Iron isotopic fractionation in Earth's Lower Mantle and Core

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Here we report the experimental determination of the mean force constant ⟨F⟩ of iron bonds in lower-mantle ferropericlase and bridgmanite, a basaltic glass, metallic iron, and iron-rich alloys of Fe-Ni-Si, Fe-Si and Fe-S using Nunclear Resonant Inelastic X-ray Scattering (NRIXS) in a high-pressure diamond anvil cell up to respective lower mantle and core pressures. Iron isotope ratios have been extensively studied to decipher the origin and evolution of planetary bodies. The enrichment of terrestrial basalts in heavy iron isotopes relative to chondrites was proposed to be a fingerprint of core-mantle segregation. However, the extent of iron isotopic fractionation between molten iron-rich alloys and silicate melts under conditions relevant to core formation is poorly known. Furthermore, the effects of the electronic spin and valence states of iron on the force constant of lower-mantle minerals remain unclear. To derive reliable force constants of iron from these samples at high pressures, we have collected extremely high-quality energy spectra over an extended energy range with very low background noise. Analysis of the NRIXS results at high pressure using SciPhon Software shows that all ⟨F⟩ values of iron alloys and basaltic glass increase with pressure, and that the ⟨F⟩ values of silicate glass are comparable to those of metal [1]. On the other hand, the ⟨F⟩ values of iron in lower-mantle minerals are found to be influenced by its spin states and lattice configurations. The calculated equilibrium iron isotope fractionation between silicate and iron at conditions relevant to high-pressure core formation in Earth is ~0–0.02 ‰, which is small relative to the measured iron isotope enrichment in terrestrial basalts of ~+0.1‰. We also found that the presence of small amounts of nickel and candidate core-forming light elements such as hydrogen, carbon, oxygen, silicon and sulfur does not have a signficant effect on the iron fractionation, as the isotopic shifts associated with such alloying are small compared to the precision of iron isotopic analyses. These results are applied to understand iron isotopic composition due to core formation and to address lower-mantle Fe isotope fractionation during magma ocean crystallization.

[1] Liu et al. (2017) Nature Comm., 8, 14377.