ELECTROLYSIS IN SPACE AND FATE OF PHAETHON

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Abstract. A new process of the energy accumulation in icy bodies (e.g., planetary satellites, cometary nuclei) is advanced which is applicable for space conditions: namely, the volumetric electrolysis of the ice containing foreign inclusions. The electrolysis takes place when the electric current, generated by virtue of the body's movement in the external magnetic field (planetary magnetospheres, the solar wind field, etc.) flows through the body.

The cosmogonical concept which treats the Sun–Jupiter system as a limiting case of a close binary star, together with the known data on mass, composition and space distribution of asteroids, allows one to assume the initial existence between Mars and Jupiter of a Moon-like planet enriched with ices and allied by its parameters to the Galilean satellites (mainly Ganymede and Callisto). If this planet was affected by the ancient solar wind with $M_o \approx 2 \times 10^{-11} M_\odot$ yr$^{-1}$ during $\sim 10^9$ yr, it could have accumulated the energy sufficient for its explosion.

The process considered seems able to explain, from a unified point of view, a large number of phenomena—such as the burst activity of comets, a considerable hydrogen excess in their tails, a noticeable long-period comet perihelia orientation toward the solar apex, the existence of asteroidal families and the separation of asteroids by their chemical composition into two main groups, the Tunguska event, etc.

The discovery on Io of active volcanoes indicates a clear need for a thorough study of possible manifestations of eruptive activity on various bodies of the solar system.

One hundred and seventy-five years ago Olbers suggested that asteroids originated from the breakup of a planet located between Mars and Jupiter. Recently, Orlov (1949) has named this planet Phaethon. The breakup hypothesis has been amply discussed (e.g., Newcomb, 1861; Daly, 1943; Putilin, 1953; Shor, 1973; Demin and Zhuravlev, 1979) and by Napier and Dodd (1973, 1974) appears to be generally plausible from the standpoint of celestial mechanics. The physical causes of the breakup (and even several breakups) are unclear. The last discussion of Olbers's idea has been initiated by the suggestion of Ovenden (1972, 1973) on a fairly recent (16 Myr ago) disappearance of a giant planet with $M_p = 90 M_\oplus$. Van Flandern (1978) put forward some additional arguments in favor of the planetary explosion. But Ovenden's idea on the giant planet breakup seems unrealistic from the viewpoint of physics, mechanics, paleontology, etc. (Napier and Dodd, 1973, 1974; Opik, 1978).

The restricted range of orbit inclinations to the ecliptic and of eccentricities ($i \leq 25^\circ$ and $e \leq 0.33$ for 98% of asteroids), not to speak of the absence of retrograde asteroids, indicates a small force of the explosion and a low mass of Phaethon. The velocity of the fragments, as derived from their orbits, is estimated by Newcomb (1861) and Putilin (1953) to be $2.7-4$ km s$^{-1}$. Different authors give for $M_p = 3-8 M_\oplus$ (see references in Putilin (1953)). Chapman and Davis (1975) evaluate the most probable initial mass of the
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asteroid belt to be \( \sim 1-2M_p \). According to Urey (1974), Moon-like bodies played an important role in the young solar system. The idea of the origin of the solar system as a limiting case of the close binary star formation (Drobyshevski, 1974) implies that there still should be hundreds of such bodies, most of them moving along irregular orbits at distances of \( \sim 10^2 \) AU. These bodies were formed in the outer layers of proto-Jupiter near the first Lagrangian point where conditions for their gas-dynamic suspension obtained as a result of gas outflow onto the Sun. At \( M_p \geq 1M_p \) the conditions of suspension broke down, the body being eventually lost by proto-Jupiter because of fast (\( \frac{dt}{d \ln M_p} = 10^3-10^4 y \)) decrease of its mass (Drobyshevski, 1978). The Galilean satellites, the last and typical representatives (particularly Ganymede and Callisto) of the Moon-like bodies, could not escape from Jupiter since it had stopped to lose matter. It is natural to assume that Phaethon, most probably, had a similar composition and structure (we accept \( M_p \sim 10^{22} \) kg, \( r_p \sim 2500 \) km). Based on the matter of solar composition, it should have contained about 40% 'rocks' and 60% water. The formation of the Moon-like bodies proceeded so fast that the energy of accretion did not have time enough to dissipate. Therefore primary differentiation occurred very fast: grains of rock, coated by heavy hydrocarbons in virtue of the Fischer–Tropsch reaction, went down and formed a core surrounded by hot water. Afterwards, radiation cooling from the surface resulted in a fast temperature drop of the water envelope and formation of the ice crust. The surface temperature of Phaethon began to be determined by solar irradiation, \( T \approx 145 \) K \( (R = 2.8 \) AU, albedo 0.5, the emissivity at thermal wavelengths 0.9). In the beginning, the flux of energy through the crust was due to ice heat conductivity \( (K \approx 3 \) W m \(^{-1} \) K \(^{-1} \)). However, at crust thickness \( \delta \sim 1-10 \) km, convection starts in ice (Reynolds and Cassen, 1979) (the Rayleigh number \( R_l = \beta \rho g c_p \delta^3 \Delta T / \nu K \gg R_l_c \approx 10^3 \)). At \( R_l / R_l_c \geq 1 \), the heat flux is \( q \approx (K \Delta T / \delta) \times 2(R_l / R_l_c)^{1/3} \) (see Palm (1975), Reynolds and Cassen (1979) and references therein; this formula describes also results of Kulacki and Goldstein (1972) experiments with an internal heating in the convective layer), where \( g = 1 \) m s \(^{-2} \) is the gravity acceleration, \( \rho = 1200 \) kg m \(^{-3} \) is the ice density, \( c_p = 2.5 \) kJ kg \(^{-1} \) K \(^{-1} \) is heat capacity, \( \beta = 1.5 \times 10^{-4} \) K \(^{-1} \) is the thermal expansion coefficient, \( \Delta T \) is the temperature drop, \( \nu = 2 \times 10^5 - 2 \times 10^{11} \) m \(^{2} \) s \(^{-1} \) is viscosity (Pounder, 1965). Even the parameters of conventional ice under terrestrial conditions, not to speak of the high pressure phases, are known very poorly since they depend on sample prehistory, the presence of impurities and so on. \( \nu \) for ice strongly increases with decreasing \( T \) and decreases with increasing deformation rate and with addition of halogen ions and hydrocarbons. Experiments on convection with the variable viscosity and rigid boundaries demonstrate the possibility of the heat flow calculation by making use of the viscosity evaluated at the average of the top and bottom temperatures (Booker, 1976). As for the planet, here the upper surface is free and the heat flow is due mainly to the volumetric heat sources (see below). So an influence of the outer layers, having the maximal viscosity, on the convection should not be very great. Thus we assume \( \nu = 2 \times 10^8 \) m \(^{2} \) s \(^{-1} \). Then at the normal chondrite energy release in rocks \( (h = 5 \times 10^{-12} \) W kg \(^{-1} \)) the water envelope should freeze all the way through in the steady state, and \( \Delta T \approx 1 \) K. The envelope will continue to be ice \( (\Delta T_{\text{max}} \approx 150 \) K) if