EXPERIMENTS IN CHONDRULE FORMATION: SIMULATION OF GAS-GRAIN COLLISIONS USING PLASMA ARCS.

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Introduction: Chondrules are the dominant component in primitive meteorites. Their modal abundance is up to 80 volume% [1]. Also, they formed very early in the Solar System (~4567 Ma [2]). This makes the formation process of chondrules a very important step in the evolution of the protoplanetary disk and planets in general.

Although the basic constraints about their formation are well known by experiments – most of them were heated to 1500–1600 ºC, followed by a rapid cooling of usually between 10 to 1000 ºC/h [3], the exact process is still not known.

Most common formation scenarios proposed are formation in a protoplanetary nebular environment. The X-wind model proposes precursor dust heated by a highly active young sun [4], while the nebular shock models assume shock fronts in the protoplanetary nebula, where precursor grains are heated by collisons with gas particles [5].

Other models assume a planetary forming environment by impacts e.g. for CB chondrites [6].

In this part of our study, we try to simulate the formation of chondrules by gas-grain collisions in a nebular environment. To acheive this, we try to heat a precursor material (silicates, sulfides etc.) in hot plasmas created by plasma arcs.

Plasma Arc Experiments: In a first step, we tested a basic set-up in the Department of Physics & Astronomy at the Open University in Milton Keynes.

An atmospheric pressure plasma arc is generated using a low voltage, solid state switching circuit to drive a Tesla coil (Fig.1). The coil has a natural frequency in the region of 325 kHz. Through mutual induction, the voltage on the primary (50V) is stepped up to achieve a sufficient voltage drop (>20 kV) between the electrodes at the top of the secondary coil, causing breakdown of the air and thus generating the plasma.

For measurement, the coil was placed on its side and material dropped vertically through the flame (Fig.2). When ignited the plasma discharge is rooted at the brass electrodes by visible hot spots and has a flame like luminous central column some 2-3mm in diameter. The 'bowing' of the plasma is due to natural convection from the high gas temperature in the ambient air (hence the term 'arc'). This particular configuration using radio frequency excitation is able to maintain non-thermal equilibrium conditions with the gas temperature significantly lower than the electron temperature. It is important to note that the gas temperature in the RF plasma is derived directly from the electrical supply without the need for exothermic gas phase chemical reactions. Current work is in air but future investigations may use an inert atmosphere.

The gas temperature has been determined in an earlier experiment through fitting of modelled spectra to observed emission spectra in the region of the N_2 second positive system. To model the spectra, a Boltzmann distribution was assumed for the upper state population with the line function of the monochromator presumed to be the dominant broadening mechanism of the spectral lines. Due to the fast relaxation time, the rotational temperature is taken to be closely coupled to the translational gas temperature. For the power dissipation of 25W, the corresponding gas temperature is in the region of >2100 K and is consistent with the low ozone production in this system.

A mixture of fine-grained (<100 µm) feldspar, olivine, sulfides and metal grains (ratios 6:4:1:1) was dropped between the two electrodes and captured below. The results were analyzed using a SEM at the PSSRI at the Open University in secondary electron mode (Fig.3, 4). Chemical analyses were obtained using EDX.

First Results: Already with this very basic set-up, abundant spherical grains were produced. Most of them show distinct areas consisting of feldspar and olivine-rich areas. No larger, pure metal or sulfide areas were so far found.

The images reveal often perfect spherical bodies, indication of completely molten droplets. Also, even more complicated structures like several spheres attached to each other were found, which are possibly analogous to compound chondrules. Also, variations in chemistry (e.g. Fe contents), exsolution lamellae and morphology of various areas in the grains indicate that the material was completely molten.

Summary & Future Work: This first experiment shows that melt droplets can be produced even with a relatively basic set-up. In the next step, we will start using the same experimental procedure for varying mineral mixtures similar to those in chondrules (olivine, pyroxene, feldspar, metal, sulfides, carbon). Also, grain-size effects will be investigated.

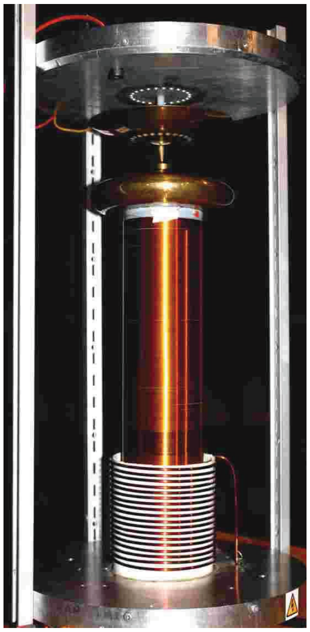

Fig.1: Tesla coil (rotated for 90 degrees in experiment).

Fig.2 : Positioned laterally, material was dropped through the plasma. Arrow = 10 mm.

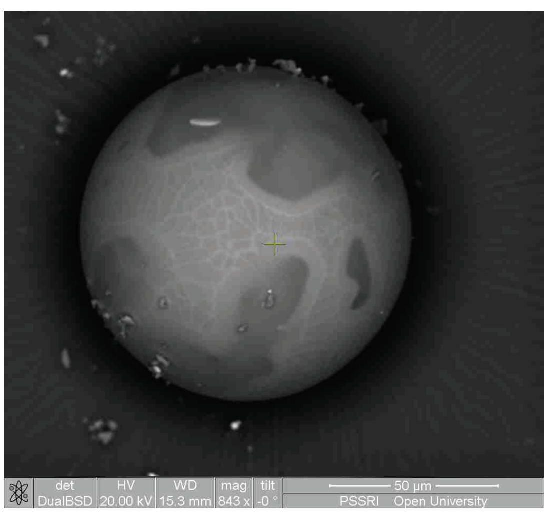

Fig.3: (SEM image) Spherical, grain consisting mainly of feldspar.

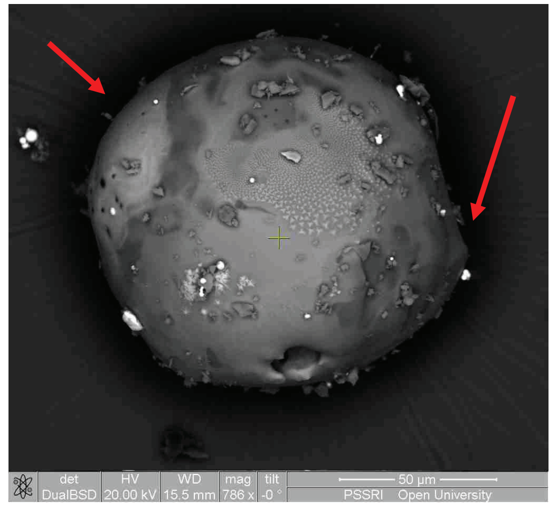

Fig.4: (SEM image) Spherical silicate-rich grain with probably a smaller one attached to it (arrow) – an anaologue to compound chondrules ? Bright areas are olivine-rich, dark areas mainly feldspar.

References:

[1] Brearley A. J. and Jones R. H. (1998) *Reviews in Mineralogy, 36,* Mineralogical Society of America. [2] Russel, S. S. et al. (2005) ASP Conference Series 341. [3] Zanda B. (2004) *ESPL 224,* 1-24. [4] Shu et al. (1997) *Science 277*,1475-1479. [5] Desch and Connolly Jr.. (2002) *Meteoritics & Planetary Science 37*, 183-208. [6] Krot et al. (2005) *Nature 436*, 989-992.