Isotope fractionation at the core-mantle boundary by thermal diffusion

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The contact between the Earth's silicate mantle and outer core of molten iron alloy is the largest thermal and compositional boundary layer within the planet. The thermal boundary layer is thought to extend tens to hundreds of kilometers above and below the core–mantle boundary (CMB) across which temperature changes by 1000 to 1500 K. High pressure and temperature experiments on silicate and core-forming liquids demonstrate that heavier isotopes preferentially migrate toward lower temperature [1,2]. In metallic liquids isotope fractionation can occur rapidly due to the high mobility of ions, reaching 0.015 ‰/°/amu for Fe isotopes at steady state [2]. We model isotopic fractionation by solving the equation

$$\frac{\partial C}{\partial t} + u \cdot \nabla C - \nabla \cdot (D \nabla C) - \nabla \cdot \left(\frac{C(1-C)\alpha D}{T} \nabla T \right) = 0$$

where C is the concentration of a given isotope, u is the velocity, D is the self diffusivity, T is the temperature and $\alpha = \alpha_o \frac{m_h - m_l}{m_h + m_l}$ is the Chapman-Enskog fractionation factor describing how isotopic fractionation depends on mass and temperature. We solve the equation using the finite-element mantle convection software ASPECT, which in addition solves the Stokes equations and the energy conservation equation for convection in the Earth's mantle [3]. Our model reproduces thermal diffusion experiments for the purely diffusive case of Fe isotope fractionation in Fe alloy liquids exhibiting enrichment in ^{56,57}Fe relative to ^{54}Fe towards cooler temperatures. Simulations of thermal diffusion at the CMB produce enrichments in ^{56,57}Fe immediately above the CMB in 100's of millions of years in material that can be entrained in upwelling plumes. The unique isotopic signature of thermal diffusion linked to the disposition of the temperature field in the vicinity of the CMB may help to reconcile some differences in the non-traditional stable isotope composition of terrestrial basalts and persumed bulk Earth.

Refs. [1] Huang et al. (2010) *Nature* 464, 396-400 & Lacks et al. (2012) *PRL*, 108, 065901. [2] Lesher et al. (2012) *Mineral. Mag*. 79(6), 2000. [3]Heister, Dannberg (2017) *Geophy. J. Intern*. 210, 833-851.