M$\not{o}$ller Polarimetry and the Magneto-Optical Kerr Effect (MOKE)

Ryan Richards

Stony Brook University

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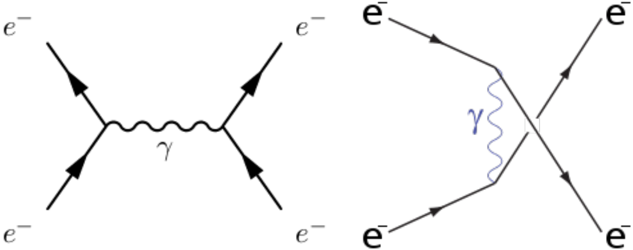
Outline

1. Møller Scattering
2. Møller Polarimetry
3. Magneto-Optical Kerr Effect (MOKE)

Møller Scattering

- Electron- electron scattering
- Occurs through the physical t and u channels respectively



- Cross section can be computed with high accuracy (QED process)
- In the center of mass frame cross section can be written as

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma^0}{d\Omega}(1 + P_t^{ll} P_b^{ll} A_{zz}(\theta))$$

Mϕller Scattering

- High energy limit yields
$$\frac{d\sigma^0}{d\Omega} = (\frac{(\alpha(4-f)}{2m_e\gamma f)})^2, A_{zz}(\theta) = -f\frac{8-f}{(4-f)^2}, f \equiv \sin^2(\theta)$$
- Can measure the beam polarization by comparing the cross section asymmetry ϵ,
$$\epsilon = A_{zz}(\theta)P_b^{ll}P_t^{ll}$$
- At 90 degrees, analyzing power is $-\frac{7}{9}$
- Lab cross section is constant
- Lab scattering angle of the scattered and recoil electrons are identical and each carry half of the initial beam energy.

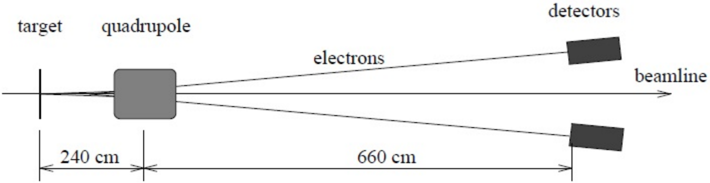
Mϕller Polarimetry

- Problem arises- Small lab scattering angle
- Let N be the count rates, with this one can define
- Quadrupole used(Hall C- late 90s) to resolve this issue- Double Mϕller Arm Polarimeter

$$N^{\pm} = L \cdot d\Omega \cdot \frac{d\sigma}{d\Omega}(1 \pm A_{zz} P_b^{ll} P_t^{ll})$$

- Expression yields

$$P_b \sim \frac{1}{A_{zz} P_t}$$



Experimental Concerns

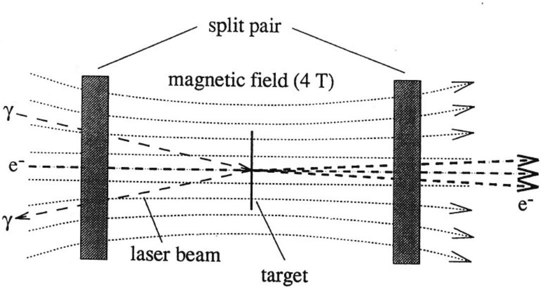
- Ferromagnetic electron targets- only 2 out about 25 electrons polarized- small effective polarized $\sim$ 8%
- Need high statistics and tight systematic control
- Background dominated by Mott scattering for heavy nuclei $\sim Z^2$ vs M$\not{o}$ller $\sim$ Z - Coincidence!
- Uncertainty in target polarization
- Levchuk effect due to the instrinsic momentum of the electrons

In Plane Polarization

- Want to determine the magnetization of ferromagnetic target (usually uses alloys)
- Polarization depends linearly on the magnetization and inversly proportional to K(g')
- Involves using pickup coils around the foils and determining the change in magnetic flux when reversing the field
- Difference in flux measured with and without the foil
- Need about measurement of the change in flux
- Flux depends of the homogeneity of the foil
- Value of g' not well known for alloys

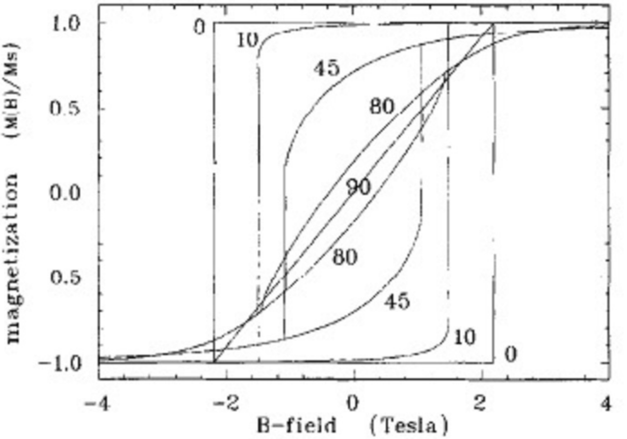
Out of Plane Polarization

- Brute Force iron target perpendicular to magnetic field direction
- $\sim$ 3 T field used since iron saturates around 2 T
- Magnetic Domains = Bulk Properties
- g' factor and electron polarization known to high precision
- Absolute measurement no longer needed

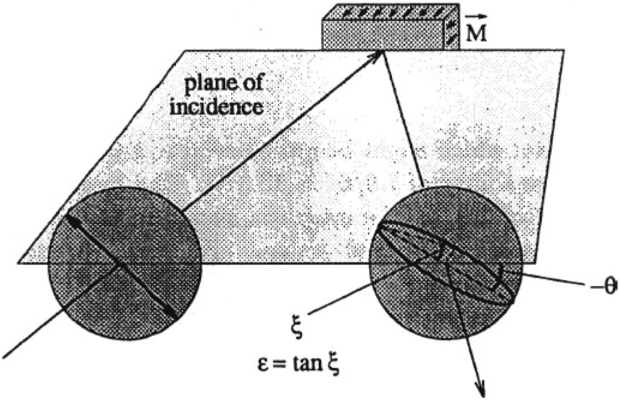


What We Hope to See

- Curves yield full magnetic information
- Hysteresis curves for various angles i.e., various types of MOKE

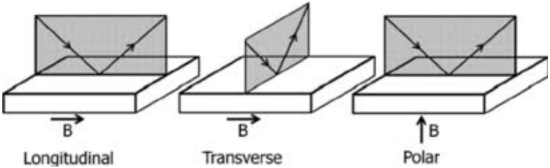


Magneto-Optical Kerr Effect (MOKE)



MOKE- continued

- Polar MOKE - $\vec{M}$ perpendicular to reflection surface and parallel to plane of incidence (P.O.I)
- Longitudunal MOKE - $\vec{M}$ parallel to reflection surface and P.O.I
- Transverse MOKE - $\vec{M}$ parallel to reflection surface and perpendicular to P.O.I



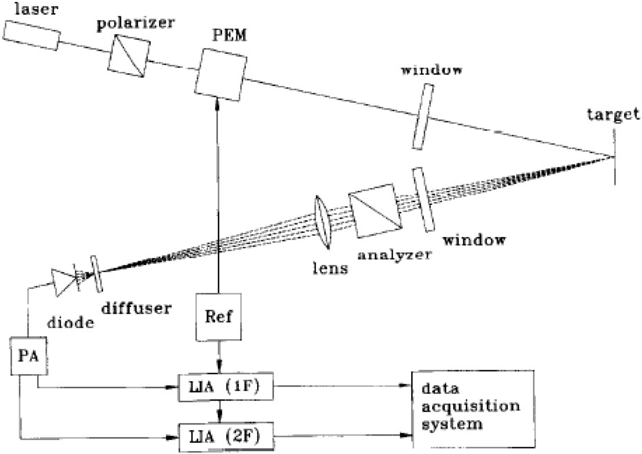
MOKE Theory

- Monochormatic wave travelling through homogeneous medium - Helmholtz equations - dispersion relations
- Refractive index n $= \epsilon\mu$ - optical frequencies $\mu = 1$ - related to long magnetic relaxation time
- Medium with damping - complex wave vector - complex n - complex permittivity
- Circular coordinates yields diagonal permittivity tensor
- Index of refraction for LH/RH different i.e., $n_c = \sqrt{\epsilon_{xx} \pm i\epsilon_{yy}}$
- Reflected amplitude expressed as

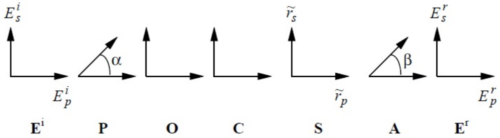
$$\frac{E_r}{E_i} = \frac{1-n_c}{1+n_c}$$

- Kerr ellipticilty ϵ - ratio of difference of reflected amplitudes of LH and RH for CP light
- Kerr rotation θ - phase shift of LH/RH CP light
- Complex Kerr angle $\Theta = \theta$- i$\epsilon = \frac{ik}{\sqrt{\epsilon_{ii}}(\epsilon_{ii}-1)}$

Optics


laser
polarizer
PEM
window
target
window
analyzer
lens
diffuser
diode
Ref
PA
LIA (1F)
LIA (2F)
data acquisition system

Optics-Cont'd



$$\mathbf{A}=\begin{pmatrix} \cos^2\beta & \sin\beta\cos\beta \\ \sin\beta\cos\beta & \sin^2\beta \end{pmatrix},$$

$$\mathbf{S}=\begin{pmatrix} \tilde{r}_p & \tilde{r}_{ps} \\ \tilde{r}_{sp} & \tilde{r}_s \end{pmatrix}=\begin{pmatrix} r_p e^{i\delta_p} & r_{ps} e^{i\delta_{ps}} \\ r_{sp} e^{i\delta_{sp}} & r_s e^{i\delta_s} \end{pmatrix},$$

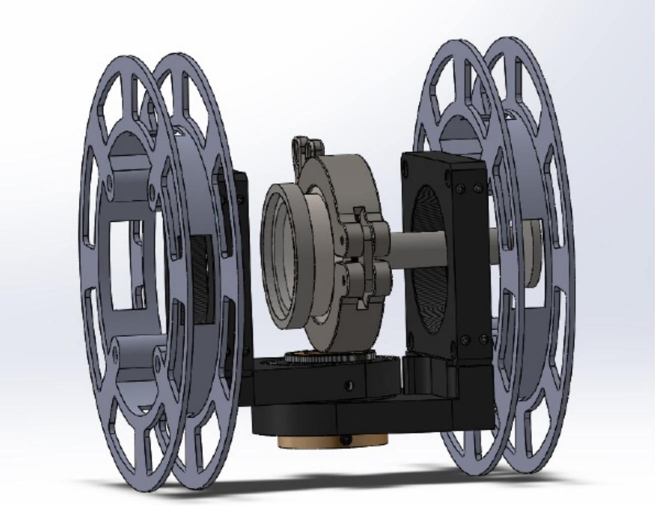
$$\mathbf{C}=\begin{pmatrix} e^{i\frac{\gamma}{2}} & 0 \\ 0 & e^{-i\frac{\gamma}{2}} \end{pmatrix}, \quad \mathbf{O}=\begin{pmatrix} e^{i\frac{\varphi}{2}} & 0 \\ 0 & e^{-i\frac{\varphi}{2}} \end{pmatrix}$$

$$\mathbf{P}=\begin{pmatrix} 1/2 & 1/2 \\ 1/2 & 1/2 \end{pmatrix} with\ \alpha=\frac{\pi}{4}$$

- $E^r = A \cdot S \cdot \cdot C \cdot O \cdot P \cdot E^i$

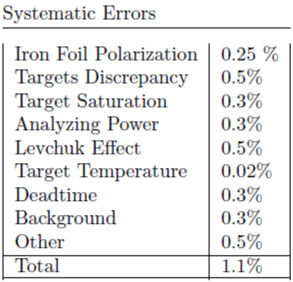
Target Implementation

Figure: CAD, Courtesy of Fernando Araiza



Stony Brook Goals

- Mimic the Kerr effect using high μ material allow (e.g. Supermendur)
- Note this would simply be a proof of principle type of measurement
- Repeat brute force polarization measurement using iron
- Consequences for future use in future experiments e.g. PREX-II.



Systematic Errors

Iron Foil Polarization	0.25 %
Targets Discrepancy	0.5%
Target Saturation	0.3%
Analyzing Power	0.3%
Levchuk Effect	0.5%
Target Temperature	0.02%
Deadtime	0.3%
Background	0.3%
Other	0.5%
Total	1.1%

References

- Thesis Stephan Robinson Kerr measurements of e- polarization
- Thesis Mathia Loppacher Mϕller polarimeter for Hall C
- L.de Bever et al, NIM A400(1997) 379 A Target precise for Mϕller polarimetry
- WS Kim , M Aderholz and W Kleemann, MST Vol4 No. 11 16 Calibration of polar Kerr rotation and ellipticity