

MAKING AMORPHOUS SILICATE AND CARBONACEOUS DUST ANALOGS AVAILABLE TO THE COSMOCHEMISTRY COMMUNITY. Joseph A. Nuth III¹, Natasha M. Johnson² and Frank T. Ferguson^{2,3}

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Introduction: Condensates formed in astrophysical environments are difficult to access as starting materials for laboratory studies of processes that might occur in protostellar nebulae. While micrograms of such materials might be found in the heart of rare, unprocessed, primitive meteorites such as Acfer 094, much larger quantities of material are required in order to conduct multiple experiments at a variety of temperatures and pressures. To solve that problem we manufacture several different varieties of “natural” simulants from flowing hydrogen gas seeded with appropriate metals and exposed to a hydrogen-oxygen flame. These samples range from simple SiO_x smoke, to more complex Fe_aSiO_x , Mg_aSiO_x and $\text{Fe}_a\text{Mg}_b\text{SiO}_x$ smokes that mimic the reactivity and spectral properties of fresh, vapor-phase condensates such as those that might form in circumstellar outflows or from vaporized materials formed by energetic processes in protostellar nebulae.

In addition, we also make carbonaceous samples formed from a flowing stream of CO on the surfaces of various catalysts during surface mediated reactions in an excess of hydrogen and in the presence of N_2 . Carbon deposits do not form continuous coatings on the catalytic surfaces, but instead form extremely high surface area per unit volume “filamentous” structures. While these structures will form slowly but over longer times in protostellar nebulae than in our experiments (due to the lower CO pressure), such fluffy coatings on the surfaces of chondrules or CAIs could promote grain-grain sticking during low velocity collisions and might provide carbonaceous feedstock for the synthesis of interesting biochemical precursors to life during metamorphism within meteorite parent bodies.

Both amorphous silicate smokes as well as carbonaceous solids are available to the scientific community for use in cosmochemical experiments thanks to support from the Planetary Science Division at NASA Headquarters.

Amorphous silicate smokes: We form grains in flames by mixing silane, pentacarbonyl iron, trimethyl aluminum, magnesium metal and oxygen in hydrogen at high temperatures and low pressures (Figure 1). Grain formation and growth occurs in microseconds and is rapidly quenched. Individual grains are small (20 - 50nm) and highly amorphous (lots of internal energy). We can make a wide compositional range of

smokes by varying the input gas mixture. Although the bulk composition of smokes is controllable, the compositions of individual grains are not: Some compositions are favored while others seem to be forbidden. Favored compositions are those found at metastable eutectics in the phase diagrams [1].

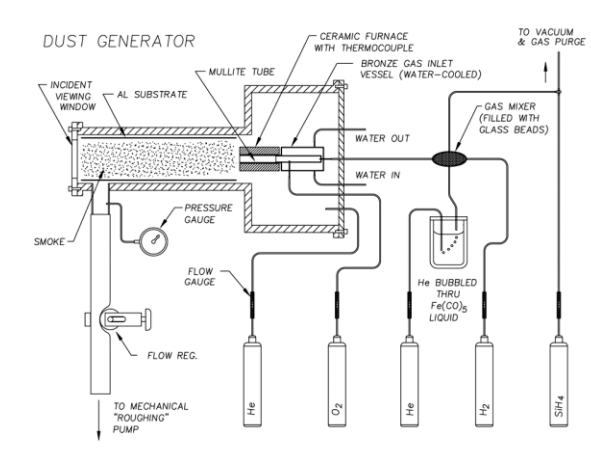


Figure 1. Schematic diagram of the dust generator used to manufacture 10 nm scale smoke particles *via* the combustion of hydrogen gas containing small amounts of silane, iron pentacarbonyl, trimethyl aluminum, titanium tetrachloride and other metal vapors such as magnesium, calcium, sodium and potassium. Molecular oxygen is typically used as the oxidant. The reaction occurs across a flame front within a resistively heated furnace at temperatures between 500 - 1500 K. Condensates are rapidly quenched and are collected on an aluminum substrate downstream of the furnace at temperatures below 350 K.

Carbonaceous Solids & Surface Mediated Reactions: We are not claiming here that surface mediated reactions constitute the single – or even the most important - mechanism that forms the full distribution of organic molecules in asteroids or comets or that are found in meteorites or IDPs. There are many different processes that can be important sources for particular compounds in many different meteorite types. However, we do believe that surface mediated reactions are a very efficient mechanism for converting nebular CO or CO_2 into solid carbonaceous materials [2]. Such solids

should be easy to incorporate into planetesimals and these carbonaceous grains could then serve as the feed stock that is transformed by various thermal or hydro-thermal processes on parent bodies into the myriad organic molecules found in natural sources [3].

In addition, while we use various industrial reactions as models of nebular processes; e.g., the Fischer-Tropsch reaction: $\text{CO} + 3\text{H}_2 \Rightarrow \text{CH}_4 + \text{H}_2\text{O}$; the Haber-Bosch reaction: $\text{N}_2 + 3\text{H}_2 \Rightarrow 2\text{NH}_3$; the water-gas shift reaction: $\text{CO} + \text{H}_2\text{O} \Rightarrow \text{CO}_2 + \text{H}_2$; or the Boudouard Reaction: $2\text{CO} \Rightarrow \text{CO}_2 + \text{C}_{\text{solid}}$; natural reactions on grain surfaces in protostellar nebulae are much more complex. For this reason it can be extremely misleading to discuss a specific model reaction in isolation when describing natural reactions that might occur on the surfaces of grains in the Solar Nebula. To avoid confusion as to which “model reaction” applies to the materials we generate we have adopted the practice of discussing *surface mediated reactions*.

Making Carbonaceous Grains: The experimental system used to generate carbonaceous grains is shown schematically in Figure 2. This system produces an intimate mixture of the catalytic material (typically amorphous iron silicate smoke) and the carbonaceous grain coatings.

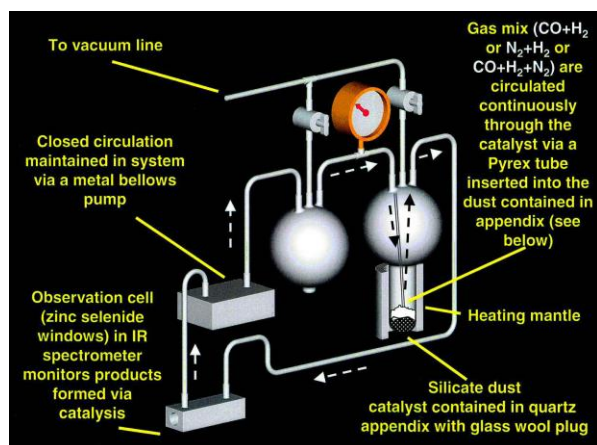


Figure 2. The catalyst is in the bottom of a quartz finger (attached to a 2-L Pyrex bulb) that can be heated to a controlled temperature. A Pyrex tube brings reactive gas to the bottom of the finger. The gas passes through the catalyst into the upper reservoir of the bulb and flows through a stainless steel tube at room temperature to a glass-walled cell (ZnSe windows) in an FTIR spectrometer. A metal bellows pump returns the gas via to the bottom of the catalyst finger to start the cycle over again. We have ten identical experimental systems: the total volume of each system is 4.7 +/- 0.1 liters.

In more recent experiments we have been able to produce carbonaceous solids using iron wire as the

reactive surface at controlled temperatures ranging up to 1000K. The iron wire surface is not “coated” by the reaction products. Instead, the surface serves more as a growth surface (Figure 3) and the carbonaceous material is easy to remove.

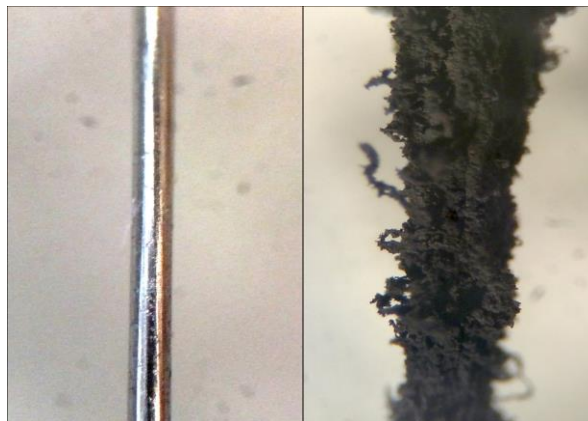


Figure 3. An optical microscope image of iron wire (.009” Diam.) before (left) & after (right) use as a catalyst for one 873K run of $\text{CO} + \text{N}_2 + \text{H}_2 \Rightarrow$ products. The grains are very easily removed from the wire.

Summary: We can supply limited quantities of both amorphous silicate smokes as well as carbonaceous solids to planetary science researchers. The most readily available products include amorphous silicate, Fe-silicate, Mg-silicate and Fe-Mg silicate smokes, carbonaceous solids intimately mixed with Fe-silicate smoke and carbonaceous solids on Fe wire. Custom compositions may also be possible as well. If interested in samples of these materials please contact one of the authors.

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References:

- [1] Joseph A. Nuth, Frans J. M. Rietmeijer and Hugh G. M. Hill, 2002, MAPS 37, 1579 - 1590. [2] Hugh G. M. Hill and Joseph A. Nuth, 2003, Astrobiology 3, 291–304. [3] Joseph A. Nuth, Natasha M. Johnson Frank T. Ferguson and Alicia Carayon, 2016, MAPS 51, 1310–1322.