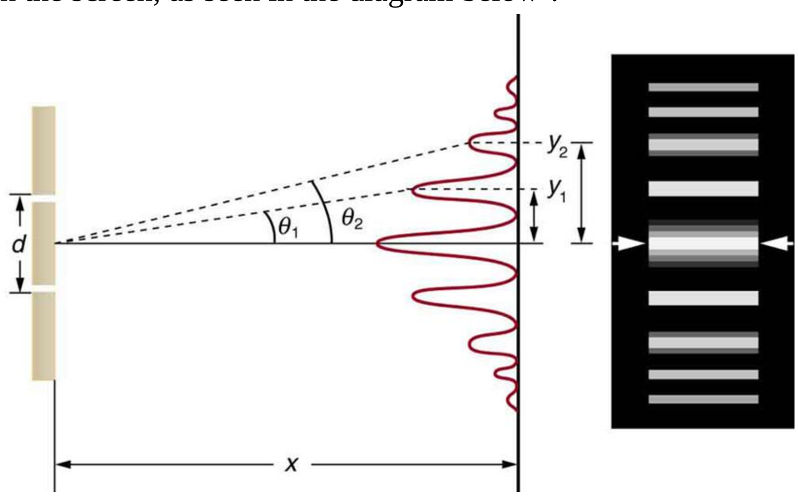
Visualizing the Multi-Slit Interference Experiment

1. Abstract
The Double Slit Experiment is fundamental to the understanding of quantum physics and the nature of light. This project will create an interactive version of the experiment's model. This program, using a 3-D space, will help users of the program visualize the actual experiment rather than having to resort to a 2-D, difficult-to-understand representation. Users will be able to manipulate many variables, from the characteristics of the diffraction grating to the distance between the grating and the illuminated screen. If time persists, exploration of Rayleigh's Criterion will be included.

2. Background
In the early 1800s, Thomas Young carried out his Double Slit Experiment that proved that the particle theory of light was incomplete[2]. He observed that as coherent light passed through a grating of numerous small slits, *fringes* (alternating bright and dark bands of light) appeared on a screen some distance away.

The slits on the grating act as point sources, diffracting the coherent light (light of a single wavelength). As the light diffracts, it coincides with the light emanating from the other slits and *interference* occurs[1]. When two sources of light interfere, they add as waves; depending on their phase difference φ they may interfere constructively or destructively. In the multi-slit experiment this phase difference between the wave functions arises from a difference in path length δ between the diffracted light. Given a multi-slit diffraction grating, the path length from the grating to the midpoint of the screen for the upper and lower halves of the grating are equal; therefore, the phase difference between the light is at a minimum. A bright fringe appears at the midpoint ($y = 0$) on the screen, as seen in the diagram below[3].



As the position y on the screen increases (as the angle θ in the diagram increases) the path length between light emanating from the slits changes. As the path length increases, the phase changes vary and periodically are equal to multiples of π and 2π (half-wavelength and full wavelength path length difference). Bright fringes, as seen on the depicted screen above, occur where the phase change is a multiple of 2π. Dark fringes occur where the net phase change is π.

Rayleigh's Criterion describes the minimum distance between objects for appreciable resolution (proper distinction). It dictates that a second peak, or interference maxima, must be at a distance away from another peak of at least half the first peak's width. This principle is the basic law governing the power of microscopes and telescopes.

3. Proposal

In any basic Quantum Physics course, analysis of the diffraction/interference phenomena of light is fundamental. I will model an interactive program depicting a multi-slit interference experiment. The user will have control over numerous variables that affect the depicted result on a visible screen in real-time.

The 3-D representation of the experiment will be much more descriptive than the other 2-D models available online. In the proposed 3-D model, a user will be able to understand the layout of the experiment and also the effect of diffraction/interference as if it was an actual lab experiment. The program will be written in VPython for ease of use and its ability to model physical phenomena well.

The layout of the virtual experiment will be as follows: a light source on the edge of the screen will be illuminating a grating of numerous small slits. As light shines through the slits, bright and dark fringes are seen on a screen some distance away from the grating. The user will be able to control (via intuitive controls on the interface) many different variables: the wavelength of light, the number of slits on the grating, the spacing between the slits, and the distance from the grating to the screen.

If possible, the principle of Rayleigh's Criterion will also be included. The representation of the principle in the program could simply be that the user will be told if the interference maxima on the screen are distinguishable or not according to the criterion.

4. Timeline and goals

My schedule (with tentative deadlines) is as follows:

Firstly: Learn how to efficiently use the Visual library of VPython. Learn LaTeX to submit all future updates and documentation.

1. As a proof of concept, recreate Young's Double Slit Experiment using the basic algebraic approximation:

$$y_m = \frac{m\lambda L}{d},$$

where y_m represents the vertical distance from the midpoint on the screen ($y = 0$) to the principal maximum, m identifies the principal maximum of interest, λ is the wavelength of incident light, L is the grating-to-screen distance, and d is the distance between the two slits on the grating. To be completed by 11/7/14, if not sooner.

2. Develop a graphical user interface for intuitive manipulation of λ, L, and d. Have the changes result in real-time variations in y_m. To be completed by 11/14/14.

3. Create a feature in the program that specifies if the slits on the screen satisfy Rayleigh's Criterion of resolution or not. This criterion is described by,
$$\theta_0 = \frac{\lambda}{a},$$
where θ_0 is the angle at which the first minimum is observed (angle is taken from the horizontal, where there is a principal maximum), and a is the width of a single slit. To be resolved, a second maximum must be placed at or beyond this minimum of the initial maximum fringe. To be completed by 11/21/14.

4. Adapt the simulation to multiple slits; this simulates an actual diffraction grating with N slits, used in spectrometers and other devices. Perhaps in this part of the simulation another aspect of resolution limitation can be included: a specific relation that sets a resolution limit on a given diffraction grating with many slits.
$$\frac{\Delta\lambda}{\lambda} \geq \frac{1}{Nm},$$
where $\Delta\lambda$ represents the resolution power, N is the number of slits, and m identifies which principal maximum is of interest. To be completed by 12/04/14.

Bibliography

[1] Feynman, Richard P.; Robert B. Leighton; Matthew Sands (1965). The Feynman Lectures on Physics, Vol. 3. US: Addison-Wesley. pp. 1.1–1.8. ISBN 0201021188.

[2] Robinson, Andrew (2006). The Last Man Who Knew Everything. New York, NY: Pi Press. pp. 123–124. ISBN 0-13-134304-1.

[3] "Young's Double Slit Experiment." OpenStax CNX. N.p., 17 Sept. 2014. Web. 15 Oct. 2014. <http://cnx.org/resources/dc45f72de39c65b1e7f2cf1a0ec14598/Figure_28_03_06a.jpg>.