Computerized Measurements

In the previous experiment, you observed interference and diffraction patterns projected onto a screen, and measured the projected patterns with a ruler. This week similar measurements will be made using a computerized data acquisition system. This allows you to go beyond "light" and "dark," to make quantitative observations of how the light intensity varies from point to point.

The apparatus

The apparatus consists of several components. Before you disturb the apparatus or turn anything on, be sure you know where all the following things are.

• The lasers are the same 632.8 nm He-Ne lasers used last time, and the same precautions apply: **Do NOT look directly into the laser beam or its reflections!**
• The targets, or holders, are the same single and double slit patterns used last time.
• Instead of observing the pattern on a screen, the light hits the end of an **optical fiber**, which guides the light into a **lux meter**. The lux meter measures the intensity of the light, generates a voltage proportional to the intensity, and displays it on a **meter**.
• A **linear motion stage** moves the end of the **optical fiber** in a straight line. You will use this to scan the optical fiber across the interference and diffraction patterns. An electronic position encoder measures the position of the stage, and converts it to a digital signal.
• You move the stage manually by slowly turning a **knob**. The care with which you do this will affect the quality of your data. You should move the stage in the same direction for all data runs, and ensure that the stage does not rock up and down vertically as you move it horizontally.
• Both the analog output of the lux meter (light intensity) and the digital encoder output (position) are connected to the **computer interface**. The computer can thus plot the light intensity as a function of position.

The computer

Log onto the computer using the name and password posted above the monitor screen. Double-click on the Data Studio icon to start the application. Click on **Open Activity** and select **WaveOptFinal**.

A. Diffraction by a Single Slit

In the last experiment qualitative observations of single slit diffraction were made to help understand the 2-slit interference pattern. This week quantitative measurements will be made.

The **minima** in the diffraction pattern are at locations such that $m\lambda = a \sin \theta$, where $a$ is the slit width, and $m$ is a non-zero integer. (The center of the pattern is bright.)

Place the **0.04 mm** wide single slit target on the laser optical bench, being careful not to disturb the vertical alignment of the optical bench and linear motion stage. Use a sheet of white paper in front of the sensor as a screen, and adjust the horizontal position of the slit to maximize the brightness of the pattern on the paper. Measure and record the distance from the **slit** to the optical fiber sensor. Verify that the optical fiber scans the entire diffraction pattern. Position your table lamp so that it does not directly illuminate the end of the optical fiber, but allows you to read the lux meter.
Turn on the lux meter, and set it to "1x", the most sensitive scale. This will send the meter off-scale in the central maximum, but is needed for the rest of the pattern. As you slowly and smoothly scan the end of the optical fiber across the diffraction pattern, the meter should show the peaks and valleys in the diffraction pattern. If you cannot see this, adjustments are needed before you attempt computerized data-taking. Ask the instructor for assistance.

Start with the sensor beyond one end of the detectable diffraction pattern. One partner can move the stage slowly and smoothly, at constant speed, in one direction only, watching the lux meter. The other partner can click the start & stop button, and monitor the data on the computer.

If you move the sensor too rapidly you will miss the fine details of the interference pattern. The computer samples the lux meter reading at a fixed frequency. Thus, it is possible to scan across details faster than the data is being recorded in the computer.

The graph shows light intensity as a function of position (in cm). With moderate care you should be able to identify three or four minima on either side of the center peak. If you can’t, please ask the instructor for help.

Once you have a good data set, you can record the positions of the intensity minima from the graph on the computer screen. The central maximum, which is off-scale on your graph, is twice as wide as the distance between adjacent minima. You can expand the graph, zoom in on a portion, and use the cursor to read the positions of the minima. Record these positions now in a table of Position versus m (using positive m on one side of the maximum, negative m on the other). Print your graph twice (once showing the full graph, once when zoomed in on some of the minima). Save the file under your name before doing the next part.

Once you have recorded the data for the single slit on your data sheet, and saved or printed everything you will need, you can continue with this next part of the experiment. Adjust the luxmeter sensitivity so that it does not go off scale in the central maximum, but such that the maximum reading is at least 80% of full-scale. Use the variable knob if needed. This typically corresponds to a luxmeter sensitivity setting of about 10 or 30. Scan the diffraction pattern, and record the data on the computer as before. With care you will see a small peak on each side of the central maximum, but probably not much more. This data is for reference in the next portion of the experiment.
B. Double-Slit Interference

Now, replace the single slits with the double slit patterns. Use the 0.04 mm slits spaced 0.25 mm apart, and measure the distance to the sensor. As before, adjust the position to maximize the light on a screen in front of the sensor. Adjust the sensitivity of the luxmeter so that it does not go off scale as you scan the central maximum, but such that the maximum reading is at least 80% of full-scale. Use the variable knob if needed. As in the previous case, this typically corresponds to a luxmeter sensitivity setting of about 10 or 30.

Record a new data set for the double slits. Notice that the 2-slit interference pattern is superimposed on the central maximum of a single-slit diffraction pattern. Expand and rescale the graph, and print a copy to include with your lab report.

The maxima in the 2-slit interference pattern are at locations such that

\[ m\lambda = d \sin \theta , \]

where \( d \) is the slit separation, and \( m \) is a non-zero integer. (The center of the pattern is bright.)

Record the positions of each maximum on your data sheet.

For the final set of data set the lux meter to "1x", the most sensitive scale. This will again send the meter off-scale in the central maximum. Scan the interference pattern and record the data. Usually you will see the interference pattern in three or four of the maxima on each side of the central maximum.

As before, record the positions of the interference maxima on the data sheet. You will miss the maxima that would have occurred in the valleys of the single slit interference pattern. Indicate on a data sheet where these are, and approximately how many were not visible. Print a copy of the graph for your lab report.

C. Data Analysis and Lab Report

In your report, please include a brief introduction to the experiment and the theory behind it. For the single and double slit interference patterns describe briefly what you measured and include a table of your data and any printouts. In the discussion and analysis section, address the following questions :

1) Qualitative relation between the diffraction and interference patterns:
Referring to your graphs (or a hand sketch) of the two diffraction patterns, identify their most important features. How are the two patterns alike, how are they different?

2) Single Slit Diffraction
You will probably have recorded the positions of 6 to 8 minima for single slit diffraction. The task at hand is to use this data, along with the known 632.8 nm wavelength of the laser light to calculate the slit width. The best result will use all recorded data to calculate the slit width and an experimental uncertainty.
Since the minima are equally spaced (except for the central maximum which has twice the usual spacing) this can be done using a graphical technique, plotting the positions of the minima vs. a set of integers. In this case, the averaging is done by fitting a straight line to the data, and the slope provides the average spacing between minima.

From your data calculate the slit width, and the uncertainty in your result. Compare your result with the stated slit width of 0.04 mm. Include enough detail for a careful reader to understand what you have done, and how you obtained your result.

Note: in deriving the slit width from the slope, you will have used the small angle approximation
\[ \sin \theta \approx \tan \theta = \frac{x}{L}, \]
where \( L \) is the distance from the slit to the sensor, and \( x \) is the distance from the center of the interference pattern to the point (maximum or minimum) of interest. In your lab report calculate the percent error made by this approximation for the largest value of \( x \) in your data. Does this introduce a significant uncertainty in your value for the slit width?

Theory predicts that the intensity of the diffraction peak adjacent to the central maximum has an intensity relative to the central maximum of \( 4/(9\pi^2) \sim 0.045 \). What do you find?

3) Double-Slit Interference:

Central Region: The data taken in the central region of the diffraction pattern (with reduced lux meter sensitivity) will have the positions of several equally spaced maxima. These can be combined, as in the previous part, to obtain the average spacing. From this the slit separation can be calculated.

From your data calculate the slit separation, and the uncertainty in your result. Compare your result with the stated slit separation of 0.25 mm. Include enough detail for a careful reader to understand what you have done, and how you obtained your result.

Side Regions: The data taken in the side regions of the diffraction pattern, at full lux meter sensitivity, will have the positions of several equally spaced maxima. There are exceptions where a minimum in the single slit pattern precludes seeing one or more maxima. The positions of the maxima can be plotted vs. integers. If the graph takes into account the missing maxima (by not plotting a position for those integers where nothing was recorded) the graph will be a straight line. As above, the slope of the line is the average spacing between adjacent maxima.

For the data on each side of the central maximum, again, calculate the slit separation and uncertainty. Compare this result with the stated 0.25 mm separation.

Finally: If you have calculated the slit separation for the central region, and for each side separately, you have three determinations. Average these determinations to obtain a final result and uncertainty.