Wave Properties of Light

Notice! You will be using laser light. Never look directly into the laser or at the reflected light!

Part One: **The Single Slit**. You will be using real equipment in this laboratory activity but the links for each section of this lab may help you better understand what is going on and also help you answer some of the questions. Some questions, especially those that ask about wavelength changes, can be answered most easily with the virtual environment.

http://surendranath.tripod.com/Applets/Optics/Slits/SingleSlit/SS.html

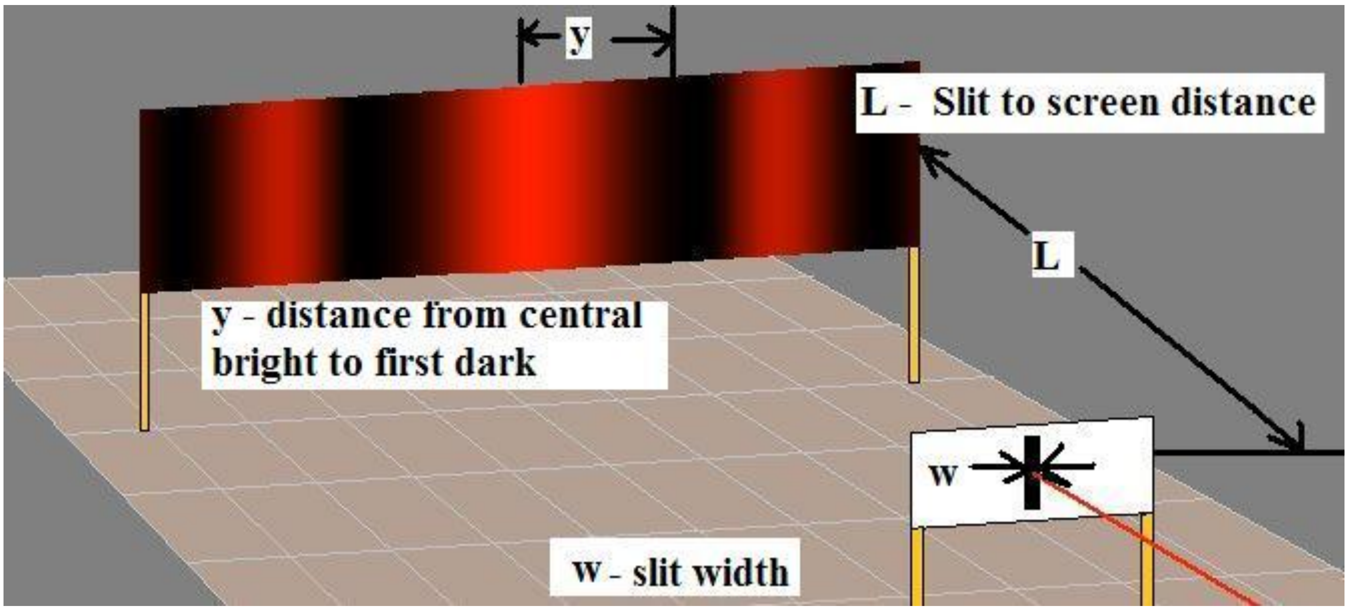

Figure 1. The single slit pattern.

Equipment: Laser, single slits of varying width, slit holder, and meter stick.

Objective: To determine the wavelength of light by observing the diffraction pattern produced by a single slit and to investigate how the single slit diffraction pattern changes with variations in slit width.

If light is allowed to pass through a narrow slit of width **w**, a pattern of light and dark areas appear due to the diffraction of the light as it passes through the slit. Diffraction is actually an interference phenomenon where light coming from different parts of the slit opening interfere with each other.

The wavelength can be calculated using the interference relationship:

$$\text{Wavelength} = \frac{w\,y}{L}$$	**w** is the slit width in mm **y** is the distance on the screen from the center bright pattern to the center of the first dark region (in cm). L is the distance to the screen (in cm).

Method:

Turn on the laser and align it so the light falls on a single slit. You should place the slit about 10 cm in front of the laser, and a white screen (a piece of paper works pretty well) should be about 2 meters away. Try several slits and distances until you get a pattern that you are happy with. It should look something like Figure 1 except the bright regions will not be very tall since the laser beam is not very tall and the distance y from the central bright region to the first dark area will likely be less than a centimeter (cm). Yours also may have more bright and dark areas.

Carefully make the measurements required to calculate the wavelength of the laser light and record them clearly here. (The width of the slit is given on the slit mask.)

w=__________________ L=____________________ y=_____________________________

(make sure to include units for each measurement, measure both L and y in cm so these units cancel each other)

Calculate the wavelength of the laser light and compare your value to the accepted value for our laser of 650 nm=0.650 μm=0.000650 mm.

Example: if L=220 cm, y= 0.8 cm, and w=.08 mm then

$$\text{wavelength} = \frac{w\ y}{L} = \frac{(0.8cm)(0.08mm)}{220cm} = 0.00029mm = 0.29\mu m$$

	A	B	C
1	wavelength=	=B4*B5/B3*1000	
2			
3	L=	220	cm
4	y=	0.8	cm
5	a=	0.08	mm
6			

	A	B	C	D
1	wavelength=	0.29	micrometer	
2				
3	L=	220	cm	
4	y=	0.8	cm	
5	a=	0.08	mm	
6				

You may want to use excel as a calculator (Optional). The worksheet at left above shows the formula and values that you would enter into an empty worksheet and the worksheet at right has just the values. The advantage of this is that we will use this same type of formula later in our lab and it ensures that errors can be easily corrected.

Show your calculations below.

$$\text{Wavelength} = \frac{\_\_\_\_\_\_ * \_\_\_\_\_\_}{\_\_\_\_\_\_\_\_} = \_\_\_\_\_\_\_\_ mm = \_\_\_\_\_\_\_\_ \mu m$$

On a clean piece of paper carefully **make sketches** of the diffraction patterns obtained by using three different slit widths. Make sure that you label your sketches for future reference. To get a fast and accurate sketch you may want to use your sketch sheet as the screen. Check with your instructor to make sure everything is set correctly and you are observing the diffraction pattern.

Use your lab equipment or the online simulation to answer the following questions.

Questions:

1. As the slit width increased the
- a) spacing between the central maximum to first minimum (y) increased
- b) spacing between the central maximum to first minimum (y) decreased
- c) spacing between maxima stayed the same

2. As the wavelength shortens the
- a) spacing between the central maximum to first minimum (y) increases
- b) spacing between the central maximum to first minimum (y) decreases
- c) spacing between maxima stayed the same

3. As the slit to screen distance L gets bigger the
- a) spacing between the central maximum to first minimum (y) increases
- b) spacing between the central maximum to first minimum (y) decreases
- c) spacing between maxima stayed the same

Part Two: The Double Slit

http://surendranath.tripod.com/Applets/Optics/Slits/DoubleSlitID/DSID.html

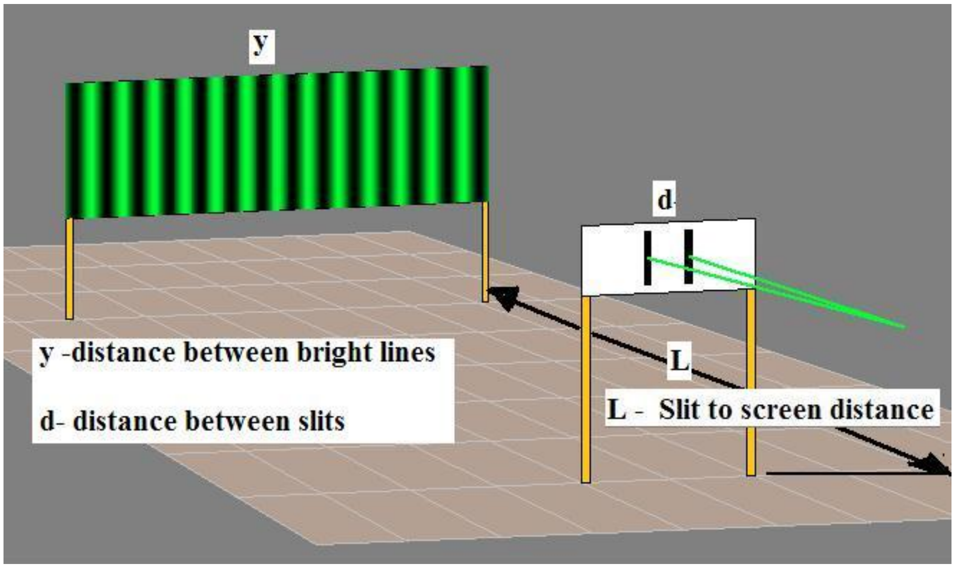

Figure 2. The double slit pattern

<u>Equipment:</u> Laser, double slits of varying widths and slit separation, slit holder, and meter stick.

<u>Objective</u>: To determine the wavelength of light by observing the interference pattern produced by a double slit and to investigate how the double slit pattern changes when the separation between the slits changes or the width of the individual slits changes .

If light is allowed to pass through a double slit, the light from one slit interferes with the light from the other slit producing an interference pattern of alternate bright and dark lines. These lines correspond to where the light interferes either constructively or destructively. (See your text for details concerning the theory). The wavelength of the light can be determined using:

$(m)\ \text{wavelength} = \frac{d\,y}{L}$	**d** is the distance between the slits (given on slit mask) **y** is the distance between bright lines and **L** is the distance between slits and screen. **m** is an integer and is called the order of the interference.

The central bright spot is for m=0, the next bright spot on either side of the central is m=1, and so on. If when you do your measurements, you measure the distance from the center (line 0) to the 5^{th} bright line from center line then m=5. The symbol λ is sometimes used here as a shorthand for wavelength

When m=1 the difference in path from one slit to the screen is one wavelength longer (or shorter) than the path from the other slit to the screen (path difference of 1λ), when m=2 the path difference is 2λ, etc. (The central maximum is also called the zeroth order, m=0, interference maximum.)

The wavelength can be calculated using:

$$\text{wavelength} = \frac{d\,y}{m\,L}$$

Note: For the single slit **y** is measured from the central **maximum** to the first **minimum, but** for the double slit **y** is measured from **maximum** to **maximum**. You will be asked to do this calculation later.

<u>Method</u>:

Turn on the laser and align it so that the light falls on a double slit (the slit separation is given on the slits). Place the slits 10-20 cm in front of the laser and place the white screen about two meters away. Try several slit separations and widths until you get one that you are happy with. **Notice that since each separate slit is also a single slit the single slit pattern is superimposed on the double slit pattern!** The double slit pattern looks like a bunch of small beads of light within the single slit pattern.

Carefully make the measurements required to calculate the wavelength of the laser light and record them clearly below. **Note**: To get the best accuracy when measuring **y** with a meter stick you want **y** to be as large as possible. You can increase **y** by increasing the distance L from the slits to the screen, decreasing the slit separation d, and by using the largest value of m (# of beads) possible.

Compute the wavelength of the laser light. Show your calculations here.

d=________________ y=____________________ L=_______________________ m=________________

(note: if y is the distance between 10 bright spots then m=10)

$$\text{wavelength}=\frac{d\,y}{m\,L}=\frac{(\_\_\_\_\_\_)(\_\_\_\_\_\_)}{(\_\_)(\_\_\_\_\_\_)}=\_\_\_\_\_\_\_\_\_\_\_\,mm=\_\_\_\_\_\_\_\_\_\_\_\,\mu m$$

	A	B	C
1	wavelength=	=(B4*B5)/(B6*B3)*1000	
2			
3	L=	220	cm
4	y=	2	cm
5	d=	0.4	mm
6	m=	10	

	A	B	C
1	wavelength=	0.36	micrometer
2			
3	L=	220	cm
4	y=	2	cm
5	d=	0.4	mm
6	m=	10	

An example of an optional excel worksheet set for this calculation.

Carefully **make sketches** of the interference patterns obtained by using two different slit spacings, and for each of these spacings use two different slit widths (four sketches total). Make sure that you label your sketches for future reference.

Use your lab equipment or the online Double slit simulation to answer the following questions.

Question: (circle the correct answer**(s)** all that apply**)**

4. As the slit separation increased the

a) spacing between maxima increased
b) spacing between maxima decreased
c) spacing between maxima stayed the same

d) the number of maxima in the central region defined by the single slit pattern (each slit is itself a single slit) increased.
e) the number of maxima in the central region of the single slit pattern decreased.

5. As the width of the individual slits increased the

a) spacing between maxima increased
b) spacing between maxima decreased
c) spacing between maxima stayed the same

d) the number of maxima in the central region defined by the single slit pattern (each slit is itself a single slit) increased.
e) the number of maxima in the central region of the single slit pattern decreased.

Part Three: Multiple Slits and diffraction gratings

http://physics.neiu.edu/vpl/optics/diffraction.html

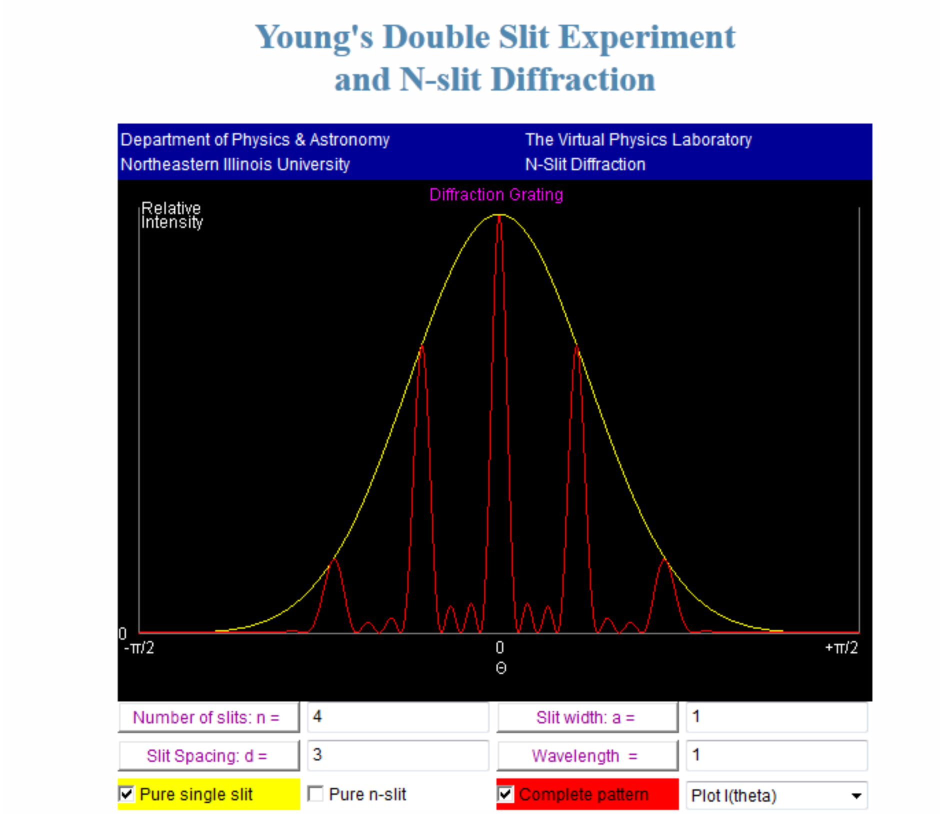

Figure 3. Multiple slits with 4 slits creating the interference pattern on the screen. Notice there are 5 total primary maxima within the yellow single slit envelope. There are 2 secondary maxima and three dark spots between adjacent pairs of primary maxima.

Got to the URL listed above Figure three and reproduce the results shown in Figure 3.

Which colored line corresponds to the single slit pattern? **Red or Yellow**

Which colored line corresponds to the double slit pattern? **Red or Yellow**

For best results when using this simulation environment to answer questions below set slit spacing **d**=3, slit width **a**=1, and **wavelength**=1.

Equipment: Laser, Multiple slit plate with 2,3,4, and 5 slits of the same width and spacing, diffraction grating, slit holder, and meter stick.

Objective: To qualitatively investigate how the interference pattern changes when light from multiple slits interfere and to extend this idea to a diffraction grating.

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<u>Method:</u> Passing the laser beam through the two slits that are on the multiple slit template, create a clear interference pattern on a screen that is about two meters from the slits. Carefully observe the pattern. Repeat this procedure for three, four, and five slits. **(Your observations should notice the primary maxima and also the weak secondary maxima that are between the primary maxima)** For the questions below you may either use your observations or the multiple slit simulation (link above Figure 3).

Question: Does the separation between the centers of the primary maxima change as the number of slits increase?(If so, how?)

Question: Does the width of the primary maxima (distance between minima on each side of the maxima) change as the number of slits increase? (If so, how?)

Question: How many weak secondary maxima do you observe between the primary maxima when you are using five slits? four slits? three slits? two slits?

Question: How many minima (local dark spots) do you observe between the primary maxima when you are using five slits? four slits? three slits? two slits?

Diffraction Grating: A diffraction grating has many slits that are very close together. If there are **N** lines per centimeter then the slit spacing **d** in cm is **1/N**. The interference pattern obeys the same mathematical relation as that for a double slit, i.e.

$$(m)\ \text{wavelength} = \frac{d\ y}{L}$$

There are two advantages of using a diffraction grating to determine the wavelength of light. First, since there are many slits creating the interference pattern, the principal maxima are very sharp (narrow) and well defined. Second, since the slit spacing is usually very small for a diffraction grating, the angular separation between the central maximum and the first order maximum is fairly large and hence it is easy to measure accurately.

Shine the laser through the diffraction grating and describe the pattern obtained on the screen. The spacing between grating line d can be calculated using d=1/N where N is the number of lines per mm given on the slit mask.

Record values needed to calculate the wavelength of light using m=1 (distance from central bright to first bright on either side, and then calculate it below. Here since m=1 y is the distance from the central bright spot to the next bright spot to the right (or left).

N=__________________

d=1/N

d=_________________ y=_____________________ L=________________________

(for the best estimates measure L from the diffraction grating to the first dot to the left or right of the central bright dot).

$$\text{Wavelength} = \frac{d \times y}{\sqrt{L^2 + y^2}} \frac{\_\_\_\_\_\_\_\_\_ \times \_\_\_\_\_\_\_\_\_}{\_\_\_\_\_\_\_\_\_\_\_\_} = \_\_\_\_\_\_\_\_\_ \, mm = \_\_\_\_\_\_\_\_\_\_\_\_ \, \mu m$$

Again Excel may be the best way to go here. The top image below shows the formulas and the bottom shows the cells with calculated numbers.

B	C	D	E	F
Wavelength	=C4*C6/SQRT(C5^2+C6^2)	mm	=C1*1000	micro-meter
N	500	lines/mm		
d	=1/C3	mm		
L	220	cm		
y	65	cm		

B	C	D	E	F	G
Wavelength	0.000567	mm	0.57	micro-meter	
N	500	lines/mm			
d	0.002	mm			
L	220	cm			
y	65	cm			