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Breakup of droplets due to high velocity flow and size distribution of fragments

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Introduction

It is considered that chondrules have been heated and melted once and cooled. However the formation mechanisms of chondrules such as heating processes have not fully understood yet. One of the characteristic features of chondrules is its 'size'. The size should have some information on the formation mechanism, and its maximum size or average size has been often discussed. We pay an attention to the size 'distribution' of chondrules and consider whether chondrules in various sizes are formed through breakup in liquid states. Here we report some results of an experiment about the breakup of liquids due to high velocity flows, based on the shock-wave heating model (e.g., Iida et al., ICARUS 142, 430, 2001).

Experiment

An experimental study of liquid deformation and breakup properties induced by a shock wave is carried out. Water, Glycerol, and their mixtures are used as samples. A shock tube facility is used for measurements of effect of shock wave disturbances on liquids in gases. Velocity of gases obtained in the experiments ranges from 10 to 60 m/s (from 1.01 to 1.12 as Mach number). The deformation and breakup processes are taken using a high speed camera with a framing speed of 4000 frames per seconds, an exposure time of 20 micro-second, and a pixel number per 1 frame of 640x256 pixels. Modes of breakup and the size distribution of droplets after the breakup are observed.

Results

First the interaction between droplets and high velocity flows is observed. The diameters of the droplets are from 0.3 to 5 mm. Various continuous phase gases and liquids are considered to provide Ohnesorge numbers (Oh) of 0.001-3 and Weber number (We) of 4-400. The breakup mode at Oh less than ~1 depends only on We and we observe 'Oscillation mode' at We less than 10, 'Bag mode' at 10-20, 'Strip mode' at 20-100, and 'Catastrophic mode' over 100. Over 1 of Oh, increasing Oh causes increases of We range for both deformation and breakup regimes. In these conditions there are some previous results of deformation and breakup modes (e.g., 'Shock-wave handbook' ed. Takayama, 1995) and our results are consistent with them.

It is shown that the cumulative number of droplet 'fragments' is represented by an exponential function. Moreover, it is suggested that the slope of the distributions in semi-log plot (which means average size) depends weakly on We, when the fragment size is normalized by the initial size of mother droplets.

The cumulative number distribution of real chondrules is also represented by an exponential function. Here assuming that chondrules are formed through a breakup of mother droplets, we estimate the initial size and We at the breakup of mother droplets. From the size distribution of chondrules normalized by initial size as a parameter, we can determine an average size of chondrules: that is, the relation between initial size and average size is determined. Using the relation between average size and We obtained from the experiments, the relation between initial size and We are determined. On the other hand, the definition of We leads the relation between We and initial size, setting a shock wave condition which is assumed for chondrule formation in the solar nebula (e.g., Susa and Nakamoto, ApJ 564, L57, 2002). Thus the intersection of these indicates the initial size and We at the breakup of mother droplets. For example, the chondrules from the chondrite Bjurbole provides a result of an initial size of ~ 5 mm and We of ~ 20.

Second, we observe that liquid attached on a solid sphere breaks up due to high velocity flows. Weber number in this case is defined comparing to the case of droplet breakup and the dependencies of breakup modes and the size distributions of fragments on Weber number are investigated.

Finally, the plausible process of breakup of chondrules is discussed.