Quantum-state-resolved X-ray multiphoton ionization dynamics

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Synopsis I present a joint theoretical and experimental study of near-ambient pressure neon gas interacting with intense X-ray free-electron laser (XFEL) pulses. Many unexpected features are identified with quantum-state-resolved ionization-dynamics calculations in the isolated-atom limit. X-ray-driven formation of hot electron plasma and its non-equilibrium evolution dynamics are investigated in the plasma limit.

Intense XFEL pulses can induce multiple sequences of inner-shell ionization events and accompanying decay processes in atoms, producing highly-charged ions. In general, X-ray multiphoton ionization dynamics have been so far described in terms of time-dependent populations of the electronic configurations visited during the ionization dynamics, neglecting individual state-to-state transition rates and energies. We extend our XATOM toolkit [1] to study state-resolved dynamics based on time-dependent quantum-state populations, by combining a state-resolved electronic-structure method based on first-order many-body perturbation theory [2] with a Monte Carlo rate-equation method [3]. This allows us to explore spectroscopic detail in XFEL experiments that have been limited with electronic configuration or super-configuration approaches.

Here we present a recent study of state-resolved X-ray multiphoton ionization dynamics of neon gas interacting with intense X-ray pulses generated by European XFEL [4, 5]. Figure 1 shows calculated X-ray emission spectra of Ne ions as a function of incident XFEL photon energy at a photon fluence of 5×10^{11} ph/μm^2. At such extremely high fluence, one can see X-ray emission from all Ne charge states both in theory and experiment. In the low-charge regime, an unexpected resonance-like peak structure emerges at a position which does not coincide with any physical resonances of Ne ions [4]. For highly charged ions, a plethora of unexpected resonance structures involving exotic multiply excited states are identified [5]. We will also discuss how insights from atomic physics are applied to understand non-equilibrium plasma formation dynamics. In our experiment, Ne gas at near-ambient pressures exposed to intense X-rays produces a hot electron plasma. Combined with plasma simulations, time-resolved X-ray emission measurement enables us to monitor how electrons cool down, eventually reaching electron-ion thermalization [5]. Our study of quantum-state-resolved X-ray multiphoton ionization dynamics opens up new opportunities for high-resolution X-ray spectroscopy of atoms and plasmas at high intensity.

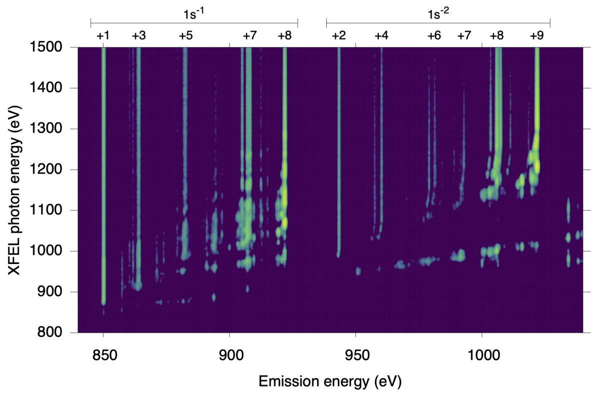

Figure 1. Theoretical 2D map of X-ray emission from Ne ions

References

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