MOKE: Principles and Measurement

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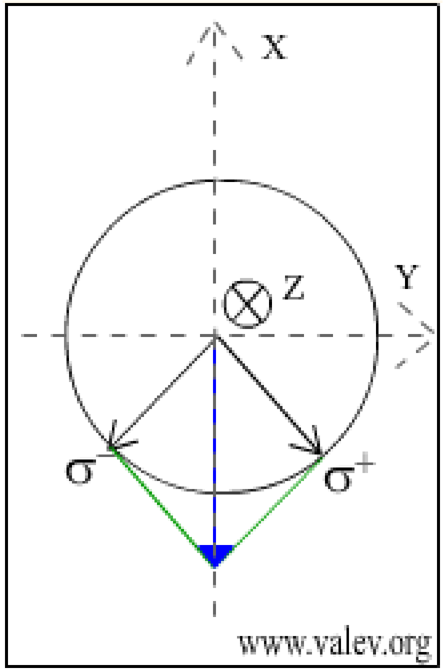
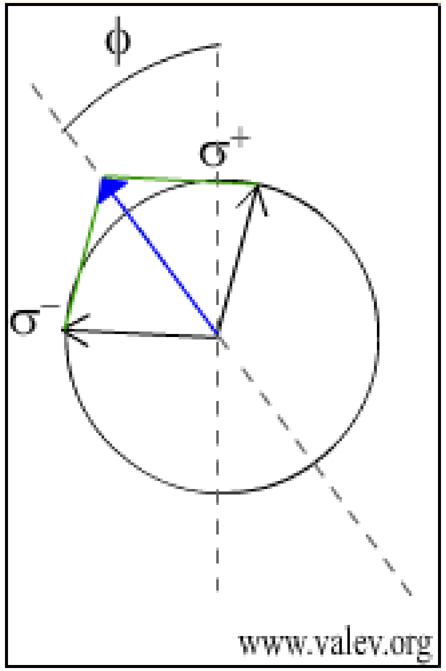
Common Magneto-optical Effects

- Faraday Effect: magnetization of material affects transmission of polarized light
- Kerr Effect: magnetization of material affects reflection of polarized light
- Reflectance magneto-circular dichroism: magnetization of material causes difference in reflectivity of right- and left-hand circularly polarized light

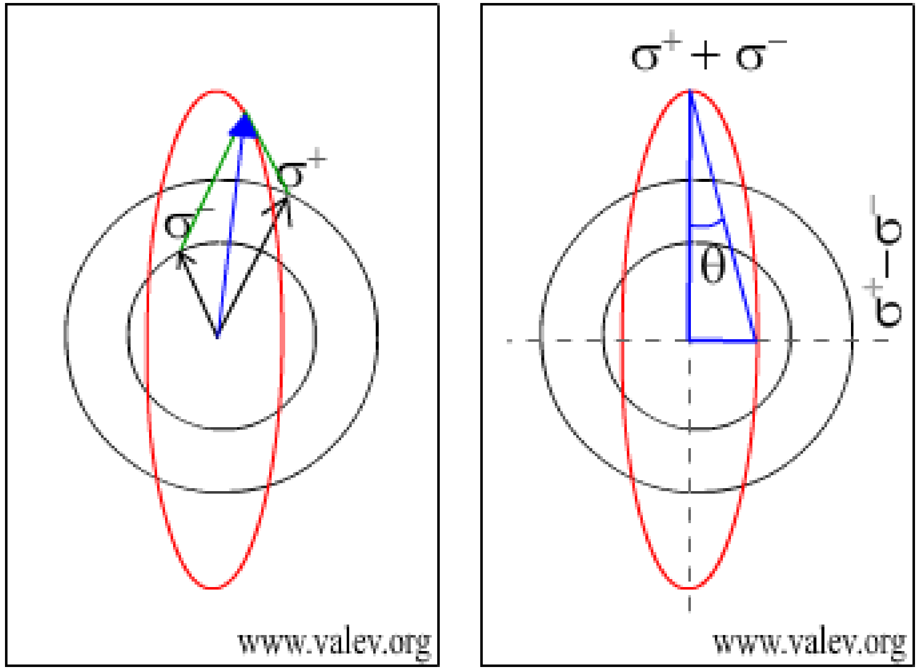
Polarized Light in Terms of Circular Polarization



Two rotations of polarizations cancel in y-direction but add in x-direction



General linear polarization: equal field strengths and phase velocities, different phases



Elliptical polarization: different field strengths and phases, same phase velocities

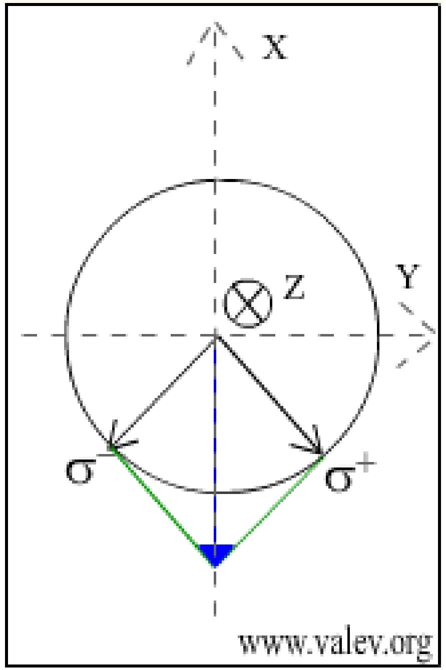
Faraday Effect

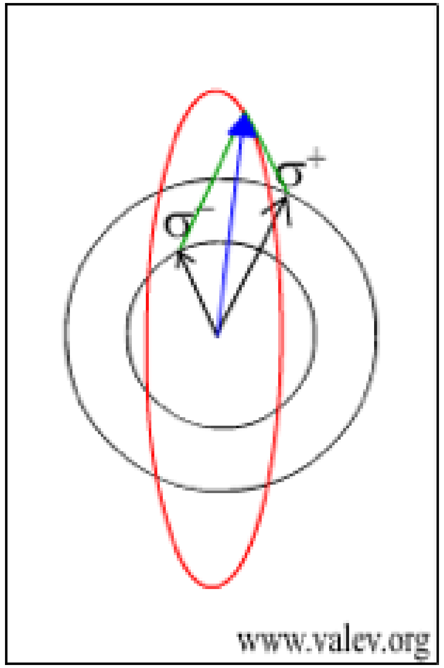
- First of the magneto-optical effects to be discovered (1845)
- Easiest to explain phenomenologically

- Propagation speeds of left- and right-hand polarized light change under application of magnetic field (tilts polarization plane)
- Absorption of left- and right-hand polarized light can be different (elliptically polarizes light)

Reflectance Magneto-Circular Dichroism (RMCD)

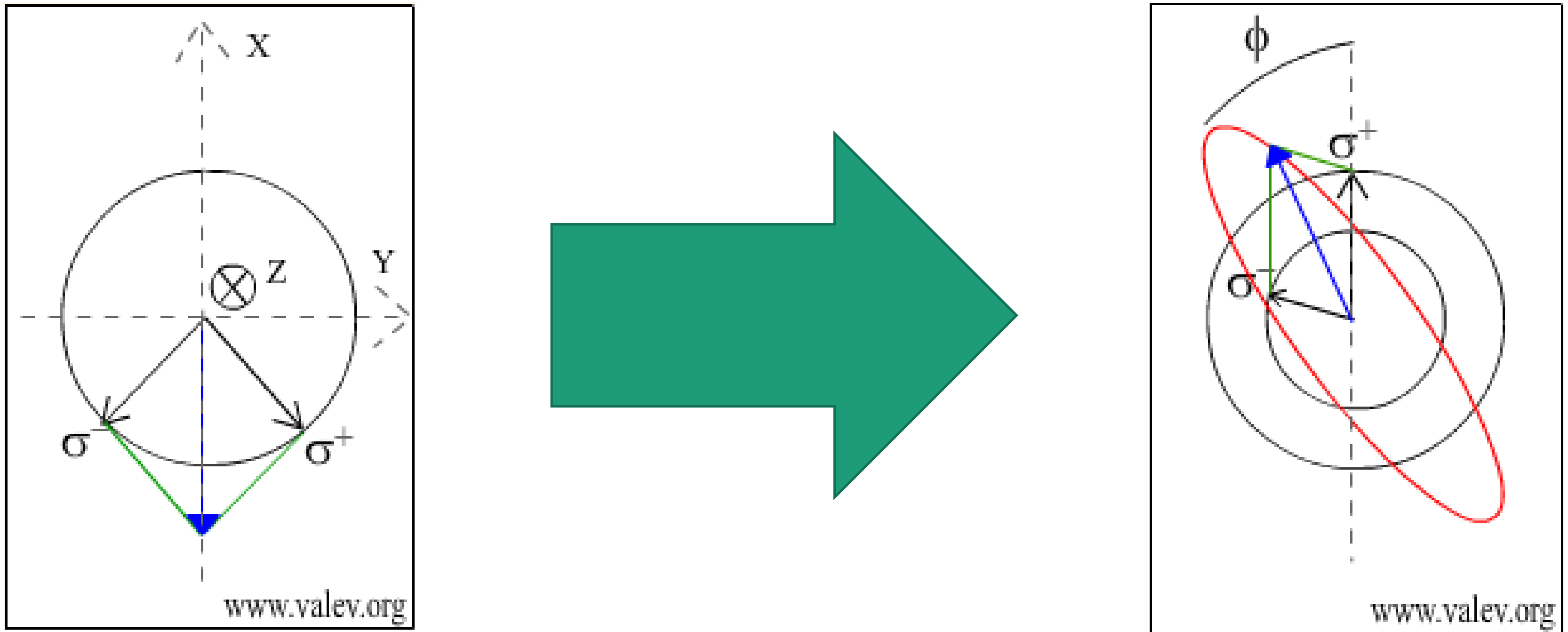
- Difference in reflectivity between right- and left-handed circularly polarized light
  - Takes linearly polarized light to elliptically polarized light, with semimajor axis aligning with original polarization axis





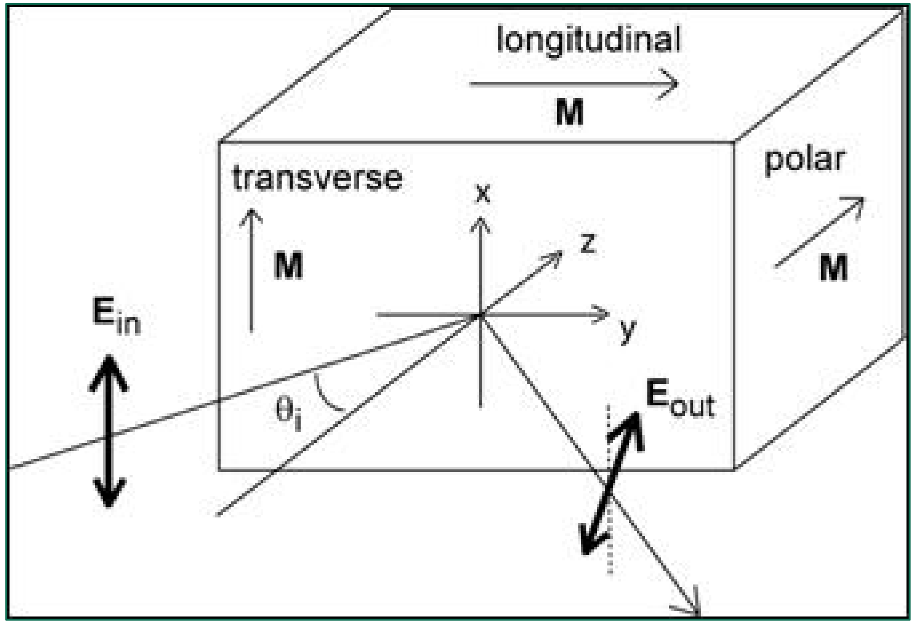
Magneto-Optical Kerr Effect (MOKE)

- Linearly polarized light incident on magnetized material becomes *elliptically* polarized
  - Takes linearly polarized light to general elliptically polarized light, with semimajor axis at angle ϕ to original polarization axis



Kerr Effect: Three Geometries

- Polar MOKE
  - Magnetization direction out of plane; incident light at near normal incidence
- Longitudinal MOKE
  - Magnetization direction in plane of surface and in plane of incidence
- Transversal MOKE
  - Magnetization direction in plane of surface and normal to plane of incidence



Theoretical Treatment of MOKE

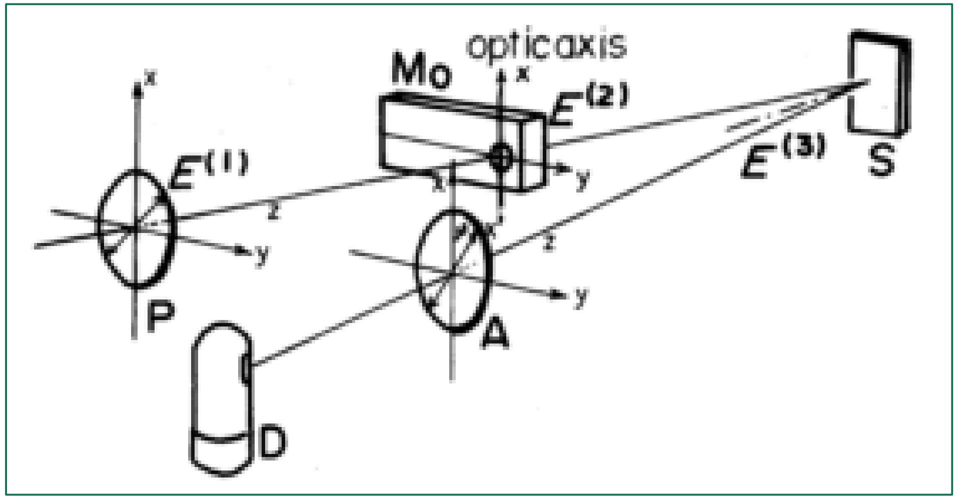
- Matrix formulation in late 1980’s-early 1990’s by Zak, Moog, Liu & Bader at Argonne National Labs
  - Matrices describing interface between layers derivable in terms of magneto-optical properties
- Later expanded formulation to multi-layered systems and systems with arbitrary magnetization directions
- Magnetization parameterized by so-called Voigt constant Q

Measurement of Kerr Rotation

- Typical measurements use λ/4 wave plate to convert elliptically polarized light back to linearly polarized
  - Kerr rotation manifests as new final plane of polarization
  - Insensitive to *direction* of magnetization (cannot recover hysteresis loop)

- Relationship between Kerr rotation and magnetization not simple to recover
  - Relative magnetization typically reported in literature

Measurement of Magneto-optic Kerr Effect using Piezo-Birefringent Modulator (J. Sato, Jpn. J. Appl. Phys. 1981)



P at 45˚ to x-axis, A at general angle ϕ to x-axis

- Photoelastic modulator (Mo) introduces phase along x-axis only
- $\delta = \delta_0 \sin(2\pi f t)$, f is modulator frequency (~50 kHz normally)
- Detector (D) measures either at frequency f or 2f

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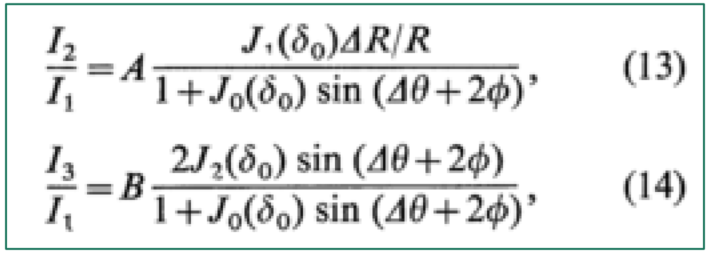
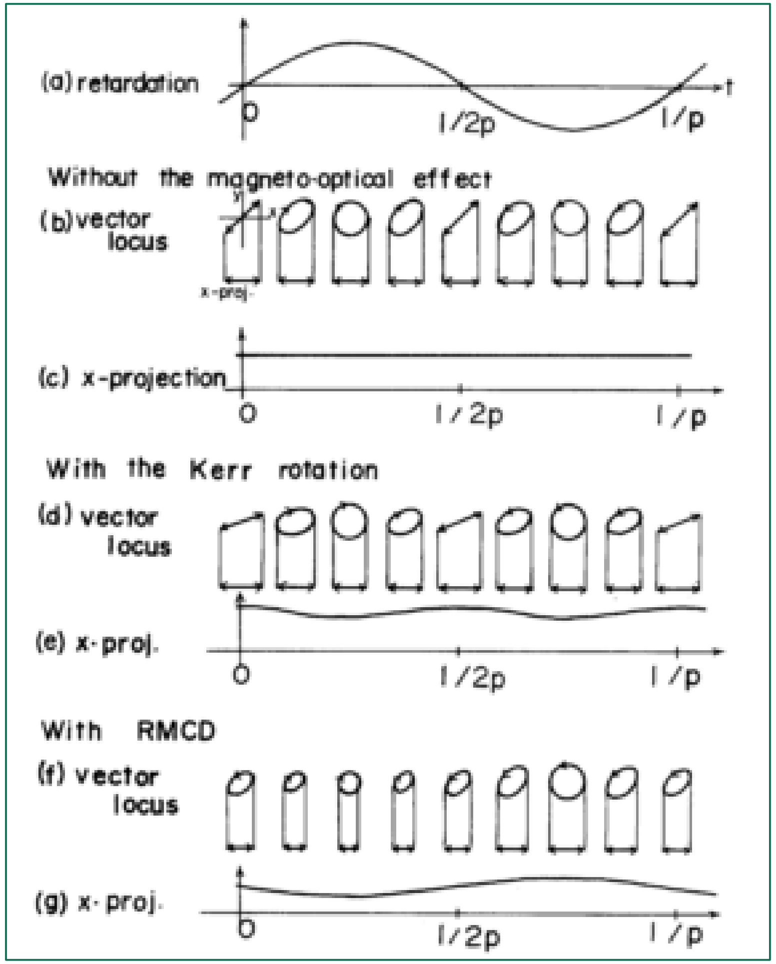


$$\frac{I_2}{I_1}=A\frac{J_1(\delta_0)\Delta R/R}{1+J_0(\delta_0)\sin(\Delta\theta+2\phi)}, \quad (13)$$

$$\frac{I_3}{I_1}=B\frac{2J_2(\delta_0)\sin(\Delta\theta+2\phi)}{1+J_0(\delta_0)\sin(\Delta\theta+2\phi)}, \quad (14)$$

- RMDC: measured at lock-in frequency f
- MOKE: measured at lock-in frequency 2f
  - $2\phi_K = -\Delta\theta$



Determining ϕ_K

- Set analyzer to 0˚
  - ${}^{I_3}/_{I_1} \cong 2BJ_2(\delta_0)\Delta\theta$
  - Requires calibration to determine constant $2BJ_2(\delta_0)$

- Set analyzer to $2\phi = -\Delta\theta$
  - ${}^{I_3}/_{I_1} = 0$
  - Requires ability to precisely measure and control angle of analyzer

Calibration of Kerr Rotation

- Replace sample with highly reflective, nonmagnetic material. Set analyzer angle $\phi = \pm\pi/4$
  - $\left({}^{I_3}/_{I_1}\right)_{\pm} = \frac{2BJ_2(\delta_0)}{1 \pm J_0(\delta_0)}$

- Ratio of 2 angles gives $J_0(\delta_0)$, and therefore $2BJ_2(\delta_0)$

Limitations of Sato Paper

- Derivation requires near zero incidence angle
  - Fresnel reflectivities depend on this

- Purely methodological; no link between optical rotation and magnetization of sample