Electron capture from atomic hydrogen by fully stripped ions of Be^{4+}, B^{5+}, C^{6+}, N^{7+}, and O^{8+} in the continuum intermediate-state approximation

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Cross sections for electron capture by fully stripped ions of beryllium, boron, carbon, nitrogen, and oxygen from ground-state atomic hydrogen have been calculated by applying the previously reported generalized formulation in the continuum intermediate-state approximation. The calculated results are compared with the existing available experimental and theoretical results.

The study of electron capture processes from atomic hydrogen by completely stripped heavy ions has recently received appreciable attention both theoretically and experimentally because of its practical applications in plasma diagnostics in fusion research. In the present Brief Report we propose to calculate the cross sections for electron capture from atomic hydrogen by the completely stripped ions of beryllium, boron, carbon, nitrogen, and oxygen in the intermediate- and high-energy region. For the calculation of cross sections we propose to apply the continuum intermediate-state aproximation (CISA), developed recently by Belkić.[1] The CISA is a two-state second-order approximation in which the intermediate continuum states are incorporated in one of the channels. This method has been shown[1] to be more reliable than the continuum distorted-wave approximation (CDWA) method for describing the capture at large impact parameters and has been found to be in excellent agreement with the measured values in the high- and intermediate-energy region, compared with the predicted values of the second Born approximation.

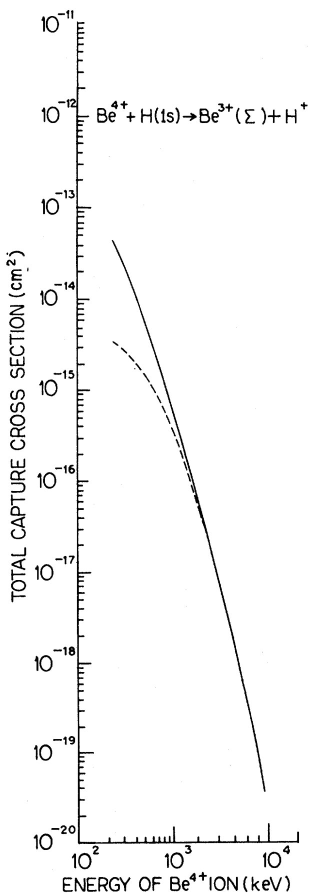

FIG. 1. Total cross sections for capture of $H(1s)$ electron by fully stripped ion of Be^{4+} as a function of laboratory energy. Theory: ——, present work; — — —, eikonal calculation of Eichler (Ref. 6).

The theoretical method and the numerical procedure, we follow here, already have been discussed in connection with our earlier investigation[2] on proton-hydrogen collision case. The present CISA computed results for beryllium are compared in Fig. 1 with the only existing theoretical results of Bransden, Newby, and Noble,[3] calculated in the two-state atomic expansion method. For boron, the present calculated results are compared in Fig. 2 with the theoretical results of the unitarized distorted-wave approximation (UDWA) calculation of Ryufuku and Watanabe,[4] two-state atomic ex-

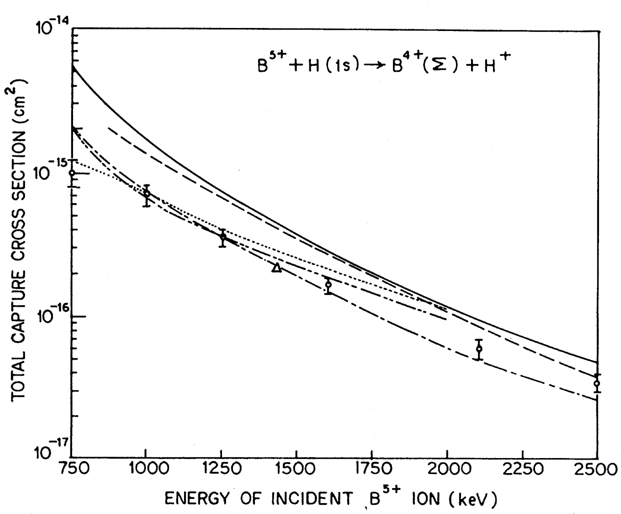

FIG. 2. Same as Fig. 1 but for B^{5+} ion. Theory: ——, present work; — — —, eikonal calculation of Eichler (Ref. 6); —·—, CDWA calculation of Mandal *et al.* (Ref. 5); · · · ·, UDWA calculation of Ryufuku and Watanabe (Ref. 4); ----, Atomic state expansion model calculation of Bransden *et al.* (Ref. 3); Δ, CDWA calculation of Crothers (Ref. 9); Experiment: ○, Goffe *et al.* (Ref. 7).

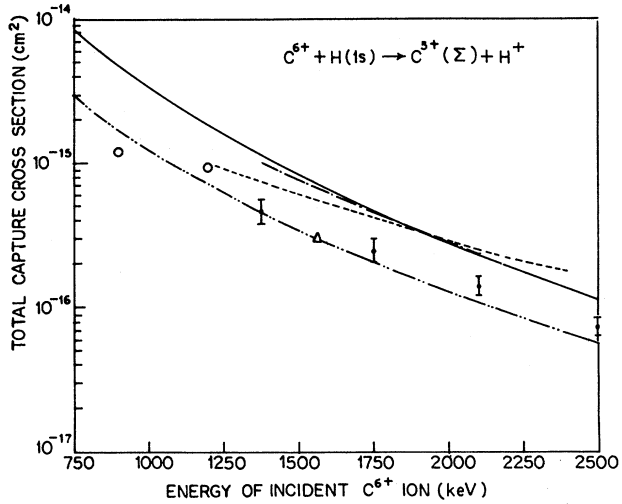

FIG. 3. Same as Fig. 1 but for C^{6+} ion. Theory: ——, present work; —·—, eikonal calculation of Eichler *et al.* (Ref. 6); - - - -, CDWA calculation of Mandal *et al.* (Ref. 5); · · · ·, UDWA calculation of Ryufuku and Watanabe (Ref. 4); o, Monte Carlo calculation of Olson (Ref. 8); Δ, CDWA calculation of Crothers (Ref. 9). Experiment: ɸ, Goffe *et al.* (Ref. 7).

pansion method calculation of Brandsen *et al.*,[3] CDWA calculation of Mandal, Datta, and Mukherjee,[5] eikonal calculation of Eichler,[6] and the experimental results of Goffe, Shah, and Gilbody.[7] For carbon, the present results are compared in Fig. 3 with existing theoretical results in the eikonal calculation,[6] the UDWA calculation,[4] the CDWA calculation,[5] the classical trajectory Monte Carlo (CTMC) calculation of Olson,[8] and the experimental results of Goffe *et al.*[7] For the case of nitrogen and oxygen, the present computed results are shown, respectively, in Figs. 4 and 5 and are compared with the available eikonal results.[6] Calculations for capture into the final states with $n \leq 8$ have been carried out for the high-incident energy region varying from 250 to 1000 keV for beryllium and for the energy region varying from 750 to 2500 keV in the case of boron and carbon in collision with neutral atomic hydrogen. Calculations for capture into the final states with $n \leq 12$ have been carried out for the high-incident energy region varying from 850 to 10 000 keV for nitrogen and oxygen.

Our results for the capture cross sections $Q(n) = \sum_{lm} Q_{nlm}$, into each complete shell for fully stripped beryllium, boron, carbon, nitrogen, and oxygen with neutral hydrogen atom as well as the individual cross sections in each sublevel $Q_{nl} = \sum_m Q_{nlm}$ are available on request. In order to compare the computed results with the available results for the total cross section $Q_{tot} = \sum_n Q(n)$, we calculate them

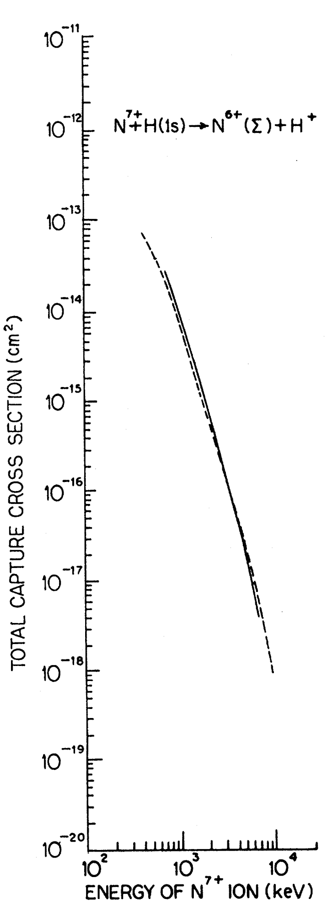

FIG. 4. Same as Fig. 1 but for N^{7+} ion. Theory: ——, present work; — — —, eikonal calculation of Eichler (Ref. 6).

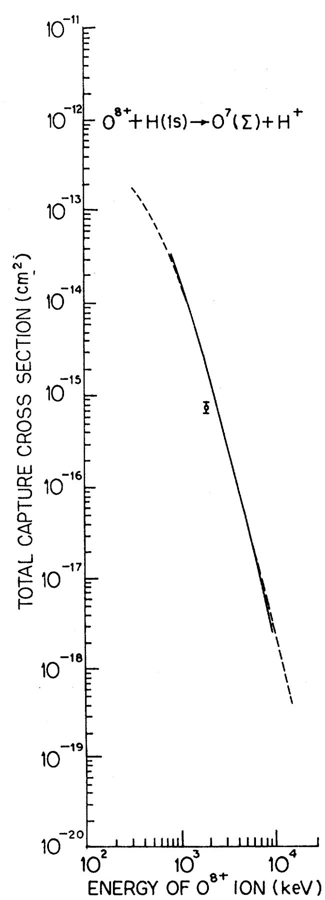

FIG. 5. Same as Fig. 1 but for O^{8+} ion. Theory: ——, present work; — — —, eikonal calculation of Eichler (Ref. 6); Experiment: ɸ, Meyer *et al.* (Ref. 10).

for each individual energy by assuming the cross section $Q(n)$ to be proportional to n^{-3} for $n \geqslant 8$ (for the case of beryllium, boron, and carbon) as in the Brinkman and Kramers approximation at high energies. In the case of nitrogen and oxygen, the n^{-3} law has been applied for $n \geqslant 12$.

From Figs. 2 and 3 it appears that for boron and carbon, the present CISA results for the total cross sections like the eikonal results overestimate the observed results throughout the energy region considered. For both these cases, the CISA curves also lie considerably above the CDWA curves which compares favorably with the experimental curve. However, the present CISA curve, like the CDWA curve shows a trend almost identical in nature with the experiment in the entire energy region considered. The values of the cross sections in the UDWA method[4] are in good agreement with the observed values at the low-energy region. However, with the increase of incident energy, the UDWA values gradually overestimate and beyond 1500 keV they tend to the CISA values as well as the eikonal values.[6] The predicted cross sections values in the two-state atomic expansion method[3] for the case of boron are always found to be small compared with the UDWA values in better agreement with the observed values throughout the energy region considered. Though the computed values of the cross sections obtained in the UDWA as well as in the two-state atomic expansion method[3] are in better agreement with the observed values as compared with the present CISA results, the cross section curves obtained in the previous methods, unlike the CISA curves, differ considerably in nature with the experimental curve. In the asymptotic region, however, the values of the cross sections obtained by all the theoretical methods almost coincide with one another. From Fig. 1, it appears that in the case of beryllium, although the cross sections obtained in the CISA method are in good agreement in the high-energy region with those obtained in the eikonal approximation,[6] there is a wide discrepancy in the values of the cross sections in the low-energy side ($E < 1000$ keV). However, for the case of oxygen and nitrogen (Figs. 4 and 5), the CISA values of the cross sections almost coincide with the eikonal values throughout the energy region considered. Unfortunately, for these cases no experimental results are available for comparison. Considering the trends and nature of the curves for the total cross sections obtained in different cases, we may conclude that the present CISA method gives reasonably good estimate and in the cases of heavy ions, the values of the cross sections at the high energy obtained by this method may be as reliable as any other high-energy methods.

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