Lab 9: Interference and Diffraction of Light

Archie Wheeler
Arnold Chand
Rahul Reddy
03.12.2012

This lab can be accessed at
www.andrews.edu/~wheelerj/lab09

Abstract

The lab was a success. In it, we successfully observed laws of refraction and interference in light when passing through single and double slits. We also were able to use this characteristic of light to measure the groove spacing of a CD and the size of Lycopodium spores. We were also able to confirm the Law of Malus for polarization.

We did encounter some sources of error. While they were not negligible, nor completely explainable at some times, they were not sufficiently large so that we had to call into doubt the equations that we were testing.

Contents

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 groove spacing of a CD.
- To measure the size of Lycopodium spores.
- To measure the Law of Malus of polarization.

Setup

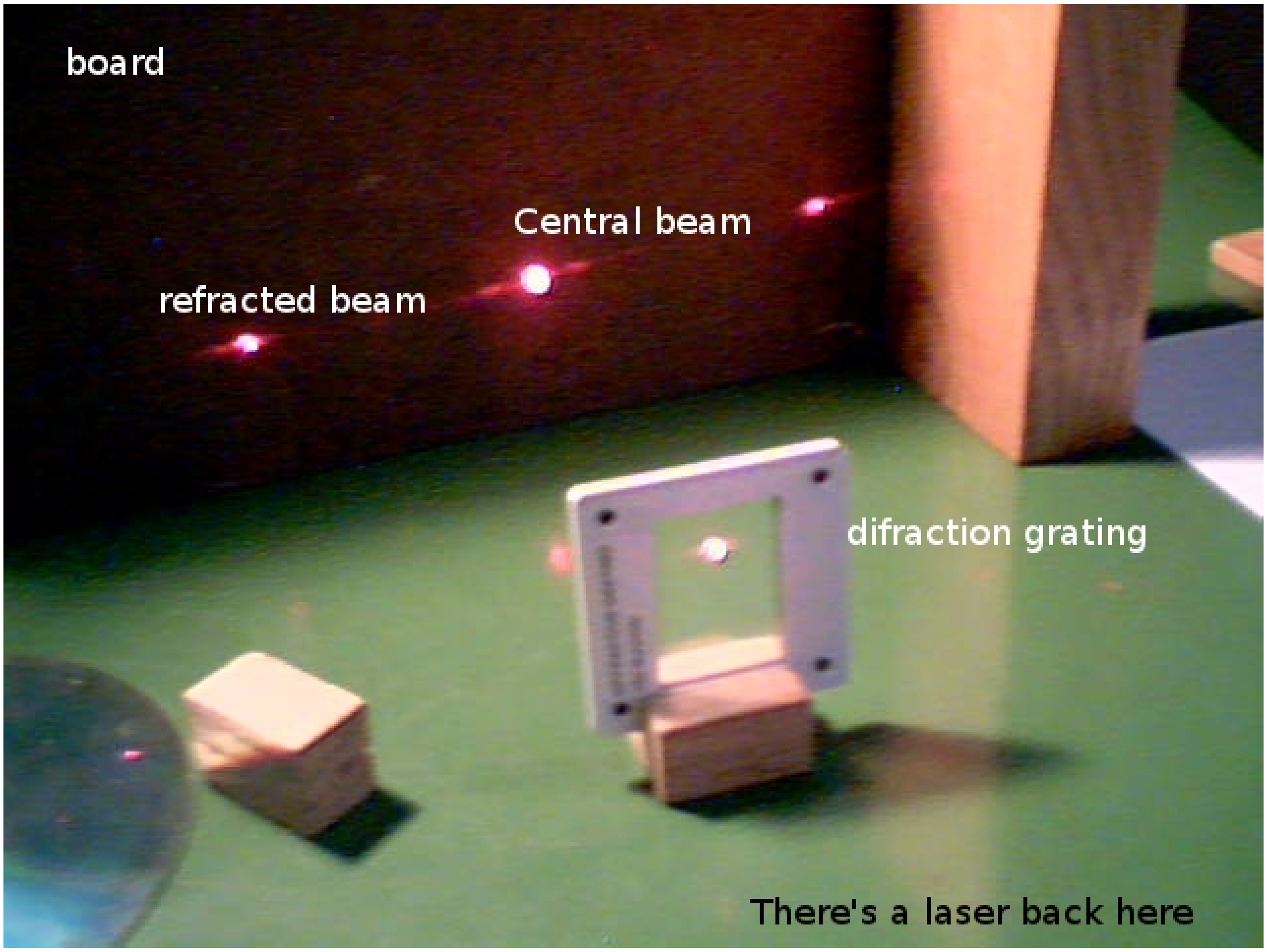
Materials:

- Helium Neon laser
- Diffraction gratings: 750 lines per mm, CD
- Slide of single slits, .02, .04, .08, .16mm width
- Slide of double slits, .04, .08mm width; .25, .5mm separation
- Foam slit holders and wood grating holder block
- Meter stick, two meter stick
- Two polarizer slides mounted on a goniometer
- Pasco light sensor
- Science Workshop and Graphical Analysis software
- Lycopodium powder and glass slide
- 100W light bulb and led light sensor
- Multimeter, leads and alligator clip connectors
- Graphical Analysis software

Methods

Part 1. Determination of the wave length of the helium-neon laser

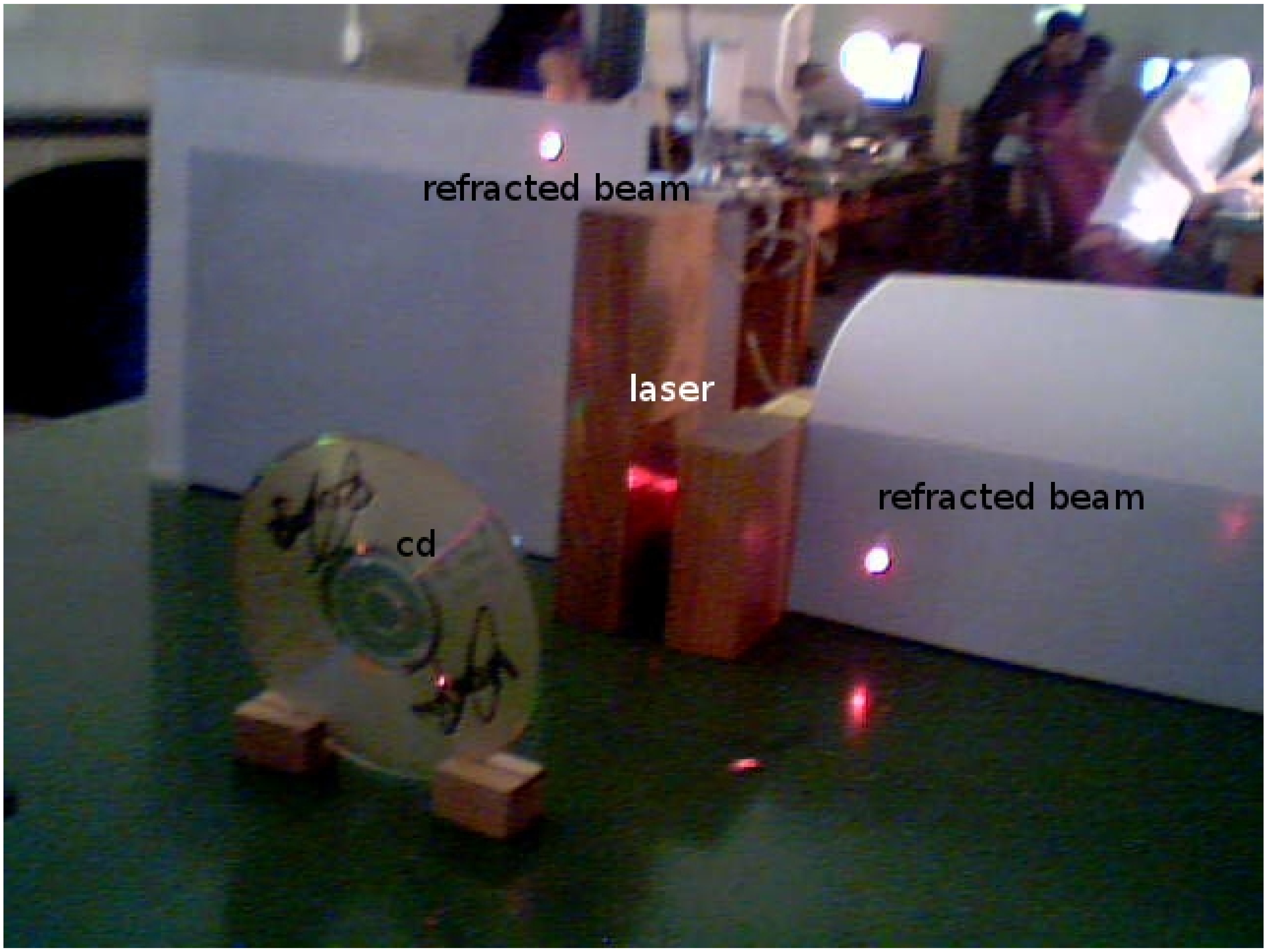
We placed the board behind the paper, and shone a laser through a diffraction grating of 750 lines/mm. When the diffraction lens was 15 centimeters behind the board, we measured the separation between the center lines.



Our setup for part 1

Part 2. Measurement of groove spacing of a CD

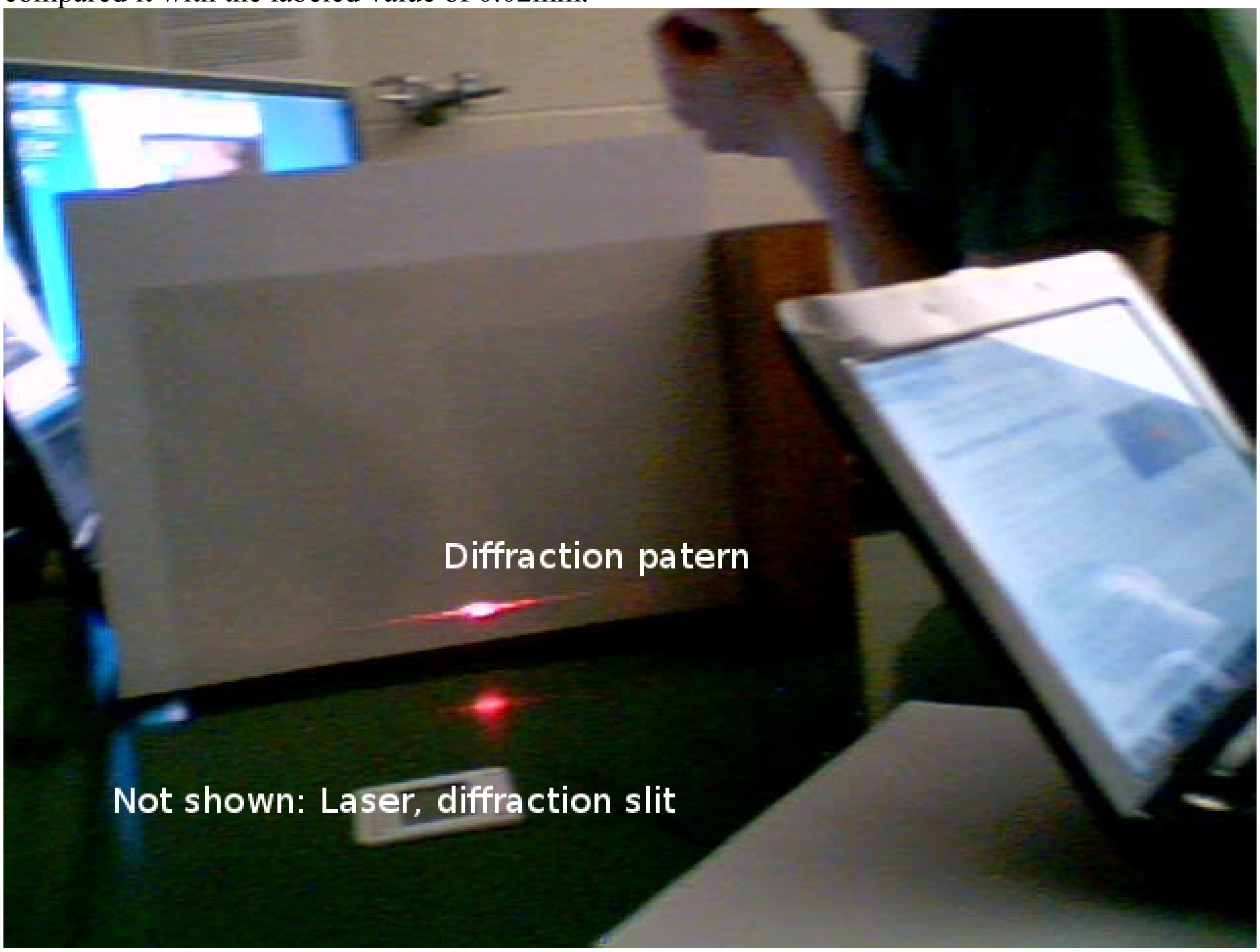
We put a CD into the foam holder and reflected a laser beam off of it. We reflected the light so that the reflected beam went straight back into the laser and produced two refracted beams on the screen on either side of the board. We marked the two centers of the maxima, and found the distance between them. Half of this distance gave us the distance away from the original beam. We used λ = 632.8nm to calculate the spacing, and compared our result with the industry standard of 1.6 μm



Our setup for part 2

Part 3. Single slit diffraction patter (0.02 mm slit width)

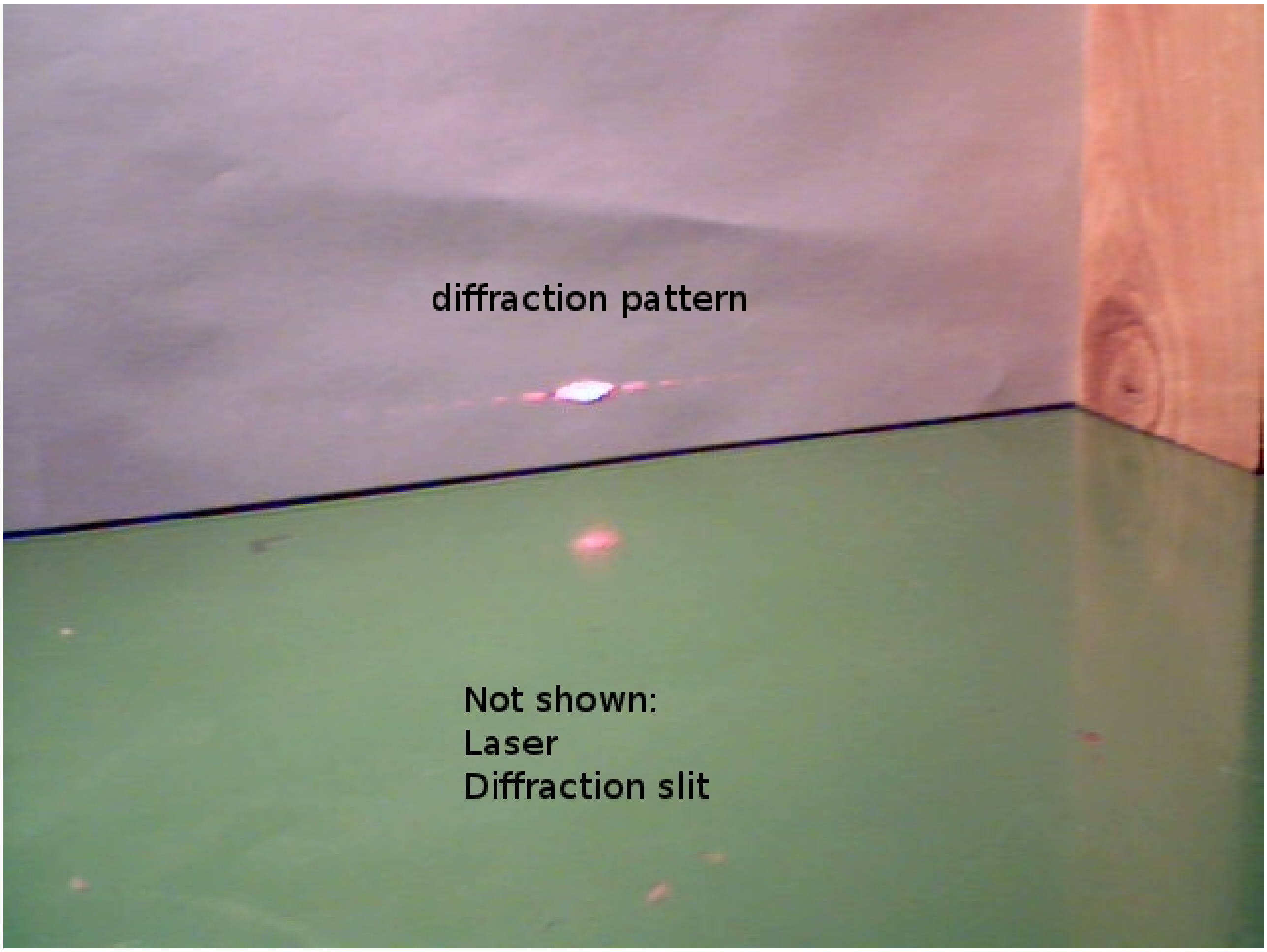
We placed a diffraction slit into the holder and taped a blank sheet of paper onto a board. We positioned the slit about 60cm away from the screen and parallel to it so that the refracted laser would make an interference pattern. We drew short lines to make positions for y_m on the screen of the locations of four or five maxima about the central maximum. We made a plot of y_m on the y-axis versus the order m on the x axis, and compared the slope of this line to $D\lambda/w$. Using $\lambda = 632.8$nm, we calculated the width w of the slit and compared it with the labeled value of 0.02mm.



Our setup for part 3

Part 4. Single slit diffraction pattern (various slit widths)

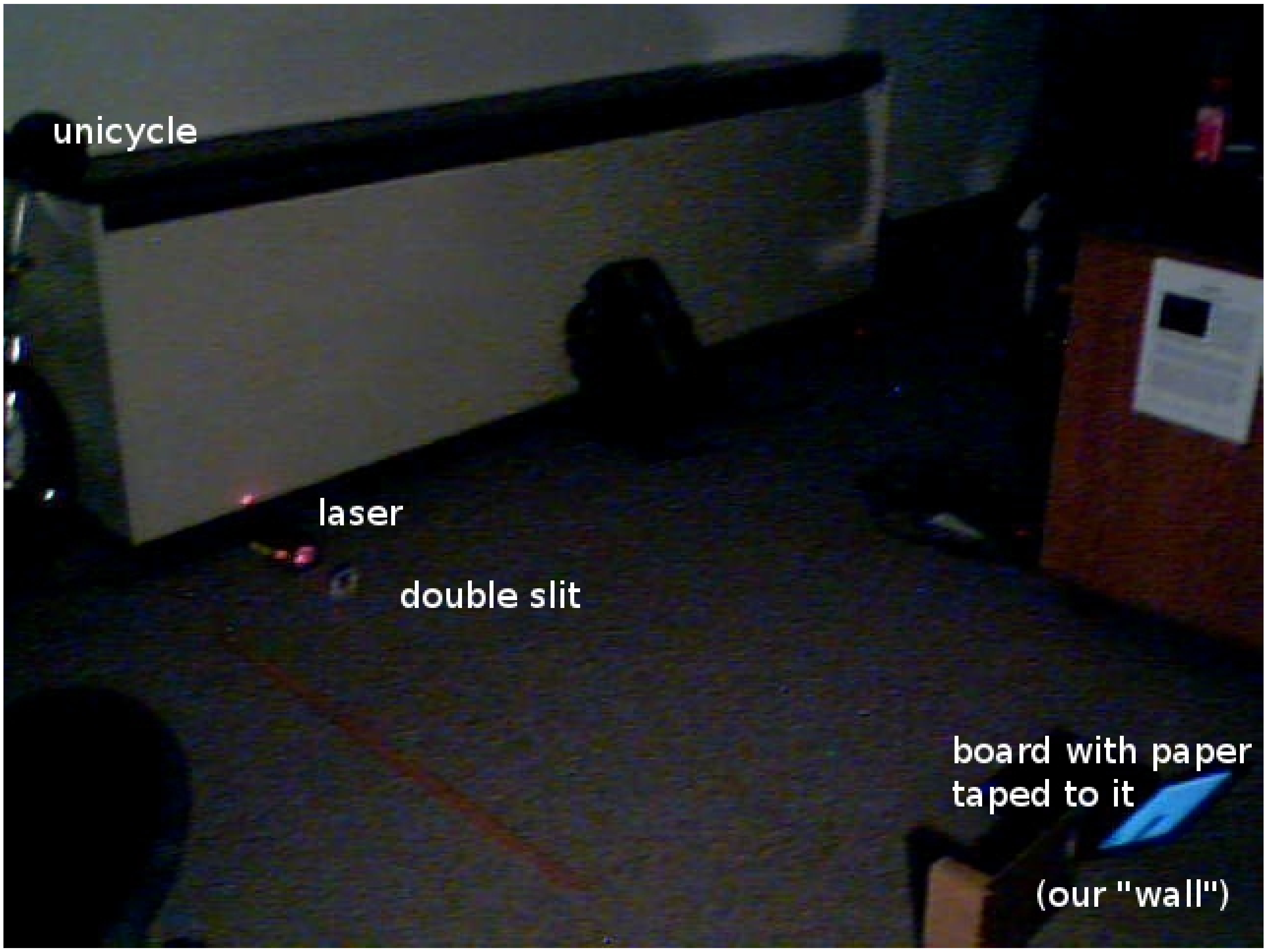
Using the approximate setup from the previous part, we repeated the experiment for various slit widths. Specifically, for 0.04mm, 0.08mm, 0.16mm. We plotted y_m on the y-axis verses 1/w on the x axis for the three data points (we threw out the previous data point because it was faulty). The slope of the line should be mDλ. We used the predicted slope to find the percent error.



Our setup for part 4

Part 5. Double slit interference (0.25mm slit separation)

We placed a double slit slide in a holder about 1.5 meters away from a wall. We directed a laser through the slit that had a separation of 0.25mm. We marked the central maximum and at the eighth maximum. We used the equation of the condition for interference maxima to predict the distance $x_m = x_8$ for the eighth interference maximum and compared the results.



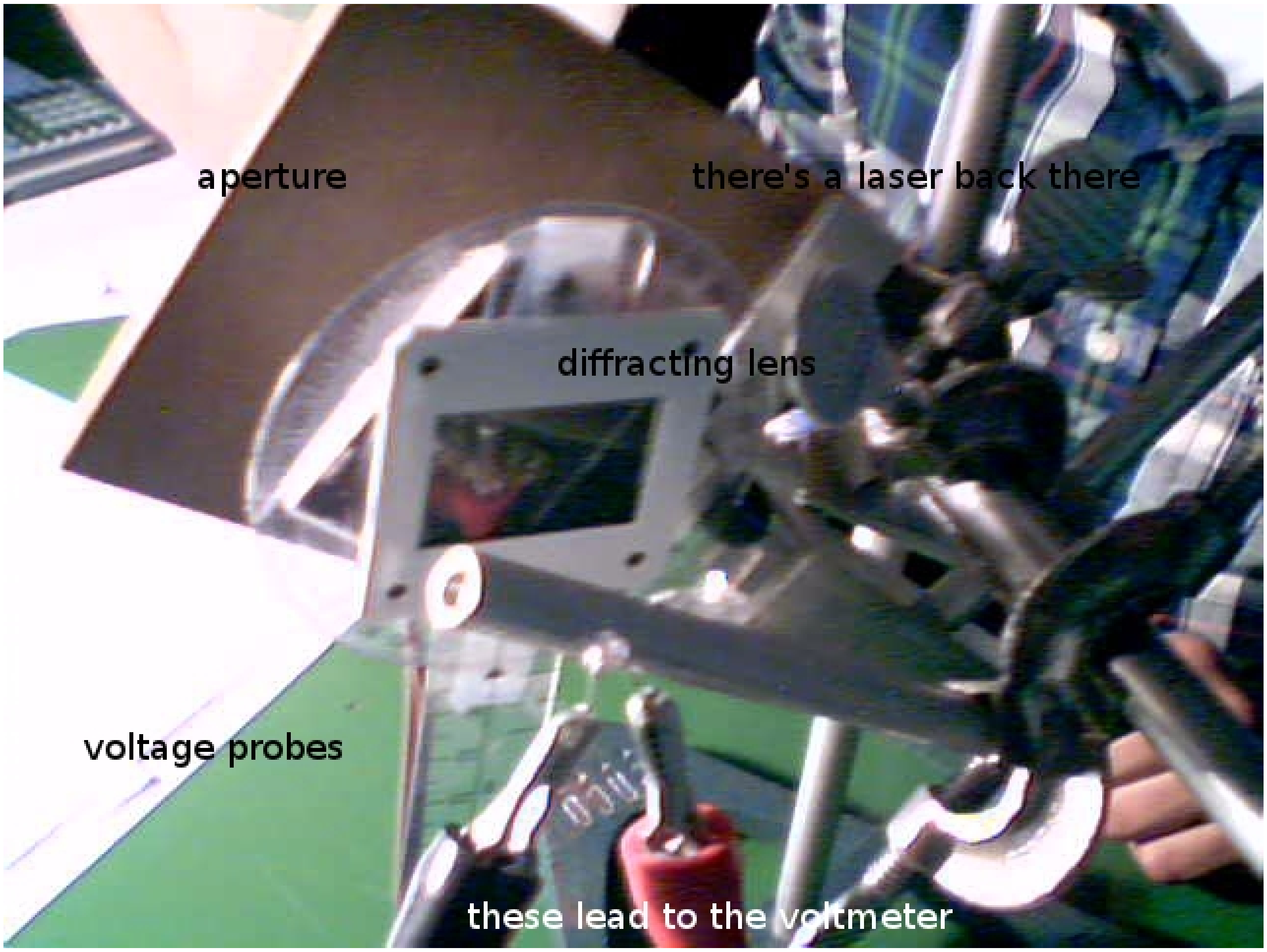
Our setup for part 5

Part 6. Double slit Interference (various slit separations)

Using the setup from the previous part, we observed how some of the double slit patterns were missing. In the lab wiki, one sees that for small angles, $\theta = n(\lambda/d) = m(\lambda/w)$ so that $n = (d/w)m$. The diffraction minimum occurs when the number n of wave lengths of path difference between the two slits is an integer ratio of d/w, and eliminating the nth interference maximum. For this experiment, we verified that this is indeed true.

Part 7. Law of Malus

We placed a light source with a 40W light bulb in front of an aperture stop. We mounted a goniometer polarizer-analyzer between the aperture and an led light detector, and used a multimeter to measure the voltage output from the led. We aligned a light polarizer in such an orientation so that the voltage would be at a maximum. We took the intensity measurements at five different angles of the second polarizer from 0° to 90°, and made a graph of I vs. $\cos^2\theta$. Using these results, we checked to see if Malus' law held up.



Our setup for part 7

Part 8. Width of Lycopodium Spores

We dipped the end of a microscope slide into Lycopodium powder so that about a half inch of the slide was covered in powder, and knocked off any excess so that a thin approximately even distribution was obtained. We set the laser about 1 meter away from the stand and shone the beam through the powder on the slide. We taped a piece of paper on the stand marked the central bright spot, and used it to measure the diameter of the circle. We measured the distance from the slide to the screen and used the equation $d=1.22\lambda L/R$ to find the size of the diffracting objects. We compared our answer to the diameter of lycopodium spores, which range from 25 to 40 μm.

Data and Analysis

Part 1. Determination of the wave length of the helium-neon laser

D=15cm
d=8.5cm

$$d\sin(\theta) = m\lambda$$

$$\lambda = \frac{\sin(\arctan\frac{y_m}{D})}{750,000/m}$$

λ = 640nm
$\lambda_{theoretical}$=632.8nm
%error = 1.14%

The error in this part was quite small, and it could have easily come from error in the width of the pencil lines we used to mark the slits, in the width of the laser beam, in a slight angular deviation from parallel or perpendicular setup, etc...

Part 2. Measurement of groove spacing of a CD

D=24cm
2y = 16.4cm
y=8.2cm
$\theta=\tan^{-1}(d/D)$=.3292rad=18.86°

$$d\sin\theta = m\lambda$$

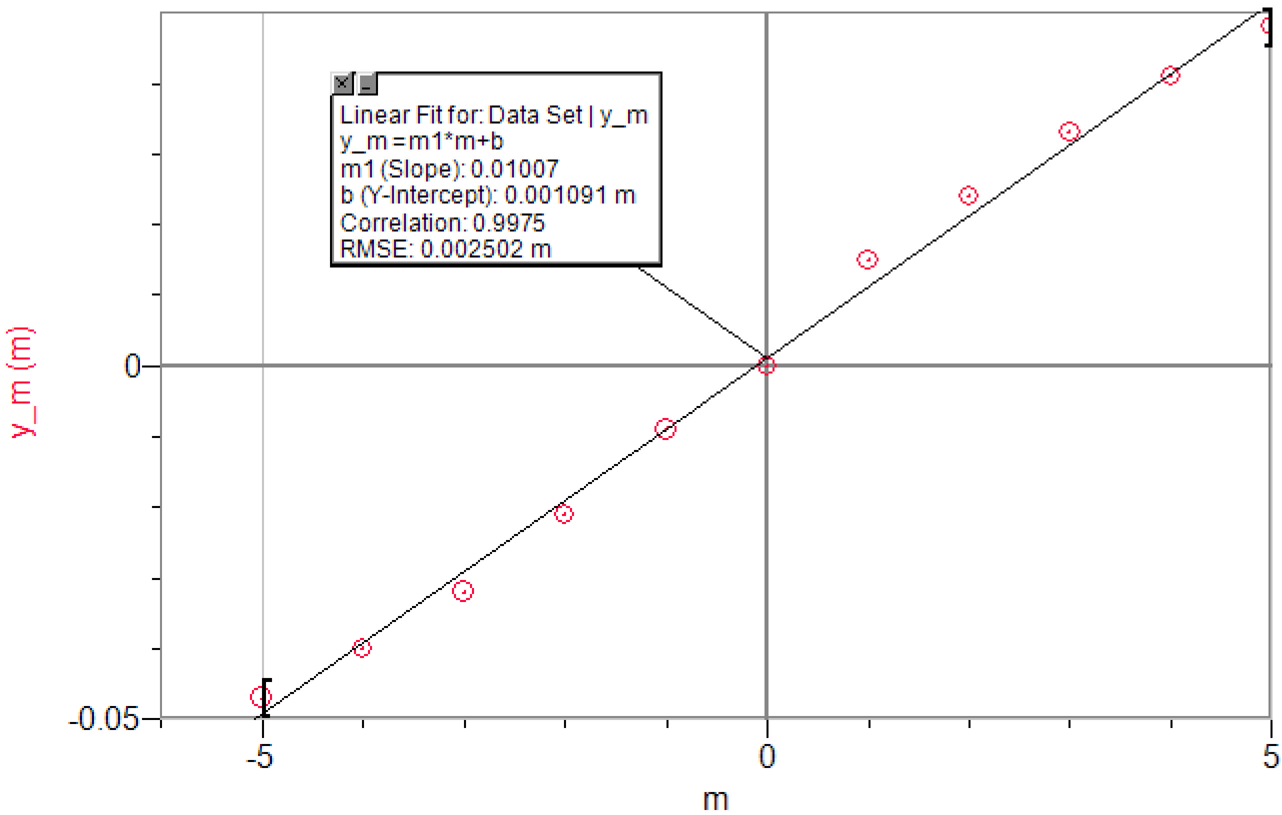
$$d = \frac{m\lambda}{\sin(\arctan\frac{y}{D})}$$

d=1.957µm
$d_{theoretical}$=1.6µm
%error = 22.33%

When we performed this part of the lab, we aligned the two dots on two different boards, and in order to get an accurate measurement of this, we had to carefully put a ruler a cross without moving the boards. However, the boards had moved, this value would have been off. Also, if we did not get an accurate or precise distance from the CD to the boards, it could have also thrown off our estimation. Furthermore, the equation that we were using works best for small angles where sin(θ) is close to θ. However, our angle was sufficiently large to make this approximation not true.

Part 3. Single slit diffraction pattern (0.02mm slit width)

m	y_m(m)
-5	-0.047
-4	-0.040
-3	-0.032
-2	-0.021
-1	-0.009
0	0.000
1	0.015
2	0.024
3	0.033
4	0.041
5	0.048



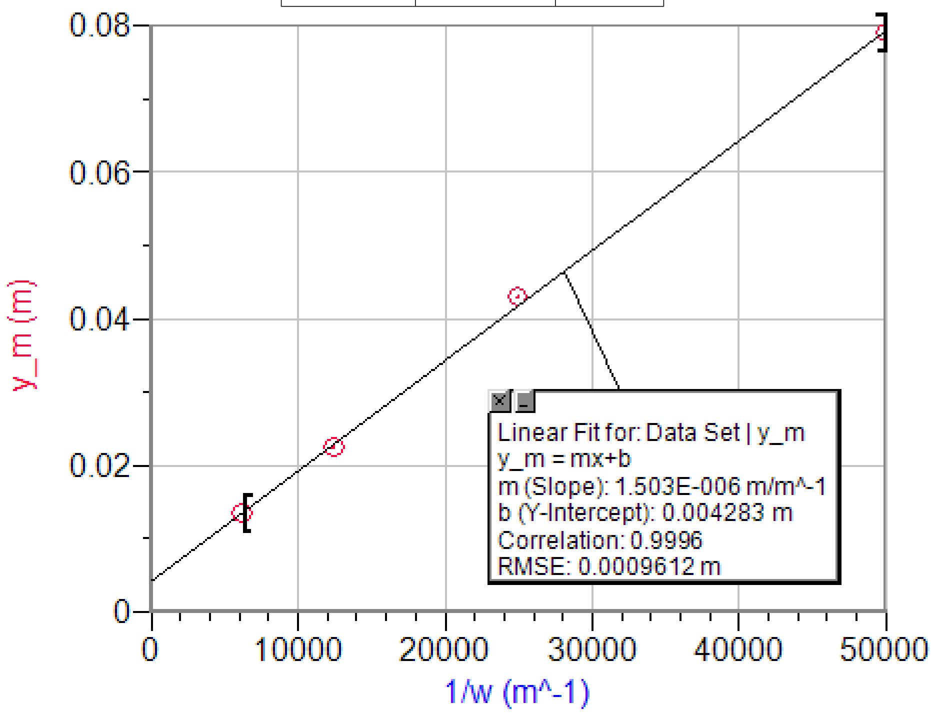
A graph of y_m vs. m. The slope is expected to be Dλ/w

slope = 0.010007m λ = 632.8nm D = 0.61m w = 0.02mm Dλ/w=0.0096502m %error = 48.15%

We believe that we accidentally used a 0.04mm slit instead of a 0.02mm slit. That is why our slope was nearly half of the expected value. Other sources of error include the fact that we assumed that $\sin(\theta) = \theta$ and that we did not have the best precision when finding the center of a maximum.

Part 4. Single slit diffraction pattern (various slit widths)

w(m)	1/w(1/m)	y_m(m)
2.00E-05	5.00E+04	0.0790
4.00E-05	2.50E+04	0.0430
8.00E-05	1.25E+04	0.0225
1.60E-04	6.25E+03	0.0135



A graph of y_{m5} vs. w^{-1}. The slope is expected to be $mD\lambda$

slope = $1.503*10^{-6}$
λ = 632.8nm
D= 0.61m
m=5
$mD\lambda=1.93*10^{-6}$ %error = 22.12%

Our graph had a correlation almost equal to one. This leads us to believe that our error was systematic. Perhaps the wavelength was different than measured, although this is not feasible because in part 1, it seemed to hold quite true. It might be possible that we had some arithmetical error in our calculations.

Part 5. Double slit interference (0.25mm slit separation)

λ=632.8nm
D=1.5m
y_8=0.028m

$$d \sin\left[\arctan\left(\frac{y_8}{D}\right)\right] = 8\lambda$$

$$y_8 = D \tan\left[\arcsin\left(\frac{8\lambda}{d}\right)\right]$$

$y_{8theoretical}$=0.0304m
%error=7.89%

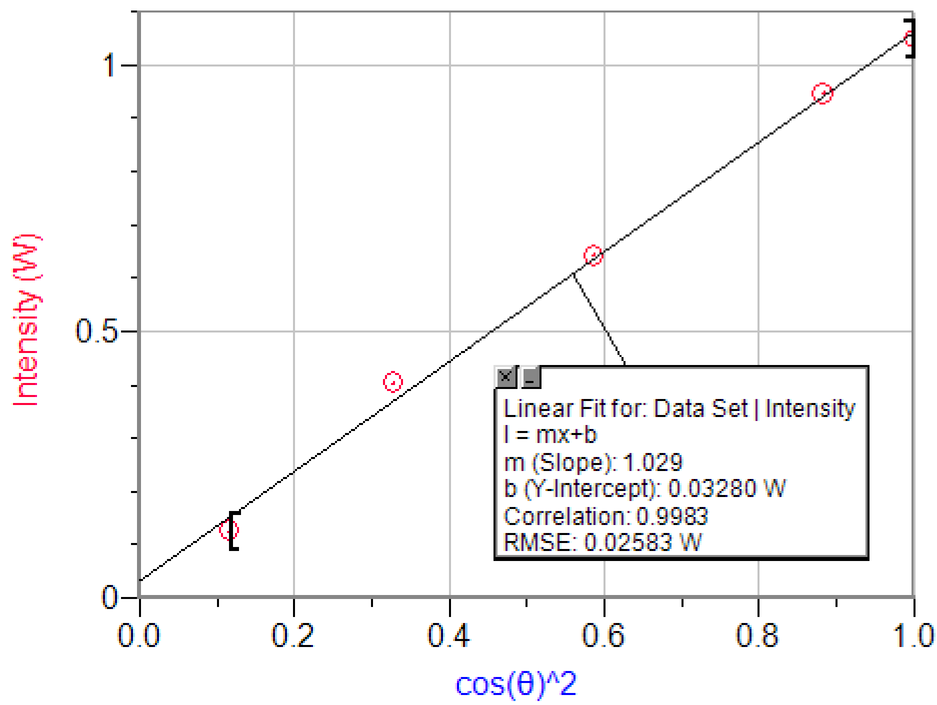
The width in this part was somewhat small, and our instruments could not accurately record variations of parts of a millimeter. This accounts for part of, but not all, of the experimental error. Other error may have come from missing the laser when making the mark with the pencil, or by wobbling the board when making the marks.

Part 6. Double slit interference (various slit separations)

It worked

Part 7. Law of Malus

θθ	cos(θ)^2	I
0	1.000	1.049
20	0.883	0.945
40	0.587	0.641
55	0.329	0.404
75	0.067	0.126



slope = 1.029 This line is fairly linear, so Malus' law holds.

Part 8. Width of Lycopodium Spores

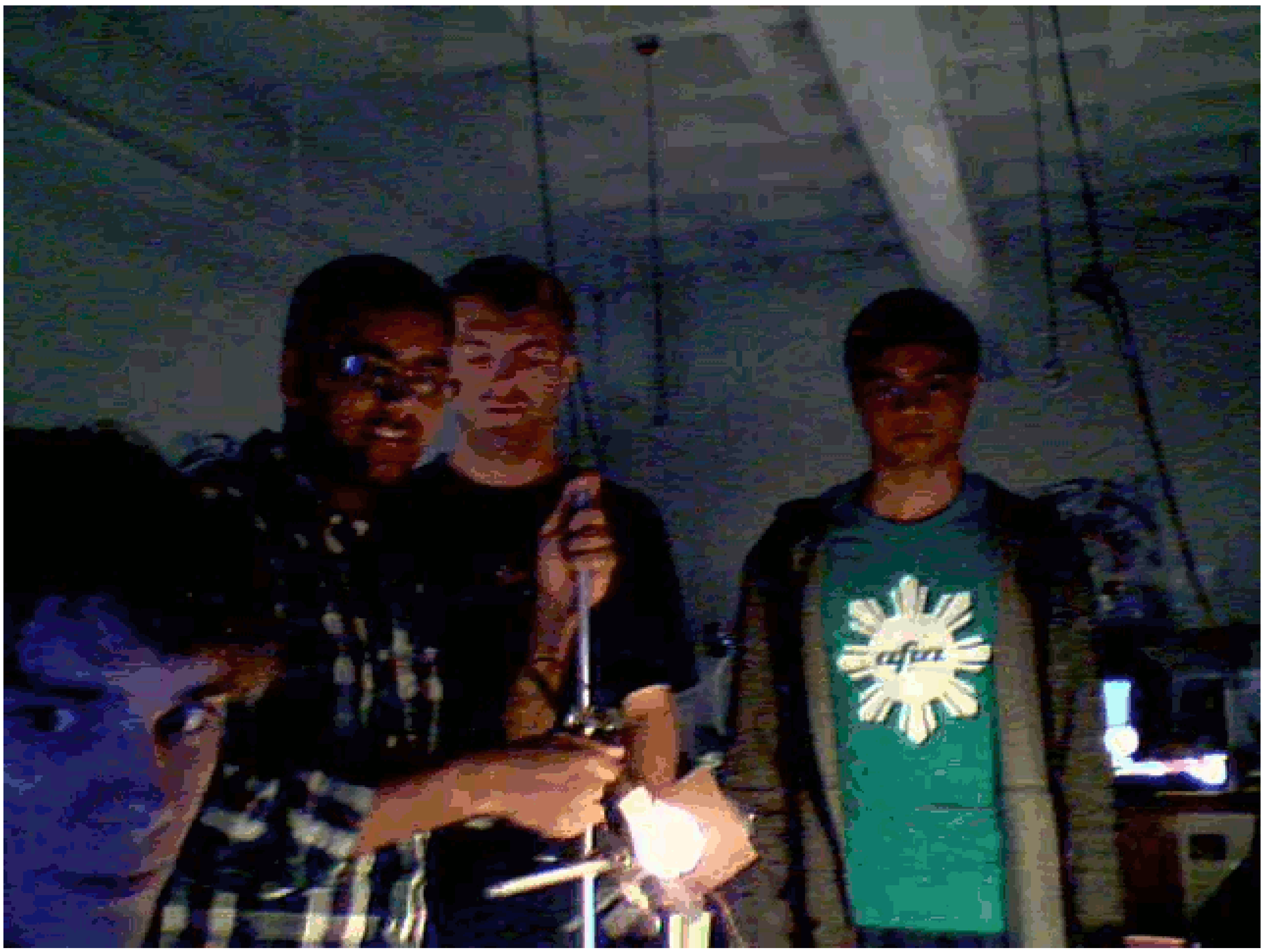
$d=0.3\,\text{cm}$
$R=0.15\,\text{cm}$
$5.85\,\text{cm}$
$\lambda=632.8\,\text{nm}$
$d=1.22\lambda L/R=30\,\mu\text{m}$
$25<30<40$:)

Conclusion

The lab was a success. In it, we successfully observed laws of refraction and interference in light when passing through single and double slits. We also were able to use this characteristic of light to measure the groove spacing of a CD and the size of Lycopodium spores. We were also able to confirm the Law of Malus for polarization.

We did encounter some sources of error. While they were not negligible, nor completely explainable at some times, they were not sufficiently large so that we had to call into doubt the equations that we were testing.

Signature



Archie Wheeler
03.26.12