The origin of life: the first self-replicating molecules were nucleotides

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Abstract

Difficulties to synthesize RNA nucleotides from their subunits in modern labs under simulated environments leads us to propose a possible process for the synthesis by cross complimentary self-replication with help of clay minerals, which might be operated on prebiotic Earth. Clay minerals are known to be good catalysts and certainly existed on prebiotic Earth. The self-replication of RNA nucleotides (monomers) may be considered as the origin of potential self-replication of some extant RNA polymers, and also the reason for homochirality of RNA molecules.

Introduction

RNA molecules possess two distinctive properties; heritability that allows passing molecular information; thus makes Darwinian evolution possible, and homochirality that allows oligomerization; thus makes polymerization possible. These properties are originated at certain stages of molecular development leading to RNA emergence on prebiotic Erath. There are efforts to synthesize RNA polymers in modern labs starting from simple molecular components presumably existed on prebiotic Earth [1-4]. It seems to be possible that entire processes leading to formation of the subunits; ribose sugar, phosphate and nucleobases (adenine (A), uracil (U), guanine (G) and cytosine (C)) were proceeded on prebiotic Earth environment, but it is impossible to explicitly specify the actual processes. Alternatively, some intermediate products might be originated from outer space and delivered to Earth. Evidence provided by meteorites supports this possibility [5]. On the other hand, the final process, the formation of the nucleotides by joining the subunits has only a very limited success in terms of yield. In order to form a nucleotide, the subunits have to be joined together by covalent bond that requires to overcome a high activation energy. Thus, there had to be a process that modified the activation energy and promoted the formation of the nucleotides to produce enough nucleotides for oligomerization.

Catalysts are widely used to increase yields in modern chemical syntheses. A role of the catalysts is to lower the activation energy. We speculate that non-biotic catalysts played an essential role in the formation of the nucleotides on prebiotic Earth. Clay minerals are known to be good catalysts and certainly existed on prebiotic Earth [6-7]. Roles of the clay minerals in the process were twofold. First, they provided surfaces on which the subunits were selectively adsorbed. This reaction consequently increased concentration of the subunits on the surface and allowed the subunits to react each other more frequently. Secondly, they strained and aligned the subunits in proper orientations so that particular reactions became easier due to reduction of the activation energy.

Self-replication of RNA enzyme without help of biotic catalysts has been demonstrated [8]. Self-replication is a special property of certain molecules, by which the molecules are multiplied exponentially. It is conceivable that self-replication with help of non-biotic catalysts might play an essential role for the formation of RNA nucleotides on prebiotic Earth. In this communication,

we explore this possibility and describe a probable process that might efficiently synthesize the nucleotides by joining the subunits on prebiotic Earth.

The Process

We propose a process for multiplication of nucleotides on prebiotic Earth. It is posited that the subunits of the nucleotides of terrestrial or exterrestrial origin existed in prebiotic oceans. The multiplication of nucleotides took place at tideland or estuary at which wet & dry cycle or pH fluctuation occurred due to tidal cycle. The subunits dissolved in the oceans were selectively adsorbed on clay minerals at the bottom of tideland or estuary. Since fresh subunits were supplied in every tidal cycle, the concentration of the subunits on the mineral surfaces were gradually increased. Once the concentration reached a certain level, it was extremely rare but a random reaction occurred and an original nucleotide consisting of, say, base (U), D-ribose and phosphate was formed. Here, the random reaction means that the reaction rate is proportional to the concentration of reactants but independent of the concentration of the product. The nucleotide might degrade before the next random reaction occurred; thus a significant increase in the concentration of the nucleotides was unlikely if the formation was solely relied on the random reaction unless the concentration of the reactants were unnaturally high. In order to increase the concentration, the nucleotides must be formed faster than degradation. As a plausible process, we propose a cross complementary self-replication of the nucleotides. The sequential steps of the process are the followings:

Step 1: A free complementary base (A) resided close to the original nucleotide is joined to the base (U) by hydrogen bond. This reaction is spontaneous because the bonding does not require to overcome an activation energy for establishing the bond.

Step 2: A free D-ribose is joined to the base (A) by covalent bond. A nucleoside is formed. This reaction is possible because the original nucleotide is preferentially oriented and in a state of lower activation energy for the bonding.

Step 3: Lastly, a free phosphate is joined to the D-ribose by covalent bond to form the second nucleotide. Again, the activation energy is lowered due to the preferential orientation.

Step 4: The hydrogen bond between the original and the second nucleotides is broken by cyclic variation of the environment due to tidal cycle, resulting in two separate nucleotides.

Steps 1-4 repeat and the original nucleotide with (U) and the second nucleotide with (A) produce the third nucleotide with (A) and the fourth nucleotide with (U), respectively. Two different nucleotides are self-replicated. The process continues as long as the subunits are supplied.

The same process occurs to the base (G) and (C) pair. If the rate of complementary self-replication exceeds the rate of degradation of existing nucleotides, the concentration of the nucleotides is expected to increase exponentially.

Discussion

The synthesis of the RNA nucleotides from the subunits by random reaction in modern labs under simulated environment of prebiotic Earth has not been convincingly demonstrated. To remedy this problem, the complementary self-replication of the nucleotides is proposed in this communication. The rationality of the process is briefly discussed in the followings.

Firstly, the valid clay minerals for the formation of nucleotides from the subunits have not been found yet. Selective adsorption of prebiotic molecules in oceans depends on atomic structure and composition of the minerals. For RNA nucleotides, montmorillonite seems a good candidate [9]. It has been shown to catalyze the formation of RNA oligomers. Oligomerization is a process of joining nucleotides by covalent bond. It is a condensation process where a water molecule is released on the reaction. Experimental investigations on montmorillonite and similar minerals may be the first step to identify right clay minerals for the formation of the nucleotides.

Secondly, the formation of nucleotides from the subunits is also a condensation process where two water molecules are released on the reaction. The self-replication reaction starts with bonding of a complimentary pair base, and then D-ribose is joined to the base to form a nucleoside. Next, a phosphate is joined to the nucleoside. Bonding is possible due to activation energy modification by the catalytic minerals. After the complemental nucleotide is replicated, the two nucleotides undergo separation. The breaking up at the site of the hydrogen bond requires energy input that exceeds the energy of hydrogen bond which is about 10 ~ 30 kJ/mole. Thermal energy at RT is approximately 2.5kJ/mole, which is not sufficient. Potential sources of the energy to surmount the hydrogen bond energy are UV energy when the surface of the mineral is directly exposed to the sun light, and flow of water molecules around the mineral surface due to tide cycle. The strength of UV rapidly weakens as the depth of sea water increases due to absorption. On the other hand, covalent bond is much stronger (400 ~ 500 kJ/mole) compared with hydrogen bond, thus it is unlikely to easily break up due to tidal cycle.

Thirdly, ribose exists in two stereoisomeric forms (D and L), and the both are presumably formed equally on prebiotic Earth. However, only D-ribose is present in naturally occurring extant RNA [10]. How this homochirality could have arisen can be understood with the present process. The original nucleotides contained D-ribose in the process was formed by chance (probability: 50%). L-ribose had the same chance. However, once D-ribose was selected, all nucleotides self-replicated from the original nucleotide naturally contained D-ribose only because L-ribose did not fit due to an atomic structure constraint of the nucleotide.

Fourthly, once sufficient nucleotides were concentrated, oligomerization started on prebiotic Earth. It is possible that oligomers grew step-wise in length and multiplied by self-replication at each step before the oligomers of the next step were formed. This possibility will be proposed in the future.

Fifthly, living things are found at hydrothermal vents on the bottom of oceans where no sunlight reaches, which is suggesting that life might be started there. However, they lack a fundamental condition, wet and dry cycle to drive condensation reactions for formation of nucleotides and polymerization. Thus, the presence of the living things is likely a result of evolution (adaptation by natural selection).

Finally, It is stressed that the process was unsuccessfully repeated countless times at many places along coast lines of oceans of prebiotic Earth for many years until finally succeeded and self-replicable RNA polymer was eventually formed.

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