In this laboratory, we will perform two experiments on “wave” optics.

1 Double Slit Interference

In two-slit interference, light falls on an opaque screen with two closely spaced, narrow slits. As Huygen’s principle tells us, each slit acts as a new source of light. Since the slits are illuminated by the same wave front, these sources are in phase. Where the wave fronts from the two sources overlap, an interference pattern is formed.

Interference maxima will occur when the overlapping waves are in phase. This happens when the path difference from the slits to the observation point is an integral number of wavelengths of the light. If $d$ is the slit separation, then the path difference, as shown in Figure 1 is $d \sin \theta$. So

$$\sin \theta_{\text{max}} = \frac{m \lambda}{d} \quad (1)$$

where $m$ is an integer.

In this experiment we will measure the angles $\theta_{\text{max}}$ for light of wavelength 650 nm, and slits of known separation 0.25 mm.

In the “ideal” two-slit interference experiment, the width of each of the two slits is much smaller than a wavelength of light. This makes each slit produce an approximately isotropic distribution, i.e. the same in all directions. But in order to produce enough
light for you to see, this apparatus has slits which are large enough that their angular distribution is not isotropic; each slit produces an intensity pattern which corresponds to diffraction by a single narrow slit. The overall result you will see is the combination of these patterns, shown in Figure 2.

![Figure 2: Intensity and diffraction “envelope” vs. angle for a similar setup.](image)

**Procedure**

1. Set up the diode laser and the slit set as shown in Figure 3.

![Figure 3: Diode laser and slit set arrangement.](image)

Then set up the white viewing screen at the far end of the optical “bench”, as shown in Figure 4.
2. Turn on the laser, and adjust the beam and rotate the slit wheel until the beam hits the double slit set which has separation \(d\) of 0.25 mm, and width 0.04 mm. **Do not look directly into the laser.**

3. Observe the interference pattern on the screen. You will probably need the room lights off for this. Fasten a piece of paper to the screen, and mark the paper at many maxima on each side of the central maximum.

4. Measure the distances from the central maximum \((y = 0)\) to the different maxima, \(\Delta y_m\). Also measure the distance from the slit to the screen. Use these to figure out the angles \(\theta_{\text{max} \ m}\). Measure \(\Delta y_m\) and find \(\theta_{\text{max} \ m}\) for maxima both above and below the central maximum \((m = 0)\).

5. Use Equation 1 to predict the same set of angles. Compare with the measurements: list or plot the differences between measured and predicted \(\theta\)'s.

## 2 Linear Polarization

Light is a transverse wave; the electric and magnetic field vectors are always oriented in a direction perpendicular to the direction of propagation (see Figure 4a). Light is **linearly polarized** when the electric field vector has a fixed orientation in the transverse plane. By convention the direction of polarization is taken to be the direction of the electric field. Light is **unpolarized** when the direction of the electric field changes rapidly and randomly with time. Light from incandescent and fluorescent lamps is unpolarized.

Unpolarized light may be polarized by filters, by reflection and by scattering. Filters, usually called “Polaroid” filters polarize light by absorbing out all the light except that which has the E-vector pointing along a specific direction (to within a sign.) This direction is called the “pass axis”.

The components of the electric field in a direction perpendicular to this axis is absorbed by the polaroid material. If polarized light with electric field \(\mathbf{E}_{\text{inc}}\) is incident on a polaroid filter, then the electric field of the transmitted light is then just the component of \(\mathbf{E}_{\text{inc}}\) along the direction of the pass axis:

\[
E_{\text{trans}} = E_{\text{inc}} \cos \phi
\]  

in which \(\phi\) is the angle between the pass axis and \(\mathbf{E}_{\text{inc}}\).
If the incident light has randomly oriented electric fields, the transmitted light is polarized along the pass axis. Since the light intensity, $I$ is proportional to the time-average of $E^2$, Equation 2 tells us that

$$I_{\text{trans}} = I_{\text{inc}} \cos^2 \phi$$

This result (a theorem) is known as Malus’ Law.

The effect of two sequential polarizing filters is illustrated in Figure 5. The first filter polarizes the incoming unpolarized light. The light intensity transmitted by the second filter obeys Equation 3, in which $\phi$ is the angle between the pass axes of the two filters. If the filters are “crossed”, i.e. $\phi = 90^\circ$, no light is transmitted.

![Figure 5: Unpolarized light incident on a set of two polarizing filters.](image)

**Procedure**

1. Set up the diode laser, the two polarizers and the light sensor with aperture disk as shown in Figure 6.

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1 Linearly polarized light is also sometimes called “plane polarized” light. There is another type of polarization, **circular** polarization, in which the electric field vector rotates in the transverse plane. We will not study this type in this laboratory.
2. Set the open circular aperture in front of the light sensor. Plug the sensor output into Channel $A$ of the Pasco interface.

3. Open the Data Studio program; select a new experiment and select the light sensor. Select the digital display for the output of this sensor.

4. Turn on the light source, and adjust the laser light spot so that it is directed through the filters and at the light sensor aperture.

5. With both polarizers set to $0^\circ$, look at the digital light sensor output. Adjust the sensor gain until this value is above at least 50%.

6. Take readings at angles $\phi$ from $0^\circ$ to $90^\circ$ in $10^\circ$ intervals. (Leave the filter closest to the light source at $0^\circ$ and change the other.) Record the angle and the intensity in a spreadsheet.

7. Plot $I$ vs. $\cos^2 \phi$. Fit the result to a straight line.