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1-D Plane Parallel Shock Waves of Dust-Gas Mixed Fluid: For Simulations of Chondrule Forming Planetesimal Bow Shocks

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Chondrules are millimeter sized silicate composition spheres that are the dominant component in most chondritic meteorites. It is considered from experiments and measurements that chondrules experienced flash heating events and melting/re-solidification in the early solar nebula. The shock wave heating model is one of the most viable models for chondrule formation. And we think that eccentric planetesimals are the source of shock waves in the solar nebula.

Planetesimal bow shocks for chondrule formation have been studied by some work (e.g., Boley et al. 2013, Ciesla et al. 2004). In those works, the dust-to-gas mass ratio was considered to be around the standard solar value, which is about 1:100. On the other hand, based on petrological studies, it is considered that the partial pressure of oxygen in the gas around the molten chondrules was considerably higher than the canonical value. If the oxygen in the gas is supplied from evaporated dust particles, the initial dust-to-gas mass ratio is estimated to be 1:1 or 10:1 (Jones et al. 2000). When the dust-to-gas mass ratio in the fluid is high enough, physical and chemical effects of dust on the flow would not be negligible. So, in order to investigate the chondule formation by shock waves in the dusty condition, we need to carry out hydrodynamical simulations with high dust/gas mass ratio.

In this study, first, we examine 1-D plane parallel shock waves of dust/gas mixed fluid with high dust/gas mass ratio. Especially, we clarify a relation between physical quantities behind the shock waves and the dust/gas mass ratio. Then, for our future study, we develop a numerical code to simulate the dust rich fluid. We assume that the size of dust particles is small enough so the motion and the temperature of dust particles are the same with those of the gas. We also assume that the dust particles evaporate completely when their temperature exceeds 2,000 K.

First, we analytically obtain the relation of the temperature, density, velocity, and the pressure between before and behind the shock wave, when the energy transfer is not taken into consideration (adiabatic case). When the dust particle is not incorporated in the fluid at all, this relation is known as the Rankine-Hugoniot relation. And we extend the relation so that the effects of dust particles are taken into account. According to the relation obtained here, we found that the density, pressure, and the velocity behind the shock do not depend on the dust/gas mass ratio, the temperature rises as the dust/gas mass ratio increases. These dependences can be understood based on the mass and the momentum conservation. The temperature behind the shock is an increasing function of the dust/gas mass ratio, because the gas number density behind the shock becomes lower as the dust/gas mass ratio increases, but the pressure should be the same, so the temperature should be higher.

Second, we carried out numerical simulations of 1-D plane parallel shock waves using the numerical code developed for this study. We found that numerical results are in a good agreement with analytical solutions. Thus, we think that the developed numerical code is applicable for for future simulations that include 2-D geometry and radiative energy transfer.

Keywords: chondrule, shock wave, hydrodynamics simulation