

## Experimental study of evaporation of CAI-like melts in low-pressure hydrogen gas and in vacuum

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Chemical and isotopic features of Type B Ca-, Al-rich inclusions (CAIs) indicate that their precursors have experienced heating events that resulted in partial melting and evaporation of relatively volatile elements and their associated isotopic fractionations [1, 2]. Although the evaporation experiments with CAI-like melts at high temperatures in vacuum (e.g., [1-5]) successfully reproduce the major chemical and isotopic features of normal and FUN CAIs, a question remained whether vacuum experiments could fully describe evaporation of CMAS melts under low-pressure hydrogen conditions of the solar nebula. Richter et al. [2] evaporated CAI-like melt at 1500°C and  $P_{\text{H}_2}=2\times 10^{-4}$  bar, but no direct comparison with vacuum experiments has been made due to very slow evaporation rates at 1500°C in vacuum. Here we report the results of the study on evaporation kinetics of Mg and Si from the same CAI-like melt that was evaporated at the same temperature (1600°C) in vacuum ( $<10^{-7}$  bar) and in low-pressure  $\text{H}_2$  gas ( $1.6\times 10^{-4}$  bar).

We used a synthetic glass (CAI4B2), of which composition is close to those of non-FUN forsterite-bearing CAIs of [6]. Low-pressure hydrogen experiments were conducted at Hokkaido University using premelted glass samples on an Ir-wire loop. The sample was heated in a vacuum furnace to 1600°C, and  $\text{H}_2$  gas was introduced to keep a constant  $P_{\text{H}_2}$  of  $1.6\times 10^{-4}$  bar during the run. After heating for a predetermined time period the sample was quenched by turning power off. Vacuum evaporation experiments were conducted at the University of Chicago using the same experimental protocol as in [2-5]. Weight and surface geometry of the samples were measured before and after each experiment. Texture and chemical composition of the evaporation residues were studied using a TESCAN LYRA3 FIB/FESEM with an Oxford AZtec X-ray microanalysis system.

Evaporation fluxes of Mg and Si were obtained by considering the weight losses and surface areas of samples. Silicon in low  $P_{\text{H}_2}$  experiments evaporate by ~35% faster than Mg:  $J_{\text{Mg}} \sim 1.4\times 10^{-7}$  and  $J_{\text{Si}} \sim 1.9\times 10^{-7}$  moles/cm<sup>2</sup>/s. Evaporation rates of Si and Mg in vacuum experiments ( $J_{\text{Mg}} \sim 3.8\times 10^{-9}$  and  $J_{\text{Si}} \sim 4.6\times 10^{-9}$  moles/cm<sup>2</sup>/s) are about 40 times slower than in low  $P_{\text{H}_2}$ . Despite different evaporation rates of Si and Mg under the different conditions, we found that their evaporation trajectories are the same.

Vacuum evaporation rate of Mg determined in this study is slightly higher than that for CAIB melt at 1600°C [3], but are in good agreement with extrapolation from higher temperatures [3]. The evaporation rates of Mg and Si in low  $P_{\text{H}_2}$  are ~40 times larger than those in vacuum, while those at 1500°C and  $1.8\times 10^{-4}$  bar were calculated to be ~100 times larger than in vacuum [2]. Mg evaporation rate measured in our experiments is consistent with the extrapolated value from [2], which calculated the evaporation rates of Mg from CAI-like melt at 1500–1300°C when the evaporation coefficient of ~0.07 was adapted. The evaporation coefficient of ~0.07 is also consistent with those reported in vacuum experiments [2, 3]. The difference in evaporation rates in vacuum and in low-pressure hydrogen can be explained by the increase in the equilibrium vapor pressures of Mg and Si in the presence of  $\text{H}_2$ . While  $\text{H}_2$  promotes much faster evaporation of Mg and Si from CAI-like melts, it does not change the evaporation trajectory. Using all available data on evaporation rates of Mg and Si from CAI-like melts, we determined activation energies E

$E_{a,Mg}=516\pm34$  kJ/mole and  $E_{a,Si}=568\pm32$  kJ/mole for vacuum evaporation. These activation energies also fit experimentally determined evaporation rates at  $P_{H_2}=2\times10^{-4}$  bar at 1500°C and 1600°C.

**References:** [1] Davis et al. (1990) *Nature*, 347, 655-658; [2] Richter et al. (2002) *GCA*, 66, 521-540; [3] Richter et al. (2007) *GCA*, 71, 5544-5564; [4] Mendybaev et al. (2013) *LPSC 44<sup>th</sup>*, Abstract #3017; [5] Mendybaev et al. (2017) *GCA*, 201, 49-64; [6] Bullock et al. (2012) *Meteoritics*, 47, 2128-2147.