# Lab: Diffraction and Interference

## INTRODUCTION & BACKGROUND:

Light is an electromagnetic wave, and under the proper circumstances, it exhibits wave phenomena, such as constructive and destructive interference. The wavelength of visible light ranges from about 400-750 nm = 0.0004-0.00075 mm, and this wavelength $\lambda$ sets the scale for the appearance of wave-like effects. For instance, if a broad beam of light partly passes through a wide slit (i.e. a slit which is very large compared to $\lambda$), then the wave effects are negligible, the light acts like a ray, and the slit casts a geometrical shadow. However, if the slit is small enough (i.e. around the same size as $\lambda$), then the wave properties of light become apparent and a *diffraction pattern* is projected.

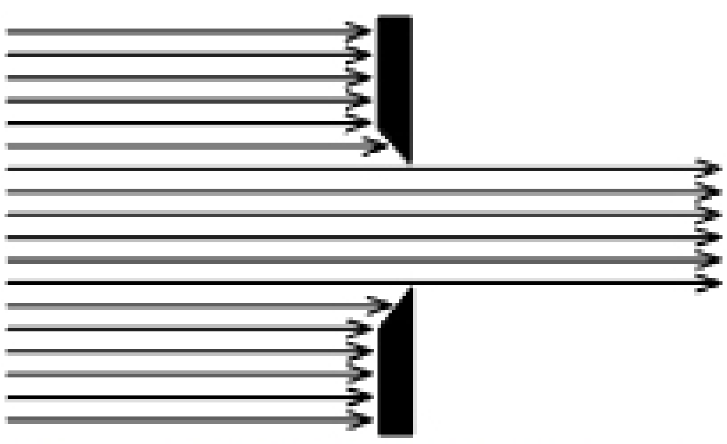


**Figure 1a. Slit large compared to λ.**

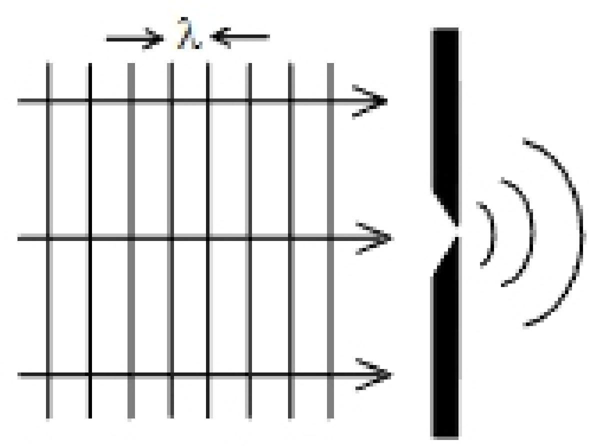



**Figure 1b. Slit small compared to λ.**

Now consider the light from **two coherent light sources** a distance **d** apart. Coherent sources emit light waves that are *in phase*, or in sync. If we think of light like a water wave, we can imagine that coherent sources emit an identical succession of wave crests and troughs, with both emitting crests at the same time. One way to create such coherent sources is to illuminate a pair of narrow slits with a distant light source.

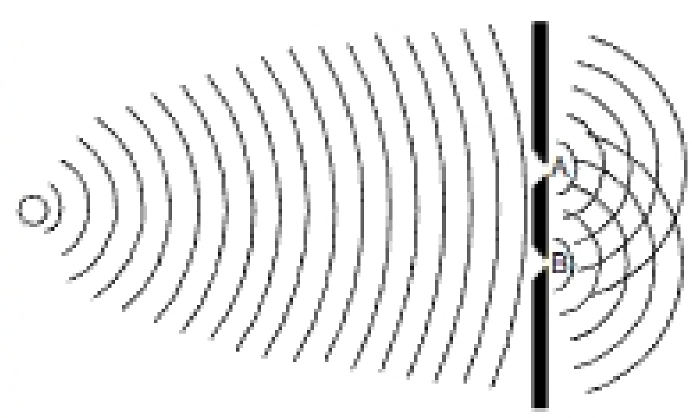



**Figure 2. Points A and B act like coherent sources.**

***Interference from two slits:*** Consider the light rays from the two coherent point sources made from slits a distance d apart (see fig. 3). We assume that the sources are emitting *monochromatic* (single wavelength) light of wavelength $\lambda$. The rays are emitted in all forward directions, but let's concentrate on the rays that are emitted in a direction $\theta$ toward a distant screen ($\theta$ measured from the normal to the screen, diagram below). One of these rays has further to travel to reach the screen, and the *path difference* is given by $d\sin\theta$.

What happens if this path difference is **exactly** one wavelength $\lambda$ (or any integer number of wavelengths)? If you look carefully, this is what is represented in fig. 3.

What happens if the path difference is $\lambda/2$, or $3\lambda/2$, or $5\lambda/2$, etc.?

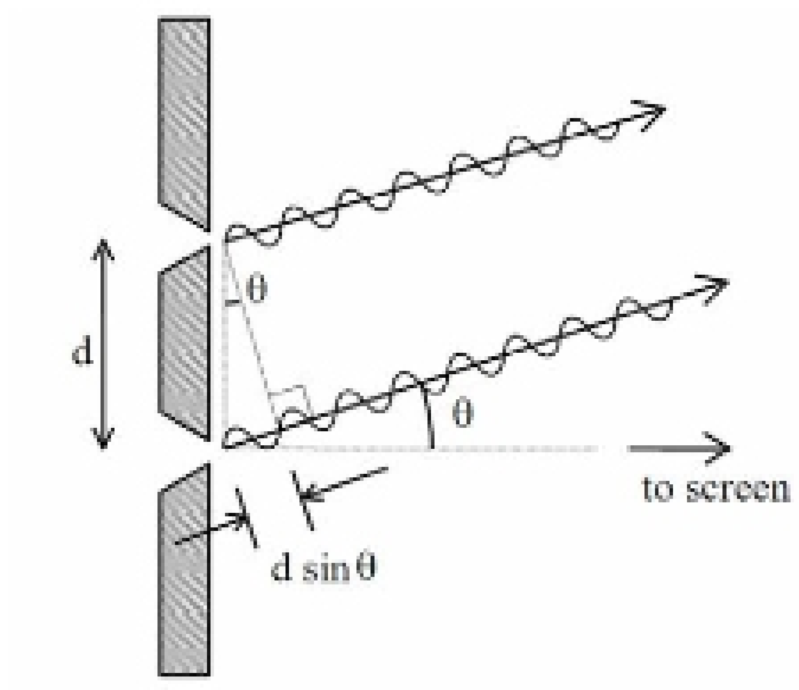
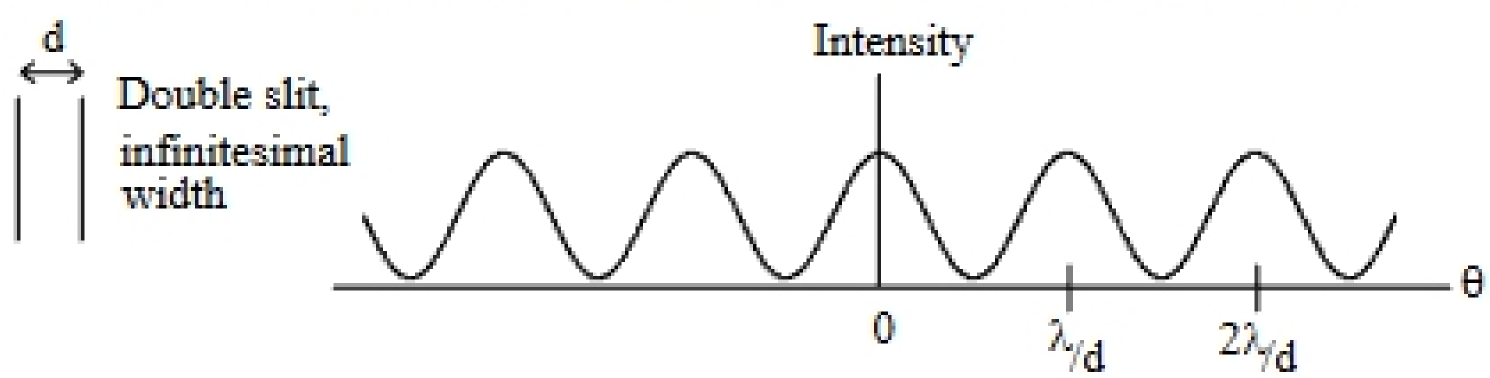



**Figure 3.**

A complete analysis yields a pattern of **intensity vs. angle** that looks like:

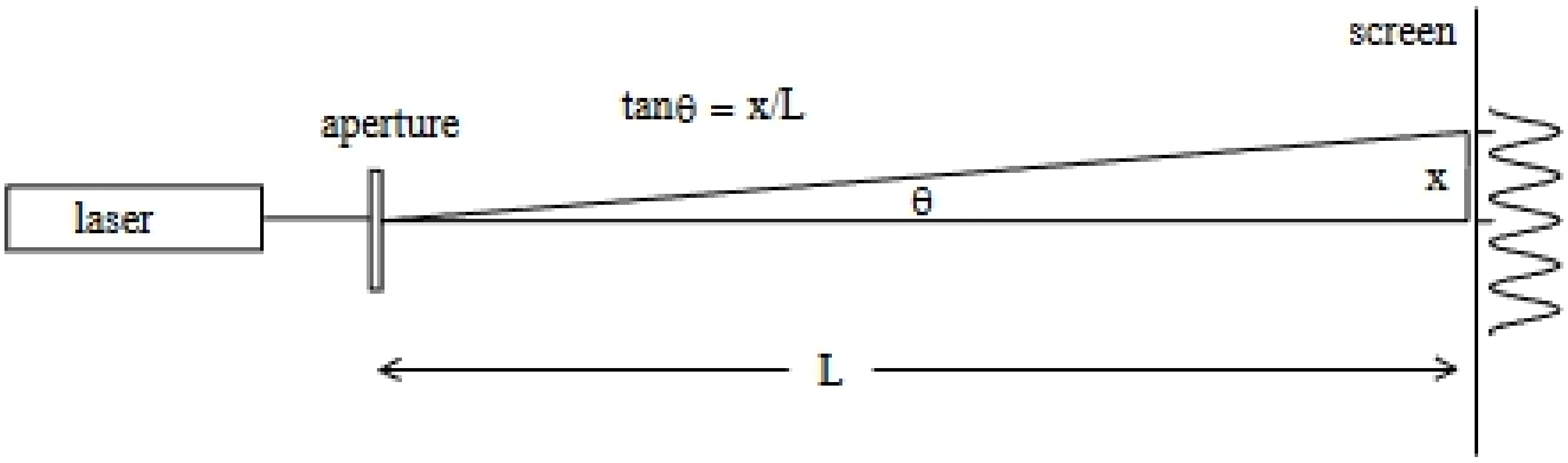



$$\left.\begin{array}{ll} \textit{Bright}: & d\sin\theta = m\lambda \\ \textit{Dark}: & d\sin\theta = (m+\tfrac{1}{2})\lambda. \end{array}\right\} \mathrm{m} = 0, \pm 1, \pm 2..$$

What happens to the above interference pattern if d is increased? What if d is decreased?

***Small angle simplification:*** If θ is small (<< 1 rad), then $\sin\theta \cong \theta$ (in radians), and maxima occur on the screen at $\theta = m\dfrac{\lambda}{d}$; minima occur at $\theta = (m+\tfrac{1}{2})\dfrac{\lambda}{d}$.

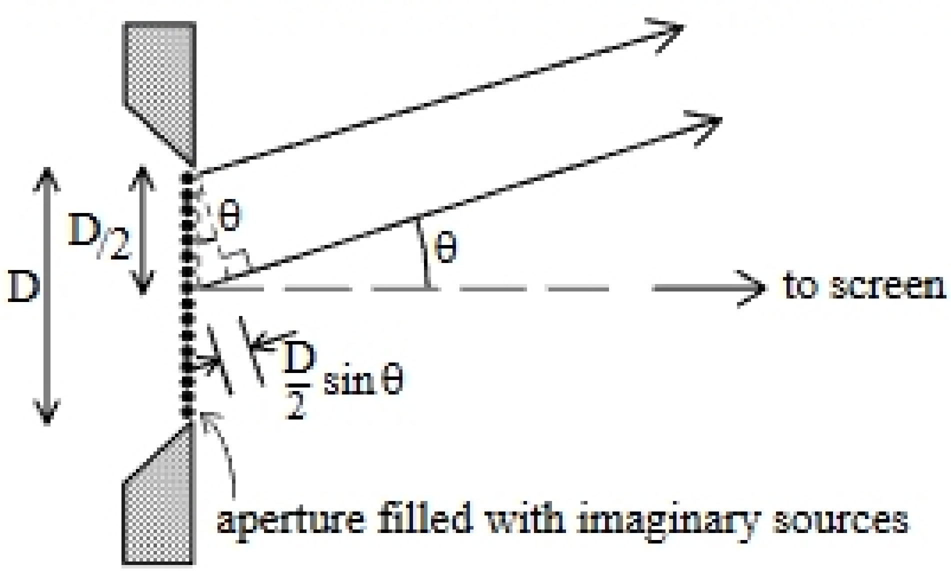
As shown below, the angle θ (measured from the center of the screen) is related to the distance x measured on the screen by tan(θ)=x/L, where L is the distance from the screen to the source of light (the aperture).




If the angle θ is small (less than a few degrees), then to an excellent approximation, sin(θ) ≈ tan(θ) ≈ θ (in radians) so the locations of the interference maxima are given by

$$\theta = \frac{x}{L} = m\frac{\lambda}{d}.$$

***Single slit diffraction:*** The uniform 2-slit interference pattern shown above is seldom observed in practice, because real slits always have finite width (not an infinitesimal width). We now ask: what is the intensity pattern from a **single slit** of **finite width** D? *Huygens' Principle* states that the light coming from an aperture is the same as the light that would come from a collection of coherent point sources filling the space of the aperture. It's as if we constructed the large slit out of a whole set of small slits, all adjacent to each other. To see what pattern the entire array produces, consider first just two of these imaginary sources: one at the edge of the slit and one in the center. These two sources are separated by a distance D/2.




The path difference for the rays from these two sources, going to the screen at an angle θ, is $\frac{D}{2}\sin\theta$, and these rays will interfere destructively if $\frac{D}{2}\sin\theta = \frac{\lambda}{2}$. But the same can be said for every pair of sources separated by D/2. Consequently, the rays from all the sources filling the aperture cancel in pairs, producing zero intensity on the screen when $\frac{D}{2}\sin\theta = \frac{\lambda}{2}$ or, if θ is small,

$$\theta = \frac{\lambda}{D}.$$ (First minimum in single slit pattern.)

The complete intensity pattern, called a *diffraction* pattern, looks like...