# Experimental determination of condensation coefficient of metallic iron and its application to nucleation in a protoplanetary disc

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Dust particles are formed by condensation from cooling gas in protoplanetary disks and around evolved stars. Kinetics of condensation and evaporation determines time scale of evolution of dust particles in the universe, and causes chemical and isotopic fractionation between condensates and gas as well. The condensation (growth) flux is expressed by the Hertz-Knudsen equation based on a classical kinetic theory of gases. The equation includes condensation and evaporation coefficients, which are measures of kinetic hindrance of condensation and evaporation, respectively. They can be a function of pressure, temperature, and gas compositions because kinetics of surface processes should depend on such physical and chemical conditions.

We have carried out condensation experiments of metallic iron under a controlled pressure of iron vapor to understand dependence of condensation kinetics on iron-vapor pressure. Metallic iron pellet was evaporated at 1300C through an alumina tube, and the incoming iron flux onto a substrate was controlled by changing the inner diameter of the alumina tube. An alumina disk was used as a substrate to avoid diffusion of elements in the substrate into condensates. An experimental duration ranged from 6 to 48 hours. The weight loss of the iron pellet and the weight gain of the alumina substrate were measured. The surface and cross-section of the condensates were observed with an FE-SEM and chemical compositions and crystallinity of condensates were analysed with EDS and EBSD. A supersaturation ratio (a ratio of the pressure of iron vapor to the equilibrium vapor pressure of metallic iron) at the surface of the substrate was calculated based on the flux distribution of iron vapor emerged from the tube and the measured evaporation rate of source. Because the incoming flux to the surface of the substrate has a relatively uniform distribution, the ratio does not have a large variation at the surface of the substrate

We got condensates of metallic iron in all the experiments. Characteristic surface structures on the surface are continuous growth steps with an interval of 10 nm. The condensates form a compact layer for experimental duration longer than 12 hours and that the thickness of the compact layer increases with time, which enabled us to estimate condensation rates. It is worth noting that condensation of metalling iron on an alumina substrate took place very easily, which is against previous estimation.

The obtained condensation flux was compared with the ideal condensation flux, and we obtained the condensation coefficients of unity within the experimental uncertainties. This means that almost all the colliding molecules incorporate into the condensates without any kinetic hindrances. This is the first experimental evidence for the condensation coefficient of metallic iron, although the value of unity has been often used in model calculations due to lack of experimental data. By using the results, we have estimated the conditions for homogeneous and heterogeneous nucleation of metallic iron in a protoplanetary disc.