ACCRETION OF FINE PARTICLES: An optical analysis of the size distribution and its application to determination of the sticking probability; Y. Higuchi, T. Okada, and N. Sugiura, Department of Earth and Planetary Physics, University of Tokyo, Japan

In the early solar nebula, the probability that two grains stick together on collision (sticking probability) is a very important factor in the accretion process of fine particles [1]. We show that the sticking probability can be estimated with laboratory experiments.

We performed preliminary experiments to determine the sticking probability of MgO. Comparing the evolution of aggregates estimated by experimental results with that by simulations, the sticking probability can be determined. MgO aggregates were formed by collisions of MgO particles which had been produced by evaporating Mg in air by heating with a YAG laser. The evolution of MgO aggregates is observed with an optical apparatus. It is designed to measure the particle size based on the principle that smaller particles tend to scatter lights at larger angles. The intensities of scattered lights can be obtained over divided scattering angles. The experimental system is shown in fig. 1. This species MgO was selected because it can be evaporated with ease.

The size distribution can be determined from experimental results with a linear programming. The difference $\delta_j$ between the observed intensity $Y_{\text{obs}}(j)$ and the calculated intensity $Y_{\text{fit}}(j)$ of scattered lights for $j$th scattered angle is given as

$$|Y_{\text{obs}}(j) - Y_{\text{fit}}(j)| \leq \delta_j,$$

where $Y_{\text{fit}} = M \cdot P$

The matrix $M$ has components of the intensities which are calculated with Mie theory for various angles and aggregate sizes. $P$ is an unknown vector whose components are the numbers of aggregates in various aggregate sizes. Given the vector $P$, the expected intensities over the scattering angles are given by a vector $Y_{\text{fit}}$. Where, the intensity for any angle is considered to be given by a linear combination of the intensities scattered by various size of particles. We derive the vector $P$ which minimizes the sum of each difference $\delta_j$ as follows.

$$\Sigma \delta_j \rightarrow \text{min}.$$

To calculate the matrix $M$ we considered porous aggregates, though Mie theory is for only spherical particles. We used the dielectric constant calculated with Maxwell-Garnet theory [2,3]. Firstly, we assumed that aggregates have a fractal structure, then, the mass density is given by a power law of the aggregate size $n$. When the aggregate is a sphere with radius $n$, the volume fraction of MgO, $f_i$ is given by the mass density. Secondly, given the volume fraction, the dielectric constant of porous spherical particles is given by Maxwell-Garnet formula. Fig. 2(a-e) show the temporal variation of results of size distributions calculated with the matrix $M$, which is derived as described here. You can see clearly the growth of aggregates. However, a discrete-dipole approximation [4,5] is useful for consideration of not only the porosity but also the fluffyness of the aggregates. We will try it in near future.
While, temporal variations of size distribution can be simulated with a coagulation equation.

$$\frac{dn_i}{dt} = p_s \left\{ \frac{1}{2} \Sigma \beta(v_i, v_j) n_j n_i \right\}$$

Where, the number density and volume of aggregates that have volume i, denote $n_i$ and $v_i$, respectively. The collision frequency $\beta$ is a function of two parameters which are volumes of two colliding aggregates. $p_s$ in the above equation is the sticking probability which we want to estimate now. In order to estimate the collision frequency, collisions between aggregates due to the Brownian motion and/or the shear of the convective air are assumed.

Comparing two temporal variations which are given by the experiment and the simulation, we can determine the sticking probability. Due to uncertainty of the collisional frequency, we have not yet obtained reliable estimation of the sticking probability.

REFERENCES


Fig.1 The experimental apparatus is shown. (a) The outline of the apparatus is shown. The chamber is made of glass. With YAG laser, fine particles are produced and they are observed with He-Ne laser. (b) He-Ne laser scattered by the aggregates is detected by a detector put behind a collimator. We can obtain the intensities of incident light to each ring on the detector as experimental data.

Fig.2 The temporal variations of size distribution of aggregates calculated with a linear programming. Each horizontal axis and vertical axis shows the aggregate diameter and the size distribution of aggregates which is already normalized, respectively. The error shows misfit of the calculated intensity relative to the observed one. The average aggregate size is given under each panel. You can see the evolution of aggregates. (t [min.])