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Fresnel and Fraunhofer Diffraction: Development of an Advanced Laboratory Experiment

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Senior Project

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Introduction

The purpose of this lab is to help the student become more familiar with, or get a better feel for what is actually occurring, when observing the effects of double slit diffraction patterns. In most sophomore labs dealing with double slit diffraction, the student simply determines the diffraction angle, and slit spacing, from marking the positions of the maxima on the screen. No attempt is made to measure the relative intensity of the interference pattern, and see how the experimental data compare with the theory of interference and diffraction. In an attempt to further clarify this phenomena, we will attempt to measure the relative intensities of various double slit diffraction set ups, and compare the actual results with the corresponding theoretical values. It may prove very helpful for the student to review chapters 40 and 41, of Halliday and Resnicks' Fundamentals of Physics, prior to commencement of this exercise.

Procedures

1. Before starting remember to always use proper safety methods when using a laser. Never look directly into the laser beam.
2. Calibrate the position adjustment device shown in Fig. 1. Count the number of turns it takes to cover a given distance and calculate how many millimeters the device travels per turn.
3. Attach the stabilizer beam to one end of the optical bench. Place the position adjustment device on top of the stabilizer beam. Pick two of the holes in the middle of the beam to begin with. Also level out the optical bench with the level adjustments shown in Fig. 2.
4. Turn the photometer on, cover the photosensor and adjust the zero. Turn it off. Take the front cover off the photosensor, and place it in position as seen in Fig. 2, by using the set screw. Place the aperture in position in the same manner.
5. Place your slits as shown in Fig. 2. The distance between the slits and the aperture should be approximately one meter. The slits settings shown in Table I all work well in this experiment. If time permits, you may wish to try them all.
6. Place the laser behind the slits as shown in Fig. 2. Leave the photometer off. Turn on the laser and make the proper height adjustments on the laser, and

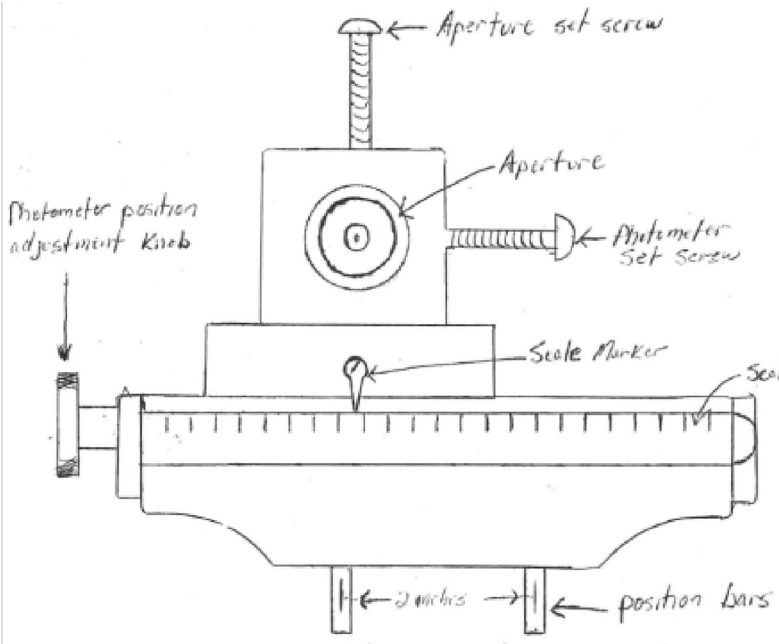


Fig. 1. Position adjustment device.

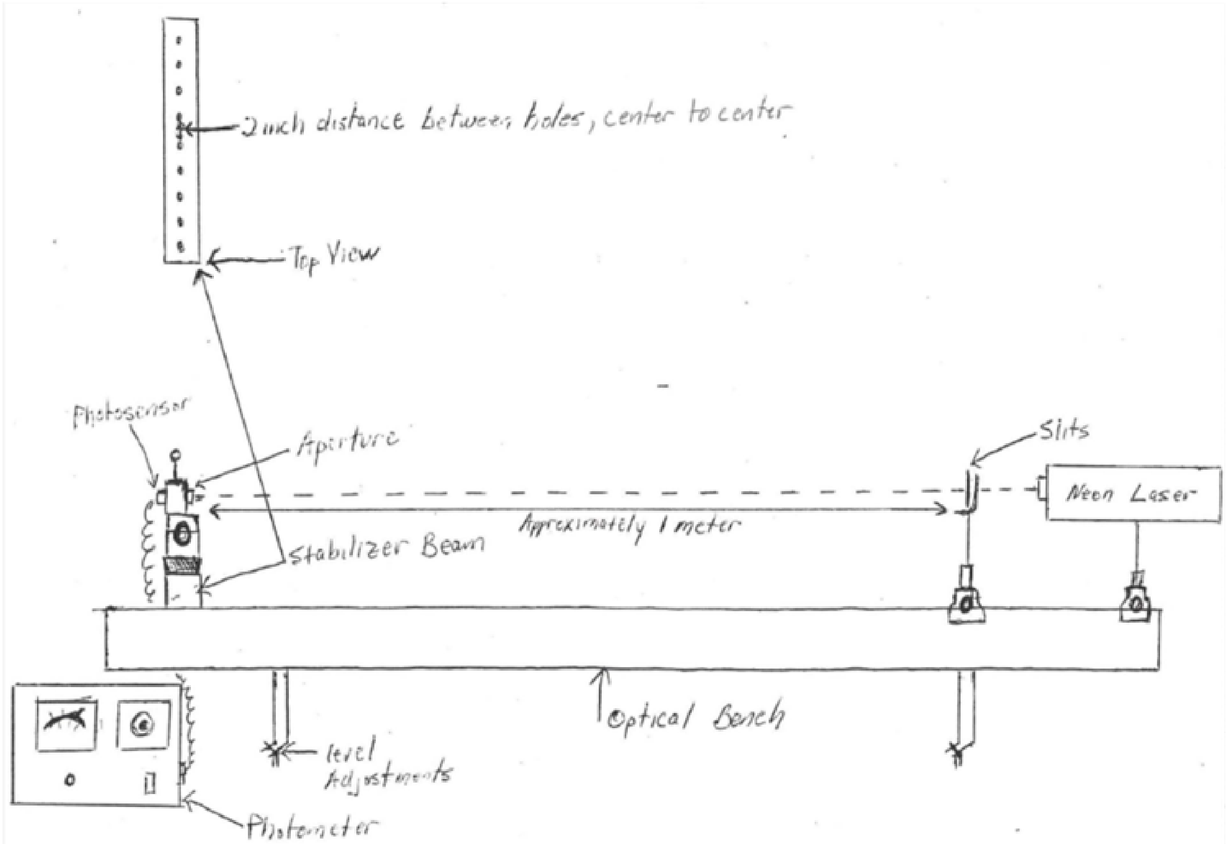


Fig. 2. Experimental setup.

the slits, so that the interference pattern is level, and hits in the center of the aperture. Make sure that you have a good interference pattern by holding up a piece of paper in front of the aperture and checking the pattern. The beam should pass fully through both slits. The pattern must be level, so that when the aperture moves along its fixed path it will travel directly through the center of the pattern, and not above or below it.

7. Record the position of the photosensor and the slits. You will need the distance between them for calculations. Also record the width of the slits being used, and the distance between them.
8. Adjust the photometer to the highest setting then turn it on. You will have to change the setting as you go through the pattern to get the proper readings. Take a reading about every quarter of a millimeter. Record the intensity at every reading. Take readings for as many of the maxima as the meter can meaningfully detect. You may have to move the position adjustment device to a new set of holes on the stabilizer beam to complete the reading. Remember the distance, from center to center, of two successive holes is two inches.

Table I. Suggested slit settings.

Slit Settings	**Width (mm)**	**Spacing (mm)**
1	0.04	0.500
2	0.08	0.250
. 3	. 0.08	. 0.500

Data

1. Take the intensity readings you have gathered, and using Mathcad make plots of the relative intensity of the interference pattern. Plot the intensity versus the position of the readings. Refer to Fig. 4.
2. Now using the Mathcad routine provided, enter in the appropriate slit width *a*, distance between the slits *d*, and the distance between the slits and the photosensor *D*, all in millimeters. See Fig. 3. The plot that follows will be the theoretical plot of the relative intensity.

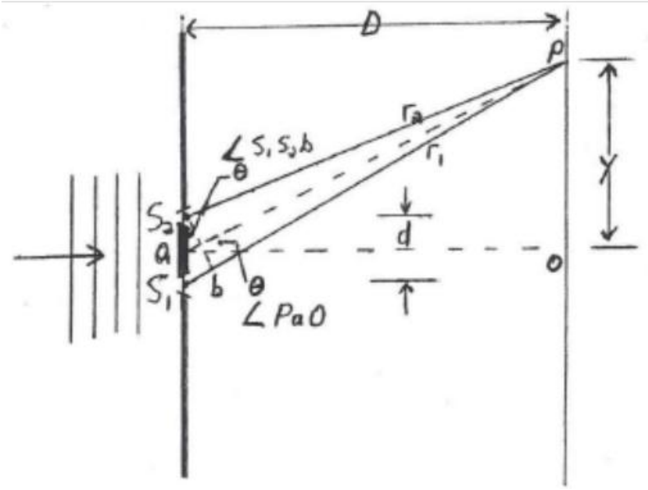


Fig. 3. Geometry of diffraction pattern.

Evaluation

1. Compare the plots. How do the relative intensities of the actual experiments compare with the theoretical ones? Is the shape of the pattern close? Do the number of fringes in the envelopes match up? How would you explain the discrepancies, if any?

Questions

1. Figure the linear distance between maxima as encountered by the photosensor for particular combinations of *D* and *d*. Remember if Θ is small enough $\sin\Theta \approx \tan\Theta$. We know $\tan\Theta = y/D$ and $d \cdot \sin\Theta = m \cdot \lambda$. Therefore $y = m \cdot \lambda \cdot D/d$ with $m = 0,1,2 \ldots$ for positions of adjacent maxima. Use this to calculate the separation distance Δy between maxima. If Θ is small the fringe spacing will be independent of *m*, or in other words simply evenly spaced.
2. What does it mean to say that two light beams are coherent? Why is it necessary that the beams emerging from S_1 and S_2 in our experiment be coherent? How did Thomas Young assure himself that the beams emerging from S_1 and S_2 in his experiment were coherent? What do we do to assure ourselves that the beams emerging from S_1 and S_2 in our experiment are coherent?
3. What is the difference between Frensel and Fraunhofer diffraction? What kind of diffraction are we dealing with in this experiment? How can both of these situations be looked at in experiments?
4. Explain in words and show graphically the interference effects demonstrated in this experiment. What is it that governs the intensity of the interference pattern that shows up on the screen, or is measured by the photometer? How does this explain why successive maxima decrease so rapidly in intensity?

Fig. 4. Mathcad analysis sheet.

The Student Edition of MathCAD 2.0 For Educational Use Only

$M := \mathrm{READPRN}\left[\mathrm{DSFRES}_{\mathrm{DAT}}\right]$ ORIGIN ≡ 1

$In := M^{\langle 2 \rangle}$ $XX := M^{\langle 1 \rangle}$ MM := length(In) $m := 1 \,..\, MM$

$I_m := 1$ $a := 0.0439$ $D := 290$ $\lambda := .55 \cdot 10^{-3}$

$d := 0.3075$

$n := 1 \,..\, 250$

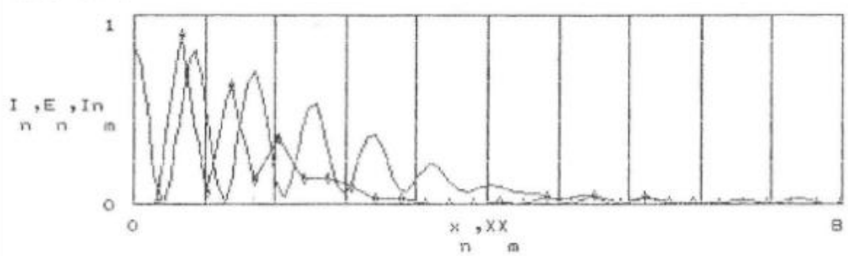
$x_n := .275 \cdot n$

$$\alpha_n := \frac{\pi \cdot a}{\lambda} \cdot \frac{x_n}{\sqrt{x_n^2 + D^2}} \qquad \beta_n := \frac{\pi \cdot d}{\lambda} \cdot \frac{x_n}{\sqrt{x_n^2 + D^2}}$$

$$I_n := I_m \cdot \left[\cos\left[\beta_n\right]\right]^2 \cdot \left[\left[\frac{\sin\left[\alpha_n\right]}{\alpha_n}\right]^2\right]$$

$$E_n := I_m \cdot \left[\left[\frac{\sin\left[\alpha_n\right]}{\alpha_n}\right]^2\right]$$

$XX := 3 \cdot XX$



x_n	I_n
0.275	0.00879
0.55	0.893936
0.825	0.066222
1.1	0.632223
1.375	0.126852
1.65	0.341667
1.925	0.135634
2.2	0.130331
2.475	0.08784
2.75	0.028862
3.025	0.027469
3.3	0.001761
3.575	0.000238
3.85	0.000185
4.125	0.013052
4.4	0.000086
4.675	0.037524
4.95	0.000768
5.225	0.044815
5.5	0.004343
5.775	0.031088
6.05	0.006498
6.325	0.012071
6.6	0.003747
6.875	0.00157
7.15	0.000163
7.425	0.000139
7.7	0.002293
7.975	0.001102
8.25	0.009971
8.525	0.00072
8.8	0.015958
9.075	0.000027
9.35	0.014503
9.625	0.000238
9.9	0.007539
10.175	0.000468
10.45	0.001513
10.725	0.000068
11	0.000048
11.275	0.000418
11.55	0.001395
11.825	0.002856
12.1	0.002175
12.375	0.00603
12.65	0.001416
12.925	0.006952
13.2	0.000382
13.475	0.004612
13.75	0.000013