LINK BETWEEN EXPERIMENTS AND MODELLING IN CONDENSATION AND FRACTIONATION IN THE PROTOPLANETARY DISC.

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Introduction: Mg-silicates and metallic iron are the two most major constituents of terrestrial planets and small bodies in the inner region of the solar system. Physical fractionation of those phases from gas during condensation of the solar nebula affects subsequent condensation path, and chemical fractionation affects the condensing phases and size distribution of the grains, which further affects physical processes. Thus, it is crucial to consider condensation processes under the control of physical separation of dusts from gas.

Present study: Condensation takes place in cooling gas, indicating the role of cooling rate of the gas as the rate-controlling factor. Dust separation from gas takes place, which is controlled by the size of dusts. Thus, there are two critical physical parameters that govern fractionation of the disc; cooling rate of gas and critical dust size for separation.

Condensation includes two elementary processes, nucleation and growth, both of which are kinetic processes. The rate of kinetic processes is generally described by kinetic parameters, and critical super-saturation ratio of gas and condensation coefficient are those responsible for nucleation and condensation rates, respectively. Thus, for chemical point of view, condensation coefficient and degree of super-saturation are crucial.

Model: We have developed a model that describes condensation of Mg-silicates and Fe metal in cooling gas with separation of dust grains as a function of cooling rate of the system and critical size for dust separation from gas. It calculates the change of bulk composition, condensing phases, size distribution of the condensed phases for those remaining within the gas and for those separated from the gas.

The model system consists of H-He-C-N-O-Mg-Si-Fe with the abundance rations of the solar abundances, the total pressure of the system is fixed at 10^{-5} bar, cooling rate of the system 10^{5} sec (cooling rime scale corresponding to chondrule formation) to 10^{13} sec (cooling time scale corresponding to protoplanetary discs), and the critical dust size for separation from gas ranged from 10^{-7} m to 10^{2} m. Condensed phases treated are forsterite, enstatite, SiO2, and metallic iron. We use the condensation coefficient and critical super-saturation ratio for Fe metal that we have experimentally obtained, and condensation coefficients of 0.1 for forsterite, enstatite, and SiO2.

Results and Discussion: The calculation results in the parameter space shown above are divided into three cases in terms of the degree of dust separation from the gas: total separation, partial separation, and total retention. The former and the latter cases represent that all the condensates behave together, and therefore, no chemical fractionation takes place though grain size distribution is quite different. The case of partial separation is most interesting situation, where the mode of nucleation and growth of dusts varies largely depending on physical conditions. Although nucleation has been thought to take place once in previous homogeneous condensation theory in a closed system, it takes place multiply if dust separation takes place, which resulted in wider grain size distribution.

Heterogeneous condensation of Fe on previously condensed forsterite is another crucial process that affects the grain size distribution and therefore subsequent condensation processes, where SiO2 that is not predicted to condense in equilibrium condensation condenses after extraction of forsterite with metal mantle. Because of large grain size, the forsterite and Fe-mantle grain is effectively separated from gas, which resulted in chemical fractionation.

Mg/Si/Fe fractionation is the most fundamental fractionation in the inner disc, and is well explained by combination of physical and chemical fractionations during condensation of the protoplanetary disc. The present results can be connected to physical model, which enables us to give thorough modeling of evolution of discs.