ELECTROSPRAY CHARGING OF MINERALS: A NEW METHOD FOR CREATING AND CHARACTERIZING HIGH- TO HYPER-VELOCITY MICROPARTICLE IMPACTS.

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Introduction: Impact cratering, one of the most important geologic processes in the solar system, played a crucial role while the solar system formed, and it continues to significantly affect planetary bodies today [1]. Because impact cratering is essential to solar system evolution, understanding the impact process and its effects on planetary bodies is a goal discussed in several NASA documents [2-5].

Impact cratering acts at scales ranging from planetesimals to micrometeorites (e.g., [6,7]), so cratering should also be studied at a variety of scales. Furthermore, in order to fully understand impact cratering and its effects, the community must integrate data from multiple sources, such as computer models, remote sensing instruments, and laboratory experiments [2].

This abstract deals with micro-scale cratering, the scale relevant to circumplanetary, interplanetary and interstellar dust [8], the Stardust mission [9,10], and regolith gardening [7]. Micro-scale cratering is well suited for studying impact chemistry, which is more poorly understood than impact physics [12]. The micro-scale is also better suited to lab experiments than impact events of larger sizes.

Existing methods for creating hypervelocity microparticle impacts in the lab are limited to conducting projectiles: metal particles or particles coated with a conductive material (e.g., platinum-coated olivine) [8,11]. An instrument that uses unadulterated mineral microparticles or astrophysical ices as projectiles would open new avenues for experimentation and help answer important, unresolved questions about the chemistry of impact (e.g., [13]).

We are developing a new method for creating high-velocity microparticle impacts in the lab. The instrument uses electrospray to charge mineral or ice microparticles and introduce them into vacuum. The charged particles are then electrically accelerated and impacted onto a plate or target. Chemical species produced by the impact event are analyzed using time-of-flight mass spectrometry.

This instrument has several advantages over existing methods. First, our instrument uses electrospray to charge mineral microparticles, eliminating the need for conducting projectiles. This improvement allows minerals, meteorites, mineral-ice mixtures, and astrophysical ices to be used as projectiles in micro-scale cratering experiments. Second, our instrument directly characterizes the chemical speciation occurring during microparticle impacts, representing a new degree of analytical ability. Thus, our instrument enables detailed investigations into the chemistry associated with geologically relevant impactors, allowing us to address questions related to space weathering, astrobiology, interplanetary dust particles, and Stardust samples.

Electrospray Charging of Quartz: Electrospray is a soft ionization technique that allows particles suspended in a solvent to be introduced into vacuum as charged species; it is often used to charge large biomolecules [15], and it has also been used to charge inorganic compounds [16]. To our knowledge, minerals had never been electrosprayed prior to our experiments. Electrospray is at the core of our instrument because it will allow us to use non-conducting particles as projectiles [17]. Creating and optimizing protocols for electrospraying mineral grains is thus the first step in our instrument development process.

The electrospray process has three steps. First, an acidified solution is pumped through a small needle in a strong DC field, which causes the solution to break into tiny, charged droplets (each with excess protons). Second, the charged droplets move through the strong potential gradient toward an orifice leading into vacuum. As the charged droplets travel, solvent evaporates from the droplets, decreasing droplet size and increasing the droplet's surface charge density. Third, when Coulombic repulsion exceeds surface tension, the unstable droplet bifurcates, and each of the resulting droplets carries some of the original droplet's charge and mass. Evaporation and bifurcation continue until the solute particle is completely desolvated. The result is a protonated solute molecule or particle [16].

Instrument Design: In order to study electrospray charging of minerals, we built an instrument that electrosprays particles and detects them using an image charge detector (Fig. 1). We have made measurements on more than 5,000 electrosprayed particles.

Immediately after building the above instrument, we verified that it worked correctly by reproducing an experiment from [18] that uses 2.19 μm diameter amino-terminated polystyrene spheres in a methanol-water solution. The test was successful.

Next, we conducted experiments to determine if quartz microparticles could be electrosprayed. Solutions of ~2-μm quartz microparticles (Fig. 2) with pH values between 0.95 and 7.60 were made. As a control, identical solutions without quartz (solvent-only solutions) were also made. The pH of the solutions was adjusted using formic acid.

We successfully electrosprayed solutions both with and without quartz microparticles. The amount of

charge on the quartz particles was significantly different from the charge on solvent-only droplets and the 2.19-μm amino-terminated polystyrene spheres used to test the instrument ($P < 0.01$). The amount of charge on quartz particles varies with the pH of the solution.

Particle Desolvation The data from these experiments indicated that the quartz particles still contained solvent by the time they reached the image charge detector. The next phase of our research therefore focused on particle desolvation. Again, we conducted experiments using solutions of ~2-μm quartz particles and a solvent-only control solution.

In order to facilitate particle desolvation, we added a heated aluminum beam tube to the instrument. Particles pass through the heated beam tube after entering vacuum but before entering the charge detector. Our experiments show that the charge on quartz particles decreases with increasing beam tube temperature (Fig. 3). In addition, the charge on solvent-only droplets decreases with increasing beam tube temperature before falling below the charge detector's detection limit (1.1 μVs) at 609°C. This behavior indicates that the beam tube becomes hot enough to completely desolvate the quartz particles. In addition, the desolvated quartz particles remain charged, a crucial observation that enables our proposed instrument for creating high- to hyper-velocity microparticle impacts.

Conclusion and Implications: We have demonstrated that electrospray can produce charged quartz particles and charged conglomerates containing quartz and water-methanol ice to use as impactors in high-velocity experiments. Based on this success, we are trying olivine microparticles, and we have requested a type 3 ordinary chondrite to use in experiments.

Once complete, our instrument will facilitate experiments that cannot be done using existing methods: experiments that use mineral, mineral-ice, or icy projectiles and directly characterize the chemical speciation occurring during the micro-scale impact events. These capabilities will allow us to explore questions related to regolith gardening, space weathering, interplanetary and interstellar dust particles, and projectile residues in impact craters. In addition, our instrument will enable experiments that may lead to a better understanding of the samples collected by Stardust [19,20] and the data from the cosmic dust analyzers on Galileo and Cassini [8].

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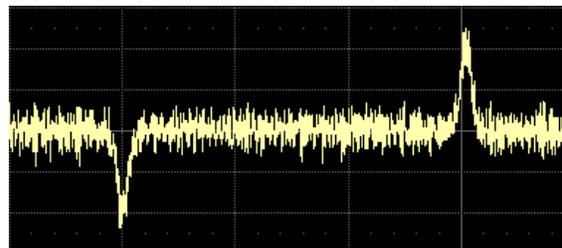

Figure 1. Typical charge detector signal for an electrosprayed quartz microparticle. The y-axis scale is 50 mV/division and the x-axis scale is 200 μs/division.
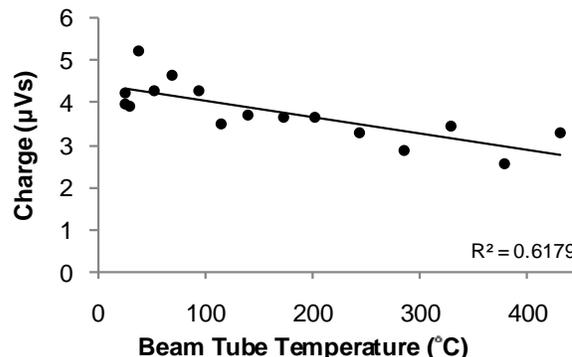

Figure 2. Relationship between the charge on quartz microparticles and beam tube temperature.