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Possible size of porphyritic chondrule in the shock-wave heating model

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Chondrules are thought to have formed through some flash heating events in the early solar nebula. Shock wave heating model is now considered to be one of the most plausible models for chondrule formation. Some studies, assuming a homogeneous temperature distribution in dust particles, have shown that the model can explain various observations of chondrules. However, the temperature distribution in the dust particles can be inhomogeneous in the shock-wave heating model, because the dust particle is heated first from the surface by the gas frictional heating and then the inside is heated by the heat conduction. Also, the gas frictional heating works only on the upstream side of the particle. Thus, the dust particles should start to melt from the surface on the upstream side of the dust particle.

Kato, Nakamoto, and Miura (2006) have used an analytic method and shown that when the particle is partially molten and a liquid mantle is present on a solid core, the stripping of the liquid surface due to the gas flow can take place. But the temperature distribution in the particle and the temperature dependence of the viscosity are not taken into account in their study. Porphyritic chondrules (PC) are thought to have experienced the temperature 200K or more below (T_{min}=1700K) the liquidus temperature. The viscosity of material below the liquidus temperature (T_{liq}=1900K) is usually high, and it may be difficult to strip off a highly viscous liquid surface from the particle. So the stripping of the liquid surface may not take place in the case of PC. In this study, we first obtain the temperature and viscosity distributions in the dust particles by solving a three-dimensional heat conduction equation. Then, we discuss the stripping of the liquid surface from the particle and the possible size of PC.

To strip off the liquid surface, the liquid part of the particle should move relative to the solid part. The timescale of the liquid flow could be evaluated using the timescale of the circulation in the liquid mantle obtained in the analytic solution, which is given by, t_{flow}(T) (Sekiya et al. 2003) On the other hand, the stripping should finish within a period when the liquid and solid parts coexist. We define the time-scale tduration(T) as a difference between the time when the temperature at a part in the particle reaches the given temperature T and the time when all the part in the particle reaches T. Then, one may think that the condition which t_{flow} is shorter than $t_{duration}$ is a condition for the stripping of the liquid surface. Then we examine that tflow and tduration as a function of the temperature in the case of shock velocity 12km/s and number density of gas 2.0×10^{14} cm^{-3}. We find that as the temperature rises, the viscosity falls, and the condition which t_{flow} is shorter than $t_{duration}$ is met. If the temperature does not reach near the liquidus temperature, the stripping can hardly occur.

On the other hand, it is necessary for forming PC to experience the temperature between the T_{min} and T_{liq}. That is to say, possible size of the porphyritic chondrule is the biggest radius met this condition. We anticipate possible size of porphyritic chondrule by using the temperature distribution in the particles. As a result, the possible size of the porphyritic chondrule is 5mm in the case of no rotation, and about 25mm with rotation of dust particle respectively.

Those critical radii are larger than those of natural PC. Thus, at least in terms of PC sizes, the shock-wave heating model is consistent with observations.