Experiment 21: Wave Optics

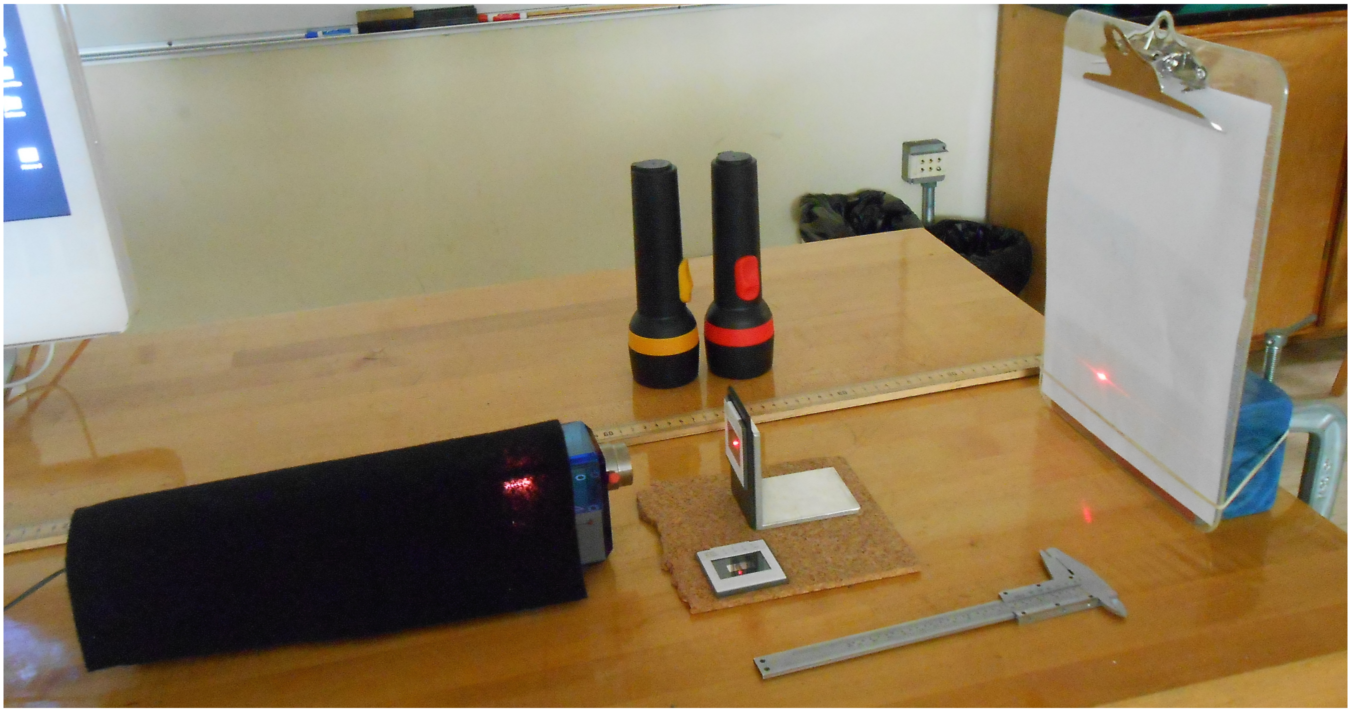

Figure 21.1: Diffraction and Interference

Not to scale: For optimal measuring, distance between the slide holder and measuring surface should be at least 1 meter.

EQUIPMENT

Laser
Black Felt
Single-Slit Slide
Double-Slit Slide
Slide Holder
Meter Stick
Vernier Caliper
Clipboard, Paper (Screen)
(1) Flashlight per person

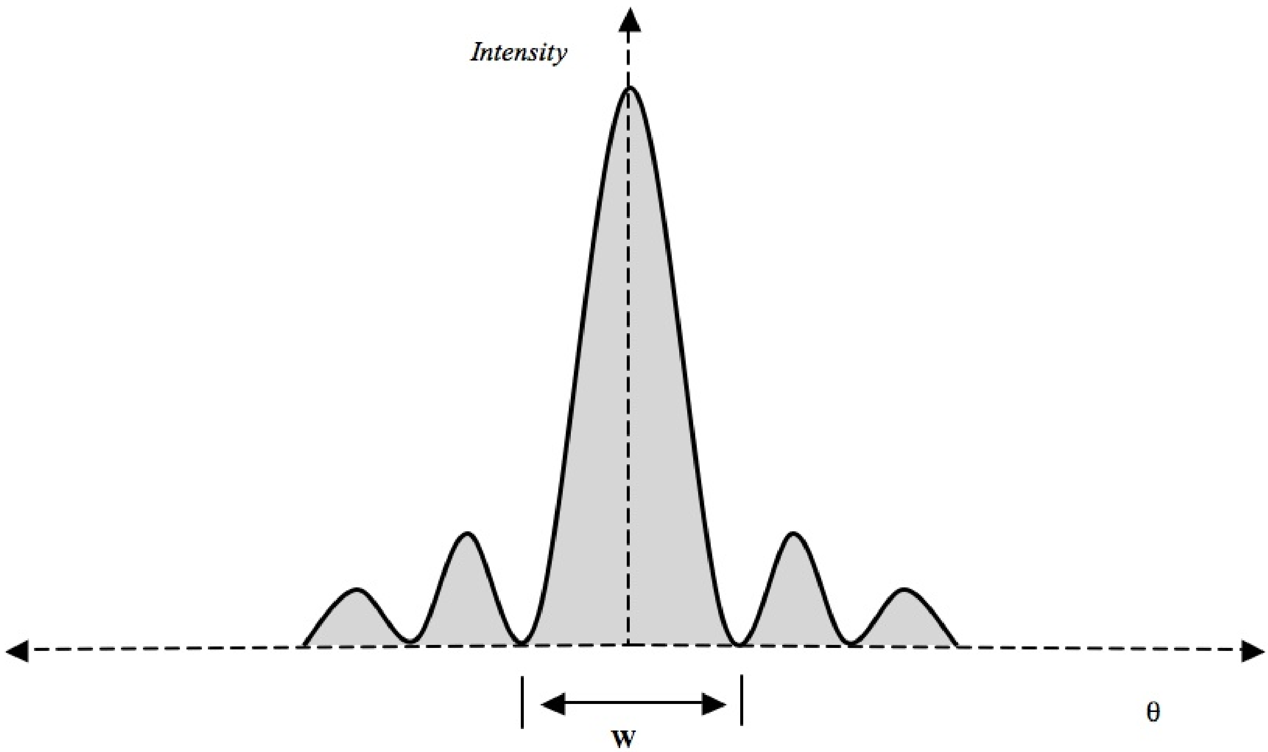

Figure 21.2: *Intensity vs. Angle* (Diffraction; Single-Slit)

Note the central envelope of the diffraction pattern. It is about twice the width of the envelopes on either side. The pattern repeats with decreasing intensity (dimmer) as the angle increases left or right of $\theta = 0°$.

"W" is measured from the *center of the dark to the center of the dark* on either side of the central envelope.

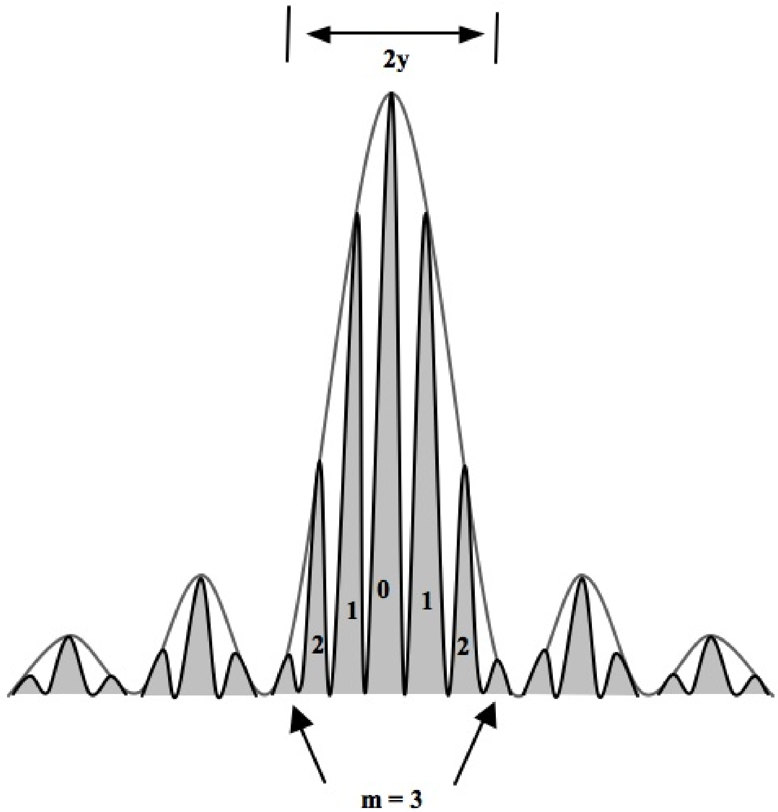

Figure 21.3: *Intensity vs. Angle* (Interference, Double-Slit)

Note the interference pattern (bright/dark fringes) contained within the envelopes of the diffraction pattern. The central envelope is about twice the width of envelopes on either side. The patter repeats with decreasing intensity as the angle increases left or right of $\theta = 0°$.

"m" is the order number of each bright fringe. m equals zero when $\theta = 0°$; m is symmetric about $\theta = 0°$. You will make a mark *through the center of each bright fringe in the central envelope*. There is, of course, an odd number of fringes in the central envelope. Use Eq. 21.4 to determine m for calculations of λ.

Advance Reading

Text: Wave optics, wavelength, frequency, electromagnetic spectrum, diffraction, interference, principle of superposition.

Objective

The objective of this experiment is to study diffraction and interference and to determine λ, the wavelength of the laser light.

Theory

Single-Slit Diffraction

Light passing through a narrow slit (slit width, D) will produce a diffraction pattern. The diffraction pattern consists of a series of light and dark bands, or envelopes.

Fig. 21.2 shows a plot of the *light intensity vs. angle* in the diffraction pattern. The slit width, D, is provided on the slide; $\delta D = 0.005$ mm. We use the small angle approximation to derive Eq. 21.1; this method requires angles in radians. The central bright envelope of the diffraction pattern subtends an angle of 2ϕ, where:

$$\phi = \frac{\lambda}{D} \tag{21.1}$$

and λ is the wavelength. The angle will not be measured directly. ϕ can be determined by first measuring the distance from the slit to the screen (L), then measuring the width of the central envelope, marked as W in Fig. 21.2.

$$2 \tan \phi = \frac{W}{L} \tag{21.2}$$

Using substitution, Eq. 21.1 and Eq. 21.2 are solved for λ, in terms of quantities that can be determined in the lab: W, D, L. The distance L should be at least 1 m for both diffraction and interference procedures.

Double-Slit Interference

When coherent light (*e.g.*, laser light) passes through two narrow slits that are close together, an interference pattern will result. The two slits are treated as if they are two points sources of coherent light. This pattern results from the addition and cancellation of light waves from the two slits, known as constructive and destructive interference, respectively. The resulting bands of light (conversely, bands of darkness) are referred to as bright fringes (or dark fringes).

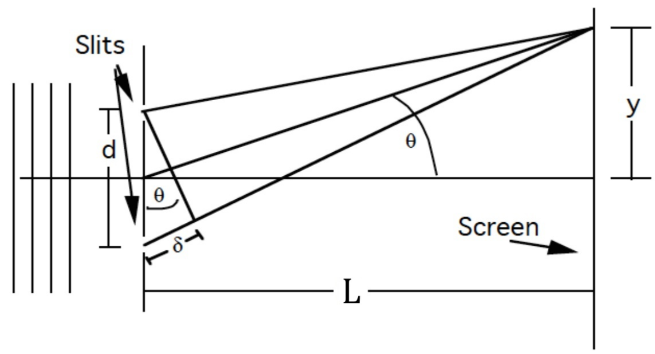

Figure 21.4: Double Slit - Path Length Difference

Constructive interference occurs when the *path length difference*, δ, is equal to an whole number of wavelengths (*i.e.*, even number of $\frac{1}{2}$-wavelengths). Destructive interference occurs when δ is an odd number of $\frac{1}{2}$-wavelengths.

Constructive interference occurs when $\delta = m\lambda$. Path length difference is necessarily: $\delta = d \sin \theta$, where d is slit spacing.

$$\delta = d \sin \theta = m\lambda \tag{21.3}$$

where $m = 0, 1, 2, \ldots$, with $m = 0$ being the central maximum fringe. The fringe order number can be found by counting the number of fringes:

$$m = \frac{\#fringes - 1}{2} \tag{21.4}$$

For small angles *measured in radians*, the small angle approximation (refer to *Experiment 11*) is useful:

$$\sin \theta \approx \tan \theta = y/L \tag{21.5}$$

Using substitution, Eq. 21.3 and Eq. 21.5 are solved for λ, in terms of quantities that can be determined in the lab: m, d, y, L.