

A Condensation Origin of Potassium and Rubidium Isotopic Variations in Carbonaceous Chondrites

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Introduction: Chondrites display depletions and isotopic variations of moderately volatile elements (MVEs) that are not yet fully understood. Potassium and rubidium are useful tracers of possible volatile depletion processes due to their moderately volatile and strongly lithophile nature (*e.g.*, [1]). Potassium isotopes, in particular, have been the focus of many recent studies on the origin of K isotopic variations and volatile depletion in chondrites, yet the results are confounding. The variations of ⁴¹K/³⁹K in chondrites have been suggested to be produced by *i*) high-temperature evaporation/condensation processes [2], *ii*) nucleosynthetic anomalies [3], and *iii*) chondrite parent body alteration and metamorphism [4]. Here we performed high-precision isotope measurements of Rb and K in carbonaceous chondrites (CCs) to test the scenarios and to elucidate the possible origin of their depletions and isotopic variations. Combining Rb and K are particularly useful because evaporation/condensation would produce correlated isotopic variations of them.

Samples and methods: The samples studied here are limited to meteorite falls because Rb and K are both fluid mobile and their compositions can be modified during residence at Earth's surface. The selected samples include eight CCs that belong to the four main groups, namely CI, CM, CV and CO. Rock chips weighing >300 mg were powdered in a pre-cleaned agate mortar, and aliquots of homogenized powder weighing ~100–120 mg were dissolved using various mixtures of HF-HNO₃-HCl-HClO₄ acids. Rubidium and K purification followed the method in [1]. Rubidium isotopes were measured using a Thermo Finnigan Neptune at the University of Chicago, and K isotopes were measured using a Nu Plasma II MC-ICPMS at the University of Washington [5]. The isotopic compositions are expressed in δ⁸⁷Rb and δ⁴¹K notations, which are the permil (‰) departures of the ⁸⁷Rb/⁸⁵Rb and ⁴¹K/³⁹K ratios relative to the reference material NIST SRM984 and NIST SRM3141a, respectively.

Results: Our calculated group means of Rb isotopic compositions are 0.16 ± 0.06 ‰ for CI, 0.12 ± 0.03 ‰ for CM, 0.07 ± 0.05 ‰ for CV, and 0.06 ± 0.10 ‰ for CO, comparable but slightly different than the values reported by [6]. The K isotopic compositions measured in this study agree well with the values reported by [3], and the group means of -0.09 ± 0.15 ‰ for CI, -0.13 ± 0.08 ‰ for CM, -0.27 ± 0.20 ‰ for CV and -0.14 ± 0.27 ‰ for CO also agree within error. We find statistically significant correlations between the isotopic compositions of MVEs Rb, K, Te [7], and Zn [8, 9] in bulk CCs. We also find statistically significant correlations between *i*) the isotopic compositions of Rb, K, Zn, and Te, and the mass fractions of the matrix [10] in the CC subgroups, *ii*) the Rb, K, Te, and Zn concentrations [10] and the matrix mass fractions, and *iii*) the isotopic compositions of Rb, K, Zn, and Te, and their respective bulk concentrations.

Discussion: The observed correlations suggest that a common process led to the isotopic variations of Rb, K, Te and Zn in the carbonaceous chondrites, which we ascribe to a binary mixing between the CI-like matrix and a hypothetical chondrule component, as has been suggested for the Te isotopes [7]. Using the CI chondrite composition as the matrix component, the degrees of volatile element depletion and isotopic fractionation of the chondrule component can be constrained. The inferred chondrule component is depleted in the MVEs and has much lighter isotopic compositions compared to the matrix (*i.e.*, CI chondrites). This suggests that partial condensation of MVEs from vapor into chondrule melt was the main driver for their depletion and isotopic fractionation, as both equilibrium fractionation between chondrule melt and vapor, and evaporation under kinetic conditions would enrich heavy isotopes in the chondrules. Using the constrained Rb and K depletions and isotopic fractionations of the chondrule component, we calculated the average chondrule cooling rate to be ~500 K/hr based on a condensation model. This cooling rate is entirely consistent with the cooling rate estimates of 10-1000 K/hr derived from laboratory experiments trying to reproduce chondrule textures [11, 12]. We therefore conclude that the depletion and isotopic variations of Rb and K in carbonaceous chondrites most likely originate from evaporation and subsequent partial condensation of them during chondrule formation, rather than from mixing of stellar nucleosynthetic products.

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