Homogeneous nucleation of silicate nanoparticles in a microgravity environment using a sounding rocket

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Silicates are the main mineral group found at the Earth's surface and are commonly composed of magnesium, iron, silicon and oxygen. Silicates have been observed to form in the outflows of oxygen-rich stars and that source is thought to have provided the building blocks for our solar system. Many silicate minerals can be found in meteorites and isotopic analyses confirm that some grains survived the processes of evaporation, condensation and aqueous alteration in the early solar system: these are presolar silicates. Astronomical observations show that most of the infrared features attributed to silicates in oxygen-rich, circumstellar outflows most likely arise from amorphous silicates. However, some high-mass-loss, oxygen-rich stars show crystalline features in their infrared spectra. The fraction of crystalline silicates is typically on the order of ~10% of the total. Experimentally, the degree of crystallinity has been confirmed to depend on the cooling rate from the gas phase, the Mg/Si ratio, the annealing temperature and time. However, a reasonable explanation for why only 10% of silicates are crystalline in these outflows, and why crystalline silicates are not detected in the gas outflows of low-mass-loss stars is not yet known. The character of the resulting silicate grains would be governed by the initial silicate nucleation process.

We conducted a set of microgravity nucleation experiments using a NASA Black Brant IX sounding rocket on October 7, 2019 to study the nucleation, growth and aggregation of silicate grains. Over a period of 460 seconds in microgravity silicate particles formed following the evaporation of starting materials previously deposited onto tantalum filaments that were resistively heated in six different experimental chambers. Particles formed via homogeneous nucleation from a supersaturated vapor after cooling in a buffer gas of either pure argon or a mixture of argon plus oxygen. The temperature and concentration of the evaporated vapor can be determined by direct imaging of a double-wavelength, Mach-Zehnder type interferometer. In addition, we successfully recovered both the payload and the particles produced during the experiment. We studied these analog presolar silicates using a transmission electron microscope. The particles have a size distribution centered at ~40 nm in diameter and are mostly amorphous but with some small degree of crystallinity in some grains. While some aggregated grains show clear boundaries between the particles, other samples show complete fusion with no observable boundaries remaining. We will discuss the nucleation of presolar grains based on the results of the further analyses of these experiments.

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