

**ELECTROPHORESIS OF ALLENDE NANODIAMONDS IN COLLOIDAL SOLUTION.** E. A. Shatoff<sup>1,2</sup>, A. P. Meshik<sup>2</sup> and O. V. Pravdivtseva<sup>2</sup>, <sup>1</sup>Physics Department, Brandeis University, MB 3096, 415 South Street, Waltham, MA 02453 (elanshatoff@gmail.com), <sup>2</sup>Laboratory for Space Sciences and Physics Department, Washington University, CB1105, One Brookings Drive, Saint Louis, MO 63130 (am@physics.wustl.edu).

**Introduction:** Electrophoresis of man-made explosion-produced nanodiamonds has been extensively explored for the manufacturing of nanodiamond coatings [1], and could be potentially useful for understanding the properties and origin of enigmatic meteoritic nanodiamonds. Previous experiments on Allende nanodiamonds demonstrated that it is possible to manipulate them using electrophoresis. Nanodiamonds are mostly negatively charged and will move towards the positive electrode [2]. The movement of the nanodiamonds could be affected by several factors: gravity, Brownian motion, as well as differences in charge due to surface defects and possible amorphous carbon coatings. The size of the nanodiamonds also may affect Stokes drag in colloidal solution and therefore electrophoresis may provide a means to separate the nanodiamonds by size. Here we present results of electrophoresis of Allende nanodiamonds in a refined experimental setting.

**Electrophoretic Procedure:** The electrophoresis was carried out inside an 18-centimeter length of Teflon tubing 2.46 mm in ID. The tube was filled with pure isopropanol and the nanodiamonds were introduced at the negative electrode. 12 $\mu$ L of an in house made Allende diamond solution was used in the experiment. Both ends of the tube were plugged and sealed with glue to reduce the evaporation of the isopropanol. The pure isopropanol used in the experiment evaporated very quickly, and any bubbles present in the tube would affect the motion of nanoparticles. Because of this, it was important to keep the conductance low so that the isopropanol didn't heat up and evaporate. At both ends of the tube gold plugs were used as electrodes to reduce the number of ions in the solution and keep the conductivity of the solution low. A constant voltage of 5 kV was applied across the tube for one hour. Current in the tube started high, around 2  $\mu$ A, but quickly decreased over the course of the experiment, to about .05  $\mu$ A. During the experiment the tube was held vertically. To investigate the influence of gravity and sedimentation two runs of the experiment were carried out, one with the negative electrode and nanodiamonds at the top and one with the negative electrode and nanodiamonds at the bottom. Previous iterations of this experiment used an open-air Teflon electrophoretic cell [2] but the conductivity of the electrophoretic medium was compromised, leading to the quick evaporation of

the isopropanol solution. We believe that because the medium, a mixture of pure water and isopropanol, was extremely ion hungry, exposure to air led to CO<sub>2</sub> being pulled out of the air to form a carbonic acid in the medium [3]. It is possible that even limited exposure to air of the electrophoretic medium could impact the results. After an hour the electrophoresis was stopped, and a series of clamps each 1.5 centimeters apart was applied to the tubing, dividing it into twelve sections. An aliquot of the liquid was taken from each section by pipette and allowed to evaporate in small platinum boats for pyrolysis in a high temperature vacuum oven. The platinum boats were weighed by a Cahn C-31 balance before and after the introduction of the nanodiamonds. As expected, most of the boats gained some weight (from 1 to 40  $\mu$ g), however, as we found later, these weight gains were not proportional to the amount of Xe-HL measured. Therefore Xe-HL concentrations in the colloidal residue turned out to be the only way to trace the nanodiamond distribution along the tube.

**Mass Spectrometry:** Sealed Pt-boats containing diamond residues were loaded into the sample system and held at 120°C for several days to remove surface contaminations. Noble gasses were released using one 1850°C single-step pyrolysis, purified from chemically active components by sequential exposure of released gases to three SEAS getters. Heavy noble gasses were separated from He, Ne, and Ar using activated charcoal at -95°C and analyzed in the mass-spectrometer Super-nome-E with sensitivity of 7E-16 cm<sup>3</sup> STP/Hz. Xenon in all our samples contained mostly Xe-HL with minor contribution from Xe-P3 and atmospheric Xe. The isotopic compositions of these components are from [4].

**Results:** In both experiments the high voltage was applied for an hour, with the only difference between the two being the direction in which the nanodiamonds were pushed, up or down. Our initial calculations suggested that the force of gravity acting on the particles would be negligible, but the results of our experiments suggest otherwise.

*Negative Electrode at the Top.* In this orientation the nanodiamonds were being pushed from the top of the tube to the bottom of the tube. The amount of Xe-HL found at different sections of the tube is summarized in Figure 1.

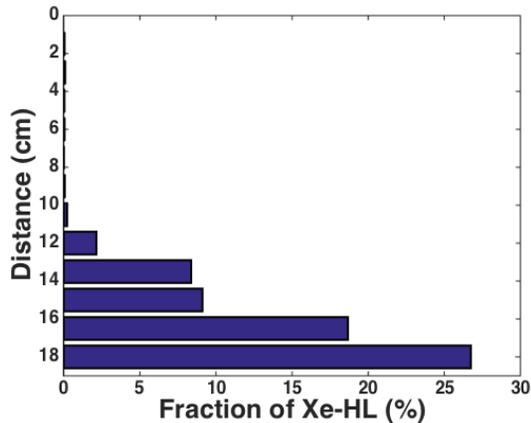


Fig. 1. Distribution of Xe-HL along the tube when the negative electrode was at the top, so the nanodiamonds moved down, the same direction as sedimentation.

Little Xe-HL was found in the upper part of the tube. The amount of Xe-HL steadily increases towards the bottom of the tube. Most of the nanodiamonds are seemingly pushed to the bottom of the tubing. The total amount of Xe-HL is consistent with the amount introduced to the tube.

*Positive Electrode at the Top.* In this orientation the nanodiamonds were being pushed from the bottom of the tube to the top. The amount of Xe-HL found in different sections of the tube is summarized in Figure 2.

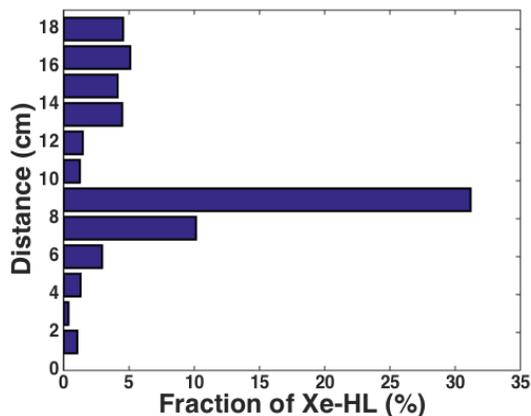


Fig. 2. Distribution of Xe-HL along the tube when the positive electrode was at the top, so the nanodiamonds moved up, against gravity.

In contrast to the first experiment, here Xe-HL is found in each section of the tube. There is an evident peak in the middle of the tube (Fig. 2). The cumulative amount of Xe-HL found in the tube is  $\sim 2/3$  of the nanodiamonds introduced at the beginning of the experiment. It is likely that the missing  $1/3$  of the nanodi-

amonds precipitated out of the solution and deposited onto one of the gold plugs.

**Discussion:** The disparity between the weight of the diamond residue and measured Xe-HL could be caused by a number of factors, including changes in weight due to the samples' environment (the samples are highly hygroscopic) or contaminants in the solution. The peak in the second experiment could also be caused by a number of factors, the most probable being a size separation because of the differing Stokes drag forces associated with moving through a fluid. We plan to perform more experiments at a lower voltage and/or a shorter duration to study the peak position in the second experiment and the full distribution of particles in the first experiment.

**Conclusions:** Clearly electrophoretic forces affect the meteoritic nanodiamonds, however, they are somewhat more mobile than we anticipated. Contrary to our expectations, sedimentation apparently affects the motion of the nanoparticles. In experiment two there is a prominent peak  $\sim 8$  cm from the nanodiamonds' starting position, indicating that there are two subpopulations of nanodiamonds with different susceptibilities to gravity. This peak tells us that one population is affected by sedimentation while another is not. What differentiates these populations and causes the peak is matter for further study, but it is clear electrophoresis could be a potentially valuable tool for tracking and understanding meteoritic nanodiamonds.

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**References:** [1] Affoune A. M., Prasad B. L. V., Sato H., Enoki T. (2001) *Langmuir* **17**, 547–551. [2] Meshik A. P., Pravdivtseva O. V., Hohenberg C. M. (2002) *LPSCXXXIII*, abstract #2011. [3] Light T. S., Kingman E. A., Bevilacqua A. C. (1995) ACS National Meeting. [4] Huss G. R., Meshik A. P., Smith J. B., Hohenberg C. M. (2003) *GCA*, Vol. 67, No. 24, 4823–4848.