Condensation Processes in Astrophysical Environments: The Composition and Structure of Cometary Grains

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Experimental data obtained in our laboratory have been quite surprising in a number of ways, ranging from the chemical composition of the condensates themselves to the evolution of their spectral properties as a function of temperature and time. None of this information could have been predicted from first principals and would not have been believable even if it had been. Analytical electron microscopic analysis of individual grains condensed from several different vapor phases indicate that such condensates form at metastable eutectic compositions. Because there are no metastable eutectics along the MgO- FeO join, condensates from a Mg-Fe-SiO vapor form pure magnesium silicate, iron silicate and metal oxide smokes. The proportions of grains at individual compositions are determined by the overall composition of the initial mixed metal vapor. Experimental studies of the spectroscopic evolution of magnesium silicate grains as a function of time at various temperatures, indicates that temperatures of ~1100-1000K are required to anneal such materials to crystallinity on reasonable (hour-to-month) timescales. Iron silicates require much higher temperatures (T >~1300K) to bring about similar rates of change in their infrared spectra.

Observations of relatively large quantities of crystalline magnesium silicate grains in comets and in older Herbig Ae and Be stars indicate that crystallization naturally occurs within protostellar nebulae. When such observations are combined with the experimental results discussed above, we infer that there must be a mechanism to circulate annealed grains from the inner nebula (< 1 AU) out to several hundred AU where grains begin to accrete into icy cometesimals. Such winds would also naturally carry gas, rich in organic molecules, freshly synthesized in the inner nebula, out beyond the nebular snowline where they could easily be incorporated into growing planetesimals. Our experiments show that our amorphous silicate smokes readily catalyze the conversion of H_2, N_2, and CO into organic species. We therefore expect that the innermost regions of protostellar nebulae will be potent factories for the production of essential prebiotic molecules necessary for the origin of simple living organisms in most protostellar systems. Whether these prebiotic molecules get the chance to evolve to more complex forms will depend, in part, on the nature of the environments where they are deposited within the system and on the timescales over which such conditions persist.