

Optical

Polarization

Fundamental Experiments

Polarization of light through reflection at a glass plate

Objectives of the Experiment

- Understanding the polarization of light with the aid of a polarizer and an analyser.
- Investigation of the polarization of light reflected on a glass plate.
- Measurement of the *Brewster angle* and the refractive index of the glass.

Principles

The phenomena of electrodynamics and magnetism were unified by the Maxwell equations for *electromagnetism*. The Maxwell equations in a vacuum can be solved by wave functions and thus describe electromagnetic waves. Such waves are transverse waves, i.e. the propagation direction \vec{k} of the wave is always perpendicular to the electric field \vec{E} and the magnetic flux density \vec{B} :

$$\vec{k} \cdot \vec{E} = \vec{k} \cdot \vec{B} = 0. \quad (1)$$

This property of the electromagnetic waves is instrumental for the phenomenon of polarization. It is also true for the solutions that the E field is aligned perpendicular to the B field

$$\vec{E} \cdot \vec{B} = 0. \quad (2)$$

Thus, the vectors $(\vec{k}, \vec{E}, \vec{B})$ form an orthogonal base of space. Maxwell also showed that the following applies for the propagation velocity c of such waves

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \approx 3 \cdot 10^8 \frac{\text{m}}{\text{s}}.$$

ϵ_0 is the electric field constant and μ_0 is the magnetic field constant. Surprisingly, the value of c was identical to the speed of light in a vacuum. Today we know that light is electromagnetic waves. Gamma and X-rays, ultraviolet and infrared light, as well as radio waves likewise are electromagnetic waves that are described by Maxwell's equations. Equation (1) means that the vectors \vec{E} and \vec{B} lie in the plane perpendicular to the propagation direction \vec{k} . As long as Equation (2) is satisfied, the vectors \vec{E} and \vec{B} may be arbitrarily rotated in this plane.

Polarization of light is the direction (alignment) of the vector \vec{E} or \vec{B} in the plane perpendicular to \vec{k} . The unpolarized light is composed of superimposed waves with all possible directions of \vec{E} and \vec{B} combined. If the direction is constant in time, we have *linear polarization*. The E field periodically changes its sign and absolute value.

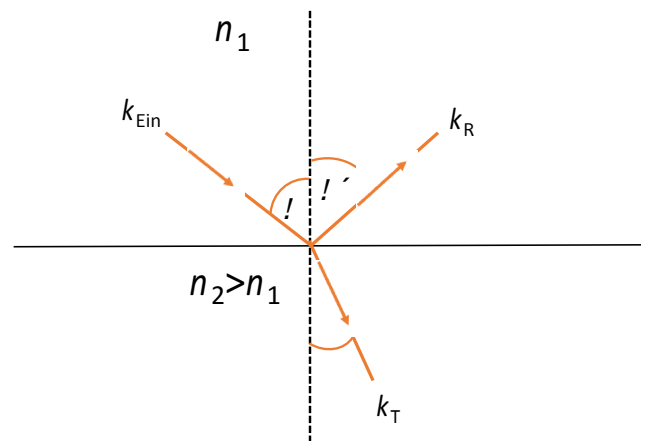


Figure 1: Schematic representation of reflection and transmission of light at a boundary surface between two media.

For *circular polarization*, the \vec{E} vector rotates in the plane perpendicular to the direction of propagation \vec{k} and has a constant absolute value.

The thermally generated light (lightbulb) is unpolarized. A light beam is polarized during the passage through certain media. This is called a polarization filter if a certain direction of \vec{E} is removed (filtered) from an unpolarized light beam. Further to this, light is partially polarized upon reflection at the boundary surface between two media. The degree of polarization depends on the angle of incidence.

Figure 1 shows the schematic representation of the reflection of light at a boundary surface between two media with the refractive indices n_1 and n_2 . $\alpha = \alpha'$ and the law of refraction or *Snell's Law*

$$n_1 \sin \alpha = n_2 \sin \beta. \quad (3)$$

Equation (3) follows directly from *Fermat's Principle*, which states that the light takes the path of the shortest time.

Apparatus

1 Plate glass cell (cuvette), 100 x 100 x 10 mm	477 20
1 Prism table	460 25
1 Halogen lamp, 12 V, 50/100 W.....	450 64
1 Halogen bulb, 12 V/100 W, G6.35.....	450 63
1 Picture slider.....	450 66
1 Transformer, 2 ... 12 V, 120 W.....	521 25
1 Iris diaphragm.....	460 26
2 Polarization filters	472 401
1 Lens in frame, f=100 mm.....	460 03
1 Screen, translucent	441 53
2 Small optical benches	460 43
1 Swivel joint with protractor scale	460 40
6 Leybold multiclamp.....	301 01
2 Stand base, V-shaped, large	300 01
2 Connecting lead, 100 cm, black	501 33



Figure 2: Experiment set-up, polarization of light by reflection on a glass plate.

The maximum polarization occurs when

$$\alpha + \beta = 90^\circ. \quad (4)$$

The reflected light is linearly polarized. The special angle α that satisfies Equation (4) is called the *Brewster angle* α_B . Equation (4) substituted into Equation (3) gives

$$\tan \alpha_B = n_2. \quad (5)$$

$n_1=1$ was used here, which is satisfied for a vacuum and is also satisfied in good approximation for air. Equation (5) is used for the determination of refractive indices.

The present experiment concerns the fundamentals of polarization. The light from a halogen lamp is linearly polarized by means of a polarization filter (polarizer) and then subjected to a qualitative analysis, using another polarization filter (analyser). The degree of polarization of the light reflected on a glass surface is observed and the refractive index of the glass is determined by measuring the *Brewster angle*.

Safety Note

Watch for heat development of the halogen lamp and do not cover the ventilation slots!

Experiment set-up

The experiment set-up is shown in Figure 2.

(a) First, for the adjustment of the optical devices:

- Attach the two small optical benches on small tripod feet and connect them with the protractor scale by means of the swivel joint.
- Align the rotation scale so that the pointer is at 180° and moves in the direction of 0° when the swivel joint is bent.
- Carefully align the optical benches in the horizontal position and leave the angle at 180°.
- Insert the halogen bulb into halogen lamp and mount it to one end of the optical bench. Use Leybold multiclips for all optical devices.

- Make sure that the optical axis (the light path) is on the side of the smaller opening angle.
- Mount picture slider with the heat protection filter for absorption of the infrared component in the halogen light to the halogen lamp.
- Mount the iris diaphragm on the optical bench in front of the halogen lamp so that the distance between the picture slider and the iris diaphragm is approximately 2 - 5 mm.
- Mount the lens at a distance of about 10 cm from the iris diaphragm.
- Mount the translucent screen at the other end of the optical bench.
- Connect the halogen lamp to the transformer with the connecting leads.

(b) Experiments with the polarizer and analyser:

- For the experiments, polarization filters are alternately added and removed. Leave the Leybold multiclips on the optical bench.

(c) Investigations of polarization of light reflected on the glass and measurement of the refractive index of the glass:

- Mount the prism table into the swivel joint.
- Place a piece of black paper (matt) or cloth in the plate glass cell and mount it on the prism table.
- Adjust the opening angle to about 160° or less and turn the plate glass cell so that the entire aperture of the iris diaphragm is visible on the screen (just out of focus).
- If necessary, reduce the aperture of the iris.
- The opening angle read between the incident light and the reflected light corresponds to 2α .
- For the experiments, polarization filters are alternately removed.

Performing the experiment

(a) Adjustment of the optical devices:

- The optical benches remain parallel – the opening angle is 180° .
- Adjust the aperture of the iris diaphragm to a diameter of 2 - 4 cm.
- Move the Leybold multiclamp with the lens along the optical bench while observing the image on the screen.
- Mount the lens so that the aperture of the iris diaphragm is focussed on the screen.
- Alternatively, focus the image on a wall behind the screen (remove the screen).

(b) Experiments with the polarizer and analyser:

- Mount a polarization filter and set it to 0° . Observe the image.
- Now mount the second polarization filter and set it to 0° as well.
- Then rotate the filter between $+90^\circ$ and -90° . Observe the image.

(c) Investigations of polarization of light reflected on the glass and measurement of the refractive index of the glass:

- Without using polarization filters, change the opening angle from 160° to the minimum in increments of 10° . Observe the image.
- Make sure that the tripod feet can move freely around the table.
- Increase the opening angle to 160° again.
- Mount a polarizing filter between the plate glass cell and the screen and set it to 0° . Repeat the first point.
- Increase the opening angle to 160° again and set the polarization filter to 90° . Repeat the first point.
- Read the opening angle at which the image is darkest. This angle corresponds to double the *Brewster* angle.

Observation

(a) Experiments with the polarizer and analyser:

- The brightness of the light spot on the screen remains unchanged when passing through one of the polarization filters and depends on its setting ($0^\circ - 90^\circ$).
- When passing through both polarization filters, the brightness changes from bright at a setting difference of 0° or 180° to dark at a setting difference of $\pm 90^\circ$.

The dependence of the intensity of the light on the setting difference of the filters is described by *Malus' Law* and is covered in experiment P.5.4.1.4.

(b) Investigations of polarization of light reflected on the glass and measurement of the refractive index of the glass:

- Without polarization filters, the brightness of the light spot on the screen does not depend on the opening angle.
- When the polarization filter is set to 0° , the brightness of the light spot on the screen decreases monotonically with decreasing opening angle.
- When the polarization filter is set to 90° , the brightness of the light spot on the screen decreases with decreasing opening angle and then increases again. The light spot disappears at an opening angle of approximately $110^\circ - 120^\circ$.

The dependence of the intensity of the light on the opening angle is described by *Fresnel's Law* and is covered in experiment P.5.4.1.2.

Measurement example

When the polarization filter on the screen was set to 90° , the light spot disappeared at an opening angle of 115° . This value corresponds to double the angle of incidence.

$$\alpha = 115^\circ / 2 = 57.5^\circ.$$

At the same time, the measured angle of incidence is the *Brewster* angle. Substituting α in Equation (5) gives the refractive index of the glass of the plate glass cell.

$$n = \tan(57.5^\circ) = 1.57.$$

For various types of glass, the refractive index values are between 1.4 and 1.9.