Controlling the Electro-Optical Response of Atoms by Intense Lasers: Time-Resolved Emergence of the Rydberg Series and the Laser-Driven Continuum Threshold

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When light in the form of a few single photons interacts with matter, it can cause excitation (bound-bound) or ionization (bound-free transitions of electrons). For a long time, these processes, "the absorption of a photon", were considered to be instantaneous. Recent experiments observing photoemitted electrons extract attosecond time delays by relying on the relatively well-understood superposition of single extreme-ultraviolet (XUV) photons with intense optical laser fields.

Here, we will approach this problem from a different perspective, not by observing the *emitted electrons*, but the *missing photons* (i.e. Fraunhofer-type absorption of light after passage through a medium). Also, here, we experimentally overlap an intense laser field with the few-photon attosecond pulses but measure the changes in the transmitted (absorption) spectrum.

After understanding the laser-perturbed electro-optical response of atoms for the example of single states, we found that we can generalize the concept to a large number of exciting science questions. I will discuss two general examples here: The buildup of a Rydberg series and the laser-driven modifications to a continuum threshold.

For the former case, we observe the emergence of a series of resonances as a function of time delay, which can be separated out of an initially broad absorption band after characteristic times. Approaching the continuum threshold, we find specific time-dependent absorption structures that reveal signs of an extremely small ponderomotive dressing of the continuum, even for intensities that are far away from the strong-field or tunneling regime (in which ponderomotive concepts usually become important). In fact, we observe a ponderomotive effect of the continuum response in our experiments perfectly within the multi-photon limit.

The full understanding and mastery of the atomic response by controlled laser fields in multi-electron systems including molecules may also inform and allow for novel designs of ultrafast quantum computers.