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Growth of forsterite and metallic iron dusts and its role in evolution of protoplanetary discs

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Protolanetary discs evolve physically and chemically, and physics and chemistry interacts particularly through dust grains, which carry radiation of the disc. The species, size distribution, and occurrece of dust grains control the temperature of the radiation field and the temperature affects the stability of solid materials. Dusts in protoplanetary disc are usually assumed to be small in size (~0.1 –1 um), which is the size observable by IR. This, however, does not represent absence of larger grains, which should be evaluated more carefully. Thus, it is crucial to investigate evolution of dusts in connection with disc physics and chemistry.
Purpose: Condensation and evaporation are the two major phase changes that take place in protoplanetary discs at low pressure, of which rate is a function of pressure, temperature, and composition of the nebular gas. The rate is shown as the Hertz-Knudsen equation, which includes a kinetic parameter for surface reactions that are determined by experiments. Homogeneous nucleation is often assumed for dust formation, through which different phases condense as independent grains, whereas heterogeneous nucleation results in formation of chemically reacted, composite, or mantled grains. We have investigated condensation of Mg-silicates and Fe metal, two most major constituents of the terrestrial planets, by model calculation taking the mode of condensation into consideration.
Condensation model: We have investigated condensation sequence and their grain size distribution in a cooling gas system with special interest to the critical condition for homogeneous/heterogeneous condensation of metallic iron onto Mg-silicate (forsterite). The model consists of two basic equations: (a) the nucleation and growth rate as a function of gas velocity, abundance of the gas species concerned, and condensation coefficient, and (b) net mass conservation, which represents that the concentration of gas species concerned decreases with progress of condensation. The model contains two parameters, total pressure, Ptot, and cooling [U+F020] time, t.
Results: Metallic iron condenses always heterogeneously on forsterite. The condensation sequence is divided into two cases depending on total pressure and cooling time scale; one is the case where metallic iron condenses with remaining Mg in the gas phase and another is the case where metallic iron condenses after total condensation of forsterite. The fomer takes place at larger cooling time (rapid cooling) and the latter at smaller cooling rate (slow cooling). The boundary moved to smaller cooling time with increasing total pressure.
Condnesation sequence and phases. When gas cools rapidly, forsterite started to grow is quickly covered by metallic iron, which resulted in a grain with forsterite core and Fe mantle. Because there still remains Mg in the gas, forsterite homogeneously condenses at lower temperature, which partly reacted with gas to form enstatite at further lower temperature. Depending on the cooling condition, SiO2 or enstatite homogeneously condenses.
Condensation sequence in slow cooling conditions is quite different. If forsterite was fully condensed when metallic iron started to condense, there remains no Mg in the gas. The forsterite is totally covered by metallic iron, which resulted in condensation of SiO2 at lower temperature due to inhibitation of enstatite formation. The micro-scale fractionation forms SiO2, which is not a phase that appears in equilibrium.
Grain size distribution. The grain size is strongly dependent on conditions. The size of core-mantle type grains reaches an order of cm when the cooling time scale is a year and the total pressure is as high as 10(3) bar. The size becomes smaller with rapid cooling or lower pressures, and homogeneously condensed phases at lower temperatures also have small size, which goes down to an order of nanometer.
Although the present work ignores the refractory component, the presenc of refractory grains as the first condesates would largely affects the subsequent condensation, grain size, and composition of heterogeneously condensed grains.