EXTREME MULTIELECTRON IONIZATION OF CLUSTERS IN ULTRAINTENSE LASER FIELDS

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Ultraintense table top lasers are characterized by a maximal intensity of I ~ 10^{20} Wcm^{-2}, which constitutes the highest light intensity on earth. Novel features of light – matter interactions emerge from the interaction of clusters with ultrashort (pulse temporal width τ = 10–100 fs) and ultraintense (I = 10^{15}–10^{20} Wcm^{-2}) laser fields. The modern research area of ultrafast cluster dynamics is transcended by moving towards ultrafast dynamics in ultraintense fields. The response of clusters to ultraintense laser fields induces well characterized ultrafast dynamics of electrons (on time scales of ~ 1–50 fs) and of ions (on time scales of 5–100 fs) in these large finite systems.

Extreme cluster multielectron ionization (involving the stripping of all electrons from light – first row atoms and the formation of heavily charged ions, e.g., Xe^{36+} at I = 10^{19} Wcm^{-2}) is distinct from that of single atomic or molecular species in terms of mechanisms, the ionization level and time scales for electron and nuclear motion. On the basis of our recent analyses and simulations, the electron dynamics of elementary and molecular clusters (e.g., $(Xe)_n$, $(D_2)_n$, $(CD_4)_n$, $(AI)_n$, $(CA_3I)_n$, with A = H, D or T) in ultraintense laser fields involves three sequential processes of inner ionization, nanoplasma formation and outer ionization. Inner ionization is dominated by a compound barrier suppression mechanism, together with ignition and screening effects. This results in the formation of a charged, energetic nanoplasma (electron energies 50eV–2keV) within the cluster (or its vicinity) and in subsequent (partial or complete) outer ionization of the nanoplasma driven by resonance effects. New features of electron dynamics and energetics are unveiled, with the dependence of these three-coupled electronic processes on the laser intensity, on the pulse shape and frequency, on the cluster size and on the electronic level structure of the constituents.

The electron dynamics processes trigger nuclear dynamics, which involves cluster Coulomb explosion with the production of highly energetic (keV – MeV) multicharged ions on the fs time scale. Under extreme conditions of cluster vertical ionization the distinction between cluster fission and Coulomb explosion was established, with Coulomb explosion being induced by extreme ionization. Cluster size scaling laws for the energetics of uniform Coulomb explosion of homonuclear clusters and of heteroclusters were established, with their cluster size and laser intensity domains. New facets of Coulomb explosion dynamics of some heteroclusters, which are analogous to multicharged transient soft matter, were unveiled.

An interesting novel development involves dd nuclear fusion driven by Coulomb explosion (NFDCE) in an assembly of deuterium containing homonuclear $(D_2)_n$ clusters and heteronuclear clusters, e.g., $(D_2O)_n$, $(CD_4)_n$ or $(DI)_n$, for which compelling experimental evidence was obtained by T. Ditmire et al. [Phys. Rev. Letters 84, 2634 (2000)] and theoretical evidence was obtained by Last and Jortner. The dramatic enhancement of D^+ ion energies and dd nuclear fusion yields driven by molecular heteroclusters of deuterium bound to heavy atoms will be emphasized. This remarkable development accomplishes an 80 years quest for the attainment of cold–hot nuclear fusion in the chemical physics laboratory.

References

1. I. Last, Y. Levy and J. Jortner, Proceed. Natl. Acad. Sci. USA 99, 9107 (2002).
2. I. Last and J. Jortner, Phys. Rev. A 62, 013201 (2000); Phys. Rev. Lett. 87, 033401 (2001); Phys. Rev. 64, 063201 (2001); ChemPhysChem 3, 845 (2002); J. Phys. Chem. A 106, 10877 (2002); J. Chem. Phys. 120, 1336 (2004); J. Chem. Phys. 120, 1348 (2004); "Electron and Nuclear Dynamics of Molecular Clusters in Ultraintense Laser Fields. III. Coulomb Explosion of Deuterium Clusters", J. Chem. Phys. (in press, 2004); "Electron and Nuclear Dynamics of Molecular Clusters in Ultraintense Laser Fields. IV. Coulomb Explosion of Heteronuclear Clusters", J. Chem. Phys. (in press, 2004).