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Polymerization of building blocks of life on Europa and other icy moons

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Abstract

The standard Gibbs energy of reaction of organic monomers, in particular amino acids (2Gly, 3Gly, Ala+Gly, and Leu+Gly) and nucleotide, to investigate polymerization in the environment of icy moons. In the surface condition on Europa, for examples, global average temperature is -173 °C, the Gibbs energy of the reactions could be negative value which means that the polymerization reaction can be proceed spontaneously with dehydration process. Following scenario from the amino acids to the origin of life in detail is not well understood, but the possibility of polymerization of organic monomers on the icy moons would be helpful to understand whether the icy moons can have an extraterrestrial habitat or not, and suggests constraints on the evolution of extra-terrestrial life.

1. Introduction

The outer solar system may provide a potential habitat of extra-terrestrial life. Most moons orbiting giant planets are covered with water ice and they are called 'icy moons'. Detection of induced magnetic fields [1] combined with imaged surface characteristics by the Galileo spacecraft [2] support that the Jovian icy moons Europa, Ganymede and possibly Callisto, may harbour liquid water oceans and may possess 'a deep habitat' underneath the icy crusts, a different style of habitability from Earth-like biosphere. But detailed chemical environment, i.e., the presence of heavy molecules and prebiotic components, are unclear because of a limitation of observational instrument. On the other hand, amino acids has been detected on the Wild-2 comet through in-situ observation by the Stardust spacecraft [3]. Thus we could imagine that the comets has such kind of amino acids universally and these materials could be supplied through the impact process to the icy moons' surface continuously.

2. Environment of Europa

Jovian icy moon Europa is one of most important candidate for an extra-terrestrial habitat. Measurement of gravity coefficients and Moment of Inertial factor of Europa can constraint the interior density distribution [4], and the thickness of the outer water shell must lie in the range of about 80 to 170 km in both models. Surface environment is quite different from the Earth. Europa's atmosphere is mainly composed of molecular oxygen [5] but quite tenuous, 0.1~1 μPa [6], thus the icy surface is exposed to sunlight and is frequently impacted by small objects and energetic particles trapped within Jovian magnetic field. The surface temperature is about -193 °C in the equatorial region and about -153 °C in the polar region [7]. Surface is tectonically active and young (~20 to 200 Ma [8]) and there are few impact craters. Non-water materials, in particular, hydrates of salts are concentrated in the cracked and disrupted terrain, which have been found through the infrared mapping spectrometer onboard Galileo spacecraft [9]. This means that the origin of these salts are strongly related to the geologic process.

3. Thermodynamically calculations

To evaluate the potential for polymerization of amino acids and other reactions of biomolecules, we performed thermodynamic calculations to find the standard Gibbs energies of reaction of aqueous species and crystalline compound which is expressed as *apparent* standard molal Gibbs energy [10],

$$\Delta G^{o} \equiv \Delta_f G^{o} + \left(G^{o}_{P,T} - G^{o}_{P_r,T_r}\right) \qquad (1)$$

Second and third term of the right side is in a different form among aqueous species and crystalline compound, respectively. The values of ΔGº for liquid H_2O at the temperature and pressure of interest were referred from a report by Helgeson and Kirkham (1974) [11], and those for H_2O ice (Ih) were taken from Feistel and Wagner (2006) [12]. The standard state convention used for liquid H_2O is one of unit activity of pure water at any temperature and pressure, whereas that for aqueous species other than

H_2O corresponds to unit activity of the species in a hypothetical 1 molal solution referenced to infinite dilution at any temperature and pressure. The standard Gibbs energies of any reaction were calculated from the following equation,

$$\Delta_r G^o = \sum_i \nu_{i,r} \Delta G_i^o \qquad (2)$$

Therein, ΔG^o_i stands for the standard molal Gibbs energy of formation of the *i*-th species at any temperature and pressure. Also, $\nu_{i,r}$ denotes the stoichiometric reaction coefficient of the *i*-th species in the reaction, which is negative for reactants and positive for products. In addition we calculated temperature profile in the Europa's ice crust assuming thickness of 40 km and 100 km in order to evaluate the possibility of the reaction in the surficial condition on Europa. We solve 1-D heat transfer equation considering heat conduction and convection with temperature dependent viscosity [13].

4. Results

In a lower temperature environment the Gibbs energies could be negative, particularly below -155 °C for 2Gly -> GlyGly + H_2O, -164 °C for 3Gly -> GlyGlyGly + H_2O, -193 °C for Gly + Ala -> AlaGly + H_2O, and -214 °C for Gly + Leu -> LeuGly + H_2O. A negative value of the Gibbs energy means that above reactions can be proceed spontaneously. For the higher pressure condition, 10^8 Pa (Fig.1 lower panel), the Gibbs energies will be a bit larger and the temperature which the Gibbs energy becomes negative will be lower, for examples, the energy for the polymerization of 2Gly will be negative below -171 °C. This means that the reaction in a deeper and warmer region of the ice crust is difficult to proceed. Europa's surface has extremely low temperature which can proceed above reactions, and polymerized amino acids can be protected from the radiolytic desorption even if only slightly inside the ice crust. In parallel, the energy for the creation of nucleoside (Adenosine) from Adenine and ribose is smaller than that for amino acids. The Gibbs energy becomes negative below -26 °C for 1 Pa, and -131 °C for 10^8 Pa. Comparing to the calculation of the temperature in the ice crust, the reaction of amino acids can occur only shallow region in the crust. In the polar region, surface temperature is few tens of K lower than equatorial region as mentioned previously. The reactions of 2Gly and 3Gly can occur even in deeper region of the crust. In addition, the reaction of the Gly+Ala cannot occur on the equatorial surface but would occur in the polar region. On the other hand, the higher value of Gibbs energy for Gly+Leu suggests that the reaction cannot occur even in the Europa's polar region. Above thermodynamical calculations show that the amino acids, particularly polymerization of 2Gly and 3Gly, reaction of Gly+Ala, and creation of nucleoside (Adenosine) from Adenin and ribose can occur on the surficial region of Europa.

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