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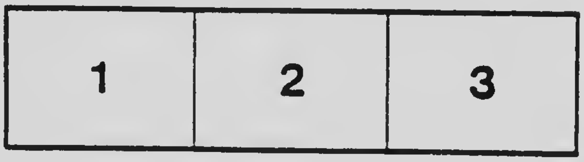
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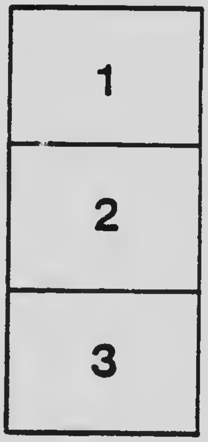
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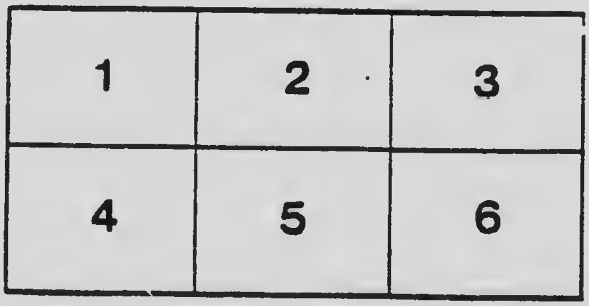
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ON THE ORIGIN OF LIFE ON THE GLOBE

BY

A. B. MACALLUM, Sc.D., F.R.S.

Reprinted from The Transactions of the Canadian Institute

Vol. VIII., Pp. 423-441

ON THE ORIGIN OF LIFE ON THE GLOBE.

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There are some subjects to which the highest intellectual interest of mankind will always be directed. Amongst these are the nature and origin of matter, the illimitable extent of the universe, the nature of the processes underlying thought, the origin and development of man, the origin and significance of religion and, last but not least, the origin of life. In these subjects are concentrated some of the profoundest problems which have ever tasked the intellectual power of man, problems the solutions of which, if they are ever reached eventually, must fundamentally affect human destiny, for that destiny, if it is to be one in which what we call progress is to participate, must ever be indissolubly associated with satisfaction of the cravings of the human intellect.

A few of the problems are cognate and, therefore, the solutions of some of these assist in the determination of the others. It is conceivable that the origin of matter and the extent of the universe are intimately related questions, and therefore, to advance towards certainty in one of them is to render less difficult the solution of the other. Further, the nature of the processes underlying thought is associated with the question of what life means on its physical side and the latter is in its turn intimately connected with the question of the origin of life. To conquer a solution in one case does more than facilitate a solution in another. It stimulates the human mind to greater effort. To the race of mountain climbers the conquest of one peak from which another of towering height may be seen, is not to daunt but to kindle an inscrutable ambition to dare and do in order that the climber may possess, for perhaps one rare moment only, the vision and the outlook from the new point of view far above the snow line.

The problem that appeared most difficult of all was the origin of life on the globe, nay the origin of life throughout the universe, if it be granted that the earth is not the only planet on which living forms have made their appearance or are making their appearance. The difficulty of the problem arose from the fact that little was known about the chemistry of the vital processes and even of the physical basis of life itself, that is, what has been commonly called protoplasm. Indeed the imagination was tasked to explain how a mixture called living matter could manifest the changes and transformations which are characteristic of life, the phenomena of assimilation, growth, reproduction and the transmission to the off-spring cells of the properties of the parent cells, the capacity to go on endlessly, if favorable environing conditions are maintained. These features of living matter have no counterpart in what is called dead or inorganic matter, and the gulf between the living and the non-living was not supposed to be bridged over by any means at the command of the thinker or the man of science. Is it any wonder that half a century ago when Darwin was writing his "Origin of Species" he should have used in the closing chapter of that work language which implied that he believed the one primordial form, from which all living things on this earth have had their origin, was called into existence by the direct act of a Creator? He laboured to show that all living forms arose from simpler forms in the past and that this evolutionary process is still going on and thus he accounted for the richly varied fauna and flora of the globe, but his mind evidently shrank from offering a solution of the question how the one parent form of all arose in the far distant past.

This was not, however, in every case the attitude of those who gave thought to the question. Twelve years after the publication of the "Origin of Species," that is in 1871, Lord Kelvin,* then Sir William Thomson, advanced the view that the impossibility of bringing about the conversion of lifeless into living matter without the aid of already living forms was as definitely established as is the law of gravitation and that consequently the only way to account for life on this planet was to suppose that it was originally borne by meteorites from outside the solar system. To this latter hypothesis he gave his full adhesion.

This theory did not receive general assent. It was recognized that even if living organisms could be so borne to our planet they would be destroyed by the intense heat generated when the meteorites began to penetrate the earth's atmosphere. Further the minimum amount of time required to transport such organisms on meteorites from the stellar system nearest to our own, namely that of α Centauri, would be about 62,000,000 years, and this at a speed of about 40 miles an hour and it would take nearly 140 years in going from Mars to the earth, at the same rate of speed. This length of time put the theory out of court,

*Presidential Address, British Association Meeting for 1871.

for organisms even under the most favorable conditions on our own planet have not in any case shown a capacity to remain germinative for more than a few years and consequently organisms which might arrive, meteorite-borne, from far distant stellar systems, even if they were not utterly destroyed by the intense heat generated at the moment of contact with the earth's atmosphere, would be utterly sterile.

This theory of the origin of life on the globe, now known as Panspermia, as already stated, did not receive general support and it would have perhaps in all discussions of the subject been deserving only of a reference had it not been revived in another form in 1903 by Arrhenius, the Swedish Chemist,* who employed the recently discovered fact of the pressure exercised by light and other radiations to show that organisms could be driven through space independently of meteorites and at a velocity enormously greater than the latter manifest. The pressure exerted by these radiations would, according to Arrhenius' calculations reduce the time for the transportation of organisms from α Centauri from 62,000,000 years to 9,000 years and from Mars to Earth to twenty days.

The greatest difficulty in the way of acc[illegible] hypothesis of Panspermia is not the great length of time, sl[illegible] as it is by the motive power of the radiations, but the intense c[illegible] light to which the organisms would be subjected in their course through space, but Arrhenius holds that this difficulty does not obtain [illegible] cites the observations made by Duclaux on *Typothrix scaber*, a[n] organism which occurs in milk and which is capable of undergoing a [illegible] exposure to bright sunlight without injury and Roux has sh[own] [illegible] the organisms causing splenic fever are not injured by bright light [illegible] they are kept in a vacuum. From this it would appear that ox[ygen] [illegible] be present in order that light shall injuriously affect bacteria.

Intense cold, Arrhenius points out, does not necessari[ly] [illegible] ously on all germs. Macfayden kept spores of bacteria at [illegible] two months without affecting them appreciably. The intense [illegible] cold should not be destructive but preservative, for the dimin[illegible] eventually, the loss of germinative power is certainly du[e] [illegible] chemical changes, the rapidity of which is greatly diminish[ed] [illegible] temperature is lowered. Thus in the case of vital processes [illegible] been investigated, a fall of 10° C. reduces the speed of reaction [illegible] therefore, the rate of reaction responsible for the ultimate lo[ss] [illegible] vita[illegible]

*Arrhenius' views on Panspermia are given in "Das Werden der Welten" (trans[lated fro]m the Swedish into German by L. Bamberger), Leipzig, 1907.

would proceed at –220° C., that is, the temperature of interstellar space, at one thousand millionth of the rate which obtains at 10° C., so that a journey of 3,000,000,000 years in space would be no more injurious in effect than one day's exposure to a spring temperature and sunlight on this planet. Inside of the solar system the temperature would be somewhat higher owing to the proximity of the sun, but the journey would be short and the microorganisms would survive.

The low temperature of interstellar space would reduce to a negligible minimum both photo-chemical changes and the rapidity of desiccation in the microorganisms on their journey. Schroeder has shown that *Pleurococcus* which grows on moist surfaces, as, for example, the bark of trees, and *Scenedesmus* whose normal medium is water, may be kept alive for twenty and sixteen weeks respectively, in a desiccator over concentrated sulphuric acid. Further, it is natural to suppose that desiccation, that is, evaporation, would be proportional to the vapour tension of water, which at –220° C., has not been directly measured, but can be computed approximately from the latent heat of evaporation by means of a formula given by van't Hoff and from it Arrhenius concludes that desiccation does not progress any farther in millions of years at –220° C., than in one day at 10° C. above zero.

The low temperature of interstellar space, therefore, reduces enormously in living matter the chemical changes that diminish vitality, the rapidity of photo-chemical changes and of desiccation and, in consequence, the life of microorganisms traversing interstellar space would be prolonged sufficiently to enable them to reach the earth and the other planets of the solar system in a condition to continue life and reproduce themselves in their new environment.

Arrhenius admits, however, that the organisms which thus arrive would in their first contact with the atmosphere of the earth encounter a temperature of not less than 100° C. due of course to that generated by friction. This he holds will not necessarily sterilize the organisms as protein, which is their physical basis, is not in the very dry state coagulated by such a high temperature, but it is exceedingly doubtful indeed if organisms which are supposed to retain in their long journey through space moisture enough to enable them to begin terrestrial life, would be profoundly unaffected by a temperature which ordinarily is germicidal.

There are in the main two objections to the Panspermic Theory, The first and chief is that it does not account in the last analysis for the origin of life, but merely assumes that life began somewhere else in the universe, how and in what form it does not explain. The higher forms of life in that planet wherever it may be, if endowed not only with mental capacity like our own, but also with intellectual curiosity, would still have to account for their primal origin and it would not serve to say that the whole universe had been sown with life from their planet home. The burden which lies on those who believe in the Panspermic theory is to prove that life did not originate primarily on this globe.

If indeed the advocates of the Panspermic Theory were to claim that life has always existed since cosmic dawn and that the first living form was as much a directly creative act as the primal genesis of matter or of force, the position taken would in my opinion be a logical one, for the inscrutable agent that brought the universe into existence, might be supposed in that very act to have purposely endowed matter with a potency which in those primal conditions could not but have been realized.

The failure to postulate such a primal endowment and its result and the supposition that life had its origin on some planet in the universe, more or less like our own, predicate that origin elsewhere but do not explain it. He who believes that life throughout the universe had a community of origin may because of his theory be richer in poetic sentiment, but it does not help himself or others to formulate a satisfactory explanation of the primal origin of life either on this globe or elsewhere.

There is one objection to the Panspermic Theory which the biologist may advance. If terrestrial forms of life owe their origin to a form generated elsewhere, the latter must have been specially fitted to begin and continue life on this globe when its water contained nothing but inorganic salt and gases, such as nitrogen, oxygen and carbon dioxide, for such a form would have to assimilate not only carbon dioxide but also free nitrogen. The organisms upon the properties of which Arrhenius relies to show the possibility of forms surviving a long journey through interstellar space are all those of a highly specialized class, some of them capable of assimilating carbon dioxide, others of living only in media containing substances which are themselves the products of biochemical synthesis. None of these have the power of synthesizing their constituents out of wholly inorganic material including carbon dioxide and nitrogen. So far as yet known only certain of the Cyanophyceæ possess that power as Beijerinck* has pointed out and these, though primitive in their structure are of a so highly specialized vegetable character as to preclude their being considered as the forms from which both animal and vegetable organisms arose. Unless there were more than one form which reached the earth from far distant stellar systems, the organism which started life on the earth must have been very simple and neither animal nor vegetable definitely in its metabolic processes, in fact, in the latter respect like the Peridineæ which are also remarkable in that in them is found an exceedingly primitive type of nuclear division which, with their metabolism, indicates that they are very archebiontic in character. Whether they assimilate free nitrogen is not known.

It must be admitted that there are in the Panspermic Theory difficulties which are not overcome in explaining how the primal organism or organisms could reach the earth from far distant planetary systems, difficulties which are concerned in understanding how an organism itself of an indifferentiated character, even if it escaped destruction in transit, could find a terrestrial medium which would permit it to thrive and reproduce itself.

Because of these difficulties one turns to the theory of the origin of life on this planet which postulates that its first living form arose as the product of the action of physical and chemical forces on the constituents of the water and the atmosphere at a certain time in the history of the globe. This mode of origin is sometimes referred to as spontaneous generation but that name has so invidious a history and has been in the past associated with such extravagant speculations that it would perhaps be wise to abandon it and adopt another. It is further not a defensible name for in no sense can life be regarded as spontaneously produced on the globe to-day and the term "spontaneous" when used in this respect implies that living forms may arise *de novo* out of non-living matter at any time under the ordinary physical and chemical conditions which now obtain. The view so implied is not a defensible one as we shall see presently and it is well, therefore, to avoid the use of terminology which carries with it such an implication.

Aristotle was the first who definitely advanced the view that living organisms first arose spontaneously, but the view was held in a more or less inchoate form by the Greek philosophers from Thales onward. The poet, Lucretius, expressed this view when he said that "the earth

*M. W. Beijerinck—"Further Researches concerning Oligonitrophilous Microbes," Kon. Akad. van Wetensch., Proceedings, Vol. 4, p. 5, 1901-2.

has rightly received the name of mother since all things are begotten of it and many living creatures arise out of it, having been generated by the rains and the warm mists formed by the sun."*

From the time of Lucretius and till the nineteenth century the belief in the occurrence of spontaneous generation was almost universal and it was not an unnatural result of the observations which were made in an uncritical age. It was well known that when a quantity of tissue like beef-muscle is exposed to the free air and sunshine at summer temperature the larval forms of flies and other insects appear in it in a few days. The explanation of their appearance there was that they were spontaneously generated in the putrefying animal flesh. This explanation was everywhere excepted until Redi, in 1668, definitely showed that when meat is placed in a wide-mouth jar and the mouth covered with thin gauze so as to permit free entrance of air and warmth, but also so as to exclude flies, no larvæ made their appearance in the medium and thus the larvæ which ordinarily grew there were not due to any spontaneous generation but to the eggs deposited by flies.

These observations of Redi were conclusive so far as they went and gradually the instances where spontaneous generation was supposed to occur became fewer the more the microscope was employed to study the occurrence and characters of forms of life known as animalculæ. It was not, however, admitted on all hands that the minute organisms such as the microscope of the seventeenth and eighteenth century revealed to the investigator arose from pre-existing forms and this view was stoutly maintained by Needham and Buffon. Needham found that when he heated infusions of animal or vegetable material in carefully corked vessels to such a temperature as would destroy germs existing in the infusions, the latter kept for a few days at the temperature of the room were found to swarm with animalculæ and therefore the latter must have arisen from matter which was not alive. This work was repeated by Buffon and Needham's results were corroborated.

It was, however, pointed out by Spallanzani that Needham's and Buffon's conclusion did not follow from their results. He found that if the infusions were heated for half an hour or more in glass vessels hermetically sealed by fusing their necks in the flame, no animalculæ

* "Linquitur ut merito maternum nomen adepta
Terra sit, e terra quoniam sunt cuncta creata.
Multaque nunc etiam exsistant animalia terris,
Imbribus et calido solis concreta vapore."
—De Rerum Natura, Lib. V. 793-790.

ever appeared in them so long as they were contained in such air-excluding vessels.

The discovery of oxygen and its properties led those who accepted spontaneous generation to claim that in these experiments of Spallanzani and others, one of the most necessary factors, namely oxygen, was excluded, and thus their results did not confute the idea of spontaneous generation. The discussion on the subject went on on this basis through the early years of the last century but it was closed only on the publication of the results of Schroeder and Dusch in 1854 and of Schroeder in 1859. These observers found that when, instead of hermetically sealing by fusion the necks of the vessels containing infusions of animal or vegetable matter, the mouths were closed with plugs of cotton wool, the infusions, which were heated as in Spallanzani's experiment, did not subsequently contain animalculæ, although the oxygen, but not the organisms, of the atmosphere gained ready entrance to the medium through the cotton wool.

The net result of the investigations of the last half-century has been to show that living matter does not originate spontaneously under any condition which obtains on the globe to-day, nor can it be granted that it may arise spontaneously in any culture medium however favorable the latter may be to the generation of living forms *de novo*. It is necessary to be thus explicit for otherwise I might be understood as accepting views which are still advanced in certain quarters, but which seem to me to be utterly untenable.

To repudiate spontaneous generation and to believe that a living form did at one time in the history of the globe arise from non-living matter are two very distinct positions to take and yet I accept them both as tenable. It is not necessary to defend the first for I have already said enough to that end. The second position is practically that already taken by biologists generally Huxley, whose address as President of the British Association for 1870 was a crushing refutation of the doctrine of spontaneous generation, practically endorsed that position in language which will bear repetition here. After indicating his inability to hold any belief as to the primal origin of life he went on to say :—"But expectation is permissible where belief is not, and if it were given me to look beyond the abyss of geologically recorded time to the still more remote period when the earth was passing through physical and chemical conditions, which it can no more see again than a man can recall his infancy, I should expect to see it appear under forms of great simplicity, endowed like existing fungi with power of determining the formation of new protoplasms from such matters as ammonium carbonates, oxalates and tartrates, alkaline and earthy phosphates and water without the aid of light."

The greatest difficulty experienced in attempting to account for the origin of life on the globe as a result of physical and chemical conditions has always been found in the complexity of the molecules of the proteins which enter into the composition of protoplasm, the physical basis of life. Forty, thirty, and even ten years ago the constitution of protein seemed an insoluble riddle. Proteins are undoubtedly the most complicated compounds known to the chemist. The latter has been able to determine the composition of as many as one hundred thousand organic compounds, that is, apart from proteins, the whole range of organic compounds, but he was unable till recently not only to synthesize the simplest protein derivatives but also to have even a faint conception of what atom groups the protein molecule is composed.

The work of Kossel and his school gave the first light on the problem. By means of hydrolysis with dilute mineral acids the protein molecule was shown to be largely constituted of amino acids, acids in the majority of cases belonging to the "fatty" series with one of the hydrogens of one or more alkyl groups replaced by NH_2 and thus giving bodies each of which is at the same time both an acid and a base. The simplest of these amino-acids is known as amino-acetic acid which is constituted thus:—

$$CH_2(NH)_2.\ COOH$$

This is one of the most abundant constituent atom-groups of the molecule of gelatine. The next higher amino-acid is α-amino-propionic acid which is commonly called alanine and which has the following constitution:—

$$CH_3.\ CH(NH_2).\ COOH$$

There are a large number of others, the more important of which are cysteine or α-amino-β-thio-propionic acid:—

$$CH_2(SH).\ CH(NH_2).\ COOH\ ;$$

Valine or α-amino isovalerianic acid,

$$\begin{matrix}CH_3\\CH_3\end{matrix}\Big\rangle CH\ \ CH(NH_2).\ COOH\ ;$$

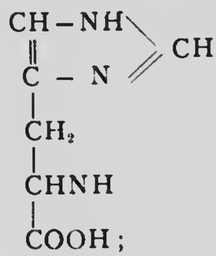
Leucine or α-amino-isobutylacetic acid,

$$\begin{matrix} CH_3 \\ CH_3 \end{matrix} \rangle CH.\,CH_2.\,CH(NH_2).\,COOH\,;$$

Arginine, or δ-guanidin-α-amino-valerianic acid,

$$NH = \overset{\displaystyle NH_2}{\overset{|}{C}} - NH\,CH_2.\,CH_2.\,CH_2.\,\overset{\displaystyle NH_2}{\overset{|}{C}}H.\,COOH\,.$$

Histidine, or β-imidoazol-α-amino-propionic acid,



Lysine or α-ε diamino-caproic acid,

$$\overset{\displaystyle NH_2}{\overset{|}{C}}H_2.\,CH_2.\,CH_2.\,CH_2.\,\overset{\displaystyle NH_2}{\overset{|}{C}}H.\,COOH.$$

The presence of these and other amino-acids in the protein molecule is highly significant. If we regard the molecule as a building or edifice then these amino-acids are the building stones and the character of the molecule must depend on the amino groups which constitute it just as the character of the building depends on the building materia used.

The occurrence of methyl groups places the relation of the proteins to the fats and carbohydrates in a very clear light. It indicates that after all the distinction between proteins on the one hand and fats and carbohydrates on the other is not a radical one and that the framework of the molecules in all three classes of compounds is fundamentally the same, namely, a chain of alkyl radicles arranged in series and groups more or less individualized in the chain. The highest number of alkyl radicles in a single group is that found in diam[illegible]-trioxy-dodecanic acid, $C_{12}H_{26}N_2O_5$, of which there are small quantities found in certain of the proteins but the most common groups are those which have less than six alkyl radicles.

In addition to the alkyl radicles there are those of benzene and indol as, for example, in tyrosine and tryptophane. These appear to be associated with the alkyl radicles but they constitute only a small percentage of the total protein molecule.

The work of Kossel and his pupils was paralleled by that of Emil Fischer. The latter devoted his energies to the synthesis of proteins in the laboratory and the success which he has achieved so far in his efforts has been such as to make it possible to hope that the synthesis of protein is a matter now of a few years' steady experiment and investigation. The compounds synthesized contain atom-groups formed of the amino-acids and because a majority give one of the reactions peculiar to peptones he has termed them peptides. The method upon which he has proceeded is to allow an acid chloride of a halogen fatty acid to act on an amino-acid as indicated in the following equation :—

$$CH_2\,Cl.\ COCl + NH_2\,CH.\ COOH = CH_2\,Cl\ CONH.\ CH_2\,COOH + HCl.$$

The resulting product is then made to react with ammonia thus :—

$$CH_2\,Cl\ CO.\ NH\ CH_2\ COOH + NH_3 = CH_2\,NH_2\,CO.\ NH\ CH_2.\ COOH + HCl.$$

The compound produced which is called glycyl-glycin can itself be converted into a chlorinated compound and that acting on glycin gives a peptide holding three amino-atom-groups :—

$$CH_2\,NH_2\ CO.\ NH\ CH_2\,CO.\ NH\ CH_2\,COOH.$$

The compound formed is diglycylglycin.

The syntheses of peptides have been effected by Fischer and his students in over one hundred cases and the largest number of amino acid radicals synthesized in the one nolecule as yet is eighteen with a molecular weight of 1213 but this suffices to show that the method employed is one by which the synthesis of protein from simpler compounds is ultimately to be accomplished. That the peptides formed by Fischer do, in the main, not differ from peptones in the manner in which their atom groups are combined is shown by the fact that trypsin, the digestive ferment, breaks a number of them up into the simple amino-acids just as this ferment does in the case of the peptones. That there is any difference at all between the more complex peptides thus formed and the peptones themselves is due to the character as well as the number of atom-groups forming part of the chain and it is, therefore, not inconceivable that having determined how many examples of each there is in the peptone chain, the artificial production of the latter in the laboratory may soon be effected. The production of peptones in this manner would lead eventually to the synthesis from them of proteins.

The results achieved so far show that the constitution of proteins is no longer an insoluble mystery and that their manufacture in the laboratory is not an impossible event. The presence of these amino acid radicals in vegetable as well as in animal proteins indicates that biochemical synthesis proceeds in the same way in both kingdoms and that practically the same construction material is used. As proteins are the material of which the material basis of life is constituted it is manifest that if we could explain how proteins first arose without the participation of living matter in the synthetic act we might be in a position to explain the origin of living matter itself.

The simplest proteins that we know are protamines which are found in the heads of the sperm cells of fishes and united there with a special compound of phosphorus known as nucleic acid. The compound in the heads of the sperm cells is responsible for the functions the sperm cells perform and it is the physical basis of the life of the sperm element. Some of these protamines are constituted of diamino acids only and are thus practically compounds intermediate between peptides and proteins but their chief significance is that they show that complex vital processes can function in such comparatively simple compounds, that is, the molecular constitution with which vital processes are associated may be of a comparatively simple kind.

The simplest proteins, that is, protamines, as well as the most complicated and highly organized proteins do not form true solutions with water but rather what is known as colloidal suspensions, suspensions, however, in which the particles suspended or held in the fluid are of so minute a size that they cannot be seen with the highest powers of the microscope. The limit of microscopic vision is about 0.14 of a micron, that is, of one thousandth of a millimetre. An object more minute than that or under one-one hundred and seventy-five thousandth part of an inch cannot be seen. To have, therefore, any evidence, that in solutions of proteins the latter are in the form of suspended particles one must employ the ultramicroscope, that is, a modification of the microscope which will reveal the presence of such particles in practically the same manner as particles of dust which float in the path of a sunbeam are revealed. If one were to stand in the course of a sunbeam and look toward the source of the light, namely the sun, no floating dust particles would be seen but if one stands aside in the dimly lighted room and looks at the beam the dust particles come out very clearly, for the light which is reflected from the numerous facies of each comes to the eyes as divergent rays and the dust particles are thus seen greatly magnified. Quite so in the ultramicroscope the light instead of coming from the reflector under the microscope straight through the microscope to the eye, is sent obliquely through the object, which in this case is a drop of colloid solution, the particles in suspension of which scatter the light as the dust particles do in the sunbeam and in consequence some of the divergent rays passing up the tube of the microscope and reaching the eye reveal the particles as greatly magnified flashing points of light. In fact the particles in such a case set against the dark background of the field appear like as if they were bright stars set in the cloudless, moonless night sky.

The ultramicroscope will not reveal the presence of particles less in diameter than one-hundredth of a micron, that is, less than one-two million five hundred thousandth part of an inch, so that the limits of ultramicroscopic vision are 1/7 and 1/100 of a micron. What their true measurement may be in the case of protein solutions we do not know but Mr. E. F. Burton* has, by an ingenious method, determined that the suspension particles of colloidal solutions of gold, platinum and silver have a diameter which ranges between 2/100 and 6/100 of a micron. It is not unlikely that these represent also the limits in the diameter of the particles in protein suspension solutions.

Now the significance of these particles comes out strikingly when it is recognized that protoplasm is constituted of myriads of such suspension particles of protein closely packed together and that the properties of living matter, that is, protoplasm, are the properties also of each suspension particle present in it. Each particle in protoplasm is in a definite sense alive just as is the protoplasm as a whole and consequently though it may not continue to live after its separation and isolation from its fellows because there has developed amongst them an interdependance, it is conceivable that ultramicroscopic particles consisting of but a few molecules of protein appropriately constituted could live separately and reproduce themselves by division when the particles had grown beyond a certain size.

*Phil. Mag., Vol. (6), 11, p. 425, 1905.

That such ultramicroscopic forms of life exist we know in a few cases at least. Beijerinck in his study of the disease of tobacco leaf found that the causative element could not be seen with the highest powers of the microscope and that it was minute enough to pass through the pores of a Chamberland filter. That the disease is due to a micro-organism and not a ferment other facts determine beyond doubt. Further, the consensus of opinion amongst those who have carefully investigated the question is that yellow fever is due to a micro organism which is ultramicroscopic and it is possible that the pathogenic agent in rabies is also an organism that is beyond the limits of microscopic vision.

It is not necessary to multiply instance, it suffices for our present purpose to note that there are to-day organisms which consist practically of suspension particles constituted of a few molecules aggregated as in the case of each protein particle in suspension in a "solution" of white of egg, and that these molecules in each single isolated particle carry on the functions which we usually group under those of life.

When in consequence we seek to explain the origin of life, we do not require to postulate a highly complex organism such as we can see even with the low power of the microscope, as being the primal parent of all, but rather one which consists of a few molecules only and of such a size that it is beyond the limits of vision with the highest powers of the microscope. Such an organism would be the smallest unit of life and it might be supposed that protoplasm arose from aggregation of such units, each more or less differentiated from its fellows, just as the higher or multicellular forms of life have arisen by aggregation of cells which have differentiated more or less, thus giving rise to differences of function in the different parts.

The question which we now must face is this:—Did conditions ever exist in the history of the globe which favoured the production by natural means of such ultramicroscopic organisms? The answer which I would make to this question is an affirmative one.

According to the Nebular Theory a great many constituents of the rock crust of the globe such as carbon monoxide, carbon dioxide, chlorine, phosphorus as phosphoric pentoxide, sulphur as sulphur dioxide and trioxide, potassium, sodium, calcium, magnesium, as well as all the water on the globe, were, when the earth was cooling down from 1200° C. to 900° C., in the atmosphere, the pressure of which on calculation was greatly over 270 times that of our atmosphere. As the temperature sank below 900° C., the sulphur dioxide, and trioxide, the phosphorus as phosphates and the sodium, potassium, calcium and magnesium compounds condensed and there remained in the atmosphere water vapour, oxygen, nitrogen, chlorine, carbon dioxide and carbon monoxide which left the pressure of the atmosphere about 270 times what it is now. When the temperature fell to 350° C. condensation took place until only a pressure of 190 atmospheres remained and as it fell lower still further condensation occurred and a further reduction of pressure obtained but it must at least have been 30 times the present pressure when the temperature was about 120° C. In this enormous pressure there must have been countless condensations and the water condensed must as often have boiled away from the hot rock crust as soon as deposition occurred. As these condensations were obtaining in the high pressure atmosphere there must have been electrical discharges of enormous voltage which would cause the formation of ammonia, and as carbonyl chloride must have been present urea must have been formed. There must have been present also in the atmosphere hydrocarbons of all kinds for the action of water on the hot rock crust must have formed them from the metallic carbides such as carbide of iron and of calcium, as probably happens to-day also in the production of petroleum compounds in connection with hot subterranean rocks. Since the temperature was high the hydrocarbons, being volatilizable, diffused in the atmosphere and in conjunction with chlorine vapour, carbonyl chloride and carbon dioxide innumerable syntheses would occur, many of them being of the chain type and with the carbon dioxide the carbonyl chloride and the ammonia present amino-acids would be formed, especially when the temperature sank below 100° C. The amino acids would also occur in the chlorinated condition which would facilitate, as in the laboratory, synthesis of polypeptides and as these would obtain in the condensations of aqueous vapor the synthesis of proteins from the polypeptides would occur in the chlorine-containing water.

This formation of amino-acids and their synthesis to form proteins would take place countless millions of times and in every variety of constitution until one giving the right composition resulted in ultramicroscopic particles which, endowed with the chemical properties of ultramicroscopic organisms, would thrive and reproduce themselves in water which contained amino-acids and which would thus supply readily assimilable food to the newly formed living structures.

Just at what temperature such a synthesis and such an origin of ultramicroscopic organisms occurred it is difficult to say but it is possible that it may have been about or slightly above 80° C. We are so accustomed to think of living forms being destroyed at a temperature above 75° C. that we are not prepared to believe that a higher temperature would leave unaffected living forms of a simple chemical constitution, but that is because we attribute to all living forms a complex chemical constitution which is easily affected by high temperatures. It is not inconceivable that of the forms of life we know even the simplest are highly complex and thus we cannot bring ourselves to understand that living forms may exist or could have existed which possess or possessed only a tithe of the properties which we attribute to living forms. With the simpler constitution temperatures somewhat above 80° C. may have been harmless in their effect on such ultramicroscopic organisms as may have first arisen.

Once arisen the forms would continue and reproduce themselves just as the ultramicroscopic particles in living matter increase in size and reproduce themselves by division in order that there may be additions to the protoplasm such as growth demands. It may be that countless forms of ultramicroscopic organisms developed and vanished before one arose endowed with the constitution and properties which would enable it to survive through all the physical conditions attendant upon its origin. Such a form once brought into being would start on its long career, out of it would develop the protoplasmic mass just visible under the highest powers of the microscope and gradually but eventually from that again the living cell, the parent form of all structures such as we ordinarily recognize as animal and vegetable organisms.

It may be objected that this explanation of the origin of life on the globe is based on conditions postulated by the Nebular Theory and that such high temperatures did not obtain if the earth was formed in the manner demanded by the Planetesimal Theory, as advanced by Chamberlin. In answer to this objection it may be said that the Planetesimal Theory does not exclude the occurrence of gaseous, molten and high temperature stages in the earth's history. Chamberlin admits that the infalls of the planetesimals to form the earth would result in high temperatures, in volatilization of many constituents of the present solid globe and that the present high temperature in the earth's interior which is assumed to be about 20,000° C. may have been inherited from an earlier stage. Further, according to Chamberlin the hydrospheres first appeared when the earth had half its present diameter, that is when it was no larger than Mars is now.

As to the temperature preceeding this period of developm Chamberlin is not quite certain, for his language is as follows:—*

"There was, however, a terrestrial source of heat and lig critical importance, namely, that arising from the infall of the tesimals. If this infall were at a rate sufficient to heat the surf of the earth above 00° C. life of the present types would have bee pro-hibited. The present stage of the inquiry does not permit an very confident opinion as to whether this excess was reached or not. Leaving this question open, it is to be noted that if, at the stage when an atmo-sphere and hydrosphere could be held, the infall of planetesimals rapid as to heat the surface to a prohibitive temperature, the rate must almost certainly have declined as the number of planetesimals the earth's feeding zone was diminished so that, long before e sup was exhausted and growth ceased, the rate must inevitably have fall below the prohibitive limit. If, therefore, the earth were too hot for li when one-fifth grown, its temperature might have become suitably mi when one-fourth, one-third, one-half, or three-fourths grown. Growth after this permissive stage was reached would be slow and the period required for its completion would still be long."

It is obvious therefore, that even the Planetesimal Theory does not negative the view that high temperatures did obtain in the earth's atmosphere before a hydrosphere was formed or even after one was developed, and that the conditions which would obtain, on the basis of the Nebular Theory, as favorable to the origin of life, would obtain in the planetesimal development of the earth.

Just at what period in the earth's history these conditions obtained it is not now possible to say. We know that highly developed forms like *Olenellus*, forms quite as highly developed and specialized as vertebrates. appeared in the early Cambrian Period, and therefore, the development of such highly specialized forms must have begun at a vastly earlier stage. But back of all this is a period incalculably longer, a period during which the cell was specializing into animal and vege-table types and back still of that period was another of still greater duration which was required to develop in the cell, still neither animal nor vegetable definitely, those peculiar processes which the animal as well as the vegetabl cell now manifests when it undergoes what is known as cell division.

To have fixed in the cell, animal and vegetable, those mitotic

* Carnegie Institution Year Book, No. 3, 1905, p. 250.

processes so that they should not have altered in all the subsequent geological eras must have required an inconceivably long period of time.

Still very much farther back must have been the date when life originated as ultramicroscopic organisms, for out of such eventually developed the cell.

The biologist, and more particularly the cytologist, reviewing these matters, is inclined to regard the length of time during which stratified rocks, including those of the Huronian Age, were laid down as but a small fraction of that which has passed since the origin of life on the earth. The geologist may perhaps not share this view, but the facts which the cytologist has ascertained are of such a character as to compel him to recognize that a period of enormous length must have intervened between the time when life first began on the globe and the time when the differentiation of the primal cell into animal and vegetable types commenced.

In closing it may be pointed out what the explanation here advanced concerning the origin of life on this globe involves. It follows, almost inevitably, that as every planet in every stellar system has passed or is passing through the same history as the earth has known, the same physical conditions have given or are now giving the same result or will ultimately do so and of course life cannot then be considered as confined to the earth only. How vast the universe may be we do not know and whether there is any limit to it we cannot say. Kapteyn* of Gröningen has from his studies on star drift advanced the view that there are two visible universes travelling in opposite directions in space. His observations and views have received the support of astronomers generally. It is conceivable that far beyond the penetration of the most efficient telescope, that is, beyond what Lucretius calls *flammantia mœnia mundi*, "the flaming ramparts of the world," there are other universes, perhaps countless in number, each with its history repeating that of our own. We do not, however, require to postulate that the depth of space is strewn with universes in order to realize the magnitude of the destiny of life. It is estimated that there are at least 300,000 suns visible in space and each of these probably has its own planetary system. On 2,000,000 planets then the story of the origin of life on earth, herein outlined, has been, is now being, or is to be, repeated and thus there is an eternal procession of life throughout the universe. There is another thought that results from this explanation of the origin of life and from

* "Star Streaming,' British Association Report [illegible] p. 257.

its consideration as valid for the who[illegible] [illegible]iverse. No one, I think, can survey the subject without bei[illegible] [illegible]led to believe that behind it all there is a vast destiny, feebly [illegible]ed a purpose, inscrutable perhaps to our finite intelligence, but still a [illegible]stiny, an end to which all things are proceeding.