# N-Slit Visualization

## Abstract

The goal of this project is to provide an interactive visualization of the intensity curve that results from the quantum mechanical effects of diffraction and interference on waves. N-Slit diffraction and interference are of the most complex topics covered in Physics 214, and many students struggle to grasp how exactly all the parameters impact the intensity curve. This web application will serve as an educational tool, providing a simple, convenient interface to study the qualitative effects of individually varying each of the parameters. This project is hosted on GitHub at https://github.com/baileytincher/N-Slit-Visualization

## Background on the Physics

N-Slit diffraction and interference are quantum mechanical effects on waves. When waves, such as light, pass through a slit they exhibit non-intuitive patterns on a distant screen. As particles pass through the slits, they develop an uncertainty in their momentum and scatter at different angles. If a detector is placed at a far enough distance, over time the collection of many particles results in a predictable pattern across the detector. For a given wavelength, this pattern is a symmetric collection of distinct “high” and “low” bands about a given axis. This axis depends on the shape of the slit. For example, a vertical, rectangular slit results in vertical bands, while a circular slit results in radial bands. The “high bands” are where the source waves constructively interfere, while the “low” bands are where they destructively interfere. For light, we describe these bands by their intensities on a distant screen. The intensity is effectively just a measurement of how bright the light is at a given point. The “high” bands correspond to regions of higher intensity, while the “low” bands correspond to regions of lower intensity. Thus, if we shine a monochromatic light source through a collection of slits pointed towards a distant screen, then we will see an interference or diffraction pattern on the distant screen. When the slits are of infinitesimal width, then the pattern we see is only an interference pattern. The interference pattern we see depends on many factors including the number of slits, the distance between the slits, and the wavelength of the light passing through. The interference pattern shown demonstrates a repeating, symmetric pattern of intensity peaks. We refer to each section of the pattern by its “order”. The first bright band nearest the center is referred to as the first order maximum, the second bright band from the center is the second order maximum, and so on. As the number of slits increases, each order of the pattern will have multiple maxima of varying height. The largest maxima is referred to as the principle maxima, and is what is typically being referred to when discussing an m-order maxima. The smaller maxima in that section are secondary maxima and typically have an intensity that is significantly smaller than the principle maxima. For each m-order, the intensities of each of the maxima are identical and do not decrease with increasing angle from the slits. Diffraction, however, is slightly different. Diffraction is the result of having slits of finite width, as opposed to the ideal slit of infinitesimally small width. For slits of finite width, the waves passing through each individual slit can interfere with each other. This effect is described by Huygen’s principle, which treats each wavefront at the slit as its own point source of waves. As a result, we see a slightly different pattern on the distant screen. For light passing through a single slit of finite width, we see a large central band in the middle of the screen that fades out with increasing angle from the slit. For many slits, the pattern we see resembles that of interference, but with the intensity curve effectively bounded by the single slit diffraction envelope. Thus, while we still maintain the m-order maxima, as the angle from the slit increases, the principle maxima are decreasing in intensity. It is actually found that the exact intensity function for diffraction is the product of the interference equation and the single slit diffraction intensity equation. Thus, we see zeros in intensity whenever either the interference or diffraction equations have a zero. Due to this, the relation of wavelength, slit width, and the distance between slits results in drastically different patterns. These effects demonstrate that light and matter can demonstrate properties of both classical waves and particles, as well as the probabilistic nature of quantum mechanics. They also correspond with what is expected from other quantum mechanical principles such as the Heisenberg Uncertainty Principle.

## Background on the Code

To complete this project I constructed a JavaScript web application that leverages the React.js and P5.js libraries. React.js is a component based JavaScript DOM library that allows the development of intuitive user interfaces, while still maintaining the flexibility for a complex backend. I chose React for its ease of integration with native HTML components with JSX/Javascript ES6 syntax. This allowed me to create a simple component based layout structure, without trying to individually manage the positions of each item on the webpage. P5.js is a JavaScript drawing and animations library based off the processing programming language. P5.js allows a very simple code infrastructure to draw and manage graphics on individual canvases. These canvases can then be treated as a sort of screen component by React. For this project I structured the layout and user inputs through React and JSX, which communicated with P5 to draw the intensity function on the canvas. The sliders on the screen are represented in the backend by React states and passed to JSX props objects. These props objects can then be passed to P5 and interpreted into numerical values for each of the variables. The React backend also handles the updating of the canvas whenever new parameter inputs are detected. The implementation of this is inefficient, but effective, as it continuously calls the draw() function in P5 at small, finite time intervals rather than when a variable is changed. There are two buttons that allow the user to choose whether they want to see just the interference pattern or the diffraction pattern. These can be viewed without resetting any of the other parameters. The parameters can be individually varied via sliders. The specific wavefunction displayed on the screen is calculated point wise and then a curve is fit to it on the screen. To accomplish this in P5 I looped over many values for theta (the angle from the normal to the slit), calculated the intensity at that point, and saved that point as a curveVertex() object. Then I let P5 fit a smooth curve to this, which results in the appearance of a smooth sine curve. The intensity function uses a direct implementation of P5's Math.sin() function. The code for the intensity function is very straight forward and can be easily modified to display a more accurate curve (however with a much more complex expansion and computation).

## Limitations of the Application

The biggest limitation of the project are the allowed/reasonable values of the different parameters. Since the intensity curve is calculated directly from the Math.sin() functions, there is the possibility to hit points in the curve with undefined values (denominator = 0). Since the P5 math library isn’t capable of mathematics such as L’hopitals rule, it can’t properly handle these undefined values of curve. Accordingly, I had to set artificial bounds on what I considered reasonable values for the different parameters. However, with certain combinations of values, these undefined points will still appear. This results in seeing negative values of intensity and sharp slopes. These, however, are only edge cases and will mostly end up unnoticed for reasonable values of the parameters.

## Opportunities for Improvement

Continuing the discussion of limitations, the biggest opportunity for improvement would be to modify the intensity function to properly handle these undefined values of intensity at edge cases. By taking a Taylor expansion of the sine curve for values where the denominator is very small, these edge cases will be eliminated, and the curve will remain smooth and display as expected. Another idea would be to allow the overlaying of the diffraction and interference patterns on the same screen. This may assist in directly demonstrating the difference between the two effects. Similarly, there could be an outline of the diffraction envelope overlayed on top of the multi slit diffraction interference pattern. This will show more clearly exactly what parameters vary the envelope, and how the envelope bounds the diffraction pattern. Another possibility would be to allow the user to save a picture of the canvas that they drew. Then one could use this project when working on reports or when trying to compare side by side different intensity curves. Though, one could also just as easily take screen snips of the web app. Finally, this project of course needs to be hosted on a public domain. This is simple enough to do and I will work to find a reasonable way to achieve this.