Lab Team #:__________ Section:__________ Date: April 4, 2019

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Young's Double Slit Experiment

Purposes:

1. To measure an "unknown" wavelength of a laser using double slit interference.
2. To estimate the individual slit width by observing the "missing orders."

Required Equipment and Supplies:

He-Ne or diode laser and mount, mounted double slits, optical stand and clamp, a supply of plain white copier paper, masking tape, "unknown" laser, mm ruler, metric tape measure, Bristol 521 Wavelength Meter (optional).

Caution:

Even though the lasers used in this lab are low power they can cause retinal damage if the beam enters your eye. Never look directly into the laser beam and be cautious not to allow reflections of the beam from shiny objects to enter your eye.

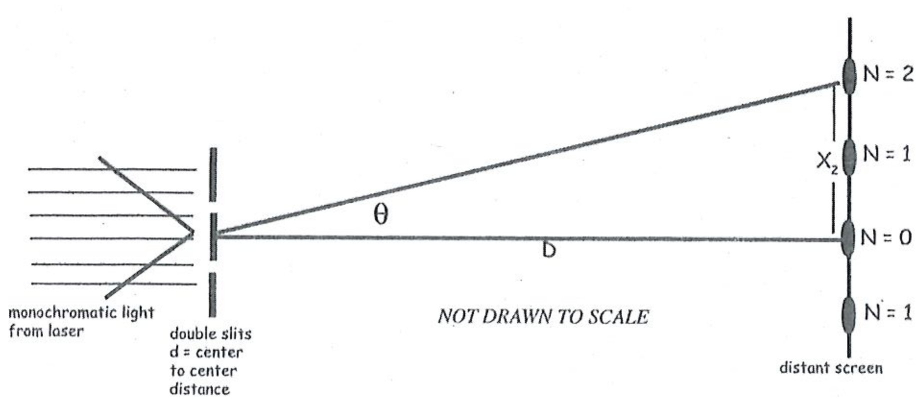
Discussion:

In 1801 Dr. Thomas Young (an English scientist) performed his famous double slit experiment which was proof that light was indeed some type of wave. Many eminent scientists, including Sir Isaac Newton, has insisted that light was really a stream of particles (corpuscles), not a wave motion. It turned out that both "camps" were partially correct. We now know that light is both an electromagnetic wave and it is "quantized" into packets of energy, linear momentum, and angular momentum called "photons."

As discussed in lecture, the maxima (bright spots) resulting from double slit interference can be found using the expression,

$$N\lambda = d\sin\theta_n \cong \frac{dx_n}{D}$$

where the various distances are shown in the figure below.



Procedure

Part 1: Calibrating the double slits (measuring d)

1. Set up the apparatus as shown on the previous page. The distance between the He-Ne laser and the double slits is not important but try to make the distance D between the slits and the screen as large as possible. If you use the lab wall as a screen, tape a piece of blank paper on the wall on which to mark your data points.

2. Using a sharp pencil (and being very careful not to reflect the laser light into your eyes!), mark the position of the center of the N = 0 order maxima (bright spots) and as many orders on each side as you can easily see. (Some of the orders will be "missing" due to single slit diffraction.) Carefully remove your paper screen and lay it on a flat surface for measurement. Don't forget to measure D, the distance from the slits to the screen.
   Alternative procedure: As the center of the maxima are hard to judge, you can consistently mark one edge (say the left side) of each "spot". The "shift" over to the edge of the maxima will cancel out when you take your measurements of X_N.

3. Use a mm ruler to measure the distances between the central bright fringe (N = 0) and each of the fringes that you marked on your paper target. It is easiest to measure from each bright fringe to the corresponding fringe on the opposite side of the pattern than to measure from the center of the pattern. Just remember to divide your values by two. Enter all of your values in the table below and complete the indicated calculations. If an order is completely "missing" just put an "x" in that space on your data table.

D = 2.80 meters $\lambda_{\text{red He-Ne}}$ = ~~632.8 nm~~ 633 nm

N	X_N (mm)	$d = N(D/X_N)\lambda$ (express in mm)
1	7	0.253
2	15	0.236
3	22	0.242
4	30	0.236
5	37	0.240
6	44	0.242
7	51	0.243
8	58	0.244
9	65	0.245
10	72	0.246

average d = 0.243 mm

3. Just to make sure things are going OK, let's compare your average value of d to the "nominal" value given by the manufacturer of the double slits. The manufacture's stated value is usually not very accurate but at least it will tell us if you are in the "ballpark". If the value of d is not printed on the mounting frame of the slits, ask your prof or lab tech to look up the value for you.

$d_{manufacturer}$ = 0.250 mm

$d_{your\ ave\ value}$ = 0.243 mm

% difference = 2.9%

4. If you only have a few % difference, continue on to the next section. If your % difference is larger, talk to your prof!

Part 2: Measuring an "unknown" laser wavelength. (Note: $\lambda_{green} = 543.5\,nm$)

1. **You are now about to become spectroscopists! Using your newly calibrated double slits, set up the apparatus as before but now use a different color laser (see the prof or lab tech). If you are moved to a different lab you will have to remeasure D. Fill in your data table as before but now calculate λ knowing d. Convert your results to nanometers (nm)**

D = 2.80 meters

N	X_N (mm)	$\lambda = dX_N/ND$ (express in nm)
1	6	520.71
2	12	520.71
3	18	520.71
4	25	542.41
5	31	538.07
6	x	x
7	44	545.51
8	50	542.41
9	56	540.0
10	62	538.07

average λ = 534.3 nm

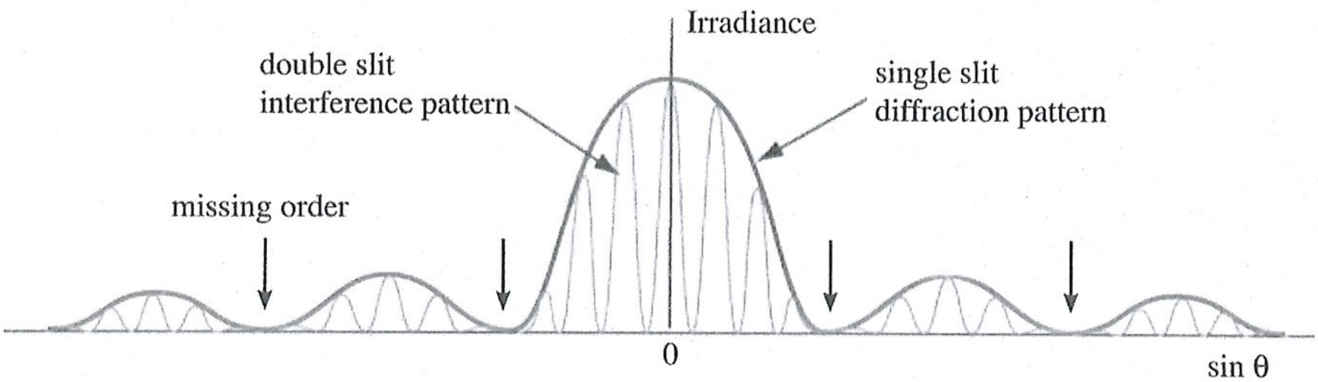
2. Your professor or lab tech will give you the accepted value of your unknown wavelength. To do this they may show you how to use a "wavemeter" to determine the true value. Enter the true value, your average value, and a % error in the spaces below.

$\lambda_{accepted}$ = 543.5 nm $\lambda_{your\ ave\ value}$ = 534.3 nm

% error = 1.7%

Part 3: Using the "missing orders."

In lecture you undoubtedly discussed the reason that some orders of the double slit interference pattern are "missing." Simply put, you are really seeing the superposition of two different patterns. The tighter pattern (with the higher "spatial frequency") is the double slit pattern that we have been using in this lab. But there is also a wider pattern with a lower spatial frequency that is cause by the diffraction of each individual slit. You can think of the single slit pattern as an amplitude modulation (or "envelope function") imposed on the double slit pattern ... similar to the way in which AM radio signals are produced. A typical case is shown in the figure below. (1)



By equating the two angles in the single slit diffraction equation for minimums and the double slit interference equation for maximums, it is trivial to show that the "missing order" numbers are given by:

$$N = d/a, \qquad N = 2d/a, \qquad N = 3d/a, \quad \text{etc.}$$

where d is the slit spacing (center-to-center) and a is the width of one individual slit. Of course, we cannot observe an infinite number of missing orders because the number of interference maxima is limited by the ratio of d/λ and, more importantly, by the dramatic decrease in the brightness of the patterns at large angles from the center.

(1) adapted from: http://web.mit.edu/viz/EM/visualizations/coursenotes/modules/guide14.pdf

1. Before disassembling your apparatus, estimate the missing order numbers for the first few cases on both the left and right hand sides of your pattern. For example, in the example shown on the previous page, the first missing order on each side is somewhere between N = 3 and N = 4. Fill in your estimates in the table below. Depending on the slit set that you used, these numbers may not necessarlly be whole numbers.

	left side	right side
N = d/a	6	6
N = 2d/a	12	12
N = 3d/a	18	17
N = 4d/a	23	22

d/a_{AVE} = 5.86

2. From the data in the table, compute an average value of d/a and round off appropriately (probably two significant figures). Enter that value in the space at the bottom of the table above. Using your experimental value of d (from Page 3), and your average value of d/a, compute the slit width a and enter it in the space below along with a percent difference between your value and the manufacturer's value that's marked on the slit set that you used.

$a_{manufacturer}$ = 0.040 mm

$a_{your\ ave\ value}$ = 0.041 mm

% difference = 3.6%

Error Propagation

$$\boldsymbol{d = \frac{ND\lambda}{X_N}}$$

Let N (10) and λ (633nm) be constant.
$D = 2.80m,\ \ \delta D = 0.01m,$
$X_N = 72mm,\ \ \delta X_N = 3mm$

$$\frac{\partial d}{\partial D} = \frac{N\lambda}{X_N}, \qquad \frac{\partial d}{\partial X_N} = \frac{-ND\lambda}{X_N^2}$$

Definition for relative error.

$$\frac{\delta d}{d} = \left\{\left[\frac{\delta D\left(\frac{\partial d}{\partial D}\right)}{d}\right]^2 + \left[\frac{\delta X_N\left(\frac{\partial d}{\partial X_N}\right)}{d}\right]^2\right\}^{\frac{1}{2}},$$

$$\frac{\delta d}{d} = \left\{\left[\frac{\delta D\frac{N\lambda}{X_N}}{\frac{ND\lambda}{X_N}}\right]^2 + \left[\frac{\delta X_N\frac{-ND\lambda}{X_N^2}}{\frac{ND\lambda}{X_N}}\right]^2\right\}^{\frac{1}{2}}$$

$$\frac{\delta d}{d} = \left\{\left[\frac{\delta D}{D}\right]^2 + \left[\frac{\delta X_N}{X_N}\right]^2\right\}^{\frac{1}{2}}$$

$$\frac{\delta d}{d} = \left\{\left[\frac{0.01m}{2.80m}\right]^2 + \left[\frac{3mm}{72mm}\right]^2\right\}^{\frac{1}{2}} = 0.0418 \rightarrow \mathbf{4.2\%}$$

$$\boldsymbol{\lambda = \frac{dX_n}{ND}}$$

Let N (10) be constant.
$D = 2.80m,\ \ \delta D = 0.01m,$
$X_N = 62mm,\ \ \delta X_N = 3mm$
$d = 0.246mm,\ \ \delta X_N = 4.2\%$

$$\frac{\partial \lambda}{\partial d} = \frac{X_N}{ND}, \qquad \frac{\partial \lambda}{\partial D} = -\frac{dX_N}{ND^2}, \qquad \frac{\partial \lambda}{\partial X_N} = \frac{d}{ND}$$

Definition for relative error.

$$\frac{\delta\lambda}{\lambda} = \left\{\left[\frac{\delta D\left(\frac{\partial\lambda}{\partial D}\right)}{\lambda}\right]^2 + \left[\frac{\delta X_N\left(\frac{\partial\lambda}{\partial X_N}\right)}{\lambda}\right]^2 + \left[\frac{\delta d\left(\frac{\partial\lambda}{\partial d}\right)}{\lambda}\right]^2\right\}^{\frac{1}{2}}$$

$$\frac{\delta\lambda}{\lambda} = \left\{\left[\frac{\delta D\frac{N\lambda}{X_N}}{\frac{dX_n}{ND}}\right]^2 + \left[\frac{\delta X_N\frac{-ND\lambda}{X_N^2}}{\frac{dX_n}{ND}}\right]^2 + \left[\frac{\delta d\frac{X_N}{ND}}{\frac{dX_n}{ND}}\right]^2\right\}^{\frac{1}{2}}$$

$$\frac{\delta\lambda}{\lambda} = \left\{\left[\frac{\delta D}{D}\right]^2 + \left[\frac{\delta X_N}{X_N}\right]^2 + \left[\frac{\delta d}{d}\right]^2\right\}^{\frac{1}{2}}$$

$$\frac{\delta\lambda}{\lambda} = \left\{\left[\frac{0.01m}{2.80m}\right]^2 + \left[\frac{3mm}{62mm}\right]^2 + [4.2\%]^2\right\}^{\frac{1}{2}} = 0.0642 \rightarrow \mathbf{6.5\%}$$

Summary/Discussion

In the box below, list what you consider to be the major potential sources of error in each part of this experiment. Suggest any practical changes to this lab that you think could potentially improve the accuracy, keeping in mind that Moorpark College does not have an infinite budget for laboratory equipment! Also discuss any applications that you can imagine for the techniques you learned. Why would anyone want to be a spectroscopist? Attach extra pages if necessary!

The experiments yielded great results consistent with the theoretical values. The distance between the slits was found to be 0.243 mm with a 4.2% uncertainty. The percent difference from the theoretical value of 0.250 mm was 2.9% which is within the margin of error. Using the results from experiment 1, the wave length of an "unknown" laser was found to be 534.3 nm with a 6.5% uncertainty. The percent difference from the theoretical value of 543.5 nm was 1.7% which is within the margin of error. Finally, the inner-width of the slits was found to be 0.041 mm which has a 3.6% difference from the theoretical value 0.040 mm.

Exp.	Theoretical	Experimental	% Uncertainty	% Difference	Within Error Marg.
1	0.250 mm	0.243 mm	4.2%	2.9%	YES
2	543.5 nm	534.3 nm	6.5%	1.7%	YES
3	0.040 mm	0.041 mm	X	3.6%	X

Since small angle approximation is used, the major sources of error include the distance uncertainty between the slits and screen as well as the distance uncertainty between the central maxima and other fringes. The experiment could be improved by increasing the distance between the slits and the screen, thus in-turn increasing the distance between fringes. The greater distances would consequently lower the uncertainty, decreasing the absolute error to value ratio. To further improve the experiment, a type of photographic film could be used as the screen to capture the double slit interference and single slit diffraction patterns. Once captured, the distances between the central maxima and fringes could be more easily and accurately measured.

Spectroscopist – The study of spectra, especially experimental observation of optical spectra or mass spectra, to determine the properties of their source.

Spectroscopy is used in physical and analytical chemistry because atoms and molecules have unique spectra. As a result, these spectra can be used to detect, identify and quantify information about the atoms and molecules. Spectroscopy is also used in astronomy and remote sensing on Earth. - Wikipedia