

ELECTROSPRAY CHARGING OF QUARTZ MICROPARTICLES FOR STUDIES OF HIGH-VELOCITY MICROMETEORITE IMPACT CHEMISTRY. T. Daly^{1,2}, S. Call², and D. E. Austin²,
¹Department of Geological Sciences, Brigham Young University, Provo, UT 84602, ²Department of Chemistry and Biochemistry, Brigham Young University, Provo, UT 84602.

Introduction: A variety of techniques have been used to study impact cratering, including computer modeling, such as hydrocode simulations [1], mixing calculations [2], and thermodynamic studies [3]; experimental work involving light gas guns [4], railguns [5], electrostatic accelerators [6], and laser irradiation [7]; terrestrial field work [8]; geochemical analyses of field samples [9]; and remote sensing [10].

These methods have been most widely used to study the physical processes that occur during cratering. The chemical aspects of cratering are not as well understood, and existing methods are limited in their ability to study impact chemistry. The development of new methods for studying cratering will help answer unresolved questions about the chemical aspects of the impact process (e. g., [11]).

Methods: We are developing an instrument that introduces innovative capabilities to the laboratory study of hypervelocity microparticle impacts, including capabilities for directly characterizing the chemical speciation that occurs during these events.

Existing methods of microparticle acceleration are largely limited to conductive particles [12]. Our method uses electrospray to charge the projectiles, which permits non-conducting particles, such as minerals and ices, to be used. This increased diversity of projectiles allows a much wider range of impact chemistry-related issues to be studied, including those relevant to space weathering, astrobiology, interplanetary dust particles, and samples returned by missions like Stardust.

Electrospray. Creating and optimizing protocols for electrospraying mineral grains is the first step in our instrument development process. Although electrospray is usually applied to biomolecules, it has also been used with inorganic compounds [13]. Electrospray has not yet been applied to minerals, but no theoretical barriers prevent them from being sprayed.

Electrospray is a soft ionization method that allows particles in solution to be introduced into vacuum as charged species [14]. In the context of our work, the chief advantage of electrospray is that it charges a particle without requiring that the particle be conductive [15]. This overcomes a significant limitation of existing methods for studying microparticle impact processes in the laboratory. In addition, very small particles (<100 nm) can probably be charged using electrospray. Other dust accelerators are limited to particles larger than this size because of agglomeration problems in the source region.

Sample Preparation. Because of its ubiquitous nature and geologic importance, we elected to begin our work using quartz. Commercially available SiO₂ nanoparticles are amorphous, and since the charging behavior of SiO₂ is phase dependent [16], it was necessary to develop our own quartz powders that are fine enough for electrospray. As very few other minerals of interest are commercially available as nanoparticles, this method development will be important as we expand the number of mineral species used in our work.

A micronizing mill is used to grind the quartz powders to ~1-2 μm diameter. Our first attempts have produced usable particles, but the method would benefit from improvement, specifically with regards to increasing the sorting, roundness, and sphericity of the particles. S.E.M. has been and will continue to be an important tool as we refine our preparation protocols.

Once quartz particles have been produced, a suspension is made and the particles are electrosprayed into a vacuum system. Parameters being investigated and optimized include solvent type, charge carrier, solute concentration, voltage, flow rate, needle size, and desolvation.

Particle Detection. Particles are detected using an image charge detector, which quantifies the velocity and charge of the particles [17]. Data from the charge detector are used to evaluate the quality of the electrospray and guide improvements in methodology.

Quartz Surface Chemistry. The quartz surface consists of two different surface groups, isolated silanol groups and silanol groups that are coupled with hydrogen bonds [18].

Implications for Electrospray Charging of Quartz. Electrospray is usually done in an acidic solution, and in such a solution protons are the charge carrier. During the electrospray process, residual charges (in acidic solution these are protons) accumulate on the particle during droplet fission.

Quartz, however, has a negative surface charge, even in the presence of protons. When all silanol groups are in their protonated state (as would be the case at extremely low pH), the surface is neutral. When some silanol groups are deprotonated, the surface is negative. As a result, quartz does not have a point of zero charge. Instead, surface charge, σ_0 , decreases asymptotically with decreasing pH. Whether or not the quartz surface can accept protons in excess of the silanol groups in solution is a matter of debate [19].

Consequently, quartz may be amenable to negative-mode electrospray [13], producing negatively-charged particles. Negative-mode electrospray uses a basic

solution instead of an acidic one, and a negative spraying potential.

In later experiments, we are also planning to use gibbsite, which has a well-defined point of zero charge point, a positive σ_0 in acidic solution [19], and should be charged through positive-mode electrospray.

Initial Results. 2.19 μm diameter polystyrene spheres have been used to test the image charge detector and the associated programs written by S. Call. The charge detector was successful at detecting the electrosprayed polystyrene spheres, and an example signal is shown in Figure 1.

Current and Future Work: Current work revolves around using the image charge detector to determine whether quartz particles are being introduced as charged species into vacuum and to study the efficacy of desolvation mechanisms. A separate instrument, described in [16] is being upgraded, which will provide the capability to accelerate electrosprayed quartz particles to high velocities, impact the particles onto a surface, and measure the chemical species produced during impact with time-of-flight mass spectrometry. Electrospray charged particles could be accelerated by either electrostatic or electrodynamic methods.

Significance: This method introduces several advantages over existing experimental techniques used to studying micrometeorite impacts. Our method overcomes major limitations with previous dust accelerators, including the requirement of a conducting particle surface. Our method is relatively inexpensive and multiple impacts can be performed in rapid succession. In addition to using mineral grains as projectiles, we will also be able to do experiments with organic-rich ices of variable composition. Direct analysis of the vapor plume produced by micrometeorite-scale impact events represents a new degree of analytical ability.

Studying the chemical speciation occurring during micrometeorite impacts is important for furthering our understanding of how sample capture in aerogel affects particle composition [20, 21]. It has implications for interpreting the projectile residues in microcraters, such as those on the Hubble Space Telescope and Long

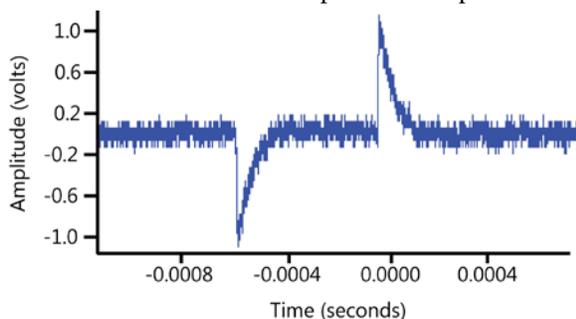


Figure 1. Example of a charge detector signal from a positively charged electrosprayed particle. Particle charge and velocity can be determined from this data.

Duration Exposure Facility. Gaining a deeper understanding of the chemical processes occurring during micrometeorite impacts is essential to deepening our understanding of space weathering and regolith evolution and may contribute new insights to the ongoing dialogue about the origins of life.

References:

- [1] Pierazzo, E. et al (1997) *Icarus*, 127, 408-423.
- [2] Pratesi, G. et al (2005) *Meteoritics and Planet Sci.*, 40, 1653-1672. [3] Sheffer, A. A. and Melosh, H. J. (2005) 2005 Workshop on Oxygen in Asteroids and Meteorites, Abstract #7021. [4] Ernst, C. M. and Schultz, P. H. (2008) LPS XXXIX Abstract #2291. [5] Miura, Y. et al (2000) *Adv. Space Res.*, 25, 285-288. [6] Manning, H. L. K. and Gregoire, J. M. (2006) *Int. J. Impact Eng.*, 33, 402-409. [7] Sasaki, S. et al (2002) *Adv. Space Res.*, 29, 783-788. [8] Hough, R. M. et al (1995) *Nature*, 378, 41-44. [9] Koeberl, C., (2003) 2003 Workshop on Impact Cratering, Abstract #8034. [10] Hartmann, W. K. and Neukum, G. (2001) *Space Sci. Rev.*, 96, 165-194. [11] Kawaragi, K. et al (2009) *Earth Planet. Sci. Lett.*, 282, 56-64. [12] Srama, R. et al (2009) DPS 41 Presentation #37.14 [13] Cole, R. B., ed. (1997) *Electrospray ionization mass spectrometry: Fundamentals, instrumentation, and applications*. [14] Fenn, J. B. et al (1989) *Science*, 246, 64-71. [15] Furerstenau, S. D. (2003) *J. Mass Spec. Soc. Japan*, 51, 50-53. [16] Zhukov, A. N. et al (2000) *Colloid J.*, 62, 309-312. [17] Call, S. (2009) M.S. thesis, Brigham Young University, 73 p. [18] Dong, Y. et al (1998) *Anal. Chem.*, 70, 4730-4735. [19] Kosmulski, M. (2001) *Chemical Properties of Material Surfaces*. [20] Stodolna, D. J. and Leroux, H. (2009) LPS XXXX, Abstract #1754. [21] Sandford, S. A. et al (2006) *Science*, 314, 1720-1724.