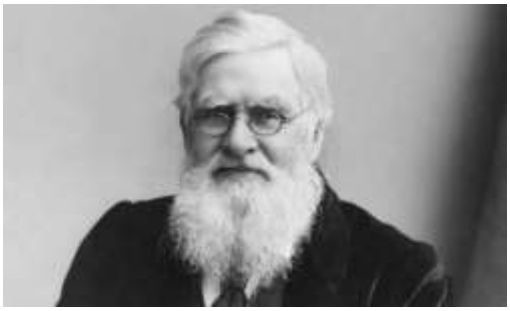
First Light: Big Bang Cosmology and the Origin of Life

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.



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 honestty probably do not have a selective advantage in terms of producing more progeny. 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."

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.*

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*?

On February 10, 2014, The American Institute of Biological Sciences (http://ncse.com/news/2014/02/aibs-opposes-oklahomas-antiscience-bill-0015389 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 being debated in many states: http://ncse.com/news.

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 *Χαος*), 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. 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.


ESPERIENZE
Intorno alla Generazione
DEGL'INSETTI
FATTE
DA FRANCESCO REDI
CARLO DATI.

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?

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. https://archive.org/details/scientificmemoi01huxlgoog

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 **Lord Kelvin**, **Hermann von Helmholtz** (1881), **Svante Arrhenius**, **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*."





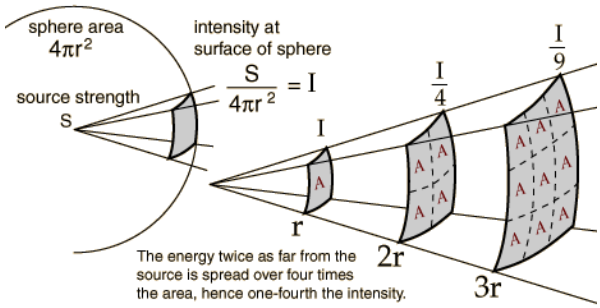
Even if the panspermia theory is true, we are still faced with the question of how living organisms originated in the universe. So although it is possible that life on Earth originated on another planet in another solar system or another galaxy, I will use **Occam's razor** and assume that **life on Earth originated from or was created from lifeless matter on Earth itself**. This does not mean that life did not

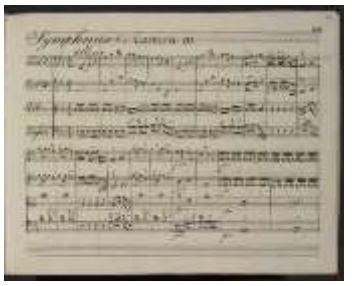
also arise from lifeless matter elsewhere in the universe, and the arguments I make apply to the origin of life anywhere. Let us now start at the beginning, the origin of the universe.

Demonstration: 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 was repeated by each person on earth (http://www.worldometers.info/world-population/), every day for a year? Why or why not?

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 Aristotle's time it was believed that earth was 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.

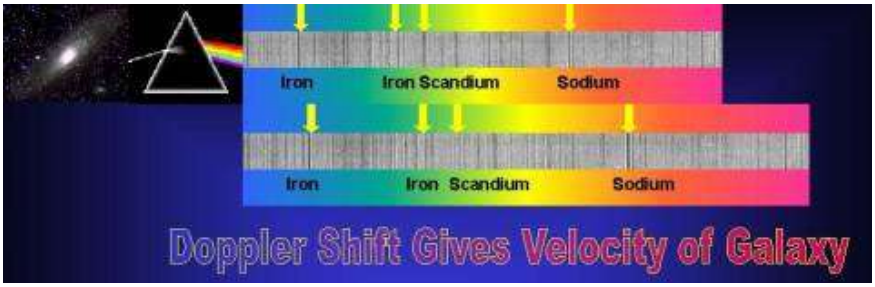




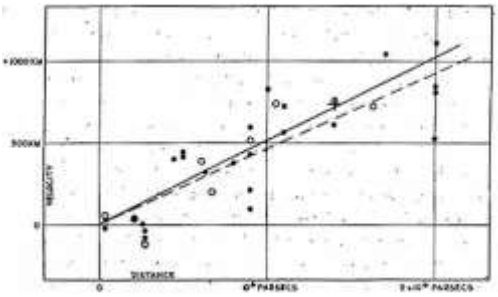
Throughout the 18th century, telescope designs improved, and **William Herschel** began to see the ***more distant stars*** which were dimmer and thus had not been seen with the older telescopes that had less light-gathering power. Herschel described light-gathering power as "*the power of penetrating 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).

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.

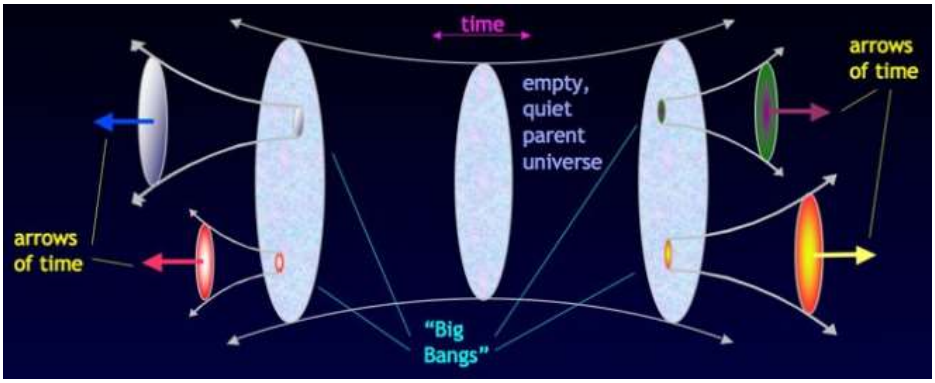
Meanwhile, **Vesto Slipher** measured the **red shifts** in the spectra of number of galaxies. Using the **Doppler Principle**, he concluded that, as a rule, the galaxies were receding from earth at tremendous velocities. We will talk more about spectral lines and red shifts next week.



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? 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 the 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!

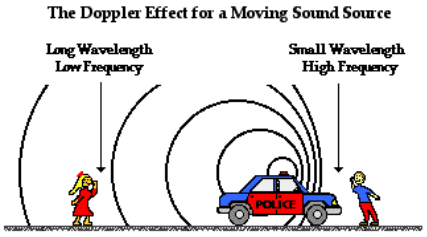


According to the modern version of the **Big Bang Theory**, at time zero, the universe exploded from an infinitesimally tiny and infinitely hot point. There was

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**.

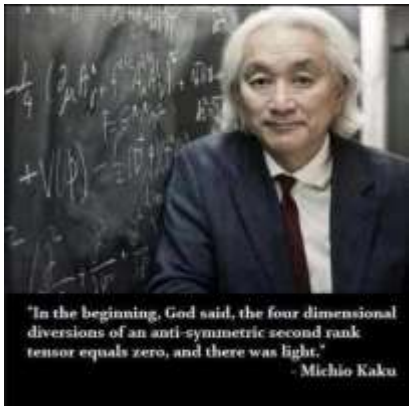
Demonstration: As the temperature (*T*) of a gas increases, it exerts more pressure (*P*) if the volume (*V*) is constant. The pressure is related to the temperature by the ideal gas law. If the container is allowed to expand and if the temperature is not held constant, the gas will cool. The ratio of 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:

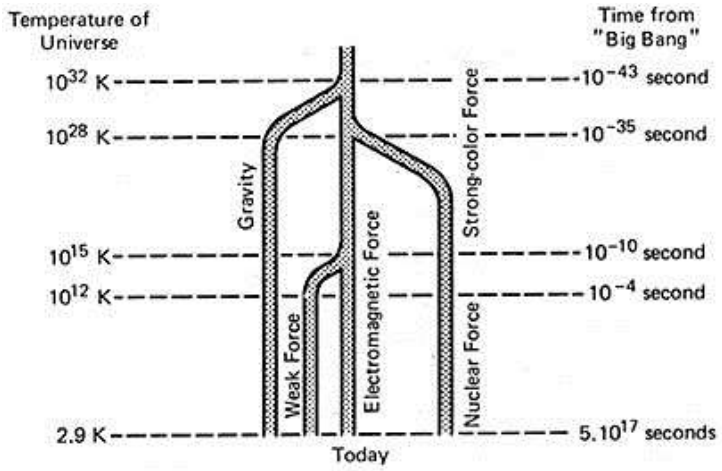


$$\text{electrical energy} = eV = kT = \text{thermal energy}$$

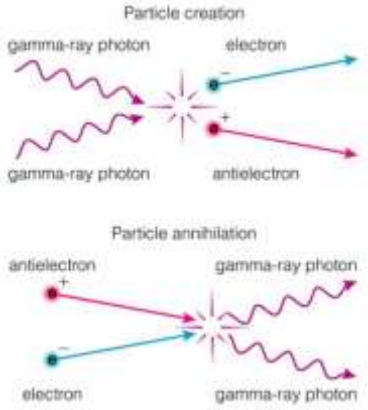
where e is the elementary charge (1.6×10^{-19} Coulombs), V is an electrical potential in Volts, and k is Boltzmann's constant (1.38×10^{-23} J/K).

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

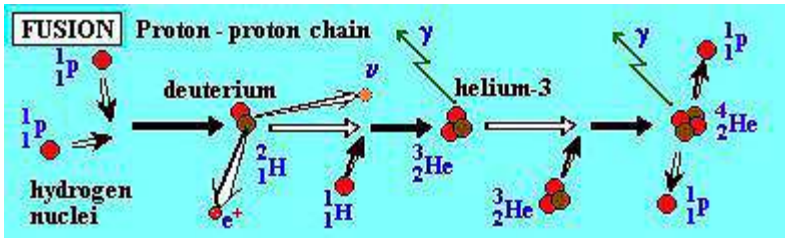
universe, the particles that carry the electroweak force separated into particles that carry the weak force and **photons**, which are the particles that carry the **electromagnetic force**.



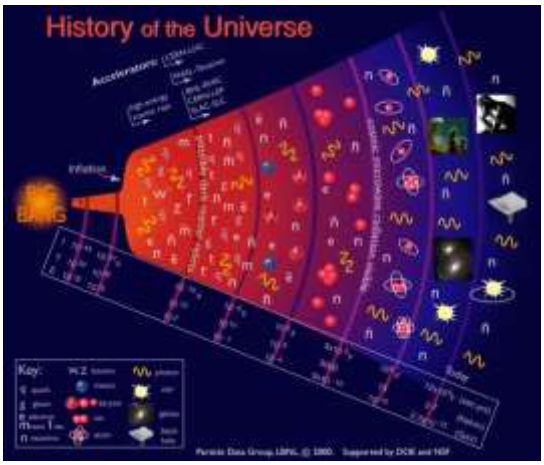
Approximately 1 millisecond after the creation of the universe, the temperature cooled enough so that electron-positron, proton-antiproton and other **matter-antimatter pairs** formed from photons and then annihilated each other to become photons again. As the universe continued to expand, particles 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.



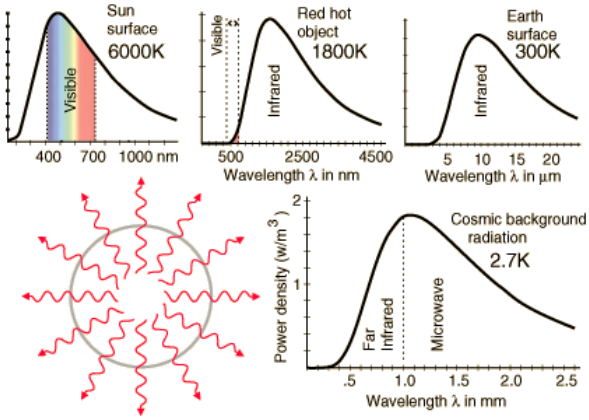
Three minutes after the big bang, the universe cooled enough to allow the formation of hydrogen and helium nuclei, in a process known as **nucleosynthesis**.



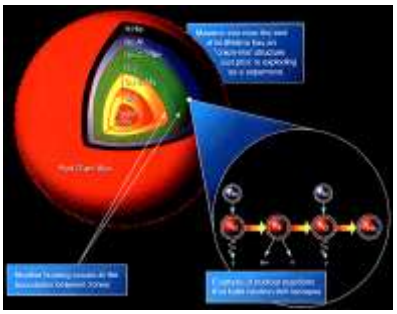
The nuclei and electrons collided with each other with energies that were too high to allow the formation of atoms. **Three hundred thousand years** after the creation of the universe, the universe cooled to about 3000 K, which is cool enough to allow the electrons to bind to the atomic nuclei and form **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.

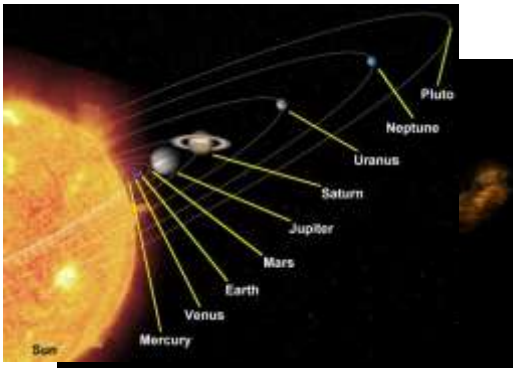


After a further **one** or **two billion years**, the atoms began to coalesce into dense areas as a result of **gravitational attraction**. The aggregation of these atoms gave rise to **stars**, including **quasars**, and collections of stars known as **galaxies**. As the atoms in the stars were pulled 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** into **helium** and other light elements, including **carbon**, **nitrogen**, **oxygen**, **sulfur**, and **phosphorous**—the **elements so important for life**.

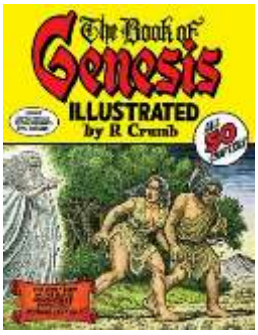


Eventually the **first-generation stars exploded**, sending fragments of dust into the universe. The energy of the explosion formed the heavier elements, including **sodium** (Na), **magnesium** (Mg), **calcium** (Ca), **iron** (Fe), and **cobalt** (Co), which were spread over the universe in the form of **cosmic dust**.

Approximately 4.6 billion years ago, on 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 gasses 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 **planets**. One of these clumps formed our home planet.

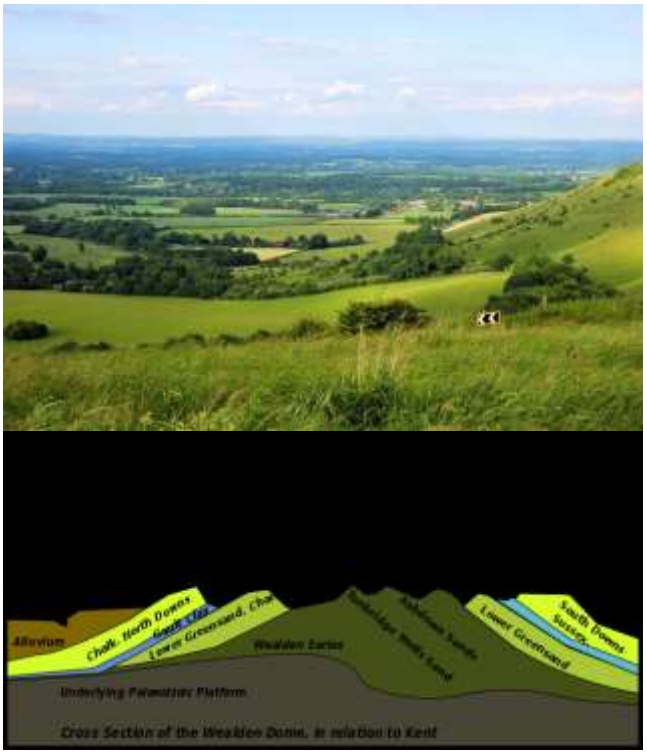


In the seventeenth century, the age of earth was determined by the theologians **James Ussher** and **John Lightfoot** by following "the begets" in the Bible. They estimated the creation of the earth to have occurred about 4000 BC. The polymath **Edmund Halley** (1715), who is well-known to you as the 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 saltness 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.

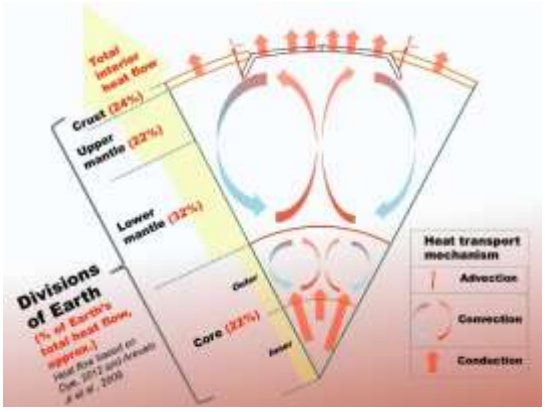
Assuming that the primeval ocean was formed by the condensation of water upon the land, and thus did not contain as much salt as it now does, **John Joly** (1899), another polymath, estimated the age of the earth to be **90 million years old**. Joly estimated the age by guessing that the total mass of the oceans is 1.322×10^{18} tons, the mass of sodium in the oceans is one percent of the mass of the oceans or 1.415×10^{16} tons, the average concentration of sodium in rivers is about 24,106 tons per cubic mile, 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 cofound. By estimating the current rate of heat flow and the current temperature of the core, Thomson concluded that "*it is quite certain*



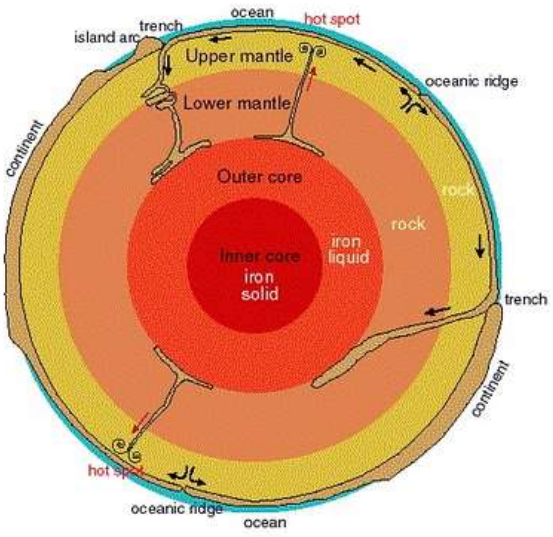
that the solar system cannot have gone on even as at present, for a ***few hundred thousand or a few million years***."

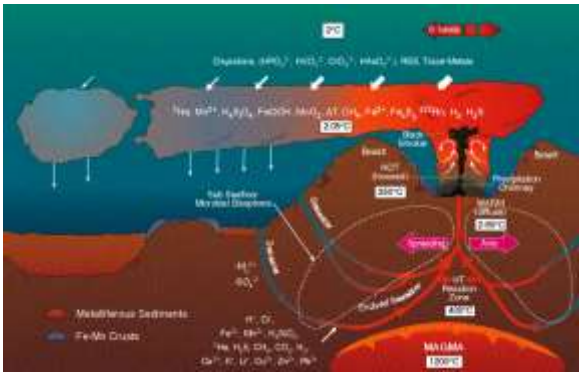
The age of the earth was estimated by **George Darwin**, Charles' son, from a determination of the present distance between the moon and the earth. Darwin assumed that initially the earth and the moon were one molten body and as a result of fission, they separated, with the moon revolving around the earth. As a result of tidal friction, the moon revolves more slowly over time and consistent with conservation of angular momentum, recedes from the earth over time. The observed rate of recession is about five inches per year. 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 (= 7.89×10^{-5} miles) per year, the moon and earth must have been in contact 3 billion years ago, making the earth even older.

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.

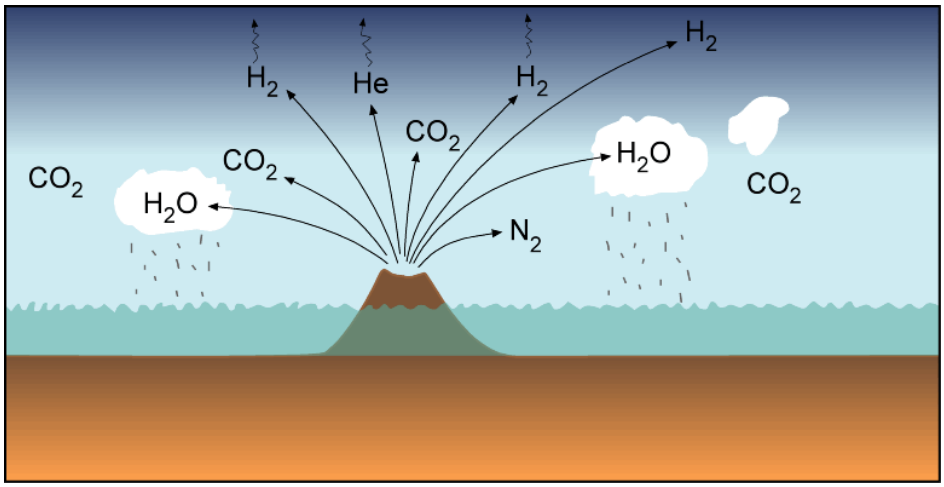
Four and a half billion years ago earth was becoming fully formed, although it was extremely hot and essentially **ocean-less** and **atmosphere-less**. Heat was primarily generated by radioactive decay in the core of the earth, although some heat may have been due to gravity pulling earth's components 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.





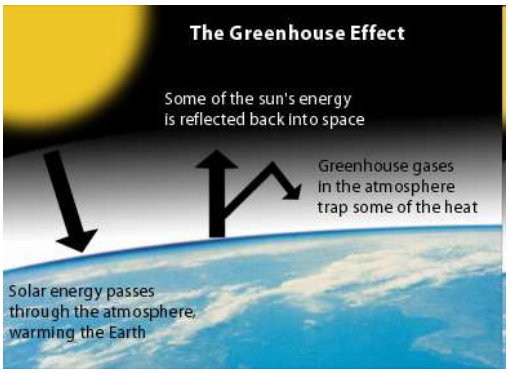
Hydrothermal vents, earthquakes, volcanism, and impacts caused gasses in rocks to be released, probably producing an atmosphere of H_2O, CO_2, N_2, as well as CO, CH_4, NH_3, and H_2S. The gravitational attraction of earth was not great enough to hold onto the lightest elements, including H_2 and He_2, 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.



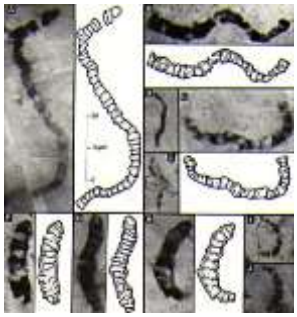
Water from outgassing reacted with CO_2 in the air to produce carbonic acid. Returning to earth as **acid rain**, the carbonic acid probably leached Ca^{2+} and Mg^{2+} from rocks and formed **limestone** ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$). **Llenroc** (Cornell spelled backwards) is formed from more recently formed limestone, most likely produced by the skeletal remains of corals.

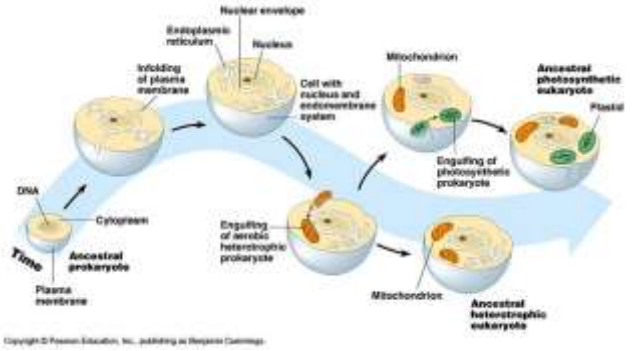
In this way, the **CO_2** was removed from the atmosphere and precipitated in sediments. Atmospheric CO_2 would have acted as a **greenhouse gas** to keep the **early earth warm**; thus knowledge of the CO_2 concentration would be useful in determining the climate of the early earth. While the actual 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.



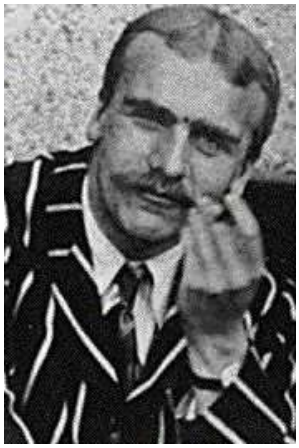
From the formation of earth 4.6 billion years ago until approximately 3.8 billion years ago, earth may have been **bombarded with meteorites or fragments of rocks** that were not included in the initial process of planet formation. Any one of these **impactors** may have hit with so much energy that 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**.

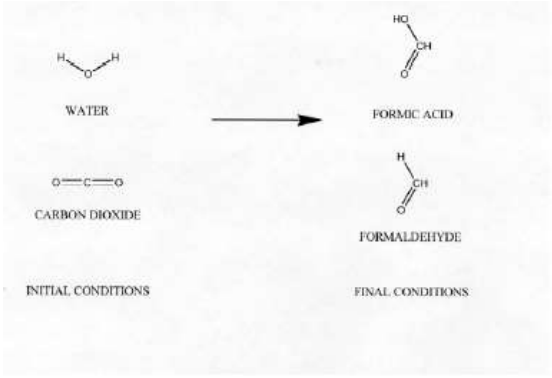


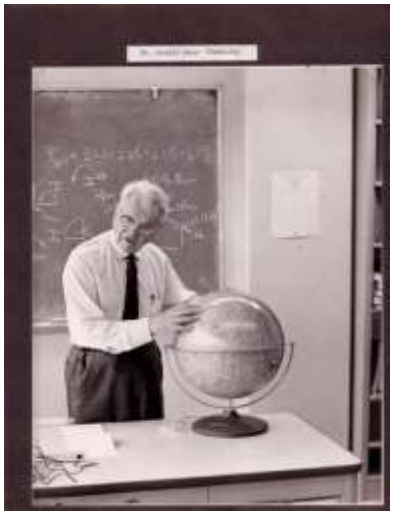


Life as we know it requires carbon-containing compounds, and we must ask: What was the **source of the organic compounds** that made up the first life on earth? It is possible that organic compounds, including urea, formaldehyde, amino acids, purines, sugars, etc., came from asteroids, comets, or meteorites. 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."*



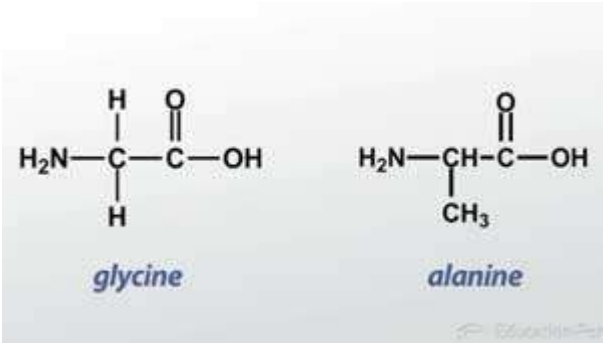
In 1951, experiments on prebiotic evolution began when **Melvin Calvin** succeeded in fixing carbon dioxide into a more reduced, organic form. They irradiated a **mixture of water and carbon dioxide** in a closed chamber with a **helium ion beam** from **Ernest Lawrence's cyclotron**. This resulted in the formation of **formic acid** and **formaldehyde**. Formic acid was first discovered by John Wray (1670) in ants (*Formica*).



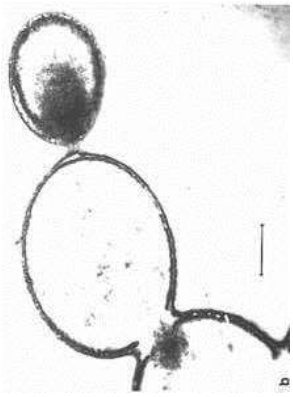


At about this same time, **Harold Urey**, who had been studying the atmosphere of Jupiter, wrote that the atmosphere of the early earth, like that of Jupiter's, may have been **reducing**, and thus may have consisted largely of hydrogen, methane, ammonia, and water. He suggested that Calvin's experiment be repeated using a **reducing**, not an oxidizing, **atmosphere**.

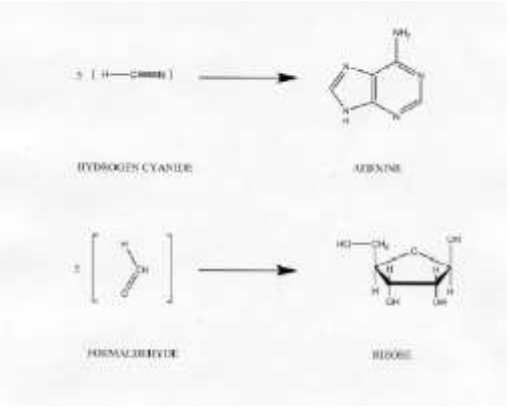
Stanley Miller, a graduate student of Urey's, created an apparatus designed to mimic this presumed early-earth condition. A gaseous mixture of methane, ammonia, hydrogen, and water was connected to a flask of boiling water. The steam created by the boiling water caused the gasses to move past electrodes, 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.

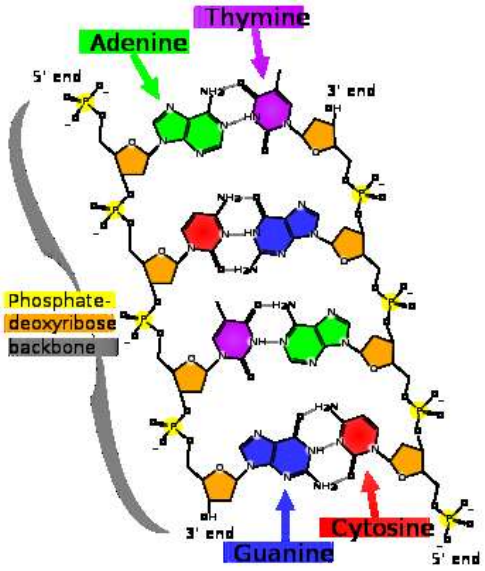


Under prebiotic conditions, amino acids can **polymerize into polypeptides** without the aid of enzymes or a template. The **peptide bonds** between the amino acids occur as a result of **dehydration reactions**. Even more complex structures like **proteinoid microspheres** can form under prebiotic conditions. 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.

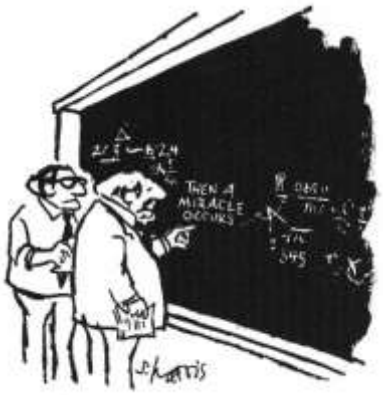


Nucleic acids can also be synthesized under early-earth conditions. Adenine can be formed from hydrogen cyanide. **Adenine** is made according to the simple overall reaction: **5 HCN ⇔ adenine**. **Ribose** and other sugars can also be made under similar conditions by the overall reaction: **5 formaldehyde (CH_2O) ⇔ ribose ($C_5H_{10}O_5$).** The adenine and ribose can lose a single water molecule and form **adenosine**. By including phosphate in the presumed early-earth conditions, nucleoside mono-phosphates, including adenosine monophosphate, guanosine monophosphate, cytidine monophosphate, thymidine monophosphate, and uridine monophosphate, as well as adenosine trisphosphate (ATP) are formed. The polymerization of **deoxyribonucleotides** would result in **DNA**.





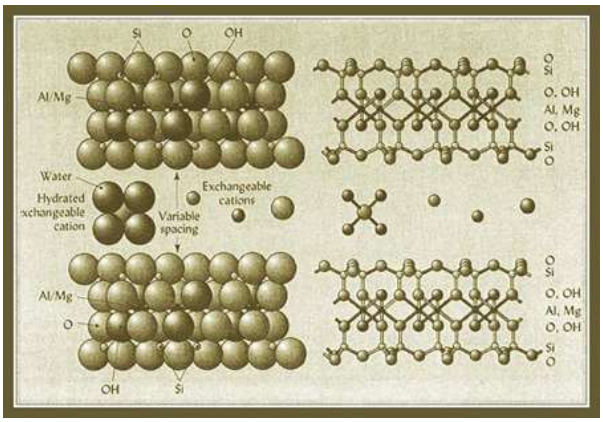
In the experiments described above, which are performed under early-earth conditions, the **yields of organic molecules and macromolecules are extremely low**. The **yields depend greatly on the reducing power** of the atmosphere used. Reducing power is related to **chemical energy** and the greater 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



"I think you should be more explicit here in step two."

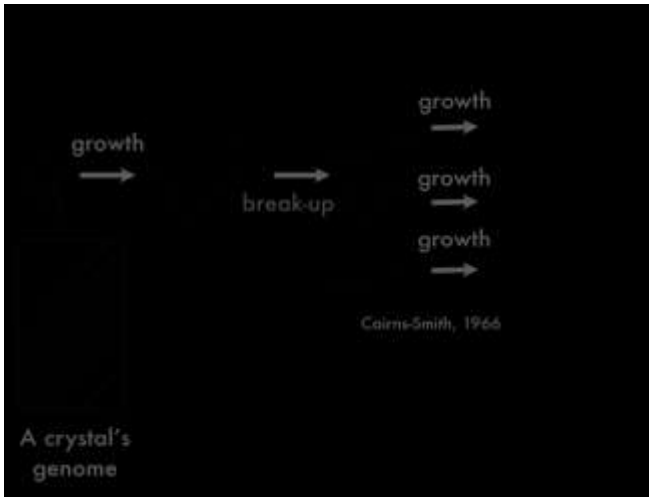
long enough time and with a large enough number of mixtures, every possible combination will eventually occur and improbable combinations eventually occur. As **Herodotus** (ca. 450 BC) said, "*If one is sufficiently lavish with time, everything possible happens*." And as **Émile Borel** suggested, with 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***."

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**.

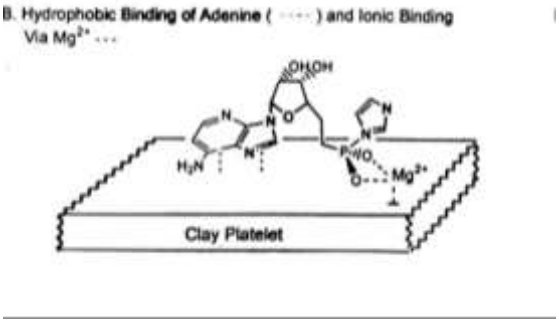


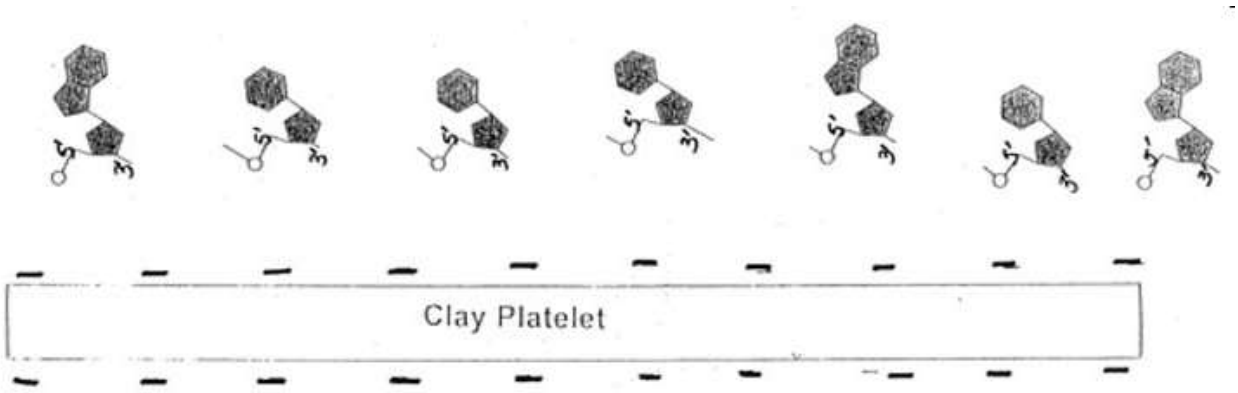
Clays are inorganic microcrystalline particles approximately 10 micrometers in diameter that are made out of hydrated aluminum silicates and other assorted cations and anions. As crazy as this idea sounds, **clays are capable of replicating themselves.**

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**.



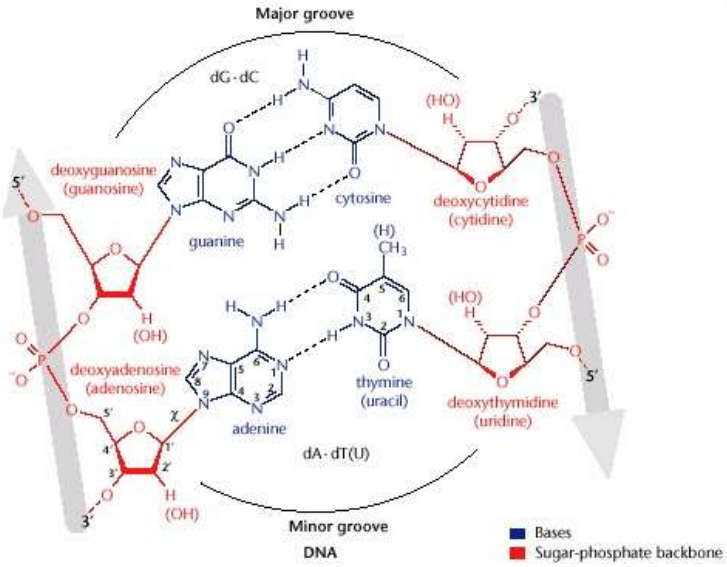
The clays may have facilitated the formation of organic molecules in prebiotic conditions. The clays may have bound nucleotides, including ATP. A given sequence of charge density on clay might have resulted in the binding and ordering of a particular linear sequence of nucleotides resulted in the performance of sequential reactions.



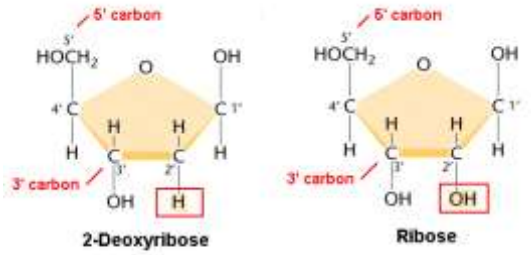


The sugar phosphates of closely bound nucleotides might have polymerized to form a backbone so that the macromolecular complex could have performed sequential reactions free in solution.

A s**equence 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.

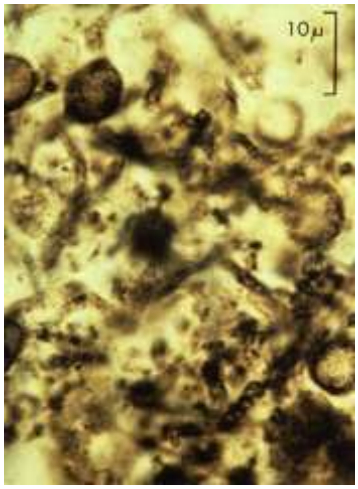


Whether clay was our ancestor, the genetic apparatus as we know it probably evolved from RNA alone, into the **trinity of molecules** that carry the **information of life**: **DNA**, **RNA**, and **protein**. DNA has an advantage over RNA as an informational molecule, in part, because its stability is 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**.



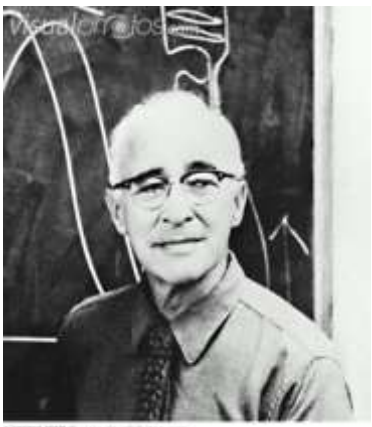
The similarities in molecules, mechanisms, metabolic pathways, and structures in living organisms point to a **single common ancestor**. Throughout history, the idea of common descent was espoused in one form or another by Empedocles, Pierre-Louis Moreau de Maupertuis (1753), Jean Lamarck (1809) and 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.*"

Charles Darwin (1859) presented evidence that since variation could be acted upon by artificial selection, evolution must take place as a **gradual** result of natural selection. **Richard Goldschmidt** (1933), who was skeptical of the well-established belief in Darwin's theory of the **gradual** origin of species by natural selection, 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.

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

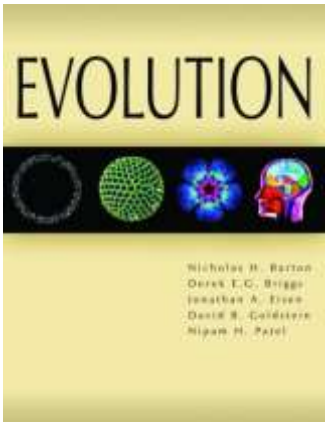
humans and primates. These cells, which are also known as Von Economo neurons, may be involved in **self-identity** and **self-awareness**. When these cells are damaged, people become "vegetables." These cells are less active in depressed people, disappear in people afflicted with Alzheimer's disease, and are more active in people with manic disorders. These cells alone are probably not sufficient to make us human.

What is the relationship between the origin of consciousness (being aware of the external world) or the origin of a **conscience** (inner knowledge) and the origin of life? 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."



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?

One more thought from George Darwin (1873) that can be found in his essay entitled, *On Beneficial Restrictions to Liberty of Marriage* published in the Contemporary Review (22:412-426): "*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?*"