Laboratory 10: Polarization of Light – Prelab

1 Polarization and electric field

Suppose that a linearly polarized wave with electric field $\vec{\mathbf{E}}_{\text{incident}}$ is incident upon a polarizing filter at angle θ relative to the polarization axis of the polarizer. The polarizer effectively splits the electric field into two vector components, one along the polarization axis and the other perpendicular to the polarization axis. The polarizing filter absorbs the component perpendicular and transmits the component along the axis. Using Fig. 1, sketch the transmitted electric field, $\vec{\mathbf{E}}_{\text{trans}}$, as accurately as possible.

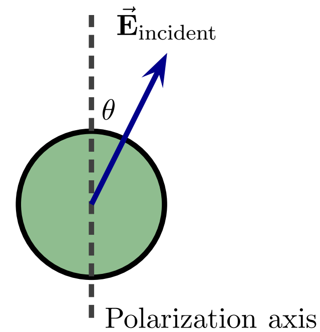

Figure 1: Electric field incident on a polarizing filter.

2 Polarization and electric field amplitude

Consider Fig. 1. If E_{incident} is the amplitude of the incident electric field and E_{trans} is the amplitude of the transmitted electric field, which of the following is true? Explain your choice.

1. $E_{\text{trans}} = E_{\text{incident}}$
2. $E_{\text{trans}} = E_{\text{incident}} \cos\theta$
3. $E_{\text{trans}} = E_{\text{incident}} \cos^2\theta$
4. $E_{\text{trans}} = E_{\text{incident}} \sin\theta$

3 Polarization and intensity

The intensity of any monochromatic light wave depends on the electric field via $I = \frac{1}{2} c\epsilon_0 E^2$ where E is the amplitude of the electric field wave. Determine an expression for the intensity of the transmitted wave, I_{trans} and show that

$$I_{\text{trans}} = I_{\text{incident}} \cos^2\theta.$$

Laboratory 10: Polarization of Light – Activity

Parts of this exercise is based on a similar exercise in *Tutorials in Introductory Physics* by McDermott and Shaffer.

1 Polarization and Polarizing Filters

This section explores the existence of polarization.

a) Look at the room lights through one of the polarizing filters. Describe qualitatively how the presence of the filter alters the appearance of the light.

b) Rotate the filter and describe whether this has any effect on the transmitted light.

c) Hold a second polarizing filter in line with the first and view the room lights through both filters (see Fig. 2). As you view the light, rotate one of the filters, keeping the other fixed. Describe how the rotation of the filter alters the appearance of the light.

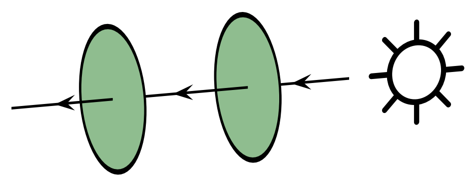

Figure 2: Two polarizing filters

d) Is it possible to accomplish the same intensity reduction effects by rotating two ordinary colored filters? Try this (if the filters are available).

2 Characterizing Polarizing Filters

A polarizing filter has an **polarization axis** or **direction of polarization**. This lies in the plane perpendicular to the direction in which the light travels. For the PASCO polarizing filters and analyzers used in this lab, the polarization axis is a direction or line which lies on the surface of the filter. Any electric field corresponding to a wave which propagates perpendicular to the filter can be decomposed into components that are parallel to and perpendicular to the **polarization axis.** An ideal polarizing filter transmits perfectly the component that is parallel to the polarization axis and absorbs perfectly the component that is perpendicular to the polarization axis. This is illustrated schematically in Fig. 3.

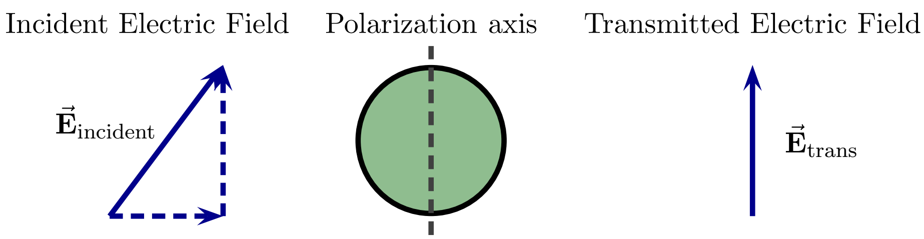

Figure 3: Operation of a polarizing filter showing the relationship between the incident and transmitted electric fields.

At any instant the electric field vector of incident light lies along one particular line. **Linearly polarized light** is such that this line stays the same as time passes. This direction of this line is called the direction of polarization of the light. **Unpolarized light** is such that the line along which the electric field vector lies fluctuates randomly and very frequently as time passes. The state of polarization of any light can partly be determined by allowing the light to pass through a polarizing filter and observing the intensity of the transmitted light.

a) Suppose that unpolarized light is incident upon a polarizing filter. Using the scheme of Fig. 3, describe whether the intensity (averaged over time) of the transmitted light varies as the polarization axis of the polarizer is rotated. Explain your answer.

b) Suppose that linearly polarized light is incident upon a polarizing filter. Using the scheme of Fig. 3, describe whether the intensity of the transmitted light varies as the polarization axis of the polarizer is rotated. Describe how the direction of polarization of the incident light is related to the polarization axis when the intensity of the transmitted light is at a minimum. Explain your answers.

c) Using one of the polarizing filters determine whether the light produced by the room lights is linearly polarized. Explain your findings.

d) Using one of the polarizing filters find a light source that produces linearly polarized light (hint: look at reflected light). Explain your findings.

e) Suppose that light passes through a polarizing filter that is held fixed with its polarization axis vertical. Using the scheme of Fig. 3, describe whether the transmitted light is polarized and, if so, what the direction of polarization is.

f) Suppose that light passes through two polarizing filters, one after the other. How are the directions of the polarization axes of the two polarizing filters related for maximum intensity? For minimum intensity? Explain your answers.

g) View a room light through the pair of polarizers and rotate the second polarizer to attain a maximum intensity. Then rotate the second polarizer to attain a minimum intensity. Through what angle (from the maximum transmitted intensity situation) did you have to rotate the second polarizer to find a minimum? Is this consistent with your reasoning in the previous question? If not, resolve the inconsistency.

h) Suppose that you are given one polarizing filter whose transmission axis is marked. Describe how you could use this to determine the polarization axis of a second polarizing filter.

i) In the prelab you showed that if linearly polarized light is incident on a polarizing filter then the intensity of the transmitted light is given by Malus' law,

$$I_{\text{trans}} = I_{\text{incident}} \cos^2 \theta \tag{1}$$

where θ is the angle between the polarization axis and the axis of polarization of the incident light and I_{incident} is the intensity of the incident light. In part (g) the first filter produced linearly polarized light and this was the incident light for the second filter. What does equation (1) predict for the intensity of the light transmitted by the second filter for the situation considered in part (g)? Is this prediction consistent with what you observed in part (g)?

3 Polarization: Malus' law

The aim of this part of the lab is to check Malus' law quantitatively.

a) Mount a PASCO light sensor to an aperture bracket and mount this to an optics track. Illuminate the aperture bracket with a laser and adjust the bracket and laser so that light is incident on the # 5 opening. Set the gain of the light sensor to $\times 1$.

b) Run Capstone and connect Light Sensor. Arrange for the data from the light sensor to be displayed in a graph and in a digits window. Click record and adjust the polarizers to verify that the light sensor is working.

c) Keep the polarizer closer to the laser fixed and rotate that which is closer to the detector in steps of about $10°$. At each angle record the intensity from the light sensor. Continue until you have about 20 data points.

d) Plot the intensity versus angle. Explain whether this appears to match Malus' law as given in Eq. (1).

e) The graph of intensity versus angle will not be a straight line and it is difficult to verify how well it matches the prediction of Malus' law. Suggest an alternative way in which the data (angle and intensity) can be manipulated and plotted so that the resulting graph should be a straight line. Carry out your method and describe how well it indicates that Malus' law is valid.

4 Three Polarizing Filters

The rules for transmission of light through one polarizing filter can be applied to transmission through multiple filters. The technique is to determine the intensity transmitted through the first filter using Eq. (1), then use this transmitted intensity as an incident intensity for the second filter. Applying Eq. (1) yields the intensity transmitted through the second filter. This process can be continued for all filters.

Consider the arrangement of three filters as illustrated in Fig. 4.

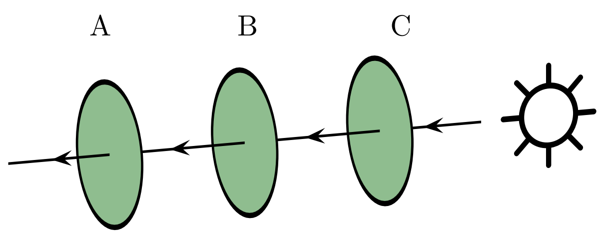

Figure 4: Three polarizing filters

a) Suppose that the polarization axes of filters B and C are perpendicular to each other. Predict, before observing, the intensity of the light transmitted by A. Describe how this depends on the angle of the transmission axis of A as A is rotated. Explain your predictions.

   Check your prediction using three polarizing filters. If your observations and prediction are inconsistent, explain how to correct the prediction.

b) Suppose that the polarization axes of filters A and B are perpendicular to each other. Predict, before observing, the intensity of the light transmitted by A. Describe how this depends on the angle of the transmission axis of C as C is rotated. Explain your predictions.

   Check your prediction using three polarizing filters. If your observations and prediction are inconsistent, explain how to correct the prediction.

c) Suppose that the polarization axes of filters A and C are perpendicular to each other. Predict, before observing, the intensity of the light transmitted by A. Describe how this depends on the angle of the transmission axis of B as B is rotated. Explain your predictions. Check your prediction using three polarizing filters. If your observations and prediction are inconsistent, explain how to correct the prediction.

5 Report

The lab exercise that you have done was broken down into many small steps, whose relationship to one another may not be obvious. In order to make sense of the entire exercise, compile a brief, informal report describing the aims, methods and results (only for part 3); excluding the data, a page should be enough. This may be written in **bullet point form.** A **guideline** of what this might contain is:

- **Introduction**
  - Describe the aim of the experiment. What is the question that it addresses?
- **Set up and Theory**
  - Briefly describe/sketch the set up that can be used to meet the aim of the experiment.
  - Briefly describe what theory is useful for understanding the situation and what it eventually predicts (include equations that form predictions). Include derivations that were essential.
- **Experiment**
  - Provide details of the experimental set up.
  - Provide the experimental data and associated calculated quantities.
  - Provide the data analysis.
- **Conclusion and discussion**
  - Describe what the experiment showed. Did it verify something? If so, what? Did it answer a question that was posed earlier? If so, how?
  - Describe possible sources of error in this experiment. Be specific (stating that "human error" is an issue without describing what human error and how it entered is not acceptable). Describe, if possible, how such errors may be reduced.
  - Describe the main conclusion of this experiment. What answer does it give?