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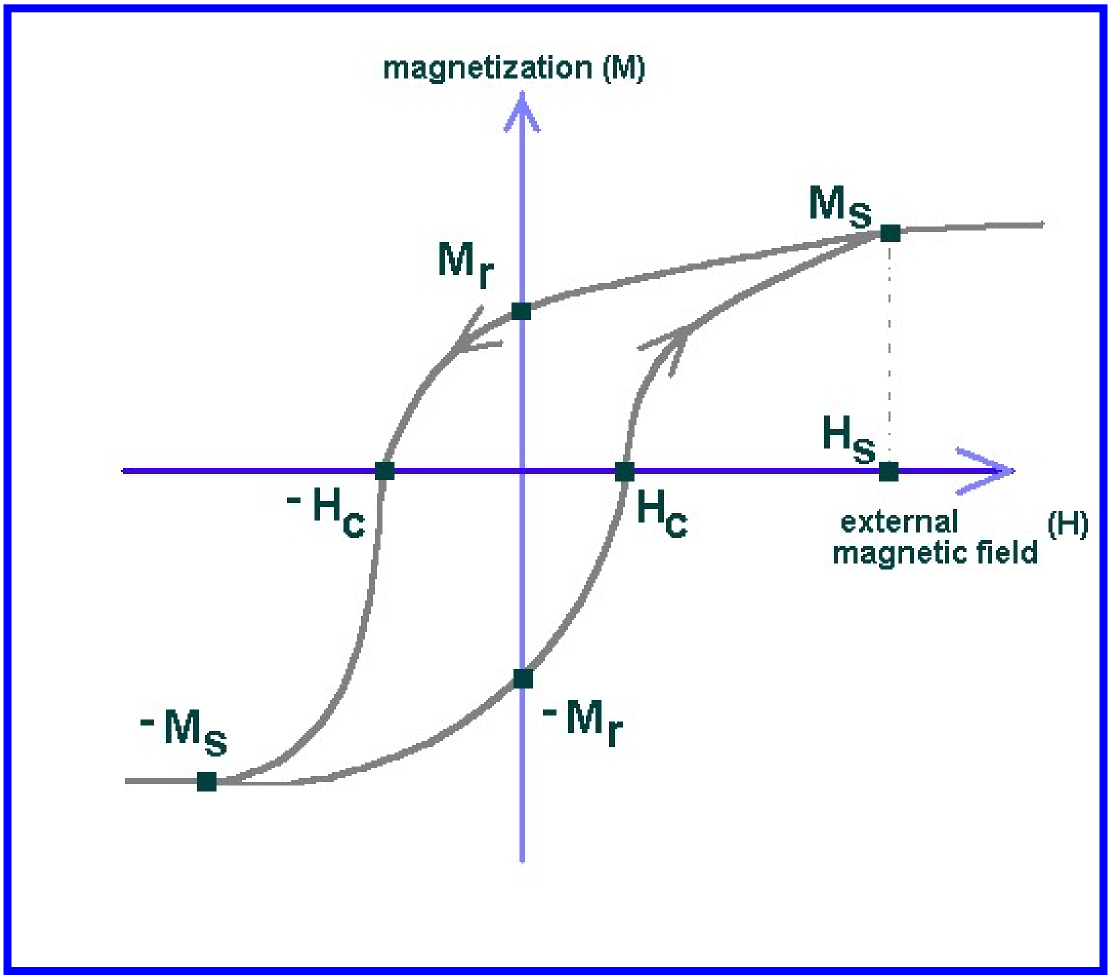
# Biaxial Magneto-Optical Kerr Magnetometer

## SAFETY FIRST

- The Kerr magnetometer uses a 632.8nm HeNe laser light source. Do not look directly into the beam.
- Make sure that you switch on the water chiller when using the big magnet. Forgetting to do this will result in serious equipment damage.

## MEASURING MAGNETIC PROPERTIES

A **hysteresis curve** is produced by subjecting a magnetic sample to a changing, external magnetic field and seeing how the magnetization of the sample changes. Some materials are hard to magnetize. It takes a strong magnetic field to produce a given magnetization in such a material. Other materials are "softer" and require less of an external magnetic field to produce the same magnetization in the sample. A hysteresis curve is nonlinear. A magnetic sample "remembers" what has already happened to it, and the magnetization depends on prior magnetization values. A typical hysteresis loop looks like this:




As the external magnetic field is increased, the magnetization of the sample will increase until it reaches a **saturation point.** Then, as the external field is decreased, the magnetization decreases, but not along the original path. Therefore, depending on how the external field is changing, the magnetization of the sample will have two different values. To see more detail on the features of the hysteresis loop, click here.

## THE KERR EFFECT

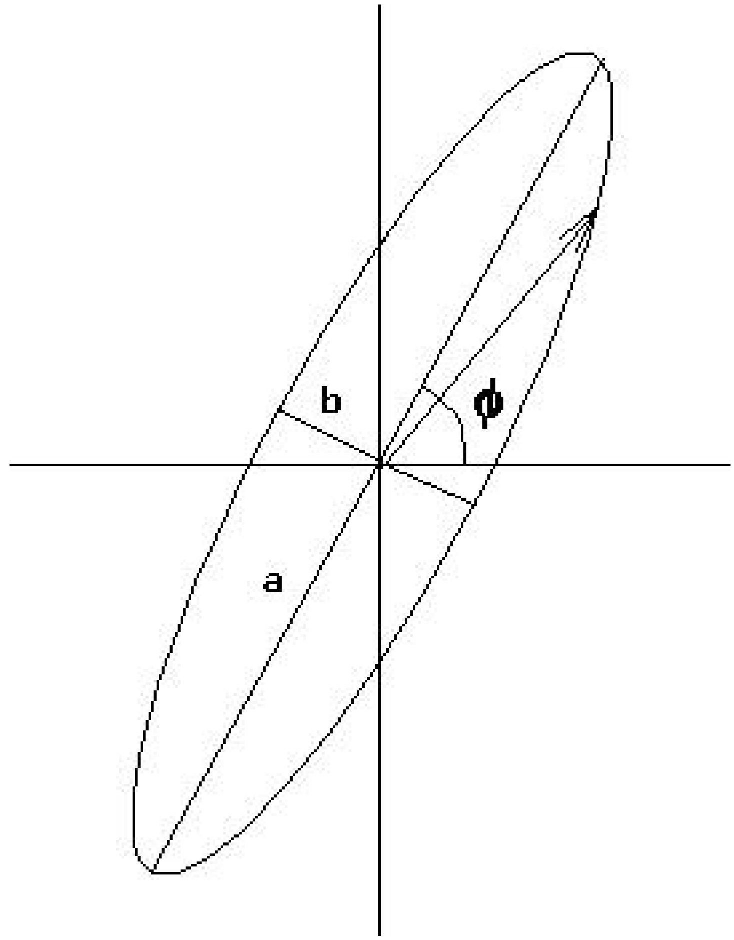
### Polarized Light

For a brief review of polarization, see the ellipsometer page.

Polarized light is described by a polarization ellipse. The shape of the ellipse mathematically defines the direction of the electric field vector as a function of time. For linearly polarized light, the ellipse is essentially stretched out until it becomes a straight line. For circularly polarized light, the ellipse becomes a circle. This is a visual way to describe the behavior of the electric field as a function of time

The Kerr effect is something that happens to light when it strikes a magnetized sample. In order to discuss the Kerr effect, we will first define two characteristics of polarized light**:** the orientation and ellipticity.

The diagram at the right describes elliptically polarized light, as seen looking into the beam. Imagine the arrow in the diagram pointing in the direction of the electric field. As time increases, the electric field will change direction, but the tip of the arrow will always stay on the ellipse. The ellipticity of the light is defined as the ratio of the major (a) to minor (b) axis length. This ratio can be seen as the ratio of light polarized in the y direction to light polarized in the x direction. The orientation of the ellipse is the angle phi in the diagram.



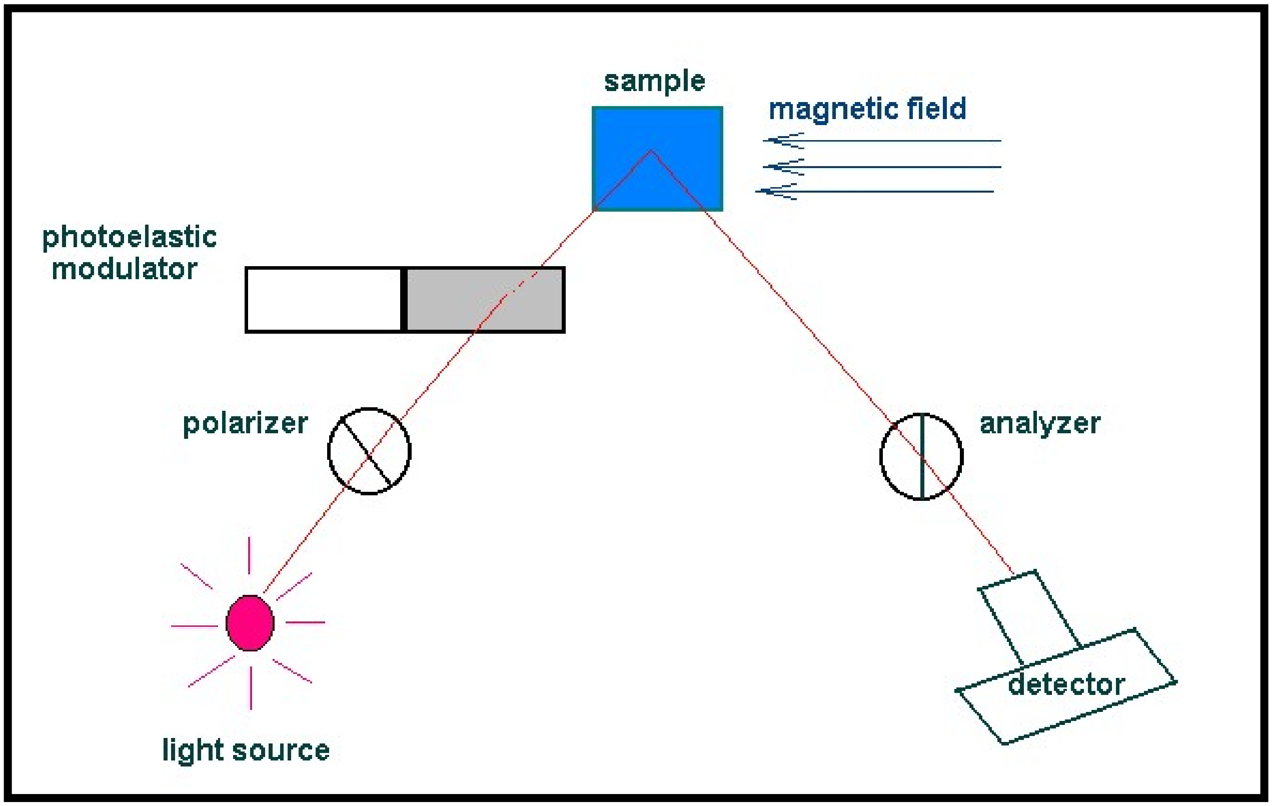

This diagram represents an incoming beam of light that strikes our magnetic sample. The beam will act as our probe to help us determine the characteristics of our sample.

**Spin-Orbit Interaction**

When light interacts with a magnetic sample, both the ellipticity and rotation of the light beam will change. This is due to the difference in absorption coefficients for right-hand, circularly polarized (RCP) and left-hand, circularly polarized (LCP) light. Linearly polarized light can be seen as a superposition of these two states. The difference in absorptions will distort the original orientation of the beam, changing the angle phi and the ratio between a and b (refer to drawing at right). The change in polarization angle is called the **Kerr Rotation**, and the change in major/minor axis ratio is called the **Kerr Ellipticity**. These changes are governed by the nature of the magnetic material and degree of magnetization. So, if the magnetization changes, the Kerr rotation and ellipticity will also change.

## MAGNETO-OPTICAL MEASUREMENT APPARATUS

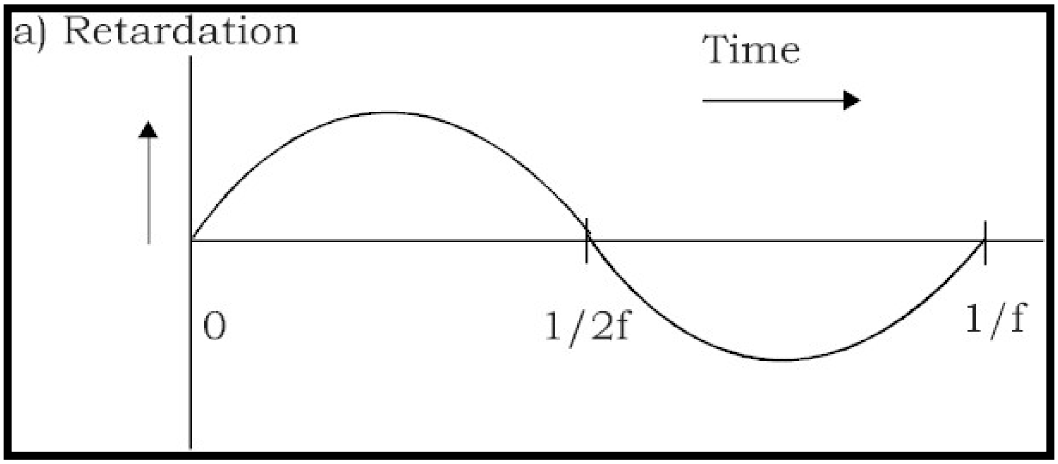
The Kerr magnetometer has the following set up:



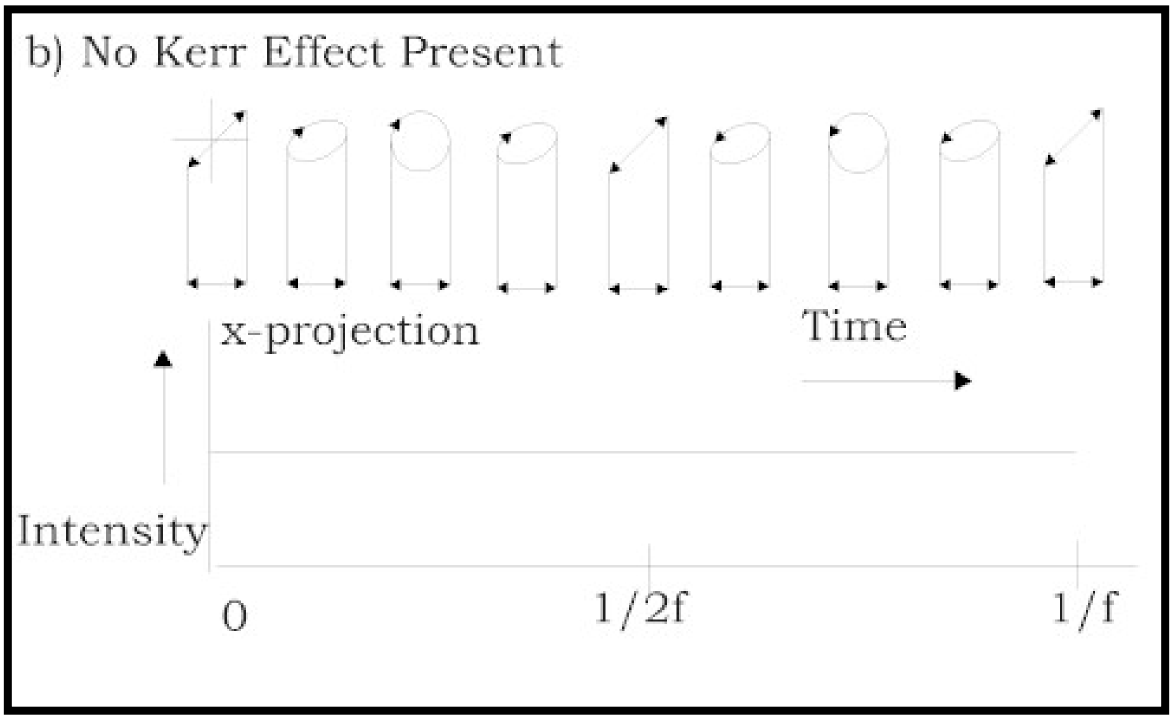

The HeNe light source is linearly polarized. The linearly polarized beam is modulated by the photoelastic modulator (PEM). The PEM changes the polarization state of the beam back and forth between RCP and LCP light. The sample rotates the plane of polarization and changes the ellipticity of the light, so that the analyzer sees a different signal than the one produced at the PEM. The detector measures the intensity of the beam.

**Photoelastic Modulator Effects on Signal**

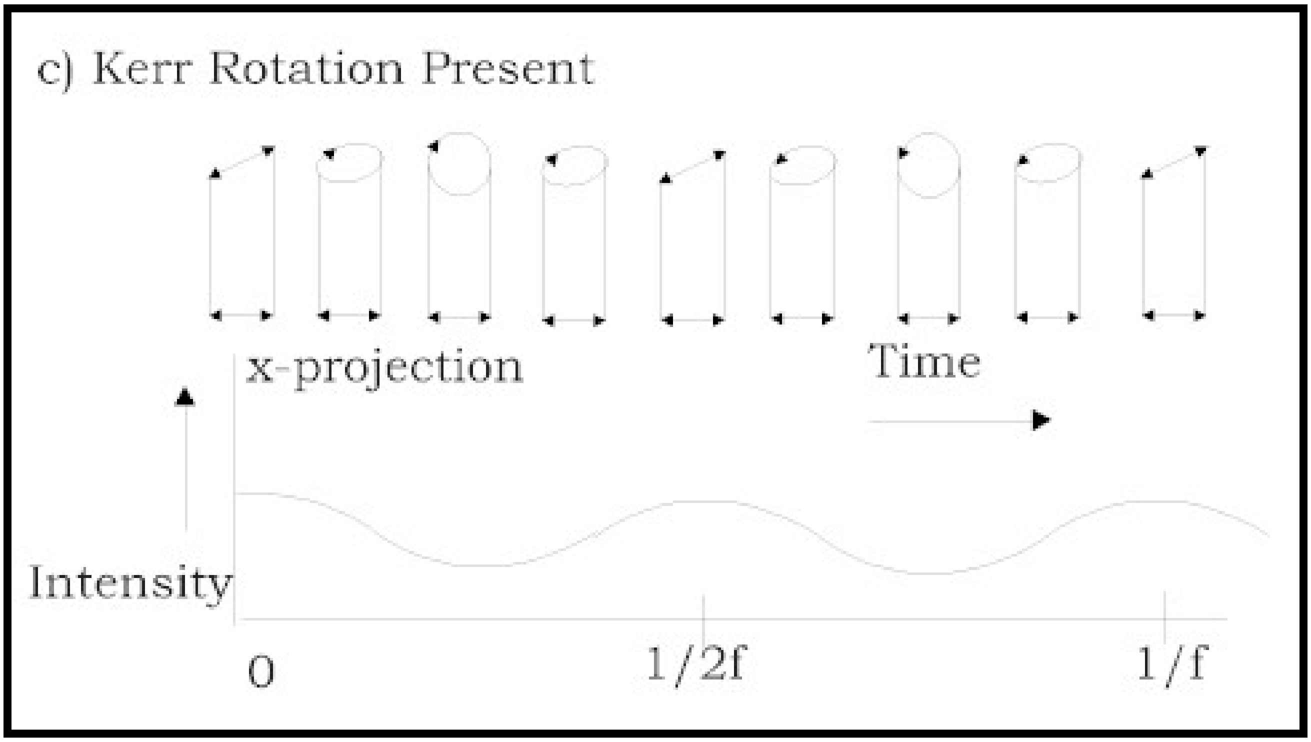
The photoelastic modulator uses a quartz piezoelectric material to vibrate a silica bar at its resonant frequency of 50kHz. The piezoelectric material is the white area in the above diagram; the silica portion is the grey area. The silica bar gets compressed and stretched; this changes the birefringence of the material. The component of light passing along the modulation axis (in the horizontal direction) will be affected by a changing index of refraction. This horizontal component will have a phase shift with respect to the vertical component. This phase shift will change at a frequency of 50kHz, making the ellipticity of the beam change at the same frequency. The diagram below shows the retardation of the x component as a function of time.



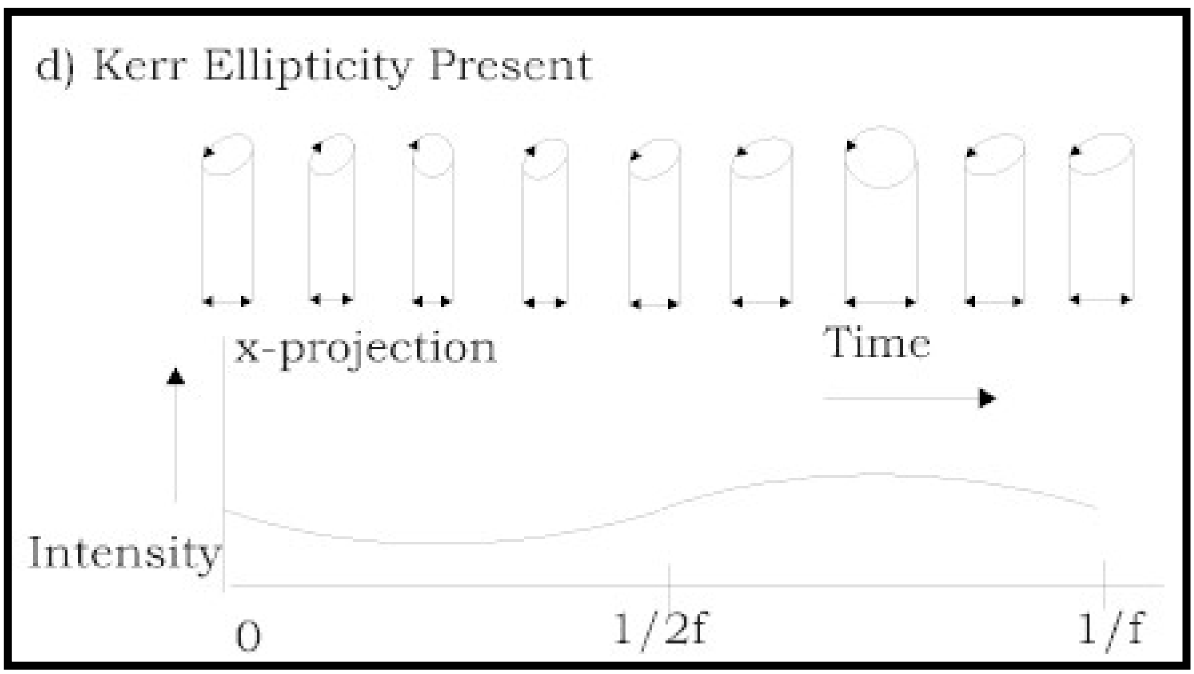

Both the x and y components will then pass through the rest of the optical set up. If there is no Kerr rotation or ellipticity present, the signal passes through unaffected. Then, the only thing changing is the ellipticity of the light beam, which will not affect the intensity at the detector. The unaffected signal will look like this:




If a Kerr rotation is present, the angle of polarization of the beam will change. Since there is a linear polarizer (the "analyzer" in the set up diagram) after the sample, the intensity at the detector will now change. The resulting signal and intensity at the detector will look like this:




If there is Kerr ellipticity present, the ellipticity of the incident beam will change. This can also be seen as a change in the ratio of major-to-minor axis in the polarization ellipse. The resulting signal and intensity would look like this:




As you can tell from the last two diagrams, the Kerr rotation will modulate the intensity at a frequency of 2f, where f is the frequency of the PEM modulation, i.e. 50kHz in our case. The Kerr ellipticity will modulate the intensity at a frequency of f.

The depth of modulation will tell you how much the light was rotated by the sample. By feeding the detector signal into a lock in amplifier and using the PEM signal to regulate it, the Kerr ellipticity and rotation can be found by determining the amounts of intensity modulation of the 50kHz (f) and 100kHz (2f) portions of the signal.

Strictly speaking above described theory is only valid for the Polar Kerr effect (magnetization perpendicular to the surface of the thin film) at perpendicular incidence. If the angle of incidence is unequal to zero degrees, the situation is slightly different. Also when the magnetization is in the plane of the film, i.e. parallel to the plane of incidence (longitudinal Kerr effect) or perpendicular to the plane of incidence (transversal Kerr effect) the situation is slightly different. Pleas find below three Mathcad files (version 8) that describe the signal analysis for the three cases:

Polar Kerr Effect    Longitudinal Kerr Effect    Transversal Kerr Effect

**STEP BY STEP PROCEDURE**