Photo double ionization of helium at 800 eV photon energy – electron angular distributions for non-dipole transitions

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Synopsis: We investigated the electron angular distribution of the correlated two-electron emission originating from the quasi free mechanism induced by circularly polarized photons at 800 eV energy.

How can a single photon couple to two electrons? The double ionization of Helium is widely believed to precede either via shake-off (SO) or knock-off (TS1). Both processes show characteristics in their energy and angular distribution [1,2]. In the U-shaped electron energy sharing, the SO electron is located at low energies, with the corresponding photo electron at high energies [3]. Since Amusia predicted 40 years ago a third mechanism, experimentalists have looked for this "Quasi Free Mechanism" (QFM) called direct double ionization process [4]. This mechanism takes place at high photon energies and manifests at dipole forbidden back-to-back emission of electrons with equal energies. Correspondingly this shows up as an enhancement of electrons with equal energies (W-shape in the energy sharing) or for He^{2+} ions with momenta at rest (p=0) and was observed for the first time in 2013 [5]. Even though it was taken care during the analysis, also inelastic scattered photons (Compton scattering) could lead to ion momenta close to zero. However the cross section to create a He^{2+} is, at the investigated photon energies, orders of magnitude smaller than the QFM. Furthermore the detailed analysis raised the question how the photon momentum ($p_\gamma \approx 0.2$ a.u.) is shared among the emitted particles.

Therefore we used the COLTRIMS reaction microscope technique [6] to unravel the double ionization dynamics of Helium. We intersected a cold supersonic helium gas jet with circularly polarized photons of 800 eV energy, originating from beamline P04 at PETRA III (DESY, Hamburg). Electrons and ions were projected with a weak electric field towards time- and position sensitive detectors. The ion side of the spectrometer was optimized to achieve maximal resolution (time- and space focussing geometry). To catch the fast electron we superimposed a strong magnetic field of ≈35 Gauss to guide the electrons towards the detector. The outstanding photon flux of P04 lead to enough data, thus we were able to derive for the first time electron angular distributions.

Figure 1 shows the angle between the two emitted electrons; note that other than usual no restriction the polarization is made. The inset on the left corresponds to a very unequal energy sharing (emitted electron <2 eV) and shows a rather isotropic angular distribution as known from the SO. With increasing electron energy (80 eV for the inset on the right), the electron angular distribution shows the well-known double lobe structure, with a nearly 90° angle between the emitted electron. This can be attributed to the TS1. This structure becomes a little narrower with increasing electron energy, until equal energy sharing. Here (main graph) an extra lobe shows up at 180° (back-to-back), which coincides to ions at rest. This is the clear evidence for the QFM and rules out other processes, such as Compton scattering. Furthermore the angular distribution in the laboratory frame (not shown here) show for electrons emitted via the QFM a 4-lobe structure (quadrupole), whereas for unequal energy sharing a dipole shows up.

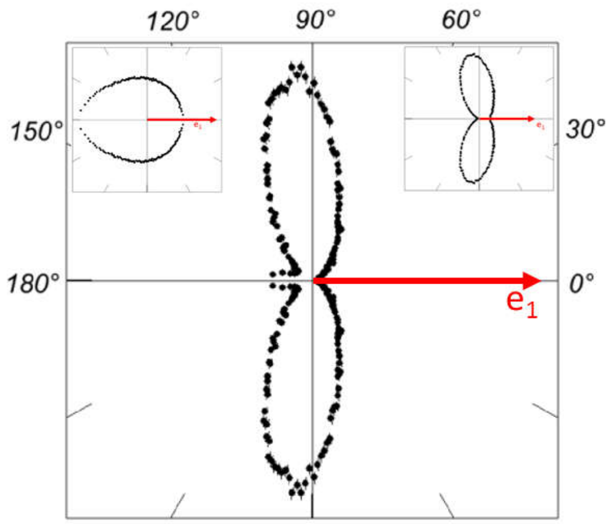

Figure 1. *Angle between the two emitted electrons. The energy of the plotted electron is 360 ± 60 eV; 80 ± 10 eV (inset, right) and <2 eV (inset, left).*

References

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