



David Herbert Lawrence or **D. H. Lawrence**, as he is better known, wrote about the sense of truth in *The Deepest Sensuality*:

*The profoundest of all sensualities
is the sense of truth
and the next deepest sensual experience
is the sense of justice.*



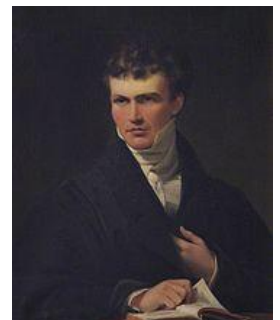
Sense of Truth

*You must fuse mind and wit with all the senses
Before you can feel truth.
And if you can't feel truth you can't have any other
Satisfactory sensual experience.*

Again, a deep understanding of science could be good for your relationship.

I believe that human beings have a “*sense of truth*.” This sense helps to analyze phenomena, including scientific phenomena, when we have incomplete information. If you believe we have a sense of truth, could natural selection account for the development of a *sense of truth*?

In a paper entitled, *On the fundamental antithesis of philosophy*, **William Whewell** discusses two kinds of truths: *necessary truths* and *truths of experience*. Necessary truths, like $2 + 2 = 4$, cannot be otherwise. On the other hand, we can imagine that the truths of experience, such as the earth orbits the sun in a year, the moon goes through its phases in a month, and the earth rotates in a day, could be otherwise. “*Necessary truths are formed from our thoughts, the elements of the world within us; and are established from definitions and axioms. The truths of experience, as*



*they appear to us in the external world, we call Facts; and when we are able to find among our ideas a train which will conform themselves to the apparent facts, we call this a Theory. This distinction and opposition, thus expressed in various forms; as Necessary and Experiential Truth, Ideas and Senses, Thoughts and Things, Theory and Fact, may be termed **the Fundamental Antithesis of Philosophy**; for almost all the discussions of philosophers have been employed in asserting or denying, explaining or obscuring this antithesis. **No apprehension of things is purely ideal: no experience of external things is purely sensational...If we think of any thing, we must recognize the existence both of thoughts and things. The fundamental antithesis of philosophy is an antithesis of inseparable elements. We are often told that such a thing is a fact and not a Theory...Does the apprehension of the fact imply assumptions which may with equal justice be called a theory, and which are perhaps false theory? In which case, the fact is no fact.**"*

We must take care and use our experience when it comes to what we accept as necessary truths. In 1984, George Orwell (1949) wrote

*"'Do you remember,' he went on, 'writing in your diary, "**Freedom is the freedom to say that two plus two make four**"?"'*

'Yes,' said Winston.

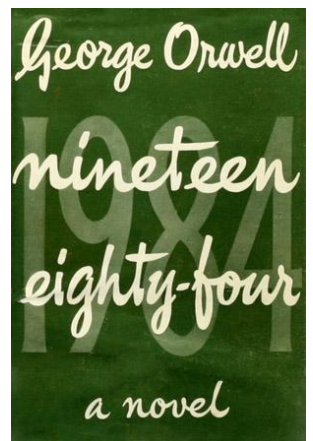
O'Brien held up his left hand, its back towards Winston, with the thumb hidden and the four fingers extended.

'How many fingers am I holding up, Winston?'

'Four.'

'And if the party says that it is not four but five—then how many?'

'Four.'



The word ended in a gasp of pain. The needle of the dial had shot up to fifty-five. The sweat had sprung out all over Winston's body. The air tore into his lungs and issued again in deep groans which even by clenching his teeth he could not stop. O'Brien watched him, the four fingers still extended. He drew back the lever. This time the pain was only slightly eased.

'How many fingers, Winston?'

'Four.'

The needle went up to sixty.

'How many fingers, Winston?'

'Four! Four! What else can I say? Four!'

The needle must have risen again, but he did not look at it. The heavy, stern face and the four fingers filled his vision. The fingers stood up before his eyes like pillars, enormous, blurry, and seeming to vibrate, but unmistakably four.

'How many fingers, Winston?'

'Four! Stop it, stop it! How can you go on? Four! Four!'

'How many fingers, Winston?'

'Five! Five! Five!'

'No, Winston, that is no use. You are lying. You still think there are four. How many fingers, please?'

'Four! five! Four! Anything you like. Only stop it, stop the pain!'

Abruptly he was sitting up with O'Brien's arm round his shoulders. He had perhaps lost consciousness for a few seconds. The bonds that had held his body down were loosened. He felt very cold, he was shaking uncontrollably, his teeth were chattering, the tears were rolling down his cheeks. For a moment he clung to O'Brien like a baby, curiously comforted by the heavy arm round his shoulders. He had the feeling that O'Brien was his protector, that the pain was something that came from outside, from some other source, and that it was O'Brien who would save him from it.

'You are a slow learner, Winston,' said O'Brien gently.

'How can I help it?' he blubbered. 'How can I help seeing what is in front of my eyes? Two and two are four.'

'Sometimes, Winston. Sometimes they are five. Sometimes they are three. Sometimes they are all of them at once. You must try harder. It is not easy to become sane.'

Does the scientific establishment ever put us in the position of being a Winston?

<https://www.youtube.com/watch?v=IyLfcNaeB7Y&feature=youtu.be>

On February 10, 2014, The American Institute of Biological Sciences

(<http://ncse.com/news/2014/02/aibs-opposes-oklahomas-antiscience-bill-0015389>



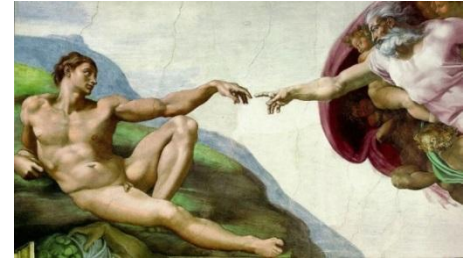
NCSE
National Center for
Science Education

http://www.aibs.org/position-statements/20140210_ok_science_ed_act.html) wrote the following about a bill being considered by the Oklahoma Legislature:

*“Advocates for this and similar legislation often assert that evolution and climate change are controversial subjects. Any controversy is purely political. **There is no legitimate scientific controversy about evolution or climate change.** Scientists have, and continue to, empirically test these concepts and with each test the evidence grows stronger and our understanding more thorough.”* Similar bills are currently being debated in many states: <https://ncse.com/news/2017>.

Charles Darwin (1859) ended his *Origin of Species* like so: *“It is interesting to contemplate an entangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent on each other in so complex a manner, have all been **produced by laws acting around us. These laws, taken in***

*the largest sense, being Growth with Reproduction; Inheritance which is almost implied by reproduction; Variability from the indirect and direct action of the external conditions of life, and from use and disuse; a Ratio of Increase so high as to lead to a Struggle for Life, and as a consequence to Natural Selection, entailing Divergence of Character and the Extinction of less-improved forms. Thus, from the **war of nature**, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved.”*

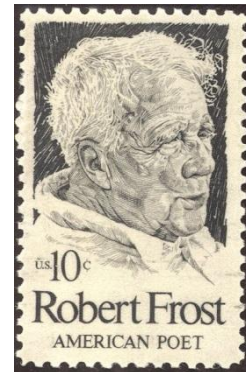


Where did life come from?

The Secret Sits

*We dance round in a ring and suppose,
But the Secret sits in the middle and knows.*

--Robert Frost



Aristotle (350 BC), who synthesized the teachings of the times into a theory of life that envisioned that living beings can **either** come from other living beings following the sexual union of male and female **or** if their type does not have sex, they can be formed **spontaneously**. It seemed to Aristotle that plants originated spontaneously from the earth; frogs sprang up from mud; fireflies came from the morning dew; and



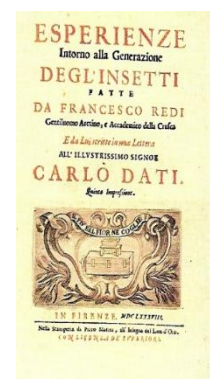
maggots, flies, fleas, and lice came from manure, decaying meat, and other filth. This conclusion, which Aristotle presented in *On the Generation of Animals*, is supported by **casual observations** of the world.

(<http://www.esp.org/books/aristotle/generation-of-animals/html/>) Indeed Lucretius (50 BC) wrote *On the Nature of Things* that “*Earth, the all-mother, is beheld to be.*” (http://classics.mit.edu/Carus/nature_things.mb.txt)

Johannes Baptista van Helmont, a physician, natural philosopher, pious heretic, searcher for truth, child of the seventeenth century, discoverer of gases (from the Greek *Xaos*), and target of the Spanish Inquisition from 1625 to 1642, had a recipe for producing mice by combining human sweat with wheat germ and leaving them alone in a jar for 21 days. However, in 1668, **Francesco Redi**, a physician, natural philosopher and poet, saw things differently with regard to spontaneous generation. In his book, *Esperienze intorno alla Generazione degl’Insetti*, Redi showed that maggots did not appear in meat when he placed the meat in a jar, and carefully covered it with fine gauze. In fact, he noticed that maggots did not arise spontaneously, but only developed when flies were allowed to lay their eggs on the meat.



T. H. Huxley translated Redi’s words (in an Address to the British Association at Liverpool in 1870): “*Here are dead animals, or pieces of meat. I expose them to the air in hot weather, and in a few days they swarm with maggots. You tell me that these are generated in the dead flesh; but if I put similar bodies, while quite fresh, into a jar, and tie some fine gauze over the top of the jar, not a maggot makes its*



appearance, while the dead substances, nevertheless, putrefy just in the same way as before. It is obvious, therefore, that the maggots are not generated by the corruption of the meat; and that the cause of their formation must be something which is kept away by gauze. But gauze will not keep away aëriform bodies, or fluids. This something must, therefore, exist in the form of solid particles too big to get through the gauze. Nor is one long left in doubt what these solid particles are; for the blowflies, attracted by the odour of the meat, swarm around the vessel and, urged by a powerful but, in this case, misleading instinct, lay eggs, out of which the maggots are immediately hatched, upon the gauze. The conclusion, therefore, is unavoidable; the maggots are not generated by the meat, but the eggs which give rise to them are brought through the air by the flies.”

The belief in spontaneous generation of large plants and animals began to wane throughout the 17th and 18th centuries, due in part to observations on sperm by **Antony van Leeuwenhoek** and on embryo development by William Harvey. However, with the discovery of **animalcules** by Leeuwenhoek (1676), the belief in the spontaneous generation of microbes became the standard belief because the microbes **seemed to appear out of nothing**.



Leeuwenhoek was a draper and probably used a magnifying glass to inspect the quality of cloth. His curiosity and observational powers led to many discoveries. His interest in the cause of taste led to the discovery of bacteria: *“Having several times endeavoured to discover the cause of the pungency of Pepper upon our tongue, and that the rather, because it hath been found, that though Pepper had lain a whole year in vinegar, yet it retained still its pungency; I did put about 1/3 of an ounce of whole pepper in water, placing it in my Study,*

with the design, that the pepper being thereby rendred soft, I might be enabled the better to observe what I proposed to my self. This pepper having lain about 3 weeks in the water, to which I had twice added some Snowwater, the other water being in part exhaled; I looked upon it the 24. of April 1676. and discern'd in it, to my great wonder, an incredible number of very little animals of divers kinds....”

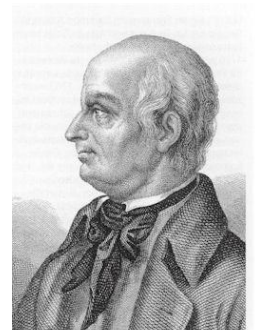
Demonstration: Observe the presence of microbes in black pepper water that was not inoculated. Did they arise by spontaneous generation?

fig: G. ~~~~~

The apparent spontaneous generation of microorganisms was **confirmed experimentally** when **John Needham** (1749), a Catholic Priest, boiled mutton gravy, stoppered it, and found that microbes grew in the boiled broth.



Lazzaro Spallanzani (1769, 1784), another Catholic Priest and natural philosopher, repeated Needham's experiment and showed that if you boiled chicken broth and the container it was in *extensively* before you stoppered it tightly, microbes would not appear in the broth. They only appeared after the stopper was opened. Thus, it appeared that microbes only seemed to arise spontaneously because they were ubiquitous. They were either already in any preparation that had not been properly sterilized or were capable of contaminating any preparation that they could enter. Spallanzani's supporters believed that he had shown that spontaneous generation was impossible, whereas Needham's supporters believed that Spallanzani had only shown that microbes need air.

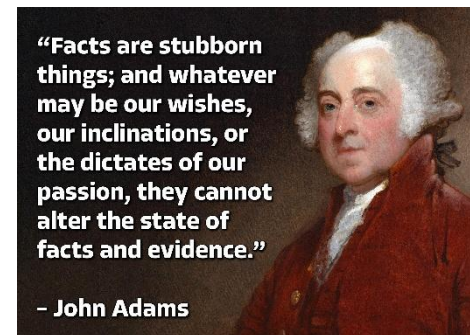


In the middle of the 19th century, **Louis Pasteur** performed the critical experiment. With his now-famous swan-shaped flasks that allowed air, but not microbes, to pass, Pasteur showed that as long as a solution is properly sterilized (e.g., **pasteurized**) and airborne contaminants excluded by cotton-wool, no microbes were generated in the broth, even when air was able to freely pass through the long neck. He concluded that there is no such thing as spontaneous generation of microbes. In his Address to the British Association in Liverpool in 1870, T. H. Huxley traced “*the path of which has been followed by a scientific idea in its long and slow progress from the position of a probable hypothesis to that of an established Law of Nature.*” That is, from Redi’s hypothesis to the Law of Nature that ***all life comes from pre-existing life***. The famous quote by T. H. Huxley, “*The great tragedy of Science—the slaying of a beautiful hypothesis by an ugly fact*” can be found in his Address to the British Association at Liverpool in 1870.

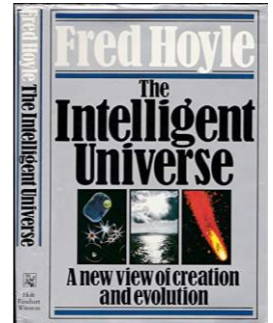
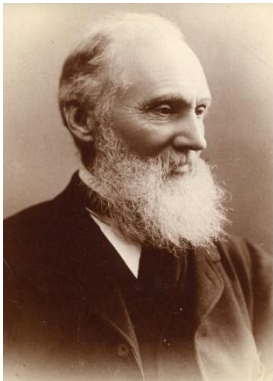
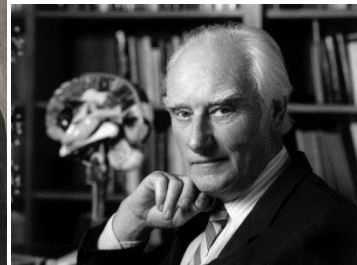


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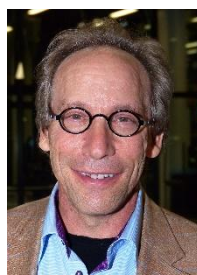
Aside: In his defense of the British soldiers in the Boston Massacre Trial, John Adams (December 4, 1770) characterized facts as stubborn things: “***Facts are stubborn things; and whatever may be our wishes, our inclinations, or the dictates of our passion, they cannot alter the state of facts and evidence.***”



If living organisms cannot originate spontaneously, and the early earth was a molten ball incapable of supporting life, then how did they originate on earth? Some scientists, including Hermann Richter (1865), **Lord Kelvin (1871)**, **Hermann von Helmholtz (1881)**, **Svante Arrhenius (1908)**, **Francis Crick (1981)**, and **Fred Hoyle** realizing that no one has yet created life in the laboratory, suggested that life cannot be created, but must come from existing life. If life can only originate from life, then life on earth must have originated in outer space and come to earth on meteorites in the form of cosmozoa, microbes, spores, or seeds. This theory is called **panspermia**, which means seeds everywhere. Arrhenius (1908) wrote, “*The Universe in its essence has always been what it is now. Matter, energy, and life have only varied as to shape and position in space.*”



Even if the panspermia theory is true, we are still faced with the question of how living organisms originated in the universe. So, although it is possible that life on Earth originated on another planet in another solar system or another galaxy, I will use **Occam's razor** and assume that **life on Earth originated from or was created from lifeless matter on Earth itself**. This does not mean that life did not also arise from lifeless matter elsewhere in the universe, and the arguments I



make apply to the origin of life anywhere. Let us now start at the beginning, the origin of the universe.

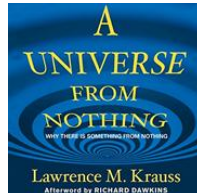
According to Lawrence Krauss, there is no creator, and the universe came from nothing. (<https://www.youtube.com/watch?v=7ImvIS8PLIo>;

<https://www.youtube.com/watch?v=46sKeycH3bE>;

<https://www.youtube.com/watch?v=MawwCJ5q-2Y>;

<https://www.youtube.com/watch?v=vwzbU0bGOdc>) This is contrary to the **first**

law of thermodynamics, which states that energy cannot be created or destroyed except by the creator. The first law of thermodynamics is not consistent with **Heisenberg's uncertainty principle** that states that energy can be created for a period of time as long as the product of the energy and duration of time is equal to or less than Planck's constant. The two laws of nature **contradict** each other, and you can decide for yourself which is more fundamental.



The first law of thermodynamics, which represents the best of scientific thinking, states that energy can be created or destroyed in the natural world because of a (supernatural) miracle. This is science as opposed to scientism.

**There are Five Free Miracles
Science Asks Us to
Give Them.**



And they will explain everything else.

In *The Emperor's New Mind*, Roger Penrose (1989) guesses just how small the possibility is in creating a universe using probability and a phase space approach:

Try to imagine the phase space of the entire universe! Each point in this phase space represents a different possible way that the universe might have started off. We are to picture the Creator, armed with a 'pin' - which is to be placed at some

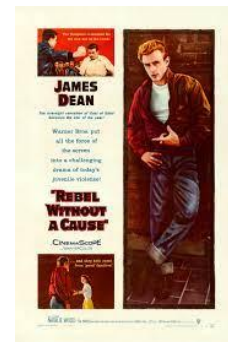
point in the phase space. Each different positioning of the pin provides a different universe. Now the accuracy that is needed for the Creator's aim depends upon the entropy of the universe that is thereby created. It would be relatively 'easy' to produce a high entropy universe, since then there would be a large volume of the phase space available for the pin to hit. (Recall that the entropy is proportional to the logarithm of the volume of the phase space concerned.) But in order to start off the universe in a state of low entropy—so that there will indeed be a second law of thermodynamics—the Creator must aim for a much tinier volume of the phase space. How tiny would this region be, in order that a universe closely resembling the one in which we actually live would be the result?

This now tells us how precise the Creator's aim must have been: namely to an accuracy of one part in 10^{123} .

Demonstration: Have you ever seen matter create itself? Using only the objects in the empty tray in front of you, create a universe. Please raise your hand when you are finished. Do you think the results would be different if the experiment were repeated by each person on earth (<http://www.worldometers.info/world-population/>), every day for a year? Why or why not? (I should give you six days and let you rest on the seventh). Out of curiosity, did anyone in this room give birth to themselves?

Imagine a movie “*A Universe without a Cause.*”

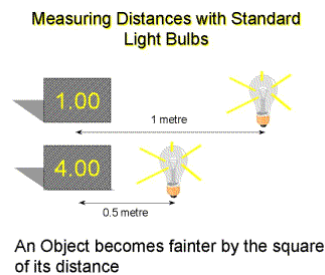
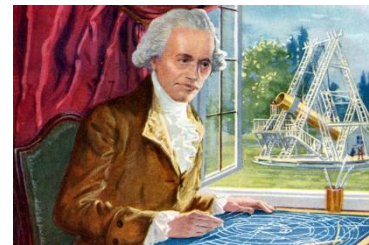
Demonstration: The transformation of energy and the **First Law of Thermodynamics**. Energy cannot be created or destroyed but it can be interconverted.



Our present idea of the origin of the universe is intimately connected with our concept of its **size**. In Ptolemy's time it was believed that earth was like a point in the center of a spherical universe. In the 17th century, **Christiaan Huygens** made attempts to measure the distance to the stars by using the **Principle of Uniformity of Nature** and provisionally assuming that the sun was a star and the distant stars had the same intrinsic brightness as the sun. Huygens assumed that the stars only appeared dimmer than the sun due to their distance. The sun served as a **standard candle**. Using the inverse square law,

Huygens estimated that Sirius, the brightest star, is 28,000 times farther from earth than the sun is. The equation is:

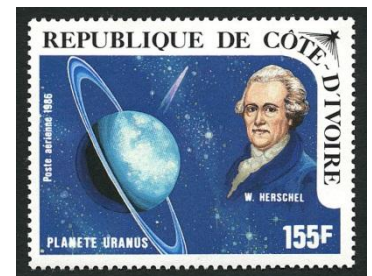
$$I_{star} 4\pi r_{star}^2 =$$



sun is. The

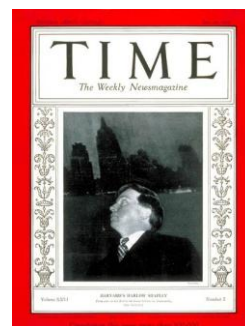
$$S_{sun or star} = I_{sun} 4\pi r_{sun}^2 =$$

Throughout the 18th century, telescope designs improved, and **William Herschel** began to see the **more distant stars** which were dimmer and thus had not been seen with the older telescopes that had less light-gathering power. Herschel described light-gathering power as “*the power of penetrating into space.*” With each improvement of the telescope, the known universe became larger and larger. William Herschel did not start out as an astronomer but became interested in astronomy as a result of his interest in **music**, which led him to **mathematics**, having read Robert Smith's (1749, 1738) *Harmonics, or the Philosophy of Musical Sounds* and *A Compleat System of Opticks*, which led him to **optics** and the **design of**

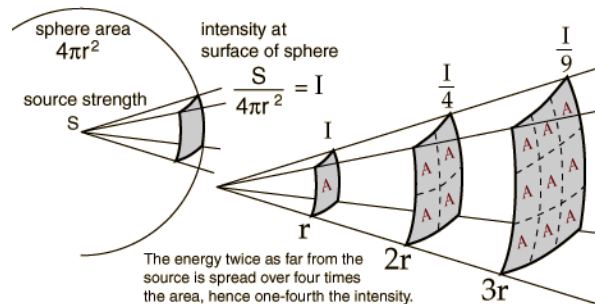


telescopes, which led him to astronomy. Herschel was indeed a polymath. He discovered many new double stars (1782, 1785, 1821), Uranus (which was originally called *Georgium Sidus* by Herschel in honor of George III in 1781), infrared radiation (1800), and he related the increased price of wheat to the paucity of sunspots (1801). His son was John Herschel.

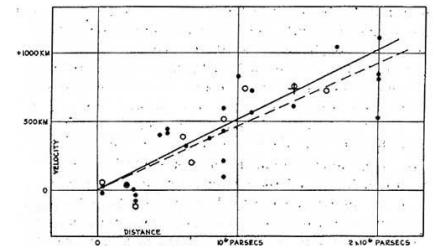
Using the giant telescopes at the Palomar and Harvard College observatories in the early 20th century, **Harlow Shapley** mapped the positions of spiral nebulae, which are now known as galaxies, using the intrinsic brightness of stars known as **Cepheids** as standard candles. While Shapley thought that the spiral nebulae were all within the Milky Way, he concluded that the Milky Way was much bigger than previously thought and therefore the universe too was *even larger* than his predecessors conjectured.



Meanwhile, **Vesto Slipher** measured the **red shifts** in the spectra of number of galaxies. Using the **Doppler Principle**, he concluded that, as a rule, the galaxies were receding from earth at tremendous velocities. We talked about Gregor Mendel and Christian Doppler last week. We will talk more about spectral lines and red shifts next week.



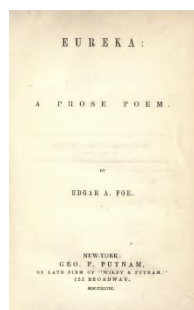
In the 1920s, **Edwin Hubble** noticed that the recession velocities determined by the **red shifts** of the spectra of galaxies were proportional to their distance from earth, and concluded that the universe was not only large but *expanding*. Hubble determined the constant of proportionality between the recession velocity and the distance from earth. The proportionality constant is known as the *Hubble constant*. If we assume that prior to the large-scale expansion of the universe all the galaxies were clumped together, we can estimate the age of the universe from the reciprocal of Hubble's constant. The current best guess for **the age of the universe is 13.8 billion years**.



How was the universe formed? According to the thirteenth century thinking of **Robert Grosseteste** (Grandy, 2014), *God created a dimensionless point of light containing both form and matter. As the point expanded, differentiation ensued to produce the material multiplicity of the cosmos. The first moment of creation, the moment of first light, hence lives on in all later moments, and this fact expresses itself in the splendor of the physical universe.*

In 1848, Edgar Allen Poe wrote in *Eureka: A Prose Poem*

Oneness, then, is all that I predicate of the originally created Matter; but I propose to show that this Oneness is a principle abundantly sufficient to account for the constitution, the existing phenomena and the plainly inevitable annihilation of at least the material Universe. The willing into being the primordial particle, has completed the act, or more properly the conception, of Creation.



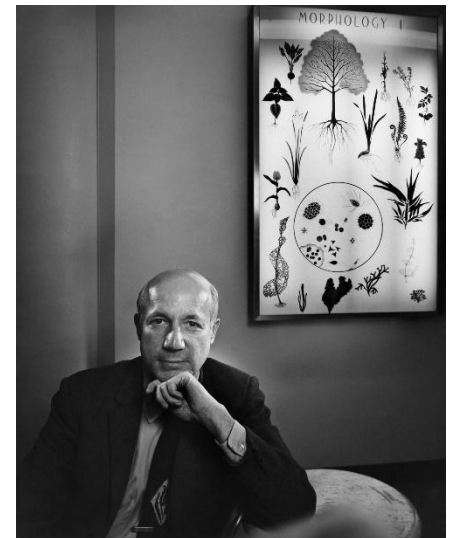
We now proceed to the ultimate purpose for which we are to suppose the Particle created that is to say, the ultimate purpose so far as our considerations yet enable us to see it the constitution of the Universe from it, the Particle.

This constitution has been effected by forcing the originally and therefore normally One into the abnormal condition of Many. An action of this character implies reaction. A diffusion from Unity, under the conditions, involves a tendency to return into Unity a tendency ineradicable until satisfied. But on these points I will speak more fully hereafter.

The assumption of absolute Unity in the primordial Particle includes that of infinite divisibility. Let us conceive the Particle, then, to be only not totally exhausted by diffusion into Space. From the one Particle, as a centre, let us suppose to be irradiated spherically in all directions to immeasurable but still to definite distances in the previously vacant space a certain inexpressibly great yet limited number of unimaginally yet not infinitely minute atoms.

Melvin Calvin (1969) wrote:

The fundamental conviction that the universe is ordered is the first and strongest tenet. As I try to discern the origin of that conviction, I seem to find it in a basic notion discovered 2000 or 3000 years ago, and enunciated first in the Western world by the ancient Hebrews: namely, that the universe is governed by a single God, and not the product of the whims of many gods, each governing his own province according to his own laws. This monotheistic view seems to be the historical foundation of modern science.



Calvin has faith in a lawmaker. In Hebrews 11:1-3 it says, *Now faith is confidence in what we hope for and assurance about what we do not see. This is what the ancients were commended for. By faith we understand that the universe was formed at God's command, so that **what is seen was not made out of what was visible.***

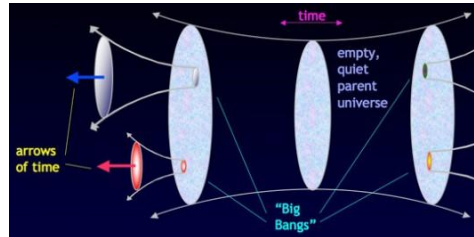
The current consensus among cosmologists is that 13.8 billion years ago, **space** and **time**, as well as all the

matter and **energy** contained in the universe, came into

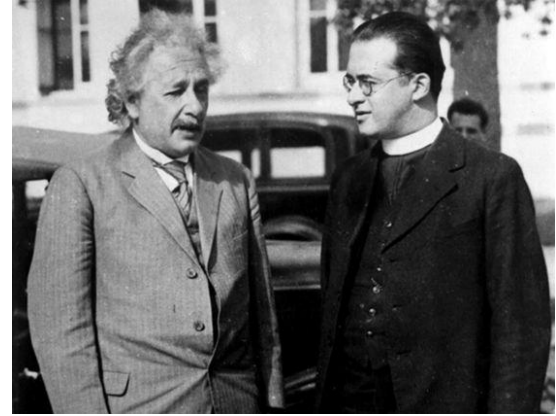
being in one gigantic explosion. This theory proffered by **Georges Lemaitre** and made popular by **George Gamow** is called the **Big Bang Theory**, a moniker given by Fred Hoyle in order to mock this cosmological creation theory. Hoyle believed that the universe was eternal and thus could not have had a beginning. Although I will only discuss the Big Bang Theory since it is strongly supported by the discovery of cosmic microwave background radiation, there is an

alternative cosmological theory, known as the **Steady-State Theory**, based on the idea of continuous creation. Currently, cosmologists, including Brian Greene and Max Tegmark, believe that there is a **multiverse**, and we live in only one of many universes that result from quantum fluctuations. I'll just discuss the one I live in, which I am happy to call the Luddite universe!

According to the modern version of the **Big Bang Theory**, at time zero, when exnihilation occurred, the universe exploded from an infinitesimally tiny and



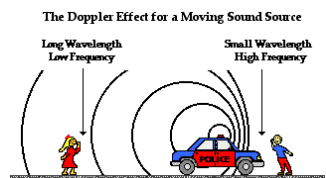
infinitely hot point. There was only **one** thing, and this force/particle had an energy equal to kT , where the temperature **T equals infinity**. According to **Albert Einstein's General Theory of Relativity**, this infinitesimally small point could not exist inside anything, because that would be something. So according to the Big Bang Theory, and *Genesis* for that matter, in the beginning there was a unity, a singularity, a **primeval atom**, as it was called by **Georges Lemaître**.



Demonstration: As the temperature (T) of a gas increases, it exerts more pressure (P) if the volume (V) is constant. The pressure is related to the temperature by the ideal gas law. If the container is allowed to expand and if the temperature is not held constant, the gas will cool. The ratio of the product of pressure and volume (PV) to temperature for a single particle is given by Boltzmann's constant (k), according to the **ideal gas law**. Imagine pumping up the sphere to such a high density, temperature and pressure and letting the walls dissolve. What would happen to the gas molecules? Would they move away from the sphere? Where would the translational kinetic energy originate?

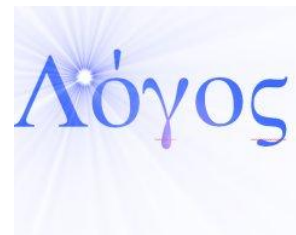


Demonstration: We will look at the acoustic **Doppler effect** which is more pronounced than the optical Doppler effect because the ratio of the speed of the object to the speed of the wave is greater for the acoustic Doppler effect. This is because the speed of sound (300 m/s) is so much less than the speed of light (300×10^6 m/s). Taking the last demonstration into consideration, how would the Doppler effect influence the



appearance of the gas molecules to an observer near the original position of the sphere or the appearance of the gas molecules to an observer towards which the gas molecules were moving?

Some people may call what was **there at the beginning** *God*, others *love, intelligence, the spirit of life, logos, or consciousness*.



Michio Kaku, a theoretical physicist, describes it in terms of a saying he saw on a tee shirt at Berkeley: *“In the beginning God said, the*

four-dimensional divergence of an antisymmetric, second rank tensor equals zero, and there was light, and it was good. And on the seventh day he rested.” Whatever we call what was there at

the beginning, the violent explosion caused the universe to

expand, and as a consequence of the **expansion**, the universe

began to cool. As the universe **cooled**, the single particle in the

universe no longer had enough energy to prevent its splitting into

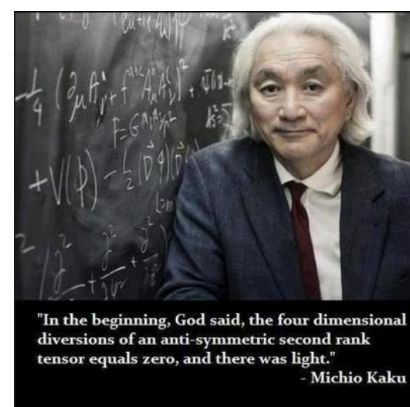
two particles, and when it split there was not enough energy (kT) to **fuse** the two

split particles back together. The particles that carry the **gravitational force**

separated from the particles that carry the **grand unified (GUT) force**. The energy

of a given particle is typically expressed in electron volts (eV). The energy of a

particle can be related to temperature (T) with the following identity:

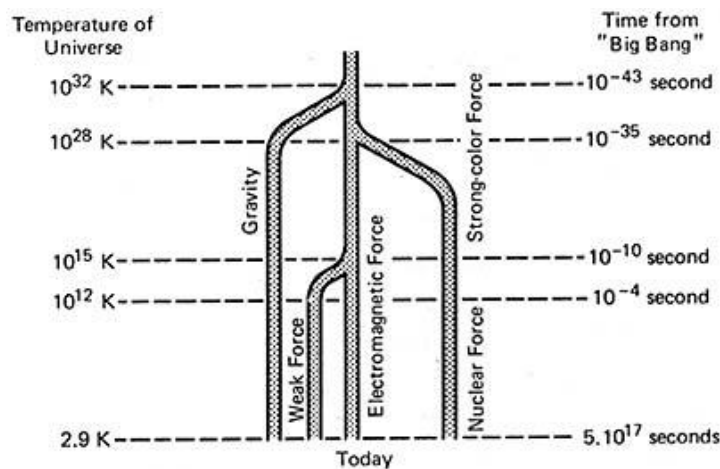


$$\text{electrical energy} = eV = kT = \text{thermal energy}$$

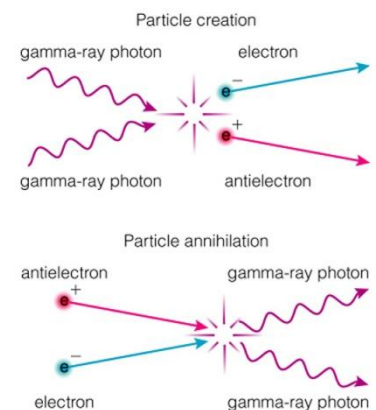
where e is the elementary charge (1.6×10^{-19} Coulombs), V is an electrical potential in Volts, and k is Boltzmann's constant (1.38×10^{-23} J/K).

As the universe continued to expand, the temperature continued to cool, which resulted in the separation of the GUT particle into particles that carry the

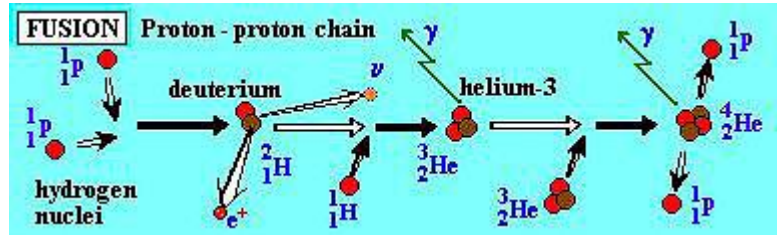
electroweak and the **strong force**. **Ten nanoseconds** after the creation of the universe, the particles that carry the electroweak force separated into particles that carry the weak force and **photons**, which are the particles that carry the **electromagnetic force**.



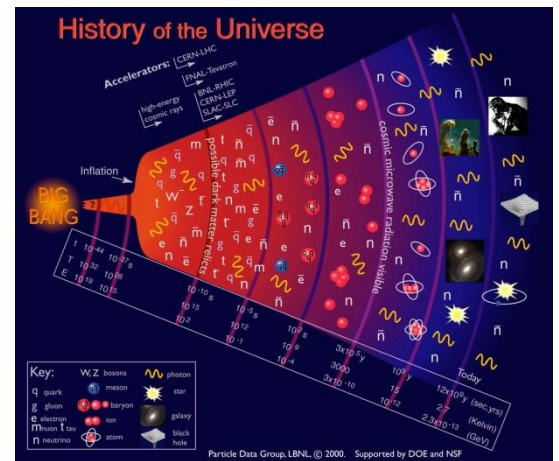
Approximately **1 millisecond** after the creation of the universe, the temperature cooled enough so that electron-positron, proton-antiproton and other **matter-antimatter pairs** formed from photons and then annihilated each other to become photons again. As the universe continued to expand, particles made of matter, such as **electrons**, **protons**, and **neutrons** remained. The whereabouts of the antimatter is a mystery that cannot be accounted for by the standard model of physics. I think that it might be what others call **dark matter**.



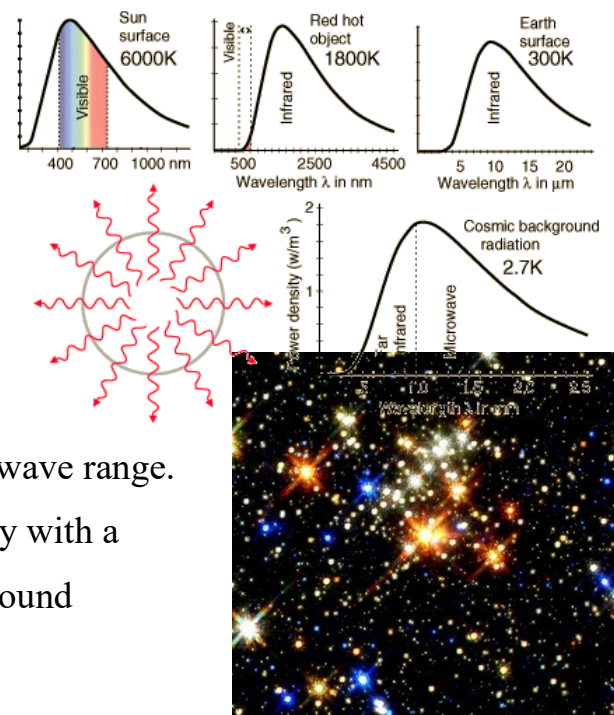
Three minutes after the big bang, the universe cooled enough to allow the formation of hydrogen and helium nuclei, in a process known as **nucleosynthesis**.



The nuclei and electrons collided with each other with energies that were too high to allow the formation of atoms. **Three hundred thousand years** after the creation of the universe, the universe cooled to about 3000 K, which is cool enough to allow the electrons to bind to the atomic nuclei and form **hydrogen atoms** and **helium atoms**.

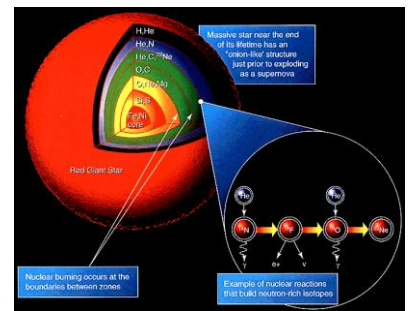


When the charged nuclei and electrons that **interact with all wavelengths of light**, became **neutral atoms**, the universe changed from being mostly **opaque** to being **transparent**. As the transparent universe continued to expand, the wavelengths of the **ancient radiation** got longer and longer. The distribution of the wavelengths in the cosmic background radiation is now in the microwave range. This is consistent with the universe being a blackbody with a temperature of 2.7 K. The cosmic microwave background



radiation is a relic of the **first light**, the **oldest light in our universe**, imprinted on the universe when it was just 300 thousand years old.

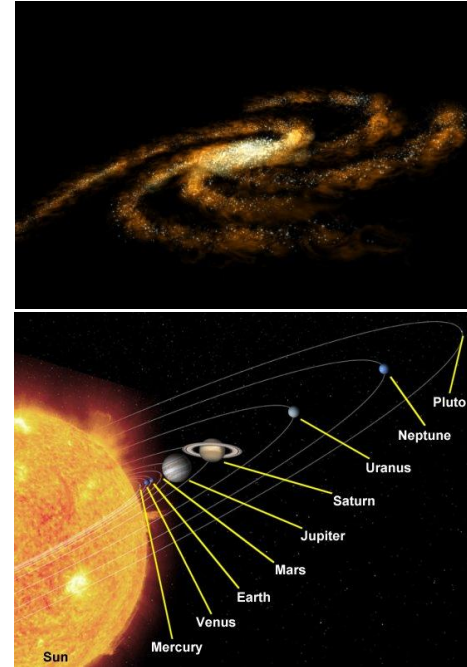
After a further **one or two billion years**, the atoms began to coalesce into dense areas as a result of **gravitational attraction**. The aggregation of these atoms gave rise to **stars**, including **quasars**, and collections of stars known as **galaxies**. As the atoms in the stars were pulled together as a result of gravitational attraction, the **gravitational energy** was transformed into **thermal energy**, and the masses of **hydrogen ignited** to become glowing stars. The **high temperatures and pressures** developed inside the stars provided the energy necessary for **thermonuclear fusion** that **fuses the hydrogen nuclei into helium** nuclei and other nuclei of light elements, including **carbon, nitrogen, oxygen, sulfur, and phosphorous**—the **elements so important for life**.



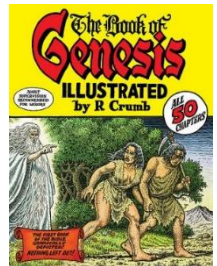
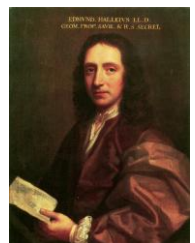
Eventually the **first-generation stars exploded**, sending fragments of dust into the universe. The energy of the explosion formed the heavier elements, including **sodium (Na)**, **magnesium (Mg)**, **calcium (Ca)**, **iron (Fe)**, and **cobalt (Co)**, which were spread over the universe in the form of **cosmic dust**.



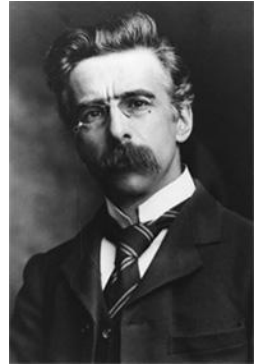
Approximately 4.6 billion years ago, midway to the edge of a **spiral galaxy** known as the **Milky Way**, a rotating cloud of gas and dust known as a **nebula** collapsed and began to spin faster and faster, just like a figure skater does, according to the **Law of Conservation of Angular Momentum**. The center of the cloud became so massive and dense; it **collapsed under gravitational pressure and ignited the gases within it to form a glowing star**, which we call our **sun**. Around the sun, other dust particles clumped together into what we now call the terrestrial and gaseous **planets**. One of these clumps formed our home planet. And as Ptolemy wrote in the *Almagest* (Book I, sect 4), the earth is spherical.



In the seventeenth century, the age of earth was determined by the theologians **James Ussher** and **John Lightfoot** by following “the begets” in the Bible. They estimated the creation of the earth to have occurred about 4000 BC. The polymath **Edmund Halley** (1715), who is well-known to you as the namesake of a comet he discovered, suggested that science may have a role to play in the determination of the age of the earth. Halley proposed that the age of the earth could be calculated from the saltiness of the sea. Halley suggested that the **sea was salty** because the water that gave rise to rivers dissolved salt out of the rocks and the rivers carried the salty water to the sea. Consequently, the sea became saltier with time.

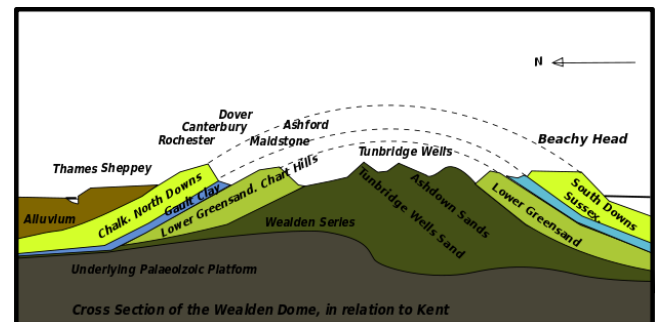


Assuming that the primeval ocean was formed by the condensation of water upon the land, and thus did not contain as much salt as it now does, **John Joly** (1899), another polymath, estimated the age of the earth to be **90 million years old**. Joly estimated the age by guessing that the total mass of the oceans is 1.322×10^{18} tons. He then assumed that rain leached the sodium out of the rocks and into the rivers, the average concentration of sodium in rivers is about 24,106 tons per cubic mile, the mass of sodium in the oceans is one percent of the mass of the oceans or 1.415×10^{16} tons, and the average amount of river water reaching the ocean is 6524 cubic miles per year.

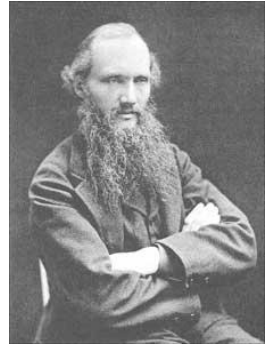
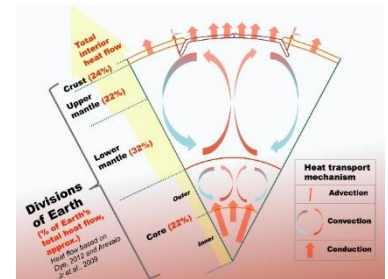


$$1.415 \times 10^{16} \times \frac{1}{6524} \times \frac{1}{24106} = 89.96 \times 10^6 \text{ years}$$

In the first edition of *The Origin of Species*, **Charles Darwin** (1859) estimated that if the wave action of the sea **eroded** a 500-foot-high chalk cliff at a rate of **one inch per century**, then the denudation of a chalk deposit in England known as **the Weald** would have taken 306,662,400 years. Darwin revised his assumptions in the second edition (Darwin, 1860) and completely removed his estimate of the minimal age of the Weald from the third (Darwin, 1861) and later editions of the *Origin of Species* after having “*been convinced of its inaccuracy in several respects by an excellent article in the 'Saturday Review,' Dec. 24, 1859.*”

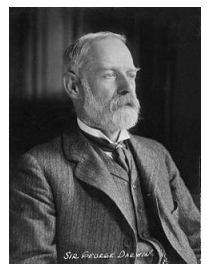
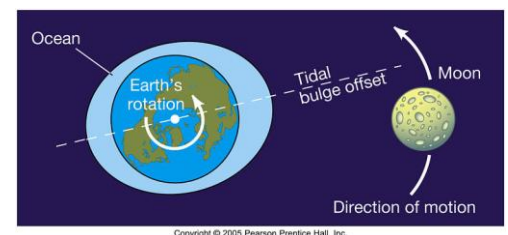


William Thomson (1864), another polymath, estimated the age of the earth from its thermal properties and his knowledge of heat flow. He knew that **temperature increases as one descends in a cave or a mine** and therefore the core of the earth must be hotter than its surface. He also knew that heat must move from the core to the surface by conduction. He also realized that since the surface of the earth does not become hotter from year to year, then there must also be a secular loss of heat from the surface. This one-way flow of heat was consistent with the Second Law of Thermodynamics that he cofounded. By estimating the current rate of heat flow and the current temperature of the core, Thomson concluded that *“it is quite certain that the solar system cannot have gone on even as at present, for a few hundred thousand or a few million years.”*



Aside: Rate of heat flow = (heat transfer coefficient) (surface area of earth) (temperature of core – temperature of surface) / (radius of the earth)

The age of the earth was estimated by **George Darwin**, Charles’ son, from a determination of the present distance between the moon and the earth. Darwin assumed that initially the earth and the moon were one molten body and as a result of fission, they separated, with the moon revolving around the earth. As a result of **tidal friction**, the moon revolved more slowly over time and consistent with **conservation of angular momentum** ($L = mvr$), receded from the earth over time. From the observed rate of recession, Darwin (1898) estimated the minimum age of the earth to be **50-60 million years** old when the earth and moon must have been in contact. According to George Gamow, given



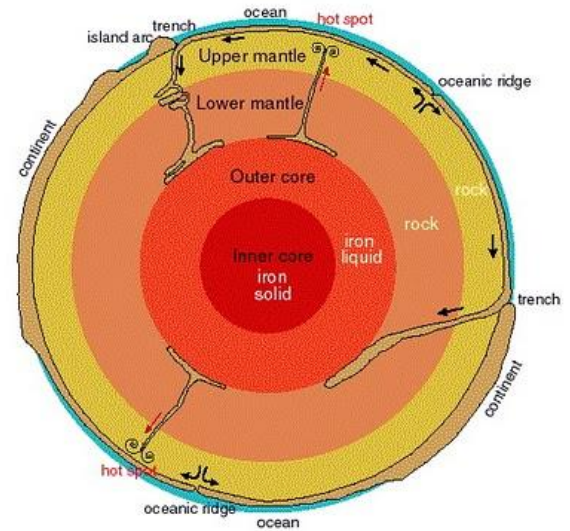
that the distance from the earth to the moon is about 239,000 miles and the moon recedes 5 inches ($= 7.89 \times 10^{-5}$ miles) per year, the moon and earth must have been in contact 3 billion years ago, making the earth even older. The actual rate of recession is about 3.8 cm/year (2.36121×10^{-5} miles/year), which would make the earth about 10 billion years old ($239000 \text{ miles} / 2.36121 \times 10^{-5} \text{ miles/year}$).

Aside: Note that the earth never had enough angular momentum to fission off the moon as George Darwin suggested and currently it is thought that soon after the earth was formed, a large body named **Theia** collided with the proto-earth blasting material into orbit that eventually accreted into the moon.

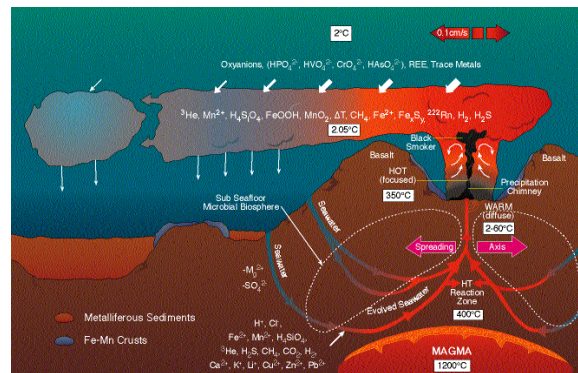
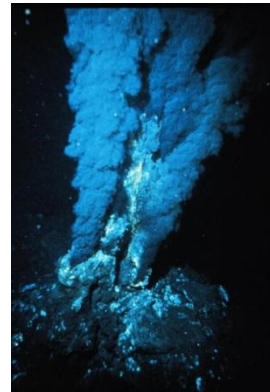


Each estimate of the age of the earth derived from scientific principles is greater than the age of the earth estimated by the theologians. Nevertheless, there is much variation as a result of the **incomplete knowledge that the assumptions** are based on. For example, the earth would be much older than William Thomson estimated from the temperature of the earth if there were a continuous source of heat generation in the core of the earth that he did not take into consideration. Indeed, such a heat source does exist. It results from **radioactivity**, which was not known until Henri Becquerel discovered it serendipitously in 1896. The age of the earth is currently determined using **radiometric dating**, which I will talk more about next week. Analysis of radioactive elements and their decay products indicates that earth and the rest of the solar system were formed between 4.5 and 4.6 billion years ago.

Four and a half billion years ago earth was becoming fully formed, although it was extremely hot and essentially **ocean-less** and **atmosphere-less**. Heat was primarily generated by radioactive decay in the core of the earth, although some heat may have been due to gravity pulling earth's components together. As a result of gravity, the dense metals such as iron sank to the core while the lighter rocky materials containing aluminum, silicon, calcium, magnesium, sodium, and potassium floated to the surface.

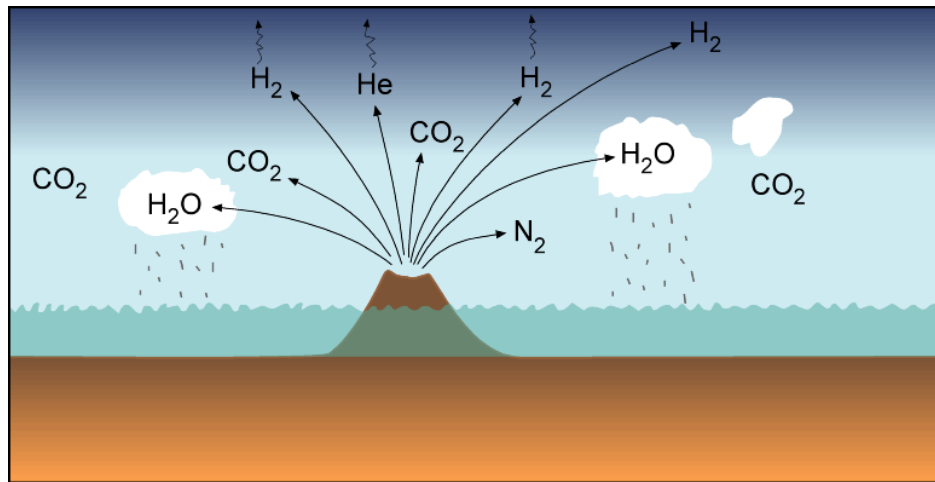


Hydrothermal vents, earthquakes, volcanism, and impacts caused gasses in rocks to be released, probably producing an atmosphere of H_2O , CO_2 , N_2 , as well as CO , CH_4 , NH_3 , and H_2S .



The gravitational attraction of earth was not great enough to hold onto the lightest elements, including H_2 and He , and thus most of the original atmosphere of hydrogen and helium was lost. The loss of hydrogen does not mean that the atmosphere became oxidizing, because there was no molecular oxygen in the atmosphere yet. The accumulation of **molecular oxygen (O_2)**, which happened during the **Precambrian**, approximately 3.4 to 2.7 billion years ago, only occurred after the origin of life and the introduction of **photosynthetic mechanisms**. It is still a mystery whether or not the early atmosphere was oxidizing, reducing, or something in between.

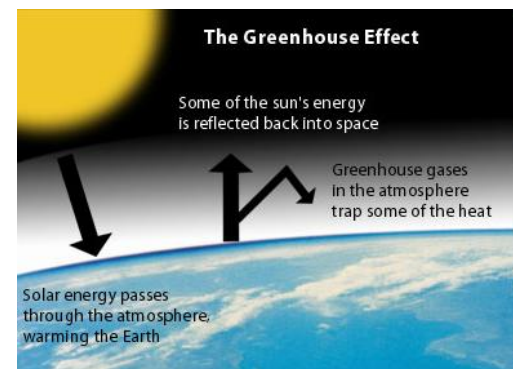




Water from outgassing reacted with CO_2 in the air to produce carbonic acid. Returning to earth as **acid rain**, the carbonic acid probably leached Ca^{2+} and Mg^{2+} from rocks and formed **limestone** ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$). **Llenroc** (Cornell spelled backwards) is formed from more recently formed limestone, most likely produced by the skeletal remains of corals.



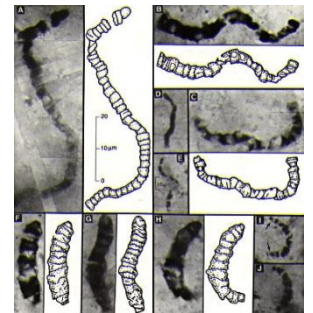
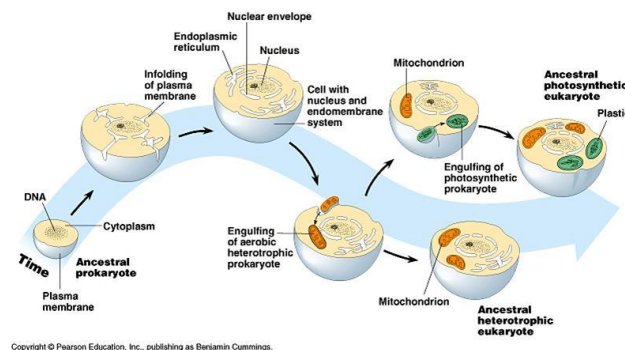
In this way, the CO_2 was removed from the atmosphere and precipitated in sediments. Atmospheric CO_2 would have acted as a **greenhouse gas** to keep the **early earth warm**; thus, knowledge of the CO_2 concentration would be useful in determining the climate of the early earth. While the actual CO_2 concentration during the formation of earth is not known, the amount of CO_2 in the atmosphere was determined by the balance between outgassing and precipitation.



From the formation of earth 4.6 billion years ago until approximately 3.8 billion years ago, earth may have been **bombarded with meteorites or fragments of rocks** that were not included in the initial process of planet formation. Any one of these **impactors** may have hit with so much energy that it would have **vaporized** any organic molecules or living organism that may have already formed. Thus, from 4.6 to 3.8 billion years ago, attempts at the creation of life would have been **frustrated** by the enormous energy provided by the impactors, and life neither could have formed nor continued.

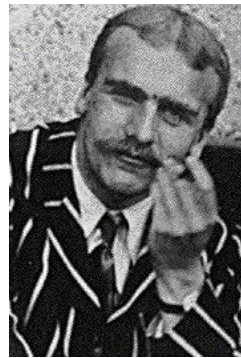


Some of the oldest known rocks, which are 3.5 billion years old, formed on earth, contain fossils that resemble cyanobacteria. Thus, **prokaryotic-like cells** appeared between **3.8 and 3.5 billion years ago**, only 300 million years after what may have been repeated sterilizations of the planet by impactors from space. **Eukaryotic cells** may have originated approximately **1.4 billion years ago** by engulfing other prokaryotic organisms in a process known as **endosymbiosis**.

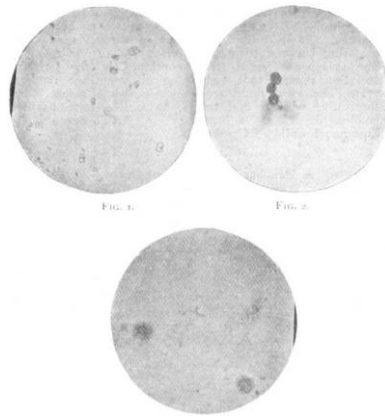
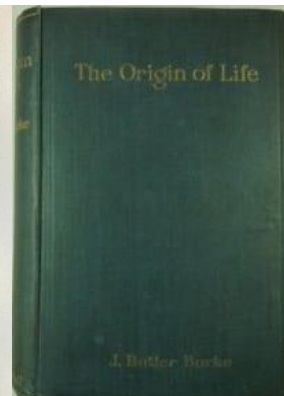
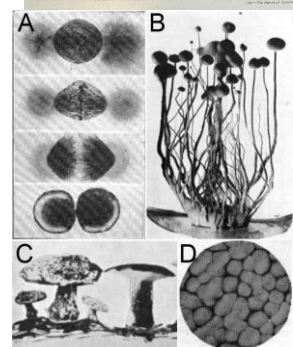


Life as we know it requires carbon-containing compounds, and we must ask: What was the **source of the organic compounds** that made up the first life on earth? It is possible that organic compounds, including urea, formaldehyde, amino

acids, purines, sugars, etc., came from asteroids, comets, or meteorites. These compounds have been found in meteorites and cyanide and acetylene have been found by NASA's Spitzer Space Telescope. However, according to **Charles Darwin**, it is likely that prebiotic chemical evolution took place on earth. Charles Darwin (1871) guessed that life began in a “**warm little pond**” when he wrote to his friend, Joseph Hooker, “*But if (and oh! What a big if!) we could conceive in some warm little pond, with all sorts of ammonia and phosphoric salts, light, heat, electricity, etc. present, that a protein compound was chemically formed ready to undergo still more complex changes.*” **John Burdon Sanderson Haldane** (1929) wrote, “*Now, when ultra-violet light acts on a mixture of water, carbon dioxide, and ammonia, a vast variety of organic substances, including sugars and ... proteins are built up. ... In this present world, such substances, if left about, decay—that is to say, they are destroyed by micro-organisms. But before the origin of life they must have accumulated till the primitive oceans had reached the consistency of hot dilute soup.*”

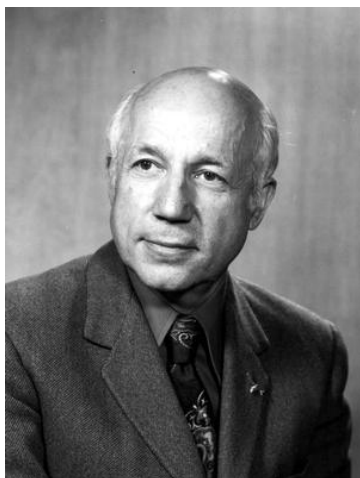


John Butler Burke (1905), working in the Cavendish Laboratory, tried to create life by exposing sterilized homemade beef bouillon to the radioactive rays of radium. The cells or “radiobes” he created seemed to grow and divide. However, Sir William Ramsay believed that the radiobes were nothing more than bubbles of oxygen and hydrogen produced when the radium rays decomposed water. The bubbles then got coated by the albumin in the bouillon so that the

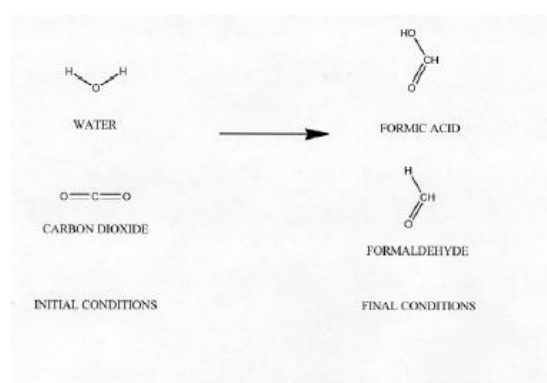


product looked like a cell, but its contents were nothing more than a mixture of oxygen and hydrogen.

In 1912, Stéphane Leduc created the term synthetic biology in his book, *La Biologie Synthétique* to describe the work he did to try to produce osmotically active life from nonlife in chemical gardens. Synthetic biology or “intentional biology” to create or modify life using DNA technology is currently very popular at many universities, including [Cornell](#).



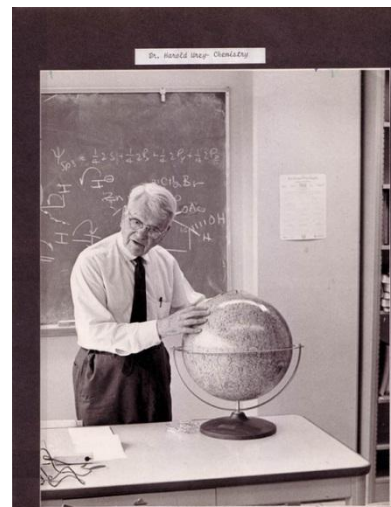
In 1951, **Melvin Calvin**, who we will encounter again when we talk about photosynthesis, conducted experiments on prebiotic evolution and succeeded in fixing carbon dioxide into a more reduced,



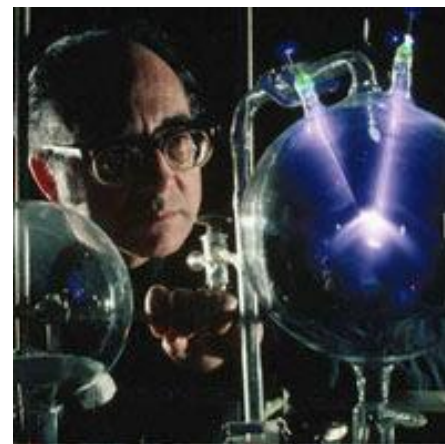
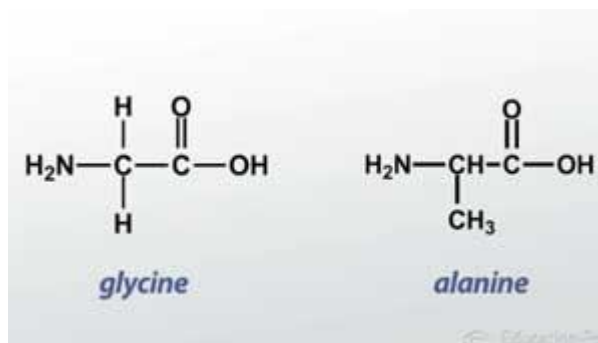
organic form. They irradiated a **mixture of water and**

carbon dioxide in a closed chamber with a **helium ion beam** from **Ernest Lawrence’s cyclotron**. This resulted in the formation of **formic acid** and **formaldehyde**. Formic acid was first discovered by John Wray (1670) in ants (*Formica*).

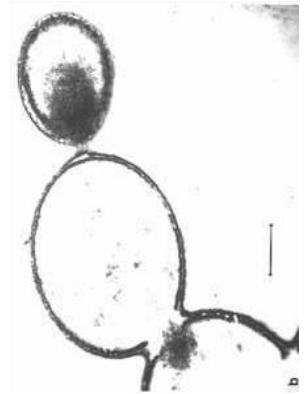
At about this same time, **Harold Urey**, who had been studying the atmosphere of Jupiter, wrote that the atmosphere of the early earth, like that of Jupiter's, may have been **reducing**, and thus may have consisted largely of hydrogen, methane, ammonia, and water. He suggested that Calvin's experiment be repeated using a **reducing**, not an oxidizing, atmosphere.



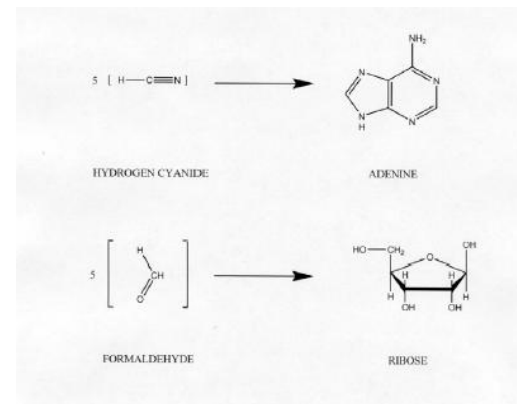
Stanley Miller, a graduate student of Urey's, created an apparatus designed to mimic this presumed early-earth condition. A gaseous mixture of methane, ammonia, hydrogen, and water was connected to a flask of boiling water. The steam created by the boiling water caused the gasses to move past electrodes, the electrical discharges of which simulated lightning in the atmosphere. A cold-water jacket caused molecules to condense and fall out of the "atmosphere." The reaction was allowed to run for a week, after which the solution, which had become deep red, was analyzed. Miller had succeeded in producing not only the formic acid and formaldehyde, but since he included **nitrogen**, he could also form **hydrogen cyanide**, which can combine with water and aldehydes to form the **amino acids**, glycine, and alanine.



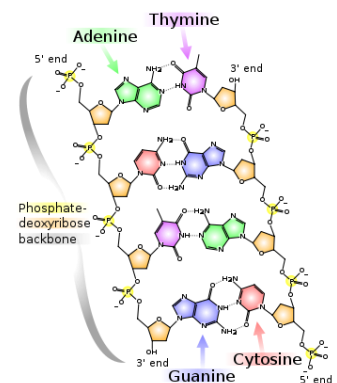
Under prebiotic conditions, amino acids can **polymerize into polypeptides** without the aid of enzymes or a template. The **peptide bonds** between the amino acids occur as a result of **dehydration reactions**. Even more complex structures like **proteinoid microspheres** can form under prebiotic conditions. Proteinoids are large, branched molecules produced when amino acid mixtures containing large amounts of aspartic acid, glutamic acid, or lysine are heated without water. When these dry proteinoids are placed in warm water and allowed to cool, microspheres are produced, and these proteinoid microspheres look similar to the microspheres found in rocks that are 3.8 billion years old.



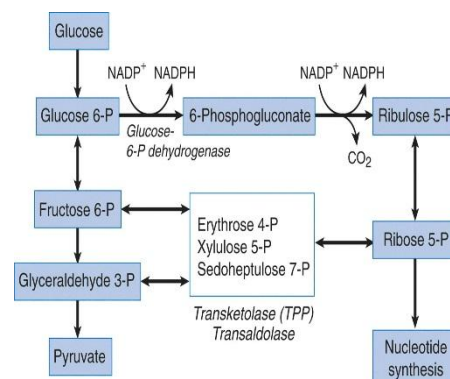
Nucleic acids can also be synthesized under early-earth conditions. Adenine can be formed from hydrogen cyanide. **Adenine** is made according to the simple overall reaction: $5 \text{ HCN} \rightleftharpoons \text{adenine}$. **Ribose** and other sugars can also be made under similar conditions by the overall reaction: $5 \text{ formaldehyde (CH}_2\text{O)} \rightleftharpoons \text{ribose (C}_5\text{H}_{10}\text{O}_5\text{)}$.



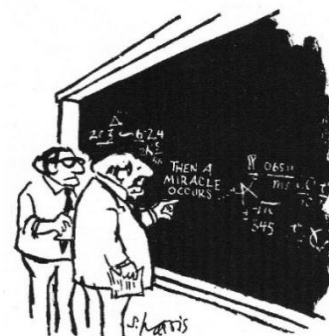
The adenine and ribose can lose a single water molecule and form **adenosine**. By including phosphate in the presumed early-earth conditions, nucleoside monophosphates, including adenosine monophosphate, guanosine monophosphate, cytidine monophosphate, thymidine monophosphate, and uridine monophosphate, as well as adenosine triphosphate (ATP) are formed. The polymerization of **deoxyribonucleotides** would result in **DNA**.



By adding **ferrous ions** (Fe^{2+}), which are enriched in early sediments, and simulating the conditions thought to resemble the primordial oceans, Keller et al. (2014, 2016) have been able to create the energy transforming **glycolytic** and nucleotide-synthesizing **pentose-phosphate pathways** without enzymes, suggesting that the origin of metabolic pathways may date back to the prebiotic world! These enzyme-free pathways can even be regulated. The Fe^{2+} -stimulated glycolytic reactions are favored at neutral pH while the Fe^{2+} -stimulated pentose phosphate reactions are favored at alkaline pH. The pathways themselves along with the Fe^{2+} **catalysts** may have been taken up by the cells that later evolved gene-encoded enzymes to facilitate these metabolic processes.



In the experiments described above, which are performed under early-earth conditions, the **yields of organic molecules and macromolecules are extremely low**. The **yields depend greatly on the reducing power** of the atmosphere used. Reducing power is related to **chemical energy** and the greater the reducing power, the greater the yield. The **yields also depend on the other types of energy available** (e.g., light, heat, lightning, cosmic rays, etc.) and the availability of dehydrating conditions. While the **probability** of various molecules coming together to form a living organism is **infinitesimally low**, it only had to happen once. During a long enough time and with a large enough number of mixtures, every possible combination will eventually occur and improbable combinations eventually occur. As **Herodotus** (ca. 450 BC) said, “*If one is sufficiently lavish with time, everything possible happens.*” And as **Émile Borel** suggested, with enough time, a

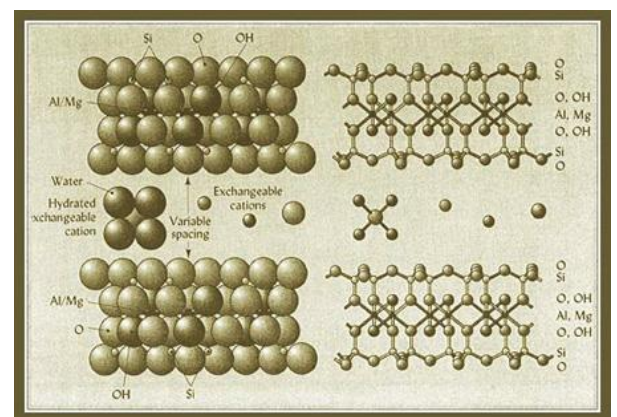


million monkeys could type all the volumes that exist in the British Museum. Yes, a miracle can occur. Michael Dowd (2007) wrote in *Thank God for Evolution!*, “*The evolutionary epic is first and foremost a celebration of the **arrow of time**.*” Although as I mentioned, Einstein wrote in a letter of condolence to Michele Besso’s mother, “*People like us, who believe in physics, know that the distinction between past, present and future is only a stubbornly persistent illusion.*” Is the arrow time fundamental or an illusion?—Your choice.

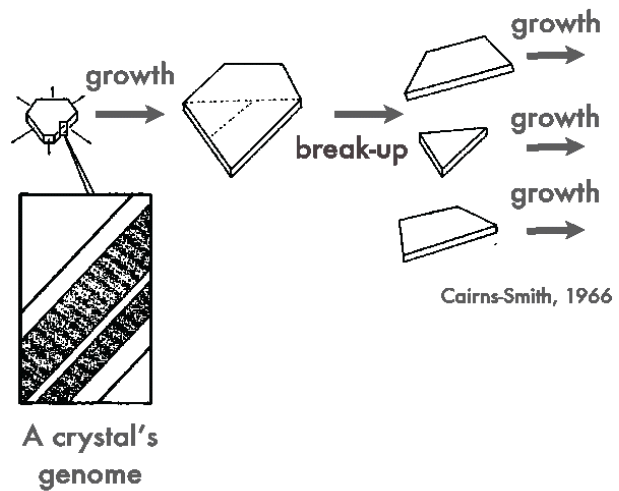
Stimulated by Charles Darwin’s *Origin of Species*, **Ludwig Boltzmann** (1886), a strong proponent of the reality of atoms, combined his interests in physics and biology and proposed that **life began with the formation of self-replicating complexes of atoms**. In order for life to evolve, it must replicate with a high yet finite degree of fidelity. However, given the complexity of the current genetic apparatus, it is unlikely that the genetic apparatus arose all at once. How then did the first self-replicating molecular structure arise? One candidate for the earliest ancestor, alluded to in *Genesis* (2:7), is **clay**.



Clays are inorganic microcrystalline particles approximately 10 micrometers in diameter that are made out of hydrated aluminum silicates and other assorted cations and anions. As crazy as this idea sounds, **clays are capable of replicating themselves**.

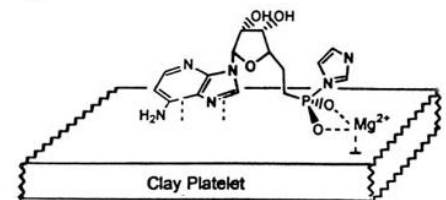
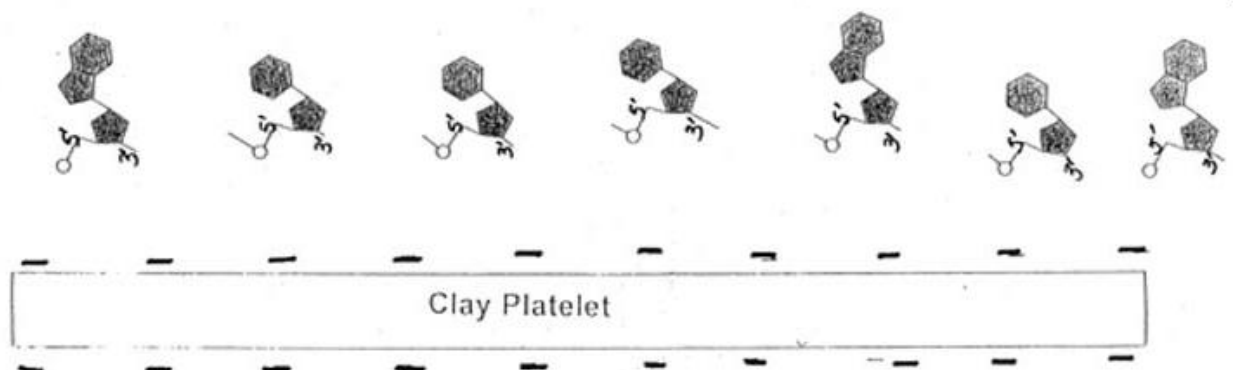


Normally, the composition of a clay crystal that forms *de novo* is determined by the relative abundance of ions in a solution. However, if a suspension of a given charge is seeded with crystals of differing charge, the **growing crystals** are typical of the **seeding clays** rather than the **suspension**.



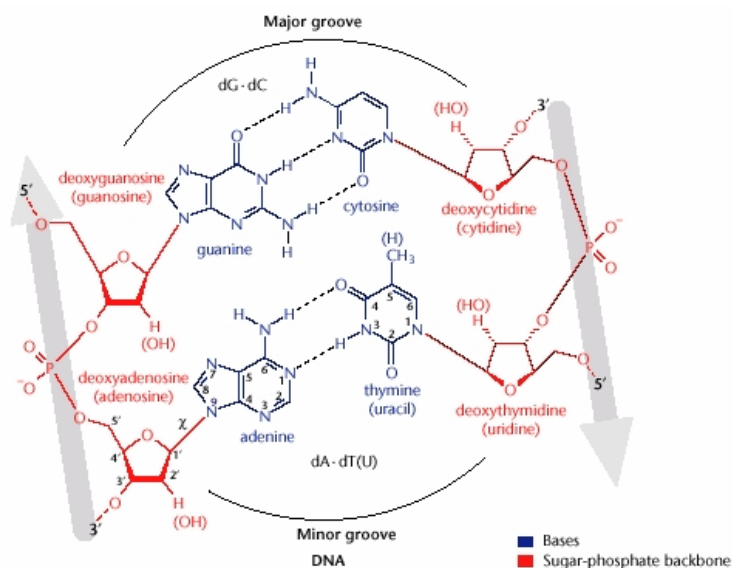
The clays may have facilitated the formation of organic molecules in prebiotic conditions. The clays may have bound nucleotides, including ATP. A given sequence of charge density on clay might have resulted in the binding and ordering of a particular linear sequence of nucleotides resulted in the performance of sequential reactions.

B. Hydrophobic Binding of Adenine (----) and Ionic Binding Via Mg^{2+} ----

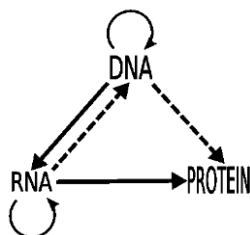
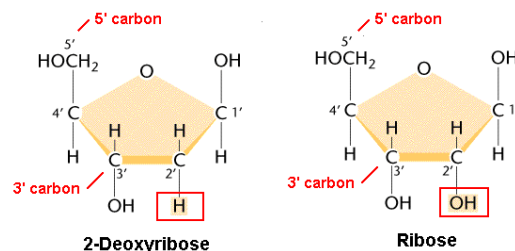


The sugar phosphates of closely bound nucleotides might have polymerized to form a backbone so that the macromolecular complex could have performed sequential reactions free in solution.

A **sequence of clay-bound nucleotides** might have contained the information necessary to **form a polymer** and to allow a **sequence of reactions**. As an added bonus, however, the nucleic acid polymer would have the ability to bind with a “**complementary nucleotide**” through the formation of hydrogen bonds and form an intermediate template so that it could **reproduce itself**. If nucleic acid could **reproduce faster** than the clays reproduced, the nucleic acids would outcompete the clays for the replicating function, in a process that Graham Cairns-Smith (1982) calls **genetic takeover**. Eventually the nucleotides left the evolutionarily challenged clays behind, and the nucleotide-based genetic code went through its own evolutionary development.



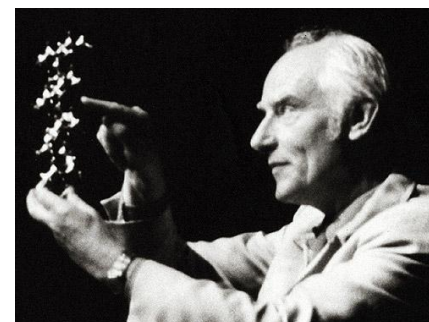
Whether clay was our ancestor, the genetic apparatus as we know it probably evolved from RNA alone, into the **trinity of molecules** that carry the **information of life: DNA, RNA, and protein**. DNA has an advantage over RNA as an informational molecule, in part, because its stability is greater than that of RNA due to the reduction of the 2'OH to 2'H.



(Klug & Cummings 1997)

Proteins, on the other hand, outperform RNA in **enzymatic functions** due perhaps to the variety of functional groups found in the **twenty amino acids** compared to the **four nucleotides**. Eventually, **RNA** provided the link between the **coding function of DNA** and the **catalytic function of proteins**.

Francis Crick (1981) co-discoverer of the structure of DNA, wrote in *Life Itself: Its Origin and Nature*: “An honest man, armed with all the knowledge available to us now, could only state that in some sense, the origin of life appears at the moment to be **almost a miracle**, so many are the conditions which would have had to have been satisfied to get it going.” He went on to say, “But this should not be taken to imply that there are good reasons to believe that it could not have started on the earth by a perfectly reasonable sequence of fairly ordinary chemical reactions. The plain fact is that the time available was too long, the many microenvironments on the earth's surface too diverse, the various chemical possibilities too numerous and our own knowledge and imagination too feeble to allow us to be able to unravel exactly how it might or might not have



happened such a long time ago, especially as we have no experimental evidence from that era to check our ideas against.”

The **National Academy of Sciences** (1999) notes that *“For those who are studying the origin of life, the question is no longer whether life could have originated by chemical processes involving nonbiological components. The question instead has become which of many pathways might have been followed to produce the first cells.”* On the other hand,

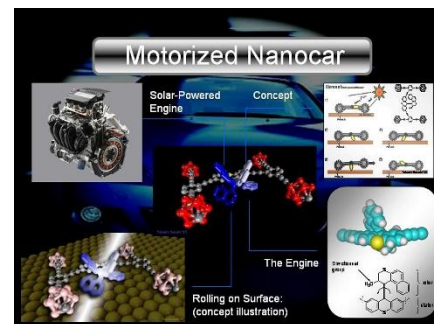
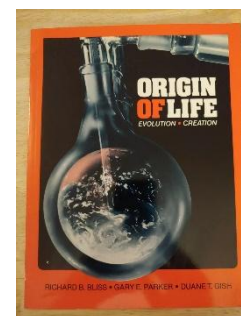
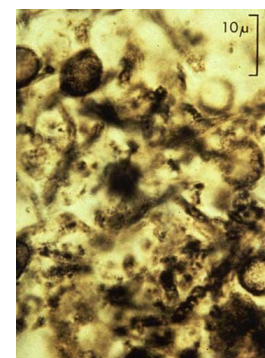
according to **James Tour** (2016), a synthetic chemist who makes chemical microcars, wrote in, *Animadversions of a Synthetic Chemist*,

“The basis upon which we as scientists are

relying is so shaky that we must openly state the situation for what it is: it is a mystery.” **Tour** (2023) presents the problems that must be overcome to solve the mystery of the chemical origin of life. He does not say that it is impossible, just that it has not been scientifically shown.

The book, *Origin of Life: Evolution·Creation* by Richard Bliss, Gary Parker, and Duane Gish (1979) is a self-guided tour of the evidence for the origin of life where they ask you to examine the evidence to determine which are facts and which are assumptions.

The similarities in molecules, mechanisms, metabolic pathways, and structures in living organisms point to a **single common ancestor**. Throughout history, the idea of common descent was espoused in one form or another by Empedocles, Pierre-Louis Moreau de Maupertuis (1753), Erasmus Darwin (1794–1796), Jean Lamarck (1809), and others. Matthias Schleiden (1853) wrote, *“This view, that the whole fullness of the vegetable world has been gradually developed out of a single cell and its descendants, by*



gradual formation of varieties, which became stereotyped into species, and then, in like manner, became the producers of new forms, is at least quite as possible as any other, and is perhaps more probable and correspondent than any other, since it carries back the Absolutely Inexplicable, namely the production of Organic Being, into the very narrowest limits which can be imagined.”

John Herschel wrote a letter to Charles Lyell on February 20, 1836, in which he called the way that one species replaced another, the **mystery of mysteries**. **Charles Darwin** (1859) presented evidence that since variation could be acted upon by artificial selection, evolution must take place over long periods of **time** as a **gradual** result of natural selection.

According to Darwin (1859), “*Although in many cases it is most difficult to conjecture by what transitions an organ could have arrived at its present state; yet, considering that the proportion of living and known forms to the extinct and unknown is very small, I have been astonished how rarely an organ can be named, towards which no transitional grade is known to lead. The truth of this remark is indeed shown by that old canon in natural history of ‘**Natura non facit saltum.**’* [Nature does not make a jump.] *We meet with this admission in the writings of almost every experienced naturalist; or, as Milne Edwards has well expressed it, nature is prodigal in variety, but niggard in innovation. **Why, on the theory of Creation, should this be so? Why should all the parts and organs of many independent beings, each supposed to have been separately created for its proper place in nature, be so invariably linked together by graduated steps? Why should not Nature have taken a leap from structure to structure? On the theory of natural selection, we can clearly understand why she should not; for natural selection can act only by taking advantage of slight successive variations; she can never take a leap, but must advance by the shortest and slowest steps.***

Darwin set up the dichotomy: The origin of species that were created by God would occur in **jumps** while the origin of species by natural selection would occur **gradually**.

Darwin was aware of the weakness of the evidence. As described, by **St. George Mivart** (1871; [Bennett, 1871](#)) in his book *On the Genesis of Species*:



“The difficulties which appear to oppose themselves to the reception of "Natural Selection" or "the survival of the fittest," as the one explanation of the origin of species, have no doubt been already considered by Mr. Darwin. Nevertheless, it may be worth while to enumerate them, and to state the considerations which appear to give them weight; and there is no doubt but that a naturalist so candid and careful as the author of the theory in question, will feel obliged, rather than the reverse, by the suggestion of all the difficulties which can be brought against it.

What is to be brought forward may be summed up as follows:

That "Natural Selection" is incompetent to account for the incipient stages of useful structures.

That it does not harmonize with the co-existence of closely similar structures of diverse origin.

That there are grounds for thinking that specific differences may be developed suddenly instead of gradually.

That the opinion that species have definite though very different limits to their variability is still tenable.

That certain fossil transitional forms are absent, which might have been expected to be present.

That some facts of geographical distribution intensify other difficulties.

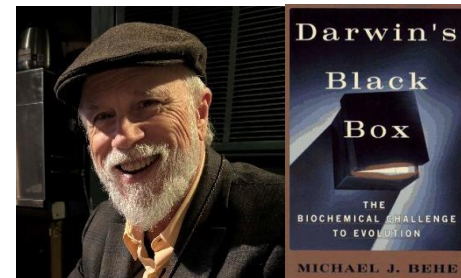
That the objection drawn from the physiological difference between "species" and "races" still exists unrefuted.

Richard Goldschmidt (1933) was also skeptical of the well-established belief in Darwin's theory of the **gradual** origin of species by natural selection, and he offered an alternative theory for the origin of species. He proposed that new species evolve through **drastic changes** that result from a mutation in a gene that influences the relative rates of various developmental processes. Such a change would create "*hopeful monsters which would start a new evolutionary line if fitting into some empty environmental niche.*" A minute change in the DNA that encodes controlling elements such as a transcription factor, an element in a signal transduction cascade, or a regulatory RNA, may provide the mechanism that leads to such a drastic change and a new evolutionary line.



Using a biochemical perspective to make sense of complex biological systems, Michael Behe (1996) argues for the incompleteness of neo-Darwinian gradualness in his book *Darwin's Black Box: The Biochemical Challenge to Evolution*. The members of Michael Behe's department have

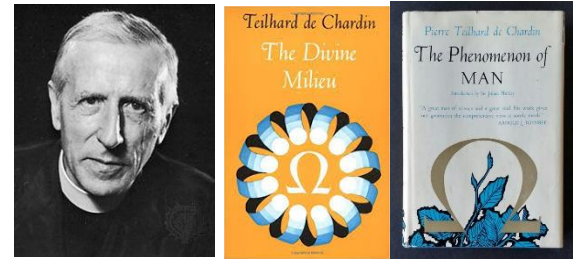
written, "*While we respect Prof. Behe's right to express his views, they are his alone and are in no way endorsed by the department. It is our collective position that intelligent design has no basis in science, has not been tested experimentally, and should not be regarded as scientific.*"



What is the relationship between the origin of life and the origin of consciousness (being aware of the external world) and the origin of a **conscience** (inner knowledge)? Is it best described by a gradual transition or by jumps? The former would imply a natural origin, and the latter would imply a supernatural origin.

In *An Essay in Aid of A Grammar of Assent*, John Henry Newman (1874) wrote, “conscience is a connecting principle between the creature and his Creator.”

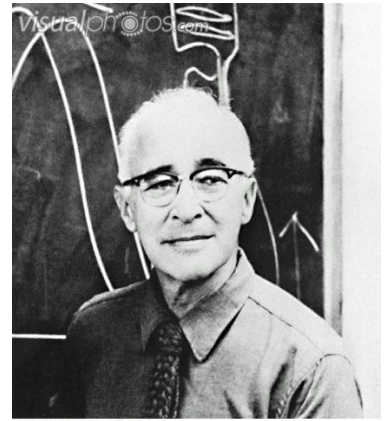
Pierre Teilhard de Chardin, a paleontologist and a priest put the two together and considered the theory of evolution by natural selection to be **God’s first step** in a much grander design. To Teilhard de Chardin, creation was a God-driven purposeful teleological process acting on matter that led towards the omega point which is union with the Godhead.



I have discussed how the **original quantum particle evolved into atoms**, how atoms gave rise to molecules, how molecules gave rise to self-replicating systems, and how self-replicating systems gave rise to cellular life. In each stage of the evolution of life in the universe, **new and surprising properties emerged** from the combination of previous entities. **Louis de Broglie** (1946) maintains that thought is an essential condition for the progressive evolution of the human race. Some cells may specialize in higher functions of thought and self-identity. A small group of **large spindle-shaped cells** has been discovered in the brains of humans and primates. These cells, which are also known as Von Economo neurons, may be involved in **self-identity** and **self-awareness**. When these cells are damaged, people become “vegetables.” These cells are less active in depressed people, disappear in people afflicted with Alzheimer’s disease, and are more active in people with manic disorders. These cells alone are probably not sufficient to make us human.



Although truly amazing, is it not possible that when you put together billions of cells that are specialized for communication that consciousness and a conscience is a natural outcome? **George Wald** (1963) captured this awe and rational thinking when he spoke in front of the president of the United States and said: *“We have been told so often and on such tremendous authority as to seem to put it beyond question, that the essence of things must remain forever hidden from us; that we must stand forever outside nature, like children with their noses pressed against the glass, able to look in, but unable to enter. This concept of our origins encourages another view of matter. We are not looking into the universe from outside. We are looking at it from inside. Its history is our history; its stuff, our stuff. From that realization we can take some assurance that what we see is real. Judging from our experience upon this planet, such a history that begins with elementary particles, leads perhaps inevitably toward a strange and moving end; a creature that knows, a science-making animal that turns back upon the process that generated him and attempts to understand it. Without his like, the universe could be, but not be known, and that is a poor thing. Surely this is a great part of our dignity as men, that we can know, and that through us matter can know itself; that beginning with protons and electrons, out of the womb of time and the vastness of space, we can begin to understand; that organized as in us, the hydrogen, the carbon, the nitrogen, the oxygen, those 16 to 20 elements, the water, the sunlight—all, having become us, can begin to understand what they are, and how they came to be.”*

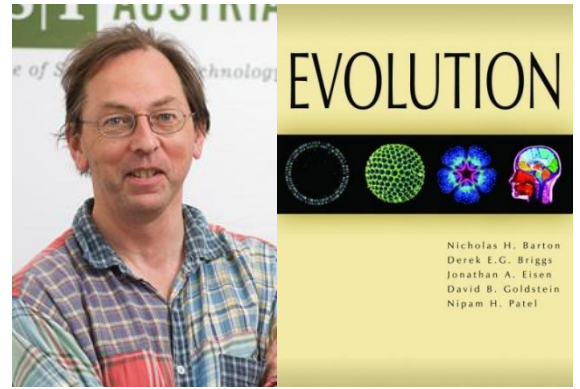


In the [CBC Massey Lecture](#) entitled, *[Therefore Choose Life](#)*, George Wald (1970) put it this way: *“The organic or evolutionary view seems to me to accord man the highest dignity: made of the stuff of stars, gathered over vast ages of time*

from the remotest corners of the universe. All the history of the universe has gone into him and ended in making this thing, man.”

According to Nicholas H. Barton et al. (2007), the authors of *Evolution* published by Cold Spring Harbor Laboratory Press, “*The exquisite biological devices that we now see appear as though carefully designed for their present purposes, and this appearance of design was long taken as evidence of an intelligent*

creator. We now know that biological function is constructed and maintained by natural selection: the gradual accumulation of variations that arise by chance and that are preserved because they aid the survival and reproduction of their carriers. The theory of evolution is a synthesis of Darwinian natural selection and Mendelian genetics. It allows us to ask not just how life evolved, but why it is as it is: Why do organisms develop from a single cell? Why is the genetic code as it is? Why is there sexual reproduction?”



The view presented in the Cold Spring Harbor Laboratory book is the standard view of scientists. It is not the only reasonable view. What are the **assumptions** upon which the standard view and your view are based? What are the **values and limitations** of the **evidence** supporting the standard view and, if it differs, your view? It certainly differs from the view of Alfred Russel Wallace (1858), the original expositor of the theory of evolution by natural selection and of T. H. Huxley (1893) in his Romanes Lecture.

In his book, *Social Environment and Moral Progress*, **Alfred Russel Wallace** (1913) weighed in on the importance of variation to the purpose of life: “*One of the weakest and most foolish of all the objections to the Darwinian theory is, that it does not explain variation, and is therefore worthless. We might as well say that Newton’s discovery of the laws of gravitation are worthless because its cause was not and has not yet been discovered, or that the undulatory theory of light and heat is worthless, because the origin of the ether, the thing that undulates, is not known, The beginnings of things can never be known, and, as Darwin well said, it is foolish to waste time in speculation about them. I think I have shown in my World of Life that infinite variability is a basic law of Nature and have suggested its probable purpose. That purpose seems to have been the development of a life-world culminating in Man—a being capable of studying, and enjoying, and to some extent comprehending, the vast universe around him, from the microscopic life in almost every drop of water to the whirling nebulae of the glittering star-depths extending to almost unimaginable distances around him.*



Looking at him thus, man is as much above, and as different from, the beasts that perish as they are above and beyond the inanimate masses of meteoritic matter, which as we now know, occupy the apparently vacant spaces of our solar system, and from which comets and stars are in all probability the aggregations due to the action of the various cosmic forces which everywhere seem capable of producing variety and order out of a more uniform but less orderly chaos.

But besides this lofty intellect, man is gifted with what we term a moral sense: an insistent perception of justice and injustice, of right and wrong, of order and beauty and truth, which as a whole constitute his moral and esthetic nature,

the origin and progress of which I have endeavored to throw some light upon in the present volume. The long course of human history leads us to the conclusion that this higher nature of man arose at some far distant epoch, and through it has developed in various directions, does not seem yet to have elevated the whole race much above its earliest condition, at a time when, by the influx of some portion of the spirit of the Deity, man became 'a living soul'.

We will now consider some of the changes which this higher nature of man has produced in the action of the laws of variation and natural selection. These are very important and are so little understood that almost all popular writers on the subject of the future of mankind are led into stating as scientific conclusions what are wholly opposed to the actual teaching of evolution...

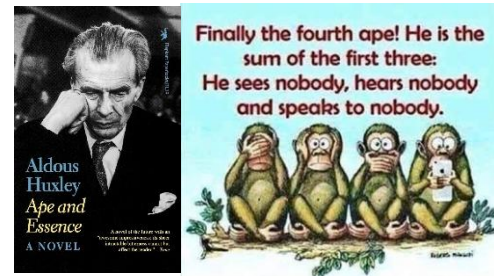
But if we...give due weight to the complete distinctness and enormous superiority of the mind of man as compared with that of other mammals, we shall be inclined to...[be] almost certain when we realize the enormous effect his mind has produced, in modifying and almost neutralizing the action of that great law of natural selection which has held supreme sway in every other portion of the organic world."

In his book *Contributions to the Theory of Natural Selection*, Wallace (1870) wrote:

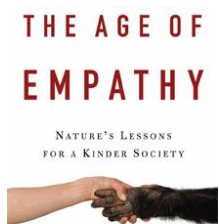
"But there is another class of human faculties that do not regard our fellow men, and which cannot, therefore, be thus accounted for. Such are the capacity to form ideal conceptions of space and time, of eternity and infinity--the capacity for intense artistic feelings of pleasure, in form, colour, and composition--and for those abstract notions of form and number which render geometry and arithmetic possible. How were all or any of these faculties first developed, when they could

have been of no possible use to man in his early stages of barbarism? How could "natural selection," or survival of the fittest in the struggle for existence, at all favour the development of mental powers so entirely removed from the material necessities of savage men, and which even now, with our comparatively high civilization, are, in their farthest developments, in advance of the age, and appear to have relation rather to the future of the race than to its actual status?"

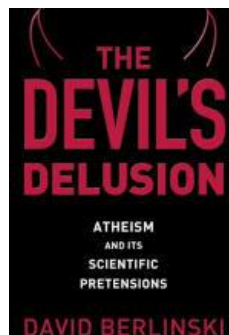
Do you define human beings, who have a material composition nearly identical to the material composition of the earth, bacteria, plants, and animals, no different in kind from those groups as the materialists do? Do you define human beings who have a skeletal structure nearly identical to that of monkeys and apes, no different in kind from those groups? Do you define human beings, who have a *moral and esthetic nature* no different or different in kind from monkeys and apes? Are we a mixture of *Ape and Essence*?



Frans de Waal (http://www.emory.edu/LIVING_LINKS/empathy/faq.html) posits: *"If an extraterrestrial were to visit earth, he would have a hard time seeing most of the differences we treasure between ourselves and the apes."* According to David Berlinski (2008), who wrote *The Devil's Delusion: Atheism and Its Scientific Pretensions*, *"The idea that human beings have been endowed with powers and properties not found elsewhere in the animal kingdom—or the universe, so far as we can tell—arises from a simple imperative: **Just look around.**"* Add up the similarities (e.g., skeletal structure and DNA sequence, being able to recognize ourselves in a mirror) and differences (e.g. musical, artistic, and architectural abilities, use of language in speaking, reading, and writing, ease in giving birth) between apes and human beings. How do you weigh the importance of each similarity and difference? If you

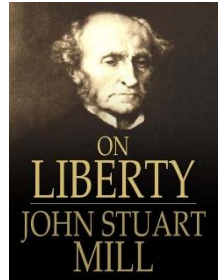


FRANS DE WAAL



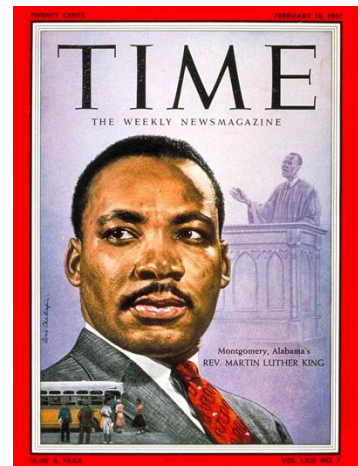
believe that human beings and apes are different in kind, what is the cause of that difference? Natural selection? A quantum fluctuation? Chance? God?

As John Stuart Mill (1859) wrote in *On Liberty*, “*He who knows only his own side of the case, knows little of that. His reasons may be good, and no one may have been able to refute them. But if he is equally unable to refute the reasons on the opposite side; if he does not so much as know what they are, he has no ground for preferring either opinion.*”



He went on to say: “*The peculiar evil of silencing the expression of an opinion is that it is robbing the human race; posterity as well as the existing generations, those who dissent from the opinion still more than those who hold it. If the opinion is right, they are deprived of the opportunity of exchanging error for truth. If wrong, they lose what is almost as great a benefit: the clearer perception and livelier impression of truth produced by its collision with error.*”

Martin Luther King (1957) said in a sermon entitled, *Overcoming an Inferiority Complex*, “*Irreligion somehow leaves us standing in a blind universe. It says to us somehow that **human life is nothing but a cosmic accident on a minor planet, a sort of haphazard by-product of blind forces.** Says to us somehow that **man is nothing but a tiny vagary of whirling electrons, a wisp of smoke from a limitless smoldering.** But then religion comes over and says, ‘Oh no,’ that this **universe has meaning** and that **every individual in this universe counts and every individual in this universe has significance** because there is a God who guides the destiny of life. There is a God who stands at the center of the universe, and he who discovers this principle begins to live.*”



Martin Luther King (1953) also wrote in “*The False God of Science*” “*Let us*

notice this morning how modern man has made a god of science...Doubtless some one has been saying, but is it not right to devote ourselves to scientific adventure? Is not science important for the progress of civilization? To this I would answer yes. No person of sound intelligence could minimize science. It is not science in itself that I am condemning, {but it is the tendency of projecting it to the status of God that I am condemning}. We must come to see that science only furnishes us with the means by which we live, but never with the spiritual ends for which we live.”

Martin Luther King was awarded the Nobel Peace Prize in 1964. His view contrasts with that of **Steven Weinberg**, who was an undergraduate at Cornell and was awarded the Nobel Prize in physics in 1979. Weinberg said at a meeting entitled,



Beyond Belief: Science, Religion, Reason and Survival, “Anything that we scientists can do to weaken the hold of religion should be done and may in the end be our greatest contribution to civilization.”

(<https://www.nytimes.com/2006/11/21/science/21belief.html>) Weinberg (1993) wrote in his book, *The First Three Minutes*, “The more the universe seems comprehensible, the more it also seems **pointless**...The effort to understand the universe is one of the very few things that lifts human life a little above the level of farce, and gives it some of the grace of tragedy.”

Here is an excerpt of a review of Karl R. Popper’s (1962) *Conjectures and Refutations. The Growth of Scientific Knowledge* by **Paul Feyerabend**: “The theory of (scientific) knowledge which was developed in the thirties by Professor Karl Popper is the first example of what one might call a **non-authoritarian epistemology**. Ancient beliefs were based on personal authority. They were

defended, or 'supported,' by reference to the dictum of such authority. The reform of the theory of knowledge that accompanied the rise of modern science eliminated the personal element, but it did not eliminate the appeal to authority, which returned in the more abstract and depersonalized form of various 'sources of knowledge,' such as Experience or Reason. Popper's contribution consists in eliminating the last element of authoritarianism, the idea that knowledge must have a foundation, and the correlated idea that its evaluation consists in investigating the manner in which it is related to this foundation. The evaluation of theories on the basis of an experience that is 'given' is now replaced by the competition of alternative ideas; the acceptance of a theory as being 'proven' by experience (or 'highly confirmed' by experience) is replaced by the acceptance of a theory that has eliminated its competitors because of its comprehensiveness, elegance, promise of future discovery, and has turned out to be the best-for the time being. In the present book, which contains articles previously published as well as some new material, Professor Popper applies this simple and revolutionary idea to a great variety of topics, ranging from scientific matters to politics...The power of Popper's nonauthoritarian point of view, its ability to throw new light upon, and perhaps to solve, problems which have arisen again and again in the history of thought becomes very evident from a perusal of these essays, which are a major contribution to philosophy and whose publication constitutes a major event in the history of this subject."

One more thought from **George Darwin** (1873), a son of Charles Darwin, who imagined a better world where **artificial selection** could be applied to human beings (eugenics). His essay is entitled, *On Beneficial Restrictions to Liberty of Marriage*, which was published in the Contemporary Review (22:412-426).



Darwin wrote, *“It is in his own case alone that man ventures to neglect the knowledge he has acquired of the beneficial effects of careful breeding....And this neglect appears likely to continue so long as the pernicious idea generally prevails that man alone of all animals is under the personal and direct management of the Deity; and yet what believer in evolution can doubt that results as surprisingly might be effected in man, as now seen in our horses, dogs, and cabbages?”*

George Darwin is echoing the thoughts of his cousin, Francis Galton (1865), *“If a twentieth part of the cost and pains were spent in measures for the improvement of the human race that is spent on the improvement of the breed of horses and cattle, what a galaxy of genius might we not create! We might introduce prophets and high priests of civilization into the world, as surely as we can propagate idiots by mating crétins. Men and women of the present day are, to those we might hope to bring into existence, what the pariah dogs of the streets of an Eastern town are to our own highly-bred varieties.”*

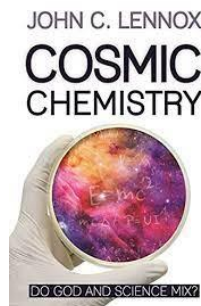
<http://galton.org/essays/1860-1869/galton-1865-macmillan-hereditary-talent.html>

You can watch a debate between Lawrence Krauss and John Lennox (2013) on the question, *Does The Cosmos Leave Space For God?*

<https://www.youtube.com/watch?v=B2eZA2kXpc0>



John Lennox discusses the question: Can a scientist believe in God?



Does the universe have a cause? Huxley and Darwin weighed in on the question:

In *The Life and Letters of Charles Darwin*, [T. H. Huxley](#) (1888) wrote, “Do they believe that anything in this universe happens without reason or without a cause? Do they really conceive that any event has no cause, and could not have been predicted by any one who had sufficient insight into the order of Nature?”

For that matter, Darwin wrote to J. D. Hooker on July 12, 1870, “[My theology is a simple muddle: I cannot look at the universe as a result of blind chance](#)”. He went on to say, “yet I can see no evidence of beneficent design, or indeed of design of any kind in the details.— As for each variation that has ever occurred having been preordained for a special end, I can no believe in it, than that the spot on which each drop of rain falls has been specially ordained.”

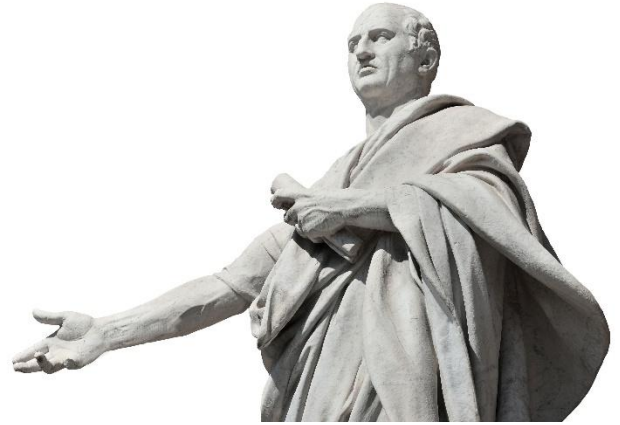
Charles S. Pierce (1878) wrote in [The order of Nature](#), which appeared in *Popular Science Monthly*, “The chance world shown to be so different from that in which we live would be one in which there were no laws, the characters of different things being entirely independent; so that, should a sample of any kind of objects ever show a prevalent character, it could only be by accident, and no general proposition could ever be established. Whatever further conclusions we may come to in regard to the order of the universe, this much may be regarded as solidly established, that the world is not a mere chance-medley.” How do you see the world—is it fundamentally governed by chance or by laws—or is this a false dichotomy? The choice is a matter of faith.



Thomas Reid’s (1865) [Essays on the Intellectual Powers of Man](#), gives an ancient and a modern view of the choice:

“The first is **Cicero**, whose words, *Lib. I., cap. xiii., De divinatione*, may be thus translated:

‘Can anything done by chance have all the marks of design? Four dice may by chance turn up four aces; but do you think that four hundred dice, thrown by chance, will turn up four hundred aces? Colours thrown upon canvas without design may have some similitude to a human face; but do you think they might make as beautiful a picture as that of the Coan Venus? A hog turning up the ground with his nose may make something of the form of the letter A; but do you think that a hog might describe on the ground the Andromache of Ennius? Carneades imagined, that in the stone quarries at Chios he found in a stone that was split a representation of the head of a little Pan, or sylvan deity. I believe he might find a figure not unlike; but surely not such a one as you would say had been formed by an excellent sculptor like Scopas. For so, verily, the case is, that chance never perfectly imitates design.’
Thus Cicero.



Now, in all this discourse I see very good sense, and what is apt to convince every unprejudiced mind; **but I see not in the whole a single step of reasoning. It is barely an appeal to every man's common sense.**

Let us next see how the same point is handled by the excellent **Archbishop Tillotson**, *1st Sermon, vol. i.*:

‘For I appeal to any man of reason, whether anything can be more unreasonable than obstinately to impute an effect to chance which carries in the face of it all the arguments and characters of design? Was ever any



considerable work, in which there was required a great variety of parts, and an orderly and regular adjustment of these parts, done by chance? Will chance fit means to ends, and that in ten thousand instances, and not fail in any one? How often might a man, after he had jumbled a set of letters in a bag, fling them out upon the ground before they would fall into an exact poem, yea, or so much as make a good discourse in prose? And may not a little book be as easily made as this great volume of the world? How long might a man sprinkle colours upon canvas with a careless hand before they would make the exact picture of a man? And is a man easier made by chance than his picture? How long might twenty thousand blind men, who should be sent out from the remote parts of England, wander up and down before they would all meet upon Salisbury plains, and fall into rank and file in the exact order of an army? And yet this is much more easy to be imagined than how the innumerable blind parts of matter should rendezvous themselves into a world. A man that sees Henry the Seventh's chapel at Westminster might with as good reason maintain (yea, and much better, considering the vast difference between that little structure and the huge fabric of the world), that it was never contrived or built by any man, but that the stones did by chance grow into those curious figures into which we see them to have been cut and graven; and that upon a time (as tales usually begin), the materials of that building, the stone, mortar, timber, iron, lead, and glass, happily met together, and very fortunately ranged themselves into that delicate order in which we see them now so close compacted, that it must be a very great chance that parts them again. What would the world think of a man that should advance such an opinion as this, and write a book for it? If they would do him right, they ought to look upon him as mad. But yet he might maintain this opinion with a little more reason than any man can have to say that the world was made by chance, or that the first men grew out of the earth, as plants do now. For can anything be more ridiculous and against all

reason, than to ascribe the production of men to the first fruitfulness of the earth, without so much as one instance or experiment in any age or history to countenance so monstrous a supposition? The thing is at first sight so gross and palpable, that no discourse about it can make it more apparent. And yet these shameful beggars of principles, who give this precarious account of the original of things, assume to themselves to be the men of reason, the great wits of the world, the only cautious and wary persons, who hate to be imposed upon, that must have convincing evidence for everything, and can admit nothing without a clear demonstration for it.'

*In this passage, the excellent author takes what I conceive to be the proper method of refuting an absurdity, by exposing it in different lights, in which every man of common understanding perceives it to be ridiculous. And although there is much good sense, as well as wit, in the passage I have quoted, **I cannot find one medium of proof in the whole.***"

So, there is no proof that the universe was created by chance (the view of the men of reason and the great wits of the world) or by a cause (the commonsense view). But do the great wits of the world rest on a scientific pillow?

The Concept of a Scientific Pillow

In his essay *Of Experience*, **Michel de Montaigne** starts out saying, "There is no desire more natural than that of knowledge. We try all ways that can lead us to it; where reason is wanting, we therein employ experience, which is a means much more weak and cheap; but truth is so great a thing that we ought not to disdain any mediation that will guide us to it." Then he introduces the concept of a **soft, easy, and wholesome pillow** to describe our **ignorance and incuriosity**, "In this universality, I suffer myself to be ignorantly



*and negligently led by the general law of the world: I shall know it well enough when I feel it; my learning cannot make it alter its course; it will not change itself for me; 'tis folly to hope it, and a greater folly to concern one's self about it, seeing it is necessarily alike public and common. The goodness and capacity of the governor ought absolutely to discharge us of all care of the government: philosophical inquisitions and contemplations serve for no other use but to increase our curiosity. The philosophers; with great reason, send us back to the rules of nature; but they have nothing to do with so sublime a knowledge; they falsify them, and present us her face painted with too high and too adulterate a complexion, whence spring so many different pictures of so uniform a subject. As she has given us feet to walk with, so has she given us prudence to guide us in life: not so ingenious, robust, and pompous a prudence as that of their invention; but yet one that is easy, quiet, and salutary, and that very well performs what the other promises, in him who has the good luck to know how to employ it sincerely and regularly, that is to say, according to nature. The most simply to commit one's self to nature is to do it most wisely. **Oh, what a soft, easy, and wholesome pillow is ignorance and incuriosity, whereon to repose a well-ordered head!**"*

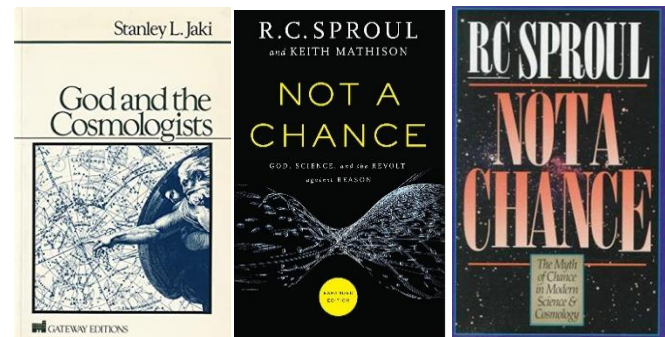
In *La science et la réalité*, **Pierre Delbet** (1913) realized that science makes use of soft pillows. He wrote, “For a long time, all questions relating to chance caused me painful discomfort. In saying how I got out of this state of anxiety, I might free some unknown friends tortured by the same preoccupation that gripped me once. Chance appears to me today as a law, the most general of all laws. It became for me a soft pillow like the one Montaigne says only ignorance and incuriosity could provide; but it is a **scientific pillow**.”



Chance cannot be a cause of anything. It describes the probability of an effect when we do not know the cause. **Aristotle** toyed with the idea of chance when it came to formal, efficient, and final causes in order to account for free will. However, he denied the role of chance as a material cause, otherwise something could come from nothing. For this reason, Aristotle assumed that the universe was eternal. Thomas Aquinas, believed that the only thing that was eternal was God, and only a creator God could create a universe from nothing. Somehow, in science, chance became an acceptable replacement for a cause—and for God.

Stanley Jaki (1989), in *God and the Cosmologists* and R. C. Sproul (1994, 2014) in *Not a Chance* lucidly argue why chance cannot be a cause. Jaki sees the word chance to indicate our ignorance of true causes. Jaki sees the assertion that chance is a cause to be “*the softest*

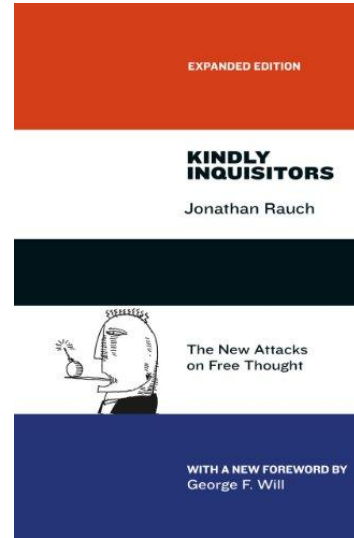
‘philosophical’ pillow in all scientific history.” He asserts that “*once more, as so often in that history, most successful mathematical formulas served as magic tools for making shabby philosophizing a most respectable attitude.*”



Stanley Jaki (1986) wrote in *Chance or Reality and Other Essays*, “...during the half a dozen years that followed the enunciation by Heisenberg of the principle of uncertainty, almost immediately a drastic meaning was grafted on it, a meaning thoroughly philosophical...*reality’s place was taken by chance, not the chance that stands for ignorance, but which stands for a philosophical ghost residing in the shadowy realm between being and non-being.*”

Karl Popper considered himself “*the last laggard of the Enlightenment.*” He had “*in mind the hope that inspired Pestalozzi, that knowledge may make us free...that we may rouse ourselves from our dogmatic slumber, as Kant called it.*”

Jonathan Rauch (2013) wrote in *Kindly Inquisitors: The difference between the amoeba and Einstein,* “*Karl Popper said, “is that, although both make use of the method of trial and error-elimination, the amoeba dislikes erring while Einstein is intrigued by it: he consciously searches for his errors in the hope of learning by their discovery and elimination.” Thus Popper’s amoeba metaphorically “knows” some things—how to find food, how to give you dysentery—but it cannot be said to be curious. Curiosity is not merely a desire to find truth, as such, it is also a desire to find error: to find new beliefs which correct the inadequacies of old ones.*



Newton’s research on the physical universe inspired all. Here are two poems about Isaac Newton written by one scientist and one poet:

Ode to Isaac Newton

--Edmund Halley (1686)

*Lo, for your gaze, the pattern of the skies!
What balance of the mass, what reckonings
Divine! **Here ponder too the Laws which God,
Framing the Universe, set not aside
But made the fixed foundations of his work.***

*The inmost place of the heavens, now gained,
Break into view, nor longer hidden is
The force that turns the farthest orb. The sun
Exalted on his throne bids all things tend
Toward him by inclination and descent,*

*Nor suffer that the courses of the stars
Be straight, as through the boundless void they move,
But with himself as centre speeds them on
In motionless ellipses. Now we know
The sharply veering ways of comets, once
A source of dread, nor longer do we quail
Beneath appearances of bearded stars.*

*At last we learn wherefore the silver moon
Once seemed to travel with unequal steps,
As if she scorned to suit her pace to numbers -
Till now made clear to no astronomer;
Why, though the Seasons go and then return,
The Hours move ever forward on their way;
Explained too are the forces of the deep,
How roaming Cynthia bestirs the tides,
Whereby the surf, deserting now the kelp
Along the shore, exposes shoals of sand
Suspected by the sailors, now in turn
Driving its billows high upon the beach.*

*Matters that vexed the minds of ancient seers,
And for our learned doctors often led
to loud and vain contention, now are seen
**In reason's light, the clouds of ignorance
Dispelled at last by science.** Those on whom
Delusion cast its gloomy pall of doubt,
Upborne now on the wings that genius lends,
May penetrate the mansions of the gods
And scale the heights of heaven. O mortal men,
Arise! And, casting off your earthly cares,
Learn ye the potency of heaven-born mind,
Its thought and life far from the herd withdrawn!*

*The man who through the tables of the laws
Once banished theft and murder, who suppressed
Adultery and crimes of broken faith,
And put the roving peoples into cities
Girt round with walls, was founder of the state,
While he who blessed the race with Ceres' gift,*

*Who pressed from grapes an anodyne to care,
Or showed how on the tissue made from reeds
growing behind the Nile one may inscribe
Symbols of sound and so present the voice
For sight to grasp, did lighten human lot,
Offsetting thus the miseries of life
With some felicity. But now, behold,
Admitted to the banquets of the gods,
We contemplate the politics of heaven;
Discern the changeless order of the world
And all the aeons of its history.*

*Then ye who now on heavenly nectar fare,
Come celebrate with me in song the name
Of Newton, to the Muses dear; **for he**
Unlocked the hidden treasures of Truth:
So richly through his mind had Phoebus cast
The radiance of his own divinity.
Nearer the gods no mortal may approach.*

A poem sacred to the memory of Sir Isaac Newton

—James Thomson (1727).

*Shall the great soul of Newton quit this earth,
To mingle with his stars; and every muse,
Astonish'd into silence, shun the weight
Of honours due to his illustrious name?
But what can man?--Even now **the sons of light,**
In strains high-warbled to seraphic lyre,
Hail his arrival on the coast of bliss.
Yet am not I deterr'd, though high the theme,
And sung to harps of angels, for with you,
Ethereal flames! ambitious, I aspire
In Nature's general symphony to join.*

*And what new wonders can ye show your guest!
Who, while on this dim spot, where mortals toil
Clouded in dust, from motion's simple laws,*

*Could trace the secret hand of Providence,
Wide-working through this universal frame.*

*Have ye not listen'd while he bound the suns
And planets to their spheres! th' unequal task
Of humankind till then. Oft had they roll'd
O'er erring man the year, and oft disgrac'd
The pride of schools, before their course was known
Full in its causes and effects to him,
All-piercing sage! who sat not down and dream'd
Romantic schemes, defended by the din
Of specious words, and tyranny of names;
But, bidding his amazing mind attend,
And with heroic patience years on years
Deep-searching, saw at last the system dawn,
And shine, of all his race, on him alone.*

*What were his raptures then! how pure! how strong!
And what the triumphs of old Greece and Rome,
By his diminish'd, but the pride of boys
In some small fray victorious! when instead
Of shatter'd parcels of this earth usurp'd
By violence unmanly, and sore deeds
Of cruelty and blood, Nature herself
Stood all subdu'd by him, and open laid
Her every latent glory to his view.*

*All intellectual eye, our solar-round
First gazing through, he by the blended power
Of gravitation and projection saw
The whole in silent harmony revolve.
From unassisted vision hid, the moons
To cheer remoter planets numerous pour'd,
By him in all their mingled tracts were seen.
He also fix'd the wandering Queen of Night,
Whether she wanes into a scanty orb,
Or, waxing broad, with her pale shadowy light,
In a soft deluge overflows the sky.
Her every motion clear-discerning, he
Adjusted to the mutual main, and taught*

*Why now the mighty mass of water swells
Resistless, heaving on the broken rocks,
And the full river turning; till again
The tide revertive, unattracted, leaves
A yellow waste of idle sands behind.*

*Then breaking hence, he took his ardent flight
Through the blue infinite; and every star,
Which the clear concave of a winter's night
Pours on the eye, or astronomic tube,
Far-stretching, snatches from the dark abyss,
Or such as farther in successive skies
To fancy shine alone, at his approach
Blaz'd into suns, the living centre each
Of an harmonious system: all combin'd,
And rul'd unerring by that single power,
Which draws the stone projected to the ground.*

*O unprofuse magnificence divine!
O wisdom truly perfect! thus to call
From a few causes such a scheme of things,
Effects so various, beautiful, and great,
An universe complete! and O belov'd
Of Heaven! whose well-purg'd penetrative eye,
The mystic veil transpiercing, inly scann'd
The rising, moving, wide-establish'd frame.*

*He, first of men, with awful wing pursu'd
The comet through the long elliptic curve,
As round innumerable worlds he wound his way,
Till, to the forehead of our evening sky
Return'd, the blazing wonder glares anew,
And o'er the trembling nations shakes dismay.*

*The heavens are all his own, from the wild rule
Of whirling vortices and circling spheres
To their first great simplicity restor'd.
The schools astonish'd stood; but found it vain
To keep at odds with demonstration strong,
And, unawaken'd, dream beneath the blaze*

*Of truth. At once their pleasing visions fled,
With the gay shadows of the morning mix'd,
When Newton rose, our philosophic sun!
Th' aërial flow of sound was known to him,
From whence it first in wavy circles breaks,
Till the touch'd organ takes the message in.
Nor could the darting beam of speed immense
Escape his swift pursuit and measuring eye.
Ev'n Light itself, which every thing displays,
Shone undiscover'd, till his brighter mind
Untwisted all the shining robe of day;
And, from the whitening undistinguish'd blaze,
Collecting every ray into his kind,
To the charm'd eye educ'd the gorgeous train
Of parent colours. First the flaming red
Sprung vivid forth; the tawny orange next;
And next delicious yellow; by whose side
Fell the kind beams of all-refreshing green.
Then the pure blue, that swells autumnal skies
Ethereal played; and then, of sadder hue,
Emerg'd the deepen'd indigo, as when
The heavy-skirted evening droops with frost;
While the last gleamings of refracted light
Died in the fainting violet away.
These, when the clouds distil the rosy shower,
Shine out distinct adown the wat'ry bow;
While o'er our heads the dewy vision bends
Delightful, melting on the fields beneath.
Myriads of mingling dyes from these result,
And myriads still remain--infinite source
Of beauty, ever flushing, ever new.*

*Did ever poet image aught so fair,
Dreaming in whisp'ring groves by the hoarse brook?
Or prophet, to whose rapture heaven descends?
Ev'n now the setting sun and shifting clouds,
Seen, Greenwich, from thy lovely heights, declare
How just, how beauteous the refractive law.*

The noiseless tide of time, all bearing down

*To vast eternity's unbounded sea,
Where the green islands of the happy shine,
He stemm'd alone; and, to the source (involv'd
Deep in primeval gloom) ascending, rais'd
His lights at equal distances, to guide
Historian wilder'd on his darksome way.*

*But who can number up his labours? who
His high discoveries sing? When but a few
Of the deep-studying race can stretch their minds
To what he knew--in fancy's lighter thought
How shall the muse then grasp the mighty theme?*

*What wonder thence that his devotion swell'd
Responsive to his knowledge? For could he,
Whose **piercing mental eye** diffusive saw
The finish'd university of things
In all its order, magnitude, and parts,
Forbear incessant to adore that Power
Who fills, sustains, and actuates the whole?*

*Say, ye who best can tell, ye happy few,
Who saw him in the softest lights of life,
All unwithheld, indulging to his friends
The vast unborrow'd treasures of his mind,
oh, speak the wondrous man! how mild, how calm
How greatly humble, how divinely good,
How firm establish'd on eternal truth;
Fervent in doing well, with every nerve
Still pressing on, forgetful of the past,
And panting for perfection; far above
Those little cares and visionary joys
That so perplex the fond impassion'd heart
Of ever-cheated, ever-trusting man.
This, Conduitt, from thy rural hours we hope;
As through the pleasing shade where nature pours
Her every sweet in studious ease you walk,
The social passions smiling at thy heart
That glows with all the recollected sage.*

*And you, ye hopeless gloomy-minded tribe,
You who, unconscious of those nobler flights
That reach impatient at immortal life,
Against the prime endearing privilege
Of being dare contend,--say, can a soul
Of such extensive, deep, tremendous powers,
Enlarging still, be but a finer breath
Of spirits dancing through their tubes awhile,
And then for ever lost in vacant air?*

*But hark! methinks I hear a warning voice,
Solemn as when some awful change is come,
Sound through the world--" 'Tis done!--the measure's full;
And I resign my charge."--Ye mouldering stones
That build the towering pyramid, the proud
Triumphal arch, the monument effac'd
By ruthless ruin, and whate'er supports
The worship'd name of hoar antiquity--
Down to the dust! What grandeur can ye boast
While Newton lifts his column to the skies,
Beyond the waste of time. Let no weak drop
Be shed for him. The virgin in her bloom
Cut off, the joyous youth, and darling child--
These are the tombs that claim the tender tear
And elegiac song. But Newton calls
For other notes of gratulation high,
That now he wanders through those endless worlds
He here so well descried, and wondering talks,
And hymns their Author with his glad compeers.*

*O Britain's boast! whether with angels thou
Sittest in dread discourse, or fellow-blest,
Who joy to see the honour of their kind;
Or whether, mounted on cherubic wing,
Thy swift career is with the whirling orbs,
Comparing things with things, in rapture lost,
And grateful adoration for that light
So plenteous ray'd into thy mind below
From Light Himself; oh, look with pity down
On humankind, a frail erroneous race!*

*Exalt the spirit of a downward world!
O'er thy dejected country chief preside,
And be her Genius call'd! her studies raise,
Correct her manners, and inspire her youth;
For, though deprav'd and sunk, she brought thee forth,
And glories in thy name! she points thee out
To all her sons, and bids them eye thy star:
While, in expectance of the second life,
When time shall be no more, thy sacred dust
Sleeps with her kings, and dignifies the scene.*

As long as we are discussing the creation of the universe, I would like to add a note about **creativity in science**. **Gerrit Verschuur** (1993), a radio astronomer wrote in *Hidden Attractions*, “*Perhaps modern university curricula should include exercises to facilitate the letting go of prejudice so as to encourage students to consider occasionally the impossible if not the incredible. Time and again significant breakthroughs in science are made by those ready and willing to take a completely different approach to a problem that has been unsuccessfully confronted by more conventional minds for years. The creative approach requires that, for a while at least, someone be willing to climb out of the mainstream and take a look at the flow of ideas from the banks of the river. How else does one obtain a clear perspective? If you are up to your neck in the water it is difficult to see where you are, and impossible to perceive the world view that can be had from the bank.*”



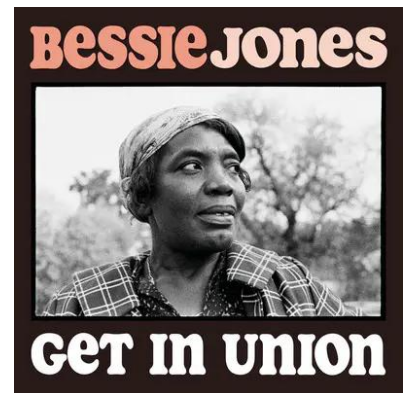
We must all find **our place in the universe**, and each of us can do that by finding our own purpose—knowing ourselves and recognizing our own special strengths. There is a story:

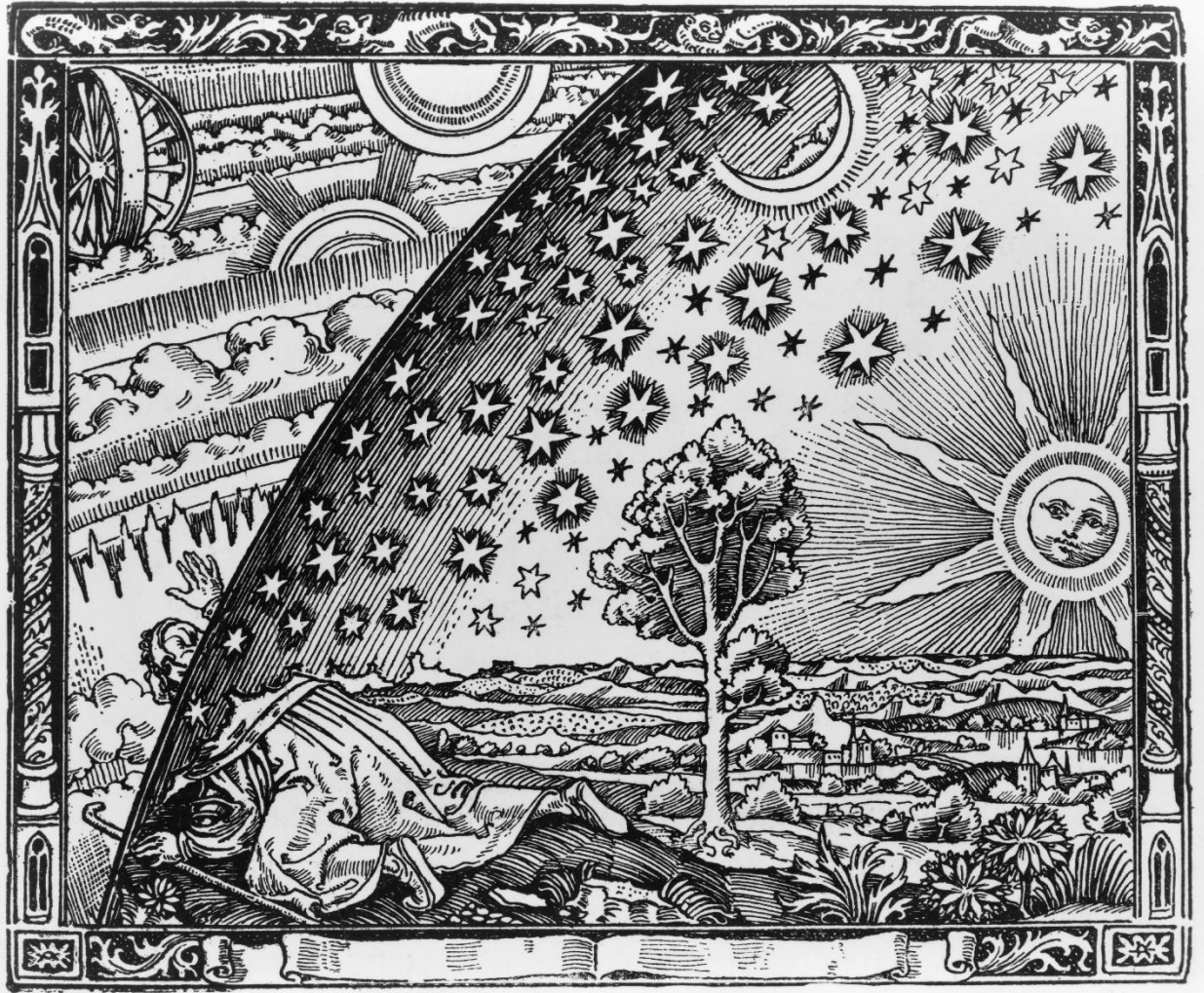
A young student asked Mozart's advice on how to write a symphony. Mozart said: *"It is a difficult and complex form. I would suggest that you first write a few keyboard sonatas, and maybe a string quartet or two, before you start thinking about writing a symphony."*

"But Herr Mozart," the student insisted, *"you were writing symphonies when you were far younger than I am."* Mozart replied: *"I never asked how."*



Bessie Jones sang about the Creation in the song, Once there was No Sun.





*A missionary of the Middle Ages tells that he had found the point where the sky and the Earth touch... from Camille Flammarion's (1888) *L'atmosphère: météorologie Populaire*.*

Morning Has Broken

A hymn written by *Eleanor Farjeon* (1931) to the Scottish folk melody Bunessan.

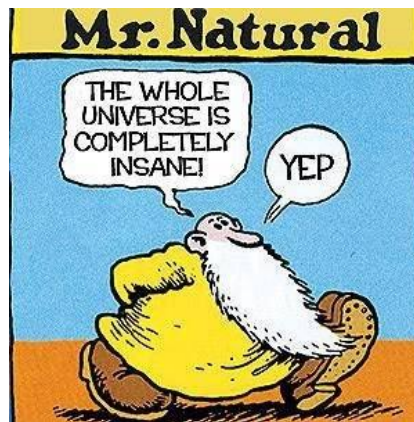
**Morning has broken
like the first morning,
blackbird has spoken
like the first bird.
Praise for the singing!
Praise for the morning!**

Praise for them, springing
fresh from the Word!
Sweet the rain's new fall
sunlit from heaven,
like the first dewfall
on the first grass.
Praise for the sweetness
of the wet garden,
sprung in completeness
where God's feet pass.

Mine is the sunlight!
Mine is the morning
born of the one light
Eden saw play!
Praise with elation,
praise every morning,
God's recreation
of the new day!

And performed by Cat Stevens later known as Yusuf Islam:

Zap Comix reports:



In his essay, Two Lectures, C. S. Lewis describes a lecture he attended:

AND SO', SAID THE LECTURER, 'I END WHERE I BEGAN. Evolution, development, the slow struggle upwards

GOD IN THE DOCK
ESSAYS ON THEOLOGY AND ETHICS

by

C. S. LEWIS
edited by WALTER HOOPER

and onwards from crude and inchoate beginnings towards ever-increasing perfection and elaboration — that appears to be the very formula of the whole universe. 'We see it exemplified in everything we study. The oak comes from the acorn. the giant express engine of today comes from the Rocket. The highest achievements of contemporary art are in a continuous line of descent from the rude scratchings with which prehistoric man adorned the wall of his cave. 'What are the ethics and philosophy of civilized man but a miraculous elaboration of the most primitive instincts and savage taboos? Each one of us has grown, through slow prenatal stages in which we were at first more like fish than mammals, from a particle of matter too small to be seen. Man himself springs from beasts: the organic from the inorganic. Development is the key word. The march of all things is from lower to higher.'

Then he describes a dream he had that night:

I dreamed that I was still at the lecture, and the voice from the platform was still going on. But it was saying all the wrong tilings. At least it may have been saying the right things up to the very moment at which I began attending; but it certainly began going wrong after that. What I remembered on waking went like this: '. . . appears to be the very formula of the whole universe. We see it exemplified in everything we study. The acorn comes from a full-grown oak. The first crude engine, the Rocket, comes, not from a still cruder engine, but from something much more perfect than itself and much more complex, the mind of a man, and a man of genius. The first prehistoric drawings come, not from earlier scratchings, but from the hand and brain of human beings whose hand and brain cannot be shown to have been in any way inferior to our own; and indeed it is obvious that the man who first conceived the idea of making a picture must have been a greater genius than any of the artists who have succeeded him. The embryo with which the life of each one of us began did not originate from something even more embryonic; it originated from two fully-developed human beings, our parents. Descent, downward movement, is the key word. The march of all things is from higher to lower. The rude and imperfect thing always springs from something perfect and developed.'

When he awoke, he thought about the two lectures:

It appeared to me that the Dream Lecturer had a good deal to be said for him. It is true that we do see all round us things growing up to perfection from small and rude beginnings; but then it is equally true that the small and rude beginnings themselves always come from some full-grown and developed thing. All adults

were once babies, true: but then all babies were begotten and born by adults. Corn does come from seed: but then seed comes from corn. I could even give the Dream Lecturer an example he had missed. All civilizations grow from small beginnings; but when you look into it you always find that those small beginnings themselves have been 'dropped' (as an oak drops an acorn) by some other and mature civilization. The weapons and even the cookery of old Germanic barbarism are, so to speak, driftwood from the wrecked ship of Roman civilization. The starting point of Greek culture is the remains of older Minoan cultures, supplemented by oddments from civilized Egypt and Phoenicia. But in that case, thought I, what about the first civilization of all? As soon as I asked this question I realised that the Dream Lecturer had been choosing his examples rather cautiously. He had talked only about things we can see going on around us. **He had kept off the subject of absolute beginnings.** He had quite correctly pointed out that in the present, and in the historical past, we see imperfect life coming from perfect just as much as vice versa. But he hadn't even attempted to answer the Real Lecturer about the beginnings of all life. The Real Lecturer's view was that when you got back far enough — back into those parts of the past which we know less about — you would find an absolute beginning, and it would be something small and imperfect. That was a point in favour of the Real Lecturer. He at least had a theory about the absolute beginning, whereas the Dream Lecturer had slurred it over. But hadn't the Real Lecturer done a little slurring too? He had not given us a hint that his theory of the ultimate origins involved us in believing that Nature's habits have, since those days, altered completely. Her present habits show us an endless cycle — the bird coming from the egg and the egg from the bird. But he asked us to believe that the whole thing started with an egg which had been preceded by no bird. Perhaps it did. **But the whole prima facie plausibility of his view — the ease with which the audience accepted it as something natural and obvious — depended on his slurring over the immense difference between this and the processes we actually observe.** He put it over by drawing our attention to the fact that eggs develop into birds and making us forget that birds lay eggs; indeed, we have been trained to do this all our lives: trained to look at the universe with **one eye shut**. 'Developmentalism' is made to look plausible by a kind of trick. For the first time in my life I began to look at the question with **both eyes open**. In the world I know, the perfect produces the imperfect, which again becomes perfect — egg leads to bird and bird to egg — in endless succession. **If there ever was a life which sprang of its own accord out of a purely inorganic universe, or a civilization which raised itself by its own shoulder-straps out of pure savagery, then this Event was totally unlike the beginnings of every subsequent life and every subsequent civilization.** The thing may have happened; but all its plausibility

is gone. On any view, the first beginning must have been outside the ordinary processes of nature. An egg which came from no bird is no more 'natural' than a bird which had existed from all eternity. And since the egg-bird-egg sequence leads us to no plausible beginning, is it not reasonable to look for the real origin somewhere outside sequence altogether? You have to go outside the sequence of engines, into the world of men, to find the real originator of the Rocket. Is it not equally reasonable to look outside Nature for the real Originator of the natural order?

LIFE AND MIND IN THE UNIVERSE

By George Wald

I have come to the end of my scientific life facing two great problems. Both are rooted in science; and I approach them as only a scientist would. Yet both I believe to be in essence unassimilable as science. That is scarcely to be wondered at, since one involves cosmology, the other consciousness.

I will begin with the cosmology.

I. A Universe That Breeds Life

There is good reason to believe that we are in a universe permeated with life, in which life arises, given enough time, wherever the conditions exist that make it possible. How many such places are there? Arthur Eddington, the great British physicist, gave us a formula: one hundred billion stars make a galaxy, and one hundred billion galaxies make a universe. The lowest estimate I have ever seen of the fraction of them that might possess a planet that could support life is one percent. That means one billion such places in our home galaxy, the Milky Way; and with about one billion such galaxies within reach of our telescopes, the already observed universe should contain at least one billion billion -- 10^{18} -- places that can support life

So we can take this to be a universe that breeds life; and yet, were any one of a considerable number of physical properties of our universe other than it is -- some of those properties basic, others seeming trivial, almost accidental -- that life, that now appears to be so prevalent, would become impossible, here or anywhere.

I can only sample that story here and, to give this account a little structure, I shall climb the scale of states of organization of matter, from small to great.

But first, a preliminary question: How is it that we have a universe of matter at all?

Our universe is made of four kinds of so-called elementary particles: neutrons, protons, electrons, and photons, which are particles of radiation. (I disregard neutrinos, since they do not interact with other matter; also the host of other particles that appear transiently in the course of high-energy nuclear interactions.) The only important qualification one need make to such a simple statement is that the first three particles exist also as antiparticles, the particles constituting matter, the anti-particles anti-matter. When matter comes into contact with anti-matter they mutually annihilate each other, and their masses are instantly turned into radiation according to Einstein's famous equation, $E = mc^2$, in which E is the energy of the radiation, m is the annihilated mass, and c is the speed of light.

The positive and negative electric charges that divide particles from anti-particles are perfectly symmetrical. So the most reasonable expectation is that exactly equal numbers of both particles and anti-particles entered the Big Bang, the cosmic explosion in which our universe is thought to have begun. In that case, however, in the enormous compression of material at the Big Bang, there must have occurred a tremendous storm of mutual annihilation, ending with the conversion of all the particles and anti-particles into radiation. We should have come out of the Big Bang with a universe containing only radiation.

Fortunately for us, it seems that a tiny mistake was made. In 1965, Arno Penzias and Robert Wilson at the Bell Telephone Laboratories in New Jersey discovered a new microwave radiation that fills the universe, coming equally from all directions, wherever one may be. It is by far the dominant radiation in the universe; billions of years of starlight have added to it only negligibly. It is commonly agreed that this is the residue remaining from that gigantic firestorm of mutual annihilation in the Big Bang.

It turns out that there are about one billion photons of that radiation for every proton in the universe. Hence it is thought that what went into the Big Bang were not exactly equal numbers of particles and anti-particles, but that for every billion anti-particles there were one billion and one particles, so that when all the mutual annihilation had happened, there remained over that one particle per billion, and

that now constitutes all the matter in the universe -- all the galaxies, the stars and planets, and of course all life.

I should like now to raise two problems to do with protons and electrons, one involving their masses, the other their electric charge.

Every atom has a nucleus composed of protons and neutrons, except the smallest one, hydrogen, which has only one proton as its nucleus. Electrons orbit these nuclei at distances relatively greater than separate our sun from its planets. Both protons and neutrons have masses almost two thousand times the mass of an electron -- 1840 times when I last looked -- so virtually the whole mass of an atom is in its nucleus. Hence the atom is hardly disturbed at all by the motions of its electrons, and an atom can hold its position in a molecule, and molecules their positions in larger structures. Only that circumstance permits molecules to hold their shapes, and solids to exist.

If on the contrary the protons and neutrons were closer in mass to the electrons, whether light or heavy, then the motions of the electrons would be reflected in reciprocal motions by the others. All structures composed of such atoms would be fluid; in such a universe nothing would stay put. There could not be the fitting together of molecular shapes that permits not only crystals to form, but living organisms.

And now, electric charge: How does it come about that elementary particles so altogether different otherwise as the proton and electron possess the same numerical charge? How is it that the proton is exactly as plus-charged as the electron is minus-charged?

It may help to accept this as a legitimate scientific question to know that in 1959 two of our most distinguished astrophysicists, Lyttleton and Bondi, proposed that in fact the proton and electron differ in charge by the almost infinitesimal amount, $2 \times 10^{-18} e$ -- two billion billionths e , in which e is the already tiny charge on either the proton or electron. The reason they made that proposal is that, given that nearly infinitesimal difference in charge, all the matter in the universe would be charged, and in the same sense, plus or minus. Since like charges repel one another, all the matter in the universe would repel all the other matter, and so the universe would expand, just as it is believed to do. The trouble with that idea is that yes, the universe would expand, but -- short of extraordinary special dispensations - it would not do anything else. Even so small a difference in electric charge would be

enough to overwhelm the forces of gravitation that bring matter together; and so we should have no planets, no stars, no galaxies -- and, worst of all, no physicists.

No need to worry, however. Shortly after Lyttleton and Bondi's proposal, John King and his group at the Massachusetts Institute of Technology began to test experimentally whether the proton and electron differ in charge, and found that the charges appear to be wholly identical. That is an extraordinary fact, and not made easier to understand by the present belief that, though the electron is a single, apparently indivisible particle, the proton is made up of three quarks, two of them with charges of $+2/3 e$, and one with a charge of $-1/3 e$.

To summarize, if the proton and neutron did not have enormously greater mass than the electron, all matter would be fluid; and if the proton and electron did not possess exactly the same electric charge, no matter would aggregate. These are primary conditions for the existence of life in the universe.

Now, to leave the elementary particles and go on to atoms, to elements. Of the 92 natural elements, ninety-nine percent of the living matter we know is composed of just four: hydrogen (H), oxygen (O), nitrogen (N), and carbon (C). That is bound to be true wherever life exists in the universe, for only those four elements possess the unique properties upon which life depends.

Their unique position in chemistry can be stated in a sentence: They -- in the order given -- are the lightest elements that achieve stable electronic configurations (i.e., those mimicking the inert gases) by gaining respectively one, two, three, and four electrons. Gaining electrons, in the sense of sharing them with other atoms, is the mechanism of forming chemical bonds, hence molecules. The lightest elements make not only the tightest bonds, hence the most stable molecules, but introduce a unique property crucial for life: of all the natural elements, only oxygen, nitrogen and carbon regularly form double and triple bonds with one another, so saturating all their tendencies to combine further.

Now, professors sometimes tell their students foolish things, which the students carefully learn and reproduce on exams and eventually teach the next generation. When chemistry professors teach the periodic system of elements, one has those horizontal periods of the elements and the professors say, "If you go down vertically, the elements repeat their same properties." That is utter nonsense, as any kid with a chemistry set would know. For under oxygen comes sulfur. Try breathing sulfur some time. Under nitrogen comes phosphorus. There is not any

phosphorus in that kid's chemistry set. It is too dangerous; it bursts into flame spontaneously on exposure to air. And under carbon comes silicon.

If that chemistry professor were talking sense, there are two molecules that should have very similar properties: carbon dioxide (CO_2) and silicon dioxide (SiO_2). Well, in carbon dioxide the central carbon is tied to both of the oxygen atoms by double bonds $\text{O}=\text{C}=\text{O}$. Those double bonds completely saturate the combining tendencies of all three atoms, hence CO_2 is a happy, independent molecule. It goes off in the air as a gas, and dissolves in all the waters of the Earth, and those are the places from which living organisms extract their carbon.

But silicon cannot form a double bond, hence in silicon dioxide the central silicon is tied to the two oxygens only by single bonds, leaving four half-formed bonds -- four unpaired electrons -- two on the silicon and one on each oxygen, ready to pair with any other available lone electrons. But where can one find them? Obviously on neighboring silicon dioxide molecules, so each molecule binds to the next, and that to the next, and on and on until you end up with a rock -- for example quartz, which is just silicon dioxide molecules bound to one another to form a great super-molecule. The reason quartz is so hard is that to break it one must break numerous chemical bonds. And that is why, though silicon is 135 times as plentiful as carbon in the Earth's surface, it makes rocks, and to make living organisms one must turn to carbon. I could make a parallel argument for oxygen and nitrogen.

These four elements, Hydrogen, carbon, oxygen and nitrogen, also provide an example of the astonishing togetherness of our universe. They make up the "organic" molecules that constitute living organisms on a planet, and the nuclei of these same elements interact to generate the light of its star. Then the organisms on the planet come to depend wholly on that starlight, as they must if life is to persist. So it is that all life on the Earth runs on sunlight. I do not need spiritual enlightenment to know that I am one with the universe -- that is just good physics.

Now let's go up a step, to molecules. By far the most important molecule for living organisms is water. I think we can feel sure that if there is no liquid water, there is no life, anywhere in the universe. Water also happens to be the strangest molecule in all chemistry; and its strangest property is that ice floats. If ice did not float, I doubt that life would exist in the universe.

Virtually everything contracts on cooling. That is how we make thermometers: a bit of red-dyed alcohol, mercury if you can afford it, put in a capillary tube contracts on cooling, and you read the temperature. Everything does this. So does

water, down to four degrees centigrade. But between four and zero degrees centigrade, where it freezes, it expands, so rapidly that the ice that forms is less dense than liquid water. The complete hydrogen bonding among the water molecules in ice holds them more widely spaced than in liquid water, so ice floats.

Nothing else does that. But what if water behaved like virtually everything else, and continued to contract on cooling? Then the increasingly dense water would constantly be sinking to the bottom, and freezing would begin at the bottom, not as now at the top, and would end by freezing the water solidly. A really large mass of ice takes forever to melt, even at higher temperatures.

In my region of the United States, New England, the fishermen wait all winter for the ponds to freeze over. That is the best time to go fishing. They take their fishing equipment in one hand, a bottle of whiskey in the other, and cut themselves a round hole in the ice. Up to that point the fish were getting along fine. These creatures live through the winter with no trouble, and as soon as the warm weather comes, that skin of ice on the surface melts and with that everything is free again. If ice did not float, it is hard to see how any life could survive a cold spell. On any planet in the universe, if a freeze occurred even once in many millions of years, that would probably be enough to block the rise of life, and to kill any life that had arisen.

And now another step up, to stars. The first generation of stars began as hydrogen, and lived by fusing it to helium. A hydrogen atom is composed of a proton as nucleus and one electron moving about it; but at temperatures of about five million degrees they are driven apart, and one is dealing with naked protons, hydrogen nuclei. Now four such protons, each of mass 1, begin to fuse to a helium nucleus of about mass 4, but in this process a very small amount of mass is lost -- four protons have a slightly larger mass than a helium nucleus -- and this tiny loss of mass is converted into radiation according to Einstein's equation, $E=mc^2$. Even so small a loss of mass yields a huge amount of radiation, and that flood of radiation pours out in the interior of what had been a collapsing mass of gas and stops its further collapse, stabilizing it, and is also the source of starlight.

Eventually, though, this process runs every star short of hydrogen. With that, it generates less energy and so begins to collapse again, and as it collapses it heats up some more. When the temperature in its deep interior reaches about one hundred million degrees, the helium nuclei begin to fuse. Two helium nuclei, each of mass 4, fuse to make beryllium, of mass 8, a nucleus so unstable as to disintegrate within 10^{-16} second (ten million billionths of a second). Yet in these enormous masses of

material and at such high temperatures there are always a few beryllium nuclei, and here and there one of them adds another helium: 8 and 4 make 12, the mass of carbon. That is how carbon comes into the universe. Then a carbon nucleus can add another helium: 12 plus 4 make 16, the mass of oxygen, and that is how oxygen enters the universe. Also carbon, even at somewhat lower temperatures, can add hydrogens, and carbon-12 plus two hydrogens make 14, the mass of nitrogen. That is how nitrogen enters the universe.

These new processes, together with its heating by collapse, have by now puffed up our star to enormous size. It has become a Red Giant, a dying star. In its dying, it has made the elements of which life is composed. It is a moving realization that stars must die before organisms can live.

These Red Giants are in a delicate condition, and by distillation and in such stellar catastrophes as flares, novas, and supernovas they spew their substance out to become part of the great masses of gases and dust that fill all interstellar space. Over eons of time, great masses of those gases and dust are drawn together by their mutual gravitation to form new generations of stars. But such latecomers, unlike the first generation of stars made wholly of hydrogen and helium, contain also carbon, nitrogen, and oxygen. And we know that our Sun is such a later-generation star because we are here, because the Earth is one of those planets in the universe that supports life.

Finally, we have a cosmic principle: To have such a universe as this requires an extraordinary balance between two great cosmic forces: that of dispersion (expansion), powered by the Big Bang, and that of aggregation, powered by gravitation. If the forces of expansion were dominant, that would yield an isotropically dispersed universe lacking local clusters, galaxies or planetary systems; all the matter would be flying apart, and there would be no large solid bodies, hence no place for life. If, on the contrary, gravitation were dominant, the initial expansion produced by the Big Bang would have slowed up and come to an end, followed by a universal collapse, perhaps in preparation for the next Big Bang. There would be no time for life to arise, or it would be quickly destroyed.

We live in a universe in which it has just lately been realized that those two forces are in exact balance, so that the universe as a whole is expanding wherever one looks, everything very distant is going away from us, but locally there are so-called local groups and clusters, where whole clusters of galaxies are held together by gravitation. Our own relatively small cluster contains, in addition to the Milky Way, the Andromeda galaxy (M31). It is very much like our galaxy, but a little

smaller, and there is also a still smaller galaxy, all part of our local group. Most of you have probably heard that we measure the expansion of the universe by the so-called red shift. The further one looks out into space, the redder the light is, compared to the same sources on earth. That is interpreted as an expression of the Doppler Effect, and taken to mean that the more distant an astronomical body, the faster it is receding from us. But the first such color shift ever to be discovered, by the astronomer Slipher back in 1912, was not a red shift but a blue shift. He was looking at our sister galaxy, Andromeda, and observed a blue shift because, far from receding, the Andromeda galaxy is coming toward us at about 125 miles per second. It is just this exact balance between the steady expansion of the universe as a whole and its stability locally that affords both enormous reaches of time and countless sites for the development of life.

I have here only sampled briefly an argument that extends much further. The nub of that argument is that our universe possesses a remarkably detailed constellation of properties, and as it happens, it is just that constellation that breeds life. It takes no great intelligence or imagination to conceive of other universes, indeed any number of them, each of which might be perfectly good, stable universes, but lifeless.

How did it happen that, with what seem to be so many other options, our universe came out just as it did? From our own self-centered point of view, that is the best way to make a universe: But what I want to know is, how did the universe find that out?

It may be objected that the question would not arise if we were not here to ask it. Yet here we are, and strangely insistent on asking that kind of question. Perhaps that indeed is the answer: That this is a life-breeding universe precisely in order eventually to bring forth creatures that ask and attempt to answer such questions, so that through them the universe can come not only to be, but to be known; indeed can come to know itself. That leads me to my other great problem, that of consciousness.

II. Consciousness

The problem of consciousness was hardly avoidable for someone like me, who has spent most of his scientific life working on mechanisms of vision. That is by now a very active field, with thousands of workers. We have learned a lot, and expect to

learn much more; yet none of it touches or even points however tentatively in the direction of telling us what it means to see.

I learned my business on the eyes of frogs. The retina of a frog is very much like a human retina. Both contain two kinds of light receptors, rods for vision in dim light and cones for bright light; the visual pigments are closely similar in chemistry and behavior; both have the same three fundamental nerve layers, and the nervous connections to the brain are much alike. But I know that I see. Does a frog see? It reacts to light -- so does a photocell-activated garage door. But does it know it is responding, is it aware of visual images?

There is nothing whatever that I can do as a scientist to answer that question. That is the problem of consciousness: it is altogether impervious to scientific approach. As I worked on visual systems -- it would have been the same for any other sensory mode, let alone more subtle or complex manifestations of mental activity -- this realization lay always in the background. Now for me it is in the foreground. I think that it involves a permanent condition: that it never will become possible to identify physically the presence or absence of consciousness, much less its content.

I of course have some preconceptions, but the only unequivocally sure thing is what goes on in my own consciousness. Everything else that I think I know involves some degree of inference. I have all kinds of evidence that other persons are conscious. It helps that they tell me so, and display other evidences of consciousness in speech and writing, art and technology. I believe that other mammals are conscious; and birds -- that business of singing at dawn and sunset makes me think that they are essentially poetic creatures. But when I get to frogs I worry, and fishes even more so. Those animals at least respond reasonably to light and some visual images. But I have worked also on the numerous and anatomically magnificent eyes of scallops, without finding any indication that these animals see, beyond reacting to a passing shadow. The last animals whose vision I worked on with my own hands were worms with great big bulging eyes, with everything you could ask for in an eye. The eyes yielded fine electrical responses to light, but I never could get the worms themselves to give any indication whatever that they responded to light. Maybe they didn't like being with me.

Any assumption regarding the presence or absence of awareness in any nonhuman animal remains just that: an unsupported assumption. Matters are no different with inorganic devices. Does the photoelectrically activated garage door resent having to open when a car's headlights shine on it? I think not. Does a computer that has

just beaten a human opponent at chess feel elated? I believe not. But there is nothing I can do to shore up those assumptions either.

Consciousness is not part of that universe of space and time, of observable and measurable quantities, that is amenable to scientific investigation. For a scientist, it would be a relief to dismiss it as unreal or irrelevant. I have heard distinguished scientists do both. In a discussion with the physicist P. W. Bridgman some years ago, he spoke of consciousness as “just a way of talking.” His thesis was that only terms that can be defined operationally have meaning; and there are no operations that define consciousness. In the same discussion, the psychologist B. F. Skinner dismissed consciousness as irrelevant to science, since confined to a private world, not accessible to others.

Unfortunately for such attitudes, consciousness is not just an epiphenomenon, a strange concomitant of our neural activity that we project onto physical reality. On the contrary, all that we know, including all our science, is in our consciousness. It is part, not of the superstructure, but of the foundations. No consciousness, no science. Perhaps, indeed, no consciousness, no reality -- of which more later.

Though consciousness is the essential condition for all science, science cannot deal with it. That is not because it is an unassimilable element within science, but just the opposite: science is a highly digestible element within consciousness, which includes science as a limited territory within the much wider reality of whose existence we are conscious. Consciousness itself lies outside the parameters of space and time that would make it accessible to science, and that realization carries an enormous consequence: consciousness cannot be located. But more: it has no location.

Some years ago I talked about this with Wilder Penfield, the great Canadian neurosurgeon. In the course of his therapeutic activities he had unprecedented opportunities to explore the exposed brains of conscious patients, and hoped in this way to discover the seat of human consciousness. I asked him, “Why do you think consciousness is in the brain? Maybe it’s all over the body.”

He chuckled, and said, “Well, I’ll keep on trying.”

About two years later, I met him again and he said to me, “I’ll tell you one thing: it’s not in the cerebral cortex!”

Shortly afterward came the exciting announcement that the so-called reticular formation in the brain stem of mammals contains an arousal center, a center that seems to wake creatures up and produce awareness. The problem with all such observations is that one cannot know whether one is dealing with a source or with part of the machinery of reception and transmission. It is as though, finding that the removal of a transistor from a television set stopped the transmission, one concluded it to be the source of the program.

How could one possibly locate a phenomenon that one has no means of identifying -- neither its presence nor absence -- nor any known parameters of space, time, energy exchange, by which to characterize merely its occurrence, let alone its content? The very idea of a location of consciousness is absurd. Just as with Heisenberg's uncertainty principle, we have more to deal with here than technical inadequacy, with a perhaps temporary lack of means of observation and measurement. What we confront is an intrinsic condition of reality. It is not only that we are unable to locate consciousness: it has no location.

Consider pain, the most primitive of sensory responses, and most closely connected with survival. I have had to kill many animals in the course of my work, and have tried always to inflict a minimum of pain. But do other animals than man feel pain? Many physiologists assert that only warm-blooded animals feel pain, and some of their publications have stated this as an official view. The National Eye Institute announced only in 1979 a first break with this position, asking workers with cold-blooded animals to try to avoid giving them "unnecessary pain." When I lop off the head of a frog, I assume that the headless body is beyond pain; but is the head? So I hastily destroy the brain, and hope that ends the problem. Yet I have heard Wilder Penfield say that once a human brain has been exposed, one could operate on it with a spoon without causing an unanesthetized patient any great discomfort. And what of a worm, any small piece of which writhes on being pinched?

Recently there has been a controversy in the American press involving some physicians having asserted that a human fetus feels pain in an abortion. The very idea should raise deep concern about the very widespread American practice of circumcising male newborns, performed routinely without anesthesia, the physicians having assured the mothers that the nervous systems of their infants have not yet developed sufficiently for them to feel pain. All such assertions are equally groundless. Even as regards so primitive a concept as pain, we are altogether baffled in trying to substantiate its occurrence or absence.

I used to show students a film made by the French zoologist Faure-Fremiet on the feeding behavior of protozoa. Many of our sturdiest concepts of the apparatus required for animal behavior are mocked by these animalcules, particularly by the ciliates; for in one cell they do everything: move about, react to stimuli, feed, digest, excrete, on occasion copulate and reproduce. In this film one saw them encountering problems and solving them, much as would a mammal. I remember best a carnivorous protozoon tackling a microscopic bit of muscle. It took hold of the end of a fibril, and backed off at an angle, as though to tear it loose. When the fibril would not give, the protozoon came in again, then backed away at a new angle, worrying the fibril loose, much as a dog might have done, worrying loose a chunk of meat. It was hard, watching that single cell at work, not to anthropomorphize. Did it know what it was doing?

But then, ciliate protozoa are the most complex cells we know. How about a cell highly specialized to perform a single function in a higher organism, a nerve cell for example, that can only transmit an impulse? Once, years ago, I was visiting the invertebrate physiologist, Ladd Prosser, at the University of Illinois in Urbana. He took me into his laboratory, where he was recording the electrical responses from a single nerve cell in the ventral nerve cord (which takes the place of our spinal cord) of a cockroach. It was set up to display the electrical potentials on an oscilloscope screen, and simultaneously to let them sound through a loudspeaker. I was hearing a slow, rhythmic reverberation, coming to a peak, then falling off to silence, then starting again, each cycle a few seconds, like a breathing rhythm. Prosser remarked, "That kind of response is typical of a dying nerve cell."

"My God!" I said, "It's groaning! You've given it a voice, and it's groaning!"

Was that nerve cell expressing a conscious distress? Is something like that the source of a person's groaning? There is no way whatever of knowing.

So that is the problem of mind -- consciousness -- a vast, unchartable domain that includes all science, yet that science cannot deal with, has no way of approaching; not even to identify its presence or absence; that offers nothing to measure, and nothing to locate, since it has no location.

III. Mind and Matter

A few years ago it occurred to me -- albeit with some shock to my scientific sensibilities -- that my two problems, that of a life-breeding universe, and that

of consciousness that can neither be identified nor located, might be brought together. That would be with the thought that mind, rather than being a late development in the evolution of organisms, had existed always: that this is a life-breeding universe because the constant presence of mind made it so.

I have been in experimental science long enough to know that when you have done an experiment that comes out surprisingly well, the thing to do is enjoy it, because the next time you try it, it may not work. So when this idea struck me, I was elated, I enjoyed it immensely. But I was also embarrassed, because this idea violated all my scientific feelings. It took only a few weeks, however, for me to realize that I was in excellent company. That kind of thought is not only deeply embedded in millennia-old Eastern philosophies; it is stated explicitly or strongly implied in the writings of a number of great and quite recent physicists.

Perhaps it was in part because I am a biologist that the idea at first seemed so strange to me. Biologists tend to be embarrassed by consciousness. As it is an attribute of some living organisms, they feel that they should know about it, and should indeed be in position to straighten out physicists about it, whereas exactly the opposite is true. Physicists live with the problem of consciousness day in and day out. Early in this century it became evident to all physicists that the observer is an intrinsic component of every physical observation. Physical reality is what physicists recognize to be real. One cannot separate the recognition of existence from existence. As Erwin Schrödinger put it: "The world is a construct of our sensations, perceptions, memories. It is convenient to regard it as existing objectively on its own. But it certainly does not become manifest by its mere existence."

Let me give a simple example of the intervention of mind in physical observation: Most readers are probably aware that radiation -- light, indeed all elementary particles -- exhibits simultaneously the properties of waves and of particles, though those properties are altogether different -- indeed, mutually exclusive. This is the prime example of a widespread class of relationships that Neils Bohr brought together in his principle of complementarity, which notes that numbers of phenomena, in and out of physics, exhibit such mutually exclusive sets of properties; one just has to live with them.

Enter consciousness: the physicist, setting up an experiment on radiation, decides beforehand which of those sets of properties he will encounter. If he does a wave experiment, he gets a wave answer; from a particle experiment he gets a particle answer. To this degree, all physical observation is subjective.

It is primarily physicists who in recent times have expressed most clearly and forthrightly this pervasive relationship between mind and matter, and indeed at times the primacy of mind. Arthur Eddington in 1928 wrote, “the stuff of the world is mind-stuff ... The mind-stuff is not spread in space and time.... Recognizing that the physical world is entirely abstract and without ‘actuality’ apart from its linkage to consciousness, we restore consciousness to the fundamental position . . .”

Von Weizsacker in 1971 states as “a new and, I feel, intelligible interpretation of quantum theory” what he calls his “Identity Hypothesis: Consciousness and matter are different aspects of the same reality.”

I like most of all Wolfgang Pauli’s formulation, from 1952: “To us . . . the only acceptable point of view appears to be the one that recognizes both sides of reality -- the quantitative and the qualitative, the physical and the psychical -- as compatible with each other, and can embrace them simultaneously . . . It would be most satisfactory of all if physis and psyche (i.e., matter and mind) could be seen as complementary aspects of the same reality.”

What this kind of thought means essentially is that one has no more basis for considering the existence of matter without its complementary aspect of mind, than for asking that elementary particles not also be waves.

As for this seeming a strange viewpoint for a scientist -- at least until one gets used to it -- as in so many other instances, what is wanted is not so much an acceptable concept as an acceptable rhetoric. If I say, with Eddington, “the stuff of the world is mind-stuff,” that has a metaphysical ring. But if I say that ultimate reality is expressed in the solutions of the equations of quantum mechanics, quantum electrodynamics, and quantum field theory -- that sounds like good, modern physics. Yet what are those equations, indeed what is mathematics, but mind-stuff? -- virtually the ultimate in mind-stuff and for that reason deeply mysterious.

IV. The Evolution of Consciousness

I think that we now possess, at least in outline, all that is needed to shape a credible view of the plan of this universe, and of the place in it of life and mind.

That view begins with a sense of the deep interpenetration of the concepts, to be, and to be known -- existence, and its recognition.

Some years ago I began to entertain the thought that a universe that to be needs to be known, to that end has taken on a design that breeds and fosters life; so that life might eventually, here and there, evolve scientists who could cast back upon the history that produced them, and could begin to understand it. That, through their knowing, the universe could achieve increasingly the reality of becoming known, of coming to know itself. Let me talk a little frank nonsense about this, make of it what you will: It would be a poor thing to be an atom in a universe without physicists. And physicists are made of atoms. A physicist is the atom's way of knowing about atoms.

Recently, to my surprise and that of some of the physicists most involved, this kind of thinking has been given the rather pretentious name, "the anthropic principle." It states essentially what I have just said: that the universe possesses the properties it does in order eventually to produce physicists. Apart from meanderings in this direction, it emerged explicitly in a short paper by Dicke at Princeton, pointing out, for example, that the Hubble age of the universe is not wholly arbitrary, since about that much time was needed for physicists to appear. I used to hear this idea expressed in the form of a joke: "Why is the world five -- or ten or twenty -- billion years old?" And the answer: "Because it took that long to find that out."

Of course, implicit in such talk is the recognition that a universe in which mind can eventually achieve such overt expression as in science, art and technology must be at its core, from its inception, in some sense a knowing universe; that it must in some sense possess mind as its pervasive and enduring attribute. What we recognize as the material universe, the universe of space and time and elementary particles and energies, is then an avatar, the materialization of primal mind. In that sense there is no waiting for consciousness to arise. It is there always. What we wait for in the evolution of life is only the culminating event, the emergence of creatures that in their self-awareness can articulate consciousness, can give it a voice and, being also social creatures, can embody it in culture: in technology, art and science.

All of this, however, provocative as it is, does not yet express what I think is the crux of the matter: A universe that through breeding life evolves eventually science-, art-, and technology-making creatures, presumably in many places, enters thereby a new phase in its evolution, that now includes means for the independent evolution of consciousness. For such creatures found societies and establish cultures. They invent languages, writing, institutions for accumulating, storing and propagating information, speculation and belief.

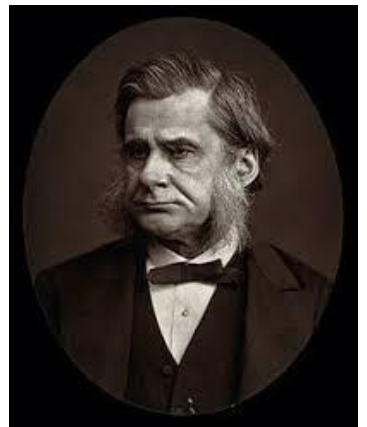
Those creatures were evolved anatomically and physiologically through natural selection, a process that involves three components: a ceaseless outpouring of inherited variations, both advantageous and disadvantageous; a mechanism of inheritance; and a competition for survival, in the course of which those organisms and properties that function better are retained, and those that function less well are discarded.

Cultures -- on our planet, human cultures -- exhibit all these elements. They -too display endless variations, both advantageous and disadvantageous to survival; mechanisms of cultural inheritance, mainly if not entirely Lamarckian (nongenetic), since they involve almost entirely acquired (i.e., learned) characters; and continuous competition, an unceasing interplay of absorption and rejection, domination and subjection.

So is launched an independent evolution of consciousness, superimposed upon and parallel with the continuing evolution of anatomy and physiology. It takes its place as an intrinsic development in cosmic evolution. That universe in which, from its inception, matter and mind have been the complementary aspects of reality, now comes to develop, and regularly, in many places, complementary systems of evolution by natural selection, physical and mental.

I think that is the substantive outcome of our argument. It accords to humankind and its like elsewhere in the universe a great place in cosmic evolution. It gives -our species here a transcendent worth and dignity, among the many kinds of creatures that inhabit our planet. It tells us our place in the universe: it is to know and create, and to try to understand, as we alone can do under our sun.

In an essay entitled, Science and Morals, T. H. Huxley (1886) states that if the definition of a Materialist is someone who 1) puts aside, as unverifiable, everything which the senses cannot verify; 2) everything beyond the bounds of physical science; and 3) and everything which cannot be brought into a laboratory and dealt with chemically, then he is not a Materialist. Otherwise, he would think that all the truths of mathematics such as the binomial theorem that Mendel relied on does not exist, and that the universal validity of the law of causation does not exist, since neither can be weighed or chemically analyzed.



Huxley goes on to say, “As I have said elsewhere, if I were forced to choose between Materialism and Idealism, I should elect for the latter; and I certainly would have nothing to do with the effete mythology of Spiritualism. But I am not aware that I am under any compulsion to choose either the one or the other. I have always entertained a strong suspicion that the sage who maintained that man is the measure of the universe was sadly in the wrong; and age and experience have not weakened [134] that conviction. In following these lines of speculation I am reminded of the quarter-deck walks of my youth. In taking that form of exercise you may perambulate through all points of the compass with perfect safety, so long as you keep within certain limits: forget those limits, in your ardour, and mere smothering and spluttering, if not worse, await you. I stick by the deck and throw a lifebuoy now and then to the struggling folk who have gone overboard; and all I get for my humanity is the abuse of all whenever they leave off abusing one another.

Tolerably early in life I discovered that one of the unpardonable sins, in the eyes of most people, is for a man to presume to go about unlabelled. The world regards such a person as the police do an unmuzzled dog, not under proper control. I could find no label that would suit me, so, in my desire to range myself and be respectable, I invented one; and, as the chief thing I was sure of was that I did not know a great many things that the—ists and the—ites about me professed to be familiar with, I called myself an Agnostic. Surely no denomination could be more modest or more appropriate; and I cannot imagine why I should be every now and then haled out of my refuge and declared sometimes to be a Materialist, sometimes an Atheist, sometimes a Positivist; and sometimes, alas and alack, a cowardly or reactionary Obscurantist.”

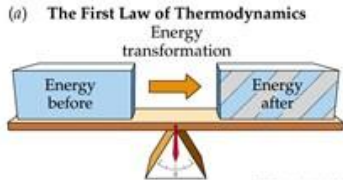
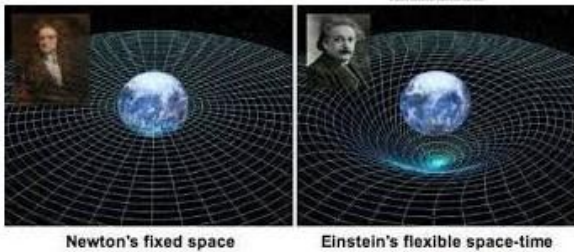
**THEN THE NOTHING CREATED
A SOMETHING, WHICH
CREATED SOME ROCKS, AND ONE OF
THE ROCKS MADE LIFE, THE END.**



Production of Sunlight and Chemical Spectroscopy

Review: Here are some of the big questions we have touched on so far:

Thermodynamics is fundamental:
A creator is necessary to create something.



Universe of **relative** spacetime created at the big bang and expanded into nothing; or energy and matter of Universe created in **absolute** space and time and expanded into absolute space over time.



Uncertainty Principle is fundamental:
Something comes from nothing.

Darwin's **Natural Selection** is fundamental and differential reproduction based on a nature that is red in tooth and claw is the whole story in explaining the origin of the bone structure and mind of human beings; or according to Alfred Russel Wallace and T. H. Huxley, natural selection is not the whole story.



There is a fundamental **truth** although because we see through a glass darkly, no one can know it completely. Faith, reason, and evidence-based science provide a way that leads to the truth; or all knowledge is socially constructed. Consequently, there is no absolute truth and nothing to have faith in.



FIGURE 1.20. Satire Fair magazine caricatures of Bishop Wilberforce (left), Thomas Henry Huxley (middle), and Charles Darwin (right). Wilberforce attacked Darwin's ideas at an 1880 British Association meeting, and Huxley—'Darwin's bulldog'—defended Darwin at this debate.

1.20, reprinted from Drawings by Agnew's Henry Fox (left: July 18, 1880, cartoon; January 28, 1871, right: Sept. 30, 1871)

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Individual identity is fundamental because each person is created in the image of God; or group identity based on the melanin content of the skin is fundamental.

There is a close relationship between chemistry and light. **Phosphorus** is a chemical that can produce light. **Hennig Brand** in 1669 was an **alchemist** who thought that he might find the **Philosopher's Stone** (*lapis philosophorum*) or the secret for converting base or ignoble metals into gold in human urine. Perhaps he was inspired by urine's golden color (produced by urobilin, a breakdown product of heme). In the process of isolating different chemicals in the urine, probably at night, he serendipitously discovered a chemical that was capable of producing light. Consequently, he named the chemical **phosphorus**, meaning **light bearer**, from the Greek *Φωσφόρος*.



Nothing Gold Can Stay by Robert Frost

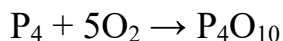
*Nature's first green is gold,
Her hardest hue to hold.
Her early leaf's a flower;
But only so an hour.
Then leaf subsides to leaf.
So Eden sank to grief,
So dawn goes down to day.
Nothing gold can stay.*

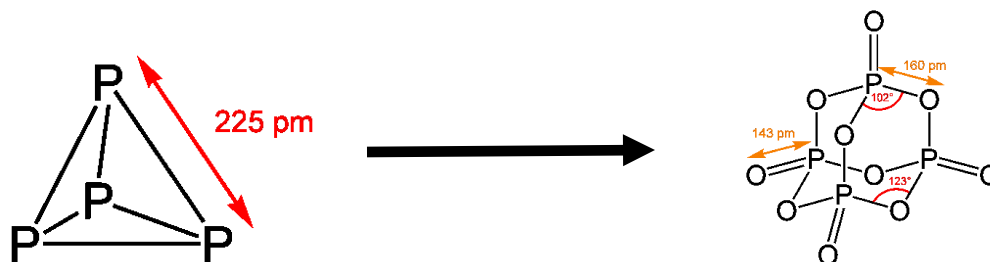


Aside: In 1980, Glenn Seaborg produced gold from bismuth using particle bombardment at the Lawrence Berkeley Laboratory at a cost of one quadrillion dollars per ounce (which at the time was worth \$560/oz).



We now know that phosphorus in the form of pure white tetrahedral phosphorus (P₄) ignites spontaneously in the presence of oxygen to form phosphorus oxide, transforming chemical energy into radiant energy (light) in the process. The rearrangement of bonds results from the rearrangement of **electrons**.

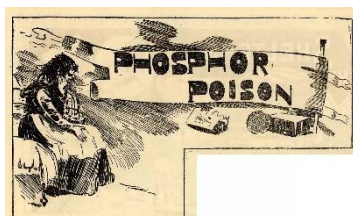
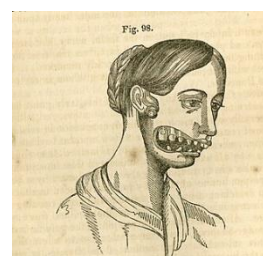




White phosphorus, which can be explosive, can be exposed to sunlight or heated to produce a *polymerized form* of phosphorus known as **red phosphorus**, which is more stable. Red phosphorus only gives off light when it is excited by friction (triboluminescence). For this reason, red phosphorus is used to produce **safety matches**.

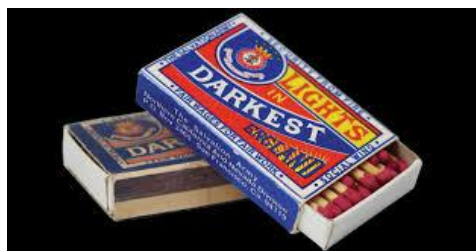


In England, match makers used white phosphorus, which became known as **yellow phosphorus**, to make matches (Lucifers) because it was cheaper than red phosphorus. However the volatile fumes of yellow phosphorus caused **phossy jaw**, a disease that workers in the match factories got.



Phossy jaw caused unbearable abscesses in their mouths, which lead to facial disfigurement.

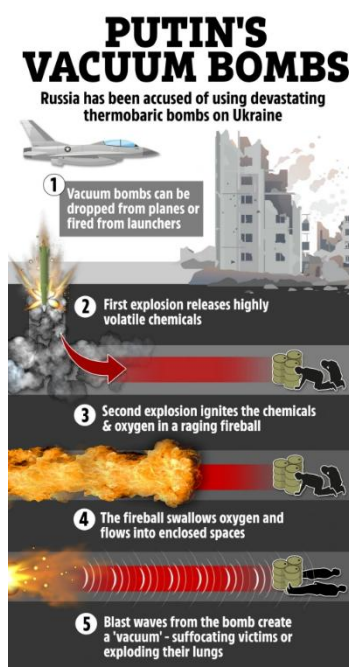
While matches made with red phosphorus could be purchased from other countries, William Booth, the founder of the **Salvation Army** wondered why matches should be imported from other countries when there were so many unemployed people in England. The Salvation Army started a match company to hire unemployed people in England to make **Lights in Darkest England** matches with red phosphorus under safe working conditions.



Salvation Army wondered why matches should be imported from other countries when there were so many unemployed



Aside: In a thermobaric or vacuum bomb, an initial anerobic explosive reaction releases tiny particles of B, Al, Mg, Si, Ti, Zr, and C into the atmosphere. Within a millisecond, these tiny aerosol particles with high surface-to-volume ratios combine with oxygen and burst into flames. They use up the oxygen in the atmosphere and because they combine with so much oxygen, a partial vacuum is created. The lack of oxygen prevents respiration and the decrease in air pressure causes lungs to collapse.



A light-emitting chemical reaction is known as **chemiluminescence**.

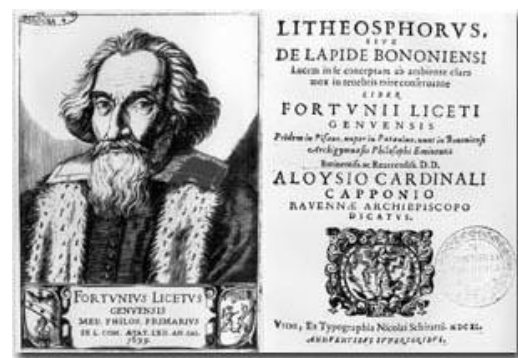
Phosphorus is not phosphorescent, as it is defined today.

Phosphorescence, which was named after phosphorus, is defined today as a **delayed re-emission of light that has already been absorbed**. Phosphorescence is also known as **photoluminescence**.

Chemiluminescent substances, such as white phosphorus, do *not* require pre-illumination to glow whereas phosphorescent substances, such as the **Bologna Stone**, by contrast, do.



The **Bologna Stone**, or litheosphorus had recently been discovered in Bologna by Vincenzo Casciarolo in his search for the Philosopher's Stone. Casciarolo (1640) wrote in *Litheosphorus*, "*that the stone was most suitable for the production of gold by virtue of its notable weight and content of sulphur. After submitting the stone to much preparation, it was not the Pluto of Aristophanes that resulted; instead, it was the Luciferous Stone, which would not itself produce gold, but which would absorb the golden light of the sun, like a new Prometheus stealing a Celestial Treasure.*" The Bologna Stone was later found to be composed of barium sulfate.



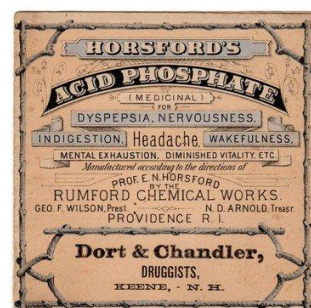
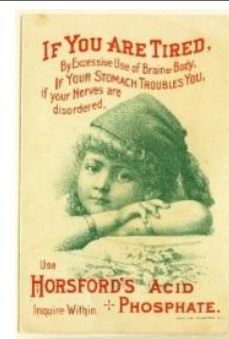
<https://io9.gizmodo.com/the-bologna-stone-was-a-glowing-mystery-for-400-years-1724589932>

The phosphorous first isolated by Hennig Brand was, as we now know, of humble human origin. **Johann Kunckel** (1676) also figured out how to produce phosphorus from urine. It was a difficult process and Kunckel reasoned that anything that comes out of the human body (at a rate of 1.4 g P/day) must also go in. Consequently, he found that many foods of animal and plant origin, when heated in a furnace, produced phosphorous. Kunckel was able to turn phosphorus into gold in that he got rich performing spectacular shows for the nobility with the phosphorus he had created. He also sold phosphorus for medicinal purposes. Indeed, **phosphorus is essential for life** as we know it as it is a constituent of all **nucleic acids**, including DNA, RNA, ATP, and the cGMP involved in vision.

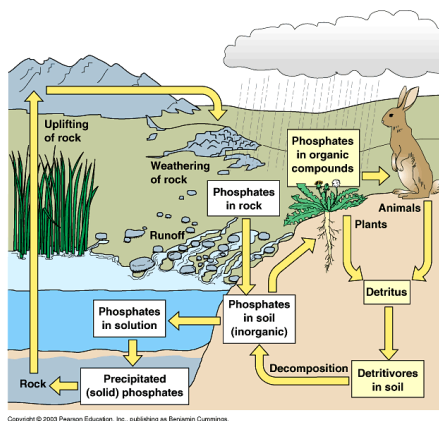
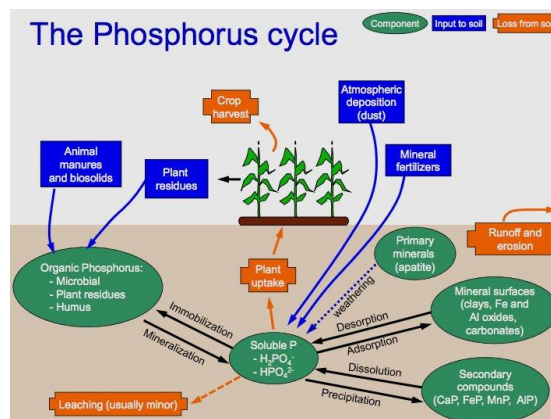


Components of Nucleic Acids

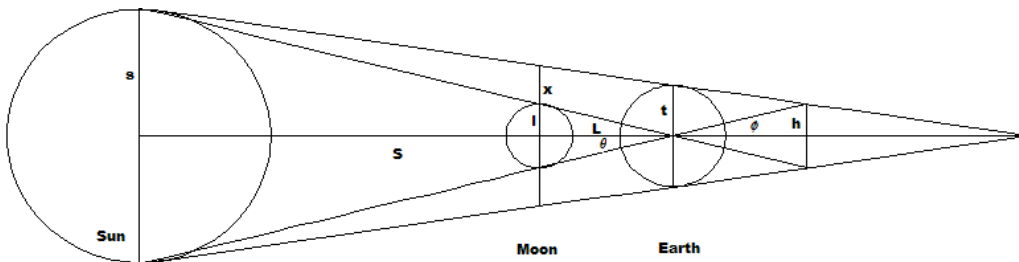
	DNA only	DNA & RNA	RNA only
Nitrogen Bases	<chem>Cc1c[nH]c(=O)[nH]c1=O</chem> Thymine	<chem>Nc1ncnc2[nH]cnc12</chem> Adenine <chem>Nc1nc2[nH]cnc2c(=O)[nH]1</chem> Guanine <chem>Nc1cc[nH]c(=O)n1</chem> Cytosine	<chem>O=c1cc[nH]c(=O)[nH]1</chem> Uracil
Sugars & Phosphate	<chem>OC[C@H]1O[C@H](COP(=O)(O)O)[C@H](O)[C@@H]1O</chem> 2-Deoxyribose	<chem>OP(=O)(O)O</chem> Phosphate	<chem>OC[C@H]1O[C@H](COP(=O)(O)O)[C@H](O)[C@@H]1O</chem> Ribose



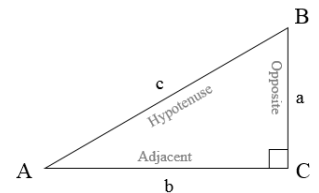
The phosphorus on earth, which was originally **produced in first generation stars**, circulates in the lithosphere (the rocky crust of the earth), the hydrosphere (the water on the surface of the earth), and the biosphere (the living organisms on earth).



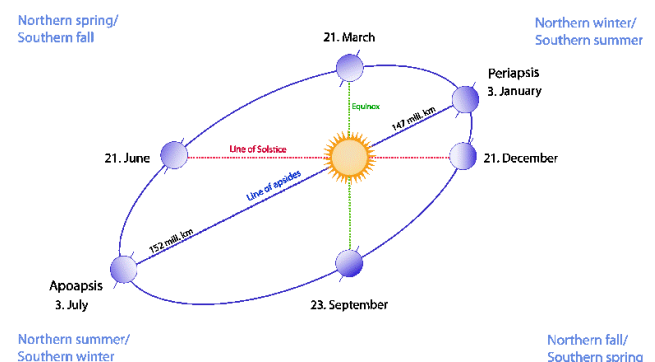
We are now going to discuss the **cause of sunlight**, but before we do, we have to understand a few facts about the sun, such as the **distance** between the sun and the earth and the **diameter** of the sun, so that we can make reasonable inferences about the cause of sunlight. **Hipparchus** (190-120 BC) estimated the mean **distance** from the earth to the sun by making measurements of the angles the edge of sun could be seen from different places on earth during a solar eclipse and used **trigonometry** to analyze the angles and lengths.



Trigonometry (from the Greek for measuring triangles (τρίγωνο)) was invented by Euclid and Archimedes in the third century BC and Hipparchus used it in the second century BC as a way of simplifying the application of **geometry** (from the Greek for measuring the earth (γῆω)) to astronomy.

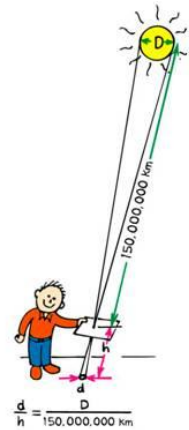


Today the **average** distance between the sun and the earth is defined as approximately $1.5 \times 10^{11} \text{ m}$ (which is a distance of approximately **8.3 light-minutes**, given that the speed of light in the vacuum of space is about $3 \times 10^8 \text{ m/s}$). This means that it takes sunlight approximately eight minutes to reach



the earth and that we see the sun where it was eight minutes ago. The distance 1.5×10^{11} m from the earth to the sun is known as 1 **astronomical unit** (au). The astronomical unit is defined as "*the radius of an unperturbed circular Newtonian orbit about the sun of a particle having infinitesimal mass, moving with a mean motion of 0.01720209895 radians per day.*" Note: $0.01720209895 \times 365.26 = 2\pi$.

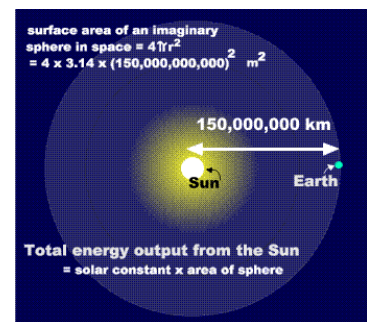
The **diameter of the sun** can be estimated using a **pinhole**. The pinhole will form an image of the sun on a piece of paper. The size of the image will depend on the distance between the image and the pinhole. Use a ruler to measure the diameter of the image (y_i) of the sun and the distance between the pinhole and the image (s_i). Using 1.5×10^{11} m as the distance to the sun (s_o), calculate the diameter of the sun (y_o) using the following formula based on the assumption that vertical angles are equal:



$$\frac{y_o}{y_i} = -\frac{s_o}{s_i}$$

The **diameter** of the sun is about 1.39×10^9 m; the radius (r_s) is 0.7×10^9 m.

We can measure the **luminosity** of the sun, which is the rate at which the sun is radiating energy, by measuring the **intensity** of sunlight at the earth's surface (I_{earth}), which is a distance r from the sun and, by assuming the sun to be a point source of light. We can then use the inverse square law to determine the power of the source (S , as we did in the second lecture) and the luminosity of the sun (L_{sun} , in Watts = Joules/second):



$$I_{earth} = \frac{L_{sun}}{4\pi r^2}$$

The average intensity of sunlight at the earth's surface is known as the **solar constant**.

A term coined by **Claude Pouillet** in 1838.

Pouillet measured the solar constant with a **pyrheliometer**, which at the time was a thermometer placed in a cylinder of water

whose blackened side faced the sun. He determined the solar constant by measuring the rate that the temperature of the water increased when the blackened side was in the sun. To compensate for the loss of heat from the thermometer to the environment, he added the rate of cooling determined when the blackened side was in the shade. Pouillet determined the solar constant to be $1.228 \times 10^3 \text{ W/m}^2$.

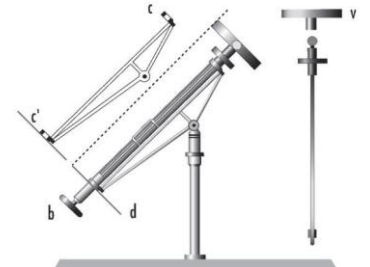
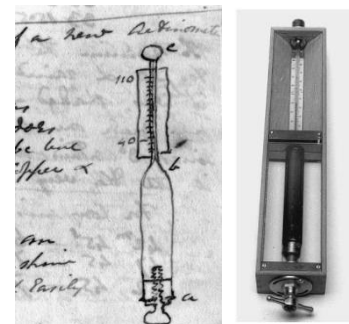


Figure 2 - Schémas du pyrhéliomètre, tel qu'il apparaît dans l'article de Pouillet de 1838.

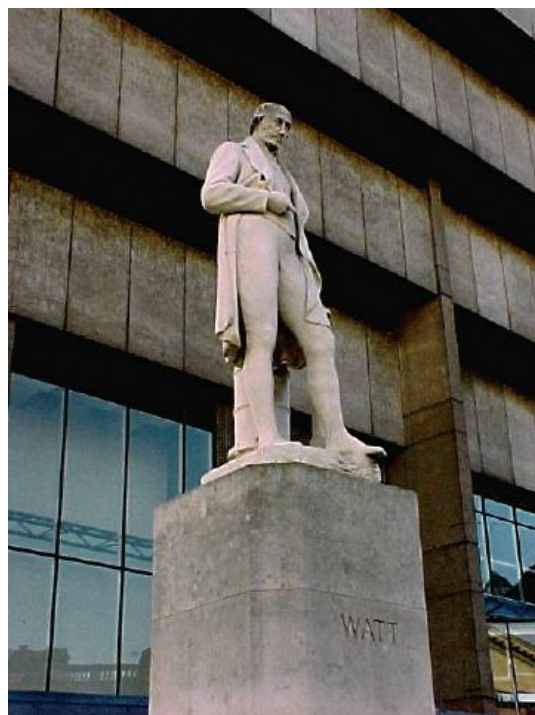
After traveling through the Alpine pass between France and Italy in 1824, **John Herschel**, William Herschel's son, got a sunburn, and unlike most others who get sunburned, he decided to design an instrument to measure the intensity of the sun. He wrote "*...the scorching effect of the Sun's rays upon every exposed part of the skin proved so severe as to excite in my mind a lively desire to subject to some precise means of measurement the cause of so disagreeable an effect.*"



John Herschel developed an **actinometer** that was in essence a thermometer placed in water in which black ink was dissolved to measure the light intensity. The light intensity was calculated from the difference between the temperature of the thermometer in the sunlight and in the shade. Herschel (1847) determined the solar constant to be $1.004 \times 10^3 \text{ W/m}^2$.

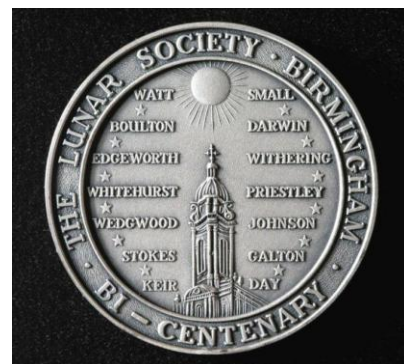


Asides on the unit of luminosity or power known as the Watt (W), which was named after James Watt. This marble statue of James Watt made by Alexander Munro in 1868 stands in Birmingham, England, the birthplace of the **industrial revolution** and the home of the **Lunar Society**. Watt is standing on a pedestal that is one square meter and the stature is known as **one Watt per meter squared**. Nowadays, only the pigeons come to visit him.



<https://www.birminghammail.co.uk/news/local-news/decaying-statue-of-james-watt-dismays-392018>

THE LUNAR SOCIETY REEL				8x32 R
2 T _◇ S	1 2 3 T _◇ S	Weasel Reel 1/2 reel of 4 & 1/2 chase All dance clockwise back to starting positions		
1 3 S T _◇			2x 1x 3x 	
Kenneth J Reid, Platinum Dance Book (Birmingham)				3C/4C longwise set.



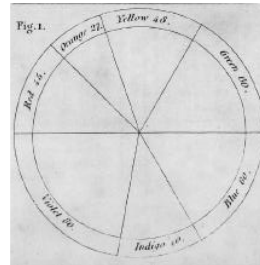
Gilded bronze statue of Matthew Boulton, **James Watt**, and William Murdoch looking at plans for a steam engine.

The rotund **Erasmus Darwin**, a physician, poet, and Charles Darwin's paternal grandfather, was also a member of the Lunar Society. Erasmus wrote, in *Zoonomia* (1796), “*Would it be too bold to imagine, that in the great length of time, since the earth began to exist, perhaps millions of ages before the commencement of the history of mankind, would it be too bold to imagine, that all warm-blooded animals have arisen from one living filament, which THE GREAT FIRST CAUSE endued with animality, with the power of acquiring new parts, attended with new propensities, directed by irritations, sensations, volitions, and associations; and thus possessing the faculty of continuing to improve by its own inherent activity, and of delivering down those improvements by generation to its posterity, world without end.*” Sound familiar?

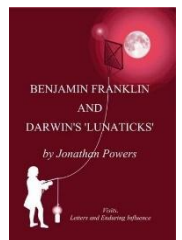


<http://www.gutenberg.org/files/15707/15707-h/15707-h.htm>

Samuel “John” Galton, a gun maker who made muskets that were given to local African chieftains in exchange for slaves and experimented with color mixing (Monthly Magazine 8, 509. 1799), was also a member of the Lunar Society. His son, Samuel, married Violetta Darwin, a daughter of Erasmus Darwin, and one of their sons was **Francis Galton**, who wrote *Hereditary Genius* and coined the word eugenics. **Josiah Wedgwood** and **Joseph Priestley** were members of the Lunar Society who were abolitionists.

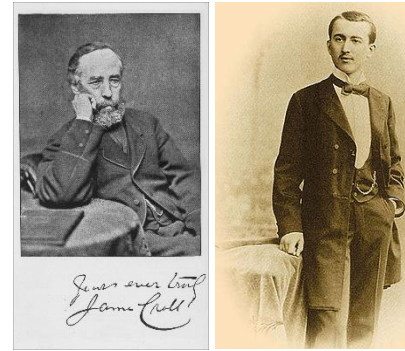


William Small, a member of the Lunar Society was one of **Thomas Jefferson**'s mathematics teachers in Williamsburg, Virginia; and **Benjamin Franklin** was a corresponding member of the Lunar Society. (I am an overseas member of the Lunar Society).

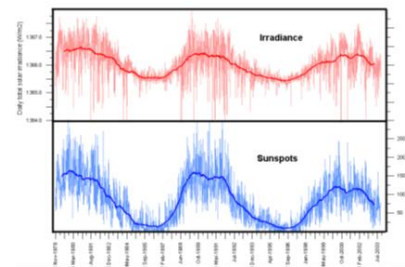


The **solar constant** is currently measured by satellite above the earth's atmosphere to be about $1.36 \times 10^3 \text{ W/m}^2$. The actual solar intensity on earth varies with latitude due to the tilt of the earth. It also varies at a given spot on earth during the day due to the rotation of the earth and during the year due to the ellipticity of the earth's orbit. The solar constant is **not constant** but represents an average of these intensities in time and space. Moreover, the actual solar intensity on earth has varied historically since the tilt of the earth, the rotation of the earth, and the

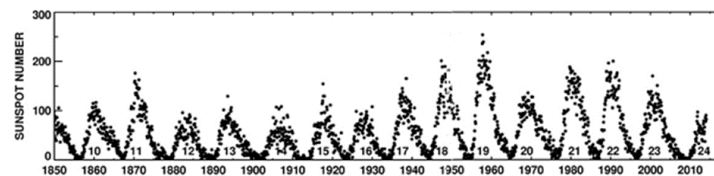
ellipticity and precession of the earth's orbit change slowly over time. **James Croll** (1885) and **Milutin Milanković** (1920) took into consideration such changes and proposed that there were long term cycles that affected the value of the solar intensity at a given spot on earth. The solar constant, which characterizes the greatest and most important source of energy available on earth, does not represent a static system, but the changing relationship between sun and the earth.



The solar constant also depends on changes in the physical processes that go on in the sun. The solar constant varies about **0.1%** cyclically with an eleven-year period that is correlated with **sunspots**, which are regions that are cooler than the rest of the sun. Faculae, which are associated with the sunspots are regions that are warmer than the rest of the sun. Since the greater intensity of faculae more than compensates for the lesser intensity of the sunspots, the magnitude of the solar constant is positively correlated with the number of sunspots.

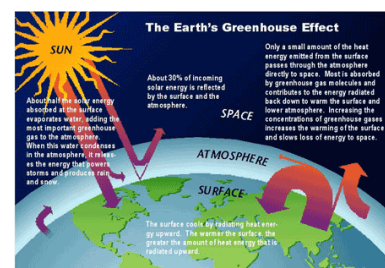


The sun is a **plasma** composed of rapidly moving charged particles that generate magnetic fields. The **11-year sunspot cycle** is also correlated with an increased flux of charged particles known as the solar wind as well as with an increased magnetic field whose polarity reverses with a 22-year cycle. The earth's magnetic field caused by the movements of the molten core, deflects the electrons and protons in the solar wind from striking the earth, and thus minimizes the rate of cosmic ray-induced genetic mutations and variability.



<http://www.ini.uzh.ch/~tobi/fun/max/timofeeffZimmerDelbruck1935.pdf>;

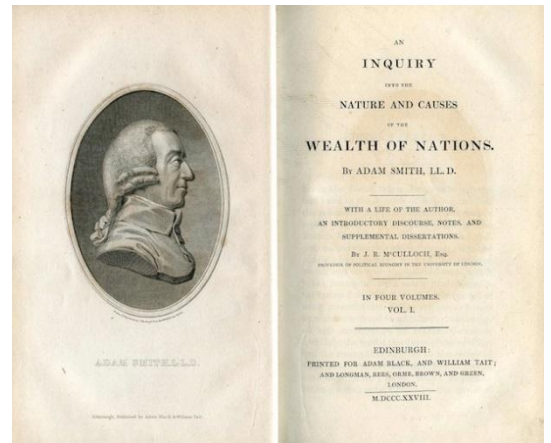
William Herschel (1801) realized that there was variability in the appearance of the sun and wrote *“The influence of this eminent body, on the globe we inhabit, is so great, and so widely diffused, that it becomes almost a duty for us to study the operations which are carried on upon the solar surface. Since light and heat are so essential to our well-being, it must certainly be right for us to look into the source from whence they are derived, in order to see whether some material advantage may not be drawn from a thorough acquaintance with the causes from which they originate.....We are not only in possession of photometers and thermometers, by which we can measure from time to time the light and heat actually received from the sun, but have more especially telescopes, that may lead us to a discovery of the causes which dispose the sun to emit more or less copiously the rays which occasion either of them. And, if we should even fail in this respect, we may at least succeed in becoming acquainted with certain symptoms or indications, from which some judgment might be formed of the temperature of the seasons we are likely to have.”* William Herschel made the first attempt to relate the appearance and disappearance of sunspots to the temperature of the earth. He could not measure the intensity of light and heat everywhere and all the factors that control the temperature of the earth, such as the CO₂ concentration in the atmosphere, but his thinking is ingenious and worth knowing.



William Herschel (1801) wrote *“With regard to the contemporary severity and mildness of the seasons, it will hardly be necessary to remark, that nothing decisive can be obtained. But, if we are deficient here, an indirect source of information is opened to us, by applying to the influence of sun-beams on the*

vegetation of wheat in this country. I do not mean to say, that this is a real criterion of the quantity of light and heat emanated from the sun; much less will the price of this article completely represent the scarcity or abundance of the absolute produce of the country. For the price of commodities will certainly be regulated by the demand for them; and this we know is liable to be affected by many fortuitous circumstances. However, although an argument drawn from a well ascertained price of wheat, may not apply directly to our present purpose, yet, admitting the sun to be the ultimate fountain of fertility, this subject may deserve a short investigation, especially as, for want of proper thermometrical observations, no other method is left for our choice.”

“Our historical account of the disappearance of the spots in the sun, contains five very irregular and very unequal periods. The first takes in a series of 21 years, from 1650 to 1670, both included. But it is so imperfectly recorded, that it is hardly safe to draw any conclusions from it; for we have only a few observations of one or two spots that were seen in all that time, and those were only observed for a short continuance. However, on examining the table of prices of the quarter of nine bushels of the best or highest prices wheat at Windsor, marked in **Dr. Adam Smith’s valuable Inquiry into the nature and causes of the wealth of nations**, we find that wheat, during the time of the 21 years above mentioned, bore a very high price; the average of the quarter being £2, 10s. $5\frac{19}{21}$ d. This period is much too long compare it with a preceding or following one of equal duration. Besides, no particulars having been given of the time preceding, except that spots in the sun, a good while before, began to grow very scarce. There might be even fewer of them from the year 1650 to 1670. Of the



21 years immediately following, we know that they certainly comprehend two short periods, in which there were no spots on the sun; of these, more will be said hereafter; but, including even them, we have the average price of wheat, from 1671 to 1691, only £2, 4s. $4\frac{2}{3}$ d. The quarter. The difference, which is a little more than 9 to 8, is therefore still a proof of a temporary scarcity....**The result of this review of the foregoing five periods is, that, from the price of wheat, it seems probable that some temporary scarcity or defect of vegetation has generally taken place, when the sun has been without those appearances which we surmise to be symptoms of a copious emission of light and heat.** In order, however, to make this an argument in favor of our hypothesis, even if the reality of a defective vegetation of grain were sufficiently established by its enhanced price. It would still be necessary to shew that a deficiency of the solar beams had been the occasion of it. Now, those who are acquainted with agriculture may remark, that wheat is well known to grow in climates much colder than ours; and that a proper distribution of rain and dry weather, with many other circumstances which it will not be necessary to mention, are probably of much greater consequence than the absolute quantity of light and heat derived from the sun. **To this I shall only suggest, by way of answer, that those very circumstances of proper alternations of rain, dry weather, winds, or whatever else may contribute to favour vegetation in this climate, may possibly depend on a certain quantity of sun-beams, transmitted to us at proper times; but, this being a point which can only be ascertained by future observations, I forbear entering farther into a discussion of it.**"

While I think that Herschel's thinking was ingenious and points to the fact that the net effect of dark-looking sunspots is to increase the intensity of sunlight, Herschel's thinking and analysis is currently pooh-poohed by those who think the

human impact on climate far exceeds the astronomical impact on climate:

<https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/grl.50846>

Aside: In May, 1921, the activity of sunspots was so intense that they caused damage to the **transatlantic cable, telegraph lines**, and also caused fires that engulfed the switchboard of the Central New England Railroad and the railroad control tower near **Grand Central Station**, is why the event is sometimes referred to as the “New York Railroad Superstorm.” It also **dimmed the lights of Broadway**.

May 1921 Geomagnetic Storm

SUNSPOT CREDITED WITH RAIL TIE-UP

New York Central Signal System Put Out of Service by Play of Northern Lights.

The sunspot which caused the brilliant aurora borealis on Saturday night and the worst electrical disturbance in memory on the telegraph systems was credited with an unprecedented thing at 7:04 o'clock yesterday morning, when the entire signal and switching system of the New York Central Railroad below 125th Street was put out of operation, followed by a fire in the control tower at Fifty-seventh Street and Park Avenue. This is the first time that a sunspot has been blamed for such a piece of mischief. From other accounts it appeared

The New York Times
Published May 10, 1921
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SUNSPOT AURORA PARALYZES WIRES

Unprecedented Disturbance Is Attributed to Solar Manifestations.

BROADWAY LIGHTS DIMMED

Theatre Crows Returning Home Amazed at the Brilliance of the Skies.

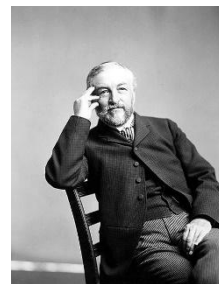
WASHINGTON, May 10.—The very worst storm known of late years.

ELECTRIC DISTURBANCES AFFECT FRENCH WIRES

Aurora Not Visible, Its Absence Being Attributed to Atmospheric Conditions.

Copyright, 1921, by The New York Times Company
By Wireless to The New York Times.
PARIS, May 10.—The disturbance which interrupted telegraphic transmission in the United States last week has been making itself felt also in

The **luminosity** or the rate in which the sun radiates energy at the sun’s surface (L_{sun}) is given by $I_{earth} 4\pi r^2$, where I_{earth} is the measured intensity on earth and r is the distance between the sun and the earth. The luminosity or power is equal to about 3.8×10^{26} W. A Watt equals a Joule/second. The **luminosity** or power is given in **Watts** while the **intensity**, which is the **rate the sun radiates energy per unit area** is given in Watts per meter squared. The **spectral distribution** of sunlight (intensity vs. **wavelength**) was first measured quantitatively under the Allegheny sky by **Samuel Pierpont Langley** in 1881.



	mm.								
$\lambda =$	.00035	.0004	.0005	.0006	.0007	.0008	.0009	.0010	.0011
	div.								
Defl.	12	55	207	246	198	129	80	58	41

Langley became the third **Secretary of the Smithsonian Institution** in 1887 and founder of the Smithsonian Astrophysical Observatory in 1890, which initially did research on solar



radiation and the solar constant. Former Cornell University President Skorton was the thirteenth Secretary of the Smithsonian Institution.

Modern measurements *above* the atmosphere give the following somewhat **continuous spectral distribution**:

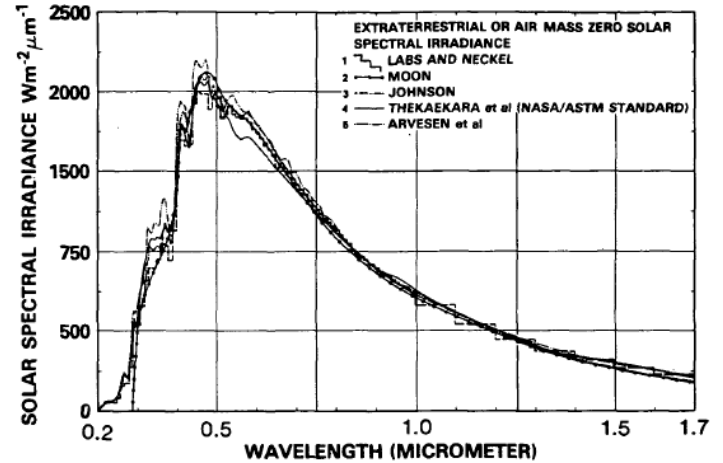


Figure 1. Solar Spectral Irradiance Outside the Atmosphere, 0.2 μm - 1.7 μm reported by: 1. Labs and Neckel, 2. P. Moon, 3. F.S. Johnson, 4. Thekaekara et al (NASA/ASTM Standard), 5. Arvesen et al.

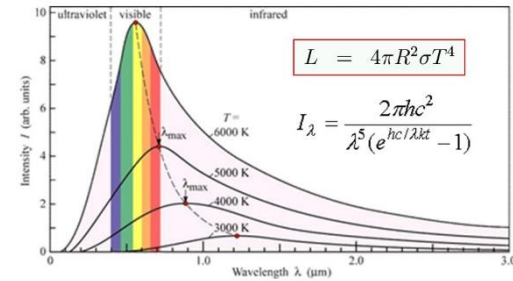
The **temperature (T) of the surface of the sun**, which is **5778 K** can be estimated from either the luminosity of the sun ($I_{\text{earth}} = \frac{L_{\text{sun}}}{4\pi r^2}$) using the **Stefan-Boltzmann law**:

$$L_{\text{sun}} = I_{\text{earth}} 4\pi r^2 = 4\pi r_s^2 \sigma T^4$$

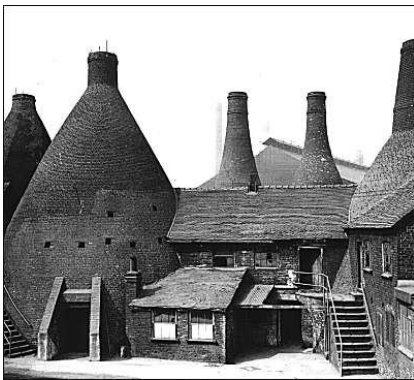
where r_s is the radius of the sun (in m) and σ is the Stefan-Boltzmann constant ($\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$), or it can be estimated from the continuous spectral distribution produced by a “hot” **incandescent body** using **Max Planck’s blackbody radiation law**:

$$I(\lambda) = \frac{2\pi hc^2}{\lambda^5 (e^{hc/\lambda kT} - 1)}$$

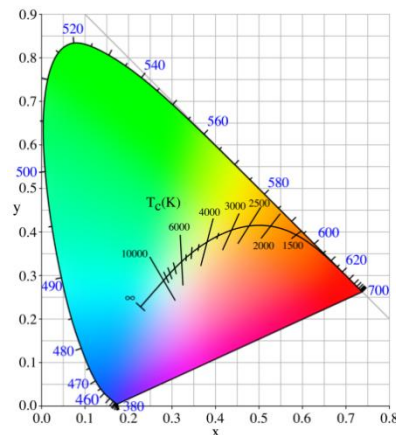
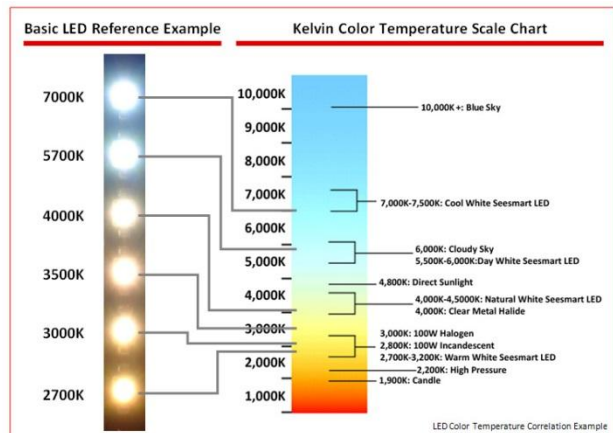
where λ (in m) is the wavelength of light, k is the Boltzmann constant ($k = 1.38 \times 10^{-23}$ J/K), c is the speed of light ($c = 2.99 \times 10^8$ m/s) and h is Planck's constant ($h = 6.626 \times 10^{-34}$ J s). The peak for the sun is in the yellow part of the spectrum which is why the sun looks yellow.

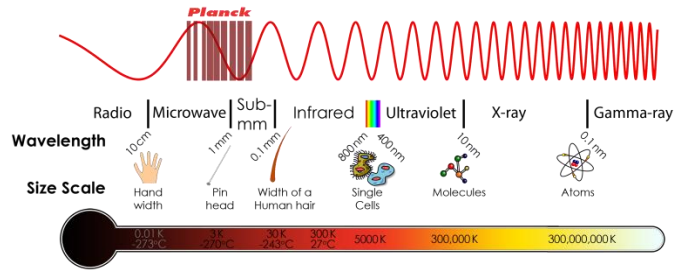


The Stefan-Boltzmann and Planck radiation laws were derived, in part, from measuring the intensity and color of radiated light from bodies of different temperatures (for example, **pottery in the kilns of Josiah and Thomas Wedgwood**). Josiah Wedgwood was a member of the Lunar Society, an abolitionist, and the grandfather of both Charles Darwin and of his wife, Emma.



The commonly observed relationship between the color (peak wavelength) and the temperature of a body are presented in various ways in the following figures:





The sun is a **star** and the relationship between the luminosity of a star and its temperature or spectral color class can be shown in a **Hertzsprung-Russell diagram**. $L/L_{\odot}$ is the ratio of the luminosity of a star to the luminosity of the sun. After the stars are assembled using gravitational energy, they spend most of their life on the main sequence (MS). The hot and luminous stars are in the upper left of the main sequence and the cool dim stars are on the bottom right. At the end of a star's life, it develops into a red giant and then into a white dwarf. The cool and brilliant red giants and hot and dim white dwarfs are shown above and below the main sequence, respectively. A star evolves onto a given place in the main sequence depending on the **initial mass** of the clump formed in a given nebula to form a **protostar**.

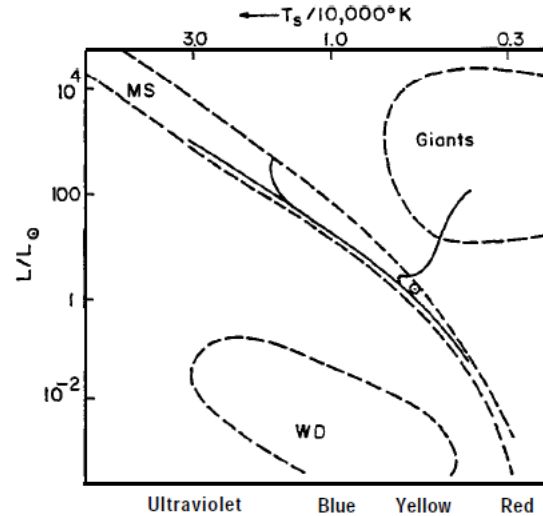


Fig.1. Hertzsprung-Russell diagram. From E.E.Salpeter, in *Apollo and the Universe*, Science Foundation for Physics, University of Sydney, Australia, 1967.

The **luminosity** of a star depends on its **mass**, which is a measure of the gravitational energy of the star and the fuel it has to burn.

$M/M_{\odot}$ on the abscissa is the ratio of the mass of a star to the mass of the sun. The solar mass is calculated from the orbits of the planets using **Newton's Law of Universal Gravitation** and the stellar masses can be calculated from the orbits of binary stars.

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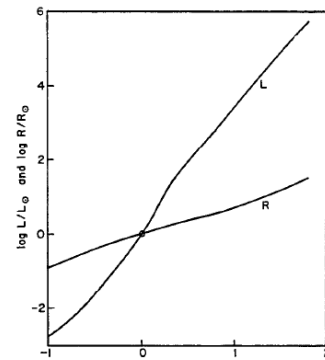


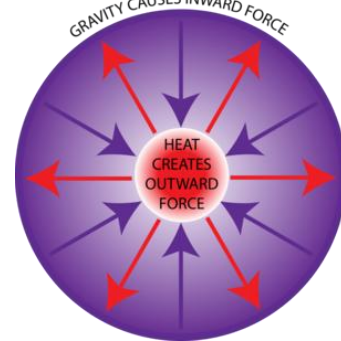
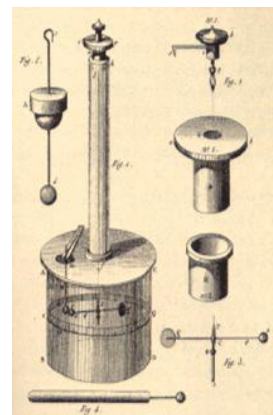
Fig. 2 Luminosity and radius of stars vs. mass. Abscissa is $\log M/M_{\odot}$. Data from C. W. Allen, *Astrophysical Quantities*, Athlone Press, 1963, p. 203. The curve for $\log L/L_{\odot}$ holds for all stars, that for $R/R_{\odot}$ only for the stars in the main sequence. The symbol $\odot$ refers to the sun.

The **most luminous** stars on the main sequence have the **greatest masses** ($150 M_{sun}$) and the least luminous stars on the main sequence have the smallest masses ($0.08 M_{sun}$, which is the **minimal mass** needed to ignite nuclear reactions).

The mass of the sun (M_{sun}) can be estimated from Newton's Law of Universal Gravitation and Newton's Second Law:

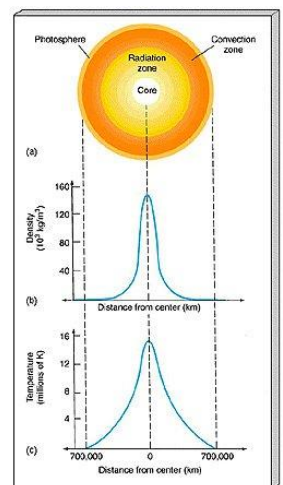
$$mg = G \frac{M_{sun}m}{r^2} = \frac{mv^2}{r} \quad M_{sun} = \frac{rv^2}{G}$$

where g (in $m s^{-2}$) is the acceleration at which a planet with mass m is falling into the sun, G is the gravitational constant measured by Henry Cavendish in 1798 using the torsion balance and is equal to $6.67 \times 10^{-11} m^3 kg^{-1} s^{-2}$, and r is the distance between a planet and the sun. The velocity (v) of a planet is equal to the ratio of the circumference



($2\pi r$) of the orbit to its period. The acceleration is equal to the velocity squared divided by the radius of the orbit ($g = \frac{v^2}{r}$). From studying the orbits of the planets in the solar system around the sun, the **mass** of the sun has been determined to be 1.99×10^{30} kg, which is about 300,000 times more massive than the earth.

If we plug in the **radius of the sun for r** , we get the gravitational force per unit mass upon any body at the **surface of the sun**. This gravitational force is so large that it could cause the gravitational collapse of the sun such that the sun would become approximately a point in approximately 30 minutes. The fact that the radius of the sun seems to be **constant** indicates that the gravitational force must be **transformed into an opposing force** when it acts on the sun itself. Indeed, it is, the compression of the sun itself results in the production of heat inside the sun. The heat causes the **dissociation of the electrons** from the nuclei of atoms forming a **plasma**. The heat also causes the ionized nuclei and electrons to move very fast and act like an **expanding gas** that exerts a **pressure** that **balances the gravitational force**. As a consequence of the hydrostatic equilibrium, the **radius of the sun remains constant**. **Radiation pressure**, which is pressure due to the force exerted by light itself, also contributes, along with gas pressure, to balance the pressure due to gravitational contractions. The **average density** of the sun is estimated from its **mass** and **volume** ($V = \frac{4}{3}\pi r^3$) to be approximately **1.4 g/cc** and the density in the center which has to balance all of the gravitational force is approximately 150 g/cc. The density of water is approximately 1 g/cc. Although we have never sampled the inside of the sun directly, we just used the



laws of nature and a little algebra to give us an idea of the internal conditions of the sun.

Hermann von Helmholtz (1856) proposed that **gravitational contraction** is the cause of the energy radiated by the sun. The gravitational energy (in Joules) of a spherical sun is related to the gravitational force per radial distance and is given by the following equation.

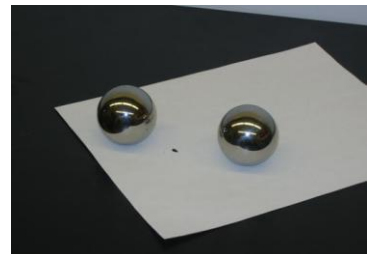
$$E_{gravitational} = -\frac{3GM_{sun}^2}{5r}$$



Demonstration: Observe the effect of gravity on two rolling objects—a double cone and a cylinder rolling down an inclined plane:



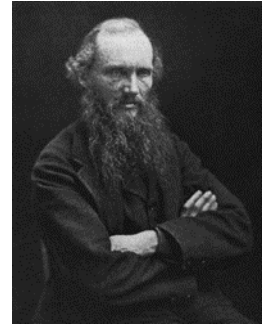
Demonstration: Converting mechanical energy into thermal energy (heat): Observe what happens to a piece of paper when you smash together the two chrome steel balls with a piece of paper in between.



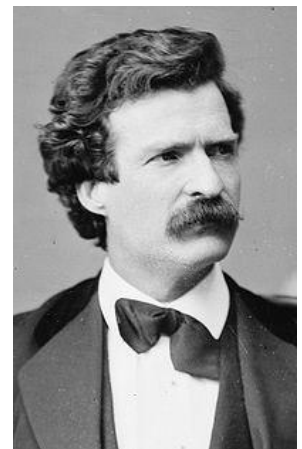
Demonstration: Converting mechanical energy into thermal energy (heat): Compress air with the fire syringe and observe what happens to the cotton.



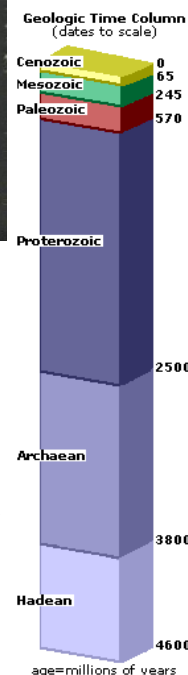
The ratio of the **gravitational energy** ($2.3 \times 10^{41} \text{ J}$) to the **luminosity** ($3.8 \times 10^{26} \text{ W} = \text{J/s}$) gives an estimate of the **time** in seconds that it would take to radiate the observed energy if the gravitational contraction served as the only source of energy. The ratio tells us that, if the conversion of gravitational energy into heat was the only source of energy in the sun, then **the age of the sun** would be about **20 million years**, which seemed reasonable in 1856. This would also give an estimate of the age of a habitable earth that depended on the light and heat of the sun. However, in **1859**, when **Charles Darwin** calculated the age of the earth to be greater than 300 million years, from the time it would take for erosion to denude the Weald, 20 million years seemed too short for the age of the sun. An old earth would be consistent with the **gradual origin of species by natural selection**. William Thomson, the **greatest living scientific authority** at the time, who later became **Lord Kelvin**, argued against Darwin. This is why Darwin withdrew his estimate of the age of the earth. According to Thomson (1862), the sun, which is necessary for life on earth, and which derived its energy from gravity, could not have provided the needed sunlight for 300 million years of evolution by natural selection.



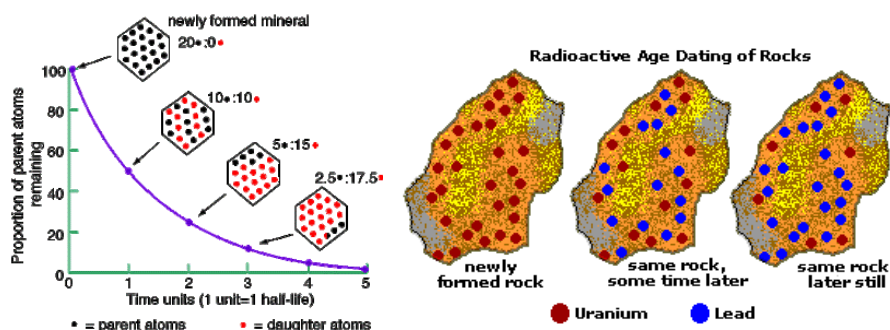
Mark Twain satirized the situation, and wrote, “*Some of the great scientists, carefully ciphering the evidences furnished by geology, have arrived at the conviction that our world is prodigiously old, and they may be right but Lord Kelvin is not of their opinion. He takes the cautious, conservative view, in order to be on the safe side, and feels sure it is not so old as they think. As Lord Kelvin is the **highest authority in science** now living, I think we must yield to him and accept his views.*”



William Thomson could not have **foreseen** the possibility of thermonuclear transformation of nuclear mass into energy to produce sunlight as the temperature of the sun stayed constant.



Henri Becquerel (1896), who was interested in what was called the **phosphorescence** of **uranium** at the time, **serendipitously** discovered **radioactivity**, which was due to the emission of electrons, when he noticed that uranium produced an **image** of itself on the photographic film it had been resting on in the **dark**. Radioactive elements are transformed into other elements during **radioactive decay** by **fission**, which was named after bacterial fission. Rutherford called the study of radioactive decay “*the new alchemy*” since radioactive decay resulted in the **transmutation of elements** for example uranium into lead. By measuring the ratio of the radioactive parent element to the stable element it transforms into in various ancient rocks, **Ernest Rutherford** and **Frederick Soddy** estimated the age of the earth. Current radiometric dating estimates the **age of the earth to be approximately 4.54 billion years old**.



Sometimes the greatest living scientific authority is *not* right. Frederick Soddy (1904) described the hullabaloo between **Lord Kelvin**, the physicist and **Charles Darwin**, the biologist concerning the age of the earth like so: *“Throughout the latter part of the last century a **controversy**, as to the possible age of the earth as a planet fitted for habitation, existed between two schools, represented by the physicists on the one side and the biologists on the other. Some of the arguments advanced by the former make strange reading at the present time.”*

In 1898, **Marie Curie**, who coined the term **radioactivity**, and her husband **Pierre Curie** isolated from uranium-rich pitchblende, polonium, named after Marie Curie’s native country and **radium**, from the Latin word *radius*, which means ray. In 1903, Pierre Curie noticed that radium released heat



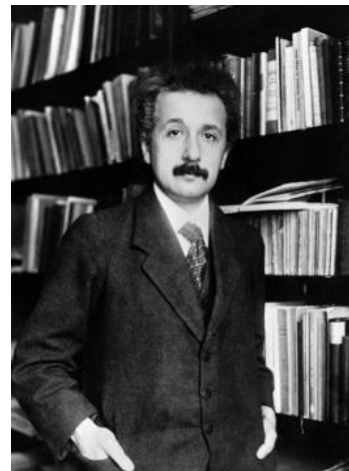
but *unlike* other thermal processes (e.g., the radiation of heat by an iron rod), the radium did not cool down to the temperature of its surroundings. **Ernest Rutherford** and **Frederick Soddy** as well as **William Wilson**, **John Joly**, and **George Darwin**, one of Charles Darwin’s sons, all proposed in 1903 that **radioactivity** might be the source of the sun's radiated energy. However, a spectroscopic study of the chemical composition of the sun by **Cecelia Payne** (1925) revealed that the sun was composed primarily of hydrogen and helium and that there were little or no heavy radioactive chemicals in the sun. This was later confirmed by **Henry Norris Russell** (1929).

In 1904, Mark Twain described the luminescence of lucifer in *Sold to Satan*, as a softly glowing, richly smoldering torch, column, statue of pallid light, faintly tinted with a spiritual green, because he was made of radioluminescent radium.

In 1905, **Albert Einstein** proposed that mass is related to energy by the famous equation:

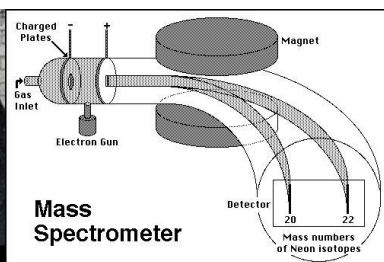
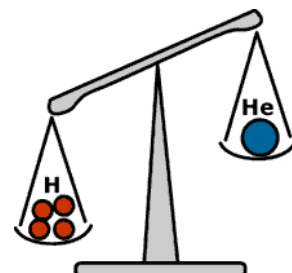
$$E = mc^2$$

In a paper entitled, *Does the inertia of a body depend upon its energy content?*, Einstein realized that because the speed of light c is so large (3×10^8 m/s) his equation meant that a **tiny bit of mass** could be transformed into an **enormous amount of energy**. He also realized that his theory could be tested with radium salts, since the emission of **energy** by radium may be correlated with a decrease in its **mass**.



Could Einstein's equation apply to **thermonuclear fusion** as well as nuclear fission? Could the source of the sun's energy be **thermonuclear fusion** as opposed to nuclear fission? **Thermonuclear fusion** results when protons, the charged nuclei of hydrogen atoms, smash into each other to form a deuteron. Under **ambient temperatures**, protons do not smash into each other because their **electric charge repels** them from other protons. However, by heating the protons to millions of degrees Kelvin, they would have enough **kinetic energy** to overcome the **electrostatic barrier** and could smash into each other.

Using a **mass spectrograph** that separates atoms and molecules according to their mass just as a spectrograph separates light according to its wavelengths, **Francis Aston** (1920) **serendipitously** discovered that one helium nucleus (with an atomic mass of 3.99 Daltons) has less mass than 4 hydrogen



nuclei, each with an atomic mass of 1.008 Daltons. Aston, who was actually interested in looking for isotopes of neon, realized that the difference in mass between four hydrogen atoms and one helium atom is a source of a tremendous amount of energy.

Aston's experimental results gave the following masses for hydrogen and helium:

mass of 1 proton (p)	$1.67358 \times 10^{-27} \text{ kg}$
mass of 4 protons (4p)	$6.6943 \times 10^{-27} \text{ kg}$
mass of helium nucleus (He)	$6.6466 \times 10^{-27} \text{ kg}$
<hr/>	
difference (4p – He)	$0.0477 \times 10^{-27} \text{ kg}$

Arthur Eddington suggested in his presidential address at the 1920 meeting of the British Association for the Advancement of Science that Aston's measurement of the 0.7% mass difference between four hydrogen atoms and one helium atom meant that, if the sun derived its energy from **thermonuclear fusion**, the sun could shine for billions of years by converting hydrogen atoms to helium.



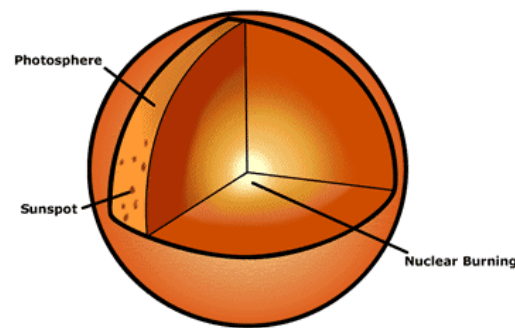
Applying Einstein's equation to the mass deficiency, we see that each fusion of **four hydrogen nuclei** (protons) into a **helium nucleus**, also known as an **alpha particle**, could result in $4.3 \times 10^{-12} \text{ J}$.

$$E = 0.0477 \times 10^{-27} \text{ kg } (3 \times 10^8 \text{ m/s})^2 = 4.3 \times 10^{-12} \text{ J}$$

In order for fusion to yield the observed **luminosity** of $3.8 \times 10^{26} \text{ W}$, 8.8×10^{37} helium nuclei would have to be formed from four hydrogen nuclei per second. This means that only $5.9 \times 10^{11} \text{ kg}$, which is a trivial proportion ($< 3 \times 10^{-17} \%$) of the sun's mass ($1.99 \times 10^{30} \text{ kg}$), would have to be burned per second and the sun

would burn for billions of years. The enormous amount of energy released from the **nuclear burning** of hydrogen into helium is nearly twenty million times **greater** than the amount of energy released by the **electron burning** of the same mass of hydrocarbon into carbon dioxide and water.

The sun, like most stars, is composed of hot gas that radiates energy into space. Heat always moves from hotter regions to cooler regions of matter, and, consequently, in the sun, the energy that is radiated from the **cooler surface** must come from a **hotter core** where it is generated. Charged particles as well as energy produced in the core also move to the surface where they are emitted.



Spectroscopic studies carried out during the 19th century showed that the sun was composed primarily of **hydrogen** (71%) and **helium** (27.1%), which was named after the sun (*Helios*) where it was first discovered. Oxygen (0.97%), carbon (0.4%), nitrogen (0.096%), silicon (0.099%), magnesium (0.0765), neon (0.058%), iron (0.14%), sulfur (0.04%), and a small amount of phosphorus make up the rest of the sun's mass.

The elements in the sun's atmosphere are identified by **Fraunhofer lines**, which are dark lines in the **continuous blackbody spectrum** produced by a

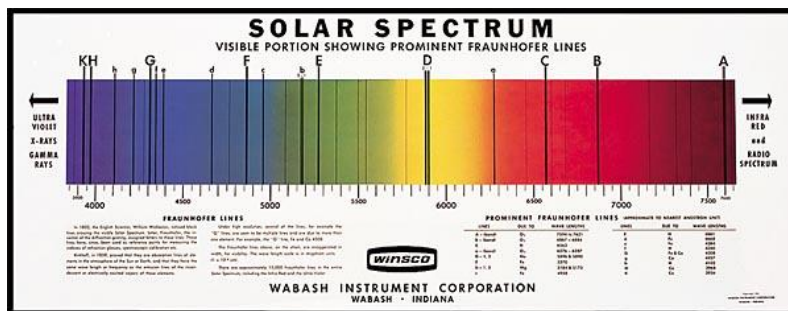
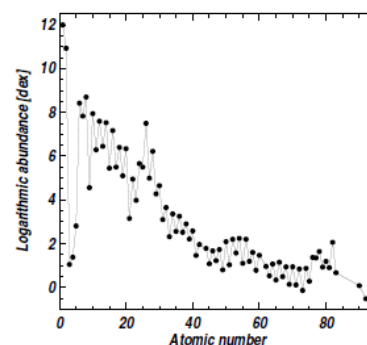
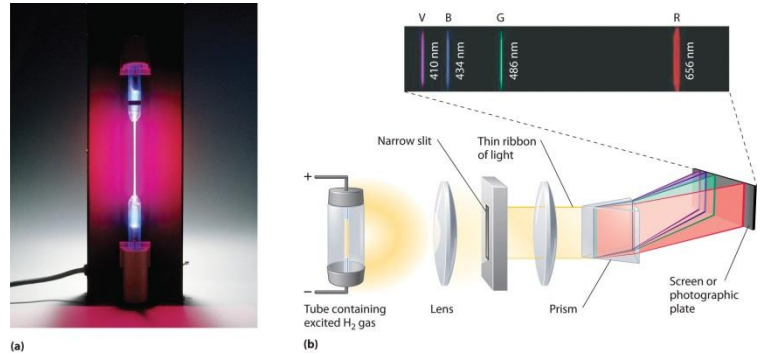


Figure 4: The present-day solar photospheric elemental abundances as a function of atomic number. As throughout this article, the logarithmic abundance of hydrogen is defined to be $\log_{10} = 12.0$.

hot glowing or **incandescent body**. The dark lines are formed because each element in the sun's atmosphere absorbs certain wavelengths and re-emits them in all directions resulting in less light of those wavelengths coming to the earth. The darker the line, the greater is the abundance of the element that causes the line.

Demonstration: Observe the spectral lines of hydrogen with your spectroscopes.

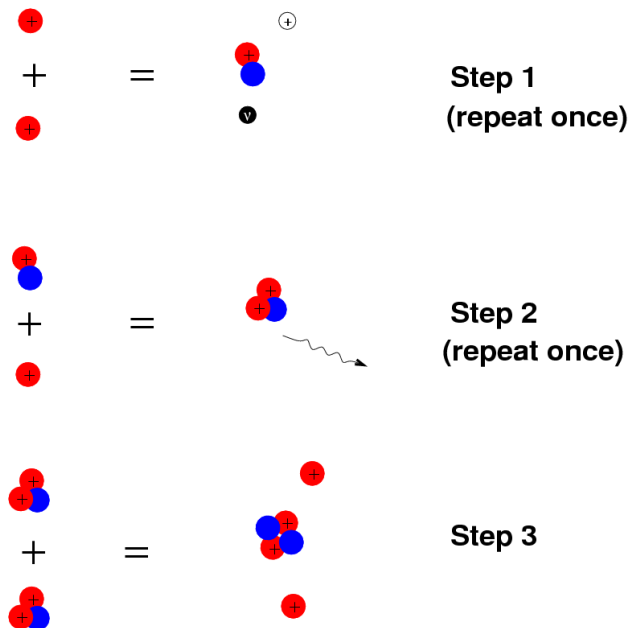


In 1938, **George Gamow** brought together astrophysicists and physicists at a meeting at George Washington University in Washington DC to exchange expertise in order to understand the sun and other stars. **Bengt Strömberg** asked the physicists there to find an explanation for the temperature, density, and chemical composition of the sun. **Hans Bethe** (Cornell), a nuclear physicist, looked at the various possible ways that nuclear reactions might occur in the sun. Bethe suggested that, if the **core of the sun were 16 million degrees Kelvin**, the **p—p (proton-proton) chain of nuclear reactions** would be the dominant source of energy production. Hans Bethe (1967) won the Nobel Prize for this work.

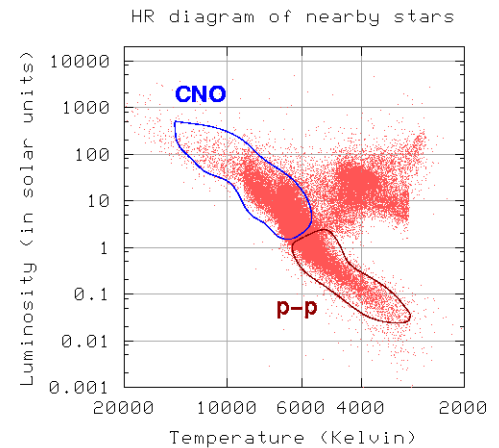
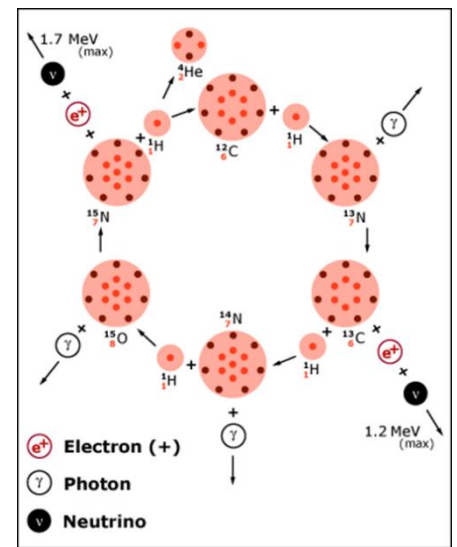




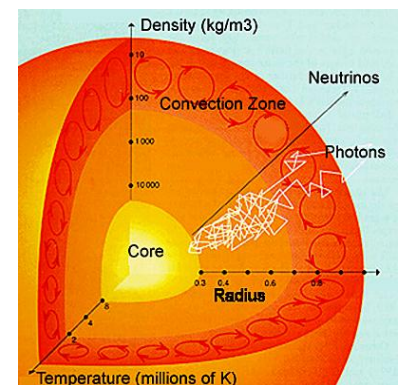
In the typical **p—p** nuclear reaction in the core of the sun (Step 1), two hydrogen nuclei (^1H , protons) are moving fast enough to overcome their electrostatic repulsion and they fuse to produce a heavy hydrogen nucleus (^2H = a deuteron = a proton and a neutron), and a positron and a neutrino are released. In Step 2, deuterons and protons are moving fast enough to overcome their electrostatic repulsion and fuse to produce a light element of helium (^3He) and a **gamma ray is released**. In Step 3, two light helium (^3He) nuclei are moving fast enough to overcome their electrostatic repulsion and fuse to form a normal helium ^4He nucleus and two hydrogen nuclei (^1H , protons), which will continue to participate in nuclear reactions, are released.



Only a small percentage of nuclei involved in the p—p nuclear reaction moves fast enough at the temperature of the core to overcome the electrostatic repulsion and fuse. At the temperature of the core of the sun, the percentage of heavier nuclei, including those of carbon, nitrogen, and oxygen that move fast enough to overcome the electrostatic repulsion is even smaller so only a small amount of fusion involving these elements take place in the sun's core. On the other hand, in stars that are more massive than the sun and closer to the top left corner of the main sequence in the **Hertzsprung-Russell diagram**, the temperature is higher and the **carbon-nitrogen-oxygen (CNO) cycle** results in the fusion of four hydrogen nuclei (^1H , protons) into a single helium nucleus (^4He , alpha particle), using carbon as a catalyst, with the emission of energy from the core in the form of gamma rays.

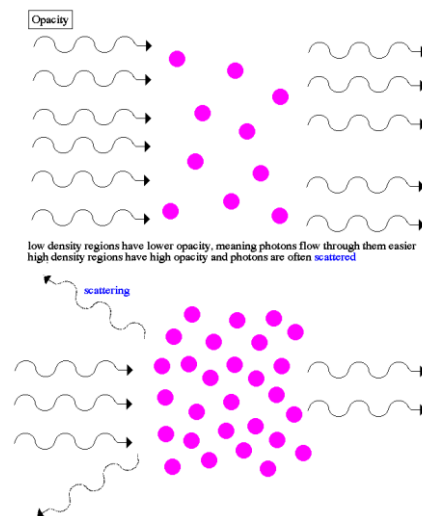


Gamma rays that are released in the nuclear reactions taking place in the **core** travel about 500 micrometers before they strike a free electron and are scattered. The scattering process goes on and on as the gamma rays proceed in a **random walk** to the surface sharing their energy with the electrons. The ionized nuclei and electrons scatter the gamma rays so completely that the sun's interior is almost **opaque** to the gamma rays (just like the plasma, containing positively charged nuclei

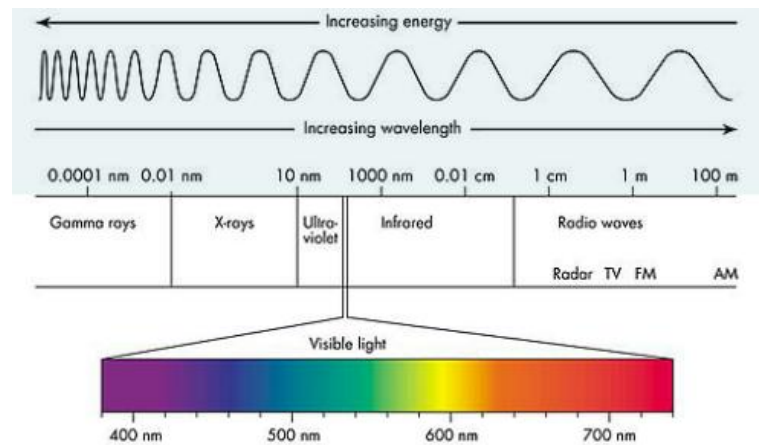


and electrons that existed from three minutes after the **big bang** to 300,000 years after the big bang, was opaque to photons).

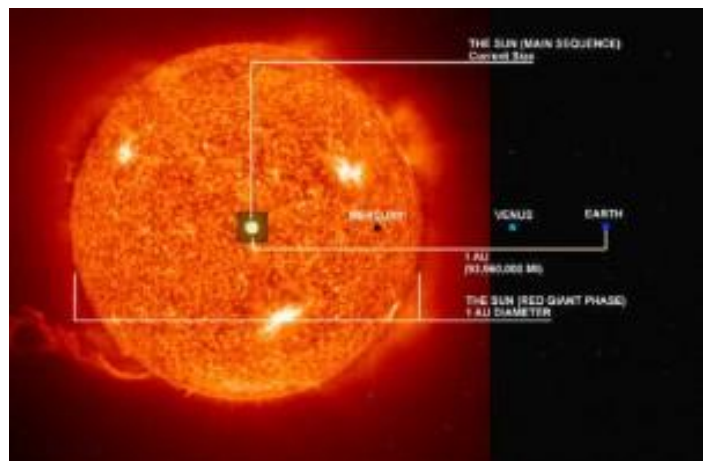
The **opacity** of the interior of the sun is due to the scattering of gamma rays by free electrons that takes place on its way from the core to the surface. With each scattering event, the energy of the gamma ray decreases so that eventually, the energy of radiation is reduced to energies in the **visible range**. As a result of numerous scattering events, it takes approximately **30 thousand years** for the photons formed in the nuclear reactions in the core to reach the surface. This is much longer than the two seconds it would take a photon at a velocity of 2.99×10^8 m/s to move the same distance through free space. Radiation is not the only way that energy moves from the core to the surface. Near the surface, energy transfer is augmented by **convection**, where warmer plasma rises and cooler plasma falls in response to gravity. Given the radius of the sun, the “speed of light” or perhaps “the slowness of light” through the sun is approximately 7×10^{-4} m/s, far less than the 3×10^8 m/s it travels from the sun to the earth’s atmosphere.



The sun was born approximately 4.6 billion years ago in the Milky Way galaxy when the **gaseous nebula**, which was composed primarily of hydrogen and helium and contained a smattering of dust, attracted itself gravitationally to form a spherical **protostar**. The gaseous **protostar** contracted as a result of the massive amount of **gravitational force** on itself. This compression resulted in the heating of the core and the eventual attainment of **hydrostatic equilibrium** where gravitational energy was balanced by thermal energy. Consequently, the diameter of the sun became stable. Given the temperature of the core, **alchemy** occurred, and hydrogen nuclei fused into helium in **thermonuclear reactions**. The alchemical transformation results in helium nuclei that have less mass than the four hydrogen nuclei that compose each one. The lost mass or 0.7% mass defect is radiated away, in part, as radiant energy that diffuses to the surface of the sun, losing energy at each scattering so that the photons are transformed from energetic gamma ray photons to photons of visible sunlight.

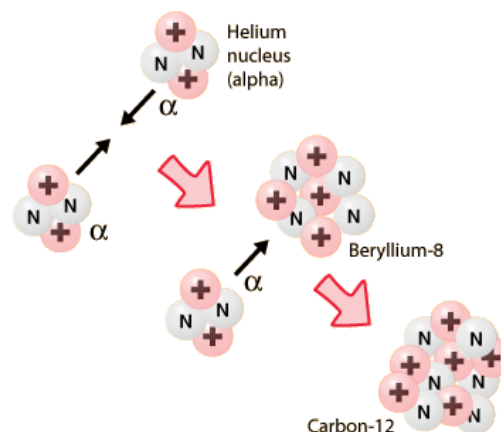


When the sun eventually consumes its supply of hydrogen, the core will be primarily composed of **helium**. No more nuclear reactions will take place in the core and it will cool and contract. However, the hydrogen outside the core will continue to burn and will expand. As the core contracts and as the

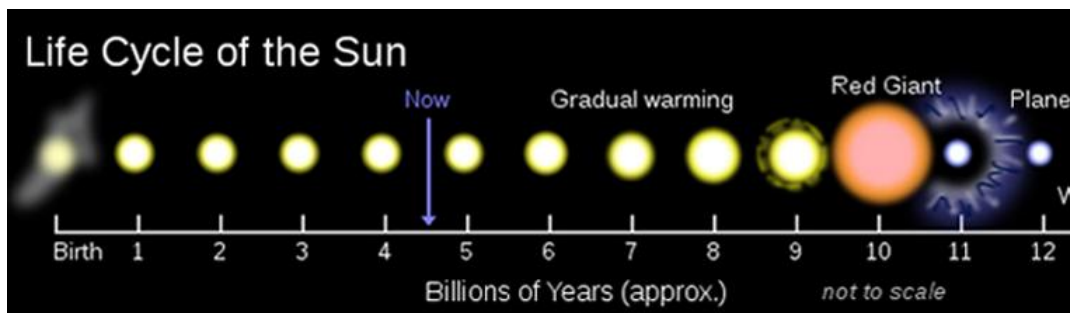


hydrogen burning shell expands, the sun will move off the main sequence and become a **red giant**.

As the central core of the sun continues to contract, the density of helium will increase and the temperature of the core will rise. When the temperature of the core surpasses a threshold (100 million degrees), it becomes possible to burn helium into carbon in the **triple alpha process**. This



burning, known as the **helium flash**, is explosive. During the explosion, the short-lived burning hydrogen envelope, known as a **planetary nebula**, is sloughed off and the bright core, now known as a **white dwarf**, is all that is left. The sun is currently about five billion years old; it will become a red giant and then a white dwarf when it is 10 and 11 billion years old, respectively.



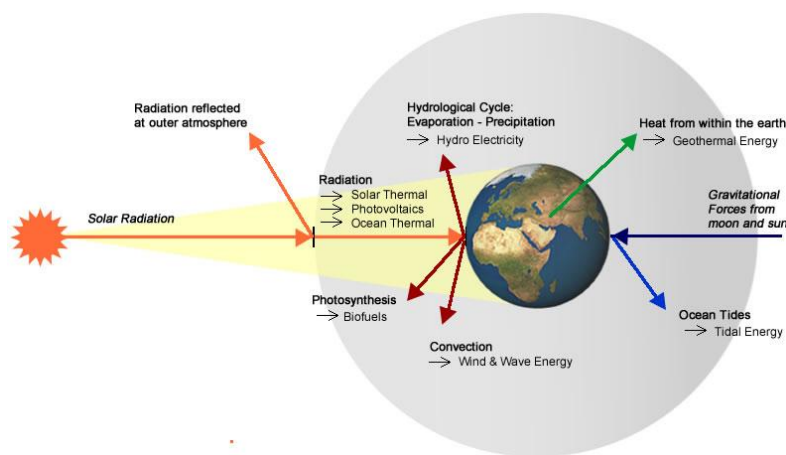
As **Dylan Thomas** wrote:

*Do not go gentle into that good night,
Old age should burn and rave at close of day;
Rage, rage against the dying of the light.*

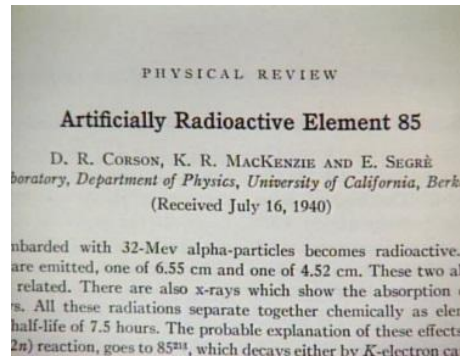
In general, the alchemical process of nuclear fusion results because the **kinetic energy** of the atomic nuclei is great enough to overcome **the electrostatic repulsion** that exists between positively charged nuclei. As the size of the nucleus

increases, it takes more and more energy to give the nuclei sufficient kinetic energy ($\frac{1}{2} mv^2$) to overcome the electrostatic energy ($\frac{q^2}{4\pi\epsilon_0 r}$) barrier. For this reason, the temperature of the star, which determines its thermal energy (kT), determines how heavy an element can be if it is to be burned. Hydrogen (1 Dalton) burns at 10^7 K, helium (4 Daltons) at 10^8 K, carbon (6 Daltons) at 5×10^8 K, oxygen (16 Daltons) at 2×10^9 K, and silicon (28 Daltons) at 3×10^9 K. The unit of atomic mass is named after the colorblind John Dalton.

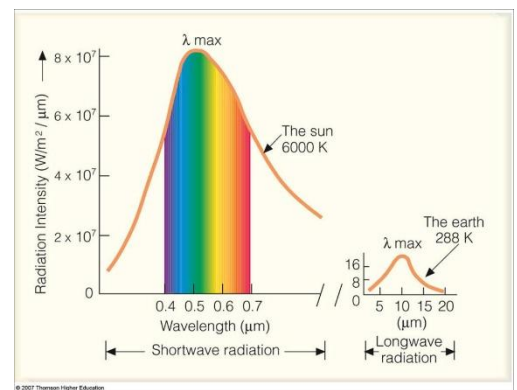
The sun is **massive** in that it has a lot of fuel to burn, and **the nuclear reactions** yield far more energy per mass consumed than **chemical combustion reactions**, which involve the **rearrangement of electrons**. The sun, which is in some respects not a renewable resource, will provide the earth with energy for the next five billion years. The sun's radiant energy warms the earth, resulting in **wind** that transports the pollen of grasses. The warmth due to the sun's radiant energy also results in the **evaporation of water** from the sea that leads to **rain on land** that is necessary for the growth of trees, shrubs, and herbs. The visible light from the sun provides the **energy for photosynthesis**, which is responsible for all the food we eat. The visible light from the sun provides information for seeing the **colors in the world** around us and for telling the **time of day**, the **season of the year**, and the **direction in space**.



President Emeritus **Dale Corson** designed a sundial so that we can tell the time.



Like the **average temperature** of the sun, the average temperature of the earth is also somewhat constant. As the sun can be considered to be an **incandescent black body** with an average temperature of about 6000 K, the earth can be considered to be a black body with an average temperature of about 288 K (58.73 F). The radiant energy of the sunlight entering the earth's atmosphere is radiated away from the earth as **mid infrared** (5 to (25-40) μm) radiation. That is, since the energy (E in J) of a photon is related to its wavelength (λ in m) by the product ($hc = 6.6 \times 10^{-34} \text{ Js} \cdot 3 \times 10^8 \text{ m/s}$) of Planck's constant and the speed of light, the average energy of photons leaving the earth is less than the average energy of photons entering the earth.



$$E = \frac{hc}{\lambda}$$

The **mid-infrared energy** radiated away from the earth, which originates from the **visible light energy** from the sun, will have little contribution to the enormous amount of cosmic **microwave** background radiation that reminds us of the first light, whether defined by Robert Grosseteste or by the Big Bang Theory.

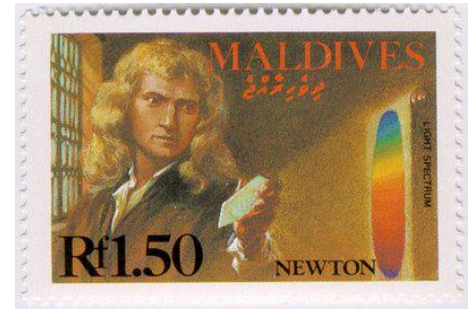
As you can see, we are able to get to know a fair amount about our sun through observation and theory. **Arthur Eddington** ended his 1920 presidential address by saying, “ *In ancient days two aviators procured to themselves wings. **Daedalus** flew safely through the middle air across the sea, and was duly honoured on his landing. Young **Icarus** soared upwards towards the Sun till the wax melted which bound his wings, and his flight ended in fiasco. In weighing their achievements perhaps there is something to be said for Icarus. The classic authorities tell us that he was only ‘doing a stunt,’ but I prefer to think of him as the man who certainly brought to light a constructional defect in the flying-machines of his day. So, too, in Science. Cautious Daedalus will apply his theories where he feels most confident they will safely go; but **by his excess of caution their hidden weaknesses cannot be brought to light**. Icarus will strain his theories to the breaking-point till the weak joints gape. For a spectacular stunt? Perhaps partly; he is often very human. But if he is not yet destined to reach the Sun and solve for all time the riddle of its constitution, yet he may hope to learn from his journey some hints to build a better machine.*”



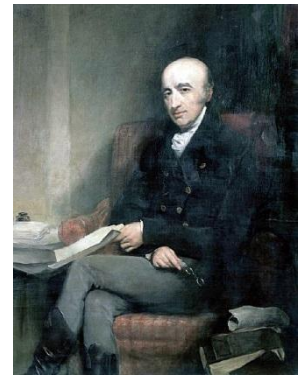
Science, when healthy, sees the values and limitations of both Daedalus and Icarus.

While the sun, like any other **incandescent body** emits a **continuous spectrum** of light with a **spectral distribution** defined only by its **temperature**, upon looking closely, the spectrum is **interrupted by dark lines**. These dark spectral lines were used by chemical spectroscopists to identify the chemicals present in the sun. Now I am going to discuss **chemical spectroscopy** itself.

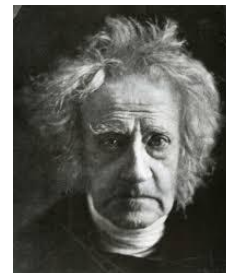
Isaac Newton accomplished with a prism what Roger Bacon realized nature accomplishes with each water droplet in a rainbow. By passing a cylindrical beam of sunlight through a prism, **Isaac Newton** (1671) revealed that the white light from the sun was composed of a continuous spectrum of colors.



By replacing the round hole that admitted the sunlight into the laboratory with a **narrow slit**, **William Hyde Wollaston** (1802) became aware of the fact that the colors of the spectrum were not continuous but separated by a series of discrete black lines. **Joseph von Fraunhofer** noticed that the **black lines** that were present in the spectra of sunlight were absent in the light from the flame of a lamp. In fact, he noticed that the light from a flaming or electrical lamp had **bright lines** in the spectrum that corresponded to the dark lines of the solar spectrum.



Thomas Mellvill (1756) discovered that when he added salts to the flame of a spirit lamp, the color constitution of the light was altered, and he wondered if sunlight might be composed of “*such colours and in such proportions as were seen in the lights of salts and burning spirits.*” **John Herschel** (1823) expanded Mellvill’s line of investigation by soaking the wick of a spirit lamp in a solution of strontium chloride or copper chloride. Upon lighting the wick, he observed that the salt produced a characteristic color when heated—**strontium** produced a flame with a “*beautiful carmine-red colour*” and **copper** produced a flame with an “*emerald-green colour.*” Realizing the importance of this discovery for chemistry, Herschel latter wrote, “*The colours thus communicated by the different bases to flame, afford in many cases a ready and neat way of detecting extremely minute quantities of them.*”



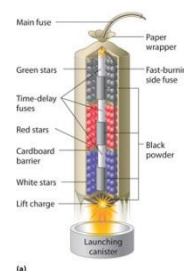
Demonstration: Observe the color of the flame of an alcohol lamp after adding strontium chloride and copper chloride individually using loops made from nichrome wire. Look at the flame with a spectroscope.



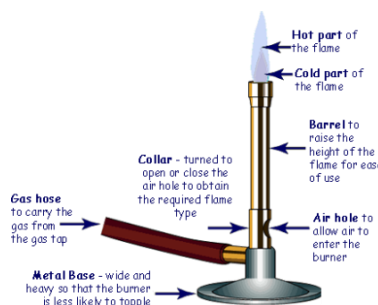
William Henry Fox Talbot (1826) came to the same conclusion as John Herschel while he was trying to develop a monochromatic lamp that would be useful for microscopy and for studying the properties of light. Talbot also suggested that “*whenever the prism shows a homogeneous ray of any colour to exist in a flame, this ray indicates the formation or the presence of a definite chemical compound.*”



Every time we see a **fireworks** display, we are reminded of the relationship between the chemical elements and the color emitted.



Gustav Kirchhoff (1863), Robert Bunsen, and others using a **Bunsen burner**, firmly established that each **chemical element absorbed** and **emitted** light waves with **characteristic discrete wavelengths**. By meticulously comparing spectra, Kirchhoff in particular showed that the **emission** of light by a given element gave rise to the **bright lines** in the spectrum, and the **absorption** of light by the same element gave rise to the **dark lines** in the spectrum. The light or dark **spectral lines** could be used to **identify chemical elements**.



Black Body and Line Spectra

Black Body

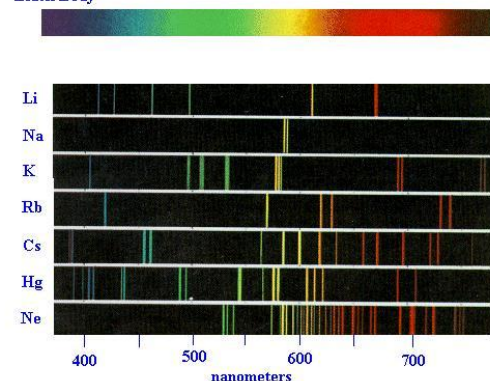
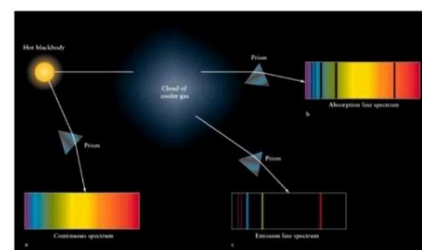
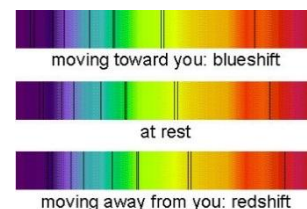


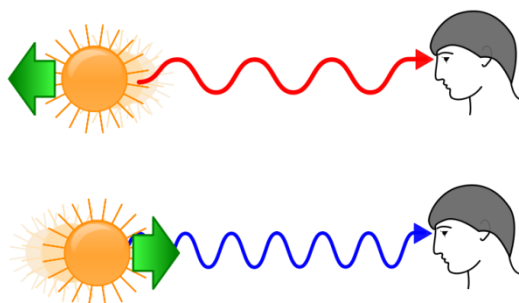
Fig: Emission & Absorption spectrum

The field of **spectrum analysis** made it possible for Kirchhoff, Anders Ångström, Norman Lockyer (1887), William Huggins (1899), and others to **identify chemical elements** not only in terrestrial samples, but also in celestial bodies, including the sun.

The **identification of the chemical elements** by their **characteristic spectral lines** should *not* depend on the velocity of the observer. However, **Ernst Mach** (1860) and Hippolyte Fizeau (1870) suggested that as a result of the **Doppler effect**, there may be a **shift** in the position of the spectral bands emanating from the heavenly bodies that depended on their radial motion. If the atom were *moving relative* to the observer, the observer would reckon that the atom was absorbing or emitting light with a different wavelength than that which was expected. **Light** emitted by atoms



moving away from an observer would be **red shifted** and **light** emitted by atoms **moving towards** an observer would be **blue shifted**.

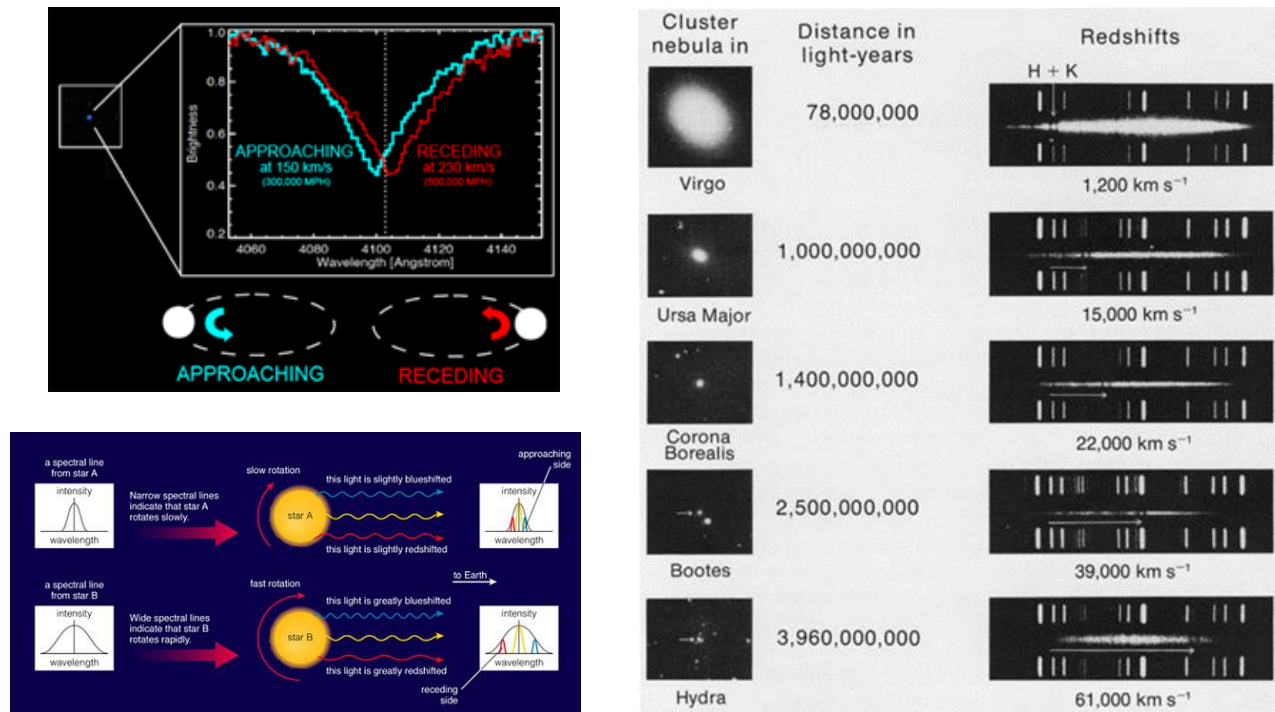


Thus, *prima facie*, it would seem that an observer at rest with respect to the atom and an observer moving relative to the atom would **identify it as an atom of a different element**. In order for the spectral line to be identified as one coming from a given element, **independent of the relative motion**, one would have to use an equation for the spectral lines that would allow any and all observers to agree on the chemical identity of the source of the emitted light. This is the principle of relativity applied to chemical identification. The transformation is:

$$\lambda_{moving} = \lambda_{stationary} \left[\frac{1 - \frac{v}{c} \cos \theta}{\sqrt{1 - \frac{v^2 \cos^2 \theta}{c^2}}} \right]$$

Chemical elements **moving away** ($\theta = 180^\circ$) from the observer would seem to be red shifted, with the **magnitude of the red shift related to the velocity**; and chemical elements **moving towards** ($\theta = 0^\circ$) the observer would seem to be blue shifted, with the **magnitude of the blue shift related to the velocity**. Assuming that the chemicals in stars are identical with the chemicals on

earth, their Doppler-shifted spectral lines have been used to measure radial, rotational, and revolutionary motion.



This is the same **red shift** based on the **Doppler effect** that allowed **Vesto Slipher** to measure the **radial velocities of the nearby spiral galaxies**, and given the extraordinary velocities that they were hurling through space, Slipher (1921) surmised, *“If the above swiftly moving nebula [galaxy] be assumed to have left the region of the sun at the beginning of the earth, it is easily computed, assuming the geologists’ recent estimate for the earth’s age, that the nebula [galaxy] now must be many millions of light years distant.”*

This is the same **red shift** based on the **Doppler effect** that allowed **Edwin Hubble** (1929) to notice *“a linear correlation between distances and velocities”* and that the recession velocities of galaxies were proportional to their distance from the sun. Hubble (1937) pointed out that the *“velocity-shifts, on a microscopic*

scale, are familiar phenomena, and their interpretation is not to be questioned. Now the red-shifts observed in nebular [galactic] spectra behave as velocity-shifts behave—the fractional shift $d\lambda/\lambda$ is constant throughout a given spectrum—and they are readily expressed as velocities of recession. The scale is so convenient that it is widely used, even by those cautious observers who prefer to speak of ‘apparent velocities’ rather than actual motion....The law of red-shifts then reads: the nebulae [galaxies] are receding from the earth in all directions, with velocities that are proportional to their distances from the earth.”

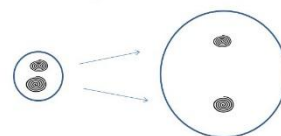
This is the same **red shift** based on the **Doppler effect** that allowed physicists who had been involved in radar during World War II to turn their instruments towards the heavens to study the cosmos at **radio wavelengths**. Astronomers at Cambridge University surveyed the sky for radio sources that produced electromagnetic radiation with a wavelength of about 1.8 m. These remote radio sources were identified with optical objects and they became known as quasi-stellar radio sources or **quasars**. These remote “radio stars” were among the first stars formed in the universe and exhibit **red shifts** that indicated that they had incredible velocities, such as 110,200 kilometers per second and greater.

The theory of relativity is based on the assumption that there are no privileged observers. Einstein (1917,1920) extended this assumption to the whole universe and found the idea that the universe might have a center to be distasteful. Consequently Einstein (1920) came up with “*the possibility of a ‘finite’ and yet ‘unbounded’ universe*” to “*free ourselves from the distasteful conception that the material universe ought to possess something of the nature of a centre.*” This is the origin of the

Where is the center, edge of the expansion ?

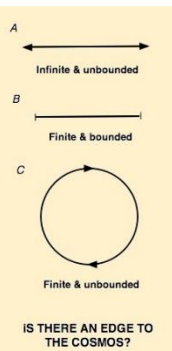
Need have no answer

Imagine  space is surface of sphere:

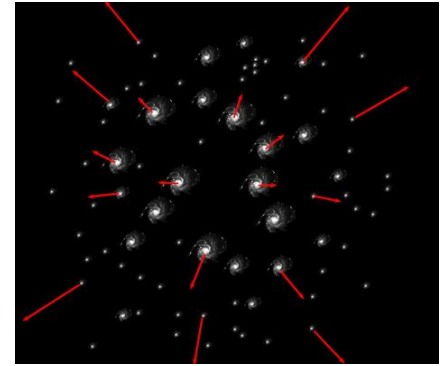
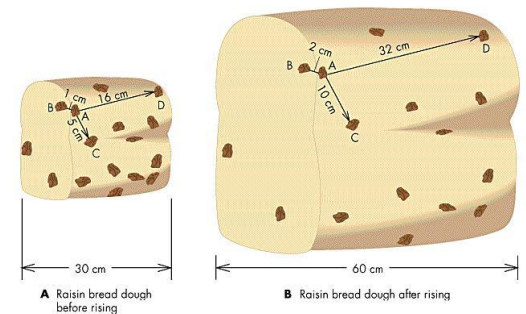


- As surface expands, galaxies move apart
- There is no center
- There is no edge (finite but unbounded)
- Space is ‘created’

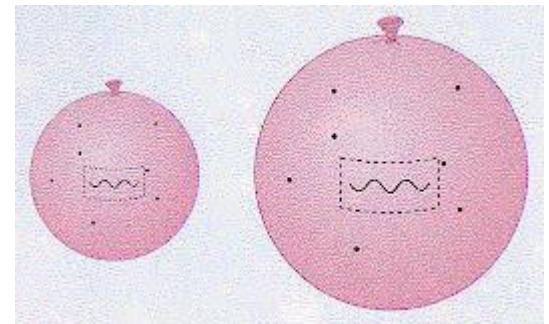
Universe could be infinite or finite, with or without boundary (we haven’t seen a boundary yet)



Cosmological Principle. According to Einstein (1931), “Alle Stellen des Universums sind gleichwertig,” which translates to “*all parts of the universe are equivalent.*” What I am calling Einstein’s Cosmological Principle was first stated by Milne (1932,1933) to postulate that “*the moving picture of the world as made by any one observer is identical with that made by any other observer,*” and “*the universe must appear the same to all observers.*” De Sitter (1934) called the assertion “*that statistically the world pictures of two different observers must be the same*” the Cosmological Principle.



The Perfect Cosmological Principle proffered by Hermann Bondi and Thomas Gold (1948) states that the universe not only looks the same to any observer in space but to any observer in time. Belief in the **Perfect Cosmological Principle** caused them to postulate the **Steady State Universe**—a Universe where there is no sign of creation because it is postulated to exist eternally. In presenting the Perfect Cosmological Principle, Bondi and Gold (1948) stated that “*The unrestricted repeatability of all experiments is the fundamental axiom of physical science. This implies that the outcome of an experiment is not affected by the position and the time at which it is carried out.*” However, experiments are as different from observations as the front end of a cow is different from the back end and the top of a leaf is different from the bottom of a leaf. While the various cosmological principles serve the principle of the economy of thought, the assumptions, if too simplistic may lead to complications in the interpretations.



The **Cosmological Principle** is an **untested assumption** and as an untested assumption, it is open to questioning. The **cosmological principle** states that on a sufficiently large scale, all observers in the universe see the same thing no matter who or where they are. By **assuming** that we are *not* in a special place in the universe where the heavenly bodies are all moving away from us and that *any observer* in the universe would see similar red shifts, **these red shifts are considered by cosmologists to be a consequence of the expansion of space** using an expanding raisin bread as an analogy. I see things differently (which is not allowed by the cosmological principle)! **In fact, Einstein's cosmological principle takes away our privileged position but gives us an authoritarian power that says everyone must see the world as we do.** I do not accept the **cosmological principle** as foundational and I do not accept the assumption that everyone no matter where they are will see red shifts, just like I believe that two observers can look at the southern sky and the northern sky and see different constellations. Therefore, I consider the red shifts to be a consequence of their **velocity in space** as opposed to the **velocity of the expansion of space**. This would make us near the center of the universe. You are free to make your own decisions. The figure below demonstrates my commonsense cosmological principle that a botanist (me) came up with: What you see depends on your position.



Jeffrey Buller (2015), author of *The Essential Academic Dean or Provost*, second edition states it this way: *It is a truism in higher education that what you see depends on where you sit.*

For what it is worth, **Aldous Huxley** wrote in Chapter II of *Brave New World* (<https://www.huxley.net/bnw/two.html>), about a method which would keep people safe from botany, which could lead to such commonsense thinking:

MR. FOSTER was left in the Decanting Room. The D.H.C. and his students stepped into the nearest lift and were carried up to the fifth floor.

INFANT NURSERIES. NEO-PAVLOVIAN CONDITIONING ROOMS, announced the notice board.

The Director opened a door. They were in a large bare room, very bright and sunny; for the whole of the southern wall was a single window. Half a dozen nurses, trousered and jacketed in the regulation white viscose-linen uniform, their hair aseptically hidden under white caps, were engaged in setting out bowls of roses in a long row across the floor. Big bowls, packed tight with blossom.

Thousands of petals, ripe-blown and silkily smooth, like the cheeks of innumerable little cherubs, but of cherubs, in that bright light, not exclusively pink and Aryan, but also luminously Chinese, also Mexican, also apoplectic with too much blowing of celestial trumpets, also pale as death, pale with the posthumous whiteness of marble.

The nurses stiffened to attention as the D.H.C. came in.

"Set out the books," he said curtly.

In silence the nurses obeyed his command. Between the rose bowls the books were duly set out—a row of nursery quartos opened invitingly each at some gaily coloured image of beast or fish or bird.

"Now bring in the children."

They hurried out of the room and returned in a minute or two, each pushing a kind of tall dumb-waiter laden, on all its four wire-netted shelves, with eight-month-old babies, all exactly alike (a Bokanovsky Group, it was evident) and all (since their caste was Delta) dressed in khaki.

"Put them down on the floor."

The infants were unloaded.

"Now turn them so that they can see the flowers and books."

Turned, the babies at once fell silent, then began to crawl towards those clusters of sleek colours, those shapes so gay and brilliant on the white pages. As they approached, the sun came out of a momentary eclipse behind a cloud. The roses flamed up as though with a sudden passion from within; a new and profound significance seemed to suffuse the shining pages of the books. From the ranks of the crawling babies came little squeals of excitement, gurgles and twitterings of pleasure.

The Director rubbed his hands. "Excellent!" he said. "It might almost have been done on purpose."

The swiftest crawlers were already at their goal. Small hands reached out uncertainly, touched, grasped, unpetaling the transfigured roses, crumpling the illuminated pages of the books. The Director waited until all were happily busy. Then, "Watch carefully," he said. And, lifting his hand, he gave the signal.

The Head Nurse, who was standing by a switchboard at the other end of the room, pressed down a little lever.

There was a violent explosion. Shriller and ever shriller, a siren shrieked. Alarm bells maddeningly sounded.

The children started, screamed; their faces were distorted with terror.

"And now," the Director shouted (for the noise was deafening), "now we proceed to rub in the lesson with a mild electric shock."

He waved his hand again, and the Head Nurse pressed a second lever. The screaming of the babies suddenly changed its tone. There was something desperate, almost insane, about the sharp spasmodic yelps to which they now gave utterance. Their little bodies twitched and stiffened; their limbs moved jerkily as if to the tug of unseen wires.

"We can electrify that whole strip of floor," bawled the Director in explanation.

"But that's enough," he signalled to the nurse.

The explosions ceased, the bells stopped ringing, the shriek of the siren died down from tone to tone into silence. The stiffly twitching bodies relaxed, and what had become the sob and yelp of infant maniacs broadened out once more into a normal howl of ordinary terror.

"Offer them the flowers and the books again."

The nurses obeyed; but at the approach of the roses, at the mere sight of those gaily-coloured images of pussy and cock-a-doodle-doo and baa-baa black sheep, the infants shrank away in horror, the volume of their howling suddenly increased.

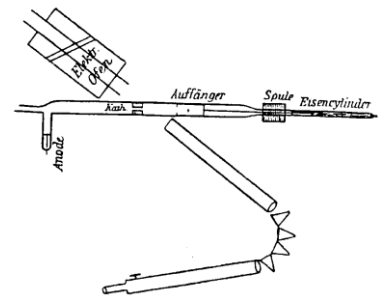
"Observe," said the Director triumphantly, "observe."

Books and loud noises, flowers and electric shocks—already in the infant mind these couples were compromisingly linked; and after two hundred repetitions of

the same or a similar lesson would be wedded indissolubly. What man has joined, nature is powerless to put asunder.

"They'll grow up with what the psychologists used to call an 'instinctive' hatred of books and flowers. Reflexes unalterably conditioned. They'll be safe from books and botany all their lives." The Director turned to his nurses. "Take them away again."

Johannes Stark (1902) realized that the **Doppler effect** would also apply to terrestrial light sources and consequently, a given chemical atom would have different characteristic spectra depending on its relative velocity. Using the positively charged atoms that make up canal rays, Stark observed that, consistent with the Doppler effect, the positions of the spectral lines emitted from the atomic ions moving **towards** him were shifted towards the **blue end** of the spectrum and the positions of the spectral lines emitted from the atomic ions **moving away from** him were shifted towards the **red end** of the spectrum. Stark used the Doppler shift to determine the velocity of the positively charged atoms that made up the canal rays.

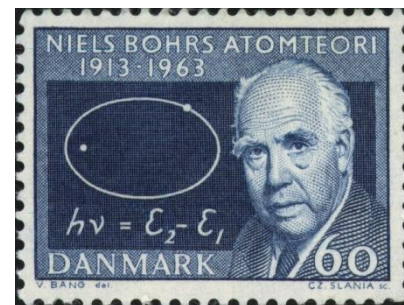
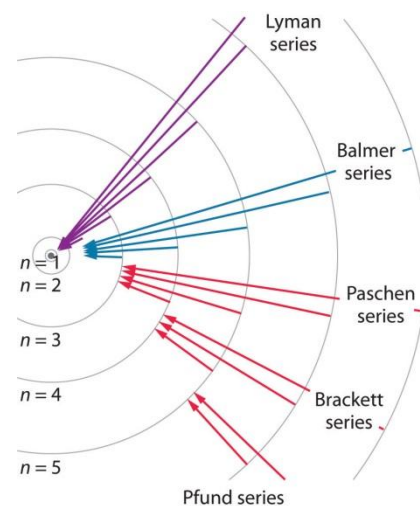


Demonstration: Observe the cathode rays (electrons) and anode or canal rays (protons). Observe the cathode rays (electrons) in the plasma globe.



In 1913, **Niels Bohr** proposed a **model** of a stationary hydrogen atom based on the **discrete spectral lines** it **absorbs** or **emits**. Bohr proposed that the reason atoms emit discrete spectral lines is because the **electrons move around the nucleus in circular orbits that can have only certain allowed radii** characterized by an integer (**$n = 1, 2, 3 \dots$**).

When a negatively charged electron jumps from an orbit to one closer to the positively-charged nucleus, it **emits** light of a given spectral line, consistent with the **electrostatic energy lost** by an atom when opposite charges move closer together. When an electron **absorbs** light corresponding to a given spectral line, the electron overcomes the electrical attraction and moves from an orbit near the positively-charged nucleus to one farther away, consistent with the electrostatic energy gained by an atom when opposite charges move away from each other.



According to Bohr, the energy (E) of each orbit (n) is given by the following formula, where R represents a constant known as the Rydberg constant, which is equal to $1.097 \times 10^7 \text{ m}^{-1}$.

$$E = \frac{Rhc}{n^2}$$

The energy (E) absorbed ($+Rhc$) or emitted ($-Rhc$) by an electron following from the initial orbit (n_i) to the final orbit (n_f) is given by:

$$E = \pm Rhc \left[\frac{1}{n_f^2} - \frac{1}{n_i^2} \right]$$

Since $E = \frac{hc}{\lambda}$, the wavelength of light that is emitted or absorbed by the transition from one orbit to another is given by:

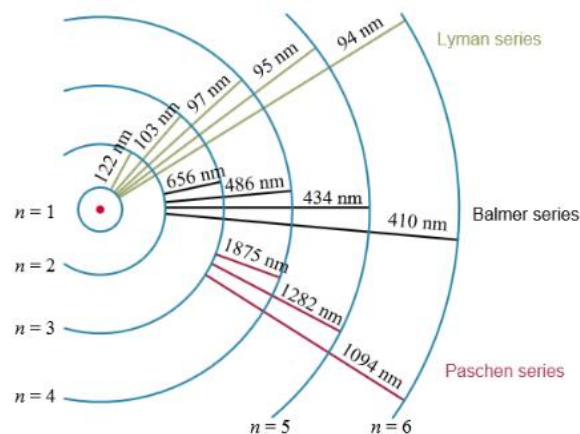
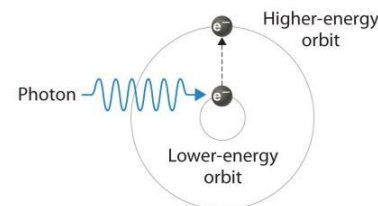
$$E = \pm Rhc \left[\frac{1}{n_f^2} - \frac{1}{n_i^2} \right] = \frac{hc}{\lambda}$$

$$\frac{1}{\lambda} = \pm R \left[\frac{1}{n_f^2} - \frac{1}{n_i^2} \right]$$

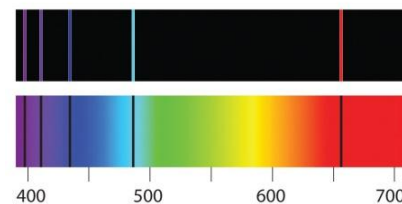
What is the wavelength emitted by an electron jumping from orbit 2 to orbit 1, closer to the positively charged nucleus? 121.54 nm.

What is the wavelength emitted by an electron jumping from orbit 3 to orbit 2, closer to the positively charged nucleus? 655.74 nm.

According to the Bohr model, the **absorption** of light by an atom and the dark band it produces can be pictured like so:

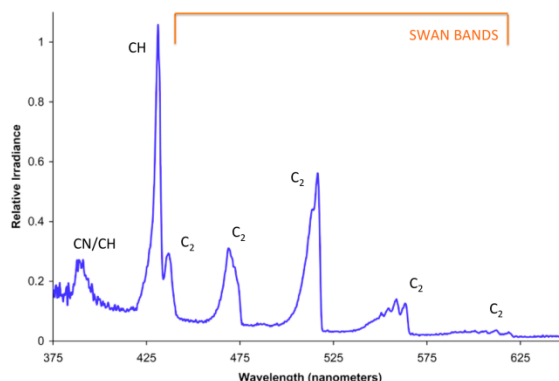


(a) Electronic absorption transition



(b) H₂ emission spectrum (top), H₂ absorption spectrum (bottom)

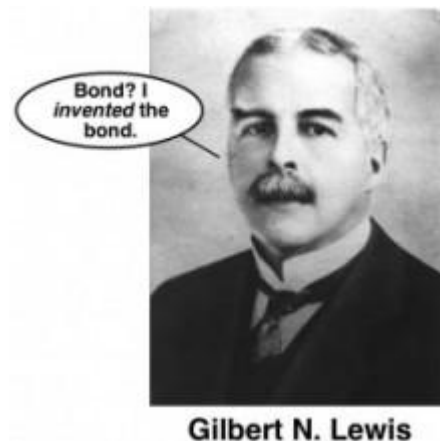
When atoms are bonded together into molecules, the molecules absorb and emit light in a manner that depends on their atomic composition and the type of bonds. When a **carbon** atom bonded to a **hydrogen** atom as **CH** cools, it emits light, when it is cooled, it absorbs light. When **two carbon** atoms, bonded together as **C₂** cool, it also emits light, but light of different wavelengths than CH. When the C₂ is cool, it absorbs light. These are the molecules that give rise to the **blue region of a flame**.



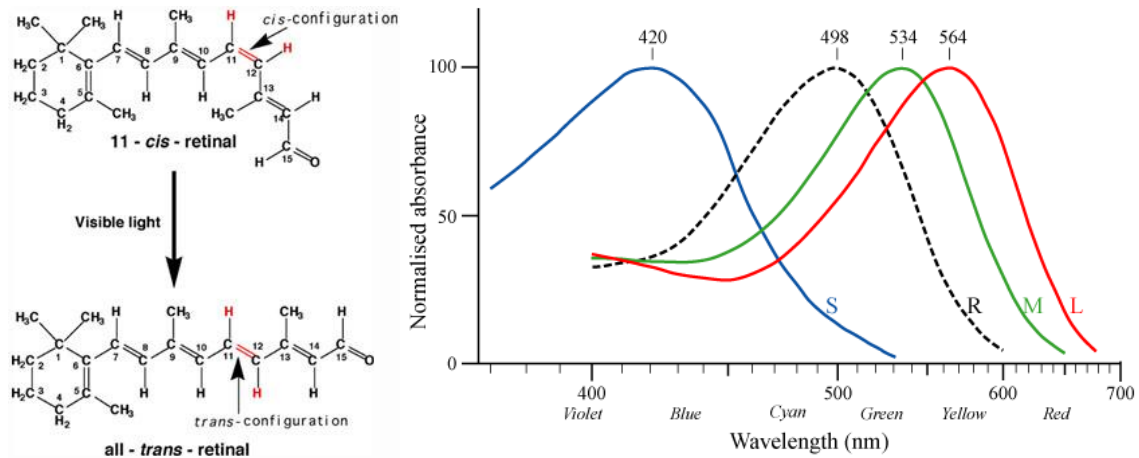
By analyzing the emission or absorption spectrum of light from a carbon-containing molecule, one can deduce its structure. Conversely, if one knows its structure, one can estimate its absorption or emission spectrum.

Below are the structures of various **pigments** that function in the absorption of sunlight that makes life possible and enjoyable. We will discuss these pigments and the processes they mediate over the semester.

The **pigments** have much in common. Notice that they each have many **conjugated double bonds** (-C=C-C=C-). That is, **single bonds and double bonds alternate, resulting in delocalized electrons** that are not bound to a single positively charged nucleus. Also notice that the **delocalized electrons** result in absorption spectra that are **more continuous** (less discrete) than those of **gaseous atoms** and **less continuous** (more discrete) than that of an **incandescent object**.

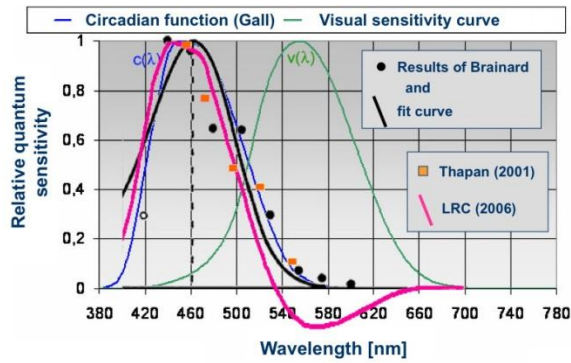
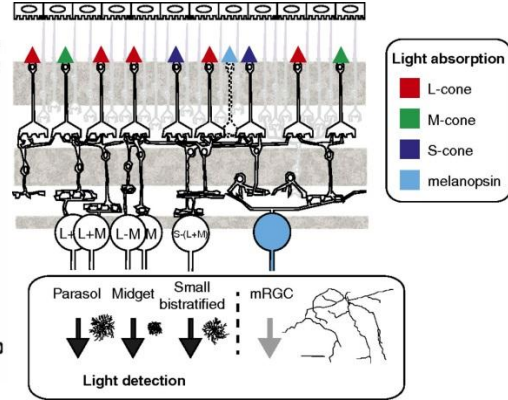


Rhodopsin and **photopsins** are **pigments** composed of **retinal** attached to different **opsin proteins** that make scotopic and photopic **vision** possible. Differences in the opsin proteins result in the differences in the peak spectral sensitivities.



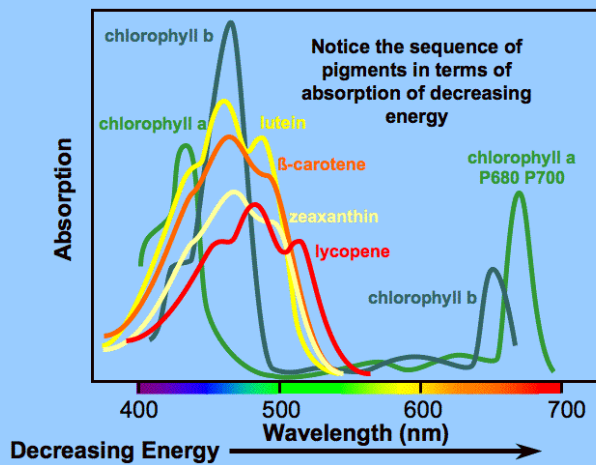
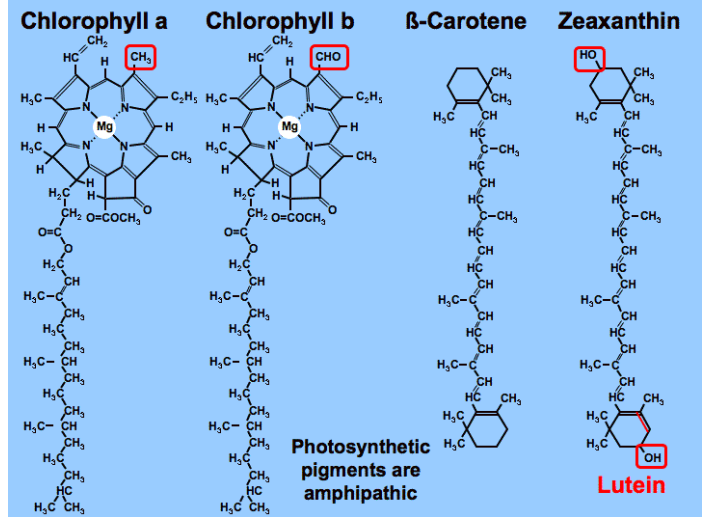
Melanopsin is another pigment found in 1-2% of the **ganglion cells** in the retina of the vertebrate eye. Melanopsin is also composed of **retinal** attached to an opsin protein. The opsin protein in human melanopsin is more similar to invertebrate opsins involved in vision than to the vertebrate opsins involved in vision. Melanopsin functions in the **pupillary light reflex response** and to **tell time** necessary to maintain **circadian rhythms** and synchronize our **sleep-wake cycle** with the natural **light-dark cycle**.

Circadian action spectrum according to different sources

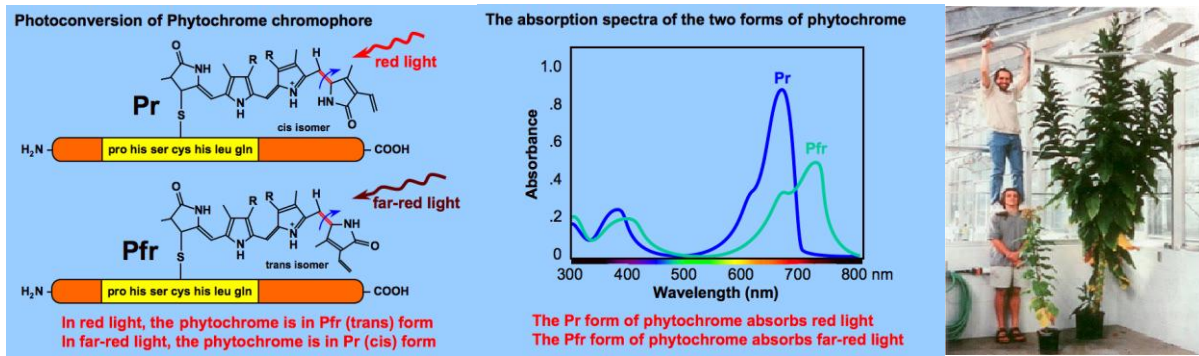


Chlorophylls, carotenoids and zeaxanthin are the **pigments** involved in **photosynthesis** in green plants.

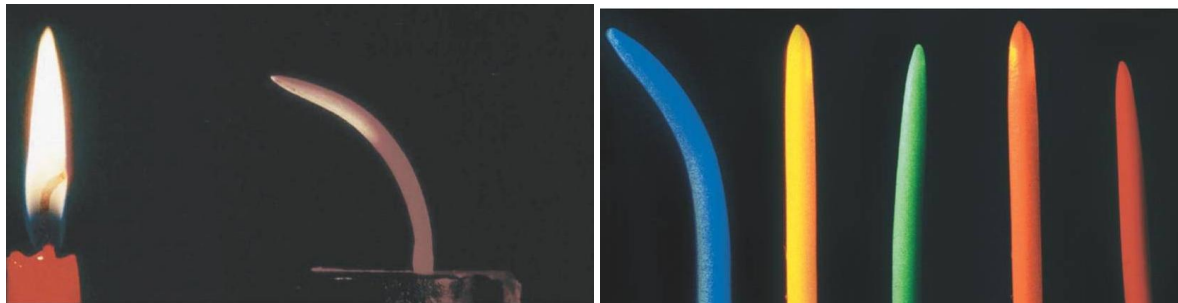
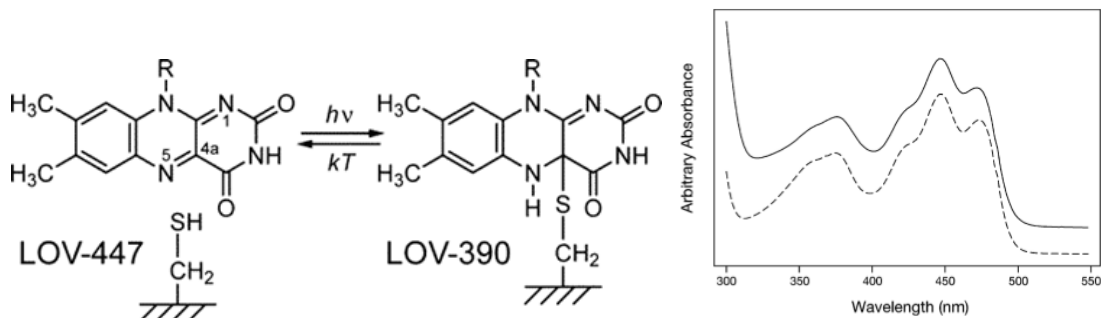
The photosynthetic pigments absorb much of the spectrum



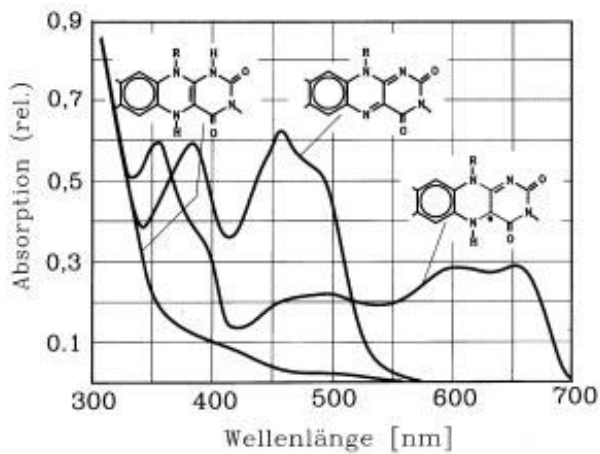
Phytochrome, phototropin, and cryptochrome are three **pigments** important for plants to respond to the environment. **Phytochrome** is a biliprotein that is involved in flowering, shade avoidance, and seed germination.



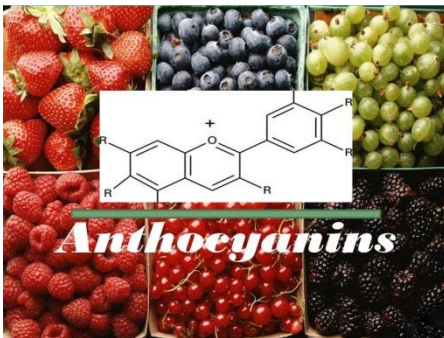
Phototropin is a flavoprotein involved in phototropism, which is the bending response towards light.



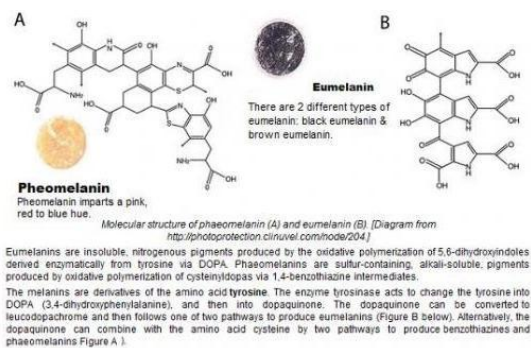
Cryptochrome, like phototropin, is another flavoprotein. It seems to be part of a light-regulated molecular clock involved in biological circadian rhythms in both plants and invertebrates.



Anthocyanins are **pigments** that make the **attractive colors** of many **flowers** and **fruits**. The color depends on the acidity of the cell.



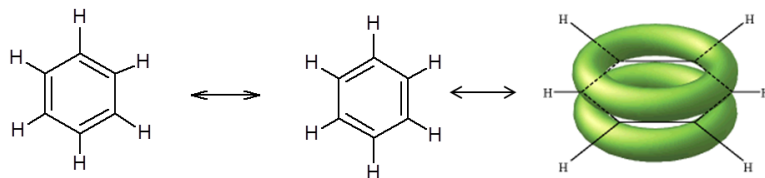
Eumelanin and **pheomelanin** are melanin pigments that color our eyes, skin, and hair.



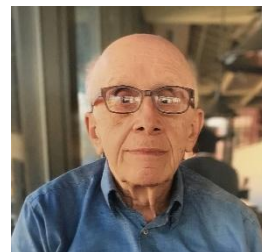
Tightly bound electrons interact with x-rays or ultraviolet light. The delocalized electrons which are far from any positively-charged nucleus, give them the right energy to interact with visible light. The delocalized electrons are found in molecules with conjugated double bonds.

The De-Localized Electron Model

Pi bonds (π) contribute to the delocalized model of electrons in bonding, and help explain resonance



While we are talking about chemicals, I will tell you about **administratium**, an element discovered by **William DeBuvitz**, who came up with the idea in February 1988 while giving a physics exam at Middlesex County College in Edison, N.J. As he read a *“memo from the college administration about the latest reorganization, with its usual increase in vice presidents, assistants to the vice presidents, etc., looked over at a large periodic chart on the wall, and it all came together:”*



Administratium

New chemical Element Discovered

The heaviest element known to science was recently discovered by investigators at a major U.S. research university. The element, tentatively named administratium, has no protons or electrons and thus has an atomic number of 0. However, it does have one neutron, 125 assistant neutrons, 75 vice neutrons and 111 assistant vice neutrons, which gives it an atomic mass of 312. These 312 particles are held together by a force that involves the continuous exchange of meson-like particles called morons.

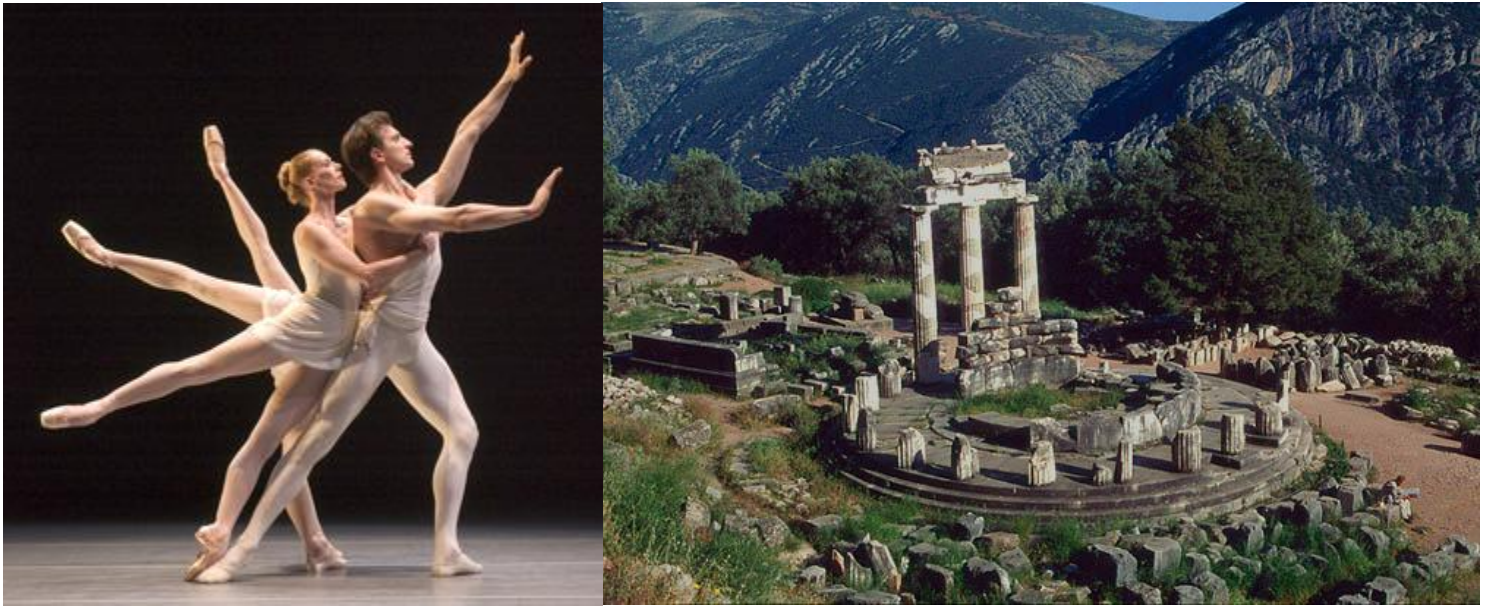
Since it has no electrons, administratium is inert. However, it can be detected chemically as it impedes every reaction it comes in contact with. According to the discoverers, a minute amount of administratium causes one reaction to take over four days to complete when it would have normally occurred in less than a second.

Administratium has a normal half-life of approximately three years, at which time it does not decay, but instead undergoes a reorganization in which assistant neutrons, vice neutrons and assistant vice neutrons exchange places. Some studies have shown that the atomic mass actually increases after each reorganization.

Research at other laboratories indicates that administratium occurs naturally in the atmosphere. It tends to concentrate at certain points such as government agencies, large corporations, and universities. It can usually be found in the newest, best appointed, and best maintained buildings.

Scientists point out that administratium is known to be toxic at any level of concentration and can easily destroy any productive reaction where it is allowed to accumulate. Attempts are being made to determine how administratium can be controlled to prevent irreversible damage, but results to date are not promising.

Sun Gods: Many cultures have sun deities. **Apollo** was the sun god of the ancient Greeks and Romans, and the subject of a ballet by **George Balanchine**.



Delphi is considered to be the place where Gaia or Mother Earth and the origin of all life lived with her son Python who was a snake. Delphi is also the place where the two eagles who were released by Zeus, one of which flew east and the other flew west, met. Consequently, Delphi was considered to be the center of the world. Around 1000 BC, Apollo the sun god and son of Zeus came to Delphi, killed Python, so he could rule Gaia and the earth. A Temple of Apollo, originally made of laurel leaves, was built over the dead snake. A priestess with prophetic powers lived in the cella of the temple. Apollo gave to the oracle of Delphi maxims such as **Know Yourself** and also helped her predict the future. Temples of Apollo, each with their own oracle, sprung up in many places. In 191 BC, the Romans took over Delphi. In 302 AD, Emperor Diocletian consulted the oracle of Apollo and was told that Christianity would lead to the destruction of the Empire. This led to

the persecution of Christians. Theodosius I retaliated and destroyed the Temple of Apollo in Delphi in 390 AD.

In Japan: **Amaterasu**, the sun god, emerges from a cave and brings sunlight back to the universe.



The Indigenous People of America have stories about the origin of day and day and called the *Legend of Rabbit and Owl* and an origin story about light called *Raven Steals the Light*.

Legend of Rabbit and Owl

A long time ago Rabbit was walking through the forest. He saw Owl sitting on a branch of a tree. There were bits of light coming through the trees, but it was hard for Rabbit to see. Rabbit asked Owl why he liked it so dark. Rabbit told Owl he didn't like the dark and he was going to make it bright like the daylight.



Owl told Rabbit that if he was powerful enough to do it. Owl told Rabbit that they should have a contest to see who could make it dark or light all the time.

Rabbit and Owl called together all of the birds and animals to witness. Rabbit and Owl explained to the animals what they were trying to do. Some of the animals wanted Rabbit to win but didn't know if they wanted it to be light all of the time. Some of the animals wanted Owl to win so it could stay dark all of the time.

The contest began. Rabbit repeated "Light, Light" and Owl repeated "Night, Night." The trick was not to repeat the other's words. If they repeated the wrong word, they would lose.

Rabbit and Owl kept on saying their words. The animals were cheering them on. All of a sudden Owl said "Light" and lost the contest.

Rabbit was the winner, and he had his wish for daylight. He decided to let there be night as well for the benefit of all the animals. This made everyone happy.

Raven Steals the Light

There once lived a very powerful chief. The chief got hold of the sun and the moon and hung them up in his house. Consequently, it became dark everywhere.

Because it was so dark, the people could not hunt or fish. When they went out to find wood to burn in their fires, they had to crawl around in the forest feeling with their hands until they found something which might be wood. Then they would bite it to make certain that it was indeed firewood.

Raven learned that the great chief had taken the sun and moon, so he went to his house to take it back. He asked the chief if he would return the sun and moon, but he would not. So, the smart black bird devised a plan.

He saw how the chief's daughter went to a small stream to get water every morning, so he hid near there and waited for her to return. When he saw her coming down the trail, he turned himself into a tiny fish, and jumped into the water. After the girl arrived, she filled a bucket with water. Then she dipped her

The Raven Steals the Light

Drawings by Bill Reid
Stories by Bill Reid & Robert Bringhurst
with a preface by Claude Lévi-Strauss



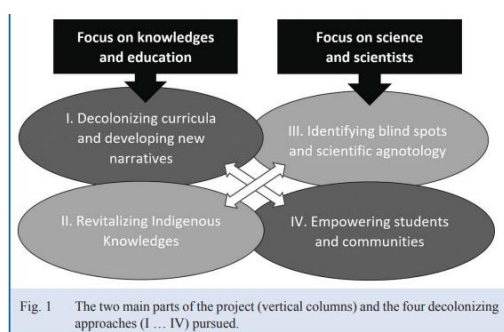
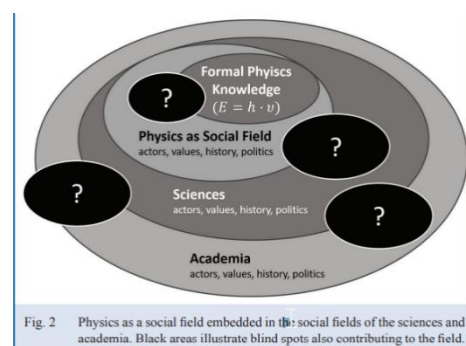
drinking cup into the stream and Raven, disguised as a small fish, quickly swam into it. She did not see Raven and drank the water.

Inside her body, Raven turned into a baby and so the girl became pregnant. After a short time, the daughter gave birth to a baby boy which was really Raven. The baby grew fast and was soon a young boy. The grandfather was very fond of his grandson and would do anything for him. One day the boy began crying for something.

The chief asked him, "What do you want, grandson?"

The boy pointed to the sun and moon hanging from the ceiling. The chief decided to let him play with them if it would make him stop crying. So, the boy took them outside and played with them for a while, but then he threw them high into the air. When the old chief ran out to see what had happened, Raven became himself again and flew away. Since that time there has been light.

There is currently a movement to **decolonize light**: “*The Decolonizing Light project explores ways and approaches to decolonize science, such as revitalizing and restoring Indigenous knowledges, and capacity building. The project aims to developing a culture of critical reflection and investigation of the relation of science and colonialism.*” Salzmann et al. (2021) describe the **project**.



Randy Wayne, an associate professor in the School of Integrative Plant Science at Cornell University who conducts research pertaining to electrodynamic theories and science's understanding of the photon, likewise said he questions the utility of alternative ways of knowing for training scientists and advancing scientific knowledge.

When not in his lab, Wayne regularly teaches a course called "Light and Life," which presents students with a vast mix of philosophical ideas, historical and cultural knowledge, and scientific concepts related to light.

In a telephone interview with The College Fix, Wayne recounted an indigenous myth about how a shape-shifting raven returned light to the world after the sun and the moon were taken by a powerful chief.

"As a creation myth and as a way to bring in other people and other people's cultures and a warm feeling for how people try to explain questions," Wayne said, "that's a great story to bring into 'Light and Life.'"

"Those are the things I include," he added. "There are a number of origin stories and ceremonies about light. I don't try to marginalize or diminish any culture."

However, stories like that "don't give us much of a way to really develop thinking through making assumptions, testing those assumptions, doing experiments, getting evidence, [and] making analysis," which are all part of standard scientific practice, Wayne said.

The **absorption of the various wavelengths** that compose sunlight and the **transmission** of others by inorganic pigments in or on glass can be appreciated when looking at the **image of Isaac Newton** in the chemically **stained glass window** of the Wren Library (Isaac Newton (1642-1727) being presented to George III (1738-1820) with



Francis Bacon (1561-1626) looking on, designed by Giovanni Battista Cipriani, 1771); the chemically stained glass window of the Olney Parish Church that depicts the **image of John Newton**; the chemically stained glass window at the Fountain Street Church in Grand Rapids, Michigan that depicts the **image of Charles Darwin**; and the chemically stained glass window at the Grace Cathedral in San Francisco that depicts the **image of Albert Einstein** and his equation $E = mc^2$.



Hans Bethe discovered how sunlight was generated by the sun. Silvan S. Schweber read a Stephen Spender (1955) poem at a celebration of Hans Bethe's Life:

I Think Continually of Those Who Were Truly Great

*I think continually of those who were truly great.
Who, from the womb, remembered the soul's history
Through corridors of light, where the hours are suns,
Endless and singing. Whose lovely ambition
Was that their lips, still touched with fire,
Should tell of the Spirit, clothed from head to foot in song.
And who hoarded from the Spring branches
The desires falling across their bodies like blossoms.*

*What is precious, is never to forget
The essential delight of the blood drawn from ageless springs
Breaking through rocks in worlds before our earth.
Never to deny its pleasure in the morning simple light
Nor its grave evening demand for love.
Never to allow gradually the traffic to smother
With noise and fog, the flowering of the spirit.*

*Near the snow, near the sun, in the highest fields,
See how these names are fêted by the waving grass
And by the streamers of white cloud
And whispers of wind in the listening sky.
The names of those who in their lives fought for life,
Who wore at their hearts the fire's centre.
Born of the sun, they travelled a short while toward the sun
And left the vivid air signed with their honour.*

And an excerpt from a poem by Philip Savage

(<https://books.google.com/books?id=MnQ1AAAAMAAJ&pg=PA3#v=onepage&q&f=false>), written at another Ivy League college:

*WHEN February sun shines cold
There comes a day when in the air
The wings of winter slow unfold
And show the golden summer there.*

*Dead ivy on the winter wall
Is glowing with an April light;
And all the wreckage of the fall*



Above the snow comes into sight.

*By a green rock beneath the pines
Are shadows blue along the snow.*

*Above the silent sun the lines
Of cloud in white procession go.*

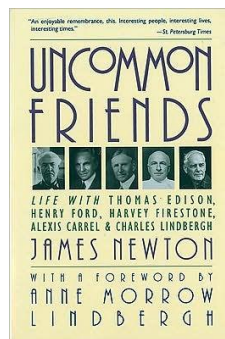
*A bloom is on the forest tops
Of red light bursting through the brown.
The ice awakes, and silver drops
Come through the meadow stealing down.*

*The sky is hushed; beneath the trees
Where silentness and night have birth,
I heard the sunset whisper, Peace!
Peace, Peace! The gods are on the earth.*

Don't forget *You are my Sunshine* performed by:

Jimmie Davis (<https://www.youtube.com/watch?v=ckKeQNCyPBU>)
The Pine Ridge Boys (<https://www.youtube.com/watch?v=xvPoll-pBCw>)
Gene Autry (<https://www.youtube.com/watch?v=1AhpWZjqMLI>)
Bing Crosby (<https://www.youtube.com/watch?v=zCUsvPgNi5Q>)
Doris Day (<https://www.youtube.com/watch?v=RUuCi4tOvQ8>)
Ricky Nelson (https://www.youtube.com/watch?v=ZGSxj_V0uhA)
Ray Charles (<https://www.youtube.com/watch?v=MvMl6MDjdak>)
Aretha Franklin (<https://www.youtube.com/watch?v=N3RthBGJL1s>)
Johnny Cash (<https://www.youtube.com/watch?v=cGa3zFRqDn4>)
Anne Murray (<https://www.youtube.com/watch?v=vHEaRFNx7tw>)
Carly Simon (https://www.youtube.com/watch?v=8z6MQ7gMi_U)
Miley Cyrus (<https://www.youtube.com/watch?v=xLQ8NOT8olk>)

In 1931, Thomas Edison thought about renewable energies, including solar and wind energy. In the book, *Uncommon Friends: Life with Thomas Edison, Henry Ford, Harvey Firestone, Alexis Carrel, & Charles Lindbergh*, James D. Newton describes a conversation between Henry Ford, Thomas Edison, and Roger Firestone that took place in March 1931:



Sometimes the three looked into the future. After they'd been discussing problems at home and abroad, the old man said suddenly, We are like tenant farmers, chopping down the fence around our house for fuel, when we should be using nature's inexhaustible sources of energy—sun, wind, and tide.

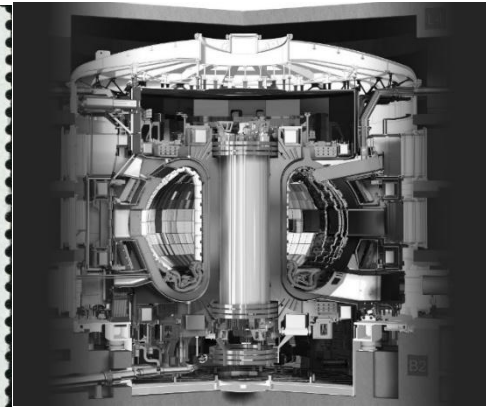
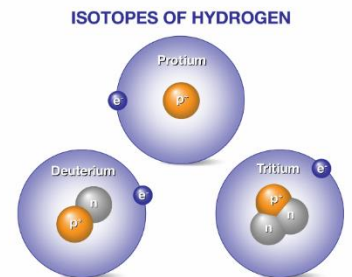
Firestone responded that oil and coal and wood couldn't last forever. They'd been tackling rubber. He wondered how much hard research was going into harnessing the wind, for example. Windmills hadn't changed much in a thousand years.

Ford said there were enormously powerful tides—for example, the Bay of Fundy. Scientists had only been playing with the question so far.

Edison said, I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait till oil and coal run out before that. I wish I had more years left.

Hopefully, **fusion energy**, which occurs in the sun, will be used to make steam to drive turbines that will **produce clean electricity** on Earth. Thirty-five nations are collaborating to build a magnetic fusion device in France that will test the feasibility of fusion as a large-scale source of energy. The device is called TOKAMAK, which is Russian for toroidal chamber with axial magnetic

field. The collaboration is known as **ITER**, which means, “The Way” in Latin. In the TOKAMAK, hydrogen nuclei exist as a plasma of charged deuterium nuclei (or deuteron—one proton and one neutron) and tritium nuclei (one proton and two neutrons). The plasma is contained by a magnet and heated to the point where the nuclei move fast enough to fuse into helium nuclei when they collide. These isotopes are used because they release more energy than p—p fusion and fuse at lower temperatures than the nuclei of other elements with greater masses. The fusion of a deuterium and tritium nucleus releases 2.8×10^{-12} Joules, which is greater than the fusion of two protons, which releases 2.3×10^{-13} Joules. The larger isotopes require higher temperatures to heat them up so they fuse upon collision. Currently it takes more energy to heat up the deuterium-tritium plasma to the needed **100 million C**, which is hotter than the core of the sun, than is released by fusion.



A General Principle about Everything and Nothing

We can learn a lesson from hydrostatic equilibrium that when something is static, it is not necessarily due to the absence of causes or forces, but to the balance of causes or forces. Remember that the sum of all real numbers is zero, and sometimes everything is difficult to distinguish from nothing—just as **ought**, meaning everything can have the same meaning as naught, meaning nothing. The sun is one example, we also talked about Herbert Spencer’s description of the destructive forces and preservative forces on race in maintaining stasis. The founders of the United States were well versed in Newton’s Laws and designed the three branches of government in a way that the forces exerted by each branch would preserve individual liberty.

Thomas Jefferson wrote to Richard Price Paris on January 8, 1789, “Bacon, Locke and Newton...I consider them as the three greatest men that have ever lived, without any exception, and as having laid the foundation of those superstructures which have been raised in the *Physical & Moral sciences*.”

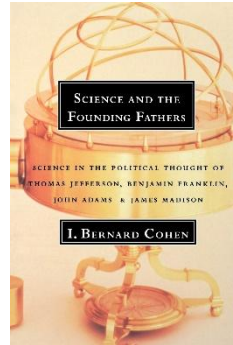
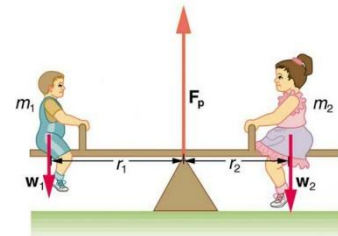
When we see stasis, consider the benefit of opposing forces, for if there were no opposing forces ($F_2 = 0$) such as friction, the tiniest force (F_1) would cause a given mass (m), be it a golf ball or a country, to accelerate (a) to infinite velocity.

Newton’s Second Law is often written as:

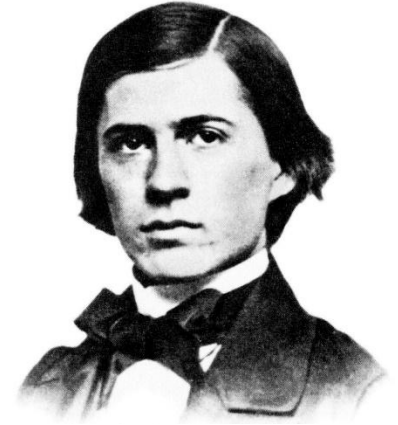
$$F = ma$$

But it is more realistic to write it like so:

$$F_1 - F_2 = ma$$



The First Rule of Reason by Charles S. Peirce (1898; with a lesson on chemical spectroscopy).



135. Upon this first, and in one sense this sole, rule of reason, that in order to learn you must desire to learn, and in so desiring not be satisfied with what you already incline to think, there follows one corollary which itself deserves to be inscribed upon every wall of the city of philosophy:

Do not block the way of inquiry.

136. Although it is better to be methodical in our investigations, and to consider the economics of research, yet there is no positive sin against logic in trying any theory which may come into our heads, so long as it is adopted in such a sense as to permit the investigation to go on unimpeded and undiscouraged. On the other hand, to set up a philosophy which barricades the road of further advance toward the truth is the one unpardonable offence in reasoning, as it is also the one to which metaphysicians have in all ages shown themselves the most addicted.

Let me call your attention to four familiar shapes in which this venomous error assails our knowledge:

137. The first is the shape of absolute assertion. That we can be sure of nothing in science is an ancient truth. The Academy taught it. Yet science has been infested with overconfident assertion, especially on the part of the third-rate and fourth-rate men, who have been more concerned with teaching than with

learning, at all times. No doubt some of the geometries still teach as a self-evident truth the proposition that if two straight lines in one plane meet a third straight line so as to make the sum of the internal angles on one side less than two right angles those two lines will meet on that side if sufficiently prolonged. Euclid, whose logic was more careful, only reckoned this proposition as a Postulate, or arbitrary Hypothesis. Yet even he places among his axioms the proposition that a part is less than its whole, and falls into several conflicts with our most modern geometry in consequence. But why need we stop to consider cases where some subtilty of thought is required to see that the assertion is not warranted when every book which applies philosophy to the conduct of life lays down as positive certainty propositions which it is quite as easy to doubt as to believe?

138. The second bar which philosophers often set up across the roadway of inquiry lies in maintaining that this, that, and the other never can be known. When Auguste Comte was pressed to specify any matter of positive fact to the knowledge of which no man could by any possibility attain, he instanced the knowledge of the chemical composition of the fixed stars; and you may see his answer set down in the Philosophie positive. 1) But the ink was scarcely dry upon the printed page before the spectroscope was discovered and that which he had deemed absolutely unknowable was well on the way of getting ascertained. It is easy enough to mention a question the answer to which is not known to me today. But to aver that that answer will not be known tomorrow is somewhat risky; for oftentimes it is precisely the least expected truth which is turned up under the ploughshare of research. And when it comes to positive assertion that the truth never will be found out, that, in the light of the history of our time, seems to me more hazardous than the venture of Andrée.

139. The third philosophical stratagem for cutting off inquiry consists in maintaining that this, that, or the other element of science is basic, ultimate, independent of aught else, and utterly inexplicable — not so much from any defect in our knowing as because there is nothing beneath it to know. The only type of reasoning by which such a conclusion could possibly be reached is retrodution. Now nothing justifies a retroductive inference except its affording an explanation of the facts. It is, however, no explanation at all of a fact to pronounce it inexplicable. That, therefore, is a conclusion which no reasoning can ever justify or excuse.

140. The last philosophical obstacle to the advance of knowledge which I intend to mention is the holding that this or that law or truth has found its last and perfect formulation — and especially that the ordinary and usual course of nature never can be broken through. »Stones do not fall from heaven,« said Laplace, although they had been falling upon inhabited ground every day from the earliest times. But there is no kind of inference which can lend the slightest probability to any such absolute denial of an unusual phenomenon.

Thomas Jefferson wrote to William Roscoe on December 27, 1820, about what the University of Virginia would be like:

for here we are not afraid to follow truth wherever it may lead, nor to tolerate any error so long as reason is left free to combat it.



Step-by-Step Derivation of the Gravitational Energy of the Sun

Consider assembling a uniform sphere of total mass (M) and radius (R). At an intermediate stage, the sphere has radius (r) and mass (m(r)), with uniform density:

$$\rho = \frac{M}{\frac{4}{3}\pi R^3} = \frac{3M}{4\pi R^3}$$

The mass inside the radius (r) is:

$$m(r) = \frac{4}{3}\pi r^3 \rho = M \left(\frac{r}{R}\right)^3$$

Now add a thin shell of thickness (dr) at radius (r). The shell's volume is

$$4\pi r^2 dr$$

so its mass is:

$$dm = 4\pi r^2 \rho dr = 4\pi r^2 \left(\frac{3M}{4\pi R^3}\right) dr = \frac{3M}{R^3} r^2 dr$$

The gravitational potential energy contribution when bringing this shell from infinity to radius (r) (interacting with the existing mass (m(r)) inside) is the work done against gravity. Treating the inner mass as a point at the center (valid by shell theorem), the potential energy for the shell is:

$$dU = -\frac{Gm(r)dm}{r}$$

Substitute (m(r)) and (dm):

$$dU = -\frac{G \left(M \frac{r^3}{R^3} \right) \left(\frac{3M}{R^3} r^2 dr \right)}{r} = -G \frac{M}{R^3} \cdot \frac{3M}{R^3} r^4 dr = -\frac{3GM^2}{R^6} r^4 dr$$

Integrate from $r = 0$ to $r = R$ to get the total gravitational potential energy (U):

$$U = \int_0^R dU = -\frac{3GM^2}{R^6} \int_0^R r^4 dr = -\frac{3GM^2}{R^6} \left[\frac{r^5}{5} \right]_0^R = -\frac{3GM^2}{R^6} \cdot \frac{R^5}{5} = -\frac{3GM^2}{5R}$$

Thus, the gravitational potential energy (self-energy) of a uniform sphere is:

$$U = -\frac{3}{5} \frac{GM^2}{R}$$

The negative sign indicates a bound system. The magnitude $\frac{3}{5} \frac{GM^2}{R}$ is often called the gravitational binding energy.

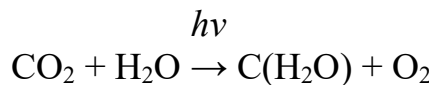
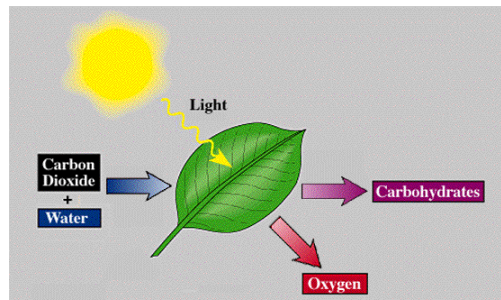
Photosynthesis: Converting Radiant Energy into Chemical Energy Pigments and Leaves



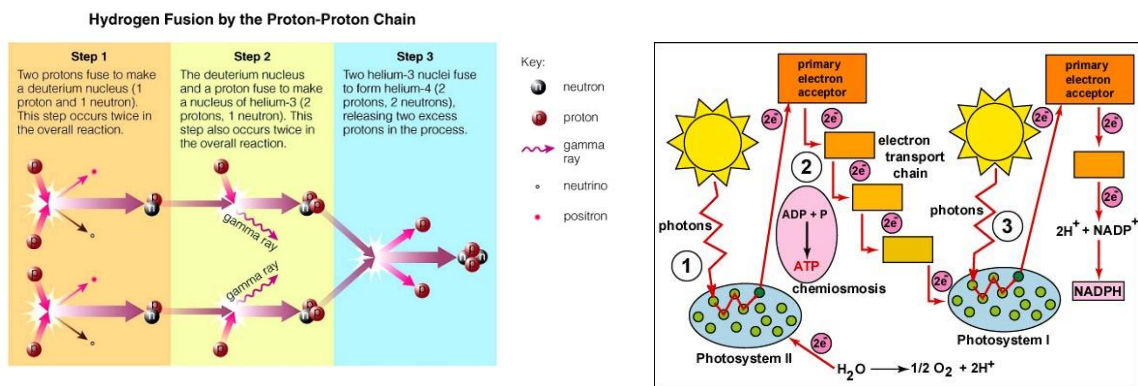
In a speech entitled, *What is Science?*, **Richard Feynman** (1969) said: “As a matter of fact, I can also define science another way: Science is the belief in the ignorance of experts. When someone says, ‘Science teaches such and such,’ he is using the word incorrectly. Science doesn't teach anything; experience teaches it. If they say to you, ‘Science has shown such and such,’ you might ask, ‘How does science show it? How did the scientists find out? How? What? Where?’

It should not be ‘science has shown’ but ‘this experiment, this effect, has shown.’ And you have as much right as anyone else, upon hearing about the experiments--but be patient and listen to all the evidence--to judge whether a sensible conclusion has been arrived at.” You can find the whole speech, which includes thinking about photosynthesis http://www.fotuva.org/feynman/what_is_science.html.

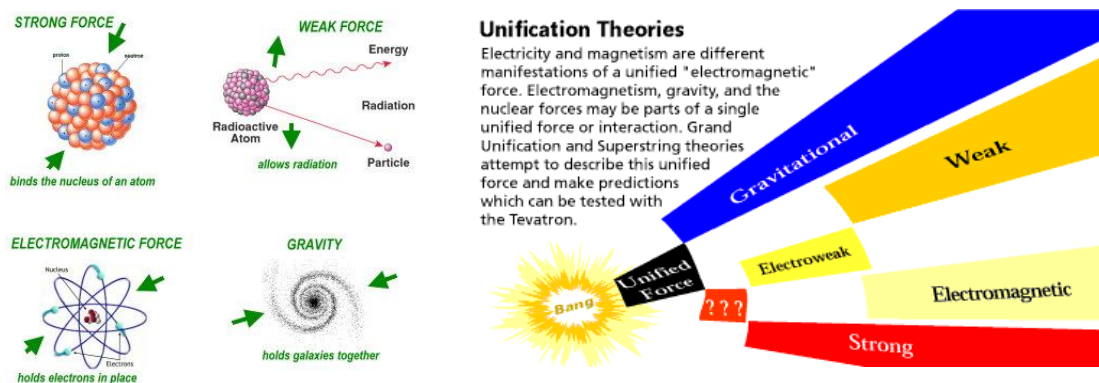
Photosynthesis is the **light ($h\nu$)-dependent chemical fixation** of gaseous **carbon dioxide** (CO_2) and liquid **water** (H_2O) into solid **carbohydrate** ($\text{C}(\text{H}_2\text{O})$) with the evolution of **gaseous oxygen** (O_2).



The “*alchemical*” production of sunlight resulted from the rearrangement of four hydrogen nuclei, each of which consists of one **proton**, into **helium** nuclei, each of which consist of two protons and two neutrons. The chemical fixation of carbon dioxide into carbohydrate by photosynthesis results from the sunlight-powered rearrangement of the orbiting **electrons**.



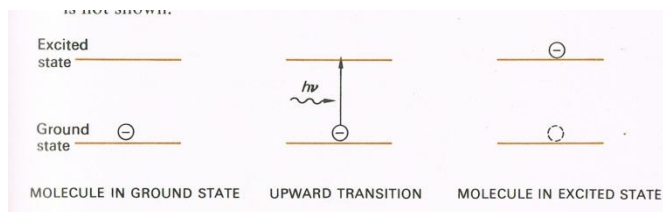
The alchemical production of sunlight involves the **weak and strong forces**. The **weak force** causes the transmutation of a proton into a neutron, a positron, and a neutrino. The **strong force** holds protons together in spite of their like charges. The photosynthetic fixation of carbon dioxide into carbohydrate involves the **electromagnetic force**.



The fixation of carbon dioxide into carbohydrate involves **the transfer of electrons** from water to carbon dioxide. The **Loss of Electrons** is called **Oxidation** and the **Gain of Electrons** is called **Reduction**. I remember these definitions using

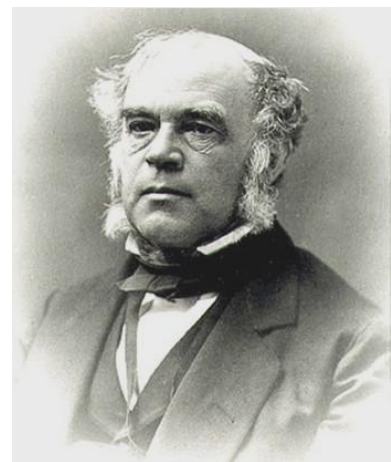
the phrase **LEO** the lion goes **GER**. The negatively charged electrons (e^-) are followed by the positively charged protons (H^+) so that there is a net transfer of $2H$ from each water molecule to carbon dioxide. This is an oversimplified and **simplistic** way of looking at the chemistry since the transfer takes place in many, many steps. However, this simplistic view leads us to look for a **pigment** that is able to **transfer electrons** in a **light-dependent** manner.

The absorption of light by a molecule such as **chlorophyll**, just like the **absorption** of light by an atom, results in the transfer of an electron from a lower energy **ground state** to a higher energy **excited state**.



It is now a commonplace that in order to use the **radiant energy** ($E = h\nu = \frac{hc}{\lambda}$) inherent in sunlight to fix carbon dioxide and water into carbohydrate, the radiant energy must be **absorbed** by a **pigment**. This is known as the **Grotthuss-Draper Law** or the **First Law of Photochemistry**. **John Draper**

(1841,1872-73), who was the keynote speaker at the 1860 meeting of the British Association for the Advancement of Science at Oxford, stated: *“That the ray effective in producing chemical or molecular changes in any special substance is determined by the absorptive property of that substance,”* *“that it depends on the chemical nature of the ponderable material what rays shall be absorbed,”* and *“the*

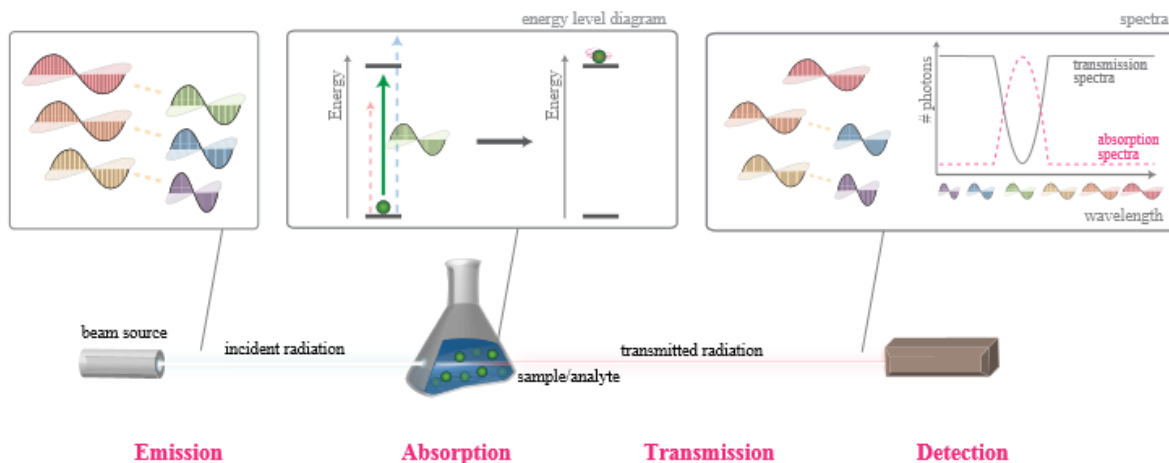


rays which are effective in the destruction of any given vegetable color are those which by their union produce a tint complementary to the color destroyed.”

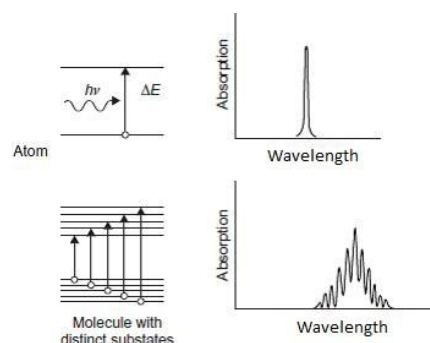
Theodor von Grotthuss (1819) performed the original experiments that led to the First Law of Photochemistry. Grotthuss noticed that an alcoholic solution of iron (III) thiocyanate, which is red, became decolorized when it was exposed to light. He also noticed that the rate of decolorization was proportional to the **intensity of the light** and the **duration of the exposure**. After seeing that other colored solutions behaved the same way, Grotthuss concluded that a photochemical reaction could be caused only by the light absorbed by the chemical substance and its **rate was proportional to the light intensity and the exposure time**. Grotthuss also noticed that green light was most effective in decolorizing iron (III) thiocyanate, which is red; blue light was most effective in decolorizing gold chloride which is yellow; and yellow light was most effective in decolorizing a starch iodide solution, which is blue. **John Herschel** (1842) discovered that paper treated with the pigments from flower petals were also decolorized by the **complementary** color of light. Grotthuss, Herschel, and Draper found that **each pigment absorbs the color of light that is complementary to its own color. Its own color is the color that the pigment transmits or reflects**.



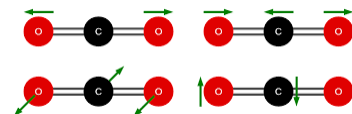
Absorption will (probably) occur if the pigment has a **transition energy** value where an **electron** can move from a **ground state** to an **excited state** that corresponds with the radiant energy of the **wavelength** of light.



An **absorption spectrum** of a given pigment is the **probability** that a **photon** with radiant energy ($E = h\nu = \frac{hc}{\lambda}$) will be **absorbed** by that **pigment**. The probability depends primarily on the **chemical structure** of the pigment, although it also depends on the environment (i.e., acidic or basic; oily or aqueous) in which the pigment exists. Since a molecule is composed of many atoms, there are many more **energy states** that correspond to **vibrational states** and **rotational states** between the various **atoms and groups of atoms** that compose the molecule. Consequently, the **absorption spectra of molecules** are broader and more complicated than the **absorption spectra of atoms**. The allowed energy states of atoms, in which the electrons orbit the nucleus, are known as **orbits** and the allowed energy states of molecules, in which the electrons are shared with one or more atoms, are known as **orbitals**. The allowed states are where the atom or molecule change by **one unit of angular momentum** ($\hbar = \frac{h}{2\pi}$, in Joule seconds) during absorption or emission. This is because each photon, no matter what its wavelength, carries exactly one unit of angular momentum ($\hbar = \frac{h}{2\pi}$).



Demonstration: Using your spectroscope, compare the emission spectrum of **carbon dioxide** with the emission spectrum of hydrogen.



Gilbert N. Lewis and **Melvin Calvin** at Berkeley and later **Robert Woodward** and **Louis Fieser** (who developed **napalm**, an incendiary weapon that is a modern form of **Greek fire**) at Harvard came up with a **set of rules** that generally predict the **absorption spectrum** of a chemical from the **number of conjugated double bonds that result in the delocalization of electrons**. Each added conjugated double bond shifts the peak of the absorption spectrum from



Gilbert N. Lewis
 $\lambda^2 = k'n$

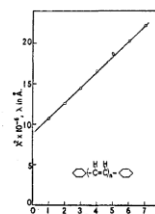
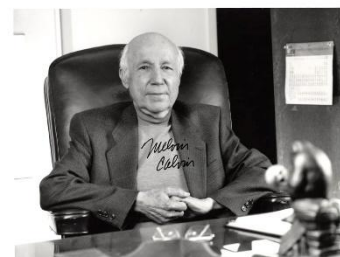
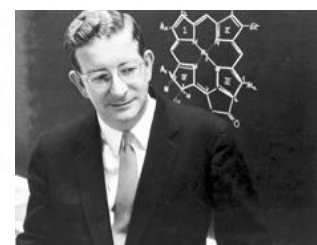


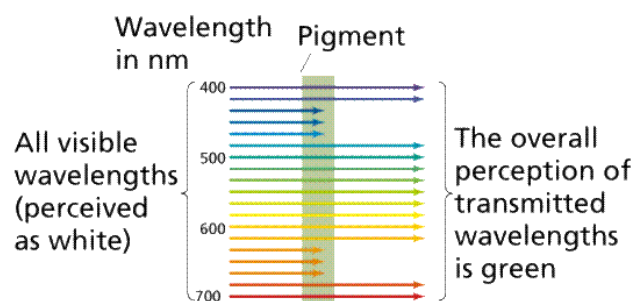
FIG. 11. Plot of the square of the wave length against the number of units of the polyenic chain



approximately **230 nm by 30 nm towards the red end of the spectrum**. This means the more conjugated double bonds, the more delocalized the electrons are from the nucleus of the atoms and the greater the probability that lower energy photons (i.e., with a long wavelengths) will be absorbed.

Demonstration: Extract chlorophyll from *Chara coralina* cells by grinding the cells with a mortar and pestle. Add a little isopropyl alcohol to

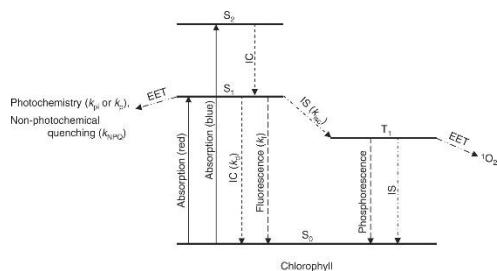
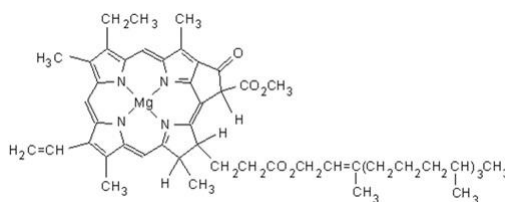
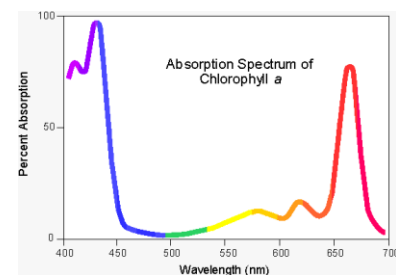
dissolve the chlorophyll. Then pour off the green solution into a little test tube. Use your spectroscope to look at the spectrum of sunlight with and without the tube containing chlorophyll in front of the slit. Which color(s) do the chlorophyll



molecules absorb and which color(s) do the chlorophyll molecules transmit? Is your result consistent with those of Grotthuss and Herschel? Here is the spectrum of the juice of a green leaf obtained by David Brewster (1834):



The **energy levels** of electrons and the number of **conjugated double bonds** in the pigment can be deduced by looking at the **absorption spectrum**. The absorption spectrum and structure of chlorophyll *a* are given below.

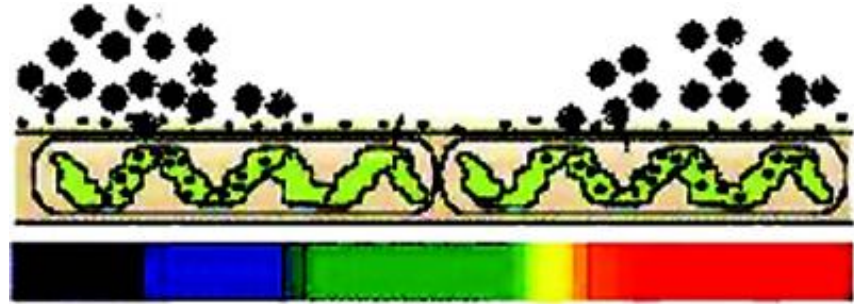


How do we know that chlorophyll *a* is involved in photosynthesis? We compare the **absorption spectrum** of the pigment with the **action spectrum** of photosynthesis. An action spectrum is a test to see which wavelengths of light are most effective in producing the desired response. We could measure the effect of each wavelength of light on **carbon dioxide fixation** using radioactive $^{14}\text{CO}_2$, or we could measure the effect of each wavelength of light on **oxygen evolution**.

Theodor Engelmann determined the effectiveness of each wavelength of light in the 1880s, sixty years before the invention of $^{14}\text{CO}_2$, in a very clever way using a microscope. Engelmann projected a spectrum of light on an algal filament on a

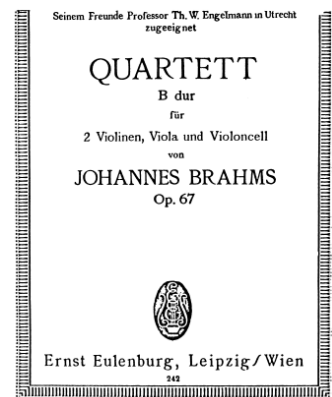


microscope slide. The most effective wavelengths would result in the greatest production of oxygen. Engelmann then put **oxytactic (oxygen-seeking)**

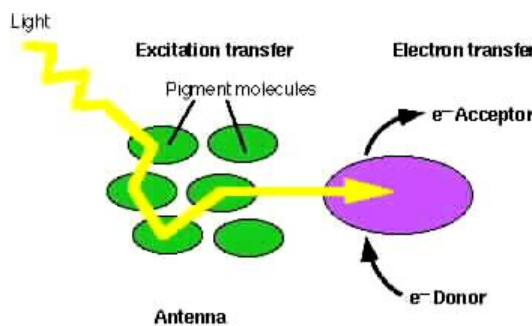
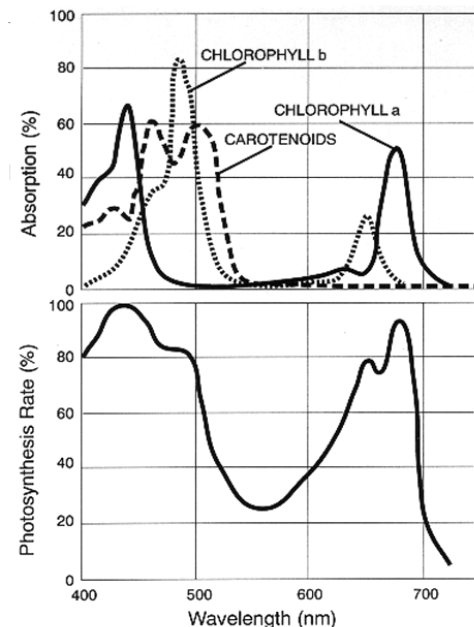


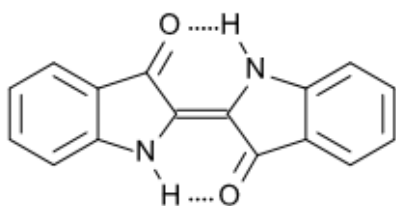
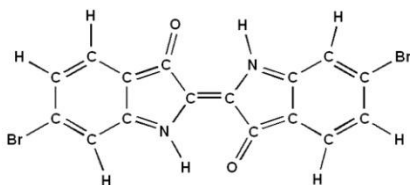
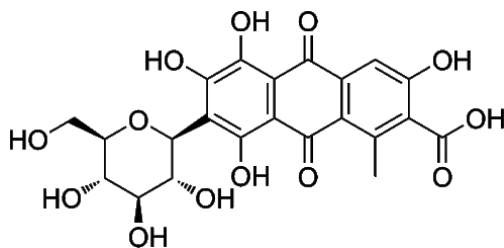
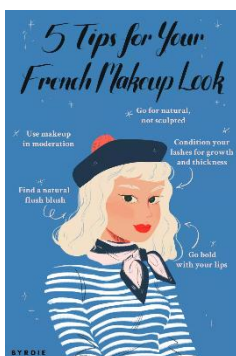
bacteria onto the microscope slide and watched to see where they went. They went to either the blue irradiated region or the red irradiated region, but not to the green region, indicating that photosynthetic oxygen evolution was stimulated most by blue and red light absorbed by chlorophyll and least by green light, the color of chlorophyll.

Thus the **action spectrum for photosynthetic oxygen evolution** determined by Engelmann matched the **absorption spectrum for chlorophyll *a***. This is strong evidence that chlorophyll *a* is the pigment responsible for photosynthesis. If you were wondering, this *is* the same Theodor Engelmann, who was also an amateur cellist, to whom **Johannes Brahms** dedicated Opus 67 for a String Quartet.

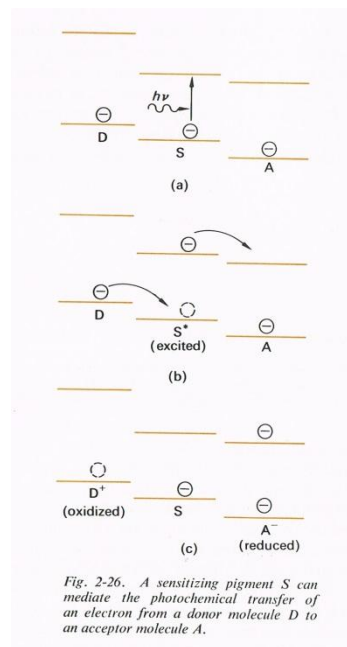


In detail, the action spectrum of photosynthesis does **not** perfectly match the absorption spectrum for chlorophyll *a*. This is because there are **other** pigments involved in photosynthesis that act as **antennae** that capture additional wavelengths of light and transfer the energy to chlorophyll *a*.

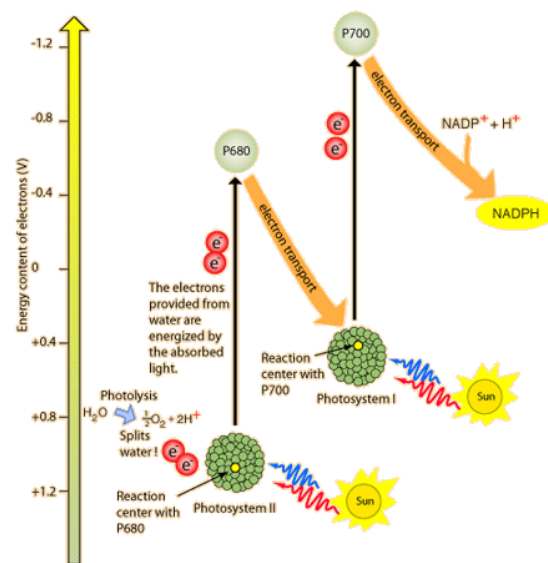




Note that these **pigments** look somewhat like each other and to **chlorophyll** in terms of having **many conjugated double bonds**. Unlike chlorophyll, the pigments in clothes and lipsticks re-radiate a larger proportion of the **absorbed** light as **infrared light (heat)**. However, for a pigment to participate in a light-driven chemical reaction sequence, such as photosynthesis, where the **energy of light** is effectively transformed into the **energy of life**, the pigment must be capable of **transferring an electron** from the excited state of the pigment to an **acceptor** which becomes **reduced** and the pigment must also be capable of **replenishing** the lost electron in the pigment from a **donor**, which then becomes **oxidized**. During photosynthesis, chlorophyll participates in **oxidation-reduction** reactions.



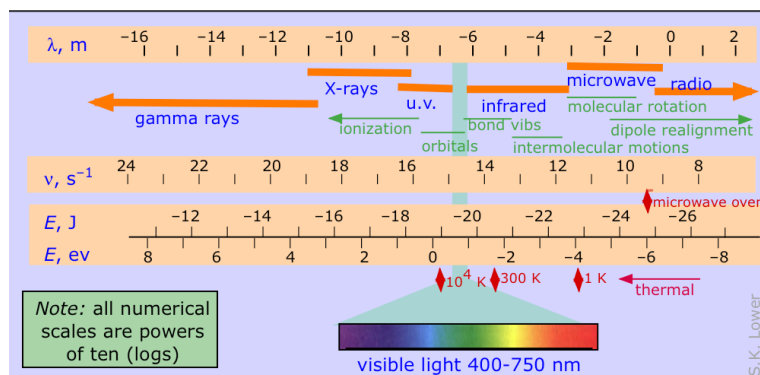
Any molecule that is capable of gaining and losing electrons has what is called a **redox potential**. The redox potential is a measure of the **affinity of the molecule for electrons**. The more negative the redox potential, the more likely the molecule will donate an electron and the more positive the redox potential, the more likely the molecule will accept an electron. When two molecules with different redox potentials are next to each other, the electron is **spontaneously** or **passively** transferred **from** the molecule with the more negative redox potential **to** the molecule with the more positive redox potential and energy that can be harnessed to do the work of life is released in the process.



On the other hand, the transfer of an electron from a molecule with a more positive redox potential to one with a more negative redox potential **requires an input of energy**. Chlorophyll can **actively** transfer an electron from an electron donor with a positive redox potential to an electron acceptor with a more negative redox potential using the **radiant energy** of the **light** that it **absorbs**. The redox potential is given in Volts, but it can be converted into an energy unit in Joules by multiplying the redox potential by a constant known as the elementary charge of an electron (ze) and is equal to -1.6×10^{-19} Coulombs. The difference in the redox energy between the ground state of chlorophyll (1.0 V) and the excited state of chlorophyll (-0.7 V) in photosystem II is $(-0.7 \text{ V} - 1.0 \text{ V}) \times -1.6 \times 10^{-19} \text{ Coulombs} = 2.7 \times 10^{-19}$



J. This is equal to the minimum energy of a photon needed to excite an electron in chlorophyll from the ground to the excited state. Given that $E = \frac{hc}{\lambda}$, what is the minimum wavelength of a photon

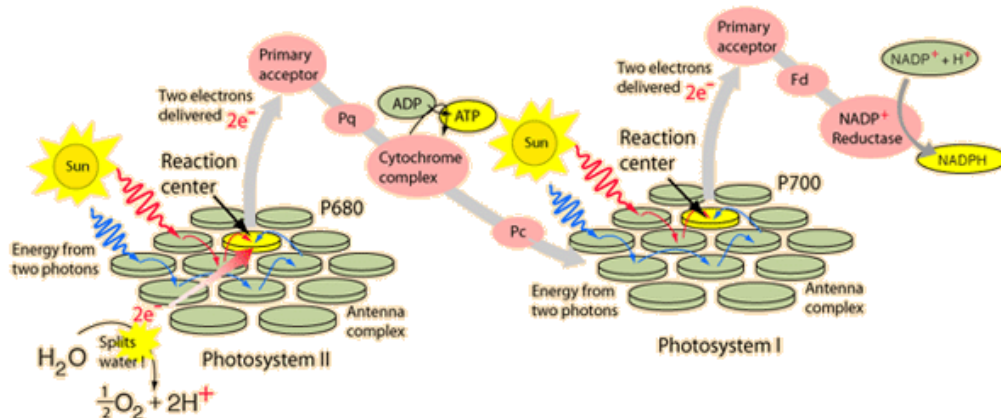


necessary to raise an electron in chlorophyll from the ground to the excited state? Does 680 nm light have enough energy?

In the light reactions of photosynthesis, there are **two steps**; both involve chlorophyll acting as a light-activated **electron pump** that transfers an electron to an acceptor with a more negative redox potential. The two steps are known as **photosystem I** and **photosystem II**.

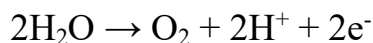
Aside: Robert Emerson, the great grandson of Ralph Waldo Emerson's brother, provided the first evidence of two photosystems using this equipment. Emerson

died in an airplane crash. The photographs are from his student mononymous Govindjee's photosynthesis museum <https://news.illinois.edu/view/6367/801235>.



Each photon absorbed by photosystem I results in the transfer of an electron to $\text{NADP}^+ + \text{H}^+$ which eventually becomes reduced to **NADPH**. *Two* molecules of NADPH can provide two hydrogen atoms to reduce *one* molecule of carbon dioxide (CO_2) to carbohydrate ($\text{C}(\text{H}_2\text{O})$). It takes two electrons and thus two

photons absorbed by photosystem I to reduce $\text{NADP}^+ + \text{H}^+$ to make one **NADPH**. Thus, it takes four electrons and **four photons** absorbed by photosystem I to produce two molecules of NADPH. In order to replenish the four electrons from the chlorophyll in photosystem I so that the process can repeat, the chlorophyll in photosystem II must absorb **four photons** and pass them on indirectly through an electron transfer chain to photosystem I. Thus it takes **eight photons** to make **two NADPHs** that are capable of reducing one molecule of carbon dioxide (CO_2) to the level of carbohydrate ($\text{C}(\text{H}_2\text{O})$). The four electrons from the chlorophyll in photosystem II are replenished from water. When two water molecules are stripped of four electrons, an oxygen molecule (O_2) is evolved, and four protons are added to the lumen.

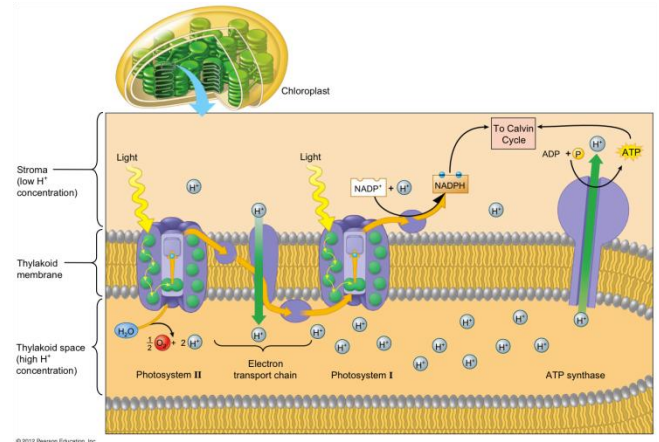


The energy (E) of a photon of a given wavelength (λ) is given by the following equation:

$$E = \frac{hc}{\lambda}$$

where c is the speed of light ($c = 2.99 \times 10^8 \text{ m/s}$) and h is Planck's constant ($h = 6.626 \times 10^{-34} \text{ J s}$). How much energy is in a photon of $680 \times 10^{-9} \text{ m}$ light? How much energy is in the eight photons needed to reduce one carbon dioxide to carbohydrate? How much energy is in 48 photons needed to reduce six carbon dioxide molecules to make a six-carbon sugar like glucose? How much energy is in 96 photons needed to reduce twelve carbon dioxide molecules to make a 12-carbon sugar like sucrose?

The light reactions described above take place on the **thylakoid membranes** in the **chloroplast**. The hydrophobic thylakoid membranes composed in part of a lipid bilayer separate two aqueous compartments known as the stroma and the lumen. As the electrons are passed along the **electron transport chain** from photosystem II to photosystem I, they simultaneously transfer protons (H^+) from the **stroma** to the **lumen**. The buildup of protons in the lumen, including those that are produced by the splitting of water and the depletion of protons in the stroma result in the **separation of charge** that is used by a protein known as the coupling factor or **ATP synthase** as an energy source to synthesize **ATP** from ADP and P_i .

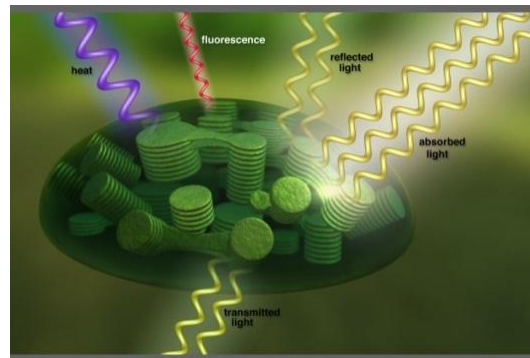


As you can see, the light-dependent **separation of charge**, whether the charges stem from electrons or from protons, provides **electrochemical energy** just like a **battery** that can be used to do the **work of life**. No work can be done without an energy input and the energy necessary for the work of life can come from various energy sources (electrical, chemical, gravitational, and radiant), all ultimately derived from the sun's gravitational and nuclear energy (and the initial big bang energy that gave rise to the hydrogen in the sun). This is **the First Law of Thermodynamics**—energy cannot be created or destroyed, but it can be interconverted. The electrochemical energy from the **charge separation of electrons** is used to **synthesize NADPH** and the electrochemical energy from the **charge separation of protons** is used to **synthesize ATP**. In the next lecture, I will tell you how the NADPH and ATP are

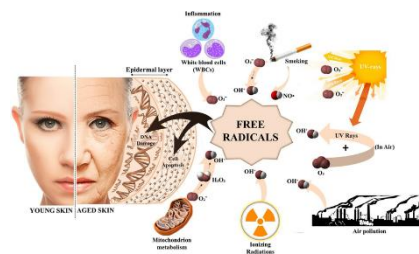


used in **light-independent reactions** to fix carbon dioxide (CO_2) to carbohydrate ($\text{C}(\text{H}_2\text{O})$).

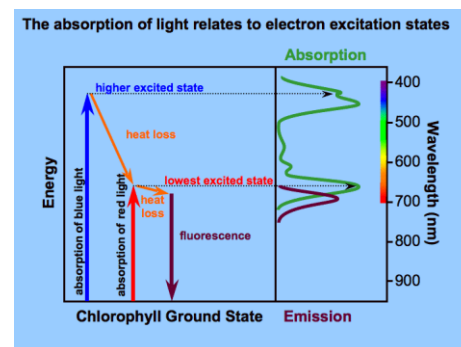
If the plant does **not** have the ability use the NADPH and ATP for fixing carbon in the light-independent reactions, the radiant energy absorbed by chlorophyll could be used to form **damaging free radicals**, which are molecules with an unpaired electron. Plants have several dissipation mechanisms to rid the plant of energy absorbed by the antenna complexes that is in excess of that used to drive the photochemical process of photosynthesis. One mechanism to reduce the production of free radicals is to re-emit the radiant energy as light in a process known as **fluorescence**.



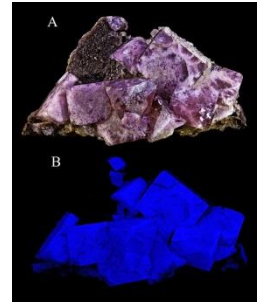
Aside: In humans, damaging free radicals are associated with aging. **Antioxidants** are used to neutralize free radicals by donating an electron to them.



Some of the absorbed energy causes the chlorophyll molecule, which looks as flexible as chicken wire, to bend or vibrate a little. Thus some of the absorbed energy is transformed into kinetic energy and eventually emitted as heat (infrared wavelengths). Since some of the energy of the absorbed light is transformed into kinetic energy, the radiant energy of the light emitted as fluorescence must be less than the radiant energy of the light absorbed. Consequently, the wavelength of the light emitted as fluorescence is longer than the wavelength of the absorbed light.

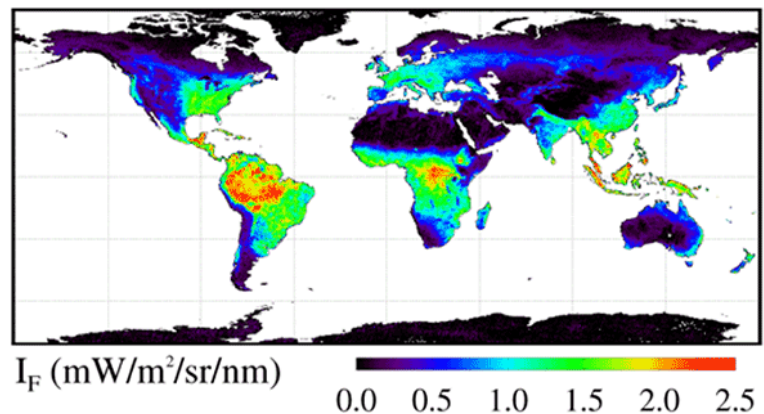


This is known as a **Stokes shift**, named after **George Stokes**, who coined the word fluorescence, named after the mineral **fluorspar** (calcium fluoride), which emitted longer wavelength blue light after it absorbed shorter wavelength invisible ultraviolet light. See the beautiful fluorescence of fluorspar in the **Timothy N. Heasley Museum** in Snee Hall (Cornell).



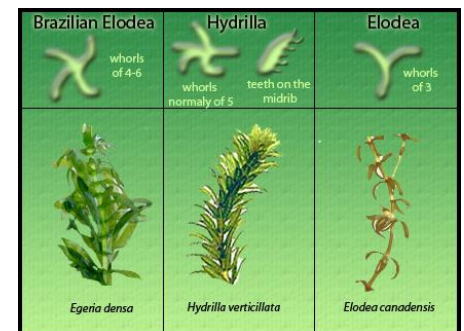
The red fluorescent light emitted by chlorophyll can be monitored by satellite. This **remote sensing** gives an estimate of the global distribution of photosynthesis.

GOME-2, December 2009



Demonstration: Using a **fluorescence microscope**, observe the fluorescence of the chlorophyll in chloroplasts of *Elodea* (a relative of *Hydrilla*). What happens to the fluorescence after exposure to blue light?

In general, the **leaf** is the **organ** of plants that specializes in photosynthesis. In fact, the word **chlorophyll** comes from the Greek *kloros* and *phyllon* for **green leaf**. Leaves are green because the chlorophyll *a* in them reflects and transmits the wavelengths of light that it does not absorb. Leaves are **not** the only photosynthetic organ. Some epiphytic orchids growing in low light conditions have **green photosynthetic**



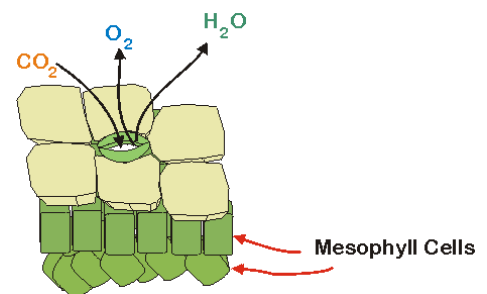
roots, cacti growing in dry deserts have no leaves, but do have **green photosynthetic stems**, some fruits and seeds, including **Mendel's culinary green peas**, and some flower parts, including the sepals of Cox's Orange and Pippin apples, are also photosynthetic.



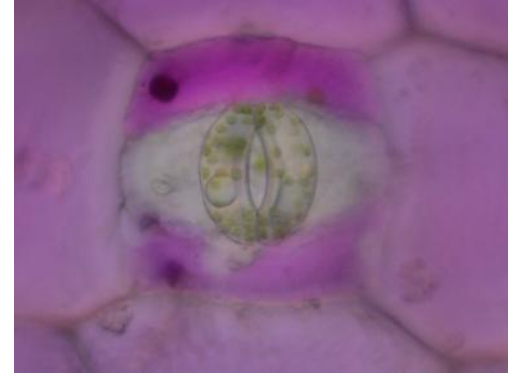
The **primary function** of a leaf is to **capture sunlight** and transform the radiant energy into chemical energy with as little as possible of the incident energy transformed into heat. Thus, the structure of the leaf **optimizes** photosynthesis under **various constraints**. Remember the tradeoffs of aperture size in the *camera obscura* and Samuel Wilberforce's discussion of compensation when selecting for one thing at the expense of another? (Wilberforce Falls on the Hood River in Canada is named after his father, William Wilberforce).



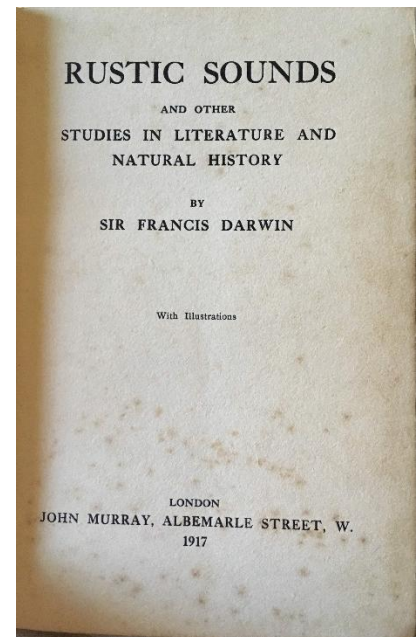
The **carbon dioxide** used for photosynthesis enters the leaf through valves in the leaf called **stomata**. When the valves are open, **carbon dioxide** can enter the leaf and can be converted into carbohydrate; however, at the same time, **water** that enters the leaf by way of the stem and the roots will be lost. If too much water is lost, the leaves will **wilt**, and photosynthesis as well as many other functions necessary for life will shut down.



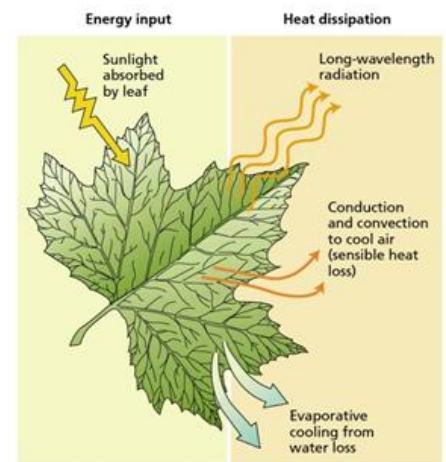
Demonstration: Using a **bright field** or **differential interference contrast microscope**, observe the stomates of *Rhoeo spathacea*.



In an essay entitled, *Picturesque Experiments* in a book entitled, *Rustic Sounds and other Essays*, **Francis Darwin** (1917) presents a series of picturesque experiments that demonstrate photosynthesis. Here is one: “*There are other methods of demonstrating the movements of the stomata. Stahl had the happy inspiration of making use of the colour-changes of cobalt chloride. A piece of filter paper soaked in a 5 p.c. solution of this salt is blue when dried, and turns pink in damp air. A dry piece of this material, applied with proper precaution to the stomata-bearing surface of a leaf, rapidly changes to pink if the stomata are open. When, however, the same trial is made on the upper surface of a leaf, where stomata do not occur, no such change occurs. If two leaves are treated at the same time, one in the normal position and the other upside down, it is delightful to watch the appearance of a pink picture of that leaf whose stomatic surface is in contact with the paper, while no such change takes place over that which exposes no stomata to the tell-tale material.*”

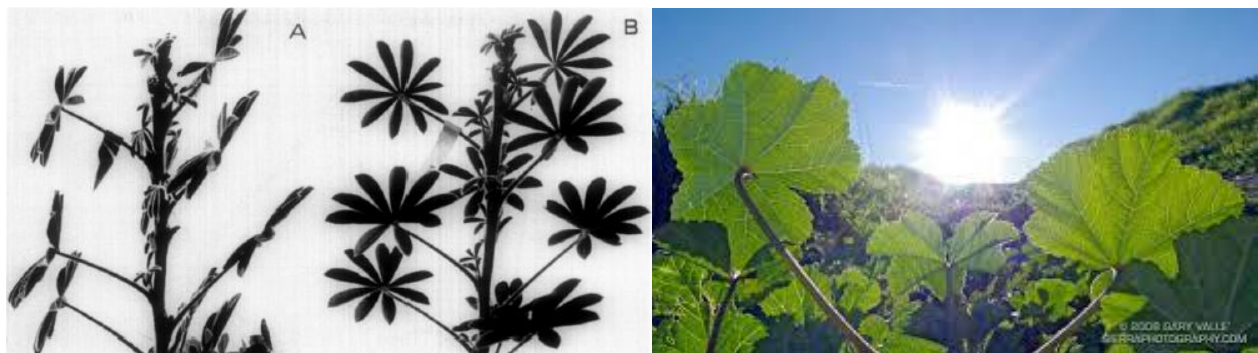


The bigger the leaf, the more sun it will capture but bigger is not always better since the bigger the leaf the more the leaf will be heated up by the sunlight. Too much heat will result in cooking the proteins in the leaf. Plants use the evaporation of water from the leaf to keep the leaf cool just like we use the evaporation of sweat to cool us. Evaporation and sweating cool the surface because it takes **heat energy to convert a liquid into a gas and the heat energy leaves with the gas**. The amount of carbon dioxide fixed by a leaf and the amount water lost by a leaf must be **balanced**.



Some plants optimize photosynthesis by tracking the position of the sun so that the leaves face the sun throughout the day. Lupin (*Lupinus pilosis*), malva, and [sunflower](http://plantsinmotion.bio.indiana.edu/plantmotion/movements/tropism/solartrack/solartrack.html) (*Helianthus annuus*) are examples of plants that perform **solar tracking** or **heliotropism**.

<http://plantsinmotion.bio.indiana.edu/plantmotion/movements/tropism/solartrack/solartrack.html>



(A)



(B)



Some species are only heliotropic when they are **well watered**. In times of drought, the leaves close up to minimize the leaf area that captures the sun and results in leaf heating and/or water loss. *Eremalche rotundifolium* pictured on the left is tracking the sun. Water-stressed *Lupinus arizonicus* pictured on the right has minimized its solar exposure until its water status improves.



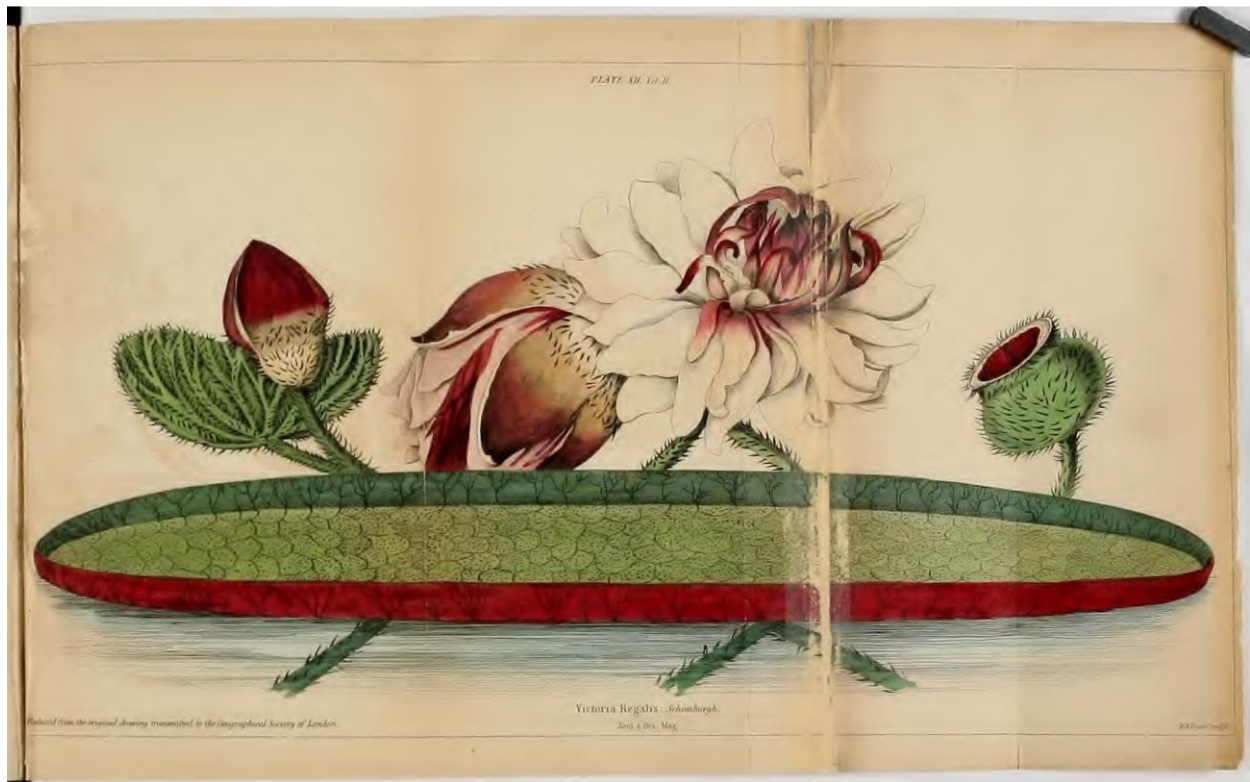
Let's look at a leaf that is growing where there is **plenty of sunlight** and **plenty of water**. This is the leaf of the water lily *Victoria regia* that lives in the still waters of the great rivers of the South America that flow into the Atlantic Ocean. In still waters there is a stunning way to collect light for photosynthesis and no plant does this in a more spectacular way than the *Victoria regia*. ***This is a leaf's leaf***. The six foot in diameter leaves float on the still water, supported from the bottom with **girder-like ribs** and **air spaces**.

Robert Schomburgk discovered this water lily in British Guiana (Guyana) which was ‘discovered’ by Walter Rayleigh in his shipboard (as opposed to alchemical), search for Eldorado—gold. Robert Schomburgk sent a leaf of the water lily along with a description and two drawings back to England. In 1837, **John Lindley** privately published twenty-five copies of a pamphlet on the plant he named *Victoria regia*, which included Schomburgk's description of the plant. A month later, John Edward Gray (1837) published Schomburgk's description of the plant and a drawing in the form of an engraving in the more-widely read Magazine of Zoology and Botany. According to Schomburgk, “*Some object on the southern extremity of this basin attracted my attention. It was impossible to form any idea what it could be, and, animating the crew to increase the rate of their paddling, shortly afterwards we were opposite the object which had raised my curiosity. A vegetable wonder! all calamities were forgotten, I felt as botanist, and felt myself rewarded. A gigantic leaf, from 5 to 6 feet in diameter;*



*salver-shaped, with a broad rim of light green above, and a vivid crimson below, resting upon the water. Quite in character with the wonderful leaf was the luxuriant flower, consisting of many hundred petals, passing in alternate tints from pure white to rose and pink. The smooth water was covered with them, and I rowed from one to the other, and observed always something new to admire. The leaf on its surface is of a bright green, in form almost orbiculate, with this exception, opposite its axis, where it is slightly bent up. Its diameter measured from 5 to 6 feet; around the whole margin extended a rim about 3 to 5 inches high, on the inside light green, like the surface of the leaf, on the outside, like the leaf's lower part, of a bright crimson. **The ribs are very prominent, almost an inch high, radiate from a common centre, and consist of eight principal ones, with a great many others branching off from them. These are crossed again by a raised membrane, or bands at right angles, which gives the whole the appearance of a spider's web, and are beset with prickles; the veins contain air cells like the petiole and flower stem. The divisions of the ribs and bands are visible on the upper surface of the leaf....When it [the flower] first opens, it is white, with pink in the middle, which spreads over the whole flower, the more it advances in age, and it is generally found the next day of pink- colour.***

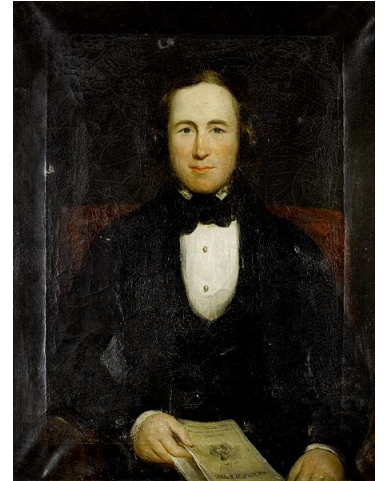




In August 1846, fresh seeds of the Victoria water lily were collected in Bolivia by Thomas Bridges and brought to the **Royal Botanic Garden at Kew**. By October, two plants were thriving but by December 12th they died.



Other batches of seeds arrived at Kew beginning on February 18, 1849. By March 23, six seeds had germinated and by the end of the summer, fifty plants were thriving. Half of the plants were distributed to cultivators of rare plants, including **Joseph Paxton**, who got a plant on August 3rd.



Joseph Paxton, the head gardener for the **6th Duke of Devonshire**, also known as the Bachelor Duke, was the first person to successfully nurture *Victoria regia* into bloom in England. The first flower fully opened on **November 9, 1849** in the great glass house he built especially for the water lily in the gardens of **Chatsworth House**.

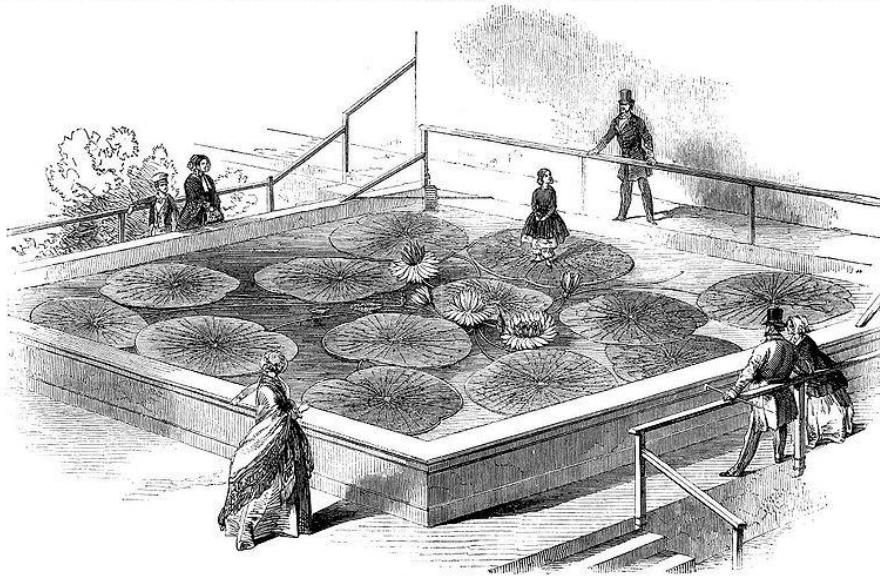


On November 13, 1849, Joseph Paxton went to **Windsor Palace** to present one of the first blossoms and a leaf to **Queen Victoria**, to whom the genus was dedicated.



As reported in the Gardiner's Chronicle in 1850, "*Some of the more vigorous leaves are, at particular stages of their growth, recorded to have increased in diameter at the remarkable rate of sixteen or eighteen inches within twenty-four hours.... The largest flower produced at Chatsworth, of which we have any record, was **thirteen inches in diameter**.... One curious fact connected with the Victoria Water Lily is **the extreme buoyancy of its large succulent foliage, occasioned by the presence of large air-cells in the thick ribs which cover like network the under surface, much aided no doubt by its large surface, and the deep pit-like recesses formed between the interlacing veins.** A child seven or eight years of age is said to have been supported by a leaf of the Chatsworth plant. The weight was, however, in this instance, distributed by means of a piece of board laid on the leaf, and on which the child stood.*"

According to an article published in 1885 by the Wisconsin State Horticultural Society (15: 143-146), "*The event brought together a distinguished concourse of visitors of the nobility and literati. A novel event was the appearance, on the occasion, of little Miss Annie Paxton, who, dressed in costume of a fairy, took her place in one of the tray-like leaves, and, like a Naiad of the waters, presided as the fairy guardian of this beautiful floral queen.*"



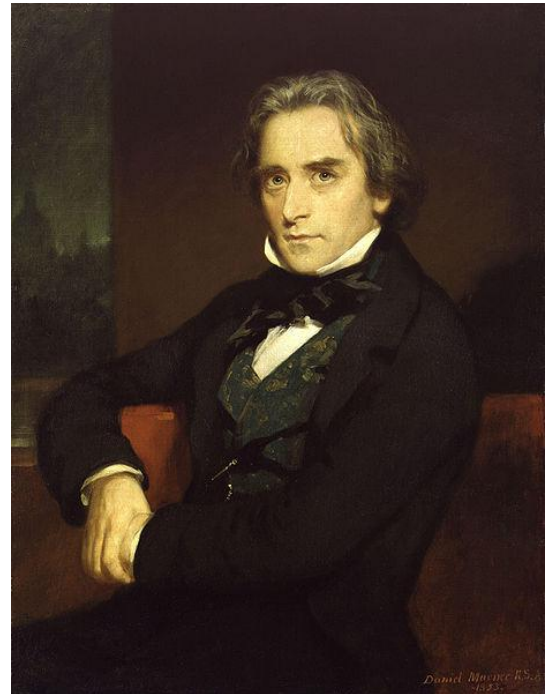
THE GIGANTIC WATER-LILY ('VICTORIA REGIA'), IN FLOWER AT CHATWORTH.

Douglas W. Jerrold wrote a poem for the occasion:

*On unbent leaf, in fairy guise
Reflected in the water,
Beloved, admired by heart and eyes,
Stands Annie, Paxton's daughter.*

*Accept a wish, my little maid,
Begotten at the minute,
That scenes so bright may never fade,
You still the fairy in it.*

*That all your life, nor care, nor grief
May load the winged hours
With weight to bend a lily's leaf,
But all around be flowers.*



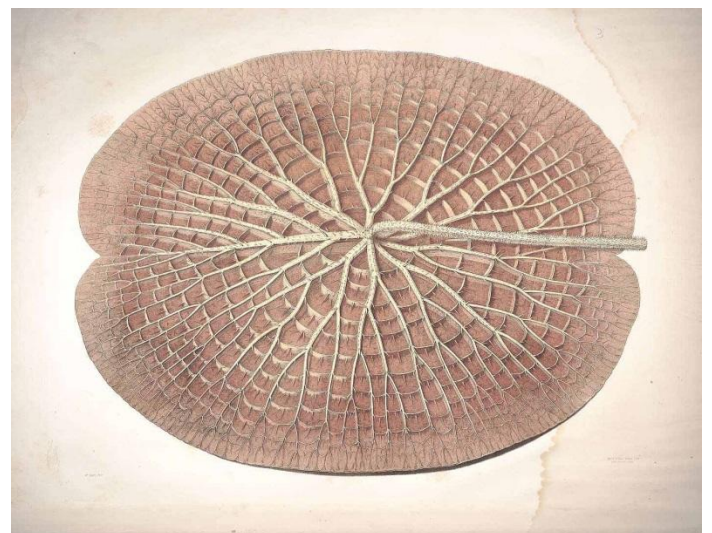
[Here](#) is a hand-written copy of the poem found in Annie's sister Blanche's notebook:



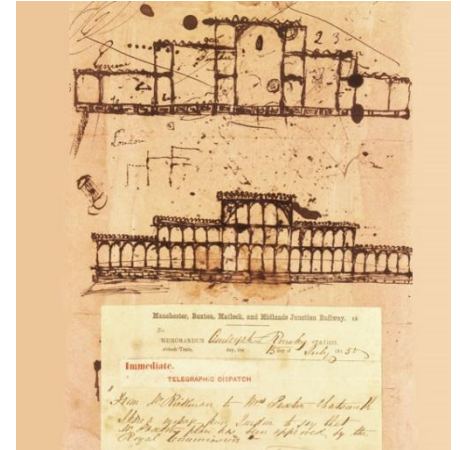
Douglas Jerrold
 Feb: 4: 1850.
 Westholpe Putney London

Poem to Miss Paxton by Douglas Jerrold.

Joseph Paxton had been experimenting with building glass houses, but his interest in *Victoria regia* and the structure of the leaf of *Victoria regia* itself had inspired him to follow new lines in the construction of the building known as the **Lily House** that would house the *Victoria regia*. Paxton's granddaughter, **Violet Rosa Markham** (1935), wrote in *Paxton and the Bachelor Duke*, "*Victoria, amiable throughout her career, apart from her house, actually contributed some structural principles to the Exhibition building. In the paper describing his design, read by Paxton to the Fine Arts Society on November 13th, 1850, he exhibited one of the marvelous leaves five feet in diameter and pointed out that its underside was a beautiful example of natural engineering. For it possessed ribs like levers radiating from the centre (where they were nearly two inches deep), with large bottom flanges, and very thin middle ribs with cross girders between each pair to keep the middle ribs from buckling. 'Nature was the engineer,' said Paxton. 'Nature has provided the leaf with longitudinal and transverse girders and supports that I, borrowing from it, have adopted in this building.'*"



The Lily House was built entirely out of glass and cast iron. Everything used to build the building had **multiple roles**. The **roof** was a light and heat adjuster; the **supporting columns, rafters, and sash bars** were also drainpipes. The **floor** was a ventilator and a dust trap. The parts of the Lily house were **prefabricated** and **modular** and could be built **inexpensively** and the same modules could be used to construct variously-designed buildings.



When it was time to design the Great Exhibition of 1851, he used the lessons he had learned from *Victoria regia*, beating out the 245 designs offered by professional architects from all over the world. Paxton's design was selected because it was **inexpensive**, did **not** use bricks and mortar, and could be built and disassembled **quickly**.

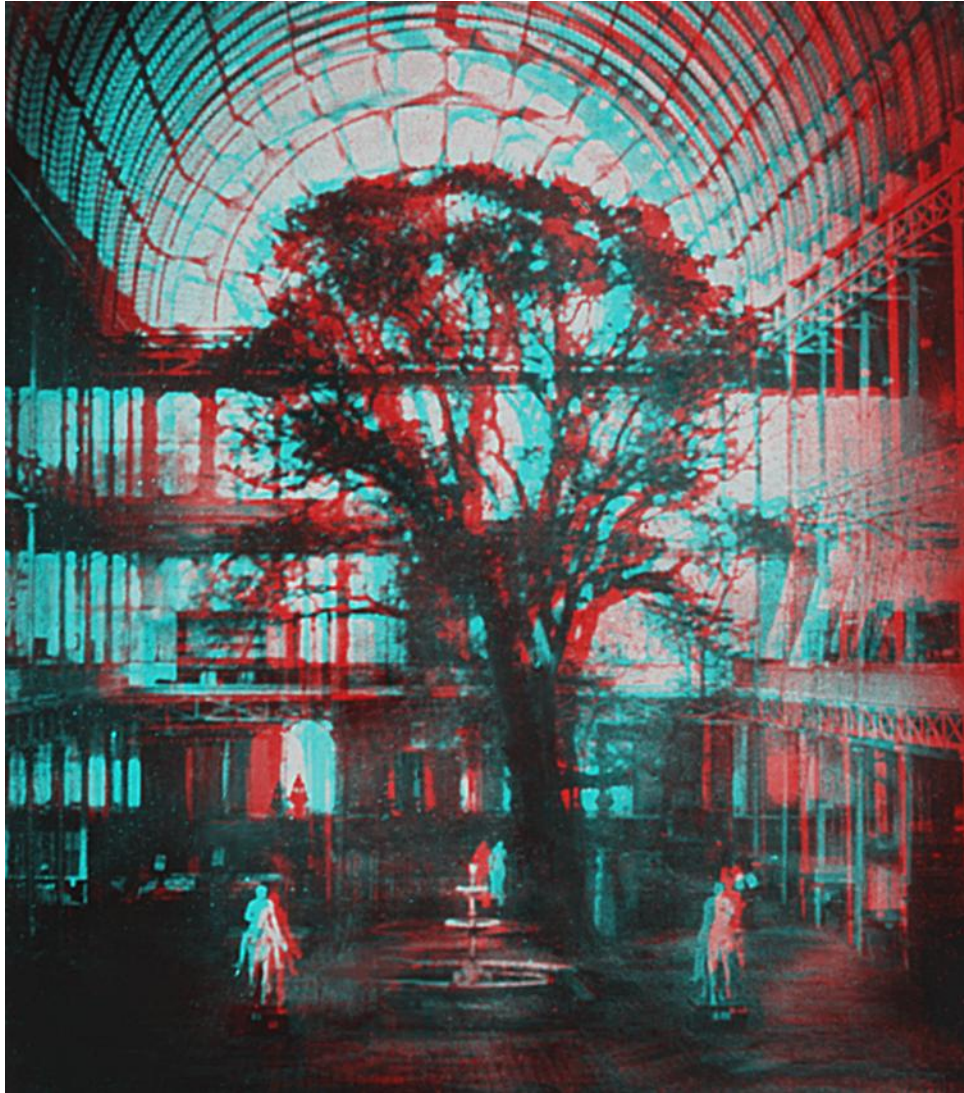
Joseph Paxton used the design principles he learned from *Victoria regia* and used to design the Lily House to design the building for the **Great Exhibition of the Works of Industry of all Nations** or the **Great Exhibition of 1851**. Douglas Jerrold, using the pseudonym “Mrs Amelia Mouser (July 13, 1850), described the building that Paxton proposed to build as the “*palace of the very crystal*” and from that time on it was known as the **Crystal Palace**, home of the Great Exhibition of 1851.



Using the principles of the **economy of nature** exhibited in the leaf of *Victoria regia*, Paxton built the Crystal Palace within nine months—on time and on budget!! **Prince Albert**, who was interested in science, trade, industry, and the arts saw the project through, and **Queen Victoria** opened the Great Exposition of 1851.

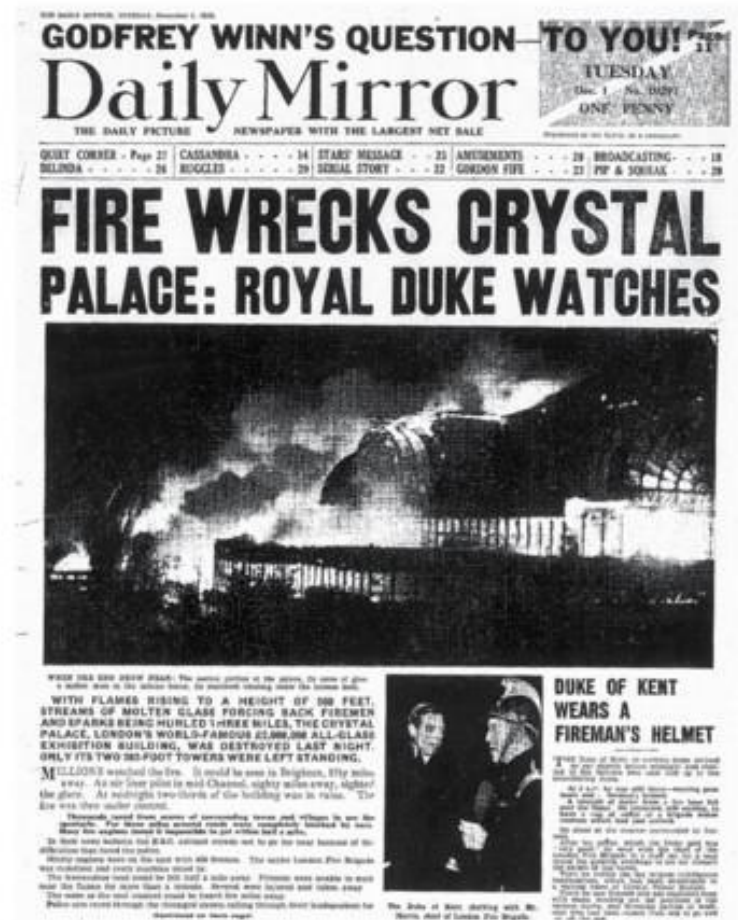


Anaglyph made from a **stereoscopic Daguerreotype** of the Crystal Palace that was taken on May 1, 1851. It gives a three-dimensional image when you view it with a red filter over the left eye and a blue filter over the right eye.



Paxton was knighted and became Sir Joseph Paxton in 1851. Paxton could not only assemble the Crystal Palace easily and quickly but he could also disassemble it easily and quickly so that he could return Hyde Park to the people.

In 1854, Paxton then moved the Crystal Palace from Hyde Park to Sydenham Hill, where it was used for many exhibitions, including a dinosaur exhibit. The Crystal Palace was destroyed in a fire on November 30, 1936. **Winston Churchill**, along with 100,000 people saw it burn. Churchill said, *"This is the end of an age."*



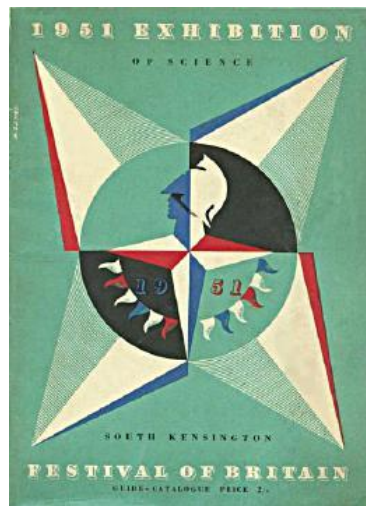
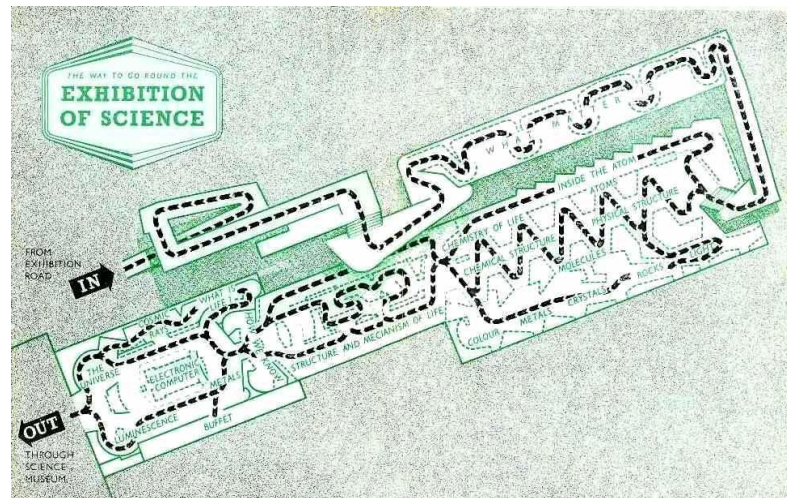
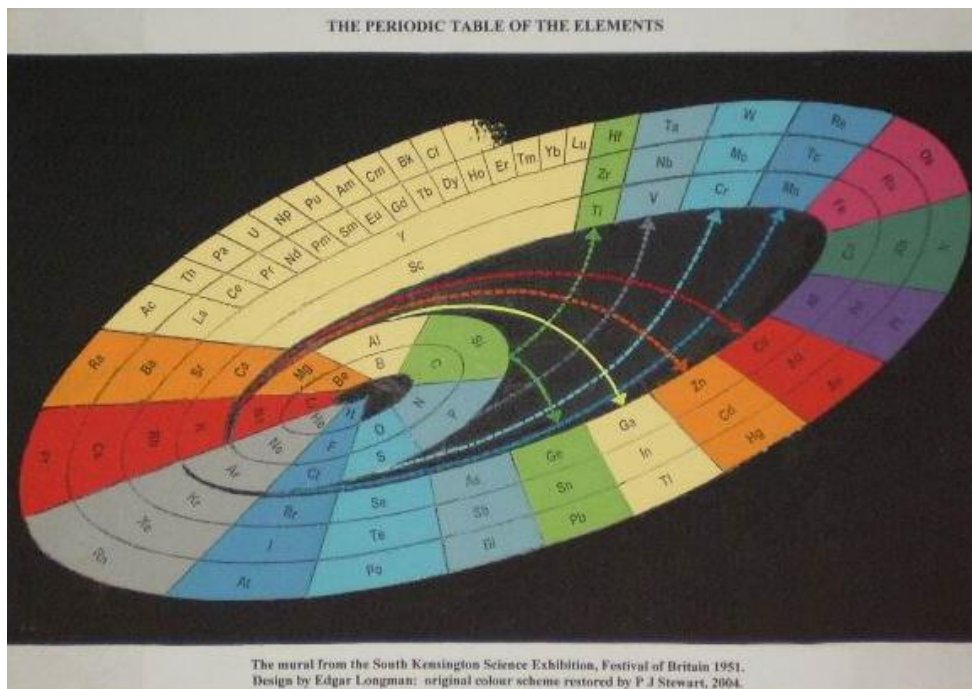
On September 23, 1851, **T. H. Huxley** wrote to his future wife, Henrietta Anne Heathorn, “*The great Temple of England at present is the Crystal Palace—58,000 people worship these every day. They come up to it as the Jews came to Jerusalem at the time of the Jubilee.*” The Exhibition of 1851 at the Crystal Palace exhibited two specimens of the duck-billed platypus and a specimen of the giant ground sloth prepared by **Richard Owen**. When the Crystal Palace was moved to Sydenham, Prince Albert wanted to include life-sized models of dinosaurs, including the carnivorous Megalosaurus and the herbivorous Iguanodon. Richard Owen, who coined the word **dinosaur** in 1841, was the scientific consultant to the sculptor, Benjamin Waterhouse Hawkins. Over a million people a year came to this exhibit to learn about and enjoy natural history as a part of Victorian culture.

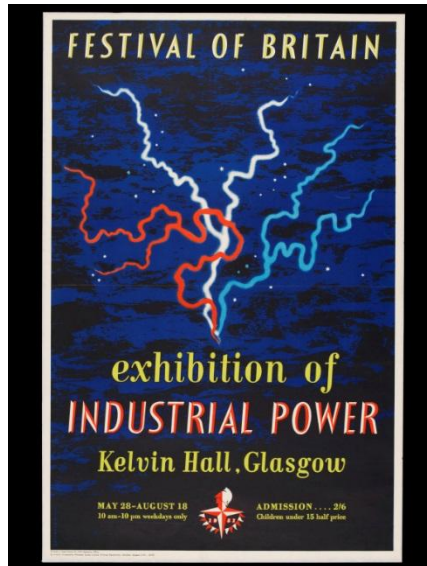
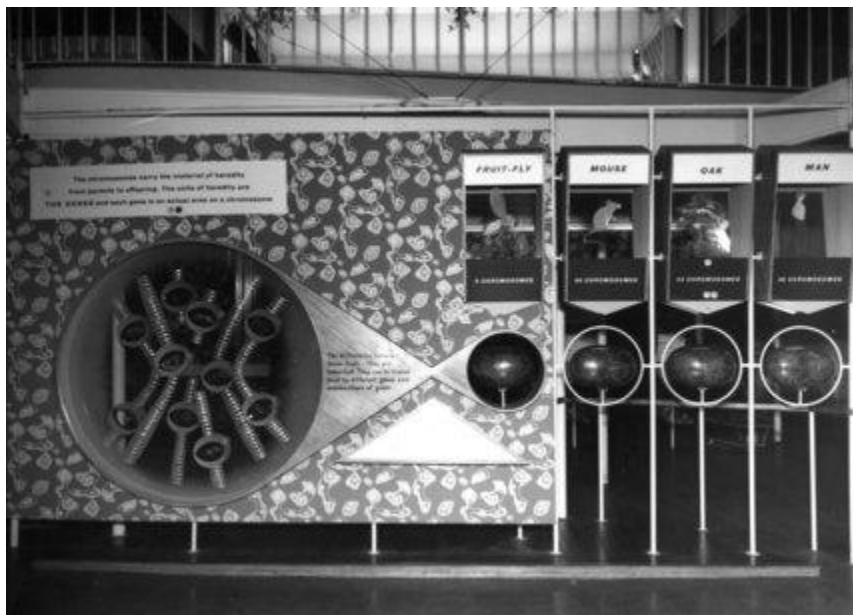


The 1951 *Festival of Britain* was originally planned to commemorate the Great Exhibition of 1851 but developed as a celebration of the post-WWII era of prosperity and progress guided by the transition from the old culture of art and literature to the new culture of science and technology as described in C. P. Snow's book, *The Two Cultures and the Scientific Revolution*.

<http://www.goodeveca.net/science1951/guide.html>

<http://www.goodeveca.net/nimrod/>





According to **Lisa Jardine**, who gave the 2009 C. P. Snow Lecture in Christ's College and daughter of Jacob Bronowski, *“There is a real reluctance to recognize the role pure science has played in the Allied victory, even as that science is hailed as the key to the future. As a consequence, science is celebrated as the source of emancipation, liberation and progress. But the context within which this is most clearly the case—the triumph of the Allies over the forces of Fascism—is left out. The omission is certainly a conscious one. Almost all those*

associated with the two Exhibitions had worked on wartime scientific developments, including radar, strategic bombing and ultimately the atomic bomb....There could hardly be a clearer example of deliberate amnesia....If science was to be represented as holding the key promises for Britain's future, he [Lord Ismay] must surely have believed it ought to be a science which was not associated with the enormity of the unimaginable scale of human casualties and suffering of those final weeks of the war with Japan."

Real estate mogul **Ni Zhaoxing** thought about bringing the Crystal Palace back to life as a 21st century cultural attraction. However the deal fell through.



In the 19th century, *Victoria regia* came to the United States where its mechanical strength also caused a stir.





There is an international contest to see how much weight the Victoria regia can hold.



Karl Niklas (Cornell), Steven Vogel, and Park Nobel study the biomechanics and biophysics of plants and their leaves.

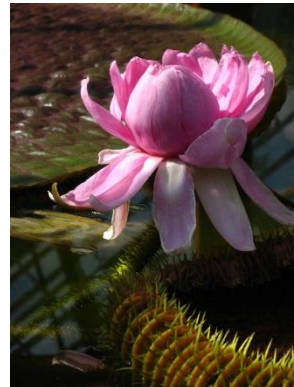


John Fisk Allen wrote and **William Sharp** illustrated *Victoria regia*, or *The Great Water Lily of America* in 1854. William Sharp drew the images on stones and printed them. Sharp was America's first **chromolithographic printer**, and this book is the earliest example of large scale color printing in the United States. We will see this book in the Rare and Manuscript Collections at Kroch Library.



Pollination in *Victoria regia* is as interesting as the leaf. The flower of *Victoria regia* is originally white and **opens at night**. Only the female parts

(pistils) of the flower are fertile while the **petals are white**. While the flower is white, the core of the flower heats up to about 95 °C. At this temperature, chemicals are volatilized which gives the flower a butterscotch and pineapple scent. This scent attracts pollen-covered **scarab beetles** that will pollinate the flower. At **dawn**, the petals close around the beetle, and they stay closed for 24 hours while the beetle pollinates the pistil. Subsequently, the male parts of the flower (stamens) become fertile. At **dusk**, the petals turn pink and the flower opens to let out the pollen-covered beetle, which can now fly to a white flower, with fertile female parts.



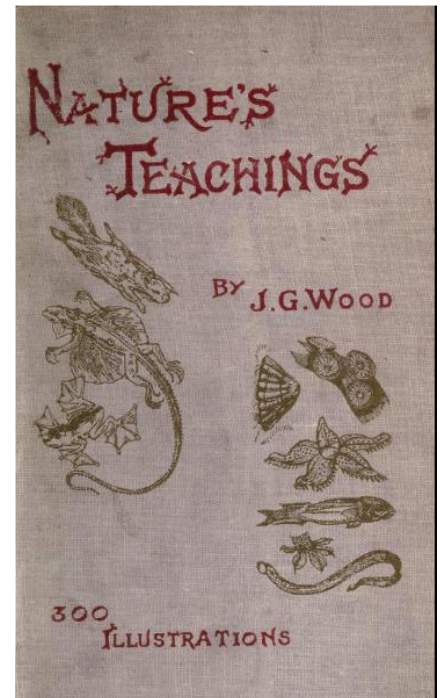
You can watch the lily grow and bloom and be pollinated in time lapse
http://www.youtube.com/watch?v=igkjcuw_n_U

Mann Library Special Collections

has *Victoria regia, or Illustrations of the Royal Water-Lily, in a Series of Figures Chiefly Made from Specimens Flowering at Syon and at Kew* by Sir William Jackson Hooker and Walter Hood Fitch printed by Bradbury & Evans for Reeve & Benham in 1851. (Call Number: QK495.N97 F5 Oversize)



In *Nature's Teachings*, the Reverend J. G. Wood (1858, 1907) wrote, “*The capabilities of the Crystal Palace had lain latent for centuries, but the generalising eye of genius was needed to detect it. A thousand men might have seen the Victoria Regia leaf, and not thought very much of it; but the right man came at the right time, the most wonderful building in the world sprang up like the creation of a fairy dream, and the obscure gardener became Sir Joseph Paxton. I have no doubt that thousands of similar revelations are at present hidden in Nature, awaiting the eye of their revealer.*” You can learn a lot from botany and looking at a leaf, the organ that specializes in photosynthesis.



Botany

by Berton Braley (1929)

*There should be no monotony
In studying your botany;
It helps to train
And spur the brain--
Unless you haven't gotany.*

*It teaches you, does Botany,
To know the plants and spotany,
And learn just why
They live or die--
In case you plant or potany.*

*You learn, from reading Botany,
Of wooly plants and cottony
That grow on earth,
And what they're worth,
And why some spots have notany.*

*You sketch the plants in Botany,
You learn to chart and plotany
Like corn or oats--
You jot down notes,
If you know how to jotany.*

*Your time, if you'll allotany,
Will teach you how and what any
Old plant or tree
Can do or be--
And that's the use of Botany!*



Prince Albert described the nature of science in a speech he gave in front of the [British Association for the Advancement of Science](#) in 1859, “To define the nature of Science, to give an exact and complete definition of what that Science, to whose service the Association is devoted, is and means, has, as it naturally must, at all times occupied the Metaphysician. He has answered the question in various ways, more or less satisfactorily to himself or others. To me, Science, in its most general and comprehensive acceptance, means the knowledge of what I know, the

consciousness of human knowledge. Hence, to know is the object of all Science; and all special knowledge, if brought to our consciousness in its separate **distinctiveness from**, and yet in its recognized **relation to the totality of our knowledge**, is scientific knowledge. We require, then, for Science—that is to say, for the acquisition of scientific knowledge—those **two activities of our mind** which are necessary for the acquisition of any knowledge—**analysis and synthesis; the first, to dissect and reduce into its component parts the object to be investigated, and to render an accurate account to ourselves of the nature and qualities of these parts by observation; the second to recompose the observed and understood parts into a unity in our consciousness, exactly answering to the object of our investigation.** The labours of the man of Science are therefore at once the most humble and the loftiest which man can undertake. **He only does what every little child does from its first awakening into life**, and must do every moment of its existence; and yet he aims at the **gradual approximation to divine truth itself.** If, then, there exists no difference between the work of the man of Science and that of the merest child, what constitutes the distinction? Merely the conscious self-determination. The child observes what accident brings before it, and unconsciously forms its notion of it; the so-called practical man observes what his special work forces upon him, and he forms his notions upon it with reference to this particular work. The man of Science observes what he intends to observe, and knows why he intends it. The value which the peculiar object has in his eyes is not determined by accident, nor by an external cause, such as the mere connection with work to be performed, but by the place which he knows this object to hold in the general universe of knowledge, by the relation which it bears to other parts of that general knowledge.

To arrange and classify that universe of knowledge becomes therefore the first, and perhaps the most important, object and duty of Science. It is only when brought into a system, by separating the incongruous and combining those elements in which we have been enabled to discover the internal connection which the Almighty has implanted in them, that we can hope to grapple with the boundlessness of His creation, and with the laws which govern both mind and matter.

The operation of Science then has been, systematically to divide human knowledge, and raise, as it were, the separate groups of subjects for scientific consideration, into different and distinct sciences. The tendency to create new sciences is peculiarly apparent in our present age, and is perhaps inseparable from so rapid a progress as we have seen in our days; for the acquaintance with and mastering of distinct branches of knowledge enables the eye, from the newly gained points of

sight, to see the new ramifications into which they divide themselves in strict consecutiveness and with logical necessity. But in thus gaining new centres of light, from which to direct our researches, and new and powerful means of adding to its ever-increasing treasures, Science approaches no nearer to the limits of its range, although travelling further and further from its original point of departure. For God's world is infinite; and the boundlessness of the universe, whose confines appear ever to retreat before our finite minds, strikes us no less with awe when, prying into the starry crowd of heaven, we find new worlds revealed to us by every increase in the power of the telescope, than when the microscope discloses to us in a drop of water, or an atom of dust, new worlds of life and animation, or the remains of such as have passed away.

Whilst the tendency to push systematic investigation in every direction enables the individual mind of man to bring all the power of which he is capable to bear on the specialities of his study, and enables a greater number of labourers to take part in the universal work, it may be feared that that consciousness of its unity which must pervade the whole of Science if it is not to lose its last and highest point of sight, may suffer. It has occasionally been given to rare intellects and the highest genius to follow the various sciences in their divergent roads, and yet to preserve that point of sight from which alone their totality can be contemplated and directed. Yet how rare is the appearance of such gifted intellects! and if they be found at intervals, they remain still single individuals, with all the imperfections of human nature.

*The only mode of supplying with any certainty this want, is to be sought in the combination of men of Science representing all the specialities, and **working together for the common object of preserving that unity** and presiding over that general direction. This has been to some extent done in many countries by the establishment of academies embracing the whole range of the sciences, whether physical or metaphysical, historical or political. In the absence of such an institution in this country, all lovers of Science must rejoice at the existence and activity of this Association, which embraces in its sphere of action, if not the whole range of the sciences, yet a very large and important section of them, those known as the inductive sciences, excluding all that are not approached by the inductive method of investigation. It has, for instance (and, considering its peculiar organization and mode of action, perhaps not unwisely), eliminated from its consideration and discussions those which come under the description of moral and political sciences. **This has not been done from undervaluing their importance and denying their sacred right to the special attention of mankind, but from a desire to deal with those subjects only which can be reduced to***

positive proof, and do not rest on opinion or faith. The subjects of the moral and political sciences involve not only opinions but feelings; and their discussion frequently rouses passions. For feelings are 'subjective,' as the German metaphysician has it—they are inseparable from the individual being—an attack upon them is felt as one upon the person itself; whilst facts are 'objective' and belong to everybody—they remain the same facts at all times and under all circumstances: they can be proved; they have to be proved, and, when proved, are finally settled. It is with facts only that the Association deals. There may for a time exist differences of opinion on these also, but the process of removing them and resolving them into agreement is a different one from that in the moral and political sciences. These are generally approached by the deductive process; but if the reasoning be ever so acute and logically correct, and **the point of departure, which may be arbitrarily selected,** is disputed, no agreement is possible; whilst we proceed here by the inductive process, taking nothing on trust, nothing for granted, but reasoning upwards from the meanest fact established, and making every step sure before going one beyond it, like the engineer in his approaches to a fortress. **We thus gain ultimately a roadway, a ladder by which even a child may, almost without knowing it, ascend to the summit of truth and obtain that immensely wide and extensive view which is spread below the feet of the astonished beholder.** This road has been shown us by the great [Francis] Bacon; and who can contemplate the prospects which it opens, without almost falling into a trance similar to that in which he allowed his imagination to wander over future ages of discovery!"

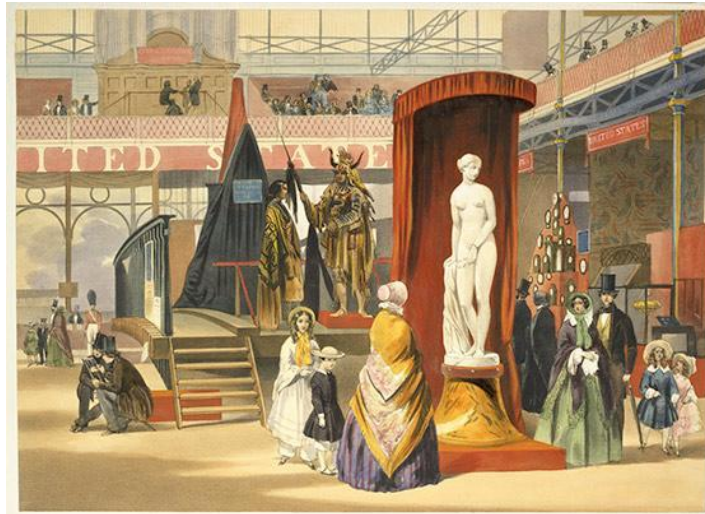
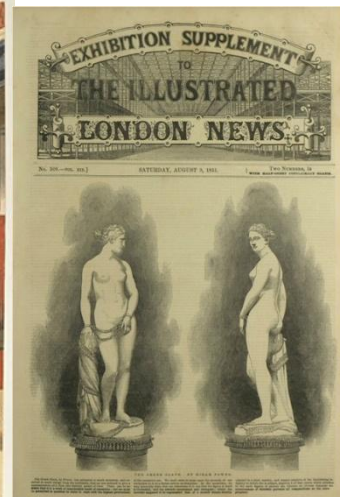
Maya Angelou saw more than leaves when looking at trees. When asked by *Life Magazine* (December 1988) about the meaning of life, she answered, "*And I am obliged to report that the answer changes from week to week. When I know the answer, I know it absolutely; as soon as I know that I know it, I know that I know nothing.*

About 70 percent of the time my conclusion is that there is a grand design. I believe that the force that created life is betting that human beings will do something quite wonderful—like live up to their potential. I am influenced largely by Blaise Pascal and his wager. Pascal advises us to bet on the toss of a coin that



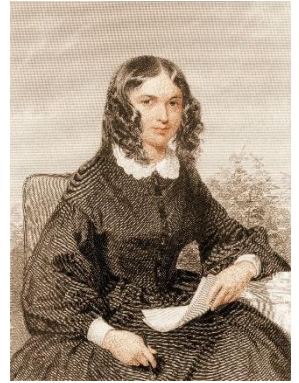
God is. If we win, we win eternity. If we lose, we lose nothing. I'm looking out a large window now and I see about 40 dogwood and maple and oak and locust trees and the light is on some of the leaves and it's so beautiful. Sometimes I'm overcome with gratitude at such sights and feel that each of us has a responsibility for being alive: one responsibility to creation, of which we are a part, another to the creator—a debt we repay by trying to extend our areas of comprehension.”

Back to the Crystal Palace. [The United States of America](#) contributed a statue to the Great Exhibition of 1851 entitled, “[The Greek Slave](#),” which celebrated the fact that Greece recently won its independence from the Ottoman Empire.



The marble sculpture, carved by [Hiram Powers](#), is an example of American neoclassical sculpture. It was the first American nude sculpture. It inspired many poems. Powers was motivated to make this sculpture when he “remembered reading of an account of the atrocities committed by the Turks on the Greeks during the Greek revolution- ... During the struggle the Turks took many prisoners, male and female, and among the latter were beautiful girls, who were sold in the slave markets of Turkey and Egypt. These were Christian women, and it is not difficult to imagine the distress and even despair of the sufferers while exposed to be sold to the highest bidder.”

Elizabeth Barret Browning wrote poems to help abolish slavery. She saw the sculpture in Florence, Italy, and then wrote the sonnet “*Hiram Powers' Greek Slave*,” which appeared in Charles Dickens’ *Household Words* in 1850.



*They say Ideal beauty cannot enter
The house of anguish. On the threshold stands
An alien Image with enshackled hands,
Called the Greek Slave! as if the artist meant her
(That passionless perfection which he lent her,
Shadowed not darkened where the sill expands)
To so confront man's crimes in different lands
With man's ideal sense. Pierce to the centre,
Art's fiery finger! and break up ere long
The serfdom of this world. Appeal, fair stone,
From God's pure heights of beauty against man's wrong!
Catch up in thy divine face, not alone
East griefs but west, and strike and shame the strong,
By thunders of white silence, overthrown.*

Abolitionist demonstrations occurred at the statue. Recognizing the irony that the United States, who fought a war with England over freedom, still had slavery, *Punch* published a picture called, *The Virginian Slave*, by John Tenniel, which was intended as a companion to Powers’ “*Greek Slave*.” Together, the two pieces of art represent the inability of the United States to recognize its own tyranny while crying out against slavery elsewhere in the world.



THE VIRGINIAN SLAVE.
INTENDED AS A COMPANION TO POWER'S "GREEK SLAVE."

You can read more about *The Greek Slave* in *The History of White People* by Nell Irvin Painter.

THE
HISTORY OF
WHITE PEOPLE
—
NELL IRVIN
PAINTER

Hypocrisy never wears well. Hannah Arendt (1963) wrote in *On Revolution*, “As witnesses not of our intentions but of our conduct, we can be true or false, and the hypocrite's crime is that he bears false witness against himself. **What makes it so plausible to assume that hypocrisy is the vice of vices is that integrity can indeed exist under the cover of all other vices except this one.** Only crime and the criminal, it is true, confront us with the perplexity of radical evil; but only the hypocrite is really rotten to the core.”



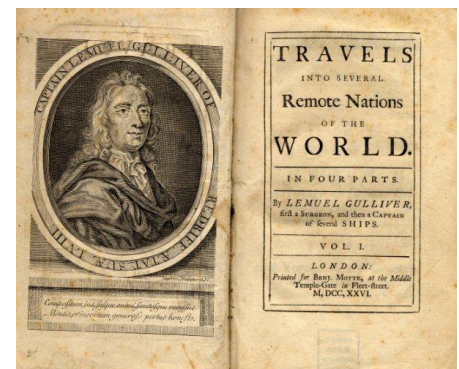
Related to not **bearing false witness** against one's self, in a reply to the [Missouri Committee of Seventy](#) (September 30, 1864), [Abraham Lincoln](#) said, “It is my ambition and desire to so administer the affairs of the government while I remain President that if at the end I have lost every other friend on earth I shall at least have one friend remaining and that one shall be down inside me.”



The word hypocrite comes from the Greek word *hypokrites*, which means an actor. *Hypokrites* is a compound noun, made from Greek words that mean an interpreter from underneath, because the actors in ancient Greek theater wore masks, and so they interpreted the story from underneath their masks.



Can sunlight be extracted from plants? In *Gulliver's Travels*, **Jonathan Swift** (1736) satirized his impression that scientists were high class beggars who used science to serve themselves rather than to improve the human condition. When Lemuel Gulliver visited the island of Laputa, he found a man who was working on the extraction of sunbeams from cucumbers:



*“The first man I saw was of a meagre aspect, with sooty hands and face, his hair and beard long, ragged, and singed in several places. His clothes, shirt, and skin, were all of the same colour. He has been eight years upon a project for **extracting sunbeams out of cucumbers**, which were to be put in phials hermetically sealed, and let out to warm the air in raw inclement summers. He told me, he did not doubt, that, in eight years more, he should be able to supply the governor’s gardens with sunshine, at a reasonable rate: but he complained that his stock was low, and entreated me ‘to give him something as an encouragement to ingenuity, especially since this had been a very dear season for cucumbers.’ I made him a small present, for my lord had furnished me with money on purpose, because he knew their practice of begging from all who go to see them.”* <http://www.shmoop.com/gullivers-travels/part-3-chapter-5-full-text.html>

<https://www.theguardian.com/science/the-h-word/2013/mar/14/science-history-satire-politics-swift-gulliver>

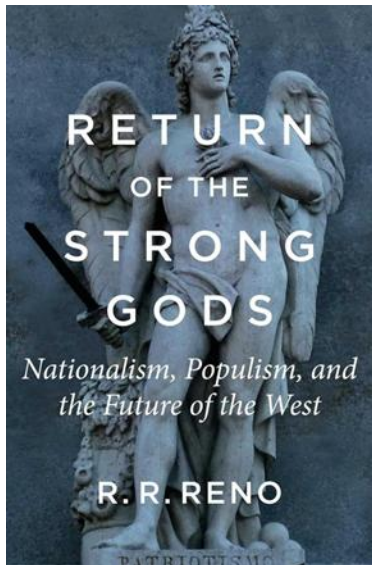


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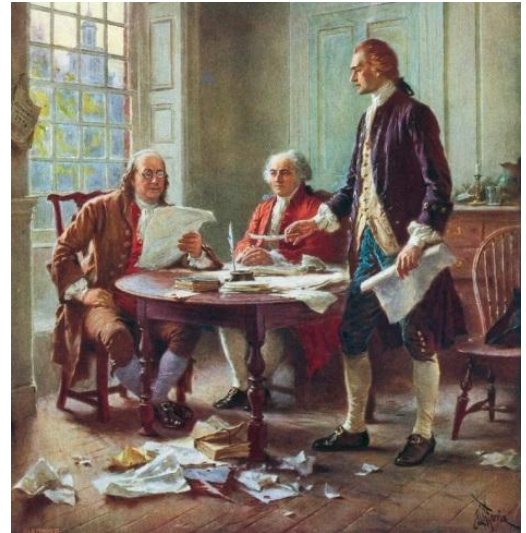
The iron and glass construction of Joseph Paxton was converted into steel (iron and carbon) and glass construction. In this way, Paxton influenced modern architecture

as seen in the Seagram Building (1958) on Park Avenue in New York City, which was designed by Mies van der Rohe. According to R. R. Reno (2021), the purpose of modernist architecture was to “*provide the West with a clean visual slate, vast expanses of faceless glass on which to write a new history of mankind.*” The modernist Seagram Building differed from previous skyscrapers like the Neo-Gothic Woolworth Building (1913) designed by Cass Gilbert and the Art Deco Chrysler building (1930) designed by William van Alen.

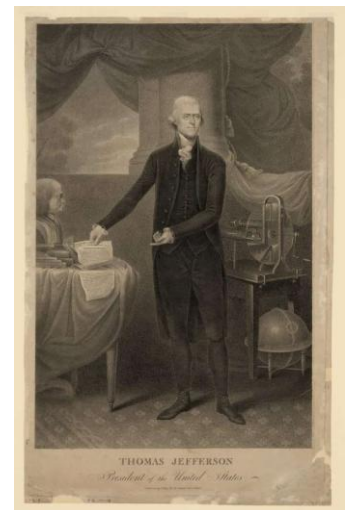


Photosynthesis: Converting Radiant Energy into Chemical Energy The Light-Independent Reactions

The **Laws of Nature describe, predict, and explain** how and why events occur in nature. The Laws of Nature serve as **summaries of a large number of observations and experimental results** that have taken place since the time humans began questioning. Once enounced and accepted, **the Laws of Nature seem right, true, self-evident**, and the **basis of building higher-level systems of reason**, whether scientific or political, based on the **always testable assumption that the law is true**. The Laws of Nature can be called **Principles**. Thomas Jefferson, John Adams, and Benjamin Franklin used the **Laws of Nature** to justify the separation of the American colonies from England in the **Declaration of Independence**:

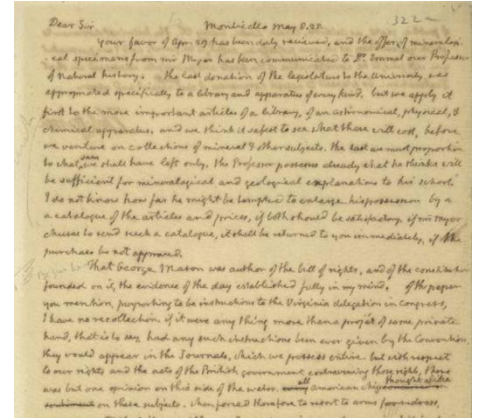


*“When in the Course of human events, it becomes necessary for one people to dissolve the political bands which have connected them with another, and to assume among the powers of the earth, **the separate and equal station to which the Laws of Nature and of Nature's God entitle them**, a decent respect to the opinions of mankind requires that they should declare the causes which impel them to the separation. **We hold these truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable Rights, that among these are Life, Liberty and the pursuit of Happiness....**”*

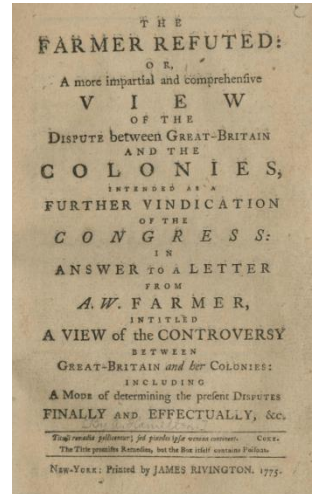


The laws of nature were seen as self-evidence truths that were an expression of not-so-common **common sense**, something that was not realized until it was expressed on July 4th, 1776, in terms **plain and fair**. Thomas Jefferson wrote in a letter to Henry Lee on [May 8, 1825](#), “*When forced, therefore, to resort to arms for redress, an appeal to the tribunal of the world was deemed proper for our justification. This was the object of the Declaration of Independence. Not to find out new principles, or new arguments, never before thought of, not merely to say things which had never been said before; but to place before mankind the common sense of the subject, in terms so plain and firm as to command their assent, and to justify ourselves in the independent stand we are compelled to take. Neither aiming at originality of principle or sentiment, nor yet copied from any particular and previous writing, it was intended to be an expression of the American mind, and to give to that expression the proper tone and spirit called for by the occasion. All its authority rests then on the harmonizing sentiments of the day, whether expressed in conversation, in letters, printed essays, or in the elementary books of public right, as Aristotle, Cicero, Locke, Sidney, etc. The historical documents which you mention as in your possession, ought all to be found, and I am persuaded you will find, to be corroborative of the facts and principles advanced in that Declaration.*”

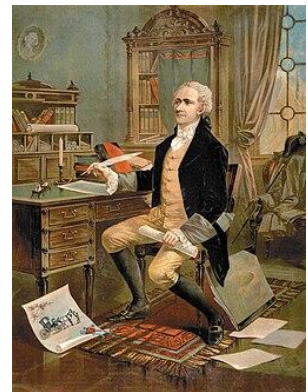
Aside: Jefferson [originally](#) wrote, “[We hold these truths to be sacred and undeniable...](#)” and Benjamin Franklin changed to: “*We hold these truths to be self-evident.*”



Alexander Hamilton (1775) wrote in [*The Farmer Refuted*](#), that there are laws of nature because there is a lawgiver (as opposed to laws made by government). Hamilton wrote, “Moral obligation, according to him [Hobbes], is derived from the introduction of civil society; and there is no virtue, but what is purely artificial, the mere contrivance of politicians, for the maintenance of social intercourse. But the reason he run into this absurd and impious doctrine, was, **that he disbelieved the existence of an intelligent superintending principle, who is the governor, and will be the final judge of the universe.**



As you, sometimes, swear by him that made you, I conclude, your sentiment does not correspond with his, in that which is the basis of the doctrine, you both agree in; and this makes it impossible to imagine whence this congruity between you arises. To grant, that there is a supreme intelligence, who rules the world, and has established laws to regulate the actions of his creatures; and, still, to assert, that man, in a state of nature, may be considered as perfectly free from all restraints of law and government, appear to a common understanding, altogether irreconcilable.



Good and wise men, in all ages, have embraced a very dissimilar theory. They have supposed, that the deity, from the relations, we stand in, to himself and to each other, has constituted an eternal and immutable law, which is, indispensibly, obligatory upon all mankind, prior to any human institution whatever.

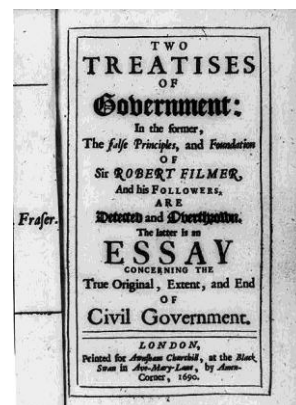
This is what is called the law of nature, “which, being coeval with mankind, and dictated by God himself, is, of course, superior in obligation to any other. It is binding over all the globe, in all countries, and at all times. No human laws are of

any validity, if contrary to this; and such of them as are valid, derive all their authority, mediately, or immediately, from this original.” Blackstone.

Upon this law, depend the natural rights of mankind, the supreme being gave existence to man, together with the means of preserving and beatifying that existence. He endowed him with rational faculties, by the help of which, to discern and pursue such things, as were consistent with his duty and interest, and invested him with an inviolable right to personal liberty, and personal safety.”

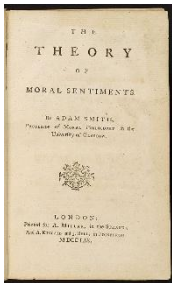
This idea of the divine origin of the laws of nature had been circulating in England. **Edward Coke** wrote in [*Calvins Case*](#) (1608), “[t]he **law of nature** is that which God at the time of the creation of the nature of man infused into his heart, for his preservation and direction; and this is *lex aeterna* (**eternal law**), the **moral law**, called. also the **law of nature**. And by this **law**, written with the finger of God in the heart of Man, were the people of God a long time governed, before the **law** was written by Moses, who was the first reporter of writer of **law** in the world.”

John Locke (1690) in his [*Second Treatise of Civil Government*](#), wrote “The obligations of the law of Nature cease not in society, but only in many cases are drawn closer, and have, by human laws, known penalties annexed to them to enforce their observation. **Thus the law of Nature stands as an eternal rule to all men, legislators as well as others.** The rules that they [men] make for other men’s actions, as well as their own, must be conformable to **the law of Nature—i.e. to the will of God, of which that [law] is a declaration.** The fundamental law of Nature being the preservation of mankind, no human sanction can be good or valid against it.”

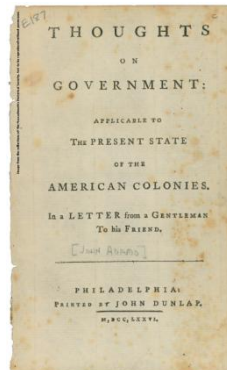


Aside on happiness: Scottish Enlightenment thinkers of the 18th century such as Francis Hutcheson, David Hume, and Adam Smith did not consider **happiness** as we do today as **fleeting sensual pleasure**, but they considered it as **deeply moral and social virtue**, which included benevolence, sympathy, tranquility of mind, and harmonious relations with others and society. Happiness was then a result of living virtuously and contributing to the well-being of others.

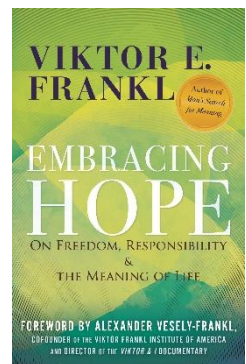
Adam Smith (1759) wrote in [*The Theory of Moral Sentiments*](#), “*The ancient stoics were of opinion, that as the world was governed by the all-ruling providence of a wise, powerful, and good God, every single event ought to be regarded as making a necessary part of the plan of the universe, and as tending to promote the **general order and happiness of the whole....**”*



John Adams (1776) wrote in [*Thoughts on Government*](#), “All sober *enquiries after truth*, ancient and modern, Pagan and Christian, have declared that the *happiness of man*, as well as *his dignity consists in virtue*. Confucius, Zoroaster, Socrates, Mahomet, not to mention authorities really sacred, have agreed in this.”

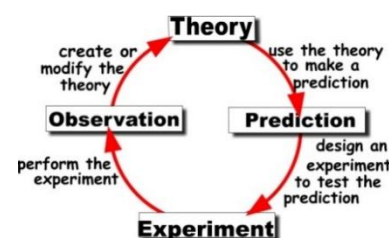


Viktor Frankl (1977) said in an interview with Roy Bobisteel, *“Anyway, you have rightly put your finger on the fact that what an individual, a human being, needs is what I like to call ‘self-transcendence.’ That is to say, being concerned with oneself or one’s own prestige, or one’s own happiness, is self-defeating. Forgive my contradicting the American Declaration of Independence [not realizing the change in meaning of the word happiness], in which you find the phrase ‘pursuit of happiness,’ I deem that ‘pursuit of happiness’ is a contradiction in terms, because happiness can never*



*really be pursued. Happiness must ensue; happiness is a side effect, happiness is a by-product and must remain a by-product of **meaning fulfillment**, of your dedication to a task, a cause greater than yourself. Or a person other than yourself.”*

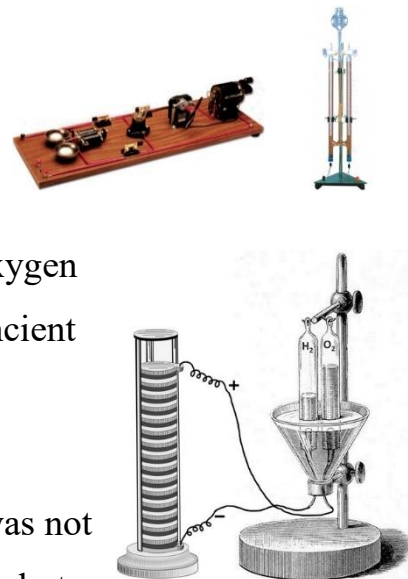
The Laws of Nature are principles, but they may not *always* apply to *every* situation. In a healthy society, the application of the Laws of Nature is questioned. For example, does every conceived individual have a right to life or is life defined by birth? Does every criminal have an unalienable right to his/her liberty? When does the liberty of society trump an individual liberty? Thomas Jefferson wrote to James Madison on January 30, 1787, *“I hold it that a little rebellion now and then is a good thing, and as necessary in the political world as storms in the physical... It is a medicine necessary for the sound health of government.”* The application of the Laws of Nature is also questioned when science is healthy. Is the Special Theory of Relativity or the Doppler effect more fundamental for describing relative motion? Is the Uncertainty Principle or the First Law of Thermodynamics more fundamental when describing material processes? Is the Cosmological Principle or the Doppler Effect more fundamental when describing our place in the universe? Everyone has a right to examine the evidence and question the self-evident nature of any Law of Nature. **Science** ends and **Scientism** begins when the loop is broken, and questioning is forbidden.



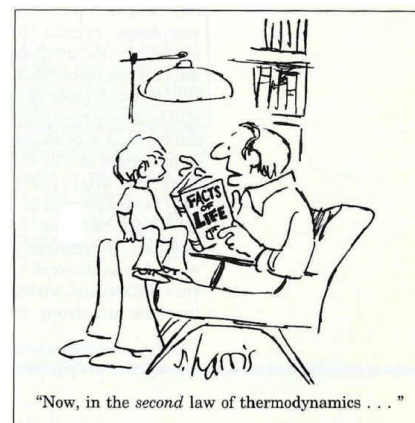
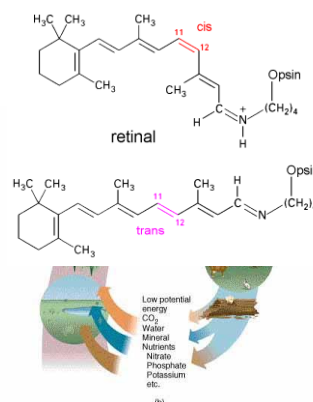
Biological processes and indeed **life itself** can be and has been described, predicted, and explained to a great degree by the **Laws of Nature**. The **First Law of Thermodynamics** is a **Law of Nature** that states that **energy** can be **interconverted** between different forms (e.g., gravitational, electrical, magnetic, chemical, radiant, and thermal) but not created or destroyed. For example, **radiant**

energy is converted into **chemical energy** and **thermal energy** during vision by absorption of a photon by the 11-*cis* retinal of the rhodopsin and photopsins in our eyes.

Demonstration: Connect the water electrolysis unit to the transformation of energy apparatus. Turn the crank and see how much energy it takes to split H_2O into $\frac{1}{2}\text{O}_2$ and H_2 . Imagine how much energy it took to create an atmosphere composed of 21% oxygen on earth. Note that water had been considered an element since ancient times, but when William Nicholson and Anthony Carlisle (1800) separated liquid water into hydrogen gas and oxygen gas, they demonstrated for the first time that water (earth, water, air, fire) was not an element (as was generally thought since the time of Aristotle.), but could be subdivided into more elementary parts.



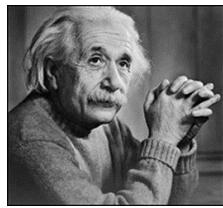
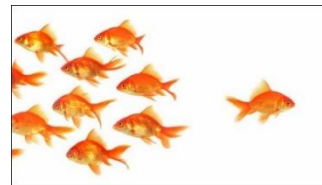
The **Second Law of Thermodynamics** is a **Law of Nature** that gives **directionality** in **time** to transformations by stating that while energy *cannot* be **destroyed** in an energy transformation, it *can* be **degraded into heat**, which at constant temperature is equivalent to **entropy**. Heat, which is also known as thermal energy is equal to the product of temperature (T) and entropy (S) where $heat = T S$. Moreover, transformations occur **passively** and **spontaneously** only in the **direction** that **gives rise to increased entropy**. For example, the absorption of light by the rhodopsin and photopsins not only results in the production of chemical energy in the transformation of 11- *cis* retinal to all-*trans* retinal but also results in the production of entropy or heat which is radiated away at the **speed of light** as **infrared**



wavelengths. There is **directionality** to the transformation since the reconversion of all-*trans* retinal to 11-*cis* retinal cannot result in the emission of light. Another example of **directionality** stipulated by the **Second Law of Thermodynamics** that has to do with vision is the transformation of the chemical energy of ATP that results in **contraction** of the muscles that move the eyeball. Heat or entropy is produced at the same time. Again, there is **directionality** because the **relaxation** of the muscle does not result in the production of ATP in part because the increase in entropy or the energy converted to heat is **dispersed** at the **speed of light**. I believe that the Laws of Thermodynamics are the two most fundamental **Laws of Nature**. You are free to believe otherwise.

Albert Einstein (1949) wrote in his autobiographical sketch, “*A theory is the more impressive the greater the simplicity of its premises, the more different kinds of things it relates, and the more extended its area of applicability. Therefore the deep impression that **classical thermodynamics** made upon me. It is the only physical theory of universal content which I am convinced will never be overthrown, within the framework of applicability of its basic concepts.*” **Arthur Eddington** (1915) wrote in *The Nature of the Physical World*, “*The law that entropy always increases holds, I think, the supreme position among the laws of Nature. ...if your theory is found to be against the second law of thermodynamics I can give you no hope; there is nothing for it but to collapse in deepest humiliation.*”

Although Albert Einstein, Max Planck, and Erwin Schrödinger did not agree with the majority of the physicists, it is conventional wisdom among physicists that **Heisenberg’s uncertainty principle** is **more** fundamental than the First Law of Thermodynamics. Heisenberg’s uncertainty principle states that energy (ΔE) can come from nothing but only for a



limited period of time (Δt) according to the following equation

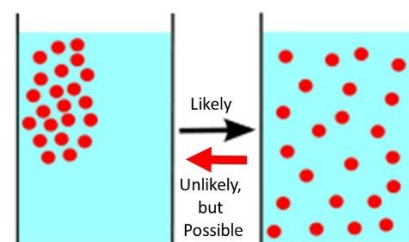
(<http://www.aip.org/history/heisenberg/p08.htm>):

$$\Delta E \Delta t \geq \frac{\hbar}{2} = \frac{h}{4\pi}$$

How long would a photon with a wavelength of 500 nm exist if it popped out of the vacuum according to Heisenberg's uncertainty principle? If it takes approximately 10^{-15} seconds for rhodopsin to absorb the photon, would you be able to see it?

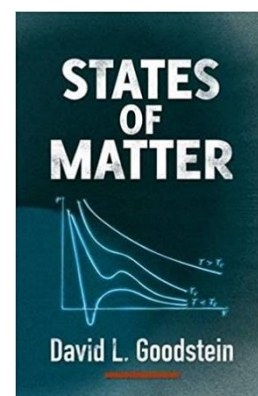


It is also conventional wisdom among physicists that **statistical mechanics**, based on the **reversibility of time**, is fundamental but the Second Law of Thermodynamics is **not** fundamental because it is based on the assumption that **time is irreversible**. Conventional wisdom states that **time itself is reversible**.

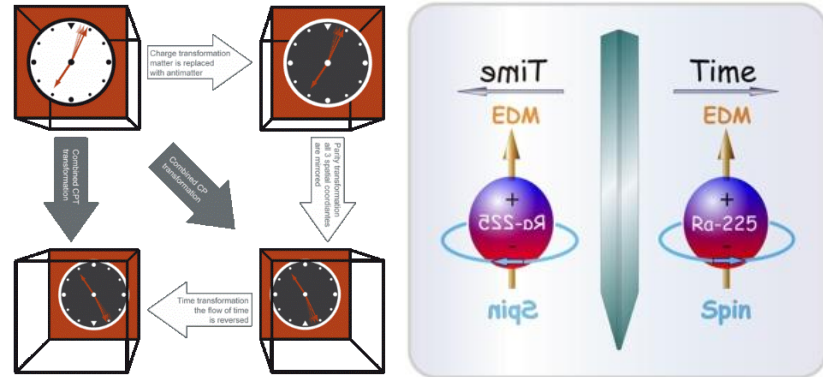


According to conventional wisdom, **chance and statistics** give us the **illusion** that time is irreversible.

Perhaps I should mention that David Goodstein (1985) noted in his book *States of Matter* that “Ludwig Boltzmann, who spent much of his life studying statistical mechanics, died in 1906, by his own hand. Paul Ehrenfest, carrying on the work, died similarly in 1933. Now it is our turn to study statistical mechanics.” Goodstein then suggests that “[p]erhaps it will be wise to approach the subject cautiously.”



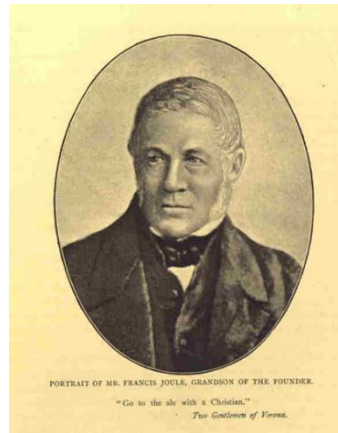
Quantum electrodynamics
(QED) considers antimatter to be
matter going backwards in time.



If you are unable to picture these descriptions of physical objects existing in the world, you are not alone. In *Natural Law and the Structure of Matter*, Werner Heisenberg (1981) described the physicists' view of the world: "*I think that modern physics has definitely decided in favor of Plato. In fact the smallest units of matter are not physical objects in the ordinary sense; they are forms, ideas which can be expressed unambiguously only in mathematical language.*"



The **First Law of Thermodynamics**, which is also known as a statement of the **conservation of energy**, was discovered, in part, and first stated quantitatively in an English brewery. Since the 12th century, Augustinian monks **brewed beer** at the priory in Market Drayton, England. The monks blessed the brew in each barrel and put a cross on the barrels that contained the superior batches. This went on until **Henry VIII** ordered the **Dissolution of the Monasteries** in the 16th century. In the 18th century, two brothers William and Francis Joule became brewers, each opening their own brewery. John Joule, Francis's son and William's nephew, took over Francis's brewery in 1813 and adopted the [red cross](#) that the monk's used to signify a superior brew as a trademark. Joule's Brewery still exists today.



JOHN JOULE & SONS
BREWERS,
STONE.

PRICE LIST OF THE CELEBRATED STONE ALES.

Marks.	Hids.	Bris.	Kids.	12 Gal.	Fks.
2 Stone Ale	90/-	60/-	30/-	20/-	15/-
1B East India Ale	90/-	50/-	30/-	20/-	15/-
2B " "	81/-	54/-	27/-	18/-	13/6
AI Export	108/-	72/-	36/-	24/-	18/-
1 Mild Ale	90/-	66/-	33/-	22/-	16/6
3 " "	81/-	51/-	27/-	18/-	13/6
4 " "	72/-	48/-	24/-	16/-	12/-
5 " "	63/-	42/-	21/-	14/-	10/6
X " "	54/-	36/-	18/-	12/-	9/-
Ex Extra Stout	72/-	48/-	24/-	16/-	12/-
P Stout	63/-	42/-	21/-	14/-	10/6

THE FOLLOWING QUALITIES ARE BREWED SPECIALLY FOR PRIVATE USE, AND WE CAN CONFIDENTLY RECOMMEND THEM.

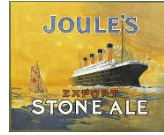
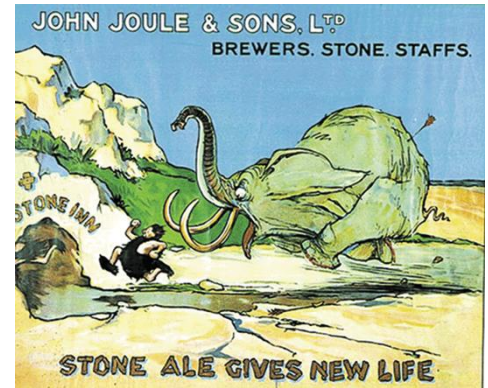
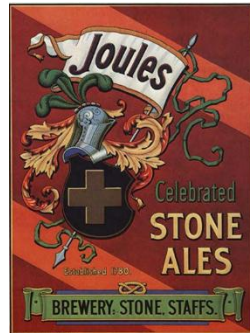
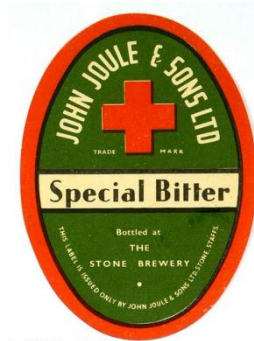
Marks	Bris.	Kids.	12 Gals.	Fks.
3S Mild Ale	54/-	27/-	18/-	13/6
4S " "	48/-	24/-	16/-	12/-
6S " "	42/-	21/-	14/-	10/6
XS " "	36/-	18/-	12/-	9/-

W. H. & J. JOULE, Stone,
Wine and Spirit Merchants,
IMPORTERS OF FOREIGN CIGARS
AND CIGARETTES.

Bottlers of Joulé's Stone Ales and Stout.
GEO. ROE'S IRISH WHISKEY.

Speciality—THE STONE BLEND OF SCOTCH WHISKY.
French Brandies, Old Rum, London Gin, Liqueurs, Cordials,
Copenhagen Cherry Brandy, Vintage Port.

Shippers of the Best Brands of Champagnes.



Around 1788, William Joule set up his brewery on New Bridge Street in Salford, England. **William** and his wife **Martha** had six children and all, but one died leaving **Benjamin** to run William Joule & Son brewery. In 1817, the brewery, which brewed ale and porter, became known as the Benjamin Joule brewery and on Christmas Eve, 1818 [James Prescott Joule](#) was *born in the brewery* to Benjamin and Alice Joule. James Joule, while a brewer too, became better known as one of the discoverers of the **First Law of Thermodynamics**.

**Ale and Porter Stores,
No. 74, MILL STREET, MACCLESFIELD.**

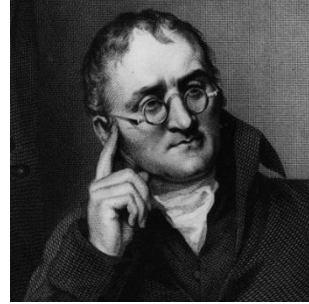
WILLIAM HANKES begs to inform his Friends and the Inhabitants of Macclesfield, and its Vicinity, that he is appointed AGENT to Mr. BENJAMIN JOULE, ALE and PORTER BREWER, Salford, Manchester.

W. H. takes this opportunity of returning his sincere thanks to his friends for all past favours, and begs to inform them, that, for the accommodation of private Families, he has continually on hand a Stock of Ale and Porter, in casks of 9 gallons each, at the following prices:—

X Ale 1s per gallon. Porter 1s 2d per gallon.
XX Ale 1s 6d per gal. Brown stout 1s 6d per gal.
XXX Ale 2s per gallon. Double brown stout 2s per gallon.

74, Mill Street, Macclesfield, Oct. 10, 1839.

While James Joule was a teenager, he was fortunate to have **John Dalton**, who was **colorblind** and the founder of the **atomic theory**, as was one of his teachers. James Joule wrote, “*Dalton possessed a rare power of engaging the affections of his pupils for **scientific truth**; and it was from his instruction that I first formed a desire to increase my knowledge by original researches.*”

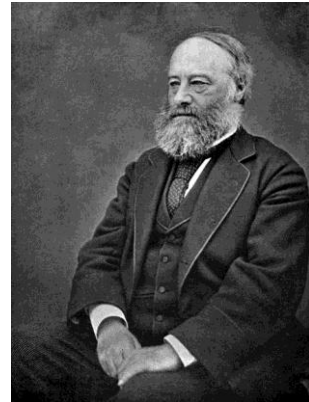


George Harrison wrote the last verse to the song *Hurdy Gurdy Man* by **Donovan**:

*When the truth gets buried deep,
beneath a thousand years of sleep,
time demands a turn around,
and once again the truth is found.*



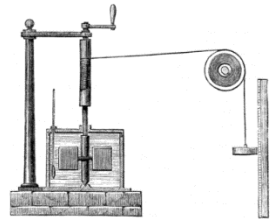
James Joule was a **businessman** who ran the brewery every day from nine in the morning to six at night until the brewery was sold in 1854. He did; however, find time to do research before breakfast and in the evening.



James Joule wanted to quantify the relationship between motion and heat; that is, mechanical energy and thermal energy. He wrote in July 1843, “*I have lately proved experimentally that heat is evolved by the passage of water through narrow tubes. My apparatus consisted of a piston perforated by a number of small holes, working in a cylindrical glass jar containing about 7 lb. of water from a mechanical force capable of raising about 770 lb. to the height of one foot, a result which will be allowed to be very strongly confirmatory of our previous deductions. I shall lose no time in repeating and extending these experiments,*

*being satisfied that **the grand agents of nature are, by the Creator's fiat, indestructible; and that wherever mechanical force is expended, an exact equivalent of heat is always obtained.***

In order to obtain more **quantitative** results, Joule used a paddle wheel driven by **gravitational energy** to **heat** the water in a cylinder, and then he correlated the increase in the temperature of water with the energy used to turn the paddle wheel. Joule concluded, “1st. *That the quantity of heat produced by the friction of bodies, whether solid or liquid, is always proportional to the quantity of force expended. And, 2nd. That the quantity of heat capable of increasing the temperature of a pound of water (weighed in vacuo, and taken between 55° and 60°) by 1° Fahr., requires for its evolution the expenditure of a mechanical force represented by the fall of 772 lb. through the space of one foot.*”



Hermann von Helmholtz (1856) used James Joule's result to model the transformation of the sun's gravitational energy into thermal energy.

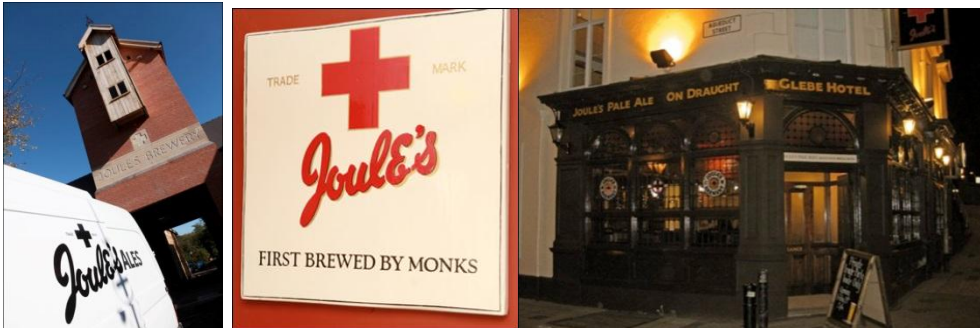


James Joule saw **conservation of energy** and the **First Law of Thermodynamics** as a way of seeing the **unity in the apparent diversity of causes and effects**. Not only did he *not* eliminate God from science with the law he helped found, but he saw the **First Law of Thermodynamics** as a manifestation of the will of God. James Joule wrote, “*Indeed the phenomena of nature, whether mechanical, chemical or vital, consist almost entirely in a continual conversion of attraction through space, living force [kinetic energy] and heat into one another....And though, as in the awful vision of Ezekiel, 'wheel may*

be in the middle of wheel’, and everything may appear complicated and involved in the apparent confusion and intricacy of an almost endless variety of causes, effects, conversions, and arrangements, yet is the most perfect regularity preserved—the whole being governed by the sovereign will of God.”

James Joule (1873) wrote, “*After the knowledge of, and obedience to, the will of God, the next aim must be to know something of His attributes of wisdom, power, and goodness as evidenced by His handiwork.... It is evident that an acquaintance with natural laws means no less than an acquaintance with the mind of God therein expressed.*” Much of science relates the parts to the whole and it is *not* impossible that having such a wide view of the whole helps to make one a great scientist.

[James Prescott Joule](#) became famous as one of the discoverers of the **First Law of Thermodynamics**. The Joule family name also lives on in the brewing industry!

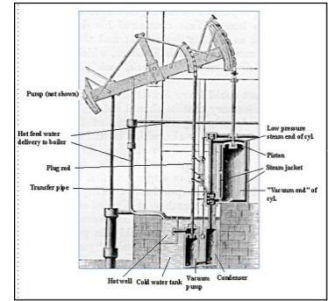
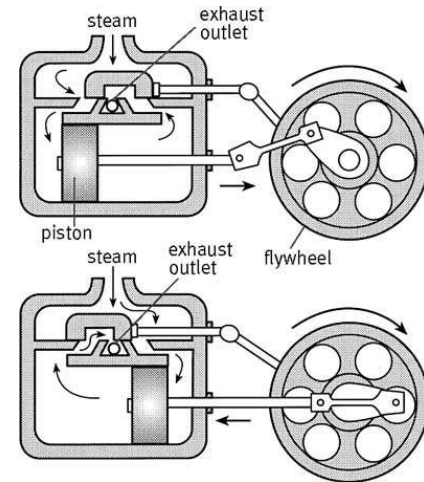
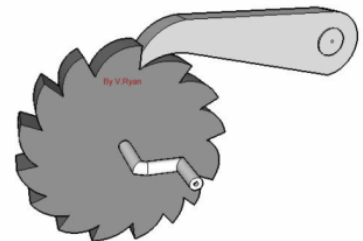


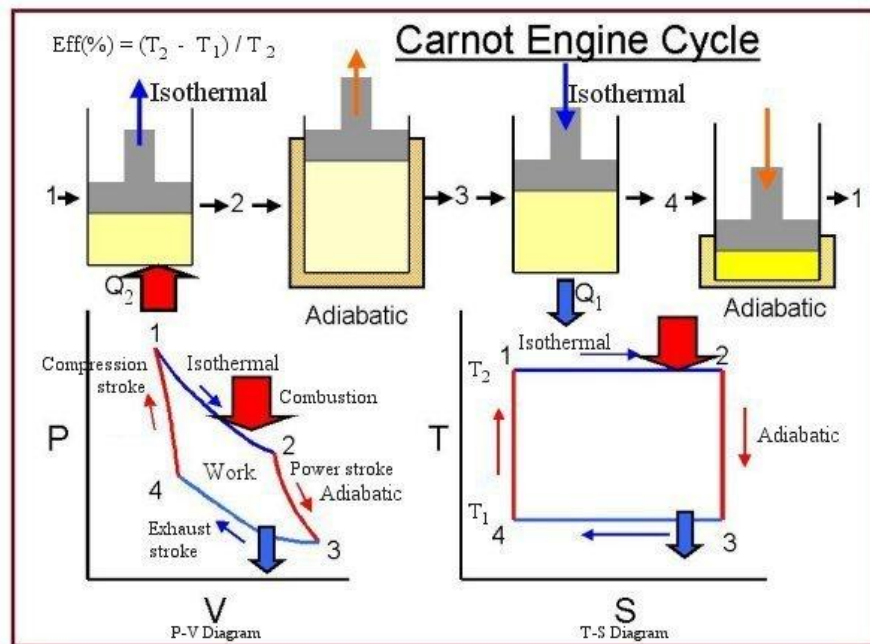
I will discuss Julius **Robert Mayer's** (1842) prior discovery of the First Law of Thermodynamics, when I discuss respiration.

While Joule and Mayer studied the **transformation of gravitational or mechanical energy into thermal energy or heat**, **Sadi Carnot** (1824) studied the **motive power of heat**, which is the reverse process. **James Watt** patented the first **steam engine** in 1781 that could produce rotary motion to power looms, water pumps, ships, tractors, and locomotives. Sadi Carnot wanted to know how efficiently **steam engines** could transform the **energy of heat** into the **mechanical movement** of a piston. He realized that production of motive power in steam engines is due to the transportation of thermal energy from a warm body to a cold body and the greater the difference in temperature, the greater the motive force would be. The hot body causes the gas to **expand**, and the cold body causes the gas to **contract**. Alternating the expansion and contraction moves a piston that is connected to a wheel that can only rotate in one direction. The temperatures of the hot and cold bodies are T_2 and T_1 , respectively. The efficiency of the Carnot engine driven by hot and cold bodies at T_2 and T_1 is:

$$\text{Efficiency} = 100\% \left[\frac{T_2 - T_1}{T_2} \right] = 100\% \left[1 - \frac{T_1}{T_2} \right].$$

What are the conditions necessary to get an engine with 0% efficiency or with 100% efficiency and no energy lost as heat?





Demonstration: See the workings of a variety of model steam engines:

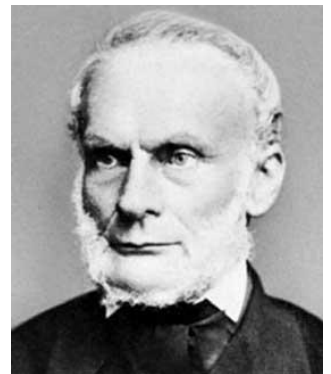
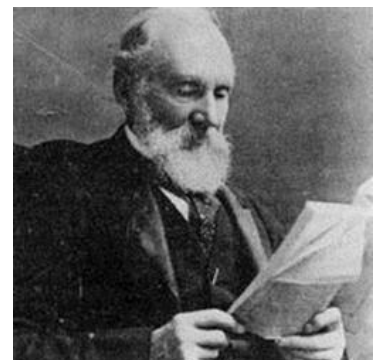


It took courage to experiment with steam engines. The 1855 *Annual of Scientific Discovery* had an article about the scientific courage:

THE COURAGE OF SCIENCE

“Courage in the battle-field is celebrated in history and in song, but little is said of the courage exhibited in pursuing scientific investigations, though often displaying more real elements of bravery than ever were called into action in war. It is said that when Arago and Dulong were employed by the French Government to make experiments upon the subject of the construction and safety of steam boilers, the task executed by the two philosophers was one of as much danger as difficulty. The bursting of boilers, to which they were constantly exposed in a limited locality, was more hazardous than that of shells upon a battle-field; and while military officers who assisted them—men of tried courage in the conflict—grew pale and fled from the scene, the savans proceeded coolly to make their calculations, and observe the temperature and pressure upon boilers almost at the very point of explosion.”

Around 1850, **Rudolf Clausius** and **Lord Kelvin** independently rediscovered Carnot’s results and realized that the engine would only have one hundred percent efficiency if the cold body were at absolute zero. Consequently, they realized while **mechanical energy** could be *completely* converted into **thermal energy**, only a *portion* of the **thermal energy** could be converted into **mechanical energy**. Recognizing that the **complete reversibility** of energy transformations claimed by James Joule’s First Law of Thermodynamics did not occur in nature, **Lord Kelvin** wrote, *“...if also the materialistic hypothesis of life were true, living creatures would grow backwards, with conscious knowledge of the future, but no memory of the past, and would come again unborn. But the real phenomena of life infinitely transcend*

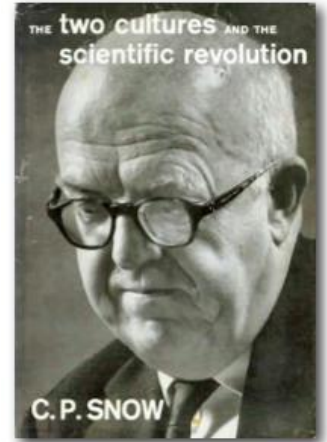


*human science; and speculation regarding consequences of their **imagined reversal** is utterly unprofitable. Far otherwise, however, it is in respect to the reversal of the motions of matter uninfluenced by life [i.e., the Carnot cycle], a very elementary consideration of which leads to the full explanation of the theory of **dissipation of energy**.*” The **Second Law of Thermodynamics** was necessary not only to explain the **ubiquity of irreversibility** but even to explain the reversible Carnot cycle.

Lord Kelvin and **Rudolf Clausius** both articulated the **Second Law of Thermodynamics** that states that in any energy transformation, **useful energy** is **dissipated** or **degraded**, and **thermal energy** is generated in its place. **Thermal energy** is the product of **temperature** (K) and **entropy** (J/K), which comes from the Greek η $\tau\rho\pi\acute{\eta}$ meaning “in transformation.” Therefore, **energy transformations** at constant temperature occur **spontaneously** and **passively** in the direction of **increased entropy** (which can be thought of generally as increased volume of matter or radiation). On the other hand, an **energy transformation** that **decreases entropy** is not spontaneous or passive but is **active** and **requires an input of energy**.

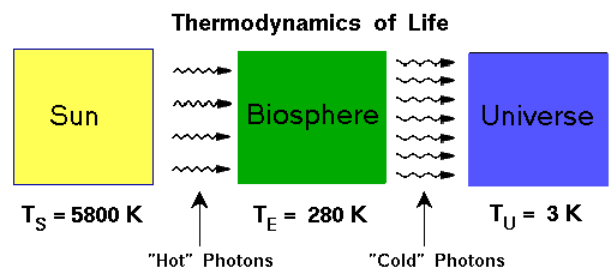
Lord Kelvin, like James Joule, was not trying to eliminate God from science by creating a new **Law of Nature**. In fact, he felt the reverse, as he wrote to J. Helder on May 12, 1906, “*if you think strongly enough you will be forced by science to the belief in God, which is the foundation of all religion.*”

C. P. Snow (1961), both a writer and a physical chemist who studied the **photochemistry** of vitamins, lamented about the failure of education in *The Two Cultures and the Scientific Revolution*, “A good many times I have been present at gatherings of people who, by the standards of the traditional culture, are thought **highly educated** and who have with considerable gusto been expressing their incredulity at the illiteracy of scientists. Once or twice I have been provoked and have asked the company how many of them could describe the Second Law of Thermodynamics. The response was cold: it was also negative. Yet I was asking something which is the scientific equivalent of: Have you read a work of Shakespeare's?”

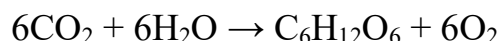


I hope you can consider yourselves to be highly educated people who could describe the Second Law of Thermodynamics. **Clausius** summarized the two laws of thermodynamics like so:

*The energy of the universe is constant.
The entropy of the universe tends to a maximum.*



Entropy is related to the **number** of entities. In terms of **photosynthesis**, in which sugar is synthesized, six molecules of carbon dioxide and six molecules of water have more entropy than one molecule of glucose and six molecules of oxygen. Therefore, in the following **photosynthetic reaction** where 12 molecules are reduced to 7, entropy decreases, and the reaction will **not** be **passive** or **spontaneous**:



The photosynthetic reaction will only occur if energy is added in the form of **radiant energy** ($48h\nu$):

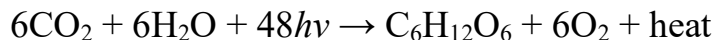
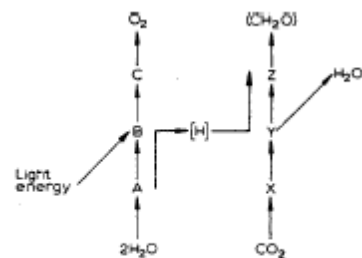
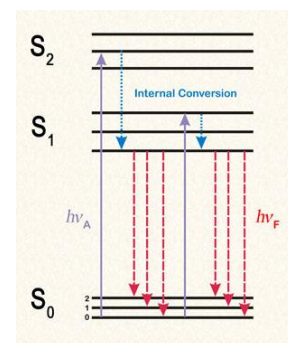


Fig.1. Elementary photosynthesis scheme.

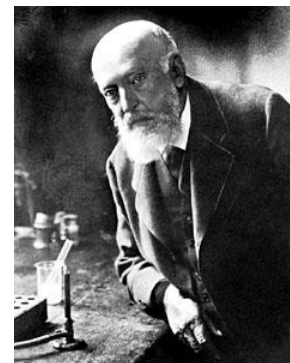
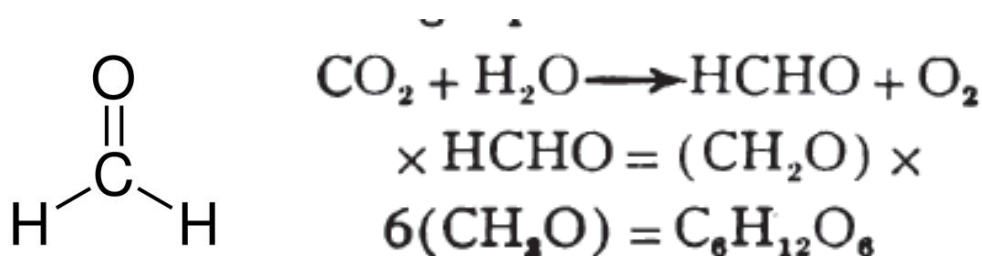
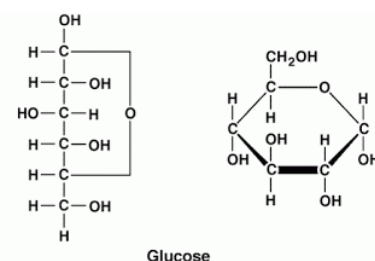
As I discussed last time, the **radiant energy** needed for this transformation is **absorbed** by **chlorophyll** in the **thylakoid membranes** which, in the **chloroplast**, results in **charge separation** of electrons (e^-) that reduce $\text{NADP}^+ + \text{H}^+$ to **NADPH** and the charge separation of protons (H^+) that result in the synthesis of **ATP** from ADP and Pi. The NADPH and ATP are used in the light-independent reactions to synthesize carbohydrates (sugars and starch). Some of the absorbed useful visible light energy is converted to **infrared heat energy** through **internal conversions**.



Burning one molecule of glucose releases 4.8×10^{-18} J of energy. The 48 photons of 680 nm light needed to synthesize one molecule of glucose have $48 \times 2.9 \times 10^{-19} \text{ J} = 1.4 \times 10^{-17} \text{ J}$ of energy. What proportion of radiant energy is given off as heat? About 0.66 or 66%. Photosynthesis is about 34 percent efficient in terms of the radiation absorbed.

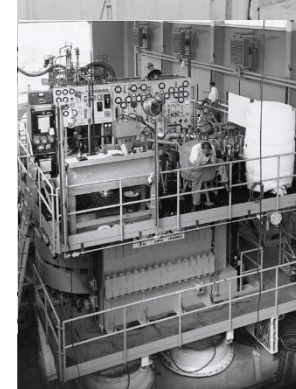
$$\text{Efficiency} = 100\% \left(\frac{48 \frac{hc}{\lambda} - E_{\text{glucose}}}{48 \frac{hc}{\lambda}} \right)$$

What is the mechanism that causes the formation of carbohydrate from CO₂? **Adolph von Baeyer** (1870) proposed that the carbohydrate formed by plants resulted from the direct light-mediated formation of formaldehyde (CH₂O), the simplest carbohydrate, followed by the condensation of six formaldehydes to make sugar.



We now know however that carbohydrate formation is the result of a light-independent **cyclic process** that takes place in the **stroma** of the **chloroplast**. The light-independent synthesis of carbohydrate involves the addition of a carbon dioxide to a five-carbon receptor molecule.

Using **radioactive** ¹¹CO₂, which they made by bombarding boron (₅B¹⁰) with deuterons (₁D²) to yield ₆C¹¹ and a neutron (₀n¹), **Samuel Ruben** and **Martin Kamen** (1939,1940) tried to **trace the pathway of carbon** in photosynthesizing barley plants and *Chlorella*, a single-celled alga that was more suited for quantitative experiments. They precipitated or centrifuged out the possible products of the photosynthetic reaction to see which molecules in the cells became radioactive first. Unfortunately, ¹¹C has a half-life of only 20 minutes, so much of the activity was gone by the time they could isolate the radioactive chemicals involved in carbon fixation. Harold Urey suggested that they make a biological tracer with a long half-life. In



1940, Samuel Ruben and Martin Kamen developed a method for producing large quantities of ^{14}C by bombarding ammonium nitrate with neutrons using the **cyclotron** in Ernest Lawrence's laboratory in order to trace the pathway of carbon and find the first products of photosynthesis. The ^{14}C they produced had a half-life of 5,730 years.

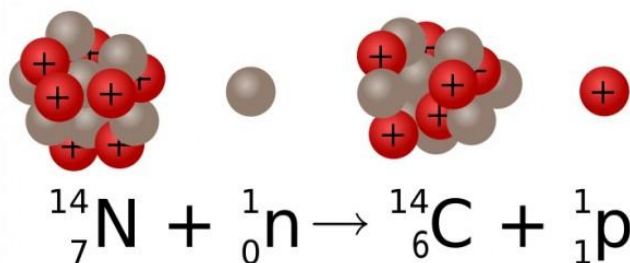


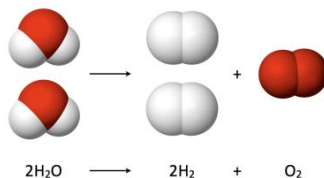
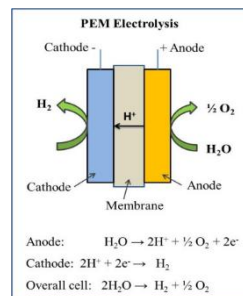
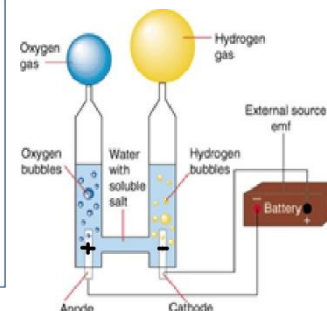
TABLE I
ISOTOPIC RATIO IN OXYGEN EVOLVED IN PHOTOSYNTHESIS
BY *Chlorella*^a

Expt.	Substrate	Time between dissolving KHCO_3 + K_2CO_3 and start of O_2 collection, minutes	Time at end of O_2 collection, minutes	Percent. O^{18} in		
				H_2O	$\text{HCO}_3^- + \text{CO}_3^{2-}$	O_2
1	0.09 M	0		0.85	0.20	..
	KHCO_3	45	110	.85	.41 ^b	0.84
	+0.09 M	110	225	.85	.55 ^b	.85
	K_2CO_3	225	350	.85	.61	.86
2	0.14 M	0		.20		..
	KHCO_3	40	110	.20	.50	.20
	+0.08 M	110	185	.20	.40	.20
	K_2CO_3					

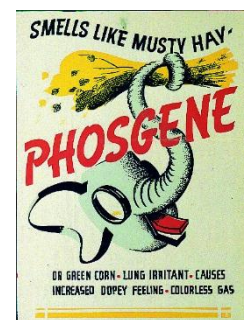
While waiting for the chance to use ^{14}C to study carbon fixation in photosynthesis, Samuel Ruben, Merle Randall, Martin Kamen, and James Hyde used a **stable isotope of oxygen** (^{18}O) and a mass spectrometer to test whether oxygen evolved from H_2^{18}O *or* C^{18}O_2 in **photosynthesizing *Chlorella*** cells. They found that the isotopic ratio ($^{18}\text{O}/^{16}\text{O}$) of the oxygen evolved was the same as the isotopic ratio of the oxygen in the water but different from the isotopic ratio of oxygen in the carbon dioxide. Thus, they concluded that oxygen evolution results from **the splitting of two water** molecules, which had been proposed by Cornelius van Niel (1935), and *not* from the splitting of carbon dioxide.

Demonstration: At the beginning of class I set up the demonstration of the First Law of Thermodynamics that

we have seen before. This time I will also use the electrical energy of a battery to split water and show you how you can determine that the gases produced are hydrogen (it produces a very pale blue flame and pops when exposed to a lighted taper) and oxygen (causes a burning taper to burst into flame).



Sunday, **December 7, 1941**, the Japanese bombed Pearl Harbor. Ernest Lawrence's laboratory prepared to fight a war and any work that did not contribute to the war effort would be put on hold. This included Ruben and Kamen's work on photosynthesis using $^{14}\text{CO}_2$. Samuel Ruben began wartime research on **phosgene** (COCl_2), a poisonous gas and died September 28, 1943, in a lab accident with the poisonous gas. Phosgene had been discovered by John Davy in 1812 when he irradiated carbon monoxide and chlorine with **sunlight**. Phosgene (COCl_2) contains no phosphorous but gets its name from the method of production, which in Greek is $\phi\omega\varsigma$ for "light" and $\gamma\iota\nu\omicron\mu\alpha\iota$ "to produce".



As a part of his wartime activities, Martin Kamen occasionally went to **Oak Ridge National Laboratory** to do research on the enrichment of ^{235}U , which was necessary to build an atom



bomb. Kamen knew but was not supposed to know that there was a neutron pile at

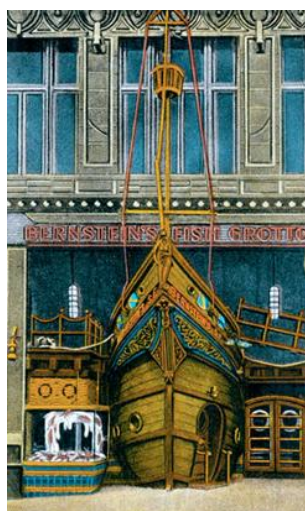
the **Clinton Works** in Oak Ridge. He asked **Charley Coryell** if it was possible to get some ^{24}Na for an experiment. After being escorted to a secret building a half hour away along a bumpy road in a car with closed blinds, Kamen received the radioactive sodium. When he opened the vial, he saw that it must be much more radioactive than anything he could have produced using the cyclotron since it **glowed purple**. He reasoned that the atomic reactor must produce a beam of millions more neutrons than the cyclotron could. Still in shock about the magnitude of radioactivity in the **glowing sample**, Martin Kamen told Ernest Lawrence about his realization. Ernest Lawrence seemed uninterested, but shortly afterwards an investigation was launched and concluded that Martin Kamen could not be trusted with classified information.

Martin Kamen realized that his **phone was tapped** and that his home on Buena Vista Way in Berkeley was being **watched by agents** who kept their cars running during a time of wartime rationing. Without revealing any secrets, Kamen reassured neighbors, including a woman seeking a divorce who thought the agents might have been detectives hired by her husband and a gay couple who worked for the civil defense and thought that *they* were not being spied on. Kamen believed that he had special troubles for security because he had “*such a wide circle of acquaintances and such varied social activities.*” He even socialized with “*leftist individuals and bons vivants.*” He even went to benefits for the Anti-Fascist Refugee League and the Soviet-America Friendship Association.

When Martin Kamen, who was a son of a Russian immigrant and a violinist himself, was at a party thrown by his friend **Isaac Stern**, the Russian-born violinist, to celebrate Isaac Stern's return from a USO tour, Kamen met the Russian consul and vice consul. **Gregory Kheifetz**, the vice consul asked Martin Kamen for help in contacting Ernest Lawrence's brother John to make an arrangement for treating an official in the Russian consulate in Seattle for leukemia. Martin Kamen contacted John Lawrence the next day. **Gregory Kheifetz** (right) called Kamen to let him know that John Lawrence had contacted him and that he would like to take Martin Kamen out for dinner to thank him before he had to return to Russia.



Kamen, Kheifetz, and his successor had dinner at **Bernstein's Fish Grotto**. But because Martin Kamen was under suspicion of being a security risk, FBI agents observed the dinner, and Kamen was **fired** by the University of California at Berkeley and all academic positions were closed to him. G-2 was building a dossier on Martin Kamen that included innuendos of moral turpitude and leftist associations.



APPETIZERS COO-COO CLAM COCKTAIL (In Season) 1.00 COO-COO CLAMS, Half Shell (6) 1.00; (12) 1.95 BABY SHRIMP COCKTAIL 1.15 PRAWNS COCKTAIL 1.25 CRAB MEAT COCKTAIL 1.25 CRAB LEG COCKTAIL 1.50 EASTERN OYSTER COCKTAIL 1.25 RING NEPTUNE JUMBO SEAFOOD COCKTAIL 2.50 EASTERN OYSTERS (6), On Shell 2.25 CRACKED CRAB 3.25; Half 1.75 HOW TO SEASON	
SOUPS OUR FAMOUS CLAM CHOWDER 50 .35 CREAM STYLE CLAM CHOWDER 50 .35 MOCK TURTLE SOUP 50 .35 CLAM BROTH 50 .35 CRAB GUMBO LOUISIANA 50 .35 BREAD AND BUTTER SERVED WITHOUT ENTRÉE 1¢	
SALADS "PIECES OF EIGHT" SALAD 3.10 Includes all lobster, crab legs, shrimp, sliced avocado and tomato. Restaurant dressing. No dressings! DINNER SALAD 50 MIXED GREENS IN BOWL 75 WITH SHRIMP 1.50 WITH CRAB MEAT 1.75 CRAB, SHRIMP, or PRAWN LOUÏE 2.35 FRUIT AND COTTAGE CHEESE 1.50 TOMATO, Filled with CRAB or SHRIMP 1.75 AVOCADO WITH CRAB or SHRIMP 2.00 HEARTS OF ROMAINE, Anchovy Strips 95	
OUR FAMOUS DE LUXE COLD SEAFOOD PLATTER A preparation of delicacies from the sea and shore. Cold whole lobster, shrimp, crab legs, clams or oysters on the half shell served with special dressing. GROTTO CHOWDER 1.75 BEVERAGE 85.50 Service for Two BLUE CHEESE DRESSING 1¢ EXTRA VEGETABLE DU JOUR 45	
Bernstein's Complete GROTTO DINNERS Choice of One: Shrimp Cocktail Grotto Clam Chowder Mixed Green Dinner Salad Butter Cheese Dressing 1¢ Extra ENTRÉES BAKED SEA BASS, ITALIENNE 3.15 REX SOLE or SAND DABS 3.15 GOLDEN FILET OF SOLE 2.95 ABALONE STEAK DORE 3.75 GOLDEN PRAWNS 3.50 DEEP FRIED SCALLOPS 3.25 ICE CREAM or SHERBET COFFEE TEA MILK	
Specialties CLOPPING or BOUILLABAISSE 3.95 Lobster tail, Clams, Crab, Shrimp and Potatoes. STUFFED LOBSTER PRINCESS 4.65 COO-COO CLAMS, Steamed, Bordelaise 2.45 OYSTERS KIRKPATRICK 2.95 DEVIL CRAB 2.75 Baked in creamy shell. Served with tartar sauce. BARBECUED COO-COO CLAMS 2.35 Served in shell with Bernstein's famous Penguin sauce. OYSTERS ROCKEFELLER 2.95 BONED SAND DABS, Sauté Meunière 2.45 BARBECUED PRAWNS, Penguin Sauce 2.50	

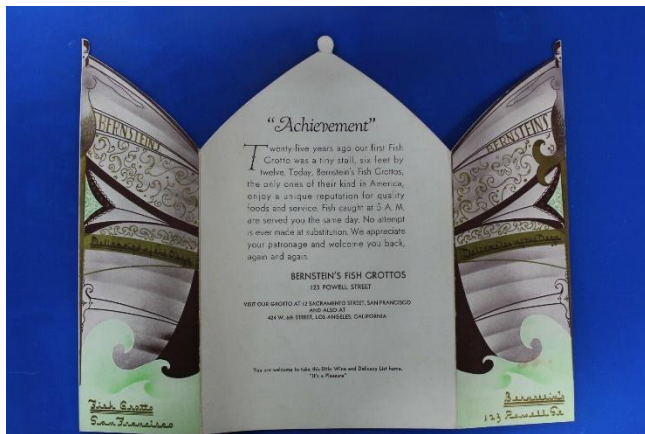
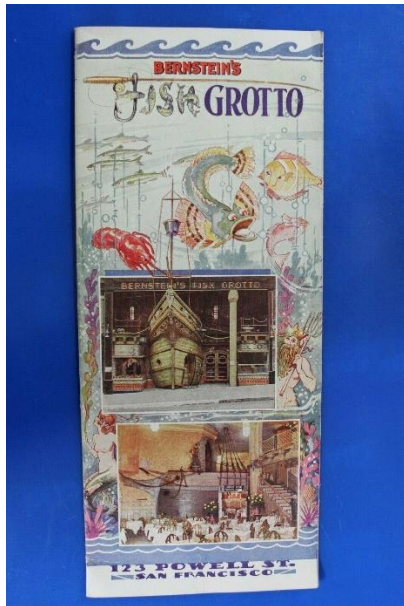
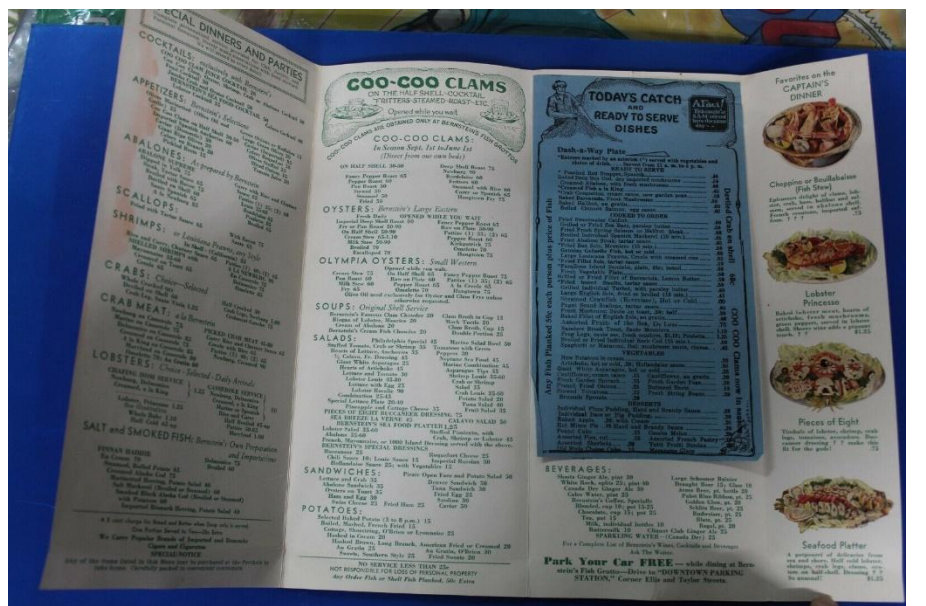
Kamen obtained his FBI files under the Freedom of Information Act and they are available at the [UCSD library](https://www.library.ucsd.edu/).

Michael Shellenberger, Bari Weiss, and Matt Taibbi, recipients of the [Dao Prize](#), are three investigative journalists who are exposing our government's involvement in the [Censorship industrial Complex](#).



Anonymous bias reporting systems used by almost every college and university today were used during Kamen's time by the **right to target the left**.





Here is a menu from a restaurant my family used to go to. These are still the prices I expect to see:

**Tourists and Travelers
Make It A Point
To Stop At One
of VALLE'S
STEAK HOUSES**

When driving through New England, everyone has made it a habit to dine at Valle's Steak Houses, famous for steaks, roast beef, lobster, and choice seafoods for over 30 years.

Valle's Steak Houses . . . in Boston, Massachusetts; Portsmouth-Kittery at the New Hampshire and Maine line; and Scarborough, and Portland, Maine. Four beautiful, air-conditioned restaurants . . . attracting over 75,000 guests each week . . . over 3,500,000 each year.

Only top quality U.S. prime and choice Western steer beef at Valle's, serving over 30,000 steaks every week.

Valle's, open every day from 7 AM - 1 AM, features a wide variety of dinner selections and special children's menus — all at thrifty New England prices.

Businessmen and club groups patronize Valle's often, to enjoy the popular four-course luncheons and extensive banquet facilities.

Each restaurant, offering ample parking for 500 cars, is close to Charterhouse Motor Lodges, and located near New England's tourist attractions and historical sites.

Visit Valle's now . . . during Valle's Thirtieth Anniversary year.

*When traveling through New England
MAKE VALLE'S A MUST!*

Visit VALLE'S . . . famous
for **STEAKS • ROAST BEEF**
LOBSTERS • SEAFOODS
for over 30 Years! 1933-1963



Blue Ribbon
1 Lb. Broiled

SIRLOIN STEAK \$2.95

1½ Lb. PORTERHOUSE
or
T-BONE STEAK **\$2.95**

Each Wed. & Fri.
TWO 1 Lb. MAINE
LOBSTERS **\$2.95**
Broiled, Broiled or
Baked Stuffed

FRESH LOBSTER MEAT \$2.95
Sautéed in Sherry
Wine Sauce

Complete Full Course
DINNERS \$1.95
Including Roast
Prime Rib of Beef \$2.95

Travelers-Tourists
Special 4-Course
LUNCHEONS 95¢ to \$1.00

Only the Finest U.S. Prime and Choice Western Steer Beef Served.
4 Convenient Locations . . . All at Main Arteries.

VALLE'S — PORTLAND, MAINE On Maine Turnpike, Exit #8

VALLE'S — PORTSMOUTH-KITTERY At Maine, New Hampshire Line, Interstate Route 95.

VALLE'S — SCARBOROUGH, MAINE Route 1 Near Old Orchard Beach.

VALLE'S — BOSTON, MASS. 6 miles from downtown Boston on Route 9, Newton.

OPEN DAILY
7 AM - 1 AM

VALLE'S
STEAK & RIB ROOM

SPECIAL MENUS FOR CHILDREN

Valle's
STEAK HOUSE

COCKTAIL LOUNGES



Martin Kamen could not get a job in academia or industry. It turned out that military intelligence had placed his name on a “*master list of **unemployables** for the information of possible employers.*” Even Linus Pauling and James Franck could not help him get a job. He finally did get a job as a welding inspector at the Kaiser shipyard in Richmond, California.



In 1945, with help from Arthur Compton and with a good recommendation from Ernest Lawrence, Martin Kamen became a professor of biochemistry at Washington University in St. Louis. Unfortunately, the FBI inherited from the military intelligence, the security file on Martin Kamen. In 1947, his passport was confiscated and in 1948, he was summoned to testify by the **House Un-American Activities Committee (HUAC)** chaired by **Representative J. Parnell Thomas** regarding the possibility that he had leaked atomic secrets to the Russians. Martin Kamen was questioned about the **Bernstein Fish Grotto dinner**. He was cleared by the HUAC on September 1948 but only got his passport back from the State Department on July 8, 1955, following his lawsuit against the Secretary of State, John Foster Dulles.

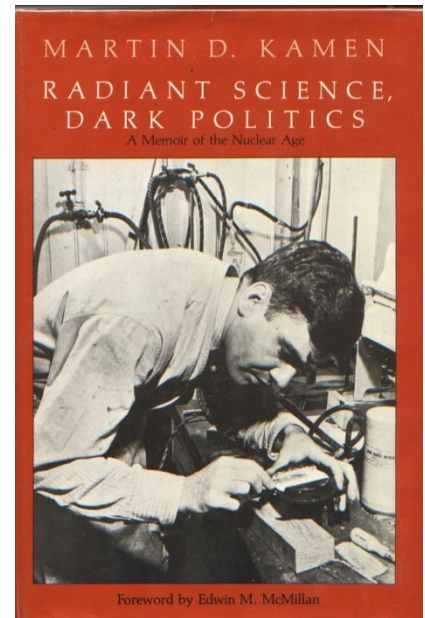


Cartoon by Dan Bishop in the St. Louis Star-Times, September 4, 1948.
Radiant Science, Dark Politics.

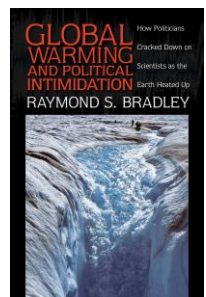
On the other hand, Rep. **J. Parnell Thomas** was **convicted of fraud**, served nine months in a federal penitentiary, and resigned from Congress. Martin Kamen (1985) chronicled his life in ***Radiant Science, Dark Politics***. George B. Kauffman (1986) wrote, “*From the pages of this*



book Kamen emerges as a *Mensch*-a multidimensional human being whose only "crime" was his gregariousness. It is not only a scientific document but also a tribute to the human spirit in its depiction of Kamen's triumph over adversity. It reads like a "Who's Who" in nuclear science and music, and it abounds with incisive character sketches of Kamen's scientific acquaintances. More than 200, including no less than 18 Nobel laureates, are mentioned, and an entire chapter is devoted to E. O. Lawrence and J. Robert Oppenheimer. As a cautionary tale, it recalls a shameful period in American history when political expediency aroused the anti-intellectualism latent in our society and an hysterical tide of anti-Communism swept the nation. For those too young to have experienced the McCarthy era and the early days of the Cold War, it will engender disbelief that such character assassinations of scientists on the basis of outright lies or the flimsiest of evidence could have been tolerated in a democracy."



Human nature is human nature and today, politics and science still make strange bedfellows:



In 1996, Martin Kamen won the **Enrico Fermi Award** given by the United States Department of Energy in recognition of lifetime achievements in energy research. According to the Department of Energy, "During the war years Kamen's liberal ideas and outgoing personality caused him to be watched by government security, including the F.B.I. In 1944, he was declared security risk and dismissed from the Berkeley Radiation Lab. A few years later he was called before the House Un-American Activities Committee. Kamen fought in the courts for over



ten years to clear his name and to regain his passport, which had been denied whenever he had been invited to attend scientific meetings abroad.”

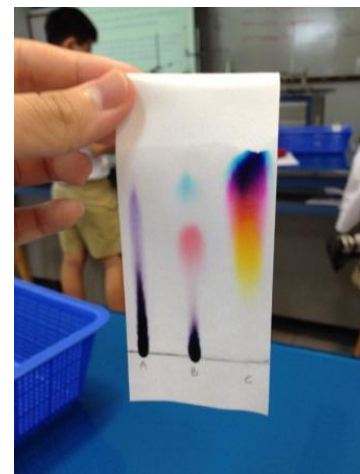
<http://science.energy.gov/fermi/award-laureates/1990s/kamen/>

I have been teaching you that **science is a human endeavor** that involves the positive aspects and the negative aspects of being human. It also involves the positive and negative aspects of government, another human endeavor. Once Martin Kamen was eliminated from his research on photosynthesis, there was room for someone else to step in.

In 1945, Ernest Lawrence asked **Melvin Calvin**, who apparently had the “correct” political views, to continue the project initiated by Samuel Ruben and Martin Kamen. Calvin and his colleagues combined the **investigative power of ^{14}C** and the use of *Chlorella* a single-celled alga that could be easily cultivated and rapidly labeled with $^{14}\text{CO}_2$ with the newly developed technique of **paper chromatography** invented in 1944, in order to identify the first products of photosynthesis.



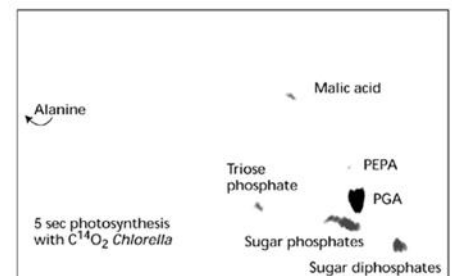
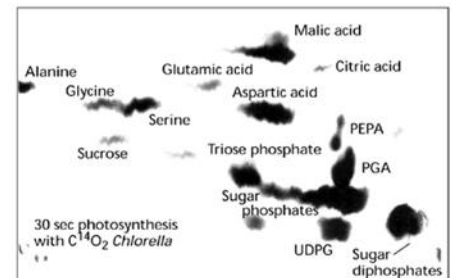
Paper chromatography had been invented to separate the amino acids in protein hydrolysates. It works by the same principle that a drop of ink on filter paper separates into a red, green, and blue band. On a paper chromatogram, each compound moves in a given solvent in a manner that depends on the affinity of the molecule for the polar water absorbed to the cellulose in the paper compared to the nonpolar solvent.



The photosynthetic reaction could be stopped rapidly by dropping the *Chlorella* cells in **boiling methanol**, which both killed the cells and extracted the products of photosynthesis.



The **extracts** were loaded onto a paper chromatogram. In this way, the products can be compared to authentic standards. It can also be determined if the products were phosphorylated by treating the extract chemically or enzymatically to remove the phosphate and seeing how they move on the chromatogram. In this way, Calvin and his colleagues discovered that **within 5 seconds**, 3-phosphoglyceric acid was labeled, and suggested that there was a **two-carbon acceptor for CO₂**.



However, as soon as they **increased the temporal resolution** of their assay, they **guessed** that the first product labeled was a six-carbon molecule formed from the joining of CO₂ to a **five-carbon molecule known as ribulose biphosphate (RuBP)**.

By following the position of the ¹⁴C in the various products over time and analyzing the energetics of each step, Calvin and his colleagues came up with the complete pathway of the photosynthetic carbon-reduction cycle, which is known universally as the **Calvin cycle**.

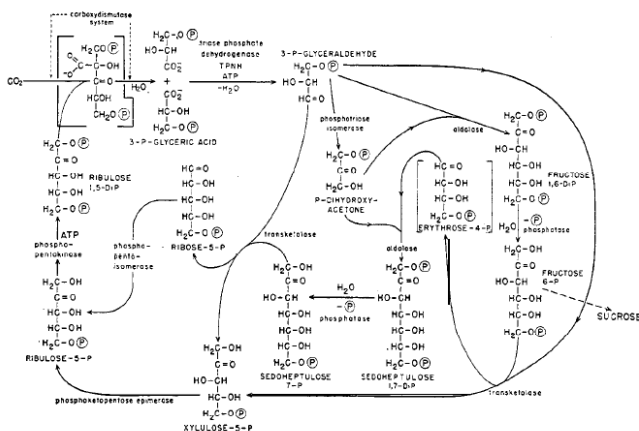


Fig. 18. The photosynthetic carbon cycle.



The ***NADPH*** formed in the light reactions is a **reducing agent** that **transfers the electrons (and protons)** necessary to reduce the CO₂ into energy-rich carbohydrate (C(H₂O)) in the light-independent reactions. The **ATP** is used as an **energy source** in the light-independent reactions to drive the Calvin cycle and regenerate the CO₂ receptor (RUBP). The sugar that is produced during photosynthesis is used by most organisms as an energy source and as a carbon source for synthesizing other carbohydrates, proteins, nucleic acids, lipids, and waxes. (Note that 1 Calorie = 4184 Joules).

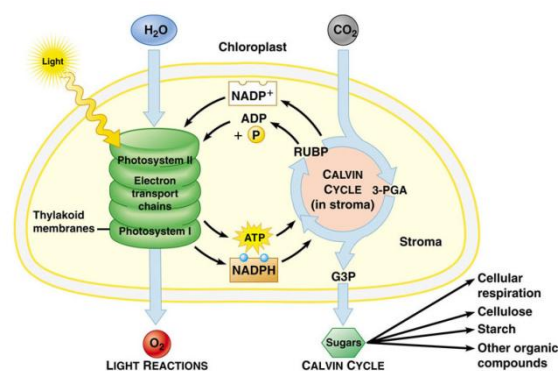
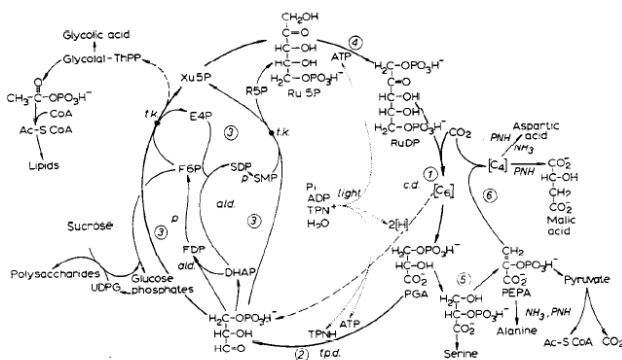
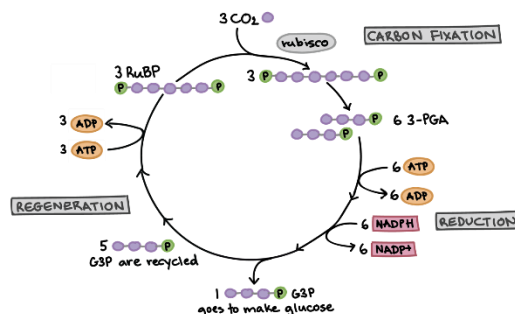
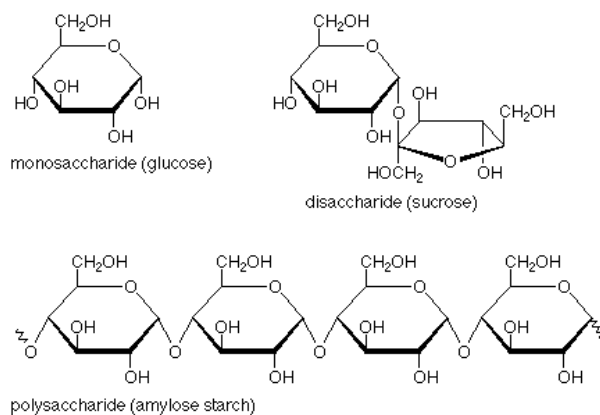


Fig. 20. The photosynthetic carbon cycle and its relation to quantum conversion and to succeeding biosynthesis.



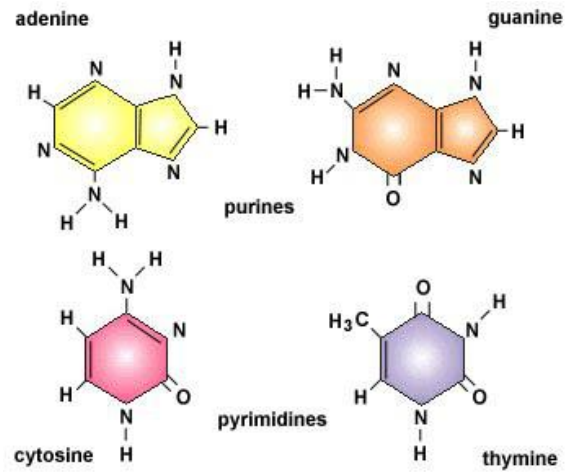
Carbohydrates (4 Calories/gram):



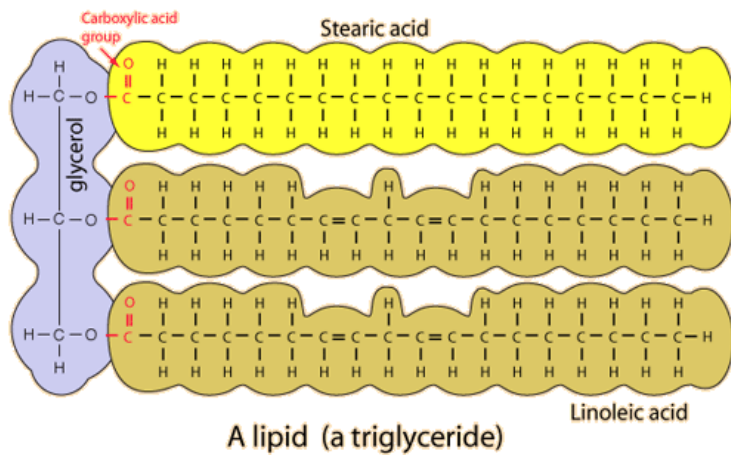
Amino acids (protein components; 4 Calories/gram):

Name	Formula	Abbreviations	Name	Formula	Abbreviations
Glycine		Gly G	Cysteine		Cys C
Alanine		Ala A	Methionine		Met M
Valine		Val V	Lysine		Lys K
Leucine		Leu L	Arginine		Arg R
Isoleucine		Ile I	Histidine		His H
Phenylalanine		Phe F	Tryptophan		Trp W
Proline		Pro P	Aspartic Acid		Asp D
Serine		Ser S	Glutamic Acid		Glu E
Threonine		Thr T	Asparagine		Asn N
Tyrosine		Tyr Y	Glutamine		Gln Q

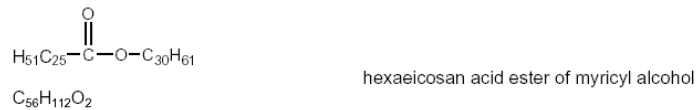
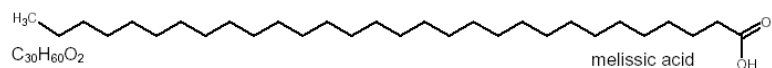
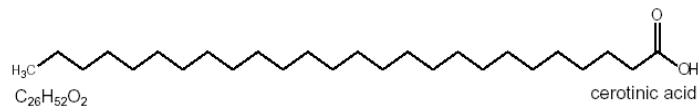
Nucleic acids components:



Lipids (9 Calories/gram):



Waxes:



Note the type of molecules that have the highest density of CH bonds. These are the hydrocarbons, including the lipids and the waxes. They will take the most energy to make, they will store the most energy, and they will make available the most energy. We will discuss them specifically in the next lecture on the chemical history of a candle.

The enzyme that is involved in the attachment of CO₂ to RuBP, resulting in the fixation of CO₂, is known as ribulose biphosphate carboxylase/oxygenase or **Rubisco** for short. Rubisco is an **extremely slow enzyme** that performs about **three** carboxylations per second. **Typical enzymes** perform between **thousands** and **millions of reactions per second**. In order to compensate for this inefficiency, Rubisco is an abundant protein and represents 25-75 percent of the leaf protein. It is the most abundant protein on earth and thankfully, its inefficiency makes plants protein-rich and nutritious to eat.

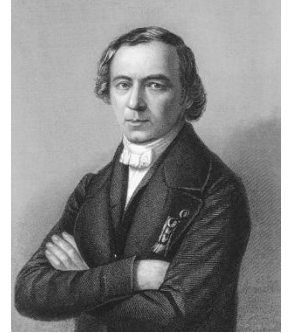
Melvin Calvin won the **Nobel Prize in Chemistry** in 1961 for elucidating the path of carbon in photosynthesis, more commonly known as the **Calvin cycle**. Perhaps if the country were not on a witch hunt at that time, Martin Kamen would have won two Nobel Prizes—one for the invention of the method to make ¹⁴C and the other for elucidating the path of carbon in photosynthesis. A *nearly* Kamen-less oral history of the Calvin group has been published. It does state that Calvin “*did not like very much (Martin) Kamen.*”

<https://archive.org/details/thecalvinlaboral01moserich/mode/2up>

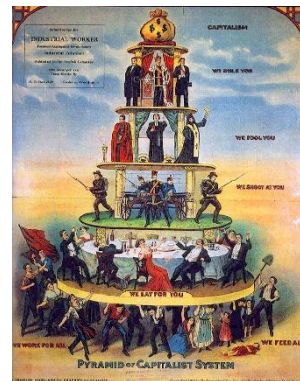
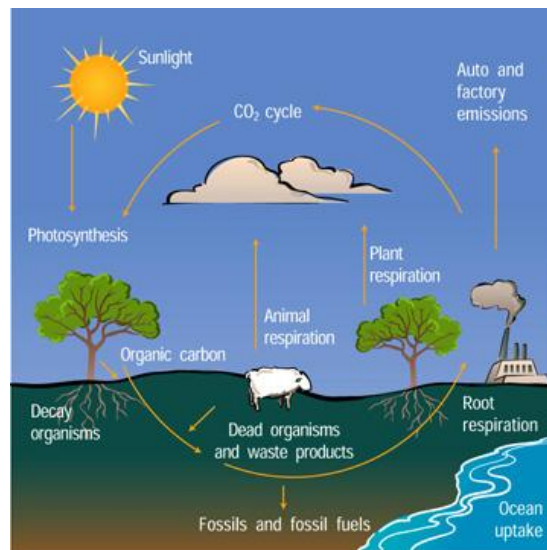
<https://archive.org/details/thecalvinlaboral02moserich/page/n5/mode/2up>



The **biotic carbon cycle** was understood by chemists in the mid-19th century. **Jean-Baptiste Dumas** wrote, “... green plants constitute the great laboratory of organic chemistry. It is they which, with carbon, hydrogen, nitrogen, and ammonium oxide, slowly build the most complex organic materials. They received from the solar rays, in the form of heat or chemical radiation, the power needed for this work. Animals assimilate or absorb the organic materials made by plants. They change them bit by bit. ... They therefore decompose bit by bit these organic materials created by plants; they bring them back bit by bit toward the state of carbonic acid, of water, of nitrogen, of ammonia, the state that permits them to be restored in the air.”



T. H. Huxley (1893) described the cycle by means of a sociological metaphor: “Thus the plant is the ideal prolétaire of the living world, the worker who produces; the animal, the ideal aristocrat, who mostly occupies himself in consuming.”



Next, we will talk about how candles and cells combust the carbohydrates and hydrocarbons consistent with the **First and Second Laws of Thermodynamics** to yield light and the energy for life.

James Joule discovered the first law of thermodynamics in the basement of a brewery that fermented the starch—a product of photosynthesis, stored in **barley** seeds. In one respect, all beers are light beers! Fermenting glucose or **grape** sugar—also a product of photosynthesis results in the production of wine. Wine too, is captured light. The next time you drink a glass of wine, remember what Dante (*Purgatorio* 30:77) wrote,

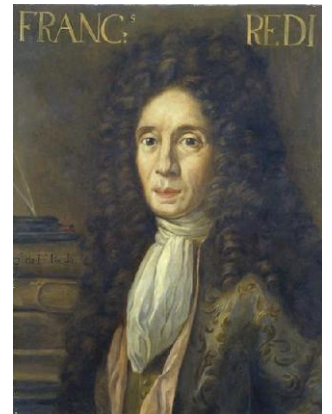


*Behold the Sun's heat which becometh wine
Joined to the juice that from the vine distils.*



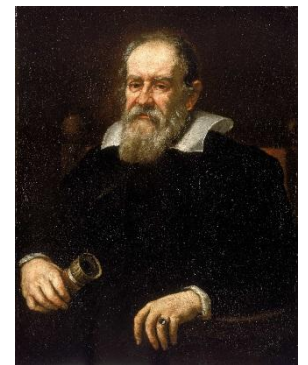
And what Francesco Redi (*Bacco in Toscana*) wrote,

*That blood so fine is a kindled ray
From the Sun, in heaven set,
Entangled and held a prey
By clustering grapes in their net.*



And what Lorenzo Magalotti (1721; *Lettere Scientifiche ed Erudite*; Letters II and V) tells us what his friend Galileo believed:

Wine is a mixture of sap and of light.



According to [Benjamin Franklin](#) (1779), “[w]e hear of the conversion of water into wine at the marriage in Cana as of a miracle. But this

conversion is, through the goodness of God, made every day before our eyes. Behold the rain which descends from heaven upon our vineyards; there it enters the roots of the vines, to be changed into wine; a constant proof that God loves us, and loves to see us happy. The miracle in question was only performed to hasten the operation, under circumstances of present necessity, which required it.”

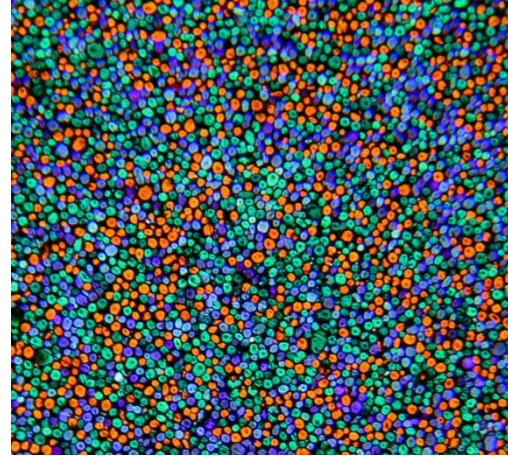


Starch, a carbohydrate formed in **chloroplasts** in the photosynthetic green part of plants or in **amyloplasts**, a type of non-green plastid found in the non-green parts of plants has been put to use in a very clever way by **Auguste and Louis Lumière** in 1904 to show the relation between light and life to make photographic images of plants, animals, people, and medical conditions. The technique is known as the **autochrome** process.

The New Lumiere Process of Color Photography by Dr. M. L. Hiedingsfeld (The Lancet-clinic (1908) v. 99, p. 785). *It affords me great interest this evening to present the latest scientific triumph in clinical and pathological photography, namely, the new Lumiere process of color photography. The first slide which I wish to present is a photograph of a variegated bouquet of flowers, which*



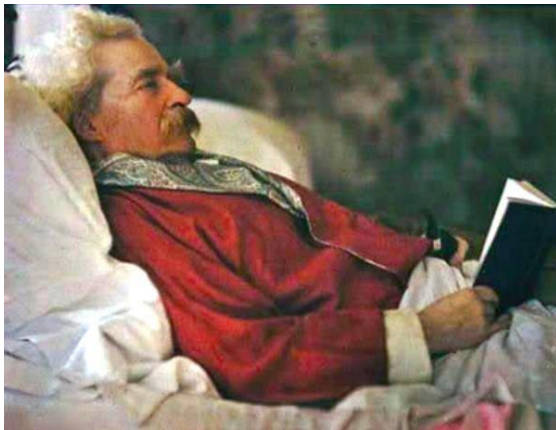
was taken with an indoor exposure of one minute, and which faithfully reproduces every variation in the shade of the original flowers; also one or two clinical photographs of patients taken under the same conditions, in which the color value of the skin lesions are also faithfully reproduced. The autochrome plates by this new process of color photography have made colored photography successful after experimentation at the hands of numerous investigators, covering a period of almost twenty years. The process is exceedingly simple. The plate is first coated with starch granules, representing the three primary colors, orange, violet and green, and then coated with sensitized silver, the same as the ordinary photographic plate. The color value of any object which is photographed is reproduced on the plate by the fact that only that ray reaches the silver through the corresponding primary color or combination of primary colors which is interposed between it and the sensitized silver. After the plate is developed the sensitized silver will only allow the corresponding light to be returned through the plate which will bring out the same colors from the combination of starch granules which primarily reached the sensitized silver. The color value, therefore, is an absolutely accurate and perfect one, and the process will be invaluable for the preservation of faithful color records of pathological specimens and certain clinical conditions. It will also prove invaluable in color microphotography, and I herewith take pleasure in showing some microphotographs which are faithful reproductions in color value of the objects photographed. The process has one serious objection, and that is that the starch granules which carry the color in the autochrome plates are more or less opaque in character and interfere materially with the sharpness and definition of the photographic image. If these granules can be replaced with some translucent

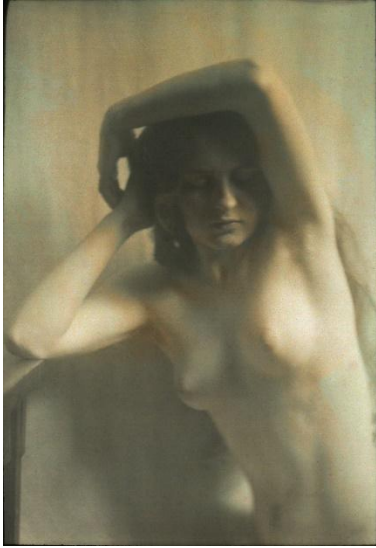
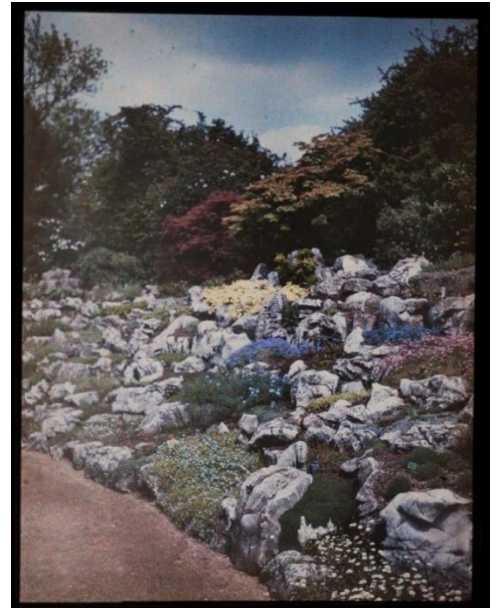


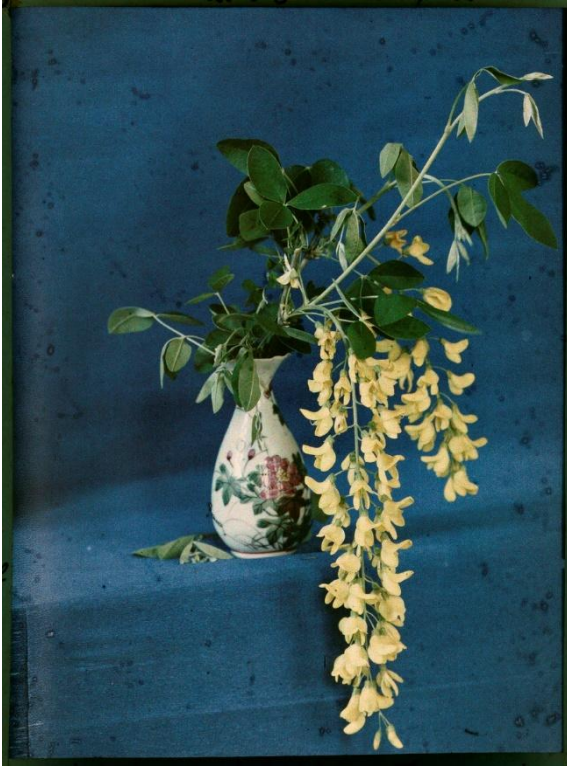
substance like gelatine it will become a highly perfected art and hold a correspondingly valuable and indispensable place in our clinical and laboratory methods.

Note that the plate was processed into a positive transparency. This is done by first developing it into a negative. Then the silver that formed the negative image is removed chemically. Then the remaining silver halide is exposed to light and developed to produce a positive image.

The **autochrome** process was incredible. Alfred Stieglitz wrote, “*The possibilities of the new process seem to be unlimited... soon the world will be color-mad, and Lumière will be responsible.*”







Here is a picture of an autochrome viewer:



http://www.luminous-lint.com/_phv_app.php?/f/_autochrome_examples_01/

<https://drculturalheritage.com/preserving-the-national-geographic-societys-autochrome-collection/>

<https://www.npr.org/sections/pictureshow/2010/05/25/127112999/autochromes>

<https://birdinflight.com/inspiration/experience/20200221-o-gorman.html>

<http://home.bway.net/jsruggs/auto.html>

<https://blog.scienceandmediamuseum.org.uk/autochromes-the-dawn-of-colour-photography/>

<https://books.google.com/books?id=8g8CAAAAYAAJ&pg=PA785&dq=Autochrome+Lumi%C3%A8re+orange+green+violet#v=onepage&q=Autochrome%20Lumi%C3%A8re%20orange%20green%20violet&f=false>

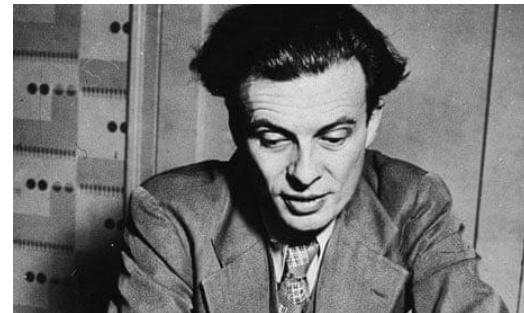
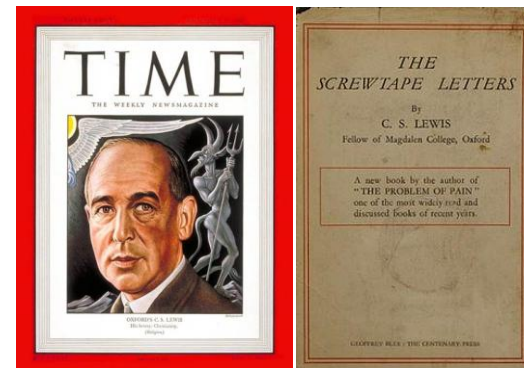
<http://theimageworks.com/pdf/100years.pdf>

<https://www.antiq-photo.com/en/collections/page/157/>

http://www.earlyphotography.co.uk/site/entry_F76.html

<https://www.europeana.eu/portal/en/explore/galleries/autochrome>

Remember how the Deltas in **Aldous Huxley's** (1932) *Brave New World* were behaviorally modified to hate books and nature? How often do you **read a book** for enjoyment and **take a walk through nature** during the day, enjoying the **sunlight** and its effects and using your **photopic** vision, or take a walk at night looking at the moon, stars, and planets with your photopic vision and the objects they illuminate with your **scotopic** vision? I hope that *Light and Life encourages* (puts in your heart) you to do just that! In *The Screwtape Letters*, **C. S. Lewis** (1942) warned against any activities in the battle between good and evil that **discourage** (take away from your heart) you from doing these two things:



My dear Wormwood,

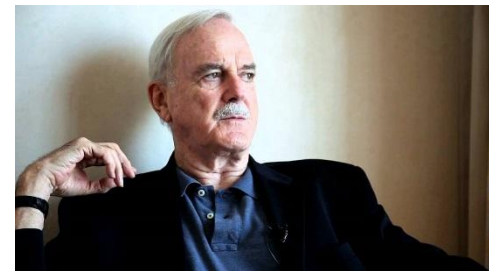
*“...And now for your blunders. On your own showing you first of all allowed the patient to **read a book** he really enjoyed, because he enjoyed it and not in order to make clever remarks about it to his new friends. In the second place, you allowed him to walk down to the old mill and have tea there—a **walk through country he really likes**, and taken alone. In other words you allowed him two real positive Pleasures. Were you so ignorant as not to see the danger of this?*

*...How can you have failed to see that a real pleasure was the last thing you ought to have let him meet? Didn't you foresee that it would just kill by contrast all the trumpery which you have been so laboriously teaching him to value? And **that the sort of pleasure which the book and the walk gave him was the most dangerous of all**? That it would peel off from his sensibility the kind of crust you have been forming on it....*

..The man who truly and disinterestedly enjoys any one thing in the world, for its own sake, and without caring twopence what other people say about it, is by that very fact fore-armed against some of our subtlest modes of attack. You should always try to make the patient abandon the people or food or books he really likes in favour of the “best” people, the “right” food, the “important” books. I have known a human defended from strong temptations to social ambition by a still stronger taste for tripe and onions

Your affectionate uncle Screwtape”

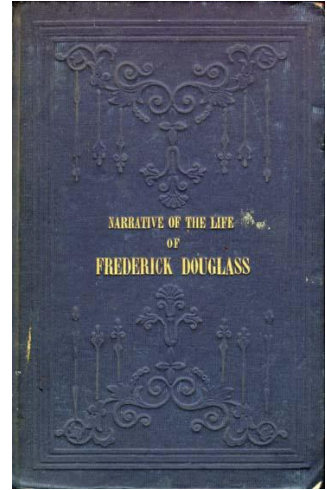
You can hear John Cleese, the Provost's Visiting Professor and former A. D. White Professor-at-Large reading Letter 13 of *The Screwtape Letters*



<https://www.youtube.com/watch?v=t8gWEZ1xJkY&list=PLA8BAC9375345E6C7&index=13>

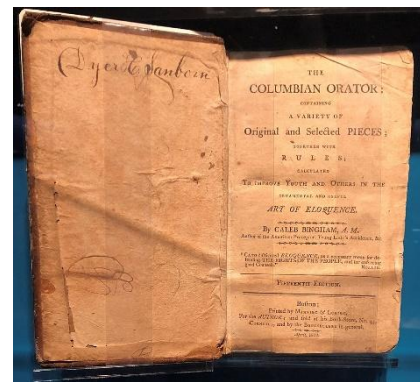
Frederick Douglass, who was born Frederick Bailey, knew the importance of reading in order to be a free person rather than a slave. In [*Narrative of the Life*](#)

[of Frederick Douglass, an American Slave](#), Douglass (1845) wrote, “Very soon after I went to live with Mr. and Mrs. Auld, she very kindly commenced to teach me the A, B, C. After I had learned this, she assisted me in learning to spell words of three or four letters. Just at this point of my progress, Mr. Auld found out what was going on, and at once forbade Mrs. Auld to instruct me further, telling her, among other things, that it was unlawful, as well as unsafe, to teach a slave to read. To use his own words, further, he said, ‘If you give a nigger an inch, he will take an ell. A nigger should know nothing but to obey his master—to do as he is told to do. Learning would spoil the best nigger in the world. Now,’ said he, ‘if you teach that nigger (speaking of myself) how to read, there would be no keeping him. It would forever unfit him to be a slave. He would at once become unmanageable, and of no value to his master. As to himself, it could do him no good, but a great deal of harm. It would make him discontented and unhappy.’ These words sank deep into my heart, stirred up sentiments within that lay slumbering, and called into existence an entirely new train of thought. It was a new and special revelation, explaining dark and mysterious things, with which my youthful understanding had struggled, but struggled in vain. I now understood what had been to me a most perplexing difficulty—to wit, the white man's power to enslave the black man. It was a grand achievement, and I prized it highly. From that moment, I understood the pathway from slavery to freedom. It was just what I wanted, and I got it at a time when I the least expected it. Whilst I was saddened by the thought of losing the aid of my kind mistress, I was gladdened by the invaluable instruction which, by the merest accident, I had gained from my master. Though conscious of the difficulty of learning without a teacher, I set out with high hope, and a fixed purpose, at whatever cost of trouble, to learn how to read. The very decided manner with which he spoke, and strove to impress his



wife with the evil consequences of giving me instruction, served to convince me that he was deeply sensible of the truths he was uttering. It gave me the best assurance that I might rely with the utmost confidence on the results which, he said, would flow from teaching me to read. What he most dreaded, that I most desired. What he most loved, that I most hated. That which to him was a great evil, to be carefully shunned, was to me a great good, to be diligently sought; and the argument which he so warmly urged, against my learning to read, only served to inspire me with a desire and determination to learn. In learning to read, I owe almost as much to the bitter opposition of my master, as to the kindly aid of my mistress. I acknowledge the benefit of both.”

When Frederick Douglass was 12 years old, he bought *The Columbian Orator* by Caleb Bingham for fifty cents. *The Columbian Orator* consisted of “Orations, Addresses, Exhortations from the Pulpit, Pleadings at the Bar, Sublime Descriptions, Debates, Declamations, Grave and Humorous Dialogues, Poetry, &c, Various Interspersed.” It taught the reader about liberty and how to speak with eloquence. It was the first book Frederick Douglass bought with his own money. Douglass (1855) wrote in [My Bondage and My Freedom](#), “Here was, indeed, a noble acquisition. If I ever wavered under the consideration, that the Almighty, in some way, ordained slavery, and willed my enslavement for his own glory, I wavered no longer. I had now penetrated the secret of all slavery and oppression, and had ascertained their true foundation to be in the pride, the power and the avarice of man. The dialogue and the speeches were all redolent of the principles of liberty, and poured floods of light on the nature and character of slavery. With a book of this kind in my hand, my own human nature, and the facts of my experience, to help me, I was equal to a



*contest with the religious advocates of slavery, whether among the whites or among the colored people, for **blindness**, in this matter, is not confined to the former. I have met many religious colored people, at the south, who are under the delusion that God requires them to submit to slavery, and to wear their chains with meekness and humility. I could entertain no such nonsense as this; and I almost lost my patience when I found any colored man weak enough to believe such stuff. Nevertheless, the increase of knowledge was attended with bitter, as well as sweet results. The more I read, the more I was led to abhor and detest slavery, and my enslavers.”*

I transcribed Joule’s handwritten notes on “*The aims of science and true spirit of research*”. This may be a draft of Joule's presidential address to the British Association meeting, Bradford 1873, which was not delivered due to Joule's ill-health. *The Aims of Science* by James Joule gives us some insight to one of the discoverers of the first law of thermodynamics.

“The examination of the works of the Almighty is a source of pure delight to every man whose mind has not been debased. He loves to behold the beauty and order of nature and his intellectual faculties are occupied by and endeavor to obtain a more intimate acquaintance with the wonders of the creation. In this view natural philosophy may be considered second in importance to religion only; for surely after the knowledge of, and obedience to, the will of God, the next aim must be to know something of his attributes of wisdom, power, and goodness as evidenced by his handiwork.

From the beginning intelligent minds have been thus occupied. When the cornerstone of the earth was laid the morning stars all sang together and all the



sons of God shouted for joy. And although it is not given to mortals to know or to enjoy as do those exalted beings yet it is our high privilege to learn by patient search and so to acquire a body of truth perpetually increasing both in quantity and in kind and bringing us nearer and nearer to the fountain of all light.

He may therefore affirm that the study of nature and her laws is essentially a holy undertaking. Bearing this in mind we shall have no difficulty in showing the spirit in which it should be pursued, the great objects it has in view and its great importance and even absolute necessity in the education of youth.

One of the chief characteristics of the spirit in which science should be pursued is a love of the wisdom which it unfolds, a love of truth for its own sake independently of a regard to the advantages of whatever kind which are expected to be derived from it. The very name philosophy [love of wisdom] shows that this feeling has always been considered the leading one. The pleasure experienced in contemplating the beautiful the harmonious the beneficent and the peace naturally produces love and this naturally leads us to seek a more intimate acquaintance with those beloved objects. Then there should be a certain inquisitiveness of mind to know that which is already unknown, a principle which is one of the most important that belongs to our nature and is in fact the philosophical cause which reconciles us to life which would be miserable indeed if it presented merely the recurrence of the same objects, and gave no hope of varied and fresh enjoyment. A third great requirement of him who pursues natural science is humility. Other acquirement may be compatible with pride of heart, to some it may be an essential qualification. A certain routine may be attained by pride, nay its votaries may be the most successful in obtaining wealth and honorable distinctions. But science will have none such. The state of mind of a proud man is wholly inimical to the success in the pursuit of truth, and invariably leads to the dark paths of error. In studying the works of nature a man should commence with the sentiment of his

ignorance, that he knows nothing and has everything to learn, he ought to have modesty in stating his opinions and be always ready to modify or even to retract them. All this is odious to a proud man. He approaches the subject with his preconceived and worthless hypothesis, he proceeds to the profane attempt to twist and distort the laws of nature to adapt them to his hypothesis, he ends by accumulating a ---- of pretended facts and fallacious theories. Thus a humble and teachable spirit are necessary to everyone who wishes to pursue truth successfully. Other characteristics are diligence, effort, patience, these which are requisite for success in any walk of life and no less in that we are now considering. These latter receive a healthy stimulus from a well regulated love of approbation, and the high hope of success.

The great object which natural science has in view is to elevate man in the scale of intellectual creature by the exercise of the higher faculties of his nature in developing the wonders of the glorious creation. The second and subsidiary object is to promote the well being and comfort of mankind & to increase his----- . These objects are done by ---- and should not be separated. The benefit to be attained is for the entire man for his soul his mind his body. The importance of each object is measured by the importance of that part of human nature which is beneficially affected. The first object therefore at least as much more important than the second as the intellect is more noble than the body. This, namely the raising man in the scale of intelligent creatures can hardly be mentioned without a rise of feeling of ourselves and even incredulity.

And yet it is evident that an acquaintance with natural laws means no less than an acquaintance with the mind of God therein expressed. This acquaintance brings us nearer to Him if such a term may be used in respect to the Infinite. One of the distinguishing features that separates us from the beasts is that the latter have no knowledge of the natural laws, a similar distinction doubtless separates us

from beings of a higher order than ourselves whose range of vision and capacity of thought are more extensive. David seems to be impressed with this when he says "I will consider thy heavens, even the works of thy fingers: the moon and the stars, which thou hast ordained. What is man, that thou art mindful of him: and the son of man, that thou visitest him? Thou made him lower than the angels to crown him with glory and worship." No one can doubt that man's nature may be raised. Scripture teaches this and this, and this has been the pervading hope & belief of all ages and nations. And although the meaning may have been generally restricted to the change which must take place in his arrival to a --- separate state of existence, yet it is not necessarily confined thereto. On the contrary an improvement in the intellectual powers of man may be expected even in his mortal state. Experience shows that this is possible. There are classes of truths which are individual, or one community can not grasp as another individual or another community can. There are truths which are readily held by the present generation which the most civilized of ancient nations were unable to comprehend as has been ably shown by Whewell in his history of the Inductive Sciences. If such a change has been wrought heretofore, what may not be expected for the future now that the sources of improvement are multiplied and deepened, and we possess the experience and the resources which have accumulated for four thousand years.

The second and subsidiary object of natural science is to promote the comfort and well being of man and to increase his luxuries. It is needless to attempt to enumerate the thousands of ways in which science ministers to this object for everywhere may we trace its beneficial influence. In the rudest state of society the bare necessities of life, food, raiment and dwelling are obtained, but whenever comfort or beauty exists it is by an application of science. It assists and supplies our natural powers by calling in the forces of nature. Heat, magnetism, electricity, chemistry, geology, optics, mechanics enable man to centre in himself

and in a far higher degree of naturally superior advantages, possessed by a variety of creatures such as strength, swiftness, extended vision. Natural history in all its branches gives him better food supplies him with medicine shields him from disease, and so tends materially to lengthen the span of his life.

Such are then the legitimate objects of science. It is deeply to be regretted that another and most unworthy object has been introduced and has gradually and alarmingly increased in prominence. This is the improvement of the art of war and the implements of mutual destruction. I know that there are those who think that these improvements will tend to put an end to war by making it more destructive. I cannot think that such an opinion is based on common sense. I believe war will not only be more destructive but be carried on with greater ferocity. Individual campaigns will doubtless be short as well as decisive, but this will necessarily cause that rapid rise and fall of states and unsettling of boundaries and constitutions which must eventually deteriorate civilization itself and render peace impossible. And thus by applying itself to an improper object science may eventually fall by its own hand. In reference to this subject we must also deplore the prostitution of science for the aggrandisement of an individuals and nations, the result being that the weaker is destroyed and the stronger race is established on its ruins. In making the above remarks, I allude to war generally, I intend no disparagement of the efforts being made to secure the integrity and liberties of Great Britain. These have been forced upon us and it is matter of congratulation that we are not responsible for the present military attitude of Europe.

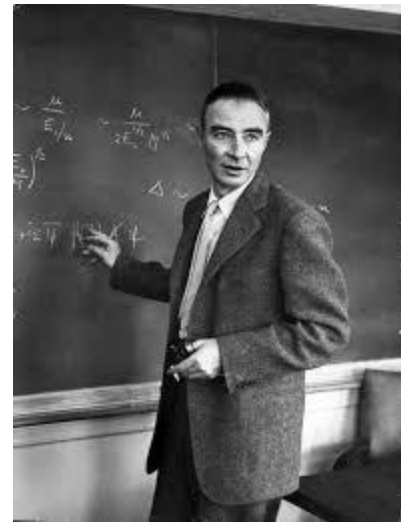
Such being the characteristics of the spirit fostered by the cultivation of natural science, and such being the great objects which are in view, it is almost incredible that anyone should be bold enough to deny its importance, nay its absolute necessity in education. Suppose a student to be thoroughly acquainted with every event which has occurred in the history of the world, suppose him to

have a perfect knowledge of every language that has been spoken by man, suppose him to have an accurate perception of the most subtle questions of industrial arts, yet however important and essential all of these and much more may be he cannot be considered more than half educated if he does not know something of the objects of the material world, their history, their forces and the laws which keep in order what would be otherwise chaos.”

In 1864, Joule signed a declaration entitled, [The Declaration of Students of the Natural and Physical Sciences](#) that affirmed his confidence in the scientific integrity of the Holy Scriptures.

J. Robert Oppenheimer (1949) wrote *Science in Being* about Research and the Liberal University:

It is above all a world in which inquiry is sacred and freedom of inquiry is sacred. It is a world in which doubt is not only a permissible thing, but in which doubt is the indispensable method of arriving at truth. It is a world in which the notion of novelty, of hitherto unexpected experience is always with us, and in which it is met by an open-mindedness that comes from having known, of having seen over and over again, that one had a great deal to learn. It is a way of life in which the discovery of error is refined, in which almost all the ingenuity that goes into experimental, analytical, or mathematical techniques is devoted to refining, sharpening, making more effective the way of finding out that you are wrong; this is the element that creates discipline. The nature of the discipline of science is its devotion, its dedication to finding out when you are wrong, to the detection of error.



I want to mention the **roots** of plants, while they spend their lives essentially in the **dark**, they are as necessary for photosynthetic food production as the leaves. They grow through the **soil** like miners, absorbing the water that is directly used for photosynthesis as well as ions, such as magnesium, iron, and cobalt that are part of chlorophyll molecules and the electron-transfer complexes that participate in photosynthesis. Soil health is thus a necessary component of the food chain. From the start of civilization in Mesopotamia, soil loss due to erosion and soil salinization due to evaporation, have contributed to the decline of civilizations.

And a final note about Lord Kelvin's visit to Cornell: While visiting Cornell on May 2, 1902, Lord Kelvin said, "*Glasgow University is one of the most picturesque in the world, but Cornell is by far the most picturesque, surpassing in this respect any he had seen in Europe, Asia, or America.*"

https://ecommons.cornell.edu/bitstream/handle/1813/25855/004_29.pdf?sequence=1&isAllowed=y



Chemical History of a Candle:

Converting Hydrocarbons into Light and Carbohydrates into ATP

Benjamin Franklin (January 17, 1706-April 17, 1790), like most other children in colonial Boston, only went to school for two years before he started work at the age of ten as an apprentice in his father's soap and **tallow candle** making shop. The tallow chandler had to boil the **suet** or **animal fat** in a vat of water to produce tallow and then pour the tallow that had been skimmed off the water into molds. We now know that tallow is primarily a mixture of the following fatty acids: palmitic acid (16:0), stearic acid (18:0), and oleic acid (18:1). Ben cut wicks, filled molds, tended the shop, and went on errands, but he disliked the hot, smelly, and dirty work of a tallow chandler. His father, Josiah Franklin, not wanting Ben to run off to sea like Ben's oldest brother, Josiah Jr. had, took Ben to the shops of various craftsmen so that Ben could pick a trade more to his liking. The fact that Ben liked to read and could write and spell well, made printing seem like the ideal craft. At the age of twelve, Ben apprenticed as a printer with his brother James. While he was never to be a chandler, as a **writer and a printer**, he held the **light of liberty** high.



In *From Boyhood to Manhood. The Life of Benjamin Franklin*, William M. Thayer (1889) wrote, “*He believes that ‘one to-day is worth two to-morrows’; and he acted accordingly, with the **candle-shop and printing office for his school-room, and Observation for his teacher.** His career furnishes one of the noblest*

examples of success for the young of both sexes to study. We offer his life as one of the **brightest** and best in American history to inspire young hearts with lofty aims.”

Read the extract of the eulogy given by the **Abbé Claude Flauchet** (1790) in [The Columbian Orator](#), which begins like so: “A *SECOND* creation has taken place; the elements of society begin to combine together; the moral universe is now seen issuing from chaos, the genius of liberty is awakened , and springs up; she sheds her divine light and creative powers upon the two hemispheres. A great nation, astonished at seeing herself free, stretches her arms from one extremity of the earth. to the other, and embraces the first nation that became so the foundations of a new city are created in the two worlds brother nations hasten to inhabit it. It is the city of mankind!



One of the first founders of this universal city was the immortal FRANKLIN, the deliverer of America.”

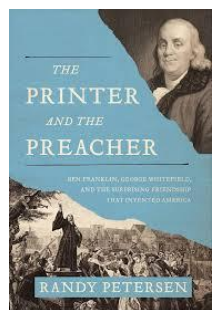
In fact, Ben Franklin, who had dinner with **William Wilberforce** at the Marquis de Lafayette’s home on October 20, 1783, was the first of the founders to break the silence about slavery, Franklin petitioned Congress in 1790 to abolish slavery.

<http://www.archives.gov/legislative/features/franklin/>

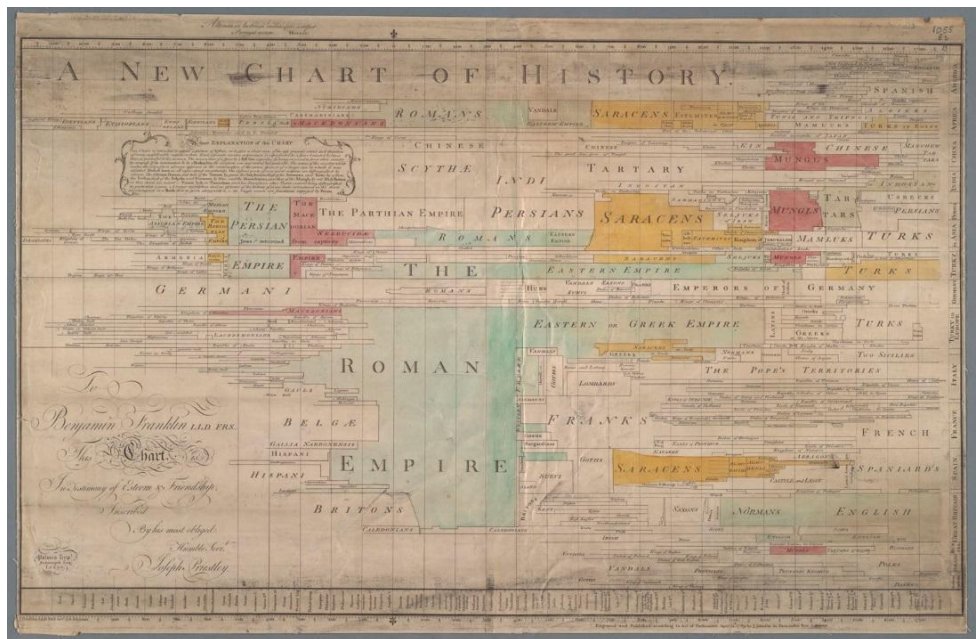


Franklin, [writing as Silence Dogood](#), railed against [hypocrisy](#) since he was 16:

It has been for some Time a Question with me, Whether a Commonwealth suffers more by hypocritical Pretenders to Religion, or by the openly Profane? But some late Thoughts of this Nature, have inclined me to think, that the Hypocrite is the most dangerous Person of the Two, especially if he



Joseph Priestley met Benjamin Franklin in London in the 1760s and they became friends. Ben Franklin encouraged Priestley, who up until this time dedicated his life to the ministry and to teaching, to also pursue his scientific interests. Joseph Priestley was inspired, and in addition to his theological and pedagogical writings, he wrote books on *Electricity*, *Perspective*, *Vision*, *Light and Colours*, and *Different Kinds of Airs*. As a teaching aid, Priestley had produced beautiful charts as a useful way of seeing the **unity in diversity**.



The English Parliament passed laws between 1660 and 1665 that prevented **dissenters** from holding political office, teach school, serve in the military, or attend Oxford and Cambridge unless they ascribed to the Articles of the Church of England. Priestley argued in these pamphlets that matters of private conscience such as education and religion should not be controlled by the state. Moreover, he advocated that women should also be educated.

AN
ESSAY
ON A COURSE OF
LIBERAL EDUCATION
FOR
CIVIL AND ACTIVE LIFE.
WITH PLANS OF LECTURES ON
I. The Study of History and general Policy.
II. The History of England.
III. The Constitution and Laws of England.
TO WHICH ARE ADDED,
REMARKS
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Proposed by Dr. BROWN, in a late TREATISE, intitled,
THOUGHTS ON CIVIL LIBERTY, &c.
By JOSEPH PRIESTLEY, LL.D.
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MDCCLXV.
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AN
ESSAY
ON THE
FIRST PRINCIPLES
OF
GOVERNMENT,
AND ON THE NATURE OF
Political, Civil, and Religious
LIBERTY,
INCLUDING
Remarks on Dr. BROWN's *Code of Education*,
AND ON
Dr. BALGUY's Sermon on CHURCH AUTHORITY.
The SECOND EDITION, corrected and enlarged,
By JOSEPH PRIESTLEY, LL.D. F.R.S.
LONDON:
Printed for J. DODDLEY, in Pall-Mall; T. CABELL, (suc-
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MDCCLXXI.

LECTURES
ON
HISTORY,
AND
GENERAL POLICY;
TO WHICH IS PREFIXED,
AN ESSAY ON A COURSE OF LIBERAL EDUCATION
FOR CIVIL AND ACTIVE LIFE.
By JOSEPH PRIESTLEY, LL.D. F.R.S.
AC. IMP. PETROP. R. PARIS. HOLM. TAURIN. AUREL. MED. PARIS.
HARLEM. CANTAB. AMERIC. ET PHILAD. SOCIUS.
— JUVAT EXHAUSTOS ITERARE LABORES,
ET SULCATA MEIS PERCURRERE LITORA REMIS.
BUCHANANI FRANCISCANUS.

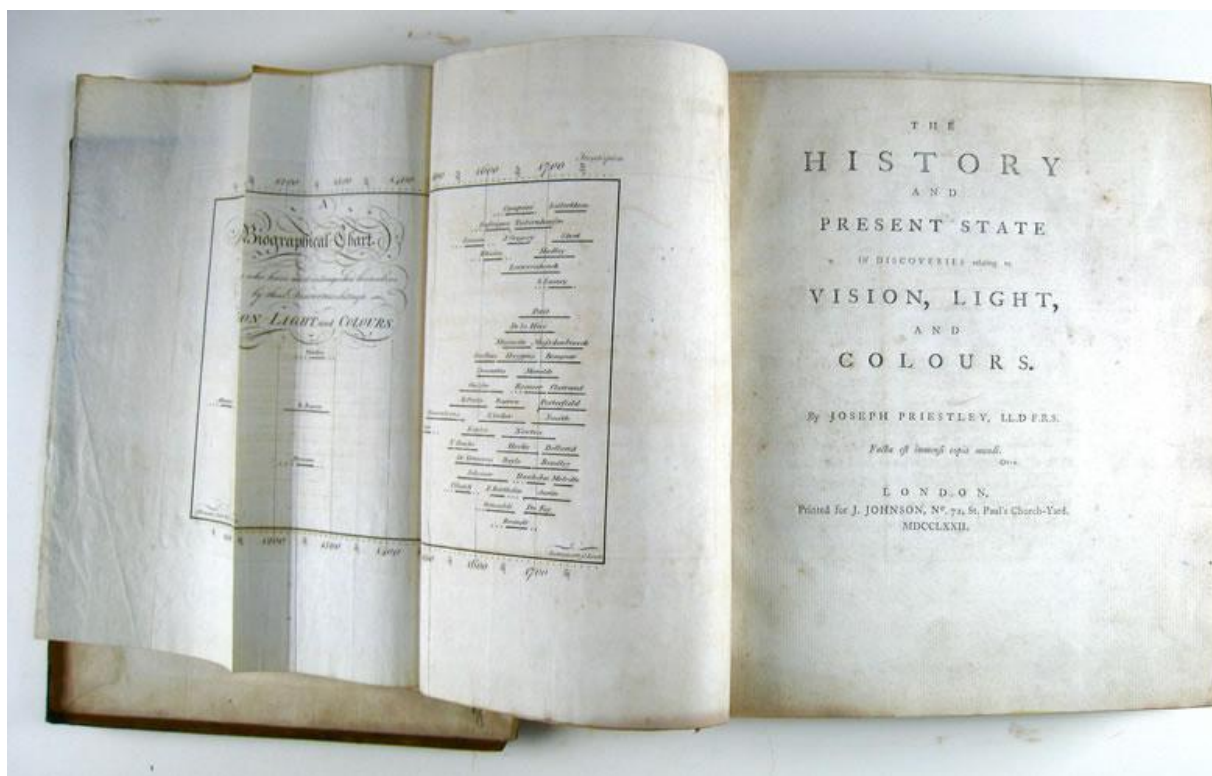
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MDCCLXXXVIII.

THE
RUDIMENTS
OF
ENGLISH GRAMMAR;
ADAPTED TO THE
USE OF SCHOOLS,
WITH
OBSERVATIONS ON STYLE.
By JOSEPH PRIESTLEY.
LONDON:
Printed for R. GRAYSON, in the Strand.
MDCCLXXI.

Ever wonder if you should say lie or lay? Here is a couplet from Priestley's (1833) *English Grammar; Lectures on the Theory of Language and Universal Grammar*:

*Beneath this stone my wife doth lie:
She's now at rest, and so am I.*

ENGLISH GRAMMAR;
LECTURES
ON THE
THEORY OF LANGUAGE AND UNIVERSAL
GRAMMAR;
ORATORY AND CRITICISM.
By JOSEPH PRIESTLEY, LL.D. F.R.S.
NOTES AND AN APPENDIX,
By JOHN DOWELL HUTT.
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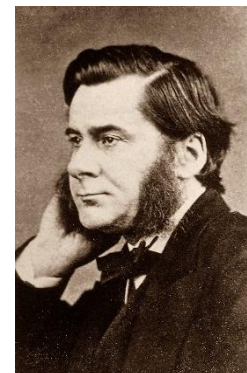
Priestley wrote in the preface to *The History and Present State of Electricity with Original Experiments*, “Human happiness depends chiefly upon having some object to pursue, and upon the vigour with which our faculties are exerted in the pursuit. **And, certainly, we must be much more interested in pursuits wholly our own, than when we are merely following the track of others.**”

Benjamin Franklin wrote a letter on [October 24, 1788](#) to Benjamin Vaughan that described Priestley as an “honest heretic,” “Remember me affectionately to the good Dr Price and to **the honest heretic, Dr Priestley**. I do not call him honest by way of distinction, for I think all the heretics I have known have been virtuous men. They have the virtue of fortitude, or they would not venture to own their heresy; and they cannot afford to be deficient in any of the other virtues, as that would give advantage to their many enemies; and they have not, like orthodox sinners, such a number of friends to excuse or justify them. Do not, however, mistake me. **It is not**

to my good friend's heresy that I impute his honesty. On the contrary 'tis his honesty that has brought upon him the character of heretic."

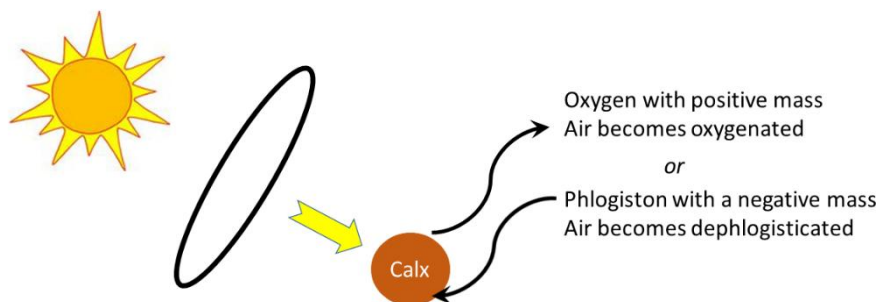
[Thomas H. Huxley \(1874\)](#) described Priestley in glowing terms:

"But I am sure that I speak not only for myself, but for all this assemblage, when I say that our purpose to-day is to do honour, not to Priestley, the Unitarian divine, but to Priestley, the fearless defender of rational freedom in thought and in action: to Priestley, the philosophic thinker; to that Priestley who held a foremost place among 'the swift runners who hand over the lamp of life,' and transmit from one generation to another the fire kindled, in the childhood of the world, at the Promethean altar of Science."



One way in which Priestley studied air on August 1, 1774 was to **focus sunlight** with a twelve-inch in diameter **converging or burning lens** onto orange mercuric calx. The mercury calx turned into liquid metallic mercury as if it captured **phlogiston** from the air so that the air became **dephlogisticated**. We now know that **mercuric calx** is **mercuric oxide** and the mercuric oxide releases oxygen in response to sunlight as opposed to gaining phlogiston from the air. That is, sunlight breaks the chemical bond between mercury and oxygen. I will call what **Priestley studied oxygen**, although he went to his grave believing it was dephlogisticated air.

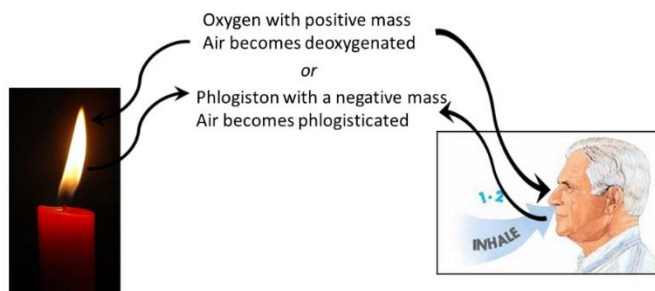




The **Gaussian lens equation** tells us that the image of the sun appeared at the focus of the lens, since the object distance, s_o is 1.5×10^{11} m, which made $\frac{1}{s_o}$ practically zero and thus made s_i practically equal to f . [Priestley's lens had a focal length of 20 inches.](#)

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}$$

In order to test the nature of the **dephlogisticated air** or really the oxygen gas given off by the mercuric calx, Priestley collected it in a bottle. He then placed a candle in the bottle and saw that it burned with a “*remarkably vigorous flame.*” Priestley also saw that a **mouse** would live longer in this **dephlogisticated air** than it would in **common air**, and he called dephlogisticated air, **vital air**.



Priestley wrote, “...to complete the proof of the superior quality of this air, I introduced a mouse into it; and in a quantity in which, had it been common air, it would have died in about a quarter of an hour; it lived at two different times, a whole hour, and was taken out quite vigorous.” This was a special air. If this air was good for a candle and a mouse, could it be good for humans too? Priestley tried breathing the oxygen he produced and wrote, “My reader will not wonder, that, after having ascertained the superior goodness of dephlogisticated air by mice living in it..., **I should have the curiosity**, by breathing it....The feeling of it to my lungs was not sensibly different from that of common air; but I fancied that my breast felt particularly light and easy for some time afterwards. Who can tell but that, in time, this pure air may become a fashionable article in luxury....From the greater strength and vivacity of the flame of a candle, in this pure air, it may be conjectured, that it might be particularly salutary to the lungs in certain morbid cases, when the common air would not be sufficient to carry off the putrid effluvium fast enough.” He also remarked, “But, perhaps, we may also infer from these experiments, that though pure dephlogisticated air [oxygen] might be very useful as a medicine, it might not be so proper for us in the usual healthy state of the body; for, as a candle burns out much faster in dephlogisticated than in common air, so we might, as may be said, live out too fast and the animal powers be too soon exhausted in this pure kind of air. A moralist, at least, may say, that the air which nature has provided for us is as good as we deserve.” Otherwise, the candle burns out long before the legend does.



CANDLE IN THE WIND

Words and Music by
ELTON JOHN and BERNIE TAUPIN
Arranged by JOAN COLETT

Moderately slow

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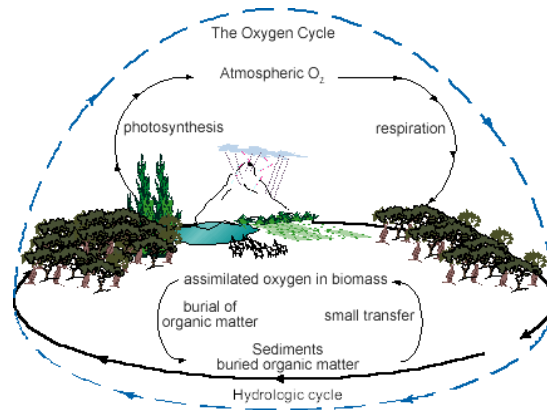
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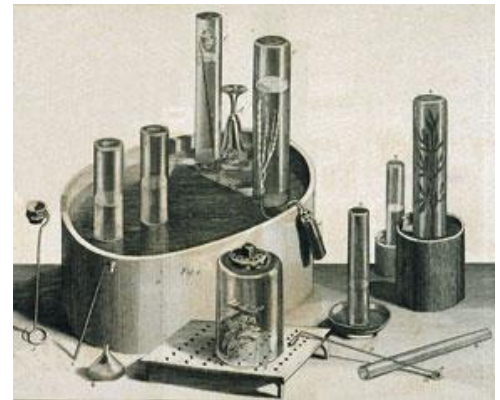
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100. The additional notes

The figure below shows the global oxygen cycle that provides the “*air which nature has provided for us [that] is as good as we deserve.*” In his Harvey Lecture, Ephraim Racker (Cornell; 1957) called this cycle the ***Priestley Cycle***.



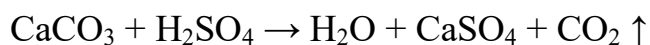
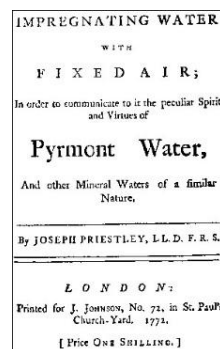
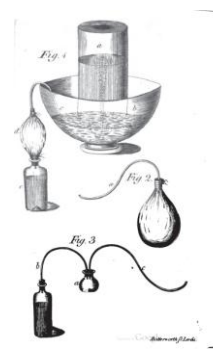
On August 17, 1771, Priestley found that if he put a **sprig of mint** in the jar, it **refreshed the air** so that a candle could burn and a mouse could live. It wasn't just the refreshing smell that refreshed the air since the **essential oil of mint** had no such ability. On the other hand, a sprig of groundsel, the worst smelling weed he could find, also refreshed the air. In fact, it was a **general property of plants** that they could refresh the air. We now know that plants evolve oxygen. Priestley's experiments were irreproducible because he never got the chance to discover that light was required for oxygen evolution.



This is because his home, his lab, and the Unitarian Meeting House where he preached were burned down on July 14, 1791, the second anniversary of the storming of the Bastille, by a mob who did not agree with his **anti-authoritarian views** regarding church and king, specifically his Unitarian philosophy and his support of the American and French Revolutions. Veto power, whether exercised by mobs and monarchs, is still veto power. *Veto* is Latin for “*I forbid*.”

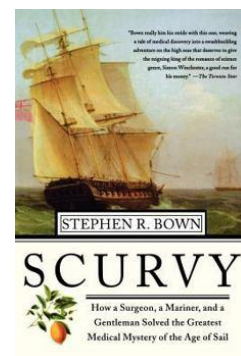


Joseph Priestley was an original thinker and a remarkable chemist who discovered other gases in addition to oxygen, including nitric oxide (NO), nitrogen dioxide (NO₂), nitrous oxide (N₂O), hydrogen chloride (HCl), carbon monoxide (CO), ammonia (NH₃), and sulfur dioxide (SO₂). Living near a brewery, he also did many experiments on the **carbon dioxide** gas that was given off by the brewery. Again we see the relationship between beer and science. One of the things Priestley (1772) did was to impregnate water with carbon dioxide to invent **seltzer water**. The seltzer water was similar to the mineral water from the German spa town Bad Pyrmont. Priestley made “seltzer water” by generating CO₂ gas by adding sulfuric acid to chalk (CaCO₃) and bubbling the gas through water.



Aside: Joseph Priestley prepared carbonated water for the Navy to fight scurvy based on a wrong hypothesis proposed by David MacBride.

Realizing that fresh vegetables prevented scurvy, David [MacBride \(1764, expanded 1767\)](#) suggested that they do so by *throw[ing] off an elastic vapour, or spirit, of surprising activity* during the fermentation of the vegetables in the digestive system. The efficacy of vegetables “***depended on their ability to yield a large proportion of air.***” The wind from greens was not a side effect; on this theory it was the medicine. Consequently, he suggested feeding the sailors wort, the sugary liquid extracted from malted grain during the mashing process before yeast is added to ferment it into beer or whiskey.



Priestley accepted that story and shortened it. In **1772** he argued that if wort helps only because it *makes* fixed air (CO₂) in the stomach, sailors could **drink the gas already dissolved in water**. Priestley suggested in the soda-water pamphlet dedicated to the Admiralty that the sailors skip the vegetables or the wort and take the air neat in water.

Joseph Priestley prepared carbonated water for the Navy to fight scurvy. The potential cure did not work because it was based on a false assumption. It was assumed that because eating fresh vegetables prevented scurvy (as discovered by James Lind), and because eating fresh vegetables was associated with flatulence (as noticed by Sir John Pringle), perhaps ingesting gas directly might prevent scurvy. What really prevents scurvy is ascorbic acid, which is found in fresh vegetables and has gone by the names of ignose, Godnose, hexuronic acid, and vitamin C that is needed to prevent scurvy.

The carbonated water was not a complete loss. In 1783, carbonated water was marketed by Joseph **Schweppe**, who kept the bottles horizontal to retain the carbonation because the cork stayed wet and expanded. Schwepes was the official drink of the **Great Exposition of 1851** in

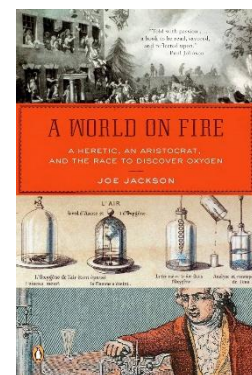


the Crystal Palace, designed by Joseph Paxton, based on the architecture of the leaf of *Victoria regia*.

In 1794, Joseph Priestley emigrated to **Northumberland, Pennsylvania**, where his family would be safe, and he would be near his friends, Ben Franklin and Thomas Jefferson. There he helped found the Unitarian Church of America and continued to do experiments.



Joseph Priestley had shared his results on dephlogisticated air with **Antoine Lavoisier** over dinner in October 1774. **Antoine Lavoisier** questioned Priestley's interpretation and later **reinterpreted** Priestley's **dephlogisticated air** in terms of **oxygenated air**. Lavoisier coined the word oxygen in 1778 from the Greek $\acute{o}\xi\upsilon\varsigma$, which means the sour taste of acids and $\gammaενήϛ$, which means “to produce.” At the time, Lavoisier's proposal of the properties and existence of oxygen did not seem all that strong since hydrochloric acid (HCl), which was certainly an acid, had no oxygen at all. Humphry Davy (1812) later showed that acids were more correctly defined by the presence of hydrogen rather than oxygen.



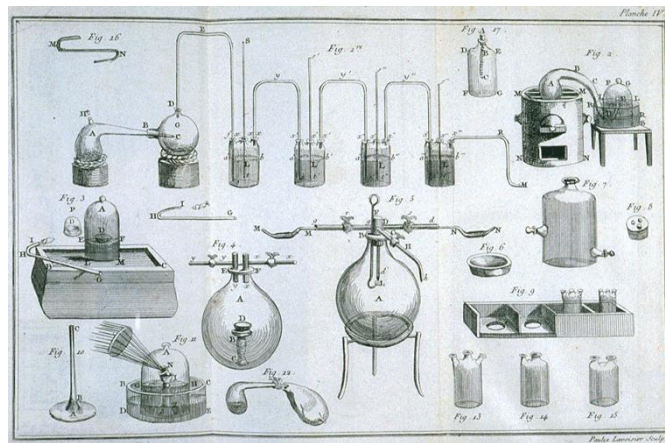
After weighing the reactants and products of various chemical reactions, Lavoisier proposed a chemical theory of the elements that stated all elements have a **positive mass** and thus calx was a combination of a metal and oxygen. When the calx was burned with a magnifying glass, it lost mass because it lost oxygen, not because it gained negative mass phlogiston. When a metal was heated, it gained mass as a result of combining with oxygen. Radiant energy provides the force to

overcome the electrostatic attractive force between a positively charged metal and negatively charged oxygen while thermal energy provides the force that allows a metal to **rust**, **burn**, or **combust** by combining with oxygen.

Lavoisier believed that **respiration** and **combustion** were **analogous** reactions in terms of chemistry. That is the **burning of food** is like the **burning of wood**. Lavoisier determined that in both cases, **combustion** results from the combination of **oxygen** with **carbon** and **hydrogen**.

Antoine Lavoisier relied on the relationship between light and life when he stated, *“In respiration, as in combustion, it is the atmospheric air which furnished oxygen...; but since in respiration it is...the blood, which furnishes the combustion matter, if animals did not regularly replace by means of food...that which they lose by respiration, the lamp would soon lack oil, and the animal would perish as a lamp is extinguished when it lacks nourishment.”*

According to Antoine Lavoisier, *“The proofs of this **identity of effects** in respiration and combustion are immediately deducible from experiment. Indeed, upon leaving the lung, the air that has been used for respiration no longer contains the same amount of **oxygen**; it contains not only **carbonic acid gas** but also much more **water** than it contained before it had been inspired.”*



That is, the formula for respiration of carbohydrate is:



Or in terms of glucose:



During combustion, the chemical energy in the reduced CH bonds is transformed into thermal energy, heat, or the product of temperature and entropy. Originally, it was thought that food powered the body by producing heat. After all human life is associated with warm bodies and death is associated with cold bodies.

We will see that, according to the **First Law of Thermodynamics**, we can transform the chemical energy of the CH bonds into the chemical energy of ATP when we consider combustion during respiration, and we can transform the chemical energy of the CH bonds into radiant energy when we consider combustion in candles. According to the **Second Law of Thermodynamics**, both processes increase entropy. The so-called reverse reaction of photosynthesis that decreases the entropy of the chemicals involved, still increases entropy overall when you take into consideration the transformation of light energy in the visible range into thermal energy in the infrared range.

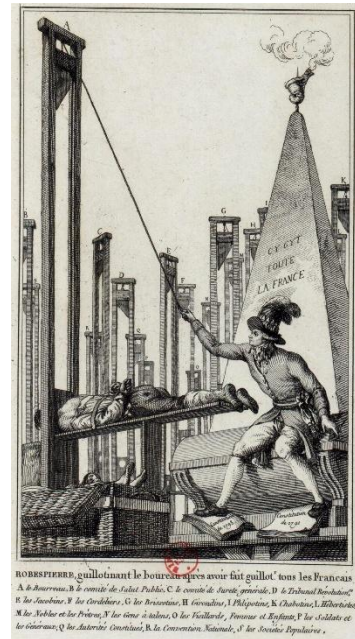
Antoine Lavoisier not only showed that **respiration** could be defined as a **combustion** process measured by the **uptake of O₂** and the **expulsion of CO₂ and H₂O**, but he and **Pierre Simon de Laplace** found using an **ice calorimeter**, that for equal outputs of CO₂, the same amount of heat was generated to melt the same amount of ice, by a respiring guinea pig and burning wood.



Like Joseph Priestley, Antoine Lavoisier never finished his experiments on respiration because he was “politically incorrect.” Lavoisier, who owned shares in a tax collection business, lost his head in a **guillotine** on May 8, 1794, during the French Revolution, which came to be known as the Reign of Terror.



In the words of [Maximilien Robespierre](#) (February 5, 1794) *“If the spring of popular government in time of peace is virtue, the springs of popular government in revolution are at once virtue and terror: virtue, without which terror is fatal; terror, without which virtue is powerless. Terror is nothing other than justice, prompt, severe, inflexible; it is therefore an emanation of virtue; it is not so much a special principle as it is a consequence of the general principle of democracy applied to our country's most urgent needs.*



It has been said that terror is the principle of despotic government. Does your government therefore resemble despotism? Yes, as the sword that gleams in the hands of the heroes of liberty resembles that with which the henchmen of tyranny are armed. Let the despot govern by terror his brutalized subjects; he is right, as a despot. Subdue by terror the enemies of liberty, and you will be right, as founders of the Republic. The government of the revolution is liberty's despotism against tyranny. Is force made only to protect crime? And is the thunderbolt not destined to strike the heads of the proud?”

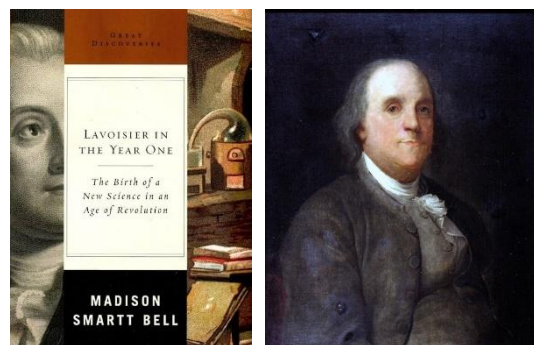
On December 19, 1793, Antoine wrote from prison to Marie:

“My dear one, you are giving yourself a great deal of trouble, and you are altering your health; yet I can do nothing to alleviate your lot. Be careful not to

sacrifice your health, for that would be the greatest misfortune. ... I have always enjoyed a happy life. You have made it so, and my thoughts follow you with the ultimate gratitude.”

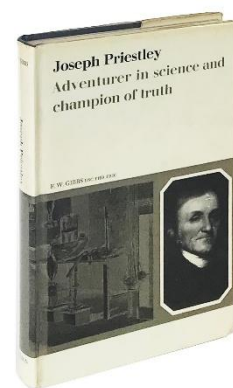
This letter is in the [Rare and Manuscript Collection](#) at Cornell.

Aside: Marie Lavoisier [painted a picture of Benjamin Franklin](#) based on a pastel created by Joseph-Siffred Duplessis.



After Antoine’s death, Madame Lavoisier married Count Rumford. We will see Antoine and Madame Lavoisier’s own books and the copper plates **Madame Lavoisier** made to illustrate *Traité Élémentaire de Chimie* when we go the Rare and Manuscript Collections.

In his book, *Joseph Priestley: Adventurer in Science and Champion of Truth*, F W. Gibbs (1965) wrote, “Throughout his life, Priestley had found strength in adversity, and even now, when everything seemed against him, he was able to say that he had never been more successful in his pursuits than in recent months. He saw hope on the political horizon, though he was still subject to public abuse.”



On July 17, 1800, Priestley wrote to his brother-in-law Mr. Wilkinson,
“My expenses have never been personal, but chiefly in the promotion of science and truth in general, to which I have devoted my time

*and whatever powers God has given me, and, therefore, I hope that the friends of science and of truth will afford me the assistance they have hitherto done. I am now as busy, and I hope as successful, as ever. My situation is in many respects favourable, especially with respect to leisure and quiet. **As to the abuse to which I am exposed here, as formerly in England, I rather rejoice in it than am concerned at it. It is what every man who does any good in the world must expect, and is much more than balanced by the approbation of persons of similar sentiments and views; and of such cordial friends I have never been destitute.** We shall rejoice together in a world in which the wicked will cease from troubling. To that state I now look forward more than to anything here, as I cannot be very distant from it, though, I thank God, my health is very good, and I may yet do something more before I leave this scene.”*

[‘It is what every man who does any good in the world must expect, and is much more than balanced by the approbation of persons of similar sentiments and views; and of such cordial friends, I have never been destitute.’](#)

One of those persons of similar sentiments and views was [Thomas Jefferson, who wrote to Priestley on March 21, 1801:](#)

It is with heartfelt satisfaction that in the first moments of my public action I can hail you with welcome to our land, tender to you the homage of its respect and esteem, cover you under the protection of those laws which were made for the wise and good like you, and disclaim the legitimacy of that libel on legislation which under the form of a law was for some time placed among them. As the storm

is now subsiding and the horizon becoming serene, it is pleasant to consider the phenomenon with attention. We can no longer say 'there is nothing new under the sun,' for this whole chapter in the history of man is new—the great extent of our republic is new—its sparse habitation is new—the mighty wave of public opinion which has rolled over it is new—but the most pleasing novelty is its so quickly subsiding over such an extent of surface to its true level again."

Roald Hoffmann (Cornell) and Carl Djerassi wrote a play in 2001 about the nature of discovery in terms of the role of Joseph Priestley, Carl Scheele, Antoine Lavoisier, and their wives. Discovery in science is often a result of the work of many people over time.



Scheele produced "[fire air](#)" before Priestley produced "dephlogisticated air," but Priestley published first. Lavoisier had a better understanding of its chemistry and named it oxygen. Davy found that the chemistry of acids, was not given by the possession of oxygen, from which oxygen got its name, but was given by the possession of hydrogen. Just who did discover oxygen?

Aside: [Fire retardants](#) spread on wildfires contain chemicals that combine with **oxygen** at high temperatures to reduce the amount of **oxygen** available to cause flames.

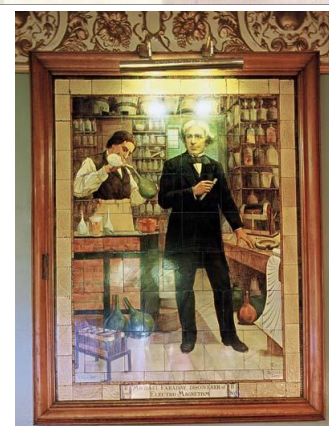


$(\text{NH}_4)_2\text{SO}_3$ (ammonium sulfite) + $\frac{1}{2} \text{O}_2 \rightarrow (\text{NH}_4)_2\text{SO}_4$ (ammonium sulfate)

On the other hand, along with lactose and pine rosin, oxygen is added in the form of [potassium chlorate](#) to form the bright white plume of smoke that signals the election of a new pope. (Black smoke is formed by giving more fuel and oxidizer. It is made from anthracene, sulfur, and potassium perchlorate).



Michael Faraday, Humphry Davy's assistant, gave a series of lectures on chemistry to children at the Royal Institution at Christmas time. His most famous lecture series is on ***The Chemical History of a Candle***, which he began by saying, "*I propose to bring before you, the Chemical History of a Candle....There is not a law under which any part of this universe is governed which does not come into play....There is no better, there is no more open door by which you can enter into the study of natural philosophy, than by considering the physical phenomena of a candle. I trust, therefore, I shall not disappoint you in choosing this for my subject rather than any newer topic, which could not be better, were it even so good.*" Today we will replicate to some degree his lecture series on ***The Chemical History of a Candle***. <http://www.rigb.org/christmas-lectures>
<http://www.rigb.org/visit-us/faraday-museum>



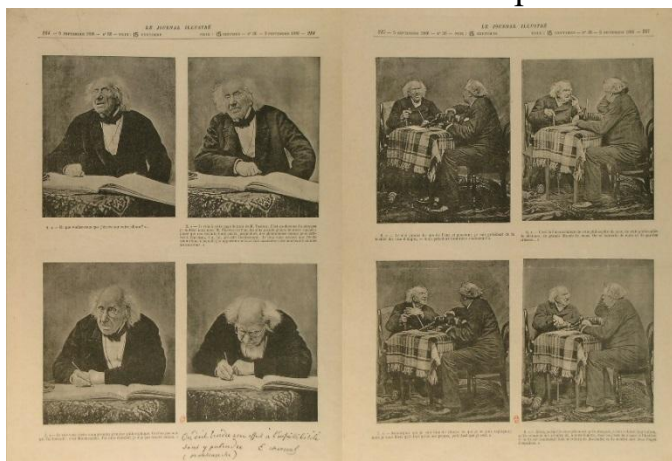
Look at all the candles in the room. They are made of malleable solids composed of water-**insoluble hydrocarbons, rich in CH bonds**, that are in the form of **hard fats** (ester of fatty acids and glycerol) or **waxes** (esters of fatty acids and fatty alcohols). One is made from **tallow**, one is made from **spermaceti**, one is made from **beeswax**, one is made from **bayberry wax**, and one is made from

paraffin. Each of them transforms the chemical energy of the hydrocarbon into radiant energy of light and heat after being ignited by a match. This **transformation**, which **disperses heat and gases** and thus **increases entropy**, is known as **combustion**. Consequently, the transformation is **irreversible** and must follow the **First and Second Laws of Thermodynamics**.

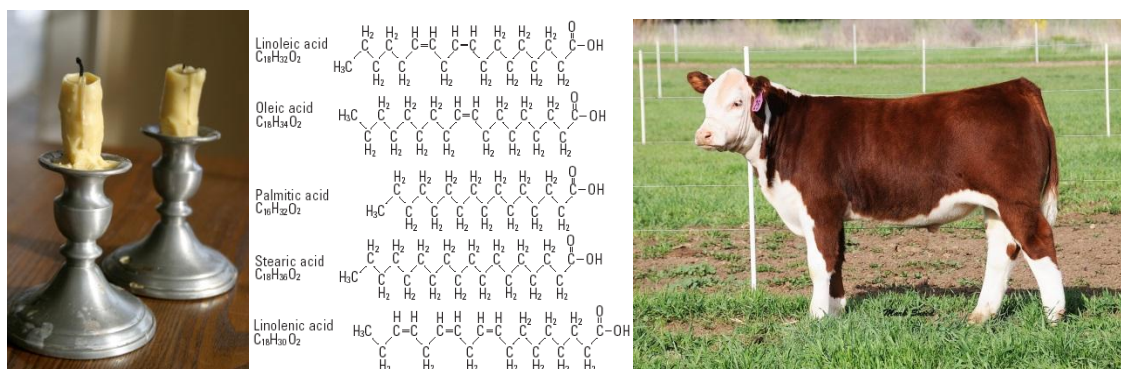
Fat is good in that it is a **very efficient form of energy storage** in warm-blooded animals since 1 gram of fat can store **9 Calories**, whereas 1 gram of carbohydrate or 1 gram of protein can only store 4 Calories. **One Calorie is equivalent to 4184 Joules**. If we stored the same amount of energy as carbohydrate (4 Calories/gram) or as protein (4 Calories/gram), we would weigh more than we do. Thus “*fat is good!*”



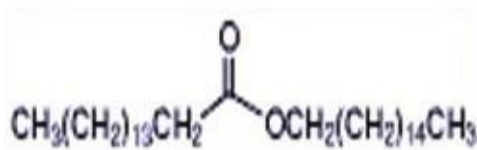
In the early 18th century, the photogenic **Michel Eugène Chevreul**, a chemist interested in the chemistry of soaps and candles, both of which were produced from natural products, determined that all fats are composed of glycerol and fatty acids. Fats, which were solid, had more stearic acid, and oils, which were liquid had more oleic acid. Stearic acid comes from *stear* (στέαρ), the Greek word for tallow, and oleic acid from the Latin cognate (*oliva*) of the Greek word *elaia* (ἐλαία) for olive. Palmitic acid comes from the word palm and was first isolated from palm oil.



We can use animal fat to make candles. Survivalists make candles out of tallow and they could eat them if it became necessary. Tallow rendered from beef suet is composed primarily of palmitic (16:0), stearic (18:0), and oleic (18:1) acids. **Tallow candles allow us to transform life into light.**



Spermaceti candles are made from a **wax** found in the heads of **sperm whales**. Spermaceti wax is composed primarily of the ester of **cetyl alcohol** and **palmitic acid** ($C_{15}H_{31}COO-C_{16}H_{33}$). **Spermaceti candles allow us to transform life into light**, and were the original candles used to define one **candlepower** in the British Metropolitan Gas Act of 1860. Whaling is outlawed and our spermaceti was made synthetically.



Bayberry candles are made from the green wax that is removed from the surface of the bayberry (*Myrica pensylvanica*). They have a wonderful smell. Bayberry wax is not actually a wax but more like plant tallow made of

triglycerides, composed of lauric acid (12:0), myristic acid (14:0), and palmitic acid (16:0). A true wax is an ester of a long chain alcohol and a fatty acid.

Bayberry candles allow us to transform life into light.



Beeswax is a true wax made from by **worker bees** by **chewing honey** made from **nectar**. In fact, the burning candles smell like honey. The bees use the wax to build honeycomb cells in a hive which the young are raised. The fresh wax is white, but it turns yellow when pollen oils and a resinous substance called propolis that is used to seal the hives is incorporated into the wax. Beeswax candles are chemically complex and are made of many components, including triacontanyl palmitate $\text{CH}_3(\text{CH}_2)_{29}\text{O}-\text{CO}-(\text{CH}_2)_{14}\text{CH}_3$ that allow us to **transform life into light**.



Historically or in parts of the world we do not see often, other organisms are used to turn life into light. For example, the **candlefish** (*Thaleichthys pacificus*) is composed of 15% fat. Indigenous people dry the fish and burn it as a candle!



Candlewood or **bogwood** formed about 4500 years ago when the climate in Ireland and Scotland changed, perhaps as a result of volcanic dust, by becoming wetter and cooler. The cool water-loving bog plants, including sphagnum moss, heathers, grasses, and sedges encroached on the oaks, pines, and



yews. In the newly formed bogs, the trees died due to lack of oxygen. The lack of oxygen in acidic waterlogged peat provided a reducing atmosphere that prevented the decomposition of the dead trees. Candle-wood or **fatwood** is harvested from the stumps of long leaf pine in Honduras and the southern United States.

As long as the **proportion of hydrocarbons is high**, whether, tallow, spermaceti, bayberry, beeswax, candlefish, or candlewood, **the chemical energy produced by life can be transformed into the radiant energy of light.**

The word candle comes from the Latin word *candere* which means “to shine.” Today we will study the **combustion process that occurs in a candle** and that gives rise to a **flame** in order to understand the chemistry of combustion and next time we will **compare and contrast** it to the **combustion process that takes place in living organisms**. Both combustion processes conform to the **First and**

Second Laws of Thermodynamics in that **one form of energy is transformed into another** and that the **transformation only occurs in one direction**. In general, combustion processes *out of the body* are hot enough to boil water ($> 100\text{ C} = 373\text{ K}$) whereas the combustion processes that take place *in the body* do so at ambient temperature ($37\text{ C} = 310\text{ K}$). **Enzymes** make it possible to perform combustion reactions at ambient temperatures.

The **photosynthetic transformation of radiant energy into chemical energy** that ultimately gives rise to all our food, and to the fats and waxes used in candles, can be looked at as the **closest thing to the “reverse process” of combustion although it is clearly not a reversal of the combustion process** and candlelight is not a result of light emission from chlorophyll (even in cucumbers). While the overall chemical formulae of combustion and photosynthesis make photosynthesis and combustion look like two words for the same reversible process, clearly and consistently with the **Second Law of Thermodynamics**, they are not reversible processes but each **irreversible** and **directional in time**.

In order to understand the combustion process that occurs in a candle, let's first characterize the flame itself. The unknown intensity of the candle flame can be measured with **Rumford's photometer** that compares the darkness of the shadow produced by the light in question to a standard candle. The test light is moved forward or backward until the shadows are equally dark. The relative intensity is calculated from the distances of the two lights to the screen using the inverse square law.

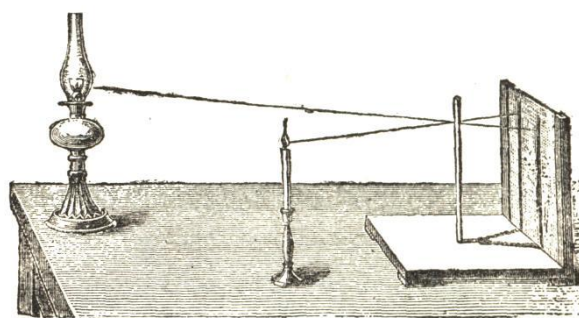
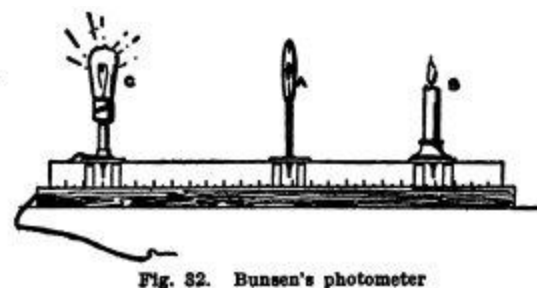


Fig. 262. RUMFORD'S SHADOW PHOTOMETER.

$$\text{Intensity of unknown light} = \text{Intensity of standard light} \frac{d_{\text{unknown}}^2}{d_{\text{standard}}^2}$$

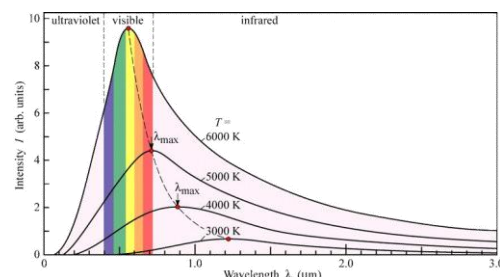
The unknown intensity of a candle flame can also be measured with **Bunsen's Photometer** where the distance between an unknown light from a piece of white paper with a grease spot is varied until the grease spot seems to disappear because it is equally illuminated on both sides. Again, the inverse square law, which we learned from geometrical optics and used to estimate the luminosity of the sun, is useful.



$$\text{Intensity of unknown light} = \text{Intensity of standard light} \frac{d_{\text{unknown}}^2}{d_{\text{standard}}^2}$$

The **temperature** of the flame can be estimated from its luminosity or intensity at the surface of the flame using the formula: $I(r)4\pi r_{\text{flame-sensor}}^2 = L_{\text{candle}} = 4\pi r_{\text{flame}}^2 \sigma T^4$, where the Stefan-Boltzmann constant can be derived from other more basic constants: $\sigma = \frac{2\pi^5 k^4}{15c^2 h^3}$. The measured **color temperature** of a candle flame is approximately **1850 K**.

Demonstration: Look at the flame through the spectroscope. Is the spectrum continuous or discrete? Although we cannot see the infrared wavelengths, the peak of the spectrum is closer to the red compared to the peak of the solar spectrum, which you can observe through the pinhole in the window. We can characterize the light emitted by the candle as a continuous spectral distribution produced by a “hot” **incandescent body** using **Max Planck's blackbody radiation law**:



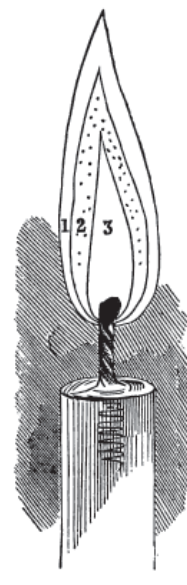
$$I(\lambda) = \frac{2\pi hc^2}{\lambda^5 (e^{hc/\lambda kT} - 1)}$$

where λ (in m) is the wavelength of light, $I(\lambda)$ is the intensity of a given wavelength at the surface of the flame, k is the Boltzmann constant ($k = 1.38 \times 10^{-23}$ J/K), c is the speed of light ($c = 2.99 \times 10^8$ m/s) and h is Planck's constant ($h = 6.626 \times 10^{-34}$ J s). Soon we will **identify the incandescent hot body** that gives rise to the continuous blackbody spectrum.

Look at the virtual image of the flame of a spermaceti candle through the 1 diopter ($f = 1$ m) and 2 diopter ($f = 0.5$ m) converging lenses aligned to form a 3-diopter compound lens ($f = 0.333$ m). A closer look shows that the flame consists of three parts, as described by Worthington Hooker. The **inner part** of the flame appears to be **dark and hollow**. The **wax is vaporized in the hollow, called region 3**, and passes into **region 2**, the borderland between the fuel in region 3 and the air in region 1.



The brightest part of the flame is caused by the **incandescence** of the **fine solid particles of carbon soot** in region 2. The **incandescent particles are also the cause of the blackbody spectral distribution**. This region is also very hot. As the carbon particles combine with oxygen, they move away from region 2 as carbon dioxide and water. As the soot particles turn to gas in region 1, the flame dims compared with region 2. The major locus of **heat** generation during the combustion process occurs in region 2 where **the fuel and the air come together**. The highest temperatures however are in the blue region, where the oxygen concentration is high and most of the chemical energy is converted to heat and not light.



What happens to the candle over time? Assuming time exists, the fact that candles get shorter over time as they use up their fuel source made possible **candle clocks**, which are among one of the most ancient timekeepers made by humans. The fact that candles get shorter over time also made **courting candles** possible. Legend has it that in the 16th -19th centuries, courting candles were lit by a girl's father to set a time limit on how long she could spend with a suitor. The suitor could stay until the courting candle burnt to the metal at the top of the candle holder—although the father could change the height of the candle based on how he felt about the suitor.



A candle gets shorter as the fuel gets used up. How does the fuel get to region 2 where it will combine with the air? In order to understand the passage of fuel to the combustion zone, let's look at the flame produced by olive oil burning lamps, which have been used at least since biblical times when the Israelites were commanded in Exodus 27:20 *“to bring you clear oil of pressed olives for the light so that the lamps may be kept burning.”*



When we light the wick, the flame travels down the cotton to the olive oil, where the flame is put out. The **liquid oil** itself does *not* burn while the flame does continue to burn above the oil at the expense of the oil. The oil can only burn when it gets to the top of the wick where it is vaporized. While the oil is initially vaporized by the heat from the match, the flame of the lamp takes over the role of vaporizer for as long as the lamp is lit. That is, some of the energy of the oil must be used to vaporize the oil.

Heat + liquid → vapor

How does the oil get to the top of the wick? The oil gets to the top of the wick by **capillary action**. Capillary action is a result of **electrostatic force of**

attraction between the molecules in the liquid and the surface of the wick that is stronger than the attractive **force of gravity** towards the earth.

The greater the surface area of the wick, the greater is the amount of electrostatic attraction and the greater the amount of capillary action. The surface area is increased by using many thin treads of cotton to form the wick. Multiple thin filaments are excellent at wicking, and they can wick bacteria from a non-sterile area such as the vagina to an axenic area such as the uterus to cause pelvic inflammatory disease (PID). This was the **unintended consequence** of the filaments attached to the Dalkon shield, an **intrauterine device (IUD)** that caused pelvic inflammatory disease (PID). What is true and good for candles is true and bad for IUDs.

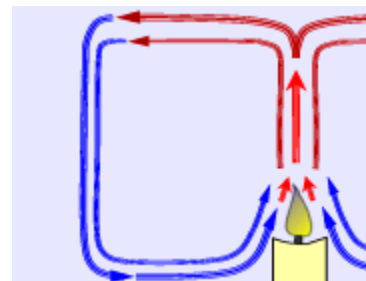


At the top of the wick of an oil lamp, the vaporized oil molecules **collide** with each other. If the molecules are hot enough, they break each other's bonds when they collide into each other and the molecules literally fragment. At the bottom of the flame, you will see a little **blue light** that results from the chemiluminescence of the C_2 and CH fragments, which will combine with sufficient oxygen at the **bottom of the flame** to form invisible molecules of carbon dioxide and water without forming more complicated soot particles. The blue region is the **hottest** part of the flame. **Above the flame**, the fragments cannot become invisible quick enough because there is not enough available oxygen. Consequently, they combine with each other and soot particles form. It is these soot particles that **incandesce** to turn the chemical energy of the CH bonds of olive oil into the radiant blackbody spectral distribution of lamp light. The soot molecules become invisible when they turn into carbon dioxide and water as they come in contact with oxygen in region 1.

Let's look at a candle, where the fuel is a solid. The flame melts the solid hydrocarbon into a cup-containing liquid. The **transformation** of **solid** fuel into a **liquid** fuel requires **heat** and some of the chemical energy of the solid fuel is used to drive this **solid-to-liquid phase transition**.



The flame also causes the current of air to move upward as a result of the flame heating the air since the heated air expands and becomes less dense. This results in a low-pressure region above the flame and the air moves from regions of high pressure to regions of low pressure. The **upward flow of air cools the sides of the candle** and makes a cup to hold the melted wax that is not cooled by the air.



The candle flame, like the oil lamp flame, is separated from and is above the liquid wax. The temperature at which the candle wax melts (transformed from a solid to a liquid) is known as its **melting point**. The melted hydrocarbon, like the olive oil, also moves up the wick against the force of gravity to make a flame by **capillary action**. The greater the number of strands and the thinner they are in a wick, the greater the surface area, the greater the electrostatic attraction, and the greater the rate of ascent of the liquid. Lower molecules are attracted to the climbing molecules and also get pulled up to the flame where the liquid hydrocarbon is evaporated, vaporized, and turned into a gas. The temperature at which the liquid wax is vaporized (transformed from a liquid to a gas) and it is able to ignite, and burn is known as its **flashpoint**. The transformation of liquid fuel into vapor fuel requires heat and some of the chemical energy of the solid fuel is used to drive this liquid-to-vapor phase transition.

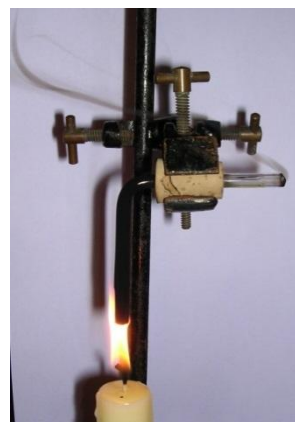
Wax	Approx. formula	H/C	melt point (F)	flashpoint (F)
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Beef Tallow	$C_{16}H_{32}O_2$	2	104	512
Bayberry	$C_{12}H_{24}O_2$	2	118	230
Beeswax	$C_{15}H_{31}COOC_{30}H_{61}$	2	144-147	399.9
Paraffin	$C_{31}H_{64}$	2.06	115-154	395
Spermaceti	$C_{32}H_{64}O_2$	2	210	500

Vaporized hydrocarbon is a fuel that can burn. You can see this by blowing out the candle and looking at the vaporized fuel as a white smoke. You can light this smoke two or three inches above the wick. When the **vapor ignites it will cause the wick to relight.**



We can show that this **vaporized fuel** is in region 3, the **dark inner hollow of the flame**. We can examine the dark region 3 by inserting a bent glass tube into this region. The vapor that comes out of the end of the tube can be ignited and the flame of the candle can be produced at a distant place. When I raise the tube to **region 2, the bright part of the flame, there is nothing to ignite.** In region 2, the vapor has already been burned, and the result is the production of a black smoke that is composed of soot particles. Region 2 is where the soot formed from the combustible vapor makes incandescent light.



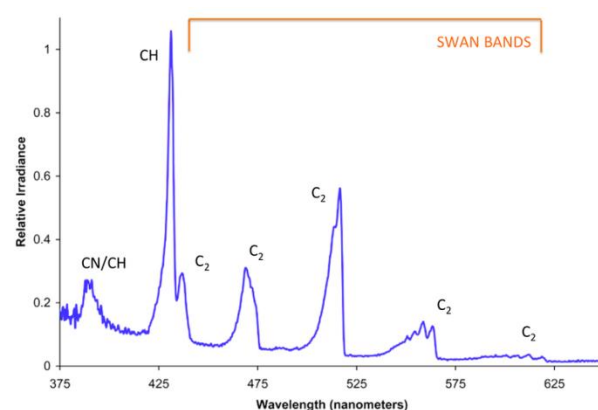
We can see, in an unusual way, where the soot particles that incandesce are localized in the flame. When the candle is illuminated by the lamp of a slide projector, one sees that the brightest region of the flame casts a shadow on the screen. Thus, **the soot particles, which are opaque and cast a shadow are in the brightest region of the flame**. Surrounding the dark shadow is a lighter shadow and surrounding that is a bright region that is a diffraction artifact resulting from the light that diffracts from the particles that make the shadow. (Next time you are looking at your own shadow on a sunny day you will see that your shadow too is surrounded by a bright halo).



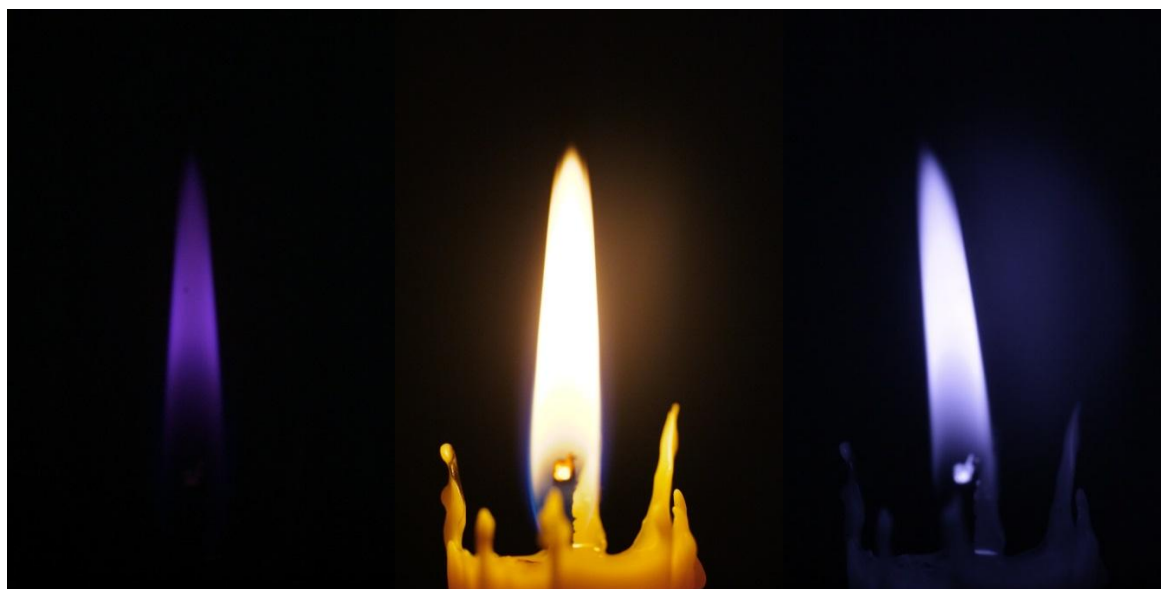
In the middle of the flame is the combustible vapor and on the outside of the flame is the oxygen that is necessary to combust the vapor. **In between these two regions is the reaction zone where the oxygen and the vapor interact to form incandescent soot particles and heat**. This is the hottest region of the flame *above* the wick. Region 2 can be visualized with a piece of paper because it is hot enough to produce a ring on a piece of paper that results from the caramelization of the top of the filter paper and soot deposited on the bottom of the filter paper.



In region 3, where oxygen is limiting, the hot vaporized fuel molecules collide with each other and break into smaller molecules such as C_2 and CH . This **oxygen-limited process** is known as **pyrolysis**, which means heat-induced breakup in the absence of oxygen. It also results in the production of free radicals. The newly formed

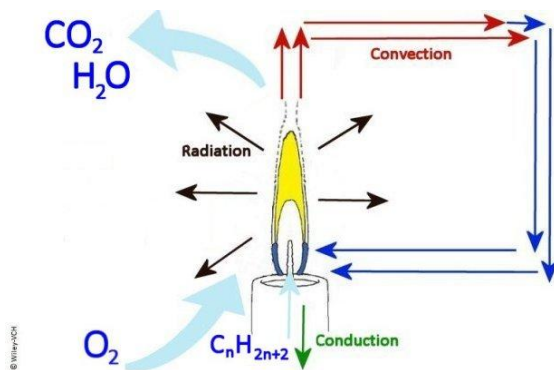


molecules transform some of their excitation energy into light energy in a process known as **chemiluminescence**. Chemiluminescence of C_2 and CH gives rise to the blue in the flame. **The blue light exists throughout the flame** but is dimmer than the continuous spectral distribution of light resulting from **incandescence**. Below are pictures of a candle flame taken with quartz lens and a filter that only lets ultraviolet light pass (l), a filter that only lets visible light pass (c) and a filter that only lets infrared light pass (r).



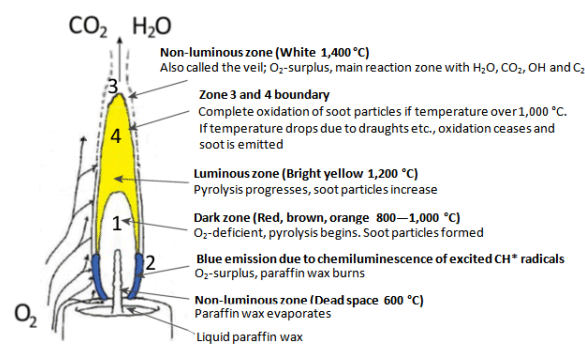
In the absence of oxygen, the pyrolytic fragments get a chance to form complicated soot particles in region 2 that can incandesce. When these soot particles are exposed to enough oxygen as they reach region 1, they turn into the invisible molecules of carbon dioxide and water, causing region 1 to be less bright than region 2.

At the bottom of the flame, the pyrolytic fragments will quickly combine with the readily available oxygen to form invisible molecules of carbon dioxide and water without forming more complicated soot particles which would incandesce. Thus, the chemical energy is mostly converted into thermal energy. Above the flame, the pyrolytic fragments cannot become invisible quick enough because there is not enough available oxygen. Consequently, soot particles form. It is these soot particles that incandesce to turn the chemical energy of the CH bonds of the fuel into the radiant blackbody spectral distribution of candlelight. The soot molecules become invisible when they turn into carbon dioxide and water as they come in contact with oxygen.



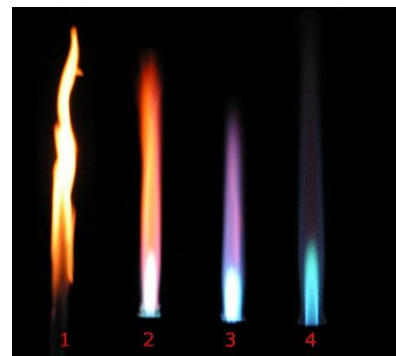
Fresh air is necessary for combustion to proceed. When we place a candle in a bell jar, the flame is extinguished after a minute or two.

Since the heat of the candle results in an upward draft of fresh oxygen-containing air, the **bottom of the reaction zone** has the most oxygen resulting in the complete combustion of the products of pyrolysis without the intermediate production of soot. In this region, **chemiluminescence** is *not* overwhelmed by the **incandescence of the soot particles** and the flame appears **blue**.



© Wiley-VCH
Source: K. Roth, Chemistry of the Christmas Candle — Part 2, DOI: 10.1002/chem.201000146

The flame in a **gas stove, propane torch, or a Bunsen burner**, has sufficient oxygen for the oxidation of the products of pyrolysis without the intermediate formation of soot. **Under these conditions, more energy is emitted as heat than as visible light.** The flames shown on the right result from increasing availability of oxygen.



Complete combustion without producing sooty intermediates allows us to cook our food efficiently and cleanly on a gas stove, but there is not enough light produced by this process to provide light. Ever think that soot could be romantic?



Soot production occurs when there is not enough oxygen to burn the initial pyrolysis products directly into carbon dioxide and water. The perfect amount of incomplete combustion produces a yellowish flame. The **wick** too is important in determining the quality of the flame. Too little combustion occurs when a wick is so big that it delivers too much fuel for the amount of oxygen available, and a black sooty smoke is produced. When the wick is too small, combustion is also limited because there is not enough fuel.

Incandescence results from the oxidation of soot particles produced by the incomplete combustion of the products of pyrolysis. **Any finely divided solid, which has a large surface to volume ratio, can incandesce.** Each *Lycopodium* spore vaporizes producing soot particles that become incandescent when they oxidize. **The large surface to volume ratio maximizes the amount of oxygen that can interact with the spore and minimizes the amount of heat that can be carried away. The result is the transformation of chemical energy into light.** The incandescence produced by ignited *Lycopodium* spores was used to produce a **flash of light by photographers** in the early days of photography. *Lycopodium* spores are used by magicians to create a clean-burning jet of fire known as dragon's breath.



Iron particles (Iron powder, but not iron oxide powder) also become **incandescent** when placed in a flame. Incandescence occurs because their large **surface to volume** ratio maximizes the amount of oxygen that can interact with the powdered iron but minimizes the amount of heat that can be carried away. A **cast iron skillet** does not incandesce because it has a much smaller surface to volume ratio than the iron powder. Unlike the *Lycopodium* spores, the iron powder remains

a solid and incandesces without vaporizing. Iron has a high affinity for oxygen. We often see rust. In order for iron to rapidly bind to oxygen though, it has to be **heated** to high temperatures or acted on **enzymatically** at ambient temperatures.

Incandescent iron can be seen when you hit a nail with a hammer. The nail becomes hot enough to combine with oxygen and bits of iron fly off due to the explosion. The spark is incandescent iron oxide formed by the burning of iron!

Electrical energy can be converted into thermal energy when a 9V battery is touched to the finely spun iron in **steel wool** that has been fluffed up. This can be used to make a fire when camping. <https://www.youtube.com/watch?v=xbwNJhJwnSs>



Likewise, on a camping trip, mechanical energy can be converted into thermal energy with a magnesium fire starter. <https://www.youtube.com/watch?v=Cz7md8ArN60>



Incandescent iron is formed by **flint and steel lighters**. The incandescent iron oxide particles produced by rubbing [flint on steel](#) can be used to ignite **charcloth** (pure carbon) and start a fire. The charcloth is made by heating cotton or linen in limited oxygen in a tinderbox for about five minutes. This lowers the ignition temperature of the fabric by eliminating the volatile components that would drain away heat necessary for volatilizing these components from the fire.



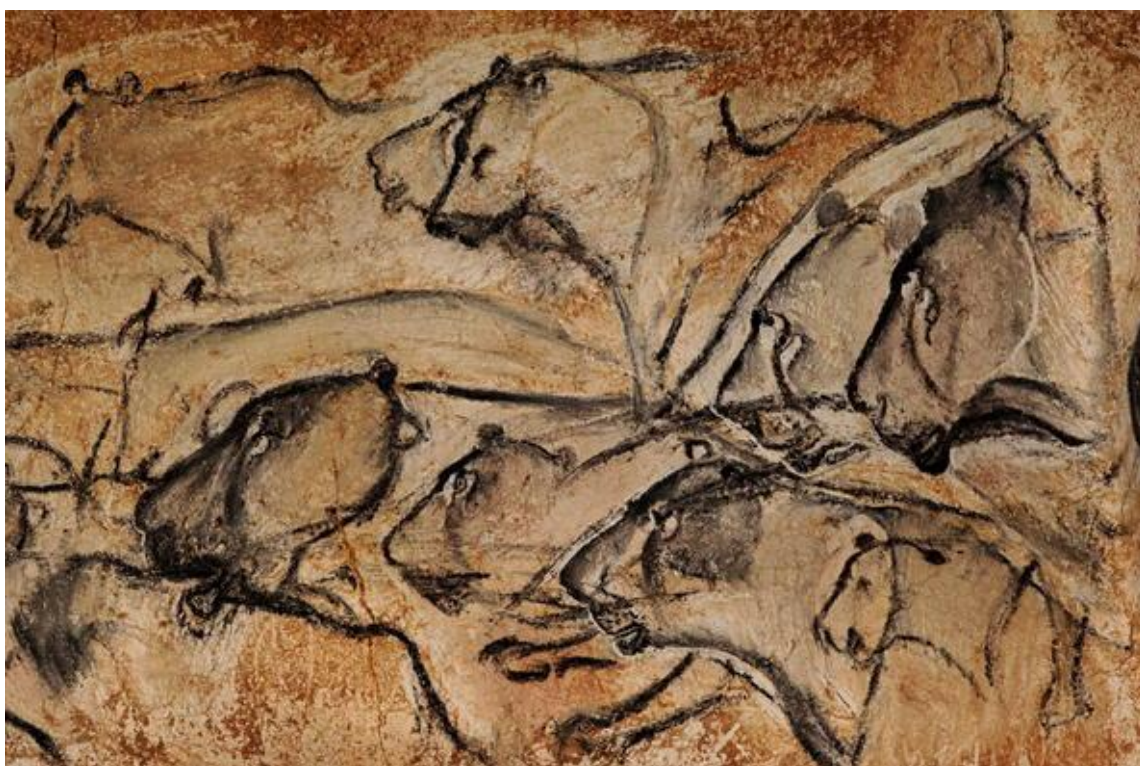
This process of heating wood ($C_{42}H_{60}O_{28}$) in the absence of oxygen (**pyrolysis**) is used to make **charcoal** ($C_{16}H_{10}O_2$). The same process is used to make **biochar**, which can be used to amend soils.



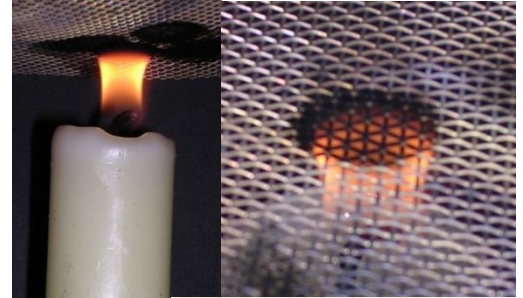
The carbon-rich solid charcoal has too little oxygen to form a flame, which is why **charcoal glows or incandesces** while **wood burns or produces a flame**.



Approximately 30,000-32,000 years ago, Cro-magnon man used charcoal to produce beautiful drawings in the caves of Grotte Chauvet Pont d'Arc, which was rediscovered by moderns in 1996.



The surface to volume ratio of an **iron mesh** causes it to carry off the heat of a flame without incandescing white. The decrease in the temperature prevents the combustion of soot particles and the flame cannot go through the mesh and is quenched. This is why a wire mesh is placed in front of your fireplace and around a **Davy safety lamp** invented by **Humphry Davy**, Michael Faraday's predecessor at the Royal Institution and used by miners to see in coal mines.



Lord Byron wrote about Davy in his epic satire, *Don Juan* (*Canto I*):

CXXXII

This is the patent age of new inventions

For killing bodies, and for saving souls,

All propagated with the best intentions;

***Sir Humphry Davy's lantern, by which coals
Are safely mined for in the mode he mentions,***

*Tombuctoo travels, voyages to the Poles,
Are ways to benefit mankind, as true,
Perhaps, as shooting them at Waterloo.*



Davy's Coat of Arms reads, *I constricted the fire: Life is safe.*

<http://www.rigb.org/our-history/iconic-objects/iconic-objects-list/davy-lamp>



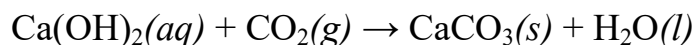
The products produced by a candle flame can be captured in a **fire balloon**. They are *not* sooty, but transparent or invisible. The soot particles are formed as a result of incomplete combustion. Incandescence does not continue when there is sufficient oxygen. So, when there is sufficient oxygen, as there is in region 1 at the margin of the flame, the carbon that makes up the soot is transformed into something else that is **gaseous and invisible**.



One of the products that formed in the flame is **water**. We can condense the gas produced by the candle flame (or from our breath) on the bottom of a dish containing ice and salt into a liquid to see if it is water. Water is the only gas that will become a liquid close to 0 C. Water is not initially in the candle. **The water formed by combustion is made of two substances, one provided by the candle, and one provided by the air.**

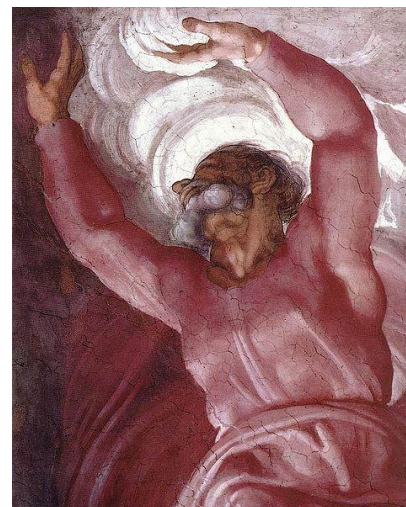
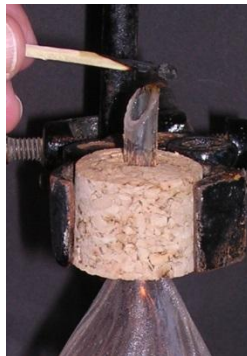


The other product that is formed in the flame is **carbon dioxide**. Carbon dioxide can be tested with **limewater**, which is an aqueous solution of calcium hydroxide. Limewater was used as a whitewash in **buon fresco painting**. Historically, it is known as the paint whitewash. The chemical reaction of carbon dioxide gas with aqueous limewater results in the production of solid calcium carbonate and water. A cloudy appearance of the limewater solution caused by the calcium carbonate indicates that the sample gas, whether from the candle or our breath, contains carbon dioxide.

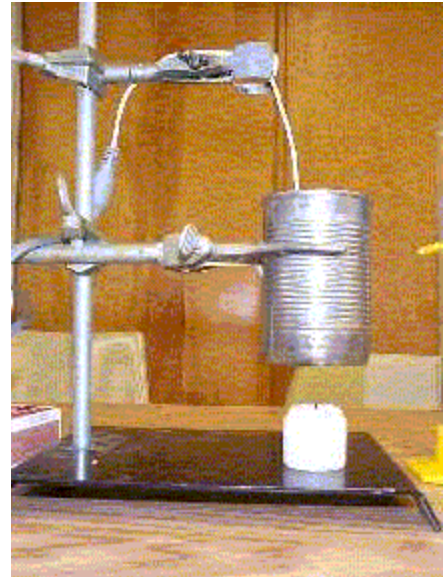


Carbon dioxide is not initially in the candle. **The CO₂ formed by combustion is made of two substances, one provided by the candle and one provided by the air.**

Carbon dioxide can also be identified by testing a gas' ability to **extinguish fire**. The gas emitted by the candle flame is able to extinguish a match. Carbon dioxide acts a **fire extinguisher** by displacing oxygen and can be used in putting out fires where there is no source of oxygen.



Now I want to show you that an unsalted dry roasted peanut can be used for a fuel to make a flame. We can also estimate the amount of thermal energy it produces when it burns by placing the burning peanut under a tin can that has been filled with 0.1 kg of water (m). After weighing the peanut (0.5-1 gram), we measure the temperature of the water with an **infrared thermometer probe**. Then we light the peanut and measure the rise in the temperature (ΔT) of the water. The amount of heat produced by the peanut is given by the following formula:



$$\text{Thermal energy} = c m \Delta T$$

where c is the heat capacity of water and is equal to 4186 J/(kg C) or 1 Calorie/(kg C). The ratio of 4.186 to 1 is the ratio of the **mechanical equivalent of heat** to the specific heat determined by **James Joule** with his **paddle wheel** in the **basement of the brewery**. The thermal energy of a peanut measured in this crude way is about 4186 J or 1 Calorie. If the difference in the initial weight and final weight of the peanut was 0.5 g, then the energy content of the peanut would be about 2 Calories/gram. This is an underestimate since much of the heat is radiated away by the metal can. How could we be more accurate?

Next time we will look at **ancient fossils** found in the **coal beds** of America to get an idea of fossil fuels and of geological time. The plant fossils still contain the carbon that they fixed photosynthetically so many years ago. The fossil fuels are mostly and most likely hydrocarbon rich deposits of ancient organisms that we

combust to release thermal energy today. We will also discuss more about respiration in living organisms that occurs at ambient temperatures.

Michael Faraday ended his lecture series on *The Chemical History of a Candle* by saying, “...you see the analogy between respiration and combustion is rendered still more beautiful and striking. Indeed, all I can say to you at the end of these lectures (for we must come to an end at one time or other) is to express a wish that you may, in your generation, **be fit to compare to a candle; that you may, like it, shine as lights to those about you; that, in all your actions, you may justify the beauty of the taper by making your deeds honourable and effectual in the discharge of your duty to your fellow-men.**”



[John Ondrasik](#) wrote a song about how Ukrainian [President Zelenskyy](#) shines like a flame and makes us think!

On May 28, 1850, Charles Dickens wrote to Michael Faraday:

“Dear Sir,

I take the liberty of addressing you as if I knew you personally; trusting that I may venture to assume that you will excuse that freedom.

It has occurred to me that it would be extremely beneficial to a large class of the public, to have some account of your late lectures on the breakfast-table, and of those you addressed, last year, to children. I should be exceedingly glad to have some papers in reference to them, published in my new enterprise “Household Words.” May I ask you whether it would be agreeable to you,—and if so, whether you would favor me with the loan of your notes of those lectures for perusal?...

Your faithful Servant,

Charles Dickens.”



Dickens used Faraday's lecture notes to write a story called the *Chemistry of a Candle* for families to read around the breakfast table

(<http://www.victorianweb.org/authors/dickens/faraday3.html>).

Faraday's candlestick has been on exhibit at the Charles Dickens Museum. <https://dickensmuseum.com/blogs/charles-dickens-museum/michael-faradays-candlestick>



Light, to the **luminaries** who created the **Enlightenment** such as

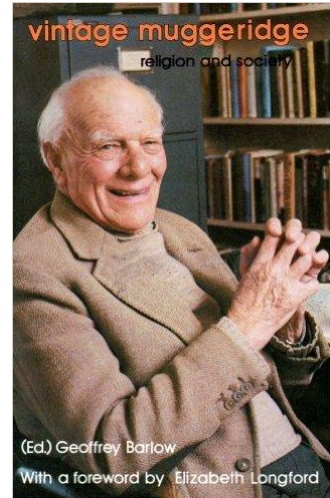
Thomas Jefferson, is freedom from ignorance. As **Thomas Jefferson** said in a letter to Tench Coxe in 1795, “***Light and liberty go together***” and in a letter to Cornelius Camden Batchly in 1822, “***I look to the diffusion of light***



and education as the resource most to be relied on for ameliorating the condition, promoting the virtue, and advancing the happiness of man.”

In an address entitled, [*The Blessing of Liberty and Education*](#), given at the dedication of a school for black children in Manassas, Virginia, [**Frederick Douglass**](#) (1894) said, “***There is fire in the flint and steel, but it is friction that causes it to flash, flame and burn, and give light where all else may be darkness. There is music in the violin, but the touch of the master is needed to fill the air and the soul with the concord of sweet sounds. There is power in the human mind, but education is needed for its development.***”

Education may not always be “*relied on for ameliorating the condition, promoting the virtue, and advancing the happiness of man.*” According to **Malcolm Muggeridge**, “*So the final conclusion would surely be that whereas other civilizations have been brought down by attacks of barbarians from without, ours had the unique distinction of training its own destroyers at its own educational institutions, and then providing them with facilities for propagating their destructive ideology far and wide, all at the public expense. Thus did Western Man decide to abolish himself, creating his own boredom out of his own affluence, his own vulnerability out of his own strength, his own impotence out of his own erotomania, himself blowing the trumpet that brought the walls of his own city tumbling down, and having convinced himself that he was too numerous, labored with pill and scalpel and syringe to make himself fewer. Until at last, **having educated himself into imbecility**, and polluted and drugged himself into stupefaction, he keeled over—a weary, battered old brontosaurus—and became extinct.*”

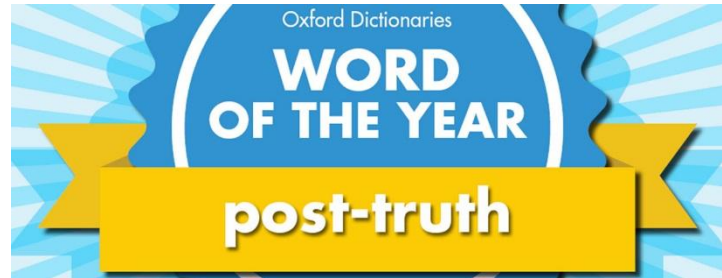


In a speech entitled, *Observation on Mental Education*, given by Faraday (May 6, 1854), who believed in one truth and that the God of the Bible was also the God of Nature wrote, “*I take courage, Sir, from your presence here this day, to speak boldly that which is upon my mind. I feared that it might be unpleasant to some of my audience, but as I know that your Royal Highness [Prince Albert] is a champion for and desires the truth, I will believe that all here are united in the same cause and therefore will give utterance, without hesitation, to what I have to say regarding the present*



condition of Mental Education... the book of nature, which we have to read, is written by the finger of God.”

In **post-modern** times, when objective truth no longer exists, the **Oxford English Dictionary** proclaimed “*post-truth*” to be the Word of the Year for 2016. Post-truth is “*an adjective defined as ‘relating to*



or denoting circumstances in which objective facts are less influential in shaping public opinion than appeals to emotion and personal belief.”

<https://en.oxforddictionaries.com/word-of-the-year/word-of-the-year-2016>

I worry about the slippage from the emphasis on *lines of reasoning* to get to the *truth* and *talking points that substitute for the truth*. For example, in June 2020, [Stephen Colbert asked Sen. Kamala Harris](#) about what she [said](#) in a primary debate for president.

Colbert: *How do you go from being such a passionate opponent on such bedrock principles for you, and now you guys seem to be pals?*

Harris: *It was a debate.*

Colbert: *Not everyone landed punches like you did, though.*

Harris (laughing): *It was a debate.*

Colbert: ***So you didn't mean it?***

Harris: *It was a debate.*

In our post-truth world, let **us** go through life considering life to be meaningful and consequently, saying what we mean and meaning what we say.

In a post-truth world, as Karl Popper (1983) says in *Realism and the Aim of Science*, “[t]here is no truth in science: there is only utility. Science is unable to enlighten our minds: it can only fill our bellies.”

Hans Christian Anderson wrote a fairy tale and a short story that relates to today’s lecture. Hans Christian Anderson’s first fairy tale, which was discovered in 2012, was entitled, ***The Tallow Candle***.



“It sizzled and fizzled as the flames fired the cauldron. it was the Tallow Candle’s cradle - and out of the warm cradle came a flawless candle; solid, shining white and slim it was formed in a way that made everyone who saw it believe that it was a promise of a bright and radiant future – promises that everyone who looked on believed it would really want to keep and fulfil.

The sheep – a fine little sheep – was the candle’s mother, and the melting pot its father. Its mother had given it a shiny white body and an inkling about life, but from its father it had been given a craving for the flaming fire that would eventually go through its marrow and bone and shine for it in life.

That’s how it was born and had grown; and with the best and brightest anticipation cast itself into existence. There it met so many, many strange creations that it became involved with, wanting to learn about life – and perhaps find the place where it would best fit in. But it had too much faith in the world that only cared about itself, and not at all about the Tallow Candle. A world that failed to understand the value of the candle, and thus tried to use it for its own benefit, holding the candle wrongly; black fingers leaving bigger and bigger blemishes on its pristine white innocence which eventually faded away, completely covered by the dirt of a surrounding world that had come much too close; much closer than the candle could endure, as it had been unable to tell grime from purity – although it remained pristine and unspoiled inside.

False friends found they could not reach its inner self and angrily cast the candle away as useless.

The filthy outer shell kept all the good away – scared as they were to be tainted with grime and blemishes – and they stayed away.

So there was the poor Tallow Candle, solitary and left alone, at a loss at what to do. Rejected by the good, it now realised it had only been a tool to further the wicked. It felt so unbelievably unhappy, because it had spent its life to no good end – in fact it had perhaps sullied the better parts of its surroundings. It just could not determine why it had been created or where it belonged; why it had been put on this earth – perhaps to end up ruining itself and others.

More and more, and deeper and deeper, it contemplated – but the more it considered itself, the more despondent it became, finding nothing good, no real substance for itself, no real goal for the existence it had been given at its birth. As if the grimy cape had also covered its eyes.

But then it met a little flame, a tinder box. It knew the candle better than the Tallow Candle knew itself. It came closer and there was bright expectation in the candle – it lit and its heart melted.

*Out burst the flame, like the triumphant torch of a blissful wedding. Light burst out bright and clear all around, bathing the way forward with light for its surroundings – its true friends – who were now able to **seek truth in the glow of the candle**.*

The body too was strong enough to give sustenance to the fiery flame. One drop upon another, like the seeds of a new life, trickled round and chubby down the candle, covering the old grime with their bodies.

They were not just the bodily, but also the spiritual issue of the marriage.

And the Tallow Candle had found its right place in life – and shown that it was a real candle, and went on to shine for many a year, pleasing itself and the other creations around it.”

<https://www.youtube.com/watch?v=IBk9qSxn390>

Hans Christian Andersen’s first short story was entitled, *The Tinder Box*.

<https://www.youtube.com/watch?v=GFURBFg1VoA>

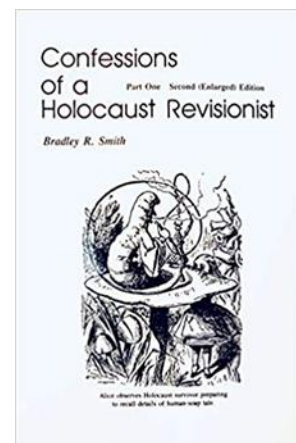


Fires are not only illuminating, sometimes that can be obscuring, casting a dark shadow into the future. We discussed the burning of the library in Alexandria. **Book burning** also occurred in 213 BC during the Qin Dynasty in China, where poetry, history, and philosophy books were considered the most dangerous because they could stimulate the imagination and readers would realize there were alternatives to the current regime. This kind of censorship or cancelation also took place in 34 **universities** in Nazi Germany on [May 10, 1933](#), when [students and professors burned books](#) that were considered dangerous because they presented non-Nazi history and culture.



Ray Bradbury wrote about the burning of books. <https://www.secret-satire-society.org/wp-content/uploads/2014/01/Ray-Bradbury-Fahrenheit-451.pdf>

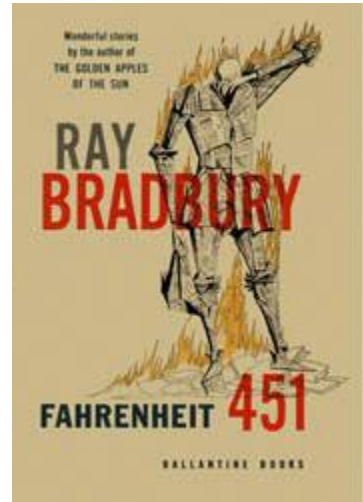
Katherine Bishop's article entitled, *Ads on Holocaust 'Hoax' Inspire Campus Debates* published in the *New York Times* on December 23, 1991, describes Bradley R. Smith, a holocaust denier and founder of the Committee for Open Debate on the Holocaust. Smith thinks that the Jews who were confined to work camps died of typhus and other diseases that became rampant near the end of the war. According to Smith, the gas chambers, to the extent they existed at all, were used only as life-saving fumigation chambers to delouse clothing and prevent disease. If you ask me, Smith is not telling the objective truth.



Perhaps is is not interested in the truth at all, but only in his own ideology. Smith describes his day like so: *"I get up in the morning, I go to the typewriter and write down the simplest things which have the most tremendous implications... I write about how all the historians are wrong, how the scholars and the intellectuals and the universities are all wrong and how I'm right."* Should

college newspapers print this revisionist “history”? Should Bradley’s book be burned?

The temperature that paper burns is **451 degrees Fahrenheit**, which explains the title of Ray Bradbury’s book (1953), *Fahrenheit 451*, which describes a dystopia where people stopped reading books for two reasons. One because they found lines in them offensive, and two because they didn’t have a long enough attention span to read a book. Eventually books were outlawed and burned by the “firemen” who worked for the state. Bradbury wrote *Fahrenheit 451* to describe a world without books because he was afraid that television, which was the smartphone of 1953, would kill people’s interest in reading books, turn them into morons, and substitute having knowledge with being bombarded with factoids. <https://www.laweekly.com/news/ray-bradbury-fahrenheit-451-misinterpreted-2149125>;



http://www.raybradbury.com/images/video/about_freeDOM.html According to Bradbury, “*I am a preventor of futures, not a predictor of them. I wrote Fahrenheit 451 to prevent book-burnings, not to induce that future into happening, or even to say that it was inevitable.*”

<http://community.seattletimes.nwsourc.com/archive/?date=19930312&slug=1689996>

“The problem in our country isn’t with books being banned, but with people no longer reading. Look at the magazines, the newspapers around us - it’s all junk, all trash, tidbits of news.”

“You don’t have to burn books to destroy a culture. Just get people to stop reading them.”



Question: *How does the story of Fahrenheit 451 stand up in 1994?*

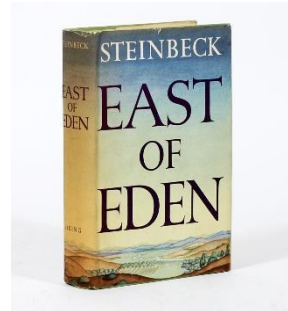
R.B.: *It works even better because we have political correctness now. Political correctness is the real enemy these days....*

Even more depressing is that I foresaw political correctness 43 years ago.

<http://diginole.lib.fsu.edu/islandora/object/fsu:168044/datastream/PDF/view>

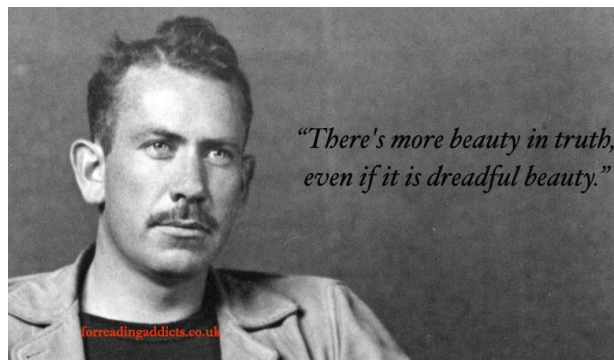
Speaking of books, John Steinbeck (1952) wrote in *East of Eden*:

And this I believe: that the free, exploring mind of the individual human is the most valuable thing in the world. And this I would fight for: the freedom of the mind to take any direction it wishes, undirected. And this I must fight against: any idea, religion, or govern-ment which limits or destroys the individual. This is what I am and what I am about. I can understand why a system built on a pattern must try to destroy the free mind, for this is one thing which can by inspection destroy such a system. Surely I can understand this, and I hate it and I will fight against it to preserve the one thing that separates us from the uncreative beasts. If the glory can be killed, we are lost.



I am always thinking of the relationship between truth, goodness, and beauty. In *East of Eden*, Steinbeck gives us this to think about:

“There’s more beauty in truth, even if it is dreadful beauty.”



Dr. Ben Carson wrote the following poem in response to the cancelling of six Dr. Seuss books:

*I do not like to cancel books. I do not like how that looks.
 I do not like it here, nor there, I do not like it anywhere.
 I do not like it in the store, I do not want it anymore.
 I do think it's time past, no longer to have thought a crime.*

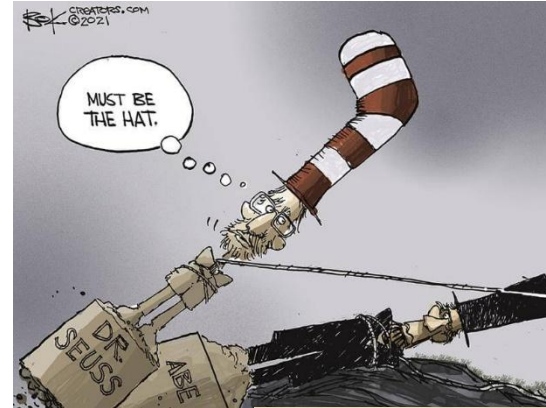


*I do hope one day to see across my country 'tis of thee,
 books used to read and learn instead of set ablaze to
 burn.*

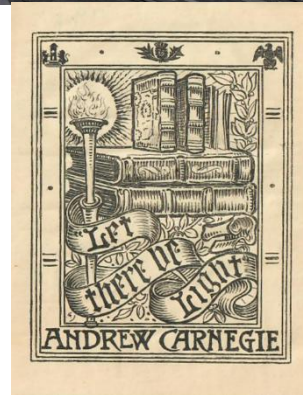
Our heritage for all to share, little patriots everywhere.

*Our nation's story rich and vast, our true history taught
 in class.*

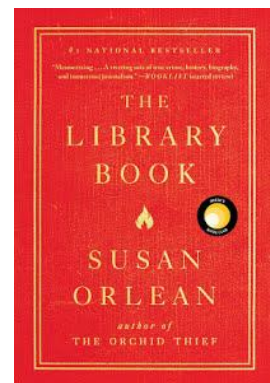
A special place for all to be, a place known for its liberty.



Between 1883 and 1929, **Andrew Carnegie** funded the creation of 2,509 Carnegie libraries in the United States and around the world. Here is his bookplate:



Susan Orlean (2018) describes the fire in the Central Los Angeles Library in **The Library Book**. Due to the perfect ratio of fuel to oxygen, the fire burned clear. *“In the physics of fire, there is a chemical phenomenon known as a **stoichiometric condition**, in which the fire achieves the perfect burning ratio of oxygen to fuel—in other words, there is exactly enough air available for the fire to consume all of what is burning. Such a ratio creates an ideal fire situation, which results in total, perfect combustion. A stoichiometric condition is almost impossible to create outside of a laboratory. It requires such an elusive, precise balance of fuel and fire and oxygen that, in a sense, it is more theoretical than actual. Many firefighters have never seen such a blaze and never will. Not long ago, I had coffee*



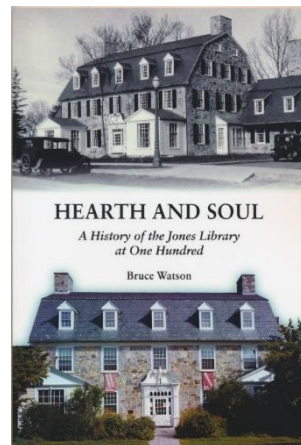
with a man named Ron Hamel. He is now an arson investigator, but at the time of the library fire, Hamel was a captain in the fire department. Although over thirty years have passed, he remains awed by what he saw that day at the library. He talked about it like someone might talk about seeing a UFO. In his decades with the department, Hamel fought thousands of fires, but he said he never experienced another that was as exceptional as the fire at Central Library. Usually, a fire is red and orange and yellow and black. The fire in the library was colorless. You could look right through it, as if it were a sheet of glass. Where the flame had any color, it was pale blue. It was so hot that it appeared icy. Hamel said he felt like he was standing inside a blacksmith's forge. "We thought we were looking at the bowels of hell," he said, tapping his coffee mug. "Combustion that complete is almost impossible to achieve, but in this case, it was achieved. It was surreal."

Bruce Watson (2019) wrote about the *Hearth and Soul* of the Jones Library in Amherst, MA that houses archival collections of works by Emily Dickinson, Robert Frost, Robert Francis, and Julius Lester. Here is a poem by Emily Dickinson—

The Poets light but Lamps

*The Poets light but Lamps —
Themselves — go out —
The Wicks they stimulate
If vital Light*

*Inhere as do the Suns —
Each Age a Lens
Disseminating their
Circumference —*



THE CHEMISTRY OF MATCHES

How Matches Work

The composition of matches varies depending on type, but safety matches are the most commonly used. They contain a strong oxidising agent in the match head, and red phosphorus in the striking surface. Striking the match causes small amounts of the oxidiser and phosphorus to combine, and the heat generated by the friction of the striking causes them to ignite.

Prior to the 1900s, white phosphorus was the active ingredient in most matches, but this could cause 'phossy jaw' and bone disorders, and was also toxic, so was replaced.



The Match

POTASSIUM CHLORATE
Main ingredient (45-55%) in heads of safety matches.



PHOSPHORUS SESQUISULFIDE

Component in the heads of 'strike anywhere' matches.



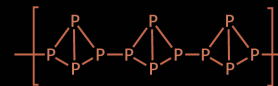
ANTIMONY (III) SULFIDE

Added to some matches to make them burn more vigorously.

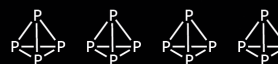
Additionally, the matches contain ammonium phosphates to prevent 'afterglow', glue to bind materials, and paraffin wax for ease of burning.

The Match Box

The striking surface of safety match boxes contains red phosphorus and an abrasive substance. When struck, a small amount of white phosphorus is produced, which ignites.



Red Phosphorus (above); White Phosphorus (below)



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<https://www.compoundchem.com/2014/11/20/matches/>
<https://www.youtube.com/watch?v=y2ErAPODA6U>

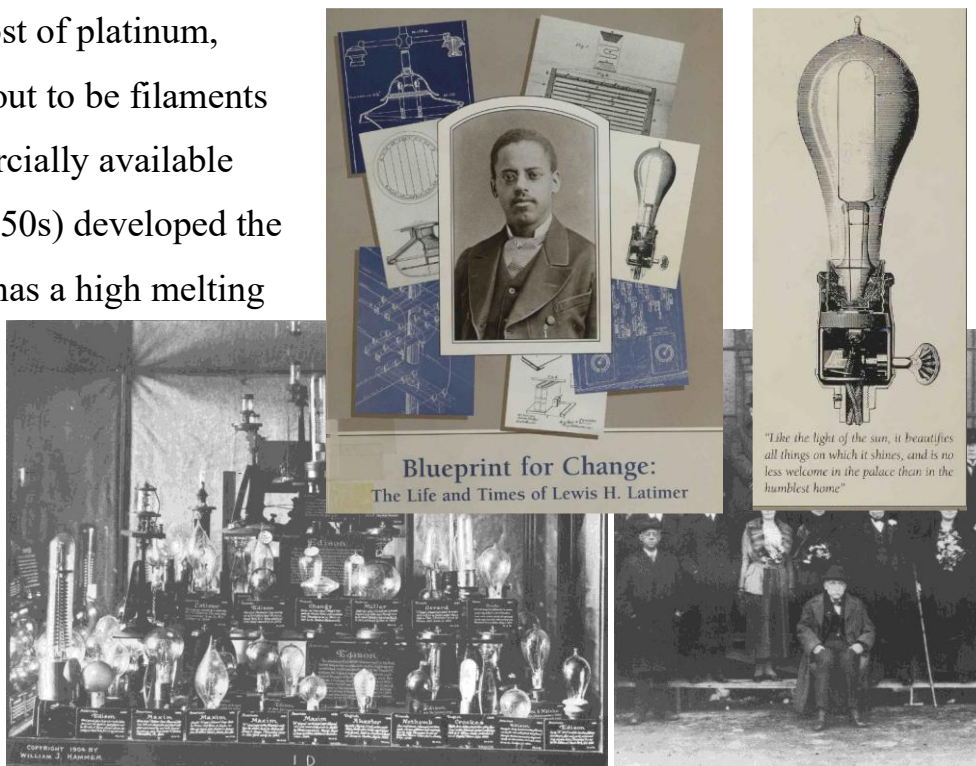
Switching the Light: From a Chemical Energy Source to an Electrical Energy Source

The invention of the [lightbulb](#):

Humphry Davy (1802) connected a battery consisting of 2,000 cells to a thin strip of platinum. The platinum became incandescent without melting. Davy (1807-1809) also connected the battery to two pieces of charcoal which would cause bright sparks to jump across the gap—creating the first arc lamp. These lamps were neither bright enough nor long-lasting enough to be used as a lamp. **Warren de la Rue** (1840) put a coiled platinum filament in a **vacuum** tube and

passed an electric current through it. In a vacuum, there were fewer gas molecules to react with the platinum, thus improving its longevity.

Because of the high cost of platinum, other materials were sought out to be filaments that could be used in commercially available lightbulbs. **Joseph Swan** (1850s) developed the carbon filament, which also has a high melting point. [Thomas Edison](#) (1879), filed for a US patent for an electric lightbulb using “*a carbon filament or strip coiled and connected ... to platina contact wires.*” [Edison](#)

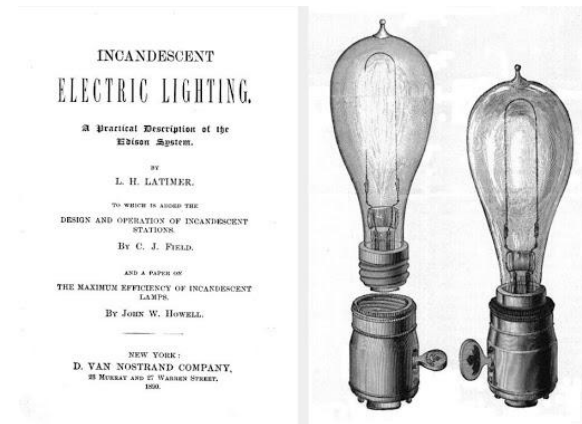


(December 31, 1879) said, “*We will make electric light so cheap that only the rich will be able to burn candles.*” [Lewis Latimer](#) (1882), whose parents, [George](#) and Rebecca (*née* Smith) Latimer, were runaway slaves, and who attended school up until fifth grade, and who, at age 15, fought in the Union Navy aboard the USS *Masasoit* during the Civil War, was one of the founding members of **Edison’s Pioneers**. He developed an improved method of heat-treating carbon filaments in the absence of oxygen. Latimer’s pyrolysis technique involved stuffing carbon filaments inside cardboard envelopes that were coated with a substance that kept the filaments from sticking before he exposed the filaments and cardboard envelopes to high temperature in the absence of oxygen. Since the envelopes expanded and contracted at the same rate as the filaments, the filaments kept their shape and no longer broke or became misshapen. Latimer’s technique allowed him

to produce a lightbulb with a longer life, making the electric lightbulb affordable so that middle class families and small businesses could illuminate their homes and workplaces with electric lightbulbs. Latimer characterized the utility of the incandescent electric lightbulb like so: *“Like the light of the sun, it beautifies all things on which it shines, and is no less welcome in the palace than in the humblest home.”*

Latimer (1890) described the working of the lightbulb in his book [*Incandescent Electric Lighting: A Practical Description of the Edison System*](#) like so:

“If the electric current can be forced through a substance that is a poor conductor, it will create a degree of heat in the substance, which will be greater or less according to the quantity of electricity forced through it. Upon this principle of the heating effect of the electric current, is based the operation of the incandescent lamp... Where copper and platinum wires readily conduct the current, the carbon filament offers a great deal of resistance to its passage, and for this reason becomes very hot, in fact is raised to a white heat or incandescence, which gives its name to the lamp. You doubtless wonder why this thread of charcoal is not immediately consumed when in this state, but this is readily accounted for when you remember, that without the oxygen of the air, there can be no combustion, and that every possible trace of air has been removed from the bulb and it so thoroughly sealed up as to prevent the admission of the air about it; and yet the lamp does not last forever, for the reason that the action of the current upon the carbon has a tendency to divide up its particles and transfer them from one point to another so that, sooner or later, the filament gives way at some point. Yet most of these lamps are guaranteed to last a thousand hours, and this at

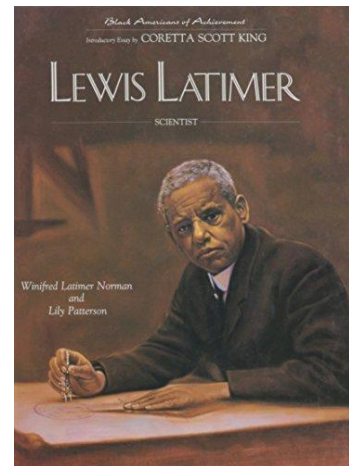


from four to six hours a day gives the lamp a life of several months.” Thus, the filament in an incandescent electric lightbulb and the soot produced when a candle burns produces illumination similarly.

Lewis Latimer was also active in civil rights. In a letter written to Richard Greener supporting the *National Conference of Colored Men*, whose goal was to draft a unified political platform for the 1896 Republican National Convention in Detroit, [Lewis Latimer](#) (1895) wrote, *“I am heart and soul in the movement (1) Because it is necessary that we should show the people of this country that we who have by our martyrdom under the lash; by our heroism on the battlefield; by our Christian forbearance beneath an overwhelming burden of injustice; and by our submission to the laws of the native land, proven ourselves worthy citizens of our common country. (2) Because there is no separation of the colored Americans from those of the white American, and it is our duty to show our country, and...the world that we are looking to the interests of the country at large, when we protest against the crime and injustice meted out to any class or conditions of our citizens. (3) Because the community which permits a crime against its humblest member to go unpunished is nursing into life and strength a power which will ultimately threaten its own existence. (4) Because our history conclusively proves that the attempt to degrade any portion, class, or race of our common people has always been fraught with more danger to the oppressor than the oppressed. (5) Because an evenhanded justice to all, under and through the law, is the only safe course to pursue for where might makes right, brute strength will supersede intelligence in the control of our communities.*

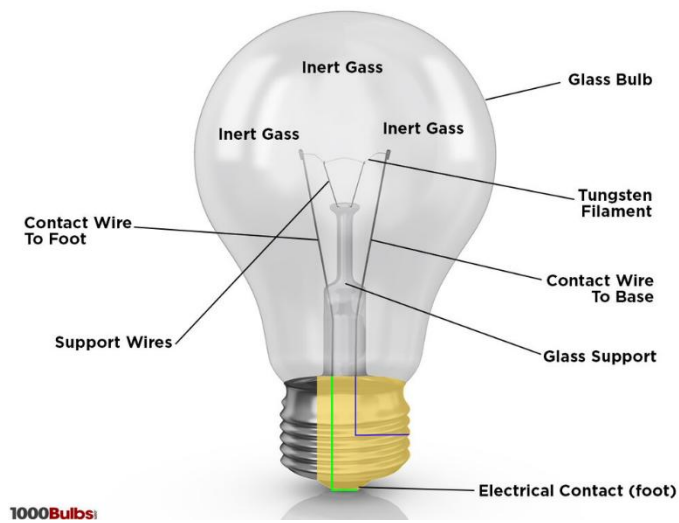
We should have a National Convention, forgetting all other considerations directs its energies to presenting its cause before the people, as it affects the people at large, presenting it as our fathers did the question of slavery, with facts and

figures, showing, as it can be shown, that where the Colored American is lynched, the white American is assassinated; that ignorance and crime go hand in hand with prejudice; that schools and churches multiply where there is neither class nor color distinctions in the law; that class legislation puts a premium on ignorance and illiteracy, in that it aids a man to think himself superior by accident of birth than by the achievements of merit and ability. ***If our cause be made the common cause, and all our claims and demands be founded on justice and humanity, recognizing that we must wrong no man in winning OUR rights, I have faith to believe that the Nation will respond to our plea for equality before the law, security under the law, and an opportunity, by and through maintenance of the law, to enjoy with our fellow citizens of all races and complexions the blessings guaranteed us under the Constitution of 'life, liberty and the pursuit of happiness.' ”***



Sándor Just and Franjo Hanaman (1904) developed a [tungsten](#) filament that lasted longer and gave brighter light than the carbon filament. [Irving Langmuir](#) (1913) found that filling a lamp with [inert gas](#) such as argon or nitrogen instead of using a vacuum slows down the evaporation of the tungsten resulting in a longer filament life. He also developed the **spiral tungsten** filament. Today's incandescent lamp is the result of the work of these and other people.





Here is a particularly pretty Yahrzeit lamp that my family uses to remember the souls of those who have died. Proverbs 20:27 *"The soul of man is a candle of the Lord."*



Here are [Poems](#) by Lewis Latimer. His father also wrote poetry.

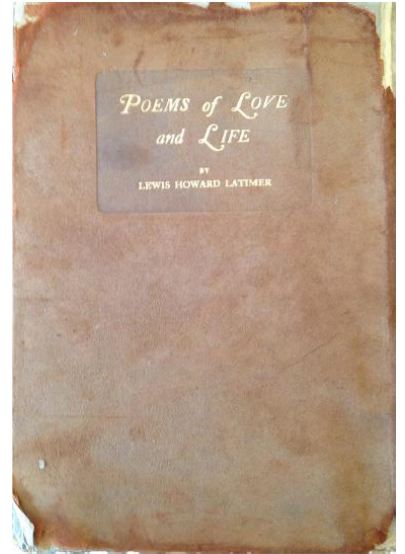
Friends

*Friend of my childhood,
Of life's early days
When together we wandered
Through bright sunny ways
Each true to the other,
Till full manhood came,
And found the old friendship
As ever the same.

Came summer and winter,
Years waxed and waned.
Youth it had left us
But friendship remained
And now as with white locks
I bend o'er life's page,
The friend of my childhood
Is the friend of my age.*

Ebon Venus (A tribute to his wife)

*Let others boast of maidens fair,
Of eyes of blue and golden hair;*



*My heart like needles ever true
Turns to the maid of ebon hue.
I love her form of matchless grace,
The dark brown beauty of her face,
Her lips that speak of love's delight,
Her eyes that gleam as stars at night.
O'er marble Venus let them rage,
Who sets the fashions of the age;
Each to his taste, but as for me,
My Venus shall be ebony.*

Like all of the Pioneers and many others who worked for Edison, Latimer held the famous inventor in high regard. These poignant stanzas are excerpted from a longer poem that Latimer wrote near the end of their long association.

Tom Edison

Who caught the lightning from the skies
And bade it gladden human eyes
To fill the whole world with surprise
Tom Edison

Who made the night vie with the day
Who bade the darkness speed away
As willed the world to work or play
Tom Edison

If there be those who took their part
To aid him in his work and art
They'r glad they lent both head and heart.
To Edison

His race is very nearly run
But this great land has since begun
To know the worth of this her son
Tom Edison*

And a poem written by John Greenleaf Whittier (1843) about George Latimer, Lewis' father:

From Massachusetts to Virginia

*The blast from Freedom's Northern hills, upon its Southern way,
Bears greeting to Virginia from Massachusetts Bay.
No word of haughty challenging, nor battle bugle's peal,
Nor steady tread of marching files, nor clang of horsemen's steel.*

*No trains of deep-mouthed cannon along our highways go;
Around our silent arsenals untrodden lies the snow;
And to the land-breeze of our ports, upon their errands far,
A thousand sails of commerce swell, but none are spread for war.*

*We hear thy threats, Virginia! thy stormy words and high,
Swell harshly on the Southern winds which melt along our sky;
Yet, not one brown, hard hand foregoes its honest labor here,
No hewer of our mountain oaks suspends his axe in fear.*

*Wild are the waves which lash the reefs along St. George's bank;
Cold on the shore of Labrador the fog lies white and dank;
Through storm, and wave, and blinding mist, stout are the hearts which man
The fishing-smacks of Marblehead, the sea-boats of Cape Ann.*

*The cold north light and wintry sun glare on their icy forms,
Bent grimly o'er their straining lines or wrestling with the storms;
Free as the winds they drive before, rough as the waves they roam,
They laugh to scorn the slaver's threat against their rocky home.*

*What means the Old Dominion? Hath she forgot the day
When o'er her conquered valleys swept the Briton's steel array?
How side by side, with sons of hers, the Massachusetts men
Encountered Tarleton's charge of fire, and stout Cornwallis, then?*

*Forgets she how the Bay State, in answer to the call
Of her old House of Burgesses, spoke out from Faneuil Hall?
When, echoing back her Henry's cry, came pulsing on each breath
Of Northern winds, the thrilling sounds of "Liberty or Death!"*

*What asks the Old Dominion? If now her sons have proved
False to their fathers' memory, false to the faith they loved;
If she can scoff at Freedom, and its great charter spurn,
Must we of Massachusetts from truth and duty turn?*

*We hunt your bondmen, flying from Slavery's hateful hell;
Our voices, at your bidding, take up the bloodhound's yell;
We gather, at your summons, above our fathers' graves,
From Freedom's holy altar-horns to tear your wretched slaves!*

*Thank God! not yet so vilely can Massachusetts bow;
The spirit of her early time is with her even now;
Dream not because her Pilgrim blood moves slow and calm and cool,
She thus can stoop her chainless neck, a sister's slave and tool!*

*All that a sister State should do, all that a free State may,
Heart, hand, and purse we proffer, as in our early day;
But that one dark loathsome burden ye must stagger with alone,
And reap the bitter harvest which ye yourselves have sown!*

*Hold, while ye may, your struggling slaves, and burden God's free air
With woman's shriek beneath the lash, and manhood's wild despair;
Cling closer to the "cleaving curse" that writes upon your plains
The blasting of Almighty wrath against a land of chains.*

*Still shame your gallant ancestry, the cavaliers of old,
By watching round the shambles where human flesh is sold;
Gloat o'er the new-born child, and count his market value, when
The maddened mother's cry of woe shall pierce the slaver's den!*

*Lower than plummet soundeth, sink the Virginia name;
Plant, if ye will, your fathers' graves with rankest weeds of shame;
Be, if ye will, the scandal of God's fair universe;
We wash our hands forever of your sin and shame and curse.*

*A voice from lips whereon the coal from Freedom's shrine hath been,
Thrilled, as but yesterday, the hearts of Berkshire's mountain men:
The echoes of that solemn voice are sadly lingering still
In all our sunny valleys, on every wind-swept hill.*

*And when the prowling man-thief came hunting for his prey
Beneath the very shadow of Bunker's shaft of gray,
How, through the free lips of the son, the father's warning spoke;
How, from its bonds of trade and sect, the Pilgrim city broke!*

*A hundred thousand right arms were lifted up on high,
A hundred thousand voices sent back their loud reply;
Through the thronged towns of Essex the startling summons rang,
And up from bench and loom and wheel her young mechanics sprang!*

*The voice of free, broad Middlesex, of thousands as of one,
The shaft of Bunker calling to that of Lexington;
From Norfolk's ancient villages, from Plymouth's rocky bound
To where Nantucket feels the arms of ocean close her round;*

*From rich and rural Worcester, where through the calm repose
Of cultured vales and fringing woods the gentle Nashua flows,
To where Wachuset's wintry blasts the mountain larches stir,
Swelled up to Heaven the thrilling cry of "God save Latimer!"*

*And sandy Barnstable rose up, wet with the salt sea spray;
And Bristol sent her answering shout down Narragansett Bay
Along the broad Connecticut old Hampden felt the thrill,
And the cheer of Hampshire's woodmen swept down from Holyoke Hill.*

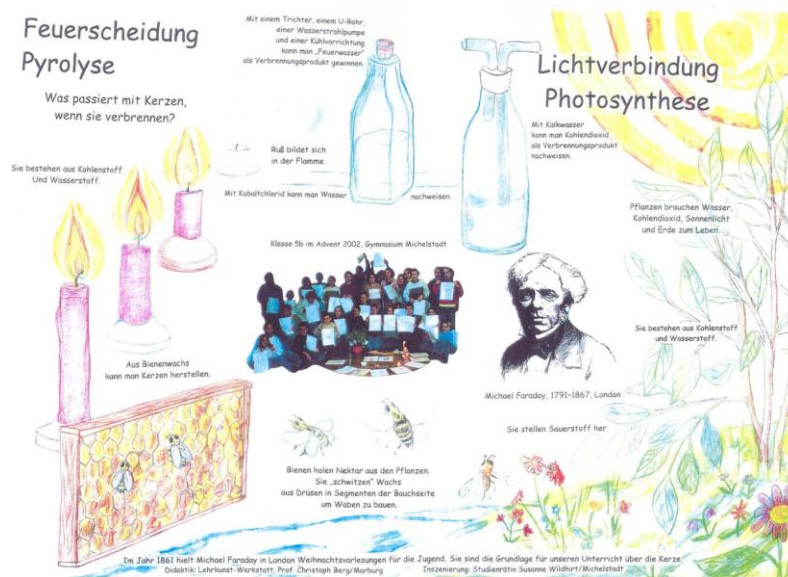
*The voice of Massachusetts! Of her free sons and daughters,
Deep calling unto deep aloud, the sound of many waters!
Against the burden of that voice what tyrant power shall stand?
No fetters in the Bay State! No slave upon her land!*

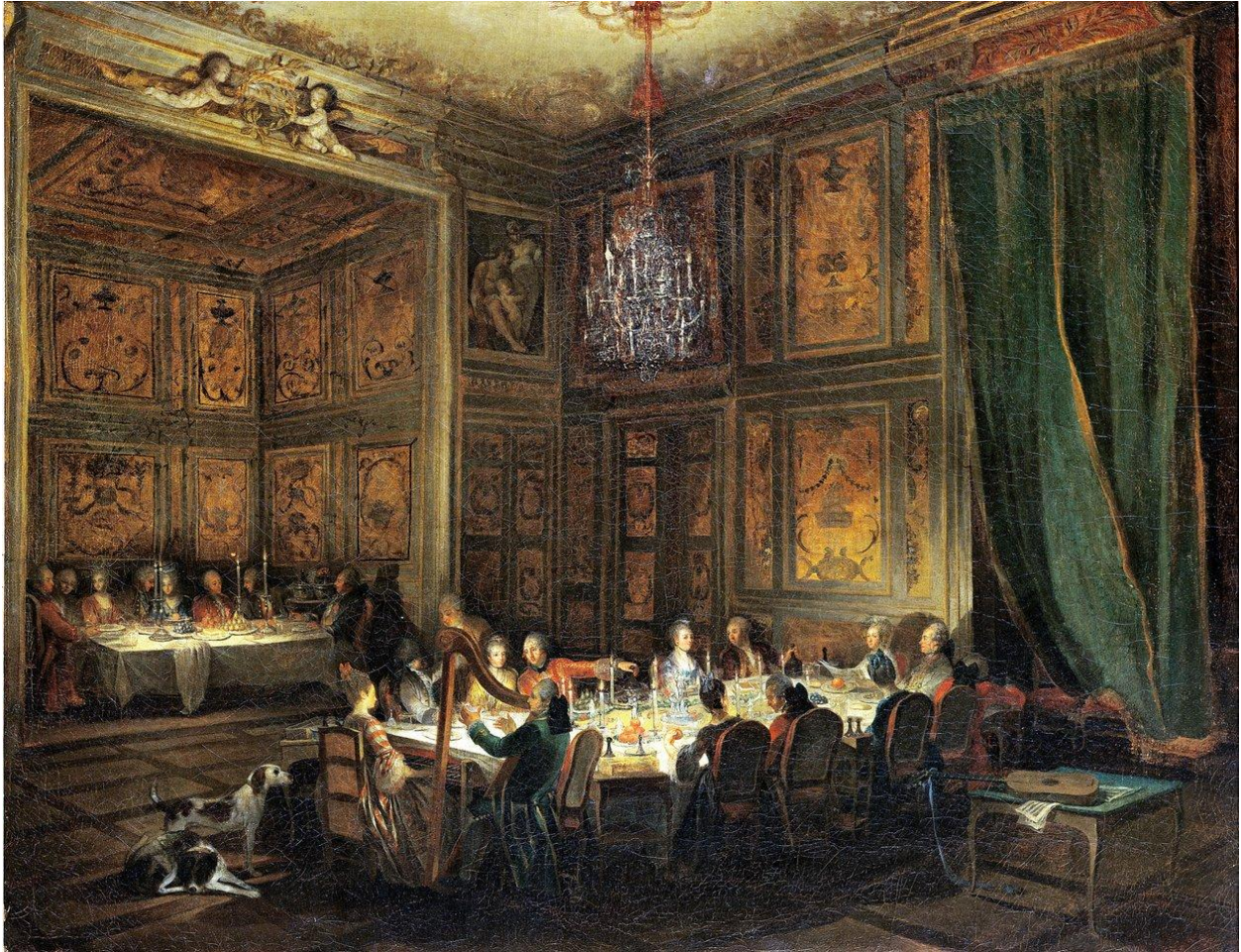
*Look to it well, Virginians! In calmness we have borne,
In answer to our faith and trust, your insult and your scorn;
You've spurned our kindest counsels; you've hunted for our lives;
And shaken round our hearths and homes your manacles and gyves!*

*We wage no war, we lift no arm, we fling no torch within
The fire-clamps of the quaking mine beneath your soil of sin;
We leave ye with your bondmen, to wrestle, while ye can,
With the strong upward tendencies and godlike soul of man!*

*But for us and for our children, the vow which we have given
For freedom and humanity is registered in heaven;
No slave-hunt in our borders, and no pirate on our strand!
No fetters in the Bay State, and no slave upon our land!*

A picture that shows how the chemical history of a candle relates to many of the topics that we will discuss this semester.





Dinner of the Prince of Conti (1717-76) in the Temple, 1766 by [Michel Barthelemy Ollivier](#)

A lightbulb over one's head symbolizes the conception or understanding of an idea. Ayn Rand (1967) wrote in [Requiem for Man](#):

"I will ask you to project the look on a child's face when he grasps the answer to some problem he has been striving to understand it. It is a radiant look of joy, of liberation, almost of triumph, which is unself-conscious, yet self-assertive, and its radiance seems to spread in two directions: outward, as an illumination of the world—inward, as the first spark of what is to become the fire of an earned pride. If you have seen this look, or experienced it, you know that if there is such a concept as "sacred"—meaning: the best, the



highest possible to man—this look is the sacred, the not-to-be betrayed, the not-to-be-sacrificed for anything or anyone.

This look is not confined to children. Comic-strip artists are in the habit of representing it by means of a light-bulb flashing on, above the head of a character who has suddenly grasped an idea. In simple, primitive terms, this is an appropriate symbol: an idea is a light turned on in man's soul.

It is the steady, confident reflection of that light that you look for in the faces of adults—particularly of those to whom you entrust your most precious values. You look for it in the eyes of a surgeon performing an operation on the body of a loved one; you look for it in the face of a pilot at the controls of the plane in which you are flying; and, if you are consistent, you look for it in the person of the man or woman you marry.

That light-bulb look is the flash of a human intelligence in action; it is the outward manifestation of man's rational faculty; it is the signal and symbol of man's mind. And, to the extent of your humanity, it is involved in everything you seek, enjoy, value, or love.

But suppose that admiration is not your response to that look on the face of a child or adult? Suppose that your response is a nameless fear? Then you will spend your life and your philosophical capacity on the struggle never to let that fear be named. You will find rationalizations to hide it, and you will call that child's look a look of "selfishness" or "arrogance" or "intransigence" or "pride"—all of which will be true, but not in the way you will struggle to suggest. You will feel that that look in man's eyes is your greatest, most dangerous enemy—and the desire to vanquish that look will become your only absolute, taking precedence over reason, logic, consistency, existence, reality. The desire to vanquish that look is the desire to break man's spirit."

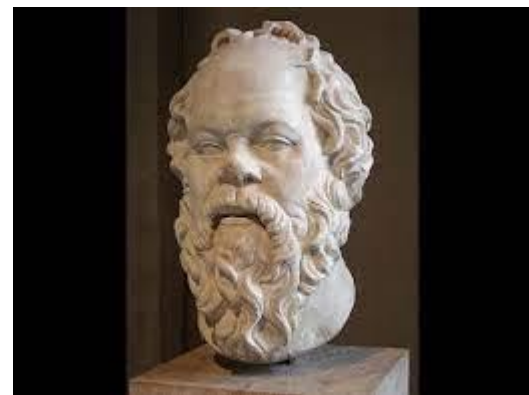


In [Theaetetus](#), Plato compares memory to a block of wax.

SOCRATES: *I would have you imagine, then, that there exists in the mind of man a block of **wax**, which is of different sizes in different men; harder, moister, and having more or less of purity in one than another, and in some of an intermediate quality.*

THEAETETUS: *I see.*

SOCRATES: *Let us say that this tablet is a gift of Memory, the mother of the Muses; and that when we wish to remember anything which we have seen, or heard, or thought in our own minds, **we hold the wax to the perceptions and thoughts, and in that material receive the impression of them as from the seal of a ring**; and that we remember and know what is imprinted as long as the image*



lasts; but when the image is effaced, or cannot be taken, then we forget and do not know.

Plato also describes the soul in terms of wax.

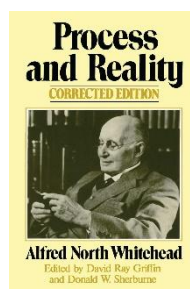
SOCRATES: *And the origin of truth and error is as follows:—When the **wax** in the soul of any one is deep and abundant, and smooth and perfectly tempered, then the impressions which pass through the senses and sink into the heart of the soul, as Homer says in a parable, meaning to indicate the likeness of the soul to **wax** (Kerh Kerhos); these, I say, being pure and clear, and having a sufficient depth of **wax**, are also lasting, and minds, such as these, easily learn and easily retain, and are not liable to confusion, but have true thoughts, for they have plenty of room, and having clear impressions of things, as we term them, quickly distribute them into their proper places on the block. And such men are called wise. Do you agree?*

THEAETETUS: *Entirely.*

SOCRATES: *But when the heart of any one is shaggy—a quality which the all-wise poet commends, or muddy and of impure wax, or very soft, or very hard, then there is a corresponding defect in the mind—the soft are good at learning, but apt to forget; and the hard are the reverse; the shaggy and rugged and gritty, or those who have an admixture of earth or dung in their composition, have the impressions indistinct, as also the hard, for there is no depth in them; and the soft too are indistinct, for their impressions are easily confused and effaced. Yet greater is the indistinctness when they are all jostled together in a little soul, which has no room. These are the natures which have false opinion; for when they see or hear or think of anything, they are slow in assigning the right objects to the right impressions—in their stupidity they confuse them, and are apt to see and hear and think amiss—and such men are said to be deceived in their knowledge of objects, and ignorant.*

THEAETETUS: *No man, Socrates, can say anything truer than that.*

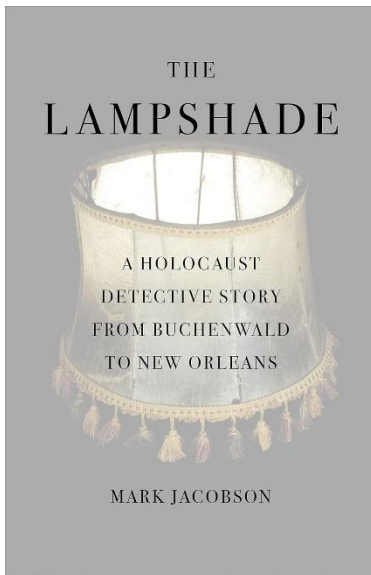
Plato still has so much to teach us. Alfred North Whitehead wrote in [*Process and Reality*](#), “The safest general characterization of the European philosophical tradition is that it consists of a series of footnotes to Plato. I do not mean the systematic scheme of thought which scholars have doubtfully extracted from his writings. I allude to the wealth of general ideas scattered through them. His personal endowments, his wide opportunities for experience at a great period of civilization, his inheritance of an intellectual tradition not yet stiffened by



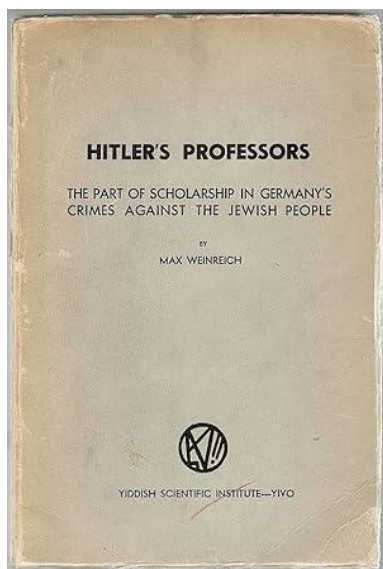
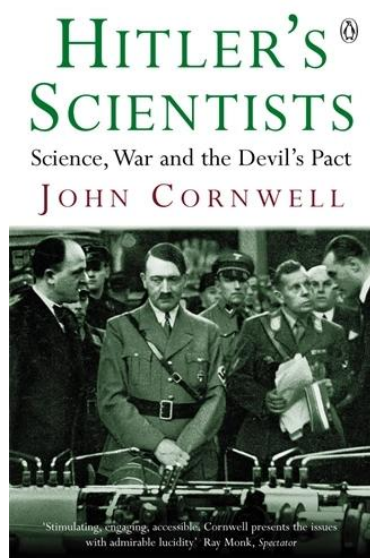
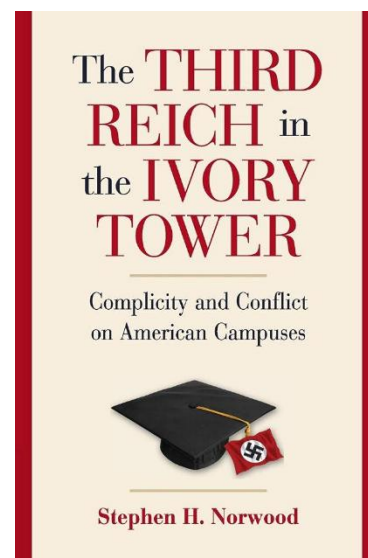
excessive systematization, have made his writings an inexhaustible mine of suggestion.”

Lampshades and the darkness of humanity

Under the direction of [Dr. Hans Müller](#), the pathologist at the Buchenwald concentration camp, Nazi Schutzstaffel (SS) soldiers produced “gifts” made of human remains. “[Human skin — preferably skin that had been tattooed — was cut from the corpses of inmates, tanned and processed into everyday objects.](#)” One of the gifts was a [lampshade](#).

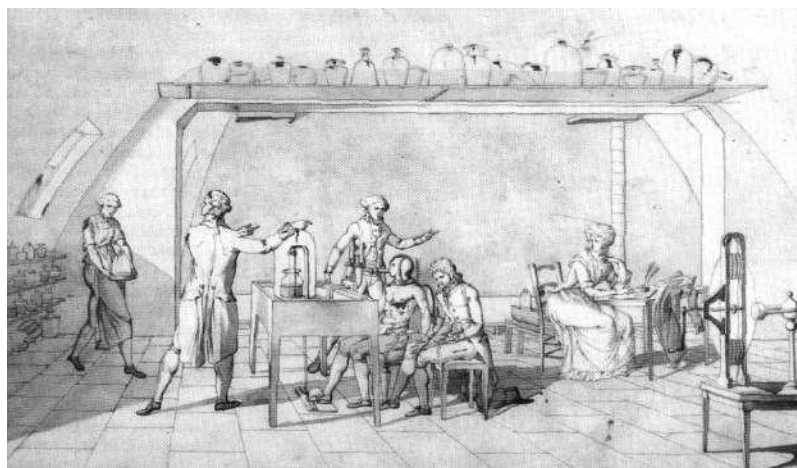


University professors, doing science without a conscience, played a role in perpetuating crimes against humanity.



Cellular Respiration: Converting carbohydrate into chemical energy without emitting visible light

A knowledge of the relationship between light and the spirit is ancient. According to Proverbs (20:27), “*The spirit of man is the candle of the Lord, searching all the inward parts of his being.*” The great chemist, **Antoine Lavoisier**, was the first scientist to draw an analogy between respiration and the chemical process of combustion.

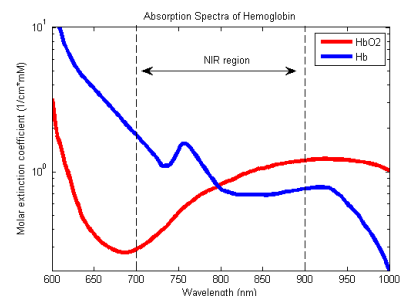


Although in 1789, he ended a memoir like so: “*One may say that this analogy between combustion and respiration has not escaped the notice of poets, or rather the philosophers of antiquity, and which they had expounded and interpreted. This **fire stolen from heaven**, this torch of **Prometheus**, does not only represent an ingenious and poetic idea, it is a faithful picture of the operations of nature, at least for animals that breathe; one may therefore say, with the ancients, that **the torch of life** lights itself at the moment the infant breathes for the first time, and it does not extinguish itself except at death. In considering such happy agreement, one might sometimes be tempted to believe that the ancients had indeed penetrated further than we think into the sanctuary of knowledge, and that the myth is actually nothing but an allegory, in which they hid the **great truths of medicine and physics.***”



[Lavoisier's laboratory](#) was filled with instruments that were precise enough to accurately weigh gases, liquids, and solids in order to demonstrate his new principle of the conservation of mass.

J. Robert Mayer, a ship's physician, originally discovered the **First Law of Thermodynamics** when he noted in 1840 the color of venous blood is redder in people who live in the tropics than in people who live in colder climates. He wrote, "*Observations which I made in the Tropics taught me to recognize the role which the blood corpuscles play in the **combustion process in the body**. In a sea voyage of 100 days, out of a passenger list of 28 there occurred no serious incidence of sickness. However, a few days after the arrival in Batavia (Dutch East Indies) there broke out an epidemic of an acute catarrhal inflammatory affection of the lungs. In the ample blood-letting which I carried out, the blood from the veins in the arm had an unusually red color, so that if I had judged by color alone I might have thought I had struck an artery....*At this point Mayer realized

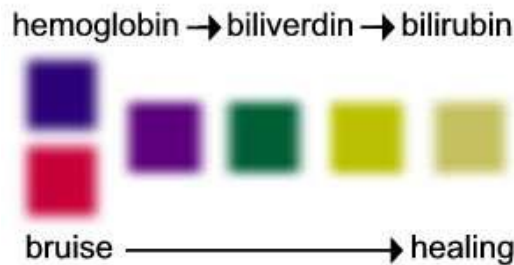
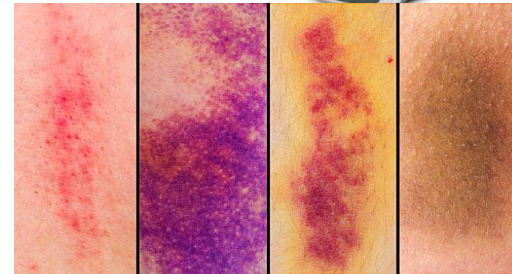


that in **tropical climates** there was no need for **combustion to heat the body** as there is such a need in **colder climates**, and consequently, there is more unused oxygen in the blood of people who live in tropical climates compared with people who live in colder climates and this is why the venous blood is redder in people who live in tropical climates compared to people who live in colder climates. Mayer also realized that physical work generates heat and that it too must be powered by combustion. Although Mayer was not sure how heat itself caused the muscles to contract.

Demonstration: Measure the oxygen content of your blood using the oximeter, which transmits two wavelengths of light through the finger to a photodetector. It measures the changing ratio of the absorbances of the red (660 nm) to the infrared light (940 nm) in order to determine the percent saturation of the **oxygen-binding hemoglobin** in the **arterial blood**.



As an aside, a bruise is initially red due to oxygenated hemoglobin and then deep purple due to the breakdown of hemoglobin.



Subsequently, the hemoglobin breaks down into biliverdin, a green pigment, which breaks down into bilirubin, a yellow pigment. Bruises typically become red, purple, green, dark yellow, pale yellow, and then disappear.

Another aside: [John Scott Haldane and other scientists](#) have shown that [nitrite preserves the red color](#) of beef by forming NO-hemoglobin/myoglobin. When cooked, NO-hemoglobin/myoglobin transforms into NO-hemochromogen, which is also red.

From his simple observation, Mayer realized that *ex nihilo nihil fit. Nil fit ad nihilum*. That is, **nothing comes from nothing, every effect must be preceded by a cause, and the effect is equal to the cause.** He then applied the **First Law of Thermodynamics**, not only to heating the human body, but to gravitational energy, radiant energy, chemical energy, kinetic energy, electrical energy, and magnetic energy.

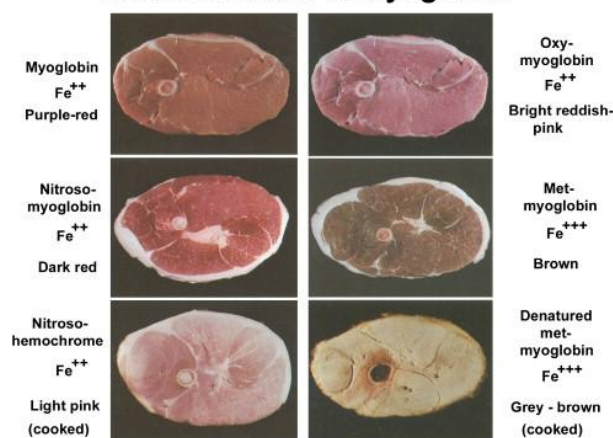
In *The Sound of Music*, Maria and Georg sang the song, *Something Good* which contains what I consider to be a truism, consistent with the First Law of Thermodynamics:

Nothing comes from nothing

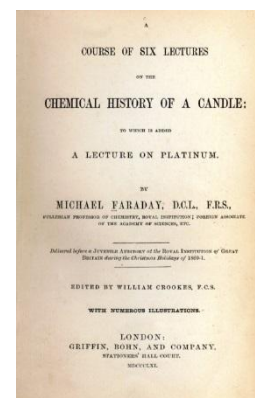
Nothing ever could

Last time we reenacted to some degree **Michael Faraday's** lecture series on *The Chemical History of a Candle*. Faraday demonstrated the analogy between combustion and respiration by showing that they both produce carbon dioxide and water. Michael Faraday is another scientist who was not trying to replace God with science. In a lecture given at the Royal Institution entitled, *Observations on the Education of the Judgment*,

Different States of Myoglobin



(Modified from Koch Supplies, 1973)



Faraday said, “...*the book of nature, which we have to read, is written by the finger of God.*”

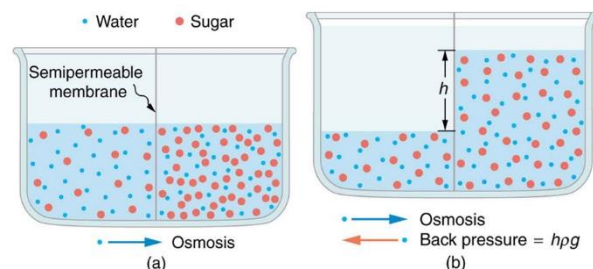
Last time we observed that the combustion process that occurs in a **candle** involves **pyrolysis**, which takes place in the dark hollow of the flame, **chemiluminescence**, which can be seen best in the blue region at the bottom of the flame, **incandescence**, which is seen in the brightest portion of the flame, and **oxidation**, which occurs at the outside of the flame (<http://vimeo.com/40271657>).

The **intracellular combustion process or the respiratory process**, unlike the burning of a candle, does not involve the transformation of chemical energy into radiant energy and the emission of visible light. So, **while the chemical analogy is good, there are limitations**. While **pyrolysis** involves the fragmentation of the fuel by exposing it to temperatures that are high enough to boil our blood, fuel fragmentation occurs very differently in intracellular combustion. How is the fuel fragmented at **ambient temperature** in living cells?

Louis Pasteur guessed that **fermentation** is respiration without air, and it not just a **chemical process** but a **vital process** that **requires living organisms**. He wrote, “*I am of the opinion that alcoholic fermentation never occurs without simultaneous organization, development and multiplication of cells....*” since he was never able to get fermentation to take place *in vitro* in the absence of living yeast. However, **Eduard Buchner** (1897) using a **German beer yeast** instead of a **French wine yeast** was able to obtain fermentation or **anaerobic respiration** *in vitro* when he added sugar to a yeast extract.

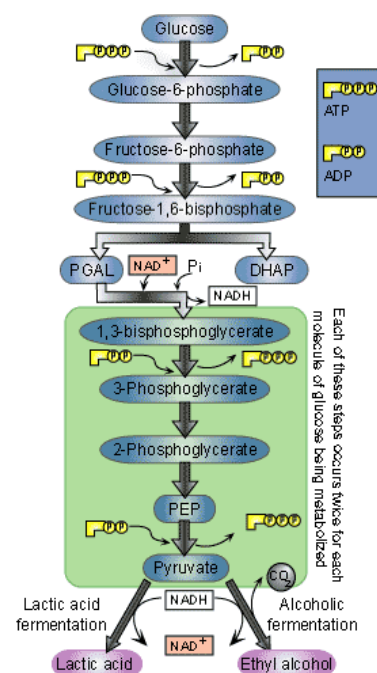


Actually, this was a **lucky** find, since Buchner was making a health tonic, and only added the sugar as a preservative, when the other antiseptics failed to keep the extract sterile. Buchner's wife made the suggestion based on her commonsense knowledge that fruit preserves are made by heating fruit in a sugar solution. The sugar acts as a preservative because bacteria cannot grow in high concentrations of sugar (or salt) because the high concentration of sugar draws water out of the bacteria by **osmosis** and they **dehydrate**.



In this way, Buchner discovered the part of the yeast that caused the fermentation of sugar in the absence of air and named the extract **zymase**, from *zyme*, the Greek word for “**yeast**,” and *diastasis*, the Greek word for “break apart.” Willy Kühne named all biocatalysts, **enzymes**, from the Greek words, *en zyme*, which mean “**in yeast**”.

In the candle, the fuel is broken down in a couple of haphazard steps by heat in a process known as **pyrolysis**. In living cells, the fuel is not fragmented by heat but is broken down in **glycolysis** at **ambient temperatures** in about a dozen sequential and ordered steps as a result of the intervention of **enzymes**. In the process of fermentation, which takes place in the **cytosol**, **hydrogen atoms** in the form of electrons and protons, are removed from the sugar in a process of **oxidation** (**loss of electrons is oxidation**). During the **oxidation process**, a net production of **two molecules of ATP** is formed from each sugar molecule. Most of the chemical energy in the original sugar molecule fragmented in glycolysis is left unavailable as lactic acid or

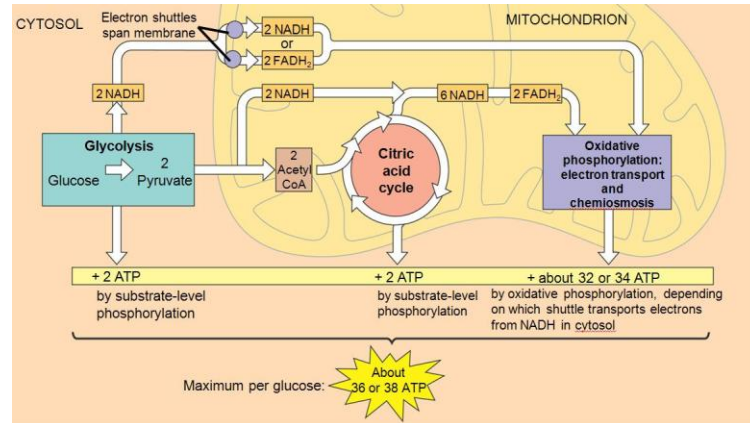


ethanol, although we make use of these products in pickling, wine, and beer making.

Aside: [Richard Feynman](#) (1963) wrote, *A poet once said, “The whole universe is in a glass of wine.” We will probably never know in what sense he meant that, for poets do not write to be understood. But it is true that if we look at a glass of wine closely enough we see the entire universe. There are the things of physics: the twisting liquid which evaporates depending on the wind and weather, the reflections in the glass, and our imagination adds the atoms. The glass is a distillation of the earth’s rocks, and in its composition we see the secrets of the universe’s age, and the evolution of stars. What strange array of chemicals are in the wine? How did they come to be? There are the ferments, the enzymes, the substrates, and the products. There in wine is found the great generalization: all life is fermentation. Nobody can discover the chemistry of wine without discovering, as did Louis Pasteur, the cause of much disease. How vivid is the claret, pressing its existence into the consciousness that watches it! If our small minds, for some convenience, divide this glass of wine, this universe, into parts—physics, biology, geology, astronomy, psychology, and so on—remember that nature does not know it! So let us put it all back together, not forgetting ultimately what it is for. Let it give us one more final pleasure: drink it and forget it all!*

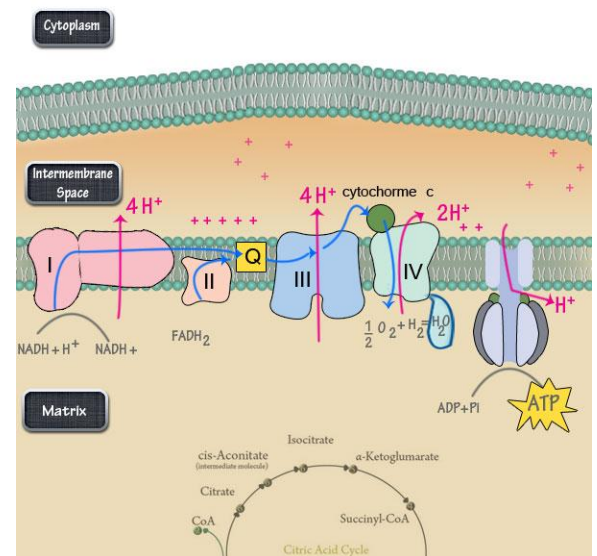
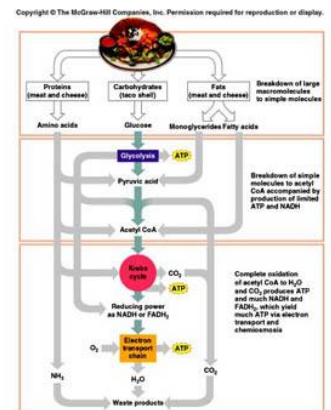


In the presence of **oxygen**, aerobic respiration takes place where the pyruvate is not turned into lactic acid or ethanol but **fully oxidized** into **carbon dioxide** and **water**.



The second leg of the oxidation of glucose takes place in **mitochondria** and results in the production of approximately **38 molecules of ATP** per sugar molecule compared with two molecules produced by fermentation alone.

In **aerobic respiration**, the electrons that are removed from the molecules being oxidized are transferred to **NAD⁺ to form NADH**, a molecule that is similar to NADPH, the hydrogen carrier that participates in photosynthesis. The NADH then passes its electrons to an **electron transport chain** composed of **iron-containing cytochromes**, which means “**cell color**.” This too is similar to the electron transport chain of photosynthesis. After all both processes transform the chemical energy of reduced molecules by oxidizing them. Moreover, as the electrons move from an acceptor with a more negative redox potential to one with a more positive redox potential, they can use the redox energy made available in the electron transfer to transfer protons from

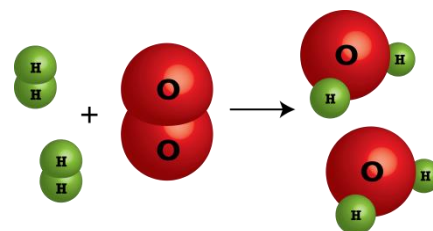


the matrix of the mitochondria to the intermembrane space. This **charge separation** is also similar to what happens during photosynthesis. The electrochemical energy of the proton gradient is then used by the coupling factor or ATP synthase to synthesize **ATP** from ADP and Pi.



All foodstuffs, including carbohydrates, lipids, and proteins as well as mixtures such as [Soylent](#), which is composed of soybean and lentil, and not to be confused with [Soylent Green](#), are enzymatically combusted so that the energy in their CH bonds can be transformed into the energy of **ATP**. We now know that **ATP is the common intermediate that is used to energize all aspects of life**, including, **mechanical work**, like muscle contraction, **biosynthetic work** like sugar, protein, and lipid synthesis, and **electrical work**, like nerve transmission.

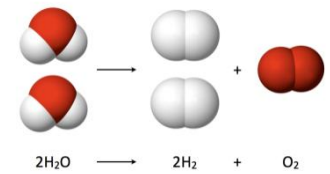
In aerobic respiration, **oxygen** functions as the ultimate electron acceptor. It is transformed into two **water molecules** when it **gains four electrons** and four hydrogen ions (protons). The oxygen gains the electrons transferred to it by **cytochrome oxidase**, an **iron**-containing enzyme. This is equivalent to the outermost region of the flame.



The rapid binding of iron to oxygen that took place in the candle when we sprinkled iron powder (but not iron oxide) in the flame or when we struck the **flint** against the **steel** took place at a temperature high enough to result in **incandescence**. On the other hand, the binding of oxygen to iron-containing **cytochrome oxidase** takes place at **ambient temperatures**.



Chemically, the formation of water by cytochrome oxidase is a reversal of the oxygen splitting that occurred in Photosystem II of photosynthesis.

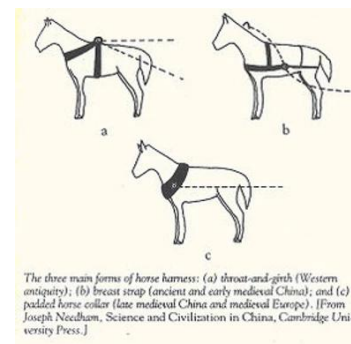


Aerobic respiration provides large quantities of energy to the cell. The many small steps involved in intracellular combustion allow some of the energy of combustion to be conserved as the chemical energy of ATP.

Aside: The original harness for horses was a **neck and girth** harness in which the straps were placed around the horse's neck and girth. If the horse pulled too much weight, its windpipe would be squeezed, which restricted the ability of **oxygen** to get to the cells. About 100 B.C., the modern harness was invented in China. It put the force on the shoulders rather than the windpipe and allowed for the pulling of heavier loads with a single horse.



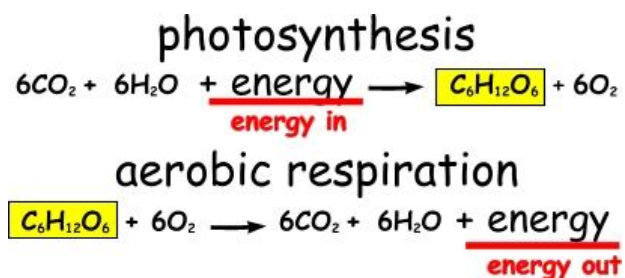
This harness arrived in Europe around 1000 A.D. By not restricting the flow of oxygen to the horse's cells, this harness allowed one man and a horse plowing the fields to do the work of 50 men. Due to the increased horsepower, food became more plentiful. The efficiency gained in the way humans could utilize horses,



resulted in increased productivity, and a surplus of food. This set the stage for the **Renaissance**.



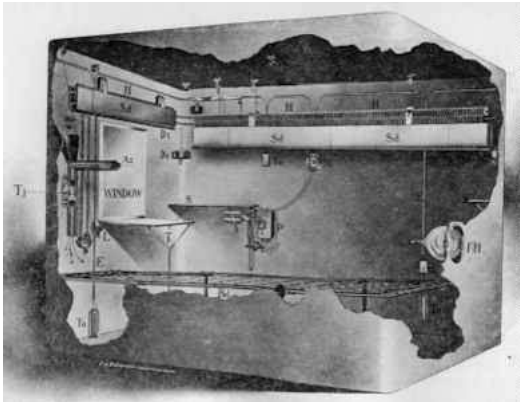
The overall equations of aerobic respiration and photosynthesis appear to represent the same reaction proceeding in reverse directions. While there are many similarities between the two reactions that take place in the mitochondria and chloroplasts in terms of generating and using charge separation of electrons and protons to synthesize ATP, respiration and photosynthesis are quite distinct and irreversible processes. The energy transducing processes of respiration and photosynthesis can be well understood in terms of the **First and Second Laws of Thermodynamics**.



Photosynthesis requires an energy input in the form of light, to reduce the entropy of the chemicals involved in photosynthesis. Entropy increases overall however because a portion of the visible wavelengths of light is converted into

infrared wavelengths, i.e., heat, thermal energy, or entropy. Aerobic respiration transforms some of the chemical energy of sugar to the chemical energy of ATP, the rest being given off as heat, thermal energy, or entropy.

Wilbur Olin Atwater treated the human body as a black box with inputs and outputs to gain insight into food, respiration, and mechanical work. In order to do this, he built in 1896 a respiration calorimeter room that measured the amount of **oxygen** taken up, the amount of **carbon dioxide** emitted, and the amount of **heat** generated when a person did any kind of **mechanical work**, for example, peddling a bicycle.

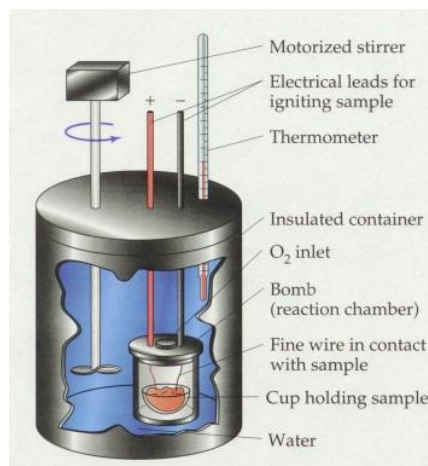


At the time Atwater did experiments, he did not know about how the energy derived by respiration was utilized by muscle contraction. He did not know about ATP and wondered, **could it be heat? Or could the electrons transferred from sugar to oxygen be used as an electric current?**

According to the First Law of Thermodynamics, to perform work, you have to ingest (at least) the same number of calories of food. Given the amount of work performed on a daily basis, Atwater recommended that active men and women eat approximately 2000-3000 Calories/day. However, “work” was typically more

strenuous 100 years ago before there were cars, computers, smartphones, washers, dryers, or even Carvana, renttherunway.com, Uber, Lyft, DoorDash, and Grubhub.

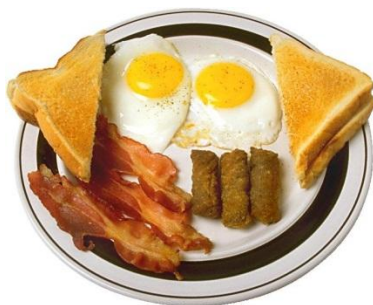
We measured the ability of a burning **peanut** to heat water. With a little more sophistication, Atwater burned thousands of foods in a bomb calorimeter to determine their “**fuel value**.” He found that in general, carbohydrates yield 4 Calories/gram, proteins yield 4 Calories/gram, and fats yield 9 Calories/gram. Atwater found that **meat** and **cereals** have a fuel value of approximately **1000 Calories/pound** whereas **fruits** and **vegetables** have a fuel value of approximately **250 Calories/pound** (= 0.55 Calories/gram). From the **calorimetry perspective alone**, fruits and vegetables did not seem to be very good foods. Modern nutrition theory at the turn of the 20th century based on the **fuel value of food** led to the “**typical American diet**” of white bread, muscle type of meat, potato, and sugar. A typical breakfast, lunch and dinner are shown below:



Nutrition Facts	
Serving Size 1 peanut	
Amount Per Serving	
Calories 11	Calories from Fat 8
% Daily Values*	
Total Fat 0.94g	1%
Saturated Fat 0.156g	1%
Polyunsaturated Fat 0.275g	
Monounsaturated Fat 0.467g	
Cholesterol 0mg	0%
Sodium 6mg	0%
Potassium 13mg	
Total Carbohydrate 0.27g	0%
Dietary Fiber 0.2g	1%
Sugars 0.08g	
Protein 0.5g	
Vitamin A 0%	Vitamin C 0%
Calcium 0%	Iron 0%

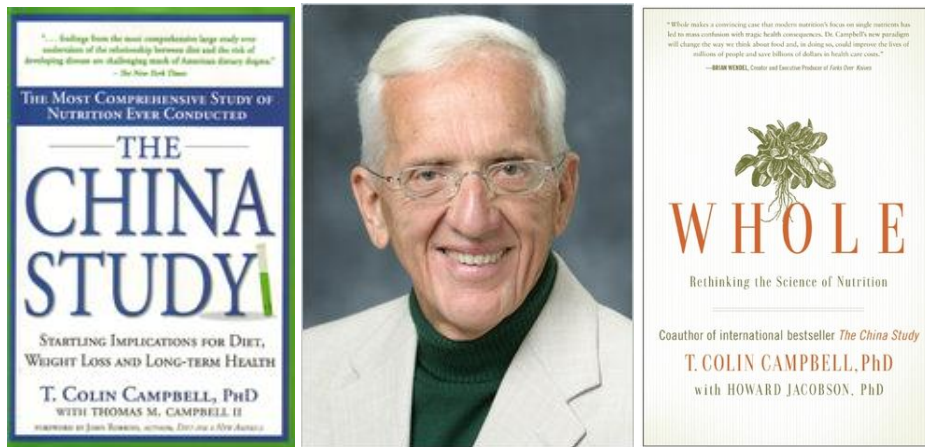
* Percent Daily Values are based on a 2000 calorie diet. Your daily values may be higher or lower depending on your calorie needs.

Nutrition Values are based on USDA Nutrient Database SR18

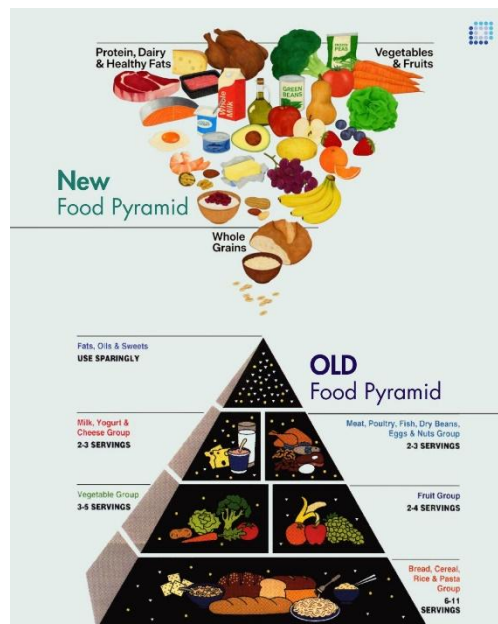


We now know that there are other things, such as **vitamins**, **minerals**, and **antioxidants** that are important in determining what good food is. We do not eat food for its fuel value alone.

The China Study written by T. Colin Campbell (Cornell) presents the gold standard of evidence for the relationship between diet and health.



And then there are the government's recommendations!



Thus ends the material for Prelim 1. (pre-micron days)

We have discussed how candles made of fats or wax can be burned for light. **Coal** is an organic rock produced from **plant products** that we use to generate steam to drive turbines that generate electricity. As a segue to describing coal balls, I will discuss coal itself. **Lignite** and **bituminous** coal are sedimentary rocks, produced from **peat** that grew in **bogs**. Lignite coal was produced during the Tertiary Period (66-2.58 million years ago). It has a high moisture and ash content, low **hydrocarbon** content, and thus low caloric value (60 Calories/gram). Bituminous coal is formed when a lignite-like coal has been subjected to high pressures. It has a higher fuel value than lignite (100 Calories/gram). Bituminous coal was produced about 100-300 million years ago. **Anthracite** coal has the lowest ash and moisture content, the highest hydrocarbon content, and thus the greatest caloric value (120 Calories/gram). This is because anthracite coal is a metamorphic rock that has been subjected to high temperatures and pressures that removed the volatile compounds that would have taken a portion of the thermal energy of the burning coal to volatilize them without producing heat. Anthracite coal was formed during the **Carboniferous Period**, about **359.2-299 million years ago**. Notice that all of the coals, because of their high density, have a much higher fuel value than fat (9 Calories/gram).

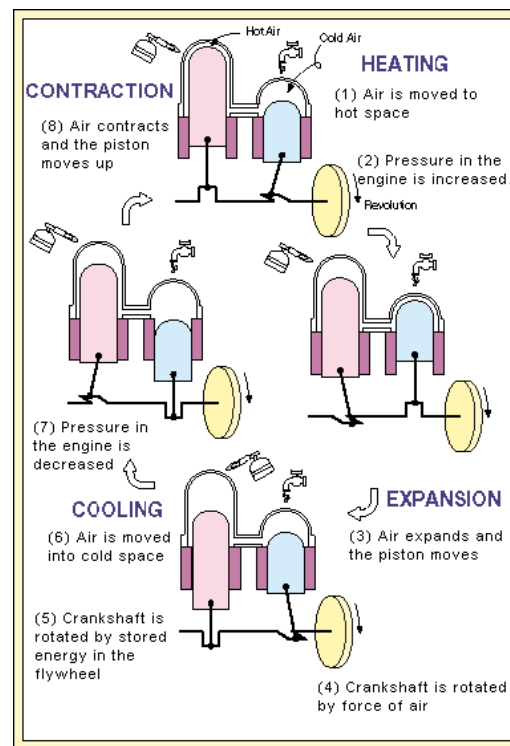


Demonstration: See how Stirling engines, a type of external combustion engine, convert thermal energy into mechanical energy.



A four-step description of the Stirling engine:

1. Most of the working gas is in the hot cylinder. When the gas in this cylinder is heated, its pressure increases and the gas expands to fill the hot cylinder and to half fill the cold cylinder. The cold cylinder is at mid stroke (partial volume).
2. The gas in the cold cylinder cools. Its pressure decreases. Because of the momentum of the flywheel, the hot cylinder begins a stroke that reduces the volume of the system.
3. Most of the gas is now in the cold cylinder and cooling continues. This reduces the pressure of the gas, and the gas contracts. The hot cylinder is at minimum volume and the cold cylinder is at maximum volume. Compression of the gas in the cold cylinder reduces the volume of the system to the minimum.
4. Now the gas has greater contact with the hot cylinder, and volume of the gas in the system increases by expansion of the gas in the hot cylinder.

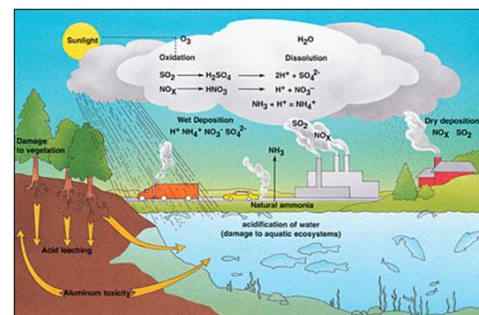


Coal in relatively stable parts of the lithosphere that have been subjected to very high pressures (5000 MPa) but relatively low temperatures (900 -1300 C) can be transformed into **diamonds**.



While it is the hydrocarbon portion of coal that is burned to turn water into steam, coal also contains other components, including **sulfur dioxide** (SO_2) that combines with oxygen and water in the atmosphere to cause **acid rain** (H_2SO_4). Acid rain devastates forests by damaging the

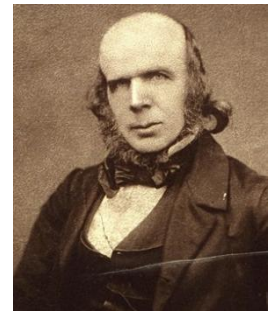
leaves of trees and leaching the nutrients from the soil so the roots cannot mine



them. Acid rain also dissolves buildings and monuments made from limestone (CaCO_3) and marble, which is composed of calcite (CaCO_3) and dolomite ($\text{CaMg}(\text{CO}_3)_2$). Marble is metamorphosed limestone.



The effect of acid rain, resulting from the **industrial revolution**, was described by **Robert Angus Smith** (1872), a chemist who lived in the industrial city of Manchester, England, in his book, *Air and Rain: the Beginnings of a Chemical Climatology*. We will talk more about Manchester, England when we discuss the relationship between coal burning, the discoloration of tree bark, and the **evolution of the coloration of peppered moths**.



Here are some of Smith's measurements of oxygen and carbon dioxide that may be of interest to you. Note that **candles go out** when the oxygen concentration falls to 18.5%.

Oxygen in the Air.

(Per cent., or, if read as whole numbers, per million.)

	Volume per cent.
N.E. sea-shore and open heath (Scotland)	20.9990
Tops of hills (Scotland)	20.9800
In a suburb of Manchester in wet weather	20.9800
" " " " " "	20.9600
St. John's, Antigua	20.9500
In the outer circle of Manchester, not raining	20.9470
Low parts of Perth	20.9350
Swampy places, favourable weather, France and Switzerland	20.9220 to 20.9500
In fog and frost in Manchester	20.9100
London, open places, summer	20.9500
In a sitting-room which felt close, but not excessively so	20.8900
In a small room with petroleum lamp	20.8400
Ditto, after six hours	20.8300
Pit of theatre, 11.30 p.m.	20.7400
Gallery, 10.30 p.m.	20.8600
About backs of houses and closets	20.7000
In large cavities in metalliferous mines (average of many)	20.7700
In currents	20.6500
Court of Queen's Bench, February 2, 1806	20.6500
Under shafts in metalliferous mines (average of many)	20.4240
In sumps or pits in a mine	20.1400
When candles go out	18.5000
The worst specimen yet examined in a mine	18.2700
Very difficult to remain in for many minutes	17.2000

Carbonic Acid in the Air.

(Per cent., or, if read as whole numbers, per million.)

	Volume per cent.
In mines—largest amount found in Cornwall	2.5000
Average of 339 analyses	.7850
In theatres, worst parts, as much as	.3200
In workshops, down to	.3000
About middens	.0774
During fogs in Manchester	.0679
Manchester streets, ordinary weather	.0403
Where fields begin	.0369
On the Thames at London	.0343
In the London parks and open places	.0301
In the streets	.0380
On hills in Scotland from 1,000 to 4,406 feet high	.0332
At the bottom of the same hills	.0341
Hills below 1,000 feet	.0337
" between 1,000 and 2,000 feet	.0334
" between 2,000 and 3,000 feet	.0332
" above 3,000 feet	.0336

The sulfur emissions that are produced by burning coal also **scatter** the sun's rays just as volcanic dust scatters the sun's rays, resulting in less sun reaching the earth's surface and subsequent **global cooling**. Robert K. Kaufmann (2011) noticed that anthropogenic forcing of the global heat load was 0.13 W/m^2 between 2002 and 2007, which was smaller than the anthropogenic forcing (0.24 W/m^2) between 1997 and 2002. Were humans becoming better stewards of the planet? No. Kaufmann suggests that during the latter time period, some of the **global warming** caused by the anthropogenic rise in carbon dioxide (CO_2) was

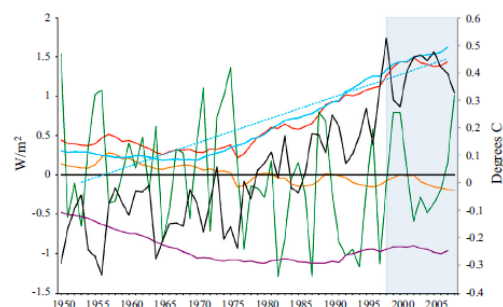
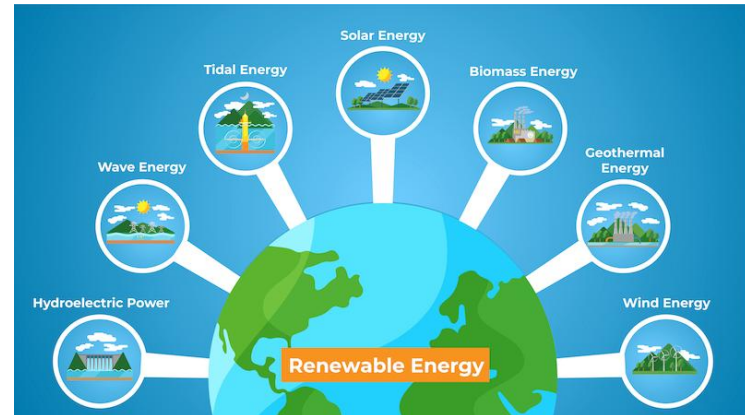


Fig. 1. Radiative forcing of anthropogenic sulfur emissions (purple line), net anthropogenic forcing (blue line), linear estimate of net anthropogenic forcing (blue dash), total radiative forcing (red line), radiative forcing of solar insolation (orange line), and observed temperature (black). The SOI (divided by 10) is given in green. SOI data are presented as annual mean sea level pressure anomalies at Tahiti and Darwin. Post-1998 period of interest (highlighted gray).

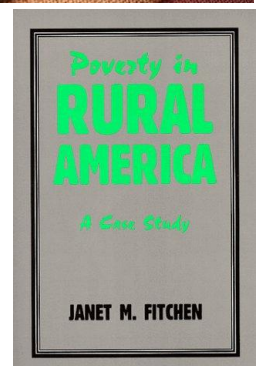
partially mitigated by the doubling of coal consumption in China between 2003 and 2007, which resulted in an increase in sulfur emissions, and a scattering away of incoming sunlight. The forcing coefficients are multiplied by the climate sensitivity factor to determine how the incoming heat changes the global temperature. I have no idea how to calculate the **climate sensitivity factor** (or if one can be calculated nearly as rigorously as the temperature changes that occur as a result of the absorption and scattering of radiation are calculated).



Are renewable energies subject to the second law of thermodynamics? If so, what does that mean?

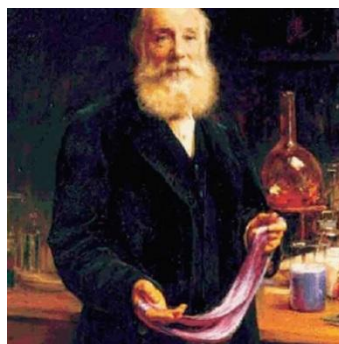
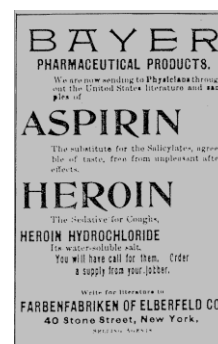


When it comes to green technologies, it is worth remembering that nothing is a renewable resource. It is also worth remembering to take into consideration the **mineral depletion of soil** that occurs by growing agricultural crops such as cotton, flax (linen), and the food for silkworms (silk), and sheep (wool) with the **depletion of fossil fuels** that occurs with the production of [olefin](#), a fabric made from polypropylene. Olefin is lightweight, colorfast, and resistant to staining, mildew, and abrasion, however, it is not biodegradable.



The influence of poor soils on multigenerational poverty in the [Ithaca](#) area was well documented by **Janet Fitchen**.

In the past, **coal gas** was distilled from **coal** to make **illuminating gas** and the residue, which is known as **coal tar**, was used as an inexpensive hydrocarbon source to make fabric dyes and pharmaceuticals.



Today we will have a chance to make **coal ball peels**. Coal balls are found in bituminous and anthracite coal seams. Coal balls are **concretions** made during the **Carboniferous Period**, 359.2-299 million years ago, when **calcium carbonate** infiltrated plant material and it **fossilized**. The calcium carbonate was probably dissolved from a layer of fossil shells in the strata above the coal. The fossilized material is the same material that makes up the coal, although in the coal balls, its structure is preserved. The coal balls themselves are not coal; they are calcium carbonate rich (76.66%) but not carbon rich (4.95%) and are not burnable.

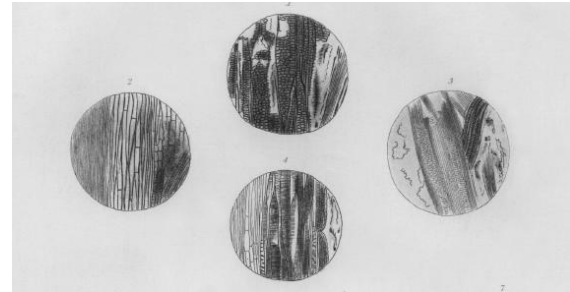
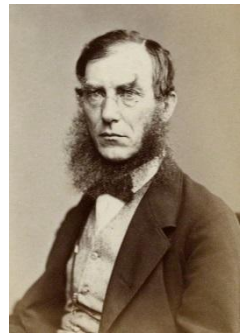
The coal beds are 10-12 meters thick and formed from many successive layers. Each **successive layer** represents an **individual flood** event in the **coal swamp**.



The flooding occurred during **interglacial periods** where the continental shelf was covered with shallow seas. During the flood periods, the dead plants did

not completely decay but turned into **peat**. **Heat and pressure in the earth transformed the peat into coal**. The structures of the plants that were transformed into coal balls were preserved.

Limestone nodules or **coal balls**, found in the coal seams of Lancashire, were first described in 1855 by **Joseph Dalton Hooker** M. D., a friend of Charles Darwin, and **Edward William Binney** Esq., a friend of James Joule. They wrote, “*A section of any of these nodules shows a confused mass of decayed and apparently decaying vegetable remains; they present no appearance of these remains having been brought together by any mechanical agency; they appear to be associated together just as they fell from the plants that produced them, and to be rotting remains of a redundant and luxuriant vegetation.*”

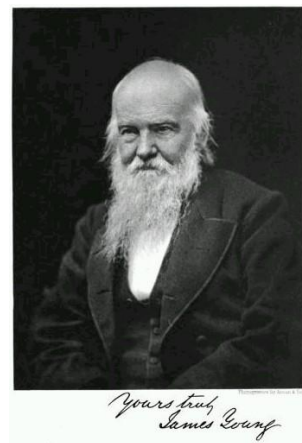


Marie Stopes and David Watson (1909) found continuity of plant stems that are continuous between two coal balls suggesting that the coal balls with the plants within them formed *in situ* and did not roll in from other places.



Binney was a partner in E. W. Binney & Co., who manufactured paraffin wax. In my **personal quest** to find the **connection between all things**, I am currently searching for a connection between E. W. Binney (1819-1881) and Binney & Smith, the company that makes **Crayola** crayons. Here is what I have so far.

E. W. Binney & Company was formed in 1851 by Edward William Binney, James Young, and Edward Meldrum. **James Young** noticed that oil dripped from the roof of a coal mine. Guessing that the oil originated from coal that was exposed to heat, he treated coal with heat and distilled out paraffin oil. Light paraffin oil, also known as **kerosene** (a term coined by **Abraham Gesner**), is used for fuel for lamps and jets, heavy paraffin oil is used for making paraffin wax, which is used for candles. *Keros* (κηρός) is the Greek word for wax.

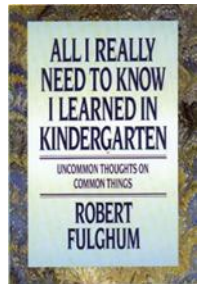


[Joseph Walker Binney](#) (born December 6, 1836), son of Richard and Elizabeth (Cowley) Binney, emigrated from England to upstate New York in 1860 and founded the Peekskill Chemical Works in 1864. I do not know his relationship to E. W. Binney or even if there is a relationship. [Joseph Binney](#) used **pyrolysis** techniques to manufacture charcoal from hardwoods and the **pigment lamp black** from animal fats and whale oil. In 1885, Joseph's son Edwin Binney and nephew C. Harold Smith became partners in Binney & Smith, who manufactured **carbon black pigment used for car tires** that previously were grayish white, and the **iron oxide pigment used to paint the red barns** seen throughout New York. They used slate to make school pencils



(1900) and paraffin to make Crayola crayons (1903). Crayola comes from the French words *craie* for chalk *oléagineux* for oily. In 1958 they introduced the box with 64 colors and a built-in sharpener. I wanted this box all my life. Amy gave me my first one along with the Robert Fulghum's book, "*All I Needed to Know I Learned in Kindergarten- Uncommon Thoughts on Common Things*," in which he wrote,

"Crayolas plus imagination (the ability to create images) - these make for happiness if you are a child. Amazing thing Crayolas. Some petroleum-based wax, some dye, a little binder - not much to them. Until you add the imagination. The Binney Company in Pennsylvania makes about two billion of these oleaginous sticks of pleasure every year and exports them to every country in the United Nations. Crayolas are one of the few things the human race has in common. The green and yellow box hasn't changed since 1937. In fact the only change has been to rename the "flesh" color to "peach". That's a sign of progress.



The way I know about "flesh" and "peach" is that when I bought my godson the trainer set, I indulged myself. Bought my very own set of sixty four. In the big four section box with the sharpener built right in. Never had my own set before. Seems like I was always too young or too old to have one. While I was at it, I bought several sets. Got one for the kid's mother and father and explained it was theirs, not his.

What I notice is that every adult or child I give a new set of Crayolas to goes a little funny. The kids smile, get a glazed look on their faces, pour the crayons out, and just look at them for a while. Then they go to work on the nearest flat surface and will draw anything you ask, just name it. The adults always get the most wonderful kind of sheepish smile on their faces - a mixture of delight and nostalgia and silliness. And they immediately start telling you about all their experiences with Crayolas. Their first box, using every color, breaking them, trying to get them in the box in order again, trying to use them in a bundle, putting them on hot things to see them melt, shaving them into waxed paper and ironing them into stained glass windows, eating them and on and on. If you want an interesting party sometime, combine cocktails and a fresh box of Crayolas for everybody.

When you think about it, for sheer bulk there's more art done with Crayolas than with anything else. There must be billions of sheets of paper in every country in the world, in billions of boxes and closets and attics and cupboards, covered with billions of pictures in crayon. Ronald Reagan and Mikhail Gorbachev used crayons, I bet. So did Fidel and the Emperor of Japan and Rajiv Gandhi and Mrs. Thatcher and Mr. Mubarak and maybe even the ayatollah. And just about everyone else you care to name.

Maybe we should develop a Crayola bomb as our next secret weapon. A happiness weapon. A beauty bomb. And every time a crisis developed, we would launch one. It would explode high in the air - explode softly - and send thousands, millions, of little parachutes into the air. Floating down to earth - boxes of Crayolas. And we wouldn't go cheap, either - not little boxes of eight. Boxes of sixty-four, with the sharpener built right in. With silver and gold and copper, magenta and peach and lime, amber and umber and all the rest. And people would smile and get a little funny look on their faces and cover the world with imagination.

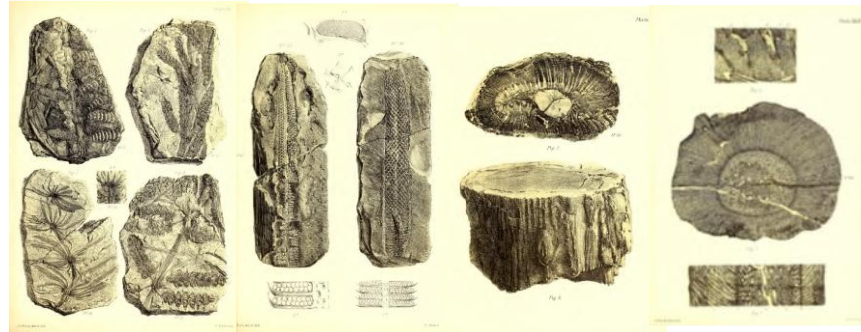
Guess that sounds absurd, doesn't it? A bit dumb. Crazy and silly and weird. But I was reading in the paper today how much money the Russians and our Congress just set aside for weapons. And I think what those weapons will do. And I'm not confused about what's weird and silly and crazy and absurd. And I'm not confused about the lack of, or the need for, imagination in low or high places. Pass the crayons, please.”

I never found a connection between Edward William Binney, son of Elizabeth (Cross) and Thomas Binney, who supplied Joule’s grandfather with malt, and Binney & Smith Crayons. I did find the following anecdotes.

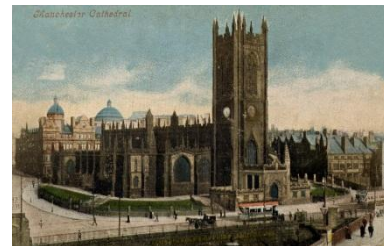
As reported in the Oxford Dictionary of National Biography, Edward William Binney learned of “***the destitution of some artisan mathematicians and botanists***” and tried to establish a public society for “***the relief and encouragement of scientific men in humble life***” (Manchester Guardian, 13 Dec 1843). However, Binney thought that the conditions imposed by Richard Parkinson, a clergyman concerned with the morality of the recipients, would ruin the proposed society’s aims. Consequently, in 1844, Binney set up a private fund where he presented donations at an annual dinner he gave for scientific artisans.

James Crowther, a porter, autodidact, and amateur botanist, and Richard Buxton, a shoemaker, autodidact, and amateur botanist were supported by Binney's fund.

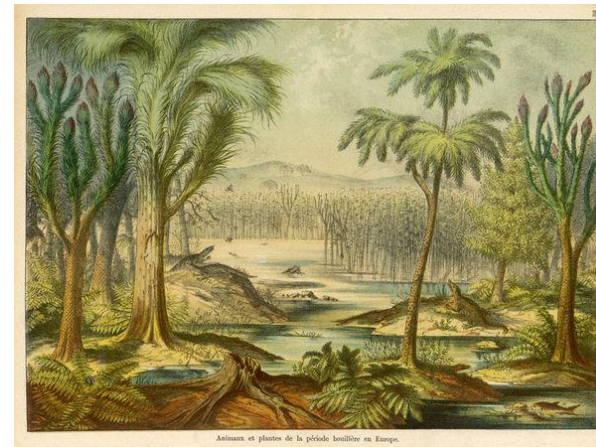
Edward William Binney was, himself, an amateur botanist. Here are some pictures from Binney's book entitled, *Observations on the Structure of Fossil Plants Found in the Carboniferous Strata*.



The carboniferous sandstone known as **Binney's Sandstone**, was named in honor of Edward Binney by Broadhurst and Simpson (1999) to “commemorate the work of a pioneer in the study not only of the geology of Manchester, but of its building stones as well.”



The carboniferous coal swamp, which included *Lepidodendron*, a tree-like fossil **lycopod**, *Calamites*, a tree-like fossil **horsetail**, and **seed ferns** may have looked like this:



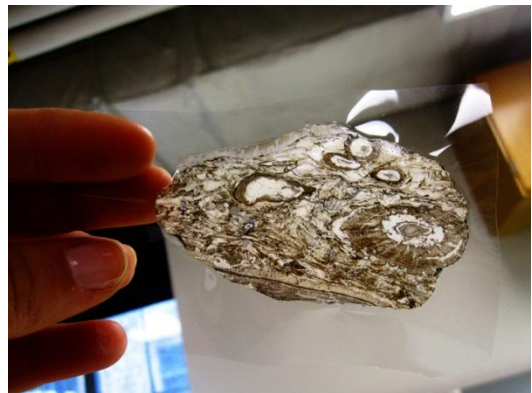
I would like you to know the small living relatives of the tall tree-like plants that gave us coal.



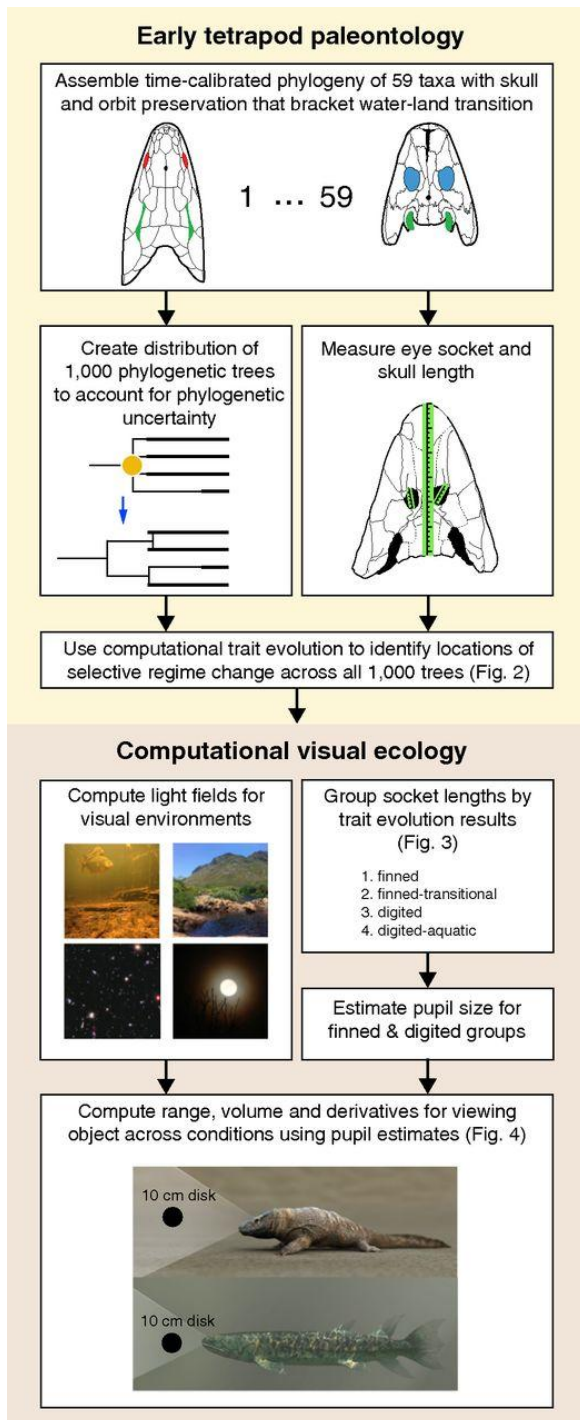
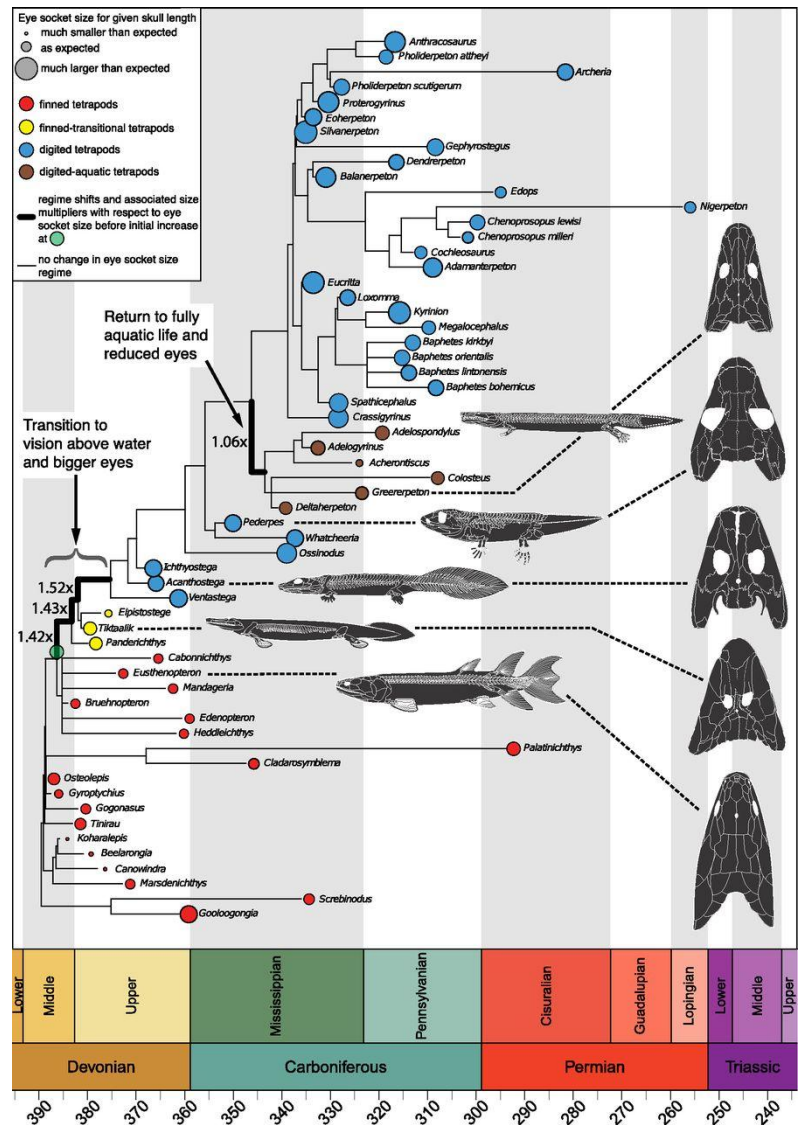


The **procedure to make coal ball peels**, given below, takes about 25+ minutes.

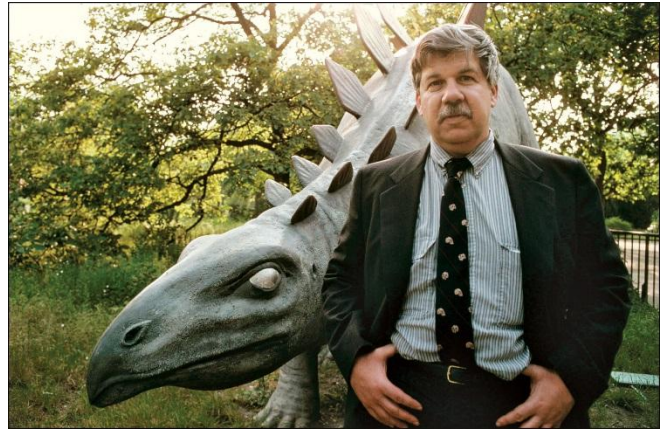
1. Polish the surface of the coal ball with carborundum (SiC), the second hardest material, for **30-60 seconds** using figure 8 motions.
2. Without touching the surface, rinse the surface with water (catching the carborundum in the tub).
3. Soak the shiny surface of the coal ball in 5% (v/v) hydrochloric acid (HCl) for **15 seconds** to dissolve the calcite without removing the organic matter that makes up the cell walls. The organic matter should turn white. Gently wash the surface with water (H₂O) at an angle.
4. Place the coal ball on its side under a heat lamp on tray of gravel until the water on the surface evaporates and the surface becomes a dull gray. The fan will speed up the evaporation process. This takes about **10 minutes**. Adjust polished surface so that it is horizontal.
5. Cover the surface (and not your clothes) liberally with acetone ((CH₃)₂CO) and then gently place a cellulose acetate sheet by slightly folding the cellulose acetate sheet and applying it from the center to the outside.
6. Wait **30 (15-40) minutes** until the acetate is dry. Then peel the cellulose acetate sheet from the coal ball surface and view shiny-side-up with dissecting microscope and take pictures.



Fossil study shows that at approximately the same time the giant plants were growing, **fish** were evolving **larger and forward-facing eyes**—perhaps to see the insects living on land that would be delicious and nutritious enough to lead to the selective advantage of **limbs** that would allow the fish to walk out of the water and on to land (MacIver et al., 2017).



The concept of deep time influenced **Stephen Jay Gould**'s definition of the meaning of life. When asked about the meaning of life by *Life Magazine* (December 1988), the paleontologist answered, "*The human species has inhabited this planet for only 250,000 years or so—roughly .0015 percent of the history of life, the last inch of*

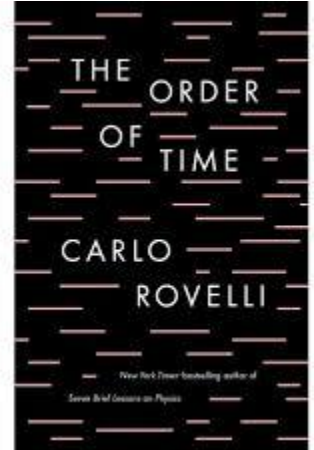


*the cosmic mile. The world fared perfectly well without us for all but the last moment of earthly time—and this fact makes our appearance look more like an **accidental afterthought** than the culmination of a prefigured plan. Moreover, the pathways that have led to our evolution are **quirky, improbable, unrepeatable** and utterly **unpredictable**. Human evolution is not random; it makes sense and can be explained after the fact. But wind back life's tape to the dawn of time and let it play again—and you will never get humans a second time. **We are here because one odd group of fishes had a peculiar fin anatomy that could transform into legs for terrestrial creatures; because the earth never froze entirely during an ice age; because a small and tenuous species, arising in Africa a quarter of a million years ago, has managed, so far, to survive by hook and by crook. We may yearn for a 'higher' answer—but none exists. This explanation, though superficially troubling, if not terrifying, is ultimately liberating and exhilarating. We cannot read the meaning of life passively in the facts of nature. We must construct these answers ourselves—from our own wisdom and ethical sense. There is no other way.**"*

According to Vice President Kamala Harris, there is "[great significance to the passage of time.](#)"

Of course, the whole idea of evolution itself is meaningless if **time is an illusion** as the theoretical physicist Carlo Rovelli (2018) claims in *The Order of Time*.

In an interview about his book, Rovelli states: “*We have learned that **time passes at different rates depending on altitude and on speed**. We have learned that the fundamental equations of physics do not distinguish the past from the future. And we have learned that our very strong intuition about the present is valid only in a relatively small bubble around us; **there is no objectively defined present in the large universe**. Those are not speculations. They are established physics.*” <https://physicstoday.scitation.org/doi/10.1063/PT.6.4.20190219a/full/>



Again, we see that science does not say something unequivocally, but scientists in different fields disagree about what are established facts. You have every right to choose which theory seems more correct to you. If established physics is correct, then the theory of evolution is meaningless. If the theory of evolution is correct, then it is time to **disestablish** physics, although on this issue physicists seem to be **antidisestablishmentarians** in such a way as could be described as **antidisestablishmentarianism**. I never thought I'd be able to use that word in a sentence!

Luminescence and the Production of Light by Living Organisms

The term **luminescence** was coined by **Eilhard Wiedemann** (1888) to distinguish the **cold light** produced by x-rays, radioactivity, and “*all those phenomena of light which are not solely conditioned by the rise in temperature*” from **incandescence** or **hot light** that comes from **incandescent** sources such as the sun, an oil lamp, a candle, a gas lamp, and an electric lamp with a carbon or tungsten filament.

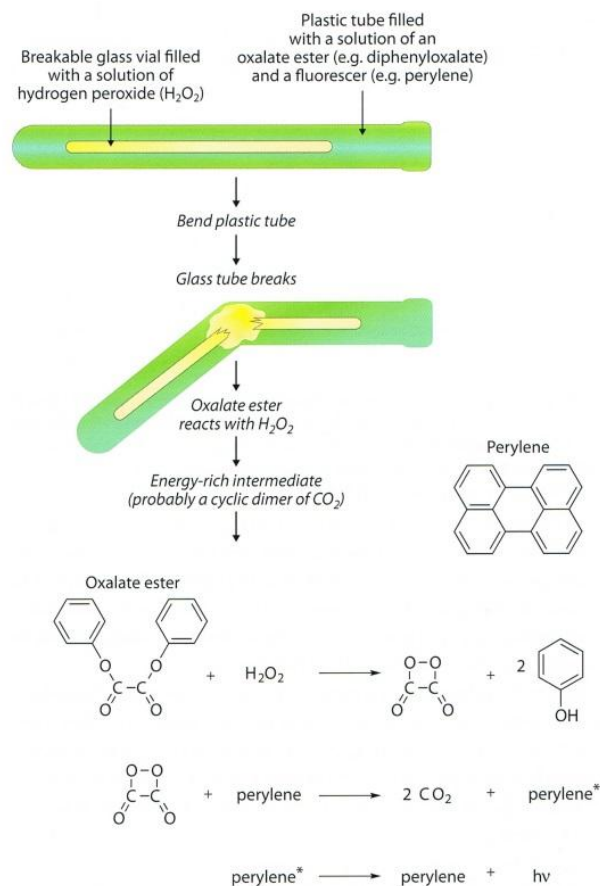


Wiedemann defined many kinds of luminescence, based upon the **type of energy transformed into light**. We have talked about **chemiluminescence**, in which light emission is the result of a chemical reaction (e.g., white phosphorous). We have talked about **photoluminescence** (e.g., Bologna stone), in which light emission is a result of the absorption of light. When the emission is somewhat immediate and transient (10^{-8} s), photoluminescence is known as **fluorescence** (e.g., chlorophyll) and when the emission is delayed (1 millisecond) and long lasting (milliseconds to hours), photoluminescence is known as **phosphorescence** (e.g., Bologna stone). **Sonoluminescence** is when light is emitted from imploding bubbles in a liquid excited by sound. **Radioluminescence** is when light emission is a result of a material being bombarded by ionizing radiation (e.g., the purple glow of the ^{22}Na that caused a huge change in Martin Kamen's life). Soon after the discovery of radioactivity, Mark Twain (1904), in [*Sold to Satan*](#), described Satan's look as not being red like a fire coal but as *a softly glowing, richly smoldering torch, column, statue of pallid light, faintly tinted with a spiritual green*, because he was made of radioluminescent radium.



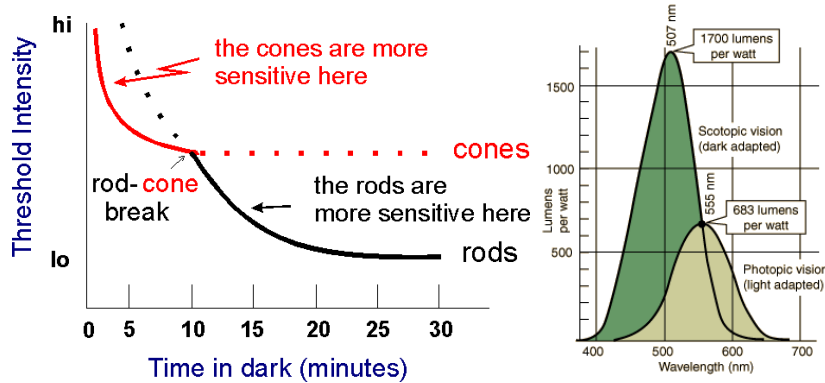
Triboluminescence is when light is emitted as a result of the mechanical breakage of bonds (e.g., flash rocks made of quartz, **Uncompahgre Ute Indian rattles**), which shoots out electrons that excite the nitrogen gas in the air and cause them to emit light. Francis Bacon (1620) wrote in *Novum Organum*, “*It is well known that all sugar, whether candied or plain, if it be hard, will sparkle when broken or scraped in the dark.*” **Wint-O-Green life savers** glow even brighter than sugar because the spark of light given off by the electrons exciting the nitrogen gas of the air is absorbed by methyl salicylate and reemitted as fluorescent light. **Electroluminescence** is when light is emitted as a result of an electric field or the passage of an electric current through a gas (e.g., neon lights) or semiconductor (e.g., light emitting diode; **LED**), and **bioluminescence** is the emission of light by living organisms.

Demonstration of luminescence or cold light: Bioluminescent bacteria: *Vibrio*; bioluminescent fungi: (*Armarillia*, *Panellus*); bioluminescent dinoflagellates (*Pyrocystis*); bioluminescent sea fireflies (*Cypridina hilgendorffii*); photoluminescent Krypton (Europium) sheets and pellets; chemiluminescent glow sticks; and triboluminescent quartz “flash rocks.”

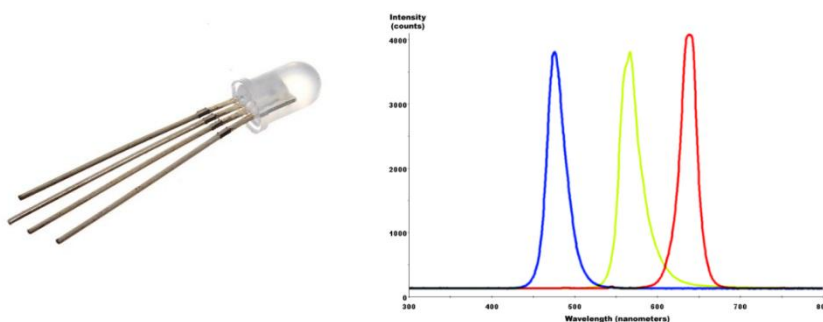
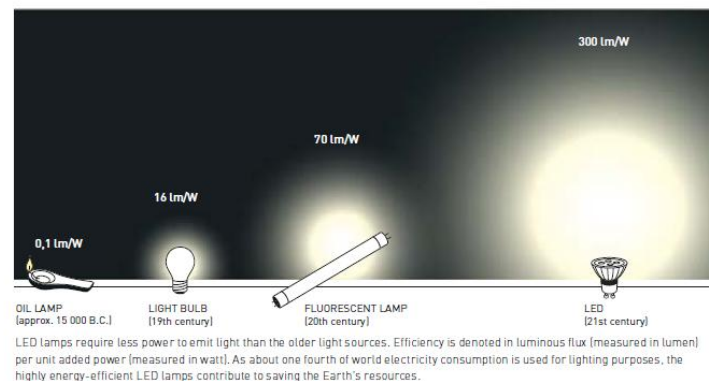


Luminescence is typically a very low light phenomenon that requires our dark-adapted, wide-open, dilated pupil, **rod-dominated**, **scotopic vision** to see. **Robert Boyle** had to do his experiments on luminescence at night and it is quaint how he described each experiment he did **yester-night**.





Currently work is being done which would allow the replacement of **incandescent light** with **electroluminescent light** produced by red-green-blue (RGB) light emitting diodes (LEDs) that minimize the amount of energy transformed into thermal energy but maximize the amount of energy transformed into white visible light that is seen by our **cone-dominated, photopic visual system**.

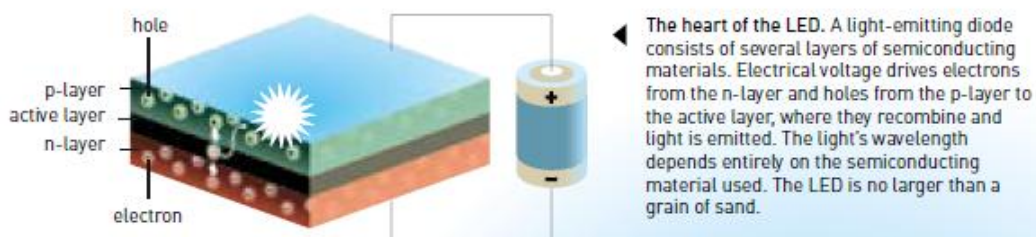
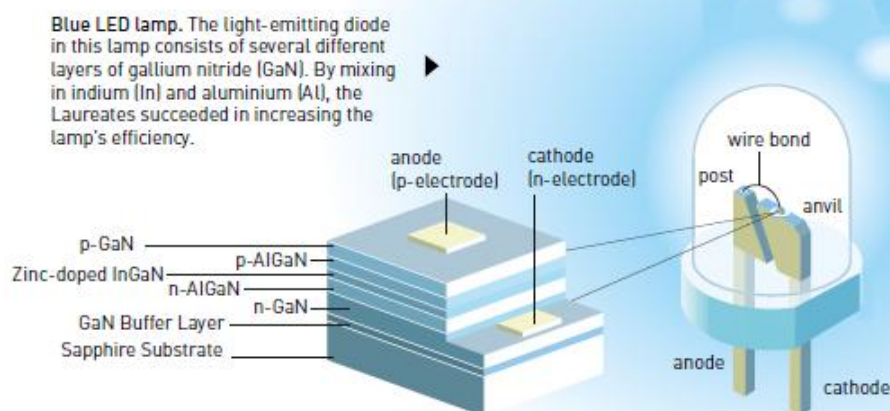


The ratio of the energy output (luminous flux in lumens) to the energy input (in Watts) is spectacular for LEDs. LEDs produce approximately 300 lumens/watt while tungsten lightbulbs produce about 16 lumens/watt. The 2014 Nobel Prize in Physics was awarded to Isamu Akasaki, Hiroshi Amano, and Shuji Nakamura *“for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources.”* *“The Laureates challenged established truths;*

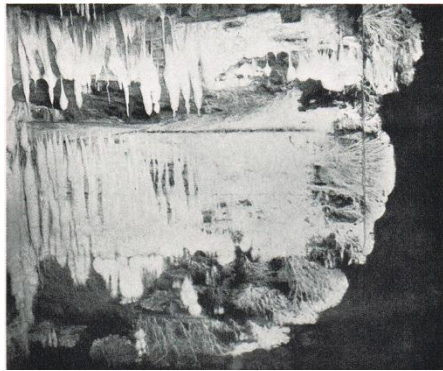
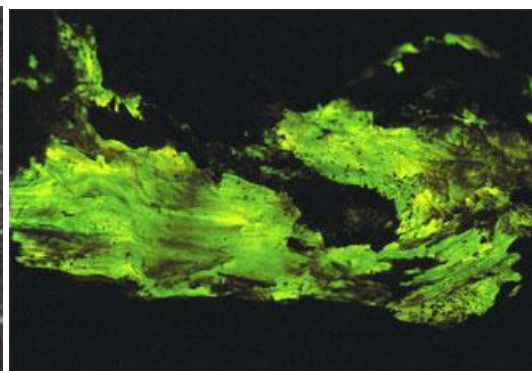
they worked hard and took considerable risks. They built their equipment themselves, learnt the technology, and carried out thousands of experiments. Most of the time they failed, but they did not despair; this was laboratory artistry at the highest level.”

http://www.nobelprize.org/nobel_prizes/physics/laureates/2014/presentation-speech.html

Since ancient times, Aristotle, Pliny the Elder, and others have noticed that rotten wood, fish, and meat emitted light. Using his vacuum pump, **Robert Boyle** (1667,1672) showed that the luminous emission of greenish-blue light from stinking fish, a rotting neck of veal, and rotten wood required **air** (which later was shown to contain **oxygen**). Clever people have used the luminescent light of rotting fish, wood, and tiny crustaceans to see at times and in spaces that that are not reached by sunlight or moonlight.

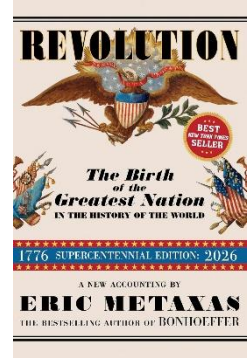


During the Revolutionary War, **David Bushnell**, while an undergraduate at Yale, designed the **Turtle**, so called because it resembled “*two upper tortoise shells of equal size, joined together.*” The Turtle was about six feet high, three feet wide and four feet long with just enough space for one person. It could hold enough air for one person for about 30 minutes. The operator drove the Turtle about 3 mph by turning a propeller with a hand crank. On the top of the Turtle, a second propeller, also turned by a hand crank, moved the Turtle up and down. The Turtle had a rudder to steer it and a foot valve to let water into a ballast tank at the bottom to submerge the Turtle. The Turtle carried a **time bomb** also designed by David Bushnell that he made from a hollow log containing 150 pounds of gunpowder and a clock to ignite it. A barometer and the needles of the compass in the Turtle were illuminated with “*fox-fire, i.e. wood that gives light in the dark.*”



David Bushnell had built the Turtle to break the British blockade of Boston harbor. However, throughout the winter, it was so cold that the fox fire was not able to glow. He sent word to Benjamin Franklin asking, “*whether he knows of any*

kind of phosphorus which will give light in the dark and not consume the air,” noting that *“he has tried a candle, but that destroys the air so fast he cannot remain under water long enough to effect the thing.”* On March 17, 1776, the British forces commanded by General William Howe evacuated Boston and the Turtle had lost its chance for action in Boston.

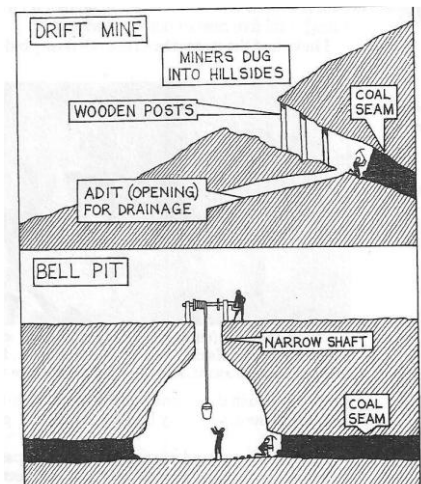


Not wanting to miss his chance to fight in warmer weather, when the fox fire would glow, David Bushnell offered the Turtle to help George Washington defend New York City from the British. The Turtle, commanded this time by Ezra Lee, was transported to New York Harbor where the HMS Eagle, commanded by William Howe’s brother, Richard Howe was moored. Unfortunately, the Turtle did not contain enough air to securely fasten the time bomb to the Eagle and move away safely. Thus, the Turtle never succeeded in helping win the Revolutionary War against the British. In this class, however, the Turtle is famous for its clever use of **bioluminescence**!

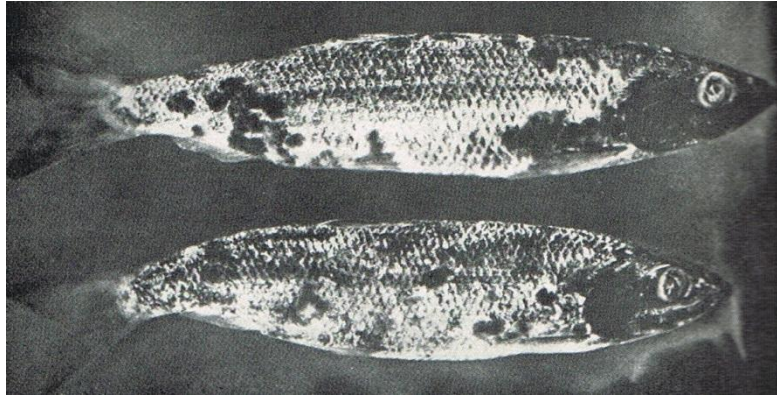
<http://connecticuthistory.org/david-bushnell-and-his-revolutionary-submarine/>

<http://www.history.navy.mil/research/library/online-reading-room/title-list-alphabetically/s/submarine-turtle-naval-documents.html#item10>

Coal weaves a thread through many aspects of light and life. With the development of the **external combustion engines** that used coal to heat water to **steam** in the late 18th century, water-powered factories were replaced by steam-powered factories. This **industrial revolution** resulted in an increased demand for coal that was greater than that that could be extracted from **drift mines** and **bell pits**. Consequently, **deep mines** were dug. The deep mines were not only



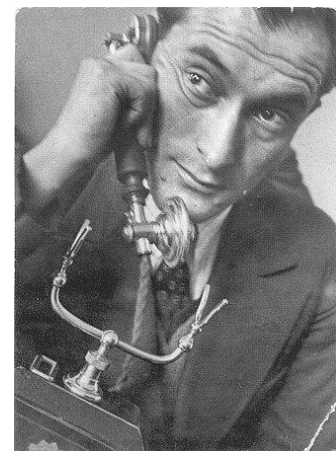
dark but contained flammable gas and explosive coal dust. For this reason, miners would



bring **bioluminescent rotting fish** to see in the mine. Miners stopped using rotting fish to illuminate the mines after Humphry Davy discovered that flame cannot pass through a screen mesh and invented the vegetable oil burning **Davy safety lamp** in 1815. Since the flame could not pass through the **screen mesh** but gases could, the lamp could also be used as a gas detector. The presence of **methane (firedamp)** in the mine would cause the flame to burn **higher and bluer**. The presence of **carbon dioxide gas (chokedamp)** and not enough oxygen in the mine would cause the flame to **burn low**. The metal gauge along the side of the lamp was used to measure the height of the flame and thus the amount of methane or carbon dioxide in the mine.



Eugene Petrov (1941), a Soviet writer, dramatist, and war correspondent wrote in his Front Diary, *“I observe many small and large **luminous blue grains** under foot. It is as though someone has trod ahead with magic **perpetual fire** trickling from his knapsack. It takes some time to realize that it is simply bits of **rotten wood** which a fatigue party has carefully collected in the forest and used to lay **luminous tracks** between the tents. Here such tracks are known as the ‘Milky Way’.”*



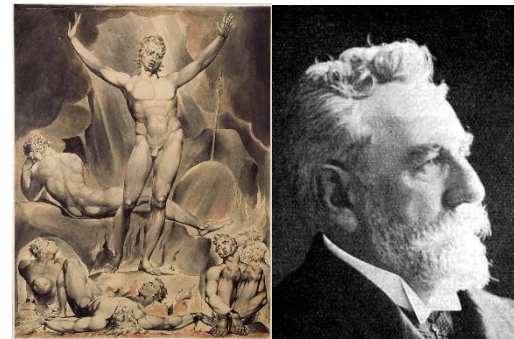
During World War II Japanese soldiers fighting in the Pacific theatre used dried ground *Cypridina* (= *Vargula*), a tiny **crustacean** mixed with water to produce weak but sufficient luminescent light to see on moonless nights. The soldiers would then rub small amounts of the solution on each other's back so that they could follow the soldier who was 15-20 feet in front of them. The soldiers may have also rubbed their hands with *Cypridina* to illuminate and read maps.



Demonstration: Observe luminescence in Sea Fireflies (*Cypridina hilgendorffii*).



Raphaël Dubois (1885) performed experiments with many bioluminescent taxa and discovered that the production of living light required **two separate water-soluble components**. The first one, which he extracted with hot water, was a heat-stable component that he called **luciferin**, after **Lucifer**, the Latin word for light-bearer. It may have come from the Hebrew word הֵילֵל (*heilel*) for morning star that appears in Isaiah 14:12 “*How you have fallen from heaven, morning star, son of the dawn! You have been cast down to the earth, you who once laid low the nations!*”

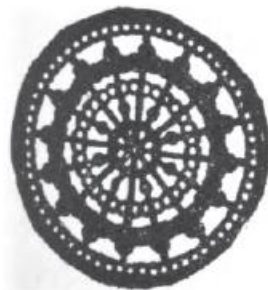
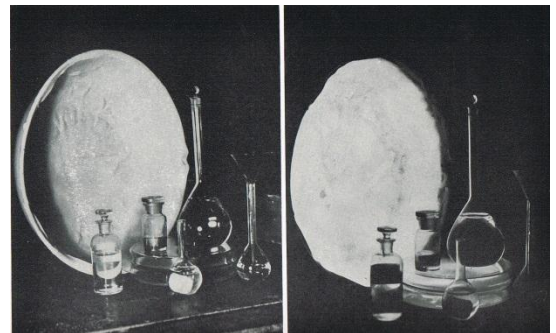


The second component, which Dubois extracted with cold water, was heat-labile and therefore an enzyme. He called the enzyme **luciferase**. The two components were **necessary and sufficient** to produce light in a test tube.

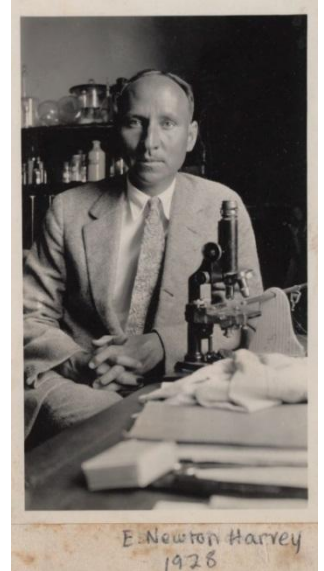


In 1896, Raphaël Dubois “*opened a new and promising field for future progress by showing the inferiority of these means [of artificial lighting] when compared with those of nature and by placing the question upon the ground of producing illumination by a new method.*” In the **Paris International Exposition of 1900**, Raphaël Dubois showed the world that six one-gallon flasks of bioluminescent bacteria could light a room sufficiently for the visitors to read newspapers without any danger of fire or explosion.

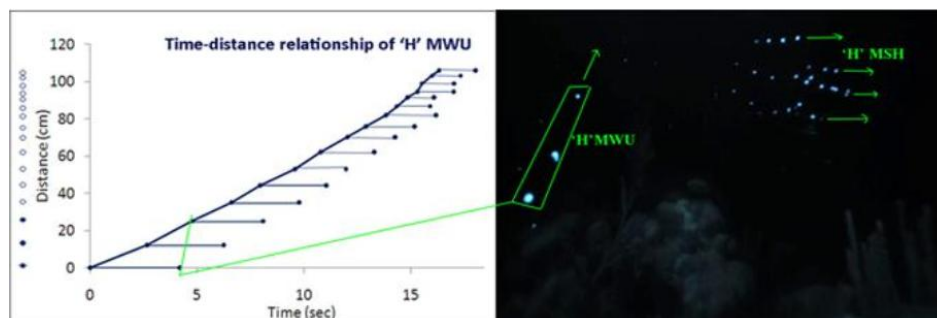
Human beings had made use of bioluminescence for light outside the home. Putting his research to practical use, Raphaël Dubois built a **bioluminescent lamp** for inside the home and created a photograph of paper lace using bioluminescent bacteria to expose the paper. E. Newton Harvey used bioluminescent bacteria to illuminate a still life.

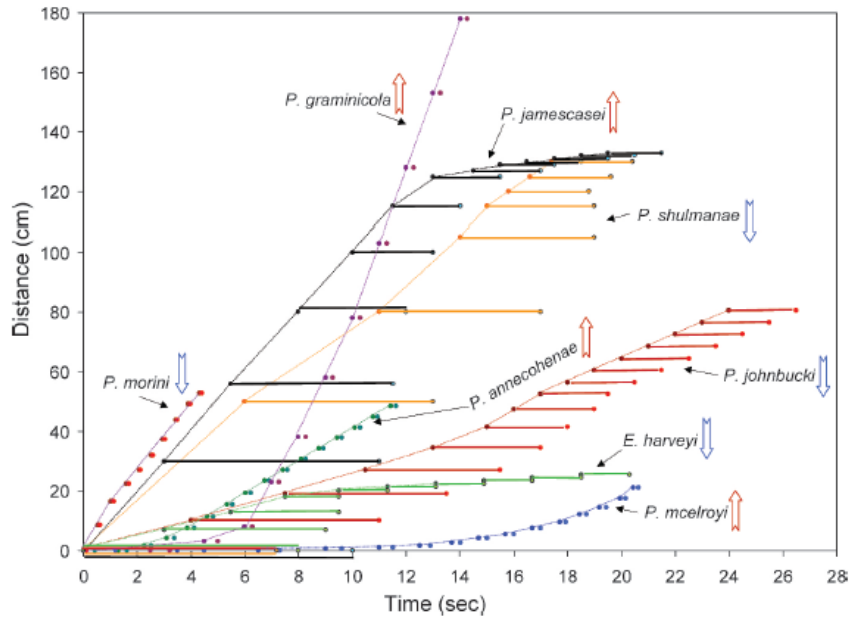
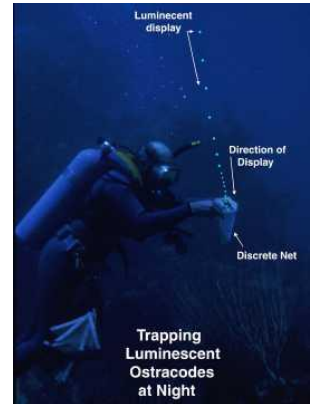


Like the 19th century naturalists, such as Charles Darwin and T. H. Huxley, at the beginning of the 20th century **E. Newton Harvey** made expeditions all over the world making observations and collecting animals. While on his honeymoon in 1916 and while he was swimming at night in the waters near the Misaki Laboratory Biological Station south of Tokyo, he became enamored by the blue bioluminescence of *Cypridina hilgendorffii*, known as the sea firefly or **Umihotaru** (海ほたる) in Japanese. *Cypridina* are scavengers that live on the ocean bottom waiting for fish to die and sink—at which time they rapidly consume the fish.



As **Jim Morin** (Cornell) observed, when the Caribbean Ostracodes like *Cypridina* are pursued by a predator, they emit clouds of blue bioluminescence as a means to escape the predator.





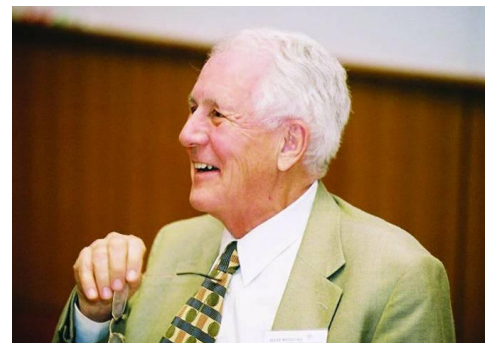
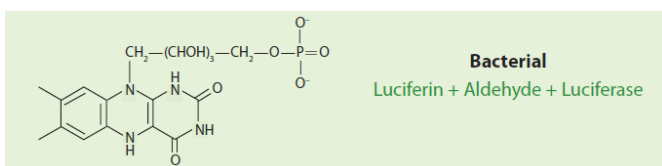
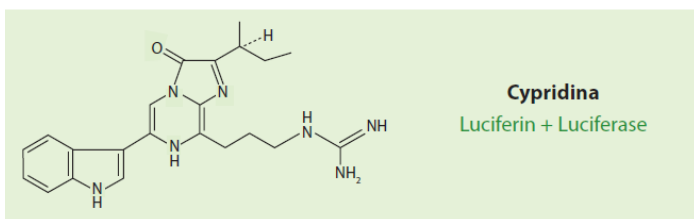
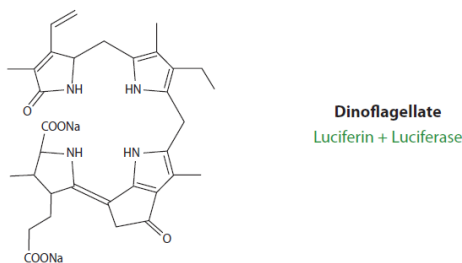
In their **courtship behavior**, which occurs on moonless nights, the males synchronously release pulses of blue bioluminescence in a species-specific manner to attract the females, who use the displays to orient and intercept the male producing it. The bioluminescence of Ostracodes is always extracellular. The courtship displays may be at risk as a result of **light pollution** coming from resorts built on the seashores where cypridinid Ostracodes live.

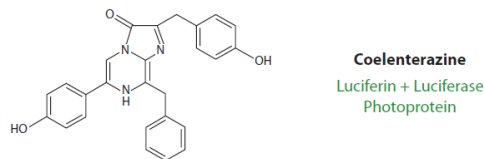
E. Newton Harvey caught *Cypridina* by suspending a large fish head by a string in shallow sandy water and waiting for swarms of *Cypridina* to eat it. After two hours, he lifted the fish head out of the water and picked off the *Cypridina*. E. Newton Harvey had a passion for bioluminescence and studied its physics, chemistry, and biology. E. Newton Harvey showed that the bioluminescent organisms all had the two components that Raphaël Dubois had discovered: a **luciferin** and a **luciferase**. However, the luciferin of one taxon would not necessarily interact with the luciferase of another. By discovering that the luciferins and luciferases from different taxa were **not** interchangeable, E. Newton Harvey learned that there was not just one kind of luciferin and just one kind of

luciferase, but **many** kinds of luciferins and **many** kinds of luciferases. He found the **diversity in the apparent unity**.

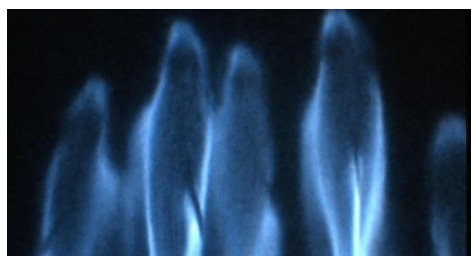
E. Newton Harvey found that **Charles Darwin's** idea that unity of function is a consequence of **common descent** does **not** apply to bioluminescence. According to **J.**

Woodland (Woody) Hastings (1996), a graduate student of E. Newton Harvey, “*Many different organisms, ranging from bacteria and fungi to fireflies and fish, are endowed with the ability to emit light, but the bioluminescent systems are not evolutionarily conserved: genes coding for the luciferase proteins (Lase) are **not homologous**, and the luciferins are also different, falling into many unrelated chemical classes.*”

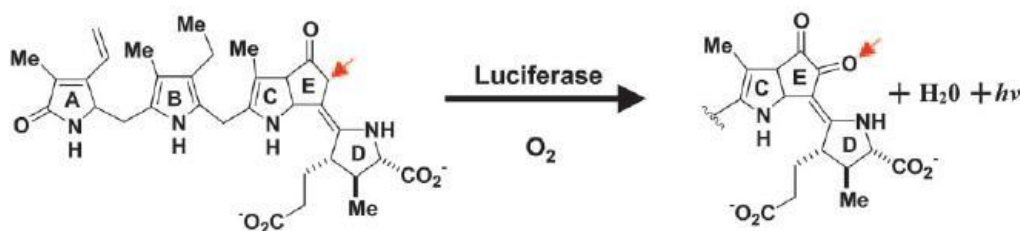




While the **specific** chemical natures of luciferin and luciferase differ, the bioluminescence they generate all follow a **general rule**: A **high-energy molecule** containing a number of **conjugated double bonds** is converted to a **low-energy molecule** in an **oxygen-requiring enzymatic process** and in the process the **energy difference is released as visible light energy**. The oxygen is usually consumed in the form of **molecular oxygen** although some systems use the peroxide anion (O_2^{2-}).



For example, the **mechanically-induced bioluminescence of dinoflagellates**, which has been shown by Esaias and Curl (1972) to function as a burglar alarm to scare away predators, is described by the following reaction:



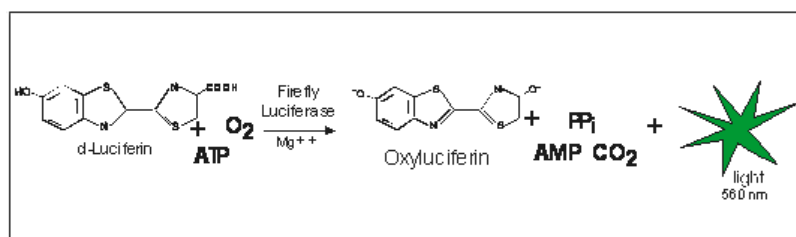
Luciferase binds **oxygen** and a reduced or high-energy form of luciferin. The luciferase functions as an **electron and proton pipe** that passes **two electrons**

and **two protons** from the high-energy form of **luciferin to oxygen**. This transfer results in the formation of **oxyluciferin**, a low-energy form of luciferin and water. In the process, the difference in the redox energy of the reduced luciferin and the oxyluciferin is transformed into visible light. In some respects, bioluminescence, where the **luciferase enzyme** acts as an **electron pipe**, is the **reverse of photosynthesis** where **chlorophyll** acts as an **electron pump**.

The mechanisms of bioluminescence in *Cypridina*, bacteria (*Vibrio*), and fungi (*Armillaria*, the honey fungus) share some similarities with dinoflagellates, although their luciferins and luciferases differ. While the function of bioluminescence in all fungi is not known, some suggest that bioluminescence in some fungi is a strategy to attract arthropods and insects that will disperse the spores. This may be true for fungi with bioluminescent fruiting bodies (e.g. *Omphalotus*, *Mycena*, *Panellus*, *Neonothopanus*; <https://blog.mycology.cornell.edu/2010/04/12/this-bark-glows-in-the-dark-bioluminescence-in-mushrooms/>), but cannot explain bioluminescence in *Armillaria*, whose underground mycelia are bioluminescent but its fruiting body (mushroom) is not. **Perhaps this is the fungal expression of ‘art for art’s sake.’**



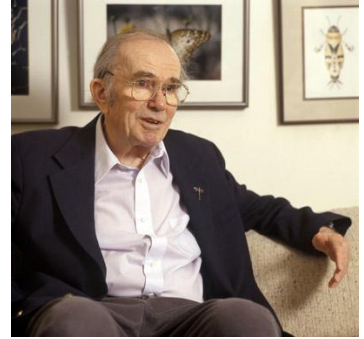
In the case of **firefly bioluminescence**, like bioluminescence in dinoflagellates, a high-energy molecule that contains many conjugated double bonds is converted to a low-energy molecule in an oxygen-requiring enzymatic process and in the process the energy difference is released as visible light energy. In the case of fireflies, however, the high-energy form of luciferin requires supplementation by **ATP** which is converted to AMP and pyrophosphate (P_iP_i). The redox energy is the primary source of energy as the energy of ATP (8×10^{-20} J) is too little to produce a photon itself ($E = \frac{hc}{\lambda} \approx 4 \times 10^{-19}$ J).



In fireflies, bioluminescence is used in **courtship behavior**. In some taxa, the male fireflies (or beetles to an entomologist) produce a sequence of light flashes in a species-specific manner. The females recognize the flash sequence and flash back once. The males recognize the single flash by the amount of time elapsed between the end of the male's sequence of flashes and the female's single flash. Then the male flies to the female and mates with her.



Now, there is a complication involved in the courtship behavior. The females of one genus of fireflies (*Photuris*) are *femme fatales* and prey on the male fireflies of



another genus (*Photinus*). The females of *Photuris* have two different light delays that they can use: one that matches their own genus and effects mating, and one that matches the other genus and effects eating. **Tom Eisner** (Cornell), author of *For Love of Insects*, showed that the females of *Photuris* incorporate a chemical known as **lucibufagin** (*luci* from the Latin for light, *bu* from the genus of toad *Bufo* that produces a similar chemical named bufalin) when they eat the lucibufagin-producing males of *Photinus*.

Lucibufagin makes the *Photuris* females and their eggs **unpalatable** to predatory **jumping spiders**. When the female *Photuris* have not eaten *Photinus* males, they do not acquire the lucibufagins and are eaten by predatory spiders. The more *Photinus* males that the *Photuris* females eat, the more lucibufagins they acquire, and the better the protection they have from predators.



There are some species of fireflies where the males all flash in [synchrony](#). For example, *Photinus carolinus* males synchronously produce a series of 5-8

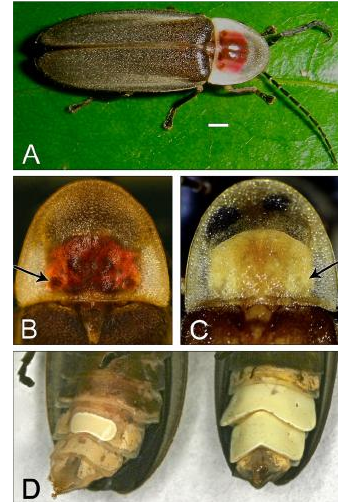
flashes followed by 8 s of darkness. They can be found in Allegany National Forest.



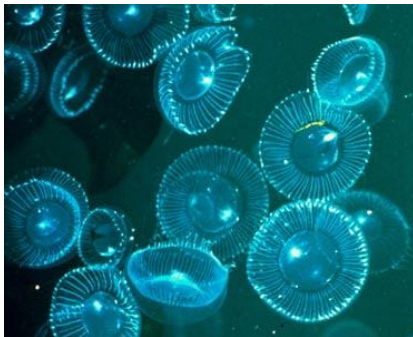
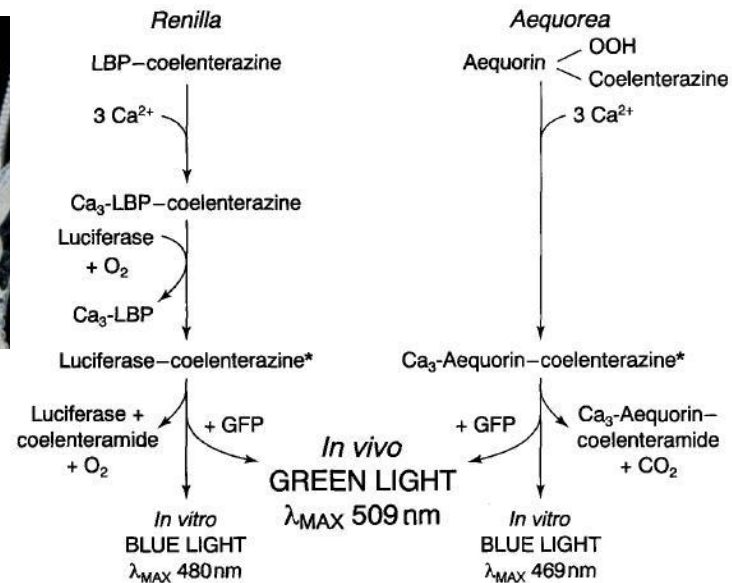
Synchronous fireflies are not so rare in Southeast Asia and species of the *Pteroptyx* genus can be seen lighting up mangrove trees!



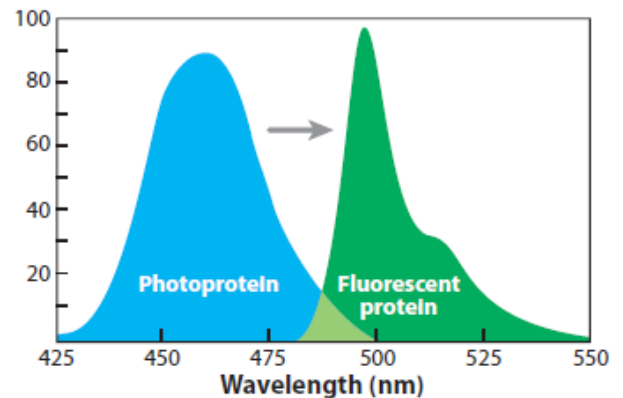
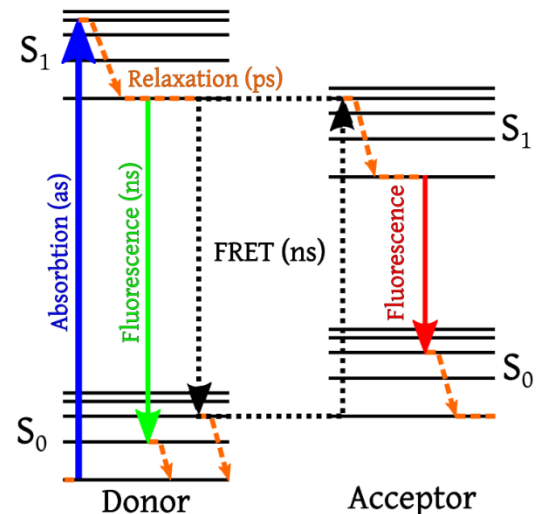
On March 6, 2010, a new species of firefly, *Photinus interdius*, was [discovered](#) in Panama that display their bioluminescent courting behavior in the afternoon from 3:10 PM to 6:00 PM before it is dark. Vencel et al. (2017) suggest that diurnal courtship is a result of optimizing the tradeoff between reduced predation risk from bats and other species of firefly (*Photuris trivittata*) and the ease of localizing a mate. The lanterns of the females (D, left) and males (D, right) have different forms (dimorphic). Interestingly, the researchers were able to attract the male by a single flash of an LED 1.6 s after the male flash.



Another variation in the production of bioluminescence is found in jellyfish (*Aequorea*) and related hydroids (*Obelia* and *Renilla*) where the luciferin is a **coelenterazine** (that they probably ingest as part of their diet).



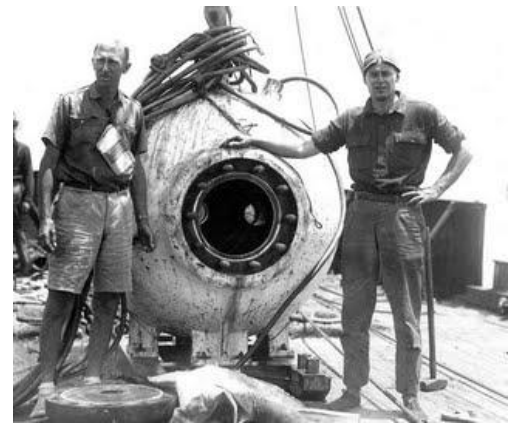
The green bioluminescence in these organisms is stimulated only when they are disturbed and perhaps it may have a defensive function. The luciferase of *Aequorea* is a protein called **aequorin**. The aequorin binds the luciferin, known as **coelenterazine** in an oxygen-dependent manner. The luciferin-luciferase complex does not emit light until it binds **calcium ions**. *Aequorea* emits blue light *in vitro*, but it emits green light *in vivo*. It emits green light *in vivo* because *Aequorea* contains a protein that fluoresces green after it absorbs blue light. When the aequorin and **green fluorescent protein** molecules are close enough (i.e., 5-10 nm) to each other, as they are in the living cell, the energy that would be emitted by aequorin after it binds calcium ions is transferred to the green fluorescent protein by a process known as **resonance energy transfer (RET)** and the green fluorescent protein emits green light. I will talk about fluorescent proteins again when I discuss fluorescence microscopy.



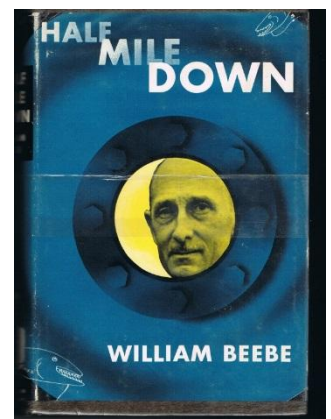
Genetically-engineered bacteria can produce the aequorin protein. This aequorin is sold as Prevagen.



Bioluminescence is *rare* in **terrestrial habitats** and nonexistent in fresh water. However, deep down in the ocean, deeper than where sunlight can reach, there is a world of **marine creatures** that **turn life into light** in order to create their own light **to see, to catch prey, to mate, and to confound predators**. **William Beebe** was a seasoned **explorer and a naturalist** who turned his attention from the jungles to the sea. He and **Otis Barton** built the **bathysphere** that allowed them to go into the depths and darkness in August 1934 where no living person had gone before, and to **discover a world of living light**.



William Beebe wrote in *Half Mile Down*, “Ever since the beginnings of human history, when first the Phoenicians dared to sail the open sea, thousands upon thousands of human beings had reached the depth at which we were now suspended, and had passed on to lower levels. But all of these were dead, drowned victims of war, tempest, or other acts of God. We were the first living men to look out at strange illumination: And it was stranger than any imagination could have conceived. It was an *indefinable translucent blue* quite

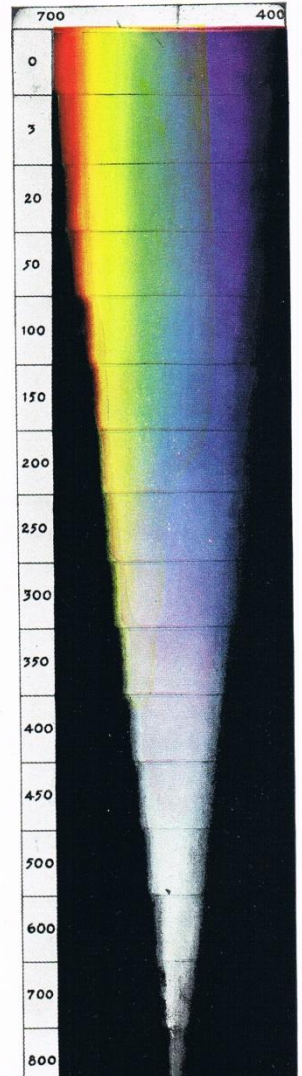


*unlike anything I have ever seen in the upper world, and it excited our optic nerves in a most confusing manner. We kept thinking and calling it brilliant, and again and again I picked up a book to read the type, only to find that I could not tell the difference between a blank page and a colored plate. I brought all my logic to bear, I put out of mind the excitement of our position in watery space and tried to think sanely of comparative color, and I failed utterly. I flashed on the searchlight, which seemed the yellowest thing I have even seen, and let it soak into my eyes, yet the moment it was switched off, it was like the long vanished sunlight—it was as though it never had been—and **the blueness of the blue**, both outside and inside our sphere, seemed to pass materially through the eye into our very beings. This is all very unscientific; quite worthy of being jeered at by optician or physicist, but there it was.”*

*“Here and at 800 feet a human being was permitted for the first time the sight of living, silver hatchet-fish, **heliographing**, their silver sides. I made Barton look quickly out so he could verify the unexpected sight.”*

See a video that shows the effect of water depth on color:

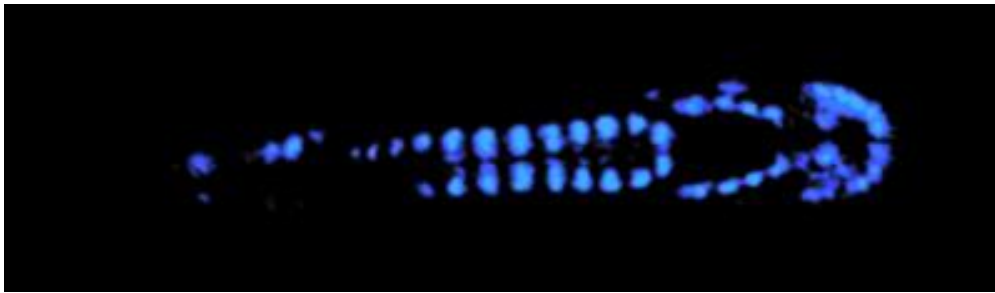
<https://www.rateyourdive.com/wiki/absorption/>





The **hatchet-fish** produce bioluminescence on their undersides as **counter illumination** to confound predators by eliminating their silhouettes that would be recognized by predators swimming beneath them. Because of the **counter illumination**,

the hatchet-fish confound their predators by becoming **invisible from below**.



*“Life again became evident around 1300 feet and mostly luminous. After watching a dozen or more firefly-like flashes I turned on the searchlight and saw nothing whatsoever. These sparks, brilliant though they were, were kindled into conflagration and quenched in the same instant upon **invisible bodies**.”*

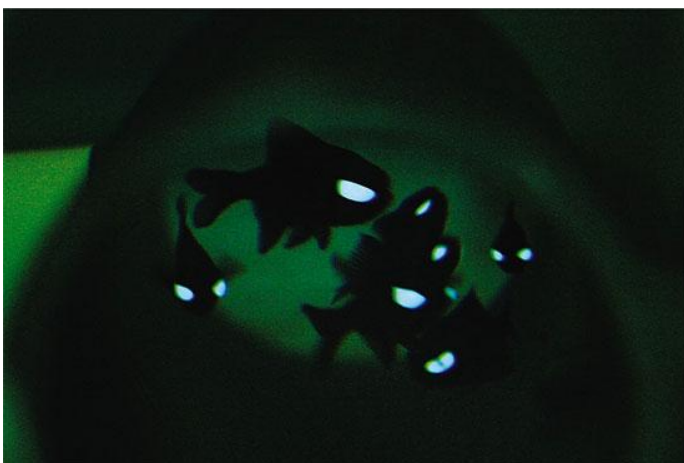


“After these dives were past..., I would feel like an astronomer might who looks through his telescope after having rocketed to Mars and back, or like a paleontologist who could suddenly annihilate time and see his fossils alive.” On the right is a picture of the luminous stars in the heavens and on the left is a picture of the luminous fish in the sea.



William Beebe estimated that at depths greater than 400 meters, ninety five percent of fish are bioluminescent.

Flashlight fish (*Kryptophanaron alfredi*; *Photoblepharon palpebratum*; *P. steinitzi* and *Anomalops katoptron*) and the giant squid farm bioluminescent bacteria in pockets near their eyes that act as **headlights** so that the hosts can see deep beneath the sea.



Dragonfish have **blue bioluminescent headlights** and **red bioluminescent headlights** that act as a **sniper scope**. The blue bioluminescent light can be seen with the **scotopic rod-dominated visual system of most deep-sea fishes**, but among the deep-sea fish, **only the dragonfish** **has the long wave photoreceptors** to see the red light that the photophores produce.



Like the Ostracodes discussed above, some deep-sea fish, crustaceans, and the **vampire squid** emit clouds of bioluminescent materials into the water to escape from predation.



Anglerfish, **viperfish** (*Chauliodus*), and **dragonfish** use **blue bioluminescent “lures”** to attract prey. Blue light travels in water farther than other colors that are absorbed more readily. The fish produce blue bioluminescent light in two different ways. The viperfish and dragonfish produce bioluminescence themselves while the anglerfish farms bioluminescent bacteria.

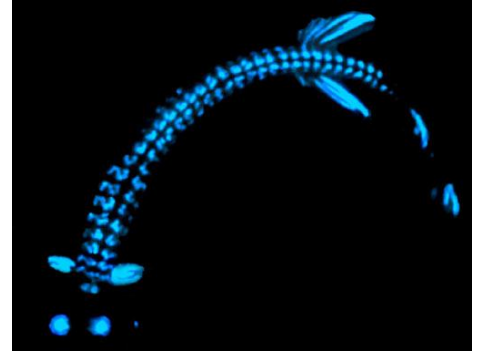


Anglerfish video: <https://www.youtube.com/watch?v=XUVerZsbYiw>

Viperfish video: <https://www.youtube.com/watch?v=ZygDDhdI5do>

Dragonfish video: https://www.youtube.com/watch?v=JZNHIqqa_FU

The **lanternfish** are undersea bioluminescent artists. They use bioluminescence for **vision**, **courtship**, and **counter-illumination**. Let's now watch these deep sea marvels in the video entitled, "*Marine Bioluminescence: Secret Lights in the Sea.*"



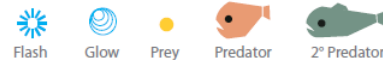
William Beebe wrote, "*In this kingdom most of the plants are animals, the fish are friends, colors are unearthly in their shift and delicacy; here miracles become marvels, and marvels recurring wonders. There may be a host of terrible dangers, but in hundreds of dives we have never encountered them. One thing we cannot escape—forever afterward, throughout all our life, the memory of the magic of water and its life, of the home which was once our own—this will never leave us.*"



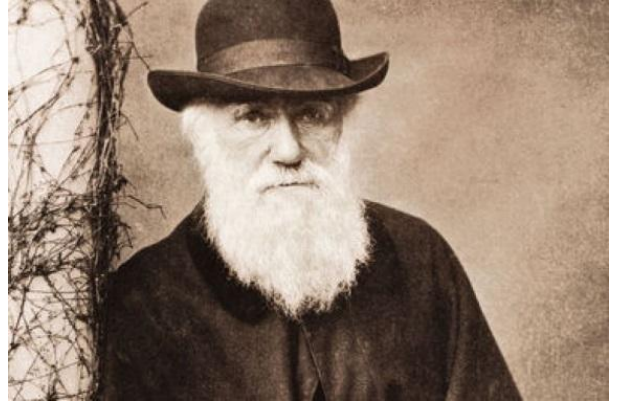
Here is a chart that summarizes marine organisms that are bioluminescent and the likely functions of the bioluminescence. But what are the functions of bioluminescence of the symbiotic bacterium *Vibrio* or the fungus, *Armillaria*?

Lars Olof Björn (1976) wrote in his book entitled, *Light and Life*, “Even for a person with a vivid imagination there are many cases of bioluminescence left for which **no sensible purpose** can be invented. What use do bacteria and protozoans have for their light emission? To explain the many cases of seemingly useless bioluminescence, some scientists have assumed that the light is a by-product of biochemical processes serving a different purpose. But this does not seem very reasonable either. The emission of a photon requires the collection of a large amount of energy in a single molecule and this must be regarded as a remarkable biochemical feat which hardly occurs by accident.” What is the **Law of Nature** that describes and explains the occurrence of bioluminescence?

DEFENSE		Startle	Dinoflagellates, squid, stern-chaser myctophid
		Counterillumination	Many: crustaceans, fish, squid
		Misdirection: smoke screen	Many: crustaceans, polychaetes, scyphozoans, chaetognaths, squids, tube-shoulder fishes, ctenophores, siphonophores, larvaceans?
		Distractive body parts	Octopoteuthis squid, brittle stars, polychaetes, siphonophores
		Burglar alarm	Dinoflagellates, jellies, others?
		Sacrificial tag	Pelagic sea cucumbers, jellies, polychaetes
		Warning coloration (deter settlers)	Jellies, brittle stars? (tube worms, clams)
OFFENSE		Lure prey or attract host (bacteria)	Anglerfishes, siphonophores, cookie cutter shark, squid?
		Lure with external light (evaluate habitat?)	Sperm whale? megamouth shark?
		Stun or confuse prey	Squid, headlamp myctophid?
		Illuminate prey	Flashlight fish, dragonfishes
		Mate attraction/recognition (swarming cue)	Ostracods, Japetella octopus? lanternfish, flashlight fish, anglerfish? syllid polychaetes, others?



Can you explain the bioluminescence of the bacterium *Vibrio* or the fungus *Armillaria* in terms of the **Laws of Nature**? Charles Darwin (1859) had a hard time. He wrote, “*The electric organs offer another and even more serious difficulty; for they occur in only about a dozen fishes, of which several are widely remote in their affinities. Generally when the same organ appears in several members of the same class, especially if in members having very different habits of life, we may attribute its presence to **inheritance from a common ancestor**; and its absence in some of the members to its loss through disuse or natural selection. But if the electric organs had been inherited from one ancient progenitor thus provided, we might have expected that all electric fishes would have been specially related to each other. Nor does geology at all lead to the belief that formerly most fishes had electric organs, which most of their modified descendants have lost. **The presence of luminous organs in a few insects, belonging to different families and orders, offers a parallel case of difficulty....**In all these cases of two very distinct species furnished with apparently the same anomalous organ, it should be observed that, although **the general appearance and function of the organ may be the same**, yet some fundamental difference can generally be detected. I am inclined to believe that in nearly the same way as two men have sometimes independently hit on the very same invention, so **natural selection**, working for the good of each being **and taking advantage of analogous variations**, has sometimes modified in very nearly the same manner two parts in two organic beings, **which owe but little of their structure in common to inheritance from the same ancestor.***”



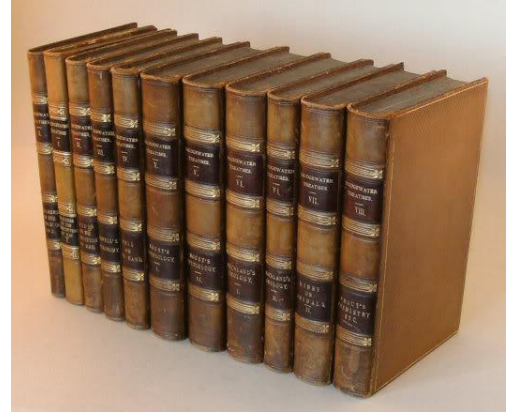
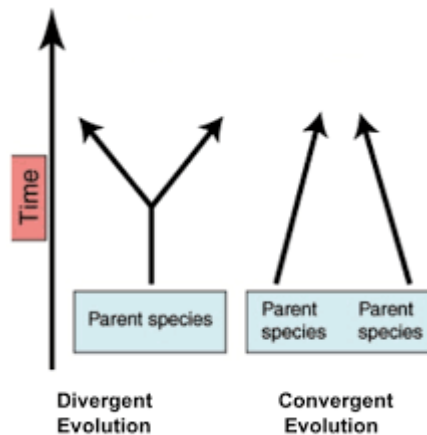
*Although in many cases it is most difficult to conjecture by what transitions an organ could have arrived at its present state; yet, considering that the proportion of living and known forms to the extinct and unknown is very small, I have been astonished how rarely an organ can be named, towards which no transitional grade is known to lead. The truth of this remark is indeed shown by that old canon in natural history of ‘Natura non facit saltum.’ [Nature does nothing in jumps]. We meet with this admission in the writings of almost every experienced naturalist; or, as Milne Edwards has well expressed it, nature is prodigal in variety, but niggard in innovation. **Why, on the theory of Creation, should this be so? Why should all the parts and organs of many independent beings, each supposed to have been separately created for its proper place in nature, be so invariably linked together by graduated steps? Why should not Nature have taken a leap from structure to structure? On the theory of natural selection, we can clearly understand why she should not; for natural selection can act only by taking advantage of slight successive variations; she can never take a leap, but must advance by the shortest and slowest steps.***”

Is bioluminescence in these taxa better described and explained by Charles Darwin’s theory of **natural selection** or by **congenital changes, mutations, or jumps**. Such jumps might give the appearance of **design** exhibiting “*the Power, Wisdom, and Goodness of God, as manifested in the Creation.*” **Francis Henry Egerton**, the 8th Earl of Bridgewater who loved to give dinner parties for dogs, commissioned the **Bridgewater Treatises** to present design in nature. As it says in Job 12:7-9, “*But ask the animals, and they will teach you, or the birds in the sky, and they will tell*

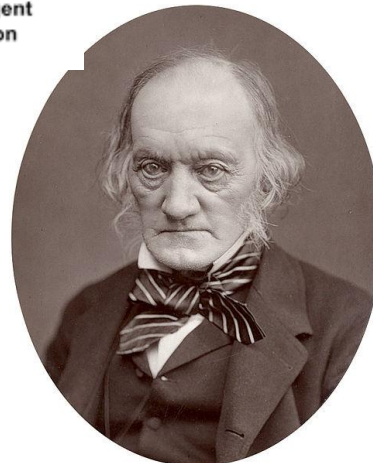


you; or speak to the earth, and it will teach you, or let the fish in the sea inform you. Which of all these does not know that the hand of the LORD has done this.”

Back to natural selection. Is bioluminescence in *Vibrio* or the fungus *Armillaria* a **random variation** upon which **natural selection** could capitalize on if its **selective value** were greater than its **cost**, or eliminate if its cost were greater than its selective value? Could bioluminescence be a result of an ancient process that has been **lost** in most organisms but **repressed** and later **revived** in other unrelated taxa where it proved useful? What are the meanings of homologous processes derived by **evolution from common descent (divergent evolution)** and analogous processes derived by **convergent evolution**? How do you distinguish convergent evolution from design?



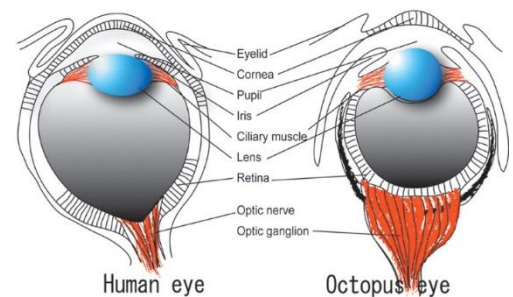
While I only pose these questions here, I want to mention **Richard Owen**, who coined the word **dinosaur**, and who was the scientific consultant to the sculptor Benjamin Waterhouse Hawkins, who produced the life-sized models of the dinosaurs for the **Crystal**



Palace after it was moved to Sydenham. Richard Owen is the 19th century scientist who introduced the terms **homology** and **analogy** in terms of **progressive evolution**.

After finishing grammar school, **Richard Owen** became an apprentice to Leonard Dickson, a local surgeon who performed post-mortems at a local prison. This led to a lifelong interest in anatomy, **comparative anatomy**, and fossil anatomy. Richard Owen studied hard tissue such as **teeth and bones** as well as soft tissue such as the brain.

In order to make sense of the basic **unity (archetype)** and **diversity** of organs, Richard Owen (1848) distinguished **homology** from **analogy**. If two or more parts are related by **common descent**, they are considered to be **homologous**. The wing of a bat and the forearm of a rat is an example of a homology. If two or more parts have some similarities in terms of **form or function**, but are not related by common descent, they are considered to be **analogous**. The wings of butterflies and bats or the **camera-like eyes** of cephalopods and vertebrates are examples of analogy. Analogous parts of organisms that are not related by common descent can be considered to be analogies that are the result of **convergent evolution** and/or **design**.



Using evidence of comparative anatomy, Richard Owen saw the **succession** of fossil organisms from the lower strata to the upper strata and the **progression** of simpler vertebrates such as fish to more advanced mammals to be a result of a “*continuous operation of the ordained becoming of living things*”—God was the **first cause** and a **number of possible second causes**, including **natural selection**

and more importantly **congenital changes** (e.g., mutations or jumps) resulted in the transformation of species. Owen did *not* believe in the immutability of species.

Based on his **personal philosophy** and his **scientific observations**, Richard Owen (1859) saw anatomical as well as spiritual distinctions between human(ity) and apes. At the **1860 meeting of the British Association for the Advancement of Science at Oxford**, Richard Owen proposed that there are sufficient differences in the brains of apes and human beings to set humans apart. Humans had a seahorse-shaped region of the brain known as the **hippocampus minor** and apes lacked a hippocampus minor. Could his **personal philosophy** have prejudiced his ability to objectively observe and interpret anatomical observations?

The young **Thomas H. Huxley**, on the other hand, made more accurate observations on the brains and did not see anatomical or any other differences to be significant enough to separate human beings struggling for existence from apes and monkeys. Then again, such a separation also went against Huxley's **personal philosophy**. Could Huxley's personal philosophy have prejudiced his ability to acknowledge the possibility that there may be more to being human than that which can be weighed, measured, and counted? Any challenge to Huxley's personal philosophy brought out the **firebrand** and **provocateur** in him. Although remember, as Huxley got older, he concluded in his Romanes Lecture that the ethical behavior of humans could not be simply a result of natural selection.

T. H. Huxley wrote to Frederick Dyster on January 30, 1859, "*both [Theology and Parsondom] are in my mind the natural and irreconcilable **enemies of Science**. ... If I have a wish to live thirty years, it is that **I may see the foot of Science on the necks of her enemies**.*" In a review of *Origin of Species*, T. H. Huxley (1860) wrote, "*Extinguished theologians lie about the cradle of every*

*science as the strangled snakes beside that of Hercules; and history records that whenever science and orthodoxy have been fairly opposed, the latter has been forced to retire from the lists, **bleeding and crushed if not annihilated; scotched, if not slain.***” On October 11, 1862, T. H. Huxley wrote to Frederick Dyster, about Richard Owen, “*Before I have done with that mendacious humbug I will nail him out, like a kite to a barn door, an example to all evil doers....*”

According to Huxley (1863), “*As if to demonstrate, by a striking example, the impossibility of erecting any cerebral barrier between man and the apes, Nature has provided us, in the later animals, with an **almost complete series of gradations** from brains little higher than that of a Rodent, to brains little lower than that of Man. And it is a remarkable circumstance, that though so far as our present knowledge extends, there is one true structural break in the series of forms of the Simian brains, **this hiatus does not lie between Man and the man-like apes, but between the lower and the lowest Simians**; or, in other words, between the old and new world apes and monkeys, and the Lemurs So far as cerebral structure goes, therefore, it is clear that Man differs less from the Chimpanzee or the Orang, than these do even from the Monkeys, and that the difference between the brains of the Chimpanzee and of Man is almost insignificant when compared with that between the Chimpanzee brain and that of a Lemur.*”

T. H. Huxley (1861) had previously expanded on the series between humans of various races and apes, “*...the cerebral hemispheres of the Bosjesman (and to a certain extent of the negro), so far as the evidence before us goes, are different from those of the white man...the same nature as most of those which distinguish the ape’s brain from that of man. In other words, if we place A, the European brain, B, the Bosjesman brain, and C, the orang brain, in a series, the differences between A and B, so far as they have been ascertained, are of the same nature as*

the chief of those between B and C....The brains of the lowest races of mankind have been hardly at all examined; and it would be a matter of great interest....Medical men living at the Cape of Good Hope, in Australia, and within reach of the Hill-men of India, will, it is to be hoped, some day solve these problems for the zoologist.”

Realizing that brain size was a function of body size, but intelligence was not, Richard Owen (1862) wrote, “Although in most cases the Negro's brain is less than that of the European, Tiedemann and the author [Richard Owen] of the present paper had observed individuals of the Negro race in whom the brain was as large as the average one of the Caucasian; **and the author concurred with the great physiologist of Heidelberg in connecting with such cerebral development the fact that there had been no province of intellectual activity in which individuals of the pure Negro race had not distinguished themselves.** The contrast between the brains of the Negro and Gorilla, in regard to size, was still greater in respect of the proportional size of the brain to the body —the weight of a full-grown male Gorilla being one-third more than that of an average-sized Negro.”

Charles Darwin (1839), on the other hand thought there were great differences between “savage and civilized man.” Darwin wrote in the *Voyage of the Beagle*: “In the morning the Captain sent a party to communicate with the Fuegians. When we came within hail, one of the four natives who were present advanced to receive us, and began to shout most vehemently, wishing to direct us where to land. When we were on shore the party looked rather alarmed, but continued talking and making gestures with great rapidity. It was without exception the most curious and interesting spectacle I ever beheld: **I could not**

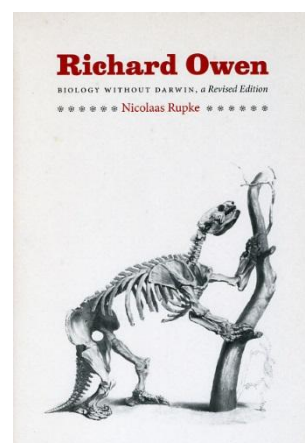
*have believed how wide was the difference between savage and civilized man: it is greater than between a wild and domesticated animal, inasmuch as in man there is a greater power of improvement.... Viewing such men, **one can hardly make one's self believe that they are fellow-creatures, and inhabitants of the same world.** It is a common subject of conjecture what pleasure in life some of the lower animals can enjoy: how much more reasonably the same question may be asked with respect to these barbarians.... They cannot know the feeling of having a home, and still less that of domestic affection; for the husband is to the wife a brutal master to a laborious slave. Was a more horrid deed ever perpetrated, than that witnessed on the west coast by **Byron**, who saw a wretched mother pick up her bleeding dying infant-boy, whom her husband had mercilessly dashed on the stones for dropping a basket of sea-eggs! How little can the higher powers of the mind be brought into play: what is there for imagination to picture, for reason to compare, or judgment to decide upon? to knock a limpet from the rock does not require even cunning, that lowest power of the mind. **Their skill in some respects may be compared to the instinct of animals; for it is not improved by experience:** the canoe, their most ingenious work, poor as it is, has remained the same, as we know from Drake, for the last two hundred and fifty years."*

<http://www.gutenberg.org/files/944/944-h/944-h.htm#link2HCH0010>

At the time, T. H. Huxley embraced **August Comte's materialist and positivist philosophy**. Huxley (1861) wrote, "***Theologians and moralists, historians and poets, impressed by a sense of the infinite responsibilities of mankind, awed by a just prevision of the great destinies in store for the only earthly being of practically unlimited powers, or touched by the tragic dignity of the ever-recurring struggle of human will with circumstance, have always tended to conceive of their kind as something apart, separated by a great and impassible barrier, from the rest of the natural world. On the other hand, the students of***

physical science, discovering as complete a system of law and order in the microcosm as in the macrocosm, incessantly lighting upon new analogies and new identities between life manifested by man, and life in other shapes,—have no less steadily gravitated towards the opposite opinion, and, as knowledge has advanced, have more and more distinctly admitted the closeness of the bond which unites man with his humbler fellows. A controversy has raged between these opposed schools....”

There are significant **similarities** and **differences** between humans and apes and there is no reason for a thinking person to deny either the similarities or the differences. Moreover, one must decide which similarities (skeletal structure) and which differences (artistic ability) are important in distinguishing taxonomic groups. There are also significant differences between individuals, and one must make sure that sufficient evidence has been collected and covariant causes eliminated before making extrapolations from limited facts that may later be proven to be unjustified. I think Nicolaas Rupke (2009) gives a fair analysis of Owen and Huxley in *Richard Owen: Biology without Darwin*. The actual two year-long scientific rivalry between T. H. Huxley and Richard Owen (as opposed to the science versus religion rivalry between Huxley and Wilberforce fabricated in the histories told by Francis Darwin and Leonard Huxley and propagated to this day) became famous and was treated with humor in its time.



Punch published **Monkeyana** in May 1861.

Monkeyana

*Am I satyr or man?
Pray tell me who can,
And settle my place in the scale.
A man in ape's shape,
An anthropoid ape,
Or monkey deprived of his tail?*

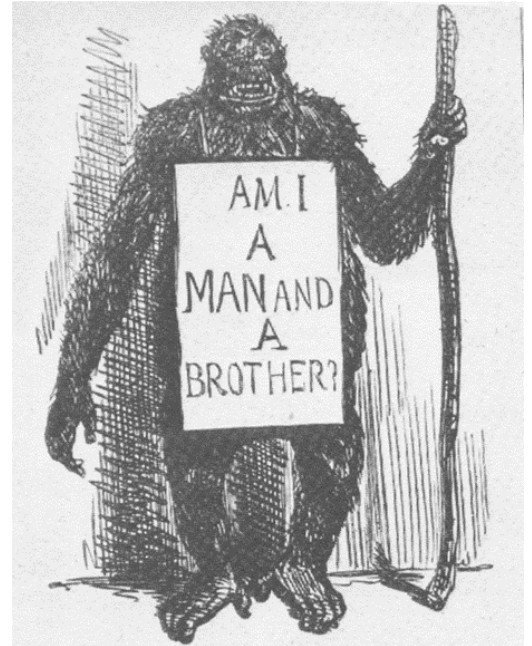
*The Vestiges taught,
That all came from naught
By "development," so called, "progressive;"
That insects and worms
Assume higher forms
By modification excessive.*

*Then Darwin set forth
In a book of much worth,
The importance of "nature's selection;"
How the struggle for life
Is a laudable strife,
And results in "specific distinction."*

*Let pigeons and doves
Select their own loves,
And grant them a million of ages,
Then doubtless you'll find
They've altered their kind,
And changed into prophets and sages.*

*Leonard Horner relates,
That Biblical dates
The age of the world cannot trace;
That Bible tradition,
By Nile's deposition,
Is put to the right about face.*

Then there's Pengelly



*Who next will tell ye
That he and his colleagues of late
Find celts and shaped stones
Mixed up with cave bones
Of contemporaneous date.*

*Then Prestwich, he pelts
With hammers and celts
All who do not believe his relation,
That the tools he exhumes
From gravelly tombs
Date before the Mosaic creation.*

*Then Huxley and Owen,
With rivalry glowing,
With pen and ink rush to the scratch;
'Tis Brain versus Brain,
Till one of them's slain,
By JOVE! it will be a good match!*

*Says Owen, you can see
The brain of Chimpanzee
Is always exceedingly small,
With the hindermost "horn"
Of extremity shorn,
And no "Hippocampus" at all.*

*The Professor then tells 'em,
That man's "cerebellum,"
From a vertical point you can't see;
That each "convolution"
Contains a solution
Of "Archencephalic" degree.*

*That apes have no nose,
And thumbs for great toes,
And a pelvis both narrow and slight;
They can't stand upright,
Unless to show fight,*

With 'Du Chaillu,' that chivalrous knight!

*Next Huxley replies,
That Owen he lies,
And garbles his Latin quotation;
That his facts are not new,
His mistakes not a few,
Detrimental to his reputation.*

*"To twice slay the slain,
By dint of the Brain,
(Thus Huxley concludes his review)
Is but labour in vain,
Unproductive of gain,
And so I shall bid you 'Adieu'!"*

Punch also published *The Gorilla's Dilemma* in October 1862:

The Gorilla's Dilemma (Excerpt)

(To Professor Owen & Huxley)

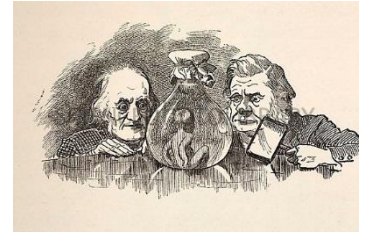
*SAY am I a man and a brother,
Of only an anthropoid ape?
Your judgment, be 't one way or 'tother,
Do put into positive shape.*

*Must I humbly take rank as quadruman
As OWEN maintains that I ought:
Or rise into brotherhood human,
As HUXLEY has flatt'ringly taught?*

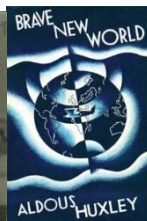
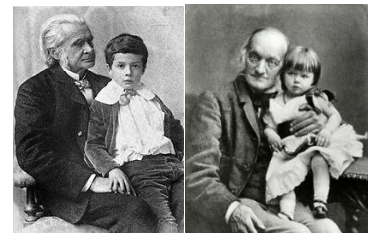
*For though you may deem a Gorilla
Don't think much of his rank in creation,
If of feeling one have a scintilla,
It glows to know "who's one's relation"—*

Charles Kingsley (1863) wrote about the rivalry in his book, *Water Babies*:

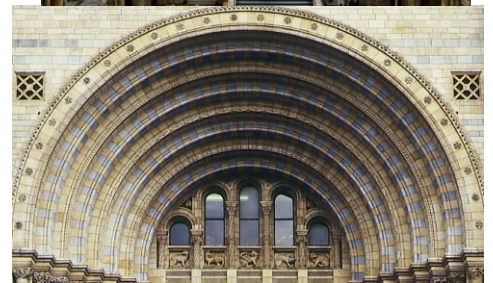
*“You may think that there are other more important differences between you and an ape, such as being able to speak, and make machines, and know right from wrong, and say your prayers, and other little matters of that kind; but that is a child's fancy, my dear. Nothing is to be depended on but **the great hippopotamus test**. If you have a hippopotamus major in your brain, you are no ape, though you had four hands, no feet, and were more apish than the apes of all aeries. But if a hippopotamus major is ever discovered in one single ape's brain, nothing will save your great- great- great- great- great- great- great- great- great- greater- greatest- grandmother from having been an ape too. No, my dear little man; always remember that the one, true, certain, final and all-important difference between you and an ape is, that you have a hippopotamus major in your brain, and it has none; and that to discover one in its brain will be a very wrong and dangerous thing, at which every one will be very much shocked.”*



What happened to T. H. Huxley and Richard Owen? They both became grandfathers. T. H. Huxley's grandchildren include Julian Huxley, **Aldous Huxley**, and Andrew Fielding Huxley.



Richard Owen became the prime mover in establishing the **British Museum of Natural History** in 1881 in South Kensington, next to the former site of the **Crystal Palace** and Great Exposition of 1851. It was a museum for both the specialists and for the general population. The building, which was a **cathedral to nature** was designed by Alfred Waterhouse. It was a Romanesque **terracotta** building that produced a **romantic skyline**. It is an example of a work of art in the service of science. In contrast to the limestone that was typically used for buildings, the terracotta was resistant to acid rain and was also washable, two desirable characteristics in coal burning-Victorian London. The terracotta could also be inexpensively made and molded into decorative plants, animals, and gargoyles. <http://nhm.ac.uk/visit-us/history-architecture/index.html>



The **British Museum of Natural History** houses collections of butterflies, beetles, fossils, plants, and animals. <http://www.nhm.ac.uk/nature-online/collections-at-the-museum/museum-treasures/charles-darwin-pigeons/index.html>



The **British Museum of Natural History** houses Charles Darwin's pigeon collection. <http://www.nhm.ac.uk/nature-online/collections-at-the-museum/museum-treasures/charles-darwin-pigeons/index.html>



The **British Museum of Natural History** houses Alfred Russel Wallace's insect collection: : <http://www.nhm.ac.uk/nature-online/collections-at-the-museum/museum-treasures/alfred-russel-wallace-insects/index.html>



The **British Museum of Natural History** has also created an excellent and free online book about *Slavery and the Natural World*

<https://www.nhm.ac.uk/discover/slavery-and-the-natural-world.html> You can see

that the world was in need of **William Wilberforce's** and his son **Samuel Wilberforce's** vision for the right to liberty for all people no matter what their color. Oddly enough, William Wilberforce is mentioned only in terms of having correspondence with **Joseph Banks** and Samuel Wilberforce and the **slave-making instinct of ants** is not mentioned at all.



Joseph Banks was a botanist, who sailed with Captain James Cook, and gave advice to King George III on how to make plants profitable. Banks initially accepted slavery as necessary part of the global economy and suggested that William Bligh, Captain of the **HMS Bounty**, collect breadfruit plants from Tahiti and transport them to the Caribbean, where the trees would be a ready source of the carbohydrate-rich fruits that could be used to feed the slaves.



In 1868, in a letter to Charles Darwin, T. H. Huxley drew this sketch **elevating Darwin to Pope**. Since then, a part of biology could be looked at as **hagiology**, the study of the life of the saints. T. H. Huxley's son, Leonard Huxley (1903), a writer, wrote *Life and Letters of Thomas Henry Huxley*. This book, along with *The Life and Letters of Charles Darwin*, written by Francis Darwin (1887), Charles' son, became the official history. The Darwin-Huxley story is basically the only story that is told. The Owen-Wilberforce story has been so marginalized as to be nearly forgotten.



The hegemony of Darwin-Huxley versus Owen continues in terms of statuary. When the **British Museum of Natural History** opened, a statue of Richard Owen was placed below a stained-glass window in the Central Hall. When Charles Darwin died in 1882, his statue was also placed in the Central Hall. When T. H. Huxley died in 1899, his statue was placed near Owen's. In 1927, Darwin's statue was moved to the North Hall. In 2009, Owen's statue in the Central Hall was replaced by Darwin's.

There were many reasons behind the Darwin-Huxley and Owen-Wilberforce polarity. But I think **materialism or naturalism versus spiritualism** was a part of it. Richard Owen did not eliminate God from the evolutionary process, Darwin and Huxley seemed to. As scientists, we (including or perhaps especially me) bring our **personal philosophy** to bear on our science. For example, I see both the value and limitations of Charles Darwin's theory of natural selection. As someone that sees the limitations more so than most scientists, I have no problem in accepting the **existence of free will** and the **meaningfulness of life** and the observational evidence that they both exist.

Others disagree. For example, in response to an essay written by Phillip E. Johnson¹, **Will Provine** (1990; Cornell) wrote, "*Evolution produces two results that cry out for explanation adaptation and diversity. Sonar in bats, **eyesight in eagles, sunlight energy capture in plants**, and adaptations in general had only one kind of explanation before Darwin; the argument from design. The same argument explained the vast diversity of kinds of animals and plants. The greatest minds in*



¹ <http://www.firstthings.com/article/1990/10/002-evolution-as-dogma-the-establishment-of-naturalism>

the history of Western Civilization, from Plato and Aristotle to Augustine, St. Thomas Aquinas, Kepler, Galileo, Newton, and Boyle, all believed that the argument from design was the only reasonable explanation for adaptations in animals and plants. When they were alive, they were right.

*As a young man, Charles Darwin was a creationist deeply impressed with William Paley's version of the argument from design. But after returning from the voyage of H.M.S. Beagle, reconsideration of what he had seen on the voyage convinced him that evolution had occurred. A short time later, when he deduced the theory of natural selection to explain the adaptations in which he had previously seen the handiwork of God, **Darwin knew that he was committing cultural murder.** He understood immediately that if natural selection explained adaptations, and evolution by descent were true, then the argument from design was dead and all that went with it, **namely the existence of a personal god, free will, life after death, immutable moral laws, and ultimate meaning in life.** The immediate reactions to Darwin's *On the Origins of Species* exhibit, in addition to favorable and admiring responses from a relatively few scientists, an understandable fear and disgust that has never disappeared from Western culture.*

*Johnson [author of *Evolution as Dogma: The Establishment of Naturalism*] has excellent reasons for fearing and despising modern scientific conceptions of the evolutionary **process.** **He clearly wants animals and plants (humans in particular-he says nothing about disgusting parasites) to have been designed by divine purpose.** He wants to have free will and divinely inspired moral laws that last forever unchanged, and I suspect that he wants to have some kind of ultimate meaning in life coupled with life after death. If modern evolutionary biology is true, then all these lofty desires are hopeless.”*

<http://www.arn.org/docs/johnson/pjdogma2.htm>

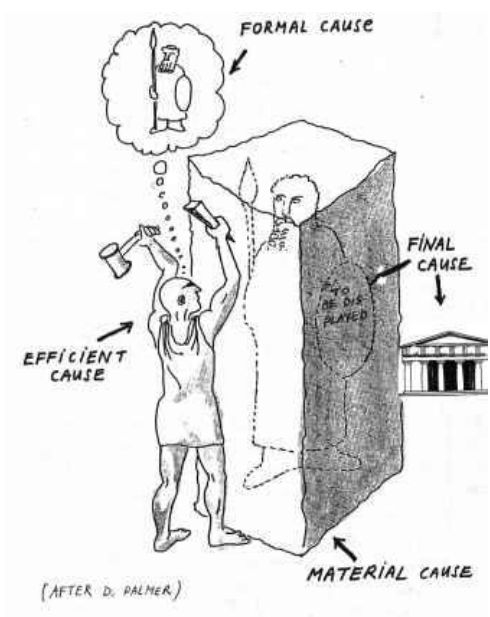
Question: Does the concept of democracy and voting have any meaning if there is no such thing as free will?

The movie “*Creation*” is a superbly done movie on Charles Darwin’s personal struggles based on the book *Annie’s Box: Darwin, His Daughter, and Human Evolution*, by Darwin’s great, great grandson, Randal Keynes.

<https://vimeo.com/71717324>



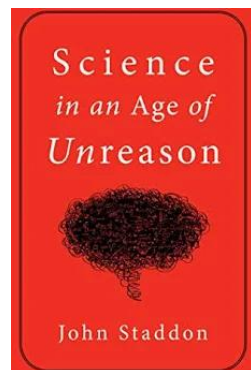
Is there room for more than one cause in science? Must we accept unconditionally that the materialist theory of natural selection will describe and explain all aspects of life? Let’s consider the story of **Theseus’s Paradox**. According to Plutarch, “*The ship wherein Theseus and the youth of Athens returned from Crete had thirty oars, and was preserved by the Athenians down even to the time of Demetrius Phalereus, for they took away the old planks as they decayed, putting in new and stronger timber in their place, in so much that this ship became a standing example among the philosophers, for the logical question of things that grow; one side holding that the ship remained the same, and the other contending that it was not the same.*” Thomas Hobbes wondered: What would happen if each of the original planks were collected after they were



replaced and then were used to build a second ship? Which ship, if either one of them, is the original Ship of Theseus? I want to say, a reasonable person can hold more than one explanation for the same object or process. **Dualism** or even **quadrupleism** is not a bad thing.

Aristotle proposed **four causes** (or explanations) that are needed to describe an object such as Theseus's ship. The **formal cause** is the form of the object; the **material cause** is the matter that makes up the object; the **efficient cause** is the mechanism of how or by whom the object is made; and the **final cause**, is the intended purpose of the object. Taking the four causes into consideration, there is no single answer to Hobbes' question about which is the original ship. By reducing the question to a single cause, we can only get a partial, although dogmatic, answer. Is it possible that the young Thomas H. Huxley dismissed any potential causes too quickly? If we are to believe that he had not lost his mind when he gave the Romanes Lecture, then the answer is yes.

Aside: In *Science in an Age of Unreason*, John Staddon (2022) reminds us that there are some questions about who we are as people that cannot be intelligently answered by assuming that there is only one cause. For example, our intelligence probably has a material cause (our genotype) as well as an efficient cause (our family nurture and our education).

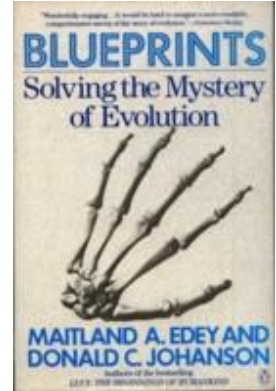
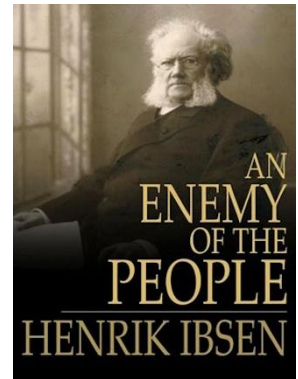


While Richard Owen's name has been lost, his theory of **analogy** and **homology**, which was presented in a lecture entitled *On the Nature of Limbs*, given at the Royal Institution in 1849, has become a cornerstone in all levels of biology. Although he was a comparative anatomist, Richard Owen realized that every grade of organization can be considered to have at least **two meaningful causes: form** that arises from an evolutionary and developmental plan, and **function** that facilitates the processes, such as movement that are necessary for life.



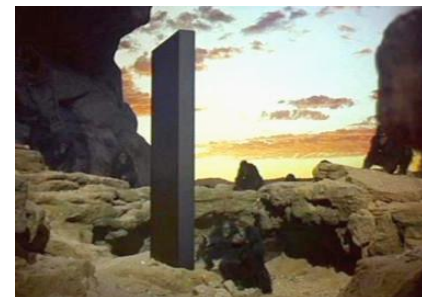
The concepts of **analogy** and **homology** can be applied to genes as well as limbs. If two or more objects are related by **common descent**, they are considered to be **homologous**. If two or more objects have some similarities in terms of form or function, but are not related by common descent, they are considered to be **analogous**. Without sufficient experimental evidence to support convergent evolution or design, gradual or saltational change, the **bioluminescent production of light** by organisms that are not related by common descent can be considered by reasonable people to be analogies that are the result of **convergent evolution** that results from **gradual natural selection, large congenital changes (e.g., genetic mutations or jumps) that have no selective advantage, and/or design**.

The **National Center for Science Education** defines anti-evolutionism in the classroom as teaching the strengths and weaknesses of evolution and teaching how to critically analyze evolution (<http://ncse.com/evolution/education/anti-evolutionism-classroom>). I obviously disagree and would not call myself an anti-evolutionist. I am just a strong believer that a healthy science demands questioning and believe that any consensus on any issue does not eliminate the possibility of questioning. **Henrik Ibsen** wrote in “*An Enemy of the People*,” “*The majority is never right. Never, I tell you! That's one of these lies in society that no free and intelligent man can help rebelling against.*” There is a trend however that treats **science as a package deal** that has been packaged by the consensus. The trend suggests that you cannot choose for yourself those parts of science that you think have strong support and reject the other parts. In their book *Blueprints: Solving the Mystery of Evolution*, Maitland A. Edey and Donald C. Johanson (1989) write, “*You can't accept one part of science because it brings you good things like electricity and penicillin, and throw away another part because it brings some ideas you don't like about the origin of life.*”



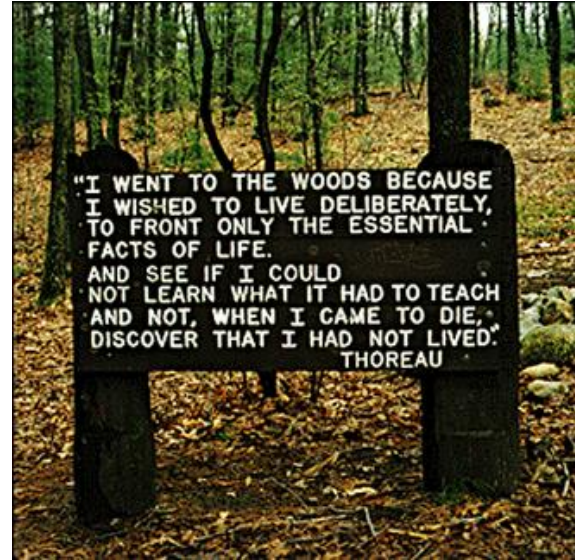
Science does not have to be **monolithic**. Use your own mind! Think for yourself! Make your own decisions! In *The Everlasting Gospel*, William Blake wrote about the importance of the mind/soul in seeing:

*This life's five windows of the soul
Distorts the heavens from pole to pole
And leads you to believe a lie
When you see with, not through, the eye.*



“I know of no more encouraging fact than the unquestionable ability of man to elevate his life by a conscious endeavor. It is something to be able to paint a particular picture, or to carve a statue, and so to make a few objects beautiful; but it is far more glorious to carve and paint the very atmosphere and medium through which we look, which morally we can do. To affect the quality of the day, that is the highest of arts.”

-- Henry David Thoreau, in *Where I Lived and What I Lived For*



Some picture windows in the city are truly beautiful! Here's a *trompe l'oeil* stained glass window designed by Richard Morris Hunt for Henry Gurdon Marquand's New York City home.



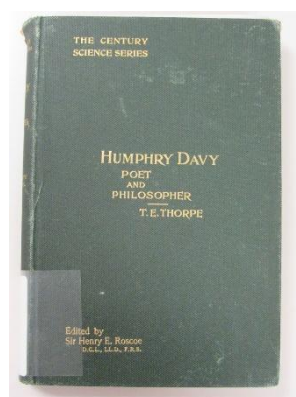
Humphry Davy, the inventor of the miner's safety lamp, the discoverer of sodium, potassium, calcium, magnesium, strontium, and barium, and the person who named N₂O laughing gas also was inspired by nature to write poetry about bioluminescence. He wrote a poem entitled, *To the Fire-flies*.



***To the Fire-flies* (1819)**

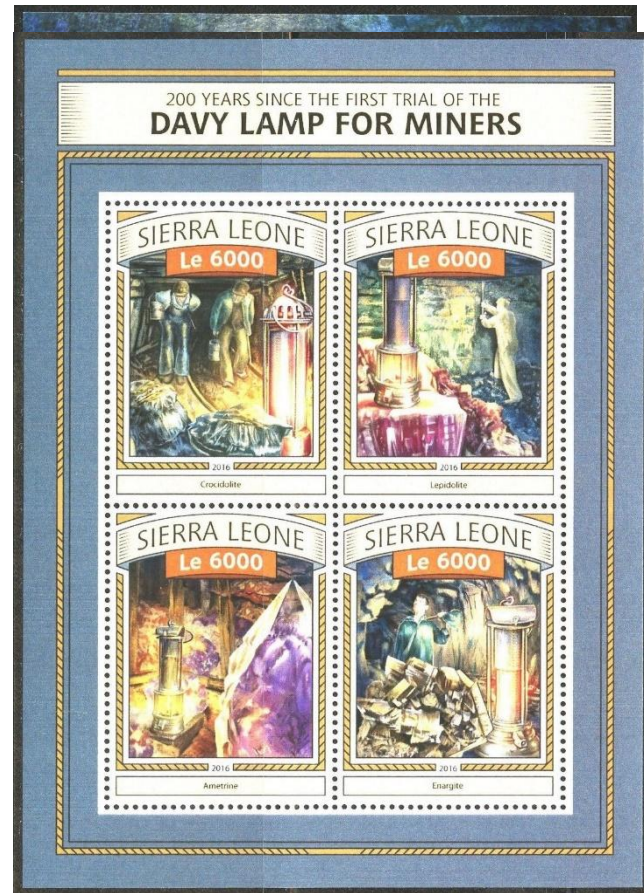
*Ye animated lamps that 'midst the shade
Of ancient chesnuts, and the lofty hills
Of Lusignana, by the foaming rills
That clothe the Serchio in the evening play!
So bright your light, that in the unbroken ray.*

*Which clothe the nearest slopes! how thro' the groves
Of Lucca do ye dance! The breeze that moves
Their silver leaves, a mountain zephyr's wing,
Has brought you here to cheer our tardy spring.
Oft had I seen ye 'midst thy orange bowers,
Parthenope! and where Velino pours
In thundering cataracts; but ne'er before
So high upon the mountains, where ye soar
E'en in mid air, leaving those halcyon plains
Where spring or summer everlasting reigns,
Where flowers and fruit mature together grow,
To visit our rude peaks, where still the snow
Glitters e'en in the genial month of flowers.
But brightly do ye move in fiery showers,
Seen like the falling meteor from afar,
Or like the kindred of the erring star.
May not the stars themselves in orbits whirl'd,
Be but a different animated world,
In which a high and lofty breath of life,
Of worlds and insects calms the wakening strife,
Commands the elements, and bids them move
In animation to the voice of Love!*



*Thou loveliest form of the celestial world,
 When in the circle of thy brightness
 Thou sheddest in the blue unclouded sky
 All thy meridian lustre! in the north,
 Above the heath-clad mountains have I seen
 Thy clear and mellow light; and when the waves
 Of the Atlantic raised their foaming surge
 Against the eternal rocks, where fabled sleeps
 The last of western Titans—then, when young
 In mind, and light of heart, thy rays had power
 To solemnize and tune to thoughts sublime
 My vagrant spirit; now, in these fair climes,
 Where in a purer and more balmy air,
 And in a sky whose tints of ether seem
 Giving a saint-like glory to thy rays,
 Thy influence is e'en stronger in a heart
 Wearied, but not yet broken or subdued.
 Yet still my heart is sensible to thee,
 As when it first received the flood of life
 In youth's full spring-tide; and to me it seems
 As if thou- wert a sister to my soul,
 An animated being, carrying on
 An intercourse of sweet and lofty thoughts,
 Wakening the slumbering powers of inspiration
 In their most sacred founts of feeling high.*

*The tempest gather'd on thy verdant hills,
 O Lusignano! The azure southern sky
 Was dimm'd by fleeting mists. Soon the dark cloud
 Form'd more compact, and to the zenith rose;
 The bright blue of the northern distance then,
 And all the mountains show'd their shaggy crests
 Of ancient chesnuts, dark and deep in shade.
 To the feverish flush of the meridian sun
 Succeeded quick a damp and sudden chill;
 The lightning flash'd. At first, a feeble light,
 Scarce seen, even in the darkest part of heaven,
 Succeeded by low murmurings; brighter gleam'd*



*Each flash that follow'd, and now louder roar'd
The thunder distant, but it soon became
The loudest burst of heaven's artillery.*

*— The whirlwind gone,
A calm, a soothing freshness soon succeed.
Thus in the mind springs new-born energy,
— Thoughts that were dead are roused,
And all the purer being wakes again.
The slime of foulness and impurity
Are borne into the ocean deep of reason,
And new creations dance upon its waves,
E'en as they purify—a thousand forms
Of beauty, and of goodness, and of grace.
The intellectual soul, freshen'd by dew
From heaven, enrich'd, is glad and green with life.*

*Again that lovely lamp from half its orb
Sends forth a mellow lustre, that pervades
The eastern sky, and meets the rosy light
The mountains all above are clear and bright,
Their giant forms distinctly visible,
Crested with shaggy chesnuts, or erect,
Bearing the helmed pine, or raising high
Their marble columns crown'd with grassy slopes.
From rock to rock the foaming Lima pours
Full from the thunder storm, rapid, and strong,
And turbid. Hush'd is the air in silence;
The smoke moves upwards, and its curling waves
Stand like a tree above. E'en in my heart,
By sickness weaken'd and by sorrow chill'd,
The balm of calmness seems to penetrate,—
Mild, soothing, genial in its influence.
Again I feel a freshness, and a power,
As in my youthful days, and hopes and thoughts
Heroical and high! The wasted frame
Soon in corporeal strength recruits itself,
And wounds the deepest heal; so in the mind,
The dearth of objects and the loss of hope
Are in the end succeeded by some births*

*Of new creative faculties and powers,
Brought forth with pain, but, like a vigorous child,
Repaying by its beauty for the pang.*

According to J. Z. Fullmer (1960), “Throughout all Davy’s poetry, parallel with the theme of permanence and change runs the eternality aspect identified as light. Eventually light became for him synonymous with his personal God. In one sense, it is fair to say that the development of his poetry reflects the development within Davy of this equation: **God is Light**. The light may be sunlight, moonlight, light from the evening star, or the cold light of fireflies In the poetry of his second period...light is generally a manifestation of the ‘One Intelligence,’ while in poems written after 1812, Davy frequently made ‘light’ identical with the ‘Intelligence’”

Humphry Davy, one of the world’s greatest scientists, was not as dogmatic as the **National Center for Science Education** and some scientists or perhaps **scient(ism)ists** today who think that some aspects of science are beyond question and have been settled by the consensus for all time. Davy realized that indeed he was one of the men that must be careful of the idols of the Tribe, the Marketplace, the Theatre, and the **Cave**. In an address delivered to the Royal Society on November 30, 1825, he said:

*“Fortunately science, like that nature to which it belongs, is neither limited by time nor by space. It belongs to the world, and is of no country and of no age. **The more we know, the more we feel our ignorance; the more we feel how much remains unknown;** and in philosophy, the sentiment of the Macedonian hero can never apply, — there are always new worlds to conquer.”*

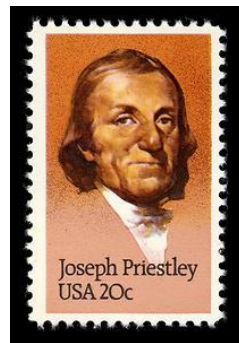
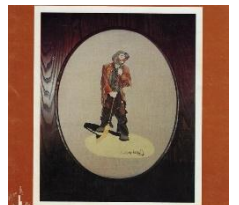
Davy also wrote in *Consolations in Travel: Or, The Last Days of a Philosopher*:

“It is surely a pure delight to know, how and by what processes this earth is clothed with verdure and life, how the clouds, mists and rain are formed, what causes all the changes of this terrestrial system of things, and by what divine laws order is preserved amidst apparent confusion. It is a sublime occupation to investigate the cause of the tempest and the volcano, and to point out their use in the economy of things, — to bring the lightning from the clouds and make it subservient to our experiments, — to produce as it were a microcosm in the laboratory of art, and to measure and weigh those invisible atoms, which, by their motions and changes according to laws impressed upon them by the Divine Intelligence, constitute the universe of things. The true chemical philosopher sees

good in all the diversified forms of the external world. Whilst he investigates the operations of infinite power guided by infinite wisdom, all low prejudices, all mean superstitions disappear from his mind. He sees man an atom amidst atoms fixed upon a point in space; and yet modifying the laws that are around him by understanding them; and gaining, as it were, a kind of dominion over time, and an empire in material space, and exerting on a scale infinitely small a power seeming a sort of **shadow** or **reflection** of a creative energy, and which entitles him to the distinction of being made in the **image** of God and animated by a spark of the divine mind. Whilst chemical pursuits exalt the understanding, they do not depress the imagination or weaken genuine feelings; whilst they give the mind habits of accuracy, by obliging it to attend to facts, they likewise extend its analogies; and, though conversant with the minute forms of things, they have for their ultimate end the great and magnificent objects of nature. They regard the formation of a crystal, the structure of a pebble, the nature of a clay or earth; and they apply to the causes of the diversity of our mountain chains, the appearances of the winds, thunder-storms, meteors, the earthquake, the volcano, and all those phenomena which offer the most striking images to the poet and the painter. They keep alive that inextinguishable thirst after knowledge, which is one of the greatest characteristics of our nature; — for every discovery opens a new field for investigation of facts, shows us the imperfection of our theories. **It has justly been said, that the greater the circle of light, the greater the boundary of darkness by which it is surrounded.**”

The last sentence is a paraphrase of a line written by **Joseph Priestley** (1790), a discoverer of oxygen in the Preface of his *Experiments and Observations on Different Kinds of Air*. Priestley too realized that he was a man who lived in a cave as described by Plato.

“The greater is the circle of light, the greater is the boundary of the darkness by which it is confined. But, notwithstanding this, the more light we get, the more thankful we ought to be, for by this means we have the greater range for satisfactory contemplation. In time the bounds of light will be still farther extended; and from the infinity of the divine nature, and the divine works, we may promise ourselves an endless progress in our investigation of them: a prospect truly sublime and glorious. The works of the greatest and most successful philosophers are, on this account, open to our complaints of their being imperfect.”



See Emmett Kelly [sweeping up the spotlight](#):

This way of thinking goes back to **Socrates' Apology**"

*"I dare say, Athenians, that some one among you will reply, 'Yes, Socrates, but what is the origin of these accusations which are brought against you; there must have been something strange which you have been doing? All these rumours and this talk about you would never have arisen if you had been like other men: tell us, then, what is the cause of them, for we should be sorry to judge hastily of you.' Now I regard this as a fair challenge, and I will endeavour to explain to you the reason why I am called wise and have such an evil fame. Please to attend then. And although some of you may think that I am joking, I declare that I will tell you the entire truth. Men of Athens, this reputation of mine has come of a certain sort of wisdom which I possess. If you ask me what kind of wisdom, I reply, wisdom such as may perhaps be attained by man, for to that extent I am inclined to believe that I am wise; whereas the persons of whom I was speaking have a superhuman wisdom which I may fail to describe, because I have it not myself; and he who says that I have, speaks falsely, and is taking away my character. And here, O men of Athens, I must beg you not to interrupt me, even if I seem to say something extravagant. For the word which I will speak is not mine. I will refer you to a witness who is worthy of credit; that witness shall be the God of Delphi—he will tell you about my wisdom, if I have any, and of what sort it is. You must have known Chaerephon; he was early a friend of mine, and also a friend of yours, for he shared in the recent exile of the people, and returned with you. Well, Chaerephon, as you know, was very impetuous in all his doings, and **he went to Delphi and boldly asked the oracle to tell him whether—as I was saying, I must beg you not to interrupt—he asked the oracle to tell him whether anyone was wiser than I was, and the Pythian prophetess answered, that there was no man wiser. Chaerephon is dead himself; but his brother, who is in court, will confirm the truth of what I am saying.***

Why do I mention this? Because I am going to explain to you why I have such an evil name. When I heard the answer, I said to myself, What can the god mean? and what is the interpretation of his riddle? for I know that I have no wisdom, small or great. What then can he mean when he says that I am the wisest of men? And yet he is a god, and cannot lie; that would be against his nature. After long consideration, I thought of a method of trying the question. I reflected that if I could only find a man wiser than myself, then I might go to the god with a refutation in my hand. I should say to him, 'Here is a man who is wiser than I am; but you said that I was the wisest.' Accordingly I went to one who had the reputation of wisdom, and observed him—his name I need not mention; he was a politician whom I selected for examination—and the result was as follows: When I began to talk with him, I could not help thinking that he was not really wise,

although he was thought wise by many, and still wiser by himself; and thereupon I tried to explain to him that he thought himself wise, but was not really wise; and the consequence was that he hated me, and his enmity was shared by several who were present and heard me. So I left him, saying to myself, as I went away: Well, although I do not suppose that either of us knows anything really beautiful and good, **I am better off than he is,—for he knows nothing, and thinks that he knows;** I neither know nor think that I know. In this latter particular, then, I seem to have slightly the advantage of him. Then I went to another who had still higher pretensions to wisdom, and my conclusion was exactly the same. Whereupon I made another enemy of him, and of many others besides him.

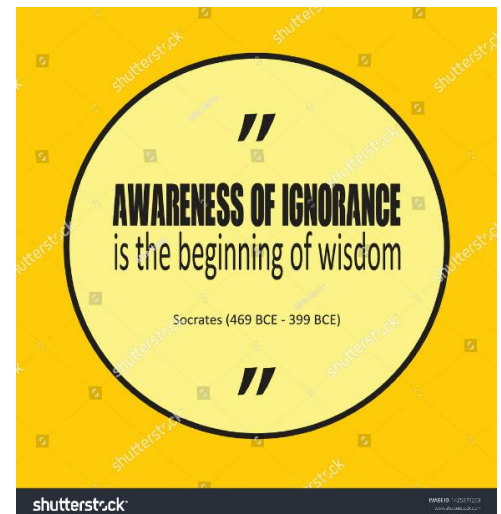
Then I went to one man after another, being not unconscious of the enmity which I provoked, and I lamented and feared this: but necessity was laid upon me,—the word of God, I thought, ought to be considered first. And I said to myself, Go I must to all who appear to know, and find out the meaning of the oracle. And I swear to you, Athenians, by the dog I swear!—for I must tell you the truth—the result of my mission was just this: **I found that the men most in repute were all but the most foolish; and that others less esteemed were really wiser and better.** I will tell you the tale of my wanderings and of the 'Herculean' labours, as I may call them, which I endured only to find at last the oracle irrefutable. After the politicians, I went to the poets; tragic, dithyrambic, and all sorts. And there, I said to myself, you will be instantly detected; now you will find out that you are more ignorant than they are. Accordingly, I took them some of the most elaborate passages in their own writings, and asked what was the meaning of them—thinking that they would teach me something. Will you believe me? I am almost ashamed to confess the truth, but I must say that there is hardly a person present who would not have talked better about their poetry than they did themselves. Then I knew that not by wisdom do poets write poetry, but by a sort of genius and inspiration; they are like diviners or soothsayers who also say many fine things, but do not understand the meaning of them. **The poets appeared to me to be much in the same case; and I further observed that upon the strength of their poetry they believed themselves to be the wisest of men in other things in which they were not wise. So I departed, conceiving myself to be superior to them for the same reason that I was superior to the politicians.**

At last I went to the artisans. I was conscious that I knew nothing at all, as I may say, and I was sure that they knew many fine things; and here I was not mistaken, for they did know many things of which I was ignorant, and in this they certainly were wiser than I was. **But I observed that even the good artisans fell into the same error as the poets;—because they were good workmen they thought that they also knew all sorts of high matters, and this defect in them**

overshadowed their wisdom; and therefore I asked myself on behalf of the oracle, whether I would like to be as I was, neither having their knowledge nor their ignorance, or like them in both; and I made answer to myself and to the oracle that I was better off as I was.

*This inquisition has led to my having many enemies of the worst and most dangerous kind, and has given occasion also to many calumnies. And I am called wise, for my hearers always imagine that I myself possess the wisdom which I find wanting in others: but the truth is, O men of Athens, **that God only is wise**; and by his answer he intends to show that the wisdom of men is worth little or nothing; he is not speaking of **Socrates**, he is only using my name by way of illustration, as if he said, **He, O men, is the wisest, who, like Socrates, knows that his wisdom is in truth worth nothing**. And so I go about the world, obedient to the god, and search and make enquiry into the wisdom of any one, whether citizen or stranger, who appears to be wise; and if he is not wise, then in vindication of the oracle I show him that he is not wise; and my occupation quite absorbs me, and I have no time to give either to any public matter of interest or to any concern of my own, but I am in utter poverty by reason of my devotion to the god.*

*There is another thing:—young men of the richer classes, who have not much to do, come about me of their own accord; they like to hear the pretenders examined, and they often imitate me, and proceed to examine others; **there are plenty of persons, as they quickly discover, who think that they know something, but really know little or nothing; and then those who are examined by them instead of being angry with themselves are angry with me**: This confounded Socrates, they say; this villainous misleader of youth!—and then if somebody asks them, Why, what evil does he practise or teach? they do not know, and cannot tell; but in order that they may not appear to be at a loss, they repeat the ready-made charges which are used against all philosophers about teaching things up in the clouds and under the earth, and having no gods, and making the worse appear the better cause; for they do not like to confess that their pretence of knowledge has been detected—which is the truth; and as they are numerous and ambitious and energetic, and are drawn up in battle array and have persuasive tongues, they have filled your ears with their loud and inveterate calumnies. And this is the reason why my three accusers, Meletus and Anytus and Lycon, have set upon me; Meletus, who has a quarrel with me on behalf of the poets; Anytus, on behalf of the craftsmen and politicians; Lycon, on behalf of the rhetoricians: and as I said at the beginning, I cannot expect*

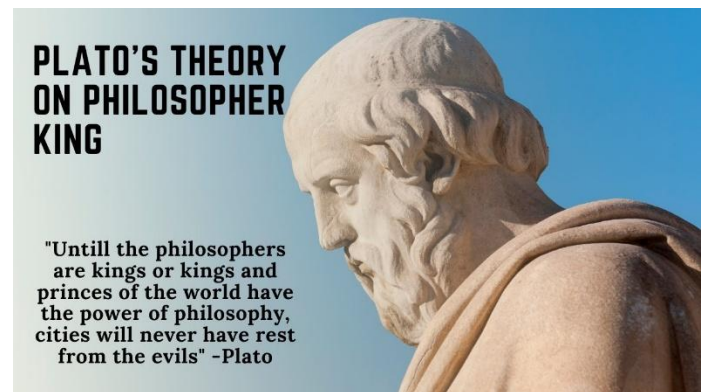


to get rid of such a mass of calumny all in a moment. And this, O men of Athens, is the truth and the whole truth; I have concealed nothing, I have dissembled nothing. And yet, I know that my plainness of speech makes them hate me, and what is their hatred but a proof that I am speaking the truth?—Hence has arisen the prejudice against me; and this is the reason of it, as you will find out either in this or in any future enquiry.”



In 399 B.C., Socrates was found guilty of corrupting the youth, given poison hemlock to drink, and was thereby canceled!

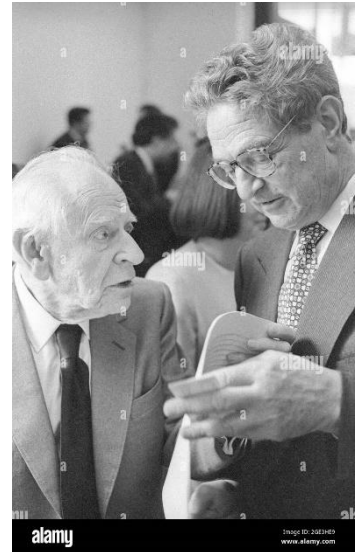
Aside: Plato resented that the democratic mob killed his beloved teacher, Socrates. When [Plato](#) wrote *The Republic*, he proposed that a [Philosopher King](#) make the decision about what is true knowledge and what should be censored.



For it is then that it is best molded and takes the impression that one wishes to stamp upon it.” “Quite so.” “Shall we, then, thus lightly suffer our children to listen to any chance stories fashioned by any chance teachers and so to take into their minds opinions for the most part contrary to those that we shall think it desirable for them to hold when they are grown up?” “By no manner of means will we allow it.” “We must begin, then, it seems, by a censorship over our storymakers, and what they do well we must pass

and what not, reject. And the stories on the accepted list we will induce nurses and mothers to tell to the children and so shape their souls by these stories far rather than their bodies by their hands. By using censorship, [the motley horde...are compulsorily excluded.](#)

In *Realism and the Aim of Science*, Karl Popper (1983) describes our knowledge in terms of conscious (critical) and unconscious (uncritical) thought, when he writes, “*Most of us, especially most philosophers, hold a great number of theories consciously, and after critical examination; and we may be prepared both to defend these by argument and to give them up when good arguments are brought against them. But we all also hold theories which we take for granted more or less unconsciously and therefore uncritically; and these uncritically held theories often contain the strongest reason for continuing to hold those other theories consciously. This has been known for a long time....*”



Consider how the circle of ignorance described by Socrates differs when it comes to Socrates’ critical thinking that emphasizes the individual and today’s Critical Theory that emphasizes intersectionality and the identity group. There is a difference between “know thyself”, the command of the Delphic deity, and the postmodernist command of “know thy identity group.”

Hear Bill Maher talk about [cancel culture](#) and [indoctrination](#) in elite schools.



I want to say that the fundamental significance of language is that it provides a method to communicate understanding. The words male and female that I used in this lecture are quite understandable. The [Ecology and Evolutionary Biology \(EEB\) Language Project](#) find these words both harmful and useful as potential alternatives as shown in the chart below. Understand?

EEB Language Project : Top 24 Submitted Terms		
Identified Term	Shared explanation for potential harm	Potential Alternative
alien / non-native / exotic / invasive	Xenophobic, anti-immigrant, and militaristic	Non-endemic species / Newly arrived species / Non-Indigenous species / Introduced species / Nuisance species
blind / double blind / plant blindness	Disability metaphor	Awareness
citizen science	"Citizen science" is harmful to non-citizens who are excluded by that language	Participant science / Community science /
feminized / masculinized	Feminized implies that "feminine" and "masculine" are biological traits rather than social constructs	Describe the specific traits
gypsy	Racial slur used to incite violence against Romani people	"Spongy moth"
man / woman	Highly anthropomorphic / Biases towards men or male traits	Male or female / Human
names after racist / eugenic / colonizers	They hold up problematic figures as noteworthy/someone to remember or celebrate	Use Indigenous names / Use local names / Name based on appearance or morphology / Remove names from concepts
survival of the fittest	Eugenics, ableism, and social Darwinism	Natural selection / Survival differences
Gender	Gender, a social construct, is often conflated with sex	Sex
Hermaphrodite	Derogatory term used to cause harm to the intersex and trans individuals.	Monoecious/intersex/bi-gametic
Indian	A discriminatory, racist, term used to describe Indigenous people	Indigenous
Male/female	These terms are used to reinforce societally-imposed ideas of a sex binary, emphasising cis-normative and hetero-normative views	Sperm-producing/egg-producing or XY/XX individual
	These terms perpetuate a non-universal heteronormative and cisnormative view of the	

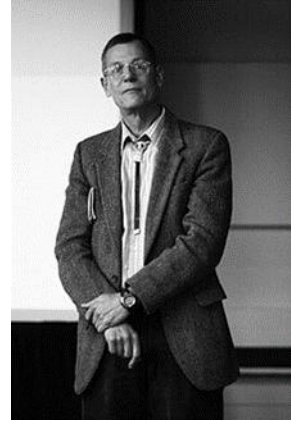
I will end this lecture with some pretty stamps of bioluminescent organisms:



Using Light to Keep Track of Time and Determine Orientation in Space:

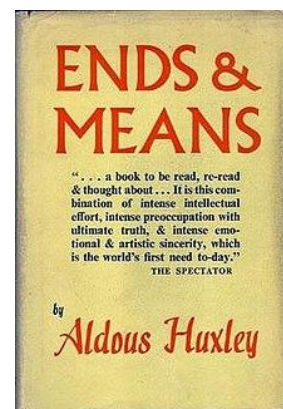
Photomorphogenesis in Plants

Last time I mentioned that Will Provine (1990, Cornell) wrote, *“As a young man, Charles Darwin was a creationist deeply impressed with William Paley's version of the argument from design. But after returning from the voyage of H.M.S. Beagle, reconsideration of what he had seen on the voyage convinced him that evolution had occurred. A short time later, when he deduced the theory of natural selection to explain the adaptations in which he had previously seen the handiwork of God, Darwin knew that he was committing cultural murder. He understood immediately that if natural selection explained adaptations, and evolution by descent were true, then the argument from design was dead and all that went with it, namely the existence of a personal god, free will, life after death, immutable moral laws, and ultimate meaning in life.”*



Provine's words represent the scientific consensus today (https://en.wikipedia.org/wiki/Scientific_consensus). But that does not mean that scientific knowledge leads to a comprehensive understanding of the fullness of life.

Remember what Aldous Huxley (1937), the grandson of T. H. Huxley, wrote in *Ends & Means*: *“No account of the scientific picture of the world and its history would be complete unless it contained a reminder of the fact, frequently forgotten by scientists themselves, that this picture does not even claim to be comprehensive. From the world we actually live in, the world that is given by our senses, our intuitions of beauty and goodness, our emotions and impulses, our moods and sentiments, the man of science abstracts a simplified private universe of things possessing only those*



qualities which used to be called 'primary.' Arbitrarily, because it happens to be convenient; because his methods do not allow him to deal with the immense complexity of reality, he selects from the whole of experience only those elements which can be weighed, measured, numbered, or which lend themselves in any other way to mathematical treatment. By using this technique of simplification and abstraction, the scientist has succeeded to an astonishing degree in understanding and dominating the physical environment. The success was intoxicating and, with an illogicality which, in the circumstances, was doubtless pardonable, many scientists and philosophers came to imagine that this useful abstraction from reality was reality itself. Reality as actually experienced contains intuitions of value and significance, contains love, beauty, mystical ecstasy, intimations of godhead. Science did not and still does not possess intellectual instruments with which to deal with these aspects of reality. Consequently it ignored them and concentrated its attention upon such aspects of the world as it could deal with by means of arithmetic, geometry and the various branches of higher mathematics.

Our conviction that the world is meaningless is due in part to the fact (discussed in a later paragraph) that the philosophy of meaninglessness lends itself very effectively to furthering the ends of erotic or political passion; in part to a genuine intellectual error—the error of identifying the world of science, a world from which all meaning and value has been deliberately excluded, with ultimate reality. It is worth while to quote in this context the words with which Hume closes his Enquiry: 'If we take in our hand any volume—of divinity, or school metaphysics, for instance—let us ask, Does it contain any abstract reasoning concerning quantity or number? No. Does it contain any experimental reasoning concerning matter of fact and existence? No. Commit it then to the flames; for it can contain nothing but sophistry and illusion.' Hume mentions only divinity and school metaphysics; but his argument would apply just as cogently to poetry,

music, painting, sculpture and all ethical and religious teaching. Hamlet contains no abstract reasoning concerning quantity or number and no experimental reason concerning evidence; nor does the Hammerklavier Sonata, nor Donatello's David, nor the Tao Te Ching nor The Following of Christ. Commit them therefore to the flames: for they can contain nothing but sophistry and illusion.

We are living now, not in the delicious intoxication induced by the early successes of science, but in a rather grisly morning-after, when it has become apparent that what triumphant science has done hitherto is to improve the means for achieving unimproved or actually deteriorated ends. In this condition of apprehensive sobriety we are able to see that the contents of literature, art, music even in some measure of divinity and school metaphysics are not sophistry and illusion, but simply those elements of experience which scientists chose to leave out of account, for the good reason that they had no intellectual methods for dealing with them. In the arts, in philosophy, in religion men are trying—doubtless, without complete success—to describe and explain the non-measurable, purely qualitative aspects of reality. Since the time of Galileo, scientists have admitted, sometimes explicitly, but much more often by implication, that they are incompetent to discuss such matters. The scientific picture of the world is what it is because men of science combine this incompetence with certain special competences. They have no right to claim that this product of incompetence and specialization is a complete picture of reality. As a matter of historical fact, however, this claim has constantly been made. The successive steps in the process of identifying an arbitrary abstraction from reality with reality itself have been described, very fully and lucidly, in Burt's excellent Metaphysical Foundations of Modern Science; and it is therefore unnecessary for me to develop the theme any further. All that I need add is the fact that, in recent years, many men of science

have come to realize that the scientific picture of the world is a partial one the product of their special competence in mathematics and their special incompetence to deal systematically with aesthetic and moral values, religious experiences and intuitions of significance. Unhappily, novel ideas become acceptable to the less intelligent members of society only with a very considerable time-lag. Sixty or seventy years ago the majority of scientists believed and the belief often caused them considerable distress that the product of their special incompetence was identical with reality as a whole. To-day this belief has begun to give way, in scientific circles, to a different and obviously truer conception of the relation between science and total experience. The masses, on the contrary, have just reached the point where the ancestors of to-day's scientists were standing two generations back. **They are convinced that the scientific picture of an arbitrary abstraction from reality is a picture of reality as a whole and that therefore the world is without meaning or value.** But nobody likes living in such a world. To satisfy their hunger for meaning and value, they turn to such doctrines as Nationalism, Fascism and revolutionary Communism. Philosophically and scientifically, these doctrines are absurd; but for the masses in every community, they have this great merit: they attribute the meaning and value that have been taken away from the world as a whole to the particular part of the world in which the believers happen to be living.

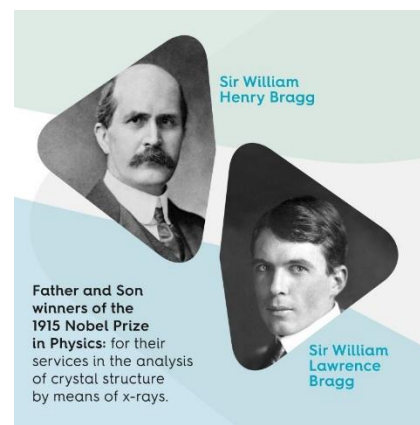
These last considerations raise an important question, which must now be considered in some detail. Does the world as a whole possess the value and meaning that we constantly attribute to certain parts of it (such as human beings and their works); and, if so, what is the nature of that value and meaning? This is a question which, a few years ago, I should not even have posed. For, like so many of my contemporaries, I took it for granted that there was no meaning.

This was partly due to the fact that I shared the common belief that the scientific picture of an abstraction from reality was a true picture of reality as a whole; partly also to other, non-intellectual reasons. I had motives for not wanting the world to have a meaning; consequently assumed that it had none, and was able without any difficulty to find satisfying reasons for this assumption.

Most ignorance is vincible ignorance. We don't know because we don't want to know. It is our will that decides how and upon what subjects we shall use our intelligence. Those who detect no meaning in the world generally do so because, for one reason or another, it suits their books that the world should be meaningless.”

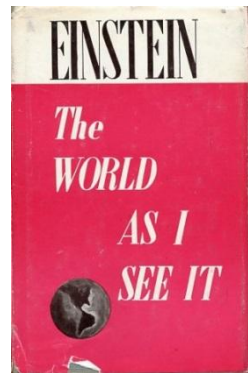
Aldous Huxley’s (1937) reconsideration of the scientific picture presented here is not unlike T. H. Huxley’s (1893) reconsideration described in his Romanes lecture.

Lawrence Bragg said at the Royal Institution on October 25, 1950, in a speech entitled, *Science and the Adventure of Living*, “The driving power behind the advance of science is a faith. I should like to attempt an expression of this faith, because science has a great power of exciting its disciples to ‘scorn delights and live laborious days.’ No one who has seen successive generations of young researchers begin their careers can fail to have been struck by the hold it gets on them. In a world of shifting values and challenged authorities pure science in its own restricted field has a clear aim which transcends personalities and national boundaries. What gives it this vision? I think it to be a profound conviction that in its search for truth science has a court of appeal, a touchstone,

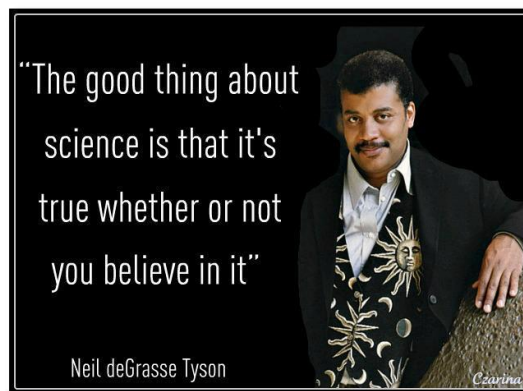


which is independent of fallible human judgement. When one has sought long for the clue to a secret of Nature and is rewarded by grasping some part of the answer, it comes as a blinding flash of revelation; it comes as something new, more simple and at the same time more subtle, and more aesthetically satisfying than anything one could have created in one's own mind. This conviction of something revealed, not something imagined, is all the stronger because of the discipline science imposes on those who would succeed. It is so essential to come to a problem with a completely open mind, and to resist the fatal temptation to warp and select the facts so as to fit in with some preconceived idea of a tidy little universe."

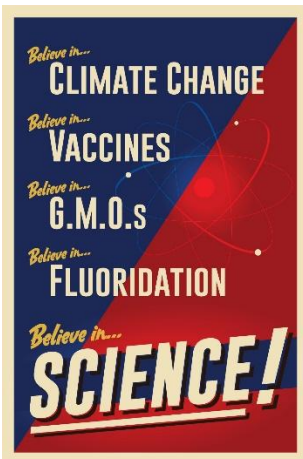
Albert Einstein resisted the scientific consensus: "*What is the meaning of human life, or of organic life altogether? To answer this question at all implies a religion. Is there any sense then, you ask, in putting it? I answer, the man who regards his own life and that of his fellow-creatures as meaningless is not merely unfortunate but almost disqualified for life.*" From *The World as I See It* by Albert Einstein (1949).



What does "*I believe in science*" mean?



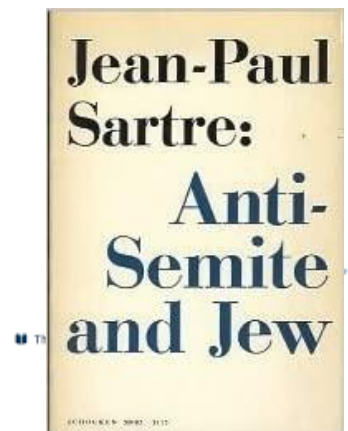
<https://www.youtube.com/watch?v=yRxx8pen6JY>



Imagine a society or even a university where people say “*I understand science*” and where leaders say with good faith, “*I understand the science and I can explain my analysis to you.*”

Science should be done, and scientific statements should be made, in good faith.

Good faith (Latin: *bona fides*) is a sincere intention to be honest, open, and fair, regardless of the outcome. **Bad faith** (Latin: *mala fides*) is a sustained form of hypocrisy, deception, and even self-deception that is likely to occur when one believes that a problem is existential, and a certain outcome is so



necessary because time will run out and one has no choice. This leads one to believe that there no need and no time to present a line of reasoning and craft a winning argument. In fact, someone who acts in bad faith “*has chosen to devalue words and reasons.*” **Jean-Paul Sartre** (1948) wrote in [*Anti-Semite and Jew*](#), “*They delight in acting in **bad faith**, since they seek not to persuade by sound argument but to intimidate and disconcert. If you press them too closely, they will abruptly fall silent, loftily indicating by some phrase that the time for argument is past.*” Sartre goes on to say, “*We have here a basic fear of oneself and of truth. What frightens them is not the content of truth, of which they have no conception, but the form itself of truth, that thing of indefinite approximation.*”

Bad faith becomes more common when one fears the uncertainties of the human condition, including the uncertainty of truth, which Sartre describes as “*that thing of indefinite approximation*”. While science once aimed at minimizing fear through scientific explanation in the search for truth, it now seems to try to instill fear and foster an intolerance to those who do not perceive the same fear.

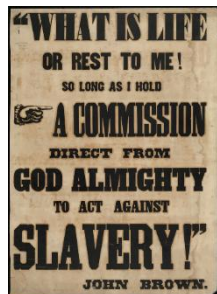
According to [Uriel Abulof](#) (Cornell), “[t]he politics of bad faith prospers because it is effective: if there is ‘no choice,’ there is no need for justification, let alone the need for taking responsibility.” As politics and science make more and more intimate bedfellows, the science of bad faith becomes more like the politics of bad faith, and scientists see no need to rigorously justify and take responsibility for their conclusions, but rather make an appeal to authority.

As human beings, we have the freedom to think critically or to be intellectually lazy. We also have the freedom to act in good faith or in bad faith. Authenticity describes the connection between conscious thinking and active doing. Jean-Paul Sartre (1948) writes, “*If it is agreed that man may be defined as a*

*being having freedom within the limits of a situation, then it is easy to see that the exercise of this freedom may be considered as authentic or inauthentic according to the choices made in the situation. **Authenticity, it is almost needless to say, consists in having a true and lucid consciousness of the situation, in assuming the responsibilities and risks that it involves, in accepting it in pride or humiliation, sometimes in horror and hate. There is no doubt that authenticity demands much courage and more than courage.***

We have been speaking about human life and in order to know ourselves better, let's define life in general. There are similarities and differences between how human beings and plants sense and respond to situations. The most authentic, true, lucid, and courageous human beings show more differences than similarities when compared with plants. As a comparison, let's discuss the consciousness of plants and how they respond appropriately to the information they take in.

Life can be **operationally defined** by a biologist as 1) the ability to **assimilate sustenance** in the form of matter and energy from the environment; 2) the ability to **transform** this environmental input at **ambient temperature and pressure** into **usable energy** (chemical, electrical, and radiant) as well as the **common and unique molecules** (including pigments, luciferins and luciferases) that make up the body; 3) the ability to **expel any waste material** that would be toxic; 4) the **ability to move** using its own energy source; 5) the ability to **reproduce the information** in the form of DNA that directs all the above processes with **near perfect fidelity** such that the near-perfect reproduction gives rise to variation; and 6) the **ability to sense and respond** appropriately to the environment. This operational definition of life does not subsume the additional requirements that contribute to our own definition of **a good and well-lived life**.



Life is a Journey by Rabbi Alvin Fine (<https://vimeo.com/42921067>)

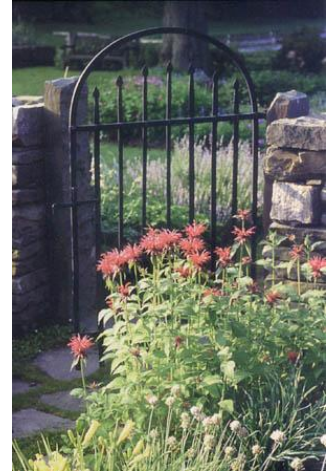
*Birth is a beginning and death is a destination. And life is a journey.
From childhood to maturity and youth to age;
From innocence to awareness and ignorance to knowing;
From foolishness to discretion and then, perhaps, to wisdom;
From weakness to strength or strength to weakness. And often, back again;
From loneliness to love, from joy to gratitude, from pain to compassion,
From grief to understanding, from fear to faith,
From defeat to defeat to defeat. Until looking backward or ahead,
We see that victory lies not at some high place along the way,
But in having made the journey, stage by stage a sacred pilgrimage.
Birth is a beginning and death is a destination.
And life is a journey, a sacred pilgrimage—to life everlasting.*

Consciousness, as defined as **an awareness of the external environment** is the first step in responding appropriately to the environment. It is a characteristic of life and may have begun with the first cell. Remember that



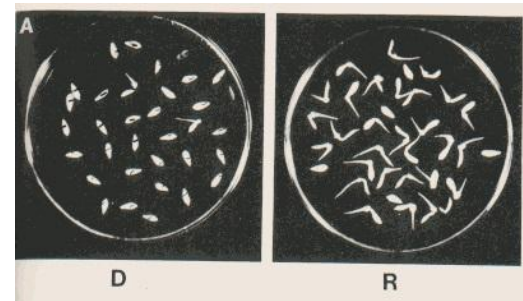
Jerome Wolken described *Euglena* as a **photo-neurosensory cell**. Consciousness differs from **conscience**, which means a **knowledge within oneself**, an inner sense of **right and wrong**, a **moral** sense, **intention**. Here we are touching on the origin of consciousness and the science that describes and explains it. Do animals, including, monkeys and apes have a conscience? A **Law of Nature** that describes the origin of conscience is still forthcoming and may be a place where science and theology meet.

Plants do not have a conscience but are conscious in that they sense the external environment and respond appropriately to the sensations. If we were to ramble through a meadow, hike through the woods, walk along the seashore, climb a mountain, or walk quietly and observantly through a garden at the **Cornell Botanic Gardens**, it would become increasingly clear that it is a normal and ubiquitous property of plants to **sense** and **respond** to their environment.

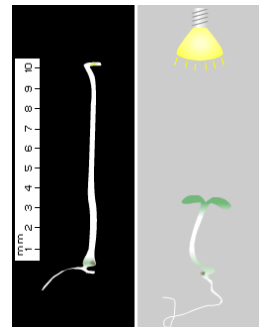


Plants depend on sunlight to power photosynthesis, where **radiant energy acts as a substrate** that is transformed into chemical energy. However, plants also depend on the **information content of sunlight** to **catalytically** affect their structure and function.

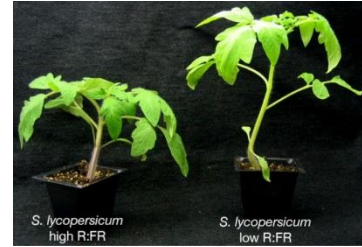
For example, some seeds, particularly those of weeds, do not **germinate** in the dark (D) but require a short burst of red light (R), given alone or as part of white light, to **germinate**.



Once the seeds germinate, many seedlings require light to retard stem growth and to promote leaf expansion and greening. Development in the dark, where the seedling appears pale and drawn out (**etiolated**) is known as **skotomorphogenesis**. Development in the light is known as **photomorphogenesis**.



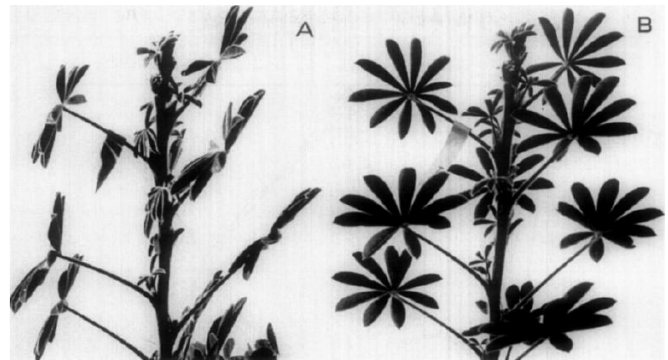
Plants also develop differently depending on whether they grow in the **shade** (where the red part of sunlight has been absorbed by the chlorophyll in the leaves above) or in **full sun** (which has plenty of red light). The **shade-avoidance response** involves stem elongation. Thinking of the etiolation response or the shade-avoidance response, we see the general biological principle of **compensatory growth, compensation, or variation on the archetype**. There is no single best way for a plant to grow because there is no single environment. In the real world, having a variety of good ways to respond to a variable environment leads to the successful life of a plant.



Some plants sense the **direction of light** and the whole plant bends or turns towards the light in a process known as **phototropism**.



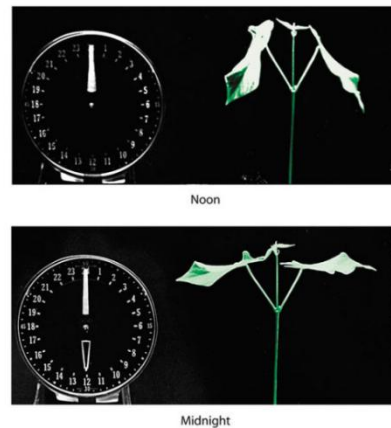
The leaves of some plants can track the movement of the sun throughout the day. The process of **solar tracking** is known as **heliotropism**.



Some plants are also able sense the **duration of sunlight**, which is a measure of day length. The response to the duration of day length or **photoperiod** is known as **photoperiodism**. Plants respond differently to **day length**. For example, **skunk cabbage** flowers in the spring when the days are short, and **chicory** flowers in the summer when the days are long.



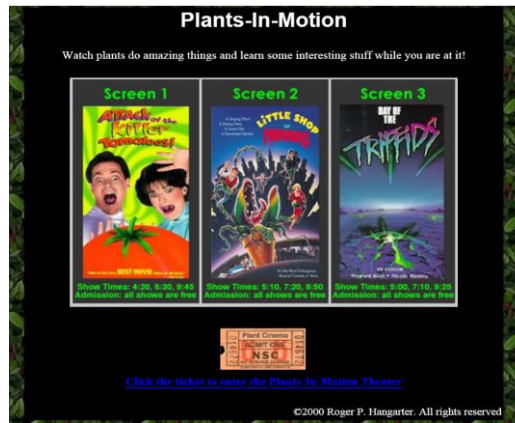
Many flowers, including the daylily and *Crocus*, can tell when the daylight begins and ends. They open in the morning and close at night. Perhaps they open for insect pollinators and close to protect the flowers from insect pests. Some leaves also change their position during the day and at night. They spread out in the day to catch the sunlight and close at night. Such daily responses may be part of a daily rhythm, known as a **circadian rhythm**, which will persist in continuous darkness, but which is reset each morning when the sun rises. **Circadian** means, about a day.



Demonstration: Sensitive plant (*Mimosa*) and Venus' flytrap (*Dionea*). See the ant?

Roger Hangarter has captured many video clips that show “**plants in motion**” where many of the motions are responses to light (<http://plantsinmotion.bio.indiana.edu/>).



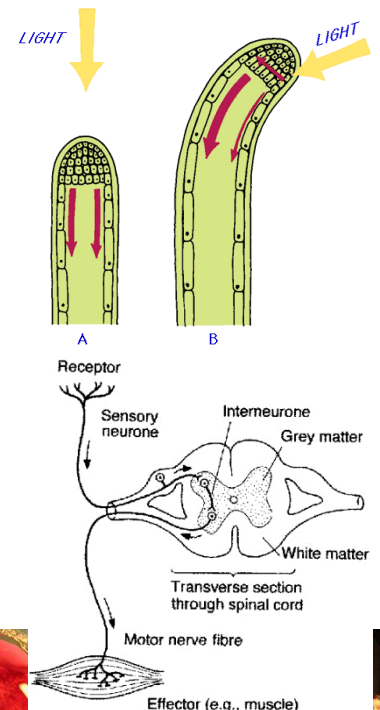
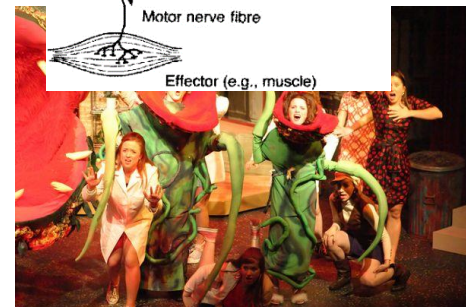


Plants are born to run!

https://canvas.cornell.edu/courses/12596/files/975457?module_item_id=295840

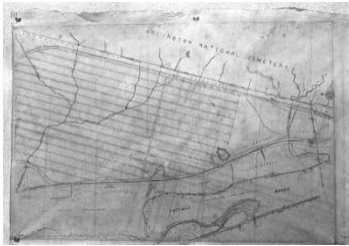
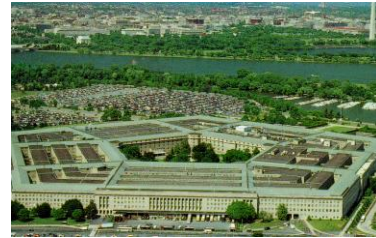
In order for plants to sense and respond to the **information** held by the environmental light, they must have **photoreceptor pigments**. When activated, these pigments must activate **signal transduction chains** (like the one we discussed that participated in vision) that lead to the **physical and/or chemical changes** that result in the appropriate **response**. Stimulus response coupling in plants has a surprising number of similarities with stimulus response coupling in humans.

Raoul Francé (1905) wrote, “*What grander lesson could the speechless plants give than that which they have taught us: that their sense life is a primitive form, the beginning of the human mind... it tells us that after **all the living world is but mankind in the making**, and that we are but a part of all.*”



I am now going to discuss the **discovery of photoperiodism**—something that occurred at the present location of the **Pentagon**. A **United States**

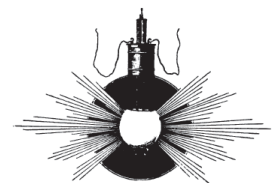
Department of Agriculture research farm known as the **Arlington Experimental Farm** once stood where the South Parking Lot of the Pentagon now stands.



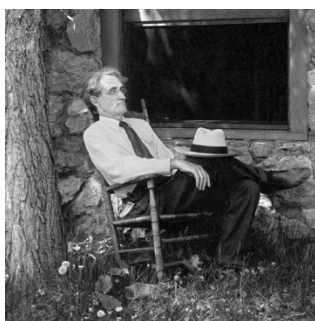
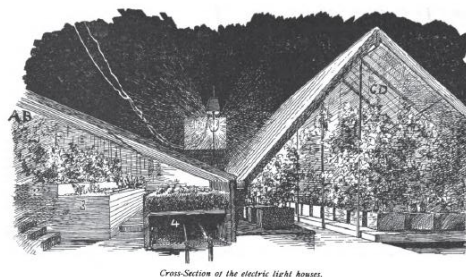
In order to make room for the military's growing needs during World War II, President Franklin D. Roosevelt signed an order to move the Experimental Farm to Beltsville, Maryland. Groundbreaking for the Pentagon occurred at the Arlington Experimental Farm site on September 11, 1941, and **Colonel Leslie Groves**, who would later oversee the Manhattan Project, oversaw the project. The **Pentagon** building was designed to have a pentagonal shape because the original Arlington Experimental Farm had a pentagonal shape.

Photoperiodism is *not* primarily a response to the intensity of light or the total quantity of light but to the **duration** and **timing** of the light and dark conditions. **Liberty Hyde Bailey's** (Cornell; 1892) use of artificial light in greenhouses led to an awareness that the **duration** of illumination has various effects on plant growth.

Electro-Horticulture.



By L. H. BAILEY.



Cross-Section of the electric light house.



Spinage grown in shop. The low plant grew under normal conditions, the slender one under the naked electric light.



Very tall and leafy mutants of tobacco plants occasionally appeared in an experimental plot at the Arlington Experimental Farm. Getting seed to propagate one of these gigantic mutants, which was known as **Maryland Mammoth**, was difficult.



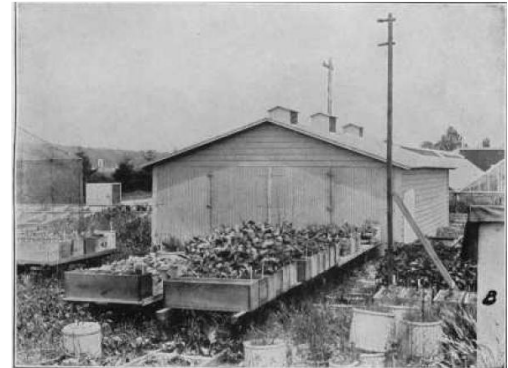
According to Harry Allard (1919), *“The great increase in number of leaves, together with a greatly elongated main stem, is accompanied by a period of vegetative vigor of such long duration that blossoming does not normally take place when the plants are growing in the field. In order to obtain seed from such plants, the usual practice has been to transplant the roots and stub, or even the plants entire, to the greenhouse in the fall, where vegetative vigor is resumed with the final production of normal blossoms and seed during the winter.”*



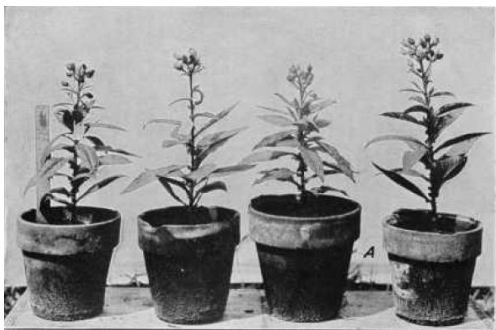
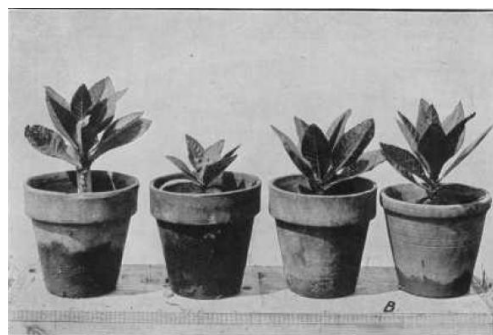
Wightman Garner and Harry Allard found that it did not matter what size pot they grew the Maryland Mammoth tobacco plants in or how well they were fertilized, the experimental plants, no matter what the treatment, would never flower in the summer even though they reached a height of 10-15 feet; and would all flower at the same time in the winter even though the plants were not yet 5 feet tall. Garner and Allard (1920) wrote, *“Obviously, then, **the time of year** in which the Mammoth tobacco develops determines whether the growth is of the giant character.”*

While the **difference in temperature** was an obvious potential cause of the difference between the behavior of plants in the summer and in the winter, the **length of daylight** could also be the cause of the difference in plant behavior in the

summer and the winter. Garner and Allard (1920) could study the influence of day length in four different ways. They could compare the behavior of plants growing at different latitudes or at different seasons of the year; or they could supplement the daylight with artificial light or prevent the daylight from reaching the plant. They chose the latter experimental treatment. In the summer of 1918, they built a **dark chamber** to limit the length of daylight experienced by the Maryland Mammoth tobacco plants and in 1919 they expanded the experimental treatment by building a **dark house** to limit the length of daylight experienced by the plants. The plants could be moved in and out of the dark house every day with trucks on steel tracks.



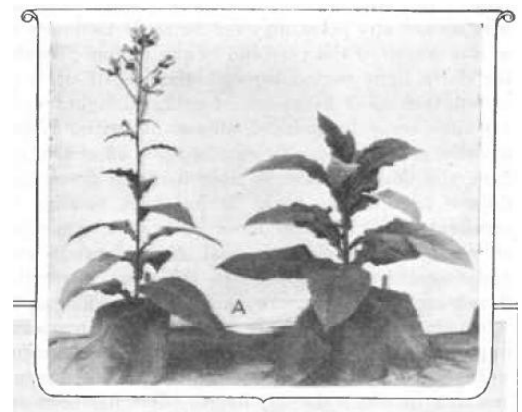
The plants grown in 8-inch pots that were exposed to **seven hours of sunlight** from 9AM to 4PM and then wheeled into the dark house flowered by August 15, 1919. The control plants grown in 8-inch pots that were kept outdoors, exposed to the **long days** of summer, had not flowered by August 15, 1919.



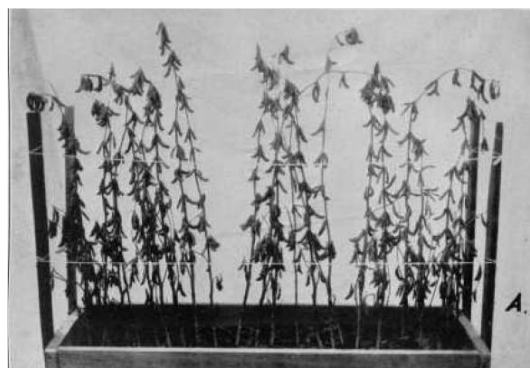
Likewise, Maryland Mammoth plants grown in 12-quart buckets that were exposed to **7 hours of sunlight** flowered and produced seeds by August 19, 1919, while the ones exposed to **12 hours of sunlight** or left outdoors did not.



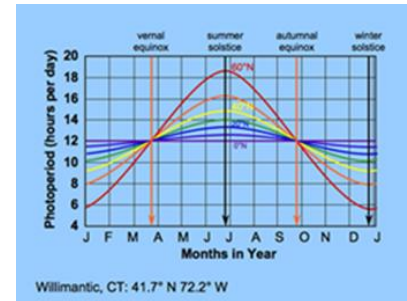
Garner and Allard had solved the problem of the Maryland Mammoth. Once they understood the role of **photoperiod**, they could get the plants to flower and set seed by growing them during the **long days of summer** by using the **dark house** or during the **short days of winter in a greenhouse**.



Garner and Allard experimented with many plants, including **Peking soybeans**. Peking soybeans exposed to **7½ hours of daylight** before being put in a dark house already had matured pods ready for harvest on September 13, 1919, while the control plants that had been left outside exposed to the **long days of summer** had seed pods that were still green and leaves that were just beginning to yellow.



Garner and Allard began to realize that each variety of soybean had its own “**critical length of day** required for furnishing the stimulus which brings into expression the processes of sexual reproduction.” Others would define **short-day plants** as plants that *will not* flower if the photoperiod is extended beyond the **critical photoperiod**, and they would define **long-day plants** as plants that *will* flower if the photoperiod is extended beyond the **critical photoperiod**.



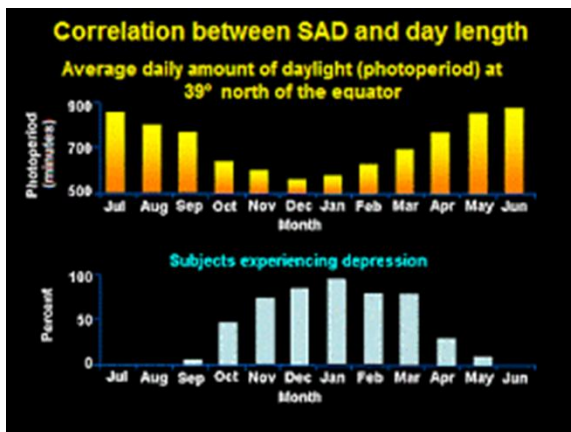
These are convenient definitions for horticulturalists and plant physiologists. However, the distinction between short-day plants and long-day plants is based on whether or not flowering is promoted or inhibited by increasing the light period about a critical value and not based on the absolute day length as it would be defined by a naturalist, where short days occur in spring and fall and long days occur in summer. For example, *Xanthium* (cocklebur) is a **short-day plant with a critical photoperiod of 15½ hours** and will *not* flower if the light period is extended beyond the critical photoperiod. *Hyoscyamus* (Henbane) is a **long-day plant with a critical photoperiod of 11 hours** but *will* flower when the photoperiod is extended beyond the critical photoperiod.



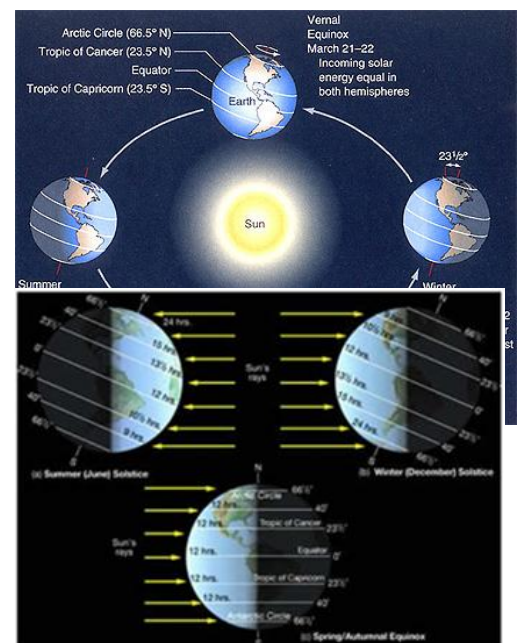
Garner and Allard (1920) ended their paper by coining the terms **photoperiod** “to designate the favorable length of day for each organism” and **photoperiodism** “to designate the response of organisms to the relative length of day and night.” Furthermore, they wrote about the possibility of photoperiodism in animals, “As to **animal life**, nothing definite can be said, but it may be found

*eventually that the animal organism is capable of responding to the stimulus of certain day lengths. It has occurred to the writers that possibly the **migration of birds** furnishes an interesting illustration of this response. Direct response to a stimulus of this character would seem to be more nearly in line with modern teachings of biology than are theories which make it necessary to assume the operation of instinct or volition in some form as explaining the phenomena in question.”*

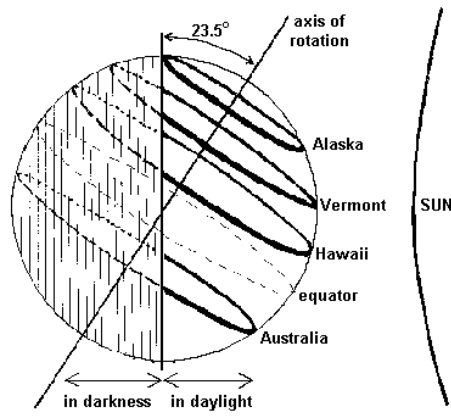
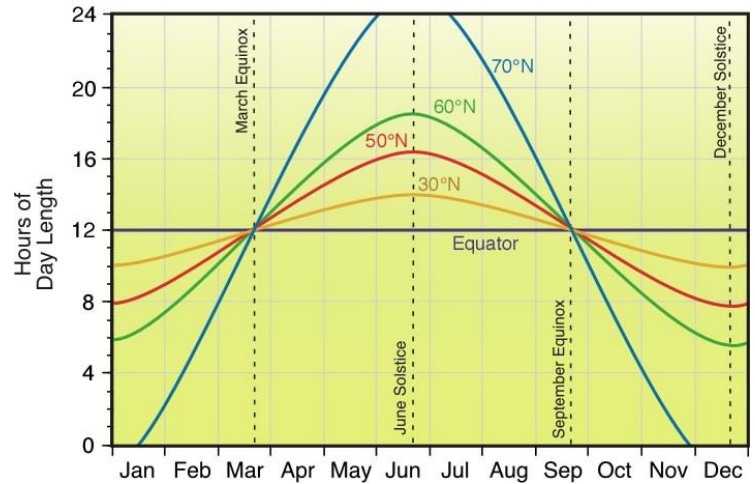
Humans are sensitive to photoperiod in terms of seasonal affective disorder (SAD).



The **day lengths** of the growing regions of earth depend on **astronomical factors**. The **day length** or **photoperiod** in the temporal regions of earth changes seasonally as a result of the **23½ degrees tilt of the earth’s axis**. During **summer** in the northern hemisphere, the earth is tilted toward the sun so that the days are longer than the nights. During **winter** in the northern hemisphere, the earth is tilted away from the sun, so the days are shorter

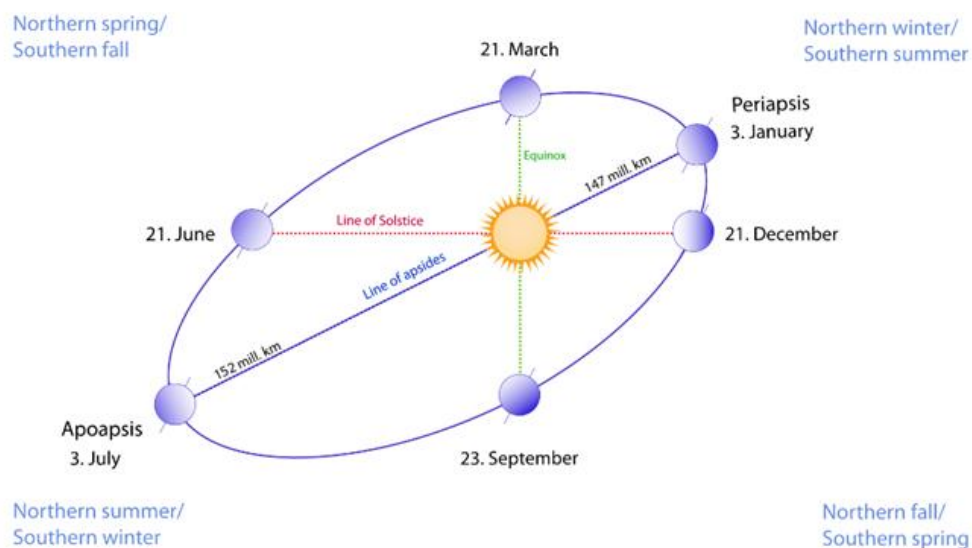


than the nights. To get a real picture of the seasonal changes imagine what would happen if the axis were tilted 90 degrees.

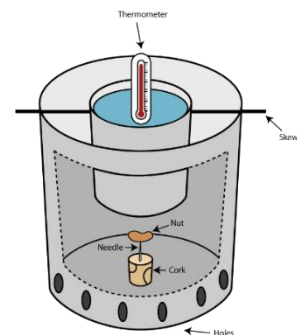


The latitude of Ithaca is 42.4440° N. The summer solstice ($\approx$ June 21) marks the longest day of the year, and the winter solstice ($\approx$ December 21) marks the shortest. On the autumnal equinox ($\approx$ September 21) and vernal equinox ($\approx$ March 21), the day lengths and night lengths are equal.

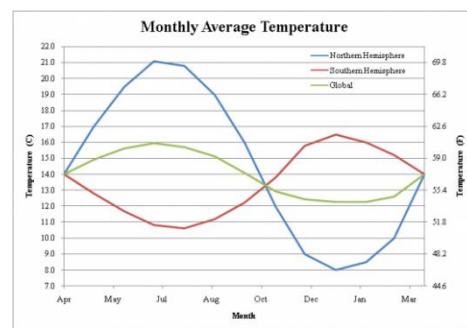
Even though the photoperiods in the northern and southern hemispheres are complementary during the year, the two hemispheres are not complementary in terms of solar radiation and temperature—two factors that also affect plant growth



and development. Because the **earth's orbit** is **elliptical** and not a perfect circle, the northern hemisphere gets less solar radiation than the southern hemisphere. This is because the northern hemisphere tilts towards the sun when it is **farthest** from the sun during the long days of its summer and the southern hemisphere tilts towards the sun when it is **closest** to the sun during our winter and during its long days of its summer.



Because of the differences in the relative proportions of land, the northern hemisphere heats up and cools more quickly than the southern hemisphere. This is because the proportion of water to land is greater in the southern hemisphere than in the northern hemisphere and water has a greater **heat capacity** than land. Remember from our **calorimetry experiment with the peanut**, the change in temperature (ΔT) in response to an input of thermal energy (TE) depends in the heat capacity (c) and mass (m) of the water according to the following equation: $TE = c m \Delta T$. The northern hemisphere has an **ocean to land ratio** of 60.7% to 39.3% while the southern hemisphere has a ratio of 80.9% to 19.1%. Consequently, annual temperature variation is moderated in the southern hemisphere compared with the northern hemisphere. Because of the heat capacity of water, summer in the northern hemisphere is hotter than summer in the southern hemisphere even though the earth is closer to the sun during summer in the southern hemisphere than it is during summer in the northern hemisphere; and winter in the northern hemisphere is colder than winter in the southern hemisphere even though the earth is closer to the sun during winter in the northern hemisphere than it is during winter in the southern hemisphere. The heat capacity of water also



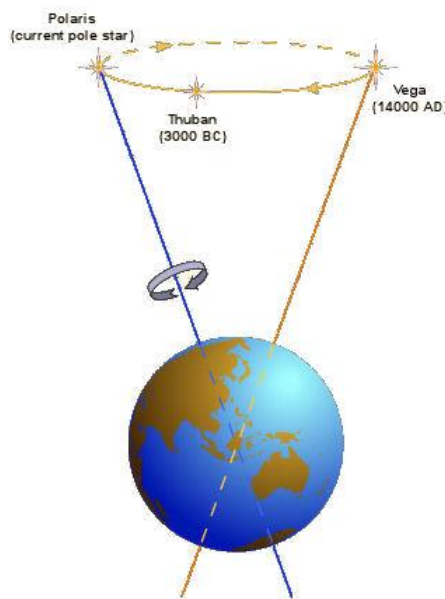
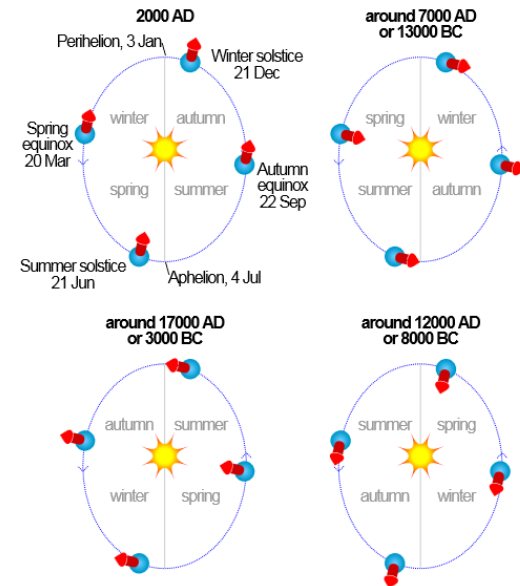
explains why the average temperature of the earth is lowest when the earth is closest to the sun and warmest when the earth is farthest from the sun.

Water is important for plant growth in many ways!!!!

Because the earth is not a perfect sphere (the radius at the equator and the poles is 6378 km and 6357 km, respectively), the gravitational forces from the sun and the moon create a torque on the axis of the earth that causes the tilt to change. The change in tilt

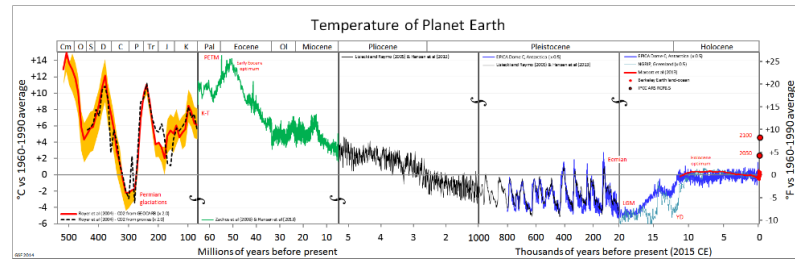
has a **period of 25,765 years** and results in a precession of the position of the sun on the first day of spring (vernal equinox). In other words, while winter currently occurs in the northern hemisphere when the earth is closest to the sun (**perihelion**), around 12000 A.D, as a result of the **precession of the equinoxes**, winter will occur when the earth is farthest from the sun (**aphelion**).

If the earth did not have a moon, the earth's seasons could change substantially. Without the Moon stabilizing our tilt, the Earth's tilt could vary wildly from no tilt (which means no seasons) to a large tilt (which means extreme weather and even ice ages).



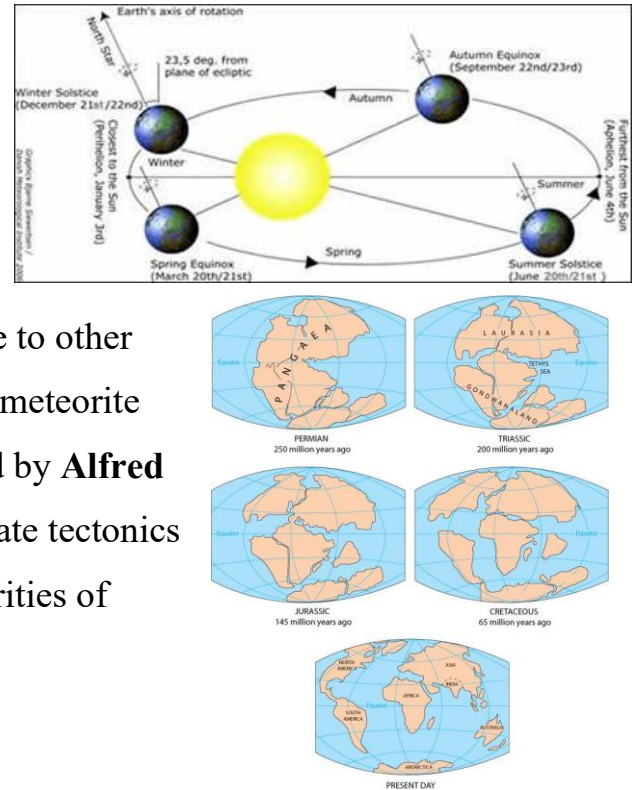
The **photoperiod** of a region, along with its temperature, water availability, and light intensity, are important factors in determining the **natural geographical distribution** or **biogeography** of plants in terms of their northward and southward distribution. Harry Allard (1948) realized that day length is a part of **climate change** that occurs over **geological time** when he wrote, “*Length of day must, therefore, always be a function of every climate. Geologists inform us that there have been great changes in world climate throughout all the great geological eras. Some climates have been characteristically warm and weakly zonal and others have been cool and strongly zonal. That there have been profound local, regional and even world-wide changes in climate*

involving length of day as well as temperature cannot be denied. The astronomical relations responsible for earth climate are very complex and

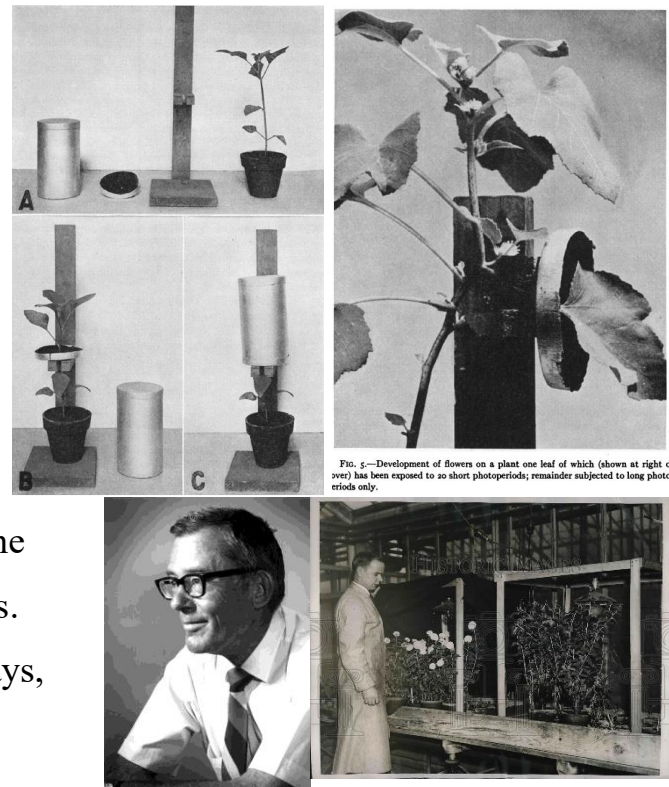


involve many factors including the earth’s obliquity, the rate of rotation, the distance and eccentricity of the path of revolution around the sun, the length of time required to complete the revolution, as well as various conditions pertaining to the intensity of the solar energy and many physical conditions obtaining upon the earth itself. The astronomer, on purely mathematical grounds, may theorize about changes in the obliquity of the axis. However, were this obliquity actually to approach zero, with the same daily rotation that we have at present, causing a uniform length of day of 12 hours to prevail over all the earth, accompanied by weak zonations of temperature, there is every reason to believe that profound changes would take place in the floristic life-form and vegetation of the earth.”

The **photoperiodic responses** of plants on earth are adapted to the **astronomical relations** between the earth and the sun. However, the profound changes that have occurred in the vegetation on earth over geological time are *not* due to a change in the obliquity of the axis, but due to other factors that have a major effect on climate such as meteorite impact and the movement of land masses proposed by **Alfred Wegener** (1915) and known as **plate tectonics**. Plate tectonics explains the shape of the continents and the similarities of fossils on different continents.

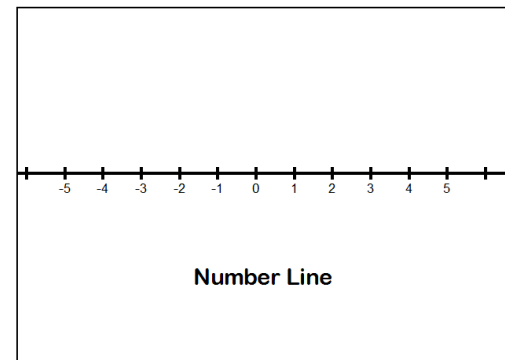


Working together for one summer, Karl Hamner and **James Bonner** (1938) found that the **leaves**, as opposed to the stems, are the organs of the *Xanthium* plant that sense the length of the day. When they removed all the leaves from a plant, the cocklebur would not flower under short days. It would flower under short days when they left one leaf. In fact, they could grow the plant under long days, slide a light-tight cylinder over one leaf so that only one leaf was exposed to short days. Even though only one leaf was exposed to short days, the whole plant flowered.



Karl Hamner and James Bonner (1938) exposed plants to various day lengths with a constant night length or to various night lengths with a constant day length and found that the length of the day was not very important for flowering in *Xanthium* but that it was essential that the **dark period exceeded 8½ hours**. They wrote that *“It seems probable that the manufacture of the substance or substances responsible for the initiation of the flowering condition in Xanthium is **not** primarily a response to duration of the photoperiod, but rather a response to duration of the dark period.”*

Indeed, realizing that the **photoperiod** and **dark period** are complements of each other, Vernon H. Blackman (1936) had already pointed out that, *“Duration of illumination rather than quantity of light is the important thing, and this is exceedingly difficult to interpret in terms of physiology. In the case of short-day plants there is some reason for believing that it is the **corollary of the period of illumination, namely the period of darkness, to which attention should be directed.**”*

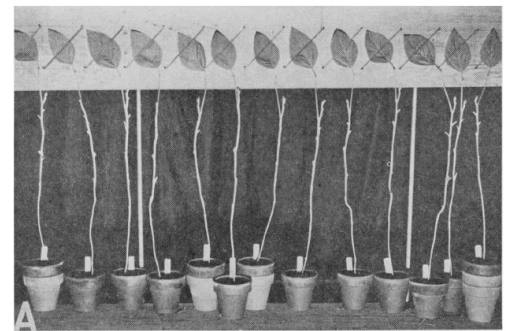


Remember the sum of real numbers equals zero and that helps you to remember that you may only be thinking of a solution to a problem in terms of the “positive” causes and not the “negative” causes.

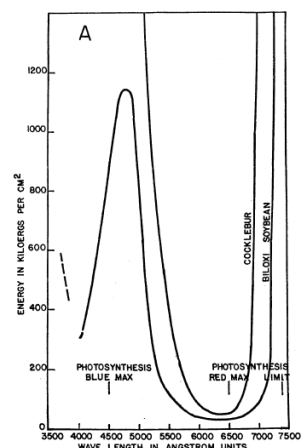
Then Karl Hammer and James Bonner serendipitously discovered that a *single* night-long dark period was enough to stimulate flowering when Edith Neidle, a graduate student of Karl Hamner's, went to the greenhouse and found that all the *Xanthium* plants were flowering. The greenhouse manager reluctantly told her that the power had been off for one night and consequently, all the plants had received a single long night. Building on this **lucky find**, Karl Hamner and James Bonner (1938) compared plants that had a 9-hour dark period with plants that experienced a one-minute flash of light 4.5 hours into the dark period. The plants that had a 9-hour dark period flowered (mac fl & fr = macroscopic flowers and fruits) as usual while the plants whose dark period was interrupted by a one-minute flash of light remained vegetative.

EFFECT OF INTERRUPTION OF DARK PERIOD BY VARYING EXPOSURES TO LIGHT ON FLOWERING OF XANTHIUM. EXPERIMENTS X-43, X-60, X-71; UNTREATED CONTROLS ALL VEGETATIVE

LENGTH OF PHOTO- PERIOD (HOURS)	LENGTH OF DARK PERIOD (HOURS)	LIGHT EXPOSURE DURING DARK PERIOD	No. OF PLANTS	CONDITION OF PLANTS AT END OF TREATMENT
15.....	9	None	12	mac fl & fr
15.....	4.5+4.5	1 minute after 4.5 hours	10	veg



What is the **photoreceptor** that **absorbs** the one-minute pulse of light that inhibits flowering? At the new USDA center in Beltsville that replaced the Arlington Experimental Farm where Garner and Allard discovered photoperiodism, **Harry Borthwick**, **Sterling Hendricks**, and Marion Parker built a **large spectrograph** to irradiate leaves of *Xanthium* or Biloxi soybean with a brief pulse of light with different wavelengths during the dark period and compare the ability of the pulse of light of a given wavelength to **inhibit** flowering. They used the large



spectrograph to obtain an **action spectrum**. An action spectrum is a plot of the effectiveness or the amount of radiant energy of a given wavelength of light needed to cause a given response.

To construct the **large spectrograph**, Parker et al. (1946) used the prisms that **Samuel Pierpont Langley** used to measure the solar insolation and determine the solar constant, a carbon arc lamp that was cadged from a Baltimore movie theatre, and a large resistor that had been discarded from the Georgetown streetcar system. Admirably, this government-run spectrograph construction project had an outside cost of \$50.

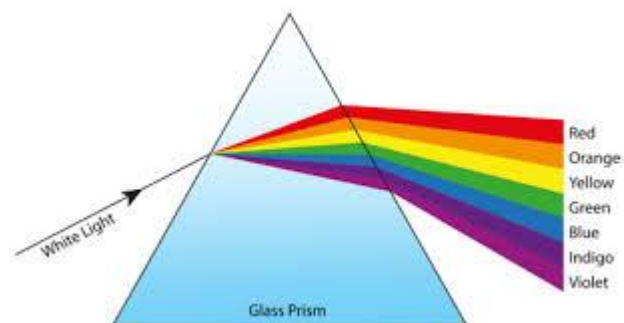
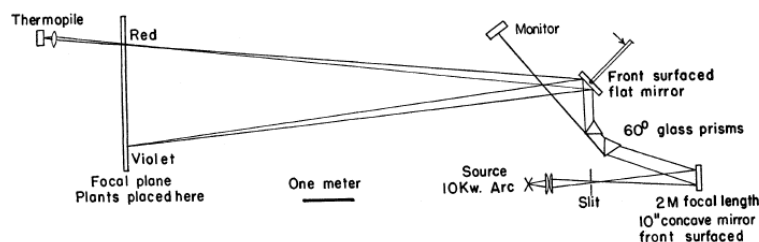


FIG. 1.—Diagram of optical path in spectrograph used for irradiation of plant leaves

The **Grotthuss-Draper Law** also known as the **First Law of Photochemistry** states that the radiant energy that causes a response must be absorbed by the pigment that mediates the response. Consequently, a **comparison** of the **action spectrum** for the inhibition of flowering with the **absorption spectrum** of known pigments would indicate which pigment was involved in photoperiodism. Parker et al. (1946) found that blue light was not effective and that red light from 600-680 nm was most effective. This **did not** coincide with the absorption spectrum of any **known** pigment, including chlorophyll.

Borthwick et al. (1952) also found that when the pulse of red-light irradiation is followed by a pulse of far-red (722-745 nm) irradiation, the inhibiting pulse of red light is nullified, and flowering occurs.

EFFECT OF VARIOUS WAVE-LENGTHS OF RADIATION ON PROMOTION OF FLOWERING OF *Xanthium saccharatum* PLANTS THAT HAD PREVIOUSLY RECEIVED RADIATION INHIBITORY TO FLOWERING

WAVE-LENGTH, Å	INCIDENT POWER (ERGS $\times 10^3$ /CM. ² /MIN.)	NUMBER OF FLOWERING PLANTS PER LOT OF 4 AFTER IRRADIATION FOR INDICATED TIME			
		16 MIN.	8 MIN.	4 MIN.	2 MIN.
6820-7020	87	0	0	0	0
7020-7215	93	1	3	0	0
7215-7450	99	3	3	3	1
7450-7700	102	1	1	1	0
7700-8010	105	0	0	0	0
8010-8300	111	0	0	0	0

Robert J. Downs (1956), also at Beltsville, showed that the pigment that inhibited flowering in *Xanthium* **could be turned on and off like a switch**. Flowering would be determined by the last irradiation. If the last irradiation was red light, flowering would be inhibited and if the last irradiation was far red light, flowering would occur.

TABLE III

EFFECT OF DAILY INTERRUPTIONS OF THE DARK PERIOD WITH SEVERAL CONSECUTIVE IRRADIATIONS WITH RED AND FAR-RED IN SEQUENCE ON FLOWER INITIATION OF COCKLEBUR AND SOYBEAN

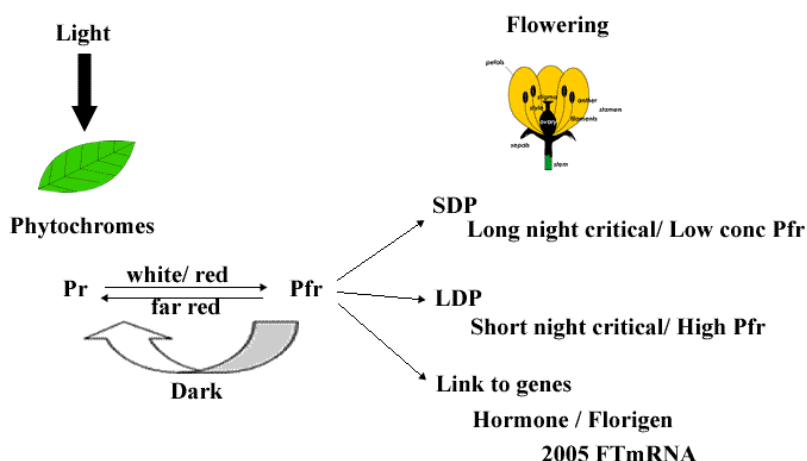
TREATMENT	MEAN STAGE OF FLORAL DEVELOPMENT IN COCKLEBUR *	MEAN NO. OF FLOWERING NODES IN BILOXI SOYBEAN **
Dark control	6.0	4.0
R	0.0	0.0
R, FR	5.6	1.6
R, FR, R	0.0	0.0
R, FR, R, FR	4.2	1.0
R, FR, R, FR, R	0.0	...
R, FR, R, FR, R, FR	2.4	0.6
R, FR, R, FR, R, FR, R	0.0	0.0
R, FR, R, FR, R, FR, R, FR	0.6	0.0

* Two min far-red from the sun. Values are for lots of 5 plants.

** Eight min of far-red from three 300-watt internal reflector flood lamps. Values are for lots of 4 plants.

According to Borthwick et al. (1952), reproduction in many plants is controlled by the length of the dark cycle and “*A dark reaction affords the measure of time and this reaction can be quickly stopped or reversed by light such as that from the rising sun.*” After reading about the **business cycle** in Arnold Tustin’s (1953), *The Mechanism of*

Economic Systems, Sterling Hendricks realized the importance of **connected linear systems that oscillate** and proposed that the pigment itself may be **photoreversible**. He also suggested



that the **dark transformation** or **reversion** of the far red-absorbing form of the pigment to the red-absorbing form of the pigment may be the **basis of the timing mechanism** that enabled photoperiodic plants to measure the length of the dark period. During the light period, the red light-absorbing form of the pigment is converted to the far red light-absorbing form and at the onset of the dark period; the pigment begins to revert to the red light-absorbing form. A flash of red light during the dark period converts the pigment to the far-red light-absorbing form and the dark period has to start again. If the dark period does not last longer than the critical dark period, no flowering occurs. On the other hand, if the red-light flash is followed by a far red light flash, the pigment reverts to the red light-absorbing form and flowering results. Whereas short-day plants (long-night plants) require a **low concentration of the far-red light-absorbing form** of the pigment to trigger the plant to flower in response to the dark period, long-day plants (short-night plants) require a **high concentration of the far red light-absorbing form** of the pigment to trigger the plant to flower in response to the dark period.

Looking back, Harry Allard (1948) realized that “*So long as there is light, terrestrial rotation, the sun, cycles of length of day will continue to operate upon plant and animal life upon the earth.*” On the other hand, the [United Nations](#) downplays the influence of astronomical factors that operate on animal and plant life, and it contends that the “[h]uman influence on the climate system is clear.”



The plant leaves sense the day length with a photoreversible photoreceptor pigment. This pigment is involved in **photoperiodism** and many other red light-stimulated **photomorphogenetic responses**. Since the pigment absorbs reddish light, it probably reflects and transmits blue light and therefore looks blue. So the members of the Beltsville group, including Warren Butler, Karl Norris, Bill

Siegelman, and Sterling Hendricks built a **special spectrophotometer** to assay the **photoreversible pigment**, and then extracted a red light-absorbing **photoreversible** blue pigment that could be transformed to a far red-absorbing greenish pigment.

Excited to show the photoreversible pigment at the Ninth International Botanical Congress in Montreal in the summer of 1959, Sterling Hendricks, Warren Butler, and Bill Siegelman drove from Beltsville, Maryland to Montreal. Every time they stopped for gas; they would check the pigment sample in the trunk. They did not realize that exposing the extracted pigment to light when they opened the trunk resulted in the conversion of the stable red light-absorbing form to the less stable far-red light-absorbing form. By the time they got to the meeting, the pigment sample had degraded, and the demonstration was a dud. The photoreversible pigment became known as “*the pigment of the imagination.*”

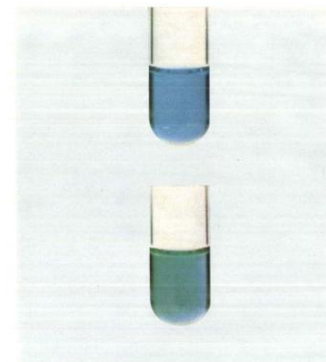
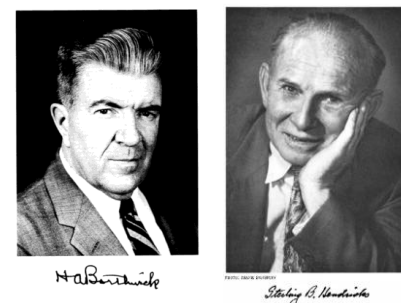


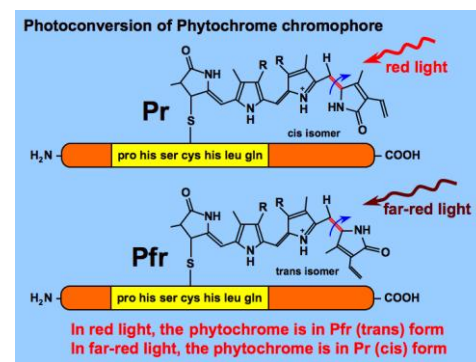
Plate 1. Photographs of highly purified large molecular weight rye phytochrome in highly concentrated aqueous solution (ca. 8 mg/ml). In the upper tube, the phytochrome is in the Pr form and thus appears blue; in the lower picture, the same tube has been irradiated with red light to convert Pr to Pfr which appears blue-green. (Photograph kindly supplied by G. Gardner of a preparation made with W. R. Briggs.)

Following the suggestion by Warren Butler to call the yet unpurified photoreversible pigment **phytochrome** from the Greek for “plant color,” **Harry Borthwick** and **Sterling Hendricks** named it in 1960. Phytochrome was finally purified in the 1980s.

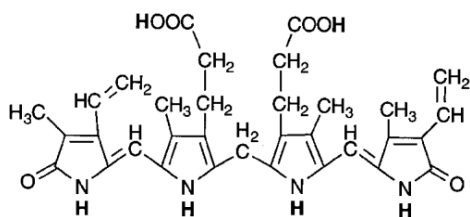
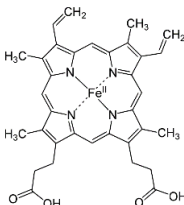
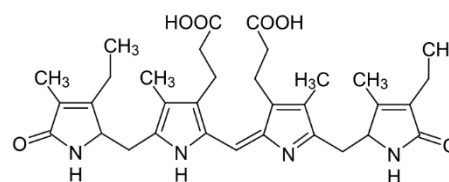
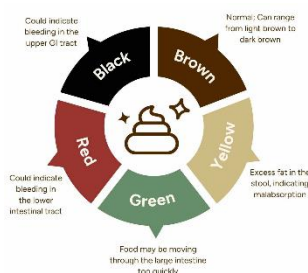
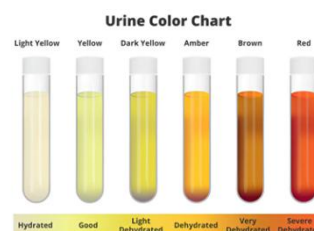


Phytochrome is a biliprotein with the following red-far red reversible structures:

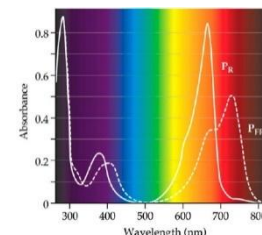
Biliprotein is named after **bilirubin** (l), which is a component of bile. Bilirubin is a breakdown product of the **heme** (c) from hemoglobin that is recycled from aged red



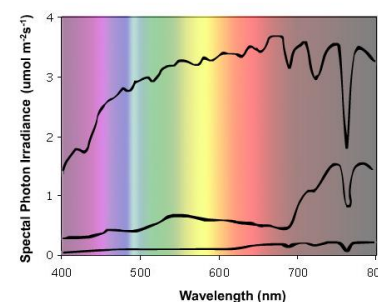
blood cells. Bilirubin gives the brown color to feces and is converted to urobilin (r) that gives urine its yellow color.



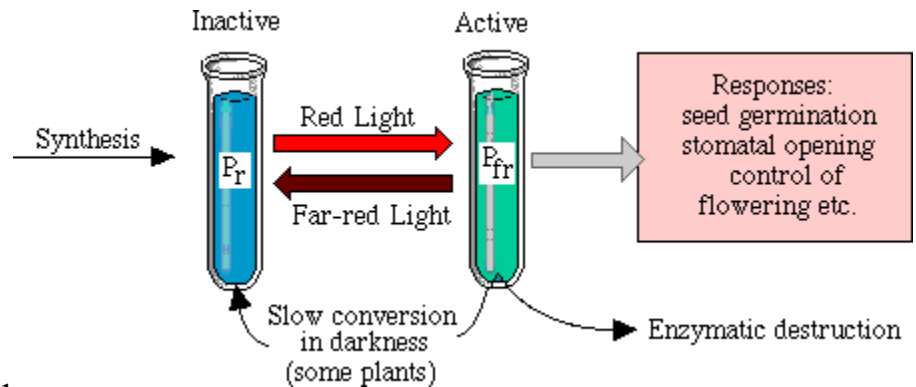
Isolated phytochrome is red-far red reversible and has **absorption spectra** that match the **action spectra** of the red-light inhibition of flowering and the far red light nullification of the red light inhibition.



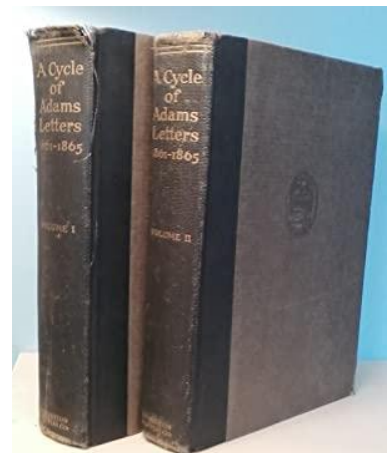
Phytochrome is involved in many other **photoresponses** in the **life cycle of plants** besides photoperiodism. These **photoresponses** include **seed germination**, the **de-etiolation response**, and the **shade-avoidance response**. The upper curve shows the spectral energy distribution of solar radiation at noon on a clear day. The ratio of red (660 nm) light to far red (730 nm) light is greater than unity. The middle curve shows the spectral energy distribution of solar radiation at noon after being filtered through a canopy of mustard seedlings. In this case the ratio of red light to far red light is less than unity. The ratio of red to far red-light inverses after the solar radiation is filtered through a canopy. Plants can sense the ratio of red light to far-red light and grow as a short sun plant or a tall shade.



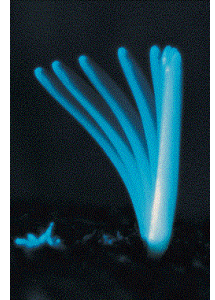
The participation of **phytochrome** in various **photoresponses** has been determined by **comparing** the **photoreversible action spectra** of these responses with the **photoreversible absorption spectra** of phytochrome. The participation of phytochrome in these responses is also determined by comparing the **photoresponses** of **phytochrome mutants** with the **wild type**.



In 1862, **Henry Adams** was thinking about the power of science to produce equity in the amount of heat and light each zone on earth received from the sun: Henry wrote from London to his brother Charles Francis Adams Jr. on April 11, 1862, *“You may think all this nonsense, but I tell you these are great times. Man has mounted science, and is now run away with. I firmly believe that before many centuries more, science will be the master of man. The engines he will have invented will be beyond his strength to control. Some day science may have the existence of mankind in its power, and the human race commit suicide by blowing up the world. Not only shall we be able to cruize in space, but I see no reason why some future generation shouldn't walk off like a beetle with the world on its back, or **give it another rotary motion so that every zone should receive in turn its due portion of heat and light. . . .**”*



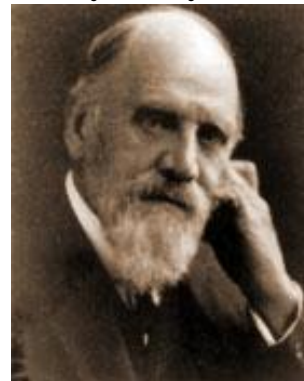
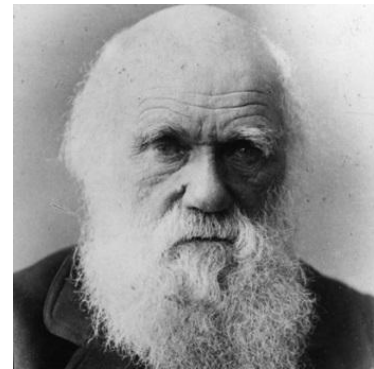
While the **photoperiodic response** helps plants to **orient in time**, the **phototropic response**, which is the **lateral bending of plants in the direction of light**, helps plants **orient in space**. Unlike the photoperiodic response, which is a response to **red light**, the phototropic response is a response to **blue light**.



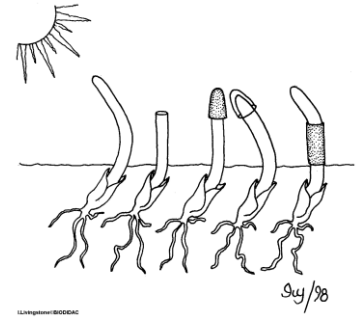
Julius von Sachs (1864) determined that phototropism is a **blue light** response by passing light through **various colored filters** and seeing which colored light caused the plants to bend.



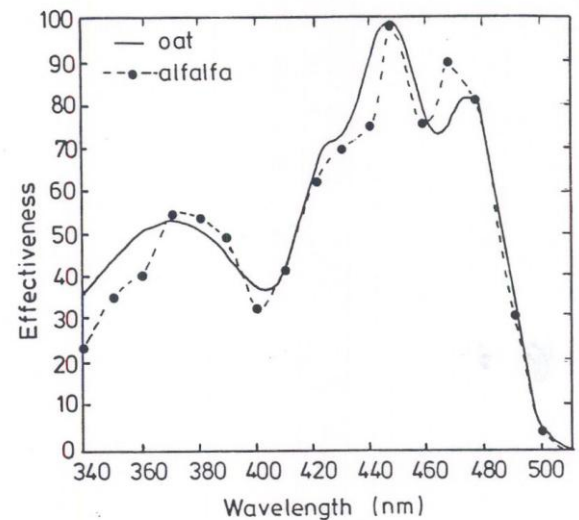
Charles Darwin (1880) and his son **Francis**, who studied *The Power of Movement in Plants*, realized that the **light acted catalytically and not as a substrate** since the light produced by the gas light, which was twelve feet from the seedlings, “*was so obscure that we could not see the seedlings themselves, nor read the large Roman figures on the white face of a watch, nor see a pencil line on paper, but could just distinguish a line made with Indian ink.*” Even when the light was so dim, the seedlings bent towards the light in three hours and the curvature occurred about an inch below the tip. Remember that in photoperiodism, light also acted **catalytically**, and a one-minute pulse of light was sufficient to determine if the plant was to be vegetative or reproductive.



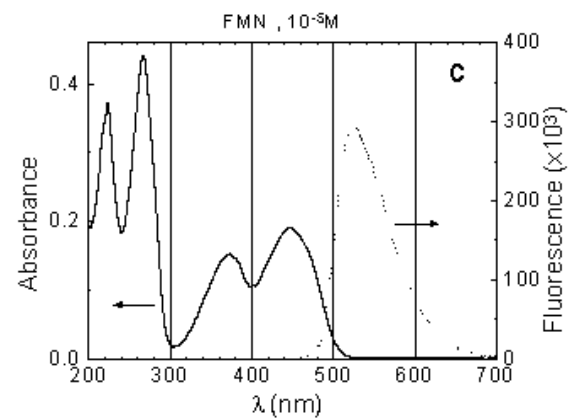
Charles and Francis Darwin determined the **site of light perception** for phototropism, by cutting off the tip, covering the tip with an opaque cap or transparent cap, or covering the middle with an opaque or transparent tube. As long as the tip was present or accessible to light, the seedling bent, indicating that the **tip of the seedling was the site of perception for phototropism**. The tip is the site of perception; it transmits a message to the middle of the seedling where the bending takes place. Remember that for photoperiodism, the leaves are the **site of perception**; they transmit a message to the buds of the plant which are the parts of the plant that flower.



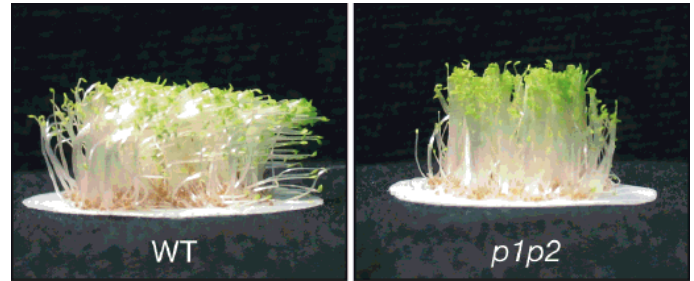
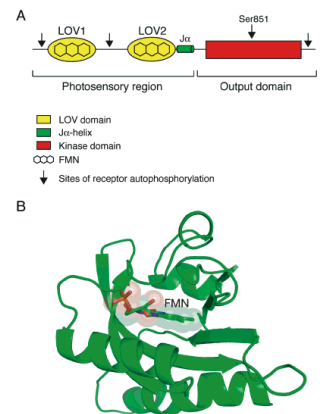
The **action spectrum** for phototropism, obtained by Kenneth Thimann and Curry (1960) shows a peak in the blue and another smaller peak in the ultraviolet region of the spectrum.



The **action spectrum** for phototropism is consistent with the **absorption spectrum** of an FMN (flavin mononucleotide)-containing flavoprotein.



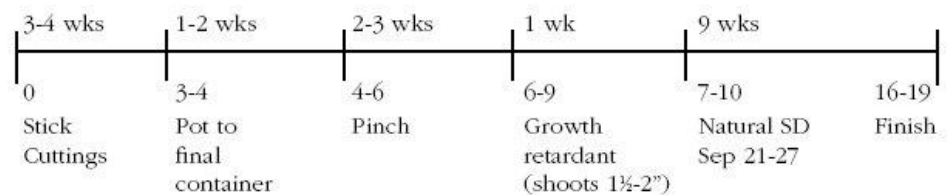
Genetic studies showed that a certain **mutant** (p1p2) that lacks a **FMN-containing flavoprotein** is unable to sense blue light whereas the wild type is phototropic and bends towards the blue light. This is strong evidence that the FMN-containing flavoprotein, now known as **phototropin**, is the photoreceptor pigment that permits plants to **orient in space**. Remember that **phytochrome** is the photoreceptor pigment that permits plants to **orient in time** with the photoperiodic response.



Photobiology is the study of the effect of light on living organisms. It is fascinating from a theoretical, experimental, and applied point of view. For example, an understanding of photoperiodism has made it possible to **force plants** to flower out of season or for a specific holiday.



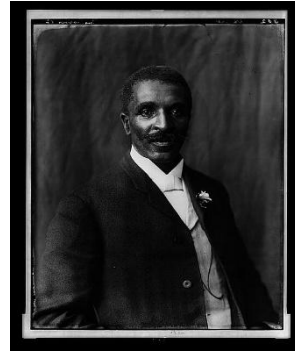
Figure 1. Scheduling Time Line for 6-inch Pinched Poinsettia



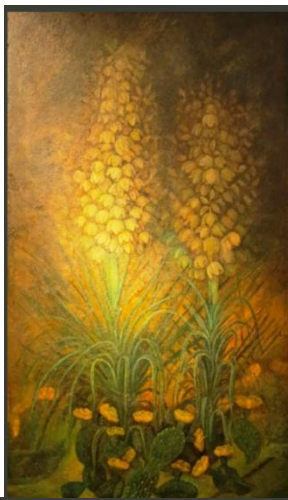
Moreover, the discovery of photoperiodism in plants has led to the understanding of the effect of seasons on reproduction and migration in animals.



George Washington Carver (1897) wrote in *Progressive Nature Studies*, “The study of Nature is both entertaining and instructive, and it is the only true method that leads up to a clear understanding of the great natural principles which surround every branch of business in which we may engage. Aside from this, it encourages investigation and stimulates originality.”



Carver was an artist, and he painted plants:

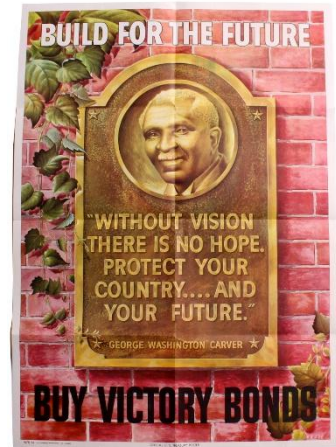


Left: George Washington Carver, *Yucca and Cactus*, ca. 1941. Oil on canvas. Above: Photo of Carver with *Yucca and Cactus*, published in *Time* magazine, November 2, 1941.



Left: George Washington Carver, *Floral still life*, nd. Oil on canvas. Right: George Washington Carver, *Illustration of root system of cow peas*, 1910. Pen and ink.

During World War I, when the German aniline dyes were no longer available to Americans, George Washington Carver developed dyes from peanuts, sweet potatoes, and Alabama clay. During World War II, he also contributed to the war effort. His image became part of the [American Innovation Dollars](#) series in 2024.



The process of becoming conscious of the environment and responding appropriately comes within a lifetime and over evolutionary time. Karl R. Popper (1972) wrote in *Objective Knowledge: An Evolutionary Approach*, “From the amoeba to Einstein, the growth of knowledge is always the same: we try to solve our problems, and to obtain, by a process of elimination, something approaching adequacy in our tentative solutions.”



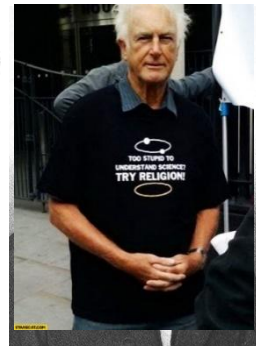
In this lecture I have been discussing the **consciousness of plants** in terms of how they sense the external world and respond in space and time appropriately to it. I started this lecture discussing the origin of consciousness in single-celled organisms such as *Euglena*. There are similarities and differences among all taxa. However, our consciousness, used in our attempt to understand truth and the **Laws**

of Nature by which the universe is governed, is so much greater than the consciousness of *Euglena*, plants, and chimpanzees.

Understanding consciousness has been a goal of scientists—scientists as Aldous Huxley (1937) noted do not speak “[f]rom the world we actually live in, the world that is given by our senses, our intuitions of beauty and goodness, our emotions and impulses, our moods and sentiments, the man of science abstracts a simplified private universe of things possessing only those qualities which used to be called ‘primary.’ Arbitrarily, because it happens to be convenient; because his methods do not allow him to deal with the immense complexity of reality, he selects from the whole of experience only those elements which can be weighed, measured, numbered, or which lend themselves in any other way to mathematical treatment.”

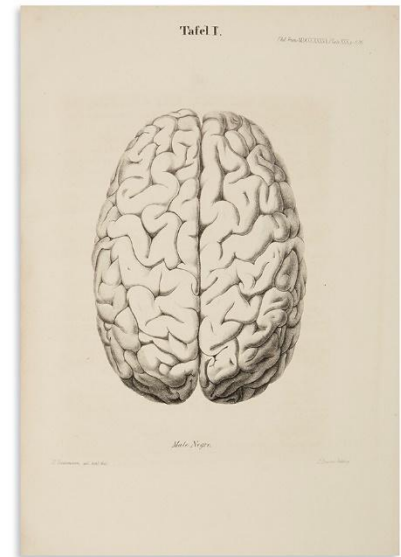
As I have told you, I am not a numerologist, when it comes to describing complex and meaningful qualities with a number, such as a GPA. Here is an historical example where the science of intelligence may not have been that intelligent.

In a paper entitled, *On the Brain of the Negro, compared with that of the European and the Orang-Outang*, **Frederick Tiedemann** (1836) began by stating the then current conclusions of science that had political and legislative implications, “*I take liberty of presenting to the Royal Society a paper on a subject which appears to me to be of great importance in the natural history, anatomy, and physiology of Man; interesting also in a political and legislative point of view. Celebrated naturalists, Camper, Soemmerring, and Cuvier, look upon the Negroes as a race inferior to the European in organization and intellectual powers, having*



much resemblance to the monkey.” It seemed like “**a belief in science,**” at the onset of Tiedemann’s anatomical work on the brain supported the institution of slavery. **A belief in science without understanding science is an a-theistic religion or scientism.**

Tiedemann did not believe in the science-based conclusions of his time. He realized that if the size of the brain was the best indicator of intelligence, then elephants would be more intelligent than human beings. He performed a study of the brain in which he took into consideration the size of the brain relative to the size of the person and drew a conclusion that was at odds with the current science and was more in line with William Wilberforce’s thinking. Tiedemann concluded, “*The brain is undoubtedly the organ of the mind. It is the part of our body which gives us the consciousness of our own existence, and through which we receive the impressions made upon the external senses, conducted to the brain by the nerves. Here the perceptions are compared and combined so as to produce ideas. In this organ, we think, reason, desire, and will. In short, the brain is the instrument by which all the operations called intellectual are carried on. It is proved by facts and observations that animals partake of feelings, sensations, and intellectual faculties in a higher degree, and approach nearly to mankind in proportion as their brain resembles more the human brain. An intimate connexion between the structure of the brain and the intellectual faculties in the animal kingdom cannot be doubted. As the facts which we have advanced plainly prove that there are no well-marked and essential differences between the brain of the Negro and European, we must conclude that no innate difference in the intellectual faculties can be admitted to exist between them. This*



*has been denied by philosophers, naturalists, and travelers, who assert that the Ethiopian race is naturally inferior to the European in intellectual and moral powers. The data upon which such an opinion is based are either **erroneous suppositions** and **false deductions** from anatomy and physiology, or **superficial observations** on the intellectual and moral faculties of the Negroes, made by partial or prejudiced travelers. Very little value can be attached to these researches, when we consider that they have been made for the most part on poor and unfortunate Negroes in the Colonies, who have been torn from their native country and their families, and carried into the West Indies, and doomed there to a perpetual slavery and hard labour in the sugar plantations. Such is the nature of the researches of Thunberg, Long, Jefferson, Estwick, Chatelux, and others. Many of them deny that the Negro is a reasonable being, and they say that all Negroes are vicious, malignant, perverse, treacherous, and faithless. They observe, that the understanding of the Negro is not capable of improvement, that their temper and disposition are incorrigible, and that they are incapable of civilization. **Some have even believed the falsely supposed natural inferiority of the intellectual and moral faculties of the Ethiopian race, to be an excuse for slavery.***

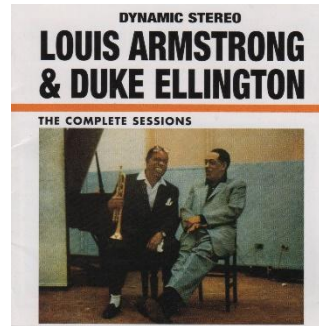
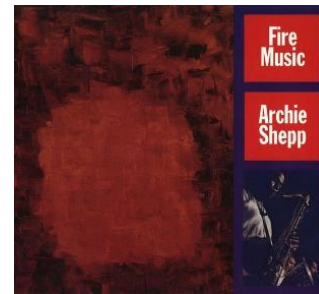
“Science” has throughout history supported racist conclusions based on anatomy, genetics, and intelligence tests. However, there have also been scientists that have fought against scientific conclusions based on erroneous suppositions, false deductions, or superficial observations. We must use our intelligence and critical thinking, not to “**believe the science**” but to **understand the science**. This is not always easy when being a believer in science gives you security in the world of the elites, and, in **Bernard Lazare**’s words, the status of a **parvenu** rather than a **pariah**, while being an understander of science gives no such guarantees.



Einstein (1954) wrote in *Essays Presented to Leo Baeck on the occasion of his eightieth birthday*, “Um ein tadelloses Mitglied einer Schafherde sein zu Können, muss man vor allem ein Schaf sen,” which means, “**To be an impeccable member of a flock of sheep, one must first of all be a sheep.**”



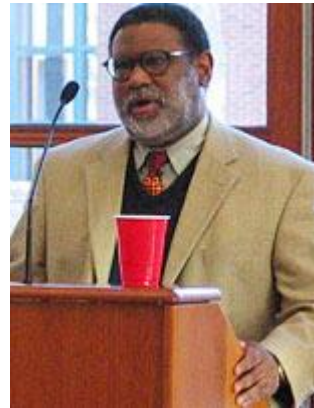
Cornel West provided examples of creative and inspiring people who even under difficult conditions were far better described as human beings than as sheep. West (1991) wrote in *Charlie Parker Didn't Give a Damn*, “**Jazz is the middle road between invisibility and anger. It is where self-confident creativity resides. Black music is paradigmatic of how black persons have best dealt with their humanity, their complexity their good and bad, negative and positive aspects, without being excessively preoccupied with whites. Duke Ellington, Louis Armstrong, and Coltrane were just being themselves.**” Another example of walking the middle road is the tenor saxophonist Archie Shepp. His 1965 album *Fire Music*, which is dedicated to Malcolm X, has the song *Malcolm, Malcolm, Semper Malcolm*, as well as *Prelude to a Kiss* by Duke Ellington. Shepp is a great example for anyone who does not aim to be an impeccable member of a flock of sheep. Indeed, jazz music itself depends on the balance between the soloist and the group, and many jazz musicians provide inspiring examples of how creative people can balance assimilation into society while maintaining cultural and personal identity.



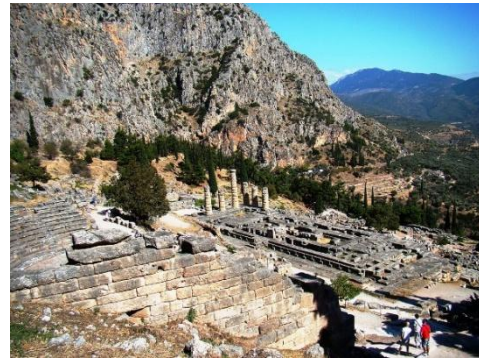
Archie Shepp was also a great and inspiring teacher to me. Here is an excerpt from an interview with him:

I leave students on their own a lot. I expect a lot from them, but I don't demand much from them. In a world like ours where more and more young people are oriented to authoritarian, submissive control, my sort of education seems disorganized and strange, peculiar. If I don't tell them what to do they don't have a damned idea in the world what to think about. And even when I tell them, they don't do it. It's not as though they do it. It's just as though they feel that the job has been done because they've been told.

Inspired by Archie Shepp, who was a professor of African-American Studies at UMass/Amherst, [John Calmore](#) (1992), a [law professor](#), wrote in *Critical Race Theory, Archie Shepp, and Fire Music: Securing an Authentic Intellectual Life in Multicultural a World*, “In the mid-1960s, Archie Shepp took his “fundamentally critical” tenor saxophone and stepped outside the **commercially laden mainstream's musical community of assumptions and voiced his dissent beyond the ways it would be tolerated within the constraints of conventional jazz**. Twenty-five or so years later, some legal scholars of color, including myself, are voicing our dissent from many of the law's underlying assumptions. It is critical race theory's basic move from bit criticism to fundamental criticism that authenticates us as intellectuals of color and legitimatizes us as exemplars of oppositional cultural practice. We are grounding critical race scholarship in a sense of reality that reflects our distinctive experiences as people of color. Race-conscious experience is a springboard from which we engage in fundamental criticism.”



I certainly believe in the concept of fundamental criticism, however, there is a difference between walking the middle road in academia and not being a sheep and walking the middle road in academia and demanding that everyone else becomes a sheep. When activism based on the foundation of postmodernism becomes so intertwined with scholarship, critical thinking is replaced by critical theory, and education is replaced by indoctrination. Human intelligence based on free will, consciousness, and conscience, is more than stimulus-response coupling. It is *different in kind* from plant intelligence, monkey intelligence, or sheep intelligence for that matter. As *Homo sapiens*, we can do what was inscribed on the Temple of Apollo, “know thyself.” Again, my view is not a fashionable view, and you are free to have your own view.



Consciousness and conscience together allow us to exercise **free will**, which I believe is a fundamental aspect of being human. According to Genesis 3, right from the beginning, human beings were endowed by the Creator with free will in terms of who we accept as knowledgeable and which stimuli we respond to: ¹ *Now the serpent was more crafty than any of the wild animals the Lord God had made. He said to the woman, “Did God really say, ‘You must not eat from any tree in the garden’?”* ² *The woman said to the serpent, “We may eat fruit from the trees in the garden,* ³ *but God did say, ‘You must not eat fruit from the tree that is in the middle of the garden, and you must not touch it, or you will die.’”*

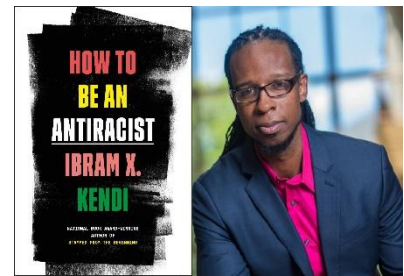
⁴ *“You will not certainly die,” the serpent said to the woman.* ⁵ *“For God knows that when you eat from it your eyes will be opened, and you will be like God, knowing good and evil.”* ⁶ *When the woman*



saw that the fruit of the tree was good for food and pleasing to the eye, and also desirable for gaining wisdom, she took some and ate it. She also gave some to her husband, who was with her, and he ate it...²² And the Lord God said, “The man has now become like one of us, knowing good and evil. He must not be allowed to reach out his hand and take also from the tree of life and eat, and live forever.”

²³ So the Lord God banished him from the Garden of Eden to work the ground from which he had been taken. ²⁴ After he drove the man out, he placed on the east side of the Garden of Eden cherubim and a flaming sword flashing back and forth to guard the way to the tree of life.

There is value in this creation story. [Ibram X. Kendi](#) (2019) wrote in *How to Be an Antiracist*, “Biological racism rests on two ideas: that the races are meaningfully different in their biology and that these differences create a hierarchy of value. I grew up believing the first idea of biological racial difference. I grew up disbelieving the second idea of biological racial hierarchy, which conflicted with the biblical creation story I’d learned through religious study, in which all humans descend from Adam and Eve. It also conflicted with the secular creed I’d been taught, the American creation story that ‘all men are created equal.’”



Kendi also rejected the value of religion in fighting racism when he learned that George Best (1578) interpreted in racial terms, the story of Noah and his son Ham, who was cursed and whose descendants were destined to be slaves.

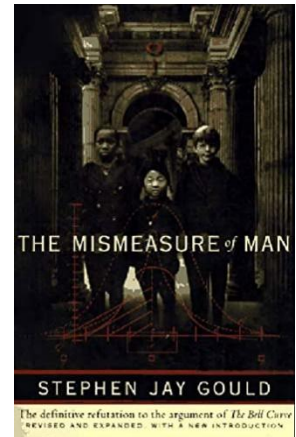
Best wrote in [A True Discourse of the Late Voyages of Discoverie](#), that Ham’s “sonne shuld be borne, whose name was Chus, who not only it selfe, but all his posteritie after him, should be so blacke &



lothsome, that it might remaine a spectacle of disobedience to all the World. And of this blacke & cursed Chus came al these blacke Moores which are in Africa.”

Kendi makes no mention of Wilberforce.

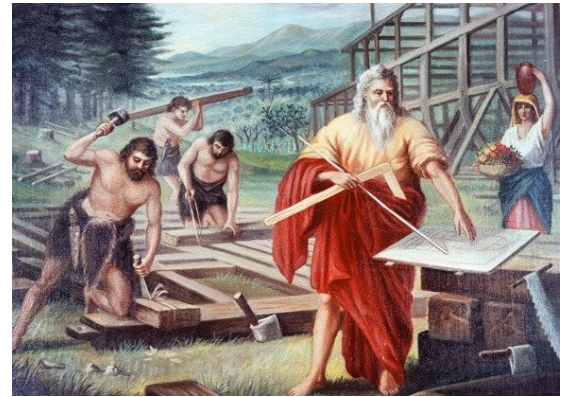
Aside: While the acceptance or rejection of slavery is a condition of the heart, both science and religion weigh in on the issue. Louis Agassiz, Samuel George Morton, and [Josiah Nott](#) were 19th Century biologists who believed that each race had a separate origin. Their work is well described in Stephen Jay Gould’s book, [The Mismeasure of Man](#). Gould (1996) writes, “Nonetheless, the polygenist argument did not occupy a primary place in the ideology of slavery in mid-nineteenth-century America—and for a good reason. For most Southerners, this excellent argument entailed too high a price. The polygenists had railed against ideologues as barriers to their pure search for truth, but their targets were parsons more often than abolitionists. Their theory, in asserting a plurality of human creations, contradicted the doctrine of a single Adam and contravened the literal truth of scripture. Although the leading polygenists held a diversity of religious attitudes, none were atheists. Morton and Agassiz were conventionally devout, but they did believe that both science and religion would be aided if untrained parsons kept their noses out of scientific issues and stopped proffering the Bible as a document to settle debates in natural history. Josiah Nott stated his goal in a forceful way (Agassiz and Morton would not have put it so baldly): ‘... to cut loose the natural history of mankind from the Bible, and to place each upon its own foundation, where it may remain without collision or molestation’ (in Stanton, 1860, p. 119).



The polygenists forced defenders of slavery into a quandary: Should they accept a strong argument from science at the cost of limiting religion's sphere? In

resolving this dilemma, the Bible usually won. After all, scriptural arguments for supporting slavery were not wanting. Degeneration of blacks under the curse of Ham was an old and eminently functional standby. Moreover, polygeny was not the only quasi-scientific defense available.”

Aside: While we are talking about Noah, I want to mention a description of him given in Genesis 6:9 that relates to how we may want to judge the actions of historic characters: *Noah was a righteous man, blameless among the people of his time, and he walked faithfully with God.* Note that his blamelessness was considered relative to the people of *his* time, not the present time.



What do you do when the authorities disagree with your own intelligence?
What do you do when you think that “*skin color is as meaningless to our underlying humanity as the clothes we wear over that skin...[and t]o be a antiracist is to also recognize the living, breathing reality of the racial mirage, which makes our skin colors more meaningful than our individuality?*” According to Kendi, a professor of history at Boston University, “[r]acist ideas are not natural to the human mind.” Kendi realized that “*marginalization in academic thought did not mean marginalization in common thought, including the kind of common thinking that surrounded me as a child.*”

Remember that science, from *scientia*, the Latin word for knowledge, provides valuable yet incomplete information about the objective world. The motto of the Royal Society is *Nullius in verba*—take no one’s word for it. If you believe that you have free will, nobody can tell you what to think—whether the authority is science, religion, or critical theory. If you believe that there is a Truth, even though you cannot know the whole truth—then nobody can make you accept their definition of truth without your consent. Authenticity is also key. You are an authentic human being when your actions are congruent with your beliefs, despite external pressures to conform.

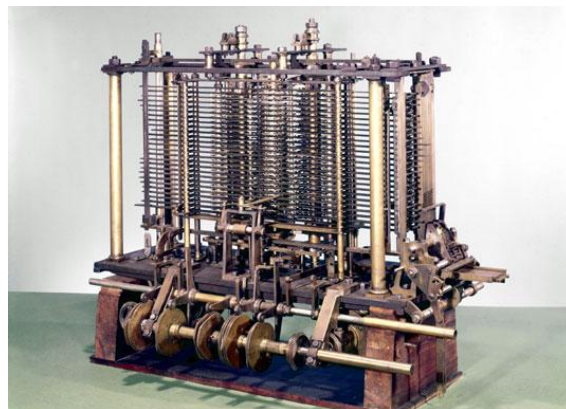
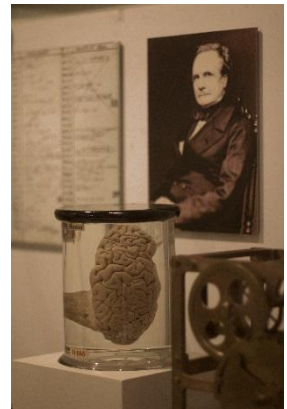


William Whewell (1837) ended his *History of the Inductive Sciences* like so “*The real philosopher, who knows that all the kinds of truth are intimately connected, and that all the best hopes and encouragements which are granted to our nature must be consistent with truth, will be satisfied and confirmed, rather than surprised and disturbed, thus to find the natural sciences leading him to the borders of a higher region. To him it will appear natural and reasonable, that, after journeying so long among the beautiful and orderly laws by which the universe is governed we find ourselves at last approaching to a source of order and law, and intellectual beauty:--that, after venturing into the region of life and feeling and will, we are led to believe the fountain of life and will, not to be itself unintelligent and dead, but to be a living mind, a power which aims as well as acts. To us this doctrine appears like the natural cadence of the tones to which we have so long been listening; and without such a final strain our ears would have been left craving and unsatisfied. We have been lingering long amid the harmonies of law and symmetry, constancy and development; and*



these notes, through their music was sweet and deep, must too often have sounded to the ear of our moral nature, as vague and unmeaning melodies, floating in the air around us, but conveying no definite thought, moulded into no intelligible announcement. But one passage which we have again and again caught by snatches, though sometimes interrupted and lost, at last swells in our ears full, clear, and decided; and the religious ‘Hymn in honour of the Creator,’ to which Galen so gladly lent his voice, and in which the best physiologists of succeeding times have ever joined, is filled into a richer and deeper harmony by the greatest philosophers of these later days, and will roll on hereafter, the ‘perpetual song’ of the temple of science.”

Charles Babbage (1838),
inventor of the mechanical
computer, responded to
Whewell’s claim that “*We may
thus, with the greatest propriety,
deny to the mechanical
philosophers and mathematicians*



of recent times any authority with regard to their views of the administration of the universe; we have no reason whatever to expect from their speculations any help, when we ascend to the first cause and supreme ruler of the universe. But we might perhaps go farther, and assert that they are in some respects less likely than men employed in other pursuits, to make any clear advance towards such a subject of speculation” by producing *A Fragment*, the Ninth and unauthorized Bridgewater Treatise. In the second edition, Babbage described the power of mathematics in understanding the Creator:

*“First, The truths of pure mathematics are **necessary truths**; they are of such a nature, that to suppose the reverse, involves a contradiction.*

*Secondly, **The laws of nature**, on which physical reasonings are founded, although some of them are considered as necessary truths, depend, in many instances, on the testimony of our senses. These derive their highest confirmation from the aid of pure mathematics, by which innumerable consequences, previously unobserved, are proved to result from them.*

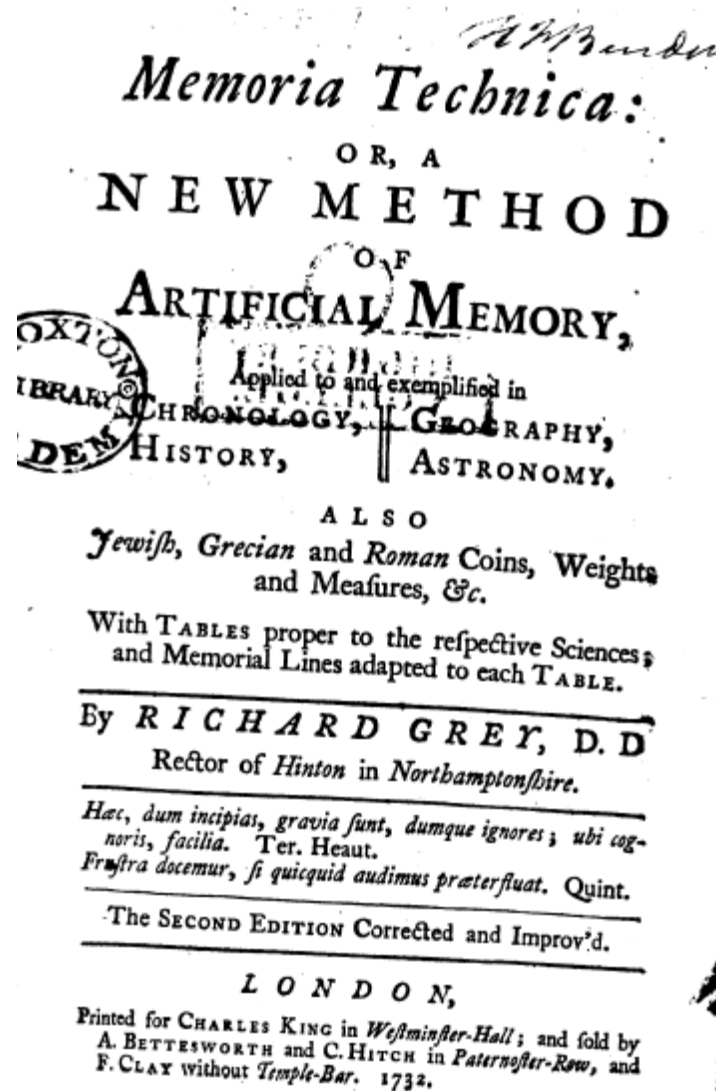
Thirdly, The truths of natural religion rest also on the testimony of our external senses, but united with that internal consciousness of intention or design which we experience in our own breast, and from which we infer similar powers in other beings. Many of the facts on which the conclusions of natural religion are founded, derive their chief importance from the aid supplied by the united power of the two former classes, and the amount and value of this support will be enlarged with the advance of those sciences.

Fourthly, Revealed religion rests on human testimony; and on that alone. Its first and greatest support arises from natural religion. I have endeavoured in one chapter of the present volume to show, that, notwithstanding the weakening effect of transmission upon testimony, a time may arrive when, by the progress of knowledge, internal evidence of the truth of revelation may start into existence with all the force that can be derived from the testimony of the senses.

The first class of truths then (those of Pure Mathematics) appears to rest on necessity. The second, (the Laws of Nature,) on necessity and our external senses. The third, (those of Natural Religion,) on our external senses and internal consciousness. The last, (those of Revelation,) on human testimony. If they admit of any classification, as subjects having a common resemblance, or as possessing different degrees of evidence, I have placed them in the only order which, in my

opinion, is consistent with truth; convinced that it is more injurious to religion to overrate, than to undervalue the cogency of the evidence on which it rests.”

Having trouble with remembering things? We can learn from the plants. In this lecture I have shown you that **plants have a real notion of time and place**. Richard Grey (1732) wrote in the second edition of *Memoria Technica: or, a New Method of Artificial Memory, Applied to and exemplified in Chronology, Geography, History, Astronomy, Also Jewish, Grecian and Roman Coins, Weights and Measures, &c.*, “I believe it will be agreed on all Hands, that, to instance in History only, **a Man who has an exact Notion of Time and Place**, finds incomparably more Pleasure, and make a speedier Progress in that Study, than he who has not.”



Plants have the ability to count. Watch this video.

Greg Gage

|

TED2017

Electrical experiments with plants that count and communicate

https://www.ted.com/talks/greg_gage_electrical_experiments_with_plants_that_count_and_communicate/discussion#t-4335

While we are talking about plants, I would be remiss not to mention the “roots” and “shoots” of oppression:



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Feds spend \$2.1M in taxpayer dollars to ‘root’ out oppression in plant sciences

DANIEL NUCCIO - NORTHERN ILLINOIS UNIVERSITY · MARCH 3, 2022

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‘We will get to the root of the systematic oppressions ... so that they can regrow as truly inclusive spaces’

The federal government has allocated \$2.14 million dollars to “root” out oppression in plant sciences.



The National Science Foundation’s Directorate for Biological Sciences recently **awarded** \$2.14 million to the American Society of Plant Biologists for the development of a multi-organization research coordination network called ROOT and SHOOT.

ROOT stands for Rooting Out Oppression Together. And SHOOT? SHaring Our Outcomes Transparently.

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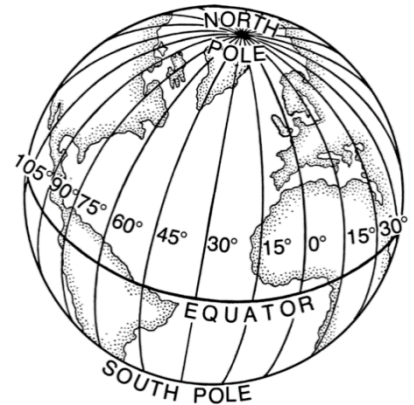
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Melanopsin, Circadian Rhythms, and Wellness in Humans

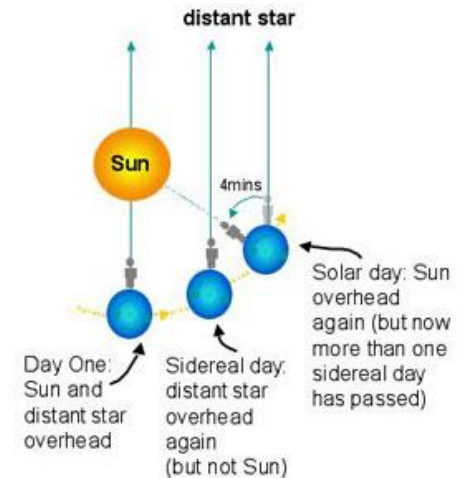
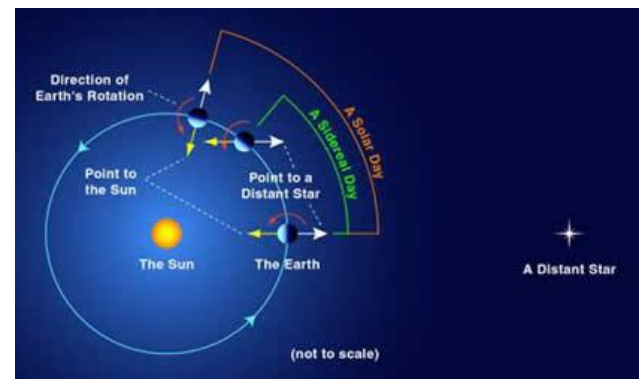
Living organisms from wildflowers to whales have **internal or endogenous biological clocks** that are normally synchronized with **the daily rotation of the earth upon its axis** that runs from the North Pole to the South Pole. The earth spins counterclockwise as viewed from the North Pole (and clockwise as viewed from the South Pole). Consequently, no matter which latitude one resides and how long the photoperiod is, the sun *appears* to rise in the east and set in the west.



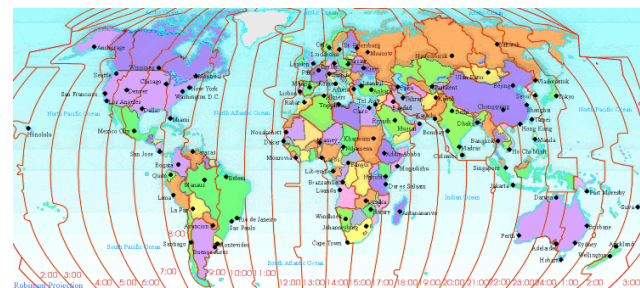
Photograph by George Rankin of the sun rise and set in the Arctic in January. Five exposures taken 1h apart.

Experience the rotation of the earth through **time-lapse photography** by Shane Black <https://www.youtube.com/watch?v=9d8wWcJLnFI>, Michael Shainblum <https://www.youtube.com/watch?v=vLUNWYt3q1w>, Andrew Arthur Breese <https://www.youtube.com/watch?v=R5LRpH62mss>, Anna Possberg <https://www.youtube.com/watch?v=8GpDXV9BfLU>, Harley Grady <https://www.youtube.com/watch?v=nam90gorcPs>, and Dimitry Pisank <https://www.theguardian.com/science/video/2015/jun/23/earth-international-space-station-timelapse-video>

The period of earth's rotation, which is known as the **solar day**, is the time it takes for the sun to appear directly overhead at two successive noons. The solar day is approximately 24 hours. Because the earth **orbits** around the sun as it **rotates**, the solar day is actually a little longer than the actual rotation period of the earth, which is known as the **sidereal day**. Because the speed of the earth as it orbits the sun is not constant but faster at **perihelion** ($r = r_{min}$) than that **aphelion** ($r = r_{max}$), the average speed of the earth around the average position of the sun is used to determine the solar day. The **sidereal day**, which is 23 hours and 56 minutes, is the time it takes for the distant stars to appear in the same position. The four minute difference between a solar day and **sidereal day** means that a viewer will see the same stars “rise” above the horizon four minutes earlier each **solar day**.



Before the widespread use of railroad trains in the 1840's, each community had its own **local time**, where twelve o'clock noon on each day was defined as the time when the sun was at its **zenith** or highest point in the sky. However, when it became crucial to coordinate train schedules to minimize train crashes on single train tracks, **standard time zones** were created that closely aligned to lines of longitude separated by 10° and **Greenwich England**, where the famous observatory was that provided maps for navigation, became the **prime meridian**.



Here is a picture of my brother Scott standing on the prime meridian.



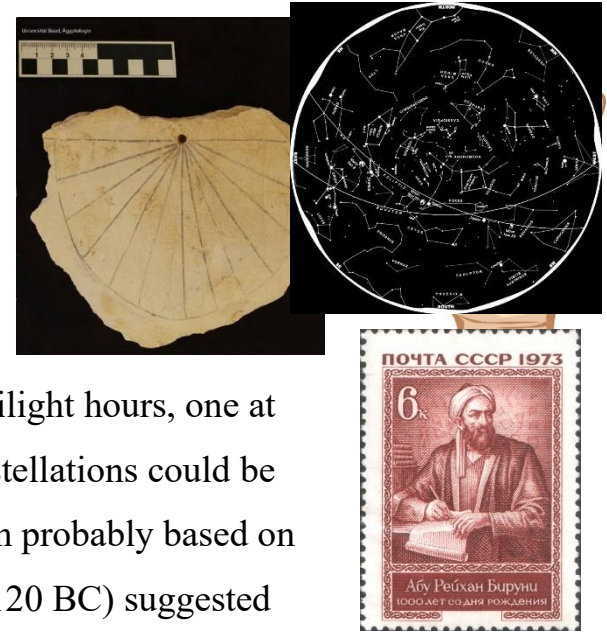
In 1918, the Standard Time Act became law in the U. S. The Official U. S. time can be found at <http://www.time.gov/>.

Currencies, temperature, lengths, mass, and even library books have been decimalized (Vera, 2009). Have you ever wondered why we never hear of **decimal time**? Decimal time was originally proposed by D'Alembert in 1754. On October 5, 1793, during the **French Revolution**. Year one was set to be nearly a year before (September 22, 1792), when the National Convention had proclaimed France a republic. [Decimal time](#) was introduced to deChristianize the calendar and to remove the 7 in the number of days in a week. The overall goal of decimalization was to decimalize everything that could be measured. With decimal time, each day was divided into ten hours, each hour was divided into 100 minutes, and each minute was divided into 100 seconds. Decimal¹ time was never popular and was abandoned on April 7, 1795, the same day that the decimal system for length, volume, and mass began. At this time, the meter was defined as one ten millionth of the distance between the North Pole and the Equator along the line of longitude passing through Paris, and the gram was defined as the mass of a cubic centimeter of water. See the current time in decimal time at <http://minkukel.com/scripts/metric-clock/>.

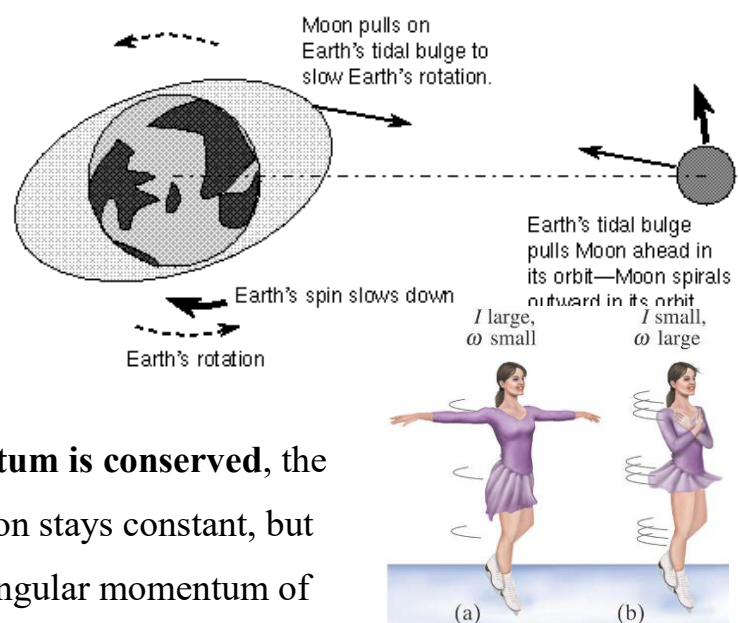


¹ The word decimation comes from the Roman times when one out of ten soldiers of an army were executed as a punishment for its cowardice.

The oldest known **sundial** was found in Egypt's Valley of the Kings, and it dates from 1500 BC. We got the 24-hour day from the ancient Egyptians (2100 BC), who divided the day into 24 hours: 10 hours of daylight (when sundials could be used to tell time), 12 hours of nighttime (when constellations could be used to tell time), and two twilight hours, one at dawn and one at dusk (when neither sundial nor constellations could be used to tell time). The hours were of unequal duration probably based on different seasonal hours of light. **Hipparchus** (190–120 BC) suggested that a day be divided into twenty-four hours, based on the measurable twelve hours of daylight and twelve hours of darkness observed on **equinox** days. According to C. Edward Sachau (1879) who translated *The Chronology of Ancient Nations*, Al-Biruni (1000), a Persian (Iranian) polymath, divided the hour into 60 minutes and the minute into 60 seconds.

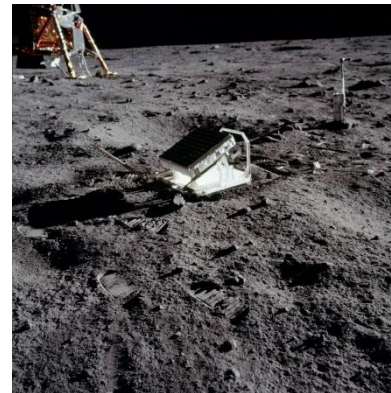


The **day length** on earth has *not* been constant over geological time because the daily period of rotation of the earth has not been constant. The length of the day has grown longer by **2 seconds per 100,000 years** as a consequence of the **tidal friction** between the earth and the moon. Overall, because **angular momentum is conserved**, the total angular momentum of the earth and moon stays constant, but the tidal friction results in a decrease in the angular momentum of



the earth and an increase in the angular momentum of the moon. The decrease in the angular momentum of the earth, means that the earth rotates more slowly on its axis and the increase in the angular momentum of the moon means that the moon orbits the earth more slowly now than it did in the past and its distance from the earth continues to increase.

The increase in the length of the period of the earth's daily rotation is supported by diverse observations. For example, **historical records of solar eclipses over China**, from which the orbits of the sun and moon have been calculated, indicate that if the period of the earth's daily rotation were not increasing, then the reported shadows produced by the eclipsed sun would not be where they were recorded to be. Moreover, the moon's orbital radius as determined by the amount of time it takes laser light to travel from the earth to the **retro-reflector arrays placed on the moon** by Apollo 11, Apollo 14, Apollo 15, and Lunakhod 2, and back to earth again, has increased by 3.82 cm/year. This is consistent with the decrease in the daily period of rotation of the earth as a result of the transfer of angular momentum from the earth's rotation to the moon's orbital motion (Dickey et al., 1994). The increase in the moon's orbital radius also results in an increase in the period of the lunar month (Runcorn, 1966).



John Wells (1963), a geology professor at Cornell, used the relationship between light and life to discover the day length on earth hundreds of millions of years ago. Wells looked at **fossil corals** from the **Middle Devonian** (387 million years ago based on **radiometric dating**) and **Pennsylvanian** (307 million years ago based on **radiometric dating**) collected near Cornell University. The fossil corals show both **annual growth rings due to seasonal changes in temperature** and **daily growth rings due to the diurnal incorporation of calcium carbonate**.

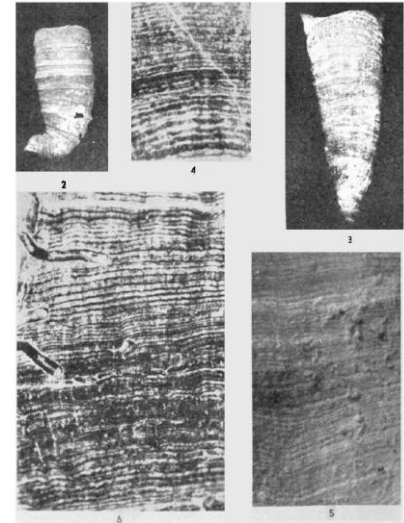
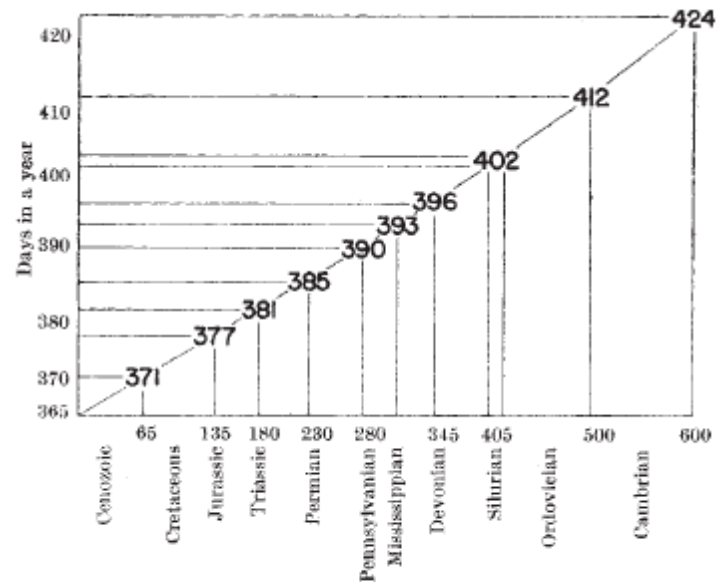


Fig. 2. *Heliophidium* halli, Middle Devonian, western New York, showing 19 annual growth increments ($\times \approx 9.5$). Fig. 3 and 4. *Heliophidium calceolatus*, Lower Silurian, Gotland: (3) corallum about 240 days old showing growth lines on epitheca ($\times \approx 2.7$); (4) growth lines on epitheca ($\times \approx 12$). Fig. 5. *Meristina arctica*, Recent, Dry Tortugas, Florida; growth lines on epitheca ($\times \approx 40$). Fig. 6. *Brachidolites arctica*, Middle Devonian, western New York; growth lines on epitheca ($\times \approx 21$).

The fossil corals from the Middle Devonian had more daily growth rings than the fossil corals from the Pennsylvanian that had more daily growth rings than the corals from the present. Wells (1963) concluded that there were about 400 days per year in the **Middle Devonian** about 387 days per year in the **Pennsylvanian** and about 365 days per year in the present.



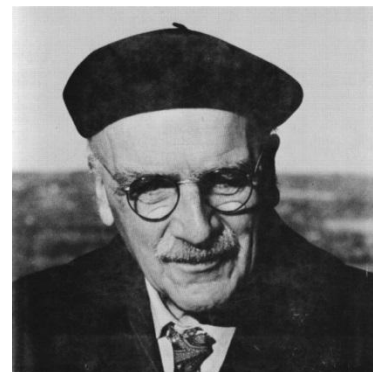
Geological time: millions of years (Kulp, 1961)
Fig. 1. Relation between days in each year and geological time (radioactive age data from Kulp, 1961)

By assuming that the period of the earth's orbit ($t = \frac{2\pi r\sqrt{r}}{\sqrt{GM_{sun}}}$ from Newton's law

of gravitation) around the sun has been constant, Wells calculated the period of the daily rotation of the earth in various geological periods. He calculated that the

daily rotation of the earth took about 21.9 hours in the **Middle Devonian**, 22.6 hours in the **Pennsylvanian**, and increased to its present value of about 24 hours.

In an article published in the *New York Times* on April 19, 1964, **John Burdon Sanderson Haldane** singled out John Wells as someone who could make great scientific strides with next to no money by using his visual system (eyes and mind) and a ten-dollar hand lens to measure the number of fifty micrometer daily growth rings in an annular ring. Haldane wrote, “*Professor Wells of Cornell University also has this quality. He collects ancient and modern coral. Those which grow in seas where the temperature varies much with the seasons often show annual growth rings like trees. Wells found that some also show daily ridges of growth, which can be counted with a good hand lens costing perhaps \$10. Modern corals show about 365 ridges a year....Silurian corals show about 400 rings a year. As the year has probably changed little, therefore the days have been getting longer. (They are getting longer, as we know, from records of ancient eclipses, among other evidence. This is thought to be due to the braking action of the tides, both in the sea and in the earth, which is not quite rigid.) Ask anyone who does not know the answer how much the apparatus cost which proved that the number of days in the year has increased [sic; he meant decreased] by 35 in 350 million years and he will probably guess at \$10 million or so.*”



A more recent analysis of the laminated tidal sediments from the **Precambrian** indicates that **900 million years ago**, the length of a day on earth was approximately **18.2 hours** (Sonnett et al., 1996).

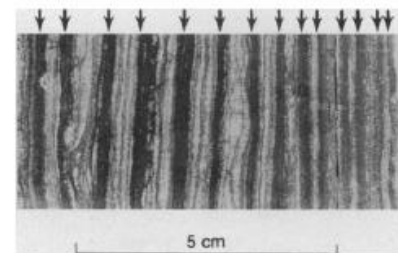


Fig. 1. Photograph of polished core of BCC tidalites. Laminae of coarse silt to fine-grained sand were transported only during the strongest spring tides. The thick dark bands (arrows) correspond to neap-tide deposition of fine-grained mud.

Now that we have a sense of the **astronomical** or environmental **clock**, independent of and **external** to our bodies, we will talk about the **endogenous biological clock** in plants, humans, and other mammals.

Like the accurate **chronometer** designed in the first half of the 18th century by **John Harrison** to determine **longitude**, biological clocks are relatively **temperature insensitive**. The daily **entraining** or **synchronizing** event (time-giver or *zeitgeber* in German) is a result of the **daily light-dark transition** that takes place everywhere on the surface of the earth except at the poles at certain times of the year.



The **entrainment** of biological rhythms with the rotation of the earth was first noticed by observing plants. As he trekked across the known world in the fourth century BC, **Alexander the Great**, a student of Aristotle, was interested in the influence of climate on the variety of plants he saw. While on the Island of Tylos (Bahrain), one of Alexander's admirals, Androstenes of Thasos, noticed that the leaflets of the **tamarind** showed sleep movements (*Botanische Forschungen des Alexanderszuges* by Bretzl, 1903). Theophrastus wrote about Androstenes' observations in his *Historia Plantarum*: The tamarind was "another tree with many leaves...that closes at night, but opens at sunrise,



and by noon is completely unfolded; and at evening—again it closes by degrees and remains shut at night, and the natives say it goes to sleep.”

That is, the leaflets opened during the day and closed at night. In 1729, the astronomer **Jean-**

Jacques d’Ortous de Mairan, who studied the **Northern Lights**,

also noticed this sleep behavior in the sensitive plant (*Mimosa*).

He put the plants in constant darkness and noticed that the cyclic behavior persisted as if the plants could sense the sun without seeing it. In 1758 **Henri-Louis Duhamel du Monceau** put a

Mimosa plant under a blanket and put it in a leather trunk in a

wine cellar. The *Mimosa* continued its rhythmic leaflet movements indicating that

the movements were independent of light and temperature changes. **Johann**

Gottfried Zinn (1759) put bean (*Phaseolus*) plants in the dark and also saw that their rhythmic leaf movements occurred independently of light and temperature

changes. In their book *The Power of Movement in Plants*, Charles and Francis

Darwin (1880) reported their observations on many genera that show sleep movements.

In 1832, **Augustin Pyramus de Candolle** (who saw nature as being at war)

expanded on the previous work by measuring the **period** of *Mimosa* leaflet

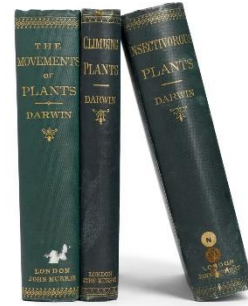
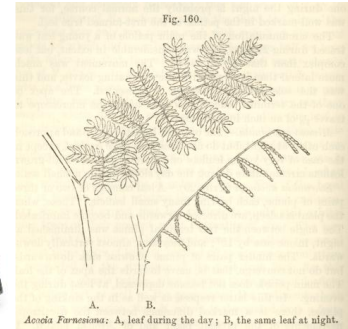
movements in the dark. He found the period to be 22–23 hours long. **Svante**

Arrhenius (1898) suggested that atmospheric electricity triggered the movements.

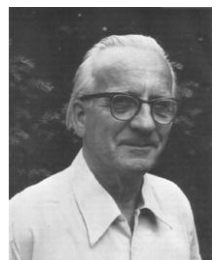
While testing Arrhenius’ suggestion that atmospheric electricity triggered leaflet movements by adding charged particles or removing charged particle

from the air, **Erwin Bünning** found that light was the factor that

synchronized leaf movement in beans (*Phaseolus*). He also found that the



John Z. Bünning



period of rhythmic movement was temperature-insensitive—just like the chronometer designed by John Harrison. Soon research began on biological rhythms in animals. Measurements of biological rhythms with high temporal resolution provided evidence that the rhythms were less than 24 hours. These experiments supported the controversial and seemingly parapsychological and metaphysical idea at the time that the period of the rhythms was not based on 24 hour changes in the **exogenous physical cues** coming from the rotation of the earth as promoted by Frank A. Brown Jr. but on an **endogenous clock** promoted by Colin Pittendrigh. Bünning (1958) wrote a book about biological rhythms called *The Physiological Clock*.

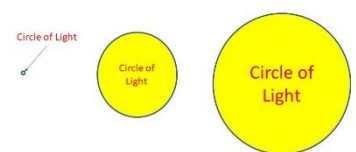
Aside: In his autobiography, Bünning (1977) wrote “*According to a long-lasting tradition in my country, every well-educated man was expected to have and to passionately defend his own ‘Weltanschauung.’ This word cannot be translated by ‘conception of the world’ or ‘world outlook.’ ‘Weltanschauung’ means to combine everything from science, religion, politics, social life, etc into one whole concept.*

This explains why in my country, even though people are not as hot-blooded as many other nationalities, extreme positions in science or politics are often defended with fanatic obstinacy.”

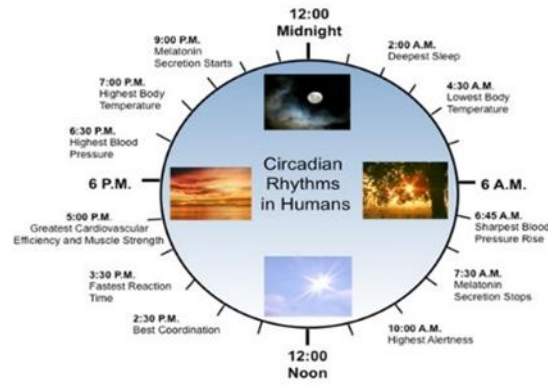
Bünning also wrote that “*certain people have a horizon with the radius $r = 0$, and this is what they call their standpoint.”*

Interestingly, Bünning’s description is an apt way of describing postmodernist **standpoint theory**, where each person has their own truth.

What is the radius of your point of view?



Studies of biological rhythms showed that in the absence of environmental cues, the biological clock is no longer synchronized with the daily light-dark period, however, the **free running** biological clock still runs with a **circadian rhythm**

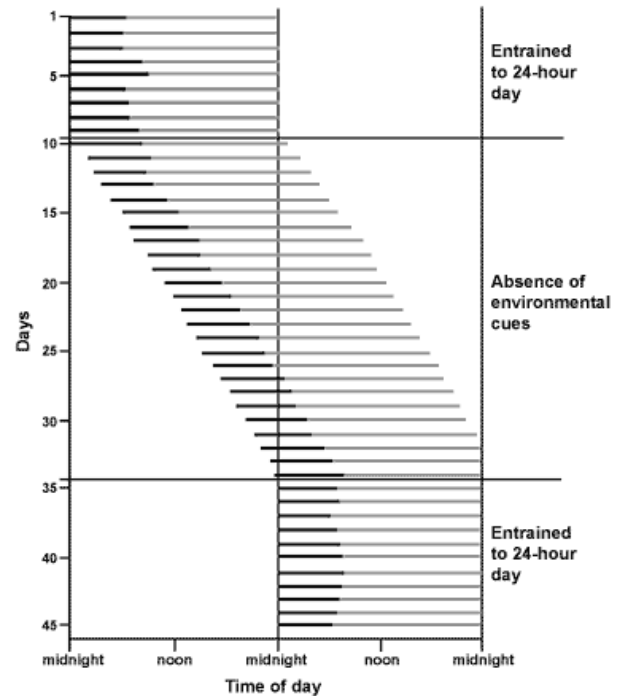


that is about or “*circa*” in Latin a day or “*dies*” in Latin. With the help of William McDonald, a professor of Classics, who was known to say that lectures were “*a means of getting information from a professor’s notes to the students’ notes without going through the heads of either,*” the word **circadian** was coined by **Franz Halberg** in 1959. The study of biological rhythms in plants set the stage for the study of biological rhythms in humans—just in time for the cold war.

While we will only discuss circadian rhythms today, remember that living organisms also exhibit **monthly** (lunar), **annual**, or **seasonal** (solar) rhythms. In addition, animals that live in tidal zones have a **tidal** rhythm.

The figure below depicts the circadian **sleep-wake cycle** of one individual person. The black lines represent the periods in which the person slept, and the gray lines represent the periods in which the person was awake. During regular

time periods of light and darkness, the sleep-wake cycle was **entrained** to a period of 24 hours. However, on days 10 through 34, when the person was isolated from any environmental cues or *zeitgeber*, the person went to sleep one hour later each day and after 24 days, the person was again going to bed at midnight. While the sleep-wake cycle continued to oscillate in the absence of environmental cues, indicating that the sleep-wake cycle rhythm is **endogenous**, the period of the endogenous rhythm was greater than 24 hours. On day 35, when the person was subjected again to the *zeitgeber* or **normal environmental cues**, the sleep-wake cycle became **entrained** and **synchronous with the daily rotation of the earth**.



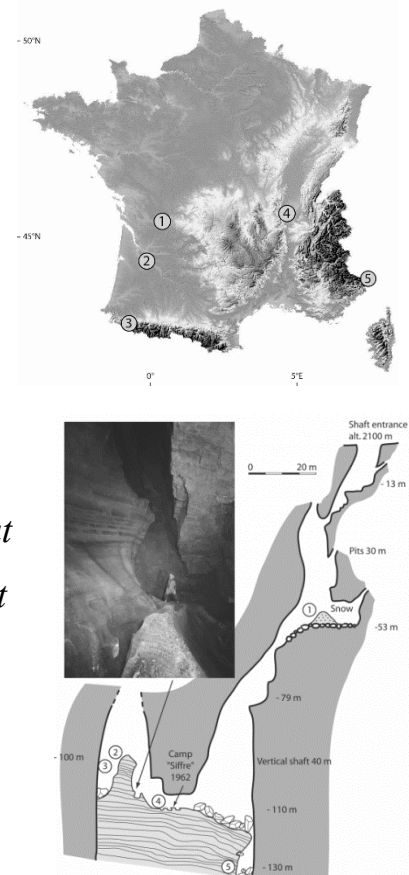
Determining the natural free-running period of the biological clock in humans began following the **Cuban Missile Crisis** in October 1962, when it seemed like people might have to live in isolation in space capsules and nuclear submarines or in underground bunkers or deep subterranean caves for a period of time during and after a nuclear war. It was discovered that the **natural, free-running period of the biological clock** of humans in **underground bunkers** or **deep subterranean caves**, where they were *not* exposed to the *zeitgeber* or **environmental cues** that **cause an entrainment or synchronization of the endogenous biological clock with the daily rotation of the earth**, is slightly *greater than* 24 h.



Aside: Due to the threat of nuclear war, private art collectors [Sterling and Francine Clark](#) decided that their art was no longer safe in Manhattan. They relocated their art to rural and isolated Williamstown, Massachusetts and founded the Clark Art Institute.



[Michael Siffre](#) loved geology, speleology, philosophy, and had a desire to investigate the mental and physical limits of human beings and our adaptive power by living for two months in **Scarasson Cavern**, which is located in the Provence-Alpes-Côte d'Azur in the southeast corner of France. In the cave, which was formed by water charged with carbonic acid (H_2CO_3) inside a subterranean glacier 375 feet underground, he was “*deprived of any points of reference in time and space.*” Siffre (1964) wrote, “*Living underground for a protracted period would mean being shut off from the daily cycle: there would be no setting sun to tell me that night was approaching. I wondered to what extent the cosmic phenomena of night and day controlled our periods of sleep and activity. In short, I wanted to investigate time—the most inapprehensible and irreversible thing. I wanted to investigate that*



*notion of time which has haunted humanity since its beginning. Perhaps time existed on three levels: that which is perceived, created by the brain, the result of conditioning to the twenty-four-hour cycle of night and day; biological time—a rhythm of activity-repose set up in the organism through the years; and objective time, measured by clocks.” Siffre found that his **biological clock** continued to work in the absence of environmental cues, but psychologically, he broke down and became depressed.*

Michael Siffre ended his book, *Beyond Time* with the following advice: “As to what I learned personally from my experience, I can only repeat that if I survived the difficult conditions in which I voluntarily placed myself, it was mainly due to my **will power**, my passionate resolve to see the thing through, and not disappoint my collaborators not lose my self-respect. I was not out to break a record; it was not a physical exploit that I intended to bring off; it was an experiment with scientific aims that I wanted and was determined to perform, come what may. Years ago an American classmate ironically repeated a folk saying that children two generations ago were made to copy in their exercise books: ‘**Where there’s a will, there’s a way.**’ I memorized it, for I sensed behind the words age-long experience. In my case, that simple truth was certainly proved more than once. And if other young fellows plan to embark upon an adventure such as mine, I can only advise them—at the risk of sounding like an old fogey—to school themselves daily in self control, which is a form of will power. Will power plays a part as important as, if not more important than, the careful choice of equipment and a rigorous course in physical training. I would tell young aspirants that, armed with this weapon, you can do a great deal; you can do anything.”

Where There's a Will There's a Way by John Godfrey Saxe

*Is Learning your ambition?
There is no royal road;
Alike the peer and peasant
Must climb to her abode:
Who feels the thirst of knowledge
In Helicon may slake it,
If he has still the Roman will
"To find a way, or make it!"*



Below are pictures of an older **Michel Siffre** in a cave in Texas, repeating and extending to six months, the experiment he performed in his twenties. (<http://www.cabinetmagazine.org/issues/30/foer.php>).



Another place where human beings are *not* exposed to any *zeitgeber* or environmental cues that cause an entrainment or synchronization of the endogenous biological clock with the daily rotation of the earth is the **Antarctic** in winter. During the autumn when the sun “rises” and “sets,” the circadian rhythms of volunteers were entrained with the daily rotation of the earth and had a period of 24 hours. However, during the 126 days of winter that occurred between January 1987 and February 1988, the **natural, free-running periods** of the endogenous circadian clocks of four volunteers were 24 hours 29 minutes, 24 hours 45 minutes, 25 hours 7 minutes and 25 hours 14 minutes. The average **natural, free-running period** of the endogenous circadian clock was 24 hours 54



minutes, which is greater than the 24-hour daily rotation of the earth. (I will discuss the discovery of fossils in Antarctica in the next lecture.)

A **Trident nuclear submarine** such as the **USS Georgia** is another place where human beings are not exposed to the *zeitgeber* or environmental cues that cause an entrainment or synchronization of the endogenous circadian clock with the daily rotation of the earth. After submergence, synchronization of the endogenous clock, in terms of **salivary melatonin** levels, is lost. Here are data from two individuals, one with a **natural, free-running endogenous clock period** of 24.32 hours, and one with a **natural, free-running endogenous clock period** of 24.75 hours. In both cases, there is a **phase shift**, and the peak of salivary **melatonin** occurs later and later. Again, the natural, free-running **period** of the endogenous biological clock is greater than 24 hours.

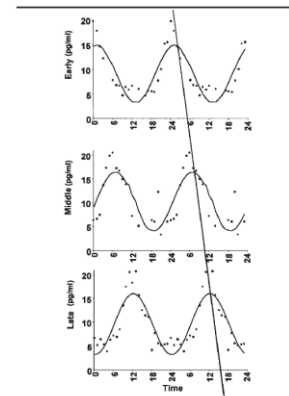


Figure 1. Double-plotted salivary melatonin data from a representative subject (1103) working the 6/12 schedule. Top graph shows data collected at the start of the study, and the middle and lower graphs show data from about 3 weeks and 6 weeks later, respectively. The best-fitting cosinor is overlaid on each data set, and a line is drawn through the acrophases. Estimated tau = 24.32 h.

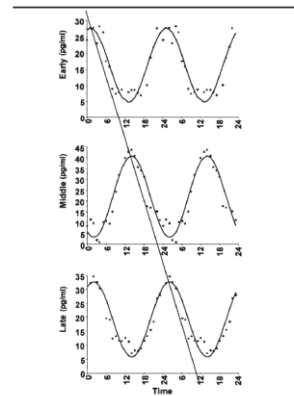


Figure 2. Double-plotted salivary melatonin data from a representative subject (1110) working the 6/12 schedule. Top graph shows data collected at the start of the study, and the middle and lower graphs show data from about 3 weeks and 6 weeks later, respectively. The best-fitting cosinor is overlaid on each data set, and a line is drawn through the acrophases. Estimated tau = 24.75 h.

More recently, **Charles Czeisler** (left) et al. (1999) found that in humans living for one month in an environment free of any *zeitgeber* or environmental cues, the **natural, free-running period** of the endogenous circadian clock is typically **24 hours and 11 minutes**.



We have already seen that it was both **useful and simplistic** to consider eye color to be a dichotomous Mendelian trait that is controlled by one gene. Likewise, it is both **useful and simplistic** to consider the period of the endogenous biological clock to be identical among individuals.

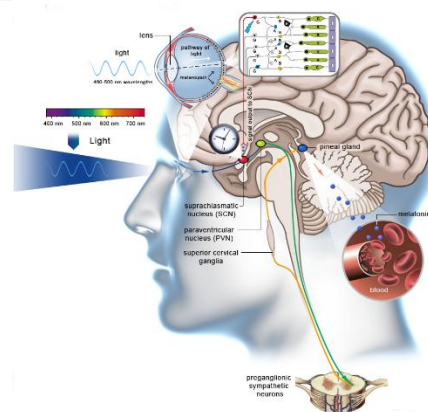
Here is some actual data on the free-running period of the endogenous circadian clock determined from measurements of the rhythms of **core body temperature, melatonin levels in blood samples, and cortisol levels in blood samples** of individuals.

Where is the endogenous biological clock? In mammals, probably including humans, the **primary** or **master** endogenous circadian biological clock is in the **suprachiasmatic nucleus (SCN)** of the **hypothalamus**.

The **suprachiasmatic nucleus (SCN)** is a group of about 50,000 cells in the **hypothalamus** of the brain that is dedicated to the time-keeping function (**nucleus**) above (**supra**) the **optic chiasm** where the optic nerves that come from both eyes cross. There are two suprachiasmatic nuclei, one connected to each eye. The function of the suprachiasmatic nucleus as the locus of the endogenous circadian clock has been demonstrated most conclusively with **ablation** (removal) and **transplantation** (replacement) experiments in **hamsters** performed by Martin Ralph and **Michael Menaker**.

Table 1. Intrinsic periods of the temperature (τ_t), melatonin (τ_m), and cortisol (τ_c) rhythms (expressed as hours:minutes) in young and older subjects in the 28-hour forced desynchrony protocol. For each subject, the estimated period of each of the three rhythms lies within the 95% confidence interval of the other two rhythms. τ_t , τ_m , and τ_c were highly correlated [Pearson correlation: τ_t versus τ_m , $r = 0.951$; τ_t versus τ_c , $r = 0.982$; τ_m versus τ_c , $r = 0.984$ ($P < 0.0001$ in all cases)]. Our composite estimate of the intrinsic period for each subject (τ) was computed by averaging τ_t , τ_m , and τ_c , if available. Constraints on the total blood collection volume and vascular access limited the number of older subjects for whom cortisol and melatonin data were available; also, in two young subjects (1145 and 1257), an inadequate number of blood samples were collected and analyzed for cortisol concentrations to obtain a reliable estimate of the circadian period.

Subject	Age (years)	Sex	τ_t ($\pm$ SD)	τ_m ($\pm$ SD)	τ_c ($\pm$ SD)	τ
Young subjects						
1105	25	M	24:16 $\pm$:02	24:14 $\pm$:05	24:17 $\pm$:10	24:16
1106	21	M	24:14 $\pm$:01	24:14 $\pm$:02	24:18 $\pm$:07	24:16
1111	22	M	24:17 $\pm$:01	24:17 $\pm$:03	24:19 $\pm$:05	24:18
1120	25	M	24:08 $\pm$:01	24:09 $\pm$:01	24:10 $\pm$:07	24:09
1122	23	M	24:09 $\pm$:01	24:07 $\pm$:02	24:08 $\pm$:09	24:08
1133	23	M	23:53 $\pm$:01	23:51 $\pm$:03	23:52 $\pm$:10	23:52
1136	22	M	24:09 $\pm$:01	24:10 $\pm$:04	24:13 $\pm$:07	24:11
1144	23	M	24:15 $\pm$:01	24:17 $\pm$:01	24:18 $\pm$:06	24:16
1145	30	M	24:09 $\pm$:01	24:11 $\pm$:04	—	24:10
1209	21	M	24:06 $\pm$:01	24:05 $\pm$:00	24:08 $\pm$:01	24:07
1257	26	M	24:19 $\pm$:02	24:23 $\pm$:01	—	24:21
Range	21–30		23:53–24:19	23:51–24:23	23:52–24:19	23:52–24:21
Mean	23.7		24:10	24:11	24:11	24:11
$\pm$ SD	2.7		00:07	00:08	00:09	00:08
$\pm$ SEM	0.8		00:02	00:03	00:03	00:02
Older subjects						
1213	74	F	24:02 $\pm$:02	—	—	24:02
1215	64	M	24:07 $\pm$:07	24:01 $\pm$:02	24:07 $\pm$:08	24:05
1304	64	M	24:03 $\pm$:03	24:09 $\pm$:07	—	24:06
1319	67	F	24:10 $\pm$:02	24:10 $\pm$:04	—	24:10
1355	69	M	24:25 $\pm$:02	24:25 $\pm$:03	—	24:25
1366	66	M	24:28 $\pm$:05	24:30 $\pm$:03	—	24:29
1375	66	M	24:19 $\pm$:02	24:20 $\pm$:05	—	24:20
1458	67	M	24:09 $\pm$:02	24:13 $\pm$:03	—	24:11
1475	72	F	24:00 $\pm$:03	24:04 $\pm$:07	—	24:02
1485	65	M	24:06 $\pm$:01	24:09 $\pm$:05	—	24:07
1490	71	F	24:13 $\pm$:02	—	—	24:13
14A6	65	M	24:04 $\pm$:02	24:07 $\pm$:02	—	24:05
1507	66	M	24:10 $\pm$:03	—	—	24:10
Range	64–74		24:00–24:28	24:01–24:30	—	24:02–24:29
Mean	67.4		24:10	24:13	—	24:11
$\pm$ SD	3.2		00:09	00:09	—	00:08
$\pm$ SEM	0.2		00:02	00:03	—	00:02



Hamsters, like other rodents are **nocturnal**. They typically sleep during the day and are active at night. It is easy to measure the sleep-wake cycle of a hamster by connecting a monitor to an exercise wheel. Martin Ralph and Michael Menaker found that a typical hamster (A,B,C) has a sleep-wake cycle of 24.1 hours when it is exposed to a cycle of 14 hours of light and 10 hours of darkness. The active time on the wheel is during the dark period. They also found that when a typical hamster (A,B,C) is placed in continuous darkness, it more or less maintains its sleep-wake rhythm, with the active time on the wheel during the dark period. Then they found that abnormal hamsters (D,E,F) have a 22 hour sleep-wake cycle and **cannot** entrain or synchronize well with the light-dark cycle. They called the hamster with abnormal rhythm a *tau* (τ) mutant.

Martin Ralph and Michael Menaker also found that when a typical hamster is mated with an abnormal hamster, the ratio of hamsters with a 24.03 hour or a 22.31-hour sleep-wake cycle was 1:1, consistent with a mating of a wild type with a heterozygote if there is only a **single gene** that is not on an X chromosome that codes for the duration of the sleep-dark cycle. They also found that when two heterozygotes with 22.31-hour sleep-wake cycle were mated, the offspring were of three types: 24-hour, 22-hour and 20-hour

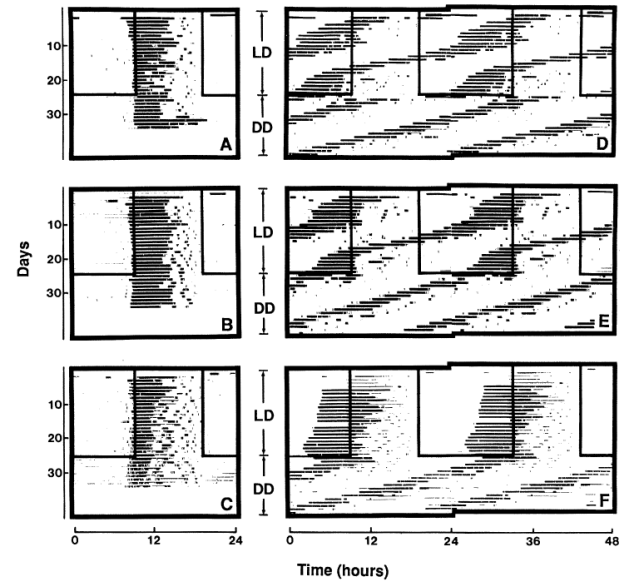


Fig. 1. Activity records (raw data) of six male F₁ littermates. Panels D to F are double plotted (as shown by the time axis). Boxes superimposed on each panel enclose the light portion (14 hours) of a light:dark cycle. LD, 14 hours of light in 100 lux; 10 hours of dark. DD, constant dark. Wheel running activity is indicated by the dark bands on each day.

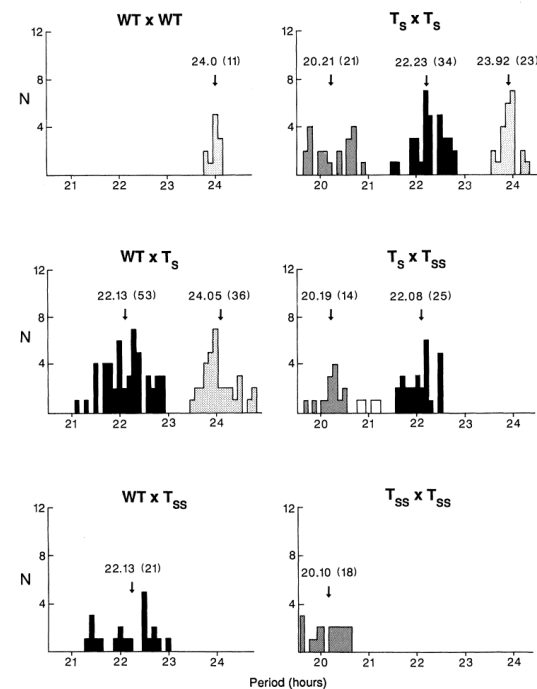


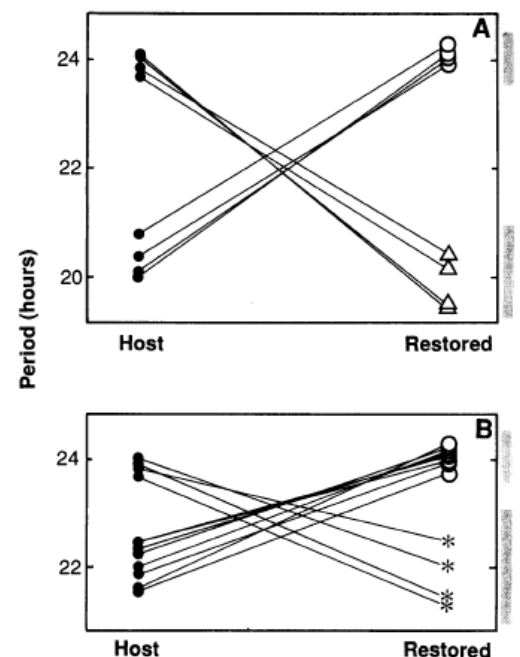
Fig. 2. Frequency distribution of τ from various crosses. After recording entrainment for 5 days, the animals were released into DD. Period was determined from the slope of a line fit by eye or regression analysis through the onsets of activity between day 4 and day 14 in DD. For statistical analysis, animals were assigned to particular groups on the basis of their phenotype: T_{ss} ($\tau \leq 21.00$ hours); T_s ($21.00 < \tau \leq 23.25$ hours); WT (23.25 hours $< \tau$). Our current data indicate that the ranges of the three groups do not overlap. Animals with τ values close to the extreme of the range for a group are routinely tested in backcrosses before genotype is inferred. Furthermore, many animals represented in this figure have been used in our breeding program, and in no case have the distributions of τ from their offspring indicated that we have been incorrect in assigning animals to a particular group. The four animals represented by the open histograms (in the $T_s \times T_{ss}$ panel) could not be assigned to a group based on phenotype alone and have not produced sufficient offspring to infer genotype; therefore, they have not been included in the statistical analysis. WT, wild type ($\tau \approx 24$ hours); T_s , putative heterozygote phenotype ($\tau \approx 22$ hours); and T_{ss} , putative homozygote mutant phenotype ($\tau \approx 20$ hours). Average τ for each group is indicated; number (n) of animals for each group is shown in parentheses; N is number of animals with a given free-running period.

sleep-wake cycles, indicating that the abnormal hamsters with a 22-hour sleep-wake cycle have **one semi-dominant allele** at one locus and the abnormal hamsters with a 20-hour sleep-wake cycle have **two semi-dominant alleles** at that locus. Can you confirm Martin Ralph and Michael Menaker's conclusion using **Punnett squares**?

	W	W
W		
τ		

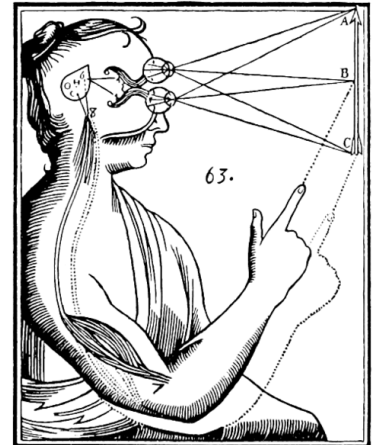
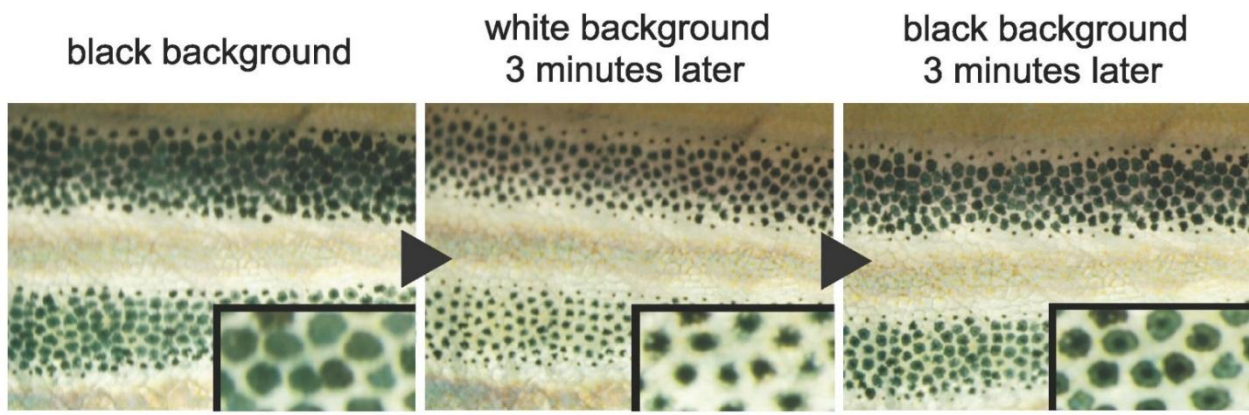
	W	τ
W		
τ		

The **suprachiasmatic nuclei** of a hamster can be ablated and replaced with the suprachiasmatic nuclei of another hamster. **Reciprocal transplantation studies** between wild type hamsters with a sleep-wake cycle of 24 hours and homozygous tau hamsters (A) with a sleep-wake cycle of 20 hours, and reciprocal transplantation studies between wild type hamsters with a sleep-wake cycle of 24 hours and heterozygous tau hamsters (B) with a sleep-wake cycle of 22 hours show that the **sleep-wake cycle is controlled by the genetics of the cells of the suprachiasmatic nuclei**. This is good evidence that the suprachiasmatic nuclei contains the circadian biological clock that regulates the sleep-wake cycle, but is the suprachiasmatic nucleus the only biological clock in the hamster that regulates



the sleep-wake cycle? Could there be other biological clocks in the hamster? Before we discuss other clocks, we will discuss how the endogenous biological clock in the suprachiasmatic nuclei is entrained or synchronized by the daily **light-dark transition** with the 24-hour period of the daily rotation of the earth.

After more than two millenia of observations and research on vision and the eye, it was a surprise to learn in 1998 that **melanopsin**, a *new* photoreceptor pigment had been discovered in the retina. In order to follow the discovery of a new photoreceptor pigment, we have to take a detour and learn about the melanophores of cold-blooded animals. When we discussed eye color, we talked about the **melanocytes in the iris** that produced **melanin-containing melanosomes**. Melanin producing cells are now called **melanocytes in warm-blooded animals** and **melanophores in cold-blooded animals**. The melanophores in cold-blooded animals, including fish, reptiles, and amphibians allow the animals to **lighten or darken their skin tone to mimic the background** in order to **camouflage themselves**—a natural **optical illusion**.



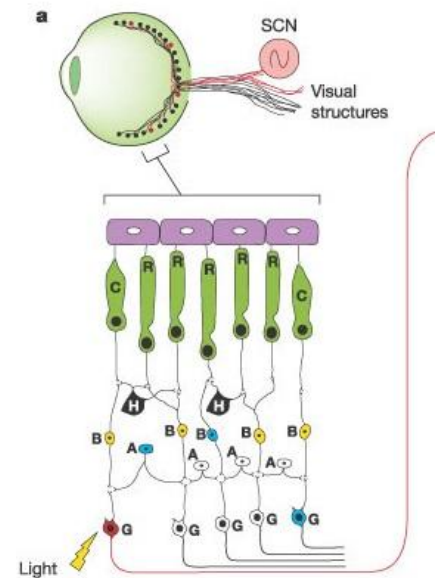
When the **melanosomes** in the **melanophores** in the skin of Zebrafish are **dispersed** throughout the cell, the melanophores in the **skin appear dark**. When the **melanosomes** in the **melanophores** in the skin of Zebrafish are aggregated in the cell, the melanophore in the **skin appears light** and the skin reflects the color of the cell beneath.



Ignacio Provencio discovered the gene for the **photoreceptor pigment** which he called **melanopsin** that controls the distribution of **melanin** in the **melanophores** of cold-blooded animals. Interestingly, a comparison of the amino acid sequence deduced from the nucleotide sequence of the melanopsin gene with the gene sequences of the visual opsins in rods (rhodopsin) and cones (photopsins) of vertebrates and the rhodopsins in invertebrates, including cephalopods and insects, shows that melanopsin of vertebrates is more closely related (**homologous**) to **invertebrate** rhodopsin (39% identity) than to **vertebrate** opsins (30% identity). How can you explain this in terms of the evolution of the eye? Common ancestry? Convergent evolution? Design?

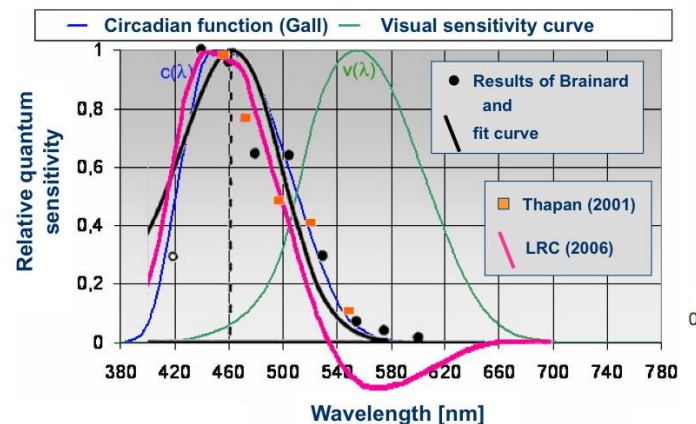


Unexpectedly, Provencio et al. (1998) found messenger RNA transcripts that coded for melanopsin, not only in the **melanophores in the skin of tadpoles**, but also in the **suprachiasmatic nuclei**, the **iris**, the **retinal pigment epithelium**, and in the **inner retina**. Two years later, Provencio et al. (2000) also discovered **melanopsin** in scattered cells in the **ganglion cell layer** of the **human retina**. The **intrinsically photosensitive retinal ganglion cells (ipRGC)**, which make up approximately 1-2% of the retinal ganglion cells, are connected directly through a bundle of neurons known as the **retinohypothalamic tract (RHT)** to the **suprachiasmatic nucleus (SCN)**. These clues suggest that light absorbed by **melanopsin** provides the *zeitgeber* to ensure the **endogenous biological clock** in the **suprachiasmatic nuclei** is entrained by light, and thereby typically synchronized with the daily rhythm of the earth's rotation.



The **action spectrum** of the **synchronization signal** involved in synchronizing the endogenous biological clock with the daily rotation of the earth matches the **absorption spectrum of melanopsin** that has a peak around 460 nm and does **not** match the absorption spectrum of rhodopsin involved in rod-dominated scotopic vision, which has a peak around 498 nm, or the photopsins involved in cone-dominated photopic vision, which has a peak around 555 nm (S-420 nm, M-534 nm, L-564 nm).

Circadian action spectrum according to different sources



How does the endogenous biological clock in the suprachiasmatic nuclei regulate the sleep-wake cycle? How does light absorbed by melanopsin in the **intrinsically photosensitive retinal ganglion cells (ipRGC)** affect the sleep-wake cycle?

The **intrinsically photosensitive retinal ganglion cells (ipRGC)** are connected directly by the neurons in the **retinohypothalamic tract (RHT)** to the **suprachiasmatic nucleus (SCN)**. Likewise, the **suprachiasmatic nucleus (SCN)** is connected by neurons to the **pineal gland**, which secretes a **soporific known as melatonin** into the blood stream. In order to understand how melatonin got its name, we have to make another detour to discuss the melanophores in cold-blooded animals.

Melatonin got its name because it can cause the **melanosomes** in dermal **melanophores** of tadpoles to aggregate. Carey McCord and Floyd Allen (1917) fed **extracts of the pineal gland** of cows to tadpoles and found that thirty minutes later, the tadpoles became lighter in color. The extract had caused the aggregation of melanosomes in the dermal melanophores.

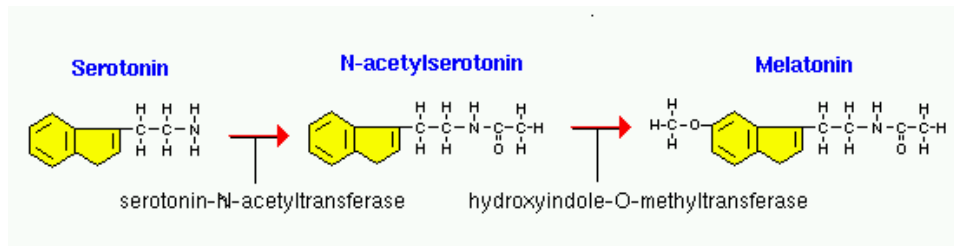
Noting that the **pineal extract** caused skin to lighten, **Aaron Lerner** (1958,1959,1960), a dermatologist, and his colleagues repeated the work of McCord and Allen, isolated the chemical that lightened the frog's skin by causing the aggregation of melanosomes, determined the structure of the **frog skin-lightening chemical**, and named it **melatonin**. **Julian Axelrod**, who



Figs. 3 and 4 Photographs made by reflected light.
Fig. 3 Normal tadpoles—just prior to pineal feeding.
Fig. 4 Same tadpoles 30 minutes after feeding acetone extract of pineal gland. The darker portions of these tadpoles are due to denser viscera—heart, gills, intestinal contents, etc. The degree of translucency is identical in all parts of the skin.



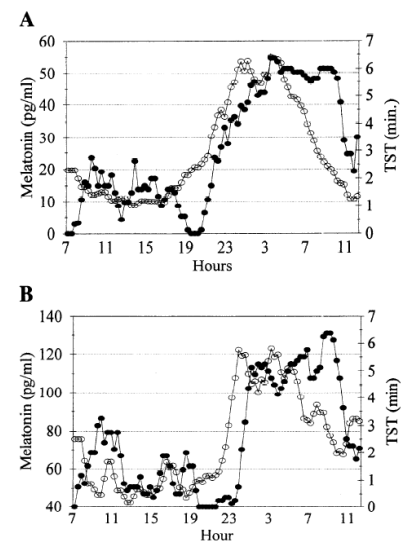
called himself a *late blooming biochemical neuroscientist*, discovered the enzymes that synthesized melatonin.



Unfortunately melatonin was not involved in causing skin-lightening conditions such as **vitiligo**. It does however seem to be involved in the **sleep-wake cycle** in humans, and melatonin had been given the nickname, the ***hormone of the darkness***. The levels of melatonin in the blood vary in a circadian fashion, **being low during daytime and high at night**. This rhythm persists for up to three weeks in individuals kept under very dim light conditions showing that **melatonin levels** in the blood are under the control of an **endogenous biological clock**.



Shochat et al. (1997) showed that an ***increase in melatonin*** in the blood **precedes sleepiness** as measured by a propensity to sleep and a ***decrease in melatonin in the blood*** precedes wakefulness as measured by a propensity not to sleep.



1. Sleep propensity (TST; ●) and melatonin (○) curves of 2 cal subjects [subjects 1 (A) and 4 (B)]. Nocturnal melatonin rise decline precede the rise and decline in nocturnal sleep propensity. Curves were smoothed by a 4-point moving average window.

Waldhauser et al. (1988) found that the **magnitude of the melatonin peak declines with age** which is correlated with the difficulty in sleeping that comes with aging.

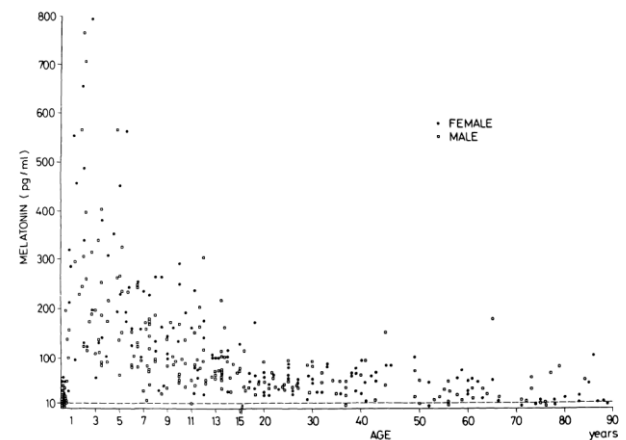


FIG. 1. Nighttime serum MLT concentrations in 367 subjects (210 males and 157 females) aged 3 days to 90 yr. For conversion of MLT concentrations to SI units (nanomoles per L), multiply by 0.0043478.

Zeitzer et al. (2000) found that an 6.5 hour exposure to as little as 106 lux of white light during early biological night **delays the secretion of melatonin into the blood**. Higher intensities (9100 lux) suppress the secretion of melatonin into the blood during the exposure and delay it when the light is turned off. Rüger et al. (2013) found that as little as 11.2 lux of 480 nm **blue light** was as effective as 10,000 lux white light, indicating that the photoreceptor pigment

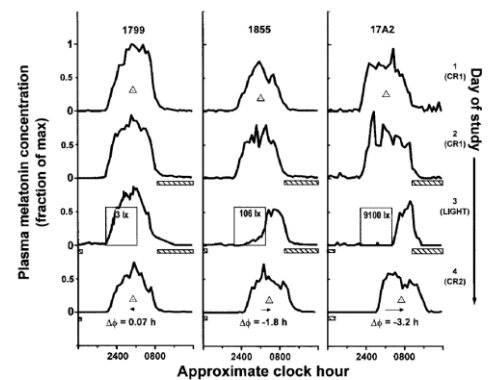


Figure 1. Phase shift of the human circadian pacemaker and acute suppression of plasma melatonin. Melatonin profiles during days on which the first constant routine (CR) (1 and 2), the single experimental light exposure 6.5 h in duration (3), and the second CR (4) occurred are shown for three representative subjects (1799, 1855, 17A2). In the dimmest light condition, exposure to the dim light stimulus (~3 lx) had little effect on either the phase of the melatonin rhythm (phase shift ($\Delta\phi$) 0.07 h) or concentration of plasma melatonin (suppression 11%). In the brightest light condition (~9100 lx), light both shifted the rhythm ($\Delta\phi$ -3.2 h) and completely suppressed plasma melatonin (98%). Exposure to dim room light (~106 lx) evoked more than half of the shift observed in the brightest light condition ($\Delta\phi$ -1.8 h compared with -3.2 h) and a nearly equal amount of suppression (88%). During the CRs and day of experimental light exposure, subjects were exposed to no more than 5 lx in the horizontal angle of gaze at any time except during the scheduled sleep episodes (hatched bars < 0.03 lx) and the experimental light exposure (labelled open boxes, see Fig. 2). Individual subject data were plotted on a time scale in which their habitual wake time was assigned a reference value of 08.00 h. Phase of the melatonin maximum (midpoint of the upward and downward mean crossings) during each CR is noted as the Δ . For graphical purposes, ordinate values were normalized to each subject's absolute peak plasma melatonin concentration.

responsible for melanin suppression and delay is sensitive to blue light, as is true of melanopsin. Here are examples of illuminance in lux under various conditions.

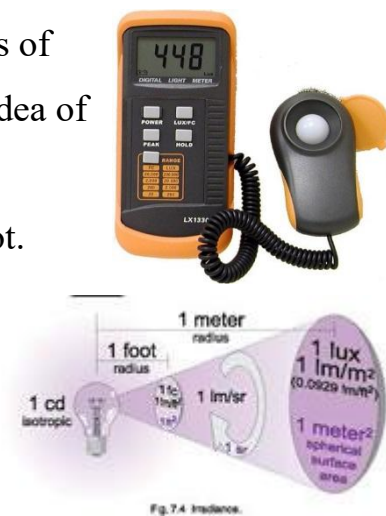
11.2 lux is **about** the brightness of twilight.

Condition	Illumination	
	(ftcd)	(lux)
Sunlight	10,000	107,527
Full Daylight	1,000	10,752
Overcast Day	100	1,075
Very Dark Day	10	107
Twilight	1	10.8
Deep Twilight	.1	1.08
Full Moon	.01	.108
Quarter Moon	.001	.0108
Starlight	.0001	.0011
Overcast Night	.00001	.0001

Lux is a **photometric unit** that measures the **brightness** of a light as perceived by the human eye with photopic cone-dominated vision. One lux is equal to **one lumen per meter squared**. Free apps are available to turn smartphones into lux meters

(<https://play.google.com/store/apps/details?id=com.notquitethem.android.luxmeter> and <https://itunes.apple.com/us/app/luxmeter/id526675593?mt=8>).

Demonstration: Use the Digital Lux Meter to measure the brightness of the light in the classroom in foot candles (fc) or in lux and to get an idea of different brightnesses in terms of lux. One lux is equal to 0.0929 footcandles, the brightness of a standard spermaceti candle at one foot. Use the Lux meter to measure the brightness of the spermaceti candle at one foot in both lux and fc. Light meters that measure the brightness of light absorbed by melanopsin or [melanopic-lux](#) are being developed.



The timing of the light pulse, in addition to its spectral composition, its intensity, and its duration, is important to know. A light pulse given near the beginning of the sleep period **delays the phase** (starting point) of the sleep-wake cycle making you less sleepy while a light pulse near the end of the sleep period **advances the phase** (starting point) of the sleep-wake cycle making you more awake. This can be visualized in a **phase-response curve**. Our response to light does *not* only depend on the physical quantities of light but also on when the light is given relative to the phase of our endogenous biological clock.

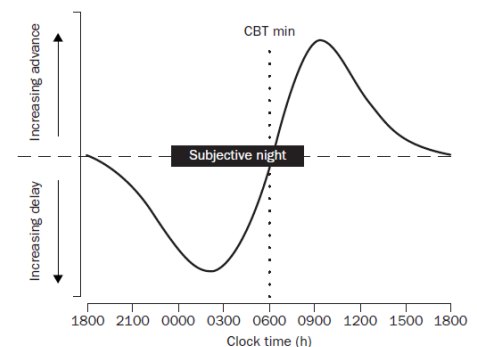
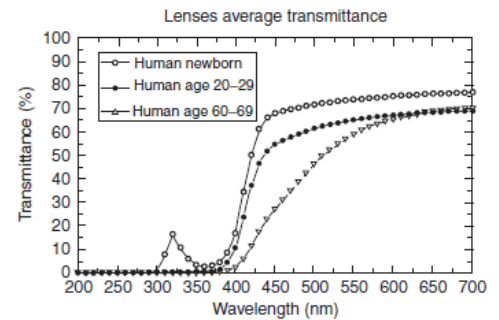


Figure 2: Phase response curve (PRC) of a human being, in response to light

Aside: Brainard et al. (1997) found that **aging** is also correlated with a **yellowing of the crystalline lens** which blocks the transmission of the blue light that suppresses melatonin.



Sleep disturbances that are associated with desynchronization of the melatonin rhythms with the daily rotation of the earth can sometimes be ameliorated by **taking exogenous melatonin at the correct time**. The effectiveness of melatonin treatment seems to be variable—perhaps as a result of individual variability in the cycles and in part due to the lack of attention paid to timing—when in an individual’s cycle one should take exogenous melatonin. An awareness and understanding of our **biological time** is especially important in our **24-hour society** (Rajaratnam and Arendt, 2001). Josephine Arendt (2000) wrote in *The New England Journal of Medicine*, “*the true potential of melatonin is becoming evident, and the importance of the timing of treatment is becoming clear. Our 24-hour society, with its chaotic time cues and lack of natural light, may yet reap substantial benefits.*”



Perhaps instead of taking **exogenous melatonin**, we can control the light around us to modulate the production of **endogenous melatonin** so we can sleep better. **Amber** bulbs and nightlights, blue-blocking filters for smartphones and tablets, and glasses that block blue light may be helpful at bedtime (<https://www.lowbluelights.com/index.asp>; <https://www.lowbluelights.com/media/19552.mp3>; Burkhardt and Phelps, 2009). It is also possible to get a free app that adjusts the **color temperature** of the displays of smartphones and tablets to the time of day—warm at night, like sunlight during the day (<http://justgetflux.com/>).



The **Yin-Yang** symbol, which shows the sun and moon embracing signifies opposites such as day and night, light and dark.



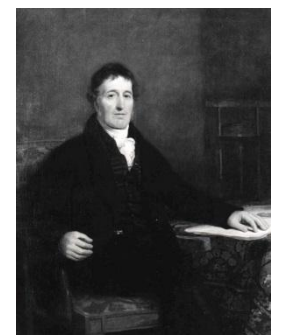
Eva Schernhammer and Abraham Haim have correlated **light at night** (LAN) that causes **circadian disruption** in the workplace and in the bedroom to increased risk of **breast cancer**.



Perhaps it is a good time to remember that throughout most of human history, **sunlight** (supplemented at night with firelight) was the *zeitgeber* that entrained and synchronized the sleep-wake cycle with the daily rotation of the earth. The firelight evolved into light from an **oil lamp** about 4500 BC and then light from a **candle** about 3000 BC. Although the technology of artificial light improved, there was a cost to using it and so it was used frugally. In London in 1417, in Paris in 1524, and in Dublin in 1616, it became required by law to put a candle in the window of houses facing the street. Then came gas street lighting.

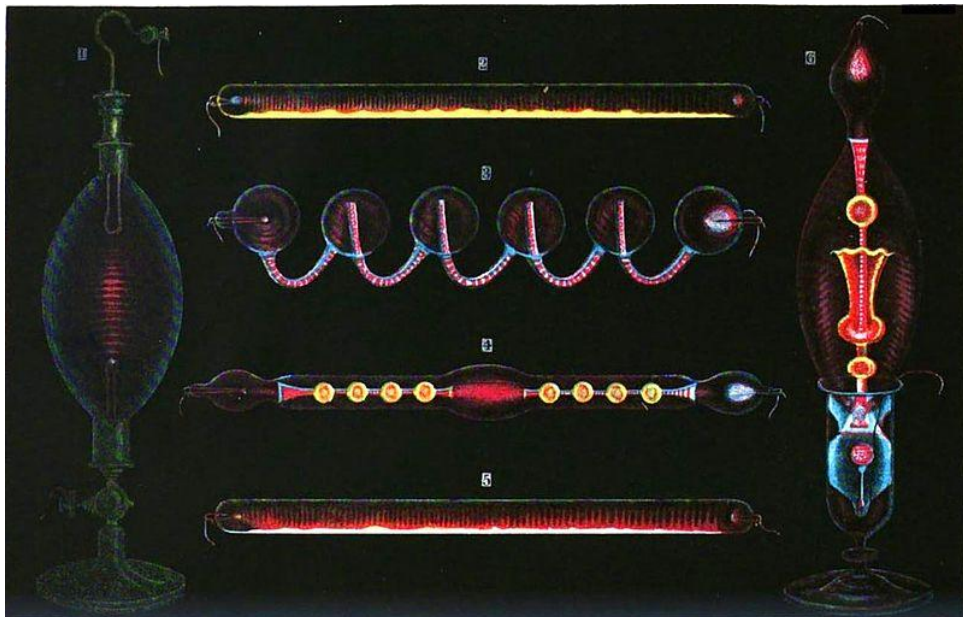


Up until 1802, coal had only been used to power steam engines. In 1802, **William Murdoch** used the coal gas produced by heating coal to produce the first outdoor gaslight. The streets of London were lit by gaslight in 1807; the streets of



Baltimore were lit by gaslight in 1816, the streets of Paris were lit by gaslight in 1829, and the streets of **Montreal** were lit in 1837.

Heinrich Geissler invented the electric arc lamp in 1857. It was a partially evacuated gas containing glass cylinder with a metal electrode at each end. When a high voltage was applied to the electrodes, an electrical current flowed through the



tube, dissociating electrons from the gas molecules. When the electrons recombined with the ions, fluorescent light was emitted. The color of light depends on which atoms were in the tube.

Electric arc lamps replaced gaslights along the streets of Paris and London in 1878 and incandescent electric street lights were introduced along streets in Newcastle-upon-Tyne and in Cleveland, Ohio in 1879. Georges Claude invented the **neon light** in 1910 and since that time it has been used to illuminate colorfully

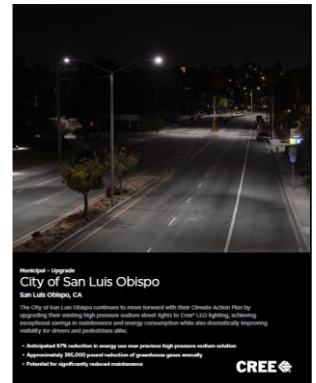


the streets in many cities, including **Times Square** in New York City and **Shibuya** in Tokyo Japan.

High Pressure Sodium vapor lamps that illuminate the streets monochromatically were introduced as street lights in 1964. The light spectrum of these lamps does ***not*** match the absorption spectrum of melanopsin and thus does not disrupt circadian rhythms.



Luminescent cold lights such as light emitting diode (LED) lamps are being introduced for street lights. They reduce the amount of energy needed to get a given amount of brightness, although the full spectrum LEDs are more disruptive to our circadian rhythms than the yellow high pressure sodium lights. Phosphorescent particles are being introduced into roads and paths.





This path, is inspired by Van Gogh's *Starry Night*
<https://studioroosegaarde.net/project/van-gogh-path>

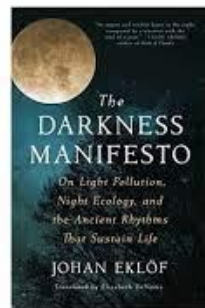
Satellite images from space show that some regions of the world are exposed to perpetual daylight—a form of **light pollution**. Other regions experience **light poverty**.



Sara Pritchard (STS, Cornell) edited a special issue of *Journal of Energy History* on light and darkness, particularly as it relates to light pollution: <https://energyhistory.eu/en/special-issue/lights-and-darknesses-looking-back-looking-forward>



Johan Ecklöf (2020) wrote a book entitled the *Darkness Manifesto: On Light Pollution, Night Ecology, and the Ancient Rhythms that Sustain Life* that beautifully describes the dependence of nocturnal animals, particularly insects, birds, and bats, on darkness and the threat of light pollution on the lives of the animals.



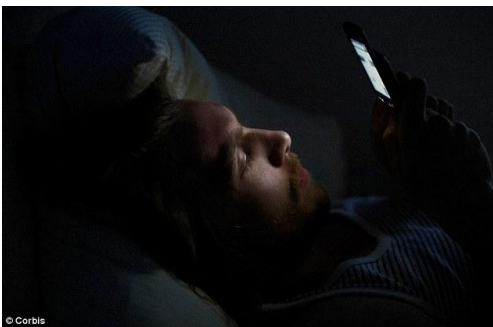
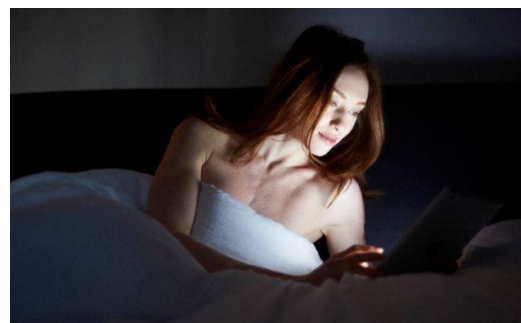
Light pollution makes it seem like the sky has become emptied of stars. Light out of place or glare due to misdirected light makes it difficult to see astronomical objects such as the **Milky Way** even in rural areas such as Ithaca.



Intelligent street lighting, produced by Twilight, uses motion sensors to brighten LED lamps only when they are needed. The use of intelligent street lighting saves energy and reduces light pollution.



And with our modern urbanized sleeping habitat, the perpetual daylight from artificial light came indoors:



And the light from smartphones and tablets at bedtime may reduce or delay the production of melatonin. Wood et al (2013) found that a two hour exposure to the blue light produced by an iPad reduces the salivary melatonin levels by 23%.

Table 1
lighting conditions (photopic illuminance in lux and CL_A measured with the Dimesimeter), predicted melatonin suppression (CS) and measured melatonin suppression after 1-h and 2-h exposures. Mean $\pm$ standard error of the mean (SEM) values are shown.

	Photopic illuminance (lux)	CL_A	CS ^b	Measured suppression (%)
1 h Tablet + blue LEDs	59 $\pm$ 5.0	648 $\pm$ 4.9	0.46 $\pm$ 0.0013	48 $\pm$ 4
Tablet + orange-tinted glasses ^a	9.8 $\pm$ 1.9	1.5 $\pm$ 0.31	0.0017 $\pm$ 0.0004	NA
Tablet-only	18 $\pm$ 3.8	19 $\pm$ 4.6	0.03 $\pm$ 0.0066	7.0 $\pm$ 4
2 h Tablet + blue LEDs	57 $\pm$ 3.8	645 $\pm$ 3.4	NA	66 $\pm$ 4
Tablet + orange-tinted glasses ^a	9.9 $\pm$ 1.6	1.5 $\pm$ 0.29	NA	NA
Tablet-only	16 $\pm$ 2.7	17 $\pm$ 3.51	NA	23 $\pm$ 6

NA: not applicable.

^a The tablet with the orange-tinted glasses condition was used as the dark control.

^b Based upon a 1-hr duration of light exposure and a 2.3 mm pupil diameter.

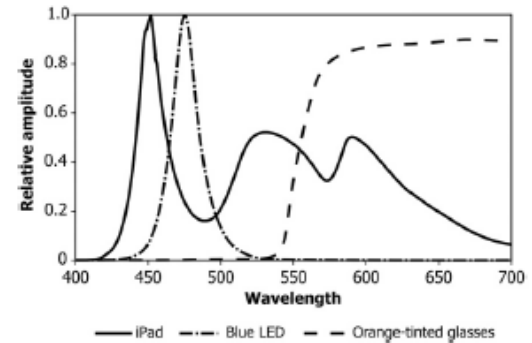


Fig. 1 Spectral transmittance of the orange-tinted glasses, the relative spectral power distribution (SPD) of a 470-nm (blue) LED, and the relative SPD of an iPad 1 (white screen, full brightness) used in the experiment.

Melatonin is not the only hormone whose levels in the blood change in a circadian manner. **Cortisol** levels also change in a circadian manner (Selmaoui and Touitou, 2003). While the levels of melatonin are correlated with sleepiness, the levels of cortisol are correlated with **wakefulness**. Since cortisol is also a hormone produced in stressful situations, **chronic stress** results in a constant production of cortisol and interferes with the ability to sleep.

Vitamin D, also known as the sunshine vitamin, is produced by the body in response to sunlight and is necessary for normal bone development. However, vitamin D is also a steroid **hormone** that can have significant effects on the body as a result of the variety of vitamin D receptors in the brain. As a result of spending less time in sunlight, more and more people are developing vitamin D deficiencies and the deficiencies are correlated with sleep disorders (Gominak and Stumpf, 2012). While studying people with headaches, Gominak serendipitously found that people who took vitamin D supplements were able to wake up rested. It seems that vitamin D reduces the level of melatonin in the body. The levels of vitamin D, like the levels of cortisol, are correlated with **wakefulness** and the **day-like physiological state**. Thus, when vitamin D supplements are taken at night,

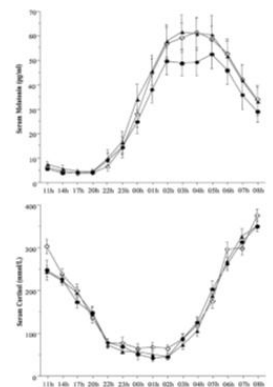


Fig. 1 Circadian rhythms of melatonin (top) and cortisol (bottom) in three different 24-h sessions spaced two weeks apart between the 1st and 2nd sessions (more than 4 weeks apart between the 2nd and 3rd sessions: 35(2), 32 (1) and 33 (4)). Each line point is the mean $\pm$ SEM of 11 subjects.

they prevent sleepiness while the same supplements taken in the morning increase wakefulness.

Anti-histamines often cause sleepiness, which led researchers to check if the hormone **histamine** changes in a circadian fashion (Brown et al. 2001). The levels of histamine, like the levels of cortisol, are correlated with **wakefulness** and the **day-like physiological state**.

Anti-diuretic hormone also varies in a circadian manner. It is highest at night so that our sleep is not interrupted by the urge to urinate.

The **Lighting Research Center at Rensselaer Polytechnic Institute** (<http://www.lrc.rpi.edu/programs/lightHealth/index.asp>) researches questions about light, health, and circadian rhythms.

Just as there is more than one chemical that regulates sleep, there may be **more than one endogenous biological clock**. Tosini and Menaker (1996) have shown that retinas isolated from hamsters have a circadian rhythm of melatonin synthesis and the period of the rhythm depends on the genotype. Retinas from wild type hamsters have a 24-hour period while retinas from homozygous tau mutants have a 21-hour period.

In conclusion, we have a **primary endogenous biological clock** in our brain and perhaps secondary endogenous biological clocks elsewhere that regulate the **sleep-wake cycle** by rhythmically releasing hormones such as **melatonin** and **cortisol** into our blood stream that affect when we go to sleep and wake up. Our endogenous biological clock can be naturally reset by sunlight as a **zeitgeber** so that it is entrained or synchronized with the daily rotation of the earth.

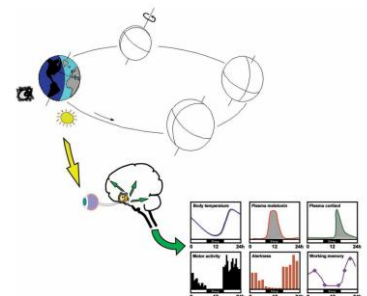


Figure 1. The physiological functions (e.g., body temperature, melatonin secretion) and behaviors (e.g., wake/sleep, alertness, working memory) show daily variations that are in phase with the 24-h circadian cycle. These variations are not passive responses to the changing outside world (i.e., the 24-h light/dark cycle) but are actively synchronized by an internal circadian timing system that is mainly synchronized by light perceived by the retina.

Melatonin does not induce sleepiness in all organisms since in **nocturnal** organisms the levels of melatonin also rise during the dark period, which is the active period in nocturnal organisms. In general, **melatonin signals the dark period**, and when the melatonin level is high, diurnal organisms get sleepy and nocturnal organisms awaken.

Exposure to bright light, particularly in the blue region of the spectrum, which is absorbed by **melanopsin** in the **intrinsically photoreceptive retinal ganglion cells (iPRGC)**, resets the phase of the endogenous clock, which regulates the timing of **melatonin** and **cortisol** release and the sleep-wake cycle so that they are no longer synchronized with the daily rotation of the earth. We can increase the amount of melatonin produced during the sleep period by avoiding bright blue light that acts as a *zeitgeber* before bedtime. On the other hand, bright blue light during the day increases our level of wakefulness.

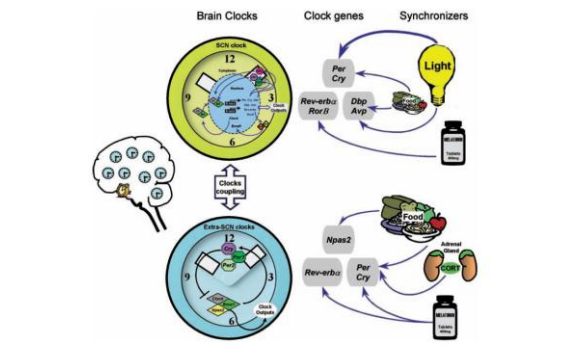
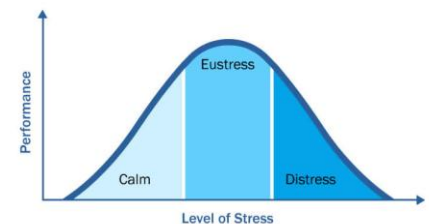
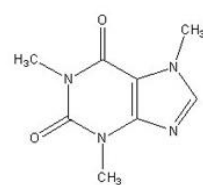


Figure 5. There are many cerebral clocks with diverse clockworks and synchronizers. Light is the major synchronizer for the SCN clock, leading to activation of transcription of *Per* genes. Other cues, such as food and melatonin, can also have synchronizing or modulating effects on the SCN clock. On the other hand, feeding cues are powerful synchronizers for most extra-SCN clocks via changes of *Per* and *Npas2* expression. Corticotropin (CORT) and other glucocorticoids secreted by the adrenal glands can affect the timing of brain oscillators expressing high density of glucocorticoid receptors like the amygdala or the hippocampus. Melatonin drives the rhythmic expression of clock genes in the pars tuberalis of the adenohypophysis.

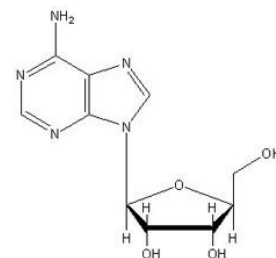
Cortisol levels are correlated with wakefulness, and we can decrease the nighttime levels of cortisol by managing our **stress levels** and quality of stress. We want no stress at night and **eustress** not **distress** during the day.



Coffee and tea, which contain caffeine, help make us alert during the day and make it harder to sleep at night. **Caffeine**

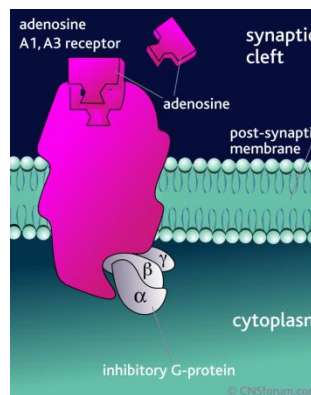


Caffeine

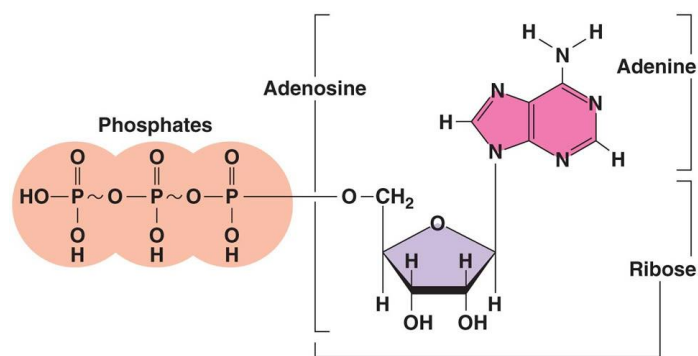


Adenosine

increases our level of wakefulness not by interacting with the endogenous biological clock but by inhibiting the binding of **adenosine** to the **adenosine receptors** in the forebrain and hippocampus that when activated by adenosine, sedate the brain and cause sleepiness. When adenosine binds to the adenosine receptor, it sedates the brain by inhibiting the release of all neurotransmitters into the synapses.



The buildup of adenosine comes from the breakdown of **adenosine triphosphate (ATP)** that occurs through **physical activity**. ATP is resynthesized from adenosine during sleep periods where the level of physical activity is low.



It is common sense and there is evidence from the National Sleep Foundation (<http://sleepfoundation.org/>) that the synchronization of the endogenous biological clock with the daily rotation of the earth results in a rested, happy, and healthy person. Indeed, **Benjamin Franklin** (1746), the son of a tallow chandler who would

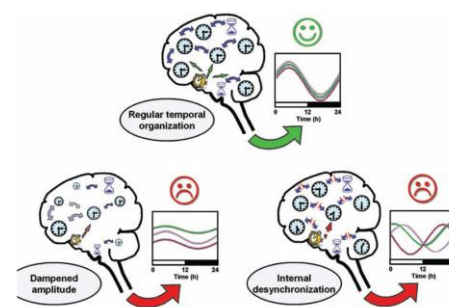


Figure 7. A regular 24-h temporal organization is thought to be important for good health. Dampening in the amplitude of circadian oscillations can affect the main SCN clock and/or some other brain clocks. Internal desynchronization can occur between brain oscillators and the SCN clock or between all of them. Dampened amplitude of circadian oscillations or internal desynchronization within the brain both lead to altered circadian organization that may have major impacts on health.



make money if people stayed up late, wrote, “*Early to bed and early to rise, makes a man healthy, wealthy, and wise.*” Christopher William Hufeland (1797) wrote in *The Art of Prolonging Life*, “*That period of twenty-four hours, formed by the regular revolution of our earth, in which all its inhabitants*



partake, is particularly distinguished in the physical economy of man...It is, as it were, the unity of our natural chronology.”

John Godfrey Saxe wrote, *Early Rising*.

"God bless the man who first invented sleep!"

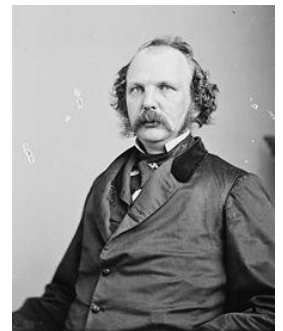
So Sancho Panza said and so say I;

And bless him, also, that he didn't keep

His great discovery to himself, nor try

To make it,—as the lucky fellow might—

A close monopoly by patent-right.



Miguel de Cervantes wrote in *Don Quixote de la Mancha* Part II, Book III, Ch. 68):

“Now, blessings light on him that first invented this same sleep! It covers a man all over, thoughts and all, like a cloak; it is meat for the hungry, drink for the thirsty, heat for the cold, and cold for the hot. It is the current coin that purchases all the pleasures of the world cheap, and the balance that sets the king and the shepherd, the fool and the wise man, even.”



T. Boone Pickens says, “*I try to live by one simple rule. Work eight hours and sleep eight hours, and make sure they are not the same eight hours.*” Other Booneisms:

https://boonepickens.com/?page_id=1283



Isaiah (52:1) reminded the Hebrews to “*Awake, awake*”, a theme that is repeated throughout the Bible.

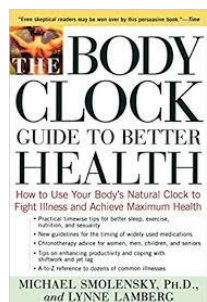


Watch a great teaching movie on biorhythms made by Eric Bittman:

<https://srbr.org/about-chronobiology/chronohistory/a-teaching-video-on-biological-rhythms/>



The human body varies throughout the day, and it is possible that the timing of some medical conditions and life-threatening emergencies may depend on the biological clock. Michael Smolensky (a student of Franz Halberg) and Lynne Lamberg (2000) tell us that like the crocodile in *Peter Pan*, we carry a clock around inside of us. They suggest that we become aware of our **body clock** or **body time**. It turns out that certain diseases and dysfunctional symptoms appear at specified times during the circadian cycle. Moreover, it may also be better to take some medications at certain times of day to increase effectiveness and reduce side effects. **Chronomedicine** takes the body clock into consideration.



In terms of our body clock, there are the best of times and the worst of times:

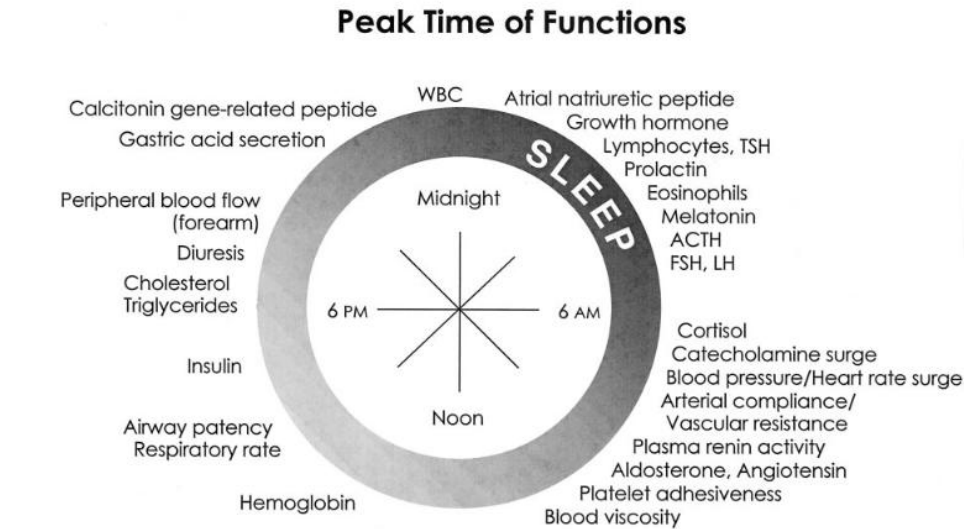
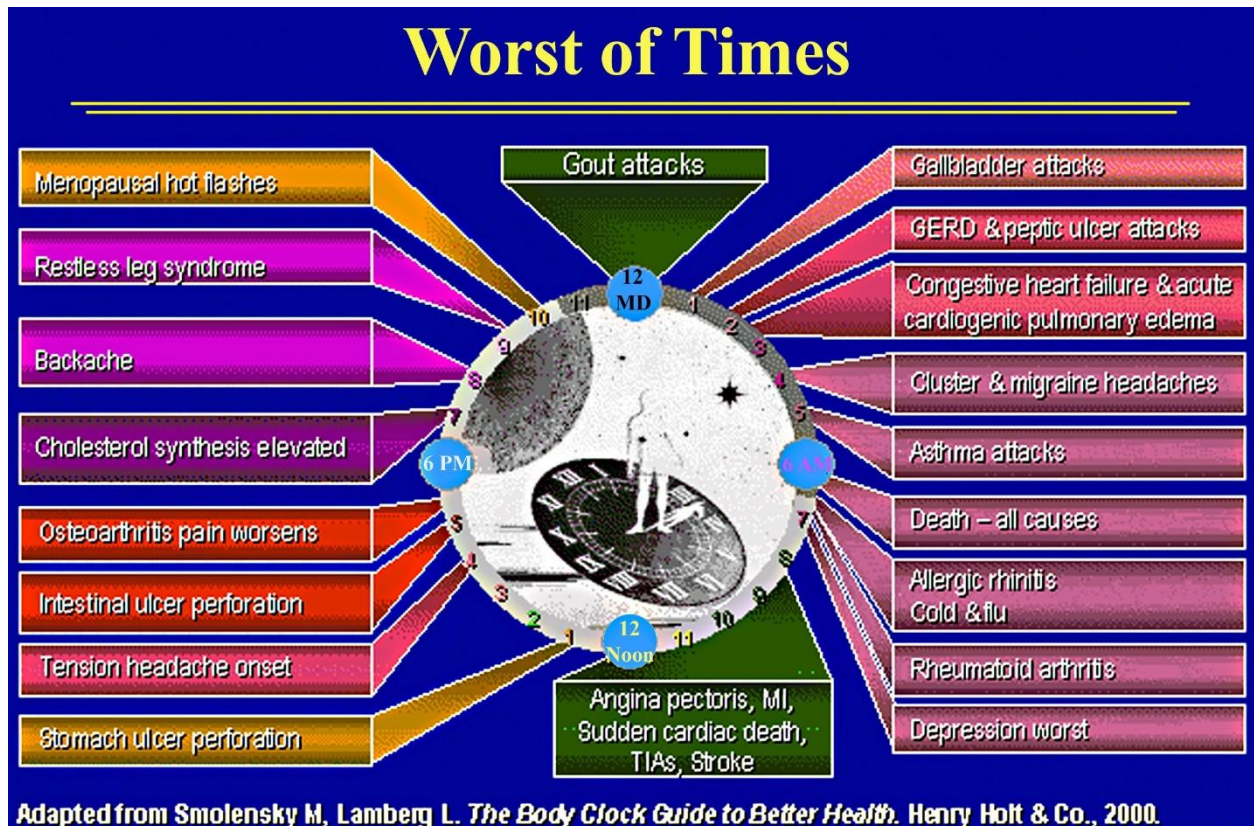
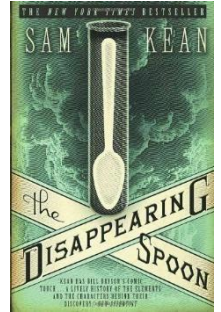


FIG. 1. Clock-like illustration of the organization of the circadian time structure shown by the peak time location of selected rhythms relative to the sleep (10:30 PM to 6:30 AM) activity (6:30 AM to 10:30 PM) routine of healthy persons. ACTH = adrenocorticotrophic hormone; FSH = follicle stimulating hormone; LH = luteinizing hormone; TSH = thyroid stimulating hormone; WBC = white blood cells. Modified with permission from Patient Care, Medical Economics for Smolensky MH, Bing ML: Chronobiology and chronotherapeutics in primary care. Patient Care Clin Focus 1997;31(Summer Suppl):1-15.¹⁹



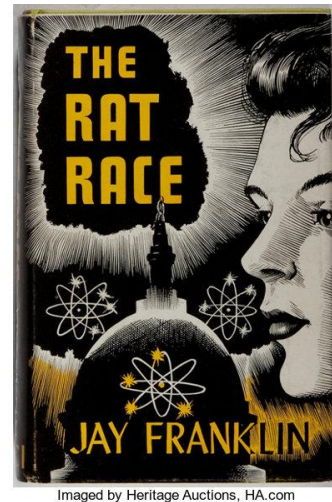
Adapted from Smolensky M, Lamberg L. *The Body Clock Guide to Better Health*. Henry Holt & Co., 2000.

Bipolar disorder may in part be due to a disconnection from the circadian rhythm reset daily by the sun. As described by Sam Kean in *The Disappearing Spoon and other True Tales of Madness, Love, and the History of the World from the Periodic Table of the Elements*, [lithium](#) may treat bipolar disorder by synchronizing the various [biological clocks](#) in a person.



Thinking about time brings us the concept of “The Rat Race”

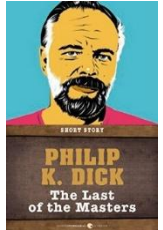
The Rat Race was used as a title for a novel written by Jay Franklin in 1947 for Colliers Magazine and first published in book form in 1950. It is dedicated *To those few rats in Washington who do not carry brief-cases.*



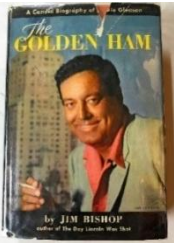
The term "rat race" was used in an article about Samuel Goudsmit published in 1953 entitled: *A Farewell to String and Sealing Wax~I* in which Daniel Lang wrote, *Sometimes when his sardonic mood is on him, he wonders whether the synchrotrons, the betatrons, the cosmotrons, and all the other contrivances physicists have lately rigged up to create energy by accelerating particles of matter aren't playing a wry joke on their inventors. "They are accelerating us too," he says, in a voice that still betrays a trace of the accent of his native Holland. In protesting against the speedup, Goudsmit can speak with authority, for in the course of only a few years, he, like many other contemporary physicists, has seen his way of life change from a tranquil one of contemplation to a rat race.*



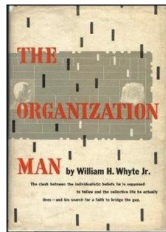
Philip K. Dick used the term in *The Last of the Masters* published in 1954: *"Maybe," McLean said softly, "you and I can then get off this rat race. You and I and all the rest of us. And live like human beings." "Rat race," Fowler murmured. "Rats in a maze. Doing tricks. Performing chores thought up by somebody else." McClean caught Fowler's eye. "By somebody of another species."*



Jim Bishop used the term rat race in his book *The Golden Ham: A Candid Biography of Jackie Gleason*. The term occurs in a letter Jackie Gleason wrote to his wife in which he says: *Television is a rat race, and remember this, even if you win you are still a rat.*

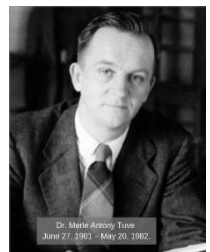


William H. Whyte used the term rat race in *The Organization Man*: *"The word collective most of them can't bring themselves to use—except to describe foreign countries or organizations they don't work for—but they are keenly aware of how much more deeply beholden they are to organization than were their elders. They are wry about it, to be sure; they talk of the "treadmill," the "rat race," of the inability to control one's direction."*



Merle A. Tuve used the term rat race in a 1959 article entitled *Is Science Too Big for the Scientist?* writing:

There is a growing conviction among many of my friends in academic circles that the university today is no place for a scholar in science. A professor's life nowadays is a rat-race of busyness and activity, managing contracts and projects, guiding teams of assistants, bossing crews of technicians, making numerous trips, sitting on committees for government agencies, and engaging in other distractions necessary to keep the whole frenetic business from collapse.



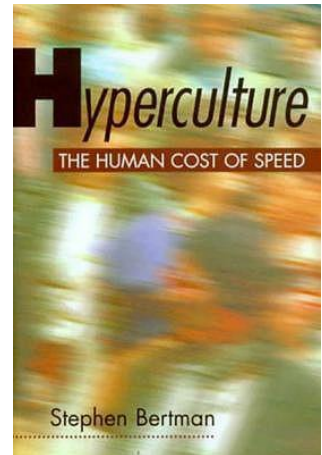
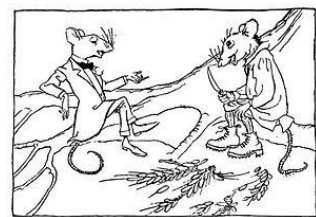
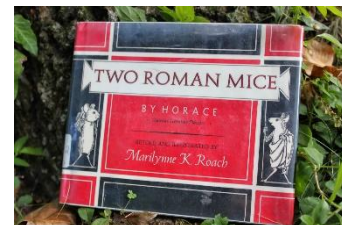
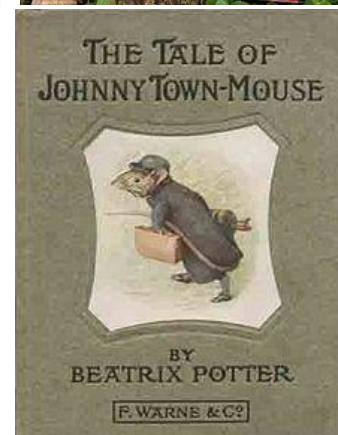
David Foster Wallace used the term rat race in his 2005 commencement speech entitled *The Most Precious Freedom*:

The really important kind of freedom involves attention and awareness and discipline, and being able truly to care about other people and to sacrifice for them over and over in myriad petty, (unglamorous) ways every day. That is real freedom. That is being educated, and understanding how to think. The alternative is unconsciousness, the default setting, the rat race, the constant gnawing sense of having had, and lost, some infinite thing.



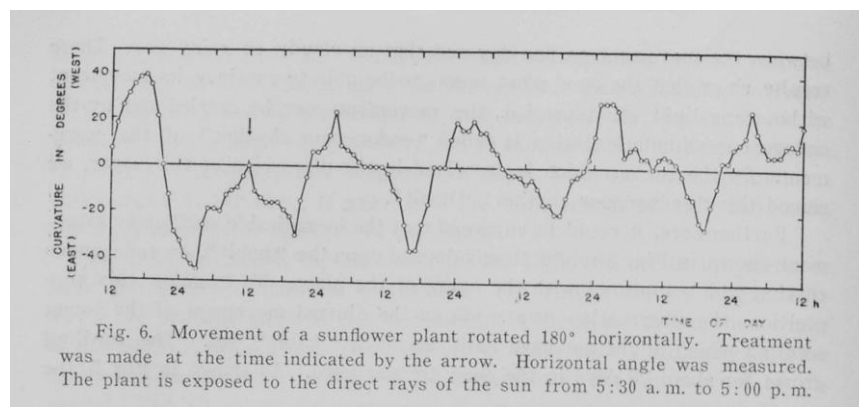
According to Stephen Bertman, in his *Satires* (II:6), Horace (1st century BC) compared citified life to a “rat race.” Here is Horace’s retelling of Aesop’s (620-564 BC) fable in *The Country Mouse and the Town Mouse*:

*Now and then Cervius my neighbour spins us a yarn,
Some apt old woman’s tale. So, if anyone praised
Arellius’ wealth but ignored his cares, he’d begin:
‘It’s said a country mouse welcomed a town mouse once
To his humble hole, the guest and the host were old friends:
He lived frugally, and was careful, but his spirit
Was still open to the art of being hospitable.
In short, he never grudged vetch or oats from his store,
And he’d bring raisins or pieces of nibbled bacon
In his mouth, eager by varying the fare to please
His guest, whose fastidious tooth barely sampled it.
At last the town mouse asks: ‘Where’s the pleasure, my friend,
In barely surviving, in this glade on a steep ridge?
Wouldn’t you prefer the crowded city to these wild woods?
Come with me, I mean it. Since all terrestrial creatures
Are mortal, and there’s no escape from death for great
Or small, then live happily, good friend, while you may
Surrounded by joyful things: mindful while you live
How brief existence is.’ His words stirred the country mouse,
Who scrambled lightly from his house: then the two
Took their way together as proposed, eager to scurry
Beneath the city walls in darkness. And now night
Occupied the zenith, as the pair of them made tracks
Through a wealthy house, where **covers dyed scarlet**
Glowed on ivory couches, and baskets piled nearby
Held the remains of all the courses of a magnificent
Feast, that had been celebrated the previous evening.
Once the town mouse had seated the country mouse
Amongst the purple, he rushed about like a waiter,
The host serving course after course, performing the role
Himself, and not unlike a slave first tasting what he served.
The country-mouse at ease enjoyed the change of style,
Playing the contented guest amongst all the good things,
When suddenly a great crashing of doors, shakes them
From their places. They run through the hall in fear, stricken*



*By greater panic when the high hall rings to the barking
Of Molossian hounds. Then says the country-mouse: 'This
Life's no use to me: and so, farewell: my woodland hole,
And simple vetch, safe from such scares, they'll do for me.'*

Remember talking about **heliotropism** in [sunflower](#) where the non-flowering plant faces the rising sun (east) in the morning, tracks the sun during the day, faces the setting sun (west) in the evening and then rotates to meet the rising sun (east) in the morning? Varying light direction is necessary to “train” the plants but the plants soon develop a “habit.” That is, the direction they face is independent of the direction of the sun. Shibaoka and Yamaki (1959) and Atamian et al. (2016) found that when they rotated a plant 180° at noon (arrow) the plant faced east in the evening, and every other evening and west in the morning and every other morning for four days. Thus, once the plant developed the “habit” the direction the plant faced depended on an entrained endogenous circadian rhythm and not on the direction of the sun.



By the way, once the sunflower plant flowers, it no longer turns to face the sun, but remains facing east.



In this lecture, we have talked a lot about **time**. If time were an illusion, as the mathematical physicist's party line states, biological clocks would *not* be a fundamental scientific concept worthy of a lecture. Although I am in a minority of one, I think **time is real and absolute** and that biology with its **bio-logic** is more fundamental than current mathematical physics. See the following three videos for Brian Greene's, Michio Kaku's, and Julian Barbour's view of time:

Brian Greene in *Fabric of the Cosmos: The Illusion of Time*

<https://www.youtube.com/watch?v=9Qu9XaF2K10>

Michio Kaku in *The True Nature of Time*

<https://www.youtube.com/watch?v=2TiQidGPHA4>

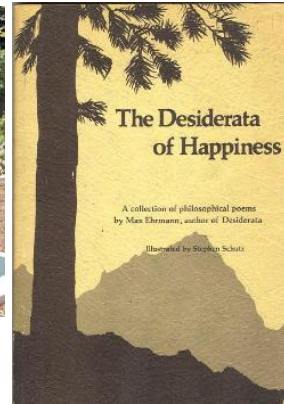
Julian Barbour on *Does Time Exist?*

https://www.youtube.com/watch?v=KkjXuS_Z1ds

I think that the **present** or **now** is fleeting, but as a part of the **universe**, you are also connected to its **past**. You are stardust in that the material that makes up your body was synthesized by stars that exploded billions of years ago. The stardust

provided the material from which the earth and all its creatures were and will be formed. All the food you eat is fundamentally synthesized using the radiant energy produced by the nuclear fusion reactions in the core of the sun. Our endogenous clocks are timed with the rotation of the earth on its axis and synchronized by the sunrise.

You are, as **Max Ehrmann** (1927) wrote in the poem *Desiderata*, which is Latin for *desired things*, “...**a child of the universe** no less than the trees and the stars; you have a right to be here.”



Desiderata: recited by Les Crane (1971), a radio and television personality, a civil rights activist mentioned in Phil Ochs's song *Love Me, I'm a Liberal*, and responsible for creating the Top 40:

https://www.youtube.com/watch?v=398_oV5ovyw

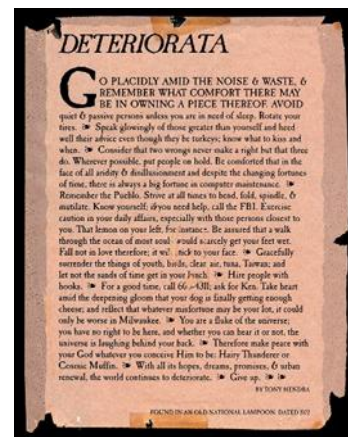
Recited by Leonard Nimoy (Mister Spock):

<https://www.youtube.com/watch?v=ZZJ1fJTzFE>

Richard Burton: <https://www.youtube.com/watch?v=GmHl0ZhhZLc>

Deteriorata (1972): a Parody by National Lampoon:

<https://www.youtube.com/watch?v=Ey6ugTmCYMk>



Over the semester we have considered time as an independent variable on which we could order various events. John F. Kennedy spoke about “our time” at the University of California at Berkeley on March 23, 1962:



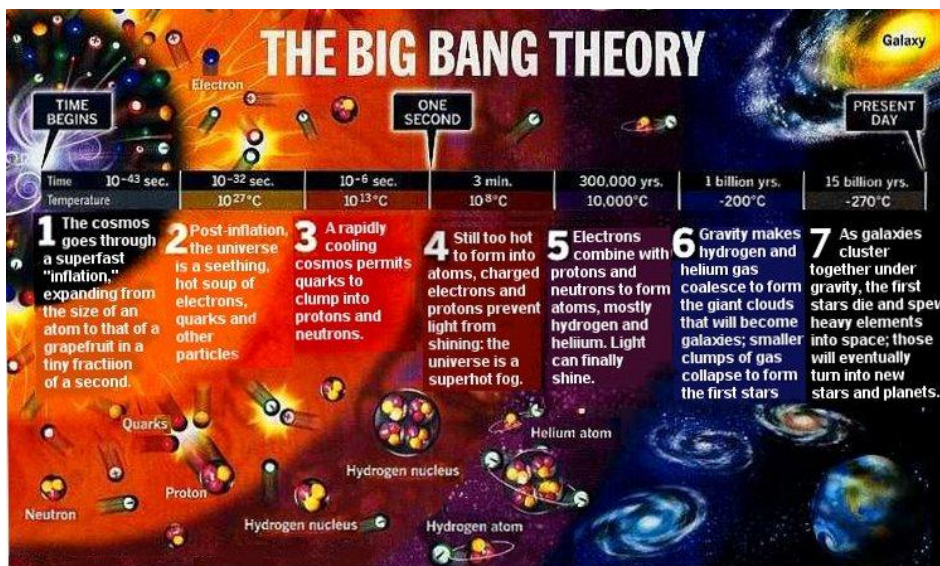
“‘Knowledge is the great sun of the firmament,’ said Senator Daniel Webster. ‘Life and power are scattered with all its beams.’ In its light, we must think and act not only for the moment but for our time. I am reminded of the story of the great French Marshal Lyautey, who once asked his gardener to plant a tree. The gardener objected that the tree was slow-growing and would not reach maturity

for a hundred years. The Marshal replied, 'In that case, there is no time to lose, plant it this afternoon.' Today a world of knowledge--a world of cooperation--a just and lasting peace--may be years away. But we have no time to lose. Let us plant our trees this afternoon.'

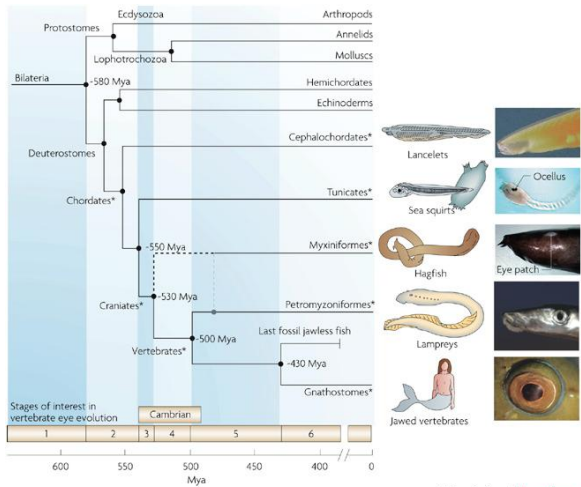
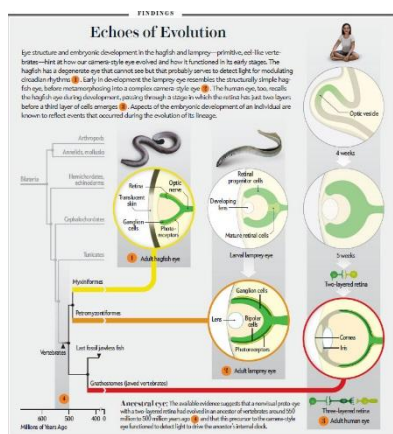
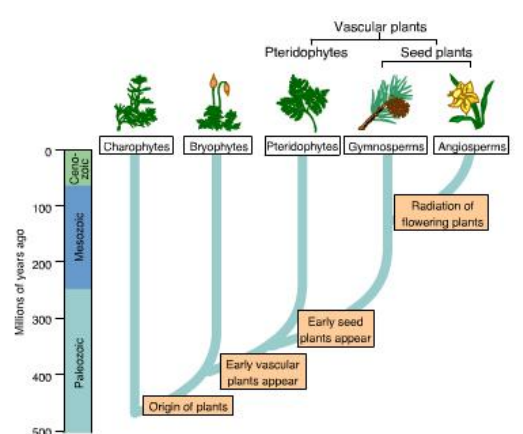
Here is a crayon [drawing](#) by John Fitzgerald Kennedy created around 1929-1930.



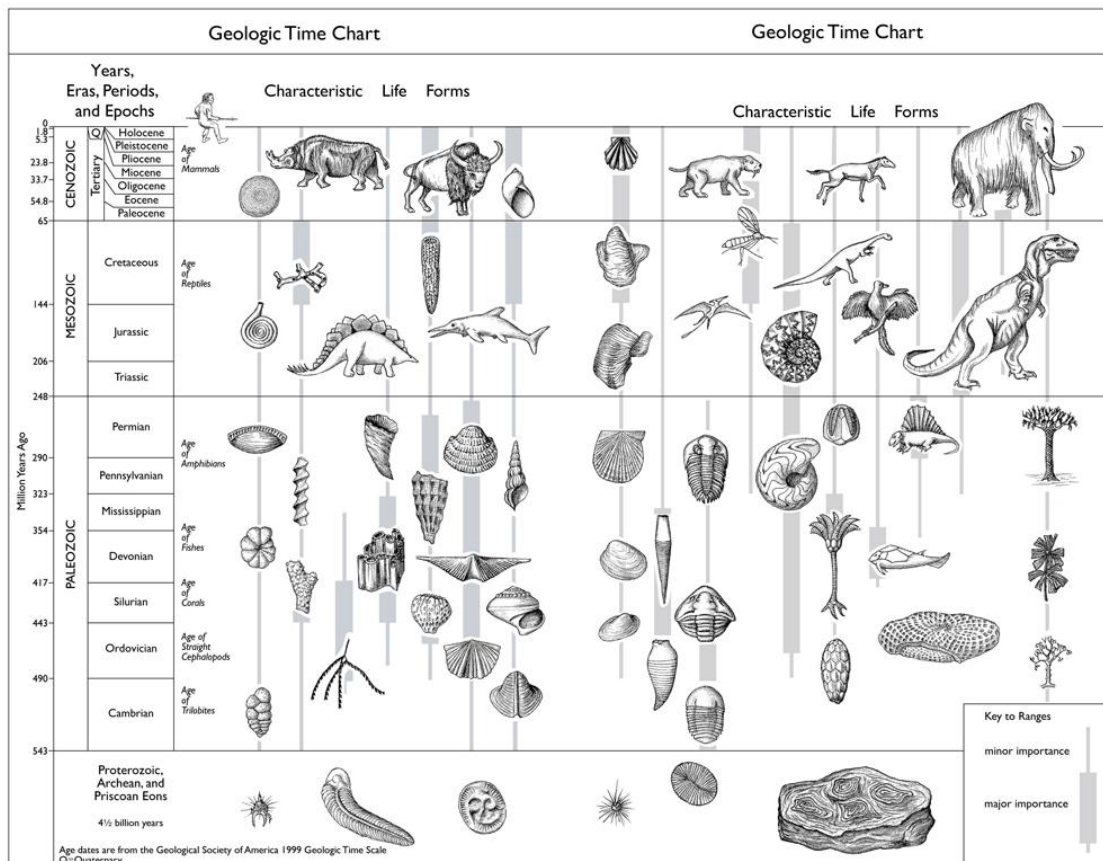
We have looked at the **big bang** in terms of astronomical time.



We have looked at the **biogenic origin of oxygen**, the **evolution of the eye**, and the **plants found in coal balls** in terms of geological time.



Below is a chart of geological time where the Carboniferous is split into the Mississippian and Pennsylvanian.



When we talked about the chemical history of a candle and charcoal, we considered our cultural history in terms of cave art produced 35,000 years ago:

Cultural history

The demands of complex technology may have pushed human culture to accelerate, though it seems to have evolved not steadily but in leaps and bounds

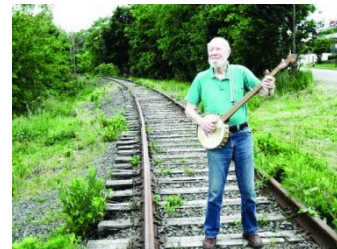
©NewScientist



In so many ways, time is necessary for musicians. Without time, there is no music. There are many songs about time:

Solomon (Ecclesiastes 3), and later **Pete Seeger** and all who covered his song, [Turn! Turn! Turn! \(to Everything There Is a Season\)](#) considered the nature of time and realized that *"There is a time for everything, and a season for every activity under the heavens: a time to be born and a time to die, a time to plant and a time to uproot, a time to kill and a time to heal, a time to tear down and a time to build, a time to weep and a time to laugh, a time to mourn and a time to dance, a time to scatter stones and a time to gather them, a time to embrace and a time to refrain from embracing, a time to search and a time to give up, a time to keep and a time to throw away, a time to tear and a time to mend, a time to be silent and a time to speak, a time to love and a time to hate, a time for war and a time for peace."*

Other songs about time:



As Time Goes By sung by Dooley Wilson:

<https://www.youtube.com/watch?v=zaAqze8ly4Y>

As Time Goes By sung by Binnie Hale (1932) with original lyrics about Einstein:

<https://www.youtube.com/watch?v=iBGDg9w5AtI>

Time is on my Side sung by the Rolling Stones:

<https://www.youtube.com/watch?v=XzcWwmwChVE>

Time after Time sung by Cyndi Lauper:

<https://www.youtube.com/watch?v=h0NkCvFD5r4>

Rock Around the Clock sung by Bill Haley and the Comets:

<https://www.youtube.com/watch?v=F5fsqYctXgM>

Time sung by Pink Floyd:

<https://www.youtube.com/watch?v=JwYX52BP2Sk>

Does Anyone Really Know What Time It Is? Sung by Chicago:

https://www.youtube.com/watch?v=7uy0ldI_1HA

Time in a Bottle sung by Jim Croce:

<https://www.youtube.com/watch?v=dO1rMeYnOmM>

Time Warp from Rocky Horror Picture Show:

<https://www.youtube.com/watch?v=tkplPbd2f60>

Feels Like the First Time sung by Foreigner:

https://www.youtube.com/watch?v=qHDy_b33cCQ

The Longest Time sung by Billy Joel:

https://www.youtube.com/watch?v=a_XgQhMPeEQ

Now's the Time sung by The Hollies:

<https://www.youtube.com/watch?v=WBfFrNpjZmc>

Now's the Time played by Charlie Parker:

<https://www.youtube.com/watch?v=ryNtmkfeJk4>

The Times They Are a Changin' sung by Bob Dylan:

https://www.youtube.com/watch?v=e7qQ6_RV4VQ

Summertime Blues by Eddie Cochran:

<https://www.youtube.com/watch?v=HWbXCz9UZYo>

Wintertime sung by the Steve Miller Band:

https://www.youtube.com/watch?v=S_rZ7to0rqQ

Summertime sung by Ella Fitzgerald and Louis Armstrong:

https://www.youtube.com/watch?v=lnXLVTi_m_M

Springtime for Hitler from The Producers:

<https://www.youtube.com/watch?v=BCIHUmjKD9U>

Funny How Time Slips Away sung by Willie Nelson:

<https://www.youtube.com/watch?v=iZaZqx9v3dU>

Night Time is the Right Time sung by Ray Charles:

<https://www.youtube.com/watch?v=PuNzqDUvods>

Blues in Time performed by Gerry Mulligan and Paul Desmond:
<https://www.youtube.com/watch?v=nhMUnYM2UPg>
Hard Time Killing Floor Blues from O Brother, Where Art Thou?
<https://www.youtube.com/watch?v=fhRmCMWdRqM>
Evening: The Sunset-Twilight Time sung by the Moody Blues:
https://www.youtube.com/watch?v=Bbs_EBRnuBw
Long Time Gone sung by Crosby, Stills & Nash:
<https://www.youtube.com/watch?v=2DUqplxIcNk>
Clocks sung by Coldplay:
https://www.youtube.com/watch?v=d020hcWA_Wg
Time After Time played by Miles Davis
<https://www.youtube.com/watch?v=FpZHjvFXprk>
100 Years by Five for Fighting
https://www.youtube.com/watch?v=tR-qQcNT_fY

The Poets also write about time:

Acquainted with the Night by Robert Frost

*I have been one acquainted with the night.
I have walked out in rain --and back in rain.
I have outwalked the furthest city light.*

*I have looked down the saddest city lane.
I have passed by the watchman on his beat
And dropped my eyes, unwilling to explain.*

*I have stood still and stopped the sound of feet
When far away an interrupted cry
Came over houses from another street,*

*But not to call me back or say good-bye;
And further still at an unearthly height
One luminary clock against the sky*

*Proclaimed the time was neither wrong nor right.
I have been one acquainted with the night.*

The Paradox of Time by Henry Austin Dobson

*Time goes, you say? Ah no!
Alas, Time stays, we go;
Or else, were this not so,
What need to chain the hours,
For Youth were always ours?
Time goes, you say?-ah no!*

*Ours is the eyes' deceit
Of men whose flying feet
Lead through some landscape low;
We pass, and think we see
The earth's fixed surface flee:-
Alas, Time stays,-we go!*

*Once in the days of old,
Your locks were curling gold,
And mine had shamed the crow.
Now, in the self-same stage,
We've reached the silver age;
Time goes, you say?-ah no!*

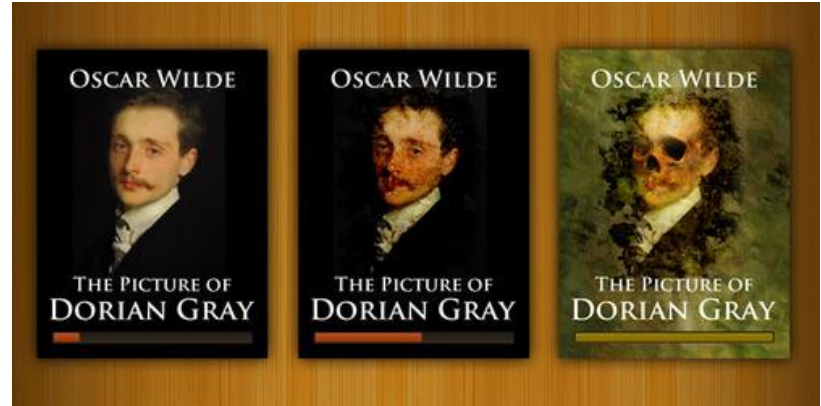
*Once, when my voice was strong,
I filled the woods with song
To praise your 'rose' and 'snow';
My bird, that sang, is dead;
Where are your roses fled?
Alas, Time stays,-we go!*

*See, in what traversed ways,
What backward Fate delays
The hopes we used to know;
Where are our old desires?-
Ah, where those vanished fires?
Time goes, you say?-ah no!*

How far, how far, O Sweet,

*The past behind our feet
Lies in the even-glow!
Now, on the forward way,
Let us fold hands, and pray;
Alas, Time stays, -we go!*

The Picture of Dorian Gray, written by Oscar Wilde (1891), gives an idea of what happens when we stay and time goes as in the case of Dorian Gray.



Various ideas of time have been expressed by artists.

Engraved by Phillips Galle after Pieter Bruegel's (1574) "*The Triumph of Time*"

<https://www.youtube.com/watch?v=NI0RXP0YioM>



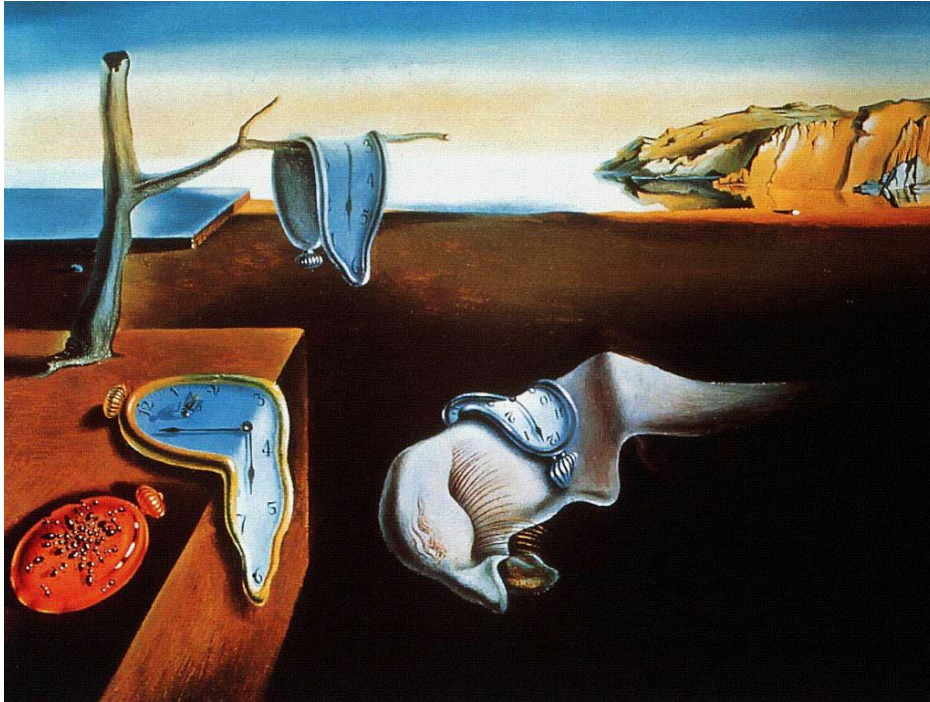
Agnolo Bronzino's (1545) *Venus, Cupid, Folly and Time*



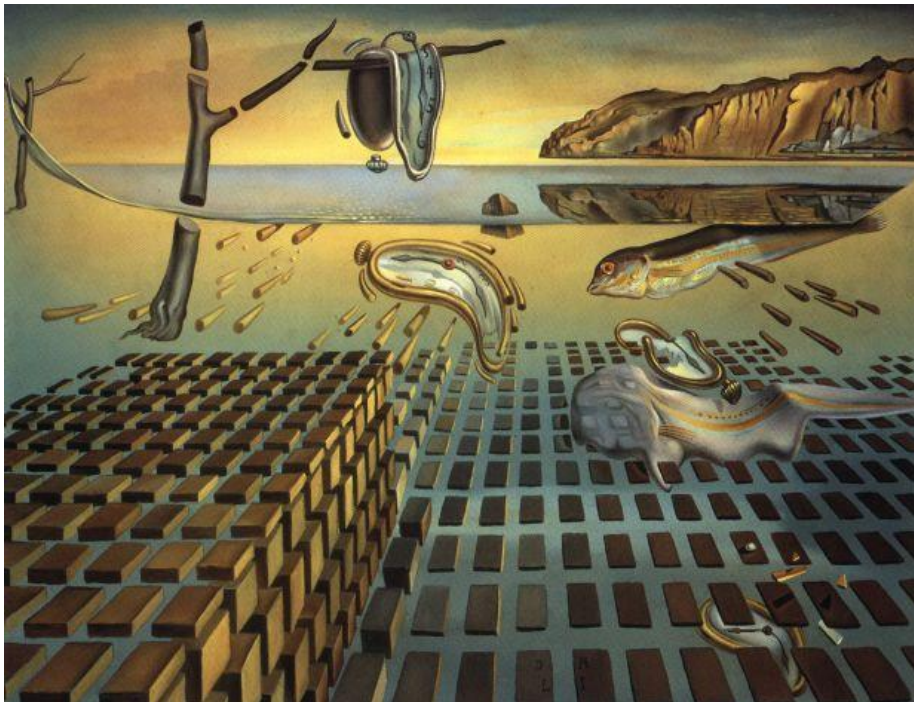
Antonio de Pereda's (1632-1636) *Allegory of Vanity*



Salvador Dali's (1931) *The Persistence of Memory*



And Salvador Dali's (1954) *The Chromosome of a Highly-coloured Fish's Eye Starting the Harmonious Disintegration of the Persistence of Memory*



Alighiero y Boetti's (1968) *Gemelli* where he is holding hands with himself.



Julie De Waroquier's (2011) *The Weight of Time*



And movies: Harold Lloyd hanging from a clock in *Safety Last* (1923)

<https://www.youtube.com/watch?v=VFBYJNAapyk>



This picture was also used in Christian Marclay's (2010) *The Clock*

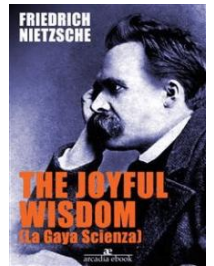
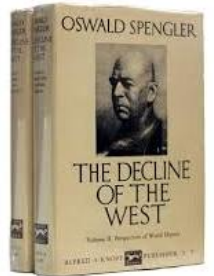
<https://www.youtube.com/watch?v=BXbQw0rE5UE>

Harold "Doc" Edgerton captured an "instant of time" with a strobe light.

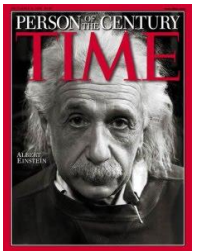


A **secular world**, from the Latin word *saecularis* meaning "temporal" should be a world that believes that time is fundamental. After all, if time is an illusion, the whole secular world is an illusion.

As a consequence of World War One (1914-1918), intellectuals and artists sought to return to another era characterized by **Johann Wolfgang von Goethe's** holistic and romantic physics rather than Isaac Newton's classical physics based on logic, with the machine guns and airplanes it produced. It also shunned classical chemistry based on logic, along with the poison gas it produced. In fact, in this new era, anything that pointed to the classical, logical, and absolute was denigrated and anything that supported the fundamental nature of the relative was celebrated. The writings of **Friedrich Nietzsche** (*The Joyous Wisdom*) and **Oswald Spengler** (*The Decline of the West*) that **vilified the absolute and celebrated the relative** were widely read. Readers hoped that society would enter a period of rejuvenation while leaving the period of decay behind.



Following World War One, which underscored the decay of Western Civilization, the idea that time and space were **relative and interdependent** proposed earlier by Albert Einstein (1905) and Hermann Minkowski (1909) rather than **absolute and independent** as Isaac Newton assumed became accepted at the pinnacle of scientific thought and celebrated by the literati and other cognoscenti. The **idea of relativism** became the foundation of everything from quantum physics to morality. From 1919 on, Einstein came to be considered the smartest man on earth, and in 1999 *Time* Magazine named him Person of the Century. (In the last lecture of the semester, I will discuss how the concept of relativism influenced quantum mechanics).



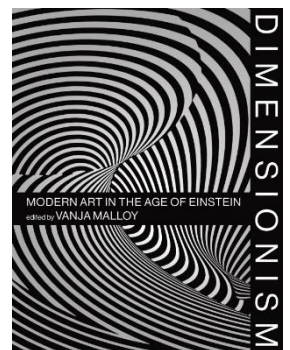
Although artists such as **Marcel Duchamp** (1911-1912; *Nude and Sad Young Man on a Train*; *Nude Descending a Staircase No. 2*; 1912; <https://www.wikiart.org/en/marcel-duchamp/all-works#!#filterName:all-paintings-chronologically,resultType:masonry>) and **Pablo Picasso** (1928, *Painter and Model*; <https://www.pablocicasso.org/picasso-paintings.jsp>) had already created art that questioned the common sense view of time and space, in 1936, the **Dimensionist Manifesto** was produced by Charles Sirató. It stated that avant-garde art should be based on Einstein and Minkowski's view of space-time (<https://www.amherst.edu/amherst-story/today/amherst-in-pictures/dimensionism-modern-art-in-the-age-of-einstein>).



THE DIMENSIONIST MANIFESTO

Paris, 1936

Dimensionism is a general movement of the arts. Its unconscious origins reaching back to Cubism and Futurism, it has been continuously elaborated and developed since then by all the peoples of Western civilization. Today the essence and theory of this great movement bursts with absolute self-evidence. Equally at the origin of Dimensionism are the European spirit's new conceptions of space-time (promulgated most particularly by Einstein's theories) and the recent technical givens of our age. The absolute need to evolve, an irreducible instinct, has sent



the avant-garde on their way toward the unknown, leaving dead forms and exhausted essences as prey for less demanding artists. We must accept—contrary to the classical conception—that Space and Time are no longer separate categories, but rather that they are related dimensions in the sense of the non-Euclidean conception, and thus all the old limits and boundaries of the arts disappear. This new ideology has elicited a veritable earthquake and subsequent landslide in the conventional artistic system. We designate the totality of relevant artistic phenomena by the term “DIMENSIONISM.” / Tendency or Principle of Dimensionism. Its formula: “N + 1.” (A formula discovered in Planist theory and then generalized, reducing to a common law the seemingly chaotic and inexplicable artistic phenomena of our age.)

ANIMATED BY A NEW CONCEPTION OF THE WORLD, THE ARTS, IN COLLECTIVE FERMENTATION (their interpenetration) HAVE BEEN SET INTO MOTION AND EACH HAS ABSORBED A NEW DIMENSION. EACH HAS FOUND A NEW FORM OF EXPRESSION INHERENT TO THE NEXT DIMENSION, OBJECTIFYING THE WEIGHTY INTELLECTUAL CONSEQUENCES OF THIS FUNDAMENTAL CHANGE. Thus, the Dimensionist tendency has led to:

I. ...Literature leaving the line and entering the plane. Calligrammes. Typograms.

Planism. (preplanism)

Electric Poems.

II. ...Painting quitting the plane and entering space. Painting in space

“Constructivism”

Spatial Constructions.

Poly-Material Constructions.

III. ...S c u l p t u r e stepping out of closed, immobile, dead forms, that is, out of forms conceived of in three-dimensional Euclidean space—in order to appropriate for artistic expression Minkowski's four-dimensional space. It has been, above all, "solid" sculpture (classical sculpture) that has opened itself up, first to inner space, then to movement, and is transformed into: Perforated Sculpture. Open Sculpture. Mobile Sculpture. Motorized Objects. And after this a completely new art form will develop: Cosmic Art (The Vaporization of Sculpture, Synos-Sense Theater, provisional denominations.) The artistic conquest of four-dimensional space / to date an artistic vacuum /. Rigid matter is abolished and replaced by vaporized materials. Instead of looking at objects of art, the person becomes the center and the subject of creation, and creation consists of sensorial effects operating in a closed cosmic space. This is how one would most concisely summarize the essence of Dimensionism: Deductive with respect to the past. Inductive with respect to the future. Alive in the present.

Helen Lundeberg's (1935) *Double Portrait of the Artist in Time* captures the artist at different times (<https://americanart.si.edu/artist/helen-lundeberg-3018>).



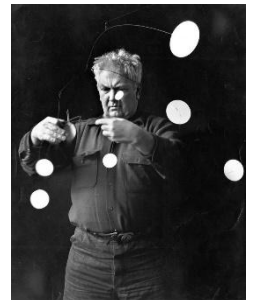
Helen Lundeberg's (1944) *Self Portrait* captures warped space.



Dorothea Tanning's (1945) *The Truth about Comets* captures transformation in time (<https://www.dorotheatanning.org/life-and-work/view/243/>).



Alexander Calder created mobiles to capture four dimensions of objects: three dimension in space and one in time (<http://www.calder.org/work/by-category/hanging-mobile>). This one is called *Triple Gong* (1948).



Let's unpack the meaning of $3 + 1 = 4$ -dimensionalism.

Four dimensionalism usually means that objects cannot be described simply in terms of absolute space, with its three dimensions and absolute and independent time, with its one dimension but must be described in terms of an interdependent space time relative to the observer. But it can also mean that objects can be described simply in absolute space and absolute time—but not in absolute three-dimensional space alone without any representation of time. The paintings and mobile above can be interpreted in terms of the relative interdependent or absolute independent conception of time and space.

Let's return to the **Ship of Theseus**. When speaking in terms of three-dimensional space alone, we have to assume that objects such as the Ship of Theseus are eternally stable and unchanging. However, as long as the **temperature** is greater than **absolute zero**, this is in direct contradiction to the **second law of thermodynamics**, and thus to me untenable. Thus, even without replacing the wooden boards, the Ship of Theseus continually evolves and deteriorates, unless energy is added. This means that there is no single definition of the Ship of Theseus, and we must always define which Ship of Theseus we are talking about.

Aside: Remember that **statistical mechanics**, which is considered more fundamental than the second law of thermodynamics by the cognoscenti, also introduces time—but time that is reversible and there are no unique moments in time. Thus, statistical mechanics allows for the deteriorated Ship of Theseus to return to its original state in principle, although the chance of it is unlikely.

Let's not be too simplistic. Is the house we live in the same house as the one we bought? If not, do we still have to pay a mortgage on this house? If not, do we even own the house? Let's use **common sense**, in science as well as society.



Tom Stoppard was not too simplistic when he wrote about the importance of temperature in considering the irreversibility of time in his play *Arcadia* (Act II Scene 3).

Hannah: What did she see?

Valentine: That you can't run the film backwards. Heat was the first thing which did not work that way. Not like Newton. A film of a pendulum, of a ball falling through the air—backwards, it looks the same.



Tom Stoppard's
ARCADIA
Directed by David Leveaux

ARCADIA opens at the Ethel Barrymore Theatre (243 W. 47th Street) on March 17, 2011.

Pictured (L-R): Bel Powley, Raúl Esparza, Lia Williams and Tom Riley

© Carol Rosegg, 2011

Hannah: The ball would be going the wrong way.

Valentine: You'd have to know that. But with heat—friction—a ball breaking a window—

Hannah: Yes.

Valentine: It won't work backwards.

Hannah: Who thought it did?

Valentine: She saw why. You can put back the bits of glass but you can't collect up the heat of the smash. It's gone.

Septimus: So the Improved Newtonian Universe must cease and grow cold. Dear me.

Valentine: The heat goes into the mix.

Thomasina: Yes we must hurry if we are going to dance.

Valentine: And everything is mixing the same way, all the time, irreversibly—



Salvador Dali

As a result of differences between Christian and Aristotelian scholarship, Étienne Tempier (1277), The Bishop of Paris issued the Condemnations of 1277 on March 7, many of which dealt with the **nature of time**. For example, *Quod evum*

et tempus nichil sunt in re, Sed solum in apprehensione or “**It is heretical to maintain that the age and time do not exist in reality but only in the mind.**”

George Santayana (1905) wrote in *The Life of Reason: Reason in Common Sense* (p. 284): “Progress, far from consisting in change, depends on retentiveness. When change is absolute there remains no being to improve and no direction is set for possible improvement: and when experience is not retained, as among savages, infancy is perpetual. **Those who cannot remember the past are condemned to repeat it.**”

The condemnations of 1277 were based on the **assumption** that the logic of the Catholic Church was infallible.

Condemnations of today are often based on the **assumption** that the logic of the scientific consensus is infallible.



Remember what **Richard Feynman** (1969) said in a speech entitled, *What is Science?*: “As a matter of fact, I can also define science another way: Science is the belief in the ignorance of experts. When someone says, ‘Science teaches such and such,’ he is using the word incorrectly. Science doesn’t teach anything; experience teaches it. If they say to you, ‘Science has shown such and such,’ you might ask, ‘How does science show it? How did the scientists find out? How? What? Where?’ It should not be ‘science has shown’ but ‘this experiment, this effect, has shown.’ And you have as much right as anyone else, upon hearing about the experiments--but be patient and listen to all the evidence--to judge whether a sensible conclusion has been arrived at.”

To get to know Feynman a little better, here is a letter we wrote to his wife Arline who died very young.

October 17, 1946

D'Arline,

I adore you, sweetheart.

I know how much you like to hear that — but I don't only write it because you like it — I write it because it makes me warm all over inside to write it to you.

It is such a terribly long time since I last wrote to you — almost two years but I know you'll excuse me because you understand how I am, stubborn and realistic; and I thought there was no sense to writing.

But now I know my darling wife that it is right to do what I have delayed in doing, and that I have done so much in the past. I want to tell you I love you. I want to love you. I always will love you.

I find it hard to understand in my mind what it means to love you after you are dead — but I still want to comfort and take care of you — and I want you to love me and care for me. I want to have problems to discuss with you — I want to do little projects with you. I never thought until just now that we can do that. What should we do. We started to learn to make clothes together — or learn Chinese — or getting a movie projector. Can't I do something now? No. I am alone without you and you were the "idea-woman" and general instigator of all our wild adventures.

When you were sick you worried because you could not give me something that you wanted to and thought I needed. You needn't have worried. Just as I told you then there was no real need because I loved you in so many ways so much. And now it is clearly even more true — you can give me nothing now yet I love you so that you stand in my way of loving anyone else — but I want you to stand there. You, dead, are so much better than anyone else alive.

I know you will assure me that I am foolish and that you want me to have full happiness and don't want to be in my way. I'll bet you are surprised that I don't even have a girlfriend (except you, sweetheart) after two years. But you can't help it, darling, nor can I — I don't understand it, for I have met many girls and very nice ones and I don't want to remain alone — but in two or three meetings they all seem ashes. You only are left to me. You are real.

My darling wife, I do adore you.

I love my wife. My wife is dead.

Rich.

PS Please excuse my not mailing this — but I don't know your new address.

Earlier we talked about how the relationship between the earth and the moon affected the length of day over geological time. Here is a picture of *The Earth from the moon* from *Le Monde Physique* by Amédée

Guillemin (1882). This book also has many figures that review the optics that we have learned this semester.



Fig. 8. — Le clair de terre sur la Lune.



Fig. 9. — Cône d'ombre d'un corps opaque. Ombre portée.



Fig. 18. — Images produites à l'intérieur de la chambre obscure.

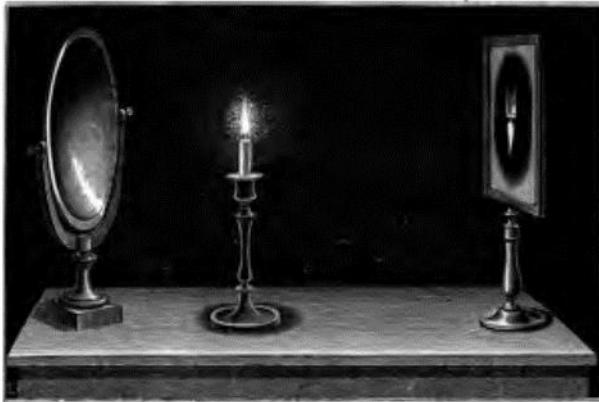


Fig. 50. — Miroir concave. Image renversée, plus grande que l'objet.



Fig. 46. — Image renversée d'une bougie.



Fig. 39. — Formation des images vues par réflexion sur un miroir plan.



Fig. 49. — Miroir concave. Image renversée, plus petite que l'objet.



Fig. 51. — Miroir concave. Image virtuelle, droite et plus grande que l'objet.



Fig. 58. — Image droite virtuelle dans les miroirs sphériques convexes.

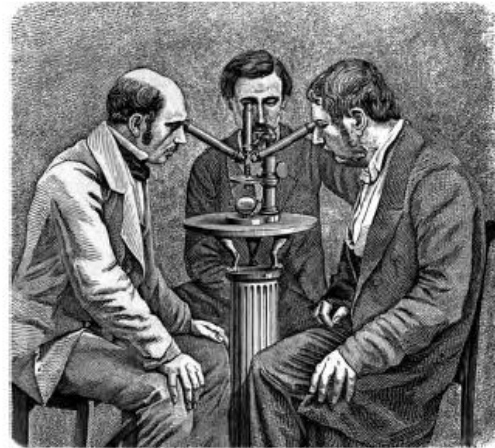


Fig. 287. — Microscope à trois corps pour les observations simultanées.

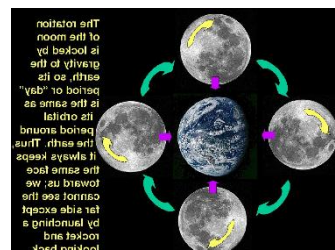


Fig. 78. — Phénomène de réflexion totale.

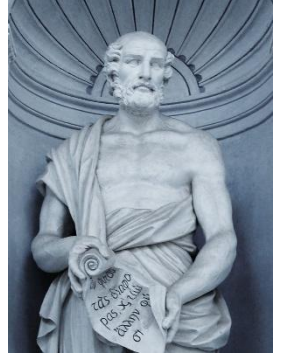


Fig. 149. — Structure de la flamme d'une bougie et coupe de la même flamme.

Aside: Since the period of rotation of the moon around its axis is 27 days and the period of the moon's orbit around the earth is also 27 days, the moon keeps the same side facing the earth and does not seem to rotate and the dark side of the moon does get illuminated by the sun!



According to Theophrastus (371- 287 BC): Συνεχές τε ... πολυτελές ἀνάλωμα εἶναι τὸν χρόνον. *Time is the most valuable thing a man can spend.*



One more thing about sleep. According to **W. H. Auden**, a professor is “*one who talks in someone else’s sleep.*”



In a [letter](#) to Hezekiah Niles, John Adams (February 13, 1818) described the unification of the thirteen colonies using a clock metaphor:

*The colonies had grown up under constitutions of government so different; there was so great a variety of religions; they were composed of so many different nations; their customs, manners, and habits had so little resemblance; and their intercourse had been so rare and their knowledge of each other so imperfect that to unite them in the same principles in theory and the same system of action was certainly a very difficult enterprise. The complete accomplishment of it in so short a time and by such simple means was perhaps a singular example in the history of mankind. **Thirteen clocks were made to strike together: a perfection of mechanism which no artist had ever before effected.***

