GENERAL SCIENCE NOTES

DID LIFE BEGIN IN AN “RNA WORLD”?

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WHAT THIS ARTICLE IS ABOUT

Recent discoveries of catalytic activity by RNA has stimulated speculation that life may have originated naturalistically through the formation and evolution of RNA molecules. This “RNA World” hypothesis has numerous shortcomings. RNA is difficult to produce chemically. The materials required for its production would not be present on a prebiotic earth. The “RNA World” scenario is not a plausible explanation for the origin of life.

Explaining the origin of life has remained one of the most bothersome problems for those espousing the view that nature can only be understood within a naturalistic philosophy. For many years the major focus of attention has been on scenarios involving the evolution of proteins. Two historical factors contributed to the emphasis on proteins. One of these was that when scientific investigation of the origin of life was beginning, the role of nucleic acids in heredity had not been established. It was reasonable at that time to suppose that proteins might be responsible for heredity. The other factor was the production of amino acids in simulated prebiotic reactions (Miller 1953). This experimental result seemed to promise the possibility of success in explaining the origin of life, even though nucleic acids were known at the time to be important also in heredity.

For many years there has been a general dissatisfaction with the protein hypothesis of the origin of life. Proteins cannot replicate themselves, making them unsuitable as a starting point for the development of life. However, there seemed to be no naturalistic alternative available until recently. This newer hypothesis has been dubbed the “RNA World” (Gilbert 1986). The basis for this model is the discovery that certain RNA molecules have catalytic properties. Since RNA also serves as a carrier of information, it seemed reasonable to suggest that ancient RNA molecules might have acted as a starting point for the origin of life. The “RNA World” hypothesis for the origin of life seems a significant improvement over the protein hypothesis, and has been the subject of considerable discussion. The plausibility of that hypothesis is examined in this paper.

Importance of RNA

RNA is present in all living cells, and has a variety of uses that are central to the requirements for life. RNA plays an important role in cellular processes, especially in protein manufacture. Molecules of messenger RNA (mRNA) contain the information needed to specify the proper amino acid sequences of proteins. The mRNA acts as a template for the assembly of protein molecules. Ribosomal-RNA (rRNA) sequences participate in reading the message on the messenger RNA and joining the amino acids together in a chain. Transfer-RNA (tRNA) molecules arrange the amino acids in proper sequence. RNA molecules also have catalytic properties (reviewed by Lamond & Gibson 1990). Messenger RNA molecules often contain non-coding sequences, known as introns. These introns are removed before the message is translated into a protein. The mechanism of removal is self-splicing by the intron, in which RNA acts as a catalyst. Ribosomal RNA can catalyze the formation of peptide bonds between amino acids in the production of a protein (Noller, Hoffarth & Zimniak 1992). Several other examples of RNA catalysis are known. The discovery of RNA catalysis has stimulated the idea that life may have originated with RNA molecules.

Since RNA can act both as a template and as a catalyst, it might be possible that an RNA molecule, acting as a “ribozyme,” could make copies of itself without the need for other kinds of molecules. One strand of a two-stranded RNA sequence could act as the template while the complementary strand could act as an enzyme, catalyzing replication of the RNA sequence (see Cech 1989). Once this step was achieved, variations in sequence would occur which could compete with each other, leading to more complex arrangements. Hypothetically, life might eventually arise. Doudna and Szostak (1989) succeeded in constructing an RNA which would make copies of a template sequence. If an RNA molecule could also make copies of its own sequence, it would be able to replicate both RNA strands, and the cycle could be repeated indefinitely. Another alternative is for two or more different RNA strands to participate in reaction cycles that catalyze each other, forming systems known as hypercycles (Eigen et al. 1981).

Reasons for Thinking RNA Preceded DNA

RNA is thought to have preceded DNA in the origin of life (Lamond & Gibson 1990). One reason for this suggestion is that RNA replication is much simpler than DNA replication, for it involves fewer types of molecules. Another reason is that cells produce DNA nucleotides from RNA nucleotides. A third reason is that RNA primers are required for initiation of DNA replication, whereas RNA polymerases (enzymes that produce copies of RNA sequences) do not require a primer.

SOURCE OF BUILDING BLOCKS FOR RNA NUCLEOTIDES

Nucleic acids are composed of three kinds of building blocks: a sugar, a phosphate, and an organic base. The base may be either a purine or a pyrimidine. These three parts combine to form a nucleotide, which is the basic building block of nucleic acids. In the case of RNA, the sugar is ribose, the purines are adenine and guanine, and the pyrimidines are cytosine and uracil. The production of these building blocks is the first step in the proposed “RNA World.”

Production of Ribose

Ribose, a five-carbon sugar, is an integral component of RNA. Ribose can be produced by the formose reaction, in which polymerization of formaldehyde is catalyzed by a base. This reaction has been proposed as the most likely prebiotic source of ribose. It requires formaldehyde, which is thought to have been present on a prebiotic earth (Kasting 1993).

Experimental Support

It seems plausible that formaldehyde might be produced in reactions among gases in a prebiotic atmosphere that is not strongly reducing (Pinto et al. 1980). Formaldehyde can also be produced by photochemical oxidation of methane. However, at present methane is produced largely as a result of biological activity, and it is unlikely to have been present in significant quantities on a prebiotic earth. Extraterrestrial sources of formaldehyde have also been proposed. Comets and interplanetary dust particles (IDPs) are another possible source of formaldehyde. Comets are said to contain about 25% organic matter, of which 4% may be formaldehyde (Chyba et al. 1990). Production of ribose from formaldehyde has been demonstrated in the laboratory.

Problems with Ribose Production

Although it is conceivable that some formaldehyde could be produced in the atmosphere of a prebiotic world, it is unlikely that significant quantities would be present. There is some doubt that formaldehyde or other organic compounds on comets would survive a collision with Earth. However, even if formaldehyde were present, this does not mean ribose would be produced. Ribose is a very minor product in a complex mixture of compounds produced in the formose reaction, and is rapidly destroyed under the reaction conditions (Shapiro 1988). Furthermore, ribose is considered to be unstable on a geologic time scale, and would probably disappear in a few hundred years (Joyce et al. 1987). A carbon dioxide atmosphere would further inhibit the desired reactions. Carbon dioxide from the atmosphere would dissolve in the ocean, producing acidic conditions that would hydrolyze sugar molecules.

Sugars may be produced in other reactions, but ribose is not one of the products. UV irradiation of formaldehyde produces pentaerythritol, and no ribose (Schwartz & de Graaf 1993). Sugars may also be formed from glyceraldehyde in the presence of iron (III) hydroxide (Weber 1992). However, only hexoses (6-carbon sugars) are formed. There seems to be no plausible prebiotic source for ribose. Additional problems of chirality (mirror image), chemical interference and decomposition of sugar make the production of ribose a major problem for a naturalistic explanation of the origin of life.

Production of Purine and Pyrimidine Bases

It is believed that cyanide present in the primitive atmosphere might be a precursor in the production of purines, pyrimidines and amino acids.

Experimental Support

Maurel states (1992) that purines can be obtained from cyanide in water. The source of cyanide is said to be a major problem in the “RNA World” hypothesis (Kasting 1993). However, hydrogen cyanide is reported to constitute about 7% of the organic matter of comets (Chyba et al. 1990), so perhaps the presence of cyanide cannot be ruled out.

Problems with Purine and Pyrimidine Bases

Kasting (1993) has pointed out that there is no plausible way of forming cyanide in a prebiotic atmosphere. According to De Duve and Miller (1991), the experimental conditions under which purines can be produced from cyanide are greatly contrived. The presence of a carbon dioxide atmosphere would inhibit the production of purines from cyanide (Chyba et al. 1990). Any purines or pyrimidines present would be hydrolyzed in the ocean made acidic by the presence of carbon dioxide. Pyrimidines are, for all practical purposes, not formed in postulated prebiotic conditions (Maurel 1992).

Problems with Phosphate

Phosphate is required to join the base-sugar pairs (nucleosides) of nucleic acids. Phosphorus is much less abundant than the other elements found in RNA. Yamagata et al. have reported (1991) the presence of polyphosphates (chains of phosphate groups) in volcanic emissions, and has suggested volcanos as a source of the phosphate required for the origin of life. One difficulty with this proposal is that polyphosphates would hydrolyze in water to form insoluble phosphates, which would precipitate to the ocean floor. There seems to be no other possible source of phosphates. An ocean associated with a carbon dioxide atmosphere will be so acidic that phosphate would not be available for chemical reactions.

FROM SUGARS, PHOSPHATES AND BASES TO NUCLEOTIDES

Problems of Assembling Nucleotides

Although the prebiotic production of the building blocks of RNA is highly implausible, there are additional problems involved in combining these units into ribonucleotides. One problem is the production of a mixture of sugars with the ribose. Extra sugars would inhibit RNA synthesis (Horgan 1991). Purines will unite with ribose when heated, but the products include many different sugar-base combinations (nucleosides) and their analogues, and only a small percentage of useful nucleosides (those with beta bonding) (Joyce et al. 1987). Pyrimidines; do not form any useful nucleosides under similar conditions. Under realistic prebiotic conditions, no nucleotides would be formed (Cairns-Smith 1985).

FROM NUCLEOTIDES TO RNA

Problems in Combining Nucleotides to Form RNA

A further problem with the “RNA World” hypothesis is that ribonucleotides may bond in different ways, only one of which is appropriate for RNA (Ferris & Ertem 1992). Ribonucleotides can occur in D- and L- forms. Only the D forms are useful in living systems, but both forms would be present in any prebiotic mixture. The presence of L-ribonucleotides strongly inhibits the addition of D-ribonucleotides on a template (Joyce et al.1987). The problem of chirality is so severe that a chirally pure medium seems a necessity for RNA to be produced (Avetisov et al. 1991).

FROM RNA TO LIFE

Even if RNA were produced, there would still be no life. The importance of RNA to the origin of life is based on the conjecture that it could act both as a source of information and as a catalyst to use that information. But RNA must be folded to act as a catalyst, and must be unfolded to act as a source of information (Green & Szostak 1992). In addition, RNA is not a good self-replicator (Horgan 1991). Even if self-replicating RNA should arise, selection would favor greatest ease in replication, and information content would probably be selected against (Wicken 1985). RNA breaks down rapidly in water (Day 1991), especially hot water, or in the presence of divalent cations (Pace 1991). Thus every step in the production of RNA is highly implausible under the proposed prebiotic conditions. Even if RNA were produced, it could not survive nor could it form the basis for a naturalistic origin of life. Some other mechanism must be sought to explain the origin of life.

CONCLUSION

Naturalistic models for the origin of life generally begin with the production of small molecules such as sugars or amino acids, which then combine to form larger molecules such as proteins or nucleic acids. These large molecules must then become organized into cellular structures that are somehow interrelated in complex ways and under non-equilibrium conditions. The “RNA World” hypothesis for the origin of life requires implausible events at each step in the sequence outlined. Small molecules are highly unlikely to have been available in any plausible model of a primordial earth. Even if small molecules were present, they would be highly unlikely to produce the large protein and nucleic-acid molecules useful for life. Even if the large molecules were present, there is no known mechanism whereby they might be organized into functional cellular or subcellular units. The “RNA World” hypothesis suffers from many of the same problems as the protein hypothesis, and has additional problems of its own. Considering the conditions necessary for the establishment of life, it appears that the most plausible explanation for the origin of life is an intelligent creator.

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