General Physics Experiment 4
Interference and Diffraction of Light

Objectives:

< To measure the wavelength of light emitted by a Helium-Neon laser.
< To observe the character of single slit diffraction.
< To observe the character of double slit diffraction.
< To measure the wavelength of microwave radiation with a Michelson Interferometer.

Equipment:

< Helium-Neon laser
< Diffraction grating, 750 lines per mm
< Slide of single slits, .02, .04, .08, .16 mm width
< Slide of double slits, .04, .08 mm width; .25, .5 mm separation
< Foam slit holders and wood grating holder block
< Meter stick, two meter stick
< Gunn oscillator assembly, tuned detector and stand
< Wire rod polarizing comb
< Masonite reflectors with aluminum cover sheets (2)
< Pasco low voltage supply
< 10 by 10 cm masonite spacing plates, 2 each 6 mm thick, 1 each 3 mm thick
< Graphical Analysis software

Physical Principles:

A diffraction grating consists of a series of opaque and transparent strips. Light passing through the grating is broken up into portions which come through each slit. The light from the various slits interfere with one another producing dark and bright fringes. Bright fringes occur when the path length of the light from adjacent slits to the screen is an integral multiple of the wavelength. When the light is incident upon the grating perpendicular to its surface this condition is satisfied at an angle from this direction given by

\[ d \sin 2 \theta m = \delta \]

(1)

where \( d \) is the distance between adjacent slits \( (d = 1/750000 \text{ m} = 1.333 \times 10^{-6} \text{ m}) \), \( \theta \) is the angle from grating-source line and \( m \) is the number of wavelengths of path length difference for light paths through adjacent slits \( (m \) is called the order of the line).

The double slit is a special case of the diffraction grating with 2 slits. Therefore equation (1) gives the condition for the location of the bright fringes.
When light passes through a single slit the light from different portions of the slit interferes again producing a series of bright and dark fringes. Total destructive interference will occur when

\[ w \sin 2m' \cdot m \delta \]  

(2)

where \( w \) is the width of the slit, \( 2 \) is the angle of the dark center from the source-slit line, and \( m \) is the number of wavelengths of path length difference for light paths from opposite sides of the slit. In the case of a small angle, \( 2m' \), the sine of the angle can be approximated with the angle itself in radians. Thus, equation (2) can be rewritten as

\[ w \cdot 2m' \cdot m \delta \]  

(3)

The equation \( 2m' \) in equation (3) is the same as the one in figure 1 and for small angles it is given by

\[ 2m' \cdot \sin \frac{y_m}{D} \]  

(4)

From equations (3) and (4) the following relation can be written

\[ y_m \cdot \frac{D \delta}{w} m \]  

(5)

**Procedure:**

**Determination of the wave length of the helium-neon laser**

Place the diffraction grating into the foam holder block. Position this holder so that the grating is 0.5 m from a wall and parallel with it. Direct the laser beam through the diffraction grating so that the undeflected beam strikes a wall perpendicularly at a distance \( D \) of about 0.5 m. Use masking tape to secure a meter stick on the wall so that the central maximum is at about the 50 cm mark and the first order maxima are on the meter stick on both sides. Rotate the grating around a vertical axis until it is perpendicular to the laser beam and the first order maxima are symmetrical about the central maximum. Record the positions \( y_m \) on the meter stick of the locations of the first order maxima and \( y_c \) the central spot. Using the given information that \( 1/d = 750,000 \text{ lines/m} \) and \( 2m = \arctan(y_m/D) \), calculate the wave length of the helium-neon laser red line from equation 1. Compare the value of \( \delta \) to the accepted value of 632.8 nm and compute the percent error from this value.

**Single slit diffraction pattern (0.02 mm slit width)**

Direct the laser beam so that it is perpendicular to the wall at a distance of about 60 cm. **Do not move the laser or this alignment will need to be repeated.** Mount the single slit slide in the foam holder block and position it in the laser beam about 50 cm from the wall. Move the foam holder block and slit slide
sideways so that the laser beam passes through the .02 mm wide slit. The diffraction pattern should have a maximum brightness and sharpness. Rotate the slit slide about a vertical axis until it is perpendicular to the laser beam so that the diffraction pattern is symmetrical about the central maximum. Use masking tape to secure a 20 cm by 28 cm sheet of white paper on the wall with the long side horizontal so that the central maximum is included near the center of the sheet and six diffraction minimum show on the sheet. Use a pencil to carefully mark short vertical lines to locate the centers of the diffraction minimum (dark bands) out through at least the fifth minimum. Remove the sheet from the wall and mark the center of the central diffraction maximum as half way between the adjacent minima. With a transparent ruler measure and record the distance \( y_m \) of each minimum from the center of the central maximum in the row with the order number \( m = 1, 2, 3, 4 \) and 5, and record your data in a table. Also, measure and record the distance, \( D \), of the slit from the wall (about 50 cm). Make a plot of \( y_m \) on the y axis versus the order \( m \) on the x axis. The slope of the line should be \( D8/\lambda \). From the slope and the accepted value of \( \lambda = 632.8 \text{ nm} \) calculate the width of the slit. How well does this compare with the labeled value of the slit width?

**Single slit diffraction pattern (various slit widths)**

Move the slide of slits until the laser beam is passing through the .04 mm wide slit and the pattern is bright and sharp and replace the sheet on the wall at a slightly different height with the central maximum near the center. With a sharp pencil mark the minima bounding the central maximum. Mark the center of the central maximum as halfway between these two minima. Also, mark the fifth minimum. Measure the distance between this fifth minimum and the central maximum and record it as \( y_m \). Repeat this for the .08 mm and .16 mm wide slits. Record the particular minimum that you are working with (suggested \( m = 5 \)). Plot \( y_m \) on the y axis versus \( 1/\lambda \) on the x axis for the four data points. The slope of this line, according to equation (5) should be \( mD8 \). Find the % error between the slope that you found and this predicted value.

**Double slit interference (.25 mm slit separation)**

Place a double slit slide in the foam holder and position it about 1.5 m from a wall. Direct the laser through the double slit that has a slit separation of .25 mm and a slit width of .04 mm and form an interference pattern on the wall. Tape an 8.5"x11" of paper on the wall with the long side horizontal and the central maximum on one side of the paper. With a sharp pencil mark the center of the central maximum and of the eighth order maximum. Use equation (1) to predict the distance \( x_m = x_8 \) for the eighth interference maximum. Compare these results. Repeat this with the laser coming through the double slit that has a slit spacing of .5 mm and a slit width of .04 mm. Observe carefully to note that because of the diffraction minimum some of the interference maximum are missing. Test these observations against the following argument. Rewriting equations (1) and (2) for small angles we see that \( 2n(d\lambda)/m(\lambda) \). In other words, the diffraction minimum occurs when the number \( n \) of wave lengths of path difference between the two slits is an integer times the ratio of \( d/\lambda \) thus eliminating the n-th interference maximum. For the first slit this means \( .25/.04 = 6.25 \) or about every 6th maximum would be missing.
Microwave Michelson Interferometer

Every lab group will take turns using the station that is already set up for this experiment. Move one of the secondary mirrors of the Michelson interferometer until a minimum (or maximum if you wish) voltage is displayed on the oscilloscope screen. Read and record the position of the leading edge of the reflector block (x_0). Move the reflector block counting successive minima (or maxima) until 10 have been observed. Record the final position of the leading edge of the reflector block (x_f). The wave length (\( \lambda \)) is 2 times this distance divided by 10. Compute the frequency of the microwaves by \( \frac{c}{\lambda} \). In this formula \( c \) is the speed of light which is approximately \( 3.00 \times 10^8 \) m/s.

Law of Malus

Every lab group will take turns using the station that is already set up for this experiment. With no interference between the source and the detector, read the initial voltage, \( V_o \), from the oscilloscope screen. Then, for angles of 20\( ^\circ \), 35\( ^\circ \), 45\( ^\circ \), 55\( ^\circ \) and 70\( ^\circ \) of the wire rod polarizing comb measure the voltage on the oscilloscope screen. The intensity of the radiation is proportional to this voltage. Complete the following table in your journal and make a plot of the voltage on the y axis versus \( \cos^2 2 \) on the x axis. The plot should be a straight line through the origin with a slope of \( V_o \), where \( V_o \) is the voltage corresponding to the incident intensity, \( I_o \).

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