EXPERIMENT 3

LIGHT POLARIZATION AND FOCAL LENGTH OF THIN LENSES

OBJECTIVES:

This experiment consists of two separate parts, parts A and B. Part A has two objectives. The first objective is to determine whether or not a given beam of light is polarized. The second objective is to experimentally verify the angular dependence of the transmitted optical power when a beam of light passes through a polarizer/analyzer pair. The objective of part B is to experimentally verify the thin lens formula by experimentally finding the focal lens of a given thin lens by imaging.

PART A:

EQUIPMENT REQUIRED

1. Optical power meter: INFOS, Model # M100.
2. HeNe laser: Coherent, Model # 31-2090-000.
3. ¼ m optical bench.
4. Holder.
5. Laboratory Jack.
6. Two linear polarizers.

INTRODUCTION:

A linear polarizer is characterized by a pass axis with a block axis at 90 degree with respect to the pass axis as shown in Figure 1.

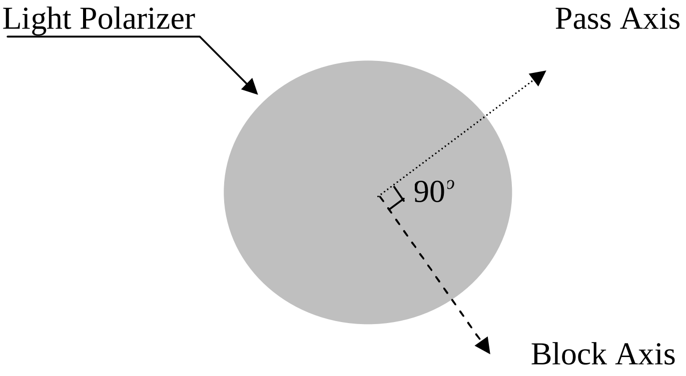


Figure 1: A linear Polarizer with Pass Axis at 90-Degree with Respect to the Block Axis.

When light beam pass through an *ideal* linear polarizer, the electric field vectore component parallel to the pass axis passes through the polarizer without loss. However, the beam's electric field vector component parallel to the block axis does not pass at all through the ideal linear polarizer. In this experiment we use a linear polarizer and assume that it approximates the operation of the ideal linear polarizer.

Now consider a linearly polarized light beam propagating in air in the z-direction, with an electric field given by:

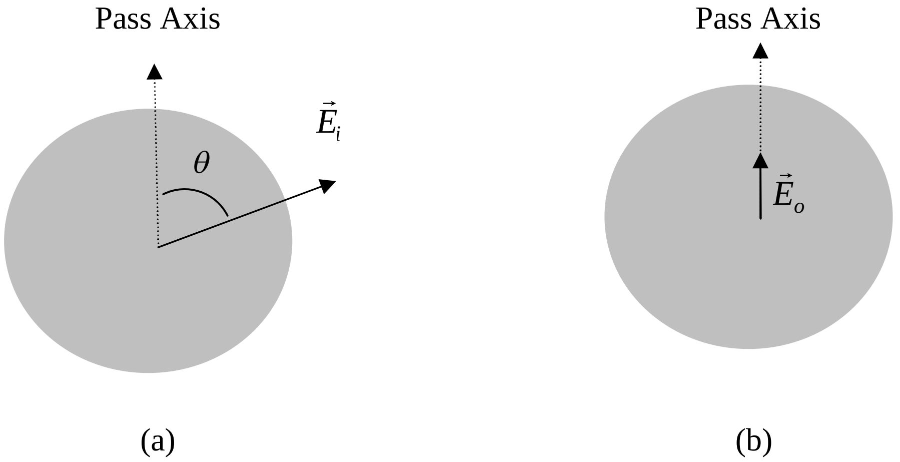
$$\vec{E} = \vec{E}_i = \vec{a}_x E_x e^{-jk_o z} + \vec{a}_y E_y e^{-jk_o z} \qquad (1)$$

Where E_x and E_y are the field amplitudes in the x and y directions, respectively and k_o is the free space phase constant. This beam will be used as input to the polarizer. Let us situate the polarizer in the $x-y$ plane (normal to the beam's direction of propagation z) and rotate the polarizer such that its pass axis becomes parallel to the y-axis (see Figure 2). The Block axis is not shown, because we know it is always at 90^o with respect to the pass axis.

As shown in Figure 2 (a), the input electric field vector makes an angle θ with respect to the pass axis of the polarizer. The output electric field vector is shown in Figure 2(b), after the beam passes through the linear polarizer. It is clear that only the y-component of the field vector passes through the polarizer, while the x-component is blocked, resulting in the output electric field:

$$\vec{E}_o = \vec{a}_y E_y e^{-jk_o z} \qquad (2)$$

This represents a beam linearly polarized in the y-direction.



(a) (b)

Figure 2: Input and Output Electric Field Vectors when a Linearly Polarized Light Beam Passes Through a Linear Polarizer. The Input Electric Field Vector is at Angle θ with Respect to the Pass Axis of the Polarizer.

For the case considered above, the amplitude of the input electric field and output electric fields are respectively given by: $E_i = \sqrt{E_x^2 + E_y^2}$ and $E_o = E_y$ which are related by the simple relationship:

$$E_o = E_i \cos\theta \tag{3}$$

Since the electromagnetic power is proportional to the square of the electric field, we can easily predict the ratio of the output to input power:

$$(\frac{E_o}{E_i})^2 = \frac{P_o}{P_i} = \cos^2\theta \tag{4}$$

Equation (4) is valid only for the ideal linear polarizer shown in Figures 1 and 2. However, we can still use equation (4) for practical linear polarizers provided we interpret P_i to be the maximum output power $P_{o,\max} = P_o(\theta = 0)$ that can pass through the polarizer (i.e. when $\theta = 0$). Thus for a practical linear polarizer, we have:

$$\frac{P_o(\theta)}{P_o, \max} = P_N = \cos^2\theta \tag{5}$$

Where P_N is the *normalized* output power. In this part of the experiment (part A), we will perform optical power measurements to verify the validity of equation (5).

From the point of view of polarization, there are two types of lasers. Either they are linearly polarized or randomly polarized. A linearly polarized laser means that the electric field vector of the laser has a specific and fixed direction. In the case of a randomly polarized laser, the electric field vector continually and rapidly changes direction in a random manner. Sunlight is another example of a randomly polarized light. In this experiment, we will find out whether the HeNe laser source in the EE 420 laboratory is linearly or randomly polarized.

During this part of the experiment, it is important to distinguish between the two angles θ and θ_p. The angle θ = angle between the *input* electric field vector and the pass axis of the polarizer, exactly as defined in Figure 2 (a). However, θ_p simply represents the *reading* of the polarizer dial. The polarizer dial used in the EE 420 laboratory has the following range $0 \le \theta_p < 360^\circ$.

PROCEDURE:

[IMPRTANT: FOR THIS PART OF THE EXPERIMENT, THE LASER MUST BE TURNED ON FOR AT LEAST ONE HOUR BRFORE RELIABLE MEASUREMENTS CAN BE TAKEN].

1- Place a polarizer between the HeNe laser source and the optical power meter as shown in Figure 3. Adjust the polarizer orientation so that the beam passes normal to the polarizer and as close as possible to the center of the polarizer.

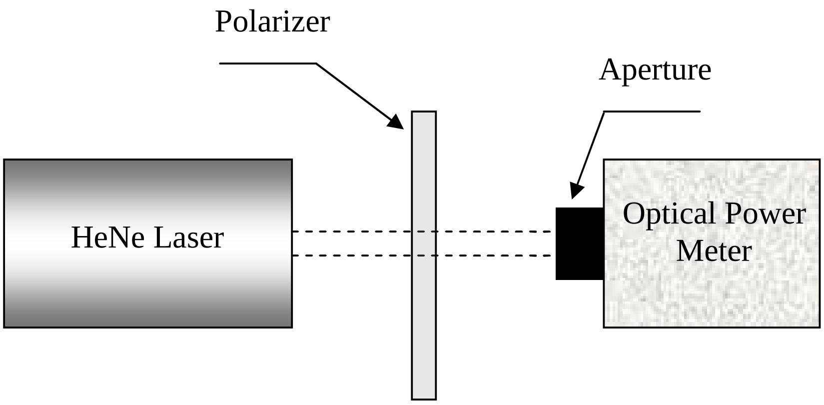


Figure 3: Setup Used for Examining the Polarization of the HeNe Laser Source Using a Linear Polarizer Placed Between the Laser and an Optical Power Meter.

2- Turn on the power meter and select the dBm scale and $\lambda = 0.85\mu m$.

3- Insure that an appropriate aperture is used at the input end of the power meter to minimize the effect of the ambient light. The power meter cover can be used an aperture.

4- Set the polarizer angle θ_p to zero degrees.

5- Adjust the position of the power meter for maximum meter reading.

6- Record the optical power in dBm in the second column of table 1.

7- Set the polarizer dial to $\theta_p = 10^o$ and record the dBm power in table 1.

8- Repeat step 7 for $\theta_p = 20^o, 30^o, \ldots.., 90^o$.

9- Covert the dBm power to mW and record the values in the third column of table 1.

10- Calculate the corresponding normalized power P_N and record its value in column 4 of table 1.

11- Plot a graph that shows the variation of P_N with θ_p. At this point the distinction between θ_p and θ is not important.

12- Using this graph, comment on the variation of P_N with θ_p. Is the HeNe laser linearly polarized or randomly polarized?

13- Place another polarizer between the HeNe laser source and the optical power meter as shown in Figure 4. The polarizer on the right-hand-side is now called *analyzer*, because it is used to analyze the linearly polarized light that emerges from the polarizer.

14- Insure that the light beam passes as close to the center of both the polarizer and analyzer.

15- Set the *analyzer angle* θ_p to 90^o.

16- Rotate the dial of the *polarizer* until the power received is minimum. The reading of the polarizer angle is not important, so we do not need to record it. *Since the power received by the meter is minimum, we are now sure that the linearly polarized light makes an angle* $\theta = 90^o$ *with respect to the analyzer pass axis*.

17- Record the dBm meter reading in the third column of table 2 (use the bottom row, which corresponds to $\theta = \theta_p = 90^o$).

18- Rotate the analyzer dial to $\theta_p = 80^o$ and record the meter reading in the third column of table 2. [*Do not change the polarizer angle*].

θ_p (Degrees)	P (dBm)	P (mW)	P_N (Unit-less)
0			
10			
20			
30			
40			
50			
60			
70			
80			
90			

Table 1: Measured Optical Power Variation with the Polarizer Angle θ_p when a Single Polarizer is Used.

19- Repeat step 18, for $\theta_p =$ 70, 60, 50, …., 10, 0, 350, 340, 330, …., 270 and 280 degrees. [*Note that the angle* $\theta_p = 350^o$ *is equivalent to* $\theta = -10^o$, $\theta_p = 340^o$ *is equivalent to* $\theta = -20^o$ *and so on*].

20- Convert the meter reading recorded in column 3 to mW and record the values in column 4 of table 2.

21- Divide by the maximum power to convert the data of column 4 to normalized power and record the resulting normalized power P_N in column 5 of table 2.

22- Plot P_N versus θ.

23- Plot equation (5) [$P_N = \cos^2\theta$] in the *same* figure.

24- Calculate the relative error between the experimental and theoretical values of P_N.

25- Discuss and comment on the results. Write some conclusions.

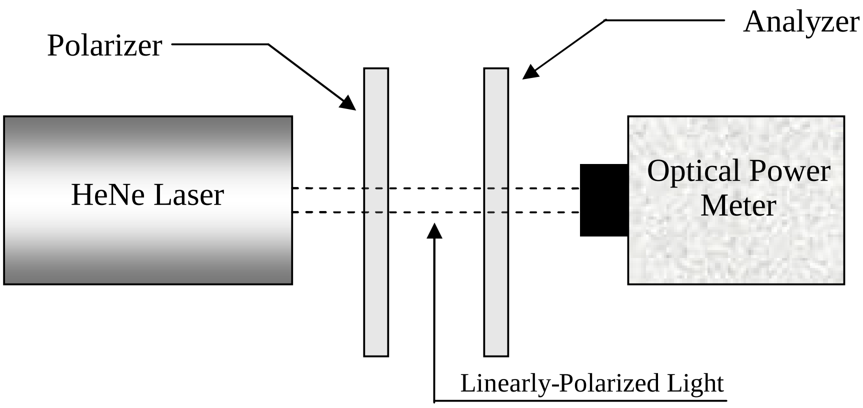


Figure 4: Polarizer/Analyzer Pair Placed between the HeNe Laser Source and the Optical Power Meter. The Laser Light is Linearly Polarized by the Polarizer Before it Passes Through the Analyzer.

θ_p (Degrees)	θ (Degrees)	P (dBm)	P (mW)	P_N (Unit-less)
270	-90			
280	-80			
290	-70			
300	-60			
310	-50			
320	-40			
330	-30			
340	-20			
350	-10			
0	0			
10	10			
20	20			
30	30			
40	40			
50	50			
60	60			
70	70			
80	80			
90	90			

Table 2: Measured Optical Power with θ for the Polarizer/Analyzer Pair Arrangement.

PART B:

EQUIPMENT REQUIRED

1- White light source.
2- 1 m optical bench.
3- White Screen.
4- Lens Holder.
5- Lens (focal length $f = 10\,cm$).
6- Lens (unknown focal length).
7- Object with holder.

INTRODUCTION:

In this part of experiment we will use the well-known thin lens formula:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \qquad (6)$$

to experimentally measure the focal length of a thin lens, where f, d_o and d_i are respectively the focal length of the lens, the object distance and the image distance (see Figure 5 in the procedure section). After forming an image, we will measure the distances d_o and d_i, from which the focal length of the lens can easily be determined, using equation (6). We will do two separate measurements. The first measurement will be done using a lens having a focal length of 10 cm. The measured value of f will then be compared with the known value. In the second measurement, the focal length of the thin length is unknown and we are expected to determine it experimentally. In doing this experiment, it is helpful to recall that a real image can be formed only if $d_o > f$.

PROCEDURE

1- Insert a lens of focal length $f = 10\,cm$ between the object and the screen, as shown in Figure 5.
2- Adjust the intensity of the white light source in order to reduce glare.
3- Set the object distance to $d_o = 12\,cm$.
4- Change the distance d_i until a *sharp* image is formed on the screen.
5- Record the value of d_i in table 3.
6- Calculate the value of the focal length using equation (6) and record it in table 3. Comment on how close this value is to $f = 10\,cm$. Comment on the sources of error if any. Discuss the results and write some conclusions.
7- Using the above procedure, determine the focal length of the lens supplied to you by the laboratory instructor and record the experimental value in table 3. Write a conclusion.

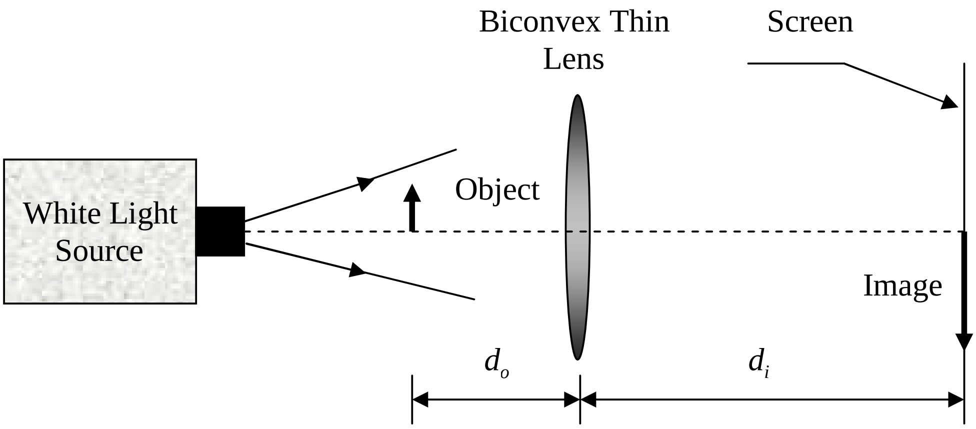


Figure 5: Image Formation Using a Thin Biconvex Lens.

Lens Focal Length	d_o (cm)	d_i (cm)	$f_{\text{experimental}}$ (cm)
10 cm	12		
Unknown			

Table 3: Imaging Data for the Known and Unknown Lenses.

QUESTIONS:

1- For the polarizer/analyzer arrangement, calculate (theoretically) the angle θ such that the transmitted power is 50% of the maximum power.

2- For the polarizer/analyzer arrangement, calculate (theoretically) the angle θ such that the transmitted power is 6 dB below the maximum power.

3- For the polarizer/analyzer arrangement, calculate (theoretically) the ratio of the transmitted electric field (for $\theta = 30^o$) to the maximum possible electric field.

4- Briefly suggest a simple method that can be done to show that sunlight is not linearly polarized. You can use only one polarizer.

5- A thin lens having a known focal length of $5\,cm$ is used for the formation of a real image on a screen. If you want to form an image at 45 cm from the lens, how far from the lens must the object be placed? What is the resulting magnification?