Experiment 8: Polarization

A monochromatic light field is always in a well defined polarization state. A linear polarizer transmits one linear polarization component while blocking the other. The *degree of linear polarization* for a light field is defined as

$$V = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$

where $I_{\max}$ and $I_{\min}$ are the maximum and minimum values of measured intensity as a linear polarizer is rotated. For linearly polarized light $V = 1$, and for circularly polarized light $V = 0$.

Polychromatic light may or may not be in a well defined polarization state. Natural light emitted by blackbody radiators (hot objects such as the filament of an incandescent lamp) usually have random polarization. Such light fields are said to be *unpolarized*, and have $V = 0$. Unpolarized light may become *partially polarized* after reflection or transmission though some optical components, and have $0 < V < 1$. Unpolarized light becomes linearly polarized after passing through a linear polarizer.

The He-Ne lasers in the Optics Laboratory are linearly polarized ($V \simeq 0.98$). The polarization direction is indicated by a mark near the exit aperture. To set the polarization direction during the experiments, rotate the laser in its mount for coarse adjustment. Then, place a polarizer on the beam and rotate it for fine adjustment. After the polarizer, the laser beam typically has $V > 0.9999$.

1 Linear polarizers

There are three small aperture and two large aperture Polaroid sheet linear polarizers in the laboratory. The transmission axes of the small aperture polarizers are marked with the the $0°$–$180°$ direction. Position a small aperture polarizer on a magnetic component holder. Rotate the polarizer as you look through it at the unpolarized room lights. Do you see any changes as you rotate the polarizer? Do you think the human eye is sensitive to polarization? Position two polarizers on the same component holder, one on each side. Rotate one of the polarizers as you look at the room lights. Explain your observations.

2 Reflection and polarization

The polarization properties of light are changed upon reflection from a surface, as dictated by the Fresnel equations of reflection. To observe this, position the white light source on the optical bench. Look at the light source through a polarizer and rotate the polarizer. Then, position the acrylic plate on the optical bench such that a portion of the light is reflected at approximately $45°$ incidence angle. Look at the reflection of the light source through a polarizer and rotate. Explain your observations.

3 Law of Malus

Consider two linear polarizers in front of a light source. **Derive** an expression for the transmitted intensity as a function of the incident intensity and the angle between the transmission axes of the two polarizers (θ), as the second polarizer is rotated. Assume that the light source has a non-zero polarization component along the transmission axis of the first polarizer. This relation is called the *law of Malus*.

To verify the law of Malus, put a small aperture polarizer on a magnetic component holder and position it on the laser beam. (Use the magnetic rotation platform to get the component holder to the correct height.) Adjust the rotation angle of the polarizer such that the transmitted intensity is maximized. Mount a large aperture polarizer on a rotation stage. Note that the large aperture polarizers are free to rotate within their mounts; be careful not to rotate the polarizer unintentionally. Position the polarizer on the laser beam after the first polarizer and observe the transmitted beam on a piece of paper. Adjust the rotation stage scale to 90°. Rotate the second polarizer within its mount such that the transmitted power is minimized. At this point you know that the polarizers are *crossed* ($\theta = 90°$). Measure the transmitted power using the optical power meter (with the He-Ne filter mounted on the detector head) at 10° intervals from 90° to 0°, and compare with the calculated curve.

Cross the two polarizers again. Place a third polarizer (small aperture) in between the two crossed polarizers. Rotate this middle polarizer to maximize the transmitted intensity and note the angle at which this happens. Explain your results.

4 Brewster angle

A linearly polarized light beam does not get reflected at a planar boundary between two optical materials if it is polarized in the plane of incidence and the incidence angle is equal to the Brewster angle

$$\theta_B = \tan^{-1}\frac{n_2}{n_1}.$$

To observe this effect, rotate the laser so that the beam is horizontally polarized. Position the large aperture polarizer on the beam as close to the laser as possible. Rotate the polarizer to maximize the transmitted intensity. Position the acrylic plate on the magnetic rotation platform and calibrate the incidence angle to zero by noting the reflection. Increase the incidence angle as you monitor the reflected spot. Try to minimize the power of the reflected spot by adjusting first the incidence angle, and then the angle of the polarizer, iterating a few times. (This method assures that you have horizontal polarization.) Note the Brewster angle and deduce the index of refraction for the acrylic plate from this value.

5 Fresnel equations of reflection

In this part, you will verify the Fresnel equations of reflection (Equations (6.2-4) and (6.2-6)). One group will do s-polarization, and the other p-polarization. For p-polarization, continue with the setup of the previous part, and measure the incident and reflected power for about six different angles angles from 0° to 90°. For s-polarization, rotate the laser by approximately 90° and rotate the polarizer by *exactly* 90° so that the beam is vertically polarized. Compare your results with the theoretical plot of intensity versus incidence angle. (Take the refractive index of the acrylic plate to be the value you found in the previous part.)

6 Total internal reflection and polarization

The p-polarized and s-polarized components of a beam experience different phase shifts upon total internal reflection. **Plot** this phase difference as a function of the incidence angle for a glass ($n = 1.5$) to air ($n = 1$) interface before you come to the laboratory. If the incident light is linearly polarized at a 45° angle to the plane of incidence (equal s and p components with zero phase difference), **find** the degree of linear polarization of the reflected light at an incidence angle of 45°.

Rotate the laser and the polarizer so that the beam is linearly polarized 45° to the vertical and the horizontal. Use the 90° prism to reflect the beam with total internal reflection. Make sure that the incidence angle is 45°. Measure the degree of linear polarization of the reflected beam and compare with the calculated value. What is the polarization state of the reflected beam?