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Accurate stopping power calculations for antiprotons and protons

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Synopsis The convergent close-coupling method is applied to calculate antiproton and proton stopping cross sections for atomic and molecular targets. Excellent agreement with experimental measurements is obtained for antiprotons in helium while unexpectedly large disagreement is found for the hydrogen molecule, which is inconsistent with very good agreement between our ionisation cross section and the experiment.

Accurate knowledge of the stopping power (SP) for protons in atoms and molecules is important for proton therapy. Proton therapy is an advanced form of cancer treatment with greater benefits over the traditional x-ray therapy. Unlike x-rays, protons can deliver high doses of radiation very accurately to the site of a tumour with much less damage to surrounding healthy tissue. Knowledge of energy losses as particles travel through matter is a leading ingredient for depth-dose simulations required for treatment planning. Therefore energy loss data needs to be highly accurate. A theory of SP was developed by Bethe [1] using the first Born approximation. The Bethe theory is applicable only at high projectile velocities. Current depth-dose simulations use improved Bethe-type theories, however even with numerous improvements accurate SP data in the entire range of projectile velocities necessary for proton therapy cannot be obtained.

The convergent close coupling (CCC) method has been developed to be a highly accurate approach to ion-atom and ion-molecule collisions (see [2] and references therein). It couples all possible channels, including rearrangement ones, and gives a complete picture of the process. The method has recently been applied to calculate the stopping cross sections (SCS). In the CCC method the SCS is defined as

$$S(v) = \sum_f (\epsilon_f - \epsilon_i)\sigma_{fi}(v), \qquad (1)$$

where σ_{fi} is the scattering cross section for the transition of the target from an initial state i to some final pseudostate f and $\epsilon_f - \epsilon_i$ is the energy gained by the target during that transition. The SP is the SCS multiplied by the number of target atoms per unit volume.

We have calculated antiproton and proton SCS for H, He, H_2, Ne, Ar, Kr, Xe and H_20. Figure 1 shows the results for antiproton in He and H_2 in comparison with experimental data [3]. One can see that agreement between the CCC results and the experiment is very good for He. However, for H_2 there is significant discrepancy between our calculations and the data from the same experiment [3]. This is unexpected. A puzzling aspect arises when we take the combined-nuclei limit (i.e., set the internuclear distance to 0) in our H_2 code we perfectly reproduce our He results. It is also important to note that our ionisation cross sections for H_2 are in excellent agreement with experiment [2]. It appears that these two facts, namely, large disagreement for SCS and very good agreement for ionisation cross sections are inconsistent with each other. More results will be presented at the conference.

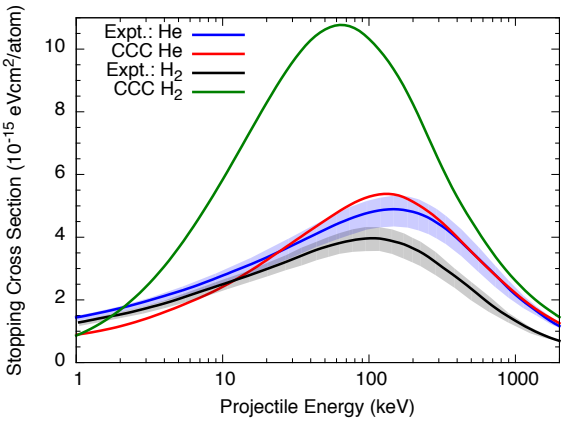

Figure 1. Stopping cross section for $\bar{p}$ in He and H_2. Experimental results [3] are shown by solid lines with shading representing the relevant error.

References

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