Teori

Snell's Law

When light passes through a dielectrica, the angle of reflection is equal to the angle of incidence, whereas the angle refraction is given by Snell's law;

$$\boxed{n_a \sin\theta_a = n_b \sin\theta_b}$$

Where n_a and n_b are known as the indexes of refraction, which are properties of different materials. A materials index of refraction n is related to the speed at which light moves through the material.

$$n = \frac{c}{v}$$

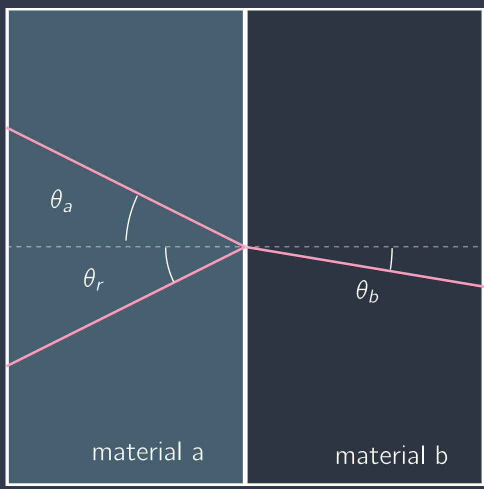


Figure 1: Depiction of Snell's Law. As the light crosses the barrier between the two dielectrica, its angle changes. This angle is called the *angle of refraction*.

Polarized light

An electromagnetic wave consists of an oscillating electric field and an oscillating magnetic field. Since these fields are perpendicular and the propagation direction is perpendicular to both fields it is a transverse wave. Every electromagnetic wave has a certain orientation in space which can be determined by using the right hand rule. This can also be used to find the polarization of the wave, where the direction of the electric field determines the polarization. E.g if the orientation of the electric field is in the y-direction the wave is called linearly polarized in the y-direction.
The visible light emitted from natural light source such as a light bulb or a laser is unpolarized. This means that the light consists of waves that are polarized in every possible direction. The light can be polarized in a specific direction by using a device called a polarizer. This device acts as a filter allowing only waves polarized in a specific angle through. Relevant for this experiment is when putting a polarizer rotated to 45 degrees in front of the laser, the electric and magnetic field of the light passing through can be split into two equally large components.

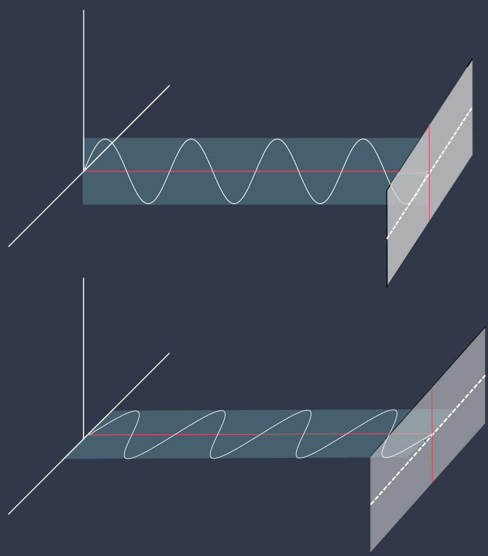


Figure 2: The top figure depicts S-polarized light, while the bottom figure depicts P-polarized light.

Fresnel's Relations

The angles of reflection and refraction are only part of the story. We are also interested in knowing how much of the incident light is reflected and transmitted. These intensities are given by the Fresnel relations, of which there are four. These relations describe the intensities of reflected and transmitted light for parallel and perpendicular polarized light. They have the

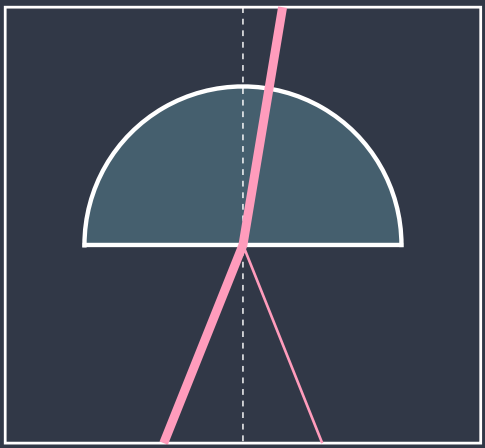


Figure 3: The proportion of light that is transmitted and reflected is described by Fresnel's relations. For both *S*- and *P*-polarized light, a greater proportion is transmitted for most angles. Notice, that when the dielectrica has a circular, the light can pass through without changing direction

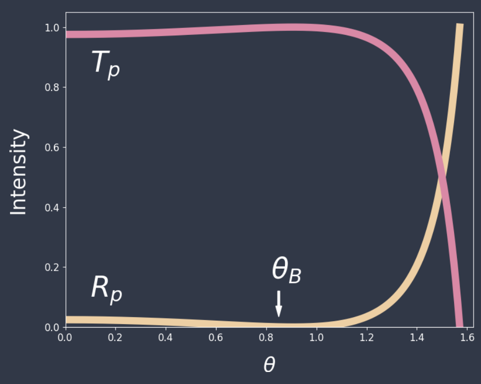


Figure 4: This plot displays the intensities of the transmitted and reflected light. The transmitted light dominates for most angles. At tne brewster angle, all light is reflected. In this case, the index of refraction is 1.5 (glass).

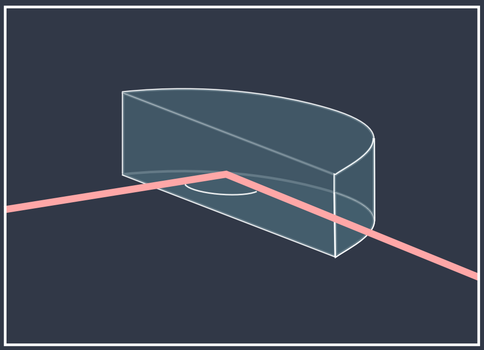


Figure 5: At the *critical angle* no light is transmitted. All of the light is reflected along the line separating the two materials.

following form;

$$R_p = \frac{\tan^2(\theta_1 - \theta_2)}{\tan^2(\theta_1 + \theta_2)}$$
$$T_p = \frac{sin(2\theta_1)sin(2\theta_2)}{sin^2(\theta_1 + \theta_2) \cdot cos^2(\theta_1 - \theta_2)}$$
$$R_s = \frac{\sin^2(\theta_1 - \theta_2)}{\sin^2(\theta_1 + \theta_2)}$$
$$T_s = \frac{sin(2\theta_1)sin(2\theta_2)}{sin^2(\theta_1 + \theta_2)}.$$

If the energy is conserved then the sum of the intensity of all the different kinds of light should be equal to the intensity of the laser.

Brewster's angle

At a specific angle determined by the index of refraction of the two materials, the reflected light is polarized in the perpendicular direction of the plane of incidence. The relation is given in Brewster's law for the polarizing angle:

$$tan(\theta_p) = \frac{n_b}{n_a}$$

The critical angle

Another angle of interest is the critical angle, which can be derived from Snell's law of refraction by setting the refraction angle to 90 degrees:

$$sin(\theta_{crit}) = \frac{n_b}{n_a}$$

At this angle no light is transmitted through the material. Instead the refracted light would move parallel with the demarcation line of the two materials. If the angle gets larger then total internal reflection occurs.

$$T_p + T_s + R_p + R_s = I_{Laser}$$

Experimental setup

The setup of the experiment is shown in the following figure:[Made by projectAlbert]. Imagetext[Setup]

Material List

- Red Laser
- 2x Polarizer
- Dielectric
- Picoscope
- Turntable
- Lens
- Light intensity detector with slit

The light from the laser moves through a polarizer set at an angle of 45°. This implies that the intensity of s- and p-polarized is equal. From the light impacts the dielectric where it is reflected and refracted. The light detector is moved to catch either the reflected or refracted. In front of the detector is a lens, which focuses the light, and anothera polarizer, which selects either s- or p-polarized light. The slit in front of the detector, changes the detectors sensitivity. In practice we move the turntable, keeping the dielectric fixed, until the intensity measured by the detector reaches a maximum. We then record the intensity, angle of incidence and angle of transmission/refraction.

0.0.1 Course of action

In the experiment we want to examine different phenomena. These are:

- Index of refraction.
- The relationship between the polarized light and the angle.
- The intensity of the total refracted light.
- The intensity of the total transmitted light.
- Conservation of the total intensity.

In order to test Fresnel's Relations we must know the index of refraction for the dielectric. Snell's law states that the index of refraction can be found

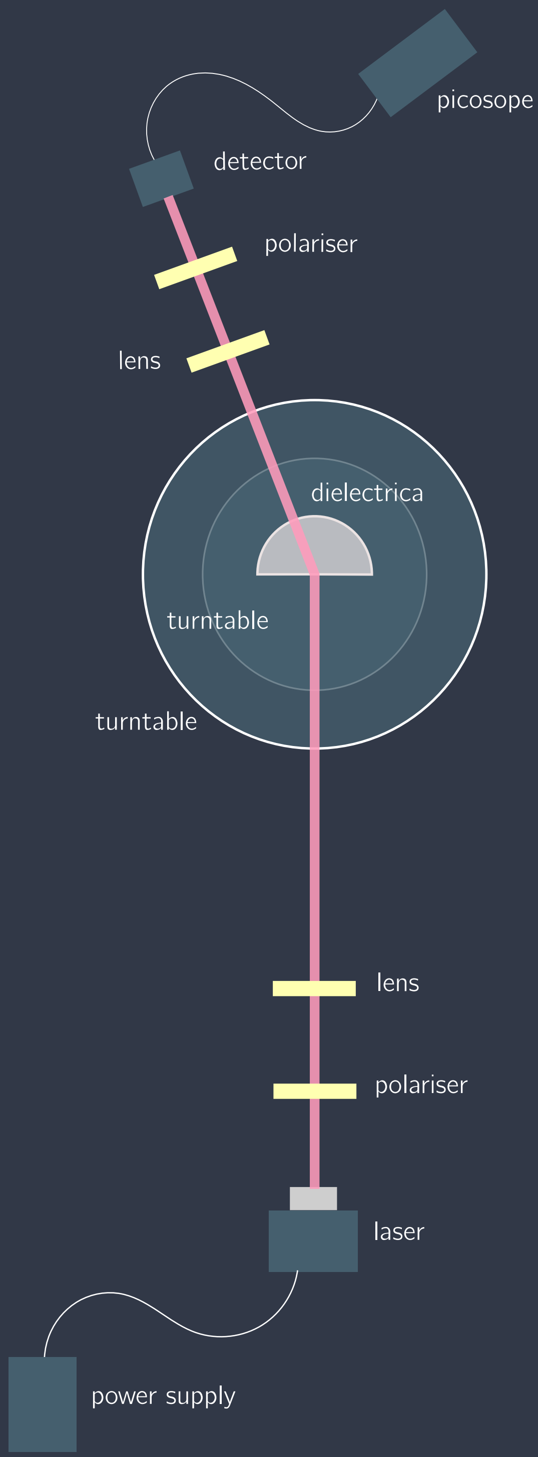


Figure 6: The setup used in the experiment.

from relation between the incidence and transmission angles. We therefore note transmission angle, for different angles of incidence.

When testing the conservation of the total intensity we can turn the dielectric and then measure the s- and p-polarized intensity for the transmitted and the reflected light. If the conservation is true, their sum should be constant. By noting the angles of incidence and transmission, we also use these measurements to test the Fresnel equation for e.g. the intensity of the p-polarized transmitted light. a

Results

What follows is a presentation of our data and results.

Snell's Law

Figure presents our data for Snell's law, we have plotted the sine of the incident angle againts the sine of the transmitted angle. Snells's law then predicts that the data is linear, with a steepness corresponding to,

$$\alpha = \frac{n_2}{n_1}.$$

As the plot shows, our data matches this quite well. We measure the value

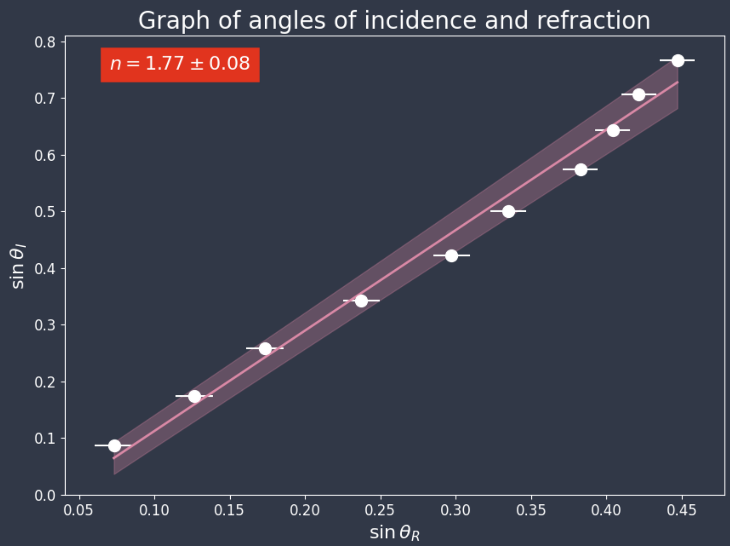


Figure 7: Graph depicting angles of incidence and refraction. The colored in area represents the uncertainty of the fit. The fit and uncertainty was decided using scipy's curve-fit function.

n to be 1.77 ± 0.08, which is in the vicinity of what we would expect. We will be using this value and uncertainty in the remainder of the experiment, as Fresnel's relations rely upon it.

Intensities

Our data measuring the intensities also seems to follow the predicted curves reasonably well. We used the fact that,

$$\theta_T = \arcsin\left(\frac{n_1}{n_2}\right)\theta_I.$$

To plot the theoretical curves for the Fresnel relations. Since we have measured the index of refraction with some uncertainty, this leads to an uncertainty in the predicted, which we have calculated using error propagation. We have also translated our uncertainty in angle to uncertainty in intensity using this same method.

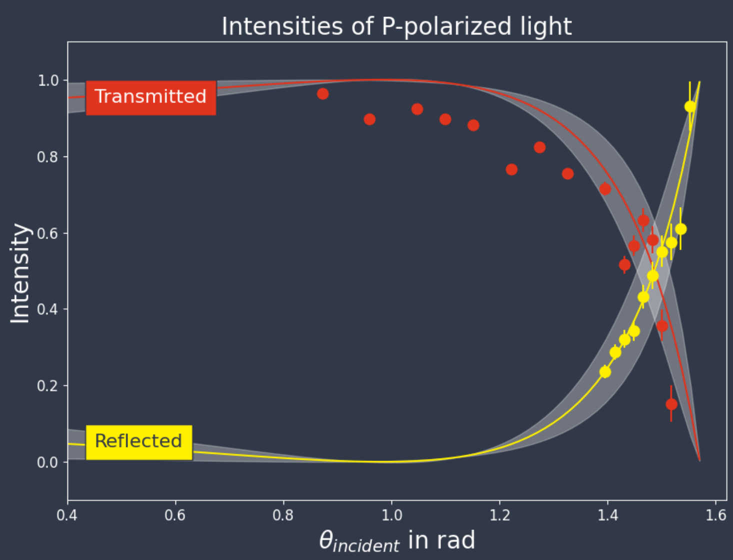


Figure 8: This graph shows the measured intensities of transmitted and reflected p-polarized light at different angles θ_I. Alongside this data is shown the curve predicted by Fresnels relations, the areas colored in represent the uncertainty in this theoretical curve. The uncertainty stems from our measurement of the refraction index. The data seems to follow the general shape of the curve.

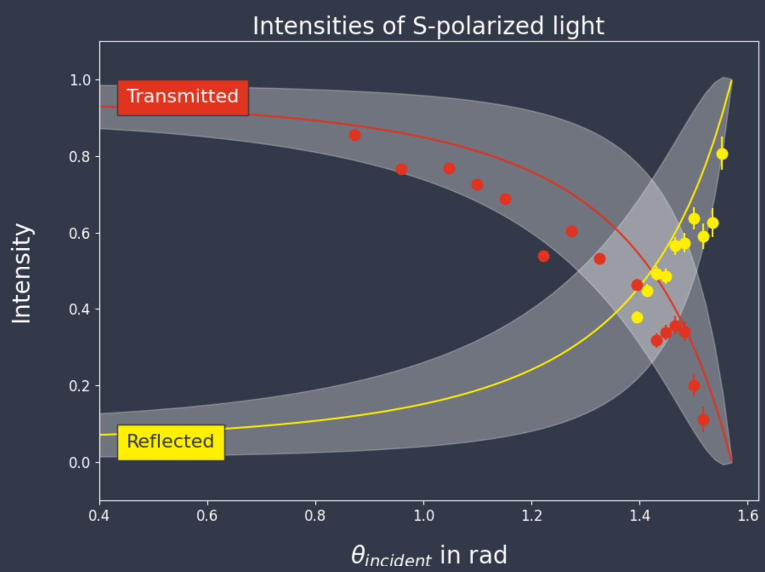
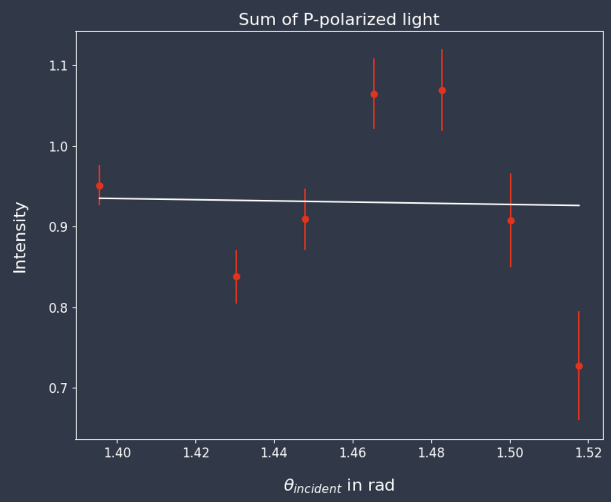
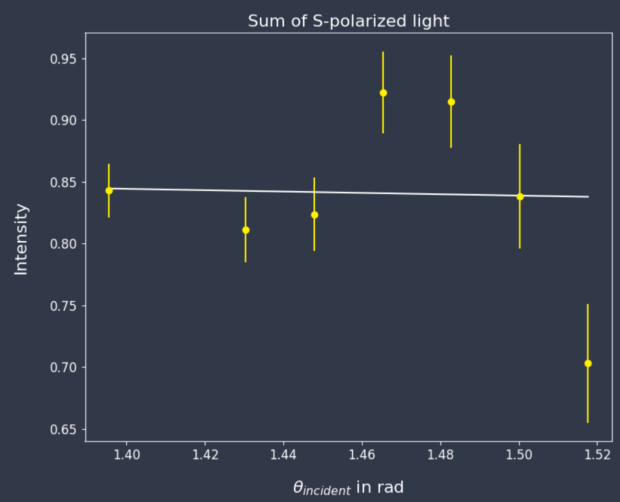


Figure 9: Plot of the S-polarized intensities. Once again, the data seems to follow curve reasonably. Interestingly the Fresnel relations for s-polarized light are more sensitive to the error in n.

Note, that the lack of points at low angles of incidence is intentional. We chose to measure more points, where the curve should be steep and sensitive to change.


Sum of P-polarized light
Intensity
$\theta_{incident}$ in rad
1.1
1.0
0.9
0.8
0.7
1.40
1.42
1.44
1.46
1.48
1.50
1.52


Sum of S-polarized light
Intensity
$\theta_{incident}$ in rad
0.95
0.90
0.85
0.80
0.75
0.70
0.65
1.40
1.42
1.44
1.46
1.48
1.50
1.52

0.0.2 Error propagation

Measurements that contains errors that should be considered include:

- The angle
- The background noise
- The width of the slit

The most influential error in this experiment, is the one associated with the measurement of the angle. The protractor has a scale of 1 degreee, so the error must be $\pm 0.5\ ^\circ$. Which when you propagate it. There is no reason to include the error of the sensor because when it was held steady it yielded an error of 0. The circular slit was used for all experiments and by using trigonometry we could determine that the error in the light actually hitting the center of the detector was negligible compared to the error in the protractor. The background noise was measured to be around 0.1 V for all angles and therefore also considered to be negligible compared to the intensity of the laser.

0.0.3 Discussion

We had some general issues while doing this experiment that ended up influencing the amount of data we were able to collect and how familiar we became with the general setup of the experiment. The first week of the exercise we both had Corona and the second week we had a lot of issues with different components of the experiment not working properly. So probably we could have produced some better data if we did not have these problems.

0.0.4 Conclusion