Wave-packet scattering in intermediate-energy p - He collisions

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Synopsis In the last years a debate arose concerning the effect of the projectile coherence on the fully differential ionization cross sections in ion-atom impact. In order to study this phenomenon a wave-packet description of the projectile is applied, and the result is analyzed as a function of the wave packet width. The results are compared to the experimental data for 75 keV p + He collisions. The data show, that the projectile coherence width influences the cross sections.

In the theory of atomic collisions there are two main ways in describing the ionization by fast ion projectiles. The impact parameter (or the semiclassical) model, using the fact that the associated de Broglie wavelength of the projectile is much shorter than the atomic dimensions, assumes a classical trajectory of the projectile, and treats with quantum mechanics only the electron system. The other model, based on quantum scattering theory, includes also the projectile into the quantum system. In this model usually it is assumed that the projectile wave packet in momentum space is sufficiently well peaked about its mean momentum [1], and a plane wave with infinite coherence length is associated to the projectile. If in an experiment the projectile scattering angle or the momentum transfer are not detected, the two descriptions lead to the same result [2]. But if fully differential cross sections (FDCS) are considered, the two models are not equivalent.

In the impact parameter model to a given final momentum distribution of the emerging particles a fixed impact parameter value is assigned, based on classical scattering [3]. In this case the transversal coherence length of the projectile is zero. In the quantum plane-wave model the scattering amplitude may be obtained as an inverse Fourier transform from the impact parameter dependent transition amplitude [4]. In this model the coherence length is infinite, and trajectories with all impact parameters interfere resulting in a certain final state.

In the present model we have assigned to the projectile a wavepacket with a Gaussian profile characterized by a finite coherence width. In the first version of this model we have multiplied the transition probability amplitude by a Gaussian depending on the value of the impact parameter peaked around b_0, the impact parameter assigned to a certain recoil ion momentum, calculated from classical scattering [5]. In this article the dependence of the FDCS on the coherence width of the projectile has been demonstrated both experimentally and theoretically.

Now we have modified our model in order describe more precisely the experiment. Here the coherence width of the wave packet is controlled in two dimensions, x (the direction of the perpendicular momentum transfer) and y (perpendicular to x and to the projectile's momentum). Consequently, in the theoretical calculations we have multiplied the transition probability amplitude by a Gaussian profile in two dimensions

$$\exp\left[-\frac{(b_x-b_{0x})^2(b_y-b_{0y})^2}{2\sigma_x^2 2\sigma_y^2}\right].$$

Here b_x and b_y are the two components of the impact parameter (the integration variable), b_{0x} and b_{0y} the components of the impact parameter assigned to a certain final momentum distribution of the emerging particles on the basis of classical scattering, while σ_x and σ_y are the corresponding standard deviations of the Gaussians. The coherence width of wave packet (Δb_x and Δb_y) is considered to be the full width half maximum of the Gaussians.

We have studied the dependence of the FDCS on the coherence width of the wavepacket assigned to the projectile for the ionization of helium by 75 keV proton projectiles. As in the experiment [5], we have analyzed the behavior of the cross sections as a function of the electron ejection angles for fixed values of the recoil ion momentum's component in the direction of the perpendicular momentum transfer. A very strong dependence on the coherence width was found mainly for the higher values of the recoil ion momentum (0.7 and 1.25 a.u.).

References

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