Equation of State for Liquid Iron under Extreme Conditions

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The Earth's core is composed mainly of iron and almost molten. Likewise, Mercury and Mars are also expected to have a partially molten iron core. Since density (ρ) and longitudinal sound velocity (V_P) are the primary observables of the Earth's liquid outer core and possibly for other planets in future, laboratory measurements on these properties at relevant high-pressure conditions are of great importance to understand the core composition and dynamics of Earth and other terrestrial planets. Our knowledge for those properties of liquid iron under high-pressure and -temperature (*P*-*T*) conditions is, however, completely limited because of the experimental difficulties. In this study, we have determined the ρ and V_P of liquid iron up to 116 GPa and 45 GPa, respectively, via static compression in a laser-heated diamond-anvil cell (LH-DAC).
We determined the ρ of liquid iron up to 116 GPa and 4350 K based on in-situ x-ray diffraction measurements at BL10XU, SPring-8 [1]. A new analytical method was applied to derive ρ from the diffuse x-ray scattering signals from the liquid. We also obtained the V_P of liquid iron up to 45 GPa by inelastic x-ray scattering (IXS) measurements in the LH-DAC at BL43LXU, SPring-8 [2]. From our new data combined with previous shock-wave data, we obtained the P–T–ρ–V_P–γ relation for the Earth's entire outer core conditions. Compared to the ρ, V_P, and adiabatic bulk modulus (K_S) of liquid iron calculated along the isentrope with T_{ICB} (the temperature at the inner core boundary) = 5400 K, the Earth's outer core have 7.5–7.6% lower ρ, 3.7–4.4% higher V_P but an almost identical K_S.
Seismology gives the density difference between the liquid and solid core at the ICB; $\Delta\rho_{ICB}$ = 0.55–0.82 g/cm^3 (e.g., [3]). Our results show that liquid iron is less dense than hexagonal-close-packed (hcp) iron [4] by = 0.32 g/cm^3 at 330 GPa and its melting point of 6230 K [5]. This is approximately half of the observed $\Delta\rho_{ICB}$, indicating that the remaining 0.23–0.50 g/cm^3 (corresponding to 1.9–4.1% of the outer core density at the ICB) should be attributed to a compositional difference between the outer and inner core.
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