Oxygen Isotopic Evolution in the Early Solar Nebula: Interpretation of the Small Oxygen Isotopic Variation of Chondrules

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Oxygen isotopic systematics observed in chondritic components provides important clues to elucidate physical and chemical processes occurred in the early solar nebula. Chondrules have O-isotopic composition similar to those of terrestrial materials with small variation. In contrast, CAIs, the oldest minerals formed in the early solar nebula, have anomalously ^{16}O-rich composition [1]. A plausible explanation for the origin of the systematics is enhancement of ^{16}O-poor H_2O concentration in the initially ^{16}O-rich inner solar nebula [2]. The ^{16}O-poor H_2O is produced by isotope-selective photodissociation of CO in the parent molecular cloud and stored as icy mantle on silicate dust in the cold outer part of the nebula. The ice-coated dust particles drift inward due to nebula gas drag [3] and releases water vapor at the hot inner nebula. As a result, the ^{16}O-poor H_2O concentrates with time and the mean O-isotopic composition of the inner nebula evolves to be ^{16}O-poor. This model is consistent with the large variation between CAIs and chondrules, however, not likely to explain the small O-isotopic variation of chondrules because H_2O concentration is expected to be temporally and spatially heterogeneous during chondrule formation.

In this study, we suggest a process which is overlooked in the previous study and possibly explains the small variation of chondrules; i.e., enhancement of silicate dust concentration in the inner nebula. Collision experiment of the nebula dust analogous implies that the typical size of dust particles would be determined by the adhesive properties of them [4]. Because silicate is less sticky than H_2O ice, dust particles would be refined after evaporation of icy mantle. The size of silicate dust is theoretically estimated to be ~ sub-millimeter, which is interestingly comparable to that of typical chondrules. Such small dust particles are well coupled with the nebula gas motion and hardly drift inward. Thus concentration of silicate dust would also be enhanced almost same degree as that of H_2O in the inner nebula. The most important consequence of this model is that, in case the concentration of H_2O and silicate dust is enhanced >~ 5 times larger than the solar abundance, the mean O-isotopic composition of the inner nebula is almost determined as the weighted mean of O-isotopic composition of H_2O and silicate in the solar abundance ratio; i.e., independent for their concentration. This suggests that temporal and spatial variation of concentration of H_2O little affects on the mean O-isotopic composition of the inner nebula as long as the enhancement is sufficiently large. Numerical simulation on the evolution of concentration of H_2O and silicate dust using typical properties of observed protoplanetary disks confirms that such large enhancement is sustained during chondrule formation in the inner nebula. Thus, the small O-isotopic variation of chondrules would be reproduced in our model.

References

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