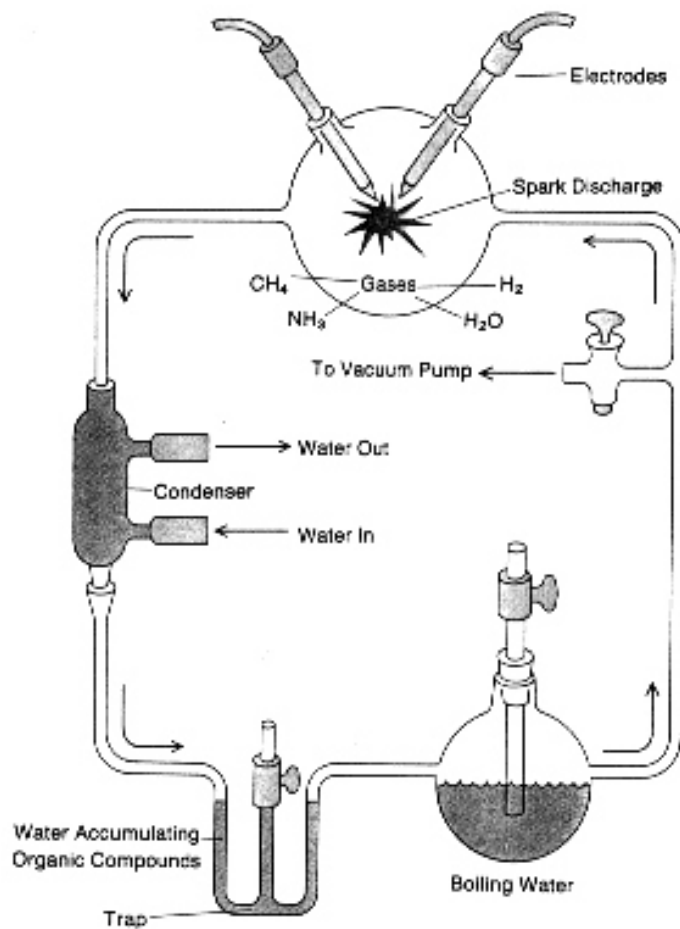


## VITALISM



Miller-Urey Experiment, 1953

### The Issues

- **vitalism** is the doctrine that life has arisen from, and is a product of, the action of a non-materialistic “vital force” or “life force” on otherwise inanimate substances
- the doctrine has two implications:
  - i) a “life force” is an essential requirement for the synthesis of organic substances
  - ii) organic life itself is the result of a “life force” acting on matter
- the first became resolved in the late 19<sup>th</sup> century as chemists

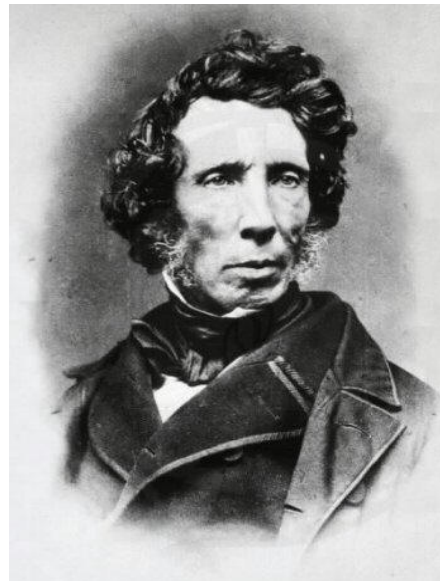
successfully synthesized a number of organic compounds identical to the natural ones, but the second one remains under scrutiny today as chemists attempt to understand or discover how replicating molecules can, or can not, arise from inanimate chemical elements

### Vitalistic Doctrines

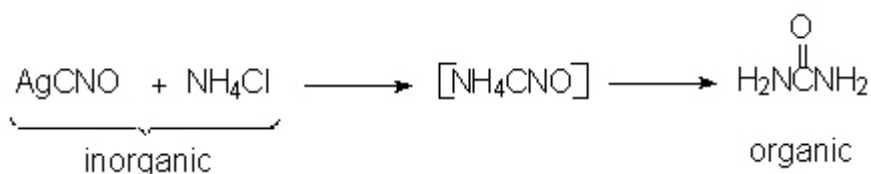
- up to about 1800, chemists dealt entirely with inorganic compounds
- after the work of Lavoisier and Dalton, chemists began to give each element, including carbon, equivalent status and their various combinations gave rise to all the compounds then known, but the substances obtained from living organisms, such as plants and animals, the “organic” compounds, were thought to require some sort of higher level organizational force, generally termed the vital, or life force

- organic compounds could be identified and characterized by decomposition and analytical experiments, it was assumed they could not be synthesized because chemists had no way of supplying the creational vital force

- in 1828, **Friedrich Wöhler** tried to prepare ammonium cyanate by heating a mixture of silver cyanate and ammonium chloride, ie,



Friedrich Wöhler



- to his complete surprise, the white solid formed was the organic

compound urea. Wöhler was astonished that the component elements could be arranged one way to form (unstable) ammonium cyanate and another way to form urea; he reported that his process was the first synthesis of an organic molecule from inorganic elements

- his synthesis did not have much of an impact on vitalistic thinking because his critics argued:

i) AgCNO was not a true inorganic compound because cyanates were generally extracted from cattle hooves and horns

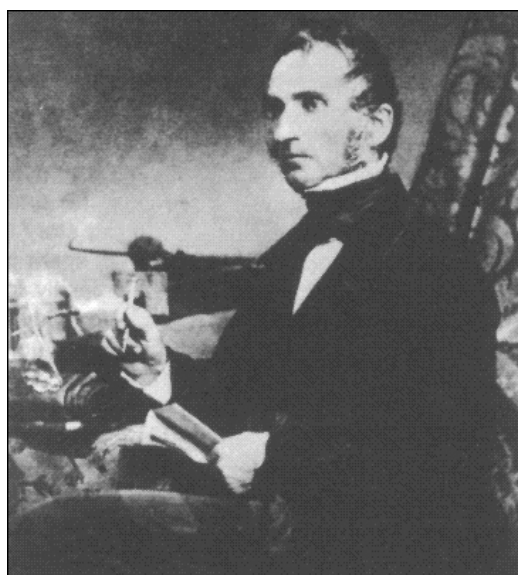
ii) urea was not a true organic substance because it was an excretion product

iii) perhaps Wöhler supplied the vital force through his contact with the reaction mixture

(but the synthesis did focus attention on the existence of isomerism, as covered in Stereochemistry)

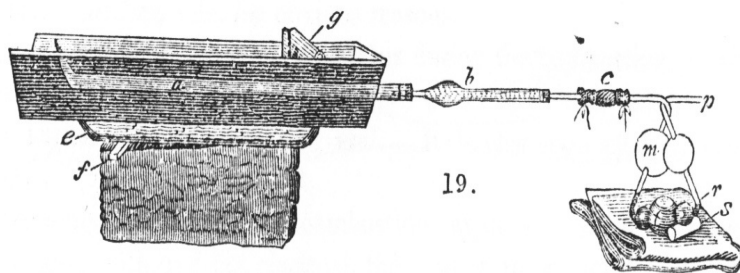
- Berzelius, who proposed the term isomerism for different compounds that had the same formula after Wöhler's discovery, believed in 1830 that organic compounds needed a life force for their synthesis and internal organization, but once formed they behaved like ordinary chemical compounds

- **Justus Liebig** (1803-1873) in 1830 perfected a simple and reliable benchtop method for obtaining the composition (and probable molecular formula) of organic compounds containing C,N,O and H by combustion analysis; he combusted organic compounds in the presence of an oxygen source (CuO) and collected the H<sub>2</sub>O, CO<sub>2</sub> and N<sub>2</sub> evolved



Justus Liebig, 1803-1873

- he and his research students (the first 'modern' research group) published a stream of analyses of quite complicated organic compounds in the following years, eg, morphine, caffeine, thereby establishing the fact that organic compounds were built from known chemical elements, mostly C,N,O and H



**Liebig's Apparatus for Organic Analysis**



**ACS logo**

- by 1838 Liebig had come to believe that chemists could synthesize organic compounds without need for a vital force, but that physiological organic compounds required the vital force for their crucial roles in living organisms, such as digestion, metabolism, decay, movement and replication

- Liebig's ideas spurred interest in the synthesis and analysis of organic compounds, but he believed chemists could never understand or replicate the vital force essential to the organic chemistry of living organisms; he claimed all those who denied the existence of a vital force were "*ignorant and presumptuous dreamers*" (text, p.V10)

- in the latter half of the 19<sup>th</sup> century, Marcellin Berthelot synthesized many well-known organic compounds, such as acetylene, naphthalene and oxalic acid, from inorganic reagents and established that a life force was not needed for the synthesis of organic compounds (see quote, p.V11)



**Marcellin Berthelot**

-Berthelot's work brought an end to the belief that a life force was required for the synthesis of organic compounds (aspect (i) ), but the role of a life force as a requirement for life itself (aspect (ii) ) is a more difficult issue to resolve

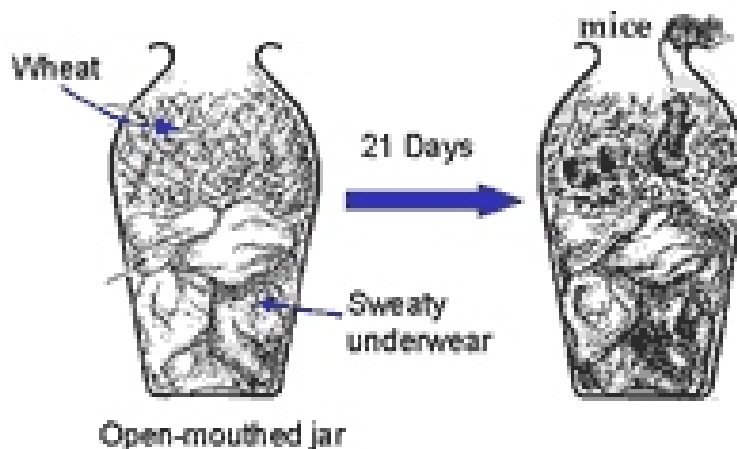
## Spontaneous Generation

- from the earliest times, many life forms were thought to emerge fully formed from lifeless environments by a process called

### spontaneous generation

- Aristotle believed plants, insects, worms, frogs, etc, sprung into life spontaneously from decaying organic material in muddy river banks or pools

- this belief remained unchallenged well into the 18<sup>th</sup> century. Van Helmont (who gave the name "gas" to all air-like forms of matter), published in the mid 1600s a (reproducible) procedure for the spontaneous generation of mice in a glass jar from sweaty old underwear and wheat (see p.V12 for recipe)

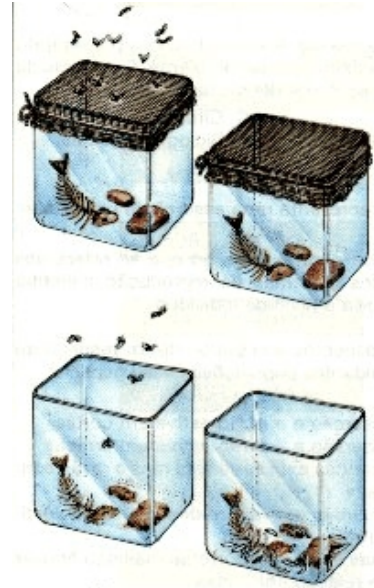


- ideas of spontaneous generation became generally known as **abiogenesis**, the emergence of life from non-life

- in a different experiment, Francisco Redi in 1668 concluded that life could not emerge from lifeless precursors; instead all life came

from pre-existing life forms, a view known as **biogenesis**

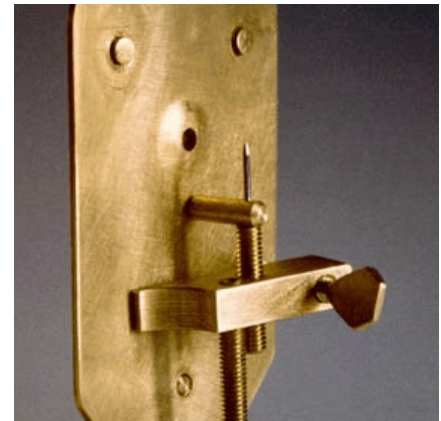
- Redi placed dead snakes in an open jar, a stoppered jar, and a jar covered with a fine gauze covering; maggots eventually appeared in the open jar, none in the stoppered jar. The maggots eventually laid eggs which later hatched into flies similar to ones which landed on the gauze and laid eggs there



- Redi concluded that the maggots had not appeared spontaneously but had hatched from eggs deposited on the dead snakes by the meat-seeking flies

- in early 18<sup>th</sup> century van Leeuwenhoek constructed the first rudimentary microscope (200x magnification) and began to publish drawings of the very tiny eggs that were laid by small insects

- these early suggestions of biogenesis were not generally accepted

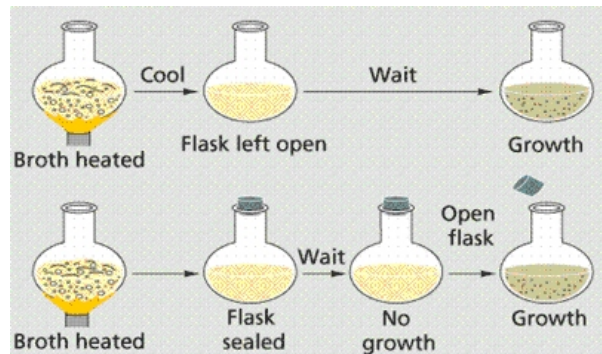


Van Leeuwenhoek microscope

- in 1711 Louis Joblot put boiled solutions of hay in small vessels, some with access to air and some without - microorganisms appeared only in the vessels exposed to air, so he concluded that air was essential to the emergence of life

- however, in the mid 1700s the English priest John Needham placed boiled mutton gravy in a vial and sealed it with a cork - after a few days some microorganisms appeared; Needham concluded **abiogenesis** could occur even in the absence of air

- Needham's results were challenged by the Italian Lazzaro Spallanzani (1729-1799), who found well-heated aqueous suspensions of various vegetable substances when sealed in glass vials remained lifeless; he concluded Needham had either not heated his samples long enough, or not sealed them adequately, or both



- Spallanzani concluded microorganisms arose from spores entering the samples from the air, ie, **biogenesis**; if samples were sterilized by sufficient heating and sealed microorganisms would not appear

- many investigators repeated versions of Needham's and Spallanzani's experiments with conflicting and confusing results, so no consensus emerged. Erasmus Darwin (Charles' grandfather) believed in abiogenesis; Joseph Priestley in biogenesis

- in 1810, the Frenchman Appart invented the process of "canning" in which well-boiled substances could be preserved indefinitely by sealing them in air-tight containers. Gay-Lussac found that the head space over canned materials contained no oxygen and suggested that oxygen was needed for the growth of microorganisms, even by abiogenic processes

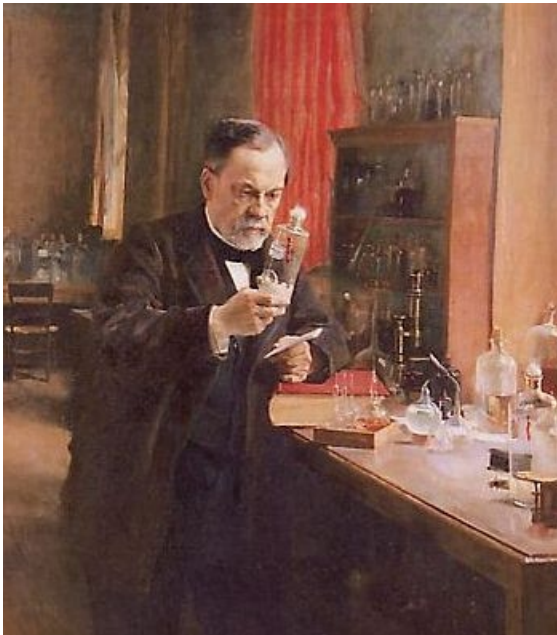
- later in the mid 19<sup>th</sup> century Schroeder and von Dusch sterilized various substances by prolonged boiling, then exposed them to air that had been well filtered by passage through cotton wool; some substances, such as meat, did not decompose but others, such as milk, did

- they concluded that some substances could decompose solely

with air [oxidative decomposition], while others required something else present in air [microbiological decomposition]

## The Pasteur/Pouchet Debate

-in the 1860s both Louis Pasteur and Felix Pouchet tried to resolve the biogenesis/abiogenesis issue, and the role of air



Louis Pasteur in his Lab



Félix Pouchet



Pasteur 'swan' flask

- both men boiled solutions of natural substances (Pouchet used hay extracts, Pasteur used yeast solutions), sealed them glass vessels, reopened them later to expose the contents to air and then resealed them

- microorganisms appeared in all of Pouchet's samples, some of them opened and resealed at the edge of a glacier high in the French Alps; Pouchet concluded air was a requirement for spontaneous generation of microorganisms

- in Pasteur's flasks, microorganisms appeared in only 4 of 19 flasks opened and resealed indoors, but they appeared in 16 of



18 opened outdoors. Pasteur concluded that air itself was not responsible for the appearance of microorganisms - instead minute spores contained in the air caused microorganism growth

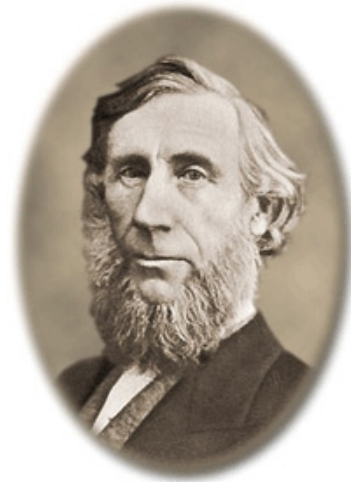
- a commission of the French Academy of Sciences was appointed to resolve the dispute, but was disbanded when Pouchet withdrew from the debate. This was an unfortunate decision for in 1876 it was discovered that spores found in hay can survive long periods of boiling temperatures and begin to multiply on subsequent exposure to oxygen

- the confusion was largely resolved by the Irish physicist **John Tyndall**, who was able to reveal the presence of microscopic particles and spores in air by shining a light beam through the air (the 'Tyndall effect'). In 1878 he demonstrated that air from which all particles had been removed by filtration was incapable of causing the growth of microorganisms in sterilized solutions

- he was able to confirm the presence or absence of minute spores in various air samples and, by repeating experiments similar to those of Pasteur and Pouchet, he found that 90% of his samples sterilized, sealed and reopened in a hayloft developed microbial growth while none of those opened on a remote mountain ledge did

- further, he showed that different spores varied greatly in their resistance to heat, the most resistant being able to survive 8 hrs of boiling in water

- Tyndall's researches convinced most of the scientific community that abiogenesis did not occur; life did not arise in sterile samples unless and until they became contaminated with pre-existing life forms



John Tyndall  
(1820-1893)

- but recognise that it is impossible for any number of experiments, no matter how well designed and executed, to prove that abiogenesis is impossible; the best science can do is demonstrate that there are no known examples and therefore that it is highly improbable that life can arise, in a short timespan, from lifeless materials

- but can life arise from inorganic materials on a geological timescale, ie, can inorganic materials by evolutionary processes organise and reconstruct themselves into molecules of ever-increasing complexity, even to a level of complexity that is characteristic of living things? Such a long-term interpretation of abiogenesis is known as **chemical evolution**

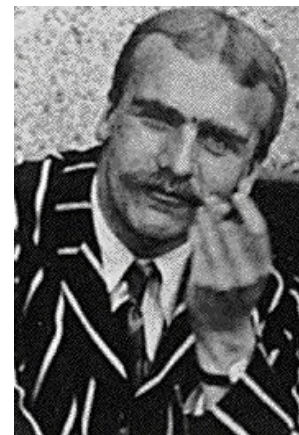
## Chemical Evolution

- the first to make a strong argument for chemical evolution was the Russian biochemist A.I.Oparin  
- in a 1924 booklet titled The Origin of Life, Oparin suggested that replicating organic molecules arose from a concentrated pool of organic compounds early in the earth's history (3-4 billion yrs ago)



A.I.Oparin

- independently the Scottish biologist J.B.S.Haldane suggested in 1928 that large amounts of organic compounds likely accumulated in the oceans of the pre-biotic earth and, by processes unknown, developed into the molecules essential for life



J.B.S.Haldane

- only in the 1950s did experimental work begin in the area of chemical evolution

- it is generally agreed that the earth condensed from interstellar material about 4.5-4.8 billion yrs ago, and the earliest forms of life, unicellular bacteria and algae, appeared on the earth by 3.1 billion yrs ago. Stromatolites, still present in Australian coastal waters are believed to be of about that age



Stromatolites

- it is also generally assumed that the primitive earth's atmosphere was hydrogen dominated, ie, a reducing environment. The reasons for this belief include:

i) hydrogen is the dominant element in the universe, and the (presumably) lifeless outer planets in the solar system have atmospheres rich in methane and ammonia



ii) meteorites that land on the earth contain metals in reduced form, eg metallic iron

iii) the deposits of iron in the oldest known sediments were formed under reducing conditions

- the change over time from a reducing atmosphere (dominated by hydrogen) to an oxidising one (dominated by oxygen) has been explained by the ultraviolet photolytic decomposition of water, followed by the preferential escape of hydrogen, and by the appearance on the earth's surface of photosynthetic organisms  
 - as oxygen builds up in the atmosphere, some of it is converted by high energy radiation to ozone, which in turn strongly absorbs

short wavelength ultraviolet radiation, thus shielding organic materials on the earth's surface from bond-breaking UV rays

- based on assumed UV radiation levels in early times and on UV-induced conversion of simple reduced inorganic molecules to higher molecular weight carbon-rich molecules, it is possible that the pre-biotic ocean might have been able to develop a 1% solution of simple organic material in about 1 billion yrs

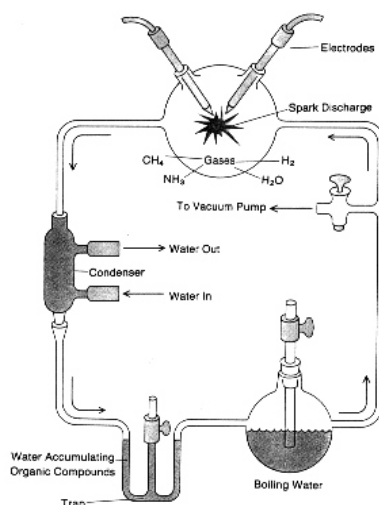
- experiments that have been done since about 1950 have tried to mimic experimental conditions that might have given rise to the fundamental organic molecules presumed to be essential for the emergence of life. A brief, and superficial, account of some of these experiments follows.

## Biomonomers

- biomonomers are the simplest organic compounds that form from reduced starting materials such as nitrogen, ammonia, methane, water and hydrogen

- when an electrical discharge is passed through a gaseous mixture of carbon monoxide, nitrogen and hydrogen, hydrogen cyanide is produced, which can react further with other simple reactants to form some amino acids

- the most influential experimental result was obtained by **Stanley Miller** (while a grad student in Harold Urey's research group), and published in 1953



**Miller-Urey Experiment,  
1953**



Stanley Miller, about 1953

- Miller exposed a gaseous mixture of hydrogen, methane, and ammonia to a high frequency electrical discharge of 60,000 volts for one week; the products, after about 1% conversion of starting material, included glycine, alanine, sarcosine, aspartic acid and glutamic acid
  - by adding water to the starting mixture, Miller obtained formic acid, acetic acid, propionic acid, glycolic acid and lactic acid as products
  - others have sparked a mixture of methane and nitrogen in the presence of ammonia, hydrogen cyanide and water and obtained 10-15% yields of aspartic acid and 5-10% asparagine
  - by including hydrogen sulfide, sparking experiments have produced cysteic acid and other S-containing molecules
- it is noteworthy that the products of these primitive sparking experiments are some (but not all) of the essential amino acids, and a few simple carboxylic acids

## **Sugars**

- in the late 19<sup>th</sup> century Butlerov observed that dilute aqueous alkali polymerizes formaldehyde into a complex mixture of sugars, and some 20<sup>th</sup> century sparking experiments on a mixture of methane, ammonia, water and hydrogen have given formaldehyde as a product
- other experiments have obtained the nucleic acid sugars ribose and deoxyribose from UV radiation of formaldehyde

## **Nucleic Acid Bases**

- of the 5 nucleic acid bases (adenine, guanine, cytosine, thymine and uracil) only adenine has been produced in primitive earth conditions, by use of an electron beam and only in very small (0.01%) yields

- in 1960 it was reported that adenine was produced by heating aqueous solutions of ammonium cyanide at 90 °C for several days; there have been some reports that porphyrin, the basic molecular unit of chlorophyll, has been produced by electrical discharge into methane/ammonia/water mixtures

- by about 1970 (where our review stops because more recent discoveries belong in a chemistry class), primitive earth experiments have produced 15 of the 20 amino acids (although in both enantiomeric forms), 4 of the 5 nucleic acid bases and 2 of the 3 nucleic acid sugars

## **Biopolymers**

- polymerization of the basic monomers into more complex natural products is assumed to have occurred on the primitive earth through the action of radiation in water. There has been only limited demonstration of such processes, but the essential amino acids have been made to polymerise into polypeptides with molecular masses of several thousand upon heating

- the thermally-produced polypeptides often form microspheres in cool aqueous solution and some have even called them “pre-cellular”

- room temperature processes have been less successful, producing only small polypeptides of about 4 amino acid units

## **Future Results**

- funding for chemical evolution experiments is quite limited, but novel reactions continue to be discovered, and there is a great deal of speculation on the genesis of DNA, RNA and the polymers such as fatty acids and proteins necessary for cell formation

- many chemists believe that future research will uncover the conditions that favour synthesis of key organic materials, such as

ordered bond formation on clay or zeolite minerals, synthesis in the hot water “smokers” under water where continental plate formation is occurring

- there are even those who favour “pangeneses” the idea that the necessary organic precursors are present throughout the universe and were seeded on the primitive earth by meteorites

- and of course there is Divine Creation, which has no need for a theory of abiogenesis, but has its own uncertainties

