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Shock-wave heating model for chondrule formation: Latent cooling due to evaporation and effect of ram pressure

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Chondrules are mm-sized silicate spherules contained in many chondritic meteorites. It is considered that dust particles in the solar nebula, which are chondrule precursors, were heated and melted through flash heating events, cooled again to solidify in a short period of time, and formed chondrules (Jones et al. 2000). High melting temperature of dust particles, which is about 2000 K, suggests the existence of strong heating events in the solar nebula. Since chondrules are ubiquitous, it is considered that chondrule formation events occurred universally in the solar nebula. Thus we can expect to get great information on the early history of the solar system by researching on the chondrule formation mechanism.

The shock-wave heating model is one of the possible models for the chondrule formation (Iida et al. 2001). In the model, shock waves in the solar nebula are supposed to be present. In the postshock region, dust particles move relatively against the nebula gas, and are heated by the friction with the gas. Basically, this model seems to be consistent with observations (Iida et al. 2001). On the other hand, comparing fractionated mineral chemistries between synthetic and natural chondrules, some restrictions on the peak dust temperature and the duration of melting phase have been obtained: High dust temperature, say above 2000 K, should not last long time, so that the observed chondrule chemistries are reproduced (Connolly & Love 1998). In addition, the postshock gas pressure should be high enough so that the molten state of chondrules is stable. These points, however, have not been addressed in the shock-wave heating model to date.

In this study, we research following two points using a theoretical model and examine if the shock-wave heating model is valid: (a) an effect of latent heat cooling due to the evaporation in regard to the peak dust temperature, and (b) a possibility that the molten dust particles can exist stably. To study the point (a), we take into account the evaporation at temperature below the boiling point. We assume that the ingredient of the dust particles is only forsterite and the evaporation rate is given by the kinetic theory of gaseous molecules (Nagahara & Ozawa 1996). To investigate the point (b), we take the ram pressure into consideration and calculate the total gas pressure acting on a dust particle. Comparing the total gas pressure and the vapor pressure of the dust particle, we examine the stability of the molten state of dust particles.

Using numerical simulations, we obtained following conclusions. (1) The latent cooling due to the evaporation keeps the peak dust temperature lower than that in the case in which the evaporation is not taken into account. That is to say that the evaporation has a function to suppress the dust temperature. This effect is particularly remarkable at the temperature beyond 2000 K. (2) In strong shock that can melt dust particles, the ram pressure becomes large enough to keep the molten particles stable. These conclusions indicate that the shock-wave heating model is a reasonable model as the chondrule formation mechanism.

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