Objective: To see how light waves interfere constructively and destructively. To observe interference and diffraction. To measure small apertures or objects from their diffraction patterns.

Apparatus: Diode lasers (red, green) & AC adapters, Single Slit Set, Multiple Slit Set, diffraction grating (or CD/DVD disc), optical bench and white rectangular projection screen (also used for Geometric Optics lab)

Introduction

You may have learned from lecture that light has wave properties, and that two light waves of the same frequency can add up constructively (bright areas) or destructively (dark areas) depending on the path difference (the difference in distance from each light wave to the point where they meet) or their phase (the point in the wave cycle at a particular point in time – for instance, a wave described by the sine function leads a wave by the cosine by 90 degrees).

Waves add up either when the original light wave is split up into two constituent waves (double slit interference) or when the same portions of the original light wave interfere with themselves (single slit or grating diffraction). The equations describing the position
of the bright spots (maxima) or dark spots (minima) of light coming out of a slit or grating projected upon a screen far away are summarized as follows:

**Single Slit**

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

Here \( b \) is the width of the single slit, \( \theta \) is the angular deflection (as measured from the middle of the central maxima, at which the path difference is zero and there is maximum addition of the two waves) of the dark areas (minima) on a screen far away, \( \lambda \) is the wavelength of the incoming light and \( m \) is the order of the minima – the higher order minima are farther from the central maxima; positive minima are to the right of the central maxima, while negative minima are to the left of the central maxima. See the diagram below:

Note that in this lab you will find single-slit diffraction to be useful in determining the sizes of very small things. For small apertures, you can determine the size from the equation above. For small obstructions, you can use the same equation if you employ what is called Babinet’s Principle - the diffraction pattern for an aperture is the same as the pattern for an opaque object of the same shape illuminated in the same manner. That
is, except for the intensity of the central spot, the pattern produced by a diffracting opening of arbitrary shape is the same as a conjugate (the inverse pattern) of the opening would produce. Therefore, the spacings between the minima will be the same for an aperture (slit) and an obstruction of the same size. Therefore, the distance from the center of the central maximum to the first minimum may not be the same for the obstruction as it is for the aperture because it is shifted away from it since the patterns of the two, superimposed on each other, would yield darkness. However, the spacing distances should be the same.

Double Slit

\[ d \sin \theta = n \lambda, \quad n = 0, 1, 2, 3, \ldots \]

Here \( d \) is the distance between the slits, \( \theta \) is the angular deflection between the adjacent bright spots (as measured from the central maxima on a screen far away). Technically, \( \theta \) is the very small angular deflection between the *small* center bright spot (within the single-slit profile), but the distances between any two adjacent bright spots is the same. \( \lambda \) is the wavelength of the incoming light and \( m \) is the order of the maxima. Do note that the angles are a lot smaller than that of the single-slit; from the diagram above, you can about 13 of them fit within the single-slit profile. Also see the diagram below:
Note that the above diagram shows an idealized double slit, which ignores the single slit character of each of the two single slits. A true double slit would exhibit closely spaced dark and light areas (fringes), superimposed over the single slit pattern. The single slit profile, or “envelope”, is said to modulate the double slit pattern, as shown below:

\[ d \sin \theta = n \lambda ; m = 0,1,2,3,... \]

The equation here is the same for the double slit case, except that \( d \) represents the spacing between grating lines (distance). You will have to calculate this from the table below, which lists lines per unit distance. The situation is still very similar to the double slit because there are many lines interfering constructively; the resulting diffraction pattern is therefore very sharp.
Red laser (L to R: front view, rear view, AC adapter). Note in the rear view the On/Off switch, the AC adapter socket, and two knobs to adjust the beam horizontally/vertically.

Green laser (L to R: front view, rear view, AC adapter). Note in the rear view the On/Off switch, the AC adapter socket, and two knobs to adjust the beam horizontally/vertically.
Single Slit Set (L) and Multiple Slit Set (R). You can rotate the wheel to select from a variety of apertures/obstructions, then aiming the laser through one of these to produce the interference/diffractive pattern.

When both the laser and Single/Multiple Slit Set are mounted on the optical bench (former aimed at the latter), the beam should hit roughly at the center of the holder circle. Fine-tune the beam by adjusting the vertical & horizontal knobs, so it hits the desired aperture/obstruction. You may need to rotate the wheel’s attachment point to the holder first.

<table>
<thead>
<tr>
<th>Single Slit Set:</th>
<th>Multiple Slit Set:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Circular Apertures</strong></td>
<td><strong>Multiple Slits and Double Slits</strong></td>
</tr>
<tr>
<td>The two circular apertures have diameters of 0.2 mm and 0.4 mm.</td>
<td>Each slit pattern is characterized by the number of slits, the slit width (a), and the center-to-center spacing (d).</td>
</tr>
<tr>
<td><strong>Single Slits</strong></td>
<td></td>
</tr>
<tr>
<td>The four singles slits have widths of 0.02 mm, 0.04 mm, 0.08 mm, and 0.16 mm.</td>
<td>**</td>
</tr>
<tr>
<td><strong>Variable Slit</strong></td>
<td>**Number of Slits</td>
</tr>
<tr>
<td>The “Variable Slit” is a wedge-shaped aperture ranging from 0.02 mm to 0.20 mm wide. Rotate the wheel to illuminate any point along the length of the slit.</td>
<td>2</td>
</tr>
<tr>
<td>Other Patterns</td>
<td>3</td>
</tr>
<tr>
<td>We won't use these in this experiment.</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>
Activities

You will use a human hair (which one lab partner will provide), the Single Slit Set (single slit) and the Multiple Slit Set (double slit, diffraction grating) to investigate interference and diffraction. Measuring the distance from the slide to the screen and the distance from the central maxima to the maxima or minima in question will give you the angle with some calculation; remember that you can utilize small angle approximations only if the distance from the slide to the screen is large compared to the distance from the minima/maxima to the central maxima.

*Make sure that the distance from the laser to the aperture/obstruction is small, and the distance from the aperture/obstruction to the screen is great – all on the optical bench. This will make your interference and diffraction as large and as easy to measure as possible.*

A. Single Slit

Devise an experiment to measure the wavelength of the laser light using a single slit. You will need the *Single Slit Set for this part.* **Use two single slits of different widths and average your results.** Note that in the equation, the only unknown variable is $\lambda$ while the other variables are known or measurable. Remember that the equation gives the positions of the minima. Compare the wavelength you measured to the labeled value.

B. Double Slit

Devise an experiment to measure the wavelength of the laser light using a double slit. You will need the *Multiple Slit Set for this part.* **Use two double slits of different spacings and average your results.** Note that in the equation, the only unknown variable is $\lambda$ while the other variables are known or measurable. Remember that the equation gives the positions of the maxima and that you should measure the distances between the small dark areas inside the single slit envelope, not the large-spaced distances between the single slit envelope minima. Since these distances are smaller than that of the single slit, you may wish to measure the width of the central single-slit envelope and divide by the number of slits therein – this is similar to determining the thickness of a single page of a book by measuring the book's thickness and dividing by the number of pages. Compare the wavelength you measured to the labeled value.

C. Diffraction Grating

Devise an experiment to measure the wavelength of the laser light using a diffraction grating. You will need a diffraction grating or CD/DVD *for this part.* **Note that in the equation, the only unknown variable is $\lambda$ while the other variables are known or measurable. Remember that the equation gives the positions of the maxima and that $d$ is the spacing between grating lines (specification is given as number of lines per unit distance).** Compare the wavelength you measured to the labeled value.
D. Measure the thickness of a human hair

Devise an experiment to measure the thickness of a human hair. You or your one of your lab partners will have to provide the hair. Explain how your experiment will measure the thickness and show all your calculations. Use the labeled wavelength of the laser. Please do not tape anything to the lasers or the Single/Multiple Slit Sets; it is difficult to remove scotch or masking tape and doing so may smear or erase the markings.

E. Green Laser (if time permits; to be done at your instructor's discretion – he/she may offer this for 10% extra credit)

In addition to the red laser, there is also the green laser. Measure the wavelength of the green laser light, using the method of your choice, and compare to the labeled value.