Fast charged projectiles - waves or particles?

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The ionization of atoms by charged projectiles is one of the most fundamental processes in atomic physics. Since the foundation of the quantum mechanics it is established, that to the projectile a wave packet may be associated. However, in many practical calculations this wave packet is approximated by a plane wave with infinite spacial extent. Another usual method for describing the ionization process is the semiclassical approximation, when the projectile is considered a classical particle, well localized in space. It was shown that if the calculated ionization cross section is not differential in the projectile scattering angle, the two methods are equivalent, the result does not depend on the coherence properties of the projectile. However, this equivalence is not valid if a cross section dependent on the projectile scattering angle is considered.

The measurement of fully differential cross section (FDCS) for the ionization of atoms by fast ions became possible only less than two decades ago. It was somehow surprising, that the measured cross sections, mainly in the plane perpendicular to the momentum transfer, were not reproduced by state of the art quantum calculations [1]. One possible explanation of this discrepancy is the different projectile coherence of the wave packet associated to the projectile: while the estimated coherence width of the C^{6+} projectile in the experiment was very small, the quantum calculations assumed infinite coherence width. This idea was formulated in an article [2], where similar cross sections were measured, but for proton projectiles with larger coherence width. The fact, that these have shown better agreement with the theoretical cross sections than those obtained with the C^6+ projectiles, suggested that the FDCSs depend on the coherence properties of the projectile.

Two of the authors of the present abstract have published previously a semiclassical calculation [3] for the ionization of He by C^{6+} ions, and have partly reproduced the experimentally observed structures in the perpendicular plane, contrary to the quantum calculations. The semiclassical calculation assumes a classical trajectory for the projectile, corresponding to zero coherence width. The fact, that the coherence width influences the calculated cross section was proven in a later study [4], where the results obtained by coherent and incoherent fast projectiles were directly compared. A joint experimental and theoretical paper [5] have shown clearly this for proton projectiles with intermediate impact energy.

In the present work we present a systematic study of the ionization of helium by fast ions, assigning to the projectile a wave packet with variable width. The dependence of the FDCS on the coherence width of the projectile is studied, and the results are compared to the experimental data.

References

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