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880TH ORDINARY GENERAL MEETING

HELD AT 12, QUEEN ANNE'S GATE, LONDON, S.W.1, AT 5.30 P.M. ON MONDAY, MARCH 14TH, 1949.

PROFESSOR R. O. KAPP, B.Sc., A.M.I.E.E., IN THE CHAIR.

The Minutes of the previous Meeting were read, confirmed and signed.

The following elections were announced :—H. K. Airy Shaw, Esq., Fellow ; L. F. Tucker, Esq., Fellow ; W. Wagland, Esq., M.R.C.S., L.R.C.P., Fellow.

The CHAIRMAN then called on R. J. C. Harris, Esq., A.R.C.S., B.Sc., Ph.D., A.R.I.C., to read his paper, entitled "The Origin of Life."

THE ORIGIN OF LIFE.

By R. J. C. HARRIS, A.R.C.S., Ph.D.

SYNOPSIS.

The current belief that the nature and origin of life must ultimately be completely explicable in physico-chemical terms is discussed in the light of history, and of contemporary knowledge of the structure and function of the cell and of its components. The theories of Oparin and Beutner are examined, with particular reference to auto-catalysis, and the properties of enzymes and of viruses, which have too often been put forward as "living crystals" or "the boundary of the living."

The conclusion is reached that "life" is a property of the intact cellular system, and that no cell component can be considered as a primal living unit.

INTRODUCTION.

IN September, 1912, Professor Schaefer[1] delivered a lecture on this subject to the British Association and, by chance, I was fortunate enough to find it. Very properly the Professor began by saying that he ought to give a definition of "life," and why he found it almost impossible to do so. The dictionary definition "the state of the living" or that following Claude Bernard, "the sum total of the phenomena common to all living beings," were obviously inadequate ; of the same character, in fact, as the definition of an archdeacon as "a person who performs archidiaconal functions." It was found impossible, too, to draw an exact definition from considerations

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[1] Schaefer, *Brit. Med. J.*, 1912, 589.

of the usual manifestations of life, since many of these, such as growth, assimilation, reproduction, irritability and so on, may be imitated, to a more or to a less degree, as we shall see later, by manifestly non-living systems. Attempts have also been made to get away completely from a cellular concept of life, which these imply, by isolating and identifying components of cells as the primal living matter. Alexander[1] believes that a living unit or entity is one that can direct chemical change by catalysis, and, at the same time, reproduce itself by autocatalysis, i.e., by directing the formation of identical units from other, and usually simpler, substances. This view has been disputed by Wilson,[2] among others, on the grounds that, since the cell contains a very large number of units which may be defined in this way, it becomes impossible to single out any one particular component as the living-stuff *par excellence*; and, also by Gowland Hopkins,[3] who wrote "we cannot, without gross misuse of terms, speak of the cell life as being associated with any particular type of molecule. Its life is the expression of a particular dynamic equilibrium which obtains in a polyphasic system. Certain of the phases may be separated, but life is a property of the cell as a whole, because it depends upon the equilibrium displayed by the totality of co-existing phases." This conception of life was taken even further by Bohr.[4] "The existence of life must be considered as an elementary fact that cannot be explained, but which must be taken as a starting point in biology, in a similar way as the quantum of action (which appears as an irrational element from the point of view of classical mechanical physics) taken together with the existence of the elementary particles, forms the foundation of atomic physics."

The consensus of opinion among biologists to-day, however, would almost certainly be that, despite the admitted complexity of the simplest cell, life and the origin of life must ultimately be completely explicable in physico-chemical terms. Increasing knowledge, some of which we shall consider later, of the structures of cell components and of viruses, they would say, confirms our belief that the simplest living organisms originated

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[1] Alexander, *Life, Its Nature and Origin*, 1948, p. 79.
[2] Wilson, *Science*, 1923, **57**, 1471.
[3] Gowland Hopkins, quoted in *Colloid Chemistry*, 1928, **11**, p. 21, ed. Alexander and Bridges.
[4] Bohr, *Nature*, 1933, **131**, 421.

gradually, and by a long evolutionary process, from simple chemical substances. It is this belief, and the evidence brought forward in support of it, that we have to consider to-night.

Spontaneous Generation.

From an historical point of view, the earliest theories put forward were those of spontaneous generation. Thales, a philosopher of the Ionian school, believed that living things developed from structure-less sea slime under the influence of heat. This idea accords well with, and definitely antedates, that of the Russian who recently claimed that mixtures of amino acids, subjected to pressures of several thousand atmospheres condensed to form protein molecules. In nature, pressures of that magnitude would be found on the sea bottom at depths of a few miles. The marine origin of life was also postulated by Anaximander (611–547 B.C.) who held an almost evolutionary hypothesis, in that each living thing had passed through a succession of developmental stages. Democritus put forward a similar thesis. The organic world had an aqueous origin, in which the atoms of lifeless, moist earth met by chance, and united with, atoms of "live, energizing fire." Aristotle (384–322 B.C.) substituted "form—the entelechy or soul of living things" for the fire of Democritus, but retained the idea that living things were produced by the union of a passive principle, "matter" with an active principle, "form." Aristotle even believed that such creatures as crabs and mice could arise spontaneously. Some historians maintain that St. Augustine (354–430 A.D.) was influenced by Aristotle in his argument that, just as God usually makes wine from grapes, but, on occasion, directly from water, so, in the case of living creatures He can cause them to be born either from the seed or from non-living inorganic matter which contained invisible seeds, "*occulta semina.*"

The doctrine of spontaneous generation was especially popular in the Middle Ages. We may briefly recall such myths as that of the vegetable origin of geese, which survived until the eighteenth century; of the "vegetable lamb"—travellers' tales of plants and whole trees whose melon-like fruits contained fully-formed lambs; and of the "homunculus"—embryo of the little man—who originated in A.D. 100. Paracelsus (1493–1541 A.D.), who gave an exact recipe for homunculus—"mix passive female principle with active male principle"—was a confirmed protagonist of the theory of spontaneous generation. Van Helmont (1577–1644 A.D.) believed, too, that mice could be obtained from wheat kernels with human sweat as the generative principle. The recipe was to place a dirty shirt in a vessel containing wheat grains and to return after twenty-one days, when there were invariably mice present!

In spite of a few experimental facts to the contrary, these beliefs persisted and both Descartes (1596–1650 A.D.) and Newton (1643–1727 A.D.) appear to have accepted them.

It was not until 1862 that Louis Pasteur was able to refute the doctrine with his convincing experimental evidence, that initially-sterile nutrient solutions remained sterile in the absence or air-borne micro-organisms. The invention of the microscope, which came into use in the latter part of the seventeenth century, had revealed a hitherto invisible world of living creatures, and it was scarcely surprising, therefore, that the spontaneous generation theory had chosen to concern itself with these rather than with mice, in the two centuries between Descartes and Pasteur.

Cosmic Panspermia.

The other important theory, from an historical point of view, need not detain us for very long. *Cosmic panspermia* postulates the continuity of life in the Universe; life becomes an eternal existent and it is, therefore, meaningless to talk about its origin. As far as this planet is concerned it must be assumed that life could have been arriving continuously from space, and was successful in propagation when the Earth's physical and chemical state became suitable. Thompson[1] believed that the first germs of life could have been brought by meteorites. According to Dastre,[2] this idea was first suggested by de Salles-Guyon, and it certainly received the support of von Helmholtz.[3] Search in meteorites, however, has revealed no sign of living matter, and the fact that some millions of years would probably be required to transfer a meteorite from the nearest stellar system to our own, cannot be said to support the hypothesis. Even the transfer from the nearest planet would take about a hundred years, and

[1] Thompson, Presidential Address to the British Assoc., 1871.
[2] Dastre, *La vie et la mort*, trans. Greenstreet, 1911, p. 252.
[3] von Helmholtz, *Über die Entstehung des Planeten-systems*, 1884.

the heating involved in the passage through the Earth's atmosphere would almost certainly be sufficient to kill any living cell. A similar hypothesis, that life may have existed indefinitely in association with the cosmic dust of the inter-stellar spaces, was first propounded by Richter.[1] Such dust could fall slowly to the Earth without undergoing the heating experienced by a larger body. Arrhenius[2] calculated that bacterial spores with a diameter of about 2×10^{-4} mm. would travel in inter-stellar space with very great speed under the force of light pressure. Once separated from the Earth, for example, such spores could thus pass beyond the limits of our solar system in about fourteen months.

If the spore should become attached to another particle of greater size, gravity would overcome the light pressure and the spore particle would then return to Earth. Arrhenius discussed the factors of heat, cold and absence of water and of oxygen, which the spore would have to endure but, omitted, apparently, to consider the question of its possible inactivation by radiations.

The resistance of bacterial spores, and even of seeds, to extremes of time and of temperature is well known. It would probably not be wise to believe all the stories recorded of the germination of wheat obtained from the tombs of Egyptian kings. Guides have been known to replenish the stocks with more modern varieties! Nevertheless, other examples are recorded in the scientific literature. Lipman[3,4] claimed to have isolated viable bacteria from the interior of adobe bricks from old Spanish missions, and from Aztec and Inca ruins, as well as from coal samples taken 1,800 ft. below the surface. He also claimed to have found an autotrophic bacterium in petroleum oil from a well 8,700 ft. deep. Confirmation of such claims as these must, of course, be sought, but there is little doubt that wheat, for example, may be stored under optimum conditions for many years.[5] Proof that the first living cell dropped on to an Earth fitted to nourish it can never be found, and the majority of biologists who have thought about the problem have usually assumed that an environment which could support life, could also have produced it spontaneously. Moreover, although it may be philosophically

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[1] Richter, *Schmidts Jarb. ges. Med.*, 1865, **126**; 1870, **148**.
[2] Arrhenius, *Worlds in the Making*, trans. Borns, 1908, p. 221.
[3] Lipman, *J. Bact.*, 1931, **22**, 183.
[4] Lipman, *Science*, 1932, **75**, 79, 230.
[5] Whymper and Bradley, *Cereal Chemistry*, 1947.

convenient to banish the cell's origin to a remote corner of the Universe where it is scientifically inaccessible, this is a comfort rather than a help in the main problem.

If cosmic panspermia is irrelevant, and if Creation is rejected, the philosopher and the scientist are left with one variant or another of abiogenesis. There have been many objections to this on the ground that even the most simple, organised living things possess a very complex, delicate and perfect protoplasmic structure. Vital processes apparently depend upon the integrity of this and upon perfect functional differentiation. It seems to some biologists highly improbable that such a complex apparatus could have arisen fortuitously (cf. Preyer[1] and Kostychev[2]).

To this plea, as we shall see, the evolutionary biologist replies —all that would be required are the simple, chemical building bricks of the living cell, and the time for a protoplasmic organisation to be formed from these by evolution.

Cell Models.

The possibility of constructing a mechanical model which would perform some, if not all, of the functions of a living cell has appealed to many, especially in the nineteenth century. The data derived from these has to a very large extent been misused by a tendency to regard the model as a living cell, and by the attempts which have been made to postulate a possible mode of origin of the first cell as a result. It must be obvious that such models have a value only in so far as the phenomena they manifest are based on the same physico-chemical processes which determine the phenomena in living cells—and not vice-versa.

Traube demonstrated osmotic forces, by which the cell takes up nutrients and excretes unwanted products, by placing a small crystal of copper sulphate in an aqueous solution of potassium ferrocyanide. A semi-permeable bag of copper ferrocyanide is formed at the crystal surface. The osmotic pressure within this bag increases as the crystal dissolves and, finally, the membrane tears, and the solution leaks out to form a fresh membrane, and so on. Others have sought a similarity between the growth

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[1] Preyer, *Die Hypothesen über den Ursprung des Lebens*, 1880.
[2] Kostychev, *The Appearance of Life on the Earth*, 1921 (in Russian).

and reproduction of cells and of inorganic crystals. In most cases, for crystals as for living organisms, there is an upper limit for growth which is not exceeded, and further accretion of material results, not in an increase in size, but in crystal or cell multiplication. There is one striking difference, however, in that the cell itself controls both its rate of growth and its rate of division, whereas in the crystal this is controlled solely by the environment. The processes of mitosis, too, which lead to the production of two identical daughter cell nuclei from the single parent nucleus, may be imitated in a solution of common salt containing a suspension of carbon particles, which are claimed to arrange and re-arrange themselves in a manner indistinguishable from the movements of the chromosomes (Leduc[1]).

The peculiar logic by which the part becomes the whole is well illustrated by a book written by Beutner.[2] The " delicate forces of crystallisation " are held by him to be influenced by the " mysterious forces of development in plant life, and even in animal and human life." Beutner quotes in support of his thesis some observations by Pfeiffer of " frost-flowers " forming on shop windows during cold weather. Pfeiffer observed irregular pictures at a butcher's shop while at a florist's shop there were " delicately-developed patterns of great beauty." The explanation advanced was that minute amounts of plant or animal " extract " deposited on the freezing window affected the " delicate forces." On such a basis, Beutner concludes (p. 28), that " a relation of some sort must exist between the growth of a crystal and that of a living thing," and further (p. 45) that " living tissues themselves are made up of diminutive crystalline elements."

We may well hope that this is an extreme example of this type of argument. It had the maximum force when scientists felt confident enough to say, as Schaefer[3] did, that "a body so important for the nutritive and reproductive functions of the cell as the nucleus—which may be said, indeed, to represent the quintessence of cell life—possesses a chemical constitution of no very great complexity, so that we may even hope some day to see the material which composes it prepared synthetically " and further " . . . a similar anticipation regarding the probability of

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[1] Leduc, *The Mechanism of Life*, 1911.
[2] Beutner, *Life's Beginning on the Earth*, 1938.
[3] Schaefer *Brit. Med. J.* 1912, 589.

eventual synthetic production may be made for the proteins of the cell substance."

Few will be found who will be willing to make such assertions to-day, but there are many who cling tenaciously to theories of the origin of life which have similar chemical and physical implications.

Life from Colloids.

Buffon (1707–1788) supposed that living matter consisted of " organic molecules," or particles which united with each other in kaleidoscopic combinations. He was, of course, unaware of the existence of the amino acids, and of the thousands of different proteins which they unite to form ; but with the discovery and characterisation of many of these proteins, and the realisation of their relationship to living matter, from which alone all are, and have been, derived, Buffon's statement contains, to-day, an even larger proportion of the truth. Pflueger, too, identified proteins with the vital processes, and distinguished " live " (protoplasmic) protein from " dead " (storage) protein. The object of the majority of those who, in recent years, have sought to find a solution to the problem of the origin of life, has been to discover the way in which such proteins were first synthesized. We shall not have the time to discuss all of these, but I should like to give a brief description of the most popular account of the origin of fatty acids and amino acids, and then to consider the nature of proteins, the enzymes which they also constitute, and the present trends of biochemical thought.

It would obviously be impossible to determine now what was the chemical and physical constitution of the atmosphere and of the surface of the Earth, at a time when cooling had proceeded sufficiently for a separation of these to have occurred. There are, however, data available for the other planets in our solar system. This is largely spectroscopic evidence, but, from it we can gain some idea of the nature of planetary atmospheres. Jupiter, Uranus and Neptune are large planets, but far away from the Sun. Their surface temperatures are, therefore, very low, of the order of —135°C. to —250°C. Methane and ammonia, either liquid or solid, are the main constituents of the surfaces.[1,2] Mars, the next nearest planet, has only a very thin atmosphere,

[1] Adel, *Physical Reviews*, 1934, **46**, 902.
[2] Russell, reviewed in *Nature*, 1935, **136**, 932.

whereas Mercury, although close to the Sun, is too small to hold an atmosphere at all. Venus, which lies between the Earth and Mercury, most closely resembles the Earth. This planet has an atmosphere, with heavy water-containing clouds in which an abundance of carbon dioxide has been detected, *but* there appears to be no free oxygen. The clouding is so heavy and continuous that no observations of the surface of Venus have been possible. On Mars, however, patches of "vegetation" have been claimed. It is generally assumed that the original atmosphere of the Earth contained no free oxygen,[1] and this must be most significant for the hypothesis under discussion. Of those elements, carbon, nitrogen, hydrogen and oxygen, required for the synthesis of amino and fatty acids, carbon probably existed in combination as metallic carbides with some small amount of carbon dioxide of volcanic origin; hydrogen and nitrogen were provided, if at all, in the form of water or steam, and ammonia respectively. Some geochemists maintain that even the nitrogen of the air must have had a biological origin.[2]

Oparin[3] was able, with these very doubtful starting materials, to give a most plausible description of the further mode of origin of some of the essential chemical "precursors" of the living cell.

Hydrocarbons were derived from the metallic carbides by the action of either superheated steam or solutions of salts leached out of the rocks. Ammonia either existed, or was built up from nitrides or free nitrogen. The mixture of hydrocarbons, steam and ammonia, declared Oparin, would then condense to give alcohols, amines, amides, ammonium salts, amino acids, fatty acids and so on. These reactions may or may not be repeatable under controlled experimental conditions, and, if they are not, well, it was always possible that they required a long time, or that the reagents existed in high energy states. Further, when this "soup" of simple compounds was just allowed to stand for many, many years, we must assume, said Oparin, that the dissolved substances "undergo reactions of condensation and polymerisation, as well as of oxidation and reduction; in other words, every type of chemical change occurring in the living

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[1] Arrhenius, *Life History of a Planet*, 1923 (in Russian).

[2] Vernadski, *Problems of Biogeochemistry, Acad. Sci. Ed.*, 1935, quoted by Oparin (*see* 3).

[3] Oparin, *The Origin of Life*, 1938.

cell. As a result, numerous high molecular weight compounds, similar to those present in living cells, may appear in the aqueous solutions . . . on long standing."

Two assumptions, at least, are involved in this account of early creation. First, that the postulated starting materials did, in fact, exist, and second, that the chemical reactions could have proceeded in the required direction. The proponents of such hypotheses know well that neither of these contentions can ever be proved rigidly to be either true or false, and, of course, "time was not a matter of great consequence."

Oparin was also aware (p. 136) that a conglomeration of fatty and amino acids, or even of fats and proteins themselves, was still a long way off, from the point of view of organisation at least, from even the simplest living cell, and he had recourse, therefore, to the principle in colloid physical chemistry of coacervation—or formation of colloidal liquid aggregates. By this means the homogeneous "soup" might have become an inhomogeneous suspension of "points of concentration." From a consideration of the surface forces involved it is probable that such coacervates would have had a "structure" in so far as the components would have a definite orientation with respect to the suspending medium. It is equally probable, too, that they would be most unstable! They must have been formed by the action of random physical forces, and hence they would probably break-up and reform continuously. It was at this stage that the "soup" had to be given an added, and evolutionary flavour; "only the most dynamically stable colloidal systems secured for themselves the possibility of continued existence," which is to say, the more stable coacervates were more stable! Moreover—and here the cell model analogies are found to be useful—"a coacervate droplet could grow by assimilation and, sooner or later, surface tension forces or external mechanical forces would cause it to break up into separate droplets" (Oparin, p. 193). This would apparently be favourable from the point of view of further growth of the coacervate, since it would establish a more favourable relationship between surface and volume, and thus increase the rate of absorption. Thus "a coacervate droplet endowed with an ability (sic!) to divide had a certain definite advantage over other droplets." For these postulations to lead to a stable colloidal "species" a further assumption must be made, namely that the daughter droplets should have a physico-chemical organisation similar to that of

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the parent droplet. The astounding primary assumption is, of course, that ability to grow should be *favourable* and *advantageous* to the droplet. The droplets could equally well have continued to form and to break-up for ever in such a system. A completely new and scientifically illusory principle has been thrust upon them, a principle which has been applied, hitherto, to living organisms only, that of "struggle for existence." How, and in what respect, can non-living matter be said to struggle?

From uniform dividing droplets of fats and proteins it was a simple further step to postulate that the growth requirements of the droplets must have become specific and that droplets containing chemical systems capable of providing them with the specific "nutrients" should again have been "selected." Finally, stated Oparin (p. 250), "a peculiar selective process had thus come into play, which resulted in the origin of colloidal systems, with a highly developed physico-chemical organisation —namely the simplest primary organisms." But, lest his readers should feel that he had "solved" the problem too easily, he continued, "even those primary organisms were not living cells." For this "the colloidal systems, in the process of their evolution had to acquire properties of a still higher order, which would permit the attainment of the next and more advanced phase in the organisation of matter. In this process, biological orderliness already comes into prominence. Competitive speed of growth, struggle for existence, and finally, natural selection, determined such a form of material organisation which is characteristic of living things of the present time."

When the laws which govern the inanimate world suffice, Oparin cites them. When they do not, he cites instead the so-called laws of biology, but applies these to still inanimate matter!

This coacervate hypothesis put forward by Oparin may be the most plausible, but it is not the only way of bridging the gap between simple chemical substances and living cells. Beutner,[1] to whom reference has already been made, preferred lightning flashes for the synthesis of more complex compounds from the more simple. He stated (p. 81) "among the countless substances formed by the lightnings, enzymes appeared and, still later, self-regenerating enzymes. Some of these were also washed into the

[1] "Beutner, *Life's Beginning on the Earth*, 1938.

ocean, where inert organic material (also, formed, one must assume, by the " lightnings ") was already piled up. Eventually, enzymatic chemical reactions started in the sea." The first two or three enzymes formed in this way must have had a very lonely time, for Beutner went on to state " millions of years must have passed before some of the enzymes formed . . . encountered a substance which they could attack."

It is possible to apply statistical analysis to the type of " lightning-flash " syntheses described by Beutner. Enzymes are proteins in nature and usually contain at least four different kinds of atom, carbon, hydrogen, nitrogen and oxygen. If we may consider Beutner's " enzyme " to have a molecular weight of about twenty thousand and to consist of carbon and hydrogen only (which really introduces almost ludicrous simplifications) it may readily be shown that even if we assumed that there were 500,000,000,000,000 lightning flashes per second, the time needed to form ONE such disymmetric molecule from material contained in a volume equal to that of the Earth would be about 10^{243} thousand millions of years.[1]

Estimates from radio-activity measurements, however, indicate that the older rocks of the Earth's crust solidified about two thousand million years ago.

We may not, of course, declare that for this reason alone no such " protein " molecule could have been formed but only that this figure gives the probability that *one* such molecule should have come into existence.

It is a habit with such authors as Beutner to introduce entities such as enzymes and viruses, to describe them as the forerunners of living cells, and to dismiss them without any attempt to examine them further. Let us now enquire more closely into their function, and relationship to living organisms.

ENZYMES.

The components of every living cell undergo complex cycles of chemical reactions by means of which energy is made available. This energy is used by the cell for the performance of mechanical work—as, for example, in movement and in cell division, for the synthesis of growth materials, for work against osmotic forces, and so on. In the laboratory the chemist is rarely able to synthesize even one chemical compound from its precursors in a

[1] du Nouy, *Human Destiny*, 1947, p. 33.

yield of one hundred per cent. Side-reactions occur and by-products are formed. Many reactions in the living cell require some twenty or thirty individual chemical steps and so it is obviously desirable that the by-products, which turn up in test-tube chemistry, should be avoided and that each chemical stage should proceed rapidly to completion in the required direction.

Catalysts—substances which take part in a chemical reaction without being changed, and which greatly increase its speed—have long been known to chemists. We may take an example from chemical industry.

Under normal conditions, hydrogen and carbon monoxide do not readily interact, but when a suitable catalyst is provided, which is usually a finely-divided metal, or metallic oxide, these gases form methyl alcohol, together with other higher alcohols. A large lump of catalyst is of very little use and a large area of surface is required, such as would be provided by fine-division. The theory of catalysis is that molecules of the reacting components attach themselves to the catalyst surface at active points ; in their "activated" states they may now combine with each other, and the compound thus formed dissociates from the surface of the catalyst, and leaves the way clear for the next reacting molecules. A small amount of catalyst, therefore, can bring about the synthesis of a large amount of end-product. Catalysts, too, may be "poisoned" and the theory explaining this, states that the molecules of the "poison" stick tightly to the catalyst surface and prevent the other normal molecules from getting to it.

In biological systems, the essential energy-providing reactions are brought about, and maintained, by enzymes. These are essentially catalysts of very complicated composition, consisting of proteins of very high molecular weight which, in turn, are often dependent upon co-enzymes, or activating catalysts, containing very small amounts of metals such as iron, cobalt, copper, magnesium or manganese. Many of the vitamins function in the cell as co-enzymes. Apart from the chemical differences in complexity between enzymes and inorganic catalysts, and the fact that the cell itself makes its own enzymes, the most fundamental difference is that enzymes are "specific." By this we mean that one enzyme has one job in the cell and usually one only. A single cell, therefore, with all its complicated chemical reactions must contain hundreds of enzymes—

although each one need be present in minute amounts only. For example, in many cells hydrogen peroxide is produced. In high concentrations this may be poisonous to the cell and an iron-containing enzyme, *catalase*, exists which breaks it down to water and oxygen. The activity of this enzyme is such that a single molecule of it will decompose 42,000 molecules of hydrogen peroxide every second.[1] We believe, too, that an enzyme works in much the same manner as an inorganic catalyst, i.e., by providing an active surface upon which the reaction which is catalysed can occur. Therein lies, too, the explanation of the specificity of enzymes, in that this surface is " shaped " in such a way as to " fit " exactly the molecules towards which the enzyme is specific. So close and so important is this " fit," that very small changes in enzymes may render them inactive. Enzymes may be poisoned, too, in much the same way as inorganic catalysts, and many of the hypotheses concerning the action of drugs, such as the sulphonamides, on mirco-organisms show that the drug may " poison " an enzyme system in the organism which is vital to its existence.

Troland,[2] in 1917, stated his conviction that the concept of specific catalysis, i.e., of enzyme action, " provided a definite general solution for all of the biological enigmas . . . what we call life is fundamentally a product of catalytic laws acting in colloidal systems of matter throughout the long periods of geologic time." We have already seen that Oparin has postulated a mechanism for the production of proteins from possible chemical precursors. Proteins, in their natural or " native " state, consist of long chains of linked amino acids which are often folded up into globules. Langmuir and others[3,4] have shown that such proteins will unfold at phase boundaries, e.g., the boundary between air and water, and will then spread out. The films thus formed are so thin that they are almost two-dimensional, in fact they are about one molecule thick and cover an enormous area, in some cases as much as 1,000 square metres per gramme. These discoveries by Langmuir paved the way for yet another theory of protein formation. The initial postulate is again a " soup " of amino acids and fatty acids. In the bulk of the mixture, the concentration of the amino acids

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[1] Baldwin, *Dynamic Aspects of Biochemistry*, 1947, p. 107.
[2] Troland, *Amer. Nat.*, 1917, **41**, 326.
[3] Langmuir, *Proc. Roy. Soc.*, 1939, **170A**, 1.
[4] Gorter, *Trans. Farad. Soc.*, 1937, **33**, 1125.

may be too low "for the rapid, direct (sic!) synthesis of proteins." At a phase boundary, however, which could exist between the surface of the "soup" and the atmosphere, or, conceivably, between the "soup" and the liquid droplets (co-acervates) suspended in it, the concentration of amino acids would probably be higher and, under the activating conditions of interfacial forces, a protein of random constitution and size might be formed.[1] The protein would then have to be removed out of the surface, either by being "rolled up by a puff of wind" or by the disappearance of one of the phases. The surface would then be prepared for the next synthesis. The assumption must also be made that one at least of these proteins has self-regenerating properties. There are some difficulties in this hypothesis. First, the spreading of native, globular proteins brings about their denaturation. The initially-soluble protein is converted into an insoluble coagulum of denatured protein. Second, even if the proteins thus synthesized were re-folded subsequently into a native state, or could be rendered soluble by a different mechanism, such a soluble protein would immediately compete with the amino acids for adsorption at an interface. It is for this reason that dilute solutions of proteins are unstable.[2] Third, proteins could only be formed in a random manner unless the surface was specially prepared. This is much easier to postulate than to demonstrate, but Langmuir and Schäfer[3] have suggested that the molecules already present on the surface could act in such a manner as to regulate the formation of more, identical molecules. Many experimental attempts have been made to test the feasibility of this "film" hypothesis of protein synthesis but, to date, no verification has been obtained.

Another more general difficulty which arises with any "soup" hypothesis is the fact that not only do many enzymes and their co-enzymes depend for their catalytic activity upon traces of metal ions but they are correspondingly sensitive to the presence of other metals and even anions. For example, an enzyme activated by magnesium ions may be inactivated by citrate ions. It is inconceivable that a "soup" formed by any of the mechanisms hitherto propounded should not have contained

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[1] Robertson, *Austral. J. Exp. Biol. & Med. Sci.*, 1926, **3**, 97.
[2] Adams, *J. Gen. Physiol.*, 1948, **31**, 417.
[3] Langmuir and Schäfer, *J. Amer. Chem. Soc.*, 1938, **60**, 1351.

anions and cations of all types, and difficult, therefore, without making even more assumptions, to see how active enzymes could have been built up. There is, of course, an " orthodox " answer to this difficulty, in general, if not in particular. Oparin believed (*loc. cit.*, pp. 174–5) that the first enzyme catalysts must have been chemically simple and not very active and that these primitive "enzymes" evolved to their present complexity.

It was Troland's original contention,[1] and that of Alexander and Bridges,[2] too, that the primal living unit was a " catalytic particle of dual activity, a particle, which can, on part of its area, conduct a continuous (*hetero-*) catalysis . . . and can, on another part of its area conduct a reproductive (*auto-*) catalysis, and to suppose that the substances formed by the continuous catalysis, together with those existing in the milieu, are the very ones needed in the reproductive catalysis." Troland believed that the gene (the ultimate particle of genetic material in the cell nucleus) was primarily autocatalytic—so that each daughter cell formed by cell division from the mother cell should contain a replica of each parent gene—but that some of the genes, at least, should be capable of sustaining specific heterocatalytic reactions as well.

This concept appears to have been well in advance of its time, and supporting experimental evidence has only recently been revealed.[3] The mould, *Neurospora,* when grown " wild," normally synthesises its own growth-factors. Some variants of the " wild-type " are known, however, for the complete growth of which, some of these factors must be provided in the culture medium. This means that these deficient strains have lost the capacity to perform one or more enzyme reactions by means of which the " wild " type is able to provide itself with these factors. There appears to be no doubt that the variants are genetically different, too, i.e., the deficiencies are hereditary. It seems, therefore, that each enzymatically-catalysed step in the synthesis of these factors from simple precursors is dependent upon the direct participation of a different gene. In this organism, therefore, the genetic material of the cell nucleus must be directly responsible for the synthesis of the cell's enzyme systems. This is what was referred to earlier when we said that each cell provided its own catalysts. If the gene is,

[1] Troland, *Monist,* 1914, Jan. 1, 42.
[2] Alexander and Bridges, ed. *Colloid Chem.*, 1928, **11**, p. 17.
[3] Horowitz, *Proc. Nat. Acad. Sci.*, 1945, **31**, 153.

in this sense, the fore-runner of the enzyme, and if each reaction chain, involving perhaps twenty or thirty enzyme-catalysed steps, would equally require twenty or thirty genes in the nucleus, the sum total of cellular organisation must be enormous. Years of "geologic" time may well have been required for its synthesis.

Moreover, no gene is known which can retain its property of hetero- or of auto-catalysis when separated from its nuclear environment. In fact, no one has ever seen a gene, and its existence is inferred from what it does. Attention has, however, been focussed upon *viruses* which seem to possess some of the properties of the genes. These resemblances are largely chemical and it is even doubtful now whether the virus is actually auto-catalytic.

Viruses.

Since 1901, hundreds of the diseases of man, animals and plants have been found to be caused by viruses. The distinction between bacterium and virus as a cause of any particular disease was, at first, based on size alone. The viruses were able to pass through filters which would retain known bacteria. Viruses, as a group, are smaller than bacteria, but they form an unbroken series with respect to size. Certain of them, such as vaccinia virus, are larger than many accepted organisms while others, such as foot-and-mouth disease virus, are smaller than some protein molecules.

From the standpoint of physics and chemistry, the plant viruses, such as that which produces mosaic disease in tobacco plants, have been more carefully investigated than animal viruses. In 1935, Stanley[1] obtained tobacco mosaic virus in the form of needle-like crystals. Of particular interest were the facts that these crystals were quite devoid of water and of any heterocatalytic activity. This lack of water, together with the crystalline structure, would appear to preclude the existence of a metabolism of the type usually associated with living organisms; and yet when these crystals are introduced into the cells of susceptible plants, they increase in quantity and the plants show all the external symptoms of mosaic disease. The virus appears to interfere directly with the normal enzymatic reactions occurring in the cells.

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[1] Stanley, *Science*, 1935, **81**, 644.

All viruses have not been obtained as crystals, and there is no valid reason for supposing that they all ever will. They all have in common, though, the ability to reproduce and multiply when within the cells of susceptible hosts. No virus has yet been discovered which will multiply under any other conditions, i.e., viruses cannot be cultured, like bacteria, in artificial media. It is probable, too, that in the infected cell the synthesis of the virus does not differ markedly from the synthesis of normal proteins and enzymes. The virus, therefore, behaves as an obligate parasite, and "persuades" the cell to provide the material for its own synthesis. In view of their chemical properties as proteins, their crystallizability (and many enzymes have also been obtained in a crystalline form) and their alleged autocatalytic reproduction, the chemist and biochemist tend to regard viruses as nucleoprotein or liponucleoprotein *molecules*, whereas the biologist and pathologist have, on the other hand, considered them to be small living organisms. Green[1] has suggested that viruses are simplified fragments of living protoplasm, arising from organisms by a process of retrograde evolution under parasitism, which involved loss of function and of associated substance, and that this process may vary in degree, resulting in forms varying from single protein molecules to entities almost indistinguishable from ordinary living organisms. Laidlaw[2] has concluded, too, that viruses probably arise by a gradual loss of substance, and of such functions as enzyme systems (which would explain why viruses would require to "borrow" the intact and functioning enzyme systems of their host cells).

Others maintain that viruses are "living" particles and thus provide a bridge between the non-living enzymes and the cell itself. It is difficult to distinguish and to disentangle these views, but until fresh facts come to light it would certainly not be true to say that the virus was the precursor of the cell, or that the cell nucleus ever passed through a stage when it existed only as a colony of elementary, virus-like living units. Pirie[3] quoted recently a statement of J. W. Beard, an American authority on animal viruses, "viruses are said to be living molecules, and autocatalytic enzymes and are likened to genes and mito-

[1] Green, *Science*, 1935, **82**, 443.
[2] Laidlaw, Rede Lecture, London, 1938.
[3] Pirie, *Brit. Med. Bull.*, 1948, **5**, 329.

chondria—in short, a fabric of concept has been woven of a plethora of woof with a paucity of warp!"

Despite the apparent ineligibility of the autocatalytic enzyme or virus for the rôle of the primal living unit, there are still those who maintain that living substance is probably being produced constantly in one form or another, but that it must fail to make itself apparent because existing living organisms would assimilate it.[1] The suggestion has even been made that it might be a crucial experiment to sterilise completely several acres of ground, to provide a "soup" similar to that which we have already considered, and, taking care to avoid contamination by extraneous living matter, to await, confidently, the eventual appearance of primitive life.

We have seen some of the difficulties involved in the synthesis of the first protein molecule. It is simple to postulate such a substance and the action of the forces of "evolution" upon it. Each tissue of each species of plant or animal, microbe or man, is able to synthesize its own special proteins, and these may be specific, not only to the species but even to the organ. It is probable, therefore, that millions of different proteins exist. Moreover, the synthesis of these proteins by the cell is controlled by enzymes, which are themselves, as we have seen, specific proteins, and the enzymes, in their turn, are probably synthesized through the activities of the genes, which again, are specific proteins. The possible chemical mechanisms by which the cell itself can synthesize its proteins have recently been reviewed by Northrop and his colleagues.[2] Without regulation, these mechanisms would only give a non-specific protein of random composition. It is difficult to assume that not only each enzyme, but each cell protein, is formed autocatalytically, because an autocatalytic reaction requires at least one template molecule of the product to be present at the beginning, and even the combined sperm and ovum of an animal would probably be too small to hold one prototype molecule for each protein of the ultimate adult animal.

The problem which has still to be solved is that of the source of the energy which the cell requires for the synthesis of protein molecules from simpler precursors. In the intact living cell, this can be provided by a "coupled" reaction, i.e., a reaction which

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[1] Allen, *Rep. Brit. Assoc.*, 1896.
[2] Northrop, Kunitz and Herriott, *Crystalline Enzymes*, 2nd Edn., 1948.

proceeds side by side with the synthesis of protein and from which energy may be transferred. It is significant that this energy may be provided by respiration processes in the cell.

The three fundamental reactions upon which all life depends have not yet been shown to be separable from *intact cells*. These are *photosynthesis*, *protein synthesis* and *nitrogen fixation*. This almost certainly means that these processes depend upon a precise structural organisation of "coupled" enzyme systems in the cell and it is very difficult to see how, for these processes, such linked enzyme systems could have "evolved," since the presence of but a single component enzyme would have conferred no "survival value" upon the organism.

The conclusion is inescapable that life is a property of the intact cell, that no cell component can be considered as the primal living unit and that, stated in these terms the problem of the origin of life becomes that of the origin of the first living cell—a problem that must escape a solution at least until we are able to demonstrate the structure of a single cell. Some idea of the magnitude of the task may be gained from the following summary of the synthetic ability of the bacterial cell.[1]

"Cells of many kinds of bacteria, furnished only with water, salts, glucose and simple sources of carbon and nitrogen, can synthesize proteins, complex carbohydrates, lipids, ribose and desoxyribose nucleic acids, vitamins and enzymes; all organized into characteristic and reproducible protoplasmic systems. The bacterium can reproduce itself and divide within half an hour at body temperature. These feats of chemical synthesis and organisation, which cannot be duplicated by the finest chemical laboratories in existence, are accomplished within a cell a few microns in length and less than half a micron in diameter."

We may feel that it will ultimately be possible to discover the exact structure of the living cell, and even to duplicate in the laboratory many of the chemical feats performed by it. We may even believe, with Beutner, that when we have been able to synthesize the first autocatalytic protein we shall know the secret, and the origin of life. Until that time comes, if in the wisdom of God it ever does come, we must conclude, with Hopkins,[2] that "life is a property of the cell as a whole, because

[1] Mudd, *Nature*, 1948, **161**, 302.

[2] Gowland Hopkins, quoted in *Colloid Chemistry*, 1928, **11**, p. 21. ed. Alexander and Bridges.

it depends upon the equilibrium displayed by the totality of co-existing phases"; and that the origin of this first cell is completely unknown and, probably, in terms of the concepts of science, unknowable.

Discussion.

The Chairman (Prof. Kapp) said: A great deal of research and careful thinking must have gone to Dr. Harris's excellent paper. The most relevant comment that comes to my mind on this account of 2,500 years of theory spinning is that every one of the theories, including those put forward by contemporaries, and in the name of science, collapse like card houses at the first faint zephyr of logical analysis. Everyone may not be able to formulate the objections as neatly and concisely as Dr. Harris has done, but surely those scientists who are authors of the most recent theories would see the objections to them soon enough if they could bring themselves to exercise any self-criticism at all. I am sure that they reason more conscientiously when they are concerned with their own special fields of study. Dr. Harris's documentation confirms, what my own reading had already proved to me, namely that many quite eminent scientists do not consider it necessary to think quite seriously when they are propounding their views about "life." In their handling of the subject one can detect three major offences against scientific method.

The first is a use of words so loose as to conceal the question under discussion, and this loose use is not remedied by a pretence at seeking definitions. When there is mention of the need to define the word "life," for instance, these authors do not trouble first to decide in which of four possible senses the word is to be understood.

(i) Sometimes one has to gather from the context that the word is used as a collective noun for all living things, just as the word "ironmongery" is used collectively for certain types of metal ware. Confusion would be avoided if we always said "living things" or "living substance" instead of "life" when we mean this.

(ii) At other times the word is used to denote a property or collection of properties. Life is said to be this or that property of the living cell, for instance, but no one would say that ironmongery was the property of knobblyness or hardness. One would say, instead, that these properties were characteristic of ironmongery. We would avoid the confusion if we said "the characteristics of living things" instead of "life" when we mean this.

(iii) At yet other times the word is used to denote the process of living. Gowland Hopkins is quoted as having said that we cannot speak of the cell life as being associated with any particular type of molecule, but that its life is the expression of a particular dynamic equilibrium. He does not say that the *cell* is an expression of this, but that its *life* is. It would have been better to have said "vital processes" instead of "life."

(iv) Lastly the word may mean an agent or influence, an entity that causes matter to assume the structure of living substance and to follow specific structural changes in specific time sequences. This, I venture to suggest, is the only use of the word that can be scientifically justified. The word is used in that sense in any discussion as to whether there is such a thing as life or not. Vitalists would say yes. Their opponents, no. This straight discussion is confused and the arguments used in it become ambiguous when the word *life* is sometimes used as a collective noun, sometimes as a set of properties, sometimes as a process and sometimes as an agent.

The second very common offence against scientific method is a failure to formulate the problem to which the theory that is being presented claims to provide a solution. These theory spinners, and I am glad to see that Dr. Harris is not one of them, do not like questions; they prefer answers. This second offence is coupled with the third one, which is a passionate desire to prove that "life and the origin of life must ultimately be completely explicable in physico-chemical terms." When one reads most of the authors whom Dr. Harris has quoted, and many others as well, one cannot avoid the conclusion that the theory spinners are more concerned to prove their faith true than to find answers to any questions of scientific importance. As good evolutionists they postulate one, or a very few, original ancestors to all living things, but they are less interested to know at what time, in what place and by what process, an original ancestor came into existence than to find a theory by which to explain the occurrence without the need of anything but physical laws and the properties of matter.

Hence all the theories that have been carefully classified in Dr.

Harris's paper (there are six) are really different disguises of the theory of "spontaneous generation." The theories differ only about the nature of the spontaneously generated organisms. Some have said that mice or maggots can thus be generated. Some that it can only be single cells, some that it can only be viruses, some that only single protein molecules can be spontaneously generated. And as Dr. Harris's quotations show, the theory spinners are as much concerned to prove that living substance is spontaneously maintained as that it is spontaneously generated.

What we have to ask before we can begin to spin theories about the origin of living substance is whether those can justify the word "completely" who say that life and the origin of life must be ultimately *completely* explicable in physico-chemical terms. Let me formulate the question in the following simple terms: Is living substance created and maintained as a result of the unaided action of matter on matter?

Mr. Ronald MacGregor said: We have the highest authority for knowing when and how life came into the world where we live.

Almighty God has told us in His word, in Genesis i, how "God said," "God created." By His word creation took place, and what was said in Genesis i—that there were animals, fish, birds, etc.—holds true to-day. Animals remain animals, birds remain birds, fish remain fish. And He created Man out of the dust, and breathed into him the breath of life—man was made in the image of God. One of our late Presidents of the Victoria Institute, the late Sir Ambrose Fleming, and very distinguished with regard to the wireless, so disbelieved in Evolution that he founded a Society to oppose this theory. Science changes from century to century, and it is my belief that when science comes to a final conclusion, it will be found to agree with Genesis i (and ii), because the Author of the Bible is the Author of Creation.

Mr. G. E. Barnes said: In view of the Chairman's remarks concerning accuracy of terminology, I should like briefly to discuss the use of another word which appears to have been used loosely and with different meanings by the various authors quoted by Dr. Harris. I refer to the word "cell."

This diversity of meaning is not surprising, since biologists themselves have given the concept more than one extension. Even to-day there exist two schools of thought on the use of the word, so that it is necessary that I should define the way in which I shall use it. I consider (and I think that this is probably the preponderating view now) that a cell is a mass of specialised protoplasm under the control of one nucleus. If this definition be accepted, the protozoa must be regarded as non-cellular organisms. This obviates the unwarranted assumption that the protozoan energid is homologous with the metazoan cell.

Now, in the days when biology was concerned more with structure than with function, the cell came to be regarded as the unit of both structure and function. To-day, however, as a result of the great increase in knowledge of the physiology of the metazoa, biologists have been forced to the conclusion that, while it still may be legitimate to regard the cell as the unit of *structure*, it is no longer possible to regard it as the unit of *function*. The unit of function is the whole organism, and not the cell.*

Furthermore, it is obvious, and Dr. Harris has assumed it throughout his paper, that the first form of living material must have been a functional unit, and not merely a structural unit. Hence, it follows that those who try to account for the origin of life solely in terms of physico-chemical phenomena must be prepared to explain the origin, not merely of a mass of unspecialised protoplasm, nor of "the simplest living cell," but of a complete organism.

These remarks, of course, add no further facts to those already discussed in the preceding paper, but they do, I think, state the problem in accurate terms. Those whose irresponsible guesswork Dr. Harris has been examining this evening might have been less bold in their published speculations if they were fully aware of the exact nature of their problem.

WRITTEN COMMUNICATIONS.

Mr. H. K. AIRY SHAW wrote: What has been said concerning the atmosphere of Venus does not seem quite to square with the account given by the Astronomer Royal, Sir Harold Spencer-Jones, in his

* For a discussion of the relation between the cell and the organism, see Lester W. Sharp, *Introduction to Cytology*, 3rd edition, 1934, pp. 20–24, 435–436.

recent little book, *A Picture of the Universe,* 1947, pp. 45–48. He says: "Attempts to detect water-vapour in the atmosphere of Venus have been unsuccessful; there can be no oceans on Venus; if there were, there would be enough water-vapour in a world as warm as she is to be easily detected. This gives the clue to the conditions prevailing on Venus. The pall which hides her surface is a pall of dust over a desert world, and not a pall of cloud" (pp. 45–46). ". . . plates sensitive to the short wave-length ultra-violet light reveal cloud markings, which must be at a high level in her atmosphere . . ." (p. 45). ". . . the vagueness of the cloud formations (which, incidentally, cannot be clouds of water-vapour but which, it is thought, may consist of formaldehyde) makes it difficult to determine the length of day on Venus" (p. 48). ". . . there is a very great abundance of carbon dioxide in the atmosphere of Venus" (p. 46).

Secondly, while it is probably strictly true to say that "no one has ever seen a gene" (I am not enough of a cytologist to dispute it), I wonder whether the statement might not be modified slightly in view of the elaborate chromosome "maps" that have been published, *e.g.*, for *Drosophila* by Morgan, Dobzhansky and others. These "maps" purport to plot the exact *situation* of the various genes on the chromosomes, and the markings give the impression that they intend to indicate schematically the actual genes. See, for example, Dobzhansky, *Genetics and the Origin of Species*, 1937, pp. 110–111.

Mr. John Byrt wrote: Although my understanding of this subject is too limited to permit any very original observations, I might just draw attention to an article by Professor Linus Pauling, entitled "Antibodies and Specific Biological Forces," appearing in *Endeavour,* April, 1948, p. 43. Dr. Pauling here presents in simple terms the theory that complex biological molecules, such as viruses and genes, are reproduced through the intermediate stage of a complementary, or "template" molecule, which would itself serve as a template for the production of a replica of the original molecule. This appears a very plausible explanation of the mechanism of reproduction, given the original complex molecule, and an environment sufficiently complex to permit the building up of the template molecule under the influence of van der Waal's forces. It accounts for the fact mentioned by Dr. Harris that "no virus has yet been discovered which will multiply under any other conditions" than within the cells of susceptible hosts. However, it brings us no closer to a "natural" solution of that profound mystery of the origin of the first complex protein molecules, and while it would be unwise to declare the problem incapable of such a solution, it is certainly true to say that the invocation of the power of the Deity provides the most reasonable solution at the present time.

Dr. Harris comments on the extreme specificity of the proteins synthesized by plants and animals. Pauling cites an interesting example of this, even in the case of the relatively simple hæmoglobin molecule: "the hæmoglobin of cold-water fishes liberates its oxygen at lower temperatures than does that of warm-blooded animals." One who can accept the chance production of protein molecules from inorganic matter will have no difficulty in explaining this in terms of its evolutionary "survival value," but to the Christian it provides just one of numberless examples of the overruling wisdom of the Creator.

A communication was also received from Mr. A. Constance, who drew attention to the enormous difficulties confronting any who would speculate on the origin of life, and to the need for humbleness of mind in dealing with such topics.

Miss L. Bush also commented upon the paper.

Author's Reply.

Mr. Airy Shaw is correct in his statements concerning the atmosphere of Venus, and I must confess to having failed to check my own early reference against a later. Wildt,* however, rejects the polyformaldehyde nature of the clouds, but confirms that oxygen is very scarce, that water is absent, and that carbon dioxide is present in great abundance (a concentration one hundred times greater than in the Earth's atmosphere). Wildt, too, has some interesting remarks to make about Oparin, viz., "the astrophysical data on which Oparin has based his speculations are largely obsolete and often incorrectly interpreted."

* Wildt, *Rev Modern Physics*, 1942, **14**, 141.

I cannot accept the point about the "visibility" of the gene. Chromosome maps have certainly been drawn which purport to show the location of individual genes. Equally, X-ray diffraction data can give maps of the location of atoms in a crystal lattice—yet the atom remains invisible and its *ultimate* nature remains obscure. Sonneborn,† the American geneticist, has stated "the classical gene may be specified by its action, properties and location. Like the ultimate particles of physics, it is invisible and is recognised by its effects. The observable effect of a gene is on the trait or traits which it determines or influences."

If Mr. Barnes means that, because there is no evidence to support the hypothesis that metazoa evolved directly from protozoa, theories purporting to explain the origin of the "first living cell" only take us as far as a protozoon, and not as far as an organism, then I agree with him. However, I fail to understand the relevance of his definition of a cell. Amœbæ, for example, are protozoa, and, equally, consist of "specialised protoplasm" under nuclear control. Moreover, no nucleus has been demonstrable in some bacteria or in the human red blood cell, although, admittedly, this latter has a very different sort of existence.

The tendency has been, as Professor Kapp has so clearly stated, for all the theories to be variants of the theory of spontaneous generation, differing only in the nature, and biological and chemical complexity, of the material generated—single protein molecules, viruses, single cells, maggots or mice. Each theorist has tended implicitly to define "living" for himself in terms of the degree of complexity to which his theory leads him. To-day, the single protein molecule is preferred to the mouse of a less sceptical age, and, in consequence, those who feel capable of demonstrating the mode of origin of a protein are equally capable of defining "living" in terms of the properties of such proteins.

We believe, as Christians, that living organisms were created, and, moreover, are maintained in being, by God. The onus of disproving this declaration rests with those whose "faith" is in the creative action of "matter on matter." The inadequacy and naivety of some of their attempts has been shown here.

† Sonneborn, *American Scientist*, 1949, **37**, 33.