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Melting experiments in the system Fe-Xe and Earth's missing xenon

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The abundances of noble gases in the Earth's atmosphere should be consistent with those in CI chondrite. However, xenon in the atmosphere is depleted relative to chondritic abundance, while lighter rare gases, Ne,Ar, and Kr, are less depleted. This is the so-called "missing xenon" problem and its reservoir has been discussed for a long time. Since xenon is too heavy to escape toward outer space, the missing xenon (Xe) might be hidden in the deep Earth.

The potential reservoirs are the mantle and core because xenon has a good reactivity under high pressure. Although extensive studies on the reactions of Xe and various mantle materials have been performed, none of those found a Xe reservoir (e.g., Sanloup et al., 2005; 2011; Brock et al., 2011). On the other hand, the alloying of iron with xenon has been expected based on the fact that Xe becomes metallic above 130 GPa (e.g., Eremets et al., 2000). While first-principle calculations suggested that the solubility of xenon in hcp iron is 0.8 mol% at Earth's core conditions (Lee et al., 2006), experimental study showed that the solid Fe-Xe reaction did not occur at least up to 155 GPa and 3000 K (Nishio-Hamane et al., 2010). Here we performed melting experiments in the Fe-Xe system to 86 GPa and 6450 K.

High pressure and temperature (P-T) conditions were generated in a laser-heated diamond-anvil cell. We used pure iron foil as a starting material. Xe was loaded cryogenically. Angle-dispersive X-ray diffraction (XRD) measurements in-situ at high P-T were conducted at BL10XU, SPring-8. The textural and chemical characterizations of recovered samples were made by using a field-emission-type scannning electron-microprobe (FE-SEM) equipped with energy dispersive x-ray spectrometry (EDS). Both cross section and surface of a sample were carefully examined by combining a focused Ga ion beam (FIB) with FE-SEM.

Any evidence for the reaction was not observed at least up to 83 GPa and 3810 K based on both XRD measurements and chemical analyses. On the other hand, chemical analysis on the sample recovered from 86 GPa and 6450 K, the highest P-T condition achieved in this study, showed Fe alloyed with up to ˜1.6 wt.% Xe as tiny grains. This sample had a difference in the texture between heated and unheated regions. We calculated the concentration of Xe in the entire molten area by assuming the heated region and the small grains of Fe-Xe alloy as a cylinder and spheres, respectively. The xenon content was estimated to be 0.02 wt. % for the heated area which is high enough to account for the missing xenon problem (10^{-10} wt.% Xe in the core). The present results could be a clue to solve the "missing xenon" paradox. Since the temperature of the present Earth's core is most likely lower than 6000 K, xenon might be incorporated into the core during Earth's early history at higher temperature.

Keywords: Missing Xe, melting experiments, High pressure and temperature, core