UCRL-2124
Unclassified Health and Biology

UNIVERSITY OF CALIFORNIA

Radiation Laboratory

Contract No. W-7405-eng-48

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Melvin Calvin

March 10, 1953

Berkeley, California

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Radiation Laboratory and Department of Chemistry

University of California

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ABSTRACT

The formation of more complex carbon compounds from simple ones through the action of radiation is used in an interpretation of the original formation of such compounds on earth. The relation of plants and animals and evolution of photosynthesis is discussed in the light of the participation of sulfur compounds in the metabolism of both groups.

(*) The work described in this paper was sponsored by the U. S. Atomic Energy Commission.

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Radiation Laboratory and Department of Chemistry

University of California

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As living beings, as well as scientists, we are all interested in our ultimate origin, both from the point of view of philosophic and scientific curiosity and for the possible clues such ideas might provide as to our uncertain future. So I thought it would be worthwhile to have a look at what we might know as scientists, as well as men, about the origin of life. A definition of the term "life" is no easy one to write, and, moreover, it is doubtful whether such a definition is necessary for the present discussion. Whatever it may be, I think we all have a fairly clear conception of it and ordinarily have little difficulty distinguishing the animate from the inanimate. It might be interesting to see if we can, on a scientific level, examine its origins in a more detailed fashion and arrive at some rational picture of what went on. Since none of us were there, we are pretty free to discuss it at liberty without fear of contradiction!

It is extremely difficult to create a new idea in this area in which men have been thinking for so long, in spite of the great strides which have been made in the more readily accessible physical sciences. Only a month

(*) Delivered at meeting of Rochester Section American Chemical Society, November 22, 1952, as after-dinner talk following the Harrison Howe Lecture.

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or two ago, a rather long article on it appeared as timely news in a popular weekly news magazine. Most of what was said in this article has been said before. It was said as early as 1928 by the well-known British biologist, J.B.S. Haldane; it was said again in 1936 by the not so well-known Russian biologist, A. I. Oparin; it was said again in 1952 by the very well-known American chemist, Harold Urey; and it will be said again here by way of introduction to our own small contribution.

In essence, this continually reiterated suggestion is that chemical molecules of a high degree of complexity were created as a result of the incidence upon the surface of the earth, prior to the existence of any living thing, of high energy radiation. These might be cosmic rays from outer space or ultraviolet rays from our own sun. The essential requirement is that they contain relatively large amounts of energy in extremely concentrated packages, such that if we were to attain them by heating, the temperature would have to be at least 50,000 degrees (for ultraviolet) and deep into the millions for the higher energies. These concentrated packages of energy, which, for present purposes, can be visualized as very high-speed particles (photons, electrons, etc.) would dismember many molecules in the course of their absorption on the earth's surface. Some of these reactive fragments, during the settling back process, would combine in new ways, which would constitute larger molecules retaining in themselves some small part of the energy of the original ray which passed through. These new and larger molecules were concentrated gradually by the evaporation of tidal pools, or something of that kind, until eventually rather large aggregates of complex molecules, even to the simple proteins or nucleic acids, might have come into being.

Now the evidence for this, until a year or so ago, was purely speculative. It seemed to us, in Berkeley, that it would be worthwhile to do an experiment or two which would give us some idea as to whether this could take place or not — whether this construction of complex molecules from simple ones could have taken place at all in a world, or in a planet, upon which no life existed. This was not difficult to do — in Berkeley, at least. We made solutions of carbon dioxide, ammonia and various other simple molecules which are supposed to have been the primordial molecules on the planet and irradiated them with the cyclotron and then had a look to see what had become of them. Sure enough, they were built into larger molecules. The carbon dioxide was reduced in such solutions by irradiation with high energy radiations, to formaldehyde and formic acid. Formaldehyde, upon irradiation in such a manner, produced molecules containing more than one carbon atom (the first two molecules mentioned contained only one carbon atom each), and we were thus able to make two-carbon atom containing molecules. From the two-carbon atom containing molecules, we made four-carbon atom molecules and the research is far from over. In the last report that I have seen, the cyclotron workers had isolated six- and eight-carbon atom containing molecules from such irradiations and I feel sure that if they wish they can make more complex ones. So, the experimental evidence for the possibility of the creation of larger molecules from smaller ones by high energy radiation is, I think, well established.

The efficiency with which the energy is used and stored in chemical substances by such a process is, however, very minute. It would require many millenia as well as a great variety of changes in the surface conditions of the earth in order to accumulate and concentrate very much complex organic material in this way, even in the absence of any independent process for its decomposition. It is, of course, possible to imagine the

appearance in such a milieu of molecules which might act as sensitizers (much as in modern photographic emulsion) to increase considerably the efficiency of capture and conversion of ultraviolet light particularly. They might also increase somewhat the specificity of the conversion, i.e., to be a bit selective of the type of molecules into which the energy is converted. Such a process might be said to constitute a very primitive form of photosynthesis, but it is difficult even to imagine this kind of purely chemical evolution proceeding very far on the road to the highly efficient and extremely specific process which we know as photosynthesis today. It seems highly likely that an organized self-reproducing mutatable structure must have arisen first. In any case, we will not pursue this line of development any further here.

The next step is the creation of a unit which could aggregate upon itself, from a homogeneous milieu, constituent molecules and thus build them up to reproduce itself like the formation of a twinned crystal (from a concentrated solution of its components) followed by its splitting. Thus, two identical units would exist where only one existed before. With this notion of self-reproduction, we have what some people have elected to call a living organism. These living organisms (these self-reproducing units) would have all sorts of molecules to draw upon. The reason for that is that there were no living things to destroy them — there were no bacteria, no organisms of any kind. So what was created by radiation, remained and accumulated. Gradually, these self-reproducing units began to use up the fragments from which they reproduced themselves. Eventually there came a time when some one essential unit was missing in the mixture in which they existed, and the structure which could not reproduce without that unit died

away, but those which at first by pure accident happened to form that unit from still simpler ones continued to exist. This cycle of exhaustion of the more complex molecules followed by success in their formation from the still plentiful simpler ones could be repeated over and over. Thus were created the biosynthetic sequences which we are gradually and laboriously mapping in the organisms of today. It is interesting to observe that such a backward mechanism as this can evolve paths of development, each turn and twist of which seems to be directed toward a desired or preconceived end.

One of the important aspects of this problem concerns the transition from a situation in which all the chemical raw materials are available ready made for the use of the self-reproducing unit into one in which no organized raw materials are available except carbon dioxide, air and water. This transition must have taken place because the latter is what we have today. The only raw materials which are freely available are carbon dioxide, water and the sun's energy. The green plant can convert these into all variety of reduced compounds which the animals then eat and convert further. But in the beginning, that was not the situation. So there must have been some transition phase between the condition in which the original things (the original self-reproducing units) had all the required raw materials and the condition which we have today in which they have not, and in which all life is ultimately dependent upon the ability of green plants to utilize the visible light from the sun to produce the organized chemical raw materials necessary for life. This last process is the one we call photosynthesis.

Here, again, the possibility exists that some observations made in Berkeley during the course of our investigation of the intimate molecular mechanism of this complex process (photosynthesis) may be of help in devising some notion of how the transition might have taken place. These

observations led to the suggestion that the molecule in which the light energy, absorbed by the chlorophyll of the green plant, is first converted into chemical energy, is a widely distributed sulfur compound. This compound has been given a number of names corresponding to the various independent discoveries of it, but I shall use one of the earliest ones, "protogen". It is found in all types of living things. Thus, the highly efficient, specific and unique energy conversion process characteristic of modern photosynthesis seems to be due to the association of two rather widely distributed types of molecules. Each of these molecules has other biological functions either for itself or for its close structural relatives. They were undoubtedly created quite independently and survived and evolved for quite other purposes, such as oxidation and oxygen transport for the porphyrin relatives of chlorophyll (hemoglobin, cytochromes) and related biosynthetical processes for protogen or its structural relatives. It is even possible that the sulfur compound may have participated in a rudimentary form of photosynthesis by itself, since it can absorb the near ultraviolet region of sunlight. Only later when the stable and highly efficient light absorbing porphyrin structure (chlorophyll) collaborated with the energy converting structure of protogen were the modern photosynthetic organisms — green plants — evolved.

The green plant thus takes a rather less unique place in the evolutionary scheme of things than it has heretofore occupied. It results merely from the appearance of a more highly efficient system for capturing the sun's energy in the chlorophyll and handing it on to this particular sulfur compound which all living organisms have and use in various ways. Thus, it seems the transition between the so-called animal world and plant world was made. As soon as very efficient photosynthetic organisms were evolved, the animal world could diversify even more, because in the green plant it had a more or less permanent source of raw materials upon which to draw.

This conclusion perhaps represents a small step in addition to the ones that have been repeatedly suggested in the past fifteen years, and it remains for the chemists, biologists, physicists to put some of these speculative notions to experimental test. Speculation has a greater chance of approaching the truth when it includes and is based upon the ever wider variety of established scientific fact. It is only in this way that we can ultimately gain a more definite and significant notion of our origin and perhaps also of our future.