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Possible Evidence of 3rd and 4th order Interactions Contributions to Double Ionization of Helium by Protons and Antiprotons

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SynopsisPublished cross sections for double ionization of helium by protons and antiprotons are analyzed in terms of the traditional interference between 1st and 2nd amplitudes. Between 3 and 10 a.u., the velocity dependence implies a dominant 2nd order interaction. For slower collisions it is shown that the velocity dependences are consistent with 3rd and 4th order interactions becoming important with these interactions having negative coefficients.

Recently, we analyzed a large data set of published cross sections for double ionization of helium [1] using the model proposed by McGuire [2] where three terms are considered, namely the 1st order shake off term, the 2nd order TS2 term, and an interference term. Since the interference term is of opposite sign for proton and antiproton impact, adding the double ionization cross sections for proton and antiproton impact removes the interference contribution. Under the assumption that the 1st order contribution is the same for proton and antiproton impact, the 2nd order TS2 contribution, σ_{2nd}, was isolated and found to have a $\ln(v)/v^4$ dependence at higher velocities. This was interpreted as implying sequential emission of two electrons via independent interactions. At lower velocities, σ_{2nd} reached a maximum and then decreased. These data and fit are shown by the black open squares and line in Fig. 1. Ref. 1 contains additional details plus references for the data used. Here we take a closer look at the lower velocity region and find that the velocity dependences in this region are consistent with 3rd and 4th order processes becoming increasingly important at lower impact en-ergies.

The absolute values for differences between the data and fit mentioned above are shown by the filled red circles with the red line illustrating these have a v^{-6} dependence above 3 a.u. The differences between the red data and line are shown by the filled blue stars which, as shown by the blue line, have a v^{-8} dependence. These velocity dependences suggest that for intermediate to high velocities, e.g., between ~ 3 and 10 a.u., the 2nd order TS2 mechanism dominates. But around the cross section maximum, the velocity de-pendence implies a 3rd order double ionization mech-anism having a negative coefficient becoming im-portant and eventually dominating below ~ 1.5 a.u. At still lower velocities, e.g., below 1 a.u., the v^{-8} de-pendence implies a 4th order double ionization mech-anism, also with a negative coefficient, becoming dominant.

Unfortunately, we do not know of any theoretical treatments of double ionization beyond 2nd order and can only state that in spite of uncertainties associated with error bars in the cross sections and several subtractions between data and fitted curves, the data in Figure 1 imply that some type of 3rd and 4th order double ionization mechanisms are present for low energy proton and antiproton impact. Finally, we do not believe our analysis is simply a fortuitous result of a polynomial fit to the data as this should yield both even and odd powers of v whereas we find only even powers to be present.

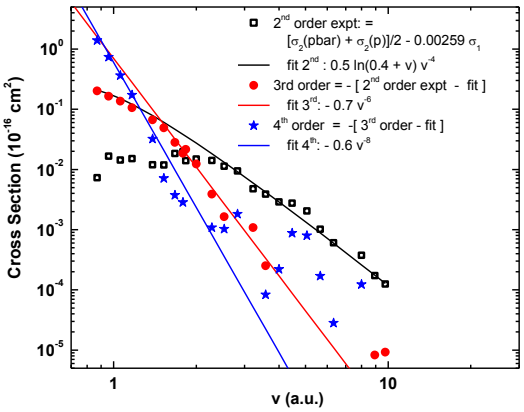

Figure 1. Possible 2nd, 3rd, and 4th order contributions to double ionization of helium by protons and antiprotons. See text for details and ref. 1 for sources of original data.

References

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