Section
Astrophysics and Cosmology

THE ORIGIN OF LIFE FROM THE ASTROPHYSICAL POINT OF VIEW

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Abstract: The problem of the origin of life is discussed from the astrophysical point of view. Most biologists and geologists have believed up to the present time that Life originated on the Earth in some initial natural chemical pre-reactors, where a mixture of the water, ammonia, methane containing species and some other substances, under the influence of an energy source like, e.g. lightning, had turned into quite complex compounds such as amino acids and complex hydrocarbons. In fact, under conditions of the primordial Earth, it was not possible to obtain such pre-biological molecules by a-bio-chemical methods, as discussed in this paper. Instead, an astrophysical view of the problem of the origin of life on the Earth is proposed and it is recalled that the biological evolution on the Earth was preceded by the chemical evolution of complex chemical compounds, mostly under extraterrestrial conditions, where it is only possible to form optically active amino acids, sugars and hydrocarbons necessary for constructing the first pre-biomolecules.

Keywords: origin of life, chemical compounds in space, ice covers of dust grains, CR and UV induced radiation chemical polymerization of ices, chiral species.

Introduction

Most biologists and geologists have believed up to the present time that Life originated on the Earth [1]. In fact, under conditions of the primordial Earth, it was not possible to obtain pre-biological molecules by a-bio-chemical methods, as discussed in this paper. The origin of pre-life can be described in general terms as a kind of process of development from the simple to the complex, i.e. from simple chemical molecules to complex molecular aggregates. The case is that there is a generally accepted astrophysical point of view that a biological evolution on the Earth was preceded by a period of chemical evolution during which the formation and organization of pre-bio-organic compounds were accomplished – predominantly under extraterrestrial conditions. It should be evident that Life as we know it clearly originated in the same way in which everything originates, step by step. Let us discuss these steps of pre-biological evolution from the astrophysical point of view.

Steps of pre-biological evolution

Step 1: just the chemistry of simple molecules.

We limit our consideration by last 10 billion years when dust particles were abundant with gas to dust mass ratio of 100 (1000) to 1. At that time in interstellar molecular clouds behind the photo-dissociation region, the simplest but the most abundant molecular hydrogen H_2 might effectively originate on dust grain surfaces with the time-scale [2]

$$t(\mathrm{H_2}) = \frac{1.5 \cdot 10^9}{n}\ \mathrm{yr},$$

that is in pre-stellar cores with $n \geq 10^6\ \mathrm{cm^{-3}}$, then $t(\mathrm{H_2}) \leq 1500$ yr. But under conditions of unshielded interstellar medium, molecules would be destroyed in [3]

$$t(\text{photodiss.}) = \frac{1}{k_0(0)\ \mathrm{s^{-1}}} = \frac{10^9 - 10^{11}}{3 \cdot 10^7}\mathrm{yr} \cong 33 - 3300\ \text{years}.$$

Thus, molecules might be accumulated only inside of clouds and proto-stellar disks. Almost 200 molecules have been detected up to 2017, and 61 molecules in other galaxies [4].

Step 2: dust and ice covers of dust grains.

Dust grains come now with SN ejections and AGB winds. Initial sizes of graphite and/or silicate cores were $\sim 0.01\ \mu$, on which $\mathrm{H_2O}$, CO, $\mathrm{CO_2}$, $\mathrm{CH_4}$, $\mathrm{NH_3}$, $\mathrm{CH_3OH}$, HAC (hydrogenated amorphous carbon) and other icy mantles grew up to sizes of $\sim 0.1\ \mu$. Time-scales for dust growth in a dense cold medium [2] were:

$$t = \frac{3 \cdot 10^9}{n}\ \text{years},$$

which means a rapid growth in the star formation regions with pre-stellar clouds with $n \geq 10^6 \mathrm{cm}^{-3}$ and $T \sim 10 - 20$ K, about in 3000 years.

Also the grain surface chemistry is very important for the origin of H, C, O, N-containing complex ices in the star formation regions [2, 3].

Step 3: complexing.

Why are ices important? The point is that complex species are more easily generated in the solid state of ice mantles of dust grains if ultraviolet (UV, 6–13.6 eV) and cosmic rays (CR, ≥ 1 MeV) radiation fields are available. A mixture of realistic ice analogues like H_2O:CH_3OH:NH_3:CO:CH_4 has produced heavy hydrocarbons (up to 30 atoms per molecule) and amino acids by UV and/or energetic particles processing in laboratory [5, 6 and references therein]. Also molecular symmetry may be broken easier in ices under molecular cloud conditions as compared with protoplanetary conditions [7]. UV- and CR-induced solid-phase radiation chemical polymerization (polycondensation) may produce complex species with time-scales about Kyrs ∼ Myrs depending on the duration of available processing. CR contribution known from laboratory experiments is as follows: complex aliphatic ≤ $C_{29}H_{60}$ and aromatic (PAH) ≤$C_{24}H_{12}$ (coronene) hydrocarbons have been synthesized in prebiotic simulation experiments by irradiation of solid CH_4 with 7 MeV protons and/or α-particles, [5, 6, 8, 9 and references therein], in short, the radiation chemical polycondensation of methane by MeV protons and α-particles. A radiation chemical yield of alkanes in such a process resulting in ≤ $C_{29}H_{60}$, is Y ~ 1 synth.mol /100 eV [6], and a monomer fraction converted to oligomer is $Q \sim Y \cdot D$ depending on irradiation dose D, $D_{exper.}$ ~ 6 eV/molecule (0.3 eV/a.m.u.) [6, 8].

Also UV radiation induced chemical transformation of ices was revealed in experiments [5 and references therein]. A mixture of H_2O:CH_3OH:NH_3:CO (100:50:1:1), irradiated by far-UV, (at 15 K) resulted in C_nH_m (n ≤ 22) hydrocarbons, and other complex species, like e.g. hexamethylenetetramine, HMT $C_6H_{12}N_4$ (very close to amino acids). Threshold doses in the experiments, for fluxes of about $3 \cdot 10^4$ photons/cm^{2}s (at 15 K), producing heavy hydrocarbons and HMT, were of $D_{exper.}$ ~ 25 eV/molecule ~ 1.4 eV/a.m.u [5].

Interestingly, glycolaldehyde and glycine ($C_2H_5O_2N$, 206.468 MHz) [4], were observed in hot molecular core (both were optically non-active). On the other hand, carbon containing complex species revealed in meteorites contain amino acids with enantiomeric excess, which were optically active [7, 9, 10 and references therein]!

Organics recycling in the Galaxy [11 and references therein] means, among other things, the following. Large molecules (nanoparticles like fullerens and polycyclic aromatic hydrocarbons, PAHs) originated in cold stellar outflows, scattered in the interstellar medium and then entered into molecular clouds. Molecules could also survive inside condensations in planetary nebulae evidencing the recycling of organics in the Galaxy, and showing, by the way, PAH and fullerens C_{60} and C_{70}!

Step 4: "separation" first.

Chemically active droplets as a model for protocells on the early Earth are widely discussed and mean, in general, "membrane first" hypothesis which needs the lipid bilayer (lipids, pospholipids, etc.) [7, 10]. McCarthy and Calvin [12] were the first who mentioned about polyisoprenoid compounds as important ingredients to form such bilayers! Yeghikyan and co-workers [9, 14] discussed some details concerning creation in space and accumulation of such species on the Earth. Thus, "membranes first" hypothesis (in aqueous environment) is also connected to polyisoprenoid hydrocarbons suggested in [12] and highlights their role. One should conclude that isoprene ((C_5H_8) -2-methyl-1,3-butadiene $CH_2=C(CH_3)-CH=CH_2$) and its derivatives play an important role as membrane forming subunits.

Where do membrane making molecules come from?

The surface of the newborn Earth was very hot (~800 K). The atmosphere was neutral (CO_2+N_2) so no direct polymerization/polycondensation was possible and also no Fischer-Tropsch synthesis above $C_{15}H_m$ might happen. There is widely accepted now that needful organics were delivered to the Earth by comets and large dust particles [9, 10, 14 and references therein]. Physical-chemical stratification in the protosolar disk revealed by models has shown that such comets and dust originated beyond the so called snow and tar lines that permits to suggest a following observational test for polyisoprenoids: the search of corresponding lines of solid polyisoprenoid hydrocarbons in the spectra of protostellar disks, that is vibrational lines of diene molecules in the range of 3.23–13.7 μm [13].

CR and VUV induced polycondensation of solid CH_4 followed with aliphatic heavy hydrocarbons up to $C_{29}H_{60}$ should be accounted as a key process of complexing. A probable aromatization due to VUV resulted in small PAH, e.g. $C_{24}H_{12}$ is also an important way to get species widely observed in space. Circumstellar disks show many predecessors of PAH with aliphatic bonds [14 and references therein].

Basics of astrobiological scenarios concerning the origin of life on the Earth

A short summary of generally accepted scenarios is given below [7,9,10,14 and references therein].

The water for oceans was delivered by comets and dust around 4.5–3.8 Gyr ago (D/H is well agreed). The terrestrial primordial atmosphere which was also created by such a way was neutral (CO_2+N_2). Organics delivered to the Earth by comets and interstellar dust particles had already have contained chiral species because molecular symmetry could not be broken under terrestrial conditions. Comets impacting the Earth with grazing trajectories (with $\alpha \leq 5^0$, 2-3 % of all impacts) created the first biochemical reactors or „little warm ponds“. Life (on Earth) appeared 3.8 Gyr ago immediately after the cessation of the „heavy bombardment“ period.

Step 5: chiralization.

Homochirality is a key distinguisher of life and chiral molecules should be important "precursors" to first living organisms [7]. Chiral molecules older than the Earth itself have been spotted in meteors and comets. The most effective mechanism to get enantiomeric enhancement is enantiomer-selective photochemistry induced by circularly polarized light of 6–13.6 eV [7].

Terrestrial organisms use one enantiomer only. Protein synthesis, gene transcription and metabolism essentially depend on homochirality. A question is raised if Miller-type experiments (CH_4, NH_3, H_2O, H_2 + Energy source resulting in complex species) are adequate. The answer is no! The point is that the terrestrial primitive atmosphere was not reduced (no H_2, CH_4 — no polymerization/condensation) and produced amino acids were racemic. So one should look for extraterrestrial conditions to get chiral species!

Now and again: the best way to get such complex molecules is grain surface reactions under appropriate irradiation of asymmetric agents. Astrobiologists now are urgently looking for such asymmetric agents for photoreactions. One may list corresponding advantage factors: circularly polarized VUV radiation, polarized electrons, magnetic fields, rotation, parity violation in weak interactions, surfaces of crystals (quartz) and clays (caolinit) [7]. Problems of seeding chirality and its amplification are also challenging.

So, a very important question should be “Where do prebiotic molecules come from?” Are they really from a natal cloud, or probably from a disk, or from other exoplanet? Astrophysicists need more precise observational and theoretical data to get first answers to such complicated questions.

Conclusions

Life on the Earth is the final product of a very long chemical evolution of matter, mainly under extraterrestrial conditions. This evolution started from the creation of the simplest molecules, survived under very hard conditions sometimes, condensed into dust when possible, began to be covered with ice and formed ice mantles of dust grains. Further, the radiation-chemical polymerization of a mixture of ices resulted in the formation of amino acids, sugars and hydrocarbons. It should be emphasized that these compounds should have been optically active, that distinguished living organisms from inanimate ones. Delivery of these substances before the birth of life on the Earth is a separate problem: most likely they were brought by comets, colliding with the Earth on grazing trajectories during the bombardment of the Earth between 4.5 and 3.8 billion years ago. There is the widely accepted point of view that Life on the Earth originated 3.8 Gyr ago [10].

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