

LETTER TO THE EDITOR

Spin-polarised photoelectrons from krypton and argon atoms exposed to circularly polarised synchrotron radiation

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Abstract. Circularly polarised synchrotron radiation has been used to produce spin-polarised photoelectrons from krypton and argon atoms (Fano effect). The results obtained experimentally in the autoionisation and the continuum regions are presented and discussed. In the case of argon they are compared with Lee's theoretical prediction.

Experimental studies of the spin polarisation of photoelectrons are of interest because one can obtain detailed and possibly full information about the parameters which describe the photoionisation process. This letter presents the results of the spin-polarisation measurements of the rare gases krypton and argon exposed to circularly polarised light (Fano effect). The experiments have been performed using synchrotron radiation because this radiation, emitted into directions above and below the plane of the electron beam, contains a large fraction of circular polarisation in the VUV region where no other methods for producing circular polarisation exist.

The apparatus used (figure 1), built at the 2.5 GeV synchrotron in Bonn, has been described earlier together with measurements of the circular polarisation of the radiation and spin-polarisation results obtained from xenon atoms (Heinzmann *et al* 1979) and molecules (Heinzmann *et al* 1980a). The radiation passes through a 10 m normal-incidence monochromator consisting of a plane grating and a concave mirror. An aperture movable up and down cuts off the radiation in the vertical direction for selecting radiation of left-handed (upper half) or right-handed (lower half) circular polarisation, respectively. The monochromatic radiation coming through the exit slit (bandwidth 0.05 nm) ionises the rare-gas atoms; its polarisation is analysed by a reflection analyser. In the wavelength range between 60 and 100 nm the circular polarisation of the radiation has been measured to be $-83 \pm 3\%$ for a vertical angular range of 1 to 3.5 mrad accepted; its absolute intensity is $(4 \pm 1) \times 10^9$ photons/(second 0.05 nm bandwidth), measured by Heinzmann *et al* (1980b) with a double ionisation chamber (Samson 1964).

The photoelectrons produced are extracted and spin analysed by a Mott detector. Because all electrons are extracted by an electric field of 30 V cm^{-1} , regardless of their direction of emission, and the size of the target is about $5 \times 5 \times 5 \text{ mm}^3$, the photoelectrons have an energy spread of about 15 eV. Therefore an electron spectrometer for the separation of electrons with different kinetic energy cannot be used in this experiment.

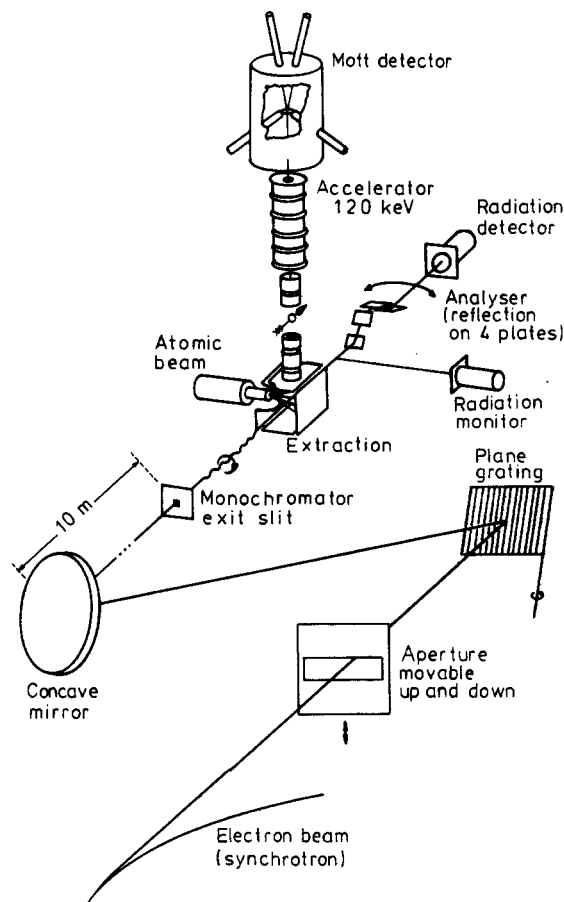


Figure 1. Schematic diagram of the apparatus.

The results of the photoionisation measurements for krypton and argon atoms are shown in the figures 2 and 3, and 4 and 5, respectively. In figure 2(a) our measured photoelectron intensities (points) are compared with the cross section measured by Saile (1976) (full curve). They are also in good agreement with other absolute cross section measurements from Carter and Hudson (1973). The resonance structure is due to autoionising processes between the first and the second ionisation thresholds (88.6 and 84.5 nm) which correspond to the final states $^2P_{3/2}$ and $^2P_{1/2}$ of the residual ions, respectively. The results shown in figure 2(a) indicate that at least the first two overlapping resonances of the broad d series and the sharp s series could be resolved in our experiment. In figure 2(b) the polarisation data measured are shown, where the vertical error bars represent the single statistical error of the spin-polarisation measurement including the uncertainty of the light polarisation and of the asymmetry function of the Mott analysis. The horizontal error bars indicated at only a few points are given by the bandwidth of the radiation used. The wavelength dependence of the polarisation also shows a pronounced structure due to autoionisation processes. It is worth noting that the polarisation curve of krypton is similar to that of xenon (Heinzmann *et al* 1979).

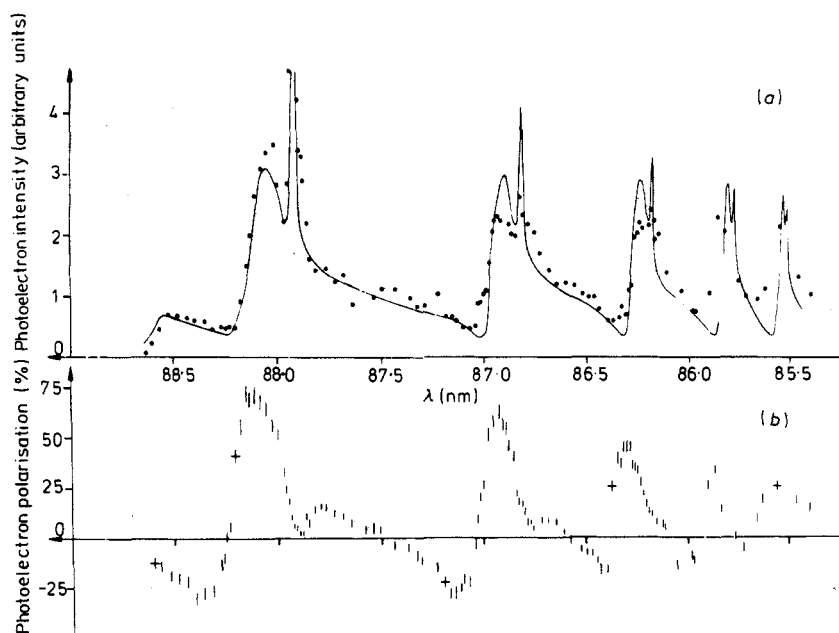


Figure 2. Photoionisation of krypton atoms in the autoionisation range. (a) Photoelectron intensity: points, this work; full curve, Saile (1976). (b) Spin polarisation of photoelectrons measured.

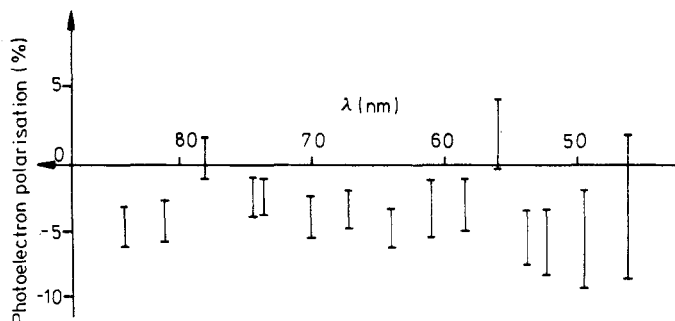


Figure 3. Spin polarisation of photoelectrons from krypton beyond the second ionisation threshold.

The polarisation of the photoelectrons obtained beyond the second ionisation threshold where the cross section does not show any resonance structure (Marr and West 1976, Huffman *et al* 1963) is shown in figure 3. Since an electron spectrometer could not be used, the polarisations measured are means of the values for electrons leaving the ions in the two ionic states $^2P_{3/2}$ and $^2P_{1/2}$. The fact that this average polarisation does not vanish indicates that the influence of the spin-orbit interaction in the continuum (Fano 1969) must not be neglected (Cherepkov 1974). This is also in agreement with the photoionisation results for xenon atoms (Heinzmann *et al* 1979).

In figure 4 the results obtained in the autoionisation range of argon are shown. Because the spin-orbit interaction is much weaker for argon than for krypton and

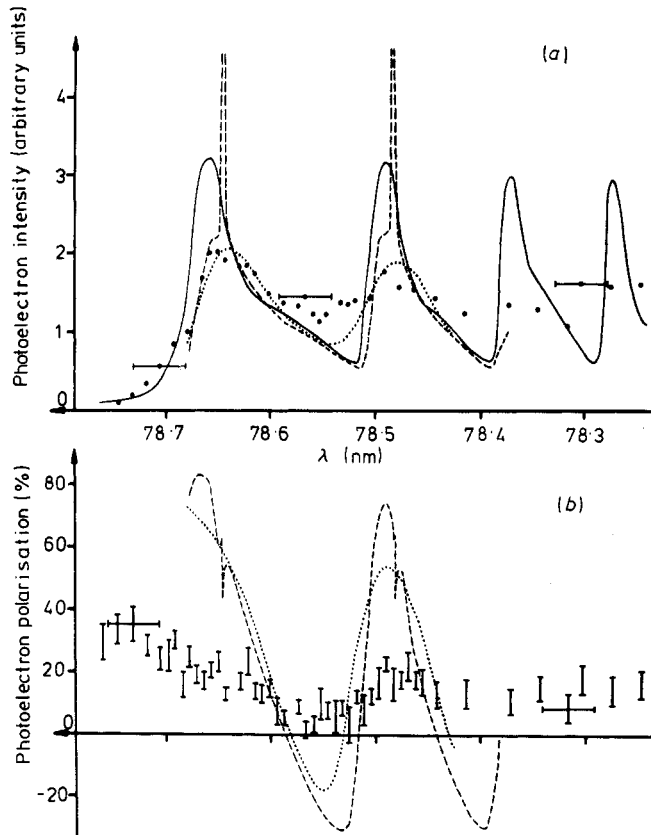


Figure 4. Photoionisation of argon atoms in the autoionisation range. (a) Experimentally obtained photoelectron intensity: points, this work; full curve, Hudson and Carter (1968). (b) Spin polarisation of photoelectrons: broken curves, theoretical prediction by Lee (1974); dotted curves, Lee's predictions, folded with experimental bandwidth of 0.05 nm.

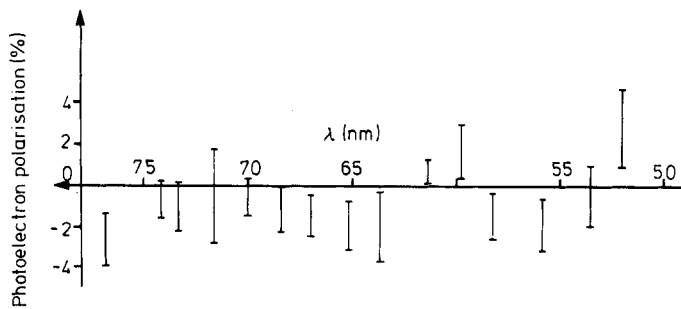


Figure 5. Spin polarisation of photoelectrons from argon beyond the second ionisation threshold.

xenon, the fine-structure splitting of the ions in argon is only 177 meV compared with 0.66 and 1.3 eV for Kr and Xe, respectively. Therefore the autoionisation resonances are closer to each other and much narrower. The bandwidth of the light, indicated at some points in figure 4 by horizontal error bars, was too broad to resolve the resonances

completely. For comparison with our measured photoelectron intensity, the cross section measured by Hudson and Carter (1968) using the smaller bandwidth of 0.004 nm is drawn as a full curve in figure 4(a). The broken curve represents the theoretical prediction of Lee (1974), which shows a slight shift towards shorter wavelengths. The dotted curves in figure 4 are identical with Lee's prediction, but folded with the experimental bandwidth of 0.05 nm. The cross section curve shows reasonable agreement with our measurement.

Unlike the case of krypton, the polarisation of the photoelectrons from argon atoms shown in figure 4(b) does not show a pronounced resonance structure. In the whole autoionisation range the polarisation is positive with maximum values of 35%. Lee's prediction (broken curve) does not show agreement with the experimental results. Even if Lee's curve is bandwidth corrected (dotted line), a discrepancy remains between the measured values and the theoretical curve. This disagreement is in contrast to the case of the measured argon cross section which agreed with the folded curve of Lee, as pointed out above.

The polarisation results obtained in the continuum region of argon are shown in figure 5. Unlike those for xenon and krypton, the polarisation values measured for argon nearly vanish (smaller than 3%). This is clear evidence that the spin-orbit interaction in the continuum no longer has an appreciable influence in the case of the lighter rare-gas atoms.

These data for krypton and argon are being used for an analysis of the photoionisation process by means of the multichannel quantum-defect theory.

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