Physics 197 Lab 4:   Light Inverse Square Law and Polarization

Equipment:

Item	Part #	Qty per Team	# of Teams	Total Qty Needed	Storage Location	Qty Set Out	Qty Put Back
Photometer with Base	PASCO OS-8520	1	8	8			
Neutral Density Filter Set	PASCO OS-8520	1	8	8			
Set of Polarizers and Accessory Holder	PASCO OS-8520	1	8	8			
Optics Bench	PASCO OS-8518	1	8	8			
Point Light Source and Power Cord	PASCO OS-8517	2	8	16			

Layouts:


Figure 1: Photometer Equipment

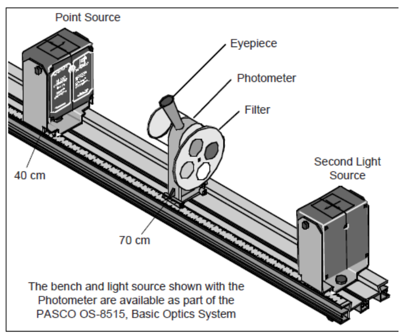

Figure 2: Setup for Inverse Square Law

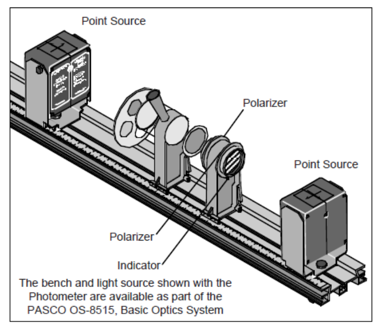

Figure 3: Setup for Polarization

Summary:

In this lab, students will investigate the falloff in the intensity of light as a point source is moved further away from a detector (Inverse Square Law) and as the angle between two polarizers is changed (Malus's Law). The students will use a photometer to do their measurements. This device consists of an eyepiece and a colored scattering surface which scatters equal amounts of light from the left and right, allowing the student to compare the brightness by eye. One light source is used as a reference. Changes are made to the other light source until the brightness from the two sources looks the same. A calibrated filter wheel allows the reference light source to be at full intensity, or 75%, 50%, or 25% of full intensity. The distance to the second light source is changed to test the Inverse Square Law (light intensity should be inversely proportional to the square of the distance to a point source). The angle between two polarizers is changed to test Malus's Law (the light intensity should vary as the square of the cosine of the angle between the two polarizers).

PreLab:

One of the properties of light is polarization. The polarization direction is taken as the direction of the electric field vector in the propagating electromagnetic wave. After passing through a linear polarizer, the light will maintain a linear polarization in the direction given by that polarizer as it propagates through free space. If the light now passes through a second linear polarizer, the intensity will be reduced depending on the relative angle ϕ between the polarization angles induced by those two polarizers. Specifically, Malus's law states that

$$I = I_{max} \cos^2\phi$$

where I_{max} is the maximum intensity that would have been observed if the two polarizers were parallel ($\phi=0$).

Calculate the angles ϕ between two polarizers which you would expect to measure for the cases where I was reduced to 75%, 50% and 25% of its maximum value.

Lab A: Inverse Square Law. This lab procedure is copied from a PASCO publication which came with the Photometer equipment OS-8520. Please include your own procedure, diagrams, discussion and data tables in your laboratory notebook. Make sure all team members share in looking through the photometer and taking data.

EQUIPMENT NEEDED

– Bench (OS-8518)
– Photometer with filter set (OS-8520)
– 2 Point light sources (OS-8517)

Purpose

The purpose of this experiment is to show that light intensity is inversely proportional to the square of the distance from a point light source.

Theory

The light from a point light source spreads out uniformly in all directions. The intensity at a given distance, r, from the light will be equal to the power output of the light divided by the surface area of the sphere through which the light has spread. Since the area of the sphere goes as the square of its radius, r, the intensity will drop off as $1/r^2$. In general, the intensity of the point light source at any distance, r, is given by

$$I = \frac{constant}{r^2}$$

Thus, the ratio of the intensity (I) of the light at a position (r) as compared to the reference intensity (I_o) measured at a position (r_o) is given by

$$\frac{I}{I_o} = \frac{r_o^2}{r^2}$$

Set Up

① Place the photometer at the 70 cm mark on the optics bench.

② Place a point light source at 40 cm. Put a neutral density filter on the side of the photometer that is opposite the point source. See Figure 1.1. Place the other light source on the same side of the bench that has the neutral density filter.

➤ NOTE: This experiment can be done using one point light source and a second light source (used as a reference) that is not a point source. If you are using only one point source, put the point source on the side of the photometer that does not have the filter.

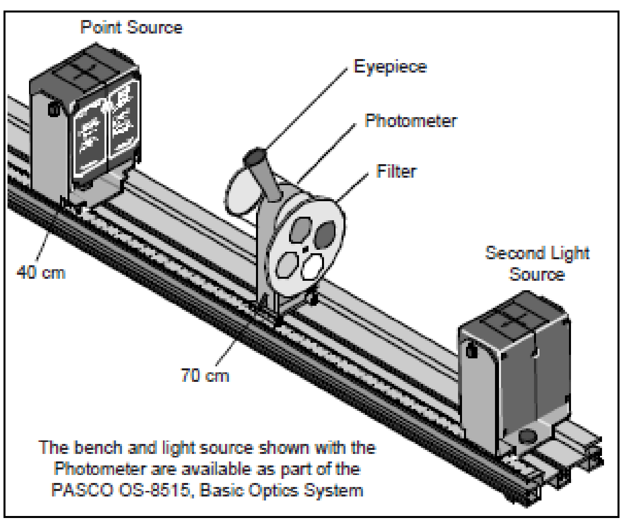

Figure 1.1: Experiment Set-Up

③ Adjust the neutral density filter for 100% transmittance.

Procedure

> ►NOTE: You may want to cover the crossed-arrow object on each light source to reduce the excess light in the room. The room lights must be off for this experiment.

① Turn off the room lights. The only sources of light should be the two point sources.

③ Look into the photometer and move the light source on the filter side to a position that gives equal intensities. The light source on the filter side will remain at this position for the rest of the experiment. This light will act as the reference intensity I_o. Record the positions of the photometer and the light source that is opposite the filter side of the photometer in Table 1.1. The position of the reference light (on the filter side) is not needed.

③ Rotate the neutral density filter to 75% transmittance. Move the point light source (the one opposite the filter side) to the position where the intensities are once again the same when viewed in the photometer. Record this new position of the light source in Table 1.1.

④ Repeat the last step for 50% and 25% transmittance.

Analysis

Table 1.1: Positions

Photometer Position = ________	Light Sources Intensity			
	100%	75%	50%	25%
Position 1				
Position 2				
Position 3				
Average Position of Point Source				
Distance from Photometer				
Calculated Intensity				
% diff				

① Using the measured positions in Table 1.1, calculate the distances of the point source from the photometer and record in Table 1.1.

② For each of the different positions, calculate the intensity using

$$I = \left(\frac{r_o}{r}\right)^2 I_o$$

where r_o is the initial distance of the point source (100%) and r is the distance at the given intensity. Note that the intensity is calculated in terms of the initial intensity I_o. Record your answers in Table 1.1.

Lab B: Polarization. This lab procedure is copied from a PASCO publication which came with the Photometer equipment OS-8520. Please include your own procedure, diagrams, discussion and data tables in your laboratory notebook. Make sure all teammates share in looking through the photometer and taking data.

EQUIPMENT NEEDED

– Optics bench (OS-8518)
– Photometer with filter set (OS-8520)
– 2 Point light sources (OS-8517)
– 2 Polarizers (OS-8520)

Purpose

The purpose of this experiment is to show that the intensity of the light transmitted through two polarizers depends on the square of the cosine of the angle between the axes of the two polarizers.

Theory

A polarizer only allows light which is vibrating in a particular plane to pass through it. This plane forms the "axis" of polarization. Unpolarized light vibrates in all planes. Thus if unpolarized light is incident upon an "ideal" polarizer, only half will be transmitted through the polarizer. (Since in reality no polarizer is "ideal", less than half the light will be transmitted.) The transmitted light is polarized in one plane. If this polarized light is incident upon a second polarizer, the axis of which is oriented such that it is perpendicular to the plane of polarization of the incident light, no light will be transmitted through the second polarizer (Figure 2.1).

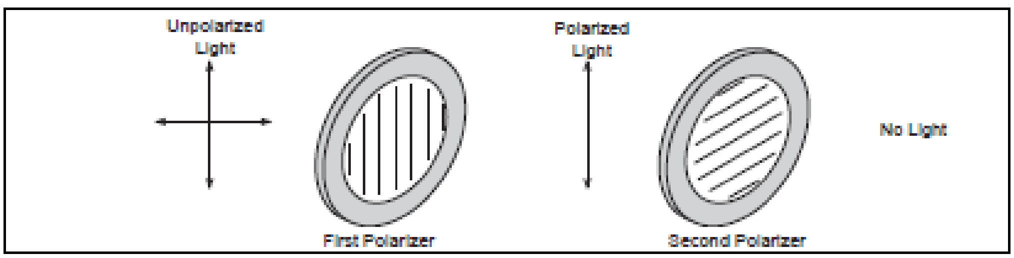

Figure 2.1: Unpolarized light incident on two polarizers oriented perpendicularly to each other.

However, if the second polarizer is oriented at an angle so that it is not perpendicular to the first polarizer, there will be some component of the electric field of the polarized light that lies in the same direction as the axis of the second polarizer, and thus some light will be transmitted through the second polarizer (Figure 2.2).

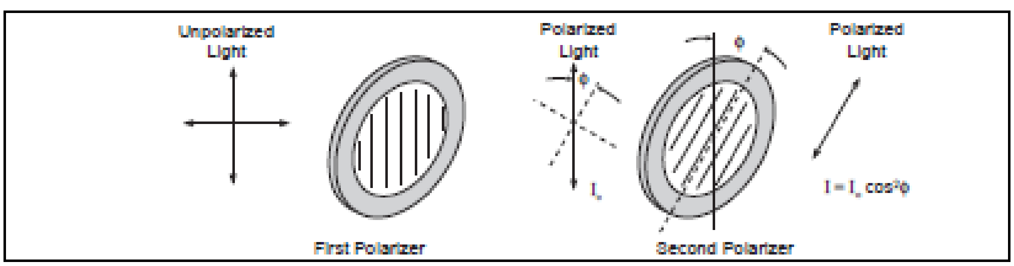

Figure 2.2: Unpolarized light incident on two polarizers oriented at an angle ϕ with respect to each other.

The component, E, of the polarized electric field, E_o, is found by using trigonometry: $E = E_o \cos\phi$. Since the intensity of the light goes as the square of the electric field, the transmitted light intensity is given by $I = I_o \cos^2\phi$, where I_o is the incident light intensity and ϕ is the angle between the axis of polarization of the incident light and the polarizer.

Notice that the two extremes work in this formula:

① If ϕ is zero, $\cos^2(\phi)$ equals one, and thus the intensity transmitted is equal to the incident intensity of the polarized light because the polarizer is aligned with the incident light and will allow all of it to pass through.

➤ NOTE: It is assumed that the incident light is polarized, not unpolarized.

② If ϕ is 90°, $\cos^2(\phi)$ equals zero, and no light is transmitted since the polarizer is oriented perpendicular to the plane of polarization of the incident light.

Set Up

① Place the photometer in the middle of the optics bench. Place the neutral density filter on one side of the photometer. See Figure 2.3.

② Place a point light source on each end of the optics bench.

③ Snap one polarizer onto each side of the accessory holder. Before beginning the experiment, check the angle calibration on the polarizers in the following way: On the side of the accessory holder that has the label, set the angle to 90 degrees. Look through both polarizers at a bright light and rotate the other polarizer until the transmitted light is at the minimum. Now the polarizers are crossed at 90 degrees. Rotate the label- side polarizer back to zero degrees. Now the two polarizers are aligned for maximum transmission. Throughout the experiment, only rotate the label-side polarizer.

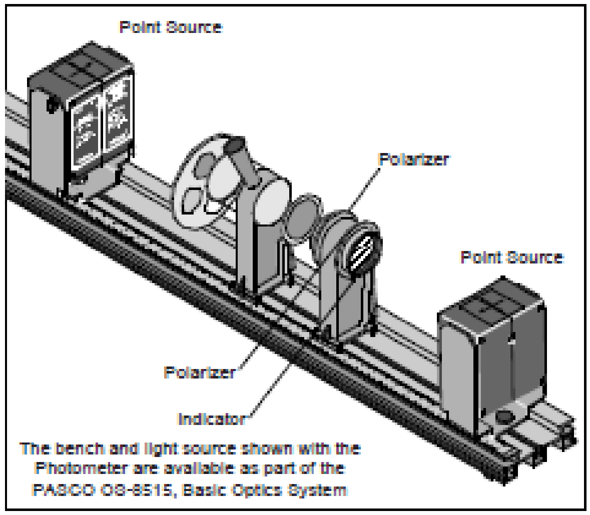

Figure 2.3: Experiment Set-Up

④ Place the polarizer accessory holder (with polarizers) on the bench between the light source and the photometer on the side opposite the neutral density filter. The label side of the polarizer holder should face away from the photometer. The polarizer holder should be close to the photometer so only polarized light will enter that side of the photometer.

Procedure

> ➤ NOTE: You may want to cover the crossed-arrow objects on each light source to reduce the excess light in the room. The room lights must be off for this experiment.

① Set the neutral density filter for 100% transmission.

② While looking into the photometer's conical eyepiece, adjust the position(s) of the light source(s) until the two sides of the orange indicator have equal intensity.

③ Set the neutral density filter for 75% transmission.

④ While looking into the photometer's conical eyepiece, rotate the label-side polarizer until the two sides once again have equal intensity. Record the angle in Table 2.1. Rotate the polarizer back to zero and repeat the measurement two more times.

⑤ Repeat the previous step for 50% and 25% transmission.

Table 2.1: Data and Results

% transmittance	75%	50%	25%
trial 1			
trial 2			
trial 3			
Average angle ϕ			
$\cos^2\phi$			
% difference			

Analysis

① For each of the neutral density filter settings, calculate the average of the three trials and record the average angle in Table 2.1.

② To calculate the predicted percentage transmittance for each case, calculate the square of the cosine of each average angle and record in Table 2.1.

③ Calculate the percent difference between the percentage transmittance and the predicted value for each case and record in Table 2.1.