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"GULLIVER"—A QUEST FOR LIFE ON MARS

Radioisotopes are used in a miniature instrument designed to detect life during early probes of the planet.

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Biologists are late-comers to the field of space exploration. The development of systems capable of launching satellites and space probes requires a highly coordinated and intensive effort in the physical sciences. It was only natural that such a program, developed largely by physicists, should emphasize physics in early space experiments. Moreover, many experiments in physics were necessary first steps into space. As payload capacity for probing space was actually achieved, biologists, who hitherto had had little cause for more than general interest in rocketry, became more attentive to the possibilities thus opened for biology and stressed the need for including their science in space program planning. Experiments were incorporated in instrument packages. and effects of the space environment on the metabolism and genetics of microorganisms and small animals were studied. The manned-flight and space-medicine efforts have also provided biological information, although these programs are directed toward accommodating man in space. Now, with the continued growth of thrust and guidance capabilities, biologists suddenly find themselves on the brink of one of man's most tantalizing experiments—the search for life beyond his planet.

With the beginning of modern science, information slowly accumulated bearing on the possibility that life exists on other planets. a question hitherto thought approachable only through philosophy and theology. The search for scientific data on this question had been confined to our solar system because of technological limitations. From feeble rays of light, carefully gathered and analyzed, astronomers and physicists deduced some pertinent facts or indications. Recently, radar and light waves have been directed at the planets so that the reflected energy might bring back with it information concerning surface conditions. Observations of the moon and planets have been summarized by Kiess and Lassovsky (1), by Kiess and Birney (2), and by the Space Science Board of the National Academy of Sciences (3). Most recently, Salisbury (4) discussed findings pertaining to the question of life on Mars. On the basis of observations and deductions, interest had focused on both Venus and Mars. However, recent data obtained by Mayer and his associates (5) have convinced these workers and others that the surface temperature of Venus is above the melting point of lead. Consequently, Mars is now thought to be the planet (with the exception of the earth) most capable of supporting life, and it has been selected by the National Aeronautics and Space Administration as the first planet to be probed by instrumented landings in an effort to find evidence of life forms. Landings within this decade are planned (6) which conceivably could resolve this age-old speculation. Among the instruments tentatively selected for the first landing is "Gulliver," a miniature mechanical device which, like the Gulliver after whom it is named, will seek exotic forms of life.

Exploration of Mars

While some biologists doubt that life exists elsewhere in our solar system, even the doubters generally agree that life-detection experiments should be included in the exploration of Mars. There are also "believers" who think, or at least hope, that the search will be fruitful. Surface features and atmospheric features provide the principal evidence in support of the two views. The surface features include (i) a relatively smooth and mountain-free land surface; (ii) extensive, light-colored areas which have been called deserts; (iii) polar caps, probably of water ice, which change seasonally; (iv) darker areas or bands of gray (or perhaps green or other colors), which some attribute to moisture advancing from the polar caps seasonally in each hemisphere; (v) the disputed "canals"; (vi) so-called "oases" or "lakes" in which the canals meet; (vii) a reddish surface color; (viii) seasonal area color changes, from green or gray in the spring to brownish-gray in the fall, suggestive of vegetation; (ix) spectrographic evidence of carbon-hydrogen bonds in large organic molecules, regarded by some as the strongest evidence of life; and (x) temperatures ranging from -70°C at the poles to 20°C during the summer season of the southern hemisphere. The atmospheric features include (i) an atmospheric pressure one-twelfth that of the earth; (ii) white cloud formations resembling high cirrus clouds and thought by some observers to be moisture, chiefly in the form of ice crystals; (iii) a blue haze, which might be ice crystals of water or carbon dioxide, or perhaps smoke; (iv) yellow clouds, interpreted as dust storms in high winds; (v) carbon dioxide at a relative concentration twice that in the earth's atmosphere; (vi) the possible presence of oxides of nitrogen; (vii) small quantities of moisture or none at all; and (viii) very small quantities of free oxygen, or none at all.

Kiess and his associates (7) proposed that the polar caps, colored areas, migrating bands, clouds, blue haze, and other phenomena are all various oxides of nitrogen in gaseous, liquid, and solid states. They concluded that life as we know it could not exist in the heavy concentrations of toxic nitrogen peroxide which they ascribe to the atmosphere. However, the theory has been contested because of the lack of clear evidence of oxides of nitrogen in spectroscopic analyses.

Scientific discussions of extraterrestrial life are almost always concerned with forms of life somewhat similar to those on the earth. Divorced from the framework of our own experience, speculation becomes meaningless. It is difficult to imagine what conditions would be necessary for the maintenance of completely novel life forms, such as forms based on silicon, or existing, say, in solid state. We can only guess at the types of instruments that might best be used to detect such forms—forms which even a human observer might fail to recognize. Hence, since we know that the many life forms on our planet are basically similar to one another in biochemistry and in structure at the cellular level, and since we know how to look for them, it is only logical that the first extraterrestrial life probes should seek life of an aqueous and carbonaceous nature. Of course, the possibility remains that alien life which evolved independently, isolated from our own, may have nothing in common with earth forms, but current knowledge dictates that the familiar be sought first.

Evidence is found on the earth indicating that life as we know it could survive many of the severe environmental conditions that exist on Mars. Organisms grow in arid deserts, hot springs, arctic regions, salt ponds, hydrocarbons, acids, and various extreme soil conditions. Viable microorganisms have been recovered from within manufactured plastic and electronic parts (8). Several attempts have been made to investigate the ability of certain microorganisms to survive simulated Martian conditions. Organisms such as *Clostridia* not only survived but grew in such tests (9).

Where, on Mars, should the exploration for life begin? The presence of moisture would seem to be the key, and moisture may exist in sufficient concentrations only locally. Observers have suggested that the moving bands mentioned earlier are bands of moisture advancing seasonally from the polar ice caps. Some scientists think we should try to obtain a moisture map of Mars by orbiting an infrared scanning satellite around it before undertaking exploration to detect life. Such a map might indicate that life exists only at particular times and places. The life probe would be sent to the area nearest the equator that has moisture and other favorable characteristics. This approach would make it possible to select carefully a place or places to land the necessary life-detection apparatus and to choose the most favorable time of the year and even the most favorable portion of the day for conducting the experiment. While this may be the ideal approach, it would be some time before the moist regions could be charted, and an even longer time before we would have the capability to land an instrument package at a particular time and place on Mars. On the other hand, if the observed yellow clouds are dust storms caused by high winds, microorganisms would be widely disseminated and localization of moisture in life-sustaining quantities might not be a significant factor. If bands of moisture traverse the planet, microorganisms might thrive during the moist intervals, remaining dormant during dry periods, or they might be continually blown about, advancing with the moist front. Otherwise, some unlikely form of motility must be hypothesized, for life cannot evolve anew during each moist period. Thus, at least in spore or dormant state, life on Mars may be ubiquitous on the surface and directly above and beneath the surface, as it is on the earth.

The first level of life that we should seek is the microorganism. The evolutionary status of Mars may be such that micro forms exist but macro forms do not. On the other hand, if macro forms exist, there would almost certainly be micro forms existing as key links in the ecosphere. It also seems that a micro form would be easier to capture and examine than a macro form, although it is quite possible that microorganisms exist on Mars in far fewer numbers per unit area than on the earth. When all of the foregoing factors are taken into consideration, there seems to be a chance that an appropriate experiment with limited probing facilities, landed without a high degree of site selection, could succeed in detecting life on Mars, should any exist. Although the hazards of rocketry, guidance, and mechanical failure may make the chance of success a fairly slim one, the reward would be so great that the National Aeronautics and Space Administration has decided to include a life probe in the first Mars landing. Furthermore, delay would jeopardize the nation's opportunity for a "first."

Experimental Considerations

A number of serious restrictions are necessarily imposed on any such instrumentation carried aboard a planetary probe in the initial series. Paramount among these are restrictions resulting from uncertain knowledge of the environment in which the experiment will be required to function. The environ mental factors cited earlier were determined through visual and spectroscopic observations; the results of these observations are not accepted without reservation, and in some cases they are disputed. However, until more extensive data are received from space probes, the present information must serve as the sole guide.

Because of the tremendous thrust needed for interplanetary voyages, minimum energy courses must be followed. Thus, launchings can be made only during periods that occur every 2 years when the earth and Mars are in opposition. Weight restrictions are very great, markedly affecting the nature of the experimental instruments and of the electronic equipment for transmission of data. Instrumentation must be light, and the power requirement must be minimal. The latter requirement

directly limits the period available for effective transmission of data; according to present estimates this would range from 4 to 24 hours. Hence, any life probe must yield information within the short time available for experimentation. In contrast to the short operational time, travel time will be 220 to 250 days. Instruments and reagents must withstand the long flight in a vacuum, unless the capsule is pressurized, and must also withstand the external radiation to which they will be subjected. Plans call for a controlled capsule temperature during the flight, although some uncertainty exists concerning control on the surface of Mars. Despite the requirement for low weight, the instruments must be rugged enough to withstand the severe shocks and vibrations of launching and landing.

Possibly the most difficult problem in preparing a capsule is sterilization. Because it is believed that microorganisms from the earth might survive the Martian environment, all possible means must be utilized to prevent carrying any contaminants to Mars. Such contamination might result in a false report of indigenous life. The significance of finding earth-type microorganisms on Mars thereafter would be doubtful, and the important task of determining whether life forms on the two planets have a common origin would be rendered far more difficult, or even impossible. Should Mars be ripe for the evolution of life, yet sterile, contamination would carry with it the awesome moral responsibility of changing the evolutionary course of the planet. Many scientists would regard such contamination as an unparalleled transgression and tragedy. Present plans require dry-heat sterilization at 135°C for 26 hours in conjunction with the use of ethylene oxide. All instruments and experiments must be able to withstand these preflight sterilization procedures.

Limitations imposed on a life-seeking experiment by our ignorance of the Martian environment and by the state of rocket technology demand that the instrumentation meet the following requirements. It must be light in weight, small, and rugged enough to withstand shock, low temperature, low pressure, and vibration; it must not deteriorate during 8 or 9 months of space flight, must operate on minimum power, and must be designed for rapid completion of the experiment; it must be sensitive to a small number of organisms and responsive to the broadest possible spectrum of species; it must be simple and reliable, must produce unambiguous results, and must be compatible with simple telemetry and capable of withstanding heat sterilization.

Radioisotope Technique

Gulliver was designed to meet these requirements (10). The highly sensitive radioisotope technique is used to detect the evolution of gas as a common product of metabolism. Other systems for detecting the existence of microorganisms currently being developed under the NASA program are based upon direct microscopy via video transmission, optical density changes in various growth media, detection of specific enzymatic reactions through fluorescent tagging, and identification of organic compounds through gas chromatography and spectroscopy. Recently, NASA tentatively designated Gulliver as the system to be included in the first capsule to be sent to Mars.

In essence, Gulliver detects the evolution of radioactive gases as end products derived from labeled substrates metabolized by microorganisms. These end products are the result of a number of alternative metabolic reactions, and a system based on their detection has a greater chance of success than one based on detection of a specific intermediate via a particular enzymatic reaction. Enzymes are complex molecules whose intricate structures render them highly specific in reacting with substrates. It is conceivable that, in a separately evolved biology, enzyme structures and intermediate products would be different from those on earth but that some of the same end products would be produced. The relative simplicity of gases evolved by microorganisms as compared with the complexity of the enzymes and substrates strongly favor this possibility. Conversely, if life exists which evolves no gases, or which evolves gases quite different from the few familiar ones of metabolic origin, then the enzymes and intermediate products will almost certainly be different from those we know. While the most universally evolved gas is carbon dioxide, the possibility of also seeking other gases, such as hydrogen sulfide, ammonia, molecular hydrogen, and methane through substrate labeling is being considered.

Utilization of the evolution of $C^{14}O_2$ from radioactive substrates as an index of microbial metabolism and growth has been investigated, and methods have been developed by Levin and his coworkers over the past 7 years (11). Experience in developing a rapid means of detecting coliform organisms provided the basis for this approach to exobiology. Investigations by Heim and his co-workers on the use of radioactive isotopes to determine the action of antimicrobial agents (12) also support this concept and the feasibility of establishing a control for the test by inhibiting metabolism. The use of the radioisotope method as a probe for extraterrestrial life was proposed to NASA in 1959, and laboratory development has been under way for more than a year and a half. The principal objective of the program is the development of a medium which will support the growth of the greatest possible number of microbial species.

Medium and Test Organisms

Appropriately labeled compounds must be added to the medium. Several criteria were used to determine what isotopes would be incorporated into the test media. The isotopes must be metabolized and incorporated into an evolved gas; they must be utilized by a wide range of organisms; and they must exhibit chemical stability. On the basis of these criteria a number of radioactive substrates have been tested, singly and in combination. These have included sodium formate-C^{14}, glucose-C^{14} (uniformly labeled), sodium acetate-1-C^{14}, sodium pyruvate-1-C^{14}, glycine-2-C^{14}, cysteine-S^{35}, a yeast extract randomly labeled with C^{14}, and an *Escherichia coli* extract randomly labeled with C^{14}. The most satisfactory of these has been a combination of formate and glucose. The activity level is 5 microcuries of each substrate per milliliter of medium. With these substrates, a medium has been developed which supports the evolution of detectable levels of $C^{14}O_2$ by representative bacteria, streptomycetes, fungi, and algae within a period ranging from minutes to several hours. The group which responds includes aerobes, anaerobes, facultative anaerobes, thermophiles, mesophiles, psychrophiles, heterotrophs, phototrophs, autotrophs, spore formers, and nonspore formers. The composition of the medium is shown in Table 1, and typical responses are shown in Table 2. Photosynthetic anaerobes may be prevalent on Mars, and it is especially encouraging to find a positive response from *Rhodospirillum rubrum* which was grown anaerobically and photosynthetically at the same time. Positive responses, although variable and relatively slow, have been obtained from the autotrophs *Thiobacillus novellus* and *T. thiooxidans*. Other media studied in this approach include a basic salts medium, a salts-plus-casein hydrolyzate medium, a medium containing some of the extracts now being used, and a simple soil extract with radioactive glucose and formate. Response to the other media has indicated that the degree of complexity of the medium of Table 1 is the most satisfactory. One may hope that, at best, 80 to 90 percent of the wide variety of organisms tested will respond. If microbial life does exist on Mars, it is likely that it will be heterogeneous and that some types will respond to the medium which is ultimately developed. It should be pointed out that testing of most of the organisms has been under environmental conditions approximating the habitat of the type in question. The purpose has been to determine a response under natural conditions, on the assumption that Martian organisms will be tested under their own conditions. In other words, no attempt is being made to impose Martian conditions in the present testing of organisms.

Table 1. Basic test medium now being used for Gulliver.

Component	Amount
K_2HPO_4	1.0 g
KNO_3	0.5 g
$MgSO_4 \cdot 7H_2O$	0.2 g
NaCl	0.1 g
$FeCl_3$	0.01 g
Amino acid hydrolyzate	4.0 g
Yeast extract	13.0 g
Soil extract	250.0 ml
Proteose peptone No. 3	20.0 g
Malt extract	3.0 g
Ascorbic acid	0.2 g
L-Cystine	0.7 g
Beef extract	3.0 g
Distilled H_2O	Up to 1 lit.

Table 2. Organisms evolving $C^{14}O_2$ when tested in the medium of Table 1.

Organism	Activity above that of control (count/min)
Response within 3½ hours	
Arthrobacter simplex	1,629
Azotobacter agilis	28,956
Azotobacter indicus	1,868
Bacillus subtilis spores	11,784
Bacterium bibulum	7,221
Chlorella sp.	323
Clostridium pasteurianum	1,698
Clostridium roseum	5,367
Clostridium sporogenes	664
Escherichia coli	65,389
Micrococcus cinnabareus	479
Mycobacterium phlei	1,913
Pseudomonas delphinii	971
Pseudomonas fluorescens	6,701
Pseudomonas maculicola	16,266
Rhodopseudomonas capsulata	365
Rhodospirillum rubrum	420
Saccharomyces cerevisiae	858
Staphylococcus epidermidis	3,219
Streptomyces fradiae	560
Xanthomonas beticola	58,189
Xanthomonas campestris	537
Response within 6 hours	
Photobacterium phosphoreum	2,423
Thiobacillus novellus	141
Thiobacillus thiooxidans	102
Response between 6 and 24 hours	
Rhizobium leguminosarium	1,123

Mixed populations in soils have been tested, with excellent responses. Figure 1 shows the results obtained from 1 milligram of a field soil which contained approximately 1000 cells, as determined by plate count. The response was rapid and large. The lag phase was very short, and the stationary phase had not been attained by the time the experiment was terminated. Figure 2 shows the response obtained when a sterilized sample-retrieval line was dragged across a pile of sand and gravel. The shape of the curve demonstrates the presence of at least two different types of organisms, in that two lag periods and two exponential slopes are present. This type of response has been observed frequently in tests of soils. In Fig. 3 the response obtained by drawing a sterilized sample-retrieval line over an asphalt surface is shown. The lag phase is longer than the first lag phase shown on the sand and gravel curve of Fig. 2 and may be due to a different type of vegetative cell or, more probably, to the presence of a spore population which would require a longer time to achieve exponential growth.

Of considerable interest are the responses obtained from desert soils, shown in Figs. 4 and 5. The soils were collected aseptically from desert areas believed to be relatively free from the influence of humans and macro forms of life in general. Figure 4 shows the curves obtained from soil samples as small as 25 and 50 milligrams. (The quantitative similarity of the results from the different-size samples indicates unequal distribution of organisms.) The curves in Fig. 5 show rapid metabolic

responses from desert organisms in both liquid and solid media. The ability to use solid media is important, as it may obviate the requirement for attitude control of the device on the surface of Mars. This problem is mentioned below.

These experimental results indicate the validity of the life-detection principles used and the practicability of the sample-collection system. The type of response demonstrated, coupled with results from an inhibited control, would demonstrate the presence of life with a high degree of certainty.

Gulliver

Figures 6 and 7 show the first two models of Gulliver (13). An "exploded" view of the second, and current, model is shown in Fig. 8. The instrument weighs approximately 1½ pounds and demands a power peak of 2 watts for several minutes and power of 200 milliwatts thereafter. According to the present concept, the life-detection experiment would be conducted as follows. Gulliver is mounted inside the instrument capsule of the vehicle. When the vehicle is still some distance from Mars, the capsule is ejected into a capture trajectory. The main body of the vehicle, containing the bulk of the various experiments associated with the mission, conducts these other investigations while flying by the planet, radios the data to the earth, and continues on into space. The capsule enters the Martian atmosphere and deploys a parachute to effect a "soft" landing. After the capsule ceases rolling, an ampule containing the radioactive medium is broken. Simultaneously, an ampule containing a weak acid is broken; the acid is thus permitted to generate nonradioactive carbon dioxide from an adjacent carbonate or bicarbonate. A pressure-release valve permits the gas to flush the radioactive medium to remove low levels of $C^{14}O_2$ generated within the medium by radioactive self-degradation during the voyage. The flushed gas is vented to the Martian atmosphere through a pressure-controlled valve. During this flushing operation, which lasts several minutes, two projectiles mounted in the capsule (each containing 23 feet of sample-collection line) are fired across the Martian terrain. One end of each line is attached to the reel inside the culture chamber. The other end is merely coiled inside the projectile head and is thus laid out over the ground surface. The lines, which are impregnated with Silicone grease for maximum adhesion of particulate matter, are wound into the culture chamber, carrying with them particles of soil obtained from the 46 lineal feet of contact with Mars. Weak spots, or tensile fuses, are built into the lines so that, in the event the lines become tangled with objects on the terrain, failure will occur at a point close to the obstruction, permitting return of the greatest possible amount of sample. While the sample port of the culture chamber is open to permit entry of the lines, the interior volume reaches equilibrium with the Martian atmosphere. The temperature of the medium will be kept slightly above freezing; in other respects the environment in the chamber and the local environment will be identical. After the lines have been reeled inside the culture chamber, the port closes, sealing the chamber. A background count of the chamber is made. The radioactive broth is then transferred from the flushing chamber into the culture chamber, immersing the sample-retrieval lines. Mounted immediately above the culture chamber is a solid-state, beta detector coated with barium hydroxide. The $C^{14}O_2$ evolved in the culture migrates to the detector and precipitates on it as barium carbonate. A system of baffles between the medium and the detector prevents direct reading of beta activity in the medium by obstructing the line of sight. At 15-minute intervals the radioactivity accumulated on the detector is read by a scaler, and the data are relayed directly to the earth by radio transmission.

The second model of Gulliver has been field-tested. Figures 9 and 10 show the results obtained from such tests. In all these figures the presence of at least two different organisms is clearly evident. There is also a possibility that three organisms are represented in Fig. 9. In the case of Fig. 9 the test was made by first sterilizing the basic instrument without the electronic components but with projectiles, retrieval lines, motor, and charges in place. With all openings to the outside covered to maintain sterility, the instrument was carried into the field, and the entire procedure was carried out by manual application of electric pulses from a battery. After the retrieval lines had been reeled into the chamber the unit was carried into the laboratory, where the detector and scaler were connected and the radioactivity was monitored. Sample collection was made from frozen ground in a Washington park while the air temperature was about 0°C. Modifications of the experimental procedure were made in obtaining the results shown in Fig. 10. A programmer was used to sequence and carry out the entire procedure; the tests were conducted during warmer weather and were completed outdoors instead of in the laboratory. Of two complete units planned for the capsule, one serves as a control for the experiment through injection of an antimetabolite. While generation of the typical population growth curve is good evidence of metabolic activity under the conditions of the test, if, with a similarly inoculated chamber into which an antimetabolite had been introduced, the curve were attenuated, the case for life would be difficult to dispute. Furthermore, in the event that the cells are in a lag or resting phase or that the generation period is so long that the exponential portion of the curve is not observed, the control permits detection of respiration levels of $C^{14}O_2$ evolution. Of course, selection of a universal antimetabolite for hypothetical organisms is hardly an easier task than development of a universal medium, but here again terrestrial biology will be called upon.

Although the basic practicability of Gulliver has been demonstrated and test data have been obtained from the instrument, much more remains to be done. A third model is now being designed. The principal innovation will be alteration of the sample-collection projectile system and the medium-handling system to render the instrument omnidirectional—that is, to permit it to function regardless of its final attitude of rest on Mars. Great uncertainty about the fate of the capsule after it lands is inevitable, and a requirement for a particular degree of attitude control would decrease the chance of success. For example, if the device were to come to rest upside down, the medium, when released into the culture chamber, would flow downward onto the beta-activity detector and ruin the experiment. The use of a fixed or solid-state medium is under development, as a solution to this problem.

Research to improve the medium is continuing, as are efforts to increase the sensitivity of the radioactivity-counting technique. As mentioned earlier, incorporation of other labels will be explored. If other labels are included, the gas adsorption surface will have to be changed so that it has an affinity for the various labeled gases that might be evolved. Extensive time-response curves are being accumulated for the test organisms in pure cultures and soils, for comparison with results from the Mars experiment and for study of the sensitivity of the method with the different species through correlation of response levels with size of inoculum (14).

Significance of the Experiment

What are the possible conclusions to be drawn from the data Gulliver may transmit from Mars? A positive response from the test chamber and a negative or significantly lesser response from the control chamber would be strong grounds for concluding that life exists on Mars. It is likely that such a result would give some information concerning the life found. The existence of more than one type of microorganism, the physiological state of the organisms, the duration of lag periods and generation times might be deduced from the data. If both test and control chambers gave positive results, this might be interpreted as evidence that the life found was resistant to the antimetabolite, that the antimetabolite was not injected, or that high background radiation masked the experiment. In this case, the shape of the curves might indicate which conclusion was the most credible. Any positive response might be the result of contamination from the earth, but sterilizing the capsule and instruments will have made such contamination very unlikely.

The discovery of life would create the need for increasingly sophisticated experiments. Only slight modification in approach and instrumentation would be required to adapt the present system to perform a wide variety of analyses. Specific metabolic reactions under various environmental and nutritional conditions could be determined for comparison with reactions of earth organism.

On the other hand, negative results would indicate that microorganisms having a biochemistry similar to those on earth were not present at the time and place of sampling. Equipment failure could also cause negative results. The data obtained might pinpoint some failures, but others conceivably could not be distinguished from negative test results, since weight restrictions would not permit inclusion in the capsule of extensive systems for verifying the operation of the equipment. Under no conditions would a negative response rule out the possibility of life, but a series of negative results might lead one to suspect that, if organisms exist on Mars, they are very different from any on earth.

The ultimate aim of exploration to detect life on Mars is to determine types, habitats, environmental ranges, distribution, population densities, and biochemistry for comparison with life on the earth. From such studies the important question of whether life on the two planets is of common origin may be answered. In any case, whether or not life forms on Mars and the earth are related, new knowledge would be gained concerning the evolution of life on the two planets.

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13. All instrumentation for Gulliver is being developed by The American Machine and Foundry Company. A. W. Carricker is project engineer; G. Perez is responsible

for the instrument design.

14. We gratefully acknowledge the early and continued encouragement of Dr. Norman H. Horowitz (department of biology, California Institute of Technology) who, since the preparation of this manuscript, has become a coexperimenter on this project.

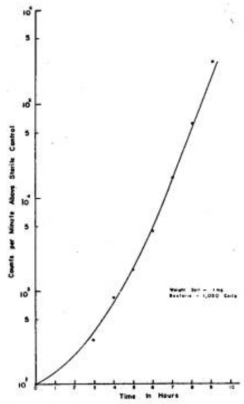


Fig. 1. Evolution of $C^{14}O_2$ by organisms in 1 milligram of field soil when inoculated into nutrient broth containing sodium formate-C^{14}.

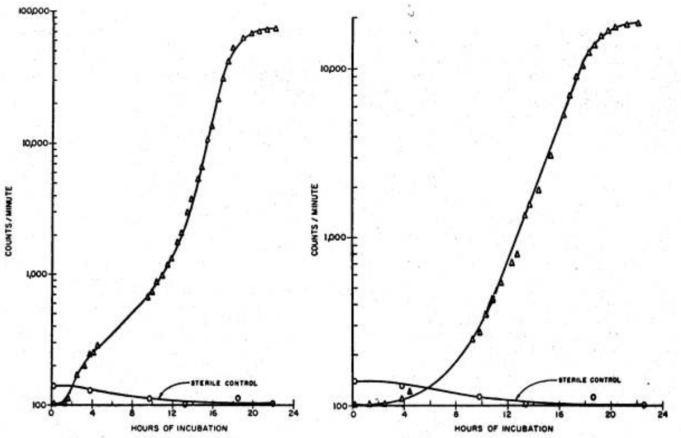


Fig. 2 (left). Evolution of $C^{14}O_2$ by organisms in a soil sample which adhered to string drawn over a sand and gravel surface. The string was placed in nutrient broth containing sodium formate-C^{14}. Fig. 3 (right). Evolution of $C^{14}O_2$ by organisms in a sample which adhered to string drawn over an asphalt surface. The string was placed in nutrient broth containing sodium formate-C^{14}.

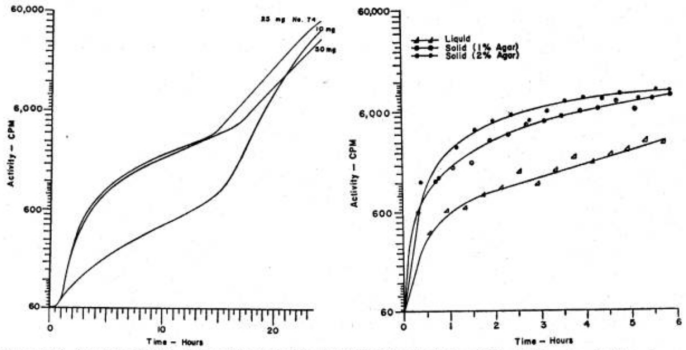


Fig. 4 (left). Evolution of $C^{14}O_2$ by organisms in various quantities of desert soil (sample No. 74, Lancaster, Calif.; surface to ¼ in.) used as an inoculum in a liquid medium (M5) containing glucose-C^{14} (uniformly labeled) and sodium formate-C^{14} as radioactive substrates. Fig. 5 (right). Evolution of $C^{14}O_2$ by organisms in 25-milligram samples of desert soil used as an inoculum in liquid and solid media containing glucose-C^{14} (uniformly labeled) and sodium formate-C^{14} as radioactive substrates.

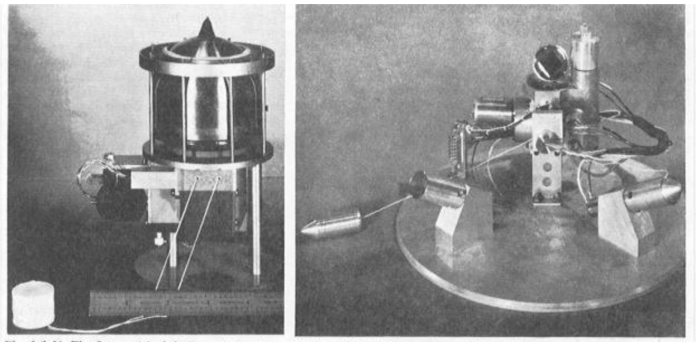


Fig. 6 (left). The first model of Gulliver, designed to probe for microbial life on Mars. Fig. 7 (right). The most recent model of Gulliver. This view shows the projectiles used to carry the soil-sample retrieval lines, the reel-in motor (at left), the broth chamber (at right and center), and the end of the solid detector, resting on the top of the culture chamber. The instrument shown has been used for field testing.

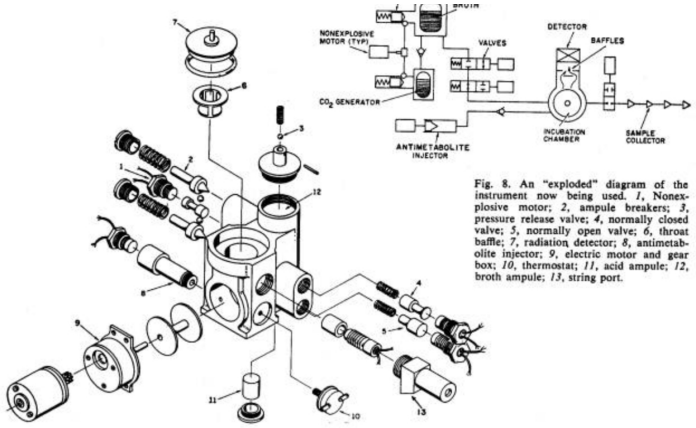


Fig. 8. An "exploded" diagram of the instrument now being used. *1*, Nonexplosive motor; *2*, ampule breakers; *3*, pressure release valve; *4*, normally closed valve; *5*, normally open valve; *6*, throat baffle; *7*, radiation detector; *8*, antimetabolite injector; *9*, electric motor and gear box; *10*, thermostat; *11*, acid ampule; *12*, broth ampule; *13*, string port.

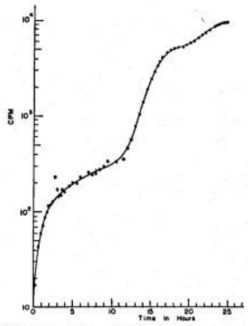
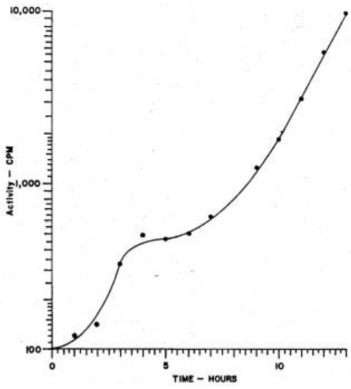


Fig. 9. Evolution of $C^{14}O_2$ by microorganisms in soil collected and cultured in a field test with the instrument now being used. The soil was collected from frozen ground.



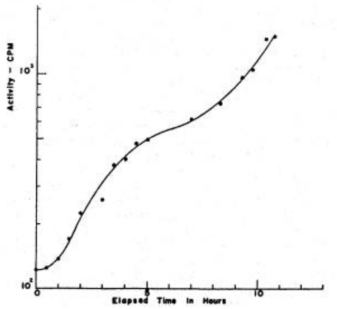


Fig. 10. Evolution of $C^{14}O_2$ by microorganisms in soil collected and cultured in field tests with the instrument now being used. The soil was collected from the Washington sailing marina 9 April 1962 (left) and 19 April 1962 (below).