As It Was In The Beginning

Chemists testing origin-of-life theories now report laboratory success using the ingredients of a recently revived recipe for the primitive atmosphere

BY LINDA GARMON

Studies of the earthly beginning of life depend on what chemical chefs believe to be the primordial soup — the simple mixture of gases that constituted the earth's primitive atmosphere. Researchers test origin-of-life theories by studying, in laboratory simulations of that primitive soup, the chemical reactions that may have preceded the emergence of life. Now, for the first time in 30 years, the widely accepted recipe for primordial soup is changing from one rich in hydrogen — composed primarily of methane (CH_4) and ammonia (NH_3) — to a hydrogen-poor atmosphere similar to today's sans the oxygen. Moreover, prominent chemical evolutionists, including Cyril Ponnamperuma of the University of Maryland, recently reported the successful synthesis of possible molecular precursors of life from the components of the hypothesized hydrogen-poor atmosphere.

This hydrogen-poor soup du jour primordial is not a new recipe. In fact, in an early and often overlooked experiment — reported in the Oct. 19, 1951, SCIENCE — Melvin Calvin and colleagues of the University of California at Berkeley synthesized various organic compounds by irradiating a mixture of water and carbon dioxide (a hydrogen-poor counterpart to methane). But the Berkeley study soon was overshadowed by an experiment that would chart a nearly 30-year course for chemical evolution research — an experiment that made it easy to forget the possibility of a hydrogen-deficient atmosphere during earth's early days.

That experiment was done by Stanley Miller of the University of California at San Diego and Harold C. Urey, then of the University of Chicago. Urey and Miller proposed that earthly life began after an energy source, probably lightning, streaked through skies of methane and ammonia and produced the first complex organic chemicals. When the two researchers recreated their concept of chemical genesis by passing electricity through a mixture of methane, ammonia and water, four amino acids — likely precursors to life — were produced.

In addition to the Urey-Miller proof that complex organic molecules could be synthesized in a primitive mixture rich in hydrogen, other factors were in favor of such a soup. The universe has an abundance of hydrogen; the present atmospheres of the planetary giants Jupiter and Saturn have high concentrations of that element. If earth's primordial atmosphere was formed from the same nebula of dust and gases that condensed to form the planets of the solar system, then it seems reasonable to assume that a wealth of hydrogen characterized that atmosphere.

Geochemists now report, however, that such an assumption may not be so reasonable after all. Earth's early envelope, they theorize, was composed of hydrogen-poor gases released from volcanoes. According to this "outgassing" theory, an atmosphere full of hydrogen either never, or for only a very short while, surrounded the earth.

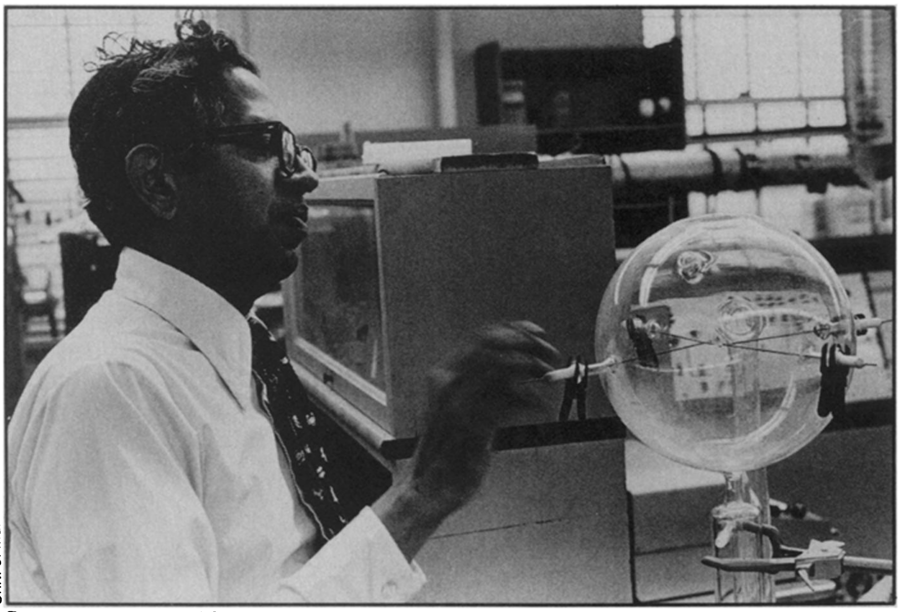
Ponnamperuma supports the less radical outgassing theory that allows a brief period of plentiful hydrogen. The short-lived atmosphere abundant in hydrogen came from the planet-forming nebula but was lost, he believes, because earth's gravitational force was not yet strong enough to hold it. Volcanic outgassings gradually replaced the escaping hydrogen-rich atmosphere. As a result, earth's primordial soup metamorphosed from a methane-ammonia (CH_4-NH_3) atmosphere, to a methane-nitrogen-water (CH_4-N_2-H_2O) mixture, to a carbon monoxide-nitrogen-water (CO-N_2-H_2O) blend and, eventually, to a carbon dioxide-nitrogen-water (CO_2-N_2-H_2O) system. In other words, the hydrogen-rich molecules methane (CH_4) and ammonia (NH_3) gave way to the hydrogen-poor carbon dioxide (CO_2) and nitrogen (N_2).

Could prebiotic organic molecules have formed from the non-organics, carbon dioxide and nitrogen? In experiments he plans to describe this spring in Atlanta at the meeting of the American Chemical Society, Ponnamperuma and colleagues set out to answer that question by exposing a variety of presumed primitive atmospheres to electrical discharges. These simulated atmospheres ranged from the hydrogen-rich to the CO_2-N_2-H_2O systems. "In every instance," Ponnamperuma says, "organic molecules were synthesized." Even in cases where water was the only hydrogen source and carbon dioxide the only carbon source, for example, simple organic products such as methane and ethane (C_2H_6) were formed — "intermediates in the synthesis leading to the molecules necessary for life." Ponnamperuma concludes that the initial hydrogen-rich atmosphere contributed much more rapidly to organic synthesis, but as long as the carbon sources of succeeding atmospheres could combine with the hydrogen from water, primordial organic chemistry continued.

While the thrust of Ponnamperuma's recent research is that organic matter could have formed in a hydrogen-poor atmosphere, he maintains that "the bulk of the organic molecules were formed under intensely reducing [hydrogen-rich] conditions." Other chemical evolutionists do not share this belief in an initial reducing soup that preceded outgassing. "No one has found the remains of a strongly reducing primitive atmosphere," says Joseph Pinto of the Goddard Institute for Space Studies in New York City. "There is no firm evidence for it in the geologic record."

On the contrary, evidence for the hydrogen-poor atmosphere lies, rather ironically, in another Ponnamperuma project — research on the rocks of Isua, Greenland. There, 3.8-billion-year-old rocks contain carbonates — minerals that could have formed only from a hydrogen-poor soup of carbon dioxide. While Ponnamperuma says the Isua rocks also contain 3.8-billion-year-old, hydrogen-rich microfossils and hydrocarbons, those claims have recently come under fire. In the Jan. 1/8 NATURE, D. Bridgwater of The Geological Museum in Copenhagen, Denmark, and colleagues conclude that the fossil-like structures in Isua rocks are "postdepositional," or contaminants. In that same issue of NATURE, the idea of ancient hydrocarbons also is criticized. It is unlikely that the hydrocarbons in Isua rocks are 3.8 billion years old, report Bartholomew Nagy and colleagues of the University of Arizona at Tucson, because such organics would have decomposed when the rocks heated to temperatures of between 400°C and 600°C during later geologic events. Instead, suggest Nagy and co-workers, the hydrocarbons came from encrusting lichens and cyanobacteria no more than a few tens of thousands of years ago.

Because of the paucity of evidence for even a short-lived hydrogen-rich earthly soup, an increasing number of researchers now are working with only those compounds that could have typified a hydrogen-poor atmosphere on embryonic earth. In experiments reported in the Oct. 10 SCIENCE, for example, Pinto and coworkers synthesized formaldehyde (H_2CO)—widely believed to have played a key role in the prebiotic synthesis of complex organic molecules — from the constituents of a simulated soup poor in hydrogen. The approaches to simulating such a non-reducing atmosphere vary from experiment to experiment, but all results thus far seem to bear the same message: Synthesis of potential molecular precursors to life is possible without the high concentrations of hydrogen long believed necessary.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Ponnamperuma with electric discharge apparatus that simulates primitive atmosphere.

Identifying the actual earthly atmosphere that hosted prebiotic synthesis, however, is only stage one in origin-of-life studies. The second difficult mystery to solve is how the primordial precursors interacted to form replicating systems that eventually evolved into simple organisms. Complicating this earthly enigma is the fact that life probably evolved in a relatively short portion of geologic time. (Earth is about 4.6 billion years old, and the oldest probable evidence of life is from 3.5-billion-year-old rocks in Western Australia.)

Some researchers who find it difficult to believe that life could have evolved so quickly from molecular ancestors have a "simple" solution to the problem: Life on earth evolved from life forms older than the earth that were brought to this planet by comets. While the consensus among chemical evolutionists is that this cometary theory of earthly life is balderdash, researchers believe that comets may have played a key role in the origin of earthly life by contributing to the gases of earth's primordial soup. This possibility was discussed last fall at the University of Maryland's Fifth Annual College Park Colloquia on Chemical Evolution. The planned National Aeronautics and Space Administration/European Space Agency international mission to fly with Halley's Comet in 1985 and 1986 would have allowed the sophisticated analysis of cometary material necessary to investigate the role these spectacular solar bodies may have played in the origin of life; unfortunately, only an ESA "fast flyby" now is in the works (SN: 1/24/81, p. 52).

Since the idea of cometary origins of earthly life has been virtually dismissed, chemists continue to wrestle with the question of what came between the synthesis of biological precursors and the emergence of life on earth. "There really is a gap right now in origin-of-life studies," says chemist David H. White of the University of Santa Clara in California. That gap, White explains, is "the most critical event in the origin of life" — the transition from chemical evolution to true Darwinian evo-

Urey: A spark for science


UCSD

Harold C. Urey: 1893-1981

Harold C. Urey believed in aiming for a bull's-eye from several directions. In his quest to unravel the origin-of-life mystery, he searched for clues not only in his famous laboratory synthesis of amino acids — using sparks of electricity through methane, ammonia and hydrogen gases to simulate supposed primordial conditions on earth — but also in Apollo mission moon rocks and hydrocarbon-containing meteorites. "He was one of the few people who stimulated activity in every direction," says chemical evolutionist Cyril Ponnamperuma of the University of Maryland at College Park.

On January 5, Urey, 86, died in La Jolla, Calif., leaving a legacy of research results as diverse as his approach to origin-of-life studies. In 1935, while at Columbia University, he was awarded the Nobel Prize in Chemistry for his discovery of deuterium, or heavy hydrogen. Urey also developed methods of separating the heavy isotopes of oxygen, nitrogen, carbon and sulfur. And during World War II, he directed the Manhattan Project's separation of uranium isotopes, which paved the way for the development of the atomic bomb. Urey later advocated international control of that nuclear technology.

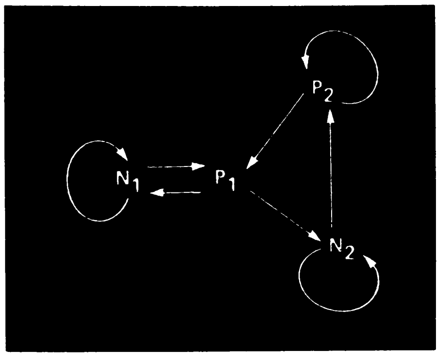
After the war, Urey pursued his chemical evolution studies at the University of Chicago, where he developed a method for determining the ocean temperatures of past geologic ages. During the birth of the space age in the late 1950s, Urey moved to the University of California, where his planetary activities included involvement in the Viking missions to Mars.

Ponnamperuma says of Urey, "There is no doubt about it: At every level, we owe a tremendous amount to him."

lution. The origin of chemical evolution is modeled using laboratory simulations of the proposed primordial soup. But the origin of Darwinian evolution, or natural selection, is distinct from chemical evolution, says White; it is the origin of reproduction, the birth of self-replication.

Researchers long have believed that the first self-replicating systems were simple — mere fragments of nucleic acids, for example, rather than whole cells. Now, White, in an attempt to close the gap in origin-of-life studies, has taken the concept of replicating fragments to the limit: He has defined an autogen — the simplest chemical system capable of genetic self-reproduction under certain assumed primordial conditions.

White's theorized autogen — described in the December JOURNAL OF MOLECULAR EVOLUTION — consists of two short nucleotide sequences, N_1 and N_2, and two simple peptide catalysts, P_1 and P_2, composed of amino acids. According to White's autogen theory, the two nucleic acid chains code for the two amino acid chains: N_1 codes for P_1 and N_2 codes for P_2. In turn, P_1 drives the replication of both N_1 and N_2, and P_2 drives the translation of both nucleic acid chains to the peptides.



White

White's theorized autogen model involves interaction between two short nucleic acid chains (N_1 and N_2) and two short peptide, or amino acid, strands (P_1 and P_2).

In addition to defining the autogen, White has used complex computer programs to determine that the chains could have been as short as 10 units, the catalytic rate as slow as 10 reactions a day and the accuracy of the system "crude" and still have succeeded. The point of this theory of a simple, catalytically slow and sloppy model for an autogen is that "only a few steps of high probability are necessary for a genetic system to originate and for Darwinian evolution to begin."

If the autogen theory can be proved correct, if the comets' precise role in forming the primitive soup can be defined, if the earthly beginning of life can be pinpointed in ancient rocks and if chemists can recreate the primordial chemical reactions, then researchers will "greatly strengthen the concept that the origin of life was a spontaneous and extremely rapid event," says White, "with no lucky accidents or highly improbable steps." □