The maximal size of chondrules in shock wave heating model: Stripping of liquid surface in a hypersonic rarefied gas.

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Chondrules, that are ferromagnesian silicates, are major component of the chondritic meteorites. Chondrules have a characteristic size distribution: it has a mean size in sub- millimeter. From mineralogical features, it is thought that chondrules were formed through melting at least once in a high temperature environment and by resolidifying with rapid cooling after that.

Many formation models for chondrules have been proposed to date, but none is widely accepted. The shock heating model is one of the most plausible models since many chondrule features are accountable. When a shock wave is generated in the solar nebula, the relative velocity between dust particles and the gas in the flow is caused, and that leads to the friction and heating on the dust particles.

When the dust melts by the shock wave heating, deformation and internal flow in the molten dust (i.e. liquid sphere) may take place by surrounding rarefied gas with a hypersonic velocity. For a completely molten and uniform liquid spherical dust particle, hydrodynamical equations with linear approximation were solved, and deformation, internal flow, and pressure distribution were obtained (Sekiya et al. 2003). On the other hand, the possible maximal size of chondrules was estimated based on the balance between the ram pressure by the hypersonic gas flow and the surface tension of the liquid particle (Susa & Nakamoto 2002).

However, when the time scale of heat conduction is longer than the time scale of melting, melting of a dust particle takes place from the surface toward the center, and the dust particle melts partially. So, a dust particle that has a central solid core surrounded by liquid mantle may be realized. If it is the case, the stability of dust particle with liquid surface and solid core against the hypersonic gas flow should be examined.

In this study, we examine behavior of liquid sphere with a solid core in a hypersonic rarefied gas flow. For that purpose, we analytically solve hydrodynamical equations with linear approximation and obtain the deformation, internal flow, and pressure distribution. As boundary conditions, a spherical solid core is considered to be at the center of liquid sphere, and the balance of force between the ram pressure by the gas flow, the surface tension, and the stress tensor is considered on the surface.

The solid core begins to move because the internal flow and the pressure distribution exert force to it. If the time scale of the solid core motion is shorter than the time scale to complete melting, it is expected that the solid core leave the liquid sphere. In other words, the liquid solution is stripped from the solid core.

The stripping is expected to occur if following two conditions are met:

1.The time scale of heat conduction is longer than the time scale of melting.

2.The time scale of the solid core motion is longer than the time scale of melting.

Estimating these time scales based on evaluations of forces on the solid core, it was found that the stripping of the liquid surface is likely to occur when the dust size, and the velocity and the density of the shock are large, because the larger the dust radius is, the longer it takes to melt completely, and because the larger the velocity and the density of the shock are, the more intense the internal flow and the pressure distribution in the liquid sphere become. Therefore, it turns out that the maximal size of chondrules can be determined by the stripping of the liquid surface. The maximal size of chondrules surviving from the stripping is estimated to be about 1 – 2 mm when shock parameters for chondrule-forming shock waves are taken into consideration. The estimated maximal size is consistent with the observed size of chondrules.

It is suggested that the shock wave heating model is an appropriate model for chondrule formation, since the maximal size may be naturally explained by the stripping of the liquid sphere in the framework of the model.