Single and Double Slit Diffraction

Reference

http://chaos.swarthmore.edu/courses/Physics50_2008/P50_Optics/01_Interference.pdf
http://chaos.swarthmore.edu/courses/Physics50_2008/P50_Optics/02_Diffraction_1.pdf

Theory

Light of wavelength λ passes through a narrow slit of width a and is viewed on a screen a distance L away. If L is much greater than λ and a, the intensity of light as a function of the transverse distance y on the screen is given by

$$I(y) = I_0 \left[\frac{\sin\left(\frac{\pi a}{\lambda L} y\right)}{\left(\frac{\pi a}{\lambda L} y\right)} \right]^2 ,$$

where I_0 is the intensity at $y = 0$. Notice that the intensity equals zero when the argument of the sine function is a multiple of π (but not zero). Therefore, zeros of the intensity occur when

$$y = m\frac{\lambda L}{a}, \qquad m = \pm 1, \pm 2, \pm 3, \ldots$$

If the light passes through two slits of width a, separated by a distance d, then the intensity pattern at the screen is the same single slit diffraction pattern, but modulated by the interference caused by the two slits

$$I(y) = 2I_0 \left[\frac{\sin\left(\frac{\pi a}{\lambda L} y\right)}{\left(\frac{\pi a}{\lambda L} y\right)} \right]^2 \cos^2\left(\frac{\pi d}{\lambda L} y\right).$$

Notice that the maxima of intensity occur when the argument of the cosine function equals a multiple of π. This means the values of y at which the intensity is a maximum are given by

$$y = n\frac{\lambda L}{d}, \qquad n = 0, \pm 1, \pm 2, \pm 3, \ldots$$

Preliminary Experiment

Set up the laser (λ = 650 nm) so that it strikes a single slit with a = 0.04 mm. Observe the pattern that forms on a screen some distance away. Notice the strong central maximum, the zeros of the intensity on either side, and the very weak maxima on either side.

Now replace the single slit with a double slit (a = 0.04 mm, d = 0.125 mm). Observe how the single slit diffraction pattern is now broken up into closely spaced maxima and minima.

Finally, replace the double slit with 5 slits (a = 0.04 mm, d = 0.125 mm). Observe how much sharper the maxima are.

Experiment

Remove the screen and place the single slit (a = 0.04 mm) about 5 cm in front of the CCD camera. In addition, place the diverging lens in front of the laser in order to spread the beam out a bit. Leave enough room between the lens and the laser to slide a neutral density filter in later. Make sure the diffraction pattern is centered on the camera's shutter. Carefully slide a neutral density filter into the beam between the laser and the single slit in order to reduce the intensity so as not to overload the CCD camera. Follow the directions for operating the camera from the computer (CCDSoft), and take the shortest exposure possible. If the image is acceptable, save it according to the instructions. Don't hesitate to vary the distance from the slits to the camera, the angle of the slit wheel, amount of background light, etc., in order to get a good image for analysis. Transfer the file to the Mac using the flash drive provided, and analyze the image following the instructions for using the ImageJ software. First set the scale of the image (each pixel is 9 μm), and then by drawing a box on the image and selecting "Plot Profile", you can obtain a plot of I(y). Save the plot with a txt extension using the save button on the plot profile window.

Load the file into KaleidaGraph and plot intensity as a function of position. Then find the positions of the central maximum and of at least 2 minima on either side using either the spreadsheet or the plot. Make a plot of these positions vs. m, where m=0 for the central maximum, ±1 for the minima on either side of the central maximum, ±2 for the next minima on either side, etc. Fit a straight line to the data, and from the slope determine the wavelength of the light. You will have to measure, L, the distance from the single slit to the CCD chip, in order to do this calculation. Include a proper error analysis. Is your value consistent with 650 nm?

Repeat the procedure using a double slit (a = 0.04 mm, d = 0.125 mm). Determine the positions of at least 10 maxima, and make a plot from which you can determine λ from the slope. Is your value consistent with 650 nm.

If time allows, repeat the procedure for 5 slits (a = 0.04 mm, d = 0.125 mm). Be careful not to overload the CCD camera. Is the diffraction pattern what you expect?