Calculations of stopping power for protons in hydrogen

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Synopsis The stopping power of H for protons has been calculated using a hybrid method. A two-centre convergent close-coupling approach has been used for the p-H contribution to the total stopping power, while the Born approximation has been used for the H-H contribution.

The study of energy loss as heavy charged particles travel through matter is of fundamental importance in many fields, including medical radiation therapy, aviation and space exploration, and astrophysics. Accurate knowledge of the stopping power of atoms and molecules for these heavy particles is of particular interest for hadron therapy, as it is a leading ingredient for depth-dose simulations required for treatment planning. The convergent close-coupling (CCC) method has been developed to be a highly accurate approach to ion-atom and ion-molecule collisions. It couples all possible channels, including rearrangement ones, and gives a fairly complete picture of the process. We have recently applied the CCC method to calculate the stopping power of various atoms and molecules for antiprotons [1, 2, 3]. Now we have shifted our attention to calculating the stopping power of hydrogen for protons.

Moving from antiprotons to protons significantly increases the difficulty of calculations. This is due to the possibility of rearrangement, whereby the proton can grab an electron forming hydrogen, which then leads to the requirement to perform calculations of H-H scattering. The stopping powers for the two possible charge-states of the projectile are then combined using the charge-state fractions to obtain the total stopping power, which is given by

$$S = f^{\mathrm{H}^+} S^{\mathrm{H}^+} + f^{\mathrm{H}^0} S^{\mathrm{H}^0}, \qquad (1)$$

where S^{H^+} is the p-H stopping power, S^{H^0} is the H-H stopping power, and f^{H^+} and f^{H^0} are the corresponding charge-state fractions. Both f^{H^+} and f^{H^0} are proportional to the electron capture cross section in p-H scattering, which highlights the importance of using a two-centre model.

Initial results have been obtained using a hybrid approach [4]. Here the two-center CCC method is used for the p-H component while the Born approximation is used for the H-H part. The two-centre CCC method expands the scattering wave function in a basis of both target and projectile states to accurately model electron capture processes. This leads to increased complexity of the scattering equations and hence an increase in the computational time required to solve them. Using the Born approximation for H-H calculations has the benefit that one can include the one-electron processes of single excitation and single ionisation and the two-electron processes of double excitation, double ionisation, and excitation with ionisation. Figure 1 shows the results obtained compared with experiment [5, 6, 7]. Excellent agreement has been achieved above 100 keV. The discrepancy below 100 keV is likely to be due to the failure of the Born approximation as the H-H contribution, accounted for using this approximation, dominates the total stopping power in this region. Current research is underway to improve the H-H component.

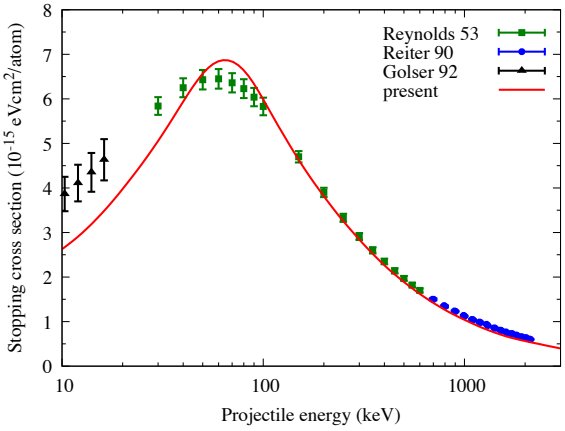

Figure 1. The total stopping power for the proton-hydrogen collision system. Our present result compared to experiment [5, 6, 7].

References

[1] J. J. Bailey *et al.* 2015 *Phys. Rev. A* **92** 022707

[2] J. J. Bailey *et al.* 2015 *Phys. Rev. A* **92** 052711

[3] J. J. Bailey *et al.* 2016 *Phys. Med.* **32** 1827

[4] J. J. Bailey *et al.* 2017 *J. Phys.: Conf. Ser.* **777** 012010

[5] H. K. Reynolds *et al.* 1953 *Phys. Rev.* **92** 742

[6] G. Reiter *et al.* 1990 *Nucl. Instr. Meth. Phys. Res. B* **44** 399

[7] R. Golser *et al.* 1992 *Nucl. Instr. Meth. Phys. Res. B* **69** 18

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