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IS THERE LIFE ON OTHER PLANETS?

A Caltech biologist considers the possibilities

by Norman Horowitz

Within the next ten years we will be sending rockets to the vicinity of the nearest planets, Venus and Mars. Within the next twenty years we will be exploring the surfaces of these planets – not with human explorers, but by means of automatic instruments landed on the planets which will send back information by radio to the earth. It will be a very long time, if ever, before human beings get as far away as Mars or Venus. But we hope to get a great deal of information about the physics and chemistry and biology of these planets long before men ever get there.

Of all the scientific problems that will present themselves to our exploring instruments, none is so interesting to the general public – or, for that matter, to scientists – as the question: Does life exist on other planets?

The discovery of life on another planet would be one of the momentous events of human history. The study of organisms of other planets would tell us whether our particular form of living matter, based on proteins and nucleic acids, is the only possible kind of life, or whether some other kind of material is capable of showing the attributes of living matter. Knowledge of this kind would greatly deepen our understanding of the origin of life on the earth.

Nucleic acids and proteins are the basic unique materials of living matter on the earth. If we understood how they were generated, we would know how life arose on the earth. They are both very complicated molecules. A good bit is known about their chemical structure, but there is still a lot of work to be done. We know that they resemble one another in one way; they are both high polymers. They are both very large molecules, composed of small sub-units, laid end to end in long chains.

As a result of discoveries of this sort – the discovery that all organisms, even viruses, are built up of these same kinds of materials—biologists have come to realize that life is a manifestation of certain molecular combinations. We know that these molecular combinations cannot have existed forever.

Cosmologists tell us that even the elements have not existed forever. Perhaps matter itself hasn't existed forever. And so it is impossible to believe that nucleic acids and proteins have always existed. Life must have had an origin at some time, and we think its origin consisted in the production of these molecules in some random kind of chemical reaction.

What can we say about the possibilities for the development of molecules of this sort on the earth? The astronomers provide us with a picture of the primitive earth which suggests in general terms how the spontaneous generation of this type of molecule may have come about. Although the question is by no means settled, many astronomers and cosmologists consider it likely that the solar system was formed about five billion years ago from a dust cloud that surrounded the sun. This dust cloud condensed into the planets. What would the cloud have been made of? The best answer we can get is to look into space around us and see what kinds of matter we find.

If you look at the distribution of elements in space, you find that one element predominates, and that is hydrogen. After hydrogen comes helium, and after helium comes oxygen, nitrogen, carbon, and the other lighter elements. It seems reasonable to assume that the dust cloud was a random sample of cosmic matter, and that it too was composed largely of hydrogen, mixed with some helium, carbon, oxygen, nitrogen, and so on. Carbon, oxygen, and nitrogen are the elements which are important for the production of the organic material that we need in order to create the first living molecules.

If we try to imagine the synthesis of something like nucleic acid or protein on the earth today, we

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find it is impossible to conceive of this happening in a spontaneous way. We can conceive of doing it in the laboratory, but we can't imagine it occurring in a lake, say, spontaneously. There are two reasons for this. First of all, any pinch of soil or drop of water that one picks up on the earth today contains microorganisms, and microorganisms are hungry all the time; when they find organic matter in their environment they consume it. That is one reason why the spontaneous generation of complicated molecules would be impossible today: they could not evolve. The generation of a molecule as complicated as a protein or a nucleic acid cannot occur in just one step. This requires a long evolution, a building up of organic compounds of ever-increasing complexity. The production of such large molecules would be the final step in a long chain of chemical reactions. This chain would be stopped by microorganisms.

Even if there were no microorganisms today, we could not imagine organic syntheses of any complexity going on in our atmosphere, or in the seas, because we have an atmosphere which contains 20 percent of oxygen. Oxygen is a reactive element. It combines readily with organic matter and destroys it. Organic materials do not have a chance to evolve into complicated structures in an atmosphere that contains as much oxygen as ours.

And that is why it is interesting to learn that the astronomers provide us, in the primitive earth, not with an atmosphere of oxygen, but with an atmosphere that is mainly hydrogen. In addition, there will be the lighter elements — carbon, oxygen, nitrogen, and the rest.

If we ask chemists what are the stable forms of carbon, oxygen, and nitrogen in the presence of so much hydrogen, they tell us that carbon will be present as methane, CH_4; nitrogen as ammonia, NH_3; and oxygen as water, H_2O. Today we've lost the methane and the ammonia, oxygen is present partly as free oxygen and partly combined as water, and nitrogen is present as gaseous nitrogen. The reason for the change is that the earth has lost its envelope of hydrogen. Hydrogen is a light gas and the gravitational field of the earth is not strong enough to hold it. In the course of time, the hydrogen has diffused out into space. But in the early stages of the development of the earth, according to this theory, it had an envelope of hydrogen, and as a result we had carbon as methane, nitrogen as ammonia, and oxygen in the form of water.

Professor Harold Urey and a student of his, Dr. Stanley Miller, who are now at the University of California campus at La Jolla, got the brilliant idea of making a mixture of this primordial atmosphere and passing a spark discharge through it to see what would happen — as if, on the primitive earth, there were lightning.

They found that a large variety of organic material was produced — of much greater complexity than the stuff they started with. Among these organic materials, interestingly enough, were a number of amino acids. Amino acids are the building blocks from which the proteins are made; so this experiment suggested the possibility that, on a primitive earth with an atmosphere containing hydrogen, there was actually the possibility of a real evolution — a building up of organic material into quite complex forms.

The beginning of life

The duration of this experiment was only a week. Nature had a couple of billion years and all the oceans in which to carry out the same experiments, instead of a 500cc flask. So this experiment and others of its kind lend support to the notion that life arose on the earth during this primitive time when the chemical nature of the atmosphere was predisposed toward the evolution of organic material. It is thought that, in the course of a couple of billion years, something as complicated as a protein molecule or a nucleic acid molecule could have been generated spontaneously by a random chemical combination.

What does this tell us about life on the other planets? According to this view, life will arise where conditions are favorable. If the other planets had an atmosphere similar to the one that we imagine the primitive earth had, and if conditions remained favorable for a sufficiently long period, then there is no reason why life could not have started on other planets as well as on the earth. There is no reason to believe that the earth is unique in this matter.

The planet nearest to the sun is Mercury, which we can dismiss as a possible abode of life *because* it is so close to the sun, is very small, and has no detectable atmosphere. Mercury is just a little larger than our moon. It keeps one face to the sun all the time, just as our moon always keeps the same side to the earth — and for the same reason. The earth exerts such a strong tidal force on the moon that it prevents the moon from turning with respect to the earth. The big tidal pull of the sun on Mercury produces the same result.

On the illuminated side the temperature of Mercury must be of the order of 400°C. The dark side is probably the coldest spot in the solar system — just a degree or two above absolute zero. It is very unlikely that any extensive organic syntheses have occurred on Mercury.

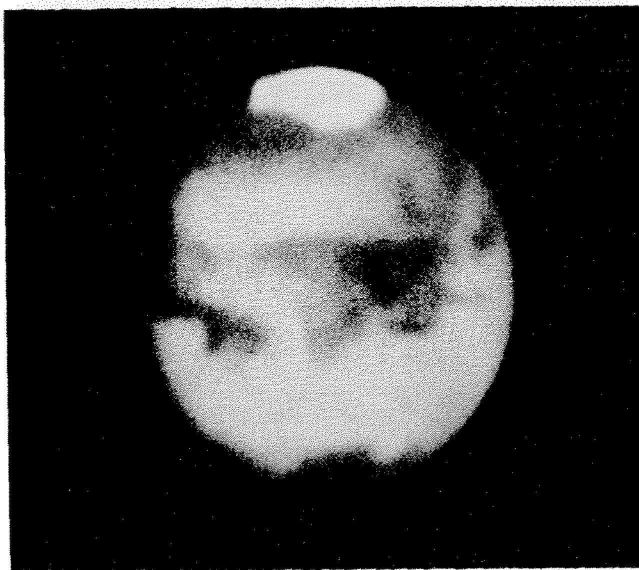
Venus, our nearest neighbor

The next planet out from the sun is Venus. Venus is our nearest neighbor among the planets. It is about the same size as the earth too. And it is not so close to the sun that you would expect *a priori* that it would be too hot for life. If a planet the size of the earth were moved to the neighborhood of Venus, a temperature increase of something like 50°C would be expected. We know of organisms that can live at temperatures 50° warmer than our own. Venus at first glance seems like a possibly interesting planet from a biological point of view.

You would think, being as close to us as it is (its closest approach is about 25 million miles) that we ought to be able to see something on Venus. Unfortunately, this is not true. Astronomers tell us that Venus is a most frustrating planet to look at. For one thing, it is between us and the sun, so that when it is closest to us, we are looking at the dark side, and we cannot see anything. When it is fully illuminated, it is on the far side of the sun — so far away that we don't see anything. When it is in an intermediate position, and we do have a look at it, we find that it is covered by impenetrable clouds; the surface has never been seen.

We know a little about the atmosphere of Venus. We know that it contains much carbon dioxide. No oxygen has been detected. And, according to recent measurements, there is the possibility of a little water. The presence of water is important for the origin of life, since water is an indispensable solvent for the kinds of chemical reactions that we are interested in.

Temperature measurements have been made by measuring the emission of radio waves from Venus, and it seems that the temperature at the surface is a good bit warmer than the 60 or 70°C predicted from the simplest calculations. It appears to be about 300°. The difference could be due to the greenhouse effect of the thick atmosphere of carbon dioxide which Venus has. Carbon dioxide traps heat, so that the planetary surface should be much warmer than would be expected if a body the size of Venus were simply placed at the right distance from the sun. If this temperature is correct, then it is not very likely that anything is living on Venus, because organic material is unstable at this temperature. Many biologically important substances decompose at temperatures far below 300°C.



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An interesting point about the temperature of Venus is that it appears, from the radio measurements, to be about the same at night as in the daytime — i.e., the dark side has nearly the same temperature as the bright side. This suggests that there are tremendous winds on the surface that circulate the atmosphere so that even at night there is no cooling.

One of the important things biologists want to learn is the actual temperature of the surface of Venus. One of the first missions of a spacecraft into the vicinity of Venus will be to make temperature measurements.

The next planet out which we know something about is the earth, and beyond the earth is Mars. Of all the planets of the solar system, next to the earth, Mars is the most favorable as a possible abode of life. Astronomers can actually see Mars. We are between the sun and Mars, so that the illuminated side of Mars can be seen fairly well. Mars is not as close to us as Venus, and it will be harder to go to Mars by rocket because we have to go away from the sun instead of toward it. So the trip to Venus will almost certainly be made before the trip to Mars, though Mars, we think, will be more interesting biologically.

The temperature on Mars has been measured. On a summer day, at the equator of Mars, it gets to about 25°C at noon. But at night it is very cold; it probably goes to −50°C or lower as soon as the sun sets, because the Martian atmosphere is very thin. Neither oxygen nor water vapor have been detected in it, and there are no open bodies of water on the planet, but there are reasons for thinking that a small amount of water is present in the atmosphere. There is carbon dioxide in the Martian atmosphere, and there is probably argon, and nitrogen. The atmospheric pressure and the climate are similar to what would obtain at the top of a 50,000-foot mountain on earth.

If one looks at Mars with a telescope, he can see polar caps on the planet. The polar caps behave like snow optically, and most people think they are snow, though this is not universally agreed on. If the cap material is snow, this is very important biologically, of course, because this means that there is water on the planet.

Growth on Mars?

Then there are the dark areas on Mars. These provide us with the only evidence we have that life exists outside the earth. Observations of these areas have led some astronomers to the idea that things are growing on Mars. The dark areas are not constant in shape. They change with the seasons. As the Martian spring comes around, observers notice a progressive darkening of these areas, moving from the pole toward the equator.

This is just the opposite of what occurs on the earth. This is because Mars is a very dry planet, according to those who believe that the dark patches are vegetation. In the wintertime, the Martian water is locked up as ice at the pole. When spring comes, the ice begins to evaporate and, as water vapor in the air, moves toward the equator. Then the plants (if they are plants) begin to grow, and this wave of darkening which can be observed on Mars continues until the summer. By summertime, it reaches the equator, and sometimes beyond it. Then it retreats.

Spectroscopic evidence also suggests that these patches may represent something living. W. M. Sinton, of the Lowell Observatory, has studied the light which is reflected from the dark patches and has compared it with the light which comes from the bright areas. The bright areas on Mars are believed to be deserts. The light coming from the dark areas, when analyzed spectroscopically, shows absorption bands which are also found in organic substances. This observation has lent strength to the idea that these changing dark areas do in fact contain carbon compounds. And if they contain carbon compounds, they may be living.

Another kind of argument has been raised in connection with the dark regions. Astronomers occasionally see great dust clouds swirling up from the desert areas on Mars. These clouds may persist for weeks. It is argued that the dust clouds settling out over the planet would eventually cover the dark patches, which would have become invisible unless they were capable of growing up through the dust layer.

What kinds of experiments can we do with instrumented rockets to find out about life on the planets?

First of all, much can be done from the earth. Our own atmosphere absorbs certain wave lengths of light so that we cannot make all the spectroscopic measurements on the planets that we would like. It is possible to mount telescopes in balloons that will bring them up above much of our atmosphere — or even to orbit them in satellites and have them automatically aimed at the planets. In this way it will be possible to get better answers to questions about the composition of the planetary atmospheres. Such measurements can also give us better estimates of the temperatures of the planets.

Knowing the composition of the atmospheres, we can get some idea of the amount of ultraviolet reaching the planets. This is important biologically because ultraviolet light is destructive to organic material; if we know what the ultraviolet flux is on the surface of the planets, it will tell us a lot about the possibilities of an accumulation of organic materials there.

Planetary rockets

Another group of experiments will be mounted in rockets that will go to the vicinity of the planets — that is, within 50,000 miles of the planetary surfaces. From these rockets we hope to take pictures of the planets and to make further spectroscopic studies in the infrared and ultraviolet. From these measurements, it should be possible to get a fairly good idea of the chemical nature of the planetary surfaces and atmospheres. More critical biological observations will be made when spacecraft finally land on the planets. One obvious experiment is to drop a television camera by parachute or balloon. In this way, evidences of large organisms and of civilizations could be obtained. It is unlikely that anything of this kind will be found on either Mars or Venus. A colleague of mine, Dr. Albert Tyler, has suggested sending a mousetrap to Mars, with a television camera to watch it. This sort of experiment is being planned, but not with a mousetrap. An experiment much more likely to succeed involves a trap which will catch, not mice, but microorganisms.

If there is life at all on Mars, there will certainly be microbial life. Microbial life is simpler than other forms; it can withstand difficult conditions more readily than higher forms of life; and, on the earth, it is ubiquitous. Automatic devices are being designed to be landed on Mars that will inoculate culture media with Martian soil and monitor the growth of microorganisms by the increase in turbidity, or by measuring metabolism. It may even be possible to observe the microorganisms through a microscope attached to a television camera.

If we do detect microorganisms on Mars by instrumented rockets, the next thing we would want to do is find out whether they are chemically similar to our own life. Do these microorganisms contain nucleic acids and proteins? This is the most fundamental question that a biologist would like to ask of a Martian organism. As Joshua Lederberg has remarked,

Scientists operate a full-scale model of a Surveyor spacecraft, scheduled to make a soft landing on the moon in 1963. At the left is Leo Stoolman (MS '42, PhD '53) of the Hughes Aircraft Company, which is building seven Surveyors for Caltech's Jet Propulsion Laboratory. At the right, Walker Gilberson of JPL checks the probe which will measure the moon's surface characteristics. While instruments analyze lunar material and atmosphere, television cameras will observe the operations.

if there are intelligent beings on Mars, this is the first thing we would ask of a Martian biochemist. If there are no Martian biochemists, then we will have to devise experiments for carrying out chemical analysis of these organisms. Possibly by that time we will be able to bring back samples of Martian soil and cultivate the organisms in our own laboratories. That is the experiment that will give us the best information of all.

I should note how important it is that we, in sending rockets to Mars or Venus, do not accidentally contaminate those planets with microorganisms from the earth. Suppose Mars did contain organic material, and perhaps even some living things. We know that if we import strange organisms from other places on the earth, into a new environment, they often find the new environment so satisfactory that they take it over and destroy the indigenous life. If such a thing occurred on Mars, it would be a scientific catastrophe.

Even if there is no life on the planets they may still be of great biological interest, because they may be repositories of organic material from past ages. Such chemical fossils would be of tremendous interest to us as possible stages in the development of our own planet. Even the moon may be of interest in this regard, as has recently been made clear by Carl Sagan of the University of California.

These are some of the prospects for the study of life in outer space. I have not touched on the question of how a totally unfamiliar form of living matter would be recognized. It is curious to note how, once we leave our familiar environment, even the question "What is life?" – which seems very philosophical and abstract here – takes on immediate practical purpose.