Electron Interactions with Helium Nanodroplets

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Pickup of atoms and molecules into superfluid He nanodroplets (HNDs) is a powerful technique to form clusters and nanoparticles at low (0.37 K) temperatures. The resulting dopant complexes are often analyzed utilizing mass spectrometry after electron ionization [1, 2]. The most abundant ions observed in the mass spectra are free of He. This is a surprising result, given the fact that cations are strongly heliophilic and droplets containing about 2 million He atoms require more than 1 keV of energy to be vaporized.

The typical log-normal size distribution of the neutral HNDs and the Poissonian pickup statistics lead to a substantial size spread of the dopant clusters. Here we report on a novel approach that reduces the size distribution of the HNDs, simply by intense ionization of the HNDs prior to the pickup. Helium droplets containing between 10^5 and 10^{10} He atoms [3] were formed and subjected to electron beams of defined energy and current [2]. Mass per charge distributions were determined by electrostatic energy analyzers for positively and negatively charged droplets [4]. Utilizing two ion sources, each followed by a spherical sector field analyzer, it was possible to unambiguously determine the charge state as well as the mass of charged He droplets. Charge states higher than 65+ as well as 5- could be assigned and neutralization as well as increasing of the charge state could be achieved by the second ion source. Perfect fractional numbers of the mass per charge ratios of product ions with respect to the charged precursor droplets indicate that fragmentation exclusively happens via very asymmetric Coulomb explosion and additional evaporation of a few He atoms. These low-mass ions have been investigated by mass spectrometer systems so far [2]. Coulomb repulsion between charges of same polarity in highly-charged He droplets will lead to minimum energy configurations in the form of Coulomb crystals. Dopants are polarized and attracted by the charge centers, which thereby act as seeds for homogeneous cluster growth. Dopant cluster ions can be liberated from the large highly-charged droplets via multiple collisions with gaseous helium in a RF-ion guide. Depending on the He pressure, dopant cluster ions can be formed with any number of He atoms attached. Tagging of ions with He atoms is currently a hot topic in ion spectroscopy. This is typically achieved in cryogenic ion traps [5-7], however, with much lower efficiency than pickup of dopants into highly-charged HNDs.

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