Redox and Thermal States and Internal Structure of Io

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We construct an internal structure model of Io taking into account the redox and thermal states. Since the building blocks of the Galilean satellites likely experience the chemical interaction with H_2O in the circum-jovian nebula, they would have strongly oxidized composition in which most of Fe and S form oxides and sulfate rather than metal and sulfide. However, the previous models of the internal structures of these satellites have neglected such highly oxidized constituents. Here we revisit the model of internal structure and composition of Io taking into account highly oxidized materials.

For the solar mixture of major rock-forming elements, the mineral combination has been calculated taking the content of O as a parameter. Phase changes of Fe and S associated with oxidation are given according to the phase diagram of Fe-S-O system of 1200 K (Lewis 1982). FeO, MgO, and other elements are partitioned into minerals following the rule of the norm calculation for simplicity. We assume the thermal history of Io as follows; First, Io forms homogeneously in mineral composition. Later, interior of Io becomes gradually molten owing to tidal heating and differentiation proceeds through the gravity separation of melt and residue. Each mineral is distributed to the crust, mantle and core along these processes. The sequence of such differentiation follows the order of melting temperature of each combination of minerals. The moment of inertia factor is calculated from the masses and average densities of each layer.

The average density and moment of inertia of model Io are calculated as a function of redox state and compared with the observed values. The observed average density is explained by an oxidized composition rich in Fe_3O_4, $MgSiO_3$ and $MgSO_4$ and poor in metallic Fe, FeS and Mg_2SiO_4. The differentiation of primitive Io that starts from this composition proceeds as follows; First, FeS and Fe_3O_4 melt at their eutectic point 1300 K, and form a FeS-rich core with dissolved Fe_3O_4. Next, $MgSO_4$ melts at 1400 K and is distributed to crust. Afterwards, plagioclase and pyroxene melt at their eutectic point 1570 K and the plagioclase-rich melt is distributed to crust. Finally, mantle consists of those residues. The norm composition of each layer after differentiation is as follows (wt% for the total mass of Io); Crust: $MgSO_4$ (11.3), albite (7.5), anorthite (1.9), enstatite (1.2). Mantle: enstatite (27.6) , magnetite (19.4), forsterite (9.3), diopside (5.1). Core: troilite (14.2), magnetite (2.5). This structure has the moment of inertia factor 0.3714, which is almost consistent with observed value 0.3768 +/- 0.00035 (Anderson et al. 2001).

Although Io has been suggested to possess lower bulk Fe/Si ratio than the solar ratio on the basis of internal structure model with Fe-FeS core and olivine-dominated mantle (Sohl et al,2002), the solar proportion of Fe and Si can be reconciled with the bulk properties of Io. Our model predicts that Io has highly oxidized composition. $MgSO_4$, mainly distributed to crust, would decompose into MgO and SO_3 under high temperature. Thus it may supply S and SO_2 which cover the surface and atmosphere of Io. The core consists of FeS and Fe_3O_4 and their eutectic temperature is lower than the maximum temperature (1700 - 2000 K) of erupted magma observed on Io (McEwen et al. 1998). So the core would be molten entirely. If the core is covered with the mantle kept at constant temperature by the tidal heating, thermal convection would not occur in the core and therefore the dynamo action would not been driven. However, the dynamo action might be possible if the tidal heating and mantle temperature gradually decline during the course of the orbital evolution. This would explain the observed anomaly in magnetic field around Io.