Strong Field Rescattering Physics:
Ultrafast Self-Imaging of a Molecule by its Own Electrons

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Rescattering physics lies at the heart of many interesting strong field phenomena, among them are high-order harmonic generation (HHG), high-energy above-threshold ionization (HATI) electrons and nonsequential double ionization (NSDI). Based on the recently developed Quantitative ReScattering (QRS) theory, we have shown that the yield of each process can be expressed as the product of a returning electron wave packet with the corresponding *field-free* electron-ion scattering cross section. The momentum distribution of the returning electron wave packet depends on the laser only and can be extracted from the strong field approximation. In this talk recent progress in applying the QRS to these rescattering phenomena will be reported.

According to QRS, field-free elastic scattering differential cross sections (DCS) can be extracted from HATI photoelectron momentum distributions. Using mid-infrared lasers we have shown recently that the returning electrons can have energies larger than 100 eV. When these electrons are backscattered the resulting DCS can be used to retrieve interatomic separations in a molecule, exactly analogous to the conventional electron-diffraction method, but with the additional benefit of temporal resolution offered by the laser. Recent experiment on O_2 by 2 μm lasers revealed that the O-O bond length shrinks by 0.1^{o}A within 5 fs – extracted at the time when the electron returns to recollide with the O_2^+ ion.

Using QRS the HHG spectra for each atom or molecule can be easily calculated using accurate photoionization cross sections. Since calculation of HHG using QRS is nearly as easy as using the strong field approximation, we have incorporated QRS into the standard macroscopic propagation of the HHG. By taking into experimental conditions into account we have been able to obtain HHG spectra that can be directly compared to experimental spectra. Recent studies include HHG from atoms at and above saturation intensities, and HHG from aligned molecules. The effect of multiple orbitals in molecular HHG has also been investigated.

The QRS has also been used to study NSDI. Two mechanisms for NSDI have been discussed in the literature, one is the direct (e,2e) electron impact ionization, the other is electron impact excitation of the ion followed by tunnel ionization. The QRS obtained correlated electron momentum spectra which can be compared to experiments. Such comparison reveals that additional mechanism for NSDI is needed – the returning electron is captured by the ion to form doubly excited states where the two excited electrons are subsequently ionized by the laser.

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