Brief Reports

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Electron-impact excitation of the lithium isoelectronic sequence

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The Hartree-Fock wave functions of Weiss for the lithium isoelectronic sequence through $Z = 10$ are used to calculate the generalized oscillator strengths (GOS) and total cross sections for excitation in length and velocity formulations of the Born approximation for all possible transitions between the initial state $n = 2$ to the final state $N = 3$. The present results for the total cross sections are compared with the available theoretical Coulomb-Born calculations and experimental data. The existence of regularities and systematic trends in the GOS and cross sections along the isoelectronic sequence are qualitatively discussed.

The electron impact excitation of positive ions has been the subject of a great number of recent experimental and theoretical investigations.[1-4] Recently,[5] we have used the concept of generalized oscillator strengths $f(K)$ calculated in the length and velocity formulations of the Born approximation to study the inelastic scattering of electrons by lithium. In this paper we report the results of the same approach for the lithium isoelectronic sequence for all possible combinations of the allowed and nonallowed transitions between $n = 2$ and $N = 3$. The general shape of the curves for different transitions is essentially the same in both length and velocity formulations. In order to examine the characteristics of different transitions, we have plotted (i) Z times $f(K)$ as a function of K/Z for transitions with no change in the principal quantum number and (ii) $f(K)$ as a function of K/Z for $n \neq N$. Here K is the momentum transfer and Z is the atomic number of the ionic target.

We have chosen $2s$-$2p$, $2s$-$3p$, $2p$-$3d$, and $2s$-$3s$ as the representative transitions. Figure 1 shows the GOS for these transitions. For $2s$-$2p$ transition we observe that as Z increases there is a gradual decrease in the generalized oscillator strength (GOS) value for small K/Z, and thereafter the order of the GOS curves gets reversed as K/Z increases and tends to zero value. This feature is not present for $2p$-$3d$. In this case the GOS curve shifts upward as Z increases and goes to zero as K/Z increases. In the case of $2s$-$3p$ transition we note that, for small K/Z, as Z increases the GOS curve shifts upward, and then as K/Z increases it passes through many minima and maxima. On the other hand the GOS curves for the nonallowed transition $2s$-$3s$ show a different characteristic than the allowed one. These differ both in magnitude and shape. In this case we note that, for small K/Z, as Z increases the GOS curve moves downward, and then it becomes flatter for large K/Z and finally tends to zero value. This type of behavior is attributed mainly to the fact that at small K the transition matrix spans fewer oscillations of the operator $\sum_{i=1}^{N_A} e^{i\vec{K}\cdot\vec{r}_i}$ and thus suffers to a lesser degree from cancellations within the integrand of the transition matrix element, but as K increases the cancellations cause each of the curves to tend to zero value. For each transition we have also shown the GOS obtained using a hydrogenic model for the target system. We note that as Z increases the GOS curve approaches the hydrogenic curve. This hydrogenic limit is attained quickly for the resonance transition and also for the transitions for which $n \neq N$ compared to other transitions. It is also observed that as Z increases, the GOS tends to zero value more quickly for $n = N$ compared to $n \neq N$ transitions.

Figure 2 shows the scaled cross sections for $2s$-$2p$, $2s$-$3p$, $2p$-$3d$, and $2s$-$3s$ transitions. We have only plotted the results obtained in the length formulation, although the values obtained in the velocity formulation do show a deviation of maximum 20% for all the transitions. However, the shape of the curves obtained in both the methods is essentially the same. We have also shown the values of the cross sections obtained in Coulomb-Born (CB) approximation by Burke *et al.*,[6] unitarized Coulomb-Born by Van Wyngaarden and Henry,[7] and the recent experimental measure-

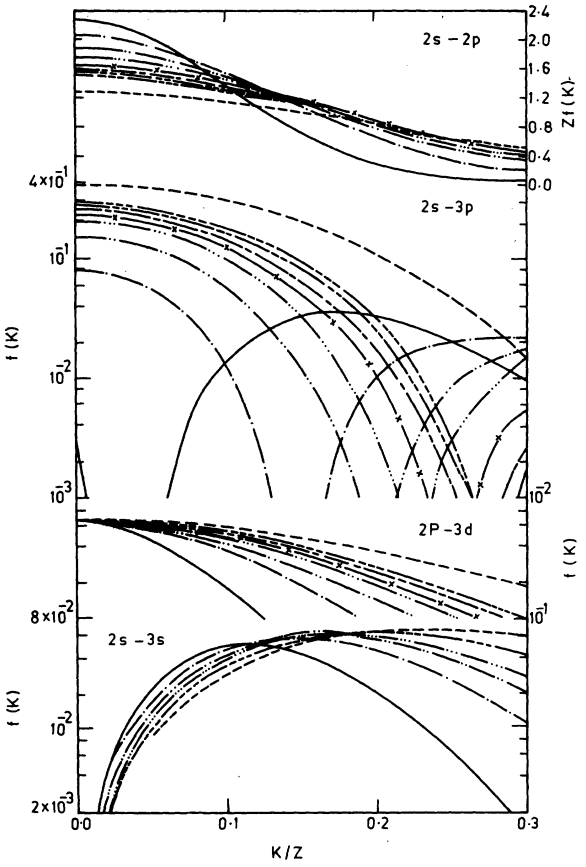

FIG. 1. The generalized oscillator strengths for the $2s$-$2p$, $2s$-$3p$, $2p$-$3d$, and $2s$-$3s$ transitions of the following: —Li; —·—·—Be^{1+}; —··—··—B^{2+}; —···—···—C^{3+}; —x—x—N^{4+}; — — —O^{5+}; — — — —F^{6+}; — — — — —Ne^{7+}; - - - - - hydrogenic.

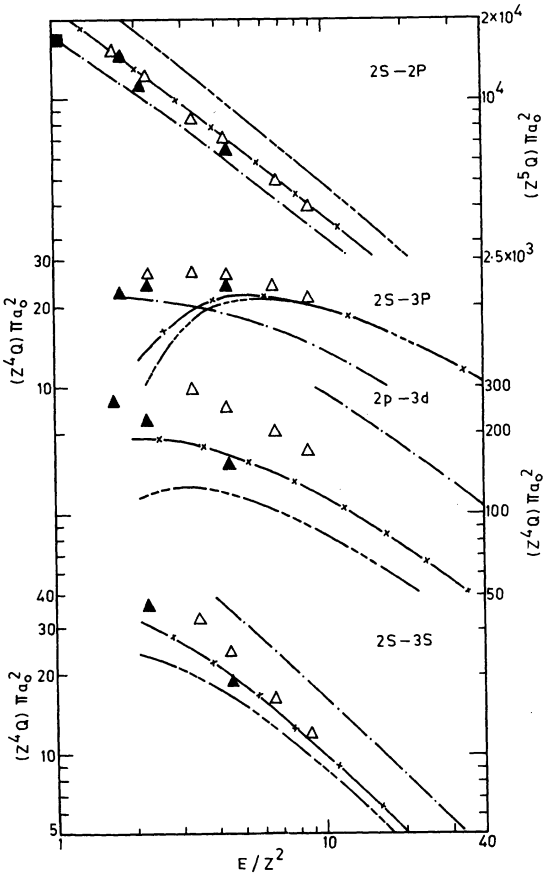

FIG. 2. The total electron impact excitation cross sections for $2s$-$2p$, $2s$-$3p$, $2p$-$3d$, and $2s$-$3s$ transitions of the following: —·—·—Be^{1+}; —x—x—N^{4+}; — — — —Ne^{7+}; △ Coulomb-Born of Bruke *et al.* (Ref. 6), for N^{4+}; ▲ unitarized CB results (Ref. 7) for N^{4+}. Experimental data ■ Gregory *et al.* (Ref. 8).

ments[8] for N^{4+} systems of isoelectronic sequence. The present results agree to within 5% for resonance transition $2s$-$2p$ and to within 8% for $2s$-$3p$ and $2s$-$3s$ transitions with the CB results for energies greater than eight times threshold. For $2p$-$3d$ transitions there is no agreement between the CB values and the present calculations. The CB results are higher by a factor of 1.5 compared to the present results even for energies as high as equal to eight times the threshold. The transitions between $n=3$ to $N=3$ states, particularly $3s$-$3d$ and $3p$-$3d$ (not shown), show a wide disagreement with the CB results. This indicates that the adjacent levels perturb each other very much, and thus we believe that the interplay of different configurations for representing the bound-state wave functions must be allowed in order to study such transitions. The primary motivation of this study has been to apply a simple theoretical approach (plane-wave approximation) using a reasonable Hartree-Fock description of the bound state for arriving at generalized oscillator strengths and electron impact excitation cross sections. From the above discussion it is clear that at high impact energies the plane-wave Born approximation is adequate in predicting the cross sections, in fact to the same degree of accuracy as that of the Coulomb-Born approximation for different members of the isoelectronic sequence.

The detailed results for the GOS and the cross sections for all members of the lithium isoelectronic sequence through $Z=10$ are available in tabular form and may be supplied on request.

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