Conditions for Compound Chondrule Formation

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Introduction: Chondrules are spherical-shaped silicate particles that are one of the main components of chondritic meteorites. They are thought to have been formed by heating (melting) events in the early solar nebula. There are compound chondrules, which are two or more chondrules fused together, in the various kinds of chondrites. Some compound chondrules seem to be formed by collisions of two independent particles during heating events. Although some researchers noticed collision probability of particles so far [1], [2], they seldom noticed the collision conditions. If two melting particles experience the high-speed or grazing collision, they cannot coalesce. Or if the viscosities of both components are too low, they cannot keep their shape and will fuse together by surface tension and we cannot observe them as compound chondrules. Thus we are necessary to consider the collision conditions to compare the various formation models for compound chondrules with the observational results. In this study, we numerically simulated the collision of two silicate drops by using the three-dimensional hydrodynamics code and examined the collision conditions for compound chondrule formation.

Condition for coalescence: Firstly, we examined 'condition for coalescence' for various parameters; the collision velocity, the collision angle, the size ratio of drops, and viscosities of drops. We can categorize the results of drops' collisions into three groups; 'Stretching separation', which occurred when the collision angle is large, 'Fission', which occurred when the collision velocity is large, and 'Coalescence'. If the drops have relatively lower viscosities (1poise), our results agree well with water and organic matter drops' collision experiments [3], [4]. In this case, the maximum velocity for 'Coalescence' ($u_{\rm max}$) is about 5 m/s. In the larger viscosity case, because the viscous dissipation becomes effective, the region of 'coalescence' is expanded to larger collision velocity and collision angle. For example, when the viscous coefficients are 10 poise and 100 poise, $u_{\rm max}$ is about 15 m/s and 50 m/s, respectively. In addition, we found that the boundary of 'Coalescence – Stretching separation' and ' Coalescence – Fission' can be expressed by comparing the kinetic energy, surface energy, viscous dissipation, and rotational energy. Then we can obtain the 'condition for coalescence' for various parameters.

Condition for keeping their shape: If we add 'condition for keeping their shape' to these results, we will be able to obtain the collision conditions for the compound chondrules fomation. In order to keep their shape, the deformation timescale has to be longer than the cooling timescale. We can examine the deformation timescale using our numerical simulations. For example, when the drops has lower viscosity (1poise), this timescale is ~10^{-4} sec. Moreover, we found that this timescale is approximately proportional to the viscosity of drops.

It is necessary for compound chondrules formation to satisfy both conditions and we should consider them when we compare the formation models with the observational results.

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