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"Let the Earth Bring Forth"

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Dr. Griffiths, Lecturer in Chemistry at the University of Leeds, discusses some of the chemical suggestions which have been proposed for the origin and very early development of life. He shows how question-begging and unsatisfactory some of the proposals are, and draws parallels between the beliefs of scientists and those of Christians.

The biblical phrase "Let the earth bring forth" (Genesis 1: 11, 24) has, in the past, received all too little attention from a scientific angle. Perhaps scientists have felt embarrassed by the picture painted by Milton in *Paradise Lost* in which he describes animals pawing their way fully grown out of the earth. Early adherents of the theory of evolution, when pressed to account for the origin of life, suggested that life arose from a single cell which had arisen by chance, or had been brought into existence by God. The chemical aspects of the subject were simply ignored because for many years biology and chemistry were considered as separate subjects: not till the 1920s did biochemistry begin to come into its own. Even so, medical training was usually the path taken to enter this field, and only within the past three decades has it been possible for the trained chemist to introduce his own approach and thinking.

The nature of the cell has been the subject of much scrutiny and the 'simple' cell is now known to be a very complex entity. Newer related research subjects include cell nuclei and cell membrane studies. The biochemist has established the nature of the building blocks of the cell, but their origin has become the concern of the organic and inorganic chemist, and of the earth scientist.

In this essay we shall think of a recent aspect of chemistry, which stands at the portals of biological sciences: this is 'chemical evolution', or 'prebiotic chemistry' as it is sometimes called. We shall attempt, from the chemist's viewpoint, to look at some of the experimental evidence reported and to relate the conclusions reached to the Christian faith.

"Let the earth bring forth." When the injunction was first given in Genesis 1 it referred to living matter, vegetation, plants and trees: on the second occasion it was to living creatures. Concerning man (v. 26) it is recorded that 'God said, "Let us make man in our image, after our likeness,"' and in the New Testament, Christ said (John 10 v. 10), 'I am come that they (mankind) might have life, and have it more abundantly.' It will be here contended that the quality and attributes of life have at times been misplaced by scientists in their investigations into the origin and nature of life, thereby producing fallacious arguments and specious explanations of the (as yet unknown) intermediate stages in the appearance of life. It is further contended that an understanding of a satisfying and abundant self-life demands, at least, a theistic approach.

Life: Some Definitions

But what is life? In one sense it is that point at which the biologist takes over from the chemist. As a personal aside, this author, when at school, was perturbed by the lack of a precise definition for life. Recognising at that time the power of prayer, and that there were many cases where the medical doctors would predict a rapid termination of life, he knew also that "the prayer of faith will save the sick man, and the Lord will raise him up" (James 5: 15, RSV). With school-boy logic he concluded that if he could learn all there was to know about the non-living, and if this knowledge was 'subtracted' from the knowledge of a living system, then the answer would be the definition of life: he is still a chemist !

Life has been defined by Perret[1] as: A potentially self-perpetuating open system of limited organic reactions catalysed stepwise, and almost isothermally, by complex and specific catalysts (enzymes), which are themselves produced by the system. This definition, however satisfying to a biochemist, will hardly please a chemist since it has nothing to say about energetics. The crystallographer Bernal[2] has suggested, as a provisional definition: A partial, continuous, progressive, multiform and conditionally active, self-realization of the potentialities of atomic electron states. This suggests that life is bound to arise because atomic and molecular interactions take place the way they do, as a result of the quantised energy levels associated with each constituent atom. These levels are invariate among identical atoms. The definition would therefore, if correct, seem to eliminate God in His creative capacity, but there is still the question "How did these levels originate ?", or "Who ordained these levels ?". We shall return to this latter point.

Belief

The beliefs of investigators colour their definitions and conclusions, sometimes consciously, but more often sub-consciously. This is not generally apparent in their contributions to scientific journals, but books and biographies are illuminating. Following on from Bernal's definition of life it is not surprising to find later in his book[3] the statement that "sooner or later both metaphysical and theistic explanations of life will be seen to be useless and essentially absurd". He therefore obviously believed that God is not involved in the emergence of life.

On the other hand, Calvin, in describing his personal experience in his book Chemical Evolution,[4] says that "The fundamental conviction that the universe is ordered is the first and strongest tenet . . . the universe is governed by a single God . . . This monotheistic view seems to be the historical foundation for modern science." Yet Calvin, too, advocates that life arose *per se*.

The Christian might well ask 'Does it matter at what stage God took the initiative in the history of the solar system so that life was brought about ?' There are two points to note here. The Christian may be, as it were, keeping pace with the scientist. When the latter says 'I cannot explain how this arose or this vital step in the sequence to life was brought about,' the Christian would reply, 'That is where God became involved'. This is, to say the least, spiritually unhealthy. As further research removes the scientist's difficulties, the Christian is continually back-tracking, and his faith is being eroded. This is essentially a 'God-of-the-gaps' approach, and in these circumstances would seem to be expressing fear rather than faith.

The second point is that God is ever present, and not remote in space. Genesis 1: 2 declares that when the form of the continents was not yet settled and the earth was dark and void of life, the Spirit of God "hovered and brooded continually, just as a bird does over its nest" (lit. Hebrew). There is no reason to suppose that God does not do the same today.

The role of God is hard to define, for the individual is involved. To some, and perhaps Calvin [4] would wish to be included here, God is recognised through the laws of nature as being immutable, regular, unaffected by time; energy levels within atoms and molecules are constant; and events, certainly at the molecular level, occur in conformity with statistical laws. To others, God is intensely involved. This means that in addition to God's involvement in macro-events of daily life, He knows the paths and trajectories of each atom and electron. Thus the involvement of God in the appearance or creation of life is a matter of individual belief, and consequently men may have the same Christian faith, but differing beliefs concerning chemical evolution.

Inevitability

The concept of inevitability arises from an inherent faith in science. Chemicals A and B, under the same conditions, always give the products C and D. When complicated organic reactants are brought together it often happens that several products could theoretically arise, but only one product may predominate because shapes and charges make molecules come together in a particular way. Chargaff's Rule,[5] that adenine (A) always pairs with thymine (T), and guanine (G) with cytosine (C), enabled Watson and Crick[6] to postulate a double-stranded helical structure for DNA, which provided an explanation of the chemistry of the molecule and its biological role as the carrier of genetic information.[7] The existence of highly plausible explanations of this kind makes it easy to see (imagine, postulate, believe) that the as yet unknown intermediate steps which gave rise to the first appearance of DNA arrived *per se.*

It cannot be too strongly stressed that molecular building-blocks do not assemble themselves into cell molecules because they are programmed to do so, or because the process is self-determined. Chemical reactions take place when the energy of the products is less than the energy of the reactants. However, change in molecular geometry, say when molecules fit together with complementary parts, as in a three dimensional jig-saw, is also a major consideration in determining whether or not combination is possible (the free energy for a reaction must be negative).

Various writers, who are both Christians and scientists, have discoursed lucidly on the role of faith in science.[8] They have demonstrated that scientists, in their approach to their subject, exercise a faith akin to that of the religious believer. Indeed, the scientist at times seems to be asking others to exercise even more faith than does the Christian — this is particularly so in the life sciences.

At this point we must begin to ask questions. We need to distinguish, where we can, between pleas for belief which refer to merely plausible suggestions and those which demand belief that events will take place inevitably given the starting conditions. Obviously this is not easy, but Christians are exhorted to " have a reason for the hope (faith) that is in them " (1 Peter 3: 15) and therefore, if they are prepared to examine their own faith, they ought also to be prepared to examine the rationalisations of prebiotic chemists. Though such an examination may not always at the time seem satisfying, in the long run it will help to clarify belief, particularly if dialogue ensues.

We shall, however, take with us the warning of Solomon, " I applied my heart to know, and to search, and to know the reason of things . . . Lo, this only have I found, that God hath made man upright; but they have sought out many inventions " (Ecclesiastes 7: 25, 29). In discussing man's ' inventions ' in the sphere of chemical evolution we have first to consider the question of relevance.

Relevance

The biologist is well aware that experiments performed *in vitro* do not necessarily give the same results as *in vivo*, and that chemical compounds given to animals do not necessarily produce the same effects in humans. However, the biologist is usually in a position to do both types of experiments and assess any differences. The prebiotic experimenter is not so fortunate, for he cannot be certain that his experiments replicate original conditions and materials. Thus to decide whether a particular set of laboratory conditions adds up to a relevant ' chemical evolutionary ' experiment is by no means easy. Many experimenters have investigated the effects of electric discharges on mixtures of water and carbon dioxide. Attention was often given to the possible production of formaldehyde since this was for many years assumed to be the first product of CO_2 fixation by green plants. More recently radiation chemistry studies have yielded much information concerning the effects of ionizing radiation on the (assumed) key molecules of CH_4 NH_3 and $H_2 0$. However, many of these experiments were not performed with the object of advancing prebiotic chemistry and hence care must be exercised in drawing conclusions, for many findings have little relevance to the Earth's early history.

Prebiotic-Earth Conditions

We shall now consider experiments which have been specifically designed to relate to supposed prebiotic conditions, and we hope to pin-point crucial areas of uncertainty and conjecture. Many of the experiments, taken in isolation, would seem to have promise and to provide partial support for a belief in life arising on its own on our planet, but our attempts at a more critical view would suggest that there are several unanswered, because unasked, questions. We do not necessarily know the answers to these questions, but we hope that, by asking them, we shall channel thoughts and investigations towards profitable lines of enquiry. It is reasonable to take the premise that reactions in the prebiotic atmosphere gave compounds that then were washed into the prebiological oceans, and subsequently these, or further reaction products, reacted with solid surfaces, possibly so that 'the earth brought forth'! We shall therefore examine each of these environments in turn.

Prebiotic-Earth Atmospheres

Several atmospheric compositions have been postulated at various stages in the Earth's early history. We may be certain that though our atmosphere is now stable, it was different in the past and changed slowly from one composition to another.

To obtain the complex carbon-containing compounds present in living matter simple precursors were sought, those first considered being gases containing only one carbon atom in the molecule. The original workers in this field were Urey, Miller, Groth and Terenin. Oxidising and reducing atmospheres were subjected to high intensity uv radiation and also to electrical discharge, since these energy sources could be assumed readily available to bring about bond formation. It emerged that, using a recycling system, a reducing atmosphere, consisting of methane, ammonia, water and hydrogen, was required for the production of various carbohydrates and a wide variety of amino acids. Oxidising atmospheres yielded no interesting products.

Let us look more carefully at these experiments. Using optimum gas ratios for amino acid production Miller [10, 11] found that only 10% of the carbon present was used up after about 100 hours of sparking and recycling of methane, ammonia, water and hydrogen. Approximately half had been converted into formic acid, and of the other carbon-containing compounds the largest component was glycine, around 1·5%. Ammonia is extremely soluble in water, being liberated on heating — Miller boiled his condensate to regenerate ammonia and water for recycling. Calvin, [12] using essentially the same apparatus but with increased proportions of ammonia and methane, and using electron bombardment as the energy input, obtained similar products, but including 0·5% HCN. Fox, [13] among others, employed thermal energy, the gases being passed through tubes at around 1,000°C and containing various paçkings ; one was silica, another alumina, thereby attempting to reproduce hot earth conditions. Essentially similar yields were again obtained.

The writer has not seen adequate discussion in books and reviews on chemical evolution of the implications impinging on astronomy and geology. There is almost a suggestion that these sciences will and must (or must and will) conclude that this Earth once had a reducing primitive atmosphere. Calvin, [9] for example, after mentioning some, but not all of the difficulties, states " But, nevertheless, it would be a reducing atmosphere in spite of that."

The constraints placed upon these other sciences are that this Earth was once a cold body. Later it heated up so that much of the land mass was molten, and then it cooled down to its present, approximately equilibrium, condition. Such a primitive history is not obvious or readily explainable by astronomers and earth scientists. A possible mechanism would involve the heating up of the Earth as a result of radio-active decay, particularly of uranium and potassium. Radiation breaks up molecules much more readily than it assists in assembling them. Thus the radiation cannot be considered conducive to chemical evolution from molecules formed in (possible) primitive atmospheres.

Another problem, not considered by prebiotic chemists, is the implications of hydrogen cyanide polymerisation. Various mechanisms have been proposed[14–17] whereby HCN may polymerise into various polypeptides and amino acids, but complete experimental proof is awaited; the last step in the proposed condensation to give adenine is, for example, yet to be experimentally established.[15] Two points seem to have escaped attention. First, the polymerisation of HCN is not quantitative and considerable quantities of cyanide would remain. Second, the stage at which cyanide formation would cease, to avoid the adverse effects of this material upon living matter, does not seem to have been evaluated. And a route for eliminating the extremely stable cyanide ion has been ignored! (*Editorial addition.* Ferrous and ferric oxides and hydroxides must have been abundant on the primitive Earth, as they still are today. Hydrogen cyanide, if present, would soon have formed Prussian Blue, but this does not appear to be known as a mineral. If HCN was originally present in the atmosphere, such a mineral should be common in the early rocks.)

The Earth's atmosphere is now an oxidizing system and contains some 80% of nitrogen. Let us consider its impact on molecules probably (or possibly) formed in a reducing atmosphere. The nitrogen cycle, involving as it does the production of nitric acid by electric sparking, would have a deleterious effect if chemical evolution was not sufficiently advanced by the time the atmosphere had become oxidizing. It could be argued that the energy input required to form molecular building-blocks diminished as the atmosphere became oxidizing, i.e., the intensity of electrical storms and the radio-activity associated with heating the Earth were now subsiding. However, this implies that nitrogen was a late arrival in the Earth's atmosphere. When it did arrive is difficult to determine. Nitrogen is difficult to detect with the astronomer's spectroscope and hence its abundance in the universe, and possible role in the formation of stars and planets, is not easy to assess. The American Mariner series of space shots to investigate Mars were needed to confirm that the light atmosphere on that planet was almost entirely nitrogen. This author has failed to find mention of primitive atmosphere experiments containing nitrogen gas. And if it were present, one could readily conclude that, because oxygen was present in water vapour, oxides of nitrogen, and hence nitric acid, would be formed. The effect of the nitrate ion upon the condensation reactions variously proposed [18] for obtaining macro-molecules has not been investigated; it is doubtful if it would be helpful.

In summary, then, on taking various processes in isolation, possible detailed steps appear to proceed readily, but an overall view reveals many problems. These have probably been considered by prebiotic chemists, but have not been published, either because they feel they are more in the province of the astronomer and earth scientist, or because it is realised that to discuss them weakens their case for chemical evolution. To argue or imply that others must find an explanation for the existence of reducing primitive atmospheres, because they consider that life could not arise of itself without this precursor, is improper and begs the question. Indeed, as we shall develop later, it would seem that, instead of life arising *per se*, pleas are being made for Special Chemistry.

Prebiotic Oceans

Many experiments have been carried out on solutions of products formed in (supposedly) prebiological-Earth atmosphere experiments. The idea is to look for further products that may have been formed from them in the prebiological oceans. Certain successes are not lacking. Seven of the amino acids present in proteins have been formed [19] by the action of uv radiation on solutions of formaldehyde, NH_4 Cl and NH_4NO_3 Ammonium cyanide solutions heated to 90°C have produced similar products. [20] Haldane [21] in his original article in 1929 described the chemicals formed by primitive atmosphere experiments as accumulating until " the primitive oceans reached the consistency of hot thin soup ". This concept has unfortunately been retained by many: we have indicated above that the concentration of organic molecules, from primitive atmosphere experiments even at the surface, would be only a few per cent under optimum conditions, and then in the absence of any adverse conditions or chemicals.

A complicating factor that seems to have been overlooked is the salinity of these oceans: solution experiments are generally performed in water. The role of dissolved salts, and their buffer effects due to their being considerably in excess of, say, amino acids, has not been investigated in the formation of biopolymers. However, fresh water systems may have been involved.

All the four bases that occur in RNA (adenine, guanine, cystosine and uracil) have been formed in simple solution experiments. The remaining base of the nucleic acids, thymine, which occurs only in DNA, has not been synthesised under any plausible prebiological-Earth conditions: in making this statement Lemmon [22] includes the word ' yet '. He later remarks that the largest specifically identified unit from dilute aqueous solution studies has been a tetrapeptide (tetraglycine). He then develops a commonly proposed high temperature route to biopolymers; ocean waves depositing their solution of dissolved amino acids in pools at high tide where there is geothermal activity. Although by heating mixtures of dry amino acids protein-like polymers, called proteinoids, have been formed, [23, 24] most naturally hot regions are acidic, low pH, and not necessarily helpful to such reactions. If fresh-water conditions are subsequently shown to be required, then regular tidal action would be considerably reduced, and the conditions required for forming biopolymers would therefore become more Special.

Experimental findings are thus tending towards the need to involve the earth. Nucleic acids, for example, contain many phosphoric acid groups, and the present level of phosphorus in sea-water is low, ranging [23] with locality and depth from below 60 up to 85 mg/m^3, and averaging [24] 70 mg/m^3. In surface waters almost half is in the form of organic phosphorus within plankton, [25] and in primitive oceans the inorganic phosphorus level would remain low as calcium phosphate is very insoluble, and the present (and presumably past) calcium concentration [24] is considerably in excess of that of phosphate, currently 0·4 g/1.

Horne [26] has recently concluded his book on Marine Chemistry with a somewhat emotional, yet in parts most perceptive, account of the origin and evolution of life in the seas. For example, he notes that 'the stones are not a temple; once in hand the building-blocks (amino acids, etc.) must be put together. How are the pieces brought together? The putting together of the pieces was a long, tedious, and delicate sequence and each step in the sequence was highly improbable. Fortunately, the time span allotted to the beginnings of life was exceedingly long, perhaps several billion years, so that the improbable was not necessarily the impossible. Biogenesis is pushed further into the realm of possibility if there were mechanisms operative for the concentration of the pieces and, in order to outrace the forces of dissolution, for the stabilization of the pieces and their combinations . . . the ancient seas were a very dilute broth . . . let us imagine, then, the proto-biological substances being absorbed on bubble surfaces, transported upwards to the sea's surface, and joined with other material absorbed there, then tossed by the waves and carried by the sea spray up on to the beaches and estuarine mud where, in the richer, warmer waters the pieces begin to react and then aggregates to grow.' He also states that 'while the details remain scarce and while many questions will remain unanswered for many years to come, perhaps forever, the answers to the principle questions now seem to be all at least foreshadowed; the principal conceptual barriers have already been breached.'

Here we see a typical example of an attempt to eradicate the presence and power of a Creatorial God. Statements like these can be so readily taken as 'proof' that the scientist has now achieved the break-through that sweeps away any need for a belief in God or His involvement in the universe: time allowed life to develop, and future time will provide the answer to the question 'How?' And should it not provide all the answers that will not be reason enough to abandon such belief. It is sad that such speculations, while showing original thinking in places, are so often based on earlier concepts that have not been borne out by experiment, for example, synonyms of the original description [21] of the primitive oceans by the evocative word 'soup' being still commonly employed.

Christians also are not blameless in this respect. The pictorial descriptions and some of the names of the Evil One, which are still with us, for example Lucifer, Son of the Morning, are based on mediæval imagery and dubious Scriptural interpretation. Christians working in the area of chemical evolution should consider the similarities in the faith exercised in the belief that life created itself with its ensuing "shibboleths", and the faith involved in Christianity, and attempt to bring them to their colleagues' attention. The special conditions, which are proving so elusive to find, must be placed alongside a God-ordered and God-ordained system.

Primitive Earth

The involvement of a liquid-solid interface is now considered crucial to the formation of biopolymers. The clay-water interface has received much attention. There are two features to be explained. First, the aggregation of simple organic molecules to more complex species, generally considered to be intermediates in the formation of nucleic acids and proteins, must be established. An explanation of the mechanisms involved would be helpful. Second, the advent of chirality. Chemical reactions obey the law of averages. Should a compound be formed, in the laboratory, which contains an asymmetric carbon atom, this compound will be obtained as a racemic mixture, with equal quantities of *d* and *l* forms. Living matter commonly employs one form, the *l* form in the case of amino acids.

"It must be admitted that the explanation of chirality still remains one of the most difficult parts of the structural aspects of life to explain . . . This question of chirality, though admittedly unanswered, is certainly one of those that can be left over for further observation and experiment: the fact that we cannot solve it now is not sufficient reason for abandoning the search for physical-chemical theories for the origin of life ", so said Bernal [27] in 1967. At that time it was generally assumed that chance decided on which stereochemical form life should be based, but the inherently difficult implication, that life arose from essentially one molecule, since no evidence for life forms using d-configurations had been found, was recognised. Some evidence to support Bernal's 'faith' has now been published. Degens, Matheja and Jackson [28] have reported the direct polymerisation of aspartic acid on the clay kaolinite and found that, over a given period of time, the l-form polymerised much more readily (25%) than the d-form, (3%). There are now a few similar papers. However, the roles of defect lattices and active sites in clays require further investigation before it can be concluded that the l-form is systematically favoured, and that the Earth brought forth life. The case for special reactions is still with us.

This is clearly brought out in a recent paper by Good [29] in which he examined the structural role of water, as influenced by clay surfaces, in the origin of life. He suggests that the hydrogel, the primitive abiopolymer that subsequently becomes a dividing coacervate droplet, " is 'probed' and 'inspected' by the flickering, dynamic framework of the ever-changing water structure, and that confirmation was the price of survival." His conclusion " that life was not the result of a unique event of transcendental improbability, but was rather the inevitable consequence of the physics and chemistry of the formation of the earth " is no more than a re-statement of Bernal's provisional definition of life. [2]

Personalizing

In writing scientific articles one of the many traps which the author tries to avoid is personalizing the inanimate. For example, 'the reaction *preferred* the addition of X . . .' House custom varies between journals and individual editors; some attempt to alter all such phrases while others remove the more humorous. This author has observed that writings on evolution and chemical evolution contain more examples than in, say, chemistry journals. The impression obtained is that molecules and cells are attributed properties of life-characteristics and self-determination, when intermediate stages are unknown, because the authors wished to avoid any suggestion of possible supernatural involvement. Further, unless they employed this technique their ability to postulate or describe related processes would be impaired, if not removed. Essentially they are employing a 'begging the question' approach. Admittedly there are occasions when such techniques improve the literary style, but an examination of the quotations already given in this essay exemplifies this point. This author has attempted to refrain from such devices, but no doubt some have crept in.

Erroneous Analogies

By imposing life-characteristics on the simpler chemical molecules the analogy is implied that the route to such molecules as DNA will be found by considering those mechanisms which would seem to follow this pattern. While it is reasonable to simplify a massive problem by selecting an approach which would seem valid and representative, and also would reduce the number of possible explanations to be considered, it is possible that certain lines of enquiry have been hampered in prebiotic chemistry by, perhaps subconsciously, restricting explanations to this programmed approach.

Further, the utilization of visual and mechanical analogies is not consistently helpful. Certainly very crude analogies, which on examination appear absurd, have helped many successful innovators; for example, Goodyear [30] maintained that since iron is improved by adding carbon, and leather by tanning, rubber also must be capable of being 'tanned'. Nevertheless the development of the cell through coacervate drops is considered by the present writer to be potentially fallacious and unhelpful.

The approach commonly adopted, for example by Calvin,[31] is to examine the membrane of a simple cell, its constituents and its properties, and then to look for simpler analogies. Small droplets can be made to come out of solution and have been observed to increase in size (personalized as 'grow') and divide into two ('reproduce'). Droplets containing polypeptides and polynucleotides having these properties have been studied in detail by the Russian biochemist, Oparin.[32, 33] They are termed coacervates and result when a solvent, usually water, contains two different macromolecular polymers that interact with the solvent, but do not interact well with each other. Phase separation occurs, one phase being dispersed within the other (continuous) one. The coacervate boundary is likened to a membrane structure, and certain properties typical of cell membranes have been obtained.[31-33] However, a simpler system, accessible to the chemist, is micelle formation. Many biologists have for a long time neglected to consider the role of the structure of water, particularly with regard to its involvement in the transport of ions across membranes. Recently the effects of solvent structure and added solutes on critical micelle concentration (c.m.c.) have been investigated. Below the c.m.c., molecules containing a hydrocarbon portion, usually a long straight chain having hydrophobic properties, and a charged portion, are unassociated in solution. Above the c.m.c. they coalesce into structures having the polar portion of the molecules at the surface. Other molecules will enter these structures — detergents are typical examples of micelle forming compounds. However, micelles may be destabilized by certain molecules, including urea, possibly by entering the micelle.[34]

It is therefore here suggested that the behaviour of the surfaces of micelles, and their interaction with structured water, be further investigated, in order to help understand the behaviour of coacervate drops and establish whether or not they are a required intermediate in the development towards cell membranes.

The Christian Faith is often communicated and explained by analogies, as in parables. The parables in the Scriptures are most illuminating and continual study reveals fresh truths.

Occasionally a dubious conclusion is reached, usually because one presses a story too far. Teachers are well aware that, should they select a poor analogy to convey a certain concept, the inapplicability of the model, in that it suggests obviously incorrect inferences when pressed too far, is one of the first points raised in discussion. The pupil has 'scored' off the teacher, and the original concept is obscured. The impact of the models and analogies used by prebiotic chemists upon the Christian Faith is first to imply that the coming together of atoms to give molecules, molecules to give polymers, polymers to give coacervates, and coacervates to give cells, was pre-ordained and self-determined by properties, arising from the various set energy levels, inherent in the atoms. That this is not (necessarily) so has been shown above. The Christian must also recognise that literary and artistic devices are used to convey this impression. The immanence of God is not diminished by these approaches.

Second, an unconscious case is being put forward for Special Chemistry. The more the subject of prebiotic chemistry is investigated with the object of finding the chemical pathway followed from primitive earth conditions to living things, the further away seems the solution. One advance here means several more questions yet to be answered satisfactorily. It is unlikely that these investigators will at some future date even begin to suggest that the 'finger of God' might be seen in the processes of chemical evolution. However, the onus is perhaps on the Christian to present the case that prebiotic chemists are essentially searching for the Special conditions that would allow life to emerge, and hence looking for the Special Chemistry involved. The parallels should be drawn with the concept of an immanent God guiding the process — to use an evolutionist's postulate, making the laws of wind and sea movement to coincide such that reacting amino acids in a tidal pool are not washed out before a vital step, say the advent of chirality, was completed. And the obvious parallel with the various concepts of Special Creation, defined as God being involved in the appearance of life on Earth, should be described. It is the writer's view that complementary views are emerging for the origin of life: Special Chemistry and Special Creation.

Some Final Remarks

In an essay of this nature it is necessary to be selective. Some possibilities for the origin of life are at present too speculative to merit prolonged attention. Was life on this planet deposited by visitors from another planet and how did their life form in turn arise? The role and necessity of trace elements for the functioning of living systems is a topic which in the future will demand attention, but probably not until the ability of a cell membrane to distinguish between ions of like charge, differing only slightly in their size and influence upon contiguous water molecules, e.g., sodium and potassium cations, has been adequately understood.

The day is probably coming when computer calculations and 'predictions' of reactions between large molecules will become feasible. Then there will be another surge of proclamations that calculations have shown the emergence of life to be inevitable. At the present time reasonably accurate *ab initio* calculations of energy levels are limited to systems containing about 50 electrons. Clementi *et al.*[35] have made an excursion into the biochemical field, but achieved disappointing results in a calculation on hydrogen bonding in a guanine-cytosine base-pair. Repeated computation and the processing of more than 2×10^9 electron repulsion integrals were required, and needed about 8 days on a 360/195 IBM computer. Expansive *ab initio* calculations do not automatically give sensible results: basis sets and parameter values must be chosen intelligently and even then the largest usable basis may be inadequate.[36]

In another early book, Job, we find 'The Lord said . . . Where wast thou when I laid the foundations of the earth? Declare if thou hast understanding' (Job 38 v. 4). This chapter, and the next three, describe an impressive research programme, including the subjects of earth science, astronomy, deep-sea research, space travel, meteorology, natural history and biology, and animal psychology, to name but the main ones. It is also suggested that while part of the research proposals God puts to Job can be resolved, some questions will remain unanswered, the answers known only to God, but the search will be rewarding.

Finally, the writer has been impressed by the similarities between the approach to knowledge taken by many scientists, and John 10: 1 – 39. Those who seek God's wisdom, but not in the right way, are called thieves and robbers ; some come even to destroy the author of Wisdom: this they seem to do, but cannot. When confronted with the evidence, like the Jews, they will not believe, and dismiss the claims with " He is mad ; why listen to Him ? " Some try to " cast stones ", but when " they tried to arrest Him, He escaped from their hands " (RSV).

Abundant life (v. 10) is thus for the seeker after truth who acknowledges, in his seeking, the presence and power of God. The (indirect) attacks by prebiotic chemists upon the role of God in the appearance of life on this Earth cannot disprove His existence and involvement, but neither can any specific actions by God be identified. What can be said is: God is immanent ; let the Earth bring forth.

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[*Editorial addition :* Attention is drawn to *The Origin and Development of Living Systems* by J. Brooks and G. Shaw, reviewed in this JOURNAL, **101**, 117.]