Experimental and Theoretical Study of Projectile Coherence Effects in Ionization of Helium by Ion Impact

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Synopsis Projectile coherence effects were observed in a kinematically complete experiment on ionization of helium by proton impact. The data and their interpretation are confirmed by a time-dependent ab initio calculation treating the projectile coherence properties in terms of a wave packet.

Puzzling discrepancies between experiment and theory in fully differential cross sections (FDCS) for ionization of helium by 1.2 GeV C^{6+} impact [1] were vividly debated for about a decade. Only a few years ago a possible explanation was offered by experimental observations for ionization of H_2 by proton impact [2]. These data suggested that the projectile coherence properties could significantly alter measured cross sections, not because of imperfections in the experiment, but due to the fundamentals of quantum-mechanics. If the transverse coherence length Δx, reflected by the width of the projectile wave packet, is large enough to coherently illuminate the target completely, interference structures are observable, but they are suppressed or even absent otherwise. In [1] Δx was much smaller than the atomic target size, but theory assumed that the projectiles were fully coherent. Another experiment on 3 MeV p + He collisions seemed to support this interpretation [3], while a study of 1 MeV p + He was inconclusive [4].

Here, we report a joint experimental and theoretical study of coherence effects in ionization of He by 75 keV proton impact [5]. The fully momentum analyzed recoil ions and scattered projectiles were measured in coincidence and the electron momentum deduced from momentum conservation. The experiment was performed for Δx=1.0 and 3.3 a.u. by changing the distance of a collimating slit before the target.

In our theoretical model, first the impact parameter dependent transition amplitude a(b) is computed by a numeric solution of the time-dependent Schrödinger equation. a(b) is then multiplied by a Gaussian wave packet describing the incoming projectile, where the width of the wave packet represents the coherence length. Finally, the scattering angle dependent transition amplitude is obtained from a Fourier transform of this product.

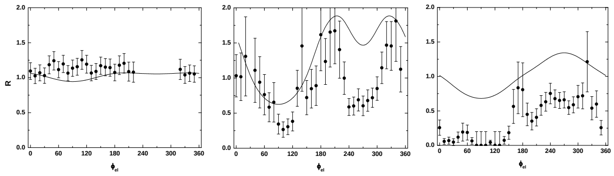

Figure 1. Coherent to incoherent FDCS ratios for various kinematic settings (see text).

In Fig. 1 the ratios between the coherent (Δx=3.3 a.u.) and incoherent (Δx=1.0 a.u.) FDCS are shown for E_{el} = 5.4 eV and recoil momentum/polar electron emission angle combinations of (from left to right) 0.2 a.u. and 25°, 0.7 a.u. and 65°, and 1.25 a.u. and 45° as a function of the azimuthal electron angle. The structures observed in experiment are qualitatively well reproduced by theory, which confirms the importance of coherence effects. Furthermore, a more detailed analysis shows that the structures are due to interference between different (non-observable) impact parameters contributing to the same (observable) scattering angle.

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References

[1] M. Schulz et al., Nature 422, 48 (2003)
[2] K. Egodapitiya et al. PRL. 106, 153202 (2011)
[3] X. Wang et al., J. Phys. B 45, 211001 (2012)
[4] K. Gassert et al., PRL 116, 073201 (2016)
[5] T. Arthanyaka et al., J. Phys. B 49, 13LT02 (2016)

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