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SYSTEMATICS OF ELECTRON, PROTON
AND PHOTON IONIZATION CROSS SECTIONS (*)

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Résumé. — Nous présentons des résultats concernant les calculations des sections, en utilisant un modèle mono-électronique à noyau non relaxé, afin de calculer des forces d'oscillateur généralisées. Nous avons trouvé que les sections d'ionisation pour l'électron et le proton peuvent être exprimées en une forme réduite et possiblement universelle. Ensuite, nous discutons la possibilité d'exprimer les sections de photo-ionisation par une forme réduite.

Abstract. — We present results on cross section calculations using a one-electron, unrelaxed core model to compute generalized oscillator strengths. It is found that the electron and proton ionization cross sections can be put in a reduced, and possibly universal, form. The possibility of putting photoionization cross sections in a reduced form is then discussed.

I. Introduction. — We have used the approach discussed in the paper on Auger transitions to compute the generalized oscillator strength (GOS) for He-Ar. In a one-electron model with an unrelaxed core the GOS per nl electron per s'l' hole is given by

\[
\frac{df_n(e, K^2, l')}{de} = \frac{\Delta E}{K^2} \langle n l | e^{i K \cdot r} | s' l' \rangle^2
\]

where \(\Delta E = E - |E_{nl}|\), \(-E_{nl}\) is the ionization threshold, \(K^2\) is the momentum transfer, and we use atomic units. The ionization cross section is given by

\[
\sigma = \frac{4 \pi a_0^2}{M_e E_p / M_p} \times \int_0^\infty \frac{dE}{(e + |E_{nl}|)} \sum_{l' = 0}^{K^2 \text{max}} \frac{df_{nl}(e, K^2, l')}{de} \frac{K d^2}{K^2}
\]

where \(M_e\) and \(E_p\) are the mass and energy of the incident projectile. In addition to the ionization cross section we have computed \(d\sigma/d\varepsilon\), the excitation cross section and the stopping power [1]. In figures 1-3 we show some results of these calculations.

![Fig. 1.](image1.jpg)

![Fig. 2.](image2.jpg)

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II. Systematics. — The proton and electron ionization cross sections and the stopping power due to ionization are similar in shape for a particular shell. In figure 4 we plot the peak ionization cross section for incident electrons as a function of the ionization energy. All cross sections are plotted as though the shells were full. The slope is in general not an integer. We then used the computed cross sections to determine a least squares fit of the form.

$$\sigma_{\text{nl}} |E_{\text{nl}}|^2 = a_{\text{nl}} \left( \frac{M_e E_p}{M_p |E_{\text{nl}}|} \right).$$

We found that all the computed cross sections could be fitted to such a curve with no cross section value deviating from the least squares fit by more than 10%. In figure 5 we compare the least squares fit cross section for ionization of the K shell by electrons for He [2], [3], Al [4], Ni [5] and Ag [6], and for C, N, O, and Ne [7] at $E_{p}/|E_{\text{1s}}| = 4$. The experimental
points are for electrons with $E_p \leq 100$ keV. It should be mentioned that we have no free parameter (internal screening parameter) to fit the data as is the case in hydrogenic calculations. Similarly least square fits have been made for the 2s, 2p and 3s shells, but there is little data with which one can compare the calculations.

The photoionization cross section is related to the $K^2 = 0$ limit of the GOS. The electron and proton ionization cross sections involve a double integral over a region of the GOS in $(e, K^2)$ space. The photoionization cross section directly measures a section of the GOS. We are examining the possibility that atomic photoionization cross sections can be reduced to a form similar to Eq. 3. However, this is as yet an open question. In figures 6 and 7 we show the calculated photoionization cross section for the 1s and 3s shells, plotted as a function of $|E_{n\alpha}|$ with $\hbar \nu/|E_{n\alpha}|$ fixed at 1.01, 21 and 51. For the 1s case it appears a reduced cross section depending on $\hbar \nu/|E_{n\alpha}|$ only can be found. However, the possibility of doing so for the 3s cross section is not apparent.

III. Conclusions. — Our calculations indicate that while one can compute electron, proton and photon ionization cross sections in a reasonably accurate way for a particular element, and reduced cross sections for proton and electron ionization, the possibility of doing so for photoionization is still an open question. Another question, which we have not yet examined, is the possibility of finding reduced expressions for $d\sigma/d\Omega$. One could then predict the secondary electron spectrum, including Auger and Coster-Kronig electrons, arising from an initial inner shell ionization event.

References