A LAMB-SHIFT POLARIMETER FOR THE POLARIZED TARGET AT ANKE

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With a Lamb-shift polarimeter (LSP) it is possible to measure the occupation numbers of the individual hyperfine states in a beam of hydrogen or deuterium. Therefore one can calculate the nuclear polarization of the atomic beam in magnetic fields of varying strength. The polarization of a slow (500 -2000 eV) ion beam can be measured too. Since effects in the ionizer, the Wien filter, the cesium cell, and the spin filter influence the measured polarization P_{Ly} value correction factors for calculating the *absolute* polarization p_z of the beam as a function of P_{Ly} have to be applied.

1 The Lamb-Shift Polarimeter

1.1 The Principle

The atomic beam of hydrogen or deuterium is ionized in an electron-impact ionizer [3,4] with an efficiency of about 10^{-3}. The ionization volume is located in a strong magnetic field ($\sim$ 160 mT) to decouple the nuclear and the electron spins. At the same time it increases the collision probability of the accelerated electrons and the beam particles. The vertical ion beam is deflected into the horizontal beamline by an electric deflector. The necessary precession of the polarization back onto the beamline direction is performed by a Wien filter. This Wien filter also acts as a mass filter and therefore only protons (deuterons) arrive in the cesium cell. By charge exchange with the cesium metastable atoms in the 2S state are produced. To define the polarization of the metastable hydrogen (deuterium) a strong magnetic field ($\sim$ 55 mT) in the cesium cell is required. The spin filter [5] transmits only metastable atoms in different single hyperfine states depending on the magnetic field. All other atoms are quenched into the ground state. In the vacuum chamber at the end of the polarimeter the residual metastable atoms are then quenched by an electric field (Stark effect). The Lyman-α photons are registered by a photomultiplier [6] sensitive only to photons with a wavelength of 121 nm.

The number of photons counted in one hyperfine state is proportional to the number of atoms with the same nuclear spin in the primary beam. From the ratio of the photons which are produced at 53.5 mT or 60.5 mT in the spinfilter the polarization of the atomic beam or a slow ion beam of 500-2000 eV is calculated. With an overall efficiency of the polarimeter of $\sim 10^{-10}$ a beam of 10^{16} atoms/s will produce some 10^6 photons/s in the photomultiplier. So the statistical error $\Delta P_{Ly} \sim \pm 0.003$ obtained in 30 s is very small.

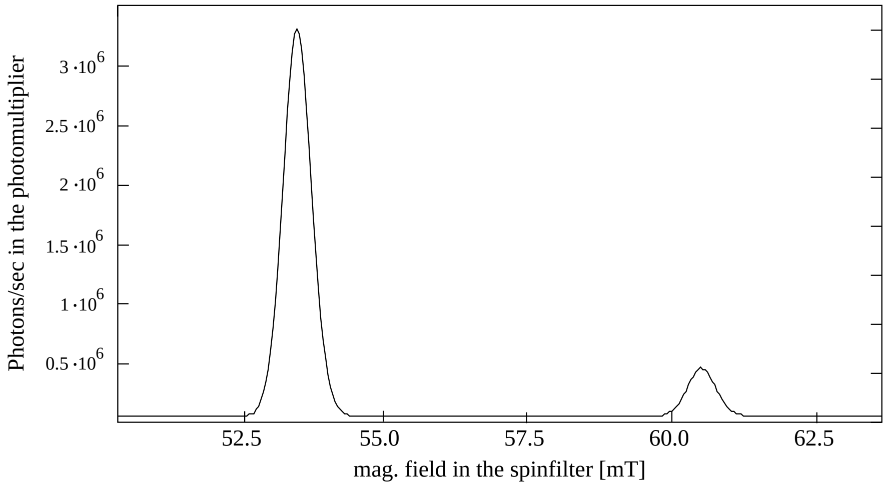

Figure 1. The Lyman-α spectrum of a polarized hydrogen beam in the hyperfine state 1. The polarization $P_{Ly} = 0.780 \pm 0.002$ was measured in less than 30 seconds.

2 The Corrections

The measured polarization P_{Ly} of the Lyman-α spectrum is different from the polarization p_z of the atomic beam. Some corrections are necessary. The knowledge of the correction factors determines the absolute accuracy which can be obtained with the LSP.

2.1 The Ionizer

The ionizer can produce protons from residual gas molecules like H_2O, H_2, C_nH_n or H_2 after the recombination of atoms in the ionizer. With atomic beam entering the ionizer an H_2^+ ion current of the same order of magnitude as the H^+ ions will be produced. So up to 10% of the proton beam is made from unpolarized particles and has to be subtracted in the Lyman-α spectrum. This will increase the polarization value by up to 10%.

The polarization of the hyperfine states 2 and 4 is a function of the magnetic field in the ionization volume. Only for $B \to \infty$ the produced protons will have the same polarization as the atoms of the beam. By varying the magnetic field in the ionizer it is possible to claculate the correction to the polarization. At 18 A in the solenoid coil only 93.5% of p_z will be measured. With this procedure it is even possible to indentify the single hyperfine substates or some mixtures of this states in the beam.

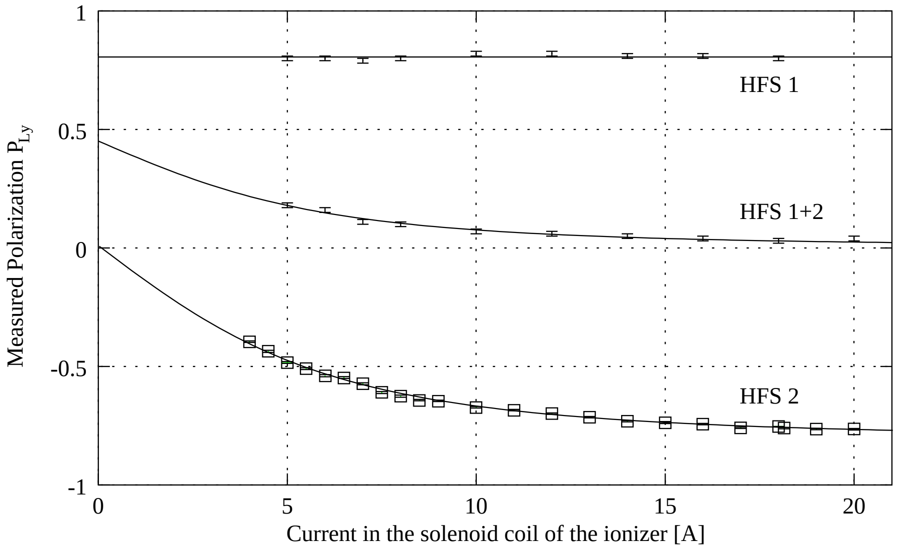

Figure 2. The polarization of an atomic hydrogen beam in the hyperfine states 1, 2 or 1+2 as a function of the magnetic field in the ionizer.

2.2 The Wien Filter

With the Wien filter the polarization vector is rotated into the horizontal direction. During this process 0.8% of the polarization will be lost for protons. For deuterons this loss will grow up to $\sim$ 1%.

2.3 The Cesium Cell

Like in the ionizer the magnetic field in the cesium cell influences the measured polarization because the production of the α_2 metastable atoms is a function of the magnetic field. Due to the small critical field (6.34 mT) of the metastable atoms 99.4% of the polarization value is conserved at 55 mT on the beam axis.

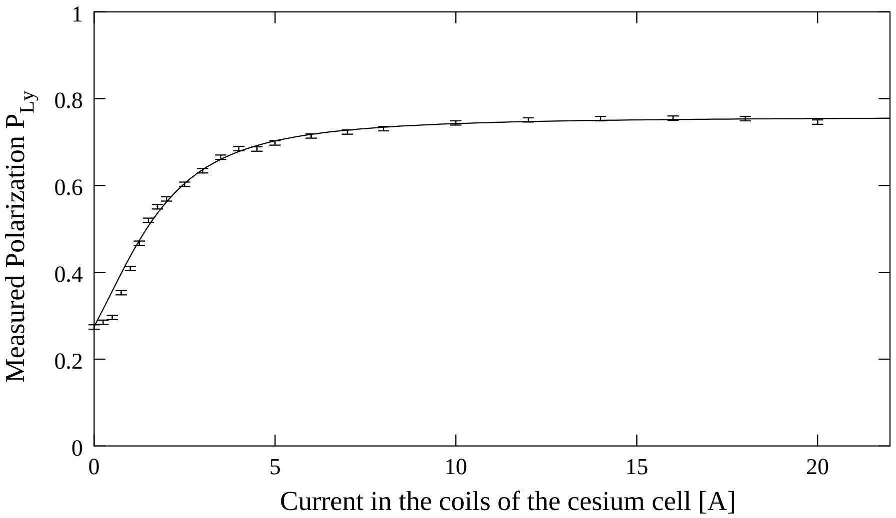

Figure 3. The measured polarization P_{Ly} as a function of the current in the magnetic-field coils of the cesium cell.

2.4 The Spin Filter

The transmission of the metastables through the spin filter depends on its magnetic field: at 53.5 mT it is nearly 1% better than at 60.5 mT. Therefore the measured polarization of the hyperfine states 1 and 4 will be higher by 0.2% and decreased for the states 2 and 3.

Thompson[7] explained that different magnetic gradients between the cesium cell and the spin filter will produce some depolarization. Therefore both gradients were designed to be the same in our LSP. However, after some small modifications, this effect will be investigated in the near future.

3 Discussion

The LSP and the ABS are working together very well. The LSP ist an excellent *relative* polarimeter with a statistical error of 0.3% within 30 seconds. To derive the *absolute* polarization of the atomic beam to high precision some known correction factors have to be applied. The known correction factors increase the measured polarization P_{Ly} of the hyperfine states 1 and 3 by about 11% and for the states 2 and 4 by about 19% with an error of 1% within 30 seconds. These corrections are dominated by effects in the ionizer. A new ionizer with a stronger magnetic field and a getter pump inside was designed to reduce these overall corrections to 5% at an error of 0.5%. This ionizer will be finished at the end of 2001.
Measurements with deuterium which will be easier due to the smaller critical field and lower background of the residual gas will be carried out in the fall of 2001.
With the present LSP it will be possible to measure the polarization of the primary atomic beam with intensities down to 1% of the present beam. It is planned to measure the polarization of atoms in a storage cell by extracting a small amount of the atoms. First tests will start in the spring of 2002.

Acknowledgments

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