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Electron impact ionization cross sections of some members of the helium isoelectronic series

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Abstract. Ionization cross sections of Li^+, B^{3+}, O^{6+}, Ne^{8+} and Mg^{10+} by electron impact have been calculated semiempirically from threshold to 30 keV. The results are in reasonably good agreement with the available experimental and theoretical data.

1. Introduction

Miller and Platzman (1957) proposed an alternative method to calculate inelastic scattering cross sections for incident energies great enough to ensure validity of the Born approximation. Vriens (1965) extended this approach to the low-energy region semiempirically. He obtained encouraging results for atoms and molecules. Here we have employed the same approach to obtain ionization cross sections of ions with satisfactory results.

2. Theory and method

Following Vriens (1965) the ionization cross section is given by

$$Q_{\mathrm{i}} = AF\frac{(E_{\mathrm{el}}-I)}{E_{\mathrm{el}}^2}\ln[1+C(E_{\mathrm{el}}-I)] \tag{1}$$

with

$$A = 4\pi a_0^2 R M_{\mathrm{i}}^2 \tag{2}$$

and

$$F = 1+(1-CI)\left(0{\cdot}025+\frac{1{\cdot}6}{CI}\right)\left(1-\frac{I}{E_{\mathrm{el}}}\right)\left(\frac{I}{E_{\mathrm{el}}}\right)^{3/2}. \tag{3}$$

Here E_{el} is the incident electron energy, I the ionization potential of the target, a_0 the radius of the first Bohr orbit of hydrogen, R the rydberg energy and C is a parameter which depends upon the shape of the generalized oscillator strength as a function of the square of the momentum transfer vector (Miller and Platzman 1957). M_{i}^2 is expressible in terms of the continuous oscillator strength as

$$M_i^2 = \int_0^\infty \frac{R}{I+\epsilon}\frac{df}{d\epsilon}\,d\epsilon \tag{4}$$

where ϵ is the energy of the ejected electron. If the incident electron energy exceeds 1 keV, E_{el} is replaced by E'_{el} where

$$E'_{el} = \tfrac{1}{2}m_0c^2\left[1-\left(1+\frac{E_{el}}{m_0c^2}\right)^{-2}\right] \tag{5}$$

m_0 is the rest mass of the electron and c is the speed of light.

Bell and Kingston (1971) recently reported the continuous oscillator strength $df/d\epsilon$ for some members of the helium isoelectronic series in both length and velocity formulations. We have used their length values. As the nuclear charge increases, the difference in results between the two formulations decreases and the continuous oscillator strengths approach the correct values. For each target, we plotted $R/(I+\epsilon)\,df/d\epsilon$ against ϵ, and obtained M_i^2 by graphical integration. The result obtained for M_i^2 by this procedure was within 5 % of the value of M_i^2 obtained by Kim and Inokuti (1970) for Li^+. The parameter C was determined in the manner indicated by Vriens (1965) either through experimental or theoretical data. Peart *et al* (1969) observe that the Born approximation gives excellent agreement with the experiments when the electron energies exceed twenty times the threshold. We therefore determined the parameter C for all the targets near this limit. In the case of Li^+ ions, experimental data (Lineberger *et al* 1966, Wareing and Dolder 1967, Peart and Dolder 1968, 1969, Peart *et al* 1969) are readily available. For other targets neither experimental nor Born cross sections are available. We therefore employed the empirical cross sections of Lotz (1967a, b, 1968) to determine the value of C.

3. Results

Table 1 displays the values of M_i^2 and the parameter C for targets under consideration. The calculated cross sections are presented in table 2. For the sake of comparison, curves are drawn. In figure 1 we have shown the Born cross sections in the length formulation of Economides and McDowell (1969), Coulomb–Born results of Moores and Nussbaumer (1970), results of Narain (1974) using Khare and Padalia's approach (Khare and Padalia 1970), empirical results of Lotz (1967a, b, 1968) and experimental cross sections of Lineberger *et al* (1966) and those of Dolder and his associates (Wareing and Dolder 1967, Peart and Dolder 1968, 1969, Peart *et al* 1969) together with our results

Table 1 Values of M_i^2 and C.

Process	$M_i^2 \times 10^3$	$C\,(\mathrm{eV})^{-1}$
$Li^+ \to Li^{2+}$	137·900	0·1330
$B^{3+} \to B^{4+}$	35·650	0·1196
$O^{6+} \to O^{7+}$	11·320	0·0842
$Ne^{8+} \to Ne^{9+}$	7·180	0·0430
$Mg^{10+} \to Mg^{11+}$	4·784	0·0312

Table 2.

Incident electron energy (keV)	Li^+ (in 10^{-19} cm^2)	B^{3+} (in 10^{-20} cm^2)	O^{6+} (in 10^{-21} cm^2)	Ne^{8+} (in 10^{-21} cm^2)	Mg^{10+} (in 10^{-21} cm^2)
0·10	17·0	—	—	—	—
0·20	44·59	—	—	—	—
0·30	47·48	10·21	—	—	—
0·50	41·58	32·70	—	—	—
0·80	—	42·95	7·41	—	—
0·90	—	43·72	16·92	—	—
1·00	28·52	44·07	21·30	—	—
1·50	—	40·75	34·77	7·15	—
2·00	17·48	36·10	44·75	11·64	—
2·50	—	—	49·65	14·82	4·15
3·00	—	—	51·21	17·20	5·27
4·00	10·18	23·70	49·90	19·62	7·13
5·00	—	—	—	20·10	8·32
7·00	—	—	—	—	9·13
8·00	5·79	14·18	36·94	18·14	9·11
10·00	4·82	11·91	32·15	16·43	8·76
20·00	2·72	6·85	19·78	10·87	6·43
30·00	1·96	4·95	14·60	8·17	5·00

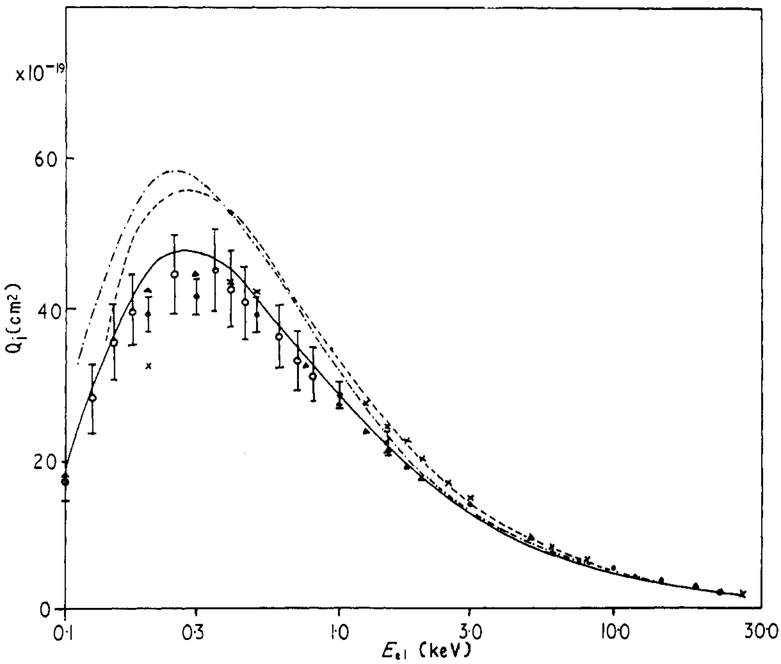

Figure 1. Ionization of Li^+ by electron impact. Experimental data: ● Wareing and Dolder (1967), Peart and Dolder (1968, 1969), Peart *et al* (1969); ○ Lineberger *et al* (1966). Theoretical results: —— present work; – – – – Economides and McDowell (1969); – · – · – Moores and Nussbaumer (1970); ▲ Lotz (1967a, b, 1968); × Narain (1974). Typical error limits are given for the experimental data.

for Li^+. Other results (Mathur *et al* 1969, Thomas and Garcia 1969, Tiwari *et al* 1970, Peach 1971) were left from comparison for the sake of clarity.

4. Discussion and conclusion

As is ovbious from figure 1, our results for Li^+ are in better agreement with the experimental results from 100 to 1500 eV than are the Born and Coulomb–Born results. At energies higher than 10 keV, both the present results, and the Born and Coulomb–Born results agree with the experimental data quite excellently. In the intermediate energy region the Born and Coulomb–Born results are in better agreement with the experimental results. The results obtained using Khare and Padalia's approach are not in good agreement at energies lower than 300 eV. However, they compare favourably at higher energies. The empirical results of Lotz appear to be in good agreement throughout the whole energy range.

Vriens (1965) observed that equation (1) is suitable for all atoms (molecules) in which one shell is mainly responsible for the ionization. It may be added that equation (1) is also quite satisfactory for ions having only one shell.

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