Phy 212: General Physics II

Chapter 35: Interference
Lecture Notes

Wave Properties of Light

1. Light is a transverse traveling electrical disturbance (wave).
2. Light is a small subset of energy referred to as electro-magnetic (EM) radiation. EM radiation propagates through space via oscillations of the electrical properties of space itself.
3. All EM waves, and the corresponding photons, travel through empty space at the same speed:

$$v_{EM} = c = 2.998\text{x}10^8 \text{ m/s}$$

4. The speed of light is a product of the wavelength & frequency of the wave:

$$c = \lambda \cdot f = 2.998\text{x}10^8 \text{ m/s}$$

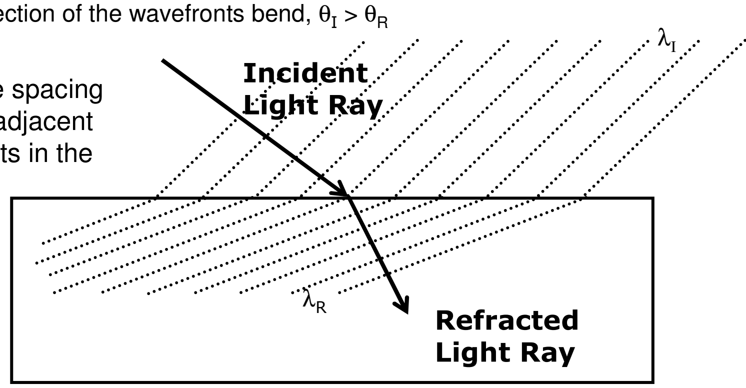
Wavelength (λ): The spatial distance from crest to crest, in m

Frequency (f): The rate of oscillations per unit time, in Hz

Light Transmission through Transparent Media

1. When incident light travels through a transparent medium other than vacuum (or air):
   a. The wave frequency remains the same
   b. The wavelength shortens, $\lambda_I > \lambda_R$
   c. The speed slows down, $v_I > v_R$
   d. The direction of the wavefronts bend, $\theta_I > \theta_R$

2. Notice the spacing between adjacent wave fronts in the diagram



Transparent Materials

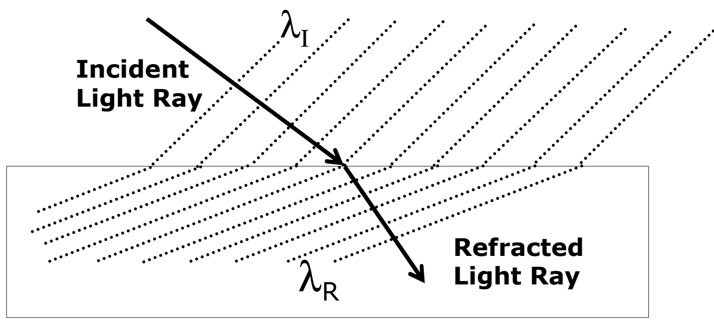
1. Transparent materials allow light rays to travel through them in straight lines
2. The apparent bending of light rays when light passes through a transparent medium is called refraction (link)
3. When light is transmitted through a substance, some electrons are forced to vibrate and/or excite.
4. As light waves are absorbed by electrons they are then re-emitted and the light is absorbed by neighboring atoms
   a. This takes time and thus there is a time delay
   b. The net result is that the average speed of light traveling through a transparent substance is less than the speed in vacuum
5. The index of refraction (n) of a substance is the ratio of the speed of light in vacuum (c) to the speed of light through a material (v_{medium}) or

$$n = \frac{c}{v_{medium}}$$

Refraction of Light

1. As light passes from air (n_{air}~1) into a different material the wave speed decreases and the wavelength shortens
2. The frequency of the light wave remains the same

$$v_{medium}=\lambda_{medium}\cdot f=\frac{\lambda_{air}\cdot f}{n}\Rightarrow\lambda_{medium}=\frac{\lambda_{air}}{n}$$

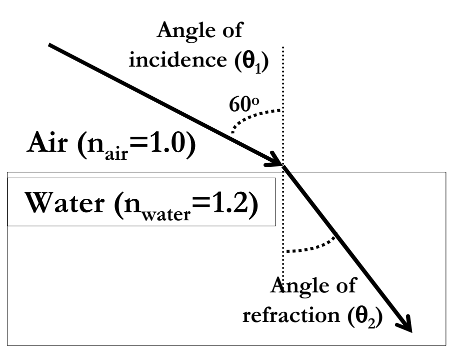


Snell's Law & Total Internal Reflection

For refracted light, the relation between the angle of incidence (θ_1) and angle of refraction (θ_2) is called the Law of Refraction (or Snell's Law):

$$n_1\sin\theta_1 = n_2\sin\theta_2$$

Example: Air to Water Refraction



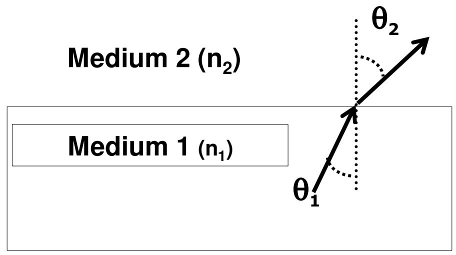
$$n_{air}\sin\theta_1= n_{water}\sin\theta_2$$

$$\theta_2=\sin^{-1}\left(\frac{n_{air}\sin\theta_2}{n_{water}}\right)$$

$$\theta_2=\sin^{-1}\left(\frac{(1.0)\sin60^o}{1.2}\right)=46.2^o$$

Total Internal Reflection

1. When light traveling though a medium(n_1) encounters an interface with different medium(n_2), some of the light will reflect back and the remainder will transmit through the new medium
2. When $n_2 > n_1$, total internal reflection will occur when the angle of refraction $\theta_2 \geq 90^o$,
3. The incident angle beyond which total internal reflection will occur is called the critical angle ($\theta_{critical}$)



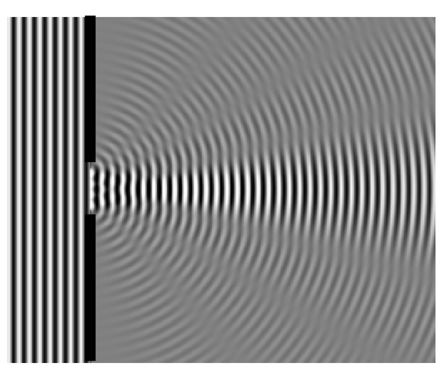
$$n_1 \cdot \sin\theta_1 = n_2 \cdot \sin\theta_2 = n_2$$

$$\text{therefore, } \sin\theta_1 = \frac{n_2}{n_1}$$

$$\theta_1 = \theta_{critical} = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

Diffraction

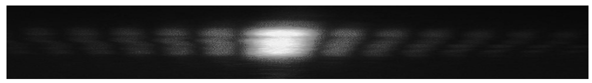
1. The wave properties of light are particularly observable as (a phenomenon called diffraction) when light passes either:
   a. Through an aperture nearly the width as the light wavelength <u>or</u>
   b. Over objects that are nearly the size as the light wavelength
2. Diffraction is the "flaring out" of light as it passes through or over a barrier of similar size.
3. The degree of diffraction increases as (link):
   a. The wavelength of the light increases
   b. The width of the barrier decreases



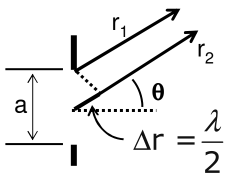
Single Slit Diffraction

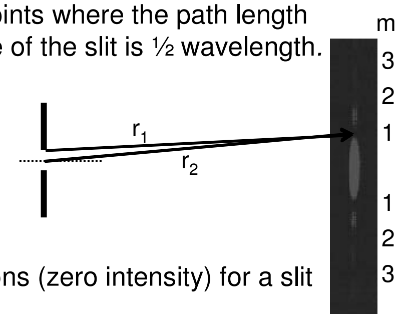
1. When a screen is placed in front of light passing through a single slit, a diffraction pattern is observed. The diffraction pattern is produced by the interference of the individual "wavelets" of light that pass beyond the slit.

Single slit diffraction pattern



2. Dark regions on the screen occur a points where the path length difference between the top and middle of the slit is ½ wavelength.



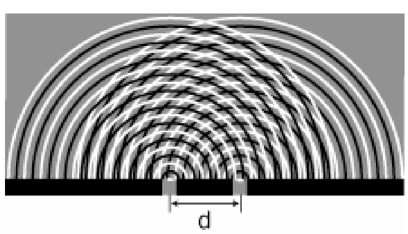


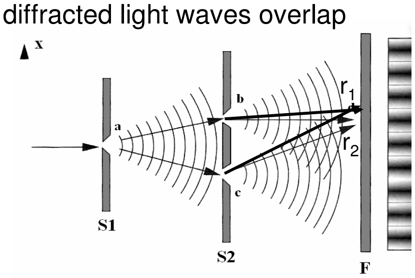
3. The angular location for the dark regions (zero intensity) for a slit width, a, is given by :

$$\sin\theta_m = \frac{m \cdot \lambda}{a} \quad \text{where } m = 0,1,2,\ldots \text{ etc.}$$

Young's Experiment & Double Slit Interference

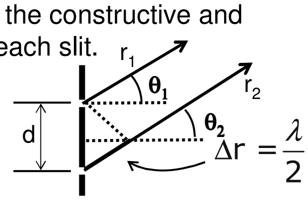
1. Double slit interference occurs when 2 diffracted light waves overlap





2. When a screen is placed in front of the double slits an interference pattern is observed. The pattern is produced by the constructive and destructive interference between the light from each slit.

   When d>>a and D>>d, then $\theta_1 \rightarrow \theta_2$ therefore:



Intensity Maximum: $m \cdot \lambda = d \cdot \sin\theta_m$

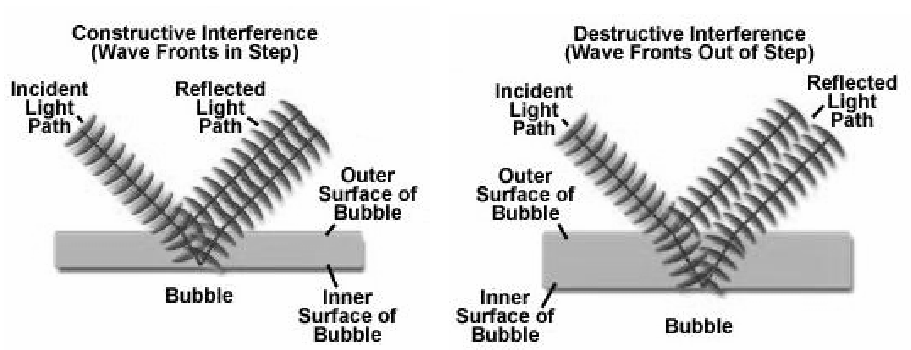
Intensity Minimum: $(m + \frac{1}{2})\lambda = d \cdot \sin\theta_m$

where m is the "order" of the maximum (or minimum): m = 0, 1, 2,… etc.

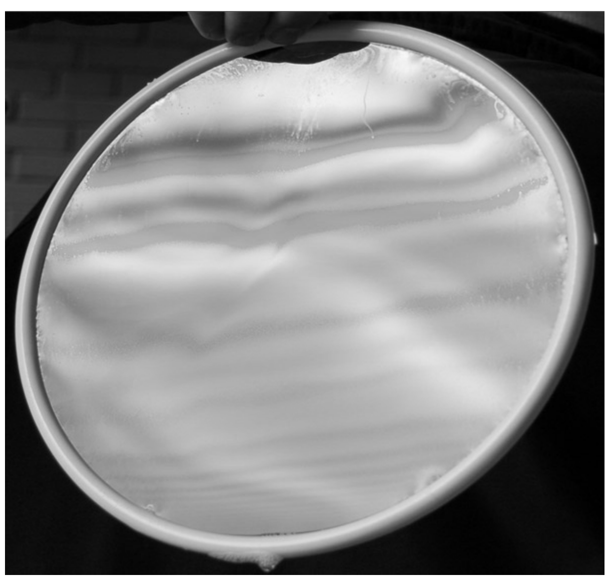
Thin Film Interference

Thin film interference occurs when light is incident on a thin film and the following occur:

1. Part of the wave reflects from the outer surface
2. Part of the wave passes through the film and reflects off the inner face



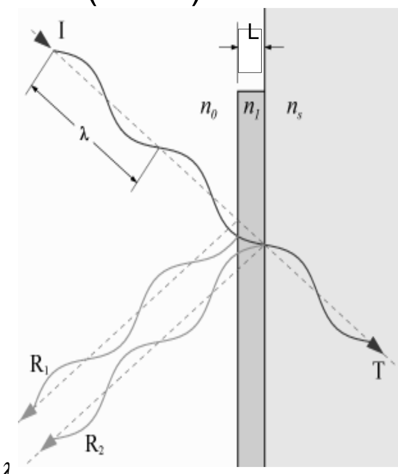
Reflections Off a Soap Bubble Film



Thin Film Interference (cont.)

Key Points:

1. The outgoing waves R_1 & R_2 will constructively interfere when the reflected rays are out of phase by 180°
2. The outgoing waves will destructively interfere when the reflected rays are in phase 180°
3. When a wave reflects off a surface where $n_{\substack{incident\\medium}} < n_{\substack{reflecting\\medium}}$:
   a. The reflected wave will under go a 180° phase shift
4. The wavelength of the incident wave, the thickness of the film and the indices of refraction all determine the characteristics of the reflected light



When $n_3>n_2>n_1$ or $n_3<n_2<n_1$:

a. *Constructive:* $\text{Pathlength} = 2L = m\lambda_{film}$

b. *Destructive:* $\text{Pathlength} = 2L = \left(m+\frac{1}{2}\right)\lambda_{film}$

When $n_3>n_2<n_1$ or $n_3<n_2>n_1$:

a. *Constructive:* $\text{Pathlength} = 2L = \left(m+\frac{1}{2}\right)\lambda_{film}$

b. *Destructive:* $\text{Pathlength} = 2L = m\lambda_{film}$