

# Calculations of differential cross sections for proton-impact ionisation of hydrogen

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**Synopsis** Differential cross sections for proton-impact breakup of atomic hydrogen have been calculated using the two-centre Born approximation and convergent close-coupling method. Both direct ionisation of the target and electron capture to the projectile continuum are included. Interference between the two amplitudes in the Born approximation leads to oscillatory triple differential cross sections when combined coherently, whereas the incoherent combination does not. Convergent close-coupling calculations of the double differential cross section are in good agreement with experiment.

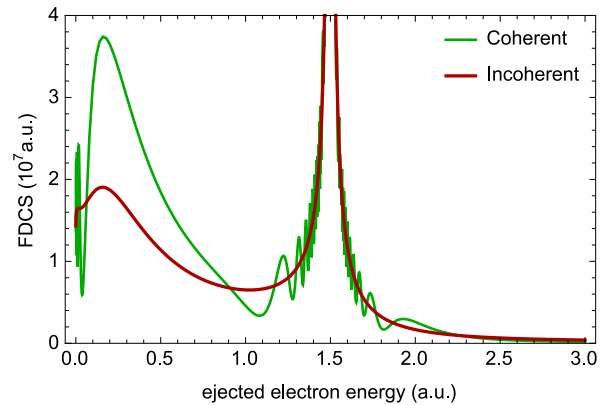
The fully differential cross section (FDCS) provides the most complete picture of the scattering process. From a theoretical point of view the FDCS for breakup processes in a Coulomb three-body system is the strongest test of theory. Although being one of the simplest three-body systems, the proton-hydrogen 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 (DDCS).

We explore the FDCS and DDCS for proton-impact breakup of atomic hydrogen using a two-centre Born approximation and wave-packet convergent close-coupling (CCC) method. Depending on the kinematical situation the breakup amplitude can correspond to direct ionisation (DI) or electron capture to the continuum (ECC). The question is then should the amplitudes for DI ( $T^{\text{DI}}$ ) and ECC ( $T^{\text{ECC}}$ ) be combined coherently (COH) ( $|T^{\text{DI}} + T^{\text{ECC}}|^2$ ) or incoherently (INC) ( $|T^{\text{DI}}|^2 + |T^{\text{ECC}}|^2$ )?

In figure 1 we show the FDCS calculated in the Born approximation 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 oscil-

lations 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].

The full two-centre CCC calculations for the FDCS and DDCS will be presented at the conference. In particular, the CCC results for the DDCS show good agreement with experiment [1].



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

## References

- [1] M. Schulz *et al.* 2010 *Phys. Rev. A* **81** 052705
- [2] H. R. J. Walters *et al.* 2015 *Phys. Rev. A* **92** 062712
- [3] A. S. Kadyrov *et al.* 2014 *Phys. Rev. A* **89** 012706

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