Thermal history of Mercury with reduced composition and the possibility of intrinsic magnetic field generated by core dynamo

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Mariner 10, which encountered Mercury in 1974, discovered the strong intrinsic magnetic field of Mercury. This suggests that a liquid outer core still remains in a metallic core and convection driven there generates magnetic field of this planet. Before the Mariner 10's discovery, it was believed that the core had been completely frozen because of the small planetary size. Therefore, the existence of magnetic field was unexpected fact.

According to the widely accepted thermal history model of Mercury proposed by Stevenson et al. (1983), the core can escape from complete freezing at present because the core melting point decreases significantly if a small amount of sulfur was mixed in the core. In this model, dynamo is driven by compositional convection due to the density change in the outer core associated with the growth of inner core that consists of pure iron.

However, this model assumes that the core and mantle compositions of Mercury are similar to those of Earth, respectively. The sulfur concentration in the core affects the melting point of the core. The mantle viscosity affects the cooling of the interior of planet. Therefore, if the composition of Mercury is different from that of Earth, the thermal history may differ from the previous model.

The reflection spectra of Mercury and the implication of O-isotope composition of meteorites (Wasson 1988) both suggest that Mercury may consist of material with reduced composition. Here, we assumed that Mercury was formed from materials with composition similar to enstatite (E) chondrite, which is the most reduced type of meteorite. In our E-chondric model, the core consists of the metal-silicate components of enstatite chondrite, and hence the weight fraction of sulfur reaches 13 wt%. This lowers the melting point of iron significantly and may prevent the inner core from growing. The mantle is drier than the terrestrial one and mainly consists of enstatite. Then, the viscosity of the Mercury's mantle is about 1000 times larger than that of the Earth's mantle and thus the cooling of interior may become inefficient. Under these assumptions, we calculated Mercury's thermal history by using parameterized convection theory or mixing length theory, and discussed the possibility of dynamo by core convection. The other conditions such as heat generation in mantle and the formulation of inner core growth are identical to those of Stevenson et al. (1983).

The result of the inner core growth, which may cause compositional convection if it occurs for the E-chondritic model, is summarized as follows. In the standard model of Stevenson et al. (1983), the inner core began to grow after 0.23 Gyr and inner core radius reaches about 1760 km after 4.6 Gyr after the formation of Mercury. On the other hand, the inner core does not grow at all in the E-chondritic model. Furthermore, the heat transport across the core-mantle boundary is too weak to cause thermal convection in the liquid core. In this case, the other mechanisms such as lateral temperature anomalies are required to produce dynamo action.

Next, we estimated the range of core sulfur concentrations and mantle viscosities allowing inner core growth along with the magnetic dipole moment generated by compositional convection with using the scaling law proposed by Olson and Christensen (2006). If the mantle viscosity is 1/10 times smaller than that of E-chondritic model and the core sulfur concentration is 6 to 8 wt%, the inner core can grow and its associated compositional convection may explain the observed dipole moment. If more detailed information for the surface composition and magnetic field of Mercury is obtained by the future missions such as Messenger and Bepi Colombo, we may understand better the thermal history and generation mechanism of magnetic field connecting with the bulk composition of Mercury.