Molecular Ionization in Ultrastrong Fields:
The ‘Nearest Neighbor’ Gateway to Highly Charged Ion Formation

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Molecular ionization in strong, quasistatic fields is a challenging topic characterized by an abundance of work for the first charge state of the parent ion. It is described in analogy with atomic tunneling ionization, where the asymptotic portion of the electron wave function tunnel ionizes through the effective barrier formed by the Coulomb potential and the external laser electric field (Fig. 1 MT). Due to the complexity of the multibody, molecular system, many pathways [1] are involved in the ionization of subsequent electrons. When the external laser field duration is short compared to the dissociation time, enhanced ionization [2] plays a critical role as an ionization mechanism. The molecular fragment is ionized by an ‘enhanced’ laser field, which is the sum of the external laser field and an assisting intramolecular Coulomb field from nearest neighbor ions in the molecule (Fig. 1 EI).

In ultrastrong fields, the final stages of molecular ionization approach an isolated ion response [3]. This occurs as the length scale between nearest neighbor ions in the molecular fragment exceeds the length scale of the tightly bound ion states (Fig. 1 AI). In this regime, the Coulomb field of the nearest neighbor ions for the molecular fragment can be neglected. Ionization of the first electron has been extensively studied. Enhanced ionization is also a well-known mechanism [4], however, the investigations are often limited to diatomic molecules such as molecular iodine. Additional studies of molecular systems in strong and ultrastrong fields are needed to generally address how molecular ionization proceeds from enhanced ionization (EI) to an isolated atomic ion (AI) response.

This work has relevance to studies in ultrastrong fields. The availability of multiple atomic species, for example, enables studies as a function of the atomic number Z and the corresponding energies of the electron shells that interact with the external field. In particular, the energy gaps between shells [5] can be used to separate ionization processes and mechanisms in strong and ultrastrong fields. We present the results for the generation of high charge states in chlorine and carbon from chloromethane as the ionization proceeds from an enhanced, nearest neighbor EI response to the AI response of isolated ions. We will conclude with updates on the next generation photoelectron spectrometer for ultrastrong fields and the Z dependent calculations of inner shell excitation at the ultimate limit of rescattering in strong fields [6].