

EXPERIMENTAL CONSTRAINTS ON THE ROLE OF EVAPORATION IN THE ORIGIN OF CALCIUM-, ALUMINUM-RICH INCLUSIONS.

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Introduction: CAIs are often enriched in the heavy isotopes of Mg and Si, with FUN CAIs enriched by as much as several 10s of ‰/amu and normal CAIs by a few ‰/amu [1,2]. The FUN CAIs are also enriched in $\delta^{17}\text{O}$ and $\delta^{18}\text{O}$ relative to normal CAIs and lie along a mass fractionation line on the three-isotope oxygen diagram [3]. A variety of experiments have shown that evaporative loss of these elements under Rayleigh conditions (in which the residue is well-mixed and the gas is promptly removed from the system) can lead to significant enrichment in the heavy isotopes of these elements. We review current knowledge of evaporative isotopic fractionation of O, Mg, Si, Ca, and Ti from CAI melts.

Experimental evaporative mass fractionation: Vacuum and low-pressure evaporation experiments follow the Rayleigh relationship, $R/R_0 = f^{\alpha-1}$, where R is the ratio of two isotopes in the residue, R_0 is the initial ratio, f is the fraction of the reference isotope remaining in the condensed phase, and α is the gas/condensed-phase isotopic fractionation factor. Simple theory suggests that α is the square root of the ratio of the masses of the evaporating species [4], but all experiments show values that are closer to 1 (less fractionating). α can vary with temperature and/or melt composition. Measurements of α values for a variety of elements are needed in order to relate observed isotopic mass fractionation effects in CAIs to the degree of mass loss of each element due to evaporation.

Magnesium has received the most attention in recent years, because it shows the largest isotopic fractionation effects in CAIs and it can be measured with high precision by modern analytical techniques. Evaporation experiments under vacuum and low-pressure H_2 show no effect on α_{Mg} , but evaporation rates are faster in the presence of hydrogen [5]. For CAI melts, α is temperature dependent (Fig. 1).

Silicon has only recently been studied in CAI melt evaporation experiments [7]. In contrast to Mg, there appears to be no temperature dependence for α_{Si} , but α_{Si} is much closer to its “idea” value than is α_{Mg} .

Oxygen has not been studied for CAI melts, but is now high on our priority list, because of renewed interest in FUN CAIs [3]. Experiments on evaporation of Mg_2SiO_4 melts show that α_{O} is somewhat closer to its “idea” value than is α_{Mg} .

Calcium and *titanium* have only been studied in vacuum evaporation experiments on CaTiO_3 melts [9], because both elements are significantly more

refractory than Mg or Si. Only HAL-type hibonite grains show significant mass fractionation effects for either Ca or Ti [10].

The use of measured α values extrapolated to the crystallization temperature range typical of Type B CAIs (Fig. 1) implies that the normal (non-FUN) Type B CAIs [2] have lost 16–66% of their initial Mg and 5–24% of their initial Si. The evaporation rates of Mg and Si from CAI melts are significantly inhibited relative to rates calculated from vapor pressures of components in melts of appropriate composition [5] using the Hertz-Knudsen equation. The degree of inhibition is usually expressed as the evaporation coefficient and has values of ~ 0.04 for CAI melts for Mg and Si. Measurements of isotopic fractionation effects and evaporation coefficients are consistent with natural Type B CAIs having lost Mg and Si by evaporation over periods of hours to days for plausible nebular pressures and temperatures between the liquidus and the solidus.

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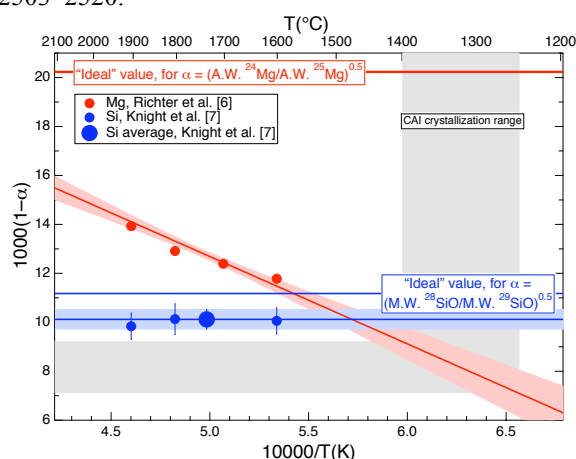


Fig. 1. Mg becomes less fractionating with lower temperature in CAI melts, whereas Si shows no apparent temperature dependence.

