PHYSICS 176

UNIVERSITY PHYSICS LAB II

Experiment 12

Geometrical Optics: Interference and Diffraction of Light

Equipment: Laser source, Single slit wheel, Double slit wheel, Large viewing screen,Two polarizers, polarizer holder, photometer, photometer attachment stand

Introduction:

The distances between the central maximum and the diffraction minima for a single slit are measured by scanning the laser pattern with a light sensor and plotting light intensity versus distance. Also, the distance between interference maxima for two or more slits is measured. These measurements are compared to theoretical values. Differences and similarities between interference and diffraction patterns are examined, including the effect of changing the wavelength of the light.
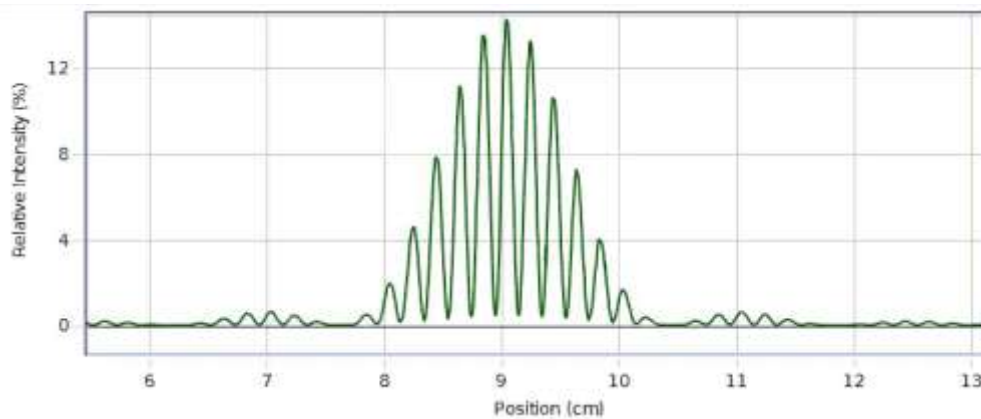
Double Slit Interference Pattern

Single Slit Theory

When diffraction of light occurs as it passes through a slit, the angle to the minima (dark spot) in the diffraction pattern is given by

Figure 1: Single Slit Diffraction

$$a \sin \theta = m\lambda \ (m=1,2,3, \ldots) \qquad (1)$$

where "a" is the slit width, θ is the angle from the center of the pattern to a minimum, λ is the wavelength of the light, and m is the order (m = 1 for the first minimum, 2 for the second minimum, ...counting from the center out).

In Figure 1, the laser light pattern is shown just below the computer intensity versus position graph. The angle theta is measured from the center of the single slit to the first minimum, so m equals one for the situation shown in the diagram. Notice that the central spot in the interference pattern is twice as wide as the other spots since m=0 is not a minimum.

Since theta is a very small angle, $\sin\theta \sim \tan\theta = x_m/L$, where x_m is the distance from the center of central maximum to the mth minimum on either side of the central maximum and L is the distance from the slit to the screen.

$$\sin \theta \approx \tan \theta = x_m/L \qquad (2)$$

It is easier to measure the distance ($\Delta x = 2x_m$) from the mth minimum on one side to the mth minimum on the other side than to try to judge the center of the pattern. Equation (2) becomes

$$\sin \theta \approx \tan \theta = \Delta x /2L \qquad (3)$$

Our accuracy will be improved by making (Δx) as large as possible. The slit width is not known very well. The uncertainty in the width is +/- 0.005 mm. That is a 25% uncertainty for the 0.020 mm slit. So instead of using the slit width to calculate a value for the laser wavelength, we use the known wavelength of the laser to calculate a more accurate value for the slit width.
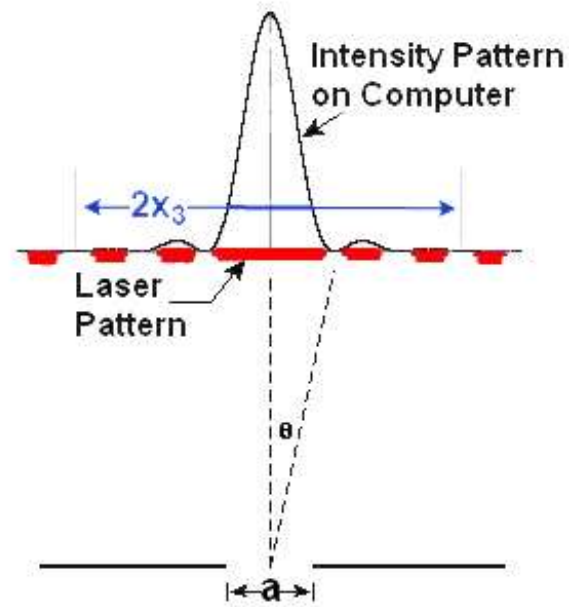
Double Slit Theory

When interference of light occurs as it passes through two slits, the angle from the central maximum (bright spot) to the side maxima in the interference pattern is given by

$$d \sin \theta = n\lambda \quad (n=0,1,2,3, \ldots) \qquad (4)$$

where "d" is the slit separation, θ is the angle from the center of the pattern to the nth maximum, λ is the wavelength of the light, and n is the order (0 for the central maximum, 1 for the first side maximum, 2 for the second side maximum ...counting from the center out).

In Figure 2, the laser light pattern is shown just below the computer intensity versus position graph. The angle theta is measured from the midway between the double slit to the second side maximum, so n equals two for the situation shown in the diagram.
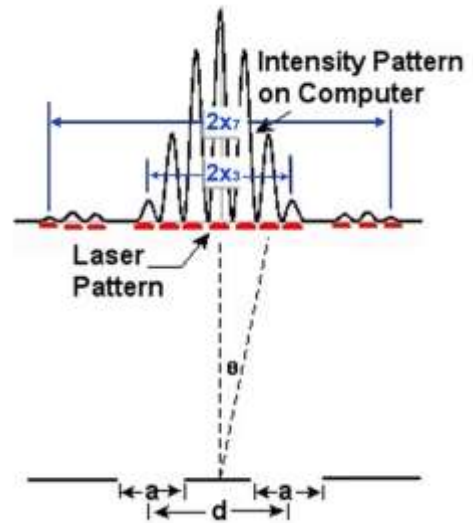

Figure 2: Double Slit Interference

As before, theta is a small angle and Equation (3) still holds:

$$\sin \theta \approx \tan \theta = \Delta x \, /2L \qquad (3)$$

where $\Delta x = 2x_n$ is the distance from the nth side maximum on one side to the nth side maximum on the other side of the central maximum and L is the distance from the slits to the screen. Since it is more accurate to measure from the nth maximum on one side to the nth maximum on the other side, we will measure $2x_n$.

Note that the single slit diffraction pattern is also present in the double slit pattern. It is responsible for the broad minima that occur (see Figure 2). This means we must be careful when counting n in the double slit pattern since a double slit maximum can be suppressed by a single slit minimum.

Polarization

Diffraction and interference effects occur with any type of wave. However, since light is a transverse electromagnetic wave, it exhibits one property not common to all waves. This unique property is called polarization.

As a light wave travels through a medium, the electric and magnetic fields oscillate in a plane perpendicular to the direction of travel. If all light waves from a given source are such that their electric field vectors are parallel, the light is said to be plane polarized. If, however, the individual light waves coming from a source have randomly oriented electric vectors the light is said to be "randomly polarized" or "unpolarized."

Unpolarized light can be conveniently plane-polarized by use of a Polaroid sheet. This is a sheet of transparent plastic in which special needlelike crystals of iodoquinine sulfate have been embedded and oriented. The resulting sheet will allow light through it only if the electric vector is vibrating in a specific direction. Hence, if unpolarized light is incidence upon the sheet, the transmitted light will be plane-polarized and will consist of the sum of the electric field components parallel to the permitted direction.

Consider what happens as unpolarized light is passed through two Polaroids as shown in the two cases below. In the first case, the first Polaroid allows only the vertical vibrations to pass. These are then transmitted by the second Polaroid, since it, too, is vertical. However, in the second case, the polarizer has been rotated through 90☞ and allows only horizontal vibrations to pass. These are completely stopped by the vertically oriented Polaroid. Therefore, no light comes through the combination.
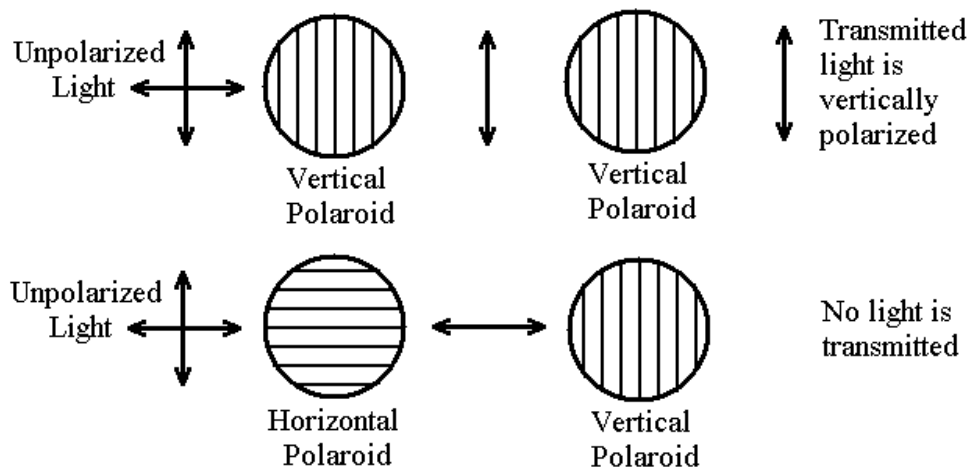
In the example shown, the two Polaroids are oriented at an angle θ between 0 deg. and 90 deg. Malus' Law tells us that if I_m is the intensity of the light transmitted when θ is 0 deg., then at any other angle the intensity of the light is $I = I_m\cos^2\theta$.
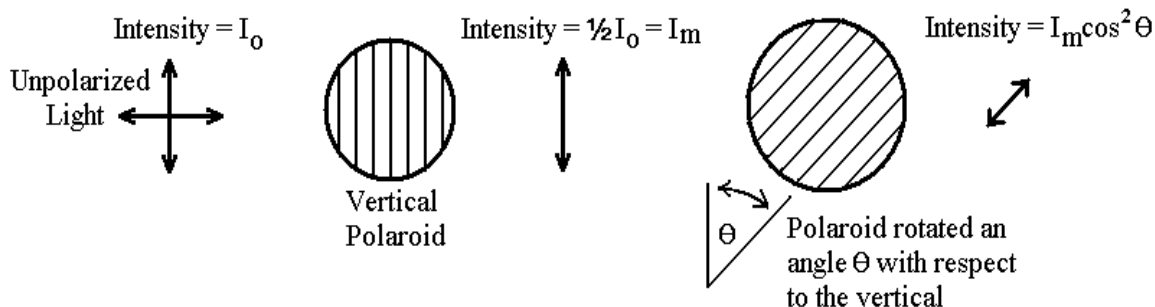
The incident unpolarized light is an equal mixture of vertically and horizontally polarized light. The first polarizer allows only vertically polarized light to pass. As a result, the transmitted light is polarized in the vertical plane and its intensity is reduced by a factor of two. When this plane polarized light of intensity I_m strikes the second polarizer, Malus' Law tells us that the transmitted light has an intensity of $I_m\cos^2\theta$. Where θ is the angle between the axis of the second polarizer and the plane of the polarized light which strikes it.

Photometer

The PASCO Model 9152A Photometer is a battery powered, self contained, medium sensitivity instrument. The unit contains a selenium photovoltaic cell, high sensitivity amplifier and meter readout. In addition to six ranges of sensitivity, the instrument features a variable sensitivity control, internal battery check, and external chart recorder output jack. The 9152A may be used either to read the light directly incident on the selenium cell or, through the use of a detachable fiber optic probe, to measure the incident light up to 30 inches from the photometer. The fiber optic probe also makes it possible to measure light in areas which would not be accessible to the photometer.

Operating Instructions

Mechanical Zero - Before turning the instrument on, check that the meter movement is mechanically zeroed. If not, turn the adjustment screw, directly below the meter face, until the needle is exactly over zero.

2.   Battery Check - Turn the Power Switch to the "BATT.TEST" position. The meter needle should read to the right of the "Replace Batt." line. If the needle reads within the line then replace the battery according to the procedure given in the Maintenance Section. (NOTE: Instruments are shipped without the battery installed.)

3.   Electronic Zero - Place the palm of one's hand tightly over the Optic Input connector which houses the selenium cell (if the fiber optic probe is not attached to the photometer) or over the end of the fiber optic probe (if the probe is attached to the photometer). When all light has been prevented from entering the selenium cell turn the Sensitivity (Lux) Switch to the "1" position and turn the Zero Adjust Knob until the meter needle reads over zero. Again, when adjusting for electronic zero make certain no light can get to the selenium cell. Turn the Sensitivity Switch to the 300 Position.

4.   Measurements With the Fiber Optic Probe - The fiber optic probe is attached to the photometer by slipping the connector of the fiber optic probe over the Light Probe Input connector on the photometer. A quarter twist clockwise locks the probe to the photometer. A quarter twist counterclockwise disengages the probe. The probe should be pointed directly at the light source to be measured. Turn the Variable Knob fully clockwise. Turn the Sensitivity Switch clockwise one step at a time until the meter reads the highest value without going off scale. The Photometer now will indicate relative intensity.

PROCEDURE A: Single Slit

1. Mount the laser on the end of the optics bench, at 0cm. Mount the High Precision Single Slit disk to the optics bench with the printed side toward the laser as shown. Turn on the laser. CAUTION: Never shine the laser beam directly into anybody's eye! To select the desired slits, just rotate the disk until it clicks into place with the 0.02 mm aperture slit illuminated by the laser.
2. Place the viewing screen on the optics track, start with 0.5 m away from the laser OR 1 meter from the laser. Whatever you chose, it must stay consistent through entire lab.
3. Place the single slit diffraction piece on the optic track at the 5 cm mark. If the laser does not go through the hole of the diffraction slit, use the knobs on the back of the laser to move it left, right, up, and down.
4. Once this is set up, observe the patterns on the viewing screen by rotating the diffraction slits.
5. Rotate to the 0.02mm slit (a = 0.02 mm) the front of the rotating screen describes the width of the slits.
6. Observe and measure the pattern that is on the viewing screen. Measure the distance of Δx.
7. Solve equation 1 using equation 3.
   a. Hint: First you must use the λ on the laser to solve for a, then use that number to solve for the calculated λ.
   b. Hint: After the calculation there will be some sort of unit conversion.

8. Put the data in the given table and repeat the single slit procedure for 0.04mm single slit.

PROCEDURE B: Double Slit

1. Note where the index foot is on the bottom of the Single Slit holder with respect to the yellow scale on the Optics Bench. Replace the Single Slit holder with the Double Slit holder so the index foot is in the same position. The distance to the screen should be the same as it was for the single slit experiment.
2. Start with the a = 0.04 and d = 0.25 double slit. Again, the front of the wheel labels each slit.
3. Make sure that the distances are the same to the single slit lab. If you cannot count the value of n, move the viewing screen back until you can count the value, then move the viewing screen back to the correct distance to take the data.
4. Measure L, n, and Δx and enter it into the data table.
5. Repeat again with the a = 0.04 and d = 0.5 double slit.
6. Solve equation 4 using equation 3, again you must start with the value of λ on the laser and solve for d, then plug that number in and solve for the calculated λ value.
7. Enter these values into the table.

The track should look like this, disregarding the lengths in-between each object.
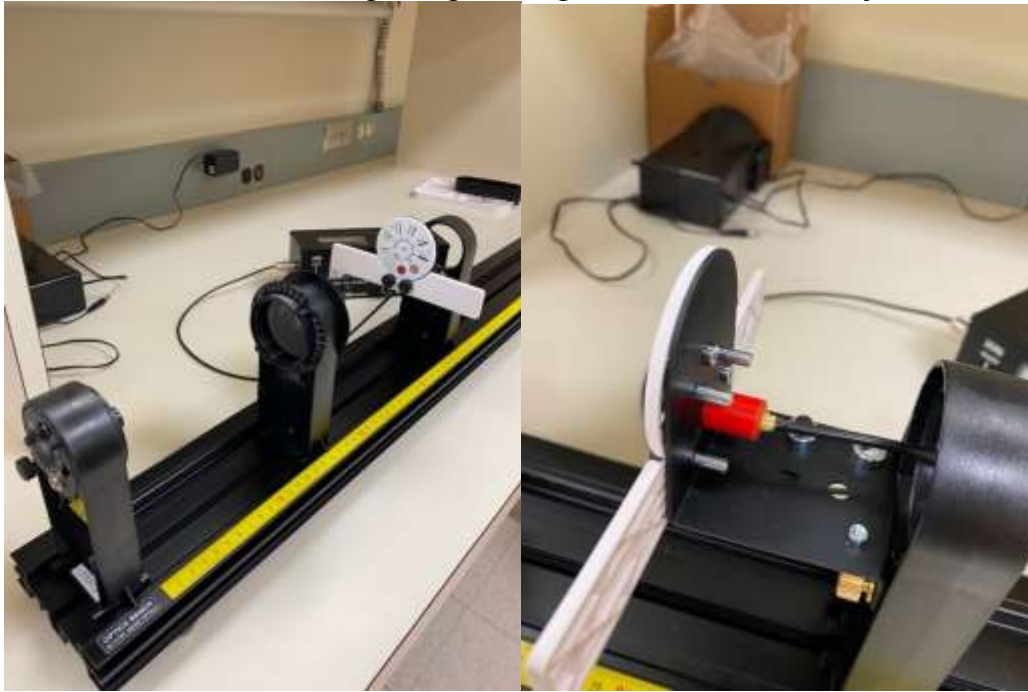
PROCEDURE C: Polarization

1. Place the laser at 0 cm and the viewing screen at 0.5 m on the track
2. Put the polarizer holder on the track along with the two polarizers. On the polarizer holder, there is a plastic 'dot' on the bottom of the open circle, this is the marker that allows you to know that degree the polarizer is at. So, to start place one polarizer at 0 degrees and the other at 180 degrees.
3. turn on the laser, and simply turn the polarizers and observe what you see.
4. Now, remove the viewing screen and place the aperture bracket in its place. Take the photometer optical cable and place it in the open circle of the aperture bracket. If the open circle isn't there, turn the wheel to change its setting. Try to line up the edge of the aperture bracket to the 0.5 m mark, it just needs to be around that point.
5. Make sure the laser is on and pointed at the optical cable, spin the knobs on the back of the laser to move it left, up, right, and down.
6. Align the two polarizers so that both have the 0 deg.-180 deg. axis vertical. Measure the intensity of the light as measured by the photometer. Now carefully rotate the second polarizer so that the angle θ between the two axes is 15, 30, 45, 60, 70, and 90 deg. Record the intensity in each case and compare with the prediction of Malus' Law.

Data Analysis A – B:

Label	a (mm)	d (mm)	m	n	Δx (m)	Calculated Slit Width	Calculated λ (nm)	% λ Diffference
0.02 mm								
0.04 mm								
0.04a-0.25d								
0.04a-0.50d								

Data Analysis C:

1.By visual inspection, under what conditions is the intensity of the light transmitted through the two polarizers a maximum? A minimum?

2. Intensity of light when both polarizers are oriented vertically (0 and 180): $I_m =$ _____ lux

θ	I (measured in lux)	$I = I_m\cos^2\theta$ (lux)
15		
30		
45		
60		
75		
90		

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QUESTIONS A - B:

1. Using your eyes, how does the single slit pattern change as you increase the slit size?

2. Using your eyes, how does the double slit pattern change as you increase the slit separation?

3. How does the Single Slit Diffraction change as you vary the slit width (a)? Does this agree with your answer to Question 1 above?

4. How does the Double Slit pattern change as you vary the slit separation (d)? Does this agree with your observations from Question 2 above?

5. How does the Double Slit pattern change as you vary the wavelength? Does this agree with your answer to the pre-lab question?

QUESTIONS C:

Explain the transmission of light that you observe through the set of two polarizers, regarding the angles that the polarizer is at, make sure to use your data.

Was Malus' Law prediction correct in calculating the intensity of light at the different non-vertical and non-horizontal angles?