1-D SHOCK WAVE SIMULATIONS OF CHONDRULE THERMAL HISTORIES FOR HIGH CHONDRULE NUMBER DENSITIES.
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Introduction: Previous detailed 1-D simulations of chondrule thermal and dynamical histories in nebular shock waves have so far demonstrated that cooling rates compatible with furnace experiment results (100-1000 K/hr) are possible only for solids-to-gas mass ratios near or below the solar value of $\sim$ 0.005 (1,2,3). In these simulations, the nebular gas density was assumed to be $\leq 10^{-9}$ g cm$^{-3}$, implying mm-diameter chondrule number densities of $\leq 0.01$ m$^{-3}$. However, analyses of the frequency of compound chondrules together with theoretical considerations indicate that chondrules formed in regions with chondrule number densities $> 6$ m$^{-3}$ (4). Also, one recent model to explain the depletion of volatile elements in chondrules requires that the precursor number density was $> 10$ m$^{-3}$ (5).

Approach: In this paper, we report new simulations using the 1-D shock model of ref. 1 (as modified in ref. 6) to investigate whether cooling rates in the 100-1000 K/hr range can be obtained for chondrule number densities exceeding 10 m$^{-3}$. For this purpose, we have carried out a series of large-scale shock model runs for such chondrule number densities while simultaneously varying other model parameters (nebular gas density, shock velocity, chondrule/dust mass ratio, solids/gas mass ratio, etc.).

Results: Runs completed so far indicate that cooling rates in the range suggested by furnace experiments are very difficult to achieve for chondrule number densities $> 10$ m$^{-3}$, even for higher nebular gas densities and for low micron-sized dust densities. The high chondrule number densities increase the opacity, which causes chondrules to be exposed to radiation from hot particles immediately behind the shock front for shorter time periods. This effectively increases the cooling rate above the 1000 K/hour limit. The addition of a significant fraction of micron-sized dust, which is needed to explain the formation of fine-grained rims around chondrules (7,8), further increases the opacity and, therefore, the cooling rates.