Ionization dynamics involving ‘quantum gratings’

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Synopsis When an atom passes through a macroscopic diffraction grating its wave function acquires a regular space structure and its collision by another particle can be thought of as scattering, of the latter, on a grating composed of a single atom (hereafter termed as “quantum-grating”). Photoionization of such a ‘quantum grating’ unveils interference features and in particular a striking difference in the photoelectron and recoil ion spectra which no longer ‘mirroring’ each other as in the case of photoionization of atoms or molecules. We show that complete information about the macroscopic diffraction grating is directly contained in the recoil ion spectra while only partly exhibited in the spectra of the electron.

In collision physics, processes involving a molecular target compared to an atom can unveil different features due to the nature of their corresponding electronic wave functions. For instance, in the ionization processes, the electron is emitted from the multi-sites of the molecule and the coherent contributions of the corresponding indistinguishable pathways lead to interference phenomena. However, research works performed in this field dealt exclusively with ionization of atomic targets including molecules and clusters. Yet, none of these studies have considered the breakup of an atom passed through a diffraction grating induced in collision with charged particles nor by absorption of photons.

Because of the uncontrolled exchanged momentum between the atom and the diffraction grating, the wave function of such an atom will acquire a wave-packet property due to the uncertainty principle. When such an atom is taken to interact with a charged particle, or a photon, the result can be viewed as scattering of the latter on an object which can be thought as a diffraction grating and will be referred to as ‘quantum grating’. Like its macroscopic analogous this quantum grating (QG) possesses a periodic spacial structure, which consists of stronger and weaker interacting parts in space corresponding to respectively larger and smaller values of the atomic probability density but constructed only from a single atom. This can be viewed as ’splitting’ the atom into a set of identical atomic ’copies’ at equidistant separation from each other. Such an atomic QG qualitatively differs from a molecular object where the ’multi-site’ structure of the electron wavefunction is due to the presence of ’real’ nuclei [1].

As an illustration Figure 1 represents fully differential crossecetions of photoelectron (upper pannel) and the corresponding recoil (lower pannel) spectra in momentum space for photoionization of a **He** atom moving initially with momentum $P_i = 800 \pm 80$ $a.u.$ passed through a diffraction grating with $N_0 = 7$ slits.

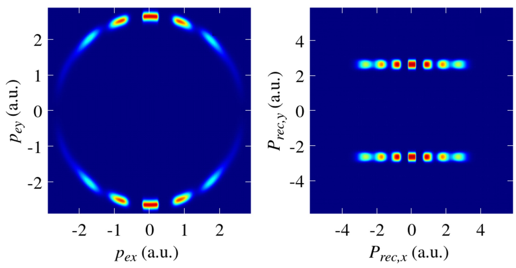

Figure 1. Photoelectron spectra $(d\sigma/d^3\mathbf{p}_e d\mathbf{P}_{rec,x})$ and the recoil spectra $(d\sigma/d^3\mathbf{P}_{rec}dp_{ex})$ of a **He** atom moving initially with momentum $P_i = 800 \pm 80$ $a.u.$ passed through a diffraction grating with $N_0 = 7$ slits, along the x-direction, whose dimensions $a = d/2 = 100$ μm

References

[1] Zhang, S. F.; Najjari, B. and Ma, X. Photoionization of a quantum grating formed by a single atom 2021 *Journal of Physics B: Atomic, Molecular and Optical Physics* **54** 15LT01

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