

Fresnel's Laws of Reflection

Objectives of the Experiment

- Understanding the polarization of light reflected at a boundary of two media.
- Quantitative validation of Fresnel's Laws of Reflection.
- Determination 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. Light is an electromagnetic wave as well. Polarization of light is the direction 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. For *circular polarization*, the vector \vec{E} 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. The fundamental principles of polarization are covered in experiment P5.4.1.1.

Polarization effects occur in particular if light interacts with matter. 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 polarized upon reflection at the boundary surface between two media. The degree of polarization depends on the angle of incidence. Similarly, the reflection factor

$$\rho = \frac{I_r}{I_0} = \frac{E_r}{E_0} \quad (2)$$

depends on the angle of incidence. Here, I_0 is the intensity of the incident light beam and I_r is the intensity of the reflected beam. 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 .

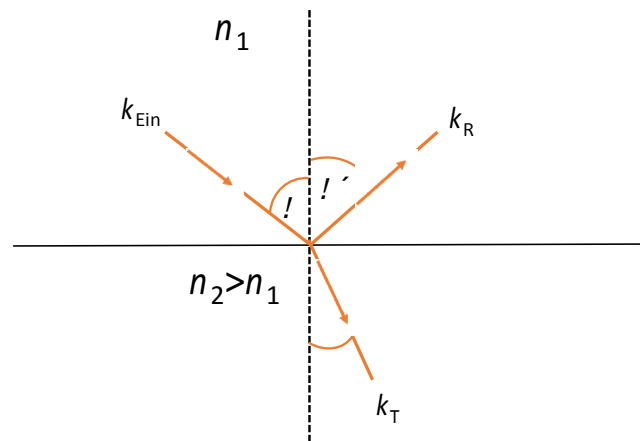


Figure 1: Schematic representation of reflection and transmission of light at a boundary surface between two media.

$\alpha = \alpha'$ and the law of refraction or Snell's Law apply

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

Equation (2) can be formulated explicitly for two types of polarization of the incident light:

1. For *vertical polarization*, i.e. vector \vec{E} is perpendicular to the incident plane, formed by the incident and the reflected light beam:

$$\rho_s = \frac{\sin(\beta - \alpha)}{\sin(\beta + \alpha)}. \quad (4)$$

2. For *parallel polarization*, i.e. vector \vec{E} lies in the incident plane:

$$\rho_p = \frac{\tan(\beta - \alpha)}{\tan(\beta + \alpha)}. \quad (5)$$

Equations (4) and (5) are called *Fresnel's Laws of Reflection* and apply to uncharged, non-conductive, and non-magnetic media.

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 Lens in frame, f=150 mm | 460 08 |
| 1 Solar cell, STE 2/19 | 578 62 |
| 1 Holder for plug-in elements | 460 21 |
| 1 Digital multimeter 3340 | 531 183 |
| 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, 32 A, 100 cm, black | 501 33 |
| 1 Connecting leads, 19 A, 100 cm, red/blue, pair | 501 33 |

It follows directly from Equation (5) that, for $\alpha = 90^\circ - \beta = \alpha_B$, the parallel polarized light is not reflected. This particular angle α_B is called the *Brewster* angle. Every vector \vec{E} of the incident light is a linear combination of these two directions. It is therefore sufficient to know Equation (2) for these two cases.

In the present experiment, reflection factors ρ_s and ρ_r are measured and compared with Equations (4) and (5). In addition, the *Brewster* angle or the refractive index of the glass is calculated through adaptation of Equation (4) to the measured values.

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 opening angle at 180° .
- Insert the halogen bulb into halogen lamp and mount the latter to one end of the optical bench. Use Leybold multiclamps for all optical devices.



Figure 2: Experiment set-up, Fresnel's Laws of Reflection.

- 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 $f = +100$ mm at a distance of about 10 cm from the iris diaphragm.
- Connect the halogen lamp to the transformer with the black connecting leads.
- Adjust the aperture of the iris diaphragm to a diameter of 2 - 4 cm.
- Mount the holder for the plug elements at the free end of the second optical bench and insert the solar cell.
- Connect the solar cell to the digital multimeter to measure the current and set it to the finest current measurement.
- Move the Leybold multiclamp with the lens $f = +100$ along the optical bench while observing the image of the iris diaphragm on the solar cell. If necessary, hold up a piece of white paper.
- Mount the lens so that the aperture of the iris diaphragm is focussed on the solar cell. If necessary, darken the room.
- Mount the lens $f = +150$ mm at a distance of about 15 cm from the solar cell.
- Move the Leybold multiclamp with the lens $f = +150$ along the optical bench and affix it at the point of the maximum current measurement.
- 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.
- Set the opening angle to the maximum (170° - 150°) and rotate the plate glass cell so that the light beam hits the solar cell and the entire aperture of the iris diaphragm is visible on the plate glass cell.
- If necessary, reduce the aperture of the iris diaphragm or the opening angle.

(b) Measuring the intensity of the reflected light:

- To perform the experiments, mount a polarizing filter directly on the plate glass cell on the optical bench between the halogen lamp and the plate glass cell.

Performing the experiment

In the experiment, the photocurrent of the solar cell is measured, which is proportional to the light intensity. Only the ratio of the intensities is relevant for the reflection factor.

(a) Measurement of the irradiation intensity I_0 and the background.

- Set the opening angle to 180° (optical benches parallel).
- Darken the room. Switch on the display illumination on the digital multimeter. Do not illuminate the solar cell.
- Switch the halogen lamp off briefly or shade it and record the indicated current value. This value corresponds to the background.
- Switch the halogen lamp on again, mount the polarization filter between the halogen light and the plate glass cell, and set it to 0°.
- Remove the plate glass cell and record the indicated current value. This value corresponds to the irradiation intensity I_0 for vertical polarization.
- Set the polarization filter to 90° and read the current value. This value corresponds to the irradiation intensity I_0 for parallel polarization.

Note

During the measurement, the iris diaphragm and the room brightness must not be altered.

(a) Recording the intensity of the reflected light for **vertical polarization**:

- Mount the plate glass cell on the prism table.
- Set the polarizing filter to 0°.
- Set the opening angle to the maximum (170°-150°) and rotate the plate glass cell so that the light beam hits the solar cell and the entire aperture of the iris diaphragm is visible on the plate glass cell. Record the opening angle and the current value.
- Reduce the opening angle in increments of 5°. After each increment, rotate the plate glass cell so that the light beam hits the solar cell and the entire aperture of the iris diaphragm is visible on the plate glass cell. Record the opening angle and the current value.

(b) Recording the intensity of the reflected light for **parallel polarization**:

- Set the polarizing filter to 90°.
- Repeat the steps above.

Measuring Example

For the measurement, the opening angle was varied from 165° to 30° in increments of 5°. The angle of incidence α is equal to half the opening angle. The measured values are shown in Figure 3. The background must be deducted from all measured values of the intensity (including I_0). Equation (2) yields reflection factors (absolute value) by normalising the measured values with the irradiation intensity I_0 and then calculating the square root. Equations (4) and (5) were adapted to the measured values. Equation (3) is used to eliminate the refraction angle β . Thus, the refractive index of the glass n_2 is the only adjustment parameter ($n_1=1$). Its value allows the Brewster angle α_B to be calculated.

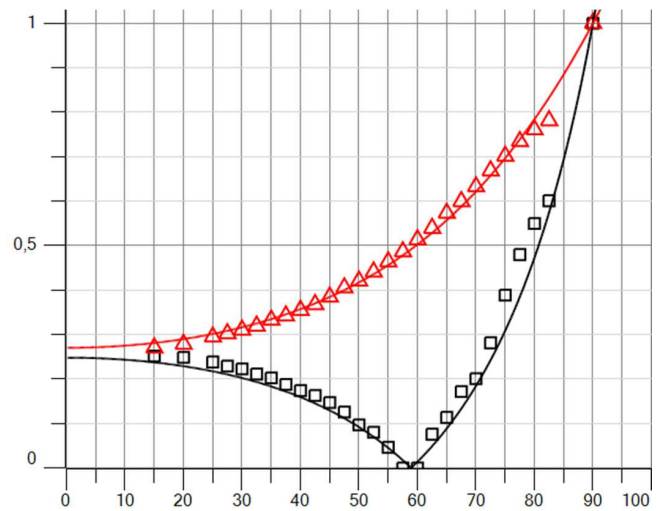


Figure 3: Measurement example of Fresnel's Laws of Reflection. In red: (Δ) Measured values of the reflection factor for vertically polarized light; (\rightarrow) adjustment of Equation (4). In black: (\square) Measured values of the reflection factor for parallel polarized light; (\rightarrow) adjustment of Equation (5).

The values of the irradiation intensity I_0 as well as of the refractive indices of the glass obtained by the adaptation are listed in Table 1. For different types of glass, the refractive index values are between 1.4 and 1.9. From the value of n_2 for parallel polarized light follows the Brewster angle $\alpha_B = 58.93^\circ$.

| | $I_0 / \mu A$ | n_2 |
|----------|---------------|-------|
| Parallel | 160 | 1.66 |
| Vertical | 140 | 1.74 |

Table 1: Values of the irradiation intensity I_0 as well as of the refractive indices of the glass obtained by the adaptation.