

POTASSIUM ISOTOPE FRACTIONATION FROM LEVITATION LASER HEATING. M. Neuman¹, C. A. Macris², P. Koefoed¹, K. Wang¹ ¹Department of Earth & Planetary Sciences and the McDonnell Center for the Space Sciences, Washington University in St. Louis, MO 63130; ²Indiana University – Purdue University Indianapolis, IN 46202 (mdneuman@wustl.edu)

Introduction: Moderately volatile elements (MVEs) have been used extensively to study the conditions of high temperature processes such as impacts and the formation of chondrules, tektites and trinitites. Potassium is one such MVE that is optimal for these types of studies due to its lithophile behavior and 50% condensation temperature of 1006 K [1]. Recent experimental work has focused on understanding the behavior of MVE isotope fractionation using high-precision measurements [e.g., 2, 3, 4]. A novel technique has recently been employed which uses aerodynamic levitation combined with laser heating to reach extreme temperatures relevant to planetary impact events while avoiding sample container contamination [2, 5, 6, 7]. These experiments used flowing gas to levitate samples which were then laser-heated at temperatures up to 2400 °C for short durations (≤ 120 s). Some of this work has been used for investigating the formation of tektites which are small, glassy objects left behind from extraterrestrial bodies impacting Earth's surface [8]. Chemical signatures of tektites have remained enigmatic where certain elements like Zn and Cu display isotopic fractionation and others like K do not [e.g., 9, 10, 11]. This has been interpreted to be caused by the higher volatility of Zn and Cu compared to K [10]. In this study, we conducted laser heating experiments to help explain the behavior of K isotopes during evaporation at conditions relevant to tektite formation.

Methods: Approximately 50 laser heating levitation experiments were conducted at Indiana University – Purdue University Indianapolis (IUPUI) with a High-Temperature Conical Nozzle Levitation (HT-CNL) system, following the methods of [6] (Fig. 1). A natural basalt and Chinese loess were used as starting materials for the heating experiments. Approximately 20 mg of each powdered starting material was fused on a hearth plate by defocused laser heating to create beads (~2 mm diameter) suitable for levitation. Fused beads of each material were saved and later analyzed to serve as the true starting composition to account for any potential volatile element loss during the fusing process. The beads were placed onto a conical nozzle and levitated by flowing argon with varying amounts of CO and CO₂ or pure oxygen. Once levitating, samples were heated with a 400 W CO₂ laser (10 μ m, IR). Run durations were set and began once the target temperature was reached, as determined by a pyrometer. Temperatures of 1800 and 2000 °C were used with durations ranging from 1 to 100 seconds.

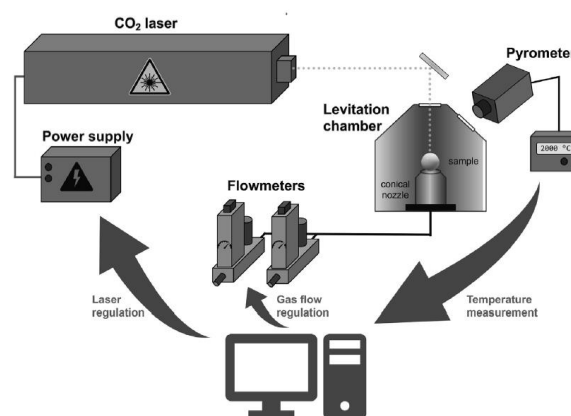


Figure 1. Schematic of the aerodynamic levitation laser furnace at IUPUI. See [5] for a detailed description.

Experimental products were processed and analyzed for major and trace elements and K isotopes at Washington University in St. Louis with the procedures outlined in a previous study [4]. Each glass bead was dissolved in doubled-distilled HF and HNO₃ acids, and 5% was taken for elemental analysis with a quadrupole-ICP-MS (Thermo Fisher Scientific iCAP Q). The remaining portions of each sample were passed through cation-exchange resin to purify K for analysis on a Thermo Scientific Neptune Plus MC-ICP-MS. Two experiments were replicated for electronprobe microanalysis (EPMA) to assess chemical homogeneity. Small sample masses (10-20 mg) meant that individual glass beads could not be split for both mass spectrometry and EPMA.

Results: The EPMA results showed that K concentrations varied by up to 7% of the average value within a particular sample. No correlations between K concentration and radial distance were observed. ICP-MS data was used to determine K loss by normalizing to Ca and the starting materials. The largest amount of K lost (75%) was seen in the basalt that experienced the highest temperature and lowest oxygen fugacity (one log unit below the iron-wüstite buffer at 2000 °C). This experiment also displayed the largest degree of K isotope fractionation (6.89 ‰ heavier in $\delta^{41}\text{K}$ than the starting material). Basalts at 1800 °C displayed less K loss and smaller isotope fractionations. Experiments at 2000 °C on the loess also resulted in suppressed K loss and isotope fractionation relative to the basalt at identical conditions.

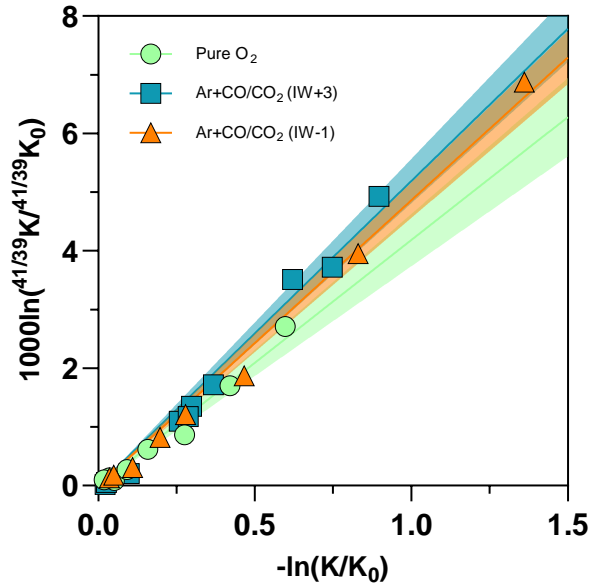


Figure 2. Potassium isotope results of basalt experiments at 2000 °C. Error bars are smaller than symbol size. Linear fits through the data provided slopes for determining α with 95% CI (shaded regions).

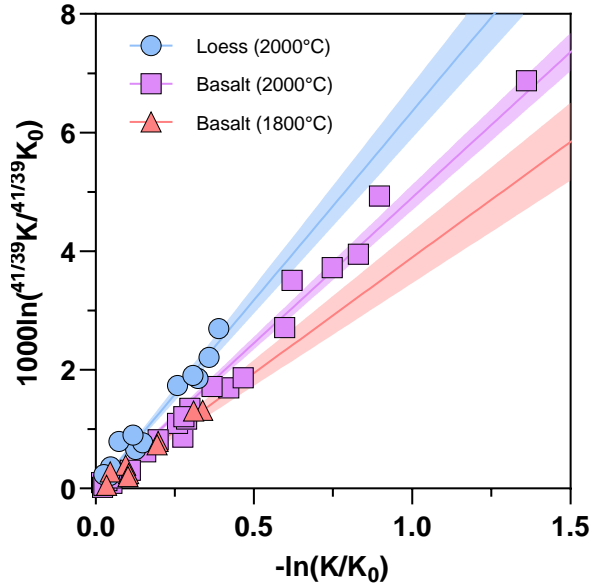


Figure 3. Potassium isotope results of all experiments, including different materials, temperatures, and gas compositions. Error bars are smaller than symbol size. Linear fits through the data provided slopes for determining α with 95% CI (shaded regions).

Discussion: Potassium isotope fractionation factors (α) were determined for the experiments with the following relationship:

$$\frac{^{41/39}\text{K}}{^{41/39}\text{K}_0} = \left(\frac{K}{K_0}\right)^{\alpha-1}$$

Basalt experiments at 2000 °C with varying oxygen fugacity yielded fractionation factors that were seemingly influenced to a minor degree by oxygen fugacity (Fig. 2). However, we assert these differences in α at our experimental conditions are caused by the mean molar mass of the gas (k) under which the samples are levitating and evaporating into. This effect has been seen in past studies where isotopic fractionation between isotopes i and j is theoretically proportional to $(\mu_{jk}/\mu_{ik})^{1/2}$ [3,12]. However, [3] showed this relationship is based on the 1/3 power instead of the square root, which was seen by [4]. Our results generally follow this relationship. Pure oxygen has the lowest mean molar mass and shows less fractionation (α closer to unity; shallower slope). The other two gases used, mixtures of 95% Ar and varying amounts of CO and CO₂, have nearly identical mean molar masses, and gave α values that overlap within error.

Considering all experiments, we observe that the loess exhibits a distinctly different fractionation factor (0.9936) from the basalt (Fig. 3). Due to limited K loss for the basalt at 1800 °C ($\alpha = 0.9961$), it appears that these data points lie close to those of the basalt at 2000 °C ($\alpha = 0.9951$) near the origin, so differences in α between the two sets of basalt are more difficult to distinguish. There are three possibilities we will assess for causing the differences in α between the loess and basalt: (i) mineralogical characteristics of the two materials, including where K is hosted and the amount of other volatile species (ii) the role of diffusion of K in the melt given the drastic chemical differences between basalt and the much more felsic loess (iii) thermodynamic characteristics of the two melt types which could cause changes in the volatility of K.

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