Transfer excitation reactions in fast proton-helium collisions

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Synopsis Fully differential cross section (FDCS) for the transfer excitation ($H^+ + He \rightarrow H + He^{+*}$) at high proton energies (630 - 1200 keV) is studied both experimentally and theoretically within the simplest Plane Wave First Born Approximation (PWFBA). The role of angular correlations in a trial helium ground state wave function is demonstrated.

Nowadays the modern experimental technique of COLTRIMS (Cold Target Recoil Ion momentum spectroscopy) allows to measure the final electronic states in electron transfer reactions even at high impact energies. As the total energy balance (Q-value) is encoded in the ion's longitudinal momentum $K_{||} = -Q/v_p - v_p/2$ an extreme high momentum resolution is necessary. They key to achieve a resolution of 0.04 a. u. (measured!) in the longitudinal direction was the construction of a thee dimensional time and space focussing spectrometer. All electron transfer events were recorded in a two particle coincidence (He^+ and H). Momentum conservation was applied to get rid of false coincidences. During off-line analysis a certain gate on $K_{||}$ selects only those events where the He^+-ion is found in an excited state, while the neutral projectile H is in its ground state.

The FDCS in the laboratory frame looks like

$$\frac{d\sigma_{n\geq 2}}{d\theta_p} = \frac{m^2\theta_p}{(2\pi)} \sum_{n=2}^{n-1} \sum_{l=0}^{l} \sum_{m=-l}^{l} |T_{nlm}|^2 \quad (1)$$

Here the proton mass $m = 1836.15$, and θ_p is the scattering angle of the hydrogen atom being in the ground state. For calculations we take $n = 2, 3$. It is enough to reach wholly satisfactory convergence at small (a few mrad) scattering angles.

A few trial helium wave functions are used for calculations. These are two highly angular correlated wave functions [1] and [2], the loosely angular correlated function [3] and one of $1s^2$ function. Results for $E_p =1$ MeV are presented in Fig. 1. At whole, shapes of curves obtained with correlated functions remind that for charge

transfer case leaving the ion in the ground state [4]. We also see that PWFBA is able to describe the experiment only at very small scattering angle around the peak, and only at energies $E_p >0.6$ MeV. At lower impact energies PWFBA fails.
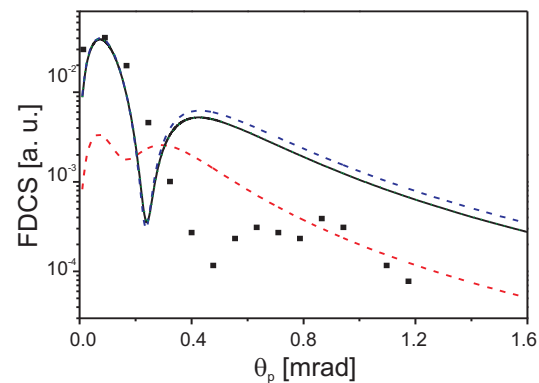

Figure 1. Experimental (full squares) and theoretical data for transfer excitation 1 MeV p + He. Solid (black) line, highly correlated helium wave function [1]; dotted (green) line (exactly on top of the black solid line), Mitroy CI highly correlated wave function [2]; dash-and-dot (blue) line, SPM CI wave function [3]; dash line (red), $1s^2$ wave function.

References

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