Two-centre Born approach to fully differential proton-impact ionisation of hydrogen: coherent versus incoherent combination of amplitudes

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Synopsis The fully differential cross section for proton-impact breakup of atomic hydrogen has been calculated in the two-centre Born approximation. Both direct ionisation of the target and electron capture to the projectile continuum are included. Interference between the two amplitudes leads to oscillatory differential cross sections when combined coherently, whereas the incoherent combination does not.

Study of the fully differential cross section (FDCS) is of fundamental importance for full understanding of atomic and molecular collision processes as it provides the most complete picture of the scattering process. From a theoretical point of view the FDCS for breakup processes in a Coulomb three-body system is the strongest test of theory as all potentials and wave functions are known analytically. Although being one of the simplest three-body systems, the proton-hydrogen differential ionisation problem still remains unsolved. That is, no single theoretical model is capable of reproducing all experimental observables. Recent experimental [1] and theoretical [2] investigations have focused on the double differential cross section.

We explore the fully differential proton-impact breakup of atomic hydrogen using a two-centre Born approximation, where depending on the kinematical situation the breakup amplitude can correspond to direct ionisation (DI) or electron capture to the continuum (ECC). One of the features of the model is that it is mostly analytical and not based on the partial-wave expansion. Consequently, it can be used as a benchmark when testing newly developed models. For example, it can be used to estimate the minimum required number of pseudostates in order to obtain convergent results in models which are based on the close-coupling formalism.

In the Born approximation the transition amplitudes for DI and ECC are given by

$$T^{\mathrm{DI}} = \langle \boldsymbol{K}_{\mathrm{T}} \psi^{-}_{\boldsymbol{k}_{\mathrm{T}}} | V_{\mathrm{PT}} + V_{\mathrm{P}} | \phi_i \boldsymbol{K}_i \rangle \qquad (1)$$

and

$$T^{\mathrm{ECC}} = \langle \boldsymbol{K}_{\mathrm{P}} \psi^{-}_{\boldsymbol{k}_{\mathrm{P}}} | V_{\mathrm{PT}} + V_{\mathrm{P}} | \phi_i \boldsymbol{K}_i \rangle, \qquad (2)$$

where V_{PT} and V_{P} is the interaction potential of the projectile with the target nucleus and electron respectively, ϕ_i is the hydrogen ground-state wave function, and ψ^- is the two-body Coulomb wave function. The questions is then should the amplitudes be combined coherently (COH) ($|T^{\mathrm{DI}} + T^{\mathrm{ECC}}|^2$) or incoherently (INC) ($|T^{\mathrm{DI}}|^2 + |T^{\mathrm{ECC}}|^2$) to obtain the FDCS?

In figure 1 we show the FDCS calculated using COH and INC combined amplitudes for ionisation of H by 75 keV protons in the forward direction. Here one can see that the COH combination of the amplitudes results in a highly-oscillatory FDCS at small ejection energies and around the velocity-matching region, whereas the INC combination does not. The oscillations in the COH combined FDCS are not unique to the forward direction either, with similar oscillations appearing at other scattering angles. From a physical point of view it is unlikely that there would be severe oscillations in the FDCS, which would suggest an INC combination of amplitudes may be the correct procedure when it comes to two-centre approaches to fully differential break-up problems. Similar results have also been found in the case of fully differential position-impact ionisation of hydrogen [3].

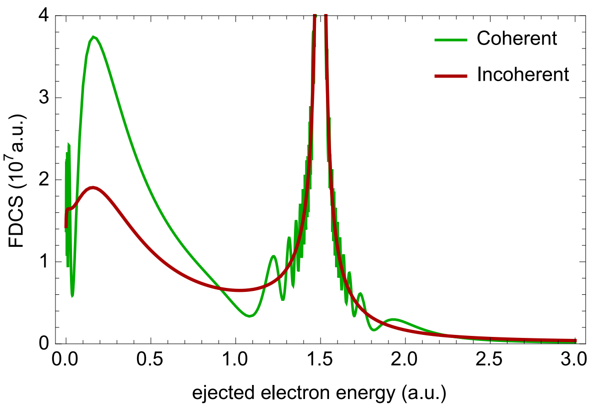

Figure 1. The FDCS from coherently and incoherently combined amplitudes for ionisation of H by 75 keV protons in the forward direction.

References

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