

Chemical reaction between molten iron and silicates and chemical evolution of the core and mantle

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In a homogeneous accretion model, silicates and metal iron-alloys were originally well mixed. Subsequent core formation in the Earth and other planetary bodies therefore requires mechanisms for separating and mobilizing the iron-alloy. Mode of core formation would have large effects on chemical compositions of the early Earth's core and mantle. Permeable flow is one plausible mechanism of iron-silicate separation, by which molten iron migrates through the solid silicate grain boundaries along an interconnected grain-edge pore network. The interconnected melt network is formed even at very low melt fractions provided the melt-solid dihedral angle is smaller than the critical value of 60 degrees.

Previous surface energy measurements at high pressures suggested that a percolation of metallic iron-rich liquid through silicate matrix is prevented due to the high surface tension of iron up to the uppermost lower mantle condition, except for the case of an oxygen-enriched sulfide melt formed under oxidizing conditions.

We measured the dihedral angle of molten iron in (Mg,Fe)SiO₃-perovskite aggregate with increasing pressure and temperature using laser-heated diamond anvil cell (LHDAC). Results demonstrate that it decreases from 94 degrees at 27 GPa and 2400 K to 51 degrees at 47 GPa and 3000 K. This value is smaller than the critical angle of 60 degrees, thus allowing iron melt to wet the grain boundaries of silicate perovskite and develop an interconnected melt network within the perovskite-dominant matrix, even at very small melt fractions.

The quenched liquid iron contained substantial amounts of oxygen and silicon as pressure and temperature increase. Such a decrease in the dihedral angle is likely due to a reduction in the iron-perovskite interfacial energy by dissolving oxygen and silicon into the liquid iron from coexisting silicate perovskite. These suggest that a wetting behaviour of core melts in the solid silicate mantle changes above 40 GPa, corresponding to 1000 km depth in the present Earth, and efficient metal segregation may have proceeded by permeable flow in a late stage of accretion.

Chemical reaction between molten iron and silicates at the core-mantle boundary could also have large effects on the evolution of core and mantle. We have conducted reaction experiments between liquid iron and (Mg_{0.9}Fe_{0.1})SiO₃-perovskite up to 97 GPa and 3150 K using LHDAC. Results demonstrated that the quenched liquid iron contains 5.3 wt% O and 2.8 wt% Si at 97 GPa and 3150 K GPa, corresponding to 2200 km depth in the present Earth, that can account for the 7% core density deficit.

We also estimated that the simultaneous solubilities of O and Si in liquid iron in equilibrium with (Mg,Fe)SiO₃ perovskite at 135 GPa and 3500 K corresponding to the core-mantle boundary condition from thermodynamical data. This results indicated that the bottom of the mantle in contact with the liquid core with less than 10% density deficit could be extremely depleted in iron. This estimation may include large errors due to the uncertainty in pressure effect, but the base of the mantle is likely depleted in iron compared to the composition of bulk mantle. Such iron-depleted mantle is buoyant and will be replaced by the normal mantle. Then, O and Si should dissolve more into the outer core by the chemical reaction between the normal mantle and liquid iron. In this manner, the core becomes more enriched in O and Si with time.