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LETTER TO THE EDITOR

Measurement of β values and branching ratios in the region of the $3s3p^6 4p\ ^1P_1^o$ resonance in Ar and the $5s5p^6 6p\ ^1P_1^o$ resonance in Xe

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Abstract. Variations in asymmetry parameter, β, and the ratio of partial photoionisation cross sections $\sigma(^2P_{3/2}):\sigma(^2P_{1/2})$ have been determined in the region of the $3s3p^6 4p\ ^1P_1^o$ resonance in Ar and the $5s5p^6 6p\ ^1P_1^o$ resonance in Xe. In both cases there is a considerable variation in β through the resonance. In Ar the β values for the spin–orbit components are similar; in Xe they are significantly different. In Xe, the branching ratio shows a modest variation through the resonance, whereas in Ar no noticeable change occurs.

We report the first measurement of the angular distribution parameter, β, for the two spin–orbit-split components of the photo-emitted outer p electrons in Ar and Xe in the region of the autoionising 'window' resonances associated with the excitation of an outer subshell s electron to the first Rydberg orbital. In Ar this resonance occurs at 465·8 Å (26·62 eV), in Xe at 591·8 Å (20·95 eV). We also measure the ratio of partial cross sections $\sigma(^2P_{3/2}):\sigma(^2P_{1/2})$ in the same spectral ranges. This branching ratio has been determined previously in Xe by Kemeny *et al* (1977); the two sets of data disagree somewhat, even when account is taken of the better spectral resolution in the earlier experiment.

The first measurement of the variation of angular distribution of ejected photoelectrons through autoionising atomic resonances was made by Samson and Gardner (1973) in the region between the $^2P_{3/2}$ and $^2P_{1/2}$ limits in Xe. Since no photoelectrons other than those associated with the $5p^5(^2P_{3/2})$ limit could be produced, no energy analysis was required. They found large variations in β from +0·9 to −0·9 in the region of the $5p^5(^2P_{3/2})\ nd$ series ($n = 7, 8$), in good agreement with the theoretical predictions of Dill (1973).

In the present experiment a high-aperture 2 m normal incidence monochromator (Ederer *et al* 1980) was coupled to the National Bureau of Standards (SURF-II) storage ring. A 1200 lines/mm grating and an 'entrance slit' (the electron orbit) of about 0·1 mm combined to produce a spectral resolution (FWHM) of 0·5 Å. A 50 mm mean-radius hemispherical electron energy analyser, set to give a resolution of about

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100 meV (Parr *et al* 1980), rotated in a plane at right angles to the incident monochromatised photon beam and was operated at a constant pass energy of 5 V. The relative efficiency of the pre-retarding (pre-accelerating) lens system was determined using the inert gases, whose photoionisation cross sections are well known.

The light incident upon the interaction region was elliptically polarised and therefore the conventional form for the angular distribution of photoelectrons was recast in the following way:

$$I(\theta) = k[1 + \beta(3p \cos 2\theta + 1)/4].$$

In this expression $I(\theta)$ is the electron intensity at angle θ to the major polarisation axis, β is the asymmetry parameter, $p = (I_{\parallel} - I_{\perp})/(I_{\parallel} + I_{\perp})$ is the polarisation of the light (measured by a three-mirror polarisation analyser) and k incorporates unknowns such as the atom number density.

At each photon energy through the two resonances, electron spectra encompassing the two spin–orbit components were measured at three angles: 0°, 45° and 90°. After correction for any geometrical asymmetry in the interaction region, the β values for each component were determined using two of the three measurements and then checked against the third. The error bars associated with the β values in figures 1 and 2, which were effectively derived from the degree of agreement between these measurements, were found to be consistent with those calculated from the RMS values of the total number of counts in the electron peaks and the uncertainty in the geometrical asymmetry correction. Once β was determined, these same data were re-used to obtain the ratio of partial cross sections $\sigma(^2P_{3/2}):\sigma(^2P_{1/2})$ and an associated error bar. This ratio was independent of any assumptions with regard to the long-term stability of the gas pressure. However, by maintaining the Ar and Xe pressures at a constant value throughout a series of runs, the *sum* of the partial cross sections could be determined through the resonance region. Variations in this sum should exactly mirror the known total photoionisation (photoabsorption) cross sections of Ar and Xe. This measurement constituted not only an important check on exactly what region of the resonance was being studied but also what spectral resolution had actually been achieved in the experiment.

The results for Ar are shown in figure 1. At the bottom of the figure is shown the variation in β for the ejected 3p electrons on passing through the $3s3p^64p\ ^1P_1^o$ resonance. The major variation in β from 0·85 to 1·7 takes place within the width of the resonance, Γ. (Γ = 80 meV or 1·4 Å, see Madden *et al* 1969.) The slit width of 0·5 Å is seen to be considerably smaller than this and therefore the 'total' cross section shown at the top of the figure and normalised to a value of 900 cm^{-1} (33·5 Mb) at 468 Å should be, and indeed is, quite similar to that of Madden *et al*. The variation of β is the same, within experimental error, for both the $^2P_{1/2}$ and $^2P_{3/2}$ components. The mean value is plotted in the figure. β values have previously been measured in this spectral region using synchrotron radiation (Houlgate *et al* 1974, Watson and Stewart 1974) but the single point at 462 Å obtained by Dehmer *et al* (1975) is indicative of the overall agreement. An *R*-matrix calculation by Taylor (1977) is in qualitative agreement with the present data. He obtains a much larger change in β from 0 to 1·8, and a width (peak-to-valley distance) that is more than a factor of two less.

Plotted on the same figure is the $\sigma(^2P_{3/2}):\sigma(^2P_{1/2})$ branching ratio. The value does not depart significantly from the straight-line value of 1·9 : 1. Thus the value of 1·93 : 1 given by Samson *et al* (1975) in the region from threshold to 25 eV above, appears to be maintained throughout the resonance region. The theoretical value (the statistical

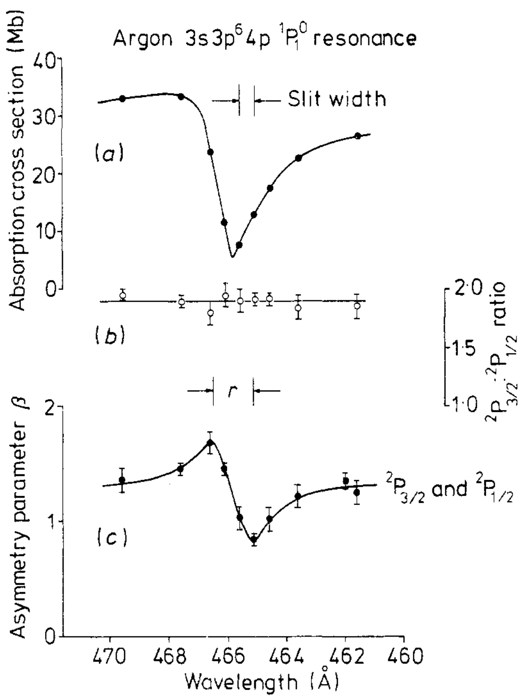

Figure 1. This figure shows (a) the photoabsorption (photoionisation) cross sections, (b) the branching ratio $\sigma(^2P_{3/2}):\sigma(^2P_{1/2})$ and (c) the asymmetry parameter β for the 3p electrons in Ar in the region of the 3s3p^{6}4p $^1P_1^o$ resonance. The data point in the bottom curve at 462 Å is from Dehmer *et al* (1975).

weight) is of course 2 : 1. The facts that the β values are the same and that the branching ratio is unchanged is taken as an indication of the weakness of the spin–orbit interaction in the case of Ar. For window resonances ($q \sim 0$) with high values of ρ^2 (the correlation index, Fano and Cooper 1965), the variation in cross section appears equally as impressive as that in β. This additional information on β should allow an almost complete characterisation of the electron correlation effects in the region of this particular resonance.

The results for Xe are shown in figure 2 in the region of the 5s5p^{6}6p $^1P_1^o$ resonance at 20·95 eV. The structure in the spectral range was first studied photographically by Madden and Codling (1964) and subsequently Ederer (1971, 1976) parameterised the strongest resonance in terms of q, Γ and ρ^2. The 20·95 eV resonance cannot be considered in any sense isolated. Indeed, the decreases in cross section, branching ratio and β at 21·03 eV are due to the existence of a further resonance centred at that energy. Even so, it is of interest to see whether the increased importance of spin–orbit interaction produces different values of β for the two components and if the branching ratio is changed as radically as suggested by Kemeny *et al* (1977). These workers used a resolution of 0·3 Å (FWHM), which is somewhat superior to the present value, but they were unable to make measurements in the cross section minimum; the $^2P_{1/2}$ component could not be seen above background. In the present experiment a strong signal was observed for both components and the major question was whether the resolution was sufficient to allow a reasonable deconvolution of the data.

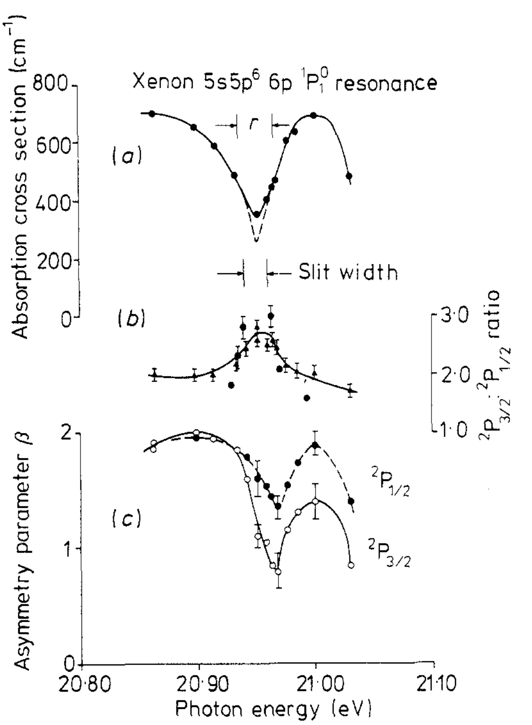

Figure 2. This figure shows (*a*) the photoabsorption (photoionisation) cross section, (*b*) the branching ratio $\sigma(^2P_{3/2}):\sigma(^2P_{1/2})$ and (*c*) the asymmetry parameter β for the 5p electrons in Xe in the region of the $5s5p^66p\ ^1P_1^o$ resonance. To avoid confusion, only a few error bars are shown. These are typical of the error bars on the remaining data points. At energies of 20·862, 20·913 and 30·933 eV the β values for the two components were the same, within experimental error. The six data points in (*b*) are taken from Kemeny *et al* (1977).

One sees at the bottom of figure 2 that the β variation for the two components is quite similar, although the $^2P_{3/2}$ component goes through larger excursions. Moreover, as in the case of Ar, the minima in β do not coincide with the minima in the cross section. It is interesting to note that the β values for the $^2P_{1/2}$ component are larger than those for the $^2P_{3/2}$ component in the resonance region whereas at 21·21 eV this component has a smaller value (Carlson and Jonas 1971, Niehaus and Ruf 1972, Dehmer *et al* 1975). The values according to Dehmer *et al* are $^2P_{3/2}$: $1{\cdot}63\pm0{\cdot}05$; $^2P_{1/2}$: $1{\cdot}77\pm0{\cdot}05$. At 40·8 eV the values reverse, $^2P_{3/2}$: $1{\cdot}58\pm0{\cdot}03$; $^2P_{1/2}$: 1·28 ($\pm0{\cdot}03$).

The variation in the ratio of partial cross sections is plotted in the middle of figure 2, but before discussing it, one should look at the top curve, where the total photoionisation cross section, normalised to a value of 700 cm^{-1} at 20·86 eV, is plotted. This curve agrees well with that of Ederer (1971) except in the region of the minimum. If one convolutes the Ederer (broken) curve with a Gaussian of FWHM 0·5 Å, one obtains the present minimum value of about 340 cm^{-1}.

The Kemeny *et al* (1977) branching ratios are shown on the same figure. There is fair agreement with their data, although the 'shape' of their curve is substantially different from ours. Their calculation based on the six earlier data points led to a theoretical value of branching ratio in the resonance minimum of 8·8 ($\pm0{\cdot}5$). If one convolutes their theoretical curve with a Gaussian of 0·5 Å FWHM, the peak value of the branching ratio expected in the present experiment would be about 5·5. We obtained an average value of approximately 2·6 in the peak region, in considerable disagreement with their theoretical predictions. This disagreement can be explained, to some extent, in terms of the different curve 'shapes' measured experimentally. It should be possible, using the present data on β and branching ratio together with the previous total cross section data, to produce a consistent picture to characterise the various interactions in the region of this particular resonance.

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