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Equilibrium chromium isotope fractionation during magma evolution in Earth and Moon

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Magma evolution is a fundamental process for understanding the compositional differentiation of Earth, the Moon, and terrestrial planets. Basalts, produced through partial mantle melting and subsequent crystallization, record the redox state and evolutionary trajectory of their source reservoirs, offering critical insights into planetary interiors. However, variations in source composition, magmatic differentiation paths, and oxygen fugacity (fO_2) lead to diverse isotopic signatures in planetary basalts. Chromium (Cr) is a moderately compatible element enriched in mafic basalts. Cr^{2+}/Cr^{3+} ratio is highly sensitive to fO_2, and the degree of Cr isotopic fractionation is directly linked to its valence ratio. Therefore, Cr isotopic fractionation during basaltic magma evolution holds great potential for providing geochemical constraints on planetary redox conditions. In this study, we calculate equilibrium Cr isotope equilibrium fractionation coefficients among major upper mantle silicate minerals and between silicate minerals and basaltic melts, considering the impact of the Cr^{2+}/Cr^{3+} ratio. Combining theoretical calculations with natural basalt samples, a quantitative framework linking magma reservoir characteristics to redox conditions is constructed.