SIGNIFICANCE AND STATUS OF EXOBIOLOGY

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ABSTRACT Although there are no direct data on extraterrestrial life, planetary observations and statistical considerations support the possibility of such life. The significance of the questions the "science" of exobiology may answer warrants its active pursuit. These questions range from whether life exists elsewhere to fundamental inquiries in all the sciences.

The title of this paper, "Significance and Status of Exobiology," has been carefully selected. The *significance* of the term "exobiology" is in dispute and there are those who declare that the subject has no *status*. The term is of recent origin and is intended to denote the study of extraterrestrial life. The argument arises not only from those normally protesting the adulteration of the English language with newly-coined words but from those who literally interpret the prefix "exo" as meaning "out of, outside, or outer layer." Some contend that a better term would be "xenobiology" in that the prefix "xeno" connotes "strange or foreign." Others feel that "biology" is sufficient, for it would encompass extraterrestrial creatures. These arguments may have semantic merit, but "exobiology" has been adopted by the National Aeronautics and Space Administration and is now a part of the literature. A dispute over nomenclature should not discourage biologists from pursuing the subject.

The more serious objection to the "science" of exobiology is that it has no status. Since there are no data on extraterrestrial life, how, some contend, can there be such a science?

The subject matter is too important to permit such "sea-lawyer" rationalization to impede its investigation. I hope to demonstrate this.

The true significance of exobiology is best revealed by the questions it can help answer. The key question is "Is life limited to this planet?" Although we have no direct data, there is indirect evidence of two kinds. The first type consists of Earth-based physical observations of Mars which suggest the existence of life on that planet. Salisbury (1) has summarized these. Perhaps the strongest evidence of this nature was the infrared spectroscopic analysis of Mars by Sinton (2) which indicated the presence of aldehydes. Recently this interpretation has been questioned by Rea and Calvin (3), but they offer no better single fit for the data obtained. The presence of water vapor on Mars has now been established (4), but in amounts which are considered too small by some to support life. Nonetheless, when all such data are considered, many scientists believe that the most likely explanation which generally accommodates them is that there is life on Mars (5).

The second type of data bearing on the question, "Is life limited to this planet?" is statistical. Although the size of the sample (one planet) is small, the statistical argument for life elsewhere is believed by many to be very strong. While Mars is generally considered to be the only other likely habitat of life in the solar system, Shapley (6) has calculated that there are more than one hundred million stars which have planets sufficiently similar in composition and environment to Earth to support life. Our sample of one tells us that life does exist and, statistically, one would have to conclude that the probability of life on other planets is very high. Of course, yet unknown factors may operate to reduce significantly or even eliminate this probability. Nonetheless, the presently available facts require that biologists become seriously concerned with exobiology even though those facts do not include direct data on extraterrestrial life.

Let us, for the sake of argument, assume that somehow the search for life elsewhere in the universe had been completed and found to be negative. The chemical and environmental information gained from the search would, nonetheless, be invaluable in resolving the *biological* question of why life arose only on Earth.

On the other hand, if alien life is found, a parade of significant questions follows. "Is the life found biochemically similar to our own?" "Are 'they' and 'we' of common origin?" The most exciting prospect would be if the two types of life were different. On the other hand, if they were similar, the old question of panspermia would come to the fore. "Does life travel the void between planets or does it arise independently?"

The search for extraterrestrial life will certainly help resolve one of the most fundamental questions in biology: "Is life a distinct, discrete entity, or is it an inevitable manifestation of matter as chemical combinations become increasingly complex?" After Darwin elucidated biological evolution, biologists appropriated the word for their exclusive use. However, the term "chemical evolution" is now used to describe the abiogenic production of life precursor compounds from inorganic chemicals under appropriate conditions. Only a few years have seen this area progress from the abiogenic production of simple organic compounds and amino acids (7, 8, 9) to the abiogenic synthesis of fairly complex intermediates (10) and the production of "proteinoids" (11). The theory (12) of continuous generation of matter in the universe has gained considerable acceptance as has the evolution of the elements from neutrons (13) or hydrogen gas (14). Is it possible, then, that life is just one segment of a vast continuum of evolution on a universal scale? To speculate, did the following developmental sequence take place as part of this continuum: Space (as far back as we dare imagine), energy, elemental particles, hydrogen, the other elements, increasingly complex compounds, structured matter exhibiting the characteristics of life, consciousness, social evolution (15)? Although there are many gaps in this theory of an evolutionary continuum, there is also much evidence for it. In the portion of the spectrum of interest to biologists, we may not be too far away from achieving abiogenic synthesis of macromolecules which are identical to those functioning in living material. The largest gap facing the biologists in attempting to explain the development of a living cell from inorganic compounds is that of structure. Even if we could synthesize all of 'the chemicals of a cell, how can we assemble these materials into specialized components such as membranes, walls, ribosomes, mitochondria, and the like? Here, too, however, there are now indications that at least part of the explanation lies in the natural geometric accommodation of very complex molecules (16). The finding of life elsewhere might shed light on the theory that the geometrically possible combinations of elements, as modified by chemical and physical constraints operating under a range of environmental conditions, inevitably produce self-replicating material subject to genetic mutation.

The interest in exobiology extends beyond possible simple alien forms of life. A question of utmost significance and fascination is "Is there *intelligent* life elsewhere?" The finding of even unicellular life on Mars would add greatly to the probability that the answer is "yes." Life on a second planet would double the size of our sample and would strongly indicate that life exists on many planets in the universe. While prospects for intelligent life do not seem favorable in our solar system, it would then be exceedingly likely that other stellar systems contain planets favorably situated and endowed to permit the evolution of intelligent organisms. The consequences of such an assumption are awesome. If the Earth is but one of a great many planets supporting life, it becomes highly improbable that the Earth possesses the most advanced form of life.

The ramifications of a positive answer to the last question posed jar the imagination. The significance includes but transcends the realm of biology. Morrison (17) has represented the growth of technology as a vertical line at some point on the galactic time scale. It would seem, thus, that, once having begun, the elucidation of all science occurs almost immediately. Therefore, those planets possessing beings of greater intelligence than ours would be beyond this infinitesimally short blip on the time scale. Contact with such beings could provide us with an almost instantaneous scientific denouement of the universe! While the time saved would be minute on the galactic scale, it would be very large compared to the life span of a man.

Such, then, is the scope of significance of exobiology. Now, what about its *status*? No one can deny that the significance greatly overshadows the status. While it is true that there are no generally accepted data, concerted research on the subject is in its infancy. We have not yet had the opportunity to deliver instruments to other planets. It now appears the possibility to do this is at hand, and it is hoped that the instrumented exploration of Mars will begin shortly. However, there are other avenues of exobiological research including highly important experiments which can be conducted in Earth-based laboratories. Origin of life experiments, the abiogenic synthesis of macromolecules, and other empirical and theoretical investigations of life are potentially important to exobiology. If we could learn flow life on Earth evolved from inorganic chemicals, we could probably answer the first question posed, "Is life limited to this planet?"

Pasteur was probably the first empirical exobiologist. He attempted to culture a piece of the Orgueil meteorite and found no growth. Today there is considerable dispute over the possible biological origin of some materials found in meteorites. Evidence was recently presented (18) for the identification of exobiological material in the same Orgueil meteorite. This evidence consists of a characteristic carbon chain length distribution of alkanes similar to that found in living material on Earth and isotopic ratios significantly different from those in terrestrial alkanes. On the other hand, the ease with which terrestrial microorganisms can contaminate meteorites has been demonstrated (19). The subject remains open. as does the possibility that the examination of meteorites can supply the first positive evidence of extraterrestrial life. However, the source of the meteorite would remain unknown.

Ground and rocket-based visual and infrared observations of Mars will be intensified during the 1965 and 1967 planetary oppositions. While information derived from these studies will not directly answer the question of life, the hospitality of the Martian environment to life, as we know it, will be better revealed.

Instruments are now under development for the biological exploration of Mars (20). These instruments look for metabolism, growth, or chemical and physical properties peculiar to living matter. NASA is now considering the possibility of sending a package containing a number of such instruments to Mars in 1969. Plans are also being studied for landing much heavier instrument capsules in 1973.

The recent extraordinary photographs obtained from Ranger 7 indicate that the moon may contain a wealth of exobiological information. The entire surface of the moon seems to be composed of in-fall. It seems likely that, since its formation, the moon has been sweeping space, actively collecting vast quantities of materials, including planetary fragments from a great variety of near and distant sources. The galactic beachcombing that can be achieved through an examination of moon samples may produce fossils or other evidence of once living organisms. Such samples should become available within the next few years.

There are engineers who believe that manned exploration of Mars will be possible in the 1980's. This would permit a detailed exploration of Mars and, perhaps more important, the return of a sample to Earth laboratories for extensive studies. While we cannot say that planning for such a mission has yet begun, at least the subject is under discussion by the space agency.

There is one other facet to the current status of exobiology. It concerns the means by which we will probe for life beyond the solar system.

Purcell (21) presents what seems to be an irrefutable case against the possibility of manned space travel far beyond the solar system. He does this solely on the basis of the propellant mass required for a round trip journey in which the ship approaches the speed of light. Assuming the development of perfect nuclear fusion propulsion, he demonstrates that the ratio of the initial mass of the rocket to the final mass is 1.6×10^9. Thus, for every pound that made the round trip, a starting weight of 1.6 billion pounds would be required. Even assuming that the ultimate is attained, the perfection of matter-antimatter propellant, the ratio of the initial mass to the final mass is 40,000. The tremendous energies thus shown to be required for manned interstellar space travel make such travel extraordinarily unlikely. It might also be pointed out that, at travel at or near the speed of light, tremendous radiation problems would result from collisions of the ship and occupants with atomic nuclei in space. In these difficulties, perhaps, lies the answer to the question raised by skeptics of intelligent extraterrestrial life, "Since they are smarter than we, why haven't they come here?"

Nonetheless, the solar system is not the limit of our exobiological exploration and indeed a brief, preliminary experiment probing beyond it has already been made. In contrast to the tremendous energies required for space travel, the electromagnetic energy required to traverse vast regions of space is quite manageable. Cocconi and Morrison (22) show that our present capabilities are sufficient to permit radiocommunication over a distance of 10 light years. Cameron (23), on the basis of the statistical frequency of environments similar to Earth, estimates that there are 2×10^6 advanced civilizations within our galaxy. He believes it highly probable that many of these contain inhabitants whose scientific achievements have surpassed our own. If so, they, too, are faced with the inefficiency of interstellar space travel. Accordingly, it seems possible that many distant societies have already contacted each other by electromagnetic communication systems. During their existences, such societies would probably continually search for new civilizations which attain the technology required to join in this communication. Hence, we may now be the target of intelligent electromagnetic signals — signals that started their journey many years ago. The preliminary search for the signals which has been made (24), entitled "Project Ozma," was conducted with the 85-foot radiotelescope of the National Radio Astronomy Observatory. Two target stars, of the type thought likely to harbor Earth-type planets, were searched during May, June. and July, 1960. No signals of extraterrestrial intelligent origin were detected, but the prosecution of such a program will take many years of painstaking work. It will undoubtedly be undertaken at a serious level.

I have attempted to show that exobiology has considerable significance and that it is rapidly improving in status. In doing so, I fear that some of the possibilities discussed may not only have taxed your imagination, but may have exceeded your credulity. Perhaps some of these offenses may have done disservice to my goal of stimulating your interest and active participation in exobiology. However, the severest test I wish to impose on your imagination has been saved until last. It is that, in a universe containing on the order of one trillion galaxies (25), each consisting of hundreds of millions of stars, there is, nestling in an arm of one galaxy, one star which swings about it a planet completely covered with the only life to be found in all that infinite cosmic desert.

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