Stanley Miller's Experiment and Its Effects on the Hypotheses of the Origin of Life

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Physical Basis of Chemistry

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In 1953, two scientists developed an experiment to try to answer the question “How did life on Earth begin?” One of those scientists was Stanley Miller, who worked at the University of Chicago with Harold Urey. Miller was one of many explorers who were fervently investigating the origin of life.

According to Urey’s earlier hypothesis, Miller assumed that free oxygen was unavailable due to the abundance of hydrogen in the air. This would cause any oxygen to automatically bond with hydrogen, due to the fact that neither atom would have a full outer valence of electrons.

Miller’s test was set up to mimic the atmosphere of the early Earth. Due to Urey’s hypothesis, Miller did not include oxygen as part of his experiment. He placed hydrogen, boiling water, methane and ammonia into an enclosed chamber (chem.duke.edu). Miller (1953) wrote that he used a U-shaped tube at the bottom of the set-up to prevent reverse circulation (p. 528). In order to speed up the reaction, Miller used an electric spark to represent lightening. He also incorporated a cooling device to cause the water to condense and be recycled in a way that simulated the clouds. With this arrangement of equipment and materials, the scientist had created an enclosed environment similar to that in which the first signs of life may have appeared.

After a week of observations, and using chromatography, Miller noticed that basic amino acids had formed in the mixture. Amino acids are the main components of proteins, which are chemical compounds that have many functions in the body including forming tissues, creating enzymes, and participating in muscle activity. From an interview with Miller, Henahan (1996)

states, “Glycine appeared after reactions in the atmosphere produced simple compounds – formaldehyde and hydrogen cyanide.” By re-creating this experiment with different gas mixtures, eleven out of the twenty amino acids can be formed (Henahan, 1996). Through the translation of DNA through RNA, amino acids are connected in polypeptide, or protein, chains.

The carbon atoms from the methane had rearranged to form organic compounds. The appearance of these organic compounds in the chamber showed that organic compounds could have possibly been formed during the Earth’s prebiotic time.

It is hypothesized that some of the nitrogen-based amino acids may have formed into proteins, and that this same process might have helped to create the first base pairs of the DNA double helix structure. Coincidentally, the double helix shape was discovered by Watson and Crick in the same year as Miller’s experiment. In later years, Juan Oro was able to create adenine, a base of DNA, in an experiment with similar conditions to Miller’s. Adenine is also a component of adenosine triphosphate, or ATP, which is used for energy in cellular respiration (PBS, 1998). With these ideas, as well as other scientists’ beliefs that oxygen developed over time in the Earth’s environment, many scholars began to consider the concept that early life forms could have been created from non-living material, and that it was possible that life forms on Earth could have been sustained and began to develop.

Now, there is other evidence that suggests the carbon in the atmosphere was in the form of carbon dioxide instead of methane. One reason for this

altered view is that volcanic gas, which was prevalent in the early atmosphere, has more carbon dioxide than methane and ultraviolet light from the sun would have destroyed the methane. According to Wikipedia, “In [current] practice, [many reducing] gas mixtures containing CO, CO_2, N_2, etc. give much the same products as those containing CH_4 and NH_3 so long as there is no O_2. The H atoms [which are not included in the former group of gases] may have come mostly from water vapor.”

Regardless of the arrangement of the atoms in molecules, it is still believed that the inorganic compounds in the atmosphere of the early Earth led to the creation and support of organisms. This hypothesis is being further studied now due to new discoveries of conditions similar to early Earth’s on other planets, as well as the finding of a bacterial fossil on Mars (Henahan, 1996). Scientists are now beginning to question how the components of amino acids came to Earth in the first place. As Henahan stated, (1996), “Years after this experiment, a meteorite that struck near Murchison, Australia, was shown to contain a number of the same amino acids that Miller identified and in roughly the same relative amounts.” Based on this discovery, some scientists are considering the possibility that amino acids were brought to Earth from space. This and other hypotheses will continue to be reviewed in the future, as the science world attempts to determine the origin of life.

Works Cited

"A Science Odyssey: People and Discoveries." PBS. 1998. 15 Mar. 2006 <http://www.pbs.org/wgbh/aso/databank/entries/do53am.html>.

"Cruising Chemistry." 15 Mar. 2006 <http://www.chem.duke.edu/~jds/cruise_chem/Exobiology/miller.html>.

Henahan, Sean. "From Primordial Soup to the Prebiotic Beach." Access Excellence. 10 Apr. 2006 <http://www.accessexcellence.org/WN/NM/miller.html>.

Miller S. L. (1953). "Production of Amino Acids Under Possible Primitive Earth Conditions". *Science* **117**: 528.

"Miller-Urey Experiment." Wikipedia. 15 Mar. 2006 <http://en.wikipedia.org/wiki/Miller_experiment>.

Classroom Activity:

Motivation:
Review the six characteristics of living things with students. Have students respond to the question "What do you think the Earth was like when life appeared on it?"

Objectives:
Students will be able to:

- describe the atmosphere of the early Earth
- describe the theory of how life began on Earth
- explain Stanley Miller's experiment
- analyze how Miller's experiment simulated the creation of organic compounds from inorganic compounds
- compose a letter from Miller's point of view

Activities:
1. Discussion / reading of the story of Miller's experiment.
2. Viewing the movies narrated by Miller on http://www.ucsd.tv/miller-urey/
3. Students attempting to recreate the Miller experiment on the same website (Authentic Assessment) (correct answer is: vacuum, water, and adding all gases but oxygen)
4. Students will use paper models of atoms to demonstrate how the components of gases and water could rearrange to produce amino acids. (See attached pictures)
5. Students completing the DNA replication activity on
   http://www.pbs.org/wgbh/aso/tryit/dna/
   "A Science Odyssey: DNA Workshop." PBS. 1998. 15 Mar. 2006
   <http://www.pbs.org/wgbh/aso/tryit/dna/>.

Evaluation:
Students will write a letter from Miller's point of view to a fellow scientist explaining his experiment and discovery.

Relevant New Jersey Standards for Science:

5.5 A. Matter, Energy and Organization in Living Systems

2. Recognize that complex multicellular organisms, including humans, are composed of and defined by interactions of the following: cells, tissues, organs, systems.

5.5 C. Reproduction and Heredity

1. Describe how the sorting and recombining of genetic material results in the potential for variation among offspring of humans and other species.

5.6 A. Structure and Properties of Matter

1. Know that all matter is composed of atoms that may join together to form molecules.

2. Recognize that the phase of matter is determined by the arrangement and motion of atoms and molecules and that the motion of these particles is related to the energy of the system.

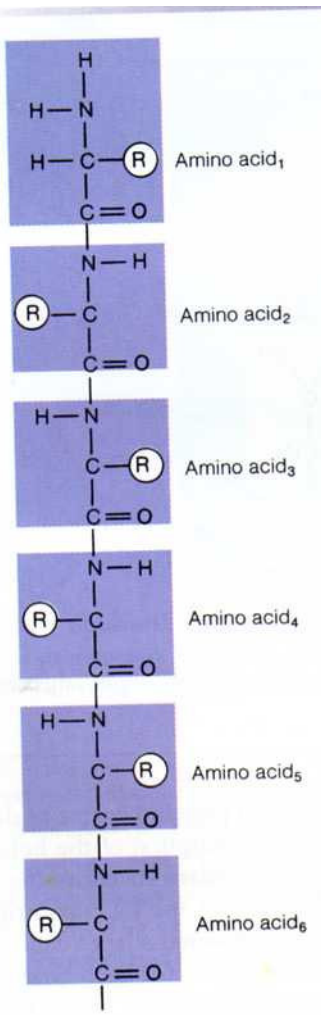
5.6 B. Chemical Reactions

1. Show how substances can chemically react with each other to form new substances having properties different from those of the original substances.

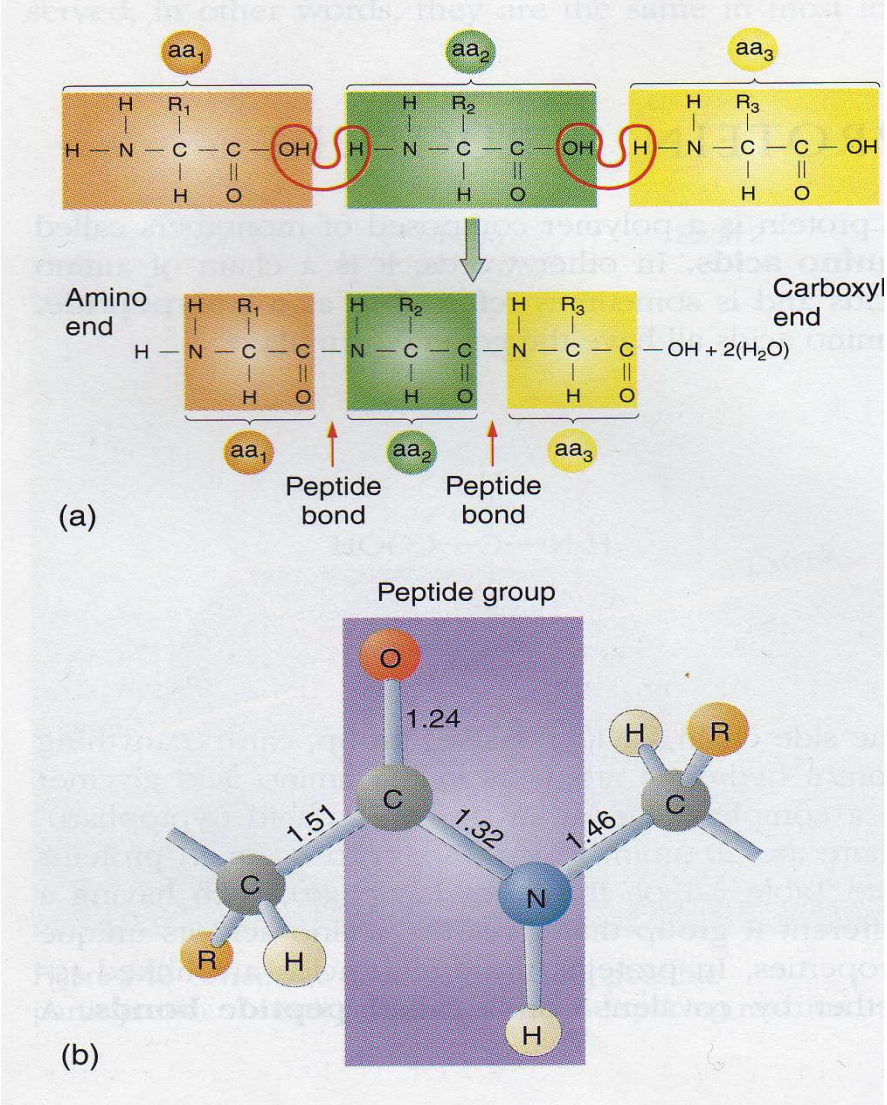
<u>Pictures of sample amino acids that can be arranged from gases used in Miller's experiment:</u>

From:

Griffiths, Anthony, et.al. <u>Modern Genetic Analysis</u>. W.H. Freeman and Company: New York, 1999.



Primary structure



From: Fox, Stuart Ira. (1999). *Human Physiology.* Boston: McGraw-Hill.