Interference of Light using Lasers

1 Object

To investigate, understand, and verify how interference of coherent, monochromatic light depends on the width, separation, and number of slits upon which the light is incident.

2 Apparatus

Laser, meter stick, caliper, slit panel, stands.

3 Theory

3.1 Single Slit

A single slit will cause diffraction of light impinging upon it. That is, the light does not simply pass through and follow a straight line to the wall or screen some distance away. The light actually bends at the edges, and a single slit diffraction pattern forms on the wall. The theory here is that the light at the slit can be thought of as many tiny point sources of spherical waves which propagate out from each source in the forward direction. In figure 1 the slit of width a is divided in half. One then looks at a ray at the top of the upper half and at the top of the lower half (*i.e.* at the middle). We can see from the geometry of figure 1 that at a certain angle θ from straight ahead that there will be a path difference δ (the additional distance the lower ray travels) given by

$$\delta = \frac{a}{2}\sin\theta$$

where a is the width of the slit. If δ is equal to half of a wavelength of the light, $\lambda/2$, then destructive

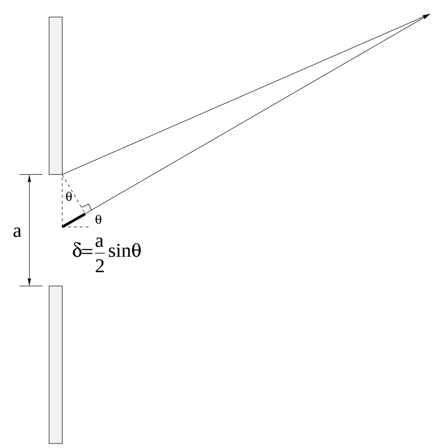

Figure 1: A single slit showing two rays and the path difference δ mentioned in the text.

interference will occur between these two rays – they add by the principle of superposition and cancel out because they are exactly out of phase by 180°. The next two rays (each one just below each of the ones shown) will also add destructively at the same angle, and so on down the pairs. This results in complete cancellation of the light at the angle θ:

$$\frac{a}{2}\sin\theta = \frac{\lambda}{2}$$

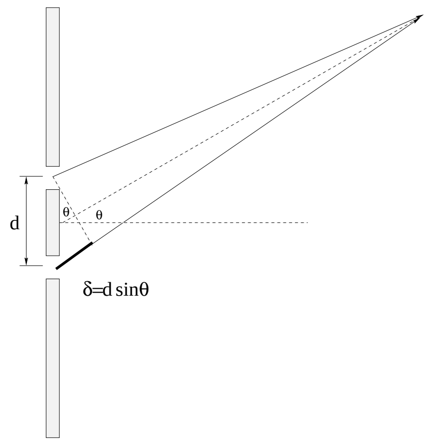

Figure 2: A double slit showing two rays and the path difference δ mentioned in the text.

If we go out to a larger angle θ and subdivide the slit into quarters, the path difference between successive upper-most rays will be $\lambda/2$ for destructive interference. The path difference between two successive rays is now $\delta = \frac{a}{4}\sin\theta$, giving us

$$\frac{a}{4}\sin\theta = \frac{\lambda}{2}$$

If we subdivide the slit still further into six parts, we get

$$\frac{a}{6}\sin\theta = \frac{\lambda}{2}$$

Noting the trend, we can write for the dark places for a single slit:

$$a\sin\theta_s = m\lambda \tag{1}$$

where θ_s is the angle for minima for the single slit, and $m = 1, 2, 3, \ldots$.

3.2 Double Slit

A double slit is shown in figure 2. Here, each slit sends out light and we can treat each as a point source sending out spherical forward waves. The path difference between the light from each slit at an angle theta is $\delta = d\sin\theta_d$, where d is the separation of the slit. For constructive interference the path difference should be an integral number of wavelengths:

$$d\sin\theta_d = n\lambda \tag{2}$$

where $n = 0, 1, 2, 3, \ldots$ is an integer. For destructive interference, the path difference should be an odd half integer multiple of the wavelength:

$$d\sin\theta_d = (n + \frac{1}{2})\lambda \tag{3}$$

where n is again an integer like above.

Furthermore, each slit produces a diffraction pattern with minima at angles given by equation 1, so that the resulting pattern is the double slit pattern with a single slit pattern superimposed. An example of the intensity as a function of angle (for $d \simeq a$) is shown in figure 3.

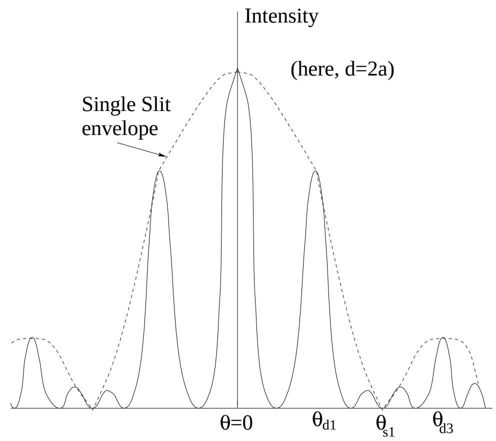

Figure 3: An intensity plot for double slit interference where $d \simeq a$ has been assumed. The single slit pattern is the envelope of the double slit pattern.

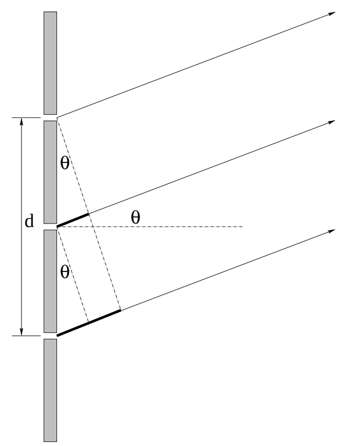

Figure 4: The geometry for the triple slit.

3.3 Multiple Slit

The situation for three slits a distance d apart is slightly more complicated. The first complete constructive interference occurs when all three rays arrive at the wall in phase. This means that the second ray has a path difference of λ with respect to the first, and the third has $\delta = 2\lambda$. Therefore, we can write:

$$d \sin \theta = 2\lambda$$

The first complete destructive interference occurs when all three waves add to zero, which is when they are all 120° or $\lambda/3$ out of phase. Using the geometry of figure 4 this can be written as:

$$d \sin \theta = \frac{2}{3}\lambda$$

The next cancellation occurs when all rays are 240° or $2(\lambda/3)$ out of phase. What happens between these two? The mid point between these two minima corresponds to the equation $d \sin \theta = \lambda/2$. Checking with the geometry shows that this is the case where the first two waves have a path difference of $\lambda/2$ (and interfere destructively), and the first and third have a path difference of λ

and interfere constructively. Hence, this point is called a secondary maximum. This is shown in figure 5.

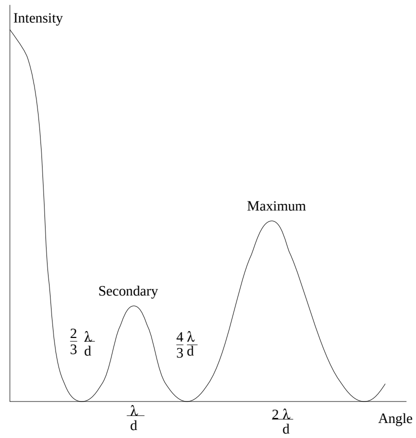

Figure 5: The intensity plot for the triple slit.

The principle maxima are still found via the following equation:

$$d \sin\theta = n\lambda \quad \text{where} \quad n = 0, \pm1, \pm2, \ldots \tag{4}$$

3.4 Grating

Diffraction gratings are covered in text books, so the result is quoted here. The equation for principle maxima for a diffraction grating is

$$d \sin\theta = n\lambda \tag{5}$$

where d is the separation between adjacent slits and $n = 0, 1, 2, 3, \ldots$.

4 Procedure

4.1 Single slits

1. Place the laser on a table and position the panel so that the beam encounters the first single slit and the pattern is projected onto the wall. WARNING: Never look directly at the laser beam with your eyes – permanent damage can occur.

2. See the accompanying figure of the slit panel as a reference for which slits are which as well as for actual values for dimensions.

3. Measure the distance from the panel to the wall and record.

4. Adjust the panel until the beam is best incident on the first single slit.

5. Adjust further until the clearest single slit pattern is visible on the wall. Then measure the distance between corresponding minima on either side of the central maximum. Do this for each of the next seven pairs of minima.

6. Repeat this for each of the other single slits.

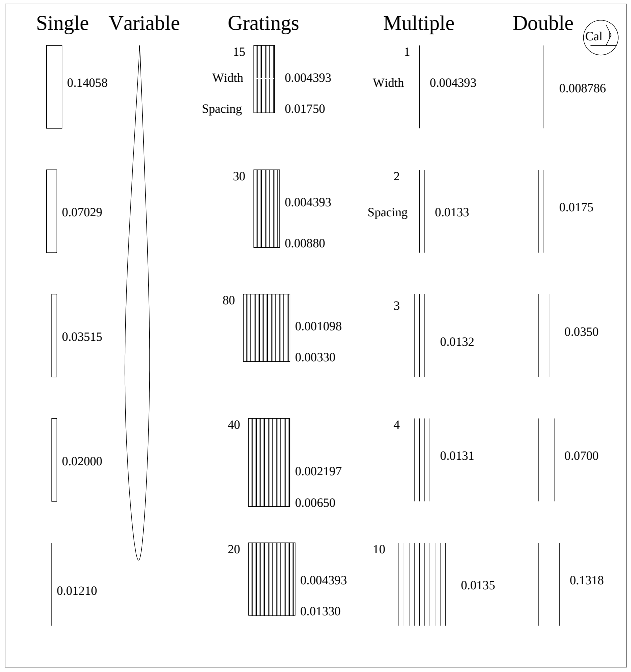

Figure 6: The panel contains single slits, a variable slit, gratings, multiple slits, and double slits as indicated. The dimensions are in cm as indicated on the figure.

4.2 Double Slit

1. Now adjust the panel so that the first double slit is illuminated and adjust so that the pattern on the wall is the best.
2. Measure between corresponding maxima on either side of the central maximum and record. Do this for each of the next seven pairs of maxima.
3. Repeat for the rest of the double slits.

4.3 Multiple Slits

1. Adjust the panel to illuminate multiple slit number 3 (one is a single slit and 2 is a double slit).
2. Measure between corresponding maxima on either side of the central maximum and record.
3. Record the number of intermediate maxima you see between each set of principle maxima.
4. Repeat for the other multiple slits.

4.4 Diffraction Gratings

1. Shine the laser onto grating number 1.
2. Measure between corresponding maxima on either side of the central maximum and record.
3. Measure the width of the grating on the plate.
4. Repeat for the other gratings.

5 Calculations

5.1 Single Slits

1. Calculate the slit widths using your data for the location of the minima for each slit. Calculate means and errors on these widths as well.

2. Compare your values to the values given in figure 6.

5.2 Double Slits

1. Calculate the slit separation for each slit using the location of the maxima in your data. Calculate means and errors on these separations as well.

2. Compare your values to the values given in figure 6.

5.3 Multiple Slits

1. Calculate the slit separations using the data for the location of each principle maximum. Calculate means and errors for each multiple slit as well.

2. Determine how many slits were in each "grating."

3. Compare to the values given in figure 6.

5.4 Grating

1. Calculate the slit separation for each grating from your data. Calculate means and errors for each slit.

2. Compare to the values given in figure 6.

3. Calculate the number of slits each grating should have using the width. Compare.

6 Questions

1. If we were to use microwaves instead of the laser, what changes would need to be made to the lab?

2. Do diffraction effects get more or less noticeable as the slit width increases? Use your data to back up your answer. Why??

3. Explain, in words, why increasing the number of slits in a diffraction grating improves the resolution capabilities of that grating. What leads to higher resolution ability?

4. Estimate the reading error in a single slit measurement to a dark spot. Assuming this error, calculate how much error you get for the slit width. Is this comparable to your statistical error for the same slit width?