DEVELOPMENT OF AN OPTICAL ELECTRON POLARIMETER WITH ARGON GAS

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Abstract

The conventional methods for measuring the polarization of electron beams are time consuming, invasive and accurate only to a few percents. An optical method has been developed to measure electron beam polarization by observing the light emitted by argon atoms following their excitation by electron impact. It has been shown that the collision induces a spin transfer from the polarized electron to the argon atom, which decays by emitting a circularly polarized fluorescence. The degree of circular polarization is directly related to the electron polarization. Such a polarimeter is under test in Mainz, on a test GaAs source available at the IKP Mainz. It will determine the polarization of a 50keV electron beam decelerated to a few eV interacting with an effusive gas jet. Argon atoms are excited by electrons of approximately 20eV. The resulting decay of the excited states produces the emission of a circularly polarized radiation line at 811.5nm which is observed and analyzed. The excitation function of the 811.5nm radiation line has been studied as a function of the energy of the decelerated electrons. We are now investigating the measurement of the fluorescence polarization through its Stokes parameters by means of a Fast Fourier Transform (FFT) analysis.

1 INTRODUCTION

The idea of measuring the polarization of low-energy electron beams by observing the fluorescence emitted by mercury atoms following their excitation by polarized electron impact was suggested by Farago and Wykes in 1969 [1]. Such a measurement was then first performed on zinc atoms by Eminyan and Lampel in 1980 [2]. So far, improvements were achieved by considering the use of noble gases whose properties make it easier to handle with the experimental apparatus and lead to more accurate results (better than 1%) [3,4,5]. We have proposed to apply this method of optical polarimetry to the measurement of the polarization of the high-energy electron beam injected into the Mainzer Mikrotron MAMI at 100kV. The purpose is to get a precise, permanent and on-line electron polarization measurement which is needed in parity violation experiments in progress in Mainz.

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2 THEORETICAL ASPECTS

2.1 General Layout

Optical polarimetry is based on the inelastic exchange collision of polarized electrons on atoms :

$$\vec{e}+A\rightarrow\vec{A}^{*}+e'$$

such that spin angular momentum is transferred to the excited atom. This excited atom eventually decays into a metastable state yielding the emission of circularly polarized light :

$$\vec{A}^{*}\rightarrow A_m+(h\nu)_\sigma$$

The detection and analysis of the polarized fluorescence provide knowledge of the electron beam polarization.

We decided to use an effusive jet of argon gas : argon has the main advantages not only to fulfill the required conditions for a significant measurement (large cross-section, high energy-gap), but also to be easy to use (cheap, easy pumping). In the case of argon, the excited state is $(3p^5 4p)\,^3D_3$ which decays to $(3p^6 4s)\,^3P_2$ by emission of a 811.5nm fluorescence line. The detection and subsequent analysis of the emitted light is subject to three conditions:

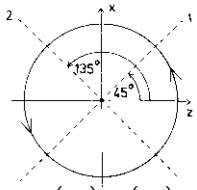
- the argon $^3D_3$ state must be directly excited (i.e. cascading from higher states must be avoided) to avoid any admixture of unknown polarization.
- any magnetic interaction of the incident electron which could cause its spin to flip must be negligible in the excitation process.
- spin-orbit coupling within the excited atom must be large enough to allow the fine structure splitting of the ^3P_J levels to have them easily spectroscopically resolved.

This favors the use of noble gases [6] and implies that the beam energy should lie between the excited state threshold (13.076eV) and the energy of the first cascading state $(3p^5 3d)\,^3P_2$ (13.903eV).

2.2 Polarization and Stokes parameters

Fluorescence light is analyzed through its Stokes parameters which are related to the initial beam polarization [7,8]. For an incident transversally polarized beam on the z-axis, the fluorescence light is observed along the y-axis in the direction of the electron spin. The intensity of the circularly polarized light emitted per unit of solid angle is proportional to $1+\cos^2\theta$, where θ refers

to the angle between that direction of detection and the y-axis [1]. It is therefore maximum in the spin direction. The linear and circular polarization are parameterized by the so-called Stokes parameters U, V and Q defined as follows:



$$Q=\frac{I(0^o)-I(90^o)}{I(0^o)+I(90^o)} \quad V=\frac{I(\sigma^+)-I(\sigma^-)}{I(\sigma^+)+I(\sigma^-)} \quad U=\frac{I(45^o)-I(135^o)}{I(45^o)+I(135^o)}$$

where $I(\alpha)$ is the intensity of the polarized light along the direction having a polar angle α in the xz-plane and where $\sigma^{\pm}$ refers to right and left handed circularly polarized light. It has been shown that for noble gases the beam polarization P is related to the Stokes parameters by V=A(1+BQ)P [6]. This requires the condition U=0, which is obtained if the excited state is a well LS-coupled state (Russell-Saunders state) and if in addition the spin-orbit interaction between the target and continuum electrons is negligible during the collision process [9]. For the $^3D_3$ level of argon, the relationship becomes:

$$V=0.6667(1+0.2222Q)P$$

It should be quoted that this relationship is only valid in an energy range unaffected by cascades [6].

3 EXPERIMENTAL SET-UP

The experimental apparatus is shown Fig. 1. It consists of a six-way cross chamber in which the beam is decelerated to around 13eV before interacting with an argon jet. The emitted fluorescence is then detected by an optical detection system and sent to the data acquisition system for analysis.

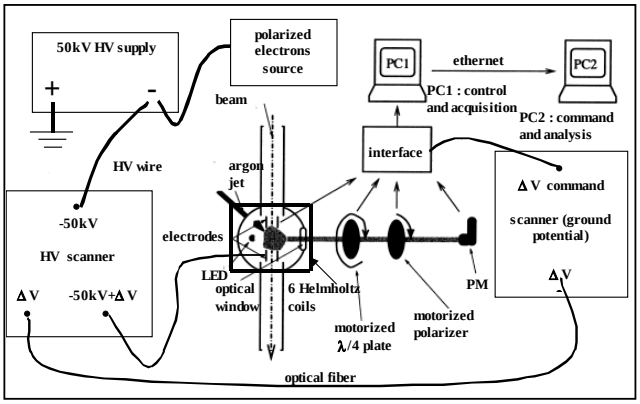


Fig. 1 : experimental apparatus (see text for details).

3.1Beam deceleration

The transversally polarized electron beam is produced from a classical GaAs photocathode at an initial energy of 50keV and an intensity up to 40μA and delivers electrons with a polarization of about 30%. The beam is decelerated to a variable energy ΔV between 0 and 200eV (and then re-accelerated to 50keV) in the target chamber by a set of three electrostatic lenses defining two gaps of 30mm each. The lenses are simple cylinders machined from brass with a diameter of 20mm and lengths of 5mm (ground electrodes) and 10mm (central decelerating electrode). The variable energy is controlled by a specific device called "scanner". The same potential used to accelerate the beam at the exit of the source is applied to the decelerating electrode and the scanner allows to add an additional voltage ΔV (0-200V).

A set of 6 Helmholtz coils has been lately added to compensate for the earth magnetic field measured to be 41μT in the interacting region. This compensation prevents spin precession and depolarization by Hanle effect [10].

3.2 Argon jet

The colliding atoms are driven to the interacting region as an effusive argon jet. The jet is produced by a 30mm long nozzle with 0.2mm diameter. It has been measured to have a conical shape with 29° half angle at the top.

The pumping system consists of a cryogenic pump of 640l/s mounted on the chamber. A turbopump coupled to a primary pump is installed higher on the beam line to improve the pumping power. A vacuum of 10^{-7}mbar can be achieved and a pressure of argon up to 4.10^{-5}mbar can be maintained during operation.

3.3 Optical detection

The analysis of the emitted fluorescence light is done through a measurement of its Stokes parameters. The circularly polarized fluorescence light is analyzed by an optical system (see Fig. 2) consisting of a continuously rotating quarter-wave plate (frequency $f=\omega/2\pi=8$Hz) and a 2-position polarizer ($\alpha=0°$ and $\alpha=90°$). A interferential filter is used to select the 811.5nm radiation line. A set of lenses is used to focus the light which is then collected by a photomultiplier (Oriel Instruments 77348).

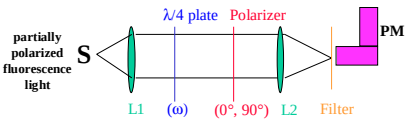


Fig. 2 : optical bench.

In these conditions the detected intensity shows for each position of the polarizer:

$$I_d^{0\%90}=\frac{I}{2}\pm\frac{1}{4}Q\pm\frac{1}{4}\cos(4\omega t)Q+\frac{1}{4}\sin(4\omega t)U\mp\frac{1}{2}\sin(2\omega t)V$$

The two detected intensity ($\alpha=0°$ and $\alpha=90°$) are modulated at two frequencies (2ω and 4ω) each of which being related to a state of polarization (circular or linear). This allows a determination of the Stokes parameters through a Fast Fourier Transform analysis of the

photomultiplier signal and consequently the determination of the beam polarization.

3.4 Data acquisition

The data acquisition system is remotely controlled, as it is not possible to access the polarimeter while the GaAs source is running. The acquisition is ensured by a National Instruments PCI-MIO-16E card with a SC-2070 board as interface. A Labview program analyses the output signal of the photomultiplier and extracts its Stokes parameters.

4 RESULTS

One of the trickiest points of the experiment is the deceleration of the electron beam. The decelerating set-up is only 13mm long, aiming to decelerate electrons of initially 50keV. Due to the severe deceleration, the beam tends to focus strongly before the interacting region and then to diverge. This entails a very small overlap between the beam and the argon jet. Calculations have been done, showing that a well-focused 1µA beam interacting with the argon jet would produce an anode signal of 50nA on our photomultiplier.

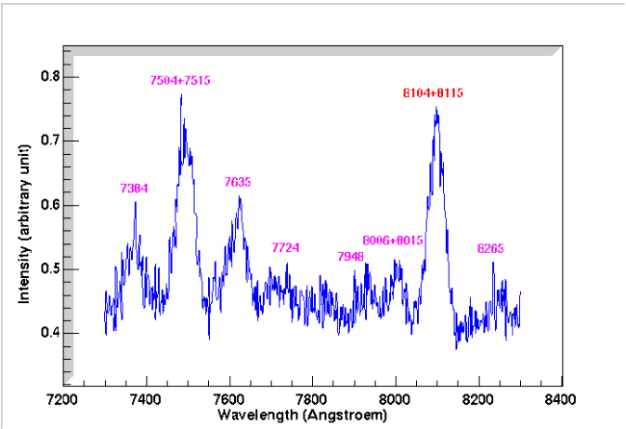


Fig. 3: argon spectrum. Theoretical wavelengths are quoted on top of each peak.

The first challenge in these conditions is to observe the clear signature of the interaction between the electrons and the atoms. This has been realized by observing the full argon spectrum with the use of a monochromator (Jobin-Yvon HR320) at a deceleration voltage of 25V for a beam intensity of 1µA (20µA at the source i.e. 5% transmission through the interaction region). Fig. 3 shows this spectrum, obtained with relatively large slits on the monochromator to favor the light collection. This configuration of the detection system does not allow to spectroscopically resolve the 7504-7515 and 8104-8115 lines. The signal/background ratio is roughly 1. It has been shown that the origin of the background is purely the photomultiplier anode dark current, measured to be 2.8nA. Altogether, it shows that the measured signal is much smaller than the expected one.

The second challenge consists in measuring the excitation function of the $^3D_3 \rightarrow ^3P_2$ fluorescence light. Fig. 4 shows the result obtained by measuring the intensity of the 811.5nm peak at different beam energies, i.e. at different deceleration voltages. The error bars account for the accuracy in extracting the peak amplitude out of the background. This result is in agreement with a previous measurement by Tim Gay et al. [4].

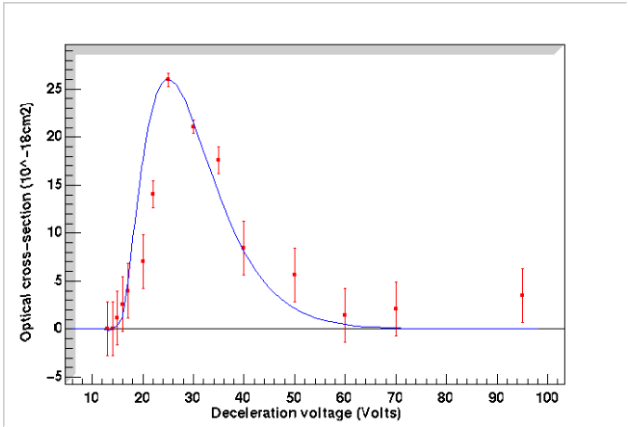


Fig. 4: excitation function of the argon 811.5nm radiation line $^3D_3 \rightarrow ^3P_2$.

5 CONCLUSION

Although it has been possible to observe fluorescence from the 811.5nm radiation line and to reconstruct its excitation function, we have not yet been able to measure the polarization. A first attempt, made without any correction of the earth magnetic field, failed to measure the 30% polarization of the beam. Helmholtz coils have been therefore installed to compensate for the earth field and new measurements are scheduled . The usage of a photocathode of high quantum efficiency in the polarized source will increase the luminosity at the experiment by more than one order of magnitude, so that an unambiguous measurement of the polarization of the emitted radiation is expected in the near future. An installation at the accelerator can only be planned after a proof of the principle. It will require an increase to 100kV potential and an improved multi-stage deceleration optics.

6 REFERENCES

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