PRODUCTION OF CHONDRULES BY LIGHTNING IN THE SOLAR NEBULA; S.J. Weidenschilling (Planetary Science Institute/SJI)

It is widely believed that chondrules were formed in the solar nebula by transient heating events that melted precursor aggregates of dust grains. The nature of the heating events is unclear, but one persistent suggestion is some sort of electrostatic discharge or "lightning" [1-5]. This idea is attractive because the formation of planetesimals involved settling of particles into a dense layer in the central plane of the nebula. This layer provided an environment with high solids/gas ratio, high opacity, and potentially high concentration of precursor aggregates. Moreover, this dense dusty layer was turbulent due to shear relative to the nebular gas [6, 7]. Such a turbulent dusty environment offers the prospect of charge separation and generation of electrical discharges of some sort. However, arguments for and against lightning remain inconclusive because of limited understanding of the generation of terrestrial lightning and difficulties of scaling such processes to very different conditions in the solar nebula [5]. In the present work I report on efforts to place other constraints on the chondrule-forming process in this context from models of particle settling and coagulation during the formation of planetesimals. Assuming "lightning" can occur, are other conditions met? Can shear-generated turbulence provided enough energy? Does particle coagulation produce sufficient precursor aggregates of the appropriate size? Are chondrules concentrated or sorted aerodynamically, and accreted efficiently into planetesimals?

Coagulation and settling are modeled numerically as described in [7]; however, the code is modified to treat two particle populations: (I) primitive "matrix" material, and (II) "chondrules." Population I has low strength and density, while Population II is strong and dense. The initial state is assumed to consist only of μm-sized grains of Population I, uniformly mixed with the gas. Coagulation and settling produce a dense layer of particles in the central plane, with shear motion that generates turbulence [7]. The turbulence releases energy at the rate $\rho V_t^3/L$ $erg\ cm^{-3}\ s^{-1}$, where ρ is the gas density, and V_t, L are the velocity and length scales of the largest eddies. The ultimate source of this energy is the potential energy of the particles in the Sun's gravity well; its release is due to their radial motion. This energy is converted with some efficiency ζ into "lightning," which heats some fraction of the total volume of gas and dust to T = 1800 K. The volume heated is determined by the energy available. Population I aggregates within a specified range of sizes are converted into Population II "chondrules" by this process. Neither component remains pure; chondrules can acquire a veneer of Population I dust (which can be converted to Population II by reheating), while larger Population I bodies can accrete chondrules. The code conserves total mass in the system while keeping track of particle populations and compositions as functions of size. The different densities of the two populations allow the possibility of aerodynamic sorting by differential settling and accretion efficiencies influenced by aerodynamic flow around large bodies [8].

The goal of this work is to determine whether plausible nebular parameters can produce Population I precursors of appropriate sizes and in sufficient numbers, and whether plausible values of ζ can produce significant abundance of chondrules during the accretion of planetesimals. The same methods can be applied to certain other chondrule production mechanisms, e.g., magnetic reconnection flares [9] or radiative heating [10], if the heating mechanism is appropriately parameterized.

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Results as of writing this abstract are preliminary and conclusions are highly tentative. It appears that for conversion efficiency $\zeta = 10^{-3}$, the rate of heating by "lightning" is too small compared with the growth rate of planetesimals to yield a significant fraction of the total mass as chondrules. Among the possible solutions to be explored are the following:

Different nebular structure which may produce more shear and turbulence.
Higher efficiency of conversion of turbulence to "lightning".
Additional sources of energy for shear-driven turbulence (e.g., including condensed H_20 in the mass of the particle layer).
Other sources of turbulence besides local shear.
Low sticking efficiency or friable Population I particles to prolong the timescale of accretion.
Other energy sources (e.g., magnetic reconnection flares).

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