

Evolution of forsterite and metallic iron dust in circumstellar discs

Hiroko Nagahara[1]; Kazuhito Ozawa[2]

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

Protoplanetary discs evolve through radial transfer, vertical movement, coagulation, and destruction of dusts, which originated in previous molecular clouds. Recent astronomical observation has shown common occurrence of crystalline forsterite, enstatite, and amorphous silicate in protoplanetary discs with various sizes; T Tauri, Herbig Ae/Be, brown dwarfs, and protoplanets in the Orion Nebula. Although it is not clear whether the degree of crystallization has relevance to the disc evolution processes or not, it is likely that the silicate grains grow and crystallize even at the surface of discs, which may suggest turbulence in the nebula and easy crystallization.

Another important observation is the finding of abundant crystalline forsterite in comets despite they are originated in the outer region of the solar system where amorphous silicates are thought to have survived stellar thermal processing. It is thus reasonable to consider the nucleation and growth of forsterite along with metallic iron, the next abundant phase, during the evolution of a protoplanetary disc.

Condensation is a kinetic process, of which rates are dependent on temperature, pressure, and gas composition. We investigate the evolution of forsterite and metallic iron dusts in a protoplanetary disc by using the model for grain formation by Yamamoto and Hasegawa (1977). The growth rate of grains is determined by the volume of condensing species multiplied by mean velocity of the condensing atoms and concentration of the species in the gas phase. The equation to describe the nucleation rate contains a parameter representing the surface energy relative to the thermal energy and a parameter representing the saturation time scale relative to the collision time scale, in addition to the condensation coefficient. The average final size, size distribution, nucleation time, nucleation rate, and number density are examined. Physical parameters are surface tension of silicates, that of metallic iron, average solar abundance of elements, and cooling time scale of the solar nebula.

The condensation rate, J , is given by the Hertz-Knudsen equation, $J = (\alpha(\text{cond})P - \alpha(\text{evap})P_{\text{eq}}) / \sqrt{2\pi mkT}$, which represents balance between forward and backward reactions in the kinetic theory of gas molecules. The parameter $\alpha(\text{cond})$ is the condensation coefficient, $\alpha(\text{evap})$ is the evaporation coefficient, P is the pressure, P_{eq} is the equilibrium vapor pressure of the species concerned, m is the weight of gas molecule, k is the Boltzmann constant, and T is the temperature. Although kinetic parameters $\alpha(\text{cond})$ and $\alpha(\text{evap})$ should be experimentally determined, experimental difficulties prevent us from obtaining those parameters for a multi-element phases. Therefore, we use the condensation coefficient for metallic iron recently obtained, and evaporation coefficient in various PH2 conditions extrapolating to the condensation conditions.

The results show that the average grain size of metal is controlled principally by the cooling time scale of gas. It is, however, not the case for forsterite, of which grain size is dependent on the α . The size becomes smaller with decreasing coefficient, that is, increasing kinetic barrier for condensation. The metal grain is as large as several μm . On the other hand, forsterite grain size is largely dependent on α , and the size distribution is wide when α is 1, but is narrow when α smaller than 1. The size distribution of forsterite for α smaller than 1 is a few microns for most grains, which is consistent with astrophysical observation.