Life on Other Stars - Part II

Enrst Stuhlinger

life on other stars

By Ernst Stuhlinger

Ernst Stuhlinger, Director of Research Projects Office, Army Ballistic Missile Agency, was born in Niederrimbach, Germany, December, 1913. He attended school at Tuebingen and received his doctorate in physics at the University of Tuebingen in 1936. He worked closely with Dr. Hans Geiger, developer of the Geiger counter, for seven years. At Peenemuende, Dr. Stuhlinger carried on research in connection with the development of guidance and control systems for the V-2 guided missile. He has gained recognition in recent years for his feasibility and design studies of electrical propulsion systems for space ships.

Part II

All the countless observations of celestial bodies, many of them with the most ingenious methods known to modern science, have not yet given us a definite proof of the existence of life in places outside of our own Earth. The only direct indication of the possibility of living matter existing on another star is the observation of green patches on the surface of Mars. These patches expand during the Martian spring and summer and recede again during fall and winter. They are commonly interpreted as being caused by green plants, probably not too different from our mosses and lichens. Other than this one observation, no trace of life has ever been observed in the universe. And yet, scientists state with a high degree of certainty that life must be expected to exist on other stars. They base this statement on a simple rule which, for a long time, has served as a most powerful and a most successful guide to the biologist. It simply states that when the necessary conditions for a certain development are fulfilled, nature initiates this development very readily. Applying this rule, we must expect that life has developed on many other celestial bodies on which the necessary conditions for its development were met at one time or another. As we assumed in the first part of this article,* there are about 100,000 planets within our galaxy which very probably are similar to Earth. That part of our universe which can be observed with today's means contains, in all likelihood, no less than ten thousand billion planets on which, at some time, conditions were favorable for the development of life.

What, then, are these conditions? First, there must be a source to supply energy in an adequate form to the living organisms. Second, there must be a source of "building material" to provide the proper raw material for their growth. Third, there must be water. Fourth, the temperature variations must be within reasonable limits, about —20°C (—4°F) to +80°C (176°F). Fifth, there must not be an excessive amount of poisons or other agents detrimental to living matter. Once life has developed on a planet, it may well adapt itself to less stringent conditions. Many organisms on Earth live and even thrive in regions where the temperature regularly drops far below zero or where there is no water or air. However, it is not probable that living organisms could grow through the very early phases of their ontogenetic development if the temperature dropped considerably below zero for longer periods or if there were no water and air.

Yet these requirements are not enough. If we fill carbon, oxygen, nitrogen, and water in a test tube, irradiate it with sun light, provide a convenient temperature and keep poisonous material out, there will still be no development of life. A living cell, even the most primitive, contains protein. The basic elements making up protein molecules are

*"Life on other Stars," part 1, SPACE Journal, spring, 1958, p. 10.

carbon, hydrogen, oxygen, and nitrogen; but each protein molecule has a very large number of atoms. These atoms are arranged in extremely complicated but very orderly patterns. Even though many different patterns of atoms may be formed just by random events in a mixture of those atoms in the course of time, it is improbable that the formation of a highly complex protein molecule, just as a random event, is completely negligible, even over a time span of millions of years. A very special force is necessary to put the atoms in the right order, to arrange them in such a way that a protein molecule results. Even so, would this complicated protein molecule, immediately after its formation be alive? Would it show the characteristic features of life, the metabolism, the regulatory processes, the growth, the tendency to procreate, the development of protective measures and, most important of all an inherent trend for evolution? These features which make live matter so characteristically different from dead matter, can they be understood at all on the basis of the laws of nature as we know them from today's physics and chemistry? Or do we have to assume a creative act from far outside the boundaries of our natural sciences? There is, I believe, only one answer which we can give in honesty: we do not know. But this very question has been with mankind as long as there has been scientific thought. It will certainly remain not only the most intriguing question of all science, but also one of the most profound questions which can be asked by man.

The physical sciences have given us a marvelous picture of the inorganic world, extending out to the remote galaxies of the universe and down into the submicrostructures of the atomic nuclei. We understand the laws that make the stars move; we can design complicated machines which utilize the forces and interactions of electric phenomena; we have learned to move through the air, and beyond it, with unbelievable speeds; and we draw almost limitless power from the interior of the atom. Biology has been no less successful in revealing the laws that underlie the world of animals and plants. The laws of physics and chemistry, correctly applied, are valid also in the realm of organic matter. And yet the fundamental question which faces the natural scientist is still unanswered: are the laws of physics and chemistry, including those still unknown, sufficient to explain the formation of living matter? All we can do is to continue our researches into the mysteries of nature, even if this question should remain unanswered for a very long time.

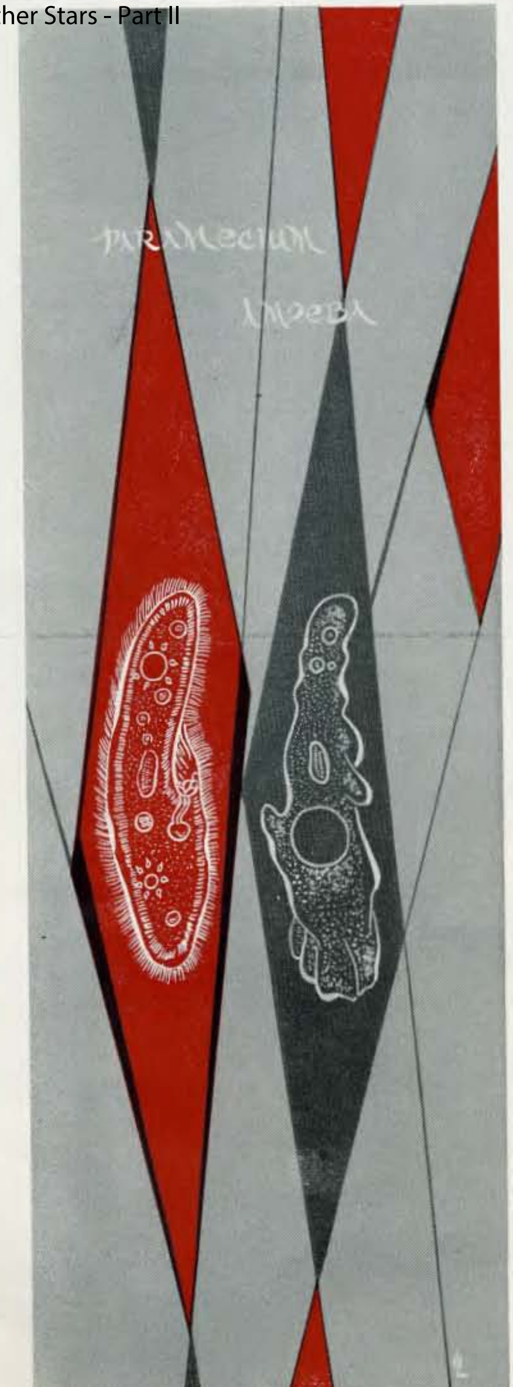
Scientists, indeed all of us, would be reluctant to assume that our little planet Earth is the only place in the vast universe on which life has developed. Although we do not know what causes a protein molecule to develop out of its basic ingredients and what makes it behave like a live protein molecule, we are confident that nature initiates this development whenever, and wherever, the conditions are right. This reasoning implies that life—even on Earth—may have started in more than one place, and more often than once. In fact, it is conceivable that molecules which possess the characteristic features of life developed many times on Earth, and continue to develop today. It should be assumed, though, that the first phases of this development, taking place in a single live protein molecule, may well take millions and millions of years and that such a molecule exhibits the features of life in such an inconspicuous manner that we may not become aware of its existence, even if we had it in our test tube.

Earth owes its life-favoring conditions to its atmosphere, its store of water, and its proximity to the Sun. The elements found on Earth are the same as those found on other celestial bodies. This can be verified by an analysis of the light which reaches Earth from other stars. The chemical compounds, however, are quite different on stars and planets. While the outer regions of the Sun consist mainly of hydrogen and helium and only traces of particularly hardy components like cyanogen, silicon fluoride, and titanium dioxide, the crust of Earth, and that of the planets, is made up of a great variety of chemical compounds. The relative abundance

of these compounds is very probably the same on the solar planets and in all likelihood, also on the planets of other stars. This, however, is only true for the solid part of the planets. Their atmospheres and their water content differ very widely. It is this difference and their distances from the heat-providing central star which makes some planets suitable for life and excludes others very definitely.

The atmosphere of Earth fulfills a number of functions which are essential for the support of life. It provides oxygen for the animals and carbon dioxide for the plants. It carries rain to the remotest places. It moderates the impact of the solar rays during the daytime, and it keeps the surface of Earth from losing its heat too quickly during the night. It shields the living beings from ultraviolet and cosmic radiation, and it protects them against the countless meteorites which constantly shower Earth.

The animal organism, being constantly at work in one way or another, needs a continuous supply of energy. Oxygen, with its great affinity to exothermic reactions with many other elements, is an ideal source of energy. Nature chose the slow combustion of oxygen with other elements as the principal supply of energy for the bodies of animals. The fuel which is burned with the oxygen of the atmosphere is normally some form of plant or animal life. It is well known that the body of an animal could not subsist on the combustion of soot or crude oil, although the amount of heat energy per gram of those fuels is much higher than that of a gram of spinach. This fact indicates very clearly that the animal body does not only require calories for its subsistence, but also a specific kind of "molecular orderliness." This peculiar feature of animal organisms will be discussed some more in a future article.



The atmosphere of Earth has not always been the same throughout the several billion years of its existence. In the beginning, there was a great abundance of light gases, particularly hydrogen, helium, methane, ammonia, water vapor, and neon. However, Earth could not retain these gases while it was still very hot. They gradually drifted out into space, and we must assume that for some period during its development Earth was without an appreciable atmosphere. To understand the reason why a planet can lose its atmosphere, we must take a look at the structure of our atmosphere in general.

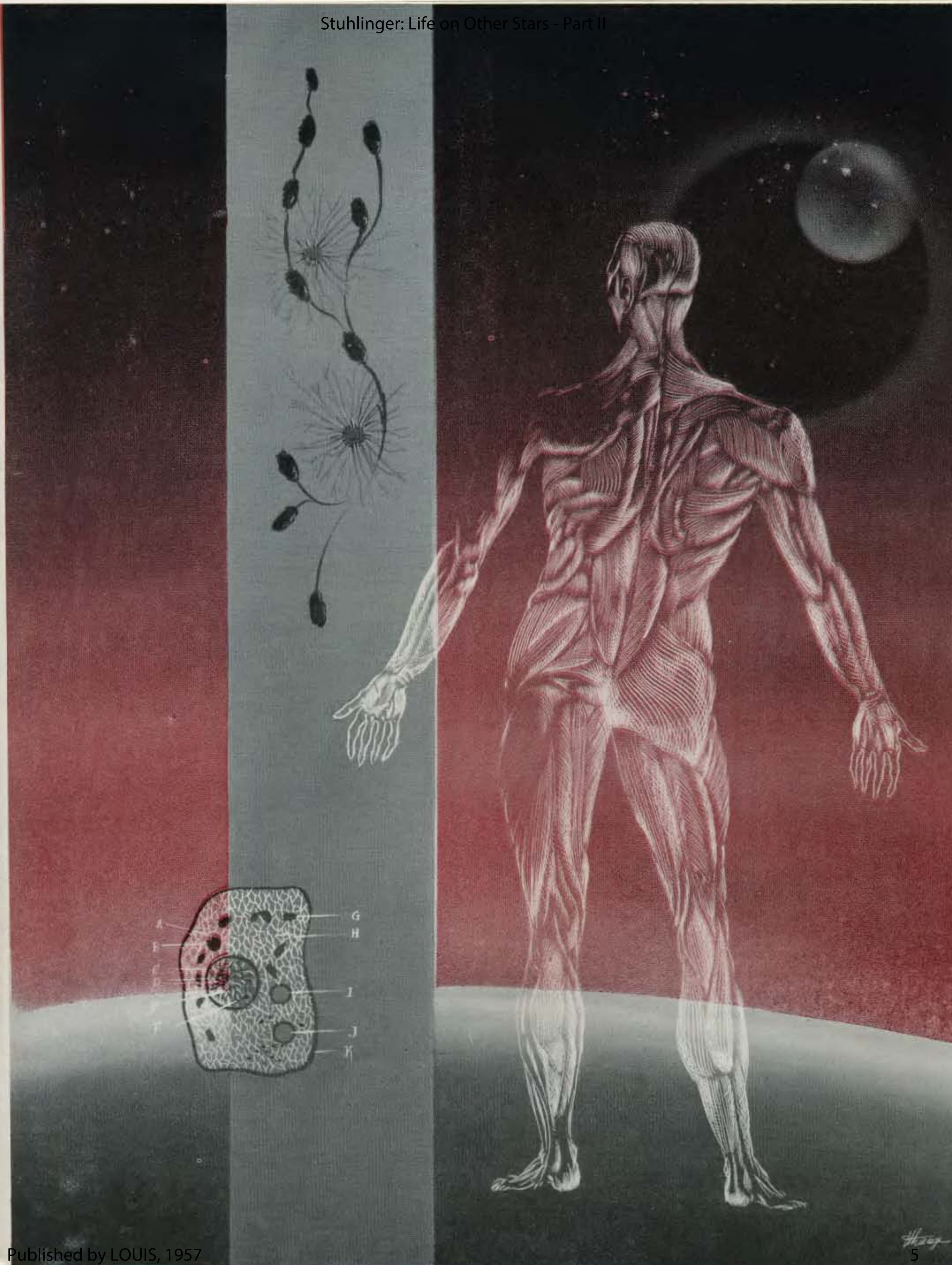
The molecules of a gas are in constant motion; their velocities and directions are distributed at random. Under conditions of normal temperature and atmospheric pressure, one cubic inch of air contains about a hundred billion billion molecules. Each of them collides with another one after a path of not more than a hundred thousandth of an inch, thereby changing its velocity and its direction. The average velocities of the molecules in a gas depend on the temperature: The hotter the gas, the higher the average velocity of its molecules. The mean molecular velocities of various gases are listed in table 1 for two different temperatures. Some of the molecules will always be faster than the average, others will be slower. The distribution of their velocities follows a so-called Maxwellian distribution curve.

The height of the atmosphere is not well defined. Its density decreases continuously on the way up, but even at an altitude of 200 miles we find still almost a billion molecules in each cubic inch. The path length between two collisions, however, has increased to many thousand miles. If at an altitude of a few hundred miles a molecule happens to acquire a particularly high velocity in a few favorable collisions, and if its direction is radially outward from Earth, it may well overcome the gravity pull of Earth's field and escape into outer space. The velocity needed for this escape is independent of the mass of the molecule, but depends on the mass and the diameter of the planet. Some characteristic escape velocities are listed in table II.

Although the average velocities of gases, even at higher temperatures, are generally lower than the escape velocities of Earth and other planets, there will always be molecules whose velocities, at one time or another, are sufficiently high to make them escape from their mother planet. In the course of millions of years, this gradual escape may well lead to a considerable rarefication, and even a total loss, of a planetary atmosphere. In the case of Earth, it did. It was only much later, after Earth had cooled down, that a new atmosphere developed. Carbon dioxide, nitrogen, and water vapor were probably the main constituents of this new atmosphere. They were released from the crust as it slowly solidified. But there was still no oxygen in the air, and if there had been, it would have been consumed again in the oxidation processes of the rocks and minerals. There was some methane and ammonia, and this almost chaotic setting was probably the backdrop on which the first live protein molecules were formed. How this possibly may have happened, or at least what we can conjecture today, will be described in more detail in the next issue of SPACE Journal. It may suffice here to note that the first living organisms were probably small coagulations of protoplasma-like matter, capable of splitting carbon dioxide with the aid of sunlight. The carbon and a number of chemical compounds incorporating carbon were retained in the organism, and the oxygen was released. We must assume that the total amount of oxygen found in our atmosphere today was produced by plant organisms.

There would be even more oxygen in the air today if the plants, after their death and during their decay, had not used up so much of it in a slow oxidation process which finally resulted again in carbon dioxide. However, throughout the ages, much of the organic matter was buried deep in the ground where it was not exposed to the oxygen of the atmosphere. A considerable amount of oxygen was therefore left in the atmosphere, and huge reservoirs of coal and oil were built up simultaneously in the deeper layers of Earth's crust. It is very interesting to note that the total amount of oxygen in the atmosphere would just about be sufficient to oxidize the total amount of coal and oil still buried under the surface.

Animal life was able to develop on earth as soon as the oxygen supply was sufficient for its support. The animal organism depends for its food entirely—either directly or indirectly—on the existence of plant life. But, the production of carbon dioxide by the animals is such a small contribution to the large-scale production by oxidation of dead plant organisms that animals could not be considered essential for the existence of plant life. It is conceivable, therefore, that a planet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contains vegetation and no animals; but it is not to be expected that there are planets populated by animals and bare of any plant-like organisms.

It is by no means certain, of course, whether life will always develop into a plant branch and an animal branch. There are numerous species of living organisms even on Earth which cannot be counted under one of these branches. Viruses, bacteria, and even some of the protozoa, do not clearly belong to the plants or the animals. Some highly specialized parasites which live in the intestines of other animals require neither oxygen nor carbon dioxide nor light for their subsistence; they live on sugar or starch which they take from their immediate vicinity, and they produce energy not from oxidation, but from a process of fermentation which is controlled by special enzymes. These parasites, of course, depend on a live host. It may be assumed with a high degree of certainty that if life develops at all, it will at first be in the form of plant-like organisms which consume carbon dioxide and release oxygen, with the help of sunlight. Carbon dioxide and sunlight are therefore mandatory for the development of life. Water, too, is absolutely essential, not only as a source of hydrogen, but also as a solvent, and as a basis for the colloids which form the bulk of the structural materials of plant cells. Most of the transportation of materials inside a living organism, plant or animal, is done by diffusion or by osmotic processes; this would be unthinkable without water. With its large specific heat, water is an ideal thermostat which helps to equalize the temperature within one organism and which protects the organism against rapid changes in temperature. It is true that life can exist for long periods of time without water, as in dry spores or seeds. However, this is a latent kind of life only, and not the active development of living organisms. There are even mammals, like the little desert mouse, which never drink water during their whole life; they synthesize it out of carbohydrates and oxygen. Even though they can live without taking water, they procure it in an indirect way, for the seeds and other food which they eat could never develop without an adequate supply of water.

Life can only develop, and subsist, when the ambient temperature is favorable. The lower limit of the temperature range suitable for life is not only determined by the freezing of the liquids within the organism, but also by the rates of chemical and physiological reactions which, as a rule, depend very sensitively on the temperature. It is true that a living body can develop and maintain a temperature considerably higher than that of the surroundings, but the temperature gradients within the outer layers of the body can not be too great. Furthermore, active temperature control is a refinement that is achieved by an organism only a long time after it has developed the basic features of life. We may safely assume, therefore, that life develops only in regions where the temperature does not drop below the freezing point of water solutions. The high-temperature limit is set by the stability of large organic molecules. Any molecule can be broken up if the temperature is raised high enough. The large molecules which are found in living matter decompose fairly easily, many of them even below the boiling point of water. Most live organisms can be killed by boiling them in water. Some algae are known to live, and even thrive, in hot springs, but these organisms are highly specialized and certainly do not represent an original development. It should be assumed that an environment which allows temperatures below about -20°C (-4°F) and above $+80^\circ$C (176°F) is not suited for the development of life.

With these restricting conditions in mind, we will now proceed to look at the solar planets as a typical planetary system, and we will ask which of them might be capable of bearing life.

TABLE 1

MEAN THERMAL VELOCITIES OF ATOMS AND MOLECULES AT DIFFERENT TEMPERATURES

	0°C	2400°
Hydrogen	1.15 mi/sec	3.4 mi/sec
Helium	0.82	2.4
Water Vapor	0.38	1.1
Nitrogen	0.31	0.9
Oxygen	0.29	0.86
Carbon Dioxide	0.25	0.74

TABLE II

ESCAPE VELOCITIES AT SURFACES OF PLANETS

	Mi/sec
Moon	1.5
Mercury	2.6
Venus	6.4
Earth	7.0
Mars	3.1
Jupiter	37.0
Saturn	22.0
Uranus	13.0
Neptune	14.0
Pluto	6.5

TABLE III

CHARACTERISTIC DATA OF PLANETS

PLANET	DIAMETER (MILES)	VOLUME EARTH: 1	DENSITY EARTH: 1	MASS EARTH: 1	GRAVITY EARTH: 1	TEMP. OF SURFACE Max. (°F)	LENGTH OF DAY (HOURS)	DISTANCE FROM SUN (SIDEREAL DAYS)	LENGTH OF YEAR (MILES x 10^6)	ORBITAL VELOCITY (MILES/SEC)
MERCURY	3,100	0.060	0.76	0.056	0.38	750°	2,105.85	87.96	35.9	29.7
VENUS	7,700	0.910	0.88	0.817	0.86	210°	718.23	224.70	67.2	21.7
EARTH	7,927	1.000	1.00	1.000	1.00	140°	23.94	365.25	92.9	18.5
MARS	4,215	0.151	0.71	0.108	0.39	90°	24.61	686.98	141.5	15.0
JUPITER	88,640	1,312.000	0.24	318.350	2.64	-200°	9.38	4,332.60	483.3	8.1
SATURN	75,100	763.000	0.13	95.280	1.17	-240°	10.03	10,759.53	886.2	6.0
URANUS	31,000	59.000	0.23	14.580	1.05	-270°	10.75	30,686.48	1,782.8	4.2
NEPTUNE	32,000	72.000	0.29	17.360	1.23	-330°	15.80	60,188.82	2,793.5	3.4
PLUTO	3,500	0.900	0.96	0.700	0.90	-370°	155.61	90,471.33	3,676.0	2.8
MOON	2,160	0.020	0.60	0.012	0.16-0.20	-240°	654.04	27.32	.24*	0.64

*DISTANCE FROM EARTH.

The amount of solar energy which is received by a given area is inversely proportional to the square of the distance between this area and the Sun. Mercury, for example, whose mean distance from the Sun is only about one-third that of Earth, receives almost nine times as much solar energy per unit area as Earth. Saturn receives almost a hundred times less. There is only a limited region around the Sun, and around each fixed star, within which a planet receives the right amount of solar radiation to make life possible. If a planet within this region has about the right magnitude, it could have developed an atmosphere which contains at least water vapor and some other gases like nitrogen and carbon dioxide. This atmosphere in turn would equalize the temperature sufficiently so that an environment favorable for the development of life would result. H. Strughold has named this favorable region around a fixed star the "ecosphere." Our Earth happens to be right in the middle of the Sun's ecosphere. Venus is at its inner, Mars at its outer margin.

Mercury, our smallest planet, (see table III) is unsuitable for life. It has the peculiar feature of always turning the same face toward the Sun, very much like the Moon always looks toward Earth with the same side. The bright side of Mercury, having eternal day, is heated up to a surface temperature of about 400°C (750°F). The "night" side, which is permanently in the shadow, is extremely cold. There is a very broad twilight zone between the hot and the cold regions because of angular oscillations of the planet; in this zone, the temperature varies widely up and down during the Mercurian year. If there is any atmosphere on Mercury—and there are optical observations which imply that there is some—its pressure is not greater than about 1/800 of that on Earth. Mercury is simply too small, and too hot on its sunny side, to retain an appreciable amount of gas as an atmosphere. It is probably mountainous, but travellers to Mercury will find nothing except "a lifeless, desolate world, with a surface parched and cracked" (Patrick Moore).

Venus, one of the most beautiful sights in the evening or morning sky, has been veiled in mystery as long as astronomers have turned their telescopes toward it. A dense atmosphere, opaque to optical observation, covers the entire planet. It is not known what this opaque gas layer consists of, but it is probable that it contains carbon dioxide, and possibly large clouds of dust. But what does it hide? Since no water vapor can be detected in the outer layers of the atmosphere of Venus, it was assumed in the past that Venus is an entirely dry and desert-like planet, whipped by terrific storms and shrouded by a permanent layer of dust clouds. Whipple and Menzel recently suggested that the entire surface of Venus may be one large ocean of water. In this case, it is not impossible that there is some kind of aquatic life on Venus. The temperature of the water would be high, but it would be below the boiling point. There is only little hope that we will learn much more about the surface of Venus until our first interplanetary spaceship circles the planet and sends sounding rockets through its atmospheric blanket.

The Moon is an entirely inhospitable place. Although it receives the same solar energy per unit time and area as Earth, there is certainly no life on the lunar surface. The temperature on the sunlit side goes up to about 120°C (250°F). In the shadow, it drops quickly down to — 150°C (— 240°F). There is no atmosphere which could equalize these large temperature differences. Even if there had been some gases during its early development phases, the Moon would have lost them very rapidly because of its small size. There might be minute traces of very heavy gases like krypton or xenon, but their existence would be insignificant for the development of life.

Mars is always named first when life on other planets is discussed. Its surface conditions are more like terrestrial conditions than those of any other known planet. Speculations about the forms of Martian life have been numerous and fantastic, and there is almost no limit to the weirdness of the Martian monsters which have been conjectured by inventive minds. Astrobiologists are now more cautious. They do not expect more than some modest, but very resistant forms of plant life, such as we find on Earth in the dry and rocky areas of the far north. The green patches which can be seen on the Martian surface, together with the relatively low temperatures + 20°C (+ 68°F) during the day, but only — 70°C (— 94°F) during the night according to G. de Vaucouleurs and G. P. Kuiper) imply a possible vegetation similar to mosses or lichens. The atmospheric density on Mars is only one-tenth of that on Earth. It contains nitrogen and carbon dioxide, but almost no oxygen. The water content of the Martian atmosphere is only a few percent of the moisture in the atmosphere above terrestrial deserts. Animal life similar to that on Earth would not be possible. A very interesting suggestion has been made by H. Strughold: it is possible that plants on Mars store the oxygen resulting from their metabolism within their tissues, thereby building up a kind of "internal atmosphere." Plant types different from ours could thus develop, and even specialized forms of animal life, drawing oxygen directly from the plants, would not be utterly impossible. However, conditions for life are not overwhelming on Mars. As H. Strughold put it, Mars has always been, and will always be, an "underdeveloped planet," as far as life is concerned. It is just a little too far away from the Sun. The greatest distance from the Sun is even much more significant for the rest of the planets. Jupiter, Saturn, Uranus, and Neptune are large enough to retain even the lightest gas, hydrogen, in their atmospheres. However, their surface temperatures are so extremely low (see table III) that none of the processes which are essential for the development of life could possibly take place. The mean densities of these four large planets are surprisingly low; the logical explanation is that considerable portions of their observed sizes are made up by atmospheres of great depth. The water, which exists unquestionably in great quantities on these planets, must be frozen. In fact, it is assumed today that each of the four

major planets has a rocky core which is covered by a layer of ice several thousand miles thick; their atmospheres above the ice coating also have depths of several thousand miles. These figures are implied by the low densities, the observed diameters, and the very pronounced flattening of the planets. The atmospheric pressure at the surface of Jupiter is about a million times greater than the atmospheric pressure at the surface of Earth. Even at much lower pressures, all gases are liquid or solid, or at least have densities equal to their densities in the liquid or solid state. The term "atmosphere" is therefore misleading; only the outermost few hundred miles of the "atmospheres" of these planets can be expected to be gaseous. Again judging from the observed densities, it must be assumed that these outer layers consist of hydrogen or helium. Jupiter and Saturn contain, in addition, fairly large quantities of gaseous ammonia. All four planets are rich in gaseous methane. Most of the ammonia, however, is frozen; the same is true for carbon dioxide, which should not be expected in gaseous form. No gaseous nitrogen or oxygen should be expected either.

We need not hope to find any traces of life on one of the four major planets. The temperatures are far too low; there is no gaseous oxygen or carbon dioxide; there is no liquid water; there is an abundance of the poisonous gases ammonia and methane. Their surfaces are deserts of frozen gases, hostile to any possible form of life. It is hard to imagine how future space travelers could ever set foot on one of these planets. They will only orbit around them at respectable distances, sending their unmanned sounding probes down into these oceans of hydrogen, helium, methane, and ammonia. The rocky core of these planets will probably never be accessible to man.

Little is known about the last and remotest planet, Pluto. It is too far away for meaningful, direct observations. But even without knowing too much about its surface conditions, the possibility of life can be excluded because of the extremely low surface temperatures.

Among the nine planets of the Sun, there are three whose orbits are within the ecosphere; but only one of them, Earth, exhibits such a favorable combination of properties that life could develop on a grand scale. Venus may bear some aquatic life; Mars very probably carries low forms of vegetation.

How long will Earth continue to offer these favorable conditions? Within the next billions of years, the Sun will heat up and expand and eventually will extend its white hot atmosphere beyond the planetary orbit of Earth. But long before that time, Earth will have lost more and more of its atmosphere. Within the next several million years, the atmosphere will gradually drift away into outer space. When the gaseous oxygen and carbon dioxide are significantly rarefied, animal and plant life in its present form will no longer be possible. Will life by then have developed into forms which can subsist under the changed conditions? Will man have found other ways to prevent the gradual decline of favorable living conditions? Will he change his Earth, long before nature does, into a place which is no longer an inviting abode for life? After all, the history of *homo sapiens* covers only some ten thousand years, and *homo sapiens technicus* has been at work for only a few hundred years.