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203-NYC-05: Waves, Optics & Modern Physics

Interference and Diffraction

OBJECTIVE: Investigate the parameters that affect interference and diffraction patterns.

ONE SLIT DIFFRACTION

Objective: Observe the effect of slit width on diffraction pattern and measure **width** "**a**" of a single slit.
Use a mechanical slit which thickness can be changed. Start by decreasing the opening of the slit and record what you observe on the screen. Explain what you see by referring to what you've learned in class. Then keep a fixed slit width "a" that produces a clear pattern on screen and measure the distance between minima of the same order (+/- s). Use expression 3,4,5 to find the slit's width. Figure 1 presents the experimental scheme.

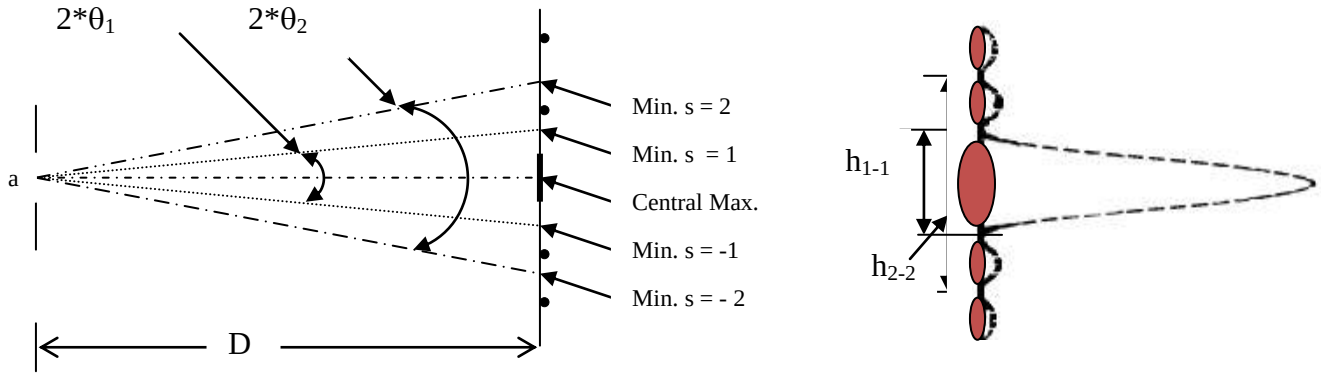

Fig 1

Minima location on screen is defined by expression $a\sin\theta_s = s*\lambda$ s = +/-1, +/-2, +/-3,..

For s = 1 $a\sin\theta_1 = \lambda \rightarrow \sin\theta_1 = \frac{\lambda}{a}$. For **small angles** $\sin\theta_1 \cong \theta_1$ and $\theta_1 \cong \frac{\lambda}{a}$ (1)

For s = -1 $\theta'_1 \cong -\frac{\lambda}{a}$ and the ***angle between the two first order minima*** is $2\theta_1 \cong \frac{2\lambda}{a}$

As $\theta_1 \cong tan\theta_1 = \frac{(h_{11}/2)}{D}$ then $2\theta_1 \cong \frac{h_{11}}{D}$ (2). So, $\frac{h_{1-1}}{D} \cong \frac{2\lambda}{a}$ and $a \cong 2\lambda\frac{D}{h_{1-1}}$ (3)

Similarly, from the second order we get $a \cong 2*(2\lambda\frac{D}{h_{2-2}})$ (4)

and for third order $a \cong 3*(2\lambda\frac{D}{h_{3-3}})$ (5)

In this experiment, one measures the distance between the **minima** of the same order (1-1, 2-2, 3-3..) and applies expressions(3, 4, 5) to find **a** – value, i.e. : $a = a_{best} \pm \Delta a$ and $\varepsilon_a\% = (\Delta a / a_{best})*100\%$.

Note_1: Starting from a given high order (**s-value**), you ***may find*** a very different "**a**" value. This means that the small angle approximation is not valid for this order. Use the proper trigonometry $\sin\theta_s = s\frac{\lambda}{a} = \frac{(h_{s-s} \setminus 2)}{\sqrt{D^2 + (h_{s-s} \setminus 2)^2}}$ (6) and then compare the result with previously found values of "**a**".

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TWO SLITS' DIFFRACTION- INTERFERENCE PATTERN

***Objective*:** Find the slits' width "**a**" and the distance between two slits "**d**".

a) Start by measuring the width "a" of a single slit in a set of two. For this, the laser beam must *hit only on one of the two slits set (fig.2.a)*. Use the "wider" set for this experiment. Identify the location of two first (+1/-1) and two second (+2/-2) order ***diffraction minima*** and measure the distance $\mathbf{h_{1\text{-}1}}$, $\mathbf{h_{2\text{-}2}}$ between them. Next, use the expressions (3,4) to find the single slit width thickness "***a***". Repeat measurement for two distances $D^{(1)}$, $D^{(2)}$.

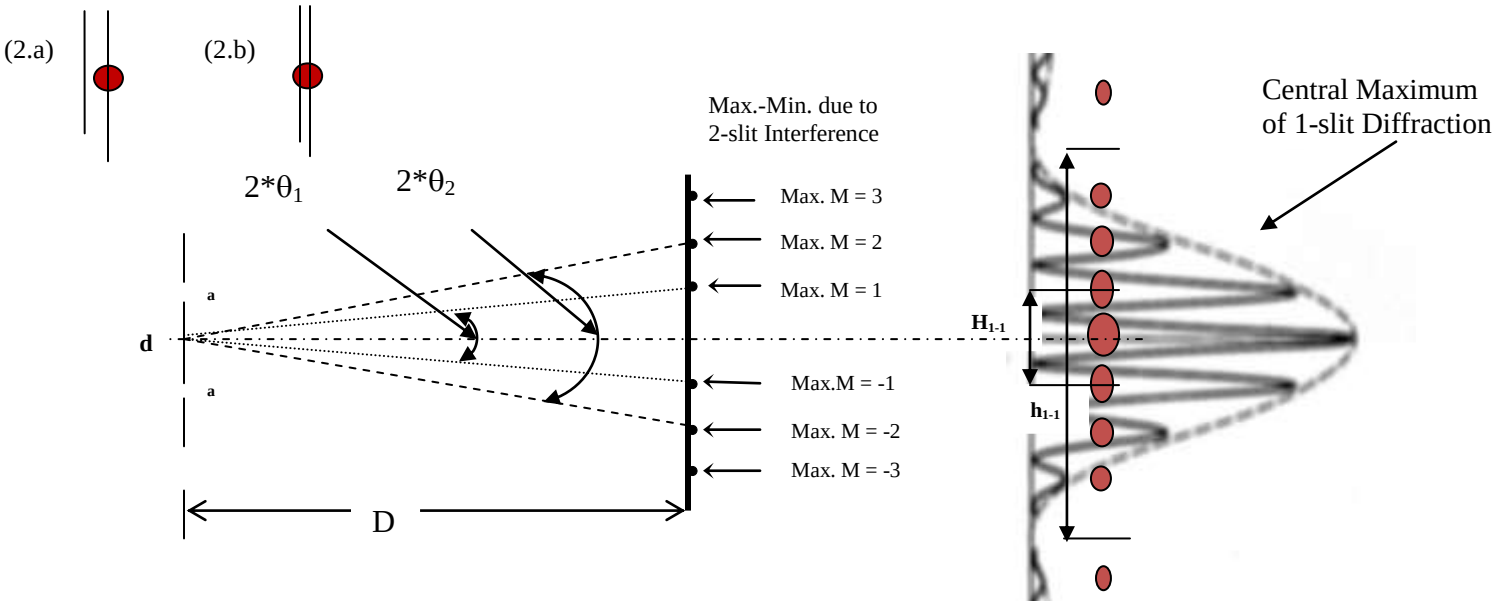

Fig 2

b) To measure the distance between the two slits, the laser beam must *cover both slits (fig.2.b)*. Use the second narrow sets for this experiment. Once you see a clear pattern on the screen, start by identifying the location of central maximum of interference (M=0) and the locations of closest missing orders ±M (*dark instead of expected bright*). Those max of interference are not seen clearly or not seen at all because at their place fall the two first order ***minima of single slit diffraction*** (s = +1/-1). Write this ***order*** $\mathbf{M_{missing}}$ in recorded data.
Next, measure the ***distance between the interference maxima of the same order*** M (ex. $H_{1\text{-}1,\ 2\text{-}2\ ,..}$**), i.e. bright fringes located** ***inside or outside the central maximum of single slit diffraction*** region. Use these data to calculate the distance between the two slits "**d**".

The formula for the directions of interference maxima is $$d \sin\theta = M_d * \lambda \qquad (7)$$

Similar calculations as in first experiment show that one may calculate the two slits **distance** "**d**" by distance $H_{M\text{-}M}$ between any two ***interference maxima*** of the same order (M =1,2,3..) and by applying the expressions;

$$d \cong 2\lambda \frac{D}{H_{1-1}} \text{ for M =1} \quad (8) \qquad d \cong 2*(2\lambda \frac{D}{H_{2-2}}) \text{ for M = 2} \quad (9) \qquad d \cong 3*(2\lambda \frac{D}{H_{3-3}}) \text{ for M = 3} \quad (10)$$

-Use **d-values"** for different order maxima (order 1,2,3) to get $d = d_{best} \pm \Delta d$ and $\varepsilon_d\% = (\Delta d / d_{best})*100\%$.
-Calculate the width " a" of each slit in this set by using the relation $\mathbf{M_{missing} = d/a}$ (11)

Note: If the found values for "**d"** are very different, disregard the small angle approximation and use the complete expression $$\sin\theta_M = M\frac{\lambda}{d} = \frac{(H_{M-M} \setminus 2)}{\sqrt{D^2 + (H_{M-M} \setminus 2)^2}} \qquad (12)$$

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GRATINGS

***Objective*:** Find the number of grooves per millimeter.

In this experiment you have to start by identifying the central maximum (M = 0) and measure the distance between **interference maxima** of the same order (+/-1, 2, 3…). Then calculate the **slits' distance "d**" in mm by using formulas (8,9,10). At the end, calculate the grooves' density by expression **$N = 1/d$ mm^{-1}**. (13)

Notes: - The gratings maxima are very fine and the low orders have almost the same intensity.
- Due to very small **d-**values, the **angles** of different order maxima **increase** quickly and you will need to use formula (12) for the right calculations.

PROCEDURE: Each group will be given a Helium-neon laser (**λ = 632.8 nm**) along with a 1-slit, 2 slits, and grating set. You will send the laser beam perpendicularly on the plane containing the 1-slit, 2-slits or the grating. The interference&diffraction patterns will be projected onto a screen (a sheet of paper where you will sketch the patterns and make the proper distance measurements). You will refer to the **middle of spots** (bright or dark) to *measure distances* between same order maxima $H_{M\text{-}M}$ and same order minima $h_{s\text{-}s}$.
Working with fringes close to central maximum offers the simplicity of small angle calculations but, when angles increase, you must verify if this approximation holds on. The ultimate goal is to determine the following:

- **What is the slit width at 1 slit experiment (known in our diagrams as "a")?**
- **What is the slit spacing at 2 slits experiment (known in our diagrams as "d")?**
- **How many lines/mm are contained in the grating experiment (known as "N")?**

Note_2

For exp 1 and exp 2:

- The screen should be placed at least 1.5m from the plan containing the slits.
- Before recording data, line up the equipment until the fringes are sharply defined on the screen.
- Repeat each measurement of the same (diffraction/interference) order, for two different screen distances ($D^{(1)}$, $D^{(2)}$).
- Complete the three tables with data (for single slit, two slits and the grating). You will calculate the "**a**" "**d**" and "***N*** " parameters and the respective uncertainties by using the data in the tables.
- Before continuing with next experiment, verify that your data produce results that make sense.

*For exp 3: No need for big distances because the **angles are not small**. So, **verify carefully** whether small angle approximation holds before writing the result in report.*

ANALYSIS & CONCLUSIONS:

Present experimental results, calculations and error calculations in one section for each experiment. At the end, you have to represent them in order with additional comments about the limits of small angle approximation, the possible effect of using higher angles (high M-orders) upon the uncertainties. Comments about the following questions might help for this section.

1) What is the measured width **"a" of the single** slit**?**

What happens on diffraction pattern when you increase /decrease this width?

What is the distance between the consecutive minima on the screen? Is it constant or not?

2) What is the spacing "**d**" between the two slits?

What should happen on diffraction pattern if this parameter is increased /decreased?

What is the distance between the successive maxima on the screen? Is it constant or not?

3) How many lines per millimeter "**N**" are contained in the grating?

What is the theoretical M_{max} for this slit?

Does this fit to the recorded number of bright spots on the screen?

Do you see a change of brightness for maxima of different orders?

What should happen if this number increases?

Experiment No 1 (**One slit with variable width**)

Keep **fixed** the **slit's width** during measurements.

Note: The D-values given in the table are used to give an idea on this distance but you may use other values. Take D from 1m to 2.5m (try to use the largest available distance for D) in Exp.#1 and Exp#2.

Table No1

Diffraction Order	$D^{(1)}$ = 1.5m	a (mm)	$D^{(2)}$ = 2.5m	a (mm)
m = 1	h_{1-1}	a_1=	h_{1-1}	a_1=
m = 2	h_{2-2}	a_2=	h_{2-2}	a_2=
m = 3	h_{3-3}	a_3=	h_{3-3}	a_3=

Experiment No 2 (Two slits with fixed width and fixed distance)

Part (a) Laser on a single slit from a set of two.

Table No2.a (1 slit diffraction)

Diffraction Order	$D^{(1)}$ = 1.5m	a (mm)	$D^{(2)}$ = 2.5m	a (mm)
m = 1	h_{1-1}	a_1=	h_{1-1}	a_1=
m = 2	h_{2-2}	a_2=	h_{2-2}	a_2=

Part (b) Laser on the two slits of a set of two.

Interference order missing $M_{missing}$=

Table No2.b (2 slits interference)

Interference Order	$D^{(1)}$ = 2.5m	d(mm)	$D^{(2)}$ = 3m	d(mm)
M = 1	H_{1-1}		H_{1-1}	
M = 2	H_{2-2}		H_{2-2}	
M = 3	H_{3-3}		H_{3-3}	
M = 4	H_{4-4}		H_{4-4}	

Experiment No 3 (Grating)

Table No3 Number of bright spots seen on the screen = ...

Interf. Order	$D^{(1)}$ = 0.2m	d (mm)	N (mm^{-1})	$D^{(2)}$ = 0.3m	d (mm)	N (mm^{-1})
M = 1	H_{1-1}	d_1=		H_{1-1}	d_1=	
M = 2	H_{2-2}	d_2=		H_{2-2}	d_2=	
M = 3	H_{3-3}	d_3=		H_{3-3}	d_3=	

Note: Take D from 0.15 to 0.4m.