Experiment 5

Polarization of Light

SAFETY CONSIDERATIONS

Today's experiment uses a Class II Helium-Neon laser. The blink reflex of the human eye is usually sufficient to prevent eye damage from brief exposure, but you shouldn't count on that. **Do not look into the beam or any reflections of the beam. Be responsible and make sure your laser beam doesn't stray outside your work area.**

5.1 INTRODUCTION

In this lab, you will explore polarization, a subtle, but important property of light. This phenomenon is most easily understood in terms of the wave-like properties of light. Our eyes are not able to sense polarization, so it remains an intangible quality which we can study only using special optical elements. We will first do some simple experiments to study its fundamental properties, then we will examine some important applications of these ideas.

5.2 THEORY

Light is an electromagnetic wave. It is composed of perpendicular oscillating electric ($\vec{E}$) and magnetic ($\vec{B}$) fields. The magnetic field is always perpendicular to the electric field in an electromagnetic wave. The direction of propagation is perpendicular to both $\vec{E}$ and $\vec{B}$, and is given by the cross product $\vec{E} \times \vec{B}$. The polarization of light is determined by describing the direction of the electric field at a given point in space and time. The intensity of light, which is what we will measure in this experiment, is proportional to E^2.

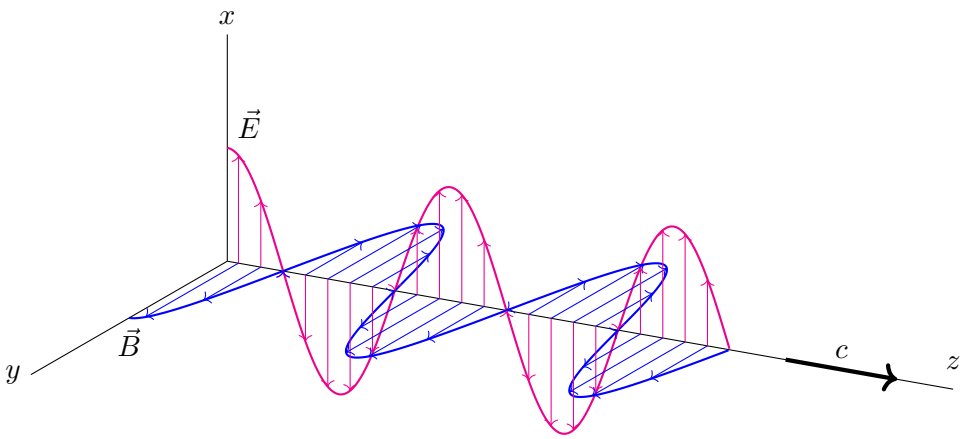


Figure 5.1: Representation of an electromagnetic wave polarized in the x-direction. The electric field oscillates in the $\pm x$-direction, the magnetic field oscillates in the $\pm y$ direction, and the wave propagates in the z-direction.

5.2.1 Linear polarization

For a light wave propagating in the z-direction, the electric field can have both x and y components.

In *linearly polarized* light, the electric field vector always points along the same line, so that the plane defined by the direction of the polarization and the direction of propagation is fixed. If we assume that the light is traveling in the z direction, then the electric field vector for linearly polarized light can always be decomposed into x and y components. Both the x and y components have the same phase, which keeps $\vec{E}$ pointing in a constant direction as given in Eq. 5.1.

$$\vec{E} = (E_x\hat{x} + E_y\hat{y})\cos(kz - \omega t) \tag{5.1}$$

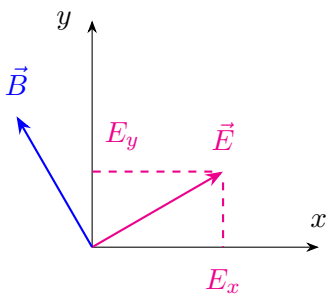


Figure 5.2: Electromagnetic wave with a direction of polarization 30° above the x-axis. The wave propagates in the z-direction, out of the plane of the paper.

Linearly polarized light is also sometimes called *plane polarized* light, since the electric field and direction of propagation define a fixed plane.

5.2.2 Producing Polarized Light

Most ordinary light sources, such as light bulbs, LEDs, and the sun, produce *unpolarized* light. The electric field direction fluctuates randomly in direction so that the incoming light is a superposition of all polarizations.

Linear Polarizer

You can produce plane-polarized light by passing unpolarized light through a material that selectively absorbs only one polarization. This is shown schematically in Fig. 5.3.

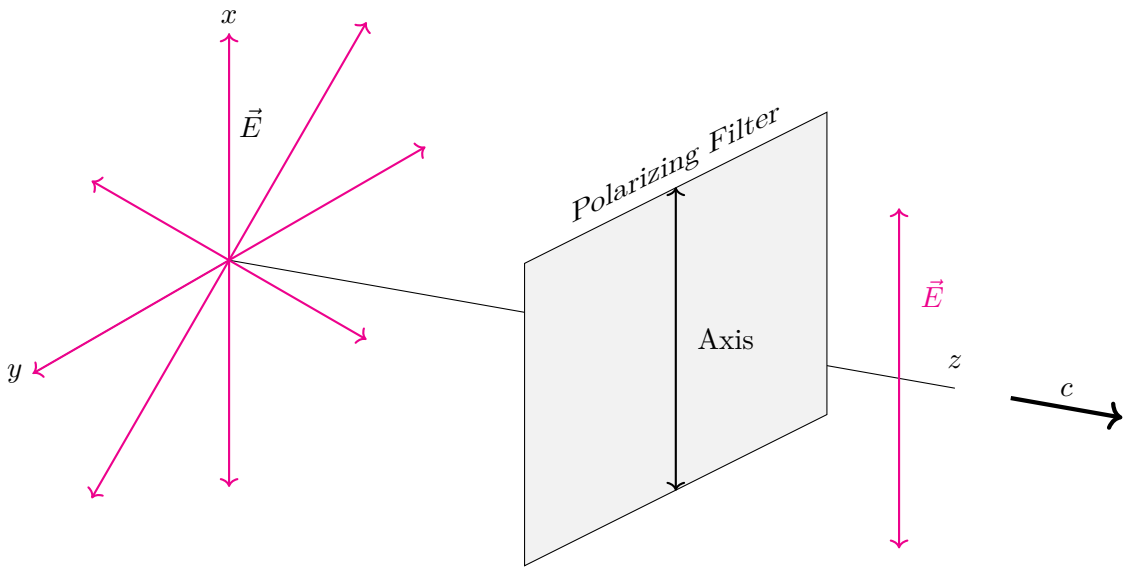


Figure 5.3: Unpolarized light passing through a polarizing filter. Components of $\vec{E}$ parallel to the axis are passed through; components perpendicular to the axis are absorbed by the filter.

Long-chain organic polymer molecules that have been made electrically conductive can be oriented into parallel lines by first embedding them in a clear plastic matrix and then stretching it. Light normally incident to a sheet of this "dichroic" material can be decomposed into two plane polarizations. One polarization has the electric field perpendicular to the long molecules, while the second has them parallel. The electric fields of light polarized parallel to the length of the molecules can move charges within the molecules, causing strong absorption of that light. However, electric fields perpendicular to the molecules are only weakly absorbed, and that light passes through the polarizer. The net result is to pass only light polarized perpendicular to the molecules' axis. There's nothing special about using molecules: if you could dexterously hang fine metal wires close enough together, you would achieve the same effect. (In fact, you can do this with longer wavelength electromagnetic waves, such as microwaves.) Any transparent medium having anisotropic conductivity will work.

Polarization by Reflection

Under certain conditions, light can also be polarized by reflection off a non-metallic surface, such as water, ice, or glass. Using polarized glasses is an effective way to reduce the glare due to such reflections. You will study this qualitatively below.

The Law of Malus

If light that is already polarized and has amplitude E_0 is passed through another polarizing filter oriented at an angle of θ (relative to the original polarization direction), only the component of the electric field along the new polarization direction is transmitted. The result then is that the transmitted light is polarized along the new polarization direction, but with an amplitude $E_0 \cos(\theta)$. Since we will be measuring intensity, which is proportional to E^2, the resulting intensity is given by the Law of Malus:

$$I = I_0 \cos^2 \theta \ . \tag{5.2}$$

Thus if two ideal polarizers are aligned, $I = I_0$, while if they are at 90°, $I = 0$. Polarizers oriented at 90° are known as crossed polarizers.

5.3 EXPERIMENTS

5.3.1 Polarization Observations

1. Identify the polarization axis for the sheets of polarizers at your station. Use one of the already-marked sheets at the front of the room as a reference, and note which orientations give maximum and minimum transmission. Note in your writeup which orientation of the sheet corresponds to the polarization axis.
2. Use your polarizers to examine the reflections from a mirror and from a shiny non-metallic surface (such as the table, floor, windows, leaves from a tree outside, etc.)
3. Examine different regions of the sky and comment on the polarization of the light in each. (Note the weather on the day you performed the lab.)
4. The Polaroid Corporation markets sunglasses made from dichroic polymer films. In addition to just absorbing light, these sunglasses are selective about which polarization of light they absorb. Which way would you orient the axis of a polarizer for sunglasses and why? (Try it if you're unsure.)
5. Note and describe the polarization of a laser source (keep the polarizer fixed for at least 30 s to see if it is constant). Now examine other sources, such as the fluorescent lights in the room and the incandescent light bulbs of your desk lamp. Which are polarized?

5.3.2 The Law of Malus

The optical bench provided has an unpolarized light source (a white LED), two rotatable polarizers, and a light detector. You will use these to explore the Law of Malus.

1. Arrange the polarizers so that the one with the rotary sensor is closest to the light sensor. The spacing between items is not critical, but keeping them all within about 60 cm works well.
2. Orient the polarizer closest to the LED source to be at 0°.
3. Launch Vernier Graphical Analysis. It should automatically recognize the rotary sensor and the light sensor.

4. You only need one graph. Use the "View Options" menu to select only 1 graph. Click on the horizontal axis and select "Angle (rad)." Click on the vertical axis and select "Illumination (lux)."

5. Both sensors need to be Zeroed. First, orient the second polarizer (the one with the rotary sensor) to 0°. Next, click on the small window showing the rotary sensor output and change the units to degrees (°) and select "Zero."

6. Next, block the light sensor so that it does not receive any light. Click on the small window showing the light intensity and select "Zero."

7. Turn on the LED source.

8. Now, as you manually rotate the second polarizer, the computer can record the angle and the intensity. Click on the "Data Collection Settings" box to set the data collection to run for 20 seconds; the default sampling rate should be fine.

9. Press "Collect" and gently rotate the polarizer a full 360°. (You don't need to get the angle exact here.)

10. Use the "Zoom" button to zoom in on the graph. Use the "Graph Options" button to apply a curve fit appropriate for testing Eq. 5.2. Be sure to check the settings box for including uncertainties in the fit.

11. Does Malus's Law describe your results? Include your graph and discussion in your report. Note that you do not have any independent measurement of the overall intensity I_0, but every other term in the fit should have an expected value.

12. Orient the two polarizers so as to give the minimum possible transmission of light. Now insert a third polarizer between the other two at an arbitrary angle. What do you see? What happens when you rotate the third polarizer while holding the outer two fixed? (You might find it handy to select "View Options" and turn on the "Meters" toggle.)

5.3.3 Crossed Polarizer Experiments

You have seen how adding a third polarizer between two crossed polarizers can result in the transmission of light—the intermediate polarizer rotates the direction of polarization so that the third polarizer does not completely block it. This can be an especially useful technique for studying optically active materials, which are those that *rotate* the direction of polarization.

Optically active materials are composed of chiral molecules, that is, molecules that have a certain handedness to them. Organic molecules can occur in two different forms (*chiralities*) when a carbon atom is bound to four different chemical groups: a left-handed (levo- or L-) form and a right-handed (dextro- or D-) form. These forms are named according to their optical activity, or their effect on plane polarized light. The right-handed form rotates the direction of the plane clockwise, while the left-handed form rotates it counterclockwise. A mixture of equal parts left-handed and right-handed forms would have no net rotation. For our experiment, we'll use a natural sugar, Karo syrup, composed principally of sugar glucose, ($C_6H_{12}O_6$) which naturally occurs in the right-handed (dextro-) form. The amount

of rotation depends on wavelength, so when Karo syrup is viewed through crossed polarizers, the color of light transmitted depends on the orientation of the second polarizer.

Similarly, some plastic materials are optically active, and the amount of rotation can depend on the stress in the material. Crossed polarizers can be used to visualize that stress.

Observations A set of crossed polarizers are set up with samples of Karo syrup and plastic. Try changing the orientation of the top polarizer (known as the analyzer in this context). Record your observations. This part can be quite brief.