Double Slit Interference:
Measuring the Wavelength of Light
Spring 2024

Introduction

The purpose of this experiment is to measure the wavelength of the red light from a Helium-Neon laser *and* to include an estimation of the uncertainty in this result. **NOTE**: *THERE WILL BE SEVERAL LASERS TURNED ON DURING THIS EXPERIMENT; EXERCISE CAUTION AT ALL TIMES!*

Theory

Figure 1 defines the variables to be measured; note that you'll see many more image orders than shown. We will assume that the wall is far enough away from the slits so that the small angle approximations are valid (for very small angles, $\sin\theta \approx \tan\theta$).

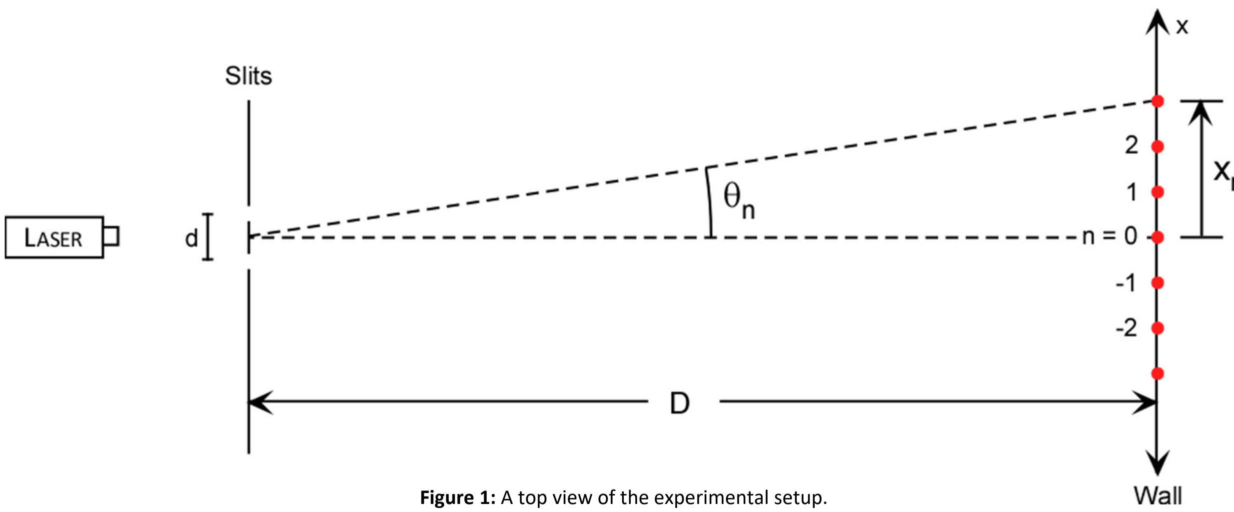

Figure 1: A top view of the experimental setup.

The condition for constructive interference is

$$n\lambda = d\sin\theta_n \approx d\tan\theta_n = d\frac{x_n}{D}$$

Solving for the positions of the bright spots we get, after some rearrangement,

$$x_n = \lambda\frac{D}{d}n$$

If we plot x_n vs. n, we should get a straight line passing through the origin with a slope $m = \lambda\frac{D}{d}$. Since we can easily measure the distance from the slits to the wall (D), and with a bit of work find the slit separation (d), it is straightforward to get the wavelength by $\lambda = m\frac{d}{D}$.

Experiment

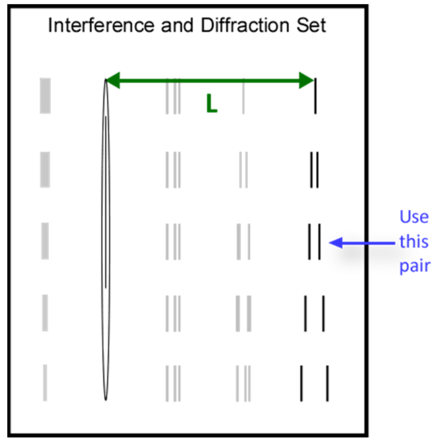

Figure 2: The Cornell Slide.

1. Shine a laser directly on the center pair of double-slits on the Cornell slide (**Figure 2**) so that a good double slit interference pattern is illuminated on a piece of paper taped to the wall.
2. Mark the position of the Cornell slide on the bench with a piece of tape. Measure **D**, the distance from the slide to the wall. *Do Not remove this tape until you leave the lab!*
3. Identify the central bright spot, and carefully mark the center of the spot. Label this position "$n = 0$".
4. Continue to mark the centers of the spots, <u>10 each to the right and left of the central spot</u>. You will find it useful to use a ruler to mark the spot centers along a straight line.
5. Remove the paper from the wall, and then label the adjacent spots ±1, ±2, etc. Remember that single slit diffraction puts a *min* on top of a double-slit interference *max*, so if a spot seems to be "missing", make sure you *skip* a number!
6. Measure the distance, x of each spot from $n = 0$ using a ruler. Measure to 0.1 *cm*, and leave all your measurements in centimeters (you'll convert at the end).
7. Enter your data in KaleidaGraph and find the slope *and uncertainty* of the x vs. n line, as well as the SSR. Recheck points that deviate from the best-fit line, and then print the graph. <u>If your SSR is much larger than 0.1 cm^2, then you should check the numbering of n</u>.
8. The slit separation can be determined using the following procedure:

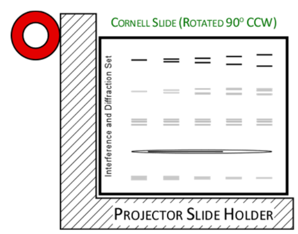

Figure 3: Place slide in Projector.

   a. Place the Cornell slide in the slide projector as follows: facing the wall, hold the slide so that you can read the label at the top. Rotate the slide 90° counterclockwise, and then place in the slide holder (**Figure 3**). This will project an image of the slits in a position that's easier for you to measure on the wall.

   b. Use a pair of vernier calipers to measure $\mathbf{d_{wall}}$, the projected distance between the *centers* of the pair of slits used, as follows: Measure the distance between the top edges of the slit images; ***reset the caliper to zero*** and measure the distance between the bottom edges of the slits (**Figure 4**). Measure near the ends of the slits as shown; this will give better results if the projector is not perpendicular to the wall.

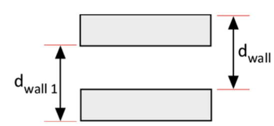

Figure 4: Measuring slit width.

9. Calculate $\langle \mathbf{d_{wall}} \rangle$, the average of your two measurements. Estimate the uncertainty of this measurement, $\Delta \mathbf{d_{wall}}$, by <u>calculating the difference (*not % Difference!*) between your two measurements of $\mathbf{d_{wall}}$</u>. *Throughout this experiment we will use the symbol Δ to represent uncertainty*.
10. Measure $\mathbf{L_{wall}}$, the length of **L** as it is projected on the wall (**Figure 2**). Then use vernier calipers to measure $\mathbf{L_{slide}}$, the length of **L** directly on the slide. <u>*Pro tip*</u>*: You can use the laptop display as a light table!*

Analysis

1. <u>*Calculating the wavelength of the laser, λ:*</u> You can now calculate **d**, the actual slit spacing on the slide, by setting up the ratio below. Since the projected image on the wall is a larger scaled version of the slide, <u>the ratio between *d* and *L* will always be the same</u>, whether measured on the slide or on the wall. Calculate your value of **d** and *check with your instructor that your value is reasonable before continuing*.

$$\frac{\langle d_{wall} \rangle}{L_{wall}} = \frac{d}{L_{slide}}$$

2. Calculate the wavelength from your values of **d** and **D**, and the <u>slope</u> from your KaleidaGraph plot. Convert the wavelength to units of nanometers (*nm*). Record your value of λ to 0.1 *nm* (recall that 1 *nm* = 1×10^{-9} *m*).
3. Ask your instructor for the actual value of λ to make sure you're on track.

Calculating the uncertainty in wavelength, $\Delta\lambda$:

- In previous experiments, we have calculated the uncertainty in a parameter by simply using the standard error in that parameter, as calculated in KaleidaGraph. In this week's experiment, the uncertainty in the wavelength depends on the uncertainty in the slope of the best-fit line as well as the uncertainty in the slit-separation, *d*. Follow the steps below to combine these uncertainties.

4. Estimate the uncertainty in the wavelength, $\Delta\lambda_{\mathbf{slope}}$, due to the uncertainty in the slope of your graph, Δm. Recall that the uncertainty in the slope is twice the standard error from KaleidaGraph:

$$\Delta\lambda_{slope} = \Delta m\left(\frac{d}{D}\right)$$

5. Another source of uncertainty comes from the measurements you made to determine the slit spacing **d**. Using your estimate of the uncertainty in your measurement of $\mathbf{d_{wall}}$, calculate the uncertainty in **d** using the following equation:

$$\Delta d = \Delta d_{wall}\left(\frac{L_{slide}}{L_{wall}}\right)$$

6. Now you can find the uncertainty in the wavelength due to the uncertainty in the slit separation:

$$\Delta\lambda_{slit} = \Delta d\left(\frac{m}{D}\right)$$

7. Which uncertainty is larger: the one due to the slope of the graph, or the one due to the slit spacing? Combine these two uncertainties by taking the square root of the sum of the squares.

$$\Delta\lambda = \sqrt{\left(\Delta\lambda_{slope}\right)^2 + \left(\Delta\lambda_{slit}\right)^2}$$

8. Compare your calculated wavelength to the actual value provided by your instructor and see if your result is consistent within the measurement uncertainty.

Discussion

- Restate your calculated value and uncertainty of λ, and discuss the source of errors involved in its calculation (*why were some lengths difficult to measure with precision?*)
- Did the actual value of λ fall within the calculated range of your measurement uncertainty?
- Of all the measurements you made in this experiment, which one do you think is the most sensitive to small measurement error? Explain your reasoning.
- <u>Be sure to attach the target sheet to the back of one of your journals!</u>

WHEN FINISHED, PLEASE TURN OFF THE FLASHLIGHT AND LASER, AND REMOVE ANY TAPE APPLIED TO THE LAB BENCH!