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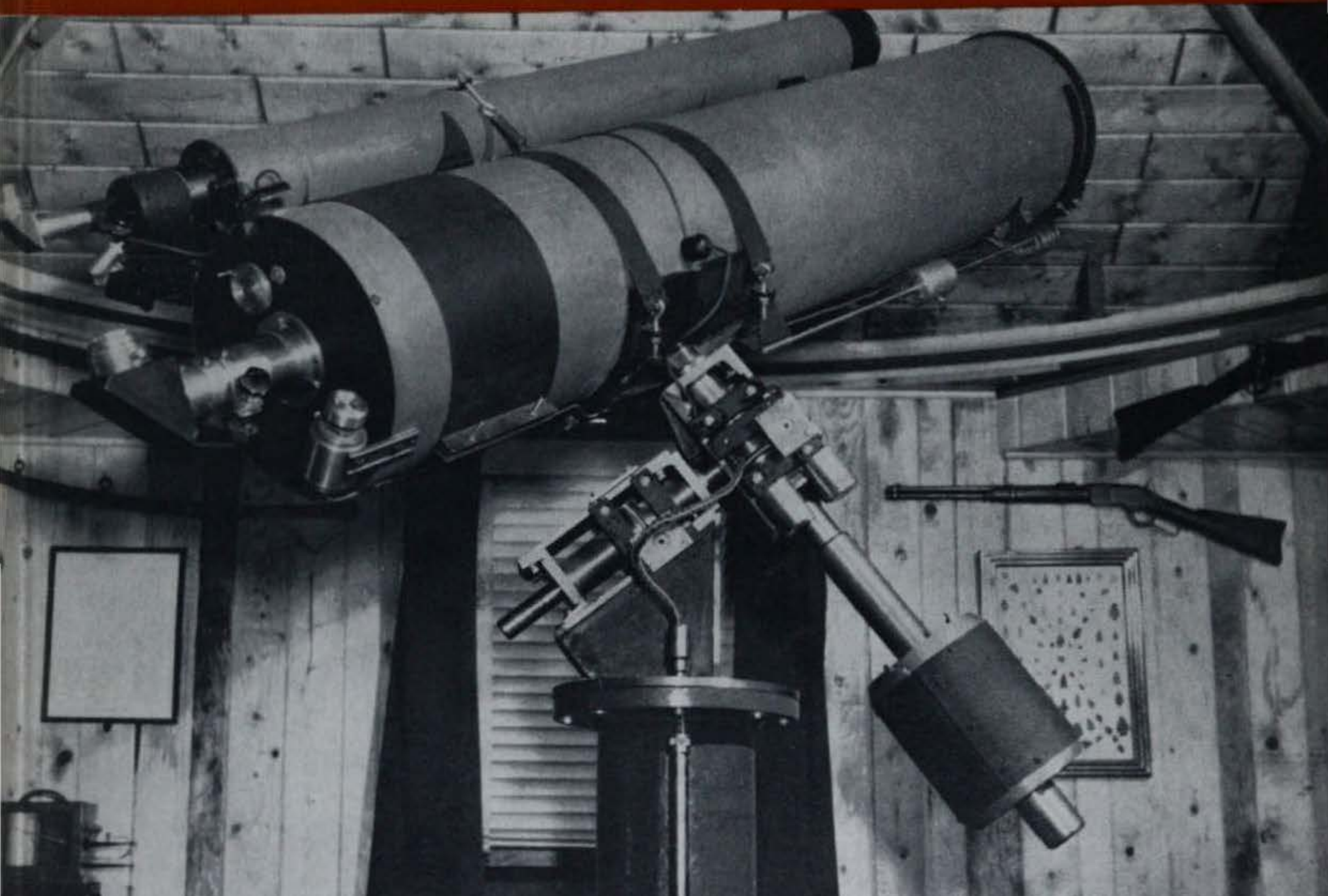

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In This Issue:

LIFE ON OTHER WORLDS

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WHEN I started working on this article I intended to use the title Astro-Biology. But the time is probably not yet ripe to recognize such a completely new discipline within the framework of astronomy. The basic facts of the origin of life on earth are still vague and uncertain; and our knowledge of the physical conditions on Venus and Mars is insufficient to give us a reliable background for answering the question: Does life exist on these planets, or has it existed in the distant past?

I have therefore adopted the title of a famous book by the Astronomer Royal, Sir Harold Spencer Jones, which has been read by many thousands of people, and has evoked enthusiastic reviews by critics such as Sir James Jeans, who wrote in *Nature*: "It is a model of what such a book should be, popular and scientific at the same time, clear but concise in its writing, with the main theme standing out unburdened by irrelevant details, and the conclusions stated with balance and fairness."

Sir Harold's book was first published in 1940. Since then there has been important new astronomical evidence, such as G. P. Kuiper's studies of the infrared spectra of the planets. There have been even more profound additions to our understanding of the origin of life on earth. And, finally, there has been a revolution in our ideas concerning the uniqueness of the solar system in the galaxy.

My own contribution to these advances is quite small, and pertains only to the last item, the place of the solar system among the stars of our galaxy. I have therefore felt some reluctance about writing on the problems of life on other worlds, but three inspiring articles have helped me to overcome this feeling. The first, in order of time, was Kuiper's revision of the chapter on "Planetary Atmospheres and Their Origin" in the 1952 edition of *The Atmospheres of the Earth and Planets* (University of Chicago Press). The second was George Wald's summarizing article, "The Origin of Life," in the August, 1954, issue of *Scientific American*. The third was a comprehensive discussion by V. G. Fessenkov entitled, "On the Physical Conditions and the Possibility of Life on Mars," in the Russian periodical, *Problems of Philosophy*, No. 3, 1954. We have here authoritative opinions by two astronomers and one biologist who have contributed to our problem. The writings of an equally distinguished chemist, Harold Urey, with whom I have also had a number of discussions, have still further influenced my own ideas.

We take the view that life is an intrinsic and inseparable property of certain aggregates of very complex organic molecules. No such aggregates have been produced artificially, but if we could make them in the laboratory, we would undoubtedly find them to be "alive."

We shall also adopt the opinion of many modern biologists and speak of a "spontaneous generation" of living molecules and their aggregates by natural processes—the formation of highly complex organic molecules in a medium containing the required kinds of atoms.

The principal building blocks of living organisms are the carbohydrates, fats, proteins, and nucleic acids. All of them are complicated structures containing dozens or hundreds of atoms. They consist almost entirely of the rather common atoms, hydrogen, carbon, oxygen, and nitrogen. All these atoms are abundant on the earth, and presumably also on other planets. The unusual feature of these molecules is that so many simple atoms are bound together in a single entity. How have they ever succeeded in being at the same place, at the same time, to combine into a single molecule?

Let us consider briefly how a simple inorganic molecule such as water, H_2O, is formed. Each atom of H has a single electron that revolves around a proton. The O atom has eight electrons, two in an inner shell and six in an outer shell. But the inner shell can never contain more than two electrons. Helium, which actually has two electrons, has its innermost shell filled to capacity and it has no further room to accommodate additional electrons. Hence, the atom of He is inert; it does not easily combine with other atoms and rarely appears as a partner in a molecule.

The second shell of electrons, as the physicists tell us, may contain as many as eight electrons. Neon atoms have a total of 10 electrons, two in the inner shell and eight in the outer. There is no more room for additional electrons in the outer shell; thus neon is also inert, and we call it a *noble* gas.

But oxygen has two empty spaces in its outer electronic shell. Hence it is chemically active. It can attract free hydrogen atoms and place the two electrons, one from each H atom, in these vacant spaces. This binds the atoms into a molecule containing a total of 10 electrons.

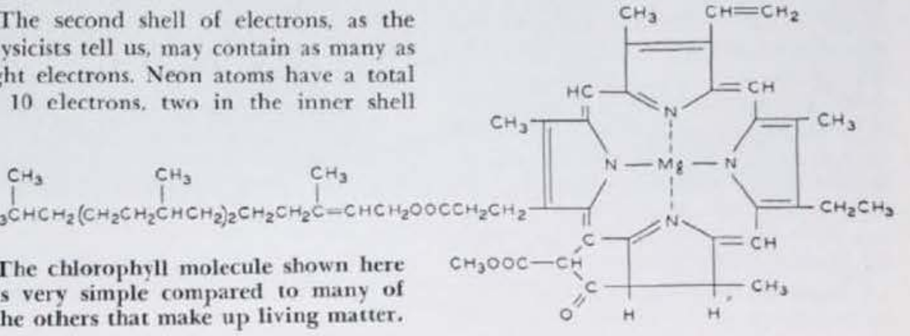
Whatever the binding forces are, the atoms must somehow get close enough together—not necessarily at one time, for conceivably an OH molecule might be formed first, which could later become H_2O.

It would seem, at first sight, that the probability of forming the complex organic molecules as the result of chance encounters between hundreds of atoms is so small as to be ruled out. And spontaneous formation of an advanced living organism is too improbable to have even once taken place during the five-billion-year history of the earth, or even on any of the millions or billions of planets that probably exist in our Milky Way galaxy!

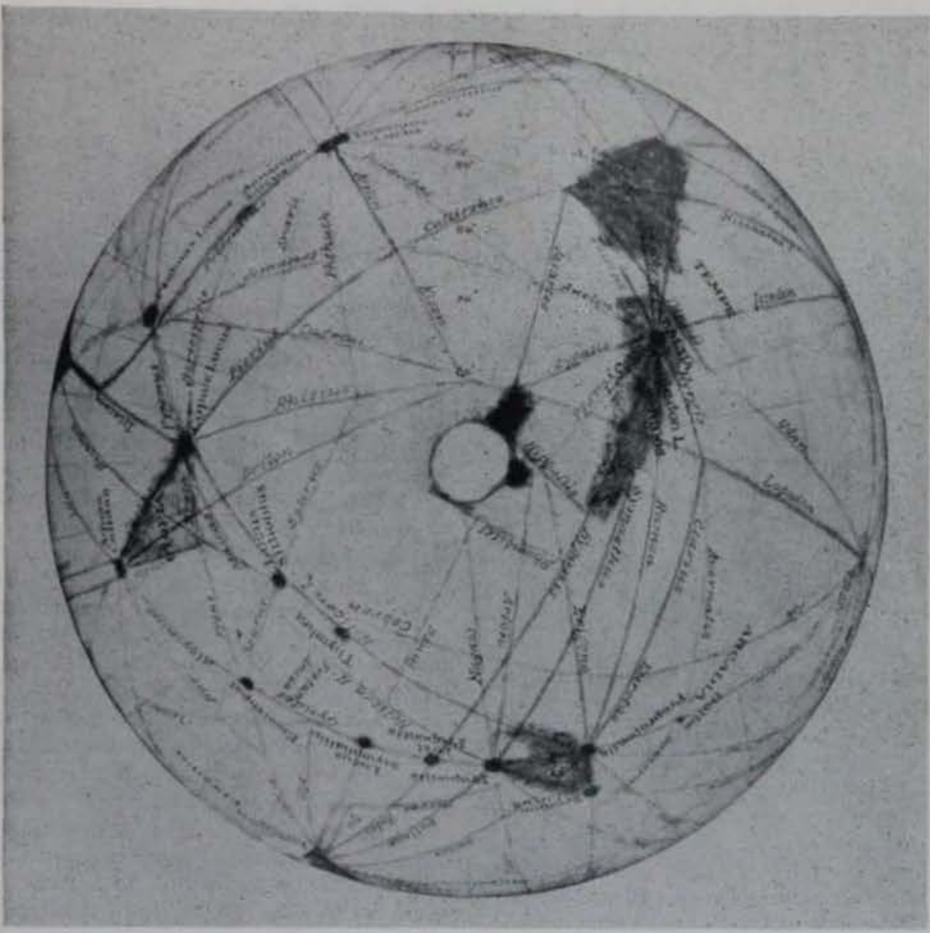
But the complex organic molecules raise less difficulty. However, the atoms must have a chance to approach one another, not once, but billions of times within a short interval.

In a solid substance, the atoms are prevented from doing this. We need a liquid or gaseous medium to satisfy this condition, say, water or air for terrestrial life.

About two decades ago, A. I. Oparin suggested that given enough time, organic molecules might form spontaneously in a gas containing water vapor, methane (CH_4), ammonia (NH_3), and hydrogen. Inspired by this idea, one of Urey's students, S. L. Miller, at the University of Chicago carried out an experiment with these gases, continuously circulating them



The chlorophyll molecule shown here is very simple compared to many of the others that make up living matter.



A Percival Lowell map of the northern hemisphere of Mars, with the north polar cap in the center, from his observations of 1901. Lowell maintained that the canals formed a geometrical network and were artificial watercourses. This view is no longer held, and later observers seldom describe the canals as narrow rulings forming so regular a pattern as this.

through a glass tube where they passed into a strong electrical discharge. At the end of a week there appeared in the mixture certain organic molecules, such as glycine and alanine, which form parts of the more complex protein molecules.

Even though the probability of the spontaneous formation of a molecule is exceedingly small, the number of atoms in water is exceedingly large, and the time interval during which some such process may have operated in nature is exceedingly long. Most biologists believe that the origin of life on earth occurred in large, warm (but not hot) bodies of water, rather than in air. If spontaneous generation had first operated in air, the primitive organisms would probably have been destroyed rapidly by the ultraviolet light of the sun.

It is thus reasonable to believe that living molecules or aggregates of molecules were formed by encounters in water. Do they have a chance to multiply, to expend energy upon the process of "living," and to combine gradually to form more complicated living beings?

Presumably there was no free oxygen in the water, or in the earth's atmosphere, before there was a vast population of primitive living organisms. Since oxygen is exceedingly active chemically, any small amount of it that might be released in volcanic eruptions, or be produced by sunlight from the decomposition of water and other oxygen-containing molecules, would be used up immediately to oxidize the solid rocks of the earth's surface. Some rocks are even now underoxidized: they seek to take up any available free oxygen and bind it up in more highly oxidized solid or liquid compounds.

Perhaps there was not even any carbon dioxide in the original nitrogen-heavy atmosphere of the earth—though on this point there is less unanimity.

It would appear that the original watery home of the primitive living molecules contained nothing that could be used for food. The molecules were compelled to feed upon each other, a rather destructive process which, unless promptly arrested, would destroy life as rapidly as it was created by spontaneous generation.

It has been suggested, however, that the process of feeding of some organic substances upon others is like the fermentation of sugar by yeast. This produces a small amount of energy, enough to satisfy the very limited living requirements of primitive organisms, and produces alcohol and carbon dioxide. Hence, even if CO_2 was not at first available it might have been produced by the organisms themselves.

Once CO_2 became available, the remaining organisms could tap a new and exceedingly rich source of energy, sunlight, without having to rely upon the wasteful process of fermentation. Sunlight enables the CO_2 to combine with H_2O, giving sugar and free oxygen. We call this process photosynthesis.

Thus all that was needed was the formation of some CO_2. Photosynthesis would then automatically produce more sugar that could again be fermented. But it would also produce free O_2, not previously available, and this paved the way for a new source of the vital need of all organisms—energy. The free oxygen would oxidize the sugar and other organic molecules, replenishing the supply of CO_2, and making more energy available.

The foregoing picture biologists have painted for us agrees reasonably well with the astronomical evidence. The original atmosphere of the earth contained no O_2 and little or no CO_2. The atmosphere and the surface of the earth, including the oceans and extending a short distance below the solid surface, constitute the *biosphere*, a layer whose present chemical composition has been greatly influenced by the presence of living organisms, chiefly the plankton of the oceans. Our present supply of free O_2, nearly one fifth of air, is almost entirely the result of photosynthesis. If all life were suddenly extinguished, the free O_2 would disappear in about 2,000 years. Similarly, it is possible that there was no original CO_2, and that all the available carbon was present in the form of the pure element, in hydrocarbons such as methane, or in metal carbides.

There is, however, no absolute certainty that *all* atmospheric O_2 was produced by living matter. Several geophysicists believe that some O_2 was freed by the photochemical decomposition of water in the atmosphere. It is more probable that a large percentage of the available CO_2 has been produced by volcanic eruptions and by chemical reactions, in the presence of water, among solid substances in the crust of the earth.

Most of air is nitrogen, N_2. This molecule is so heavy that the earth can now prevent it from escaping into space. But the gas neon, which is almost as heavy, is present only in minute quantities. Undoubtedly, at some time in the distant past, the temperature of the earth was much higher than now. Since the velocities of the molecules are larger at high temperatures, we believe that most of the neon then escaped, and with it the nitrogen and water vapor. Thus the N_2 and H_2O in the atmosphere today must be of "secondary" origin. N_2 escapes from volcanoes and fumaroles, and water vapor may have been produced from the breakdown of hydrated silicates in the earth's crust—containing "fossilized" water.

But N_2 is also exhaled by certain abundant bacteria. For this reason V. I. Vernadsky has suggested that the present N_2 gas in our atmosphere is partly biogenical and partly tectonic in origin.

Let us now turn to the problem of life on Mars. The observations show that its atmosphere contains no free O_2, certainly less than 0.1 per cent of its abundance in air. Water vapor has not been found, but its existence is inferred from Kuiper's demonstration that the polar caps consist of hoar frost. The abundance of H_2O in the Martian atmosphere is less than 1/1,000 of what we find in air. There is a considerable amount of CO_2, several times as much as in air. The total amount of atmosphere on Mars above every square centimeter is about 1/10 the air above the earth. About 98 per cent of it must be N_2, which is unobservable in the accessible region of the spectrum. Argon and CO_2 together constitute almost two per cent, the former presumably being of radioactive origin on Mars as on the earth. Other gases constitute less than 0.5 per cent.

There are no permanent free water basins on Mars. Any moisture that may result from the melting of the polar caps is of a seasonal character.

The temperature on Mars averages 30 to 40 degrees centigrade lower than on the earth. On the Martian equator, the mean temperature is $-10°$ or $-20°$ C., with the noontime maximum at about $+20°$ C. Near the poles the average temperature is about $-60°$ C. Fessenkov believes that Martian conditions are similar to what we might expect on a hypothetical terrestrial plateau 10 miles high.

It is clear that with the absence of water there does not now exist a biosphere on Mars. No life can originate there at the present time. The absence of free O_2 confirms this. The abundance of N_2 and CO_2 indicates that they are not of biogenic origin.

But perhaps conditions on Mars were different in the distant past. Did life come into being when there was more water? Fessenkov, while admitting we cannot answer this question, argues that the green regions on Mars are not caused by vegetation, even the primitive kind of lichens and mosses considered by Kuiper. He refers to the absence of the spectral features of chlorophyll in the reflected sunlight, which rules out all more advanced types of vegetation. He also remarks that the observed temperatures of the green regions are about 15 degrees warmer than those of the adjoining yellow deserts. Both kinds of regions receive the same amount of solar radiation per square centimeter, Q. But the reflectivity (or albedo) of the yellow regions is about 0.30, and of the green regions only 0.15. Hence the yellow regions use only $Q(1 - 0.30)$ of solar radiation for heating the surface, while for the green regions the amount is $Q(1 - 0.15)$. By Stefan's law the temperature of a heated area is proportional to the fourth root of the amount of radiation used for heating. This gives the relation:

$$T^4_{green} = T^4_{yellow} \ (1-0.30)^{1/4} / (1-0.15)^{1/4}.$$

The result is $T_{green} - T_{yellow} = +15°$. This is exactly in accordance with the observations. But living organisms use energy to maintain growth and reproduction: Areas covered with vegetation are always cooler than similar areas devoid of plant life. Fessenkov concludes that the green areas reflect sunlight as would a dark surface of inorganic matter—perhaps some green-colored rock or shale of a kind that may be found in many of our own deserts.

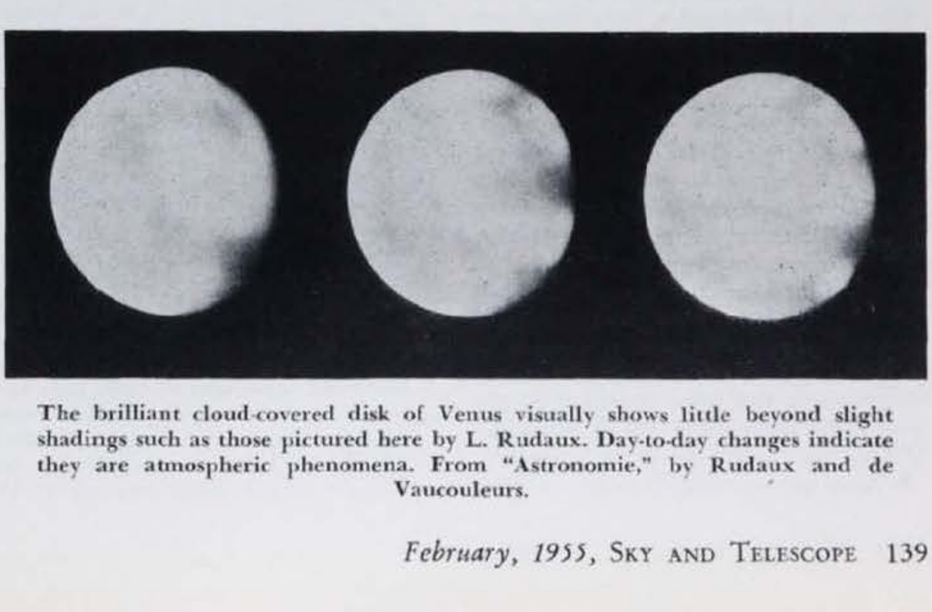
The argument is sound and interesting, but it does not exclude the existence of a sparse distribution of lichens or mosses, covering only a fraction of the entire area and yet giving it a greenish tinge. The cooling produced by such primitive plants might be negligible. Perhaps the intervening surface consists of a kind of inorganic substance that is intrinsically darker than that of the yellow regions, and is for this very reason better suited to support the existence of the lichens or mosses.

Nevertheless, the present conditions on Mars are so unfavorable to the origin of any living organisms, that any lichens or mosses which may now grow in the green areas would cause us to believe that there once was more liquid water on the surface of Mars.

In many respects, the planet Venus is even more interesting than Mars. In mass and size it resembles the earth. The escape velocity of the molecules (10 kilometers per second) is nearly the same as for the earth (11 kilometers per second), instead of five kilometers per second as for Mars. The amount of solar radiation is greater, and the surface temperature may be considerably higher than that of the earth. Perhaps it is so hot, above the boiling point of water, that there could be no oceans. But this is unlikely: at least the polar regions of Venus may be below 100° C.

We never see the surface of Venus. It is permanently covered with clouds of unidentified composition. The atmosphere of Venus resembles that of the earth in total amount and in its density distribution. But there is no observed free O_2 or water vapor. Instead, an amazing amount of CO_2 has been revealed by the spectroscope.

Until quite recently, astronomers concluded that the invisible surface of Venus is completely devoid of water and is a dry, dusty desert with no life of any kind. The absence of free O_2 seems to support this view; and the presence of CO_2 and probably also N_2 need not disturb us, since we have already concluded that on Mars these gases are probably not of biogenic origin. If these views are correct, we conclude that life has never existed on Venus in the past—its temperature would never have been lower than at present, and it is improbable that there could have been any water in the liquid state. There remains the rather vague possibility—supported by little more than wishful thinking—that life may come into existence on Venus in the future. It is conceivable that its atmosphere might clear up and gradually reduce the influence of the greenhouse effect of the CO_2 and dust in its atmosphere. If the surface temperature should drop well below 100° C., water might appear from tectonic causes and organisms could then be produced by spontaneous generation. Spencer Jones, in his book referred to previously, said: "Venus appears . . . to be a world where life may be on the verge of coming into existence and Mars a



The brilliant cloud-covered disk of Venus visually shows little beyond slight shadings such as those pictured here by L. Rudaux. Day-to-day changes indicate they are atmospheric phenomena. From "Astronomie," by Rudaux and de Vaucouleurs.

world where life is in the sere and yellow leaf."

There can be no question that the absence of water vapor in the atmosphere of Venus is our greatest difficulty. Because of the great similarity of the earth and Venus, we should have expected that H_2O would be abundant. It is therefore necessary to re-examine the evidence. We are certain that there is no observable H_2O above the cloud layer of Venus. But perhaps it could be present below the clouds, on the surface, and even in the clouds themselves. This question has been treated by D. H. Menzel and F. L. Whipple (see *Sky and Telescope*, November, 1954, page 20). They suggest that the surface of Venus is *completely* covered with water. No continents stick out above the level of the ocean. This prevents the destruction of atmospheric CO_2 through the formation of carbonates in the rocks (a process that we have already considered as maintaining the equilibrium content of CO_2 in the atmosphere of the earth). The temperature *above* the clouds of Venus is −39° C., according to W. Sinton. At this temperature most water vapor would be frozen out, and it is not surprising that we do not observe it spectroscopically.

The ideas advanced by Menzel and Whipple are so revolutionary that it is difficult to appraise them at this time. But if confirmed they would certainly justify the confidence of Spencer Jones that Venus is a planet of life in the beginning. The fact that there is no O_2 would indicate that there has not yet appeared any large amount of vegetation.

I want to refer, in conclusion, to the problem of life elsewhere in the galaxy. Spencer Jones reached the pessimistic conclusion that "such a special combination of circumstances is needed to account for the solar system that it can be inferred that relatively few stars have

(Continued on page 146)

ASTRONOMICAL SCRAPBOOK

Schroeter's Observations of Mars

A HUNDRED and fifty years ago the world center of lunar and planetary studies was the little North German town of Lilienthal, near Bremen. Here were the observatory and optical shops of J. H. Schroeter (1745-1816), chief magistrate of the neighborhood, who for nearly 30 years kept unflagging watch upon the moon and planets. Here his assistant, K. L. Harding, discovered the third asteroid, Juno, and the famous F. W. Bessel began his career.

Fate was unkind both to Schroeter and to his reputation. The decades of war that convulsed Europe finally engulfed him in April, 1813, as Napoleon sought to regain his slipping hold on Germany. Lilienthal was sacked and burned by the French army of General Vandamme, and Schroeter lost at one stroke his observatory, records, magistrateship, and wealth. Unable to resume observing, he died three years later.

This enthusiastic amateur, the Percival Lowell of his age, has been underrated by later astronomers. His own work overlapped that of his more versatile, brilliant contemporary, William Herschel, whose fame has obscured all other observers of his time. Again, it has been Schroeter's misfortune to be remembered more for his faulty rotation periods of Mercury and Venus than for being the first astronomer to devote a lifetime to telescopic study of the planets. And, finally, the row of fat volumes devoted to his findings on Mercury, Venus, Jupiter, Saturn, and the moon, was written in a fantastically unreadable style that left their contents largely unnoticed.

The Lilienthal astronomer published no book on Mars, although he had followed this planet intensively. It was long supposed that his manuscript of Martian observations had been destroyed in the ruin of his observatory. Finally recovered among the family papers of a nephew, the Mars writings were published in 1881 by the Dutch astronomer, H. G. van de S. Bakhuyzen, together with 216 of Schroeter's drawings.

A curious delusion pervades this book —that the Martian markings were mere wind-blown cloud formations in a thick atmosphere that veiled the true surface of the planet. Acting on this belief, Schroeter from night to night carefully estimated the times when various dark markings crossed the central meridian of the planet, in an effort to measure Martian wind velocities. These markings can often be identified; hence Schroeter's transit times might be used in combination with recent observations to determine the rotation period of Mars with high precision.

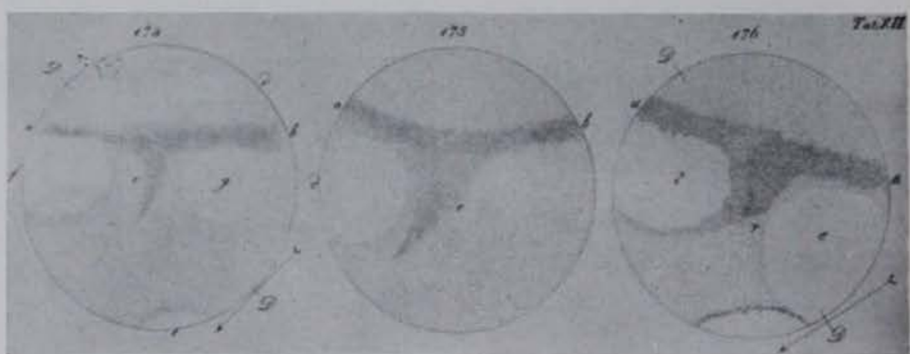
No one has ever done this, and in fact this valuable material seems to have been totally overlooked. Heretofore, in studying Martian rotation, only Schroeter's drawings have been used, and they are ill-suited for the purpose.

The drawings are, nevertheless, of much value in looking for surface changes on Mars, for they were made with instruments respectable even by modern standards. Schroeter's first large telescope was a reflector of 7-foot focus, made by William Herschel; and in 1792 he acquired a 9.3-inch, f/17 Schrader reflector which Lalande called the finest telescope in existence.

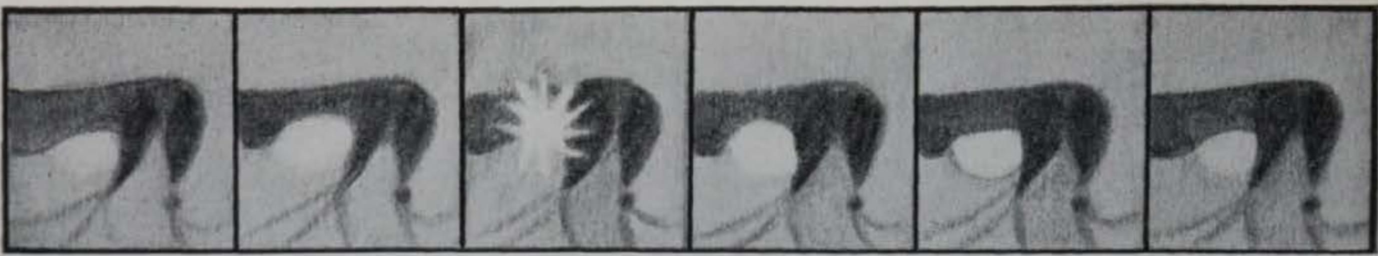
While most of the features in these drawings are identifiable on present-day maps, there is a very striking exception. This is a dark region nearly as large as Texas, marked on 16 of Schroeter's sketches of 1798-1800, which is no longer to be found. Two drawings made by Herschel in 1783 also show it. Bakhuyzen, who wrote in German, named it *Spitze B*; we might call it the *Arrowhead*.

Both Schroeter and Herschel represent this as a long triangular marking much like Syrtis Major. Its location can be found on the Mars map on pages 268-269 of the August, 1954, issue. The base of the Arrowhead was near longitude 225°, latitude −15°, at the edge of Mare Cimmerium; it stretched northward over the canal Cyclops and Pambotis Lacus. These last two may be its remnants.

The disappearance of this vast tract—for two decades one of the most easily seen features on Mars — is the most striking change yet recorded on the surface of the red planet. Its explanation is an intriguing puzzle. J. A.



Three Schroeter drawings of Mars, made with a 9.3-inch reflector during the favorable opposition of 1800. Left to right: On November 2nd, the Arrowhead was near the center of the disk, extending downward toward the north polar cap; 3½ hours later that night, the Arrowhead had rotated leftward out of view, and Syrtis Major was centrally located; on November 4th, the Arrowhead was again central. From Schroeter's "Areographische Beitraege," Leiden, 1881.



Six stages in the unusual brightening of Edom Promontorium, July 1, 1954, at intervals of 2, 1, 1, 2, and 2 seconds. The color of this feature changed from yellowish white to very bright pure white, and then back to yellow or yellowish white. These observations are by Mr. Saheki, at 330x and 400x.

the disappearance of the light, as in 1951. A meteorite fall on Mars might produce both light and a cloud, but meets difficulty in accounting for flare durations as long as five minutes, recorded in 1937 and 1951. A fourth interpretation that may be rejected as unreasonable is an artificial origin, for this requires "Martians," of whose existence there is no scientific evidence.

A remaining possibility is volcanic eruptions. These may explain the light and the dust cloud formation. However, the observed duration of the light may be too short, and the probable scarcity of water on Mars may raise difficulties—terrestrial volcanoes eject large quantities of steam.

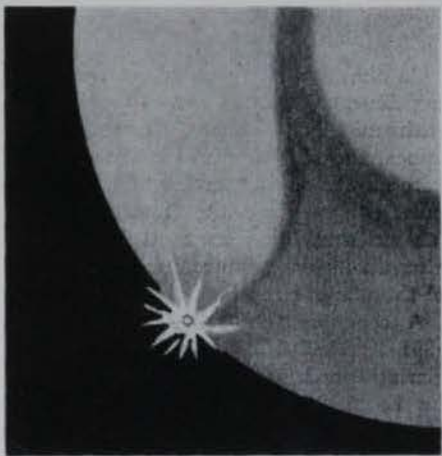
As an observer of Mars, I cannot say definitely at present whether the gray clouds and flares are in any way connected with volcanic activity on that planet. But I am confident of the reality of the phenomena, and believe that future observations will make their nature clear.

COMMENTS BY DR. D. B. MCLAUGHLIN*

Mr. Saheki and his collaborators are to be congratulated on the care with which their observations have been made and reported—and on clearly separating observed facts from interpretation.

The reported great height of the clouds is somewhat surprising at first glance. However, Seymour Hess has pointed out (*Journal of Meteorology*, 7, 7, 1950) that the Martian troposphere may extend up to 45 kilometers above the surface, instead of the 10 kilometers for the earth. Volcanic ash would easily be carried to the top of the troposphere, and, for a great eruption like that of Krakatao in 1883, might well be projected considerably higher. The observers' estimates may be excessive, for a slight irregularity in a regular outline, such as the limb of a planet, can be so obvious to the eye as to be overestimated. Thus a height appreciably less than 100 kilometers for a Martian ash cloud seems not impossible, and may not conflict with the observations.

The bright flares were of enormous intensity compared with any volcanic glare recorded on the earth. It is questionable whether even the 200-inch telescope could show the fire-pit of Kilauea at the distance of Mars, even beyond the planet's terminator. It would certainly not be visible on the illuminated disk. The "fiery cloud" of Mt. Pelee (which destroyed St. Pierre in 1902) was probably two kilometers in diameter and very hot, but not brilliantly glowing. Later clouds erupted by Pelee appeared dull by daylight. The fire-fountain of Vesuvius on August 8, 1779, might have been visible from the moon as a 5th- or 6th-magnitude star. From Mars it would have appeared to be of the 16th or 17th magnitude, at a close opposition. If these Martian flares were volcanic, they would indicate that Martian volcanism is characterized by occasional great outbreaks of incandescent gas a few kilometers in diameter and with temperatures very far above those known in terrestrial volcanism.



Sizuo Mayeda's bright flare on Mars was sketched by him on June 4, 1937, with an 8-inch reflector at 500 power.

Such enormous differences justify considerable skepticism as to a volcanic interpretation. Perhaps it would be worth while to explore the possibility of a solar reflection from oriented ice crystals suspended in the Martian atmosphere—a sort of sun-dog phenomenon in reverse! The slim chance that something of this sort might be involved is suggested by the fact that a whitish cloud was seen.

*Dr. McLaughlin's comments were sent to us when he transmitted Mr. Saheki's manuscript to *Sky and Telescope*.—ED.

LIFE ON OTHER WORLDS

(Continued from page 140)

families of planets," and consequently "life elsewhere in the universe is . . . the exception and not the rule." He points out that while we might find occasional stars with planetary systems, only perhaps one planet in a thousand or a million might support life. Even so, he says, "the total number of worlds that are suitable for life would yet be considerable, so vast is the scale on which the universe is constructed."

We have not as yet actually observed a single real planet outside the solar system—only some faint companion stars whose masses are intermediate between those of Jupiter and the sun. But all the evidence accumulated during the past decade concerning the physical properties of the sun shows that it resembles in all observable respects the billions of other stars in the Milky Way with similar masses and temperatures. We *must* infer that this similarity extends to the manner in which all these stars were formed. It is unreasonable to suppose that one in a thousand or one in a million of these billions of stars underwent a catastrophic process resulting in the formation of planets—without at the same time producing other, *observable* differences in such properties as the axial rotations of the stars.

Since we cannot adduce a proof one way or the other, we must rely upon what seems to be the most logical hypothesis. And this is without doubt the assumption that all, or at least most, dwarf stars of the solar type have planetary systems. The total number of planets in the Milky Way may thus be counted in the billions.

As to how many can support life, we might adopt the solar system as a typical sample. This would give us one out of nine for the kind of advanced organisms we find on earth, and perhaps one out of nine which we might describe with Spencer Jones as "a planet of spent life," and another one out of nine with life in the embryonic state. Thus, the total number of planets with some form of life on them could still be in the billions!