Kinetic condensation of supersaturated solar nebula gas and its relevance to the variation of chondrule compositions

Hiroko Nagahara[1]; Kazuhito Ozawa[2]

[1] Dept. Earth Planet. Sci., Univ. Tokyo; [2] Univ. Tokyo, EPS

Compositional variation of equilibrium condensation of the solar nebular gas has been well studied since 1960th, but the effect of condensation kinetics has not yet been studied so far. Equilibrium condensation of the solar nebular partly succeeds in explaining the meteoritic components, particularly CAIS, whereas, the diversity of chondrule compositions has been attributed to be that of the precursors and/or change due to evaporation. The diversity, however, has not been satisfactorily explained at least by evaporation.

In the present study, we have developed a new kinetic model to describe composition change of a multi-component condensed phase during condensation as well as evaporation under kinetic conditions. It is applied to investigate the path of condensing silicate melt by using parameters available from evaporation experiments. Based on the results, the diversity of chondrules in primitive ordinary chondrites is considered.

The condensation model adopted in this study is an extension of the evaporation model for multi-component systems developed by Ozawa and Nagahara (2001), which is based on the Hertz-Knudsen equation. In order to extend the model to condensation reactions, a kinetic model properly describing surface reaction in both undersaturated and supersaturated conditions is required.

The closed-system model is applied to silicate melt in the present study, but is applicable to any condensed phases if kinetic parameters are available. Crystallization in the silicate melt and condensation of other phases are neglected for simplicity. The calculation was done in the nondimensionalized form, and thus the time-scale is determied if several variables, such as free evaporation rate (or free evaporation rate), size of melt sphere, and hydrogen pressure, are given.

Kinetic parameters for evaporation, such as activation energy of evaporation and chemical fractionation factors, are optimized for the present model on the basis of free evaporation experiments on silicate melts, in which the total mass loss data are available. The free evaporation rates are used as references to model composition and temperature dependence of the net flux of each components. The parameters related to condensation, such as degree of supersaturation, condensation coefficients, are unknown and thus regarded as free parameters. The system is assumed to be closed at constant volume. Metallic iron is subtracted from the total Fe according to the supposed redox state. The initial values of FeO and CaO+Al2O3 are varied to find the optimal values to model the variation of Type I chondrules. Molar volume of silicate melt is according to Lange & Carmichael (1987).

As compared to the equilibrium path, which is more shifted to the Mg-rich side than that from linteratures, mostly because of the ignorance of composition dependence of the fractionation factor for Mg and Si, the kinetically controlled condensation paths are much more nonlinear. The nonlinearity increases with the cooling rate and the degree of supersaturation. By adjusting the initial FeO and CaO+ Al2O3 abundance, we have found that 80 – 50% and ~70% of the solar abundance is appropriate to reproduce the chemical diversity of the Type I chondrules.

In summary, the newly developed kinetic condensation model enables us calculation of composition path of supersaturated gas, and the application to chondrules shows chemical fractionation of refractory componente before accretion of precursor of chondrules and condensation of volatiled as matrix of chondrites.