Collisional Destruction of Chondrules in Shock Waves and Conditions of Initial Dust to Gas Mass Ratio for Chondrule Formation

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Chondrules are thought to have formed through some flash heating events in the early solar nebula. One of the most plausible models is the shock wave heating. When a shock wave is generated in the solar nebula, a relative velocity between gas and the dust particle is raised, and dust particles are decelerated by the gas drag force caused by the relative velocity. And they are heated by the drag heating.

The drag force acting on a dust particle depends on the relative velocity and the radius of the dust particle. A time scale with which the relative velocity decreases to a half of the initial value is proportional to the dust radius and inverse of the relative velocity. Thus, smaller particles stop earlier than larger particles. This means that relative velocities among dust particles with different sizes are raised behind the shock wave front and that mutual collisions among dust particles may occur. Since the collision velocity could be 1 km s^-1 or more, collisional destruction of chondrules may occur as well. If the collisional destruction takes place significantly, we may not expect that the shock-wave heating is responsible for the chondrule formation.

Here, we investigate the collisional destruction probability of dust particles in the postshock region along the shock-wave heating chondrule formation model. The shock-wave heating model by Miura & Nakamoto (2004) is used to calculate the gas flow and motions of dust particles simultaneously following hydrodynamical and thermodynamical equations. Then, we can obtain the velocity and the spatial number density of dust particles as a function of the dust radius and the place. Also, we can evaluate the relative velocity of a dust particle with respect to other dust particles and the number of collisions at each place. And we can evaluate whether or not the target particle is destructed by the collision using a criterion described below. By counting the number of destructive collisions for a certain dust particle, we can evaluate the destruction probability.

Laboratory experiments of the collisional destruction of dust particles show that dust particles are expected to be disrupted when the impact meets a certain condition. Here, we adopt a simple criterion given by e M is less than f m V^2/2, where e = 3 x 10^6 erg/g (Takagi et al. 1984), M is the mass of the target particle, m is the mass of the projectile, V is the relative velocity between two dust particles, and f is the efficiency assumed to be f = 0.3 in this study.

Size distribution of dust particles before entering the shock wave is assumed to have a lognormal form. The mean radius is set to be 250 micron and the dispersion of the distribution is log_{10} 2. Three initial dust to gas mass ratio cases are examined: 0.001, 0.01, and 0.1. Note that the solar abundance value of the dust/gas mass ratio is about 0.01.

When a target dust particle is larger than a critical radius, the destruction probability of the particle exceeds unity, implying that the dust particle is expected to be destructed in the shock wave. The critical radii for each initial dust/gas mass ratio in a case of shock wave with the shock velocity vs = 8 km s^-1 and the preshock gas density n0 = 10^14 cm^-3 are 330 micron (for (dust/gas)_init = 0.1), 750 micron (0.01), and 2 mm (0.001), respectively. And those for a case with vs = 40 km s^-1 and n0 = 10^11 cm^-3 shock wave are 130 micron (for (dust/gas)_init = 0.1), 310 micron (0.01), and 730 micron (0.001), respectively. Therefore, to reproduce sizes of chondrules in ordinary chondrites with the shock-wave heating model, the initial dust to gas mass ratio should be of the order of or less than 0.01.