

## Photosynthesis: Converting Radiant Energy into Chemical Energy The Light-Independent Reactions

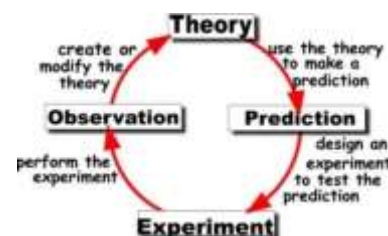
The **Laws of Nature describe, predict, and explain** how and why events occur in nature. The Laws of Nature serve as **summaries of a large number of observations and experimental results** that have taken place since the time humans began questioning. Once enounced and accepted, **the Laws of Nature 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 ....**”*

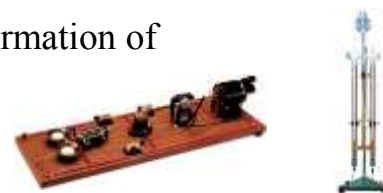
The Laws of Nature are principles but they may not *always* apply to *every* situation. In a healthy society, the application of the Laws of Nature are questioned. For example, does every conceived individual have a right to life or is

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 are 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  $\text{H}_2\text{O}$  into  $\frac{1}{2}\text{O}_2$  and  $\text{H}_2$ . Imagine how much energy it took to create an atmosphere composed of 21% oxygen on earth.



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.

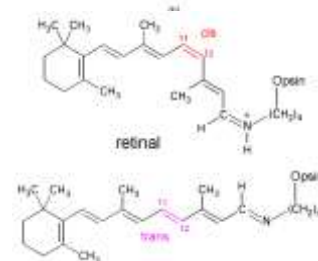
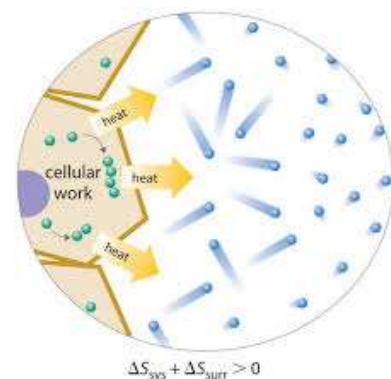
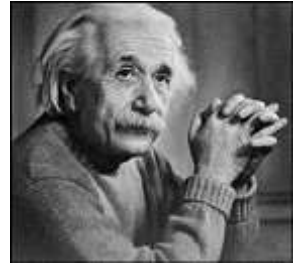
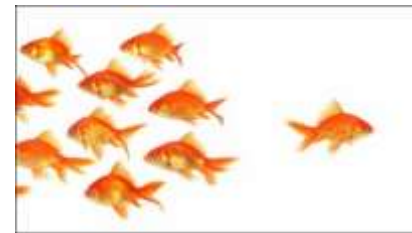


Fig. 1. Diagram of the human eye.

**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 ( $\Delta E$ ) can come from nothing but only for a limited period of time ( $\Delta t$ ) according to the following equation



(<http://www.aip.org/history/heisenberg/p08.htm>):

$$\Delta E \Delta t = \frac{\hbar}{2} = \frac{h}{4\pi}$$

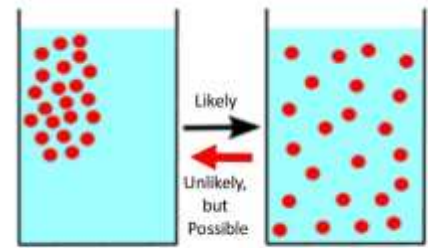


How long would a photon with a wavelength of 500 nm exist if it popped out of the vacuum according to Heisenberg’s uncertainty principle? If it takes approximately  $10^{-15}$  seconds for rhodopsin to absorb the photon, would you be able to see it?

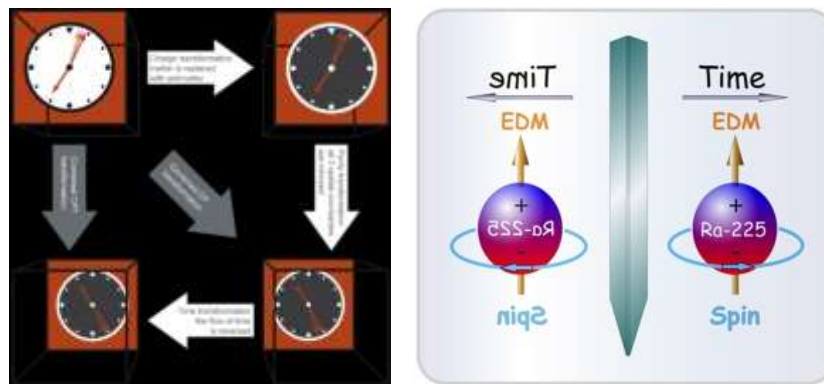




It is also conventional wisdom among physicists that **statistical mechanics**, based on the **reversibility of time**, is fundamental but the Second Law of Thermodynamics is **not** fundamental because it is based on the assumption that **time is irreversible**. Conventional wisdom states that **time itself is reversible**. According to conventional wisdom, **chance and statistics** give us the **illusion** that time is irreversible.



**Quantum electrodynamics (QED)** considers antimatter to be matter going backwards in time.



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 12<sup>th</sup> 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 16<sup>th</sup> century. In the 18<sup>th</sup> 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.

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.

**W**ILLIAM 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.*

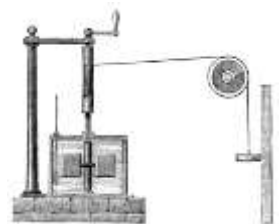


**James Joule** was a **business man** who ran the brewery every day from nine in the morning to six at night until the brewery was sold in 1854. He did however; find time to do research before breakfast and in the evening.



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.

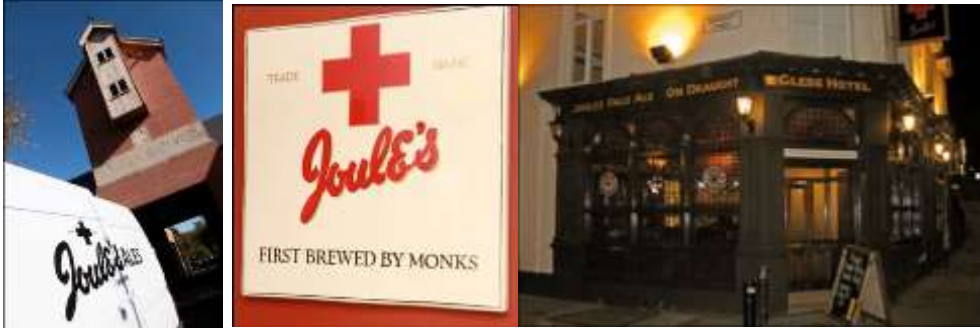


James Joule saw **conservation of energy** and the **First Law of Thermodynamics** as a way of seeing the **unity in the apparent diversity of causes and effects**. Not only did he *not* eliminate God from science with the law he helped found, but he saw the **First Law of Thermodynamics** as a manifestation 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.

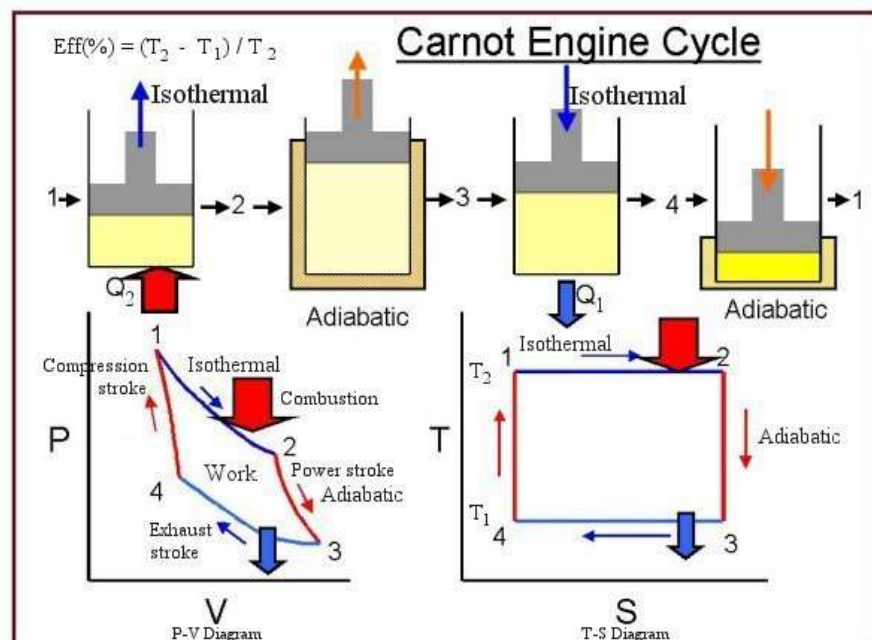


James Prescott Joule became famous as one of the discoverers of the **First Law of Thermodynamics**. The Joule family name also lives on in the brewing industry!



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, 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

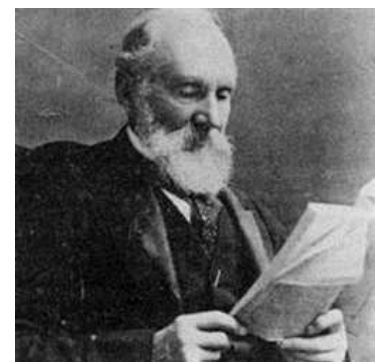
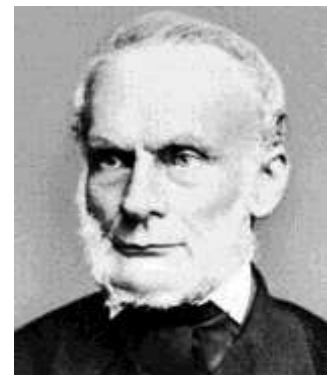
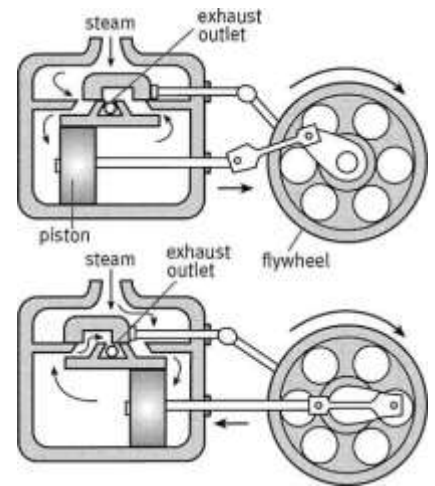


thermal energy from a warm body to a cold body and the greater the difference in temperature, the greater the motive force would be. The hot body causes the gas to **expand** and the cold body causes the gas to **contract**. Alternating the expansion and contraction moves a piston that is connected to a wheel that can only rotate in one direction. The temperature 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?

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*

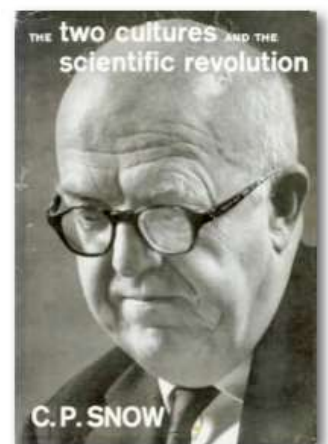


*utterly unprofitable. Far otherwise, however, it is in respect to the reversal of the motions of matter uninfluenced by life [i.e. the Carnot cycle], a very elementary consideration of which leads to the full explanation of the theory of **dissipation of energy**.*” The **Second Law of Thermodynamics** 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  $\eta$   $\tau\rho\pi\acute{\eta}$  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.”*

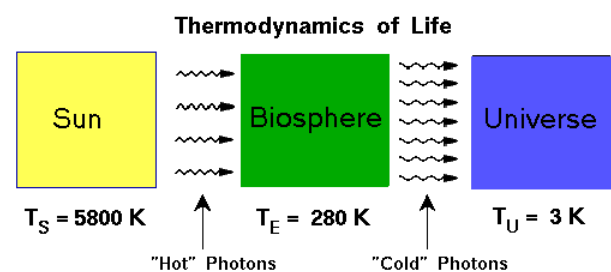
**C. P. Snow (1961)**, both a writer and a physicist, lamented about the failure of education in *The Two Cultures and the Scientific Revolution*, *“A good many times I have been present at gatherings of people who, by the standards of the traditional culture, are thought **highly educated** and who have with considerable gusto been*



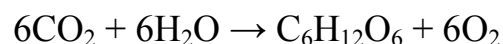
*expressing their incredulity at the illiteracy of scientists. Once or twice I have been provoked and have asked the company how many of them could describe the Second Law of Thermodynamics. The response was cold: it was also negative. Yet I was asking something which is the scientific equivalent of: Have you read a work of Shakespeare's?"*

I hope you can consider yourself 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** ( $48h\nu$ ):

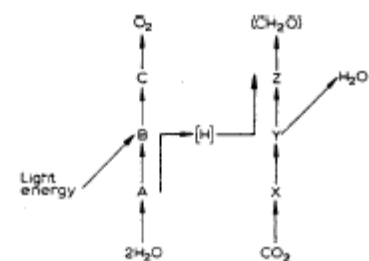
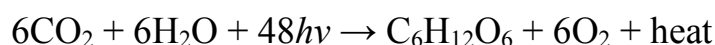
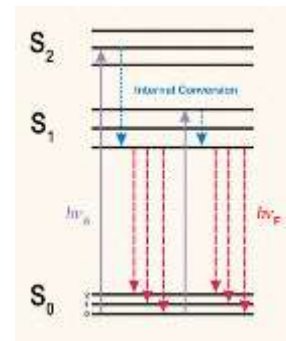


Fig.1. Elementary photosynthesis scheme.



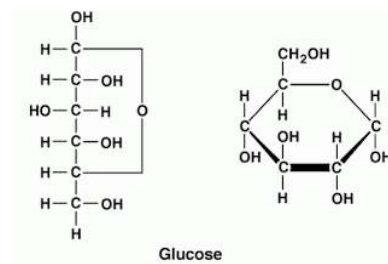
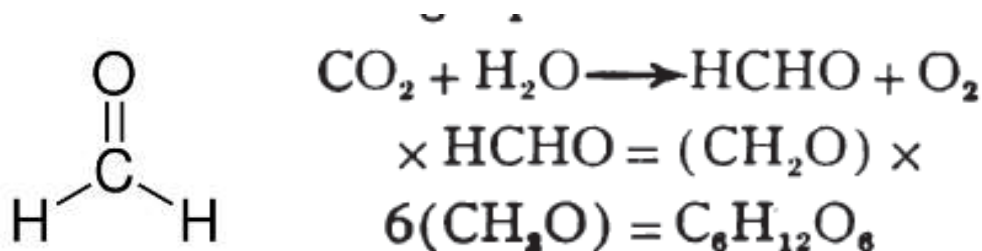
As I discussed last time, the **radiant energy** needed for this transformation is **absorbed** by **chlorophyll** in the **thylakoid membranes** which, in the **chloroplast**, results in **charge separation** of electrons ( $e^-$ ) that reduce  $\text{NADP}^+ + \text{H}^+$  to **NADPH** and the charge separation of protons ( $\text{H}^+$ ) 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  $4.8 \times 10^{-18}$  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  $\text{CO}_2$ ? **Adolph von Baeyer** (1870) proposed that the carbohydrate formed by plants resulted from the direct light-mediated formation of formaldehyde ( $\text{CH}_2\text{O}$ ), 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**  $^{11}\text{CO}_2$ , which they made by bombarding boron ( $_{5}\text{B}^{10}$ ) with deuterons ( $_{1}\text{D}^2$ ) to yield  $_{6}\text{C}^{11}$  and a neutron ( $_{0}\text{n}^1$ ), **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,  $^{11}\text{C}$  had 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. In 1940, Samuel Ruben and Martin Kamen developed a method for producing large quantities of  $^{14}\text{C}$  by bombarding graphite with deuterons ( $\text{H}^+\text{D}$ ) using the **cyclotron** in Ernest Lawrence's laboratory in order to trace the pathway of carbon and find the first products of photosynthesis. The  $^{14}\text{C}$  they produced had a half-life of 5,730 years.



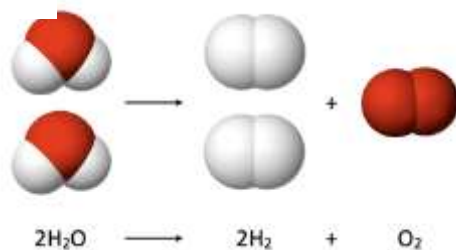
While waiting for the chance to use  $^{14}\text{C}$  to study carbon fixation in photosynthesis, Samuel Ruben, Merle Randall, Martin Kamen and James Hyde used a **stable isotope of oxygen** ( $^{18}\text{O}$ ) and a mass spectrometer to test whether oxygen evolved from  $\text{H}_2^{18}\text{O}$  **or**  $\text{C}^{18}\text{O}_2$  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.

TABLE I  
ISOTOPIC RATIO IN OXYGEN EVOLVED IN PHOTOSYNTHESIS  
BY *Chlorella*<sup>a</sup>

Expt.	Substrate	Time between dissolving KHCO <sub>3</sub> + K <sub>2</sub> CO <sub>3</sub> and end of O <sub>2</sub> collection, minutes		Percent O <sup>18</sup> in		
		minutes	minutes	H <sub>2</sub> O	HCO <sub>3</sub> <sup>-</sup> + CO <sub>3</sub> <sup>2-</sup>	O <sub>2</sub>
1	0.09 M	0		0.85	0.20	..
	KHCO <sub>3</sub>	45	110	.85	.41 <sup>b</sup>	0.84
	+0.09 M	110	225	.85	.55 <sup>b</sup>	.85
	K <sub>2</sub> CO <sub>3</sub>	225	350	.85	.61	.86
2	0.14 M	0		.20		..
	KHCO <sub>3</sub>	40	110	.20	.50	.20
	+0.08 M	110	185	.20	.40	.20
	K <sub>2</sub> CO <sub>3</sub>					

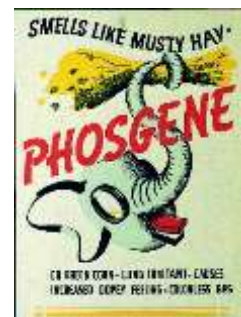
**Demonstration:** At the beginning of class I set up the demonstration of the First Law of Thermodynamics that we have seen before. This time I will also use the electrical energy of a battery to split water and show you how you can determine that the gases produced are hydrogen (it produces a very 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 and 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 <sup>14</sup>CO<sub>2</sub>. Samuel Ruben began wartime research on **phosgene**, 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 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  $^{235}\text{U}$ , 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  $^{24}\text{Na}$  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, 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



APPETIZERS	
COO-COO CLAM COCKTAIL (in Season)	1.00
COO-COO CLAMS, Half Doz. (10-12) (12)	1.50
HAUT SHRIMP COCKTAIL	1.15
PEANUT COCKTAIL	1.25
CRAB MEAT COCKTAIL	1.25
CRAB LEG COCKTAIL	1.50
EASTERN OYSTER COCKTAIL	1.50
KING NEPTUNE	1.50
HUMID SHAPPOO COCKTAIL	2.50
EASTERN OYSTERS (1/2 Doz.)	2.25
CRACKED CRAB - Whole Lbs. Half	1.75
SOUPS	
OUR FAMOUS CLAM CHOWDER	.75
THE FISH STYLE CLAM CHOWDER	.75
MONK FISH SOUP	.50
CLAM BROTH	.50
CRAB GUINO LOUISIANA	.50
SALADS	
"FISHES OF EIGHT" SALAD	2.50
DINNER SALAD	.75
MIXED GREENS IN BOWL	.75
WITH SHRIMP	1.50
WITH CRAB MEAT	1.50
CRAB SHRIMP or PRAWN LOUISIANA	2.50
FRUIT AND COTTAGE CHEESE	1.50
TORTINI, FISH or CRAB or SHRIMP	1.50
AVOCADO WITH CRAB or SHRIMP	2.00
HEALTHY OF ROMANE, Anchovy Straps	.50
OUR FAMOUS DE LUXE	
COLD SHAPPOO PLATTER	
Specialties	
CHOPPING or BULLHADDER	2.50
STUFFED LOBSTER PRINCES	4.00
COO-COO CLAMS, Seasoned, Baked	2.45
OYSTERS KIRKPATRICK	2.00
DEVEIL CRAB	2.75
BARBECUED COO-COO CLAMS	2.25
OYSTERS BUCKELLER	2.50
BONED SAND DABS, Tender Meat	2.45
BARBECUED PRAWNS, Piquante Sauce	2.50

him. G-2 was building a dossier on Martin Kamen that included innuendos of moral turpitude and leftist associations.

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.

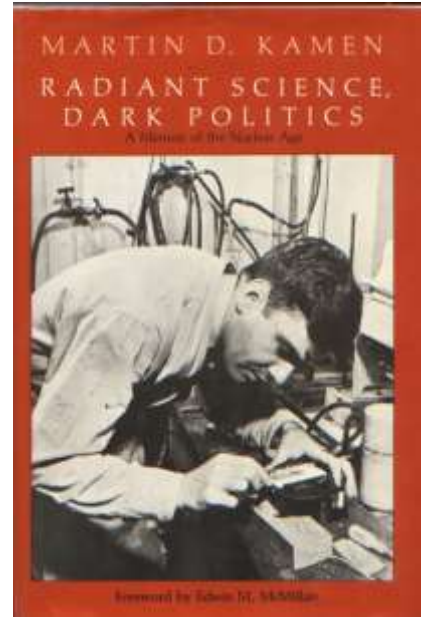


Cartoon by Dan Bishop in the St. Louis Star-Times, September 4, 1948.  
Radiant Science, Dark Politics.

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.*”



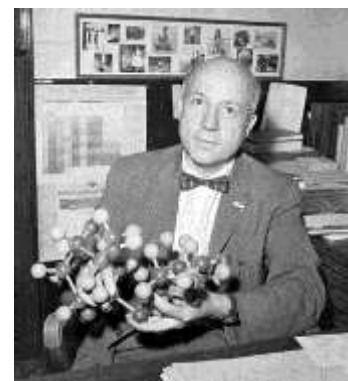
In 1996, Martin Kamen won the **Enrico Fermi Award** given by the United States Department of Energy in recognition of lifetime achievements in energy research. According to the Department of Energy, “*During the war years Kamen's liberal ideas and outgoing personality caused him to be watched by government 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.”*

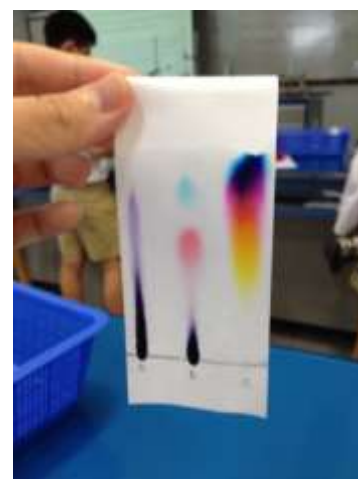
<http://science.energy.gov/fermi/award-laureates/1990s/kamen/>

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  $^{14}\text{C}$**  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.

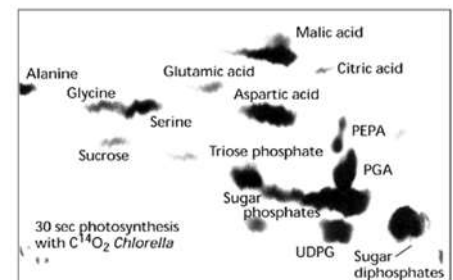
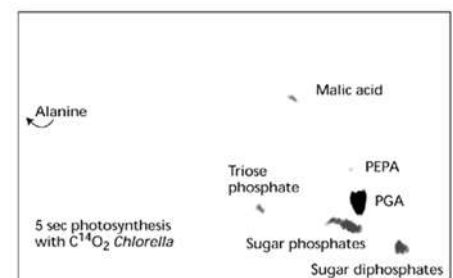




The photosynthetic reaction could be stopped rapidly by dropping the *Chlorella* cells in **boiling methanol**, which both killed the cells and extracted the products of photosynthesis.



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 CO<sub>2</sub>**.



However, as soon as they **increased the temporal resolution** of their assay, they found that the first product labeled was a six-carbon molecule formed from the joining of CO<sub>2</sub> to a **five-carbon molecule known as ribulose biphosphate (RuBP)**.

By following the position of the <sup>14</sup>C 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**.

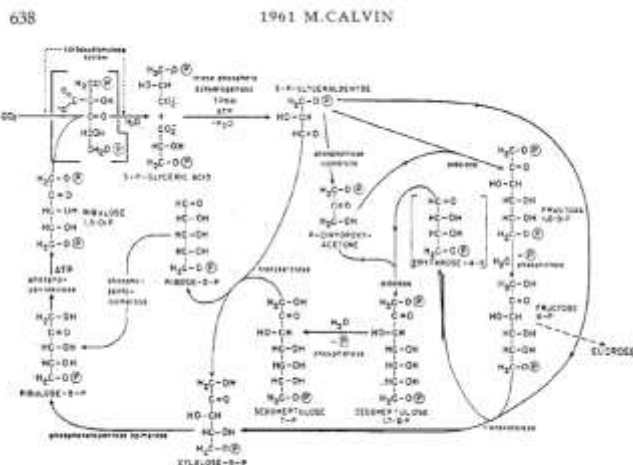


Fig. 18. The photosynthetic carbon cycle.



The *NADPH* formed in the light reactions is a **reducing agent** that **transfers the electrons (and protons)** necessary to reduce the CO<sub>2</sub> into energy-rich carbohydrate (C(H<sub>2</sub>O)) 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 CO<sub>2</sub> 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.

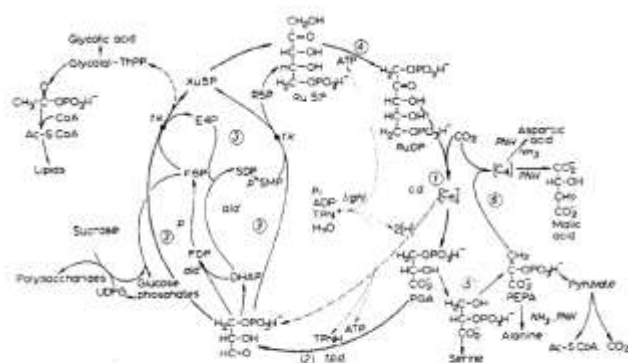
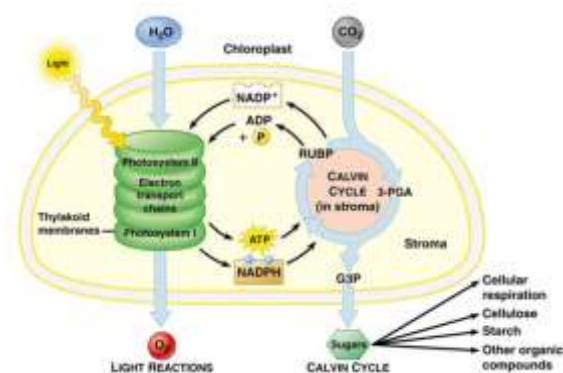
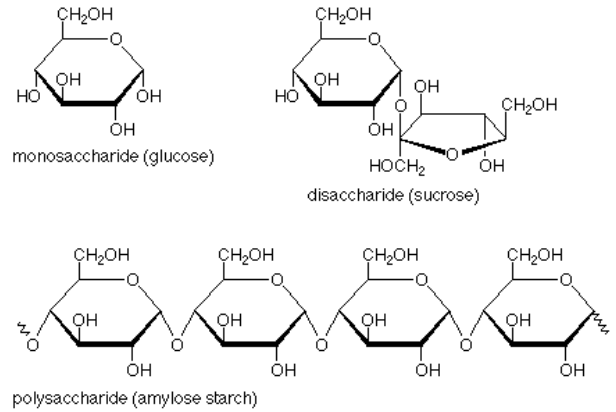


Fig. 20. The photosynthetic carbon cycle and its relation to quantum conversion and to succeeding biosynthesis.

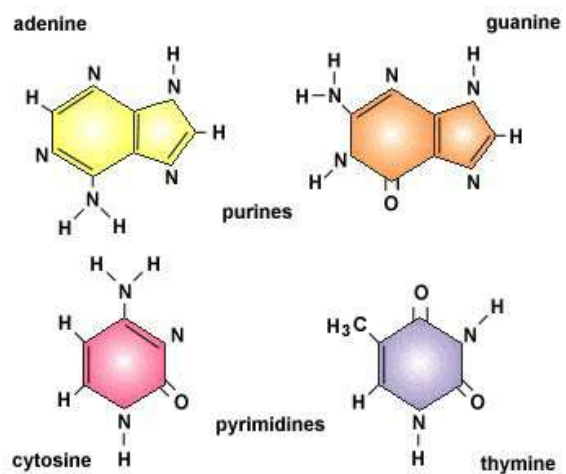
## Carbohydrates (4 Calories/gram):



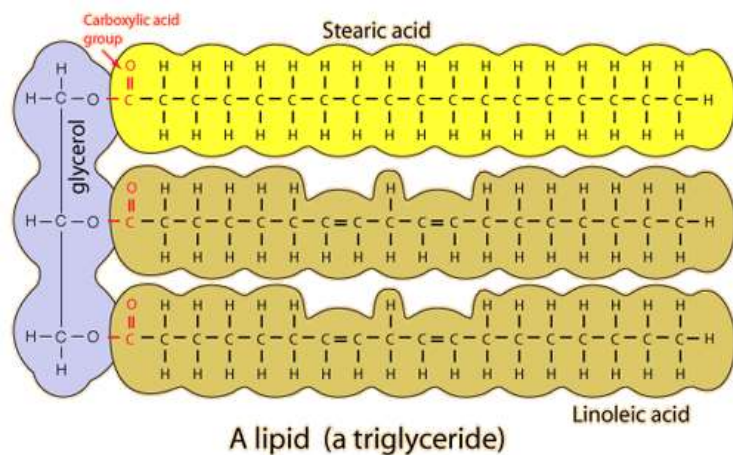
## Amino acids (protein components; 4 Calories/gram):

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

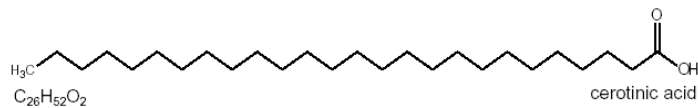
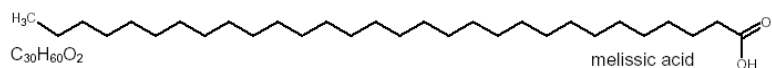
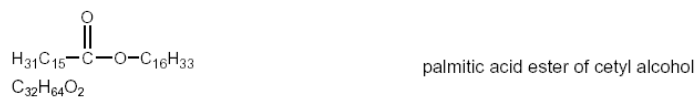
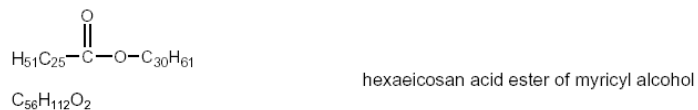
Nucleic acids components:



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 CO<sub>2</sub> to RuBP, resulting in the fixation of CO<sub>2</sub> 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.

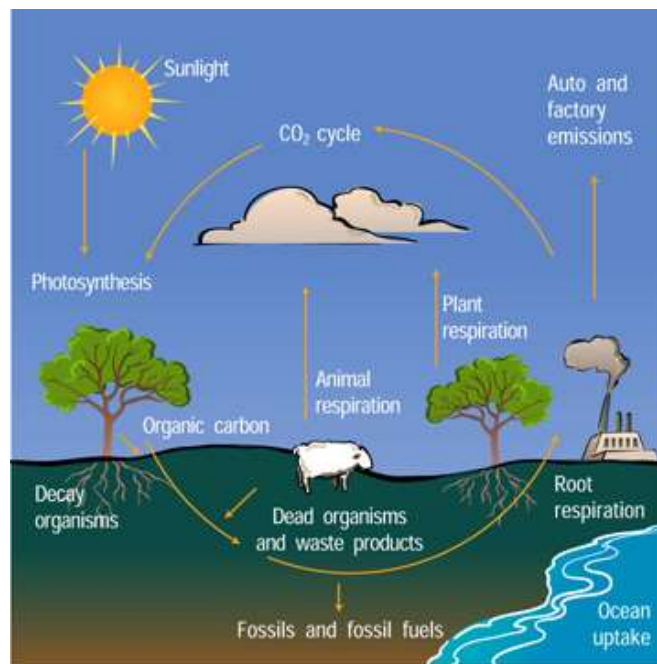
Melvin Calvin won the **Nobel Prize in Chemistry** in 1961 for elucidating the path of carbon in photosynthesis, more commonly known as the Calvin cycle. Perhaps if the country were not on a witch hunt at that time, Martin Kamen would have won two Nobel Prizes—one for the invention of the method to make <sup>14</sup>C and the other for elucidating the path of carbon in photosynthesis.



The **biotic carbon cycle** was understood by chemists in the mid-19<sup>th</sup> 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.”* 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.



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 (*Lettere Scientifiche ed Erudite*; Letter V) tells us what his friend Galileo believed:

*Wine is a mixture of sap and of light.*



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 to discourage (take away from your heart) you from doing these two things:

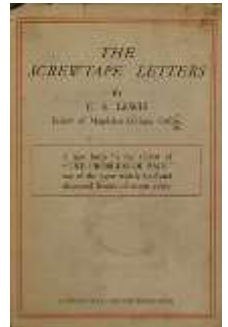


*My dear Wormwood,*

*“...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>