Chapter 28 Physical Optics

- **Visible light** Remember that visible light has wavelengths that fall between 390 nm – 780 nm (3900 Å – 7800 Å). 390 nm corresponds to violet and 780 nm corresponds to red. One Ångstrom (Å) = 10^{-10} m = 0.1 nm.

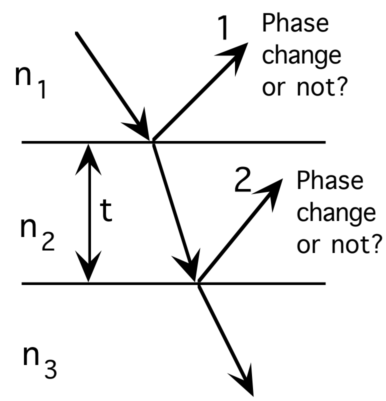
Section 28-1 Interference of Light Since light is a wave, light waves can be superposed just like mechanical waves. Interference of light waves occurs when two or more light waves with a fixed phase difference interact at the same point in space. If the phase difference remains constant, the sources are said to be *coherent*. If the phase difference varies over time, then the sources are said to be *incoherent*, since they will form no fixed pattern of constructive and destructive interference. Interference can range from constructive (where the waves add to form a larger positive or negative amplitude- Fig. 28-1(a)) to destructive (where waves add and cancel out- Fig. 28-1(b)). For two coherent sources, the critical condition is whether the path length difference ($L_2 - L_1$) is equal to a whole wavelength multiple (mλ; constructive) or an odd integer multiple of half wavelengths $\left(\left(\frac{m\,\lambda}{2}\right)\text{; destructive}\right)$.

Section 28-2 Young's Double Slit Young's experiment examined the interference between two monochromatic light sources– light passing through a pair of slits. In Young's case, the two light sources originate from a single monochromatic source so the two light sources are guaranteed to be in phase when leaving the slits. The observed interference pattern consisted of bright and dark fringes.

A *geometrical derivation* for the bright fringes (constructive interference) shows that the path difference is: $d \sin\theta = m\lambda$. In this expression m = the order of the fringe, with m = 0 being the central bright fringe and m = ±1, ±2, ±3, ... appearing on either side of the central bright fringe (maximum). For dark fringes (destructive interference), the path difference is: $d \sin\theta = \left(\frac{m'\,\lambda}{2}\right)$,(m' = ± 1, ± 3, ± 5, ...). By using the approximation, $\frac{m\lambda}{d} = \sin\theta \approx \frac{y_m}{L}$, you can find the position (y_m) of the m^{th} order bright fringe with respect to the center of the central bright fringe ($m = 0$, $y_o = 0$). The location of the m'^{th} order dark fringe can be found similarly using $\left(\frac{m'\,\lambda}{2\,d}\right) = \sin\theta \approx \frac{y_{m'}}{L}$.

Section 28-3 Thin Films Interference As seen in chapter 14 (Fig 14-7), waves that are reflected can be inverted. The same can happen to light as it is reflected at the boundary between two materials. There are two possibilities because either $n_1 > n_2$ or $n_1 < n_2$. If $n_1 < n_2$, then the reflected light ray is 180° out of phase with the incident light ray. If $n_1 > n_2$, then the reflected light ray is in phase with the incident light ray. The transmitted light ray is always in phase with the incident wave. An additional effect that must be considered is that the wavelength of light within a transparent material is different than it is in air. For example, when light passes from air into glass, the wavelength becomes $\lambda_g = \frac{\lambda_o}{n_g}$.

In order for light to interfere in thin films, there must be three layers of material, i.e. the middle layer is the "film". As shown in the figure at right, the question you must answer first is whether or not phase changes occur at each boundary for the reflected rays. To answer this you must know the index of refraction for each layer.



Note that it is the middle layer with thickness d for which the path difference is 2t.

The condition for a interference maximum then depends on 2t, the wavelength in the middle layer, and whether or not phase changes occur at the boundaries. To the right is a table showing the conditions for a 180° phase change at both boundaries (i.e. 2 phase changes). For one phase change, the constructive and destructive labels would reverse in the table.

For 2 Phase Changes:

$2\,t = \dfrac{m\,\lambda_0}{n_f}$	*CONSTRUCT.*
$2\,t = m'\,\dfrac{\lambda_0}{2\,n_f}$	*DESTRUCT.*

Section 28-4 Diffraction Examining light as a wave phenomenon is the subject of physical optics. It is necessary to consider the wave nature of light when the wavelength (λ) of the light is about the same size (or larger) as the opening (W) through which the light passes. When $\lambda \geq W$, light *bends* around the opening or obstacle– an effect called diffraction. Diffraction occurs for all types of wave motion, not just for light.

- **Single slit diffraction** There are two types of diffraction: Fresnel (near-field: for a point-like source) and Fraunhofer (far-field: for a source that behaves like plane waves). Fraunhofer diffraction is the type that will be dealt with in this section. The condition for a diffraction dark fringe (minimum) to occur is given by: $W \sin\theta = m\,\lambda$. The position y_m of the minima can be found using the same technique as was used for double slit interference.

Section 28-5 Rayleigh criterion Holes (as well as solid disks) will create diffraction patterns when exposed to light. The size of the hole (as well as the wavelength of the light) is critical. To just resolve two separate images the first minimum of one diffraction pattern falls at the peak of the second diffraction pattern. This Rayleigh criterion can be expressed in terms of the angle between the peak and first minimum: $\sin\theta = \dfrac{1.22\,\lambda}{D}$ (where D is the diameter of the opening: hole, lens, iris,...) . For small angles (which is usually the case): $\theta_{min} \approx \dfrac{1.22\,\lambda}{D}$.

Section 28-6 Diffraction gratings A diffraction grating consists of several slits that are equally spaced. The effect of using many slits is to make the maxima narrower and the minima (dark fringes separating maxima) broader. For a grating with several thousand slits, the maxima become very fine lines (for rectangular slits) with complete dark between them. It only makes sense to define the maxima (bright fringe) location: $d \sin\theta = m\,\lambda$.