Ionization of Clusters in Strong X-ray Laser Pulses

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The advent of femtosecond laser pulses has triggered numerous activities in the field of laser-matter interaction due to the available high intense fields from these ultrashort pulses. So far being restricted to visible or infrared wavelengths, the new X-ray free electron laser (XFEL) sources, under construction at DESY in Hamburg and at the LCLS in Stanford, will deliver intense laser pulses at high frequencies (from VUV to hard X-ray) and thus open a new regime of strong-field atomic physics.

Here we present theoretical investigations of intense XFEL impact on argon clusters by means of a mixed quantum/classical approach. In this laser regime the interaction is notably different from long-wavelength pulses which is evident from the small ponderomotive energy ($E_{\text{pond}} \approx 1 \text{eV}$). Despite the high intensities the laser-atom interaction is of non-relativistic and perturbative nature. Ponderomotive effects are completely negligible with small quiver amplitudes ($\Delta x \ll 1 \text{Å}$). Ionization starts from the inside because of large photoionization cross sections for the inner shells. Multiple single-photon ionization is possible, in particular because the inner-shell holes created by photoionization are refilled by fast Auger-like processes. Due to this almost instantaneous refilling the inner shells can be ionized many times during the pulse and thus the atoms can be efficiently “pumped dry”. Finally, the generated local ionic charges in the cluster may be screened by the weakly bound valence electrons of neighbour atoms.

In comparison to a single atom we find that ionization of the cluster is suppressed (cf. the Figure), which is in striking contrast to the observed behavior of rare-gas clusters in intense optical laser pulses. We have identified two effects responsible for this phenomenon: Firstly, the high positive space charge of the cluster hinders electron emission since the space charge is not compensated by a large quiver motion. Secondly, delocalization of electrons (due to the screening) reduces photoionization as well as autoionization drastically. Their relative impact is shown in the Figure.

This may have important consequences for XFEL imaging applications since it implies a higher damage threshold.

Reference: