D2 - Fresnel Diffraction

Andrew Kim[1*†] and Kendall Graff[1†]

[1]Department of Physics, University of Illinois Urbana Champaign, Champaign, USA
[*]Writing Student. NetID: andrewk3
[†]These students contributed equally to this lab.

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Abstract

The purpose of this experiment was to observe the principles of Fraunhofer and Fresnel diffraction. Using the lab set-up, both Fraunhofer and Fresnel diffraction patterns were observed in the lab and compared against simulations. The Fraunhofer diffraction patterns were markedly similar, but the Fresnel patterns varied from the expected patterns due to the imperfect experiment set-up.

1 Instruments and Apparatus

The experiment had a very simple single set up consisting of: a single red He-Ne of wavelength 632.8 nm, a photodiode detector on a stepper motor connected to the lab computer, and two slide holders all arranged in a line perpendicular to the motion of the detector with the laser at one end and the detector at the other. The slide holders were there to hold one of four slides: two slit slides consisting of a single slit slide with a slit width of 0.04 mm and a double slit slide with the same slit width but a slit separation of 0.5 mm, and two obstacle slides including a narrow obstacle slide that was a wire of thickness 0.27 mm, and a semi-infinite plane slide that was an open slide with half of the opening covered by a razor blade.

There were two possible ways of setting up the set up, however. The first was the set up for Fraunhofer diffraction, in which the slides are placed 1 m from the detector. The second was the set up for Fresnel diffraction, where the obstacles were placed 1 m from the detector, but between the obstacle and the laser was placed the single slit slide, 0.215 m in front of the obstacle. The purpose of this was to simulate a light coming in from infinity, and will covered more in the theory section.

2 Procedure

The first step of the lab is to align the laser such that it hits the detector when the detector is in the center of its 5 cm track. The second step is to observe Fraunhofer diffraction patterns. Set up the single slit slide in one of the slide holders such that its diffraction pattern is horizontal on the detector and the center of the pattern is aligned with the center of the detector's 5 cm track. Record the data the voltage, current, and logarithm of the current data from the detector, and do the same with the double slit slide. Be sure to record the maxima and minima of the patterns along with their positions.

Observing the Fresnel diffraction patterns happens in a similar way: position the set up in order to observe Fresnel diffraction, and observe how the obstacles interfere with the light. The only thing mildly different is the orientation: the diffraction pattern of the single slit is still horizontal on the detector, but now the shadows of the obstacles should be at the center of the detector track. For the semi-infinite plane, the shadow should start at the center of the track. The data recording is the same, along with the specific attention to the maxima and minima.

Relevant Equations and Theory

Diffraction patterns in general are caused by the wave nature of light. When a wave front encounters an opening, it bends around the ends of the opening's corners. This curving allows the wave to destructively interfere with itself, and creates the diffraction pattern.

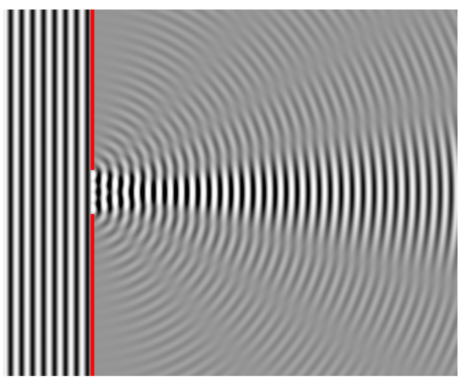


Figure 1: Approximation of wave diffraction from an incident plane wave. Image taken from Wikipedia, created and uploaded by Dick Lyon.

There are several ways to approximate diffraction patterns in several situations. The two ways this lab looks at are Fraunhofer and Fresnel diffraction approximations. Fraunhofer diffraction is the type of diffraction shown in Figure 1, and involves a wave passing through one or several slit openings. In the Fraunhofer limit, the diffraction is given by the equation:

$$I(x) = I_l(sin\beta/\beta)^2(sin(N\alpha)/sin\alpha)^2 \tag{1}$$

Where $\beta = \pi asin\theta/\lambda$, $\alpha = \pi dsin\theta/\lambda$, $\theta = tan^{-1}(x/r)$, a is the slit(s) width (0.04 mm), d is the distance between slits (0.5 mm), N is the number of coherent sources (number of slits), r is the distance of the viewing plane from the slit pattern (1 m), I_l is the intensity from a single source (69.925 in the single slit, 34.801 in the double slit), λ is the wavelength of the light (632.8 nm), and x is the position in the diffraction pattern (ranges from 0 to 5 cm). As can be seen, in the case where N = 1, the function depends only on the β term.

The other diffraction pattern this lab observes is Fresnel diffraction, which occurs when light is blocked by an obstacle. In this lab, the obstacles are a thin wire and a semi-infinite plane represented by a razor blade. The Fresnel pattern depends on a single parameter $u(x) = x(2/\lambda r_0)^{1/2}$ through two Fresnel integrals:

$$C(u) = \int_0^u cos(\pi t^2/2)dt \tag{2}$$

and:

$$S(u) = \int_0^u sin(\pi t^2/2)dt \tag{3}$$

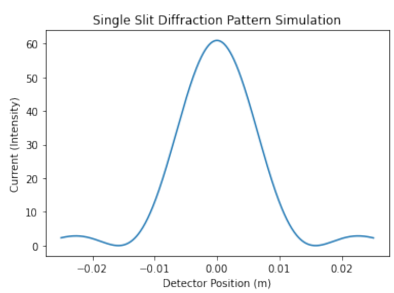
From these equations, one can obtain the intensity pattern. The intensity pattern for the semi-infinite plane is:

$$I(x) = \frac{I_0}{2}[(\frac{1}{2} - C(u(x)))^2 + (\frac{1}{2} - S(u(x)))^2] \tag{4}$$

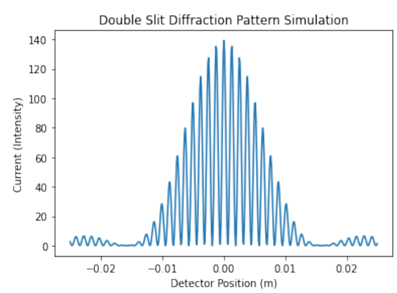
When the obstacle is thin, such as the wire this lab uses, the diffraction pattern must be calculated using a reduced width $\Delta u = w/\sqrt{2/\lambda r_0}$. This makes the thin obstacle diffraction pattern:

$$I(u) = \frac{I_0}{2}[(1 + C(u - \Delta u) - C(u + \Delta u))^2 + (1 + S(u - \Delta u) - S(u + \Delta u))^2] \tag{5}$$

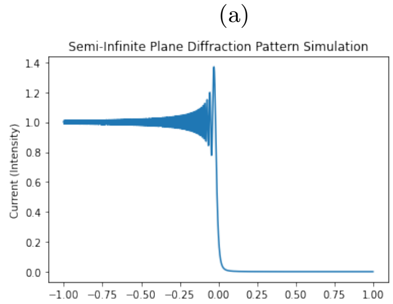
Shown below are simulation plots of both the Fraunhofer diffraction patterns and the Fresnel diffraction patterns:



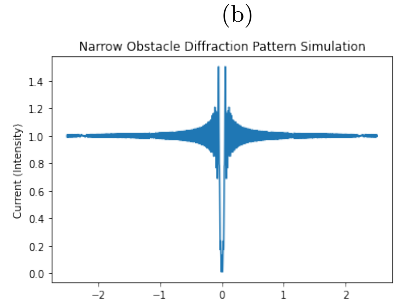
(a)



(b)



(c)



(d)

Figure 2: The diffraction pattern simulation plots. Plots a and b were created by plotting the intensity equations, while plots c and d were created through the *Fresdiff1.exe* program.

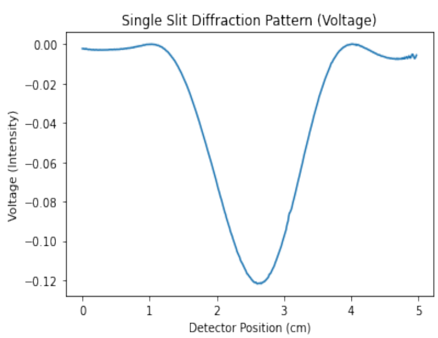
Note that x-axis of the real observations will run from 0 to 5 cm for the vast majority of the patterns. While the semi-infinite plane and the narrow obstacle plots are good indicators of the shape of the pattern, they do not represent how Fresnel diffraction occurs in real life, especially in this lab. Since this lab uses a single slit to simulate a light source at infinity, the Fresnel diffraction patterns will look like variations on the single slit diffraction pattern. This difference of the Fresnel diffraction when the source is real and at a distance ρ can be shown by exchanging the variable x for x':

$$x' = x\sqrt{\frac{\rho + r_0}{\rho}} \tag{6}$$

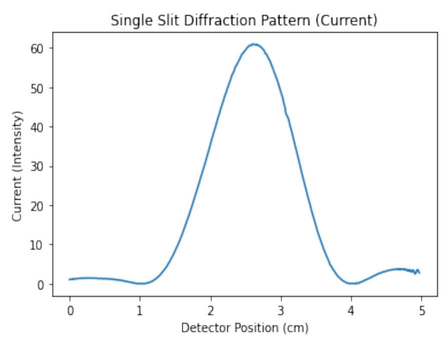
Where x' replaces x in the Fresnel equations.

3 Results and Discussion

The diffraction pattern for the single slit slide was:



(a)



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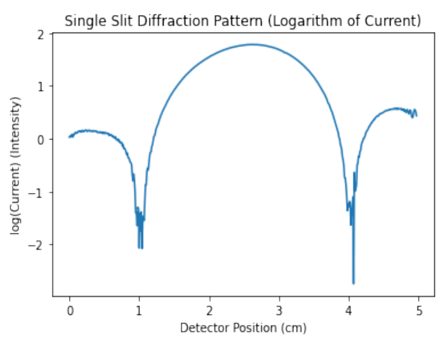
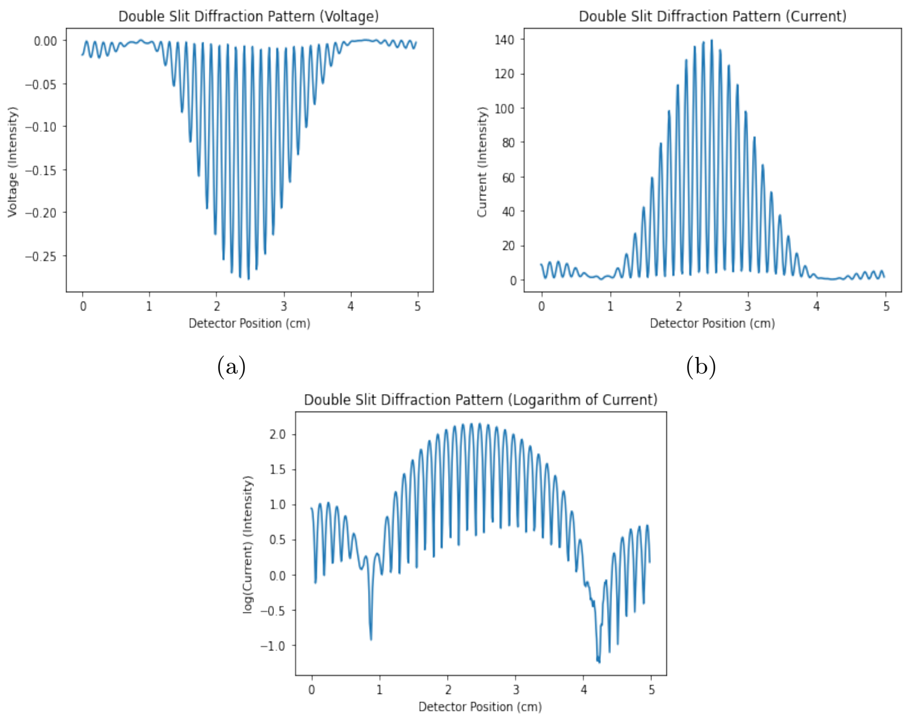


(c)

Figure 3: The diffraction patterns for the single slit slide, a is the observed voltage, b is the observed current, and c is the base-10 logarithm of the observed current.

The maximum point of the single slit diffraction pattern occurs at 2.6 cm and has an intensity of 60.925. This is rather close to the simulation, which gave the maxima at 2.6 cm (translating to the coordinate system of the observations) with the same intensity of 60.925. The minimum of the observed pattern is at 4.07 cm with an intensity of 0.0018. The simulation, however, gave the minimum at 0.92 cm with an intensity of 1.17e-3.

The diffraction pattern for the double slit slide was:

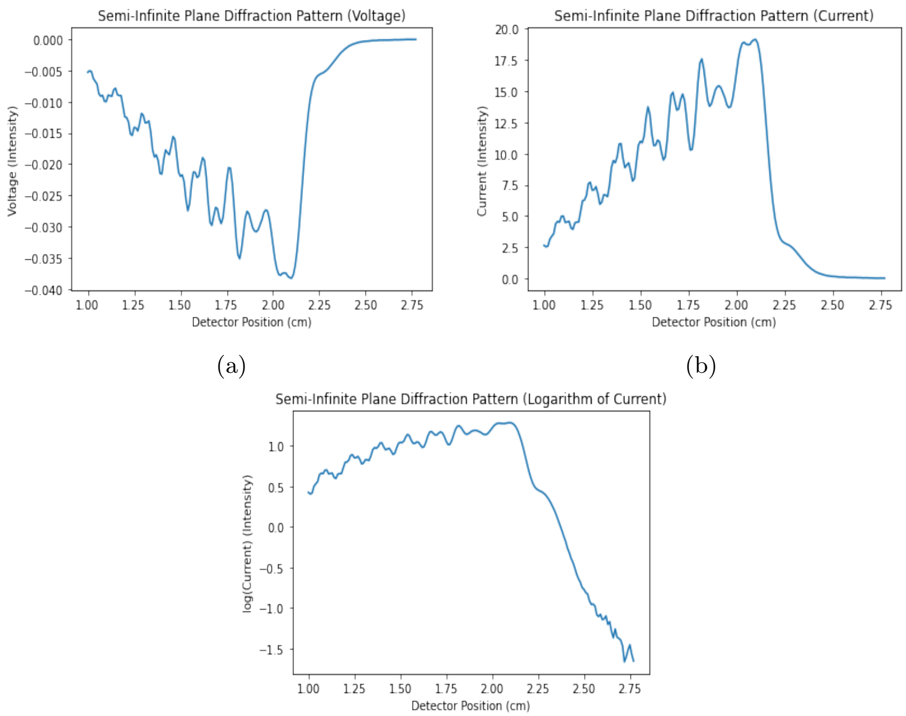


(a) (b) (c)

Figure 4: The diffraction patterns for the double slit slide, a is the observed voltage, b is the observed current, and c is the base-10 logarithm of the observed current.

The maxima of the two slit diffraction pattern occurs at 2.47 cm and has an intensity of 139.207. Once again, this is close to the simulation, which gave the maxima at 2.5 cm with an intensity of 139.208. The minima of the observed pattern is at 4.23 cm with an intensity of 0.054755. The simulation, however, gave the minimum at 0.92 cm with an intensity of 0. The maxima of both the single and the double slit patterns were consistent with their simulations, but the minima were not. Most importantly, these observed patterns matched the shape of their expected simulations.

Moving onto the Fresnel diffraction patterns, the semi-infinite plane patterns were:

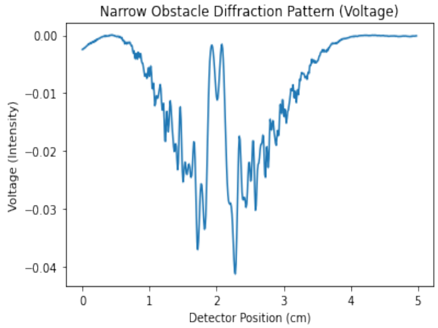


(a) (b) (c)

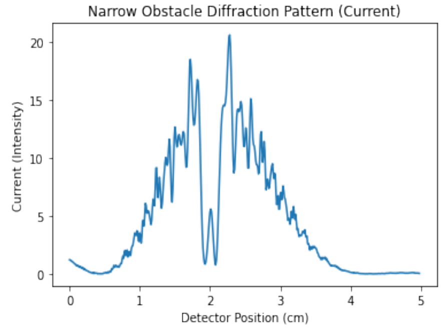
Figure 5: The diffraction patterns for the semi-infinite plane. The labels follow the same conventions as the other two figures. Note that the graphs run from 1 to 2.75 cm.

The minima of the semi-infinite plane is rather obvious, it is about 0 intensity at every point past 2.57 cm. The maxima occurs at 2.1 cm and has an intensity of 19.149. The simulation has the maxima at 2.471 cm, with an intensity of 1.37. It has the same extended minimum, although it starts at 2.5115 cm. The forms of the patterns, however, are markedly different from one another.

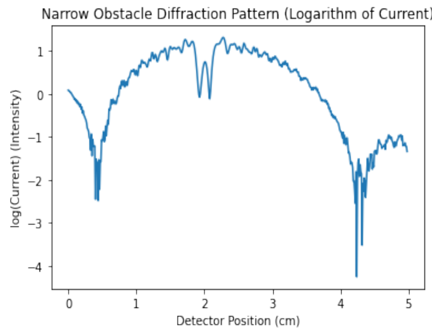
The diffraction patterns for the narrow obstacle were:



(a)



(b)



(c)

Figure 6: The diffraction patterns for the narrow obstacle. The labels follow the same convention as the other figures.

The maxima for the narrow obstacle is located at 2.27 cm with an intensity of 20.6. The simulation has its maxima at 2.554 cm with an intensity of 1.5. The minima for the narrow obsticale is located at 4.23 cm with an intensity of 0, whereas the simulation has its minima at 2.509 with an intensity of 0.0118. The form of the observation vaguely resembles the simulation, but is rather different.

General Observations and Conclusion

Starting with the least important difference: the shift of the Fraunhofer patterns (and to a lesser extent, the Fresnel patterns) off of the center probably occurred due to an improper alignment of the patterns on the detector. If the slide holder was rotated even by a small fraction of a degree off of the horizontal, then the pattern would shift on the perpendicular.

Moving to the more drastic differences, there are a couple reasons why the Fresnel diffraction patterns were rather dissimilar to their simulations. One important one is that this is an obstacle diffracting a diffraction pattern, not a plane wave. The simulations assume that the intensity of the source is constant on the interval, but since the source used is a single slit, the intensity already followed a single slit diffraction pattern to begin with. That is why the semi-infinite plane is increasing before its drop and why the narrow object is not oscillating around 1. Another reason why the patterns are so different is the obstacle placement. The simulations could place the obstacles exactly on the center of the detector interval, but in the lab these had to be lined up by sight. This is why the narrow obstacle pattern has its obstacle dip off of center and why the semi-infinite plane has its extended drop off. The final reason why these plots are so different is the graphing. The simulation program created several thousand data points at very close intervals. The detector observed less than two hundred data points at intervals that seem rather distant in comparison. This probably led to the much tighter and closely packed simulation curves.

In the end, the diffraction patterns and their elucidation to the wave nature of light can be clearly seen. The Fresnel diffraction patterns show quite obviously that light will infringe upon the shadows of obstacles and create interference patterns there. The Fraunhofer diffraction patterns show how light can be used to destructively interfere with itself. Altogether, a fundamental understanding of diffraction has been achieved.