K-shell capture by He^{2+} and Li^{3+} on carbon and neon

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We have extended our earlier investigation on asymmetric collisions in the framework of a modified peaking impulse approximation for the case of collisions of fully stripped ions of helium and lithium with carbon and neon. As the charge of the projectile is high, we propose to find an exact estimate of the contribution of charge transfer into higher excited states of the projectile. The contribution of charge transfer into $n=2$ states is never found to exceed 12% in the entire energy region of 0.3–3.0 MeV/amu. Total cross sections compare fairly well with existing experimental results.

The study of electron-capture cross sections by heavy particles from heavier targets has been the subject of active interest[1,2] during the last few decades. The results of our earlier investigation[3] on K-K capture by protons on carbon, nitrogen, oxygen, neon, and argon were found to be encouraging for such asymmetric collisions. The formulation was based on the peaking impulse approximation with some modification in the framework of the distorted-wave formalism. The success of the theory lies in the fact that it accounts for the intermediate continuum states and the residual potential in the entrance channel of the matrix element falling faster than the Coulomb potential. However, in a recent review article, Bransden and Dewangan[4] called it a Vainshtein, Presnyakov, and Sobelman (VPS) approximation. Most of the recent work[5–7] on asymmetric collision is confined to proton impact only. In all these calculations, the K-K capture contribution was estimated and multiplied by a factor of 1.2 to account for the contribution from all other higher excited states. In the present collision systems we apply the same theoretical procedure as suggested in our earlier investigations.[3] As the projectile charges are higher than 1, a significant contribution may be expected from higher excited levels. We exactly calculate the cross sections into the excited states which are being generated by parametric differentiations. In a many-electron target, an exact treatment of the active electron is itself a formidably difficult task. As a consequence, one has to resort to some approximate schemes. The conventional procedure is to describe the active electron by a hydrogenlike wave function with an effective charge which is determined to be either $Z_{\text{eff}}=Z_T-\frac{5}{16}$ or $(-2n^2\varepsilon_i)^{1/2}$, where ε_i is the initial binding energy and n is the principal quantum number of the active electron in the target. The former one is called the Slater-Screening (SS) model and the latter is called the binding-energy screening (BES) model. We have adopted both screening procedures in order to have a comparative study of the accuracy of the two methods. The limitations and shortcomings of the above-mentioned two screening procedures (BES and SS) were discussed

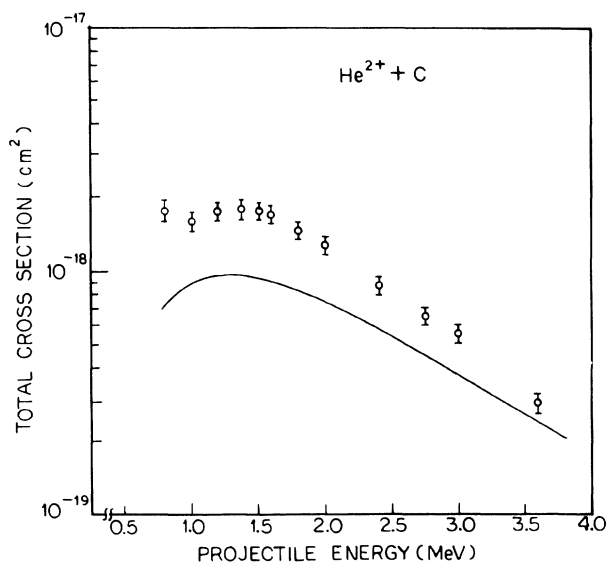

FIG. 1. Total capture cross sections by He^{2+} from the K shell of carbon. Theory: solid line, present results; experiment: ○, Rødbro *et al.* (Ref. 8).

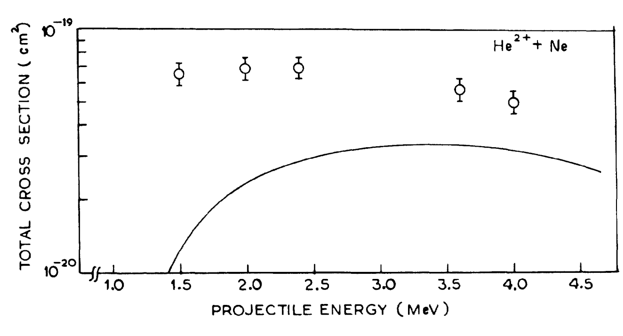

FIG. 2. Total capture cross sections by He^{2+} from the K shell of neon. The same legend as Fig. 1 is used.

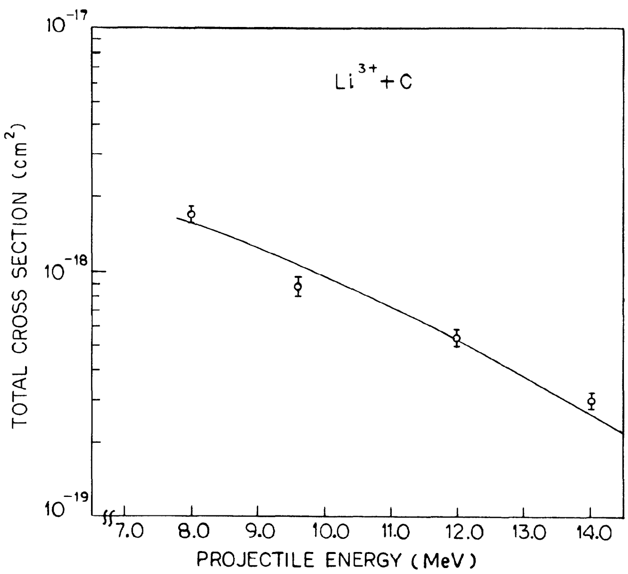

FIG. 3. Total capture cross sections by Li^{3+} from the K shell of carbon. The same legend as Fig. 1 is used.

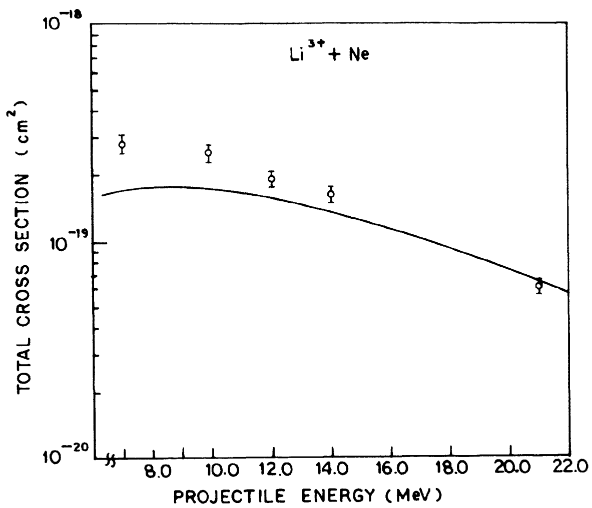

FIG. 4. Total capture cross sections by Li^{3+} from the K shell of neon. The same legend as Fig. 1 is used.

thoroughly by Decker and Eichler[7] in the course of their studies on asymmetric collisions. They also suggested a procedure for a consistent account of the active electron, which is beyond the scope of our present formalism.

The results of our calculation are given in Figs. 1–4. For a relative comparison of the contributions from higher shells, explicit results are given in Tables I and II. Total cross sections have been calculated by applying the n^{-3} law from $n \geq 3$ shells, which is given by the relation

$$\sigma_{\text{tot}}=\sigma_{1s}+1.616(\sigma_{2s}+\sigma_{2p}) .$$

In our calculation we multiplied the results obtained from the active electron by a factor of 2 to account for other electrons in the K shell. Figure 1 displays the results of the He^{2+}+C collision. From the figure it is evident that the results have a trend similar to that of the experimental results of Rødbro *et al.*[8] At energies about 1.2 MeV/amu, our calculated results agree within 14% of the experimental results. The maximum obtained by the present theoretical procedure is found to occur at the same incident energy of 0.46 MeV/amu as that of the experiment. The magnitudes of the cross sections in these two cases, however, differ considerably. The results of the He^{2+}+Ne collision are displayed in Fig. 2. The results are not very satisfactory in comparison to the experimental results[8] over the entire energy region. Our calculated results for the Li^{3+}+C collisional system are shown in Fig. 3. The calculated results show very good agreement with the experimental results[8] at all energies. Present calculated results for the Li^{3+}+Ne collision are compared with the experimental results in Fig. 4. It is evident from Fig. 4 that the results are in good agreement with each other, particularly at projectile energy of 3 MeV/amu, where the agreement is within 5%. However, from the above studies it appears that our calculated results for the cross sections are in fair agreement with the experimental data of sufficiently high velocities (well above the broad maximum). The present method of a modified peaking impulse approximation is essentially a high-energy approximation and as such there is a gross discrepancy with the observed findings in the low- and even at the intermediate-energy region. Our results displayed so far have been calculated in the SS model. We have not displayed the calculated results in BES model because the results do not even produce the structure of the total cross section as predicted by the experimental results of Rødbro *et al.*[8] The reason for this is that the main contribution to the transition amplitude arises when the initial- and final-state wave functions overlap. The BES model yields incorrect wave functions in the vicinity of the nucleus and hence incorrect high-momentum components which are very important in energetic electron

TABLE I. K-shell capture cross sections by He^{2+} impact.

Energy (MeV)			C target (10^{-19} cm^2)			Energy (MeV)			Ne target (10^{-20} cm^2)		
	σ_{1s}	σ_{2s}	σ_{2p}	σ_{tot}	σ_{expt}		σ_{1s}	σ_{2s}	σ_{2p}	σ_{tot}	σ_{expt}
0.99	7.60	0.66	0.09	8.82	16.0±1.9	1.50	1.22	0.06	0.01	1.33	6.71±0.66
1.38	8.26	0.83	0.09	9.74	18.0±1.6	2.40	2.61	0.14	0.02	2.86	7.15±1.0
2.40	4.88	0.58	0.06	5.92	8.8±0.6	3.60	3.06	0.18	0.02	3.38	5.66±0.6
3.60	2.10	0.27	0.03	2.59	3.0±0.22	3.99	2.96	0.17	0.02	3.26	5.06±0.6

TABLE II. K-shell capture cross sections by Li^{3+} impact.

Energy (MeV)	C target (10^{-19} cm^2) σ_{1s}	σ_{2s}	σ_{2p}	σ_{tot}	σ_{expt}	Energy (MeV)	Ne target (10^{-20} cm^2) σ_{1s}	σ_{2s}	σ_{2p}	σ_{tot}	σ_{expt}
7.98	12.64	1.60	0.21	15.56	16.6±1.5	7.0	16.10	0.78	0.08	17.48	28.5±5.7
9.87	7.40	0.98	0.13	9.20	8.7±0.9	11.97	14.47	0.81	0.08	15.92	19.3±2.1
11.97	4.24	0.58	0.08	5.31	5.3±0.6	14.0	8.57	0.53	0.06	9.53	16.2±2.2
14.00	2.56	0.36	0.05	3.21	3.1±0.4	21.0	5.96	0.37	0.04	6.62	6.3±1.0

capture. From Tables I and II it appears that a 9–12 % contribution of total charge transfer comes from the $2s$ state only in the case of carbon as a target, whereas there is a 5–9 % contribution in the case of neon as a target. As a whole, a 1–3 % contribution comes from the charge transfer to the $2p$ state for both the targets. This small amount of contribution from the charge transfer into the $n=2$ level may be explained in terms of the momentum distribution of the active electron in the initial and final state as shown by Andriamonje *et al.*[9]

In the case of a highly asymmetric collision involving a many-electron target, we are of the same view as Decker and Eichler[7] that the Slater-Screening model is more reliable over other existing models. At high-energy collisions, K-K capture would have a dominant contribution to K-shell capture even if projectile charges are increasingly high.

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