Potentialities and Ramifications of Life Under Extreme Environmental Conditions

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AT A TIME when man ventures his first tentative step into the wide spaces of the universe, it may be appropriate to take renewed stock of the most precious good we want to transfer to other worlds: life. We are curious to know how living matter will stand the shock of leaving its birthplace, the earth, and how it will cope with the possibility of facing its counterpart, another inhabited world. In preparation for this event we should scan the potentialities of life on our own planet as we find them today and as they have developed during the last billion years. We will have to supplement this knowledge by laboratory experiments probing further the limits of life under extreme conditions. Finally, we can take another step and conclude from the structure of the hereditary material on the ramifications of life.

Roaming our planet, we find a variety of environmental conditions which obviously are not conducive to the development of living matter or which exclude its existence entirely. Temperature is one of the factors essential to life. At one extreme of the biological temperature scale the blue-green algae *Oscillatoria* simmers at a temperature of 85° C. in the geysers of Yellowstone, and spores of the hay bacillus are resistant even to prolonged boiling. At the other extreme, the Alaskan stonefly, *Nemoura columbiana,* lives and propagates at the freezing point of water. A number of living organisms have been exposed

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experimentally for several months to much lower temperatures, including liquid helium. Bacteria, spores, seeds, and lower animals survive this treatment in suspended animation. However, the temperature range of *active* life is obviously limited to 0° to 50° C. Under these conditions, enzymes develop their greatest activity.

At low temperature, the rate of life's chemical reactions is too sluggish. At high temperature the protein of the enzyme molecules is irreversibly denatured. The denaturation of proteins in its outset is not caused by rupture of covalent bonds but by disturbances of weak bonds, such as those of hydrogen, between amide groups on which the intricate spatial building of enzymes is based. Extremes of living conditions are found in the "hadal" trenches of the earth's oceans. Fish have been caught at a depth of 7,130 meters, and sea anemones, sea cucumbers, bacteria, and other animals have been recovered from the 12,000 meter Philippine trench. The hydrostatic pressure at these depths is over a thousand atmospheres. Last year I reported on experiments with animals at very low atmospheric pressure.[1] Some low animals and bacteria survive at an ambient pressure of a few millimeters of mercury for long periods.

Other physical factors which assert an influence on the processes of life should be considered also, and the limitations of life under the influence of these forces collected and determined. Magnetic, electric, and gravitational forces are of great interest in this respect. Time, as a parameter of life, must also be investigated. The probable delayed aging process of living matter, traveling at a speed approaching the speed of light, poses intriguing problems and opens vistas which may bring a solution to man's dream of eternal youth.

Not only physical conditions but the chemical environment also exercises a deep influence on the potentialities of life. In extreme cases we become aware of this factor by observing the struggle of life under the influence of volcanic exhalations or on soil deficient in one of the trace elements. These observations can readily be extended in the laboratory. Toxicology offers numerous examples that the presence of certain chemicals excludes the existence of living matter. It seems evident that the unadulterated chemical environment in which we live is actually the fittest one for organisms.

The fitness of water for life is unique. With its high specific heat and latent heat of vaporization and fusion, water, to a great extent, assures our planet of its temperate climate and contributes to the temperature regulation of higher animals. The function of water in living matter as a solvent is unsurpassed. It is doubtful whether liquid ammonia, which is sometimes mentioned as an alternate basis for life on planets, can serve the same purpose as water. Carbon also belongs to the group of elements best fitted for life's processes. Carbon not only forms bindings with itself but also combines with other elements to create a multitude of so-called organic compounds. The element next to carbon, silicon, differs widely from carbon in its chemistry and is unlikely to form the basis for a living world. Attempts should be continued to eliminate all possibilities of a noncarbon-centered world. Such work will insure space travelers against unpleasant surprises.

In connection with the matèrial composition of living matter, an "antiworld," in which all particles are opposite in charge to our own world, has to be considered remotely. In this antiworld, the hydrogen atom has an antiproton as its nucleon and a positron in place of the electron. However, we do not need to strain our imagination concerning life in such an antiworld since encounters with it would mean annihilation for both sides.

To supplement observations concerning the influence of extreme environmental conditions on the great variety of living things, we can concentrate our interest on a phenomenon which is common to the whole living world—heredity. A broad biochemical masterplan for the propagation of life has evolved in recent years. The progress in polymer chemistry, in general, and nucleoprotein chemistry, specifically, has revealed aspects of great simplicity which are likely to shed new light on the potentialities of life.

The biochemical substances primarily connected with heredity are the nucleoproteins of the cell nucleus. Desoxyribonucleic acid (DNA) was found to be a principal carrier of genetic information. This compound forms a long chain in which phosphoric acid and desoxyribose alternate as links. Up to 3,000 sugar molecules may be linked by phosphoric acid in one chain. Attached to the sugar molecule are two kinds of purines, adenine and guanine, and two kinds of pyrimidines, cystosine and thymine. The DNA-molecule is coiled with the flat ribose molecules stacked like cards in a pack. Actually, a pair of macromolecular chains connected by hydrogen bindings are wound around a common axis. The stacking of the ribose molecules gives the structure a great stability in the form of a backbone which is a characteristic of hereditary material. In a not yet understood way the stacking is also connected with the replication or reduplication of this structure during mitosis.

Of greatest interest, however, is the simplicity of the sidechains of the nucleic acid which consists of four different molecules only. The sequence of the sidechains is the key to the specificity and the coding ability of the DRN-molecule, the carrier of hereditary information. Since the hereditary material of all living matter has the same four kinds of molecules in the sidechains, we must assume that the purines and pyrimidines were already present in the primordial "soup" which was formed during the biochemical part of evolution on our planet. The use of these molecules in the first living material about a billion years ago must have been so successful that no basic sidechains of a similar kind were developed later. We can readily imagine and actually synthesize other purines and pyrimidines, and we may wonder how organisms with such a change in their hereditary material would look. Such ramifications of life, based on possible variations in the hereditary molecules, may confront earthlings on voyages to other worlds.

Ribonucleic acid (RNA), a close relative to the desoxyribonucleic acid, is another substance which is closely related to the hereditary process and to the formation of new cell material. The RNA-molecules are observed in the nucleus, but their main source is located in the microsomes of the plasma. Various kinds of evidence suggest that these molecules are connected with the organization of proteins. The information stored in the RNA-molecules in the form of a template or pattern directs the aggregation of single amino acids to form the most complicated proteins, even enzymes.

The energy necessary for the chemical binding of amino acids is transported from the sites of carbohydrate metabolism in the mitrochondria to the microsomes, the site of protein formation, by adenosine triphosphate. This is another compound which uses adenine as main constituent. A number of other vital cell components with adenine as main constituent, are the coenzymes, I, II and A.

A similar variety of uses of a certain basic molecular structure is observed in the example of the tetrapyrrol ring. The ring is encountered in substances connected with the transport and metabolism of oxygen and also in the energy binding chlorophyll. The tetrapyrrol ring as well as adenine can very likely be traced back to the origin of life and even beyond that to the period of biochemical evolution. This limitation in building blocks may have contributed considerably to the economy and stability of living matter, but it certainly limited its possible variety and ramification. Early events during the biochemical evolution period have obviously imposed many restrictions on the later biological evolution. This startling thought can be expressed more bluntly by stating that we still live with some crucial molecules formed, possibly by chance, in the primordial swamps several billion years ago. We have to consider the possibility of ramifications of life caused by the preponderance, during the biochemical period of evolution, of molecules other than the ones mentioned as crucial for the development of the forms of life on earth. In combination with variations of the hereditary molecules such a possibility would give extraterrestrial living material an unknown appearance and new potentialities.

The last remark leads to a final point. We are aware of the fact that the potentialities of life based on carbon compounds and water are very sensitive to extreme environmental changes. Even with man taking a deliberate lead in the evolutionary process, and trying to accelerate it purposely in a certain direction, the product of such an artificial selection based on our present biochemical stock would not be adequate to cope with the environmental conditions to be expected nearly anywhere outside our planet. The psychosocial evolution of the last quarter of a million years, however, has enabled man to accumulate a wealth of experience concerning matter and energy. This experience will eventually enable him to create a habitat for his body in nearly any part of the universe. The control of matter and energy by the human mind, ultimately, will make life limitless in space and time.

REFERENCES

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