Xenon Clusters in Intense VUV Laser Fields

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Only recently, in an experiment using the new free-electron laser at DESY (Hamburg, Germany), intense VUV--cluster interactions were observed [1]. Xenon clusters were found to absorb a very large number of VUV photons, many more than had been anticipated---based on the experience with long-wavelength lasers. Each xenon atom in a cluster consisting of thousands of atoms absorbed about 30 12.7-eV photons from an FEL radiation pulse of about 100 fs duration and 7×10^{13} W/cm^2 peak intensity. Xenon ions up to a charge state of 8+ were detected. Isolated xenon atoms, on the other hand, became primarily singly ionized by the VUV-FEL radiation.

A theoretical description of the experiment is presented [2], which accounts for the main observations. The key aspects analyzed in this theory include, first, the formation of a nanoplasma: Within a few fs, each xenon atom in the cluster becomes singly ionized by one-photon absorption. While a few electrons can escape from the surface of the cluster, the majority remains inside the cluster volume. Second, in the high-density cluster environment, multiple collisions among electrons can occur, as well as scattering of electrons from ions. The former are essential for maintaining a well-defined electron temperature throughout the VUV-FEL pulse. The latter supplies a mechanism for extracting energy from the radiation field, in a process known as inverse bremsstrahlung. Inclusion of electron--ion interactions beyond the level of standard hydrogenic models proves to be crucial for understanding the experiment. Our treatment of inverse bremsstrahlung is based on perturbation theory combined with a Herman-Skillman-type ionic potential. The screening of the ionic potential by the plasma electrons is incorporated at the level of the Debye model. Coupled rate equations for the production of ions via VUV-photon absorption in the plasma and for the heating of the plasma through inverse bremsstrahlung are integrated numerically. In the final step, the total energy absorbed during the laser pulse is redistributed as the entire cluster plasma undergoes thermalization.

Nonlinear optical effects appear to play a minor role in the Hamburg cluster experiment.

References:

[1] H. Wabnitz *et al.*, Nature **420**, 482 (2002).

[2] R. Santra and C. H. Greene, Phys. Rev. Lett. **91**, 233401 (2003).

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