LAB 2: POLARIZED LIGHT

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In this lab, you will

- Investigate polarized and non-polarized light sources by using a variety of fixed linear polarizers and rotatable linear polarizers.
- Invent and perform your own polarization experiment.
- Submit a write-up that describes the experiment you invented and performed.

PRE-LAB QUESTIONS

Prelab Questions:

You may assume ideal polarizers for these prelab questions.

1) Suppose an unpolarized beam of light, from the sun, of intensity 200 watts per square meter passes through an ideal polarizer. Let's say the polarizer is oriented horizontally. For an ideal polarizer, only the component in the same direction as the polarizer passes through and the other component is blocked.
   a. Using components, describe why the intensity (in watts per square meter) of the light after it passes through the polarizer is $I = 100$ watts per square meter.
   b. Suppose that a second polarizer is placed after the first polarizer, and oriented vertically. What intensity of light comes out from the two polarizers?
2) Look up (or write down if you know already) the frequency of AC power in the US. Write down the frequency and cite the source of your information. You will be able to see this frequency from our plugged-in lamps.

EQUIPMENT

Fluorescent lamp in box, Pasco diode laser, Lens, Fixed orientation polarizer, Two rotatable polarizers, Silicon photodetector, Oscilloscope and BNC cable, Neutral density filters, Breadboard, Mounts

EXPERIMENT

1. Measure the polarization of an ordinary light source.

   Set up the lamp, lens, and aperture so that your detector is illuminated across a gap of a few inches. (*Tip:* Read ahead and leave room to put all your optics components in there.) Put a rotatable polarizer in the gap and plot the intensity (voltage) as a function of angle. What can you say about the polarization state of the lamp light?

   NOTE: you may need to put a neutral density filter before the polarizer to keep the detector voltage below 10V.
2. *Two polarizers.* With the same set up, put a fixed angle polarizer (is it vertical? Horizontal? Slightly tilted?) before the rotatable polarizer and repeat the experiment. What do you learn about the polarizers you are using?

3. *Three polarizers.* With the same setup, set the rotatable polarizer for minimum transmission (90° from the fixed polarizer) then insert a second rotatable polarizer between the fixed polarizer and the rotatable one. Record transmission as a function of the angle of the middle polarizer.
4. *Laser.* Replace the lamp, lens, and aperture with a diode laser and repeat the first experiment. You will DEFINITELY need some neutral density filters for this one. (You may need to use a 2-mirror system to put the laser at the right height on the optical table for your polarizers and detector.)
   What do you learn about the polarization of the laser and/or the polarizer?

For the write up:

5. *Experimental design.* Invent and perform an experiment to convincingly demonstrate that the light emerging from a polarizer has its polarization direction determined by the direction of the polarizer, independent of the light entering the polarizer.
6. Discuss your results and conclusions drawn from them for all experiments with your instructor.

WRITE-UP

Your assignment is to write procedure and results sections for your experiment in 5.

ANSWER TO PRE-LAB QUESTION 1

Unpolarized light includes waves polarized at every angle. But we can decompose all these angles into horizontal polarized light and vertical polarized light, and there's no preference between them (because it's unpolarized) so there will be equal amounts.

Then the polarizer absorbs (removes) all the vertical light and the horizontal light passes through. That cuts the light in half.

THEORY BACKGROUND

The polarization of light is described by the electric field vector of the underlying electromagnetic radiation. Plane polarized light has its electric field confined to a single plane which can be described by a 2-D vector in the plane perpendicular to the direction of wave motion, a vector that gives the direction of polarization $\vec{\vec{P}}$. For a monochromatic plane wave, we can write a probability amplitude (wave function) for the light moving to the right in the form

$$\overrightarrow{E(x,t)} = \overrightarrow{E_0} cos(kx - \omega t)$$

or in exponential form as

$$\overrightarrow{E(x,t)} = \overrightarrow{E_0} e^{i(kx - \omega t)}$$

where k is the wavenumber and ω the angular frequency of the light. When the light falls onto a polarizer, the electric field vector is split into its components parallel to and perpendicular to the acceptance plane of the polarizer (which we can describe by a unit vector $\vec{\vec{P}}$). Only the component parallel to $\vec{\vec{P}}$ is transmitted and the new electric field is purely in that same direction. If the polarizer allows through a fraction f of the incident amplitude ($0 \leqslant f \leqslant 1$), then simple vector theory suggests that the transmitted wave function should be

$$\overrightarrow{E_f(x,t)} = f(\overrightarrow{E_0} \cdot \vec{\hat{P}})\vec{\hat{P}}e^{i(kx-\omega t)}$$

In this lab, you will explore that theory and its implications for working with light.

NOTE that you do NOT detect the wave function directly. Instead you observe the **energy** that the wave deposits in a detector. That energy is proportional to the squared magnitude of the wave function. For a vector wave function like this, that means that you have to BOTH do a regular dot product with the vector part AND a z^*z trick with the complex part. The asterisk superscript means that you replace every imaginary constant i with $-i$. For example, if we have a wave

$$\overrightarrow{E(x,t)} = \overrightarrow{E_0}e^{i(kx-\omega t)}$$

then its complex conjugate is

$$\overrightarrow{E^*(x,t)} = \overrightarrow{E_0}e^{-i(kx-\omega t)}$$

This means that the intensity, I (a scalar), is given by the relation

$$I \propto \overrightarrow{E^*(x,t)} \cdot \overrightarrow{E(x,t)}$$

Note that $\propto$ is the “proportional symbol”, not the Greek letter alpha.

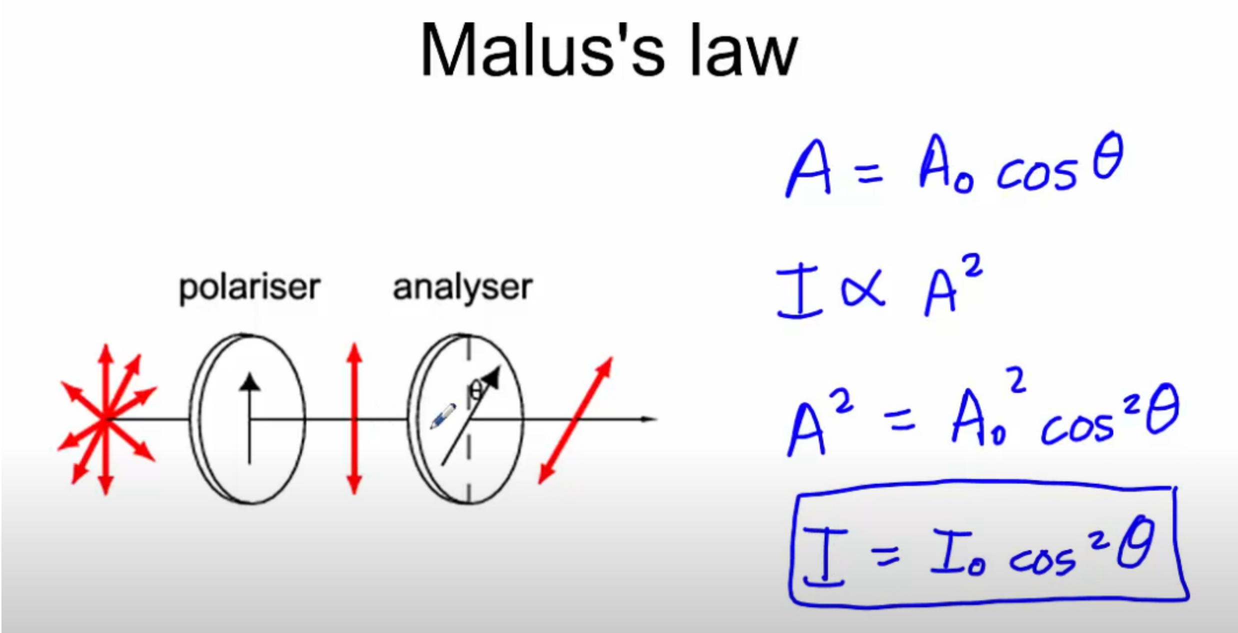
Malus' Law

If a wave with probablity amplitude $\vec{z}_{in}$ falls on an ideal polarizer oriented at an angle θ to the direction of polarization then the wave vector for the transmitted wave points in the same direction as the polarizer and has probability amplitude magnitude $z_{in}\cos\theta$.

Example 1: If a polarizer is crossed with (perpendicular to) an incoming polarized wave of light, then the magnitude of the outcoming probability amplitude is $z_{out} = z_{in}\cos 90° = 0$, so we get $P_{out} \propto z^*_{out} z_{out} = 0$ zero of the light transmitted. Crossed polarizers block all light. You can do this calculation for any angle θ.

Example 2: If unpolarized light passes through a polarizer that is oriented at an angle of 15°with respect to the vertical, half of the light will pass through, and it will now be polarized at an angle of 15°with respect to the vertical $(z = z_{in}\sqrt{1/2})$. If this polarized light then passes through a polarizer that is oriented at an angle of 35°with respect to the vertical, then we need to consider the difference in angle, $\theta = 35° - 15° = 20°$. So it follows that $z = z_{in}\sqrt{1/2}\cdot\cos(20°)$, which means that the intensity out is $I_{out} \propto |z_{in}|^2(1/2)\cos^2(20°)$. Writing this in terms of the input intensity I_{in},we obtain: $I_{out} = I_{in}(\frac{1}{2})\cos^2(20°)$, so 40% of the light gets through the pair of polarizers. Also the outgoing light will be polarized according to the last polarizer: oriented at an angle of 35° with respect to the vertical.

See also:



https://www.youtube.com/watch?v=utY72MD-Ii4