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APPLICATION OF A THRESHOLD ELECTRON SPECTROMETER IN SPIN RESOLVED PHOTOELECTRON ANALYSIS

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The paper shows that threshold photoelectron spectroscopy can be succesfully performed, even if the spin polarization is the object of interest. Using circularly polarized radiation from the Bonn 2.5 GeV synchrotron photoelectrons from argon atoms produced directly at threshold have been analyzed with respect to their energy by means of a threshold electron spectrometer and with respect to their spin in order to test this combined method. The comparison of the experimental result with predictions of a RRPA-calculation shows quantitatively good agreement.

Experimental work in recent years has clearly demonstrated that spin polarization of photoelectrons is the rule rather than the exception for most atomic and molecular systems [1]. One way to get polarized photoelectrons is the Fano effect, a spin polarization transfer from the ionizing light (circularly polarized synchrotron radiation) to the photoelectrons produced even if they are extracted by an electric field regardless of their direction of emission. The main disadvantage of this method in photoionization experiments with molecules and heavier atoms is that photoelectron spectroscopy could not be performed due to the pronounced energy spread of the photoelectrons caused by the strong electric extraction field used. Furthermore the use of a conventional differential electron spectrometer to resolve the photoelectron emission with respect to the kinetic energy also requires angular resolution of not worse than $\pm 5°$ in order to keep aberration terms small enough and to achieve a reasonable energy resolution. Thus integral detection of photoelectrons emitted regardless of their direction of emission is not compatible with energy resolution using a conventional differential electron spectrometer. Furthermore, an angular resolved photoelectron emission experiment would result in an intensity loss of about two or three orders of magnitude [2] additional to the intensity loss of 10^3 in the spin polarization analysis using Mott scattering [3]. Photoelectron spectroscopy studies resolved simultaneously with respect to spin and emission angle could therefore only be performed up to now using intense unpolarized or linearly polarized light from rare gas discharge light sources [2].

The intensity of the circularly polarized VUV radiation from the 2.5 GeV synchrotron in Bonn used for the measurements of the Fano effect mentioned above was two orders of magnitude too low for a similar angle resolved experiment. However, the energy resolution for the spin polarization transfer experiment could be achieved in another way: It is the purpose of this paper to demonstrate that the application of a threshold electron spectrometer, a well-known method [4] especially in molecular photoionization, is successfully usable in spin resolved photoelectron spectroscopy.

The threshold spectrometer used for first measurements with argon atoms was capable of an energy resolution of 3 meV [5]. The overall experimental arrangement at the Bonn synchrotron, which is described in detail elsewhere [6], is schematically shown in fig. 1. The synchrotron radiation passed through a 10 m normal incidence monochromator with a plane holographic grating (4960 lines/mm) and a concave mirror, using the electron beam as a virtual entrance slit. The radiation emitted from the tangential point was cut off in vertical direction by an aperture movable up and down for selecting radiation of left-handed (upper half) or right-handed (lower half) circular polarization, respectively. The circular polarization of the monochromated radiation behind the exit slit has been measured by means of a four-mirror-arrangement: the radiation emitted in the upper or lower directions with respect to the synchrotron plane had a degree of circular polarization of $\pm 75\%$.

Photoelectrons were produced in the central region of the threshold electron spectrometer, which is schematically shown in fig. 2. The argon atomic beam, produced by a capillary array, was pumped by means of a liquid helium-cooled cryo pump. Electrons, originating from the interaction volume, were accelerated in the

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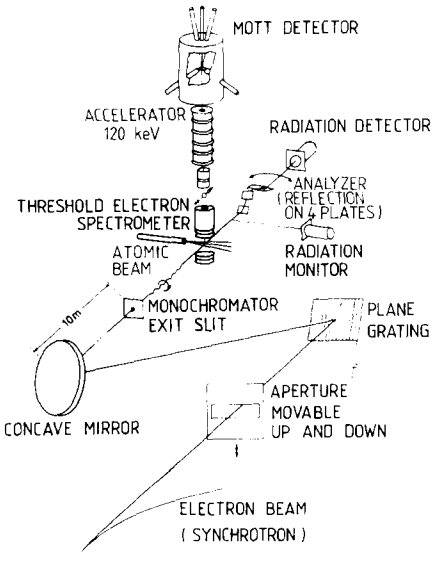

Fig. 1. Schematic diagram of the apparatus.

homogeneous electric field (0.4 Vcm^{-1}) of the parallel plate condenser. According to the Abbé law of electron optics, only electrons with very low initial kinetic energy, produced at the ionization threshold, enter the first aperture with a direction almost parallel to the axis of rotation of the drift tube. They are transmitted therefore through the second aperture, whereas electrons with higher kinetic energy are still divergent after acceleration. Electrons, which are ejected along the axis of the drift tube, cannot be suppressed, whatever their kinetic energy may be. They produce a background which, however, can be made small enough by choosing appropriate apertures. Magnetic fields were compensated by means of three pairs of Helmholtz coils and a Mu metal shielding. After passing the second aperture, the threshold electrons were accelerated to 80 eV and then to 3.5 keV kinetic energy in the subsequent five element zoom lens, which serves for focusing the electron beam into the acceleration tube. The spin polarization of the photoelectrons was analyzed by Mott scattering at 120 keV. The detectors in backward and forward directions allowed the simultaneous registration of spin polarization data and intensity spectra.

An argon threshold spectrum, obtained by scanning the monochromator, is shown in fig. 3. This spectrum was registered with a channel electron multiplier directly behind the five element zoom lens with a background pressure of 2×10^{-5} mbar in the vacuum chamber. The halfwidth of the peaks corresponding to the final ionic states $Ar^+ {}^2P_{3/2}$ and $Ar^+ {}^2P_{1/2}$ of 0.09 nm mainly represents the resolution of the optical monochromator, whereas the electron band passing the analyzer has a fwhm of 3 meV [5].

Fig. 4 shows in the lower part the spin polarization value measured for the $^2P_{3/2}$ final ionic state of argon [38 ± 10%] as a filled bar (bandwidth 3 meV). The other data points [7] were obtained without the threshold spectrometer [the horizontal error bars are given by the optical bandwidth of 0.08 nm]. The full and the dashed curves are RRPA calculations by Johnson et al. [8] and MQDT calculations by Lee [9], respectively. In the

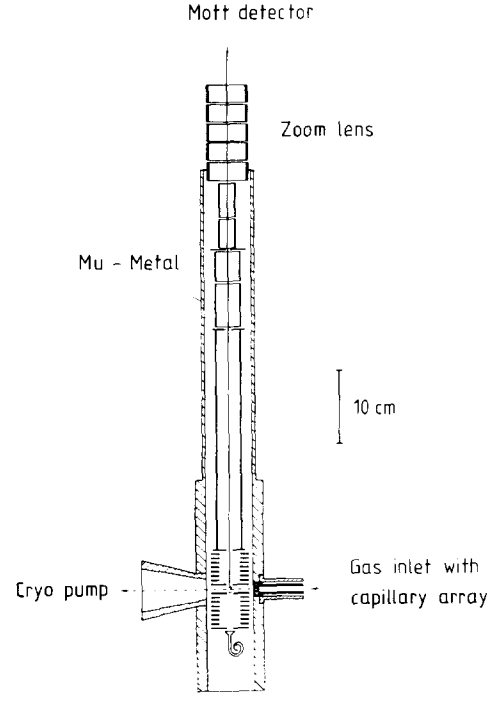

Fig. 2. Set-up for the threshold electron spectrometer.

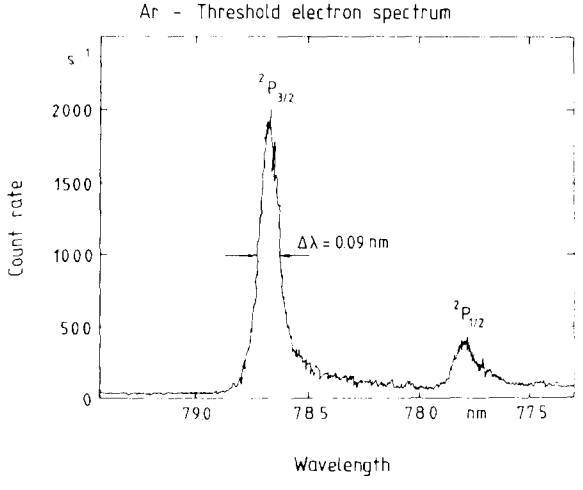

Fig. 3. Intensity spectrum obtained by scanning the monochromator with argon as target gas.

upper part of fig. 4 the points represent the photoelectron intensities measured, the full curve the experimental results of Hudson and Carter [10] and the dashed curve the calculation by Lee [9]. The agreement between the experimental and the theoretical results in fig. 4 is poor because of the energy bandwidth in the experiment which has the same magnitude as the pronounced resonance structure predicted by the theories and shown in fig. 4, too. This was the reason to increase the energy resolution in the experiment by a factor of 5 using the threshold electron spectrometer.

Fig. 5 shows our experimental results in comparison with the measured [10] and theoretical [8,9] curves which are folded, however, with our experimental bandwidth. Indeed, fig. 5 shows that the RRPA calculation [8] (solid curve) agrees very well with the experimental results after the convolution process, more than the MQDT theory [9] does. The use of the threshold electron spectrometer enabled us therefore, to test different theories with respect to their validity although pronounced resonance structure of the cross section and of the spin polarization determine the photoionization process. Due to the fact that the intensity of the circularly polarized synchrotron radiation in Bonn was only 10^9 photons per second [11] which is relatively low compared with the intensity of VUV radiation produced by discharge lamps [2], the count rates in the Mott detector

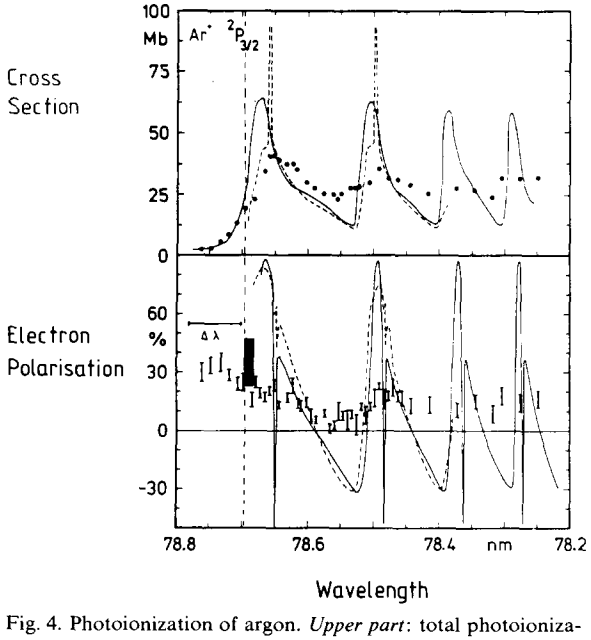

Fig. 4. Photoionization of argon. *Upper part*: total photoionization cross section; points: experimental results, this work and ref. 7, solid curve: measurements by ref. 10, dashed curve: theoretical prediction by ref. 9. *Lower part*: spin polarization of photoelectrons; error bars: this work and ref. 7, solid curve: RRPA calculation by ref. 8, dashed curve: MQDT calclation by ref. 9.

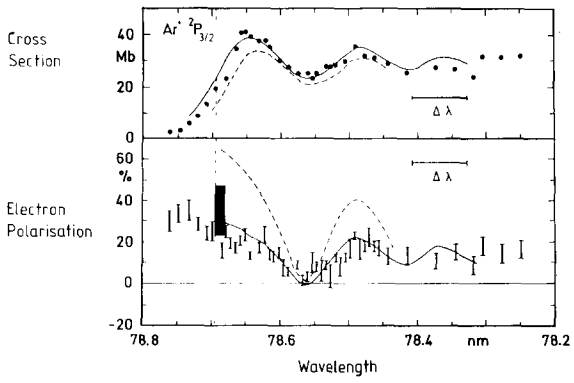

Fig. 5. Photoionization of argon, the same as in fig. 4, but with curves which are folded with the bandwidth of this work.

were 0.2 cts s^{-1}. Therefore, after the measurements with argon atoms experiments with molecules proved to be impossible to be performed in Bonn, because molecules generally have a smaller photoionization cross section than argon atoms. In molecular photoionization the use of the threshold electron spectrometer would yield much more information because of the large number of different photoionization thresholds of molecules corresponding to different final ionic states including vibrational fine structure. Work with the new storage ring BESSY where two orders of magnitude more intensity of circularly polarized synchrotron radiation are expected will probably enable us to continue spin resolved photoelectron spectroscopy also with targets having small cross sections. The result of this paper shows that the technique of combining a threshold photoelectron spectrometer with spin polarization analysis works and yields an energy resolution in spin polarization spectroscopy which could neither be obtained using better resolving optical monochromators nor conventional electron spectrometers.

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