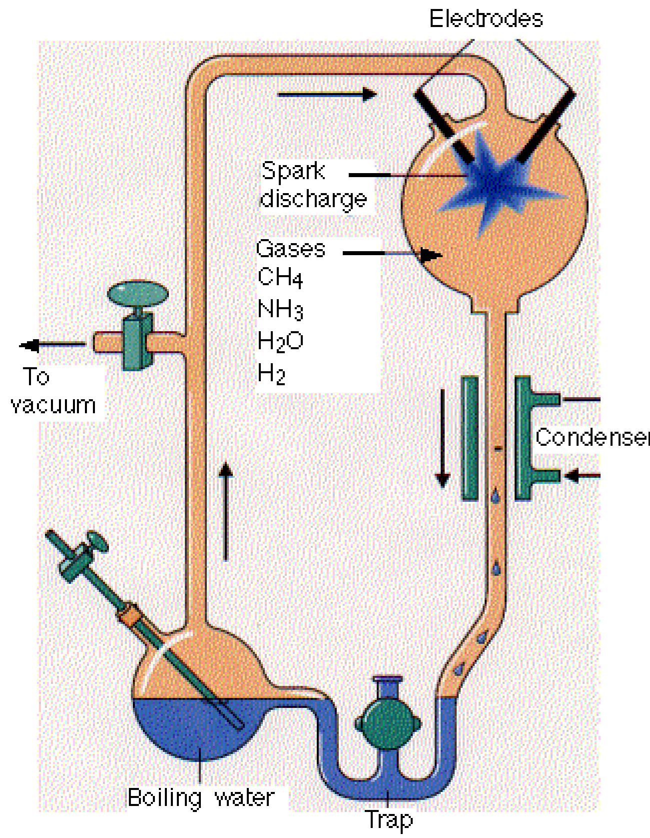
1. Miller's Experiment

Stanley Miller, a graduate student in biochemistry, built the apparatus shown here. He filled it with



- water (H_2O
- methane (CH_4)
- ammonia (NH_3) and
- hydrogen (H_2)
- **but no oxygen**

He hypothesized that this mixture resembled the atmosphere of the early earth. The mixture was kept circulating by continuously boiling and then condensing the water.

The gases passed through a chamber containing two electrodes with a spark passing between them.

At the end of a week, Miller used paper chromatography to show that the flask now contained several amino acids as well as some other organic molecules.

In the years since Miller's work, many variants of his procedure have been tried. Virtually all the small molecules that are associated with life have been formed:

- 17 of the 20 amino acids used in protein synthesis, and
- all the purines and pyrimidines used in nucleic acid synthesis.
- But abiotic synthesis of **ribose** — and thus of **nucleotides** — has been much more difficult. However, success in synthesizing pyrimidine ribonucleotides under conditions that might have existed in the early earth has recently (**Nature** 14 May 2009) been reported.

One difficulty with the primeval soup theory is that it is now thought that the atmosphere of the early earth was not rich in methane and ammonia — essential ingredients in Miller's experiments.

Representative amino acids found in the Murchison meteorite. Six of the amino acids (blue) are found in all living things, but the others (yellow) are not normally found in living matter here on earth. The same amino acids are produced in discharge experiments like Miller's.

Glycine	Glutamic acid
Alanine	Isovaline
Valine	Norvaline
Proline	N-methylalanine
Aspartic acid	N-ethylglycine

2. Molecules from outer space? (Panspermia theory of life)

The Murchison Meteorite

This meteorite, that fell near Murchison, Australia on 28 September 1969, turned out to contain a variety of organic molecules including:

- purines and pyrimidines
- **polyols** — compounds with hydroxyl groups on a backbone of 3 to 6 carbons such as glycerol and glyceric acid. Sugars are polyols.
- the amino acids listed here. The amino acids and their relative proportions were quite similar to the products formed in Miller's experiments.

The question is: were these molecules simply terrestrial contaminants that got into the meteorite after it fell to earth.

Probably not:

- Some of the samples were collected on the same day it fell and subsequently handled with great care to avoid contamination.
- The polyols contained the isotopes carbon-13 and hydrogen-2 (deuterium) in greater amounts than found here on earth.
- The samples lacked certain amino acids that are found in all earthly proteins.
- Only **L** amino acids occur in earthly proteins, but the amino acids in the meteorite contain both **D** and **L** forms (although **L** forms were slightly more prevalent).

The ALH84001 meteorite

This meteorite arrived here from Mars. It contained not only a variety of organic molecules, including polycyclic aromatic hydrocarbons, but — some claim — evidence of microorganisms as well.

Furthermore, there is evidence that its interior never rose about 40° C during its fiery trip through the earth's atmosphere. Live bacteria could easily survive such a trip.

Link to a discussion of the possibility of life on Mars and more on the ALH84001 meteorite.

Organic molecules in interstellar space

Astronomers, using infrared spectroscopy, have identified a variety of organic molecules in interstellar space, including

- methane (CH_4),
- methanol (CH_3OH),
- formaldehyde (HCHO),
- cyanoacetylene (HC_3N) (which in spark-discharge experiments is a precursor to the pyrimidine **cytosine**).
- polycyclic aromatic hydrocarbons
- as well as such inorganic building blocks as carbon dioxide (CO_2), carbon monoxide (CO), ammonia (NH_3), hydrogen sulfide (H_2S), and hydrogen cyanide (HCN).

Laboratory Synthesis of Organic Molecules Under Conditions Mimicking Outer Space

There have been several reports of producing amino acids and other organic molecules by taking a mixture of molecules known to be present in interstellar space such as:

- ammonia (NH_3)
- carbon monoxide (CO)
- methanol (CH_3OH) and
- water (H_2O)
- hydrogen cyanide (HCN)

and exposing it to

- a temperature close to that of space (near absolute zero)
- intense ultraviolet (uv) radiation.

Whether or not the molecules that formed terrestrial life arrived here from space, there is little doubt that **organic matter** continuously rains down on the earth (estimated at 30 tons per day).

3. Deep-Sea Hydrothermal Vents

Some deep-sea hydrothermal vents discharge copious amounts of hydrogen, hydrogen sulfide, and carbon dioxide at temperatures around 100°C. (These are not "black smokers".) These gases bubble up through chambers rich in iron sulfides (FeS, FeS_2). These can catalyze the formation of simple organic molecules like acetate. (And life today depends on enzymes that have Fe and S atoms in their active sites.)

Assembling Polymers

Another problem is how **polymers** — the basis of life itself — could be assembled.

- In solution, hydrolysis of a growing polymer would soon limit the size it could reach.
- Abiotic synthesis produces a mixture of **L** and **D** enantiomers. Each inhibits the polymerization of the other. (So, for example, the presence of **D** amino acids inhibits the polymerization of **L** amino acids (the ones that make up proteins here on earth).