THE ORIGIN OF LIFE

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We know that there has been life on earth for more than a billion years. How it began is still a mystery. One thing which helped to start it was probably the deadly poison, prussic acid. When the earth was new, the only rain that fell on it was a rain of molten iron. In that iron-drenched atmosphere began the series of chemical reactions which the author traces in this article and which led, he believes, to the origin of life. Perhaps the clues now provided will help chemists to solve the ancient problem of creating life.

ONE of the most surprising failures of modern chemistry has been its failure to create life. Living matter consists of the same chemical elements as everything else in the world. It has been analyzed many times. Yet the chemists have not been able to duplicate it. All life comes from previous life. We cannot create it anew. The beginnings of it all are lost in the dim, mysterious past of the earth.

This past, however, grows yearly less mysterious. Astronomers and geologists continue to explore it more and more successfully. And some of the newest facts which they have won provide, it now appears, new light on the mysteries of life. We can formulate new theories of life origin. We can see new clues to why the chemists have failed so completely to reproduce creation.

These new theories begin with the origin of the earth itself. They end in the surprising conclusion that the two substances most intimately associated with the beginnings of life are almost the last two which you would imagine as fitted for this creative rôle. One of them is the deadly poison, prussic acid. The other is the equally deadly gas, carbon monoxide, the gas which exists in the exhaust of automobile engines and which kills people who stay in closed garages while the engine is running.

A third substance probably involved in the creation of life on earth was water. Among these three, water, prussic acid, and carbon monoxide gas, there occurred some billions of years ago that remarkable chemical reaction which began the course of evolution and which culminated, at last, in the mind of man, the marvelous instrument which now begins to recover and to understand it all.

All present-day life consists, you remember, of the material called protoplasm. If you examine under a microscope any fragment of living matter, such as a meat fibre or a bit of a leaf, you will find it composed of separate, roundish grains like tiny sacks. Those are the living cells. Inside each cell is the whitish, translucent jelly of the protoplasm. Bacteria and other very simple creatures consist of but one cell each. More complicated creatures, like men, consist of many cells built up together to form the organs of the body. All living cells seem to be a good deal alike. All of them contain protoplasm, and this appears to be much the same in all kinds of creatures. The problem of the origin of life is really the problem of the origin of protoplasm.

By means of the fossils in the rocks of the earth the history of this protoplasm can be traced back quite a long way but not far enough to reach its origin. In almost the deepest (and therefore the most ancient) rocks which we know there are traces of tiny living creatures apparently a good deal like certain kinds that live to-day. Some of these resemble the modern bacteria which we call "germs". Others are like the tiny one-celled plants which occasionally make green scums on the surface of the water in stagnant ponds. These are the most ancient creatures which we know about with any assurance. Estimates of the age of the rocks in which they are found indicate that they were living about 1,400,000,000 years ago. At that time they were probably the highest forms of life on earth.

This time is so vast that it is difficult to realize. Suppose you drew a line from New York to Chicago to represent the whole fourteen hundred million years. On this scale the time since Julius Caesar would be represented by just five feet, about the distance you would move if you took two steps from one end of the line.

Within this fourteen hundred million years represented by the full line has occurred all the long drama of developing life: the origin of the many-legged and hard-shelled sea creatures of the ancient ocean, the evolution of the first fish, the later adventure of those fish-like creatures who came out on land and began to people it, the astonishing Age of Reptiles when vast creatures bulkier than modern locomotives stalked the earth and fought each other in the swamps and deserts of the time.

But this is not all of the story of life. Still earlier than these simple one-celled creatures which we find fossilized in the ancient rocks there seems to have been life on earth. In the few known rocks which belong still deeper in the earth's crust, and are still more ancient, we find no actual fossils, but we do find carbon in the form of graphite, and iron in the form of iron ore. There is reason to believe, on chemical grounds, that neither the graphite nor the iron ore could have been formed except by the aid of living creatures, creatures not unlike those which have actually been found in somewhat later rocks. Geologists believe, therefore, that terrestrial life began some millions of years before we find any fossils to represent it. The minimum date is probably about one and one-half billion years.

These dates, by the way, are not merely guessed at. There exists a clock by which they have been measured, probably with considerable accuracy. This clock is the radioactive element named uranium. Uranium is one of the elements of the famous radium group. All these elements slowly decompose, giving out relatively great amounts of energy in the form of "rays" and becoming converted meanwhile into other elements. The final stage of the process is the familiar metal lead.

The rates of these radioactive disintegrations are known. Accordingly, if one determines chemically the amount of uranium now present in a specimen of some radioactive mineral and determines also the amount of uranium-produced lead present in the same mineral, it is possible to calculate the time which has elapsed since that mineral was formed. Calculations like these, made on uranium minerals found in the earliest known rocks, have led to the estimates just quoted for the age of the earliest forms of life.

Mere dates do not greatly help us, of course, to determine the *manner* of life's beginning. Although the earliest creatures evidenced by the rocks are very simple ones it is apparent that there must have been a long history of development still farther back. We must bridge a considerable gap, both in structure and in chemical behavior, between non-living matter and those earliest and simplest forms of protoplasm.

To bridge this gap, even in theory, has proved so difficult that a few scientific men have resorted to what is really a mystical explanation. They assume that life involves some mysterious "vital force" entirely different from other physical forces and presumably undiscoverable by human experiments.

This, I submit, is a lazy man's view. It saves thinking by the simple expedient of removing the troublesome problem to the realm of the unthinkable. The same remark applies to the theory, propounded a few years ago by the distinguished Swedish physicist, Svante Arhennius, that life was created somewhere else in the universe and drifted across space to our earth in the form of fine particles of dust. This merely carries the problem of life origin off to some distant world which we know nothing about. Again we are conveniently relieved of the necessity of thinking about it at all.

To those who happen to like these mental anodynes they are, no doubt, satisfying enough. But the majority of scientific men do not like them. We prefer to believe that the phenomena of life are like everything else in the world in that they obey the established laws of chemistry and physics. If we have failed to duplicate life, — as we unquestionably have, — it is not because life is mysteriously and undiscoverably different, but merely because we have not yet found exactly the right combination of chemicals and circumstances to make creation a possibility.

This is just where the new knowledge provided by the astronomers and geologists comes to our aid. To see how this happens we must begin at the other end of our story and consider the origin of the earth.

Until the last two years two theories of earth origin have been current among scientific men. One was the famous Nebular Hypothesis of Laplace. The other was the more recent Planetesmal Hypothesis of Chamberlin and Moulton. It is unnecessary to pay much attention to these two hypotheses, for both of them have proved to be wrong, or, at least, to be incomplete. The theory of earth origin now generally accepted is due largely to the distinguished British physicist Doctor J. H. Jeans, formerly a professor in our own Princeton University. This theory is so essential to the suggestions of life origin which we are considering that it must be outlined with some completeness.

According to Doctor Jeans the earth began in a cosmic misfortune of our sun. This happened between eight and ten billion years ago. At that time the sun was a giant star, much larger than it is now, probably cooler, and consisting of gaseous matter much less dense than the solar substance is at present. The outer boundary of this vast gaseous globe may have extended as far as the present orbit of the earth.

There are still many such giant gaseous stars among the heavenly bodies. The famous Betelgeuse is one of them. Arcturus is another. Still a third is the remarkable variable star called Mira, recently measured at the Mount Wilson Observatory.

The giant sun of those days had no planets. It was merely a single star, like millions of others. But one day the misfortune arrived. Another vast star, flying along through space, chanced to come too near our sun. The gravitational attraction, tremendous between two such vast and massive bodies, played havoc with the gaseous matter of the sun. Some of this matter was actually pulled out of the sun in a long rod or filament, reaching out toward the passing star.

Gradually the star moved on. Some of the matter pulled out of the sun fell back into it. Another part of this matter probably went off forever into space, perhaps by itself, perhaps accompanying the star which had done the damage. Still a third portion of the extracted matter began to revolve around the sun in more or less circular orbits. This matter condensed presently to form the earth and the other planets.

We know fairly well the chemical composition of the material which was pulled out of the sun to become the substance of our solar family. Also we know that it was hot and gaseous. We even know, indeed, about how hot it was. It was approximately 7000 degrees, Fahrenheit; much hotter than the hottest furnaces which we possess on earth but far cooler than the matter of some of the greater, white-hot stars.

Knowing this chemical composition and temperature, we can calculate with reasonable assurance many of the circumstances and changes in this newly-born gas bubble which was to become, some billions of years later, the laboratory for the creation of life.

In the first stage of its history the earth bubble was gaseous throughout. Its chief constituent was gaseous iron, this metal evaporating, just as water does, when the temperature is above some 4500 degrees, Fahrenheit. Mixed with this gaseous iron were the vapors of aluminum, calcium, and the other rock-forming elements, just as gaseous oxygen, nitrogen, carbon dioxide, and so on, are mixed together in the present atmosphere of the earth.

Slowly the globe of hot, metallic gases cooled on its outer surface. Presently the outermost layer of iron vapor condensed to droplets of molten iron. Under the influence of gravity these droplets fell toward the centre of the globe. Thus began the second stage of earth history, the period of the Rain of Iron.

At first it is probable that these rain-drops of molten iron were evaporated immediately by the heat of the interior, just as desert travelers see to-day the rain-drops from clouds high up in the air evaporate in the hotter air close to the ground, producing no actual rain at all. But gradually the interior of the gas bubble cooled off also. Soon there accumulated at its centre a ball of molten iron. Thus originated the iron core which scientists believe, on the ground of much diverse evidence, still fills the central third or so of the earth.

But the hot gases of the primitive earth contained many other elements beside iron. As the gases cooled some of these other elements began to condense also. At a temperature of about 3000 degrees, Fahrenheit, slightly above that of a modern blast furnace, the chemical elements that make up rocks began to fall as rain in place of the earlier rain of iron. The liquid lava thus produced was less dense than molten iron. It floated on the surface of the ball of liquid iron previously accumulated at the earth's centre. Thus arrived the third stage of earth history, that of the Ocean of Lava.

Cooling continued. There were changes in the chemical composition of the falling rain of lava. The more condensable elements were exhausted from the atmosphere; those less easily condensable began to liquify in their turn. These were added to the rain of molten rock and to the substance of the sluggish lava sea, which formed the surface of the growing ball. Finally all the rock-forming elements were condensed out of the atmosphere, leaving only the permanent gases together with a few rather volatile elements such as sulphur and phosphorus. At the same time the surface of the lava ocean began to cool and to crust over in spots, much as ice crusts form in bitter weather on the surface of a wind-tossed lake. Unlike ice, these lava crusts would sink.

Finally the sunken lava crusts filled up the molten ocean. Liquid lava gave way to solid rock. There arrived the fourth stage of earth history, that of the Waterless Crust.

At this point the cooling of the earth altered entirely in character. Heat passes through solid rock only very slowly. So soon as the upper layer of the earth was solid and continuous the heat from the central core could no longer get out and pass off into space. It was as though the earth were swathed in asbestos. Indeed, it is probable that most of the original heat of the core is in it yet. The centre of the earth is probably almost as hot as when it first condensed in the period of the Rain of Iron.

Nevertheless, in spite of this bottling up of its internal heat, the earth did not cool off at once to its present temperature. The reason lay in the sun. The sun, remember, was still a giant star. It gave off vastly more heat than at present. This heat was sufficient, we can calculate, to keep the earth at a temperature of some 1400 or 1500 degrees, Fahrenheit, far above the boiling point of water.

But life could not begin until there was liquid water. There could be no liquid water until the earth's surface had cooled below 212 degrees. There ensued, therefore, a long period of waiting while the sun cooled and contracted in size. As this happened the earth's surface gradually cooled too, always in correspondence with the heat received from the sun. Finally it reached the critical temperature of 212 degrees. Pools of boiling water began to accumulate in the deeper depressions of the crust.

Now, at last, it was possible for the chemistry of life to begin. We enter the present stage of earth history, the stage of the Watery Ocean. There will be one more stage in the future, the stage of World-wide Ice.

The first ocean and the air above it were of very different compositions from the ocean and air of the present time. It is possible to determine, with considerable probability, what some of these differences were. But to do this we must return to some things which happened in earlier stages of the story, while the earth was still a bubble of white hot gas.

One of the effects of heat on matter is to break up chemical compounds. If you expose some water, for example, to a hot enough fire the water will be broken up into its constituent elements, hydrogen and oxygen. In the primeval earth-bubble, therefore, there were no chemical compounds. All the chemical elements existed separately; gases of iron and carbon and aluminum and all the rest.

But as the earth bubble grew somewhat cooler certain chemical compounds became possible. The first of them was probably the oxide of titanium, but as this is of no known importance to the story of life we need not consider it. What we do need to consider are the next two compounds to be formed. These were carbon monoxide gas and either prussic acid itself or the closely related and interconvertible compound which chemists call cyanogen.

These are the compounds which always form when a hot mixture of the three gaseous elements, oxygen, hydrogen, and nitrogen, is allowed to cool slowly. These three gases were present, together with the other elements, in the primeval gas bubble. As the gases cooled the two compounds, prussic acid and carbon monoxide, had to form. It was inevitable.

At a little later stage of the cooling another chemical reaction occurred. Hydrogen gas and oxygen gas combined to form water; or rather to form steam, for the earth was still far too hot for any liquid water to exist.

Meanwhile successive combinations with the condensing iron and other metallic elements and with the hot, liquid rock removed from the primitive atmosphere all of the oxygen gas which had not been used up already in the formation of carbon monoxide gas or of water.

We can now calculate what was the composition of the air and of the ocean when, in the course of time, the earth became cool enough to hold a watery ocean at all. The air contained no gaseous oxygen as it does now. All the oxygen had gone into chemical combinations. Whether the air contained any gaseous nitrogen is uncertain. What it unquestionably did contain were carbon monoxide gas and prussic acid gas.

But prussic acid gas is quite soluble in water. Accordingly the primitive ocean must have absorbed considerable amounts of this material. The water would dissolve, also, a small amount of the carbon monoxide gas. Salt and other substances may have been present too, as they are in the ocean to-day. In this ocean, full of the deadly prussic acid and overlaid by an atmosphere containing large amounts of a poisonous gas no less deadly, the first life arose.

We can even perceive a probable path by which this life may have arisen. By the destructive treatment of protoplasm, as, for example, with caustic chemicals, it is possible to break it up into certain simpler chemical substances a number of which belong to a group called amino acids. These amino acids are comparatively simple compounds of four elements: oxygen, hydrogen, carbon, and nitrogen. The simplest of them all is named glycocoll.

Now it is at least a curious coincidence that this very compound, glycocoll, may be produced, and has been produced in chemical laboratories, by a succession of chemical reactions between just these three substances which we have seen must have been present in the primeval ocean: prussic acid, carbon monoxide, and water.

It is probable that this is far more than a coincidence. We are now at the very border of our present knowledge and one cannot be too positive, but it is reasonable to assume that in that ancient ocean, saturated with two of the most violent poisons known to man, there occurred some natural chemical synthesis of glycocoll or of a similar material.

This would not give life. But it would be a first step toward it. Astronomic calculations indicate that the date of this ancient, prussic acid ocean was probably about five billion years ago. During the three or four billion years which were to elapse before the period when we find actual traces of life in the rocks there was ample time for such simple substances as glycocoll to undergo additional chemical changes and combinations and to be built up up into more complicated forms, perhaps at last into substances equivalent to our modern protoplasm. Although the individual steps cannot yet be traced it is probable that by some such path as this the first germs of life arose on earth.

New ways are open, then, for attack on the problem of artificial life. We must not try these creative experiments in air, for the air of our modern laboratories contains gaseous oxygen and no oxygen was present in those long ago days when the first life was being formed. We must work, on the other hand, with solutions of carbon monoxide and of prussic acid in water. We must see just what will happen when these solutions are exposed to conditions as similar as possible to the conditions of the ancient ocean.

Will some chemist create life in this way? Perhaps. Certainly many chemists will try.

OCTOBER SMOKE

THE children all along the street
  Are burning leaves;
Their shouts are intertwined as fire
  Curling in sheaves.

In ruddy shadows they run, they laugh,
  They rake the flames;
Their elders breathe the acrid dusk
  And cry their names:

"O, Jean! come now, it's getting late!"
  Far off one calls,
"Bil-*lee! Bil*-lee!" They straggle in,
  And evening falls.

—*Berenice K. Van Slyke*

Autumn

From a Woodcut by Julius J. Lankes