Shock-wave heating model for chondrule formation: condition to reproduce chondrule shapes

Hitoshi Miura[1]; Taishi Nakamoto[2]; Masao Doi[3]

[1] none; [2] Tokyo Tech; [3] Physics, Tsukuba Univ.

Chondrules are millimeter-sized, once-molten, spherical-shaped grains abundant in chondritic meteorites. They are considered to have formed from chondrule precursor dust particles (precursors) in the solar nebula; they were heated and melted through flash heating events and cooled again to solidify in a short period of time. However, it has not been resolved what mechanism have been formed chondrules in the solar nebula. The important point is to reproduce physical/chemical properties of chondrules (chemical/isotopical abundances, textural types, external shapes, sizes, and so forth). The shock-wave heating model is one of the most plausible models for chondrule formation, in which the precursors are heated by the gas frictional heating in the high-velocity gas flow. We carry out the three-dimensional hydrodynamic simulation of the molten precursor (droplet) exposed to the gas flow in order to explain the physical features of chondrules (e.g., Miura and Nakamoto 2006).

Recently, we notice the reproduction of three-dimensional chondrule shapes. Tsuchiyama et al. (2003) measured the three-dimensional shapes of twenty chondrules extracted from Allende meteorites (CV3) by using the X-ray micro-tomography. The external shapes were approximated as three-axial ellipsoids with a-, b-, and c-axes (axial radii are A, B, and C (A is equal or greater than B, and B is equal or greater than C), respectively). They found that 16 samples show the external shapes close to a perfect sphere (group-A) and the 4 remaining samples are prolate shapes (group-B).

In our previous study, we showed that the external shapes of group-B prolate chondrules can be reproduced in a plausible situation expected from the shock-wave heating model. In this model, the precursors were heated in the high-velocity gas flow. It is considered that the precursor before melting has an irregular shape, so the gas flow would cause a net torque on the precursor. Therefore, the molten precursor exposed to the gas flow is likely to be rotating. In addition, it is likely that the rotation axis is perpendicular to the direction of the gas flow unless the precursor has a peculiar shape (e.g., propeller). Then, the droplet cools and solidifies to form chondrule. The droplet just before solidification should be so viscous that the time scale of deformation is much longer than the period of the rotation. In this case, the gas flow can be approximated as axis-symmetry about the rotation axis. The droplet is elongated along the rotation axis by the axis-symmetrical gas flow. Finally, such prolate droplet solidifies to form the group-B prolate chondrule.

Here we report that the analysis of the droplet shapes for more general situations; (i) various gas ram pressures and (ii) rotation axis not perpendicular to the gas flow. In our previous study, we assumed a constant value of the gas ram pressure. However, the ram pressure depends on the shock conditions (shock velocity, gas density, and so forth). We discuss the conditions to reproduce the chondrule shapes by considering the dependence on the gas ram pressure. In addition, we also assumed in our previous study that the rotation axis is strictly perpendicular to the direction of the gas flow. However, the situation that the rotation axis inclines slightly can be considered. In this case, the axis-symmetric gas flow is not symmetry in the direction of north and south. It suggests that there might be an asymmetric chondrule shape in the direction of north and south, which cannot be expressed by the three-axial ellipsoid approximation. Based on above analysis, we discuss the conditions to reproduce the chondrule shapes and its diversity.

References: [1] Miura and Nakamoto, 2006, Icarus, in press (astro-ph/0611289). [2] Tsuchiyama et al., 2003, Lunar & Planetary Science Conference, abstract#1271.