INTERFERENCE and DIFFRACTION

Short description:
In this experiment you will use interference effects to investigate the wave nature of light. In particular, you will measure diffraction patterns produced by one or more slits, and the results will be used to determine the wavelength of the light.

Equipment:

- Optical Bench
- Red Laser
- Multiple-slit accessory with holder
- Viewing screen and Ruler

Theory:
When coherent light, such as that from the laser used in this experiment, passes through one or more slits in a screen, we can think of the light reaching the screen as the superposition of waves coming from different points of the slits. These waves interfere when they reach the screen – often we call the effects of interference between waves from the same slit “diffraction” and those of interference between waves from different slits “interference”, but it is the same phenomenon in both cases (diffraction is the interference of a ray of light with itself).

Diffraction

Figure 1 shows the intensity distribution of the diffracted light for a single slit of width \( a \). At the center of the pattern (\( y=0 \)) the rays from all parts of the slit add (interfere constructively). At the first minimum (\( y_1 \)) the two sides of the slit produce waves out of phase by \( 2\pi \), and because there are also all phases in between, they add up to zero.

![Figure 1 - Diffraction](image)
The positions of the minima in Fig. 1 are given by the equation

\[ m\lambda = a \sin \theta, \quad m = 1, 2, 3 \ldots \]  

(1)

The position of the first minimum on the screen (\(y_1\) in Fig. 1) is \(y_1 \sim L\lambda/a\), in the small-angle approximation. Notice that the width of the central maximum in Fig. 1 is twice that of the secondary maxima and that the secondary maxima get progressively weaker as \(\theta\) increases. The location of the maxima is about halfway between two minima.

Interference

When light passes through two slits, if they are infinitely narrow there are only two waves interfering and we get a \(\cos^2\) pattern as shown in Fig. 2.

\[ (m + 1/2)\lambda = d \sin \theta, \quad m = 0, 1, 2, \ldots \]  

(2)

The maxima in Fig. 2 are given by

\[ m\lambda = d \sin \theta, \quad m = 0, 1, 2, \ldots \]  

(3)

(Note that the horizontal axis is the path length difference – if we plotted against the distance \(y\) on the screen, the first maximum would be at \(y \sim L\lambda/d\).)

If the slits are not infinitely narrow, many waves from the same slit can interfere (“diffraction”). This has no effect at the center of the pattern (\(y = 0\) or \(\theta = 0\)), since the waves travel the same path length to the screen (they are in phase). As \(\theta\) increases, the waves from each individual slit get more and more out of phase with each other, and the maxima get smaller, until at \(y_1\) (defined in Fig. 1) the intensity goes away entirely, as in Fig. 1. We can think of the intensity graphed in Fig. 1 as an “envelope” controlling the height of the peaks in Fig. 2. If the slit width is much smaller than the slit spacing (\(a \ll d\)) then the length scale on which this “diffraction envelope” changes is much larger than the length scale of the interference peaks in Fig. 2 (\(y_1 \sim L\lambda/a \gg L\lambda/d\), the spacing between maxima.) Thus the overall pattern looks like Fig. 3.
(Mathematically, this is the product of the two functions plotted in Fig. 1 and Fig. 2.)

**Preliminary questions:**

1. Light of wavelength 600 nm passes through a single slit of width 0.1 mm and is then projected onto a screen 2 m away. What is the angular width of the central diffraction maximum?

   What is the width in cm of this maximum on the screen?

2. A double slit, which has a center-to-center slit separation of 0.3 mm, is used in place of the single slit in (1). What is the angular width of an interference maximum?

   What is the width in cm of a maximum on the screen?

**Procedure:**
Set up the laser at one end of the optical bench and place the single slit disk in its holder about 3 cm in front of the laser. Cover the screen with a piece of paper and attach it to the other end of the bench so the paper faces the laser.

**Question:** When the slit width is increased, does the distance between minima increase or decrease?
Find the **variable width slit** and use it to check if your answer to the previous question was correct.

**PART 1: Single slit – Diffraction**

Select the $a = 0.04$ mm slit by rotating the slit disk until the 0.04 mm slit is centered in the slit holder. Adjust the position of the laser beam from left-to-right and up-down until the beam is centered on the slit.

Determine the distance from the slit to the screen.

$$L = \text{__________cm}$$

Note that the slit is actually offset from the centerline of the slit holder.

With the room lights off, mark the positions of the minima in the diffraction pattern on the paper the screen. With your writing light on, measure the distance between the two first order ($m = 1$) marks, and record this distance. Do the same for the second order ($m = 2$) marks.

Sketch below the pattern you observe:

![Pattern Sketch](image)

Use your data to determine the wavelength of the laser light.

<table>
<thead>
<tr>
<th>Order of the minima</th>
<th>Distance between the two marks</th>
<th>Wavelength $\lambda$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m = 1$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$m = 2$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

You should get a value from both the first and second order minima. Does your value seem reasonable?

Change the slit width to $a = 0.02$ mm. Sketch this pattern also. (No calculation.)

![Pattern Sketch](image)
PART 2: Multiple slits – Interference

Remove the single slit disk, and install the multiple slit disks. You will now do much the same set of measurements as in part 1 to explore the nature of the multiple slit interference patterns. In this case, however, you will mark the maxima, not the minima.

Use the double slits of separation \( d = 0.25 \text{ mm} \) (and \( a = 0.04 \text{ mm} \)). Increase distance \( L \) between the screen and the slit as much as possible. Mark the positions of the 1\(^{\text{st}}\) and 2\(^{\text{nd}}\) order maxima, and measure the separation between them.
From this data, again calculate the wavelength of the laser light.

<table>
<thead>
<tr>
<th>Order of the maxima</th>
<th>Distance between the two marks</th>
<th>Wavelength ( \lambda )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( m = 1 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( m = 2 )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Compare to your previous value obtained for \( \lambda \).

What will happen to the interference pattern if you increase the slit separation \( d \) ?

After writing down your prediction, try it and see if you are correct.

What happens when you send the laser beam through more than two slits? Describe your observations.