Extraterrestrial Biology - Prospects and Problems

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INTRODUCTION

People have probably speculated about the existence of living organisms on other heavenly bodies since the beginnings of human existence on this planet. Certainly, even a cursory examination of the interests of contemporary man, as exemplified in his news media, his entertainment, and even his current literature would reveal the in-roads that the concept of extraterrestrial life have made on his thinking. Today, as the United States and the Soviet Union stand at the threshold of intensified activity in "space exploration," it might be useful to examine briefly what the prospects and some of the problems are in the coming search for extraterrestrial life.

MAJOR THEMES

Two general arguments form the basis for the view that extraterrestrial life is not only possible, but widely distributed in the universe. The first of these is that living organisms are essentially complex organizations of organic molecules resulting from a long and continuing process of chemical evolution. This idea holds that the process of evolution began with the origin of the universe and led to the formation of the elements within the stars themselves (e.g., 1, 2). Then, following the formation of planetary systems, over relatively short periods of time, simple components of primitive planetary atmospheres condensed to yield organic molecules of increasing complexity until at some point a primitive replicating system resulted. Experimental support is growing for the contention, first propounded by Oparin (3), and soon thereafter by Haldane (4), that the origin of terrestrial life had its beginnings in a reducing atmosphere of methane, ammonia, water, and hydrogen in the primitive terrestrial atmosphere. Miller (5), in 1953, showed that certain amino acids and other organic compounds were formed when this "primitive atmosphere" was subjected to a spark discharge continuously in a closed system. Since those initial results, numerous investigators, using a wide variety of energy sources and the "primitive atmosphere" as starting material, have been able to detect a large array of organic compounds of biological interest. The rapidly moving developments in this field have been recently reviewed by Ponnamperuma (6, 7), and are briefly summarized in Plate 1.

That the initial period of transition from simple precursors to living systems on Earth may have been relatively short is now becoming apparent. Fossilized microorganisms resembling both bacilli and algae have recently been discovered in terrestrial samples that are 3.0 to 3.4 billion years old (8 - 10). Therefore, if biological evolution had progressed to the point where both bacterial and algal forms were already present 1 to 1.5 billion years after the formation of the planet, the critical era during which life first appeared on Earth must have occurred soon after the Earth was formed, certainly well within the first billion years.

The second major theme concerns the probable number of sites in the universe where chemical evolution, of the type envisaged on this planet, may have taken place. The astronomers point out that the Sun, about which the planets of our solar system orbit, is but one of more than 100 billion stars in our galaxy, the Milky Way. For comparison, in Plate 2 is presented a photograph of the neighboring galaxy, in the constellation Andromeda, with its billions of stars. In turn, as the astronomers probe the distant recesses of the universe, it is evident that hundreds of millions or billions of additional galaxies are visible (e.g., see Plate 3). The number of stars in the universe thus seems to be staggering.

That many stars may have planetary systems of their own has been considered by a number of astronomers. For example, Hoyle (11) estimated that in our galaxy there are probably about 100 thousand million planetary systems. Brown (12) came to the conclusion that just about every star should have a planetary system associated with it. Indeed, he went so far as to suggest that, on the average, each star should have two planets in its planetary system at distances that would receive sufficient radiation to support life. Other authors (Huang (13); Shklovskii and Sagan (14)) also considered the probable occurrence of planets capable of supporting life, that is, planets having appropriate temperatures, masses, and life times. And in this connection, the latter authors concluded that at least a billion stars with potentially habitable planets exist within our own galaxy.

The interplay of these two themes - first that life evolves from simple precursors when conditions on a planet favor the condensation of these materials to more complex substances, and second, that among the enormous number of stars in the universe, planetary systems and, indeed planets with suitable environmental characteristics will appear - suggests that the search for extraterrestrial life can hardly meet with failure.

DIFFICULTIES OF DISTANCE

While the "statistics" discussed above tend to lead us to the conclusion that extraterrestrial life is widespread, and invite us to imagine ourselves in some not too distant time, making detailed expeditions to distant stellar systems, the vastness of space itself may well preclude any explorations beyond the solar system. In an interesting paper in which he considered some of the limitations to interstellar space travel, Von Hoerner (15) emphasized the enormous distances involved as follows:

"In order to help visualize (these) astronomical distances, I will describe them with a model of scale of 1:180 billion. The earth, then, is a tiny grain of desert sand, just visible to the naked eye orbiting around its sun, which now is a cherrystone a little less than 3 ft. away. Within approximately the same distance, some few feet, lies the goal of our present space travel: the other planets of our solar system, such as Mars and Venus. But the nearest star, Proxima Centauri, is another cherrystone 140 miles away . . . just for fun one may add the distance to the Andromeda Nebula, the next stellar system comparable to our own galaxy: in our model it is as far away as, in reality, the sun is from the earth."

Will man be able to span the tremendous distances involved? While the stars closest to the Sun are about 4 light years away, it has been pointed out (13, 14) that within the immediate vicinity of our solar system, stars about 10 light years away might be of more potential interest from the point of view of extraterrestrial life. To reach such a star would, of course, require a rocket system that could escape from our solar system. Such a rocket is well beyond our present capability, since a speed of 18 miles per second would be required. A system of this type traveling to one of the stars of interest, 10 light years away, would take about 100,000 years to reach the star and another 100,000 years to make the trip back to Earth.

Von Hoerner (15) in considering the possibilities of interstellar space flight, pointed out that if a rocket engine could be developed capable of using the energy of fusion of hydrogen into helium for propulsion, a spacecraft could be accelerated to about 36,000 miles per second. Even such a system, however, would only reduce the round trip time to such a star to about 200 years.

It has also been claimed (14) that if spacecraft could be propelled to reach velocities approaching the speed of light, the time dilation phenomenon would come into play. For passengers on the spacecraft, the elapsed time for a trip could be less than for those on Earth. The advantages of such relativistic travel would become increasingly great as the distance to be traversed increased. At such velocities, a round trip to the Andromeda galaxy, for example, would require about 30 years for the crew while the elapsed time back home would be a few million years!

Clearly, if relativistic travel could be achieved, and it should be mentioned that some authors (cf. 16) have challenged the time dilation concept, it would necessitate the development of completely new forms of propulsion, such as one based on the complete annihilation of matter. Whether such engines can ever be developed, of course, is open to conjecture. But even if this were possible, other considerations enter in. Oliver (17) estimated that for a crew of several men making a round trip to the nearest stellar system, alpha-Centauri, in a spacecraft weighing a thousand tons, 33,000 tons of matter would have to be annihilated en route! His conclusion, shared by others who have analyzed the prospects for interstellar space travel (15, 18), is that almost certainly the technological requirements are so overriding that for all practical purposes we will be restricted in our space travels to the solar system.

SOME TARGETS IN THE SEARCH

It now appears reasonably certain that the Earth's neighbor, the Moon, will be the first extraterrestrial body to be explored. Both the Soviet Union and the United States are rapidly moving toward the development of this capability. The prospects of finding life on the Moon are extremely slim, however. The present lunar physical characteristics - lack of an atmosphere, both very high (daytime) and very low (nighttime) temperatures, high ultraviolet flux - would seem to rule out the Moon as a likely abode of life.

Of the other planets in the solar system, the inner planets, Mercury and Venus, do not appear to be reasonable targets in the search for extraterrestrial life, at least on the basis of current knowledge of these planets. Although relatively little is known about the planet Mercury, it is known to sustain extremely high temperatures on the side facing the Sun, and low temperatures in the reverse hemisphere. Together with an extremely thin atmosphere these conditions would seem to preclude life on this planet (14). Similarly, Venus with its high surface temperatures (19, 20, and data from the Venera 4 spacecraft, which reported temperatures of 280° C on the dark side of the planet) appears to be very inhospitable to life. On the other hand, Libby (21) recently claimed a possibility that water icecaps exist at the poles of Venus and suggested that, therefore, there might be regions on the planet mild enough to support life.

Beyond Mars, the planets Jupiter, Saturn, Uranus, and Neptune are thought to be similar in their general physical characteristics (19). The current information about Jupiter indicates that this planet has abundant quantities of ammonia, methane, hydrogen, and probably water vapor in its very deep and turbulent atmosphere (22). Sagan (23) has pointed out that the current atmosphere of Jupiter is analogous to the "primitive atmosphere" from which terrestrial life is presumed to have been formed, and that the turbulent conditions in the Jovian atmosphere could, even today, be the site of production of large quantities of abiogenically produced organic matter. Despite the extremely low temperatures on that planet, it has been suggested (22) that, at some levels of the upper atmosphere, temperatures from 0° to 80° C probably exist, leaving open the possibility that some forms of life may be present in the hostile Jovian atmosphere. Indeed, Siegel and Giumarro (24) recently described the isolation of a unique organism from terrestrial sources that was grown in the presence of high concentrations (50 to 95%) of ammonia together with methane and hydrogen.

Beyond Jupiter, Saturn is thought to have an atmosphere similar to that of Jupiter. If this is the case, then many of the considerations, however tentative, about Jupiter would also apply to Saturn. We know so little at this time about the more distant planets of our solar system that very little can be said, even speculatively, about the chances of finding living organisms on them, although it would appear that these planets are too cold and too dark to support living systems.

MARS

Of all the planets of the solar system, Mars seems to have a range of environments most like that of the Earth, and therefore it represents the best available target in the search for extraterrestrial life. Mainly as a result of astronomical observations, but also from data obtained from the Mariner IV flyby of 1965, many of the gross physical characteristics of that planet are reasonably well known (25). The planet, which orbits the Sun at a mean distance of approximately 140 million miles, has a diameter approximately one-half that of the Earth and a mass one-tenth that of the Earth. Mars is inclined at an angle of approximately 25° perpendicular to its orbit (compared to an angle of 23.5° for the Earth) and thus that planet experiences seasonal changes as it rotates about the Sun. Since the Martian period of rotation is also very similar to that of the Earth, being 24 hours and 37 minutes, day-night cycles are analogous to that on Earth.

The major surface features of the planet (Plate 4) include the white "polar" regions, now thought to be composed of frozen carbon dioxide and ice (26), and the so-called "bright" and "dark" areas. The polar caps are known to wax and wane with the seasons, diminishing in extent during the "summer" season in a particular hemisphere and then growing larger in the "winter" months. As the ice cap recedes with the approach of summer, there is also a "wave of darkening" in the hemisphere, during which the dark regions appear to become darker. In the past, this darkening has been ascribed by many authors to be the result of stimulation of plant growth, related to the presumed increase in available water. While the "darkening" phenomenon is generally accepted by astronomers, the biological explanation remains without experimental verification.

The results of determining the surface temperature by various techniques agree that the average surface temperature, across the planet, is about 50° colder than that of the Earth. Maximum temperatures near the equator have been estimated to rise to as high as about 30° C for a few hours per day during a Martian summer, but to fall to -70° to -80° C that same night in the same place. Daily temperature fluctuations in the range of 100° are the general rule across the planet.

The atmosphere of Mars has been probed spectroscopically from balloons and from Earth-based telescopes, and also by radio-occultation methods (27). The total pressure of the atmosphere is probably close to 10 millibars, or about 1/100th of the total atmospheric pressure on Earth. Within the Martian atmosphere, two gases have been identified: carbon dioxide and water, although neither of these has been quantitatively determined with any great accuracy. Carbon dioxide is thought to represent the major gaseous component of the atmosphere while water at best constitutes only a very minor constituent. The water vapor in the Martian atmosphere has been estimated to be of the order of 1/1000th the amount in the Earth's atmosphere. Repeated efforts to detect oxygen in the Martian atmosphere have failed, and if it is present, oxygen must represent a minute fraction of that atmosphere. Whether or not nitrogen is present is not known, although it is presumed to be a constituent of that atmosphere (25).

The Mariner IV flyby not only yielded results of interest in connection with the structure and composition of the Martian atmosphere but it also collected data on the density of cosmic dust _en route_ between the Earth and Mars. It also made measurements of the magnetic fields around that planet. In the latter connection, the data indicate that little or no magnetic fields exist around Mars. Not only does this conclusion indicate the possibility of a different internal structure than that of the Earth, but the absence of a magnetic field may also mean that the surface of the planet is subjected to considerably greater bombardment by charged particles from the Sun. The rarity of the Martian atmosphere, together with the absence of oxygen (and therefore ozone) in that atmosphere would also suggest that the planetary surface is subject to far more intense ultraviolet radiation than is the Earth, although the planet is often covered by a thin "blue haze," which may effectively absorb considerable ultraviolet radiation (25).

MARINER IV PHOTOGRAPHS

The Mariner IV, of course, had as its primary mission the photographic reconnaissance of the surface of the planet as it flew past, roughly from pole to pole. Approximately one-half of one percent of the surface was photographed as the Mariner relayed to Earth 21 pictures, the closest approach to Mars being 6,118 miles.

Plate 5 is one of the most interesting of the pictures, the 11th picture. This was taken from about 7,800 miles above the planet and covers an area of approximately 25,000 square miles. As in other pictures of the series, numerous craters are visible over the surface of the planet; the largest one seen here is over 100 kilometers in diameter. Of interest is the fact that the large crater seen in the center has been extensively eroded so that only about half of the crater wall is now visible. From this and the other photographs of the series, it can be deduced that variations in surface elevation of the order of several thousand feet exist. We must anticipate, then, that over the surface of the planet large variations in local environments are possible as one goes from pole to equator and from low to high regions of the planet. On this basis (28) there should be a wide spectrum of ecological "niches," affording many permutations and combinations of environments for a Martian biota.

That the Mariner IV photographs did not detect life on the planet came as no surprise - even to the most enthusiastic exobiologists. As pointed out (14) it has been virtually impossible to detect life on Earth from the many thousands of photographs taken of this planet by U.S. weather satellites. Mariner IV did not, and could not, settle the question of the presence of life on Mars. It did, however, corroborate or extend many of our estimates of the physical characteristics of that planet. To recapitulate these properties, the present physical environment on Mars is very bleak. There is little or no oxygen; there are large temperature extremes; the average temperature is low; the atmosphere is very thin and contains extremely small quantities of water. There is probably no free water on the surface, and probably a high flux of ultraviolet radiation at least some of the time. This is not, by terrestrial standards, a favorable environment for life!

ADAPTATIONS OF ORGANISMS

But, if the biologist is impressed by any overriding property of terrestrial life, it is by the adaptability of organisms. If life on Earth started in a primitive "soup," the first surviving organisms have evolved into an almost infinite number of environmental niches. Organisms, particularly microorganisms, are found to grow under such widely divergent conditions as in boiling springs of Yellowstone Park, where the temperatures are constant at about 96° C (29) and in perpetually frozen lakes of Siberia. Some are so fastidious that they cannot long survive outside the warm, moist nutritive recesses of the animal body, while others, the autotrophic bacteria, live in the soil or in bodies of water using hydrogen or ammonia, or even iron or elemental sulphur, as their energy sources. Some microorganisms, isolated from the deep sea floor (at 7,000 to 10,000 meters), die at ambient pressures at sea level and grow only at pressures matching their native habitat, 700 to 1000 atmospheres (30). Others isolated from the sea - the halophilic bacteria - are also killed, unless they are cultivated in an environment containing 30% (by weight) of salts.

Modern astronomers (14, 31) argue that there is evidence to support the contention that Mars may have been warmer at one time, and that it contained a heavier atmosphere, than it does at present. Under such conditions, the development of living forms, once started, could have proceeded under more favorable conditions than exist on Mars at present. Based on analogy with terrestrial life, then, it is not unreasonable to imagine that evolutionary adaptive processes on that planet could have selected organisms with increasing resistance to dehydration, to lower temperatures, to higher ultraviolet fluxes, etc., as Mars slowly, and over long periods of time began to lose its atmosphere.

SIMULATION STUDIES

In attempts to assess the probabilities of life on Mars, several laboratory groups (e.g., 32-34) have placed terrestrial microorganisms, or terrestrial soil samples, into simulated Martian conditions. In a variety of "Mars boxes" such parameters as temperature, humidity, pressure, and atmospheric composition have been used singly and in combination. Needless to say, this approach is only as good as our information is about the planet itself. Nevertheless, the general findings have been that many microorganisms have survived for long periods under such conditions. For example, Packer, et al. (34) found that organisms survived temperature cycles of -60° C to $+20^{\circ}$ C for several months even when subjected to "simulated" Martian ultraviolet irradiation.

In one such investigation Young and co-workers (33) subjected cultures of several bacteria to a Martian daily temperature regimen of 20 hr at -70° C and 4 hr at 25° C. Some of these cultures died while others, after a few cycles, began to increase in numbers (Plate 6). Other strains derived from such "adapted" cultures managed to grow very well under even more rigorous conditions in which they were kept at -70° C for all but 15 minutes of each day (Plate 7).

From what is known about the planet, taking all of the physical characteristics of Mars into account, it seems quite clear that the limiting factor for life on Mars is likely to be the unavailability of water. Temperature fluctuations, low atmospheric pressures, lack of oxygen, ultraviolet and other kinds of radiation are all secondary to this problem. It has been argued (35) however, that water in the form of ice may exist as a permafrost layer beneath the surface of the planet. Under that condition, local areas of thermal activity might well make available liquid water at or close to the surface (28).

SOME PROBLEMS IN PLANNING "LIFE DETECTION" EXPERIMENTS

The considerations that lead us to conclude that Mars is currently the best target in the search for extraterrestrial life - the plausibility of the concept of an early genesis of life from methane, ammonia, and water, and the idea that, once formed, living organisms might have successfully adapted to changing conditions on that planet - do not, however, mean that Martian organisms would necessarily be chemically or morphologically analogous to terrestrial forms. Instead of l-amino acids, for example, Martian organisms may have proteins comprised of d-amino acids. Rather than the 20 amino acids common to terrestrial organisms, Martian proteins may be built of fewer or more amino acids. Furthermore, these acids may not include any of the particular amino acids commonly found in terrestrial organisms. Perhaps, in order to filter out ultraviolet radiation, and also to conserve water, fats or waxes unfamiliar to us have become major constituents of Martian organisms. The point of these examples is that we really have no idea just how far apart the process of chemical evolution, let alone biological evolution, may have diverged on Mars and on the Earth.

This problem leads to difficulty in planning so-called "life-detection experiments." Chemical tests for compounds commonly found in terrestrial organisms - say, l-aspartic acid or D-glucose - are considered to be "high risk" determinations because a negative result would not be conclusive. As another example, all terrestrial organisms appear to rely on certain adeninenucleotides as their main energy carriers. And exquisitely specific and sensitive assay systems have been devised (36) to detect adenosine triphosphate (ATP), the major compound of this type. Suppose, however, that Martian organisms use guanosine triphosphate (GTP) instead of ATP in the same physiological role as we use ATP. Then the very specificity of an ATP test would preclude our discovery of GTP (and possibly of life) on Mars!

On the other hand, less specific chemical tests - for example, a test for the presence of organic carbon - while reducing some of the "risk" involved in such a test, have another kind of limitation. In this case, a positive determination could only be suggestive of the presence of living organisms. As we have already seen (Plate 1), large numbers of organic compounds - some of great biological interest - can be formed without the intervention of biological catalysts. Therefore the finding of organic matter would by no means constitute proof of a living system.

In considering what kinds of evidence might be most definitive in the search for extraterrestrial life, those that measured some end result of a complex concatenation of subprocesses would be most diagnostic. For example, if we were to land a microphone on the surface of Mars and were to hear, sometime later, a voice yelling, "Watch where you land these things next time!," we could be certain that no simple process, or series of processes, could have produced such a response. Only a remarkably intricate, well-structured series of processes - i.e., only a highly integrated system like a living being - could be the ultimate source of such a message.

Along these lines, several suggestions have been made to measure the growth of extraterrestrial organisms in some suitable medium (36). Clearly, multiplication of an organism requires that all of its nutritive requirements be met; a large array of biochemical processes must be synchronized so that the final result is an increase in the number of organisms. Any single biosynthetic route, if not properly satisfied, could become the limiting factor and prevent an increase in numbers. Measurements to detect growth, then, would be quite convincing if they were positive. They have the further advantage (37) of amplification. That is, under appropriate circumstances, a small number of organisms that might otherwise escape detection - for example, by organic analysis - after several rounds of multiplication, could now readily be detected.

But the great dilemma in trying to devise a system to detect the growth of organisms in some largely unknown environment like Mars is that, in our ignorance of the detailed conditions of that environment, we might well attempt to "grow" these organisms under conditions that to them are very hostile. In the case of micro-organisms on Mars, should we inoculate them into a medium containing D-glucose or should they be given some other energy source? Should they be incubated at 30^{o} C? at pH 7? Indeed, should we even use an aqueous medium? Perhaps, like the halophilic bacteria that lyse when put into "physiological" media (where water is much more readily available), Martian organisms would be killed.

Most of the uncertainties associated with trying to design a growth experiment in the search for extraterrestrial life apply also to assays for individual enzymes. It has been suggested (37) that, like certain enzymes present in terrestrial soils, Martian surface samples might contain enzymes that could be readily assayed. In principle, there would be certain advantages in testing for individual enzymes. Under optimal conditions, they have very high catalytic activity, generally many orders of magnitude higher than that of inorganic catalysts. Unlike tests for growth, which could be limited by a single factor such as the omission of some essential trace nutrient, enzymatic activity depends on only the availability of the substrate for the enzyme and, occasionally of one or two appropriate cofactors. Another advantage is that certain enzymes, like phosphatases and urease (38) in terrestrial soils, may be released into the soil upon the death of soil organisms. These enzymes are then often found to be present in samples in which little or no "life" can be detected.

Even though tests for enzymes on another planet require fewer assumptions than tests for growth, a number of uncertainties in this procedure still make it a "high risk" type of assay. As in the case of trying to estimate the optimal environment in which to grow extraterrestrial organisms, such factors as pH, temperature, metal ion availability, water activity, and substrate concentration would essentially have to be assumed in conducting the assays.

There are even possible ambiguities in making inferences from pictures. We can, of course, imagine a picture sent back from Mars that contains one or more objects of such complexity and form that it would provide compelling evidence for the existence of life. But Martian organisms may well be relatively small, scraggly, things - perhaps microorganisms too small to be seen except by microscopic methods. Ingenious techniques are being developed (36, 39) for automated scanning of soil samples for the presence of microorganisms, and it might appear that at the level of microphotographs, it should be easy to discriminate between the living and the nonliving. But it is a relatively common observation to minerologists to find inorganic filaments, globules, and other "life-like" particles in their specimens of rocks, sediments and meteorites (cf. 40).

That pictures may be misleading is also apparent in Plate 8. This is a microphotograph of some of the microspheres synthesized by Fox (41). This preparation was made by heating a mixture of amino acids and subsequently dissolving the polymerized material in water. As the saturated solution of "proteinoid" cools, millions of microspheres settle out of the solution. As is seen in this plate, the microspheres have obvious similarities to biological materials. Indeed, with no additional information but the picture, a team of biologists might well conclude that the sample photograph showed a large variety of different organisms.

APPROACHES TO THE PROBLEM

Only some of the more obvious difficulties have been presented in the section above. From them it is evident that any single assay or experiment to detect life on Mars or some other planet has a high probability of leading to ambiguous conclusions, except by the greatest stroke of luck. Clearly, the question of determining the presence of life on another planet will probably require many different determinations, preferably on the same material, before reasonable conclusions can be drawn. Since there is no single, simple definition of life, if in order to "define" life, one has literally to describe it in terms of its properties (i.e., its chemistry, physiology, and its morphology), if one has to define fully and carefully the gray area between the living and nonliving in order to arrive at a definition of life, it should not come as a surprise that, in engineering terms, no single, simple test will suffice. Proof for the presence of life on another planet has to be deduced from many observations and tests. These each will yield only partial answers but, by a series of approximations, we will get closer and closer to a definite conclusion - a process more or less in the nature of approaching the asymptote of a hyperbola.

Basically, three schemes can be visualized for obtaining the necessary information. One is to automate a large multifunctional laboratory, which could perform chemical and other analyses and also carry out all the necessary sophisticated tests *in situ* on another planet. Such a concept (42) visualizes a more or less complete computer-based laboratory capable of sampling an extra-terrestrial environment, making preliminary determinations and then, depending upon the results of these determinations, going on to a variety of tests and procedures, the results of all of which could then additively allow a reasonable inference as to the presence of living organisms. In the face of so much ignorance about the detailed environment of Mars, and because of the technical break-throughs that would have to be solved in order to carry out such a massive effort, it seems unlikely that this approach will be given serious consideration at this time.

The second scheme is less likely to appeal to the enthusiastic exobiologists who are eager to obtain the crucial answers in the shortest possible time and to those who would minimize the number of chances of contaminating the planet. In this view, experiments and analyses would begin with further probing of the Martian environment, its topography, atmosphere, surface composition, etc. Then, armed with more details about the physical properties of the planet, and after further detailed reconnaissance and study of the planet, we could make a series of determinations, the results of each one being evaluated before designing the next flight, until the number of unknowns about the planet was so reduced that what we now consider "high risk" experiments could be carried out with reasonable chances of success.

Finally, the third route would be to obtain samples of Mars and bring them back to Earth where they could be studied in detail with the full armamentarium of science brought to bear on the critical question of whether that planet contained living organisms.

SCIENTIFIC MOTIVATIONS

Despite the severe technical problems and the scientific ambiguities that have to be faced, it should be emphasized that biologists are profoundly interested in the search for extraterrestrial life. It now seems to be clear that, on Earth, living organisms, despite their vast diversity, are fundamentally similar. The chemistry and biochemistry, the cellular structure, is essentially the same in a bacterium as it is in a baboon. The uniqueness of terrestrial life is seen, for example, when animal viruses can be propagated inside a common soil bacterium or when proteins of a bacterial virus can be synthesized by chloroplasts extracted from a green plant (43)! The conclusion seems inescapable that all terrestrial life is derived from some single ancestral type.

What is completely obscure, however, is whether in the biota of some other planet chemical, biochemical, physiological, morphological, or evolutionary processes similar to those for terrestrial organisms also occur. Are terrestrial organisms the way they are because of some chance accident of early evolution, or are there as yet undiscovered reasons for the <u>kinds</u> of chemistry and organization that we find in terrestrial living forms?

Clearly, if living organisms are found on another planet, and if they are found to have properties uniquely different from organisms in the "terrestrial class," our concept of life would be significantly broadened. Indeed, even if life is not found elsewhere, particularly on planets where the environmental conditions are not thought to be inimical to living organisms, we would have much to think about in trying to explain the absence of life there. New hypotheses about the origin of terrestrial life would almost certainly emerge in this case.

So, while we cannot make a very strong case for life on nearby Mars, and while there are obvious difficulties to be overcome in the search for life on that and other planets, there is so much to be learned about biology that the effort must be undertaken. Thus, many biologists feel that the search for extraterrestrial life is the most important scientific objective of the space program. For example, in a study by the Space Science Board of the National Academy of Sciences (44), this group concluded, "The biological exploration of Mars is scientific undertaking of the greatest validity and significance. Its realization will be a milestone in the history of human achievement. Its importance and the consequences for biology justify the highest priority among all objectives in space science - indeed in the space program as a whole."

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LIST OF PLATES

Plate 7- Growth of bacteria exposed to more severe Martian temperature regime. Here, as in Plate 6, only the periods above freezing are shown. Once again the numbers of viable cells have increased about a thousand-fold. (Courtesy Dr. Richard S. Young).

Plate 8- Microspheres produced by heating a mixture of amino acids. Seen under oil immersion (970X). (Courtesy Dr. Sidney Fox)

Primitive Atmosphere	Energy Sources	Building Blocks	Basic Components	
Water	Ultra Violet	Amino Acids	Proteins	Living Cells
Hydrogen	Electric Discharge	Purines	Nucleic Acids	
Ammonia	Ionizing Radiation	Pyrimidines	Polysaccharides	
Methane	Heat	Carbohydrates	Lipids	
	Meteoroids	Fatty Acids		

Plate #1

A-29053-6

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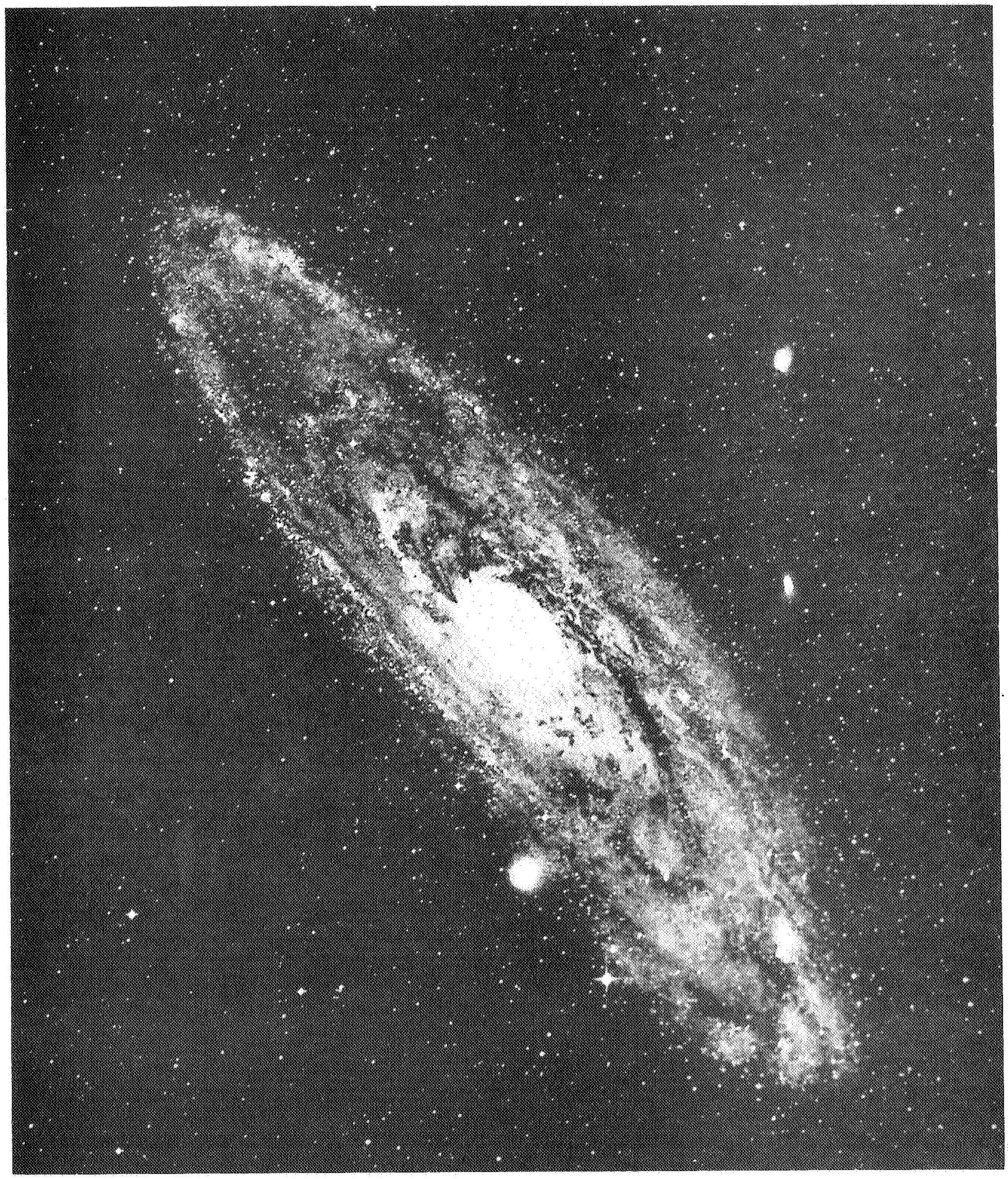

Plate #2

LICK OBSERVATORY PHOTOGRAPH

A-33091-3

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Plate #3

MOUNT WILSON AND PALOMAR OBSERVATORIES PHOTOGRAPH

A-40852

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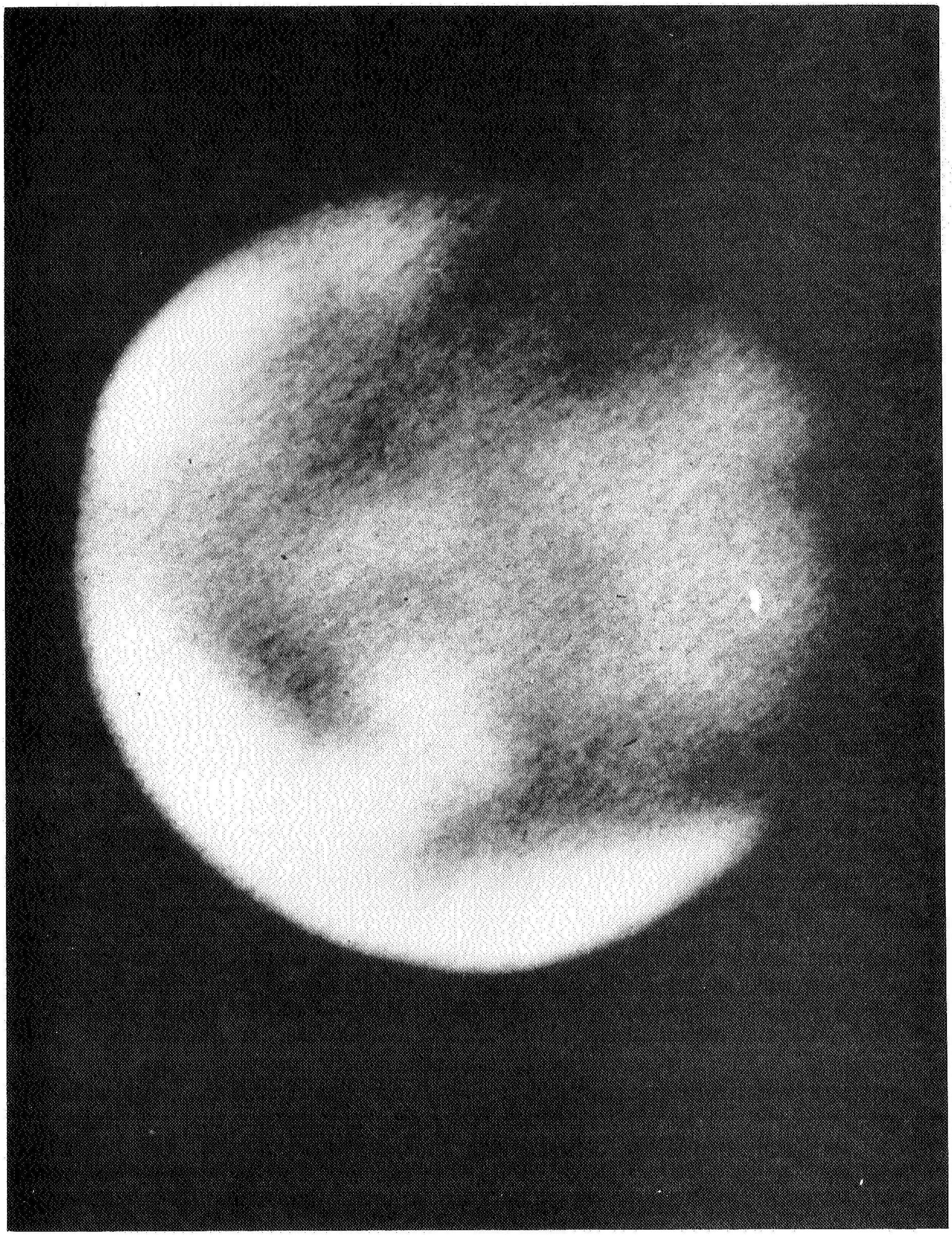

LICK OBSERVATORY PHOTOGRAPH

Plate #4

A-31847-5

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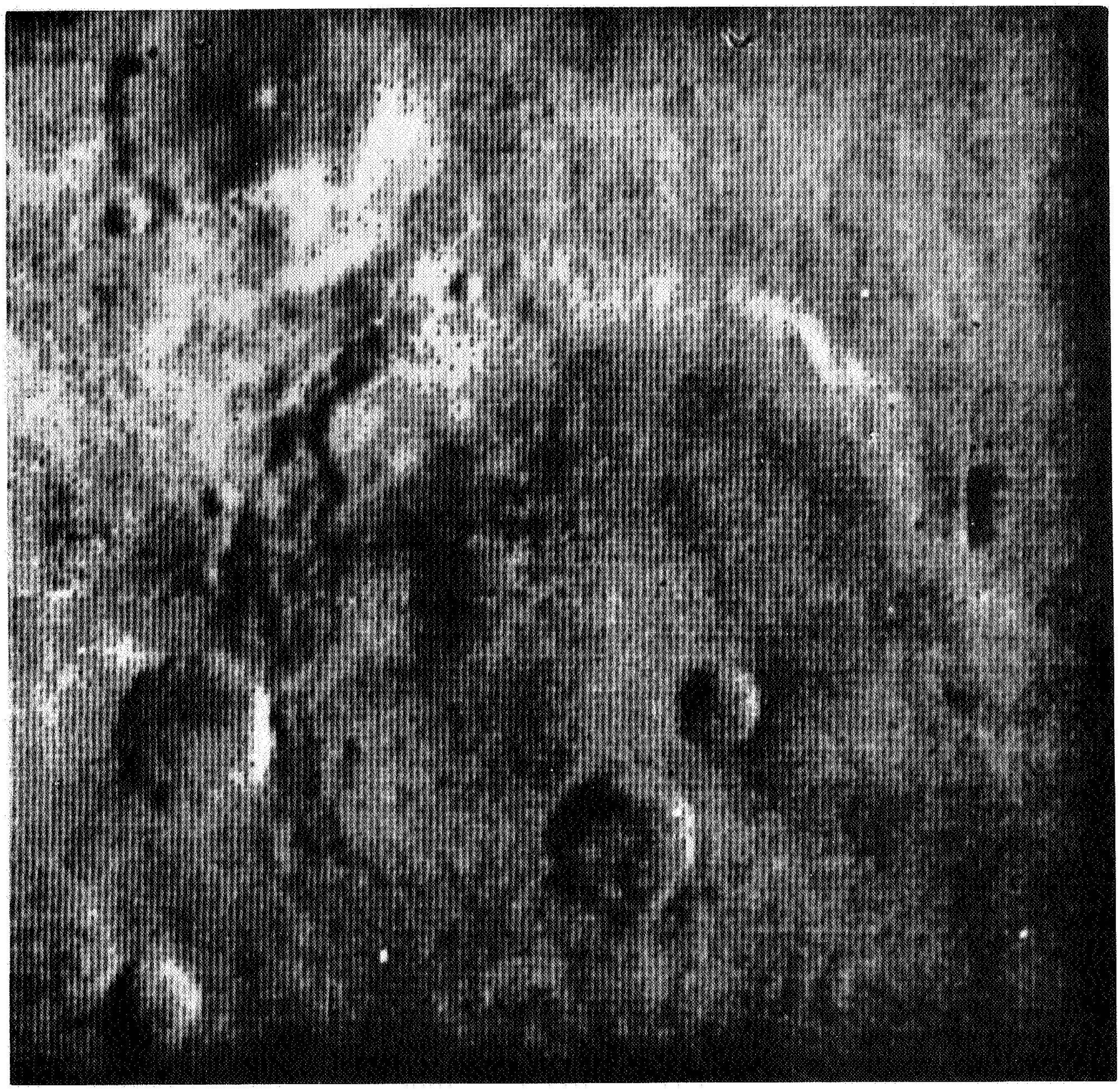

Plate #5

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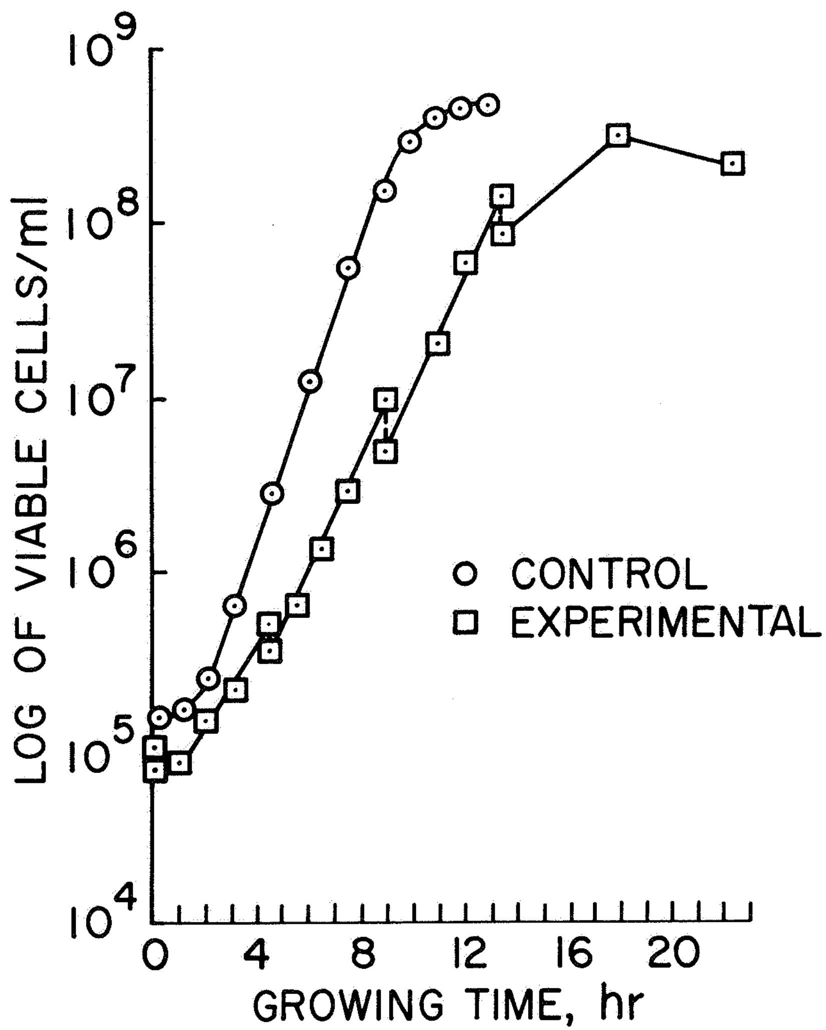

Plate #6

A-30732-1

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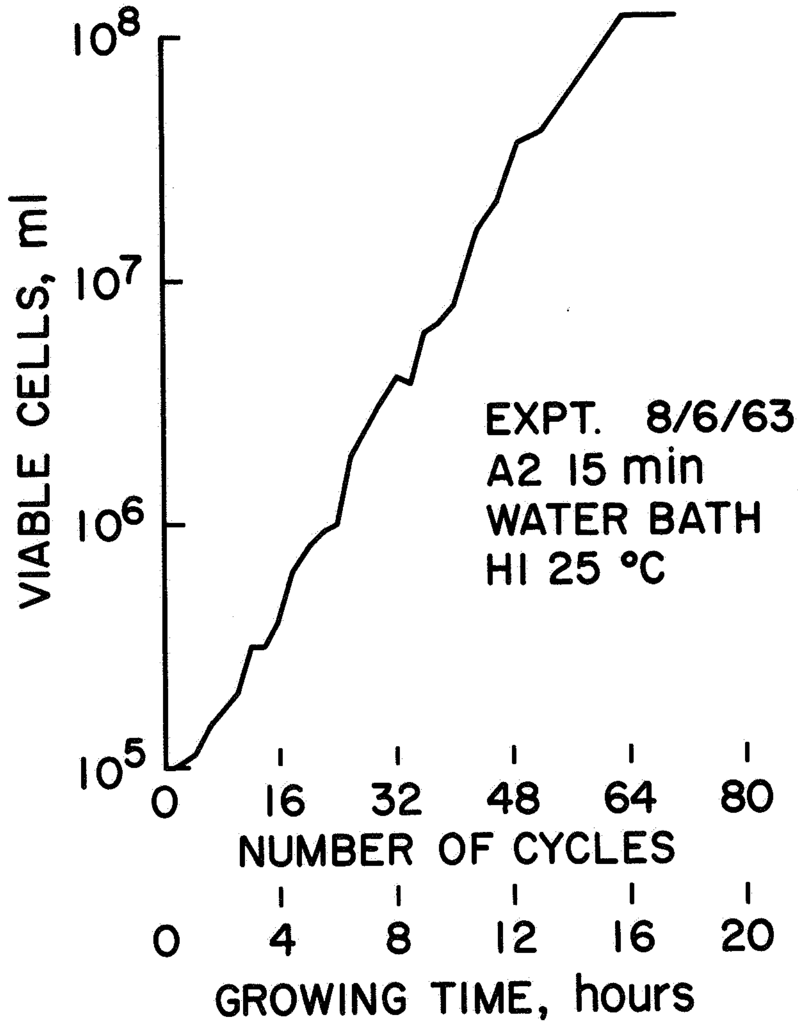

Plate #7

A-31720-1

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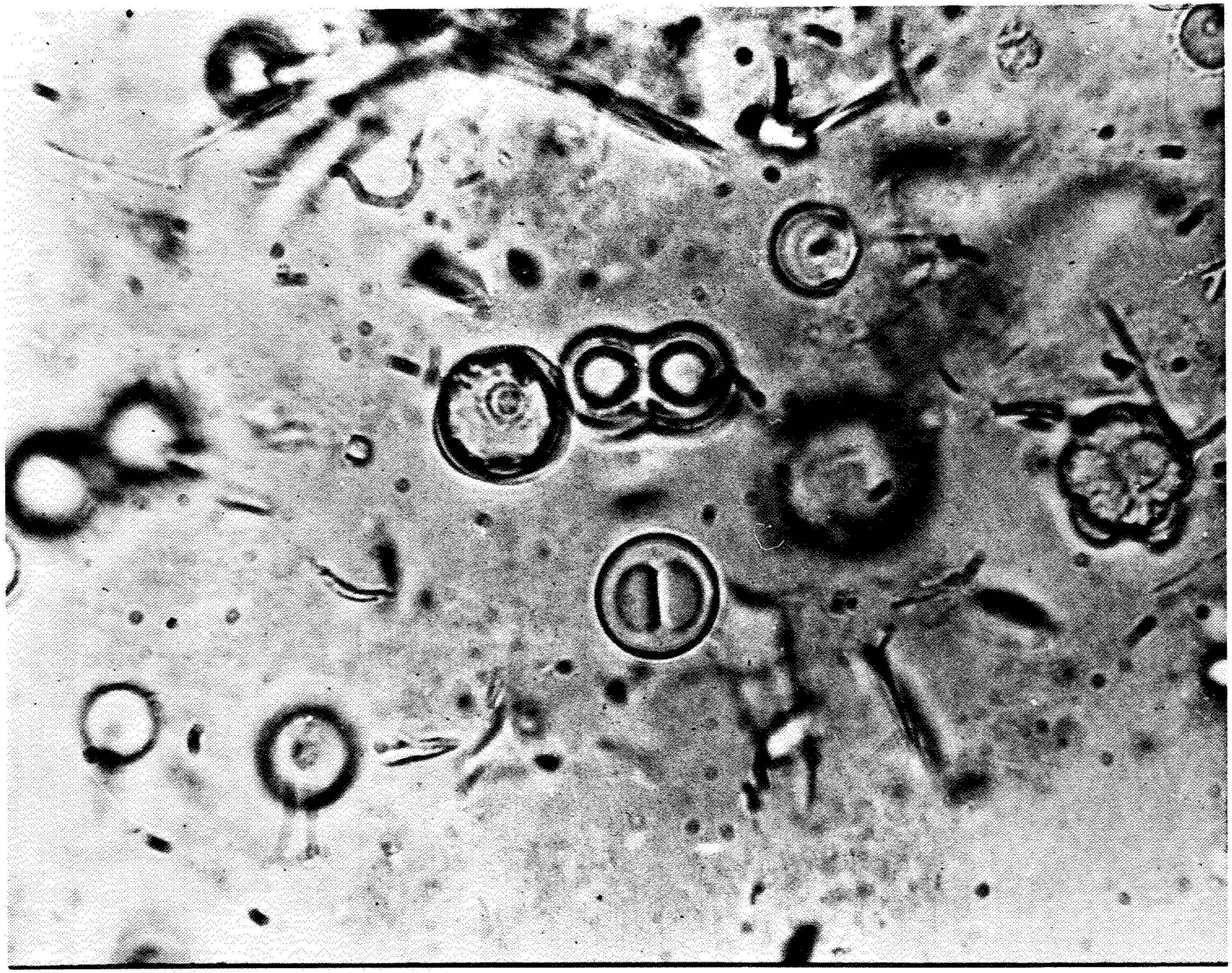

Plate #8

A-28942-2

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