EFFECTS OF LIGHTNING IN THE SOLAR NEBULA: PARTICLE SIZE DISTRIBUTIONS AS A FUNCTION OF TIME AND DISTANCE FROM THE IONIZATION CHANNEL. Joseph A. Nuth III[1] and John A. Paquette[2], [1]NASA's Goddard Space Flight Center, Solar System Exploration Division, Code 690, Greenbelt MD 20771 USA (joseph.a.nuth@nasa.gov) [2]NASA Senior Postdoctoral Fellow, Astrochemistry Branch, Code 691, Greenbelt MD 20771 USA.

Introduction: Lightning has been suggested as an energy source that may have left its signature in the meteoritic record both as magnetized particles and as chondrules and several studies of nebular lightning have been published [1-3]. Lightning may also have played a role in the evolution of the oxygen isotopic signature of solids throughout the first million years of nebular history [4]. While other explanations certainly exist for both chondrule formation and for establishment of the oxygen isotopic signature of nebular dust [5-11], there may be another signature that could be indicative of lightning in the nebula: particle size distributions for silicate condensates found in the most unaltered chondritic meteorites [12]. For this reason we have begun to model the lightning induced vaporization of silicate dust and the subsequent nucleation, growth and coagulation of grains in a typical nebular environment.

Lightning in the primitive solar nebula may have driven important aspects of the chemistry of dust, including the non-mass-dependent fractionation of oxygen isotopes. In order to model such processes a much more quantitative understanding of the effects of lightning on the grain size distribution and the composition of solids in the nebula is required than is currently available.

These models are quite general at the moment as there are many parameters whose effects need to be understood, including, but not limited to the temperature and duration of an average nebular lightning bolt, the aggregation state of the initial nebular grain population, the scale of mixing between lightning struck dust and fresh presolar materials.

General Plan of the Model: We begin the calculation by using the MRN interstellar grain size distribution [13-14] and allow the grains to coagulate for specific times prior to the initial lightning bolt. We treat the temperature of the bolt as a free parameter (currently 2000K) but intend to carry out calculations over a range of temperatures. The grains within concentric shells around the ionized channel vaporize as heat is transferred into their environment via conduction through the gas according to their equilibrium vapor pressures. (Future models will incorporate a vaporization coefficient into these equations.) Heat is transferred by conduction, and vapor is allowed to diffuse from one zone to the next in this initial model. However, we do not allow diffusion of dust from one zone to another under the assumption that grains diffuse rather slowly compared to vapor and exchange with adjacent zones would more or less balance out. We also do not account for the shock heating of the surrounding gas due to "thunder" resulting from the rapid expansion of the ionization channel over the short duration of the lightning event. While this shock wave might be important in preheating the gas farther from the ionization channel [e.g. 15], the net effect should be nearly equivalent to using a slightly higher gas temperature in the ionization channel.

When the current flow in the ionization channel ceases (another free parameter) the gas cools and begins to nucleate. The SiO clusters grow, depleting the refractory vapor of SiO, Fe, Mg and equivalent amounts of oxygen, then begin to coagulate. Further away from the ionization channel, the temperature of the gas may still be increasing due to outward diffusion of the heat from the lightning bolt, though the peak gas temperature will not reach the same level as in the ionization channel. As the grains in each concentric radius bin vaporize, the model tracks their particle size distribution. Once the peak temperature is achieved and the gas begins to cool both homogeneous as well as heterogeneous nucleation and grain growth will occur until the refractory vapor phase is depleted. Coagulation will then begin as in the ionization channel.

Near-Term Science Goals: There are currently no constraints on the size of a nebular lightning bolt or on its peak temperature and duration, yet these parameters are essential if we want to model the effects of lightning on nebular materials. If lightning dissipates a specific fraction of the accretion energy of the disk, then constraints on the size, temperature and duration of an average lightning bolt also yield contstraints on their frequency.

The first goals of this study are to calculate the size-frequency distribution of grains effected by a single lightning bolt as a function of the temperature of the bolt and distance from the ionization channel as a function of time for comparison with grain size distributions in primitive meteorites. We may eventually be able to put upper or lower limits on either the temperature or the duration of the average lightning bolt based on comparisons with the grain size and composition distributions in meteoritic matrix.

Caveats: For this initial model we are only following the vaporization, nucleation and growth of the silicate grains and there is already a wealth of unconstrained free parameters such as the evaporation coefficient for presolar dust or the condensation coefficient for the vapor, the sticking coefficients for growth or coagulation and the sticking coefficient for heterogeneous growth of refractory vapors on surviving (partially vaporized and possibly crystalline) grains. These are in addition to the model parameters describing the lightning bolt itself. While more refractory minerals such as corundum, spinel or hibonite may be present in primitive meteorite matrix, the majority (by mass) of fresh nebular condensates will consist of oxides of silicon, magnesium and iron. Previous laboratory studies of grain nucleation and growth [16], and models of these processes in circumstellar outflows [17] suggest that iron metal grains do not nucleate directly from the gas and that both iron and magnesium grow separately on freshly nucleated $(SiO)_x$ clusters to yield amorphous magnesium silicate and amorphous iron silicate grains.

Once nucleation and growth are completed, the model then tracks grain coagulation. In principle, if we follow the composition of all grains in an aggregate we should be able to predict not only the average composition of the silicates formed but also the compositional distribution of iron-magnesium silicate minerals that could form by thermally annealing the aggregate. If we assume that the annealing or sintering occurs without loss of material, then we can also predict the final grain size distribution as a function of composition.

References:

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