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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

[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

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[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 crystallime 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-

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[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.

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

881st ORDINARY GENERAL MEETING

HELD AT 12, QUEEN ANNE'S GATE, WESTMINSTER, S.W.1, ON MONDAY, 28TH MARCH, 1949.

REV. C. T. COOK IN THE CHAIR.

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

The following elections were announced :—The Lord Bishop of Worcester (Rt. Rev. W. Wilson Cash, O.B.E., D.D.), Vice-President; Rev. Principal H. S. Curr, M.A., B.D., B.Litt., Ph.D., Vice-President; Rev. R. R. Neill, M.A., Fellow; A. MacA. Gillespie, Esq., O.B.E., M.D., D.T.M., F.R.C.P., Fellow; Rev. Gordon I. Thomas, Member; R. Schram, Esq., Associate.

The Chairman then called on C. A. E. Turner, Esq., M.Sc., to read his paper on "Puritan Origins in Science."

PURITAN ORIGINS IN SCIENCE.

By C. E. A. TURNER, M.Sc.

SYNOPSIS.

In the middle ages the Roman Catholic church did little to encourage experimental inquiry in science, but favoured traditional views. Later, as a result of the Reformation, the view came to be widely held, particularly among the Puritans, that God's works ought to be explored for His glory and for the good of mankind. In England, Puritan influence was largely to the fore in the foundation of the Royal Society.

Investigation has shown that those holding Puritan views made very considerable contributions to science in the seventeenth century. Among the 24 scientists named, were the naturalists, Grew, Ray and Willughby; the physician, Sydenham; the economists Graunt and Petty; the educationalist, Hartlib, together with the physicists and mathematicians, Boyle, Newton, Briggs, Wallis and Wilkins.

After the Restoration, interest in science for its own sake declined, and increasing interest in its exploitation for gain led to the beginnings of the great divorce between science and religion.

THE BACKGROUND AND FAITH.

THE Schoolmen of the Middle Ages were interested in seeing an integrated universe. Using largely *a posteriori* methods they were content if facts or fictions about the physical world would fit their views. In an age when authorities were to be accepted, their science was largely non-experimental, but copied from books which mixed truth and fable. The Roman Catholic Church favoured this learning which had been already approved by it, and by which the studies and views of its members were readily checked. This was the learning fostered in the monasteries, where it fitted the ideal of escape from a physical world "inferior, contemptible and reserved for destruction." The free inquiry and accurate observation, characteristic of modern science, if not forbidden were suspect, liable to be regarded as heretical or connected with witchcraft, astrology and chicanery. Consequently the study of science became sterile. Much of the material taught was useless and divorced from reality, as witness the difference between the maps of the monks and those of the mariners.

At the Renaissance in the fifteenth century the situation was not improved. The increased interest in classical literature tended to add the tradition of the ancients to the dead weight of Rome. So the movement was chiefly helpful on the arts side, and even there crystallised into concentration upon style and form rather than upon content and thought.

When the Reformation came, the authority of the Church could be disregarded in Protestant lands, and there was a reaction even to follow an opposite course. Emphasis was now placed on individual knowledge of and faith in God for salvation, rather than on dependence upon the rites and dogma of the Church. This personal responsibility was transferred over to learning. Many were obliged to accept the expansion of knowledge through geographical discovery, and they felt free to examine the world around them, as well as their Bibles, for themselves. In the hands of some the Reformation became a process of secularisation which was never the intention of its pioneers. Luther particularly and Melanchthon opposed the new Copernican astronomy as being anti-religious. Calvin frowned upon some scientific work. However, their protestant ethic encouraged scientific inquiry by the removal of man-made prohibitions.

The Puritans are regarded as being the essence of Protestantism, as those whose only authority was the Bible. In it they found encouragement to observe, experiment and discover the contents and secrets of a universe created by God for His glory (Col. i, 16). They read in the poetry of the Scriptures of God "Who made heaven and earth, the sea and all that therein is;

which keepeth truth for ever " (Ps. cxlvi, 6); of " Him that by wisdom made the heavens " (Ps. cxxxvi, 5); of " His wonders in the deep " (Ps. cvii, 24); Who " hangeth the earth upon nothing " (Job xxvi, 7); that " He telleth the number of the stars; He calleth them all by their names " (Ps. cxlvii, 4). They were called upon to " remember His marvellous works that He hath done " (Ps. cv, 5) and note " that one generation shall praise Thy works to another " (Ps. cxlv, 4). They exclaimed, " I will praise Thee; for I am fearfully and wonderfully made " (Ps. cxxxix, 14); " Thou hast created all things, and for Thy pleasure they are and were created " (Rev. iv, 11).

Their way of life was to be " pure," " in doctrine showing uncorruptness, gravity, sincerity " (Titus ii, 7) based upon personal discovery of truth. Theirs was a serious calling, free from tradition and eschewing ritual and unprofitable amusements. Robert Barclay, the Quaker, in " Apology for the True Christian Divinity " (1675) recommended the study of natural philosophy as a remedy for idleness and spending time on plays and " flesh pleasing." Puritans were taught to be " diligent in business, serving the Lord " (Rom. xii, 11), and were consequently industrious and painstaking, systematic and methodical.

These people knew God as reliable, unchanging and working according to immutable laws, seen on the spiritual side in the law of predestination, of sowing and reaping (Gal. vi, 7) and on the other in the physical laws of matter. Reason was regarded as a divine gift. Richard Baxter thought faith not " rationally weighed " was but a dream or fancy or opinion. John Ray referred to " divine Reason running like a Golden Vein through the whole leaden Mine of Brutal Nature." Order was a rule of life for the Puritans. Things were to " be done decently and in order " as " God is not the author of confusion but of peace " (1 Cor. xiv, 40 and 33). It was a law of the material universe where He " worketh all things after the counsel of His own will " (Eph. i, 11). Whitehead says they were also a people with an intense imagination. This was required for seeing the Unseen and was another quality added to those above, which together particularly fitted them for the pursuit of scientific studies.

Nehemiah Grew, in " Cosmologia Sacra " (1701), wrote " God is the Original End and we are bound to study his works." John Ray uses almost as his motto " O Lord how manifold are thy works! In wisdom Thou hast made them all " (Ps. civ, 24).

The glory of God was the transcending purpose of this spiritually-minded people as they walked among the things of earth. God was Creator and actively interested in His work. They were humbly to follow and find Him in the creation which at least partly made Him known (Rom. i, 20).

Coupled with this motive was that of social utility. Loving the neighbour was interpreted as being interested in his welfare, in the care of the poor and weak. Francis Bacon was no Puritan, but he had coined a phrase which Robert Boyle and other Puritans re-echoed as the two-fold object of their scientific activities: "The glory of God and the relief of man's estate." This is written over the work of these men, but with the reservation in many cases that the latter is subsidiary to and included in the former.

It is this kind of people described above that the author has in view in this paper rather than the adherent of a particular sect or party. Consequently it will be seen that the Puritans were not necessarily narrow-minded, but careful observers walking through God's world and admiring His handiwork. They were not confined to one particular type or social class, but among them, as will be seen below, there was a variety, and, what is more, a breadth of intellectual interests. Whitehead describes the seventeenth as the century of genius. For science, it was the century of origins, of dispelling the darkness of the quackery and superstition of alchemists, astrologers and dosers, one of widening, lightening horizons and expanding heavens. In it we find no real conflict of science with religion, but a happy integration of various departments of knowledge, especially in Puritan thought, as all being branches of Divine revelation to God's regent, man.

It will be appreciated that scientific works do not always, or even generally, reveal religious beliefs. Biographers often neglect or fail to appreciate, according to their tastes, the scientific or the religious aspect of a man's life. It is consequently often difficult to discover if a scientist was truly Puritan, or whether or not his religion, if mentioned at all, was merely nominal. This study leaves much more investigation to be done and can only give a partial picture of the work of Puritan scientists. It is confined largely to seventeenth century England. Puritan participation in science is bound up with the history of the whole of that period. The author seeks here to deal only with those who were known to be Puritans or followers of that tradition, and with their investigations which were original rather than their repetition of others' experiments for amusement or technical application. It will be realised that in addition to these, there were other scientific pioneers who were truly religious, as well as those whose religion, if any, was not known. Such are not included, as they cannot be described as holding Puritan views. The Puritans were also pioneers in both the science of education and scientific education, but this is the subject of another investigation on which the author is engaged and which cannot be included in this short paper.

H. T. Pledge, in "Science Since 1500," indicates the geographical distribution of the scientists. He shows by maps that they were more numerous in the industrial areas of the seventeenth century (which were nôt always those of to-day) and also where the Puritan and Parliamentary causes proved to be the strongest in England, i.e., in East Anglia and Kent. Similarly on the Continent, apart from brief periods in Italy, the scientists were largely drawn from Protestant lands such as the Netherlands, some German states and Huguenot France. Robert K. Merton in both "Puritanism, Pietism and Science" in *Sociological Review, XXVIII*, Jan., *1936*, and in "Science, Technology and Society in Seventeenth Century England" (Osiris IV) confirms this. He shows numerically the preponderance of Protestant scientists from the seventeenth century onwards. C. F. Richardson in "English Preachers and Preaching" (New York, 1928) suggests that the Royal Society, with all its interest in the new and experimental philosophy, began with a small group of learned men who were chiefly Puritan divines. The people to whom he refers were the "Invisible College," which met at Oxford from 1645 and later in London as well, Boyle, Wilkins and Petty being some of its prominent members. Dorothy Stimpson similarly in "Puritanism and the New Philosophy in Seventeenth Century England," in *Bulletin of Institute of the History of Medicine III* (*1935*), states that only one was definitely non-Puritan, while it is uncertain about two of this group. Of the original members of the Society when granted the Royal Charter in 1662, forty-two (or sixty-two per cent.) were Puritans of the total of sixty-eight. This was in spite of the facts that Puritans were in a minority in England and that the Royal Society was formed in the strongly anti-Puritan Restoration period. It must be remembered too that a number of other Puritan scientists would not care to join this group, which was under Royal patronage.

The Men and Their Work.

Interested in seeing God through His creation, Puritans found much to delight them in the beauties of the biological sciences. It has been suggested that Puritanism began with John Hooper Bishop of Gloucester, who pleaded for a "purifying of the Church from its very foundations." It seems neither unexpected nor inappropriate that one of his contemporaries should be both botanist and Puritan. William Turner (d. 1568), Dean of Wells, was educated at Pembroke Hall, Cambridge, with his friend Nicholas Ridley, who became fellow-martyr with Latimer in the Marian Persecution. During these fiery days Turner, with others, went into exile on the Continent and was further influenced toward Calvinism. On his return he proved himself Puritan in his violent objection to ceremonial, vestments and bishops. While on the Continent he had also busied himself in collecting plants and information for his great work, "A Newe Herball" (London, 1551). He appears to have been a learned and sound judge of scientific matters, and was the first Englishman to make a systematic study of botany. He complained he had found no physician at Cambridge with a knowledge of plants, so his book indicates the coming of a new era for the science.

Nehemiah Grew (1641–1712) was the son of Obadiah, an Oxford man, who was a Parliamentary divine and schoolmaster. The son, educated at Pembroke College, Cambridge, studied plants and animals as that which "came at first out of the same Hand and were therefore the Contrivance of the same wisdom." He was encouraged by his half-brother, Henry Sampson (1629–1700), who became an ejected minister at the Restoration, and, like many others, turned to medicine, producing some original work in papers on morbid anatomy. Grew, like Sampson, went to the University of Leyden, which gladly received Puritans, and there graduated Doctor of Medicine. He contributed papers on botany to the Royal Society, was elected Fellow and became its Secretary. His "Anatomy of Plants" (1682) is perhaps his chief claim to recognition as a scientist. It was printed at the request of the Royal Society and is a systematic and well-illustrated description of plant structure. He made use of the microscope, employed terms such as plumule and radicle, and made observations on acids, salts and flavours in plant bodies. In his dedication to Charles II, he says, "Your majesty will find that there are Terrae Incognitae in Philosopby as well as in Geography"; and to John Wilkins, then Bishop of Chester, "I hope your pardon if while you are holding that best of books in one hand, I here present some pages of that of Nature into your other: especially since your Lordship knoweth very well how excellent a commentary this is on the former; by which in part God reads the world his own definition of their Duty to him." Grew's interest in the Scriptures is seen in his acquiring enough Hebrew to read the Old Testament in the original. His last work, "Cosmologia Sacra, or a Discourse of the Universe, as it is the Creature and Kingdom of God" (1701) is an argument against Spinoza, the nature of God being deduced *a priori* and *a posteriori* from the necessity of His being and from His handiwork.

Also in the line of Puritan biologists was John Ray (1627–1705). Son of a blacksmith, educated at Catherine Hall and Trinity College, Cambridge, through the generosity of a squire, he became in turn lecturer in Greek, Mathematics and the Humanities as well as a clergyman. At the Restoration he would not conform and resigned his fellowship, becoming a private tutor. Later he educated the orphaned sons of his friend, Francis Willughby. The work of these two is closely connected in various branches of biology. Ray appears to have introduced a common system of classification of plants and animals. In "Methodus Plantarum Nova" (1682) he classified plants by their fruits and in part by the flower and the leaf. He also wrote "Historia Insectorum" and "Historia Plantarum." He studied fossils and suggested their true origin. In other works he divided animals according to their digits and teeth. His "Wisdom of God manifested in the Works of Creation" (1691) was based on lectures he gave in Trinity College when a Fellow there. In it he refers to the works of More, Cudworth, Stillingfleet, Parker and Boyle on the subject. The object of the book was to establish "belief in a Deity," to "illustrate His attributes of power and wisdom and to stir up and increase in us the Affection and Habits of Admiration, Humility and Gratitude." Ray rejected the hypotheses of Aristotle, the Epicureans, of Descartes and even of Boyle. He regarded God as no idle spectator after He had originally set the world in motion. God's wisdom is seen in the multitude, structures and functions of the various creatures he mentions. He quotes numerous scriptures, including his favourite, "O Lord, how manifold are Thy works! In wisdom hast Thou made them all" (Ps. civ, 24). From this study he suggests we are to learn to be thankful, to take care not to mar God's work, especially the human body, and to use all for God's service, while we are to prize and value our souls inhabiting these bodies. This book became very popular and had passed to its fifth edition by 1709, the twelfth by 1759 and at least the fifteenth by 1827.

The early death of Francis Willughby (1635–1672) at thirty-seven was a great grief to Ray. They had been friends from their days together at Trinity with Isaac Barrow. They had travelled together at home and abroad, observing plants, birds, fish, animals and insects. Willughby came from a titled family and was always very studious, not wasting time even from his childhood. He was one of the original Fellows of the Royal Society. His great works were "The Ornithology of Francis Willughby" and "Historia Piscium." Willughby consented to the printing of the former "considering that the publication of them might conduce somewhat to the illustration of God's glory." Both appeared posthumously, the first in 1678 and the latter in 1686. Ray edited them and was possibly responsible for part of the contents. The Royal Society and Bishop Fell regarded these well-illustrated books of sufficient importance to pay the heavy cost of printing them.

A lesser light is James Newton (1664–1750), a friend of Ray and of the great Moravian, John Comenius. This man was a graduate in medicine who kept a private lunatic asylum. He studied botany as relief from his unpleasant calling and published "A Compleat Herbal" containing descriptions of several thousand plants with plates. He apparently wrote another similar work, remarkable for describing forty varieties of apples.

Adam Martindale (1623–1686), whose Oxford course was abandoned through the Civil War, was tutor, schoolmaster, Parliamentarian army clerk, chaplain and nonconformist minister. He wrote on a variety of subjects, including Christianity. Works on mathematics, buoys, Cheshire salt and particularly on the treatment of land by using salt, marl, lime and burning, were his chief contributions to science.

An interesting character was Joseph Glanvill (1636–1680). Educated at Oxford, he became chaplain to one of Cromwell's lords. He was particularly interested in psychical phenomena, and perhaps approached nearer to the truth than many, in his explanation of some witchcraft being due to supernatural causes, in "Philosophical Considerations touching Witches and Witchcraft" (1666). He wrote "The Vanity of Dogmatising" (1655), anticipating the possibility of telegraphy and other inventions. It was later published as "Scepsis Scientifica or Confest Ignorance the Way to Science" (1665) which as its title suggests, was an important work in the dawn of a scientific age.

At the Restoration a number of the two thousand ejected ministers and fellows of colleges turned to medicine for a livelihood. Many of these played a humble part in this century from which honest orthodox medicine grew up. Some other Puritans followed the profession as their normal calling and were found among its most distinguished members. Jonathan Goddard (1617–1675) was an Oxford man who became physician-in-chief to the Parliamentarian army, a member of the Little Parliament and of the Council of State. He became Warden of Merton College, Oxford, but was ejected at the Restoration. His lectures given in 1648 at the College of Physicians to illustrate the wisdom and goodness of God in the structure of man had made him famous. He became Gresham Professor of Physic, and lived in that College, doing experiments for the Royal Society, while he wrote on chemistry and medicines. Seth Ward, Bishop of Salisbury, spoke highly of him and described him as the first Englishman to make a telescope.

Richard Mead (1673–1754), son of an ejected minister, studied medicine at Leyden. He became a popular physician, attending the Restoration Court, collected coins and formed a large library. He wrote on poisons, the itch mite and the history of medicine. In "Medica Sacra" he gave an accurate account of the diseases mentioned in the Bible.

As he was such an outstanding physician, Thomas Sydenham (1624–1689) was called the "English Hippocrates." Born into an active Puritan family, he saw much service as a captain in the Parliamentarian army. Eventually resuming his studies at Oxford while Petty was teaching by the novel practice of dissection, he graduated there in arts and medicine. Sydenham was a man of deep piety, strong religious convictions and independence of thought. Among his manuscripts is "A Short Treatise on Natural Theology." His "Observationes Medicæ" (1676) is considered to be his greatest work. He practised medicine, breaking with tradition and adopting a scientific attitude to make a definite advance in the subject.

Two names are outstanding in seventeenth century science. Of these, one is that of the Hon. Robert Boyle (1626–91). Being of noble birth he had means to travel on the Continent and was apparently converted during his twenty-one months' stay in Geneva, if not earlier. He acquired fluent French, some Italian and studied astronomy. Returning home, he performed various experiments and conducted dissections with the help of Sir William Petty. On settling at Oxford he set up a laboratory in which he employed another famous scientist, Robert Hooke. There the "Invisible College" held its meetings from about 1645. When Boyle moved to London he set up another laboratory with Hooke's aid. On the formation of the Royal Society in this city he became one of the original Fellows, and contributed numerous papers. He wrote among many other things "The Usefulness of Natural Philosophy" (1664) and "The Excellence of Theology compared with Natural Science" (1673). In "The Christian Virtuoso" he states he found few atheists among scientific men and that Christians see more than others of creation. He regarded God as the good Creator of a mechanical universe in which the perfection and intricacy of design showed His glory. Miracles were admissible but infrequent interventions on His part. Boyle's work, all undertaken for "the glory of God and the good of man," shows a great width of learning, of experimental skill and insight.

Remaining an alchemist throughout his life, he did useful work in clearing away much of the debris of the past and became known as "The Father of Chemistry." His "Sceptical Chymist" was published in 1661. He criticised Aristotle's and the alchemists' elements, suggesting instead an atomic theory of indivisible particles of one elementary substance and combination by corpuscles. He was the first to use the term "analysis" in chemistry and employed systematic "wet" methods for it. He separated a number of compounds and the element phosphorus. His study of the chemical effects of heat and of combustion was important. That of gases and vacua led to the formulation of the Pressure-Volume law for gases which bears his name. Thermometry also occupied his attention. He described a box with a lens forming the first camera, which had to wait nearly two hundred years for a film.

Deeply religious, Boyle had a tender conscience which caused him to decline all titles and orders. He refused offers of advancement if he entered the ministry. Because of the oath involved he would not accept the honour of the Presidency of the Royal Society. His missionary interest was shown in the gift of two-thirds of the income of his Irish estates to Irish Church work and one-third to Gospel work among the American Indians. He became president of the Society for the Propagation of the Gospel. As a director of the East India Company, he was active to promote spiritual work in its distant sphere of influence. He corresponded and wrote voluminously about Christianity and Science. John Evelyn wrote to him about founding a "physio-mathematical" college. Always against Hobbes and materialism, he left an endowment for lectures to be delivered annually to defend the Faith against unbelievers.

John Bainbridge (1582–1643) was educated at Emmanuel College, Cambridge. He kept a school and practised medicine. After studying mathematics and astronomy in his leisure time he was appointed professor of astronomy at Oxford. At first giving in to the popular idea that comets foretold events, he later wrote "Antiprognosticon" against astrology, and thus helped to clear the path for future workers.

Another Puritan from Emmanuel, a hot-bed of the faith, was the young clergyman, Jeremiah Horrocks (1617–1641). He, too, lifted his eyes to the heavens, using crude instruments as a self-taught astronomer. Although dying so young he was distinguished for his observation of the transit of Venus. His study of the moon's motion yielded important information. He appeared to have some idea of the satellite's elliptic orbit and of gravity. Newton acknowledged the value of his work and many scientists lamented his early death.

While Isaac Newton (1642–1727) was no true Puritan, his genuine interest in Christianity, his knowledge of the Scriptures, his ascetic life and integrity, and even his Arianism and dislike of Roman Catholics, make him at least belong to the Puritan type. From a child he showed a taste for science. Educated at Trinity College, Cambridge, he learned mathematics there under the Lucasian Professor. This interesting man was Isaac Barrow, an Anglican and Royalist, who, however, took the Parliament's "Engagement", led a blameless life and wrote against Romanism. He recognised Newton's ability and, in order to give more time to theology, was glad to resign the professorship of mathematics in his favour. Newton's work of discovering the binomial theorem and differential calculus in mathematics, gravitation and the nature of planetary motion in astronomy, with that on the refraction of light and on the telescope, mark him out as the outstanding British scientist of the century, if not of all time. His "Principia," published in 1687, if imperfectly understood rapidly became world-famous.

Much has been written about Newton's work and religious views. Some suggest he kept his science and religion apart. This is belied by his life and his own words. In his "Optics" he referred to "a powerful everliving Agent . . . able by His Will to move Bodies. . . ." Also in 1692 he wrote four letters "containing some arguments in proof of a Deity" to Dr. Richard Bentley, who was about to deliver the first Boyle memorial lectures in defence of Christianity. In the first he wrote, "When I wrote my Treatise (his 'Principia') about our system, I had an Eye upon such principles as might work with considering men for the Belief of a Deity and nothing can rejoice me more than to find it useful for that Purpose." This may reveal where he found the inspiration for his work. In the other letters the themes of design and the need for a Creator are prominent. The third for example contains "The growth of new systems out of old without the mediation of a divine Power seems absurd." The extent and content of all Newton's work will probably never be known, as he apparently lost or destroyed many of his papers. It is noteworthy that for forty years after the publication of the "Principia" he published no great scientific work. J. W. N. Sullivan says he was a genius of the first order in matters which he did not consider of first importance. He had a mathematical interest in everything and this with his mysticism led him to spend his later years in Bible chronology, prophecy and alchemy. He was Whig Member of Parliament for his university and very successful in conducting the recoinage as Master of the Mint. Fellow of the Royal Society and then its president for the last twenty-four years of his life, he was also the first to be knighted for scientific work.

Among important mathematicians of the century, it is interesting to see Puritan names prominent. John Napier (1550–1617), a Scot educated at St. Andrews University, and a sincere Christian, zealously Protestant, was a pioneer worker on logarithms and the decimal notation. It may be said that his were the first calculating machines. They were in the form of rods and plates and were described as "Napier's Bones." A landowner, he was also interested in soil chemistry. His spiritual interests are shown in his commentary on the Book of the Revelation.

Henry Briggs (1561–1630), a Yorkshireman educated at St. John's College, Cambridge, became lecturer in physics at Oxford, Gresham professor of geometry and later succeeded Savile as professor of astronomy at Oxford. He was a friend of the staunch Protestant, Archbishop Ussher, so respected by Cromwell. Briggs on several occasions visited Napier in Scotland and they together improved logarithms, changing them to the base 10 for general use.

Henry Gellibrand (1597–1636) was educated at Oxford and became friendly with Briggs, who recommended him for the Gresham professorship of astronomy. He held Puritan meetings in his rooms and encouraged his servant, William Beale, to publish an almanack for 1631, substituting martyrs' names for those of saints. Beale was imprisoned for this but acquitted before the High Commission Court with Laud dissenting to the verdict. Gellibrand published works on mathematics, including trigonometrical tables, on navigation and magnetism. He also completed the manuscript of "Trigonometria Britannica," left unfinished by his friend Briggs.

A lesser light, but a humble godly man, was Ralph Button (d. 1680). Educated at Oxford he became Gresham professor of geometry. With Parliamentarian sympathies he was a member of the committee to reform Oxford and became Public Orator. Ejected at the Restoration, he kept a school, and under the Clarendon Code suffered six months' imprisonment for it.

John Wallis (1616–1703) was a scholar of Emmanuel College, Cambridge, and became a man of remarkably wide learning. As well as the usual theology, Greek and Latin, which he wrote and spoke with ease, he knew Hebrew and French, and studied ethics, metaphysics, physics, mathematics, medicine and anatomy. He was interested in arithmetic which his brother taught him during one Christmas vacation, but he regarded it as suitable only for mechanics. He became a noted dialectician, was ordained and became a private chaplain. After deciphering an important Royalist letter he was appointed official decipherer to Parliament and later to William III. Moved by his patriotism and keen sense of humour, using deciphering, he played a practical joke on the Dutch astronomer Huygens about some scientific matter. Cromwell had great respect for him, but Wallis was opposed to the execution of Charles I. He became an early member of the Royal Society, and was appointed Savilian professor of Geometry at Oxford in 1649. His scathing pamphlets answered the foolish pseudo-mathematical materialism of Hobbes, and included one entitled "Due correction for Mr. Hobbes or schoole discipline for not saying his lessons right, in answer to his six lessons directed to the Professors of mathematicks, by the Professor of Geometry (J. W.)".

Born and educated in Oxford, John Wilkins (1614—1672) took orders, becoming a vicar and a chaplain. He married Cromwell's widowed sister, favoured the side of Parliament and became Warden of Wadham College, Oxford, where his rule was mild and beneficent. Deprived at the Restoration, he was given a rectorship and later appointed Bishop of Chester, in which office he showed leniency to nonconformists. He was one of the Invisible College, an original Fellow of the Royal Society and its first secretary jointly with Henry Oldenburg, a German evangelical. Wilkins was a man of wide interests, sympathetic, of considerable ability and possessed of a vivid imagination. He wrote voluminously on mathematics, astronomy and religion. His "Mathematical Magick or the Wonders that can be performed by Mechanical Geometry" (1648) is a textbook of mechanics, describing various machines and discussing, without altogether dismissing, the possibility of aeroplanes and submarines. Ray, Willughby and others helped him with what has been described as his greatest work, "An Essay towards the real Character and a Philosophical Language," published in 1668. His "Principles and Duties of Natural Religion" (1678) anticipates Bishop Butler's celebrated "Analogy of Religion."

Economic science also had its Puritan pioneers. John Graunt (1620–1674) was a London haberdasher and a man of great integrity, who had been brought up as a Puritan and had been captain of a train band for the Parliamentarian defence of the city, but became a Roman Catholic in his latter days. Because of his valuable work in social science he became one of the few non-university men elected Fellow of the Royal Society. His great treatise was published in 1661, entitled "Natural and Political Observations upon Bills of Mortality . . . with reference to Government, Religion, Trade, Growth, Ayre, Disease." It had passed to its fifth edition by 1676, and the last was edited by his friend Petty, who was particularly grieved at his death.

The work of Sir William Petty (1623–1687) is also outstanding, as he wrote "A Treatise on Taxes and Contributions," and on vital statistics in his "Essays on Political Arithmetic." After a chequered early life in England, at sea and on the Continent, he reached Oxford and studied medicine, joining the group there that eventually formed the Royal Society, of which he was a founder member. Interested in mathematics and mechanics from childhood, he contributed various papers and produced a number of inventions, including a double-keeled ship and a means of mechanical propulsion in a vessel. He was a fellow of Brasenose College, Oxford, and deputy to the professor of anatomy during the Commonwealth. A Protestant with broad views, he became Cromwell's Physician-General in Ireland. While there he conducted a survey and produced an accurate map of the country.

When only twenty-five he wrote "Advice of W. P. to Mr. Saml. Hartlib on the advancement of some particular parts of learning," a tract in which he advises a break with classical education and its "rabble of words," and advocates the founding of a hospital and college of mechanics, a kind of technical university, to advance science by research and publications. The effects, he suggests, would include there "not being so many unworthy preachers of Divinity, pettifoggers in Law, quack-salvers in Physick, . . ." and "Divines having so large a Book of God's works added to that of his word, may the more clearly from them both, deduce the wisdome, power and goodness of the Almighty."

He refers to the "most excellent Idea" of John Pell (1611–1685) about mathematics, written to Hartlib. This suggested the erection of a mathematics library, the librarian to note and "give testimonial after examination to all sorts of practisers as Pilots, Masters, Landmeters, Accomptants." Pell had been educated at Trinity College, Cambridge, and was apparently a fine all-round scholar. He corresponded with Briggs, and Cromwell appointed him mathematics lecturer and then his agent to the Protestant cantons of Switzerland.

Samuel Hartlib (1600–1670), a Puritan and son of a Pole, is worthy of note here, as he persuaded several to write on education, science and religion. Among his own works on these subjects, he advocated "erecting a College of Husbandry Learning" (1651). He acted generally as a clearing house for various ideas making for progress in Protestant Christian unity, promoting education and fostering useful arts and inventions.

Conclusion.

The investigations of R. K. Merton mentioned above, included a study of vocational interests. He found that the peaks for both natural science and medicine were reached at about 1650, after which the graphs remain level. Interest in religion from this point shows a distinct decline. It is particularly interesting to find this occurring after Puritanism had become established and before its political defeat at the Restoration. It is also after the beginning of the Invisible College and before the founding of the Royal Society, containing Cavalier elements, at the beginning of the reactionarv period. R. H. Tawney in "Religion and the Rise of Capitalism" and G. N. Clark in "Science and Social Welfare in the Age of Newton," both see Puritanism as a main driving force in scientific investigation and application. None can blame it for the ills of the Industrial Age which developed as religion declined. Some have suggested that the mechanistic interpretation of the universe found in Boyle and Newton led to the rise of eighteenth century Deism. The expressed views of these two men shows that they thought otherwise.

Interest in pure science appears also to have declined at least for a time. Charles II and his court were too often either interested in scientific experiments as toys for the idle or as gain for the avaricious. His Majesty regarded Boyle's weighing of air (1669) as a matter for laughter and the playwrights Shadwell and Butler followed him. At one period the Royal Society was in danger of being dissolved through lack of financial support and poor attendances at its meetings. The position improved toward the end of the century, perhaps as the fame of Newton spread.

Exhaustion after controversy, persecution, counter-persecution and war, together with the suppression of Puritanism under the Clarendon Code, may account at least in part for the decline in religion. The emphasis generally began to shift from "the glory of God" to "the relief of man's estate," and that often interpreted as personal gain. Interest in problems of navigation, war and industry was growing. Engineering science became a major preoccupation as the Industrial Revolution was on its way. The truth is that generations were arising who were no sons of their Puritan fathers. The Royal Society had always excluded theology from its discussions. Science began to be divorced from religion. Although possessed of new knowledge and powers many scientists began to drift, as they neglected the chart of Scripture, the compass of conscience and the star of Christ.

DISCUSSION.

The CHAIRMAN (the Rev. C. T. COOK) said: J. R. Green, in his *Short History of the English People*, has paid tribute to the manner in which the Puritans shaped the life and character of our nation. They created our love of freedom and broke down barriers which, in other lands, have divided class from class. Their influence in the spheres of commerce and education has also received just recognition. What has not been so generally appreciated is the part they have had in the promotion of scientific study. I feel sure, therefore, that you will agree that Mr. Turner, by his researches into this subject, has rendered notable service to the memory of a religious community to whom we all owe an immeasurable debt. More than that, this paper is a timely contribution to the present conflict between the Christian view of the world and the various trends of materialistic philosophy, whether represented by Karl Marx, Bertrand Russell, Julian Huxley, or Walter Lippmann.

Mr. Turner has made it clear beyond question that scientific investigation finds its best opportunity under the wing of Evangelical Christianity. As he has indicated, the atmosphere of the Roman Catholic Church is not favourable to free inquiry. Copernicus, Galileo, and Descartes, who were Roman Catholics, found themselves hampered at every turn by the harsh rigidity of Romish tradition. Even to this day the Roman system has not succeeded in combining the humblest faith with keen scientific insight. A few apparent exceptions, in actual fact, may be said to prove the rule, for the achievements of Roman Catholic scientists are due to their having persevered in spite of the attitude of their Church.

The Puritan spirit, on the other hand, derived from a lively study of the New Testament, has consistently encouraged men and women to "prove all things," and to "hold fast that which is good." It has laid tremendous emphasis upon personal responsibility, and has encouraged men to bring an independent judgment to bear on scientific problems. To an exceptional degree. Puritanism has been the inspiration of individual initiative.

Then, again, as we are reminded in this paper, full value must be given to the mental illumination which springs from a personal assurance of God. Mr. Turner has told us how Professor Whitehead has described the Puritans as a people "with an intense imagination." In this the Evangelical Christian, as the modern counterpart of the seventeenth-century Puritan, has an advantage over the secularist. He finds in God the inspiring principle of the whole range of his life and thought, and therefore it would seem reasonable to expect that a humble walk with God must bring an element of divine illumination, not only in regard to the interpretation of spiritual truth, but even in connection with scientific research. One recalls, in this connection, a remarkable confession on the part of Thomas Henry Huxley. Huxley was on terms of intimate friendship with Professor Haughton, from whose religious convictions he differed profoundly. One day Huxley remarked to Haughton that though he set little store by the opinions of other religious opponents, he respected Haughton, for he knew how sincerely he believed in the Christian Faith. He then added: "I should very much like to know how it is that you believe what I can't believe." "May I speak frankly?" said Haughton. "Certainly," said Huxley. "Then," replied Haughton, "I don't know how it is, except that you are colour blind." Huxley was much struck, and said: "Well, it may be so. Of course, if I were colour blind, I should not know it myself."

Dr. H. G. Wood has suggested that Puritan hatred of lying, and insistence on absolute truthfulness, have probably not been without effect in developing the scientific temper. Point is given to this observation by recent happenings in Soviet Russia, where some of the ablest scientists have been "purged" because they have not sufficiently subordinated their scientific studies to Marxist ideology.

In conclusion, I venture to suggest that this is a day of exceptional opportunity for Christian witness in relation to scientific problems. Scientific men to-day are not nearly so cocksure as were some of the early advocates of the Evolutionary Theory. Despite everything that may be said to the contrary by Dr. Julian Huxley, scientists are less confident that the scientific method of observation is sufficient to explain the Universe. As Dr. Arnold Aldis declared a few years ago: "The scientist finds himself on the threshold of the Beyond, where reason cannot take him."

Dr. E. WHITE said: Mr. Turner's paper is important in two respects. First of all it represents a considerable amount of historical research, bringing to our notice details of the life and work of many pioneers in the realm of science and medicine. For instance, Dr. Sydenham was the great pioneer of modern clinical medicine. It was not easy to break away from the long tradition of Hippocrates and the Arab physicians. Dr. Sydenham taught us to make careful clinical observations and follow them up with scientific inferences. In this way he made new discoveries, notably in the disease named after him, Sydenham's chorea.

Secondly, the paper is important in its demonstration that the Christian faith is not incompatible with scientific research and knowledge.

The opponents of Christianity have spoken as though Christian teaching bound the intellects of men, and they have talked about free thought as a pre-requisite for scientific thinking; but there can be no such thing as free thought. We cannot think that two and two make five. We are bound by the structure of our minds to think along certain lines. The man who excludes God from his mind, and rejects the revelation of God in Christ, is certainly not free in his thoughts. The story of these early scientific investigators, as it has been unfolded to us in Mr. Turner's paper, demonstrates that Christianity and true science are not opposed. The Voice of Nature and the Voice of Revelation are one, for they are the Voice of God.

Mrs. DOROTHY BEACH also spoke, drawing attention to the knowledge possessed both by Isaiah and Pythagoras concerning the shape of the earth.

Lieut.-Colonel P. W. O'GORMAN wrote: Mr. Turner's interest in the Puritan contributions to the history of medicine and the support given by doctors to the foundation of the Royal Society of London is to be welcomed. It is pleasing to observe how religiously-minded were these Puritan scientists. We should do well to have such sturdy upholders of the glory of God now-a-days when we suffer sorely from a general decline in religion and the advancement of communism and materialism.

Mr. Turner might remember that members of the Roman Catholic Church before the Renaissance were only fellow-pupils of the defective science of their day, which was dominated by Aristotle. Monasteries then, as now, were not mistakenly "fitted for the ideal escape from a physical world, inferior, contemptible and reserved for destruction," whatever that might mean. Nobler motives had their place—the greater glory of God, charity for neighbours, self-education, peace and the conservation of sacred Scripture (the monastic institutions were devoted to the multiplication and embellishment of holy Scripture).

Nor was there any discouragement of science by the Church. On the contrary the dozen existing universities, founded by the Popes, were well advanced. (*See* J. J. Walsh, *The Popes and Science; The Thirteenth: Greatest of Centuries; Makers of Modern Medicine*, etc.)

Author's Reply.

It is gratifying to note the kindly reception given to the paper in expressions of its value to the Christian faith and also in the helpful comments.

In his remarks as Chairman, Rev. C. T. Cook has apparently answered in unconscious anticipation Lieut.-Colonel P. W. O'Gorman's defence of the part played by the Roman Catholic Church. It is appreciated that this body stands against materialism and for the honour of God and His truth. It is also agreed that some monasteries were the custodians and teachers of the learning, including "the defective science" of their own and past ages, but the schools of the nobles' courts and of the tradesmen's guilds also played a part. The Christian interest in the healing sciences was also preserved by the monks, but it was left to medical men like Sydenham, as Dr. E. White suggests, to go beyond Caius and Linacre, clearing away the debris of the past and making advances for the blessing of man.

Mediæval universities were institutions for teaching and discussion, taking no part in scientific research. The science that was taught lacked the backing of experiment and critical temper. Whatever the official attitude of the Roman church was, the activities of its officers were often against scientific investigation, as Mr. Cook states. Typical were the superior who refused to observe or believe the sunspots seen through a telescope by one of his monks and the priests who declined to look into Galileo's instrument, while it was 1234 before Pope Gregory IX permitted the teaching of even Aristotle's Physics, and the works of Copernicus remained on the Index of forbidden books until 1822. Discoveries before the Reformation truly were made in spite of, rather than because of encouragement from Rome, and it must be remembered that there had not yet separated a rival body.

The Christian has really nothing to fear from the investigation of the truth of God's creation, but needs to beware of calling theory fact and speculation discovery. As these Puritans showed, it is God's intention that His universe should be explored and understood, His word, as Mr. A. G. Tilney so ably states, encouraging such study. The 1949 Puritan can follow on in the endeavour to see science and religion integrated for God's glory and man's blessing.