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The role of condensation coefficient on the grain growth around stars

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Introduction: Recent observation by infrared spectroscopy has revealed the presence of amorphous and/or crystalline silicate dusts around evolved stars or young star discs. The species, size, shape, composition, and orientation if they are crystalline, of the dusts control the optical properties of dusts, which further control the radiation field of discs. Thus, the formation and growth of dusts are fundamental processes for the evolution of circumstellar and young star discs.

Condensation coefficients: Condensation is a kinetic process that comprises nucleation and grain growth. In both atomistic processes, the condensation coefficient or the sticking coefficient plays a key role in the nucleation and growth rates, which linearly affects the rate. The coefficient is a number of atoms incorporated into the condensed phase relative to number of colliding atoms to surface of the condensed phase, which ranges from 0 to 1. Experimental determination of condensation coefficient is crucial for consideration on the evolution time scale of disks. Because of experimental difficulties, we have very limited data for the coefficients. In previous model calculations, either a of unity for all the species at all the conditions or evaporation coefficients instead for condensation coefficients have been used. This is, however, incorrect, and condensation coefficients as a function of temperature and pressure should be experimentally determined. In a companion paper by Ikeda et al. (this volume), we show the condensation coefficient of 0.9 to 1 for metallic iron in near equilibrium conditions.

Model: Growth of metallic iron and forsterite in circumstellar environment around evolved stars and in discs of young stars such as solar nebula is evaluated by using the model for grain formation by Yamamoto and Hasegawa (1977). The growth rate of grains is shown by the volume of condensing species multiplied by mean velocity of the condensing atoms and concentration of the species in the gas phase. The average final size, size distribution, nucleation time, nucleation rate, and number density are calculated. The condensation coefficient for metallic iron, which was experimentally determined, and larger dependence on temperature and pressure is used for forsterite on the basis of smaller evaporation coefficient of forsterite than metallic iron.

Crystalline dust formation in astrophysical environments: The calculation results show that the average grain size of metal is controlled only by the cooling time scale of gas but not by the condensation coefficient. It is, however, not the case for forsterite, of which grain size is dependent on a; the size becomes smaller with decreasing a, that is, increasing kinetic barrier for condensation. The average grain size of metallic iron and forsterite in the out flow of evolved stars is very small. In order for them to become large enough to be observed with IR, they should be coalesced to grow in the circumstellar discs by shock heating.

The condensation coefficient plays scarce role on the growth time of metallic iron, which results in similar size distribution irrespective of a. The metal grain is as large as several mm. On the other hand, forsterite grain size is largely dependent on a, and the size distribution is wide when a is 1, but is narrow when a is larger than1. The size distribution of forsterite for a smaller than 1 is a few mm for most grains, which is consistent with astrophysical observation. Although the average grain size and the size distribution of forsterite, however, can vary if the dependence of a on temperature and pressure are different, it would not become larger than metallic iron because a would never be as large as unity for forsterite. In conclusion, silicate dust condensed in the solar nebula should be smaller than metallic iron by about an order of magnitude, and the size distribution is much narrower for forsterite than metallic iron.