ASTRAKHAN STATE UNIVERSITY

PHYSICAL FUNDAMENTALS OF OPTOELECTRONIC SYSTEMS ANALYSIS

Lecture 1. Physical Fundamentals of Optics and Magnetooptics.

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Content

- **- What is light**
- **- Polarization of light**
- **- Malus’s Law**
- **- Double refraction**
- **- Main magnetooptical effects**
- **- Magnetoactive materials**
- **- Test questions:**
- **Test**

Light is electromagnetic waves. An electrical vector E plays a major part in all processes of light-substance interaction so it is called a light vector.

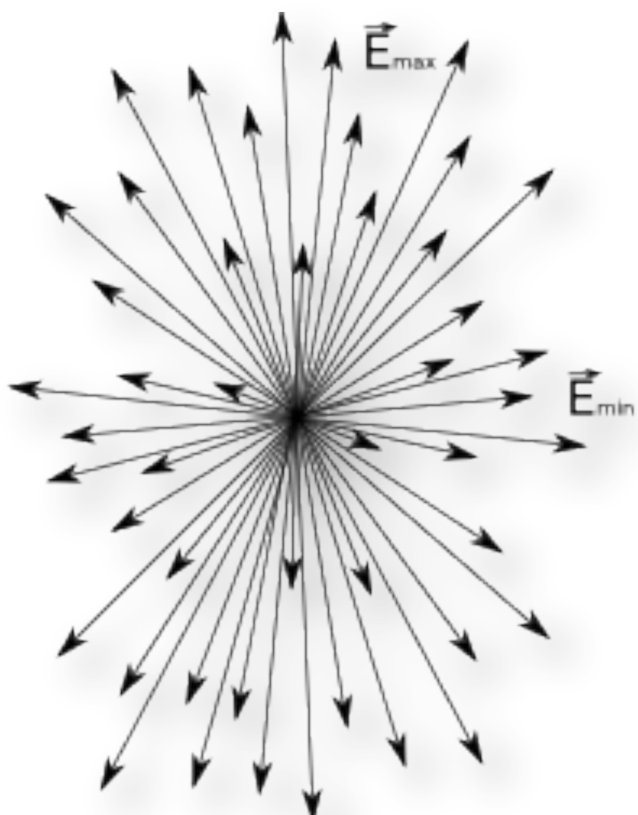
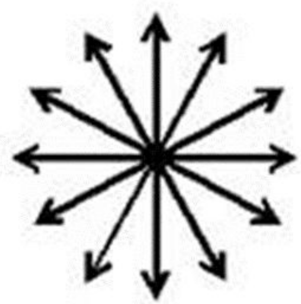


Fig. 1.1. Non-polarized light



If the directions of fluctuations change haphazardly, while the amplitudes in all directions are uniform, the wave is called natural.

If fluctuations occur in a single constant direction, the wave is called linearly polarized.

It the fluctuations occur in different directions, but in certain directions the fluctuation amplitudes are greater than in others, the wave is called partially polarized

Polarizer

A polarizer is a device to obtain fully or partially polarized optical radiation from radiation with random polarization characteristics.
This device readily lets the waves parallel to its polarization plane pass, while the waves perpendicular to the polarization plane of the device can not pass.

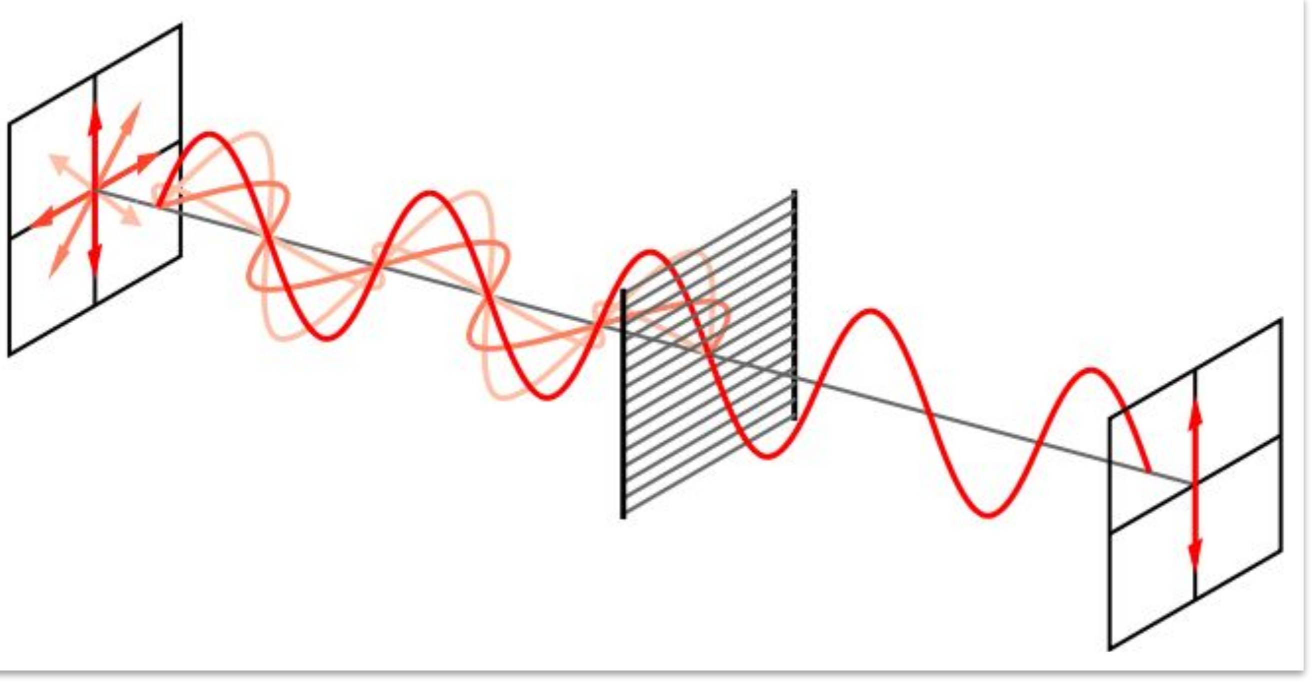
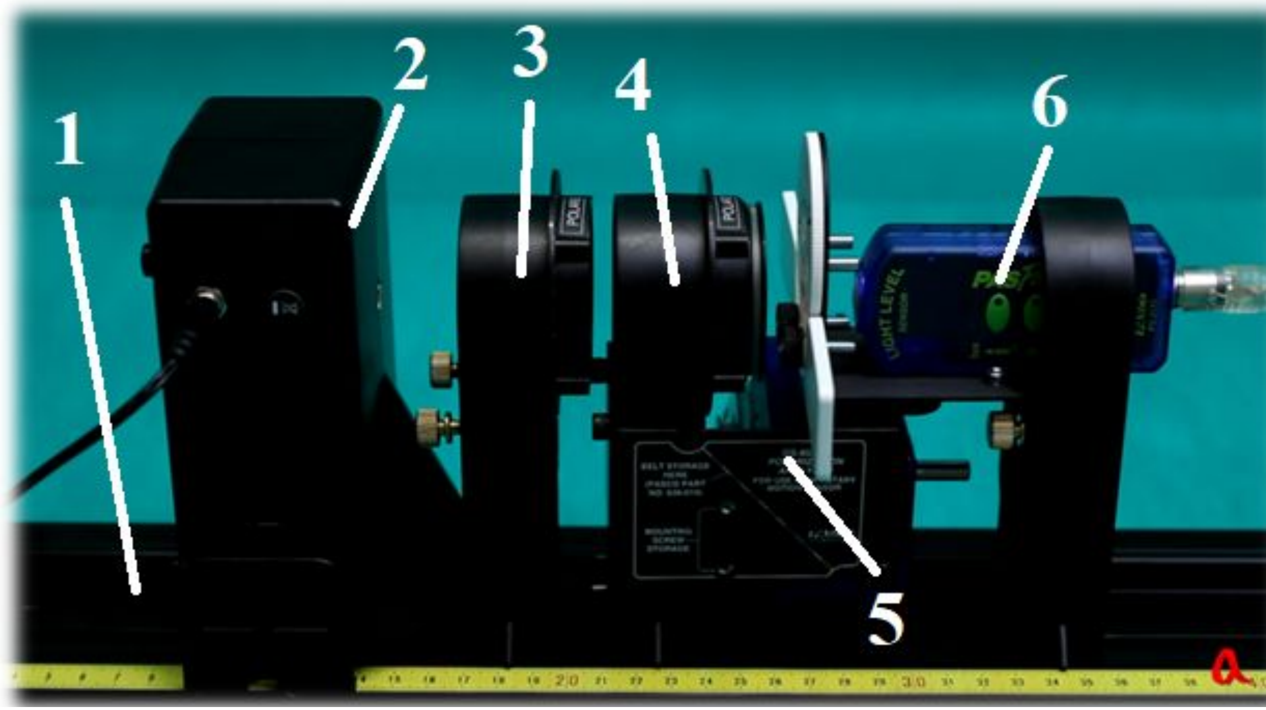


Fig. 1.2. Non-polarized light passing through a polarizer

Experience 1.1. Polarization of light

- Equipment:
- 1. optical bench
- 2. light source
- 3. polarizer
- 4. analyzer
- 5. rotation sens
- 6. light sensor



Working process:

- 1. A light source is installed on the optical bench. Let's move the polarizer closer to the light source. Then comes the analyzer connected to the rotation sensor. The last is the light sensor.
- 2 Turn the analyzer and see how the light sensor indication depends on the rotation angle.
- 3. The experiment is carried out in the dark to get rid of extraneous illumination.

Here's how the light sensor indication depends on the rotation angle. The maximum is obtained when the axes of both polarizers are parallel. The minimum is obtained when they are perpendicular. At the minimums, the illuminance does not drop to zero, because polarizers are not ideal.

Let’s replace the angle with the square of its cosine. This dependence is linear with good accuracy, so the Malus Law is fulfilled even when corrected for polaroids’ non-ideality.

Malus's Law

$$I = I_0 \cos^2 \varphi$$

I_0 is the intensity of the light impinging on the light polarizer

I is the intensity of light coming out of the polarizer

φ is the angle formed by polarization planes of impinging light and a polarizer.

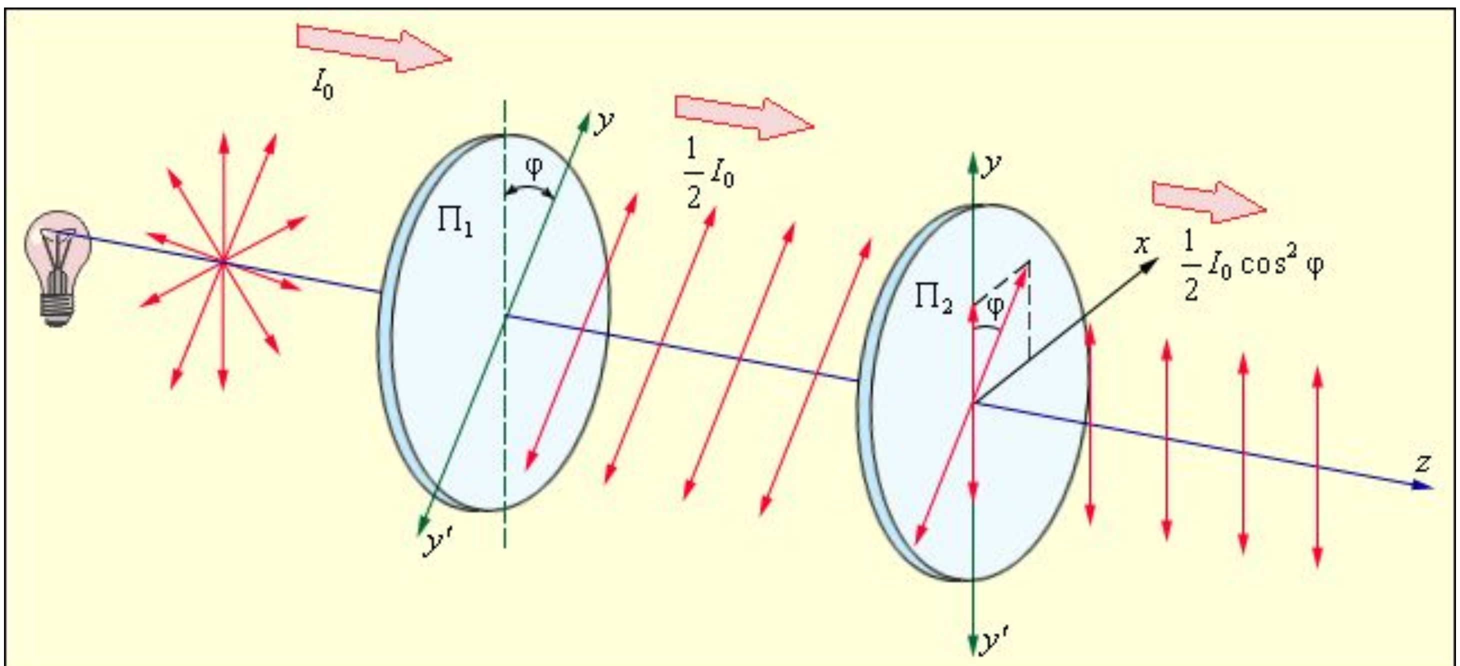


Fig. 1.3. Action principle of Malus's law

Ways to get polarized light

Lasers. The light generated by a laser is linearly polarized because it is not produced by spontaneous emission, as it happens in case of hot bodies, but by stimulated emission where all the emitted photons have the same frequency, phase and direction as the photons that induced the emission of excited atoms.

Light scattering. Light scattered in the direction perpendicular to the beam is flatly polarized.

Polarization under reflection and refraction

If natural light impinges on a reflecting surface of a dielectric material (glass, mica etc.) at an angle θ_B, meeting Brewster's condition :

$$tg\Theta = \frac{n_2}{n_1}$$

"Claude Mirror"

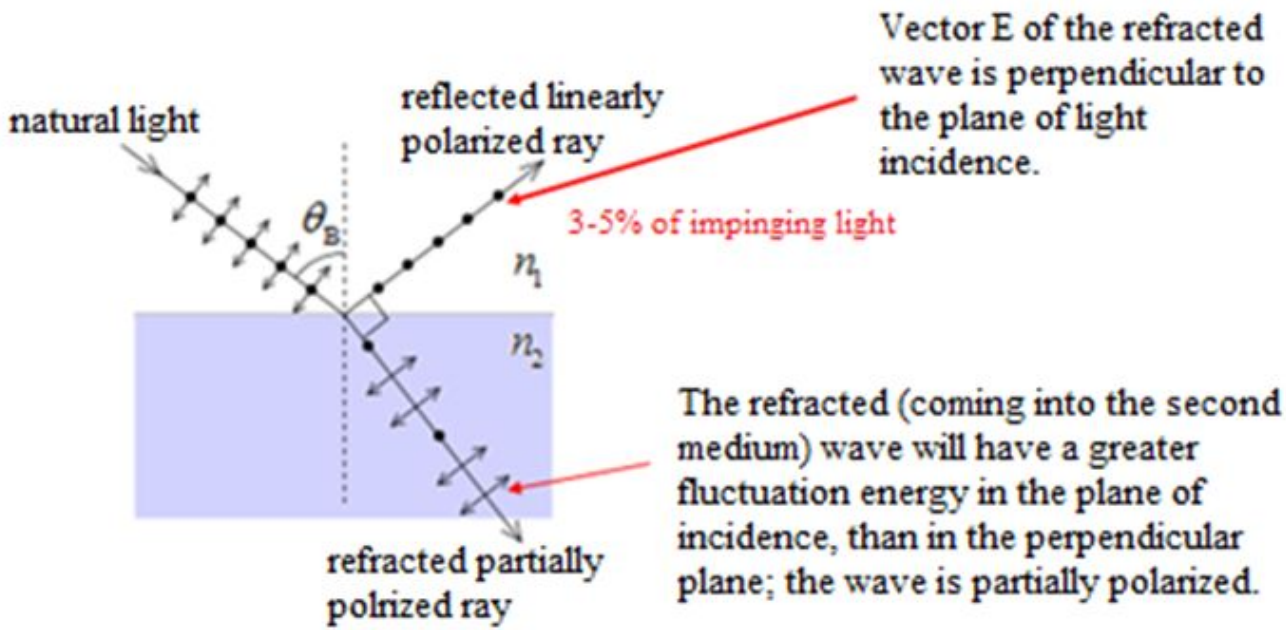


Fig. 1.4. Polarization under reflection and refraction

Multiple reflection through a “stack of plates” is used in practice.

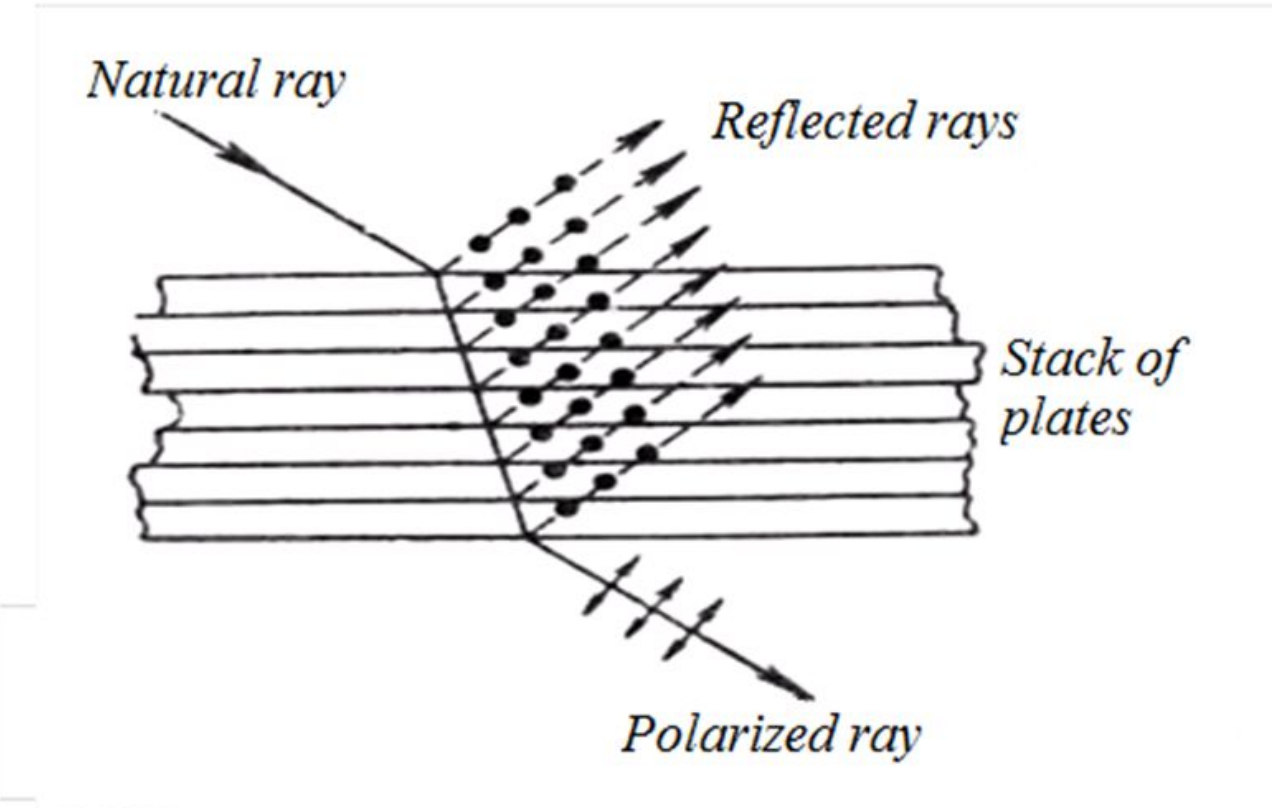


Fig. 1.5. Reflection of light through a “stack of plates”

Polarization by double reflection in crystals.

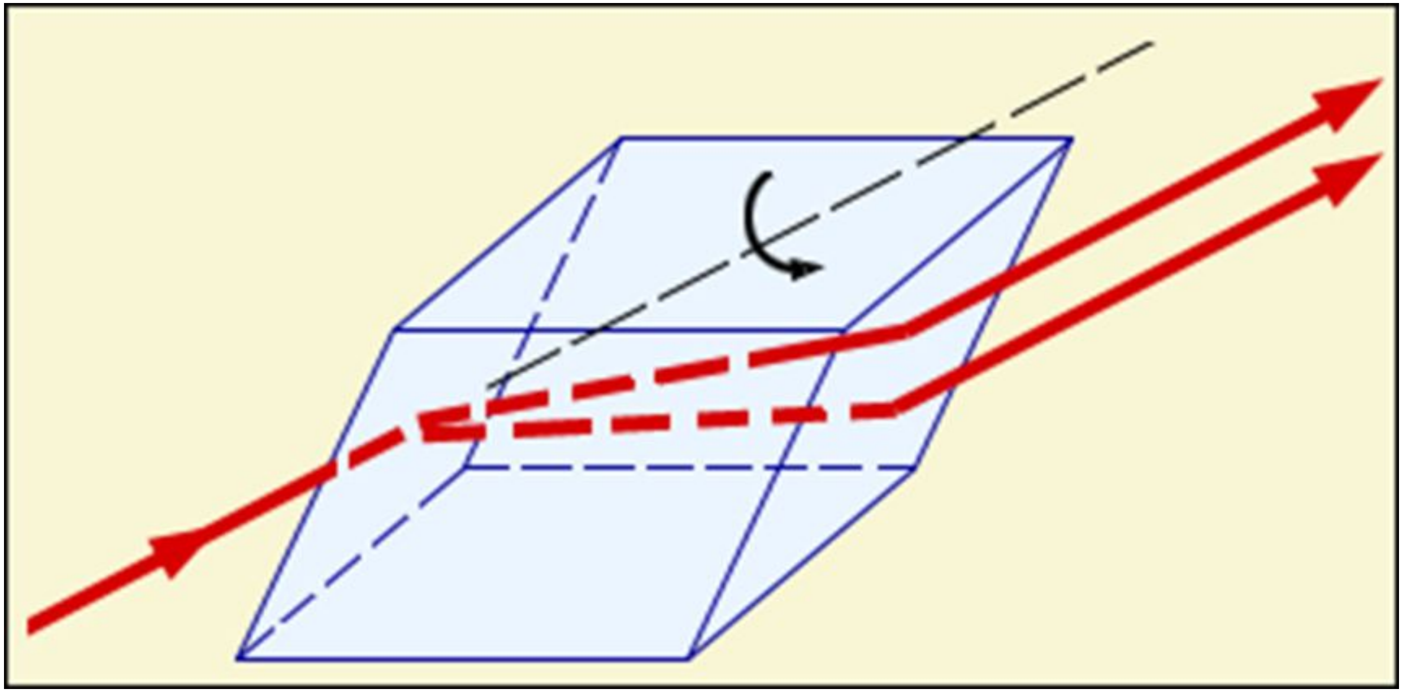
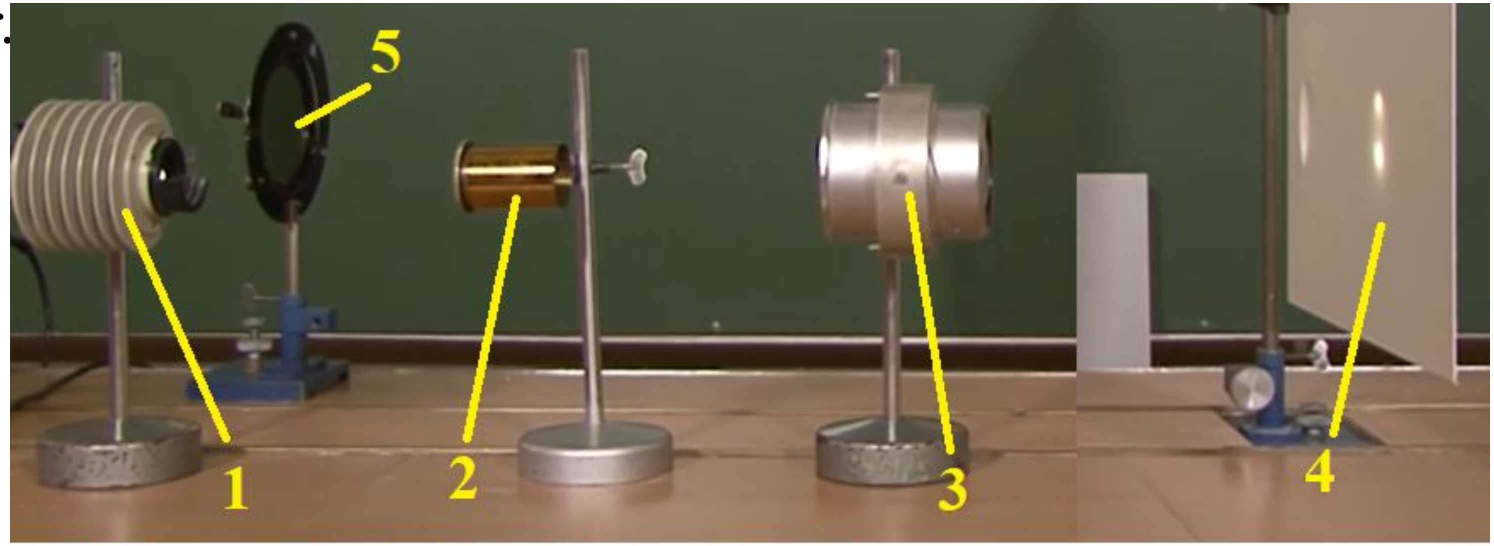


Fig. 1.6. The figure shows double refraction in a crystal

In crystals there are one or several directions that make velocity of light independent of the vector orientation. These directions are called optical axes of a crystal.

Experience 1.2. Double refraction

- Equipment:
- 1. Light source.
- 2. Uniaxial crystal (feldspar crystal) on a rotating stand.
- 3. Collecting lens.
- 4. Screen.
- 5. Analyzer.



Working process:

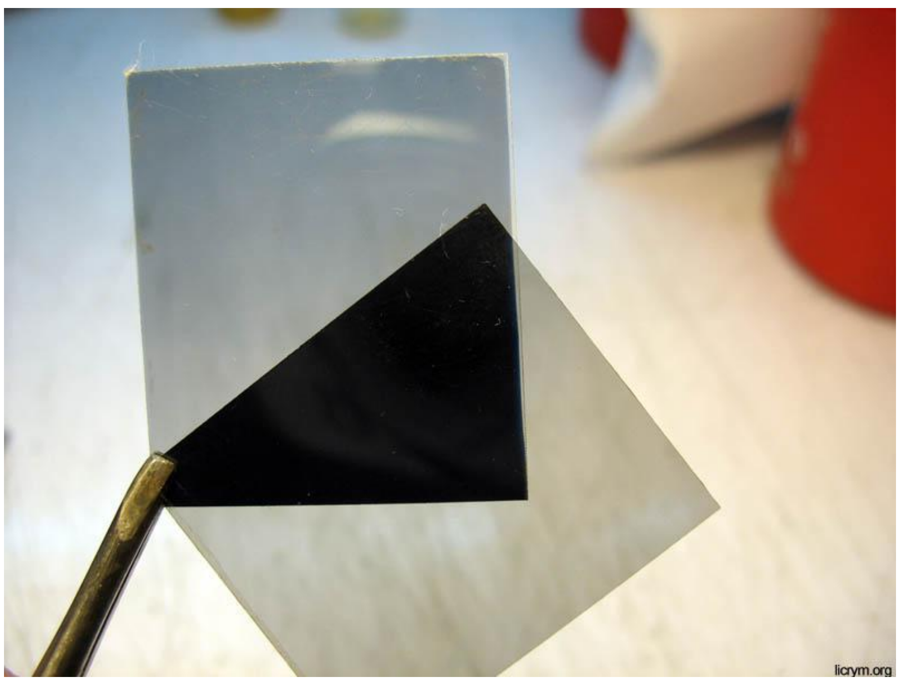
- **1. We assemble the installation for the double refraction observation. Light from the source falls normally on the crystal.**
- **As a result, there are two spots on the screen:**
- **the central spot is extraan ordinary wave;**
- **the displaced spot is an ordinary wave.**
- **2. When the crystal is rotated, we observe an extraordinary ray rotation around a fixed central spot.**
- **3. Install the analyzer behind the crystal so that both spots are visible.**
- **4. Turn the analyzer. Observe alternately blackout spots.**
- **5. Install the analyzer so that both spots are visible. Now turn the crystal. As a result, we observe periodic spots' disappearances with an extraordinary wave simultaneous displacement.**

Conclusion:

- non-polarized light falling normally on the anisotropic crystal optical axis divides into two completely polarized in mutually perpendicular beam directions (or, as they say, two waves) - ordinary, which propagates along the original direction (along the crystal axis), and extraordinary, which deviates from the original light propagation direction.
- This effect is called double refraction.

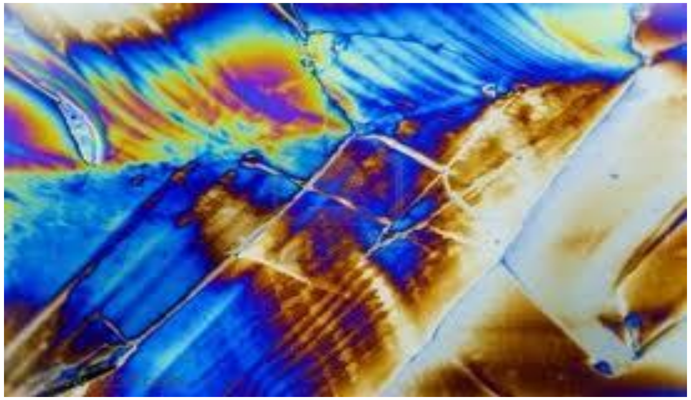
Polarization of light passing through absorbing anisotropic substances

So called polaroids are obtained by applying a thin coat of crystal flakes of tourmaline or herapathite on glass.



Application of polarization:

- Adjusting the light and blanking out glares;
- Blanking out light that is specularly reflected from smooth dielectric surfaces;
- Polarization microscopy;
- Contrast enhancement;
- Crystallographic research and photo-elastic analysis.



Main magnetooptical effects

Zeeman effect. An atom constitutes a magnetic dipole with magnetic moment $\vec{\mu}$ and additional energy ΔE, gained by the atom in magnetic field $\vec{H}$:

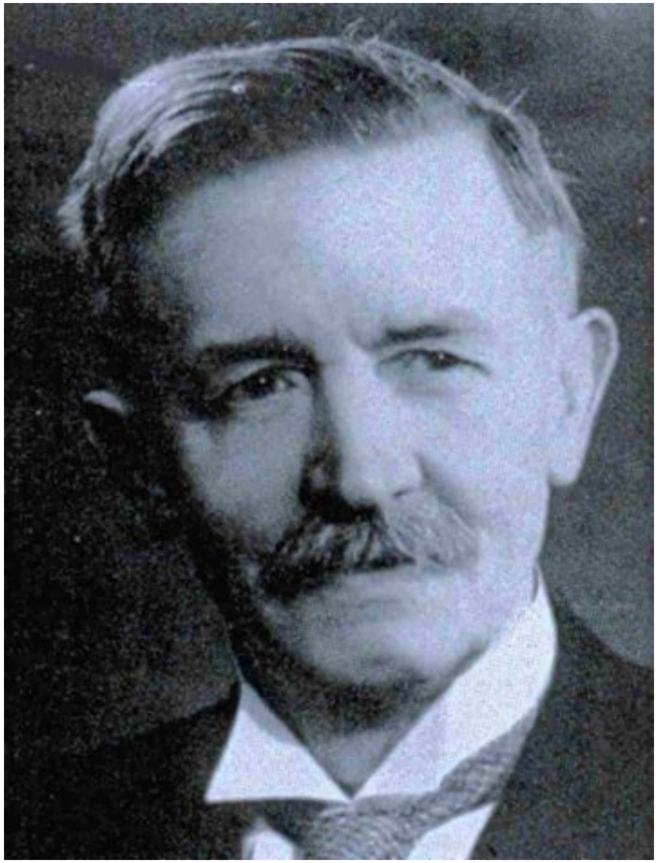
$$\Delta E = -\left(\vec{\mu}\vec{H}\right)$$

Normal Zeeman effect.

Under normal Zeeman effect a spectral line is split into two components in the magnetic field with intensity H, if the phenomenon is observed along the force lines of the magnetic field, or into three components if the phenomenon is observed perpendicular to the direction of force lines.

Anomalous Zeeman effect.

Most elements have a far more complicated picture of spectral lines splitting when an external magnetic field is present: in some cases there are many components with complex character of polarization.



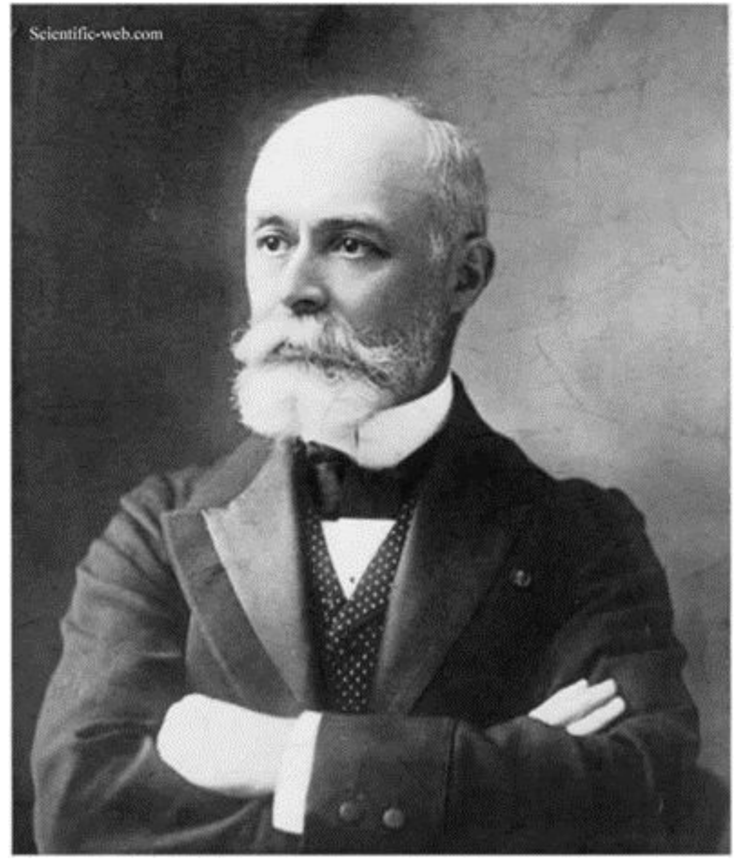


Fig. 1.7. French physicists Aime Cotton (left) and Henri Mouton (right)

The Kerr effect

Magnetic linear birefringence (the Cotton-Mouton effect).

The Cotton-Mouton effect is a birefringence of light in an optically isotropic substance, placed into a magnetic field that is perpendicular to a light ray; the phenomenon was researched by Aime Cotton and Henri Mouton, French physicists.
Difference of refraction indices of n_0 ordinary and n_e extraordinary rays is proportional to the light wavelength, λ, as well as to the squared H intensity of a magnetic field:

$$n_e - n_0 = \lambda C H^2$$

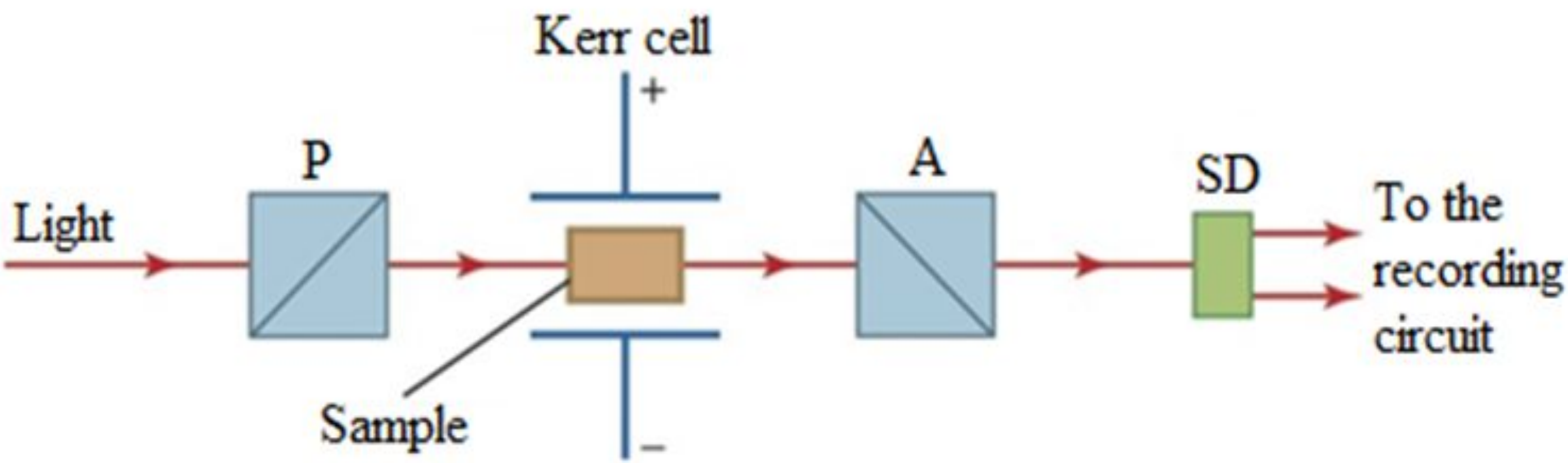


Fig. 1.8. A Kerr cell ((P) – with crossed polarizers, (A) – an analyzer,
(SD) – a light sensitive device)

Magnetoactive materials

Magnetoactive materials (magnetic materials) are materials that significantly change its magnetism under the influence of the excitation magnetic field.

The influence of the magnetic field is exercised with a force that can be characterized by the magnetic induction vector B:

$$B = \mu\mu_0 H,$$

Substances are subdivided into three types:

Diamagnetics

are substances that do not have a magnetic moment when an external magnetic field is absent and become magnetized in the direction opposite to the action of the internal magnetic field.

Paramagnetics

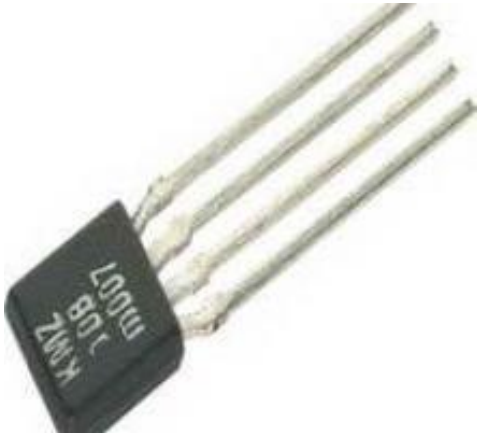
are substances consisting of atoms with intrinsic magnetic moments, but when an external magnetic field is absent these moments are chaotically oriented and magnetization of a substance upon the whole is not observed.

Ferromagnetic

substances are capable of having magnetization when an external magnetic field is absent.

Magnetoactive materials include:

1. Square-loop materials;
2. Magnetostrictive materials;
3. Thermomagnetic materials;
4. Magnetooptic materials;
5. Magnetoresistive materials etc.



The use of magnetic materials in magneto-optic devices is based on the Faraday effect (Fig. 1.10) that means that when a linearly polarized ray of light K_1 is distributed along the magnetization vector M, polarization plane E rotates.

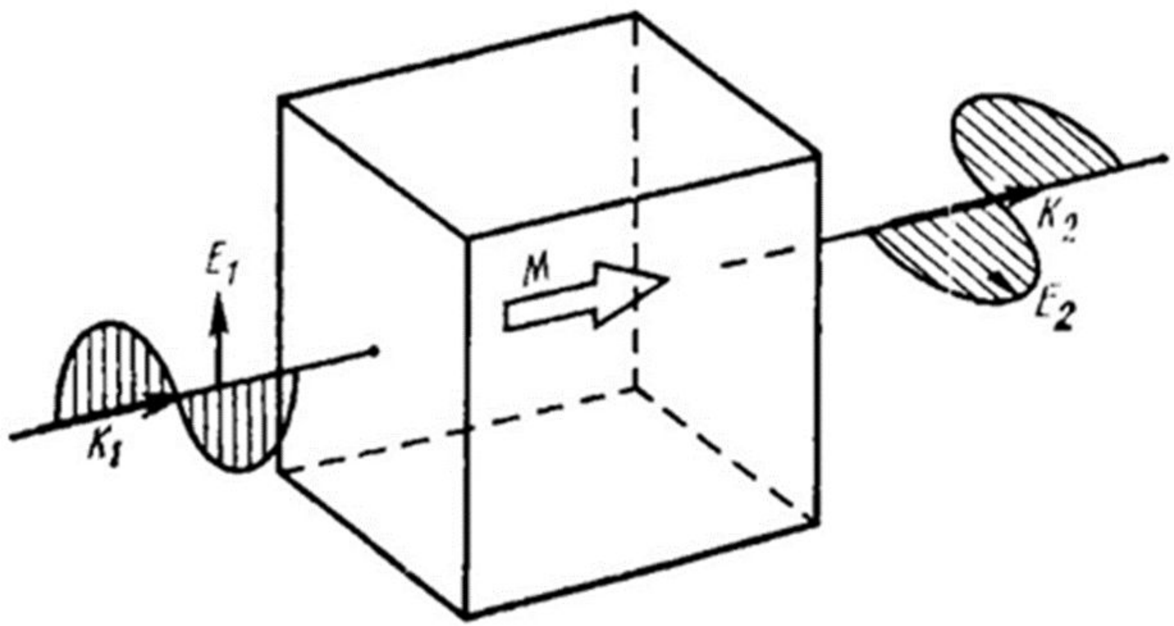


Fig. 1.10. The Faraday Effect

Test questions:

1. What materials are called magnetoactive?
2. What types of magnetoactive materials do you know?
3. Where magneto-optic devices are used?
4. What applicators has the polarization process?
5. What are the types of wave propagation?

Test

1. Magnetoactive materials are:

A) magnetic materials with special properties: rotation of polarization plane when light is reflected;

B) magnetic materials with special properties: rotation of polarization plane when light passes through;

C) magnetic materials with special properties: rotation of polarization plane when light is reflected or passes through;

D) magnetic materials with special properties: rotation of intensity vector direction.

2. What magneto-optic effect serves as a basis of the work of magneto-optic devices?

A) the Cotton-Mouton effect;

B) the Kerr effect;

C) the Faraday effect;

D) the circular dichroism effect.

3. Where are magnetoactive materials used?

A) electrical engineering;

B) radio technology;

C) computer engineering;

D) all the above.

4. The formula of the gadolinium-gallium garnet is:

A) $Y_3Al_5O_{12}$;

B) $PbO - B_2O_3$;

C) $Nd_2O_3Y_2O_3$;

D) $Gd_3Ga_5O_{12}$.

5. What is the essence of the Czochralsky process?

A) crystal growing by means of pulling;

B) a polarization plane rotates;

C) growing one crystal on the other;

D) an intensity vector rotates in the electromagnetic field.

Answer key:

1	2	3	4	5
A	C	D	D	A