FORMATION OF METEORITIC CHONDRULES BY LIGHTNING.
John T. Wasson and Kaare L. Rasmussen, Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90024, USA.

Petrographical evidence of rapid melting and cooling indicates that the heating mechanism for forming chondrules was of a pulsed nature. Retention of volatiles in chondrule interiors, also indicates that energy dissipation following formation was rapid. Chondrules rarely show evidence of multiple melting events, thus a suitable scenario must also allow for removal of chondrules from the production zone after formation. These requirements limit the number of realistic chondrule formation mechanisms, the most probable being the lightning model (1,2,3). In particular, recently proposed "interstellar meteor" mechanisms (4,5) involve a heat pulse that is too long to allow volatile retention, and if interstellar dust mainly consists of fine grains, such chondrules would not be expected to show the observed degree of heterogeneity.

Previous models (1,2) have not proposed a plausible source of turbulent energy needed to generate the lightning. We suggest that it is derived from shear forces between the dust-rich median plane and the overlying gas-rich regions of the nebula (3). Such a dust-gas separation should occur relatively rapidly after accretion-induced turbulence has dissipated. We follow Weiden-schilling (6) and assume a nebula pressure of $6 \times 10^{-5}$ atm and a background temperature of 400 K at 1 AU. We assume a surface density $\sigma$ of dust of ca. 20 g/cm$^2$, mostly concentrated at the median plane of the nebula. This dust we assume to be a mixture of 10% coarse chondrule precursor particles and 90% fine (25 nm) particles. The difference is velocity AV) between the gas component and the dust component is $1.3 \times 10^{-4}$ cm/s, corresponding to an energy dissipation of $W_a=0.5 \times 10^{-7}(AV)^2 \cdot q \cdot N_{rev}$ where $q$ is the yield in the energy transfer, and $N_{rev}$ is the number of the revolutions in the turbulence cell in which the dissipation takes place. The energy available from the turbulence, $W_a/q$ is ca. 170 erg/cm$^3$/y.

A serious problem is the low breakdown potential of the H$_2$ gas at low nebular pressures, since this limits the amount of energy that a single bolt can release. However, the presence of fine dust raises the breakdown potential to 6.8 V cm$^{-1}$ and yields a bolt radius of 2.8 mm and an energy of 1.9 x 10$^{10}$ erg at 1 AU. The energy needed to melt a standard chondrule of mass 10 mg and radius 0.9 mm is $1.3 \times 10^8$ erg, thus a standard bolt releases ca. 150 times more energy than needed to melt one chondrule. Only rarely would more than one precursor particle be in the bolt region. The chondrule precursors correspond to a required density of $3.3 \times 10^{-10}$ g/cm$^3$ in the median plane. The energy needed to melt these grains is 4.3 erg/cm$^3$. Comparing this to the estimate of 170 erg/cm$^3$/y turbulent energy, efficiency of conversion of turbulent energy to lightning bolt energy could have been very low.

Our model ceases to produce standard chondrules at ca. 2.5 AU, but is still able to produce the smaller chondrules observed in CM and CO carbonaceous chondrites out to ca. 3.5 AU.
CHONDRULE FORMATION BY LIGHTNING

Wasson, J.T. and Rasmussen, K.L.