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LETTER TO THE EDITOR

Electron impact ionisation of Li-like and Be-like carbon and nitrogen ions

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Abstract. Electron impact ionisation cross sections of the Li-like ions C IV and N V and the Be-like ions C III and N IV are calculated in a no-exchange Coulomb–Born approximation. Inner-shell ionisation is included but not autoionisation. Comparison with available theoretical and experimental data has been made. In C IV, the results agree with the recent calculations of Golden and Sampson and with exchange–classical impact-parameter calculations, which are about 30% higher than the crossed-beam experimental results of Crandall and co-workers. In N V the results agree with those of Golden and Sampson but are now in close agreement with Crandall *et al.*

In a previous paper (Moores 1972) results of calculations of electron impact ionisation cross sections for positive ions in a no-exchange Coulomb–Born approximation were presented. In that work the bound and ejected electrons were assumed to move in a scaled Thomas–Fermi potential (Moores and Nussbaumer 1970) and the ejected electron energy integration was performed over the half-range. In this letter we present some hitherto unpublished data for C IV, N V, C III and N IV ions, obtained in the same approximation using the same computer program. The results are shown in table 1. Results for ionisation out of the 1s shell may be calculated from the formula

$$Q_{1s} = \frac{2Q_R}{I_{1s}^2} \pi a_0^2$$

Table 1. Outer-shell (2s) ionisation cross sections in units of 10^{-18} cm^2 as a function of X, the ratio of incident electron energy to ionisation energy, which is given in parentheses after the name of the ion.

X	C III (47·86 eV)	N IV (77·47 eV)	C IV (64·48 eV)	N V (97·88 eV)
1·25	5·36	2·11	1·49	0·67
1·5	8·67	3·37	2·35	1·07
2·25	12·66	4·83	3·33	1·50
3·0	13·16	4·98	3·40	1·53
4·0	—	—	3·18	—
4·5	11·88	4·47	3·03	1·35
6·0	10·28	3·86	2·60	1·16

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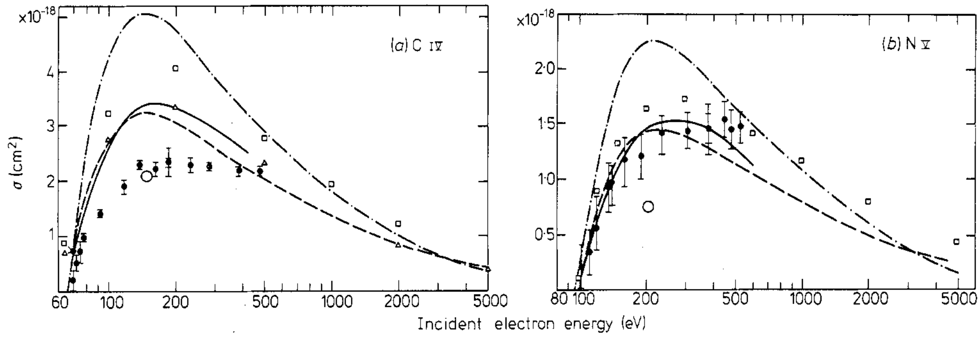

Figure 1. Cross sections for electron impact ionisation of (*a*) C IV, and (*b*) N V. Present data, ——; Crandall *et al* (1978), ●; result inferred from rate measurement by Kunze (1971), ○; Lotz (1968) formula, □; ECIP, Barfield (1978), △; Salop (1976) (classical theory), —·—·; Golden and Sampson (1977), ---.

where I_{1s} is the K-shell ionisation energy in rydbergs. Q_R has been estimated from the calculations of Rudge and Schwartz (1966) by interpolating their Coulomb–Born (ii) no-exchange results for hydrogenic ions of charge $Z = 2$ and 128. The no-exchange results were chosen in order to be consistent with the outer-shell calculation. The value of Z chosen for the interpolation was 6·6 for both carbon and nitrogen ions. This was considered to give sufficient accuracy since the results are quite insensitive to values of Z between 5 and 8 and in any case the inner-shell ionisation contributes a relatively small contribution to the total. In fact, these contributions were found to be negligible over the energy range considered in this paper. Total cross sections for C IV and N V are compared with other existing theoretical and experimental data in figure 1. For C IV the present results, the exchange–classical impact-parameter calculation and the scaled infinite-Z Coulomb–Born exchange results of Golden and Sampson (1977) are in close mutual agreement below 400 eV. At the peak all three calculations lie about 30% higher than the crossed-beam experimental results of Crandall *et al* (1978), which, however, agree with the single point of Kunze at about 150 eV derived from a plasma-observed rate coefficient. Since configuration interaction effects are unlikely to be of major importance at least below 300 eV, the discrepancy could be accounted for possibly by the distortion of the incident and scattered electron wavefunctions from the pure Coulomb form assumed in the quantum-mechanical theoretical treatments or possibly by the approximate treatment (in the case of Golden and Sampson) or the dropping (in the case of the present results) of electron exchange. The fact that these two calculations agree implies that the exchange and interference terms in the calculations of Golden and Sampson must practically cancel. The classical calculation of Salop (1976) and the semi-empirical formula of Lotz (1968) are both in worse agreement with experiment, the former being over a factor of two higher at the peak. As far as the theory is concerned the overall picture is rather similar for N V. However the two Coulomb–Born calculations are now in excellent agreement with experiment up to 400 eV; and in the case of the present results, beyond 500 eV. This agreement would imply that not only do exchange and interference terms cancel, as in C IV, but also that distorted-wave effects are unimportant. However it seems strange that there could be such a big difference between C IV and N V in this respect when their nuclear charges only differ by one unit. In N v the result derived from Kunze's (1971) measurement (at 200 eV) is almost a factor of two below the results of Crandall *et al* (1978). The differences in shape between observed and calculated cross sections above 200 eV for C IV and above 300 eV for N V are undoubtedly due to neglect in the theory of inner-shell excitation followed by autoionisation. In some preliminary calculations of the scattering of electrons by C V, autoionising states of the type $1s2s^2$, $1s2p^2$ and 1s2s2p are found at between 290 and 315 eV above the ground state of C IV. Such states would lead to enhancement of the ionisation at these energies and above via transitions of the type

$$1s^2 2s + e^- \rightarrow 1s2l2l' + e^- \rightarrow 1s^2 + 2e^-.$$

Higher autoionising states of the form $1s^2 2lnl'$ will also contribute as the energy increases. More elaborate calculations which employ close-coupling wavefunctions for the initial bound ion and for the final state of ion plus ejected electron are currently in progress. Such calculations will automatically include the effects discussed above since they include both open and closed channels in the ejected-electron wavefunction.

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