Moller Polarimetry in Jefferson Laboratory Hall A: Using the Magneto-Optical Kerr Effect to Measure Target Polarization

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Introduction

In the coming few years, Hall A at Jefferson Lab will be the site for the MOLLER experiment. One of the requirements for this experiment is $< 0.5\%$ precision on measurements of the electron beam polarization.[1] In order to acheive this, updates have been made to the Hall A Moller Polarimeter to reduce systematic errors, specifically those due to the target polarization.

Moller polarimetry infers the polarization of the beam by measuring the asymmetry of scattering rates between right and left helicity electrons. The polarimeter in Hall A uses a polarized electron beam that hits a polarized iron foil target at near-normal incidence. The following relationship is used to precisely measure the beam polarization:

$$A = \frac{N_+ - N_-}{N_+ + N_-} = P^{\text{beam}} \cdot P^{\text{target}} \cdot \langle A_{zz} \rangle$$

where A is the asymmetry, $N_\pm$ are the rates of $\pm$ helicity, $P^{\text{beam(foil)}}$ is the beam(foil) polarization, and $\langle A_{zz} \rangle$ is the average analyzing power, which is a function of the CM scattering angle.[1]

The polarimeter is especially sensitive to target angle/alignment. Even a 1° deviation in beam incidence can result in a much higher uncertainty.[2][1] The first step in discerning the optimal target angle for minimal systematic error in the beam polarization measurement is to show that the target is being magnetized to saturation, i.e., the target is completely polarized.

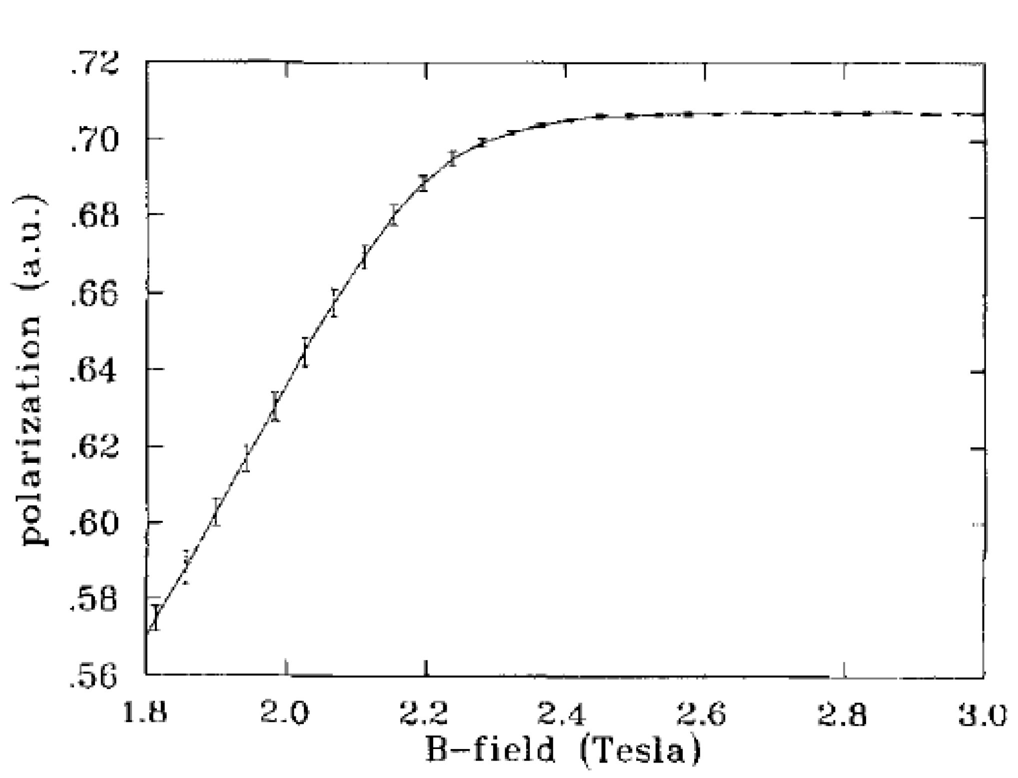


Figure 1: Expected [3] dependence of polarization vs. applied magnetic field for a saturated target.

Kerr Apparatus

To calculate the target polarization to very high precision, we must prove that the target foil is magnetized to saturation. When polarized light is reflected off of a magnetized surface, it gains a Kerr rotation, θ_K, and a Kerr ellipticity, ϵ. This is the core idea of Magneto-Optical Kerr Effect (MOKE), and we can construct an apparatus that is able to extract θ_K and ϵ as shown in Figure 2.

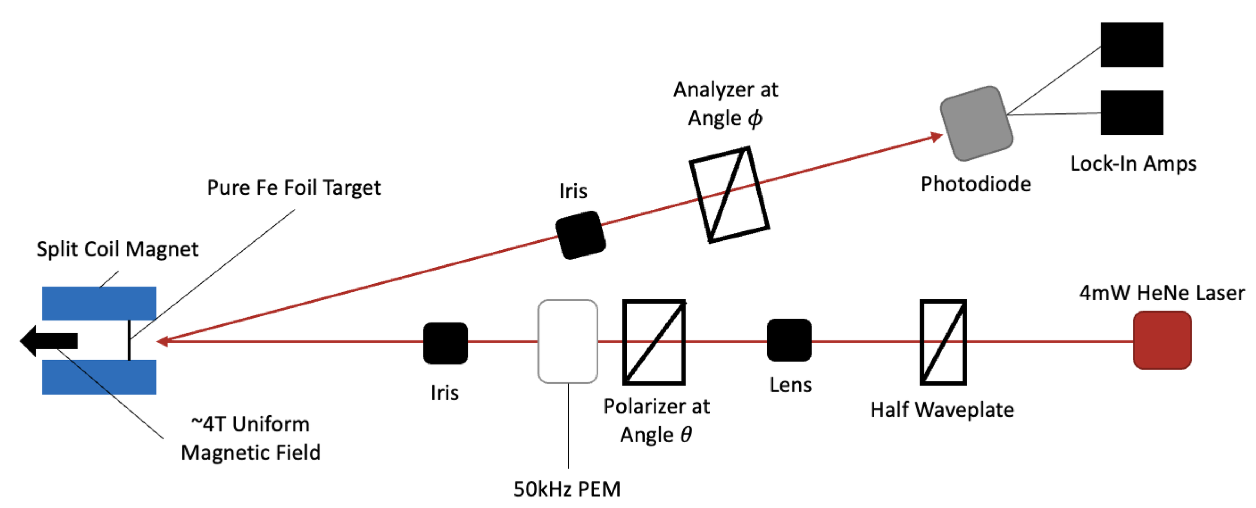


Figure 2: Sketch of our Kerr apparatus.

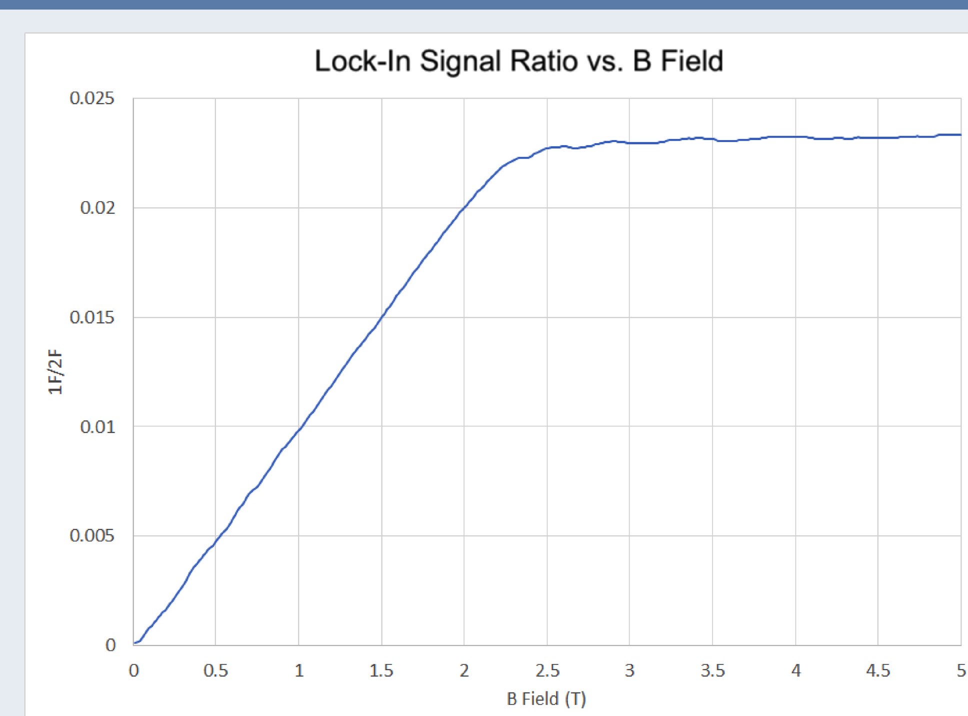
Method

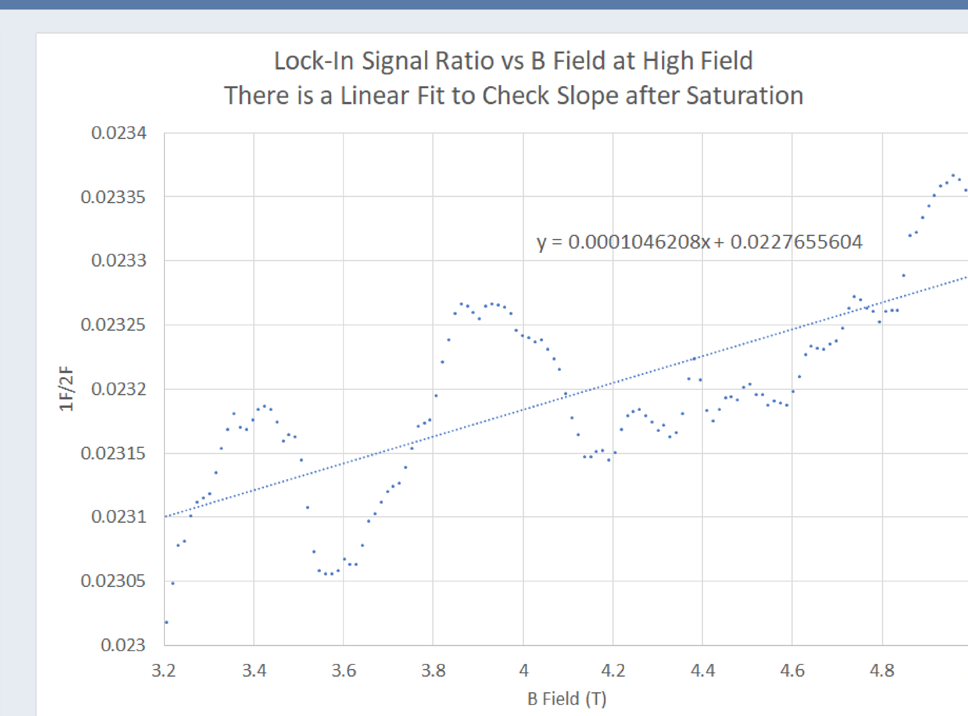
In order to show saturation we use our lock-in amplifiers to isolate the following signals [4]:

- $1F$ - the AC-component amplitude of the reflected light intensity at the frequency of our photoelastic modulator (PEM), which is proportional to ϵ
- $2F$ - the same AC-component amplitude at *double* the frequency of our PEM, which is proportional to θ_K

A PEM uses mechanical compression to periodically vary the refractive index of a fused silica plate through which the laser passes, modulating the polarization of the light. Most importantly, the ratio $1F/2F$ is directly proportional to the magnetization of the target.[3] Thus, if we can show that this $1F/2F$ ratio saturates as we increase the magnetic field, then we are able to prove that the magnetization of the target foil also saturates.

Important Result





This is our best result showing saturation. After the ratio plateaus, it increases by 0.5% per Tesla, which is five times greater than we are aiming for. Compare this to Figure 1 which is our goal for the behavior of the magnetization of the target.

Modulated Interference

We have yet to show that the target foil is fully saturated. While we have many ideas of possible causes for this lack of saturation, the only explanation we were able to find explicit evidence of was modulated interference in the PEM. Modulation of the intensity of the transmitted light can be observed at the same frequency as the PEM due to multiple internal reflections and variations in optical path length.[5]

We were able to see evidence of modulated interference on an oscilloscope connected to our PEM. However, we were also able to show that our PEM was highly sensitive to temperature fluctuations because they can affect the optical path of the light within the PEM. This temperature dependent effect was so dominant that we were unable to properly quantify any other sources of error. Thus, without a fully temperature controlled environment for the PEM we cannot show precise saturation.

Conclusion

The use of MOKE to prove target saturation is a promising method, but we have yet to see fully satisfactory results. Once we are able to demonstrate foil saturation, we can use this apparatus to measure the sensitivity to foil angle/alignment. This will allow us to reduce systematic error in beam polarization measurements, which will in turn help the MOLLER experiment to achieve its proposed level of precision.

References and Acknowledgements

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