Life In Space

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To the historian looking backward from future time, this century will be memorable for a number of climaxes in the evolution of human culture: the concentration of national power in global conflict, the shrinking of the globe by air transport and wireless communication, the exploitation of nuclear energy, the technological revolution of computers and automation, the reunification of the sciences, the unravelling of the physical mechanism of life. All these movements have a common focus in the exploration of space, the million-fold extension of human activity from the earth's crust to the reaches of the solar system. The same power and resources that can count down the survival of the civilized man can also light his noblest aims.

What do we seek in space? Not astronomical numbers. Emptiness multiplied is at most very little. The journey does give us two unique rewards: a perspective on our own planet and a prospect on other worlds. The first pioneering steps in space - the orbiting satellites that can analyze our atmosphere, show our weather, speed communications, help navigation, or warn of global dangers - are already doing their useful tasks and begin to show their merits in advancing scientific knowledge of the earth. Now, as our vehicles become more powerful, we must measure our reach and attend to our objectives in exploring the other celestial bodies. Among these objectives, the discernment of other life is the most subtle and demanding, for it insists: "Know thyself."

The ancient units of measure: inch, foot, mile, scale the everyday activities of primitive life. To measure space we need new, ever larger units. The earth's diameter is a convenient inch for nearest space. In these inches, our moon, the nearest celestial body, is an arm's length away (30 times 8000 miles). Earth to sun, extending in these big inches a thousand feet (93 million miles) is the first basic measure of the astronomer, the "astronomical unit". Thus, the first five planets circle the sun, as shown in the figure, at 0.4, 0.7, 1, 1.5, 5.2 units - Mercury, Venus, Earth, Mars, Jupiter. The ninth planet, Pluto, bounds the solar system at 40. Shift scale and make this unit a bigger inch. Then space is empty (except for meteorites and comets) from the yard of the solar system to the four miles of the next star. This twice scaled mile is about the same as the "light year" of astronomical maps. We have shifted scale once to measure the earth, again to match the domain of sun to star. The next scale gains the galaxy; one more begins to measure the universe.

Rocket propulsion has given us vehicles to look more closely at this front yard. With human arrogance or humor we sometimes call this neighborhood "outer space", but this does not enlarge it from an infinitesimal part of the universe. Within the limits foreseen by present day science, these tools, and our expectations for them are neatly contained within the solar system, but the restraint leaves much to do. The limit is of time as well as space. To propel matter at very high speeds would expose it to impacts with interstellar dust at enormous energy. For vehicles with more temperate speed, the solar system would consume months and years, the next star many millenia. Our main contact with outer space - the stars and galaxies - must remain radiation: the light that Galileo taught us to capture with telescopes; more recently, radio waves; and with the use of satellites, other radiations that are obscured by our atmosphere and can only be sensed by the devices we now send beyond it. Can we detect life in outer space? We have but one hope for it, to hear the rhythm of intelligent purpose amidst the cosmic static. Then we may have a shortcut around the perplexities of detecting life by observation and discovery. The shortcut is conversation. In fact, the particular character of local life may well be the most pertinent gossip for the interstellar telegraph. But not until we have learned to communicate, and discovered a counterpart earth - among how many worlds who can say? ~~- this challenge is to the radio engineer.~~ Meanwhile, we have discoveries to make in our front yard, the nearer space of the solar system.

The main theme of planetary research is evolution - to learn the physics and chemistry of the birth and development of the solar system. This encompasses the questions that life must emphasize, how life came to one - or more? - of its planets. Spacecraft have three immediate uses. They can lift telescopes into orbit past the murkiness of our atmosphere; they can carry instruments to the planets for radio communication back to the earth; they might bring back samples of the surface of the moon, of Mars, of Venus, for the most detailed study in our own laboratories. The first two plans are materializing within the next few years. The third plan must, and might just as well wait for the data from the first two; it may take another decade to build the staged rockets needed to return even a minute sample from Mars. What of a fourth, man in space?

Man is in space already, and far deeper than the few hundred miles of the brave journey of the astronauts. For the near future he cannot move his own fragile, demanding body very far from home, but his senses are multiplied on the spacecraft, and his intelligence gives meaning to the signals from the radio receiver here on earth. In the course of time, we shall know enough of space to warrant the immediate presence of man, with the convergence of three paths of knowledge - the means to send him there and back, the hazards of human spaceflight and how to counter them, the knowledge of space from our simpler instruments that will guide his performance of useful tasks.

Moving a telescope outside the atmosphere gives larger advantages than might be thought for a journey of a few hundred miles. From the standpoint of the detection of life, or at least the conditions most promising for life, the telescope's main function is to study a planet's atmosphere. Different gases, oxygen, carbon dioxide, water vapor, which are so important for earthly life, have characteristic "colors" in ultraviolet and infrared light; these are, of course, largely confused by the earth gases through which our present telescopes must look. In fact, of the 50 octaves of electromagnetic radiation which reach the top of the earth's atmosphere, and which can convey the most important information from the world outside, only a dozen octaves reach the ground in reasonable strength. Many of these radiations would be most informative precisely because they do react strongly with gases in their path. A vantage point in space will also improve the performance of the telescope in resolving small details which are now obscured by the shimmering of the air. A medium-size telescope looking into space from the airless moon could see, as is now impossible, whether the nearer stars have their own planets revolving about them. The suggestion also reminds us how little we now know of even the closest neighbors beyond our "front yard".

The second plan needs subtler thoughts that go further past familiar scientific practice. These new experiments must be pared to the lightest weight; they must then still promise enough return to justify the cost and effort of being planted on the surface of a celestial body. The data they collect must then be channelled over the 50-million mile radio link from Venus or Mars to the earth. Physical scientists can readily frame many straightforward and compelling proposals. The biologist needs the same measurements - temperature, air pressure, humidity, salt content, acidity, and other chemical features of the planet - to frame his later experiments with the confidence of orderly and knowledgeable planning. We may well have to rely on painstaking surveys that will approach more complex questions only after several preliminary steps. But we would be impatient to make some more inspired early probes, and at all odds must put great care in defining the objectives of the long range research program. We would like to narrow our questions to bring them within the range of our familiar skills. But we are bound to expect important differences from earthly life and are left with the puzzling task of framing rather general questions of a planetary biology. Yet, it is precisely for the reason that biology so far has been earth-bound, that its experimental material has not had the generality enjoyed by physics and chemistry, that exobiology is such a poser for theoretical biology. Further, The occurrence of life in the solar system, and the possible survival and spread of terrestrial life are vitally important considerations in the overall direction of the exploration of space. We are therefore impelled to make an independent study of the possibility of extra-terrestrial life, even before we have all the information on planetary environments that will help to perfect our conclusions. The study of the planets by telescope astronomy can give us at least a preliminary basis for analysis.

The nearest celestial bodies are the moon, Venus, Mars and Jupiter and will surely be on the itinerary for the explorations of the sixties. Some of their important features are summarized in this table.

THE SOLAR SYSTEM
in a nutshell

		Average Distance from Sun			Size in Earths		Chances of Life
		Miles	Earth Diameters	Astronomical Units	Diameter	Mass	
	Sun	---	---	---	109	332,000	A bit warm
I	Mercury	36 million	4,550	0.39	0.4	0.6	Too close to sun; lighted surface very hot and no atmosphere
II	Venus	67 million	8,400	0.72	.97	.8	May be quite hot on surface; if so not likely
III	Earth	93 million	11,700	1	1	1	Probable, but not yet verified by spacecraft experiments
	Moon	236 thousand (from earth)	29 1/2 (from earth)	1/400 (from earth)	.27	.01	No atmosphere, hence no active life. Might carry evidence of traces from elsewhere
IV	Mars	142 million	18,000	1.5	5.2	.1	Reasonably suitable except very dry; may still support life
V	Jupiter	483 million	61,000	5.2	11	318	Very cold by earth standards, but rich in carbon, hydrogen, etc. and may therefore have a unique life system
VI	Saturn	886 million	1,120,000	9.5	9	95	
VII	Uranus	1.8 billion	2,200,000	19	4	15	Very little known; may resemble Jupiter but colder
VIII	Neptune	2.8 billion	3,500,000	30	4	17	Colder still
IX	Pluto	4 billion	4,500,000	39	1±	1±	May resemble earth in composition but extremely cold

Of all the fact of planetary conditions, the abundance of water may be the most pertinent condition for the distribution of life, as it is on earth. Where deserts are irrigated, life rapidly flourishes. Vegetation in the polar regions is only indirectly discouraged by cold; its main effect is to lock up moisture in snow and ice. And where plant life is sparse, animals can not find food. This need for water has a deep seated basis in biochemistry. All living cells contain far more water than any other component. Water plays many roles in the economy of the cell but above all it is the indispensable solvent. The intricate work of the cell requires the ready intermingling of many kinds of molecules. This could only occur in solution - and if not in water, we cannot readily point to any alternative (except at very low temperature, at which ammonia and other gases might liquefy.) Many other substances are vitally important to our own existence; for example, the oxygen in the air we breathe. But we should not exaggerate the generality of its importance, which does not rest on so fundamental a basis. ~~For example,~~ The vegetable kingdom in general and many simpler animals can survive without an external supply of this gas. Even quite complex forms of life should be able to thrive without oxygen, even though they might miss the more efficient burning of foodstuffs compared to fermenting them. Poisonous gases, like formaldehyde or carbon monoxide in a planetary atmosphere might preclude human life, but man is not the measure of all things. In fact, probably nothing would be more encouraging to our speculations than certain evidence for formaldehyde and water, a brew that was persuasively urged for Venus not many years ago, but which does not seem well founded now.

Life on the moon, on Mars, even on Venus, is an ancient fancy - and a recent one too, both in science and science fiction. Within vivid recollection astronomical enthusiasts have mapped the roads and irrigation canals of Mars; the man-in-the-moon has an older history and green cheese might still have some adherents. Clouded Venus has always left and still leaves more to the individual imagination. One way or another, these fancies have been discredited. If the canali of Mars were roads, we could hardly see them, and no one does see them now. But "not knowing" should scarcely be confused with "knowing not". The experiment remains.

We have to admit that the theoretical outlook is dampened by our consideration of water. The moon would be closest and handiest for study, but we are already certain that it is not quite large enough for its gravity to hold an atmosphere. Its surface would make a splendid laboratory for the study of vacuum harder than readily attainable by any device here. Any water on the surface would long since have evaporated into space - some of these atoms will even have distilled over the earth. Professor Harrison Brown at California Institute of Technology has recently pointed out that we should still expect some traces of ice on the moon - condensed in sunless crevices whose low temperatures even compete with the high vacuum. But these cold spots make it even more certain that the surface has no water, as it has no air, no weather of any kind, no present life. The moon is a marvelous relict of ancient times, a wonderful object to trace the primeval formation of the solar system, for its features have not been subjected to the continual metamorphosis of the weather-beaten earth. The moon is, however, a target of relentless impact of meteorites. These are particles ranging in size from single atoms to small planetoids orbiting in space until they happen to collide with the moon or a planet, or are drawn into the sun. These meteorites rain on its surface unhindered by the atmosphere that fires their passage to the earth. The fossil moon therefore has its own sediments, a timeless record of cosmic history in the accumulated deposits of these materials collected from interplanetary space. Meteorites that have fallen on the earth are among the most valuable natural space probes. But here we can only study the ones that have survived passage through the atmosphere, and can be identified and separated from earthly matter. With great luck and ingenuity, a spacecraft might capture a few particles from free space. The moon will have collected them for a billion years.

It would be of exceptional interest for cosmic biology to know whether meteorites can bridge the void from one planet to another. There are already strong hints that some glassy meteorites have fallen on the earth from the moon. The earth's atmosphere makes the removal of particles (by natural processes) much more difficult, and the possibility is hotly debated. The moon's surface is almost the only place where we might find direct evidence of such an outflow from the earth. If the traces can be proven on the moon, we then could calculate that all the planets had interchanged fragments, perhaps even planetary systems of one star with another. This interchange would be much less than between the earth and its moon and we might have no hope of finding direct evidence of it. But the arrival, once in geological time of a single fragment bearing a living spore would have immense potentialities for the future of a planet. The original purity of the moon's surface is thus an important scientific asset that should be conserved until we can plan our search for earthly traces on it.

Venus, the nearest planet in its own orbit, lies about a third of an astronomical unit in towards the sun from the earth. Because of its interior position, Venus is in line with the sun just when it lies closest to the earth and would otherwise be most readily studied. The brilliance of the planet is due not only to its relative nearness and size, which is about that of the earth, but also to the high reflectivity of layers of clouds which completely envelop it and which have, so far, prevented astronomers from seeing any of its surface details. The thickness of these clouds had, in previous years, led many astronomers to expect that the surface of Venus would be relatively dark and cold despite the planet's being closer to the sun. This view was seemingly confirmed by measurements of the intensity of infrared radiation emitted from the planet and detected in our telescopes. More recently, similar measurements at radiowave frequencies have suggested much higher temperatures. These discrepancies can be reconciled if we suppose that the radiowaves are emitted by a very hot surface while the infrared measurements indicate the temperature of the top of a cold high layer of clouds. The heating of the surface would be attributed to the "greenhouse effect" of the high content of carbon dioxide in the atmosphere, A gradual warming that many meteorologists have inferred for the earth is similarly explained by the slight increase in our own atmospheric carbon dioxide resulting from industrial activity. By allowing shorter wavelength radiations to penetrate to the surface but preventing the re-irradiation of longer waves generated by surface heating, the carbon dioxide would have a blanketing effect quite comparable to the glass frames in a greenhouse. Life might be expected to be adaptable to a considerable range of temperature, perhaps even exceeding the wide ranges that it finds on earth. However, present measurements by these radiation methods indicate a surface temperature for Venus of about 400° F. - a reasonably hot oven in which neither liquid water nor typical organic molecules could long survive. If these measurements were confirmed by direct access of experimental instruments (i.e., a thermometer) we would have no basis to pursue a search for life in familiar form. In fact, we would be hard put to design complex instrumentation of any kind that could long withstand such heat. However, we know so little about the planet - it is hard to doubt the indicated temperatures but is somewhat less certain to exactly what layer they refer - that we ought not to take it for granted that these results apply uniformly to every layer of the planet Venus to which life might have access. Most of the moisture on the planet will be found in its higher atmosphere where more moderate temperatures may also prevail. Perhaps, then, the place to look for any life on Venus is not on its searing surface but in the clouds themselves.

Our own atmosphere bears a surprising amount of life - the birds and insects and more pertinently, a wide variety of vegetable and microbial spores, though we doubt whether any forms live out their full cycles in the air. However, we may have cause to breed such aerial ~~plantation~~ plankton if we do not find it naturally.

On earth, green plants have taken up most of the primeval CO_2 and, by photosynthesis, released its oxygen to the atmosphere. The carbon is partly represented in now living organisms, much more in deposits in the earth, coal, oil, peat and scattered carbon. With little CO_2 in its atmosphere, the earth re-radiates the sun's heat and remains tolerably cool. From this comparison we might argue that plant life, maintained on Venus, would convert this planet to another earth. If the surface is too hot, the clouds may be the only extensive place for the introduction of such plant life. Naturally we must know much more than we do about Venus' upper atmosphere before we start taxing its real estate.

In the geography of the solar system, we stand about halfway between interior Venus and exterior Mars. Being somewhat further from the sun, its temperature regime might be slightly chillier than ours, but it might likewise have retained a larger fraction of water and other important volatile material. But Mars has only about a tenth of the earth's ~~gravity~~ mass and therefore despite its cooler situation, it has only been able to retain a thin atmosphere, most of the lighter gases having already escaped. What remains might be compared to our own atmosphere at a height of 40,000 feet. This is too thin for human breath but enough to give the planet a turbulent weather judging from the massive dust storms that have been seen through our telescopes. We still know relatively little of the chemical composition of this thin atmosphere. Of the 50,000,000 and odd miles to the planet, the first 50 - earth's atmosphere above the telescope - give us the most trouble. Thus, the only gas of which we have any definite knowledge in the Mars atmosphere is carbon dioxide; it is generally inferred that there is very little, if any, oxygen or water vapor and that nitrogen makes up the main bulk of the gas. As a place for human habitation, even exploration, Mars would be considerably less congenial to human access and modification than the bottom of our oceans. But it is the abundance of water that must dominate our evaluation of the planet as a home for adaptable forms of life.

What then of water? Spectrograms have not yet given direct evidence of it in the Mars atmosphere, nor can we find seas of liquid water on the surface, but the frost is there to see as polar caps which wax and wane during the local winter and summer. The details of this weather circulation, how much water may be trapped in the subsoil of the temperate zones, are the key to the Martian mystery. Many astronomers have commented on the changing extent and color of dark patches that appear in these zones and particularly behind the receding polar caps in spring. These observations, reminiscent of a vegetation cycle, have been bolstered by Sinton's spectroscopic measurements. through the Palomar telescope: the infrared color of the dark patches corresponds to that of a layer of organic material. But this still leaves some doubts. Carbonaceous colors could mean life, but could also come from some inanimate process. Dollfus has seen the granularity of the Mars surface change with the season, also just as if this were the growth and decay of small plants. Taken together, these studies give little encouragement for the development of a Martian life as rich as earth's, but they do not rule out a marginal biology whose urgent need is the finding and retention of water.

Could we readily plant a single instrument on each of our sister planets, we would ask about Venus' heat and Mars' humidity. (For a Californian to comment on the earth at this point might start a distracting argument.)

Jupiter, the next planet after Mars, is a formidable five units from the sun, a distance that already makes this a cold planet. Its chemistry is altogether unlike the group of rocky planets we have just discussed - the earth and its neighbors have only the dregs of the volatile material which is the average composition of the universe, most of this having been distilled off by the sun's energy. Jupiter is immensely larger than earth, but its specific gravity is very low and it must be composed mainly of condensed liquors and ices of hydrogen, oxygen, carbon, and nitrogen and their compounds. We have very little insight into the details of the molecular chemistry of such a planet, but the very listing of its general composition attracts the interest of both the organic chemist and the astrophysicist. These substances are the raw material of the evolution of life, on the one hand, and of the evolution of the universe on the other.

It will take some presumption to plan the direct approach to this huge and mysterious planet. Its gravity, three times the earth's, must be resisted by the landing vehicle. The low density of the surface material will call for bulky, buoyant structures. The depth of the atmosphere, and the violence of its electrical storms (already heard in our radio receivers), will complicate the task of communication which distance already makes difficult.

Saturn is still farther away, almost ten units from the sun, but its moon, Titan, is unique in displaying a measurable atmosphere. Its substance should correspond to that of the major planets, with some of the more volatile gases boiled off. It would be harder to navigate to, but otherwise might be easier to contact than the major planets themselves, and we can expect to hear more of it among the ambitions of future years.

In discussing life on nearby planets, we rely upon our earthly understanding of it. We feel we would have no great difficulty in deciding whether a specimen from Mars was living or not, even if it had unique marks of its origin. When we turn to Jupiter's life, we can be sure that it could have no resemblance to the earth's. The physics and chemistry of Jupiter are far too different. The low temperatures alone would forbid earthly life.* But

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*Perhaps even this is too dogmatic - the temperatures a few hundred miles deep in Jovian seas might be far more temperate. ~~From a biological standpoint the visible surface should perhaps be compared to the outer atmosphere of the earth. This is thinner, but its composition might discourage otherworldly astronomers from believing that the earth could be inhabited. At an altitude of miles, the earth's atmosphere consists of hydrogen at a temperature of~~

just the chemistry of a C-H-O-N rich planet, operating at low temperatures and high pressures, will offer us many perplexities of decision, whether some metabolic process should be called "living" or not. The very strangeness of this group of planets (which includes the similar Saturn, Uranus and Neptune) makes them especially attractive for scientific discovery. Before we run to Jupiter, we must learn to crawl to Mars; but if we find no life on Mars, we recognize it well enough to be able to guess why.

Eager to find the fair maidens of Venus, or at least the green men of Mars, some readers might be impatient of these pessimistic expectations. What values might emerge from knowledge of Martian life, if it is indeed so harshly limited by the shortage of water? An understanding reply calls for a closer look at the scope of contemporary terrestrial biology, which in turn may help fo focus on precise goals in "exobiology", the study of life beyond the earth.

In recent years, many physical scientists have turned their attention to biology, expecting to find sweeping theoretical principles of the same sweeping generality they knew in physics and in chemistry. After a period of disappointment, or naive exuberance, many have discovered new problems requiring great experimental finesse. But they have had little chance to use or emulate the grand theoretical structure of physics,.

Biology has had an amazing development as a scientific discipline, and perhaps remains the closest to man's worthy preoccupation with himself. But its domain has been limited to this one planet, to the ways in which one spark of life has illuminated one speck in the cosmos. By contrast, the basic laws of physics are derived from the motions of the stars, and we know the scope of chemistry from the spectra of galaxies at the boundaries of the observable universe. The most productive ideas in physical theory have come from abstract fancies of possible worlds. But these fancies are disciplined, as they are provoked, by experimental facts. To speculate about "possible organisms" in the same way would be as difficult for present day biology as it would be futile without the hope of experimental search and test.

These observations about biological theory are of the kind that may be better tolerated in family discussion than in public view, and they are perhaps exaggerated. Biological science has catalogued the earth's plants and animals. It has begun to explain the cell as a mechanism of physics and chemistry. We need no longer doubt that this explanation will be as complete as scientific explanation can be in any field. But we have no way of knowing whether all possible kinds of life have been developed on the earth, or whether entirely different principles might serve the vital experiment elsewhere. In the face of this uncertainty, most biological generalizations seem unimportant or trivial. One theoretical principle still stands out, perhaps the only one that we would confidently expect to have universal application. This is Darwin's principle of evolution.

According to the evolutionary principle, organisms are liable to numerous unpredictable changes, mutations which are transmitted to their offspring. Those which result in a better fit to the environment are saved for the next generation. The species thus achieves a better adaptation. A more elaborate use of the same evolutionary principle explains how organisms become more complex and varied to fit all the niches that support life on the planet.

The evolutionary principle makes no specific assumptions about the chemistry of the organism, or of the genetic material within. It should therefore be quite general in its range of application. It is appropriate, and maybe unavoidable, to rely on evolution to even define life; This may not always be easy in a foreign context. To put the matter as simply as it deserves, we would attribute "life" to any system that evolves in such a way as to remind us of the evolution of earthly life. We do not always see evolution in action, but can judge it by its end results. On earth we infer evolution when we cannot otherwise explain how the complexity of amoeba or posy could have materialized by any less magnificent process.

Evolution is the main principle of theoretical biology; it may prove to be the only one by its very nature. The variety of existing life is only partly determinate; many organisms that might have been, have failed to occur just by chance. If there are other fundamental principles, they will have to be the rules that set the actual limits to the possibility, not just the actuality of evolutionary change.

Could man's intelligence be multiplied, or his life span lengthened? Must crop plants be intolerant of salt or brackish water? Why must animals depend on plants for vitamins and amino acids, instead of synthesizing them directly? These are some of the less demanding questions that ~~such~~ a comprehensive biological theory should approach. But for present purposes they are too particular. Then, what common principles do pervade life on earth?

The evolutionary principle was impelled by the obvious resemblance in form among species, but only the boldest theoreticians of the last century would have predicted the commonplace facts of present day biochemistry. Despite their outward variety, the central components of all organisms are the same: their genetic material consists of nucleic acids; most of their structure consists of proteins. We are beginning to understand how the chemical properties of these substances underlie their functions in the cell. But all cells have the same general composition in regard to these components: the boiled down residues of the beef muscle would be hard to tell from the mushroom sauce; the nucleus of the human nerve cell from the virus that might attack it.

The conception of the central unity of terrestrial life has quickened the search for the origins of life. If we knew how specific proteins and nucleic acids first appeared on the earth, we would have most of what we need to understand the further development of life. In the world now, proteins and nucleic acids are produced only as manifestations of life, as copies of what had evolved before. But we are learning to strip the cell, to isolate only the essential needs for these elementary reactions, and to continue them in the test tube. And before long it should be possible to emulate a protein and a nucleic acid and build accurate copies ourselves. But how did this come about spontaneously, without preexisting cell or brain to guide it?

We can hardly answer this question in any depth without an accurate picture of the chemistry of the earth when life first appeared on it. We believe that the primeval atmosphere had little free oxygen, but much methane, ammonia and water vapor - in fact not very different from the present substance of Jupiter. Solar radiation can convert such an atmosphere into a wide variety of complex compounds as Oparin had predicted and Urey and Miller showed in the laboratory. From this point we are less certain, just which compounds would be formed, and which conditions would most likely close the gap to the living molecules. Studies on other planets and on interplanetary dust can give indispensable help to analyzing the early history of the earth, and thus aid biology whether or not life has actually developed elsewhere.

These observations lead to a fundamental question for exobiology. Are nucleic acids the only substances that can function in any heredity, or are they merely the ones that the path of earthly life has encountered? Are proteins, chains of just twenty amino acids, likewise the only way of building up cell-like structure, or the accidental result of early chemical evolution on earth? These questions might be answered in two ways. Presumptuous man might imitate Nature, to mimic primitive life, furnishing substitute compounds. More humbly, he might ask Nature the outcome of its own experiments at life, as they might be manifest on other globes.

From this standpoint, the chemistry of exotic life looms far more important than its dragons. The most marginal life form on Mars could still answer these basic questions, and help teach us the limits of life's construction. Sterile Mars, if it yielded historic traces of unsuccessful trials at life might be no less informative.

What practical means do we have to answer our questions in exobiology, or more concretely, the Martian biology? First we should review the practical limitations. Our plans require the conjunction of planetary geometry, rocket vehicles, radio communications and, not last, sturdy experimental instruments. The geometry dictates that Martian flights be launched during a brief interval that recurs about once every two years (December 1962, November 1964, January 1967). The voyage itself will take another half year. The current generation of American vehicles might barely manage the next encounter with Mars given luck and ingenuity in guidance techniques. The first consideration is not distance, but the fact that the Mars orbit is tilted with respect to the earth's.

The cost of moving and guiding a vehicle out of the earthly plane is prohibitive: the encounter with Mars must be planned to occur at just the time and place of the crossing. Thus at the hypothetical encounter of July 1965, the earth will be over 100 milion miles away, three times further than the sometimes closest approach, but there is no help for it, and the communications must be planned accordingly. NASA, the U.S. Space Agency has indicated its plans for approaches to Mars in 1964-1965, using the Centaur vehicle now being developed, and in 1967 with the more powerful Saturn vehicle. The USSR has not discussed its planetary program but it has already launched one attempt toward Venus and presumably will not overlook the 1962 opportunity for Mars.

These first missions might carry instrumental payloads of the order of 100 pounds to the vicinity of the planet or about a tenth as much payload in a reentry vehicle (nose cone) that aimed to reach the planetary surface. These figures are rough guesses from engineering calculations, but it is clear that early approaches to Mars will not accomodate more than a few pounds of instruments. Power and communications capacity are likewise severely limited.

We have little room here to mount a trap for bear and should leave this possibility to the plainest and most useful of experimental approaches, photography of the local scene by television technique. With further space, additional experiments more specifically oriented to biology can be accomodated, provided they are conceived, planned, funded and built on time. If present proposals are naive, this is in keeping with our exquisite ignorance of the territory.

Even if we wished otherwise, we might be obliged to focus attention on the search for small organisms - like the earth's bacteria - that would fit in a compact testing device and could be caught from the air or the surface of the ground with the least trouble. At least on earth it is the microbes that are found everywhere - truly in all the air, waters and soil. How will the microbes be recognized? Three hundred years ago, Leeuwenhoek first used a microscope to discover the presence of microbial life everywhere, and we would use the same criteria of form, motion and development. We can also separate the microbes floating them away from denser mineral particles in dust and soil. These measures, even if they could also be undertaken in the first experiments, would still not answer our questions of chemistry. These are not easily managed with simple machines in any case. But the technique of micro-chemistry is probably easier to automate than chemistry on a large scale, and the means of doing this are being studied now. Microscopy at specific wavelengths of ultra-violet light would be especially useful here, a technique whose further development would be of great advantage to other contemporary problems in cell biology.

To reinforce these observations on individual microbes, other chemical tests can be envisaged. The choice here is largely a matter of choosing the most sensitive tests that can readily be automated, and that might be pertinent to life. An especially attractive possibility is a means of detecting minute amounts of certain enzymes which may signify the presence of even a few microbes in a sample of dust. Of course, we have no certainty that Martian organisms have the same biochemical makeup: this is precisely what we hope to discover. The uncertainty should provoke humility but not paralysis. As the problems, opportunities and urgencies of planetary biology are more widely recognized, we may expect a more skillful reduction of some of these ideas to practical instruments. Especially after we have made the first tentative probes, more precise and imaginative plans are bound to materialize. Meanwhile, with the little we have in background information and experimental capability we must make some beginning.

It is a pointedly human story (it was first told of Babel) that our approach to the outer world is divided among the nations. In fact the rivalry has doubtless generated far more political support for explorations by each power than might have been possible altogether in a happier more peacable world. This is an old story - it may tell the only positive use of nationalism. Certainly we are all happier that rocket vehicles should be competing starward than fired at one another. But it should not spoil the zest of competition to join in measures that will enlarge the adventure with advantage to all. International cooperation in space work has had some success, largely in the spirit of the IGY, but it is a disappointing fragment of what would be possible even at arm's length and in the framework of the most competitive aspirations. Perhaps the domain of space research near the earth still has military and economic implications that encourage distrust or balkiness. This is hardly a factor in planetary exploration and least of all in scientific exobiology. If there is any area where international cooperation might work it should be here. The free and easy substitution of experiments and vehicles might be too much to expect, and detailed cooperation at this level might be too cumbersome to work. However, in 1964 - 5 for example, some coordination in communications is almost essential for the accurate tracking of planet-bound vehicles. Further, the launch opportunity of that year could be used to full advantage only if each launching country planned to fly expeditions of several vehicles, to back one another up in communications, long term experiments, and insurance against vehicle and guidance failures. The technological challenges as well as the scientific importance of the missions are hardly matched by isolated efforts of single flights at biennial intervals. Such expeditions, being spaced along the path around the sun from earth to Mars would also give us an unexampled opportunity to study the solar system "weather" from several places and angles simultaneously, which saves a great advantage for the unexpected event that every flight works perfectly. In this respect, too, a degree of international planning and coordination would be very helpful, apart from the mere multiplication of efforts.

The year 1964 is bound to see much emphasis on planetary missions; Venus and Mars then will intersect earth's orbit at a time when several vehicles in various countries could be ready for them. Hopefully the political climate on earth will encourage the great powers to reinforce their efforts.

Whatever the limitations of these early trials, there is one biological experiment we should avoid - the careless introduction of earthly life to a planetary target. If this could spread on Mars, it might be the worst scientific blunder in human history, destroying forever the chance of studying the original life form of the planet. Depending on the organism, it could also have other serious consequences for the chemistry of the planet and the availability of its resources for further exploration. We cannot properly assess this hazard until after we have surveyed the planet to know where earthly organisms might take root. Until then, fortunately, it should not be an intolerable burden to cleanse and fumigate our spacecraft to a meticulous standard as the launching agencies have indicated both in the U.S. and the USSR.

Scientists today are impelled to justify their work by pointing to the practical fruits of research, the sooner or later return of dollars and cents, of good or gadgetry. As science becomes technically more complex, and expensive, it must depend on the generosity of society, namely, the taxpayer who (should one believe it?)has no other concern. And it is especially tempting to appeal to this argument when, in fact, the economic returns for scientific investment are so immense. However, it would be tragic both for science and society if obvious yield totally dominated the path of scientific endeavor - this stultifies science as the understanding of nature, and answers only the practical problems that are already half-solved for our knowing how to ask the questions. Expeditions beyond the earth may be among the most costly experiments so far undertaken, but they should warrant their cost as one of the very aims of the human adventure. Dante wrote how Ulysses exhorted his companions to join his heroic journey on the great ocean: "Remember the seeds of your being: you were not made to live like beasts, but to seek the fulfillment of virtue and understanding."* This spirit of the first explorer of the western tradition moves us today. Against this inspiration the expectation of practical returns is both truth and anticlimax.

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*This unforgettable passage (Inferno, 26) is not well-rendered in English - "Considerate la vostra semenza: fatti non foste a viver come bruti ma per seguir virtute e canoscenza." Dante qualifies for the astronautic tradition in a remarkable prediction that the other side of the moon is relatively smooth - as Lunik II verified.