Complete First-Order Three-Body Approach to Proton-Hydrogen Collisions

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Seven decades have passed since Oppenheimer, and Brinkmann and Kramers, provided first calculations of electron transfer in proton-hydrogen collisions. This lowest order approximation (OBK approximation) which neglects the proton-proton interaction, was found to overestimate total cross sections by factors 4 to 5. More than two decades later Jackson and Schiff showed that inclusion of the internuclear interaction reduces the cross section results to experiment (JS approximation). Though, soon after it was realized that also the latter faces inherent difficulties. Nevertheless, over the years work along these lines has given rise to considerable progress in the theoretical understanding of the process of interest.

However, in our opinion even this simplest charge transfer process does not yet have a satisfactory theoretical description in the medium to high energy region. As far as total cross sections are concerned, two perturbative methods should be mentioned as giving the best agreement with experiment among all high energy theories. They are the continuum distorted wave (CDW) and the boundary corrected first Born (B1B) approximations. Clearly, a much more stringent test of theoretical models is provided by a comparison of calculated results not only for total but in addition also for differential cross sections with the corresponding experimental data. Indeed, both CDW and B1B in general fail to describe the latter. One of the reasons for this failure lies in a specific feature common to CDW and B1B: both are one channel approximations, i.e. neither contributions to the final particle arrangement coming from other reaction channels nor the interference between different states in a given channel, are taken into account.

In view of these facts a method is still called for which would properly take into account all possible reaction channels and explain the total cross section as a consequence of the correct description of the corresponding differential cross sections. The three-body Faddeev approach, though not having been applied as widely to atomic collision problem as other, more traditional methods, has as we believe the desired capacity. As is well known and is stated in the latest review on the state art of energetic ion-atom collision theories [1], applications of the Faddeev approach to atomic collisions are impeded mainly by the difficulties arising from the complicated singularity structure of the two-particle Coulomb T-matrix which is the basic dynamical ingredient in this formalism. The difficulties stem essentially from two sources; namely, the off-shell Coulomb T-matrix develops nasty singularities in the on-shell limit and in addition has, in case of an attractive interaction, an infinite number of (bound-state) poles. Another reason why the Faddeev approach appears to remain unpopular in atomic physics can be ascribed to wrong three-body calculations published earlier in a number of papers (e.g., [2]).

In our work we demonstrate that the above mentioned difficulties have been overcome in our investigations which are based on a further development of the impact parameter Faddeev approach proposed earlier [3]. The progress consists in our gained ability to exactly include the two-particle off-shell Coulomb T-matrices in the first order direct and the exchange contributions to the effective potentials (”’triangle amplitudes”’). Results of calculations of proton-hydrogen collisions, with only the ground state of the hydrogen in both the direct and rearrangement channels retained, will be presented. The calculated total and differential cross sections for the electron transfer reaction as well as differential elastic scattering cross sections show a very good agreement with experimental data, over a wide range of incident energies. Some results of our calculations are shown in Figs 1,2.

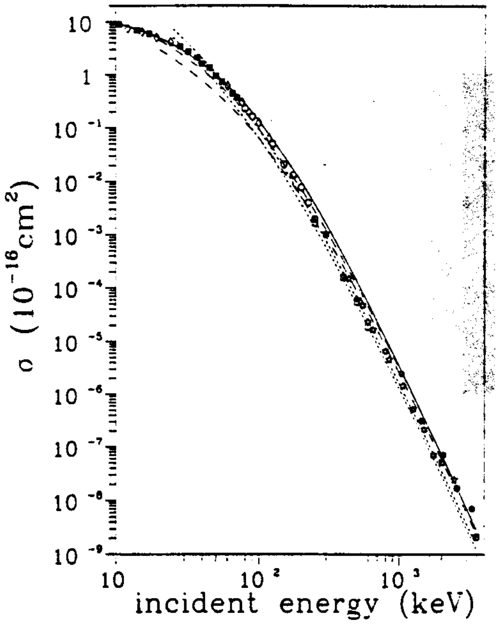

Figure 1: Integrated cross sections for electron capture by H^+ from $H(1s)$: solid line, present results for (1s -1s) transition; dotted lines, CDW [4]; dashed lines, B1B [5]; in each case lower line presents calculation for 1s-1s transition, upper line is the cross section summed over all final states (1s - $\sum$). Experimental data are taken from the references given in [6].

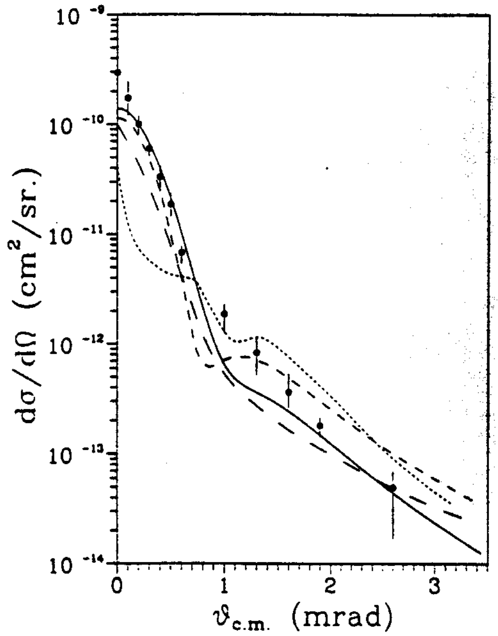

Figure 2: Differential cross section for electron capture by H^+ from $H(1s)$ at 60 keV: solid line, present results (1s-1s); dotted line, CDW (1s-1s) [4]; short-dashed line, B1B (1s -$\sum$) [7]; long-dashed line, MS (1s) [8]. Experimental points ($\sum$) are from [9].

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