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Experimental Constraints on Sulfur Isotopic Fractionation During Planetary Differentiation

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Volatile elements are essential for life and planetary evolution, and their delivery to Earth has profound implications for habitability. These elements may have been incorporated during Earth's main accretion phase [1], or later via the late veneer, following core formation [2]. Determining the dominant process is key to understanding Earth's volatile inventory.

Sulfur (S) is a key tracer for volatile delivery due to its dual nature as a siderophile and volatile element, making it sensitive to planetary differentiation processes like core segregation and partial volatilization during a magma ocean phase. Earth's basalts have variable $^{34}S/^{32}S$ sulfur isotope ratio signatures. $\delta^{34}S$ estimates for mantle sources range between -1.3±0.3‰ and -0.7±0.1‰ (ref. [3]), differing from chondrites (0.04±0.31‰) [4,5]. Whether this difference between basalts and chondrites reflects a core/mantle equilibration event, sulfur evaporation from a magma ocean, or geodynamic evolution of Earth's mantle remains uncertain. Experimental data have suggested that metal-silicate isotopic fractionations are resolvable but remain small, leaving most of the isotopic shift unexplained [6]. However, previous experiments relied on volatile-saturated conditions, which could inhibit fractionation.

We conducted new piston-cylinder experiments using an experimental set up that does not induce volatile saturation. A triple-isotope technique combined with a time series were used in order to thoroughly assess sulfur isotopic equilibrium. In experiments lasting up to 6 hours, we observe a small but resolvable equilibrium isotope fractionation between metal and silicate, consistent in direction and magnitude with previous results [6]. This suggests that volatile saturation is not major driver of isotopic fractionation in the studied system. These results indicate that batch fractionation between Earth's mantle and core may account for a fraction of the isotopic shift observed between terrestrial basalts and chondrites.

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