Elastic Scattering Of Spin Polarised Electrons From Krypton

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Abstract. Calculated values of the Sherman function for krypton at 60 and 65eV incident electron energy show large predicted values and a rapid dependence on energy for the sign of the asymmetry. These unexpectedly large asymmetries have prompted an experimental investigation of this target. In this paper the current status of these measurements and further theoretical and experimental results for the Sherman function for elastic scattering of spin polarised electrons from krypton will be discussed.

INTRODUCTION

The scattering of spin-polarised electrons from atoms yields an immediate means of probing spin-dependent interactions. A sensitive spin-dependent observable is the left-right asymmetry in the scattering of the spin up/down electrons by the target. An asymmetry in the scattering of polarised electrons elastically scattered from noble gases can only arise from the spin-orbit interaction of the projectile electron in the field of the atom. Electrons, with a degree of polarisation P perpendicular to the scattering plane, impinging on a noble gas target are scattered. Measurements of the difference in the number of electrons scattered at equal angles to the left and right of 0° yields the asymmetry A such that

$$A=\frac{N_L - N_R}{N_L + N_R} = S_A P \ , \tag{1}$$

where S_A is called the asymmetry function and for elastic scattering is equal to the Sherman function, S [1]. Equivalently if the electron polarisation can be switched without affecting the beam or introducing experimental asymmetries, N_L and N_R can be replaced with scattering intensities on one side but for up $N\uparrow$ and down $N\downarrow$ electron polarisations respectively.

In this paper we present new calculations of the Sherman function for elastic scattering from krypton at 60 and 65eV incident electron energy which predict large values of the Sherman function, and a rapid dependence on energy of the sign of the asymmetry. These unexpectedly large asymmetries at 60 and 65eV have prompted our investigation of this process.

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THEORY

The details of the derivation of the Dirac equations for the case of elastic scattering of electrons from closed-shell atomic systems has been given elsewhere [2]. Consequently, we will present only a brief outline of our procedure. In the relativistic Dirac treatment of electron scattering, the large and small radial components, $f_\kappa(r)$ and $g_\kappa(r)$, of the scattered electrons satisfy the coupled first-order differential equations

$$\frac{\mathrm{d}}{\mathrm{d}r} f_\kappa(r) + \frac{\kappa}{r} f_\kappa(r) - \alpha\left[\frac{2}{\alpha^2} - V(r) + \varepsilon\right] g_\kappa(r) - \alpha W_Q(\kappa;r) = 0 \tag{2a}$$

and

$$\frac{\mathrm{d}}{\mathrm{d}r} g_\kappa(r) - \frac{\kappa}{r} g_\kappa(r) + \alpha[-V(r) + \varepsilon] f_\kappa(r) + \alpha W_P(\kappa;r) = 0 \tag{2b}$$

subject to the boundary conditions

$$f_\kappa(0) = g_\kappa(0) = 0, \tag{3}$$

$$f_\kappa(r)_{r\to\infty} \to C_\kappa(k)\sin\left(kr - \frac{l\pi}{2} + \delta_\kappa(k)\right), \tag{4a}$$

and

$$g_\kappa(r)_{r\to\infty} \to C_\kappa(k)\frac{ck}{E+c^2}\cos\left(kr - \frac{l\pi}{2} + \delta_\kappa(k)\right), \tag{4b}$$

where $\delta_\kappa(k)$ is the phase shift and $\alpha = 1/c$ is the fine-structure constant. In equations (2a,b), the potential $V(r)$ is given by the sum of the usual static potential and an adiabatic dipole polarisation potential while the terms $W_P(\kappa;r)$ and $W_Q(\kappa;r)$ represent the large and small components of the non-local exchange interaction between the incident electron and the atom. For the definitions of the remaining parameters in the above equations the reader is referred to Ref [2].

Once the phase shifts have been determined the direct and spin-flip scattering amplitudes, $f(\theta)$ and $g(\theta)$, can be determined from the expressions

$$f(\theta) = \frac{1}{k}\sum_{l=0}^{\infty}\left[(l+1)T_l^+(k) + lT_l^-(k)\right]P_l(\cos\theta) \tag{5a}$$

and

$$g(\theta) = \frac{1}{k}\sum_{l=0}^{\infty}\left[-T_l^+(k) + T_l^-(k)\right]P_l^1(\cos\theta) \tag{5b}$$

with

$$T_l^\pm(k) = \frac{1}{2i}\left[\exp\left(2i\delta_l^\pm(k)\right) - 1\right]. \tag{6}$$

Here $\delta^{+}_{l}(k)$ is the so-called spin-up phase shift corresponding to $\kappa = -(l+1)$ while $\delta^{-}_{l}(k)$ is the spin-down phase shift corresponding to $\kappa = l$. Once the scattering amplitudes have been determined, the Sherman function $S(\theta)$ can be determined according to

$$S(\theta) = \frac{2\,\mathrm{Im}\left\{ f^{*}(\theta)\, g(\theta) \right\}}{\left| f(\theta) \right|^{2} + \left| g(\theta) \right|^{2}} . \tag{7}$$

APPARATUS

An overview of the experimental apparatus can be seen in figure 1. Light from a diode laser of wavelength 780nm is passed through a linear polariser, liquid crystal variable retarder combination to produce circularly polarised light which produces longitudinally polarized photoelectrons from a GaAs crystal. The electrons pass through a 90° deflector and exit with transverse polarisation. The electron beam is then focused onto the gas target by an electrostatic lens system. The gas enters the system through a single capillary. Electrons which are scattered from the gas are collected by a hemispherical electron energy analyser. The analyser is able to be rotated through an angle of 30°-130° in the scattering plane. The electron polarisation may be monitored by the use of a Mott detector operating at 100keV.

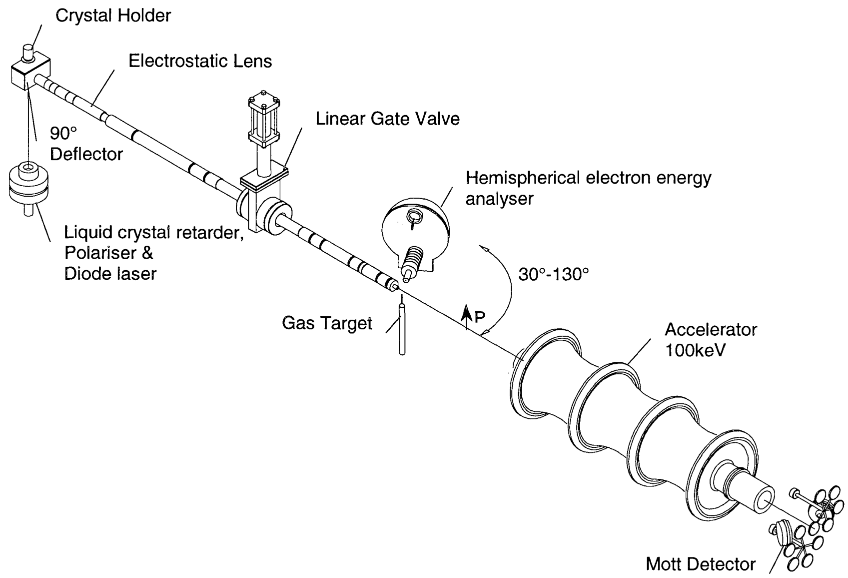

Figure 1. Schematic diagram of the experimental set-up.

The standard GaAs polarised electron source is used in this experiment. Polarised electrons are produced by photoemission from a negative electron affinity (NEA) surface. The NEA surface is produced by the application of caesium and oxygen to the GaAs surface which has first been heat cleaned at 660°C. The emission current for the duration of this experiment was 6-8μA with an associated 'half life' of approximately three weeks. Due to losses in the electrostatic lens system this current was reduced to 100-150nA in the interaction region.

A single hemispherical electron energy analyser detects electrons in the scattering plane. The inner and outer hemispheres of the analyser are 65mm and 125mm in diameter respectively. The entrance and exit apertures of the analyser are 1mm in diameter. The energy resolution of the analyser was determined to be 0.55eV FWHM. A set of electrostatic aperture lenses image the interaction region at the entrance to the hemispherical energy analyser; the geometrical acceptance angle of the analyser is ±2°. Electrons of appropriate energy to pass through the electron energy analyser are detected by a channel electron multiplier. Pulses from this device are passed through a simple pick-off circuit into a discriminator via a preamplifier and are counted by standard counters. The angular positioning of the analyser is achieved by a stepper motor connected to a personal computer. The analyser angular calibration was performed by comparison of measured argon elastic cross sections with previously published results [3].

RESULTS

Figure 2 shows the angular dependence of the Sherman function for elastic scattering from krypton in the energy range 50-100eV. The solid line in each case is the present calculation. As problems with the Mott detector prevented a reliable calibration measurement of the polarisation of the incident beam, the experimental results were normalised to the theory at 60eV, 70° scattering angle, yielding a spin polarisation of 20%. This same inferred polarisation was then used in the determination of the Sherman function at the other energies. At 50eV other experimental results for the Sherman function are available [4,5] for comparison (Figure 2 (a)). The latter values are obtained from polarisation measurements of the scattered electrons produced by an initially unpolarised electron beam. There is generally good agreement with Refs. [4] and [5], except at 40° where Ref. [4] appears to overestimates the Sherman function. There is also good agreement with theory across most of the angular range, except in the region 130°-150°, where theory predicts a large, varying asymmetry. At 100eV (Figure 2(d)) our experimental results are compared with results from Ref. [4], and with theory. Again there is good agreement with previous experimental data and with the present theory. At 60 and 65eV, there are no other experimental results for comparison. Figures 2(b), (c) show our data and the theoretical calculation. There is satisfactory agreement between theory and experiment at smaller angles, but the very large predicted values of the Sherman function near 110° (with a sign change in going from 60 to 65eV) are not observed in the experimental results. Given the predicted rapid variation as a function of energy, we also measured the asymmetry 2eV above and below 60eV, but found no evidence for the large values predicted by the theory. As these large asymmetry values coincide with the minimum in the differential cross section, determining S in this region becomes difficult experimentally and theoretically. Further measurements in this angular and energy range are planned.

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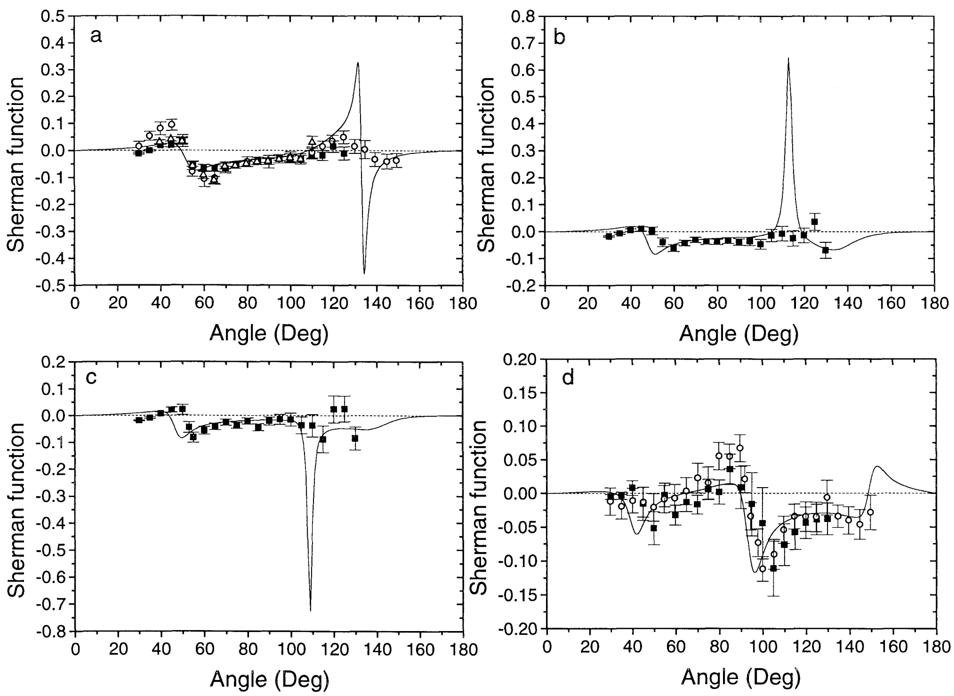

FIGURE 2. Sherman function for elastic scattering from krypton at energies of (a) 50eV, (b) 60eV, (c) 65eV and (d) 100eV. ■ Our experimental results. Electron polarisation measurements from ○ Ref[4], △ Ref [5]. — Present calculations.

REFERENCES

1. Kessler, J., *Polarized Electrons*, Springer Verlag, Berlin, 1976, pp.38-48.
2. McEachran, R. P., and Stauffer, A. D., *J. Phys. B: At Mol Phys.* **19**, 3523-3538 (1986).
3. Panajotović, R., Filipović, D., Mariković, B., Pejčev, V., and Kurepa, M., *J. Phys. B: At. Mol. Phys.* **30**, 5877-5894 (1997).
4. Schackert, K., *Z. Phys.* **213**, 316-322 (1968).
5. Beerlage, M. J. M., Quing, Z., and Van der Wiel, M. J., *J. Phys. B: At. Mol. Phys.* **14**, 4627-4635 (1981).