Ultrafast cluster dynamics in ultraintense laser fields

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Ultraintense table top lasers are characterized by a maximal peak intensity of $I_M \sim 10^{21}$ W cm^{-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 ($I_M = 10^{15}$-10^{21} W cm^{-2}) laser fields. The modern research area of ultrafast dynamics is transcended by moving from femtosecond dynamics on the time scale of nuclear motion towards ultrafast attosecond electron dynamics in ultraintense fields. The response of clusters to ultraintense laser fields induces well characterized ultrafast dynamics of electrons (on time scales of $\sim$ 100 as-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} W cm^{-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, dominated by a compound barrier suppression mechanism This results in the formation of a charged, energetic nanoplasma (electron energies 50 eV-2 keV) within the cluster (or its vicinity) whose response induces (partial or complete) outer ionization.

The electron dynamics processes trigger nuclear dynamics, which involves cluster Coulomb explosion (CE) with the production of highly energetic (keV-MeV) multicharged ions on the fs time scale. Uniform CE of homonuclear multicharged clusters is replaced by nonuniform explosion of heteroclusters. Under extreme conditions of cluster vertical ionization the distinction between cluster fission and CE was established, with CE being induced by extreme ionization. Divergent cluster size scaling laws were established for the energetics and ion kinetic energy distribution in the uniform CE of homonuclear clusters and for 'expanding bubbles' of light ions in the CE of heteroclusters, together with their cluster size and laser intensity domains. New facets of CE dynamics of some heteroclusters, which involve transient self-organization in multicharged transient soft matter, were unveiled.

A significant novel development involves dd nuclear fusion driven by CE (NFDCE) in an assembly of deuterium containing heteronuclear clusters, e.g., $(D_2O)_n$, $(CD_4)_n$ or $(DI)_n$, for which compelling theoretical-computational evidence was obtained by

Last and Jortner, which was experimentally confirmed at Saclay in France, at the Lawrence-Livermore Laboratory in California, and at the Max-Born Institute in Berlin We shall emphasize the dramatic enhancement of D^+ ion energies and dd nuclear fusion yields triggered by energetic boosting of D^+ nucleons driven by CE of heteroclusters of deuterium bound to heavy atoms. This remarkable development accomplishes an 80 years quest for the attainment of table-top nuclear fusion in the chemical physics laboratory. Recent developments pertain to table-top nucleosynthesis in assemblies of nanodroplets, which are of astrophysical interest.

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