

**MAGNETO-OPTICAL EFFECTS**<sup>1</sup>Farhodov Feruz Oybek ugli, <sup>2</sup>Saidova Shahrizoda Adham kizi

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**ABSTRACT**

Electronic data storage today is unimaginable without magnetic disks. This article provides information on magnetic optical effects that can modulate these signals, their past and present capabilities. This article lists the first magneto-optical effects and modern magnetic optical effects, their advantages and disadvantages.

**KEYWORDS:** *Laws of physics, magnetism, optics, magnetic optical effects, plane of polarization, intensity of light, nanostructured materials, Faraday effect, Zeeman effect, Kerr effect.*

**INTRODUCTION**

Mankind has long been familiar with light and optical phenomena in the whole lifetime of the development. Magnetism has also been uncovered familiarity field for centuries, and especially in ancient China, magnetic stones were used to orient in a certain direction. It was not long before the first ideas about the interdependence of the fields of optics after magnetism emerged. In the middle of the 19th century (1845), experiments conducted by the English scientist M. Faraday revealed the interrelationship between these two fields, and at the same time the new field was the originally strode step in the field of magnetic optics.

According to this effect, known as the Faraday effect, the plane of polarization of light alters its previous appearance when a system is placed in an external magnetic field during the passage of light or an electromagnetic wave through matter. For example, when a vertically polarized light beam passes through an object in an external magnetic field, it changes the plane of polarization at an angle, called the Faraday angle, which depends on the external magnetic field, the type of magnetic material.

This research was followed by some scientists in the field of magnetic optics. In particular, a desirable magnetic optical school was developed in Russia, professors G. S. Krinchik, A.K. Zvezni, R.V. During Piserov's experiments, Faraday angles were observed that were large enough (several degrees) in film ribbons with a thickness of a few microns. After the discovery of these film ribbons, magnets began to be used as a transmitter of optical waves in data recording. In modern magnetic optics, magnetic optical effects began to be observed in specially prepared nanostructured materials, rather than homogeneous film ribbons. In such materials, it enables us to observe in detail the range of magnitudes of magnetic optical effects. For example, in Kerr's equatorial effect, the intensity of a wave returning or passing through a magnetic medium varies proportionally to the degree of magnetization of the medium. Researches and observations of Faraday and Kerr effects on special nanostructured film ribbon allow to enhance these effects. There are several approaches in describing the intensification of these magnetic optical processes.

The first approach is called magnet-photon crystal. In this case, the magnetic film ribbons are periodically placed, for example, first a layer of magnetic material, then a layer of non-magnetic material, then a magnetic layer, and so on, alternating several dozen layers in a row all processes are prepared. In this case, it is possible to observe an increase in the resonance of the Faraday and Kerr effects. The second approach is performed using a plasma coating. In this case, the magnetic substance is combined with nanostructured metals (gold, silver). An increase in the resonance of the Faraday and Kerr effects can be observed in this prepared compound. It is

important to note that magnetic optical effects are observed to be several tens of times stronger in special structural substances than in homogeneous substances.

The results of magnetic optical effects observed in special nanostructured materials were of great interest to me personally. Because these magnets naturally have the ability to change the plane of polarization or the intensity of light by changing the properties of a substance placed in an external magnetic field using optical effects. This allows the generation, modulation and processing of signals of different wavelengths using magnetic optical effects. Therefore, work is underway to increase the value of these effects.

Magnetic optical effects can be widely used in the following areas:

- to clarify the effective mass and concentration of charge carriers in semiconductors;
- to study of zonal structures of semiconductors;
- to amplitude modulation of laser beams on optical communication lines;
- to prepare optically unconnected elements;
- to study the structure of molecules;
- to study of domain structures of ferromagnetic film ribbons;
- to practice magnetic optical recording and use of data.

The above-mentioned fields do not "reveal" all the possibilities of magnetic optics. The Faraday effect is also used to study the magnetic field of ionized gas and cosmic electrons in interstellar space. Various studies on magnetic optical holography are being conducted in different countries, which makes it possible for computer science to record and store data in three dimensions. Interest in Faraday and other magnetic optical effects increased, especially with the advent of nanophotonics.

In this article, we will try to describe the physical properties and characteristics of several magnetic optical processes.

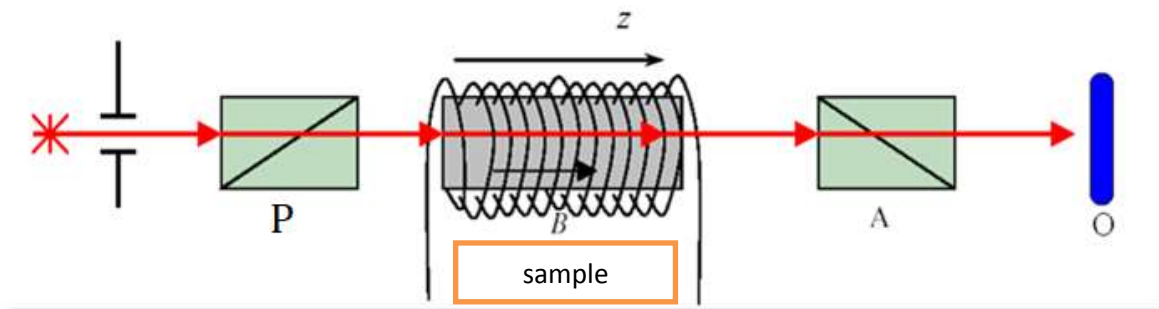
#### Magneto-optical effects

*I was able to electrify the light beam,  
I was able to illuminate the magnetic power lines.*

*M. Faraday*

**Faraday effect:** By the second half of the 19th century, the doors of a new field had opened for physicists around the world. By 1845, Faraday was the first to observe the connection between the still uncoordinated "branches" of physics and the branches of optics and magnetism.

To observe Faraday's phenomenon, we place a non-magnetic substance (K), such as a piece of glass, between the poles of an electromagnet. First, we place the polarization planes of the polarizer (P) and the analyzer (A) perpendicular to each other, that is, in the first case, no light appears on the screen.



After that, the subject (K) begins to be affected by magnetic field lines through the electromagnetic circuit. We transmit linearly polarized \* light through the glass in such a way that the lines of light and the magnetic field are in the same direction. It can be seen that matter K rotates in the plane of polarization, which is observed and measured by conventional methods.

The quantitative laws of the phenomenon were discovered by Faraday, and Verde examined them in more detail in a number of objects.

**Faraday-Verde's law:** the angle of rotation of the plane of polarization is directly proportional to  $ph$ , the length of the path of light in matter is  $l$ , and the induction of the magnetic field is  $B$ .

$$\varphi = VB l \quad (1)$$

where  $V$  is the Verde constant. The Verde constant depends on the type of substance being observed, the frequency of the electromagnetic light, and the temperature. According to the above law, under the influence of a magnetic field, all objects change the plane of polarization, even at a very small angle.

By changing the angle of rotation of the polar plane according to the Faraday effect, we can change the light intensity according to the law of Malus  $I = I_0 \cos^2 \varphi$  and this enables us to modulate the light rays \*.

Experiments have shown that in many substances, the plane of polarization turns to the right, that is, to the side where the electromagnetic coils are wrapped (in which case we observe the light in the direction of the magnetic field). Such substances are called positive substances, but in some paramagnetic substances the plane of polarization turns to the left, such substances are called negative substances. Keeping in mind we may realize that the direction of rotation of each object depends on the direction of the magnetic field and not on the direction of light propagation.

#### The classic description of the Faraday effect:

According to Fresnel, the plane of polarization of light changes as a result of the circular double refraction of light. Linear polarized light can be divided into two and a half amplitudes of left and right polarized light. In this case, the angle of rotation in the plane of beam polarization passing through the substance is:

$$\varphi = \frac{\pi l}{\lambda_0} (n_{\text{chp}} - n_{\text{oring}}) \quad (2)$$

where  $l$  - is the length of the optically active medium;

$\lambda_0$  - is the wavelength of light in vacuum;

$n_{\text{left}}, n_{\text{right}}$  - refractive index of "left" and "right" waves.

Due to the unequal values of  $n_{\text{left}}$  and  $n_{\text{right}}$ , the "right" and "left" waves propagate at different speeds in the medium. The difference in angular velocities of a wave in an optically active medium in a magnetic field:

$$\Delta\omega = \frac{eB}{m_e} \quad (3)$$

$e$  - is the electron charge,  $m_e$  - is the electron mass, and  $B$  is the induction of the permanent magnetic field.

The optical refractive index of the medium depends on the frequency, it means that the *dispersion* is available in the medium.

$$n_{chap} - n_{o'ng} = \frac{dn}{d\omega} \Delta\omega = \frac{dn}{d\omega} \frac{eB}{m_e} \quad (4)$$

from the formula (2)  $\lambda_0 = \frac{2\pi c}{\omega}$ , we may get the following:

$$\varphi = \frac{l}{2c} \omega \frac{dn}{d\omega} \frac{eB}{m_e} \quad (5)$$

using the equation found from the formula (5) into the formula (1) we find the normal constant of Verde-Vn.

$$V_n(\omega, T) = \frac{e}{2m_e c} \omega \frac{dn}{d\omega} \quad (6)$$

The above relationship is called the formula of Beckerl.

**Zeyeman effect:** In 1896, 50 years after Faraday's first magnetic-optical discovery, Zeyeman discovered a weak change in the frequency of spectral lines under the influence of an external magnetic field. The schematic device of Faraday's experiment in 1862 corresponds to the principle structure of the Zeeman device. In this experiment, Faraday tried to observe changes in the spectrum of sodium vapors under the influence of a magnetic field. However, the spectral apparatus has a low resolution and a weak magnetic field no change in spectral lines was observed as a result. In addition to changes in spectral lines, Zeeman also observed the polarization properties of spectral lines according to Lawrence's instructions.

When observing the very narrow green-blue line of cadmium, a geyser tube or vacuum arc is placed between the electromagnetic poles, which can generate a single 10,000 to 15,000  $\text{G}$  magnetic field. An electromagnetic core is drilled to record the longitudinal effect (magnetic field tracking). Light is incident on a diffraction grating or interference spectroscopy with a high resolution (approximately 100,000) ( $S_p$  in the diagram). To analyze the polarization of the emitted light, L-lens, N-analyzer and a quarter-wave plate are placed in the beam path.

In the absence of a magnetic field, simplest spectral lines with frequency  $\nu$ , such as H, Zn, Cd, is described as follows:

In a magnetic field across a field (doublet) –  $\nu - \Delta\nu$  va  $\nu + \Delta\nu$ .

In a magnetic field the (triplet) –  $\nu - \Delta\nu$ ,  $\nu$ ,  $\nu + \Delta\nu$ .

According to Lawrence, we consider monochromatic light to be the result of the motion of an electron under a simple harmonic law, under the action of a quasi-elastic force. In the absence of a magnetic field, the motion of an electron can be thought of as a harmonic oscillation in any direction. We divide this motion of the electron into three components, the first parallel to the magnetic field, the second perpendicular to the magnetic field and the right circular, and the third perpendicular to the magnetic field and the left circular plane.

According to Lawrence's law, the force exerted by a field on a particle moving in a magnetic field with velocity is:

$$F = q \cdot B \cdot v \cdot \sin\alpha$$

$q$  – is the charge amount of the particle,  $B$  is the magnetic field induction

$\alpha$  – is the angle between  $\vec{v}$  and  $\vec{B}$  vectors.

In the first case ( $\alpha = 0^\circ$ ), the electron moving parallel to the magnetic field is not affected by any force from the field, because  $\sin\alpha = 0$ .

In the second and third cases ( $\alpha = 90^\circ$ ), an additional  $\pm eBv$  force is applied by an electric field perpendicular to the magnetic field along the radius of curvature of the electron direction to the center of the curve or in the opposite direction. The oscillation across the field does not change and continues at the initial frequency  $\nu$ .

**Kerr effect:** If a line of polarized light strikes the surface of a magnetic object and returns, the plane of polarization of the light is reversed. The elliptical polarity changes as the intensity of the light changes. These physical phenomena are called the Keer effect.

The Keer effect is divided by 3 according to the relationship between the plane of magnetism of the substance, the plane of propagation of the light incident on it, and the normalR transmitted to the surface. In general, when a linearly polarized light beam returns from the surface of a magnetic object, it becomes polarized, the major axis of the ellipse forms an angle with the original linear polarized light (the plane of polarization changes), and the intensity of the light also changes. The Keer effect is similar to the Faraday effect, in that in both cases the electromagnetic light interacts with the magnetic medium. Both effects are related to the non-diagonal components of the dielectric constant ( $\epsilon_{ij}$ ) tensor, which is a linear function of the external magnetic field and the magnetization magnitudes.

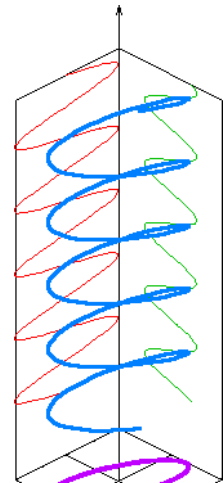
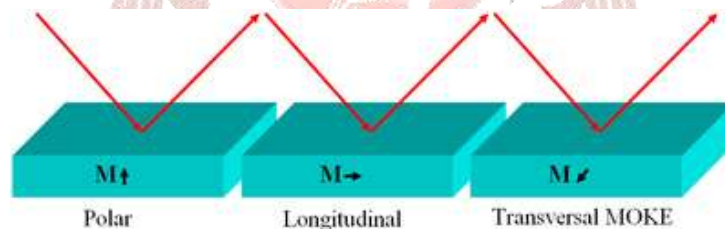
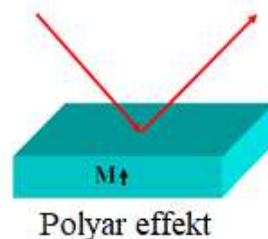


Figure 1. Elliptical polarization



Keer polar effect:



In Keer's polar effect, the external magnetic field or magnetism is perpendicular to the plane of the sample, and both poles (s and p) can be observed. A much better effect is observed when light strikes the surface vertically, and the magnetic permeability tensor is determined by a simple equation with respect to  $\epsilon_{ij}$ , deflection  $\vartheta$ , and ellipticity  $\psi$ . If the light is propagating along the Z axis:

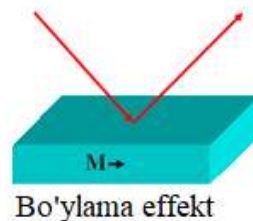
$$\tilde{\Phi} = \vartheta + i\Psi = \frac{i\epsilon_{xy}}{\hat{n}(\epsilon_{xx} - 1)}$$

$\hat{n} = n + ik$  - complex refractive index.

According to the above equation, in a non-absorbing medium in which the dielectric constant tensor always consists of a real component, the rotation of the plane of polarized light is not observed.

Under the influence of an external field, the Keer effect is linear, and the sign of the angle of rotation varies with magnetism. For non-ferromagnetic substances, this effect is sometimes referred to as the "Faraday polar effect in reflected light."

#### Keer meridial (meridional) effect:



This effect is also known as Keer's longitudinal or meridian effect. The magnetization vector is parallel to the plane of the incident light along the plane of the reflecting surface. Larger values of the angle of incidence make this effect better.

#### Keer equatorial effect:



This effect is also called Keer's cross effect. In Keer's equatorial effect, the magnetization is perpendicular to the plane of the incident light, parallel to the plane of the sample. This effect is observed when the polarity component is perpendicular to the magnetization (p-component), which is equal to zero for the case of parallelism to the magnetization (s-component). Keer's equatorial effect is the first-order magnetization effect. As a result of the change in the reflection coefficient of the substance under the influence of magnetism, the light intensity changes and a phase shift of the linearly polarized light is observed. This effect is observed only in absorbing substances, especially in materials where the complex part of the dielectric constant tensor is not equal to zero. At real values of the dielectric constant tensor and the s-components of the polarized light, a very weak quadratic effect is observed.

#### Nonlinear effect of magnetism:

In addition to the polar, meridional, and equatorial effects, there are also quadratic effects on the magnetism of the polarization plane. This effect is called Keer's quadratic effect and is known to us by the Vogt and Cotton-Muton effects.

Magnetic optical media:

According to the effect of electromagnetic waves, magnetic optical materials are divided into two classes.

In first-class materials, the magnetic optical effect affects the electron orbital motion of the magnetic field (Zeeman effect). This class includes diamagnets and single-axis symmetrical transparent substances in which diamagnetism is always present. The observed magnetic optical effects are very weak.

The second class of materials includes ferromagnetic substances and low-temperature non-metallic paramagnetic substances. In these substances, magnetic optical effects are caused by the effect of a magnetic field on the electron spin-orbital motion.

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