Angular Distribution of Photoelectrons

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Lock-in Amplifiers up to 600 MHz
Angular Distribution of Photoelectrons*

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Recently, by means of photoionization and photodetachment measurements (so-called “photoelectron spectroscopy”), it has been possible to obtain important quantities such as ionization potentials, electron affinities, cross sections for electron photoejection, relative transition probabilities to excited states, etc.\(^1\)\(^-\)\(^9\) However, lack of knowledge of the angular distribution of ejected electrons has hampered really accurate measurements in most of these experiments.

We outline a simple calculation for determining the photoelectron differential cross section. For linearly polarized light the angular distribution has the general form

\[
d\sigma/d\Omega = (\sigma_{\text{total}}/4\pi)[1 + \beta P_{\pm}(\cos \Theta)],
\]

where \(P_{\pm}(\cos \Theta) = \frac{1}{2}(3 \cos^2 \Theta - 1)\), \(\sigma_{\text{total}}\) represents the total cross section, \(\Theta\) measures the angle between the direction of the ejected electron and the polarization of the incident light. \(\beta\) is an asymmetry parameter, given for an \(l\) (e.g., \(s\), \(p\), \(d\), \(\cdots\)) state by

\[
\beta = \frac{l(l-1)\sigma_{L-L}^2 + (l+1)(l+2)\sigma_{L+1}^2 - 6(l+1)\sigma_{L+1}\sigma_{L-L} \cos (\delta_{L+1} - \delta_{L-L})}{3(2l+1)[l\sigma_{L-L}^2 + (l+1)\sigma_{L+1}^2]}. \tag{2}
\]

Here \(\beta\) ranges from \(\beta = 2(d\sigma/d\Omega \sim \cos^2 \Theta)\) to \(\beta = -1(d\sigma/d\Omega \sim \sin^2 \Theta)\). In Eq. (2) \(\delta_i\) is the phase shift of the \(i\)th partial wave and

\[
\sigma_{L-L} = \int_0^{\infty} R_0 R_+ R_{L-L} dr
\]

is the usual dipole radial matrix element. Equation (2) has been derived by Bethe\(^10\) for a one-electron atom, but can apply to many electron atoms (even for equivalent \(l\)-electrons) provided the magnetic sublevels of the initial state are equally populated and the wavefunctions are represented by antisymmetrized products of spin orbitals. The same form as Eq. (1) is obtained in the presence of configuration interaction and intermediate coupling. Averaging over the rotational orientations of molecules also gives this form.

Numerical calculations have been carried out for several negative ions (\(C^-\), \(O^-\), \(F^-\), \(I^-\)) using the Robinson and Geltman\(^11\) potential, which is adjusted to give the correct binding energy. For the photoejection of an \(s\)-type electron, as in \(H^-\), only an outgoing \(p\) wave results. Then from (2) the angular distribution shows a \(\cos^2 \Theta\) behavior for all photon energies. For the photoejection of a non-\(s\)-type electron, two competing outgoing channels exist and the form of the anisotropy will depend on the interference

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**Fig. 1.** The asymmetry parameter \(\beta\) as a function of photon energy for the photodetachment processes: \(C^- (1S) + h\nu \rightarrow C(2P) + e^-\), and \(O^- (2P) + h\nu \rightarrow O(4P) + e^-\). For unpolarized light the angular distribution is still represented by Eq. (1) if \(\beta\) is replaced by \(- (1/2)\beta\) and if \(\Theta\) measures the angle between the ejected electron and the light beam.
between the \( l'' = l' \pm 1 \) partial waves. Results for the 
ejection of a \( p \) electron from \( C^- \) and \( O^- \) (typical of 
the negative ions investigated) are shown in Fig. 1. 
The remarkable finding is that for an energy of several 
electron volts close to threshold, the angular distribution 
of these photodetachment electrons is predicted to peak at right 
angles to the polarization vector, rather than along the 
polarization vector. At threshold, \( d\sigma/d\Omega \) is isotropic 
(see Fig. 1), as only outgoing \( s \) waves contribute, and 
far from threshold, \( d\sigma/d\Omega \) tends toward a \( \cos^2\theta \) dis­
tribution. However, preliminary calculations for photo­
ionization of argon, krypton, and xenon show, a few 
vols from threshold, only positive \( \beta \) values, in qual­
itative agreement with Ref. (7).

Figure 2 compares our calculated angular dis­
tribution for the photodetachment of \( H^- \) and \( O^- \) with 
the experimental data of Hall and Siegel. We con­
clude that measurements which are sensitive to the 
form of the photoelectron angular distribution (par­
ticularly for non-\( s \) electrons) should be carefully ex­
amined for possible systematic errors.

Angular Dependence of the Laser Photo­
detachment of the Negative Ions of Carbon, 
Oxygen, and Hydrogen*

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In the preceding Communication, Cooper and Zare1 show that in certain cases photodetachment differ­