Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

PPS24-11 Room:A02 Time:May 27 15:00-15:15

Do icy grains evaporate by an accretion shock?

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Gravitational collapse of a molecular cloud is a transient process to form protostars and protoplanetary disks. The infalling envelope onto the Keplerian disk often induces accretion shocks at their boundary. Recent ALMA observations suggested evaporation of icy grains at the shocked region [1,2]. The icy grain evaporation would considerably affect the chemical environment of the nebula. The shock conditions for the icy grain evaporation were calculated numerically in a few papers [3,4]. However, the effect of emissivity of icy grains has not been investigated systematically. The smaller the emissivity is, the higher the temperature of icy grains will become even in the same shock condition. The emissivity generally varies with the size, composition, and structure of icy grains, and then may change the evaporation condition. In this study, we revisited the evaporation condition for various icy grains using realistic emissivity.

We adopt a two-step calculation method to obtain the detailed thermal history of icy grains in the post-shock region. First we calculate the post-shock gas structure as a function of the distance from the shock front [5]. The shocked gas parameters just behind the shock front were determined by the Rankine-Hugoniot relation using the pre-shock parameters: a shock velocity and a pre-shock gas number density (J-type shock). The shocked gas is gradually cooled by line emissions from CO molecules and thermal collisions with non-evaporating sub-micron silicate grains. We consider a one-dimensional plane-parallel post-shock geometry, so the gas temperature and density are determined as a function of the distance from the shock front. Second we calculate the thermal evolution of icy grains using the post-shock gas structure obtained in the first step. The emissivity of icy grains was given by performing a Planck mean of a wavelength-dependent absorption efficiency, which was calculated from the dielectric function or the complex refractive index data. We solved the evaporative shrinkage of icy grains to obtain the evaporation condition, namely, the shock parameters with which the icy grain evaporates completely.

The numerical results indicate that the shock condition for the icy grain evaporation strongly depends on the emissivity. For example, the icy grain composed of pure CO_2 is evaporatable by the observed accretion shock [1,2] because of its small emissivity. However, if the icy grain contains considerable amount of silicate components, it has much larger emissivity and therefore hardly evaporates by the same accretion shock. Our results showed that the emissivity of the icy grains is one of the important factors to determine whether the icy grain evaporates by shock heating or not. This implies that it is possible to constrain the size, composition, and structure of the interstellar icy grains from the observational evidence of icy grain evaporation by accretion shocks.

References: [1] N. Sakai et al. (2014), Nature, 507, 78. [2] H.-W. Yen et al. (2014), ApJ, 793, 1 (20pp). [3] D. A. Neufeld and D. J. Hollenbach (1994), ApJ, 428, 170. [4] T. Aota et al. (2015), ApJ 799, 141 (9pp). [5] H. Miura and T. Nakamoto (2006), ApJ 651, 1272.

Keywords: Accretion shock, icy grain, Shock heating, Evaporation