

PHYS 214 Exam 1 Review

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Exam Review 1:

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Units for the Exam

- Waves
- Interference
- Diffraction

Wave Equation

General Wave Propagation: $y(x, t) = A \cos(kx - \omega t + \phi)$

k = wave number (how the wave repeats in SPACE) [m^{-1}]

ω = angular frequency (how the wave repeats in TIME) [**rad/s**]

ϕ = phase shift (the starting phase of the wave) [**rad**]

$kx - \omega t + \phi$ = phase

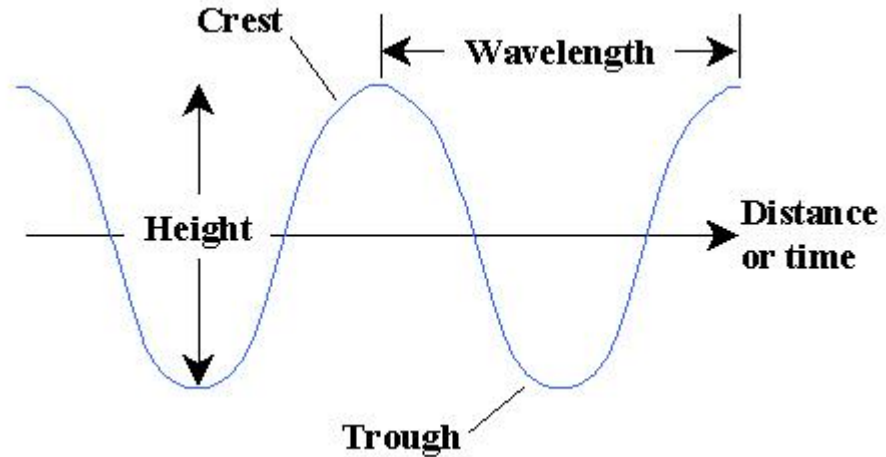
Properties of Waves

$$\lambda = 2\pi/k; \quad f = \omega/2\pi$$

$$v = \omega/k \quad v = \lambda f$$

$$I_{\text{average}} = |A|^2/2$$

$$f = 1/T$$



Note: if the x axis is a measure of time, then the part shown by the wavelength would be the period, not wavelength

Interference

Superposition (adding): A fancy way of saying that when two waves interact, the resulting wave is the SUM of the two individual waves

$$y_1(x, t) = A_1 \cos(k_1 x - \omega_1 t + \phi_1)$$

$$y_2(x, t) = A_2 \cos(k_2 x - \omega_2 t + \phi_2)$$

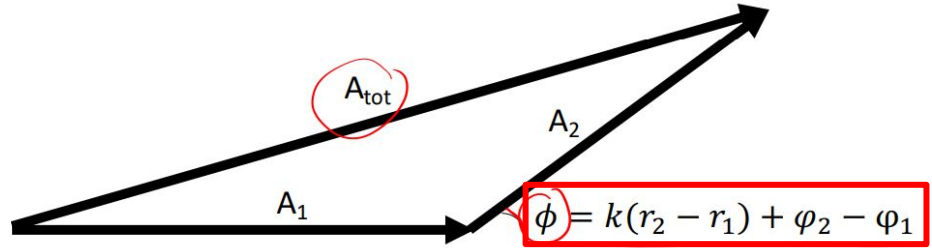
$$y_{\text{tot}}(x, t) = y_1(x, t) + y_2(x, t) = A_1 \cos(k_1 x - \omega_1 t + \phi_1) + A_2 \cos(k_2 x - \omega_2 t + \phi_2)$$

If $\phi_1 = \phi_2$, the angular frequencies (ω) are the SAME, and the distance is the SAME, then the waves are IN PHASE

Phasors and Law of Cosines

$$A_{\text{tot}}^2 = A_1^2 + A_2^2 + 2A_1A_2\cos(\phi)$$

(given in terms of A, B, and C on the equation sheet)

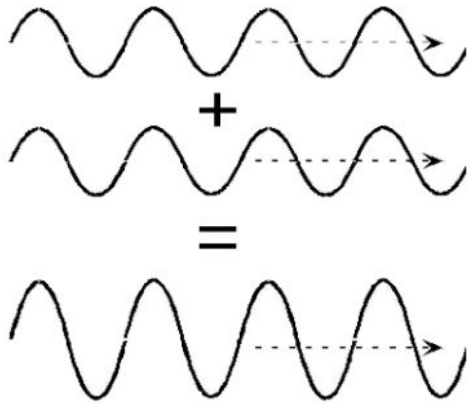


To note:

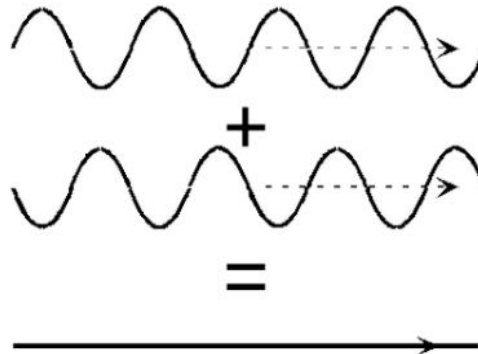
- The Law of Cosine usually has a -, but we are using the outside angle so it becomes +
- This is the **General Equation** and works for waves with different amplitudes

Interference (Cont.)

Phase difference = $k(r_2 - r_1) = \phi$ for a two source system at different distances



Constructive



Destructive

In general, for two sources with the same amplitude/intensity:

$$I_{\text{tot}} = 4I_0 \cos^2 \left(\frac{\Delta\phi}{2} \right)$$

In your equation sheet, this is written as:

$$I_{\text{total}} = 2A^2 \cos^2 \left(\frac{kr_1 + \phi_1 - kr_2 - \phi_2}{2} \right)$$

I_0 is the intensity from a single beam

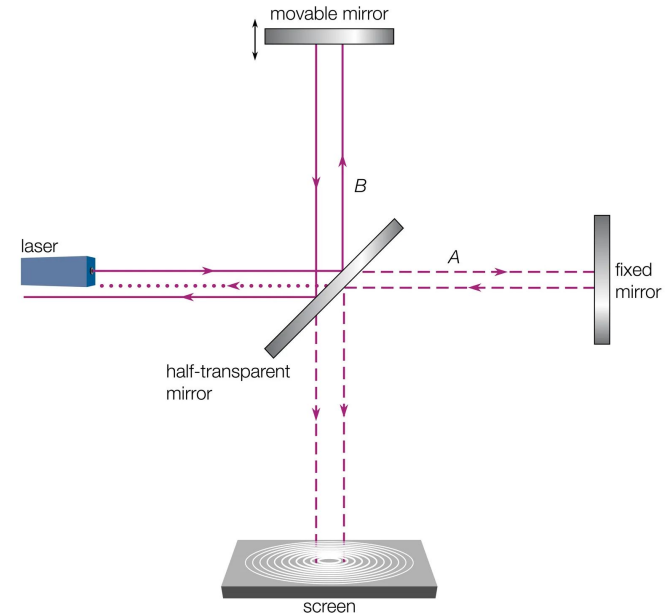
$I_0 = \frac{I_{\text{source}}}{4}$, this is due to the beam getting split twice

Example Problem - Interferometer

A Michelson interferometer is illuminated by a laser of power $P = 5 \text{ mW}$ and wavelength $\lambda = 632.8 \text{ nm}$

You want to adjust one of the mirrors to get a **new power of 2 mW**.

How far do you have to move the mirror to achieve this new intensity?



Example Problem - Interferometer (Cont.)

$$I_0 = \frac{P}{4} = \frac{5}{4} = 1.25 \text{ mW}$$

Example Problem - Interferometer (Cont.)

$$I_0 = \frac{P}{4} = \frac{5}{4} = 1.25 \text{ mW}$$

$$I_{new} = 4I_0 \cos^2\left(\frac{\Delta\phi}{2}\right)$$

Example Problem - Interferometer (Cont.)

$$I_0 = \frac{P}{4} = \frac{5}{4} = 1.25 \text{ mW}$$

$$I_{new} = 4I_0 \cos^2\left(\frac{\Delta\phi}{2}\right)$$

$$\Delta\phi = 2 \cos^{-1}\left(\sqrt{\frac{I_{new}}{4I_0}}\right) = 2 \cos^{-1}\left(\sqrt{\frac{2}{4(1.25)}}\right) = 1.77 \text{ rad}$$

Example Problem - Interferometer (Cont.)

$$I_0 = \frac{P}{4} = \frac{5}{4} = 1.25 \text{ mW}$$

$$\Delta\phi = \frac{2\pi}{\lambda} (L_2 - L_1) = \frac{2\pi}{\lambda} (2\Delta x)$$

$$I_{\text{new}} = 4I_0 \cos^2\left(\frac{\Delta\phi}{2}\right)$$

$$\Delta\phi = 2 \cos^{-1}\left(\sqrt{\frac{I_{\text{new}}}{4I_0}}\right) = 2 \cos^{-1}\left(\sqrt{\frac{2}{4(1.25)}}\right) = 1.77 \text{ rad}$$

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$$I_{new} = 4I_0 \cos^2\left(\frac{\Delta\phi}{2}\right)$$

$$\Delta x = \frac{\Delta\phi\lambda}{4\pi} = \frac{1.77 * (600 * 10^{-9})}{4\pi} = 84.6 \text{ nm}$$

$$\Delta\phi = 2 \cos^{-1}\left(\sqrt{\frac{I_{new}}{4I_0}}\right) = 2 \cos^{-1}\left(\sqrt{\frac{2}{4(1.25)}}\right) = 1.77 \text{ rad}$$

Example Problem - Interferometer (Cont.)

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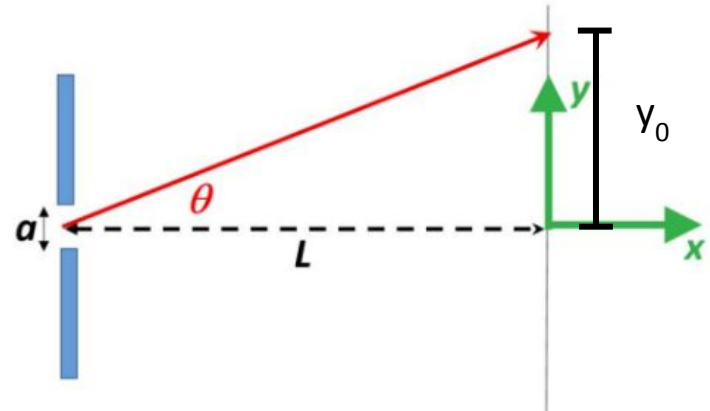
$$\Delta x = 84.6 \text{ nm}$$

$$\Delta\phi = 2 \cos^{-1}\left(\sqrt{\frac{I_{new}}{4I_0}}\right) = 2 \cos^{-1}\left(\sqrt{\frac{2}{4(1.25)}}\right) = 1.77 \text{ rad}$$

Diffraction

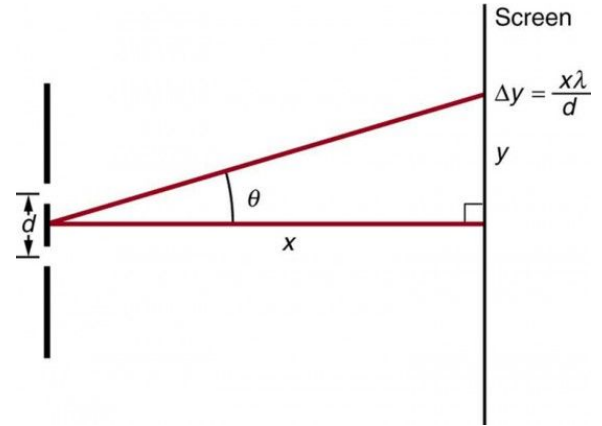
- Single slit diffraction:
 - a = slit width
 - θ_o = angle of first minimum
 - λ = wavelength
- **Small $a \rightarrow$ Large θ_o**
- Small angle approximation:
 - $\theta \cong \sin(\theta) \cong \tan(\theta) \cong y_o/L$
- Spot size:
 - Radius $\rightarrow y_o = L \cdot \tan(\theta) \cong L \cdot \theta$
 - Width $\rightarrow 2y_o = 2L \cdot \tan(\theta) \cong 2 \cdot L \cdot \theta$

$$a \sin(\theta_o) = \lambda$$



Diffraction (cont.)

- Double slit diffraction:
 - d = distance between slits
 - $\theta_{\max}$ = angle for mth maximum
 - $\theta_{\min}$ = angle for mth minimum
 - m = integer ($m = 0, 1, 2, \dots$)
 - Note: 0 denotes the central maximum
- **Small $d \rightarrow$ Large θ**
- Small angle approximation also applies to these questions too



$$d \sin(\theta_{\max}) = m\lambda$$

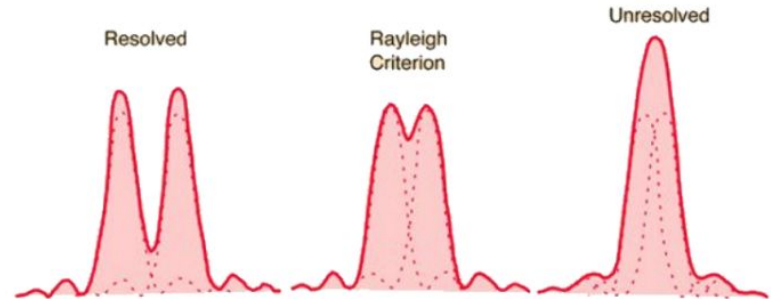
$$d \sin(\theta_{\min}) = (m + \frac{1}{2})\lambda$$

Diffraction (cont.)

- Circular aperture diffraction
 - Similar to single slit; 1.22 factor
- Rayleigh Criterion:
 - Center of the diffraction maximum from the first object falls onto the diffraction minimum from the second object
 - ie. $\theta_o \leq \theta_{\text{objects}}$
 - θ_o = angle of first minimum of central bright spot
 - For multiple objects θ_o is the minimum angle required to distinguish the two objects
 - θ_{objects} = angle between two bright spots

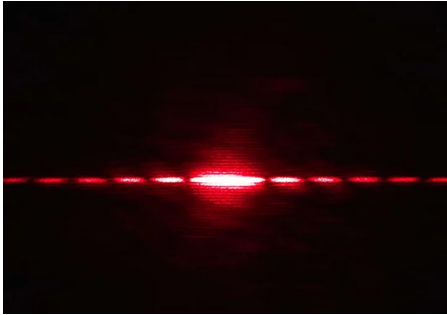
D - Diameter of lens

$$D \sin(\theta_o) = 1.22\lambda$$

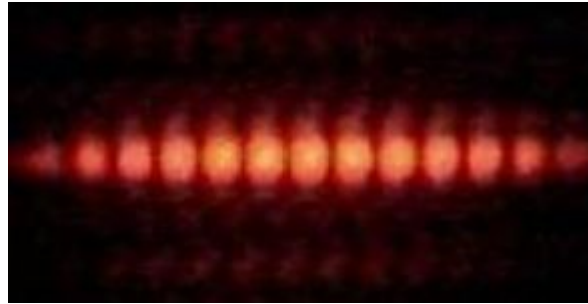


Diffractions In Real Life

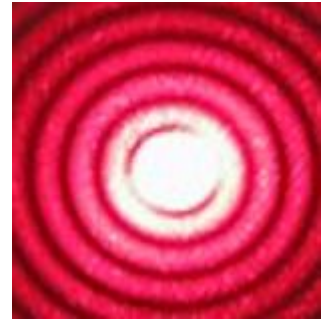
Single Slit Diffraction



Double Slit Diffraction



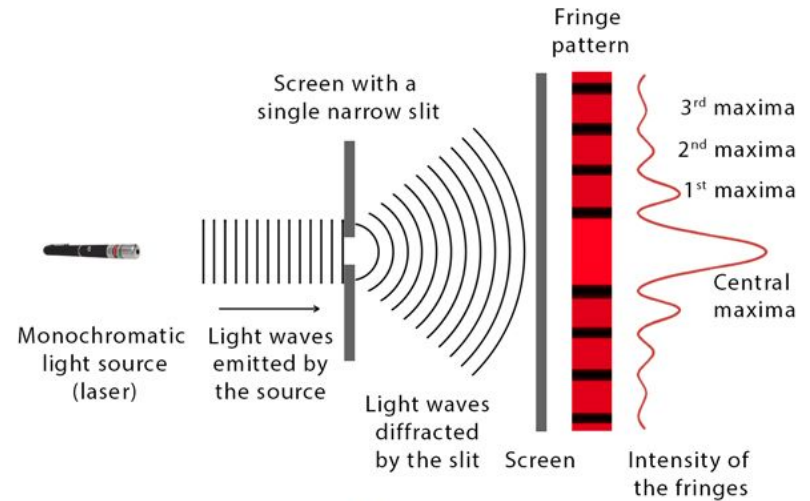
Circular Aperture Diffraction



Example Problem - Diffraction

A laser with wavelength $\lambda = 500 \text{ nm}$ illuminates a single slit width of $a = 0.1 \text{ mm}$. A screen is placed $L = 2.00 \text{ m}$ from the slit.

Find the **vertical position y_4** on the screen of the fourth minimum measured from $y = 0$ (center of first maximum)



Example Problem - Diffraction (Cont.)

$$a \sin(\theta_0) = m\lambda$$

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Example Problem - Diffraction (Cont.)

$$a \sin(\theta_0) = m\lambda$$

$$a\theta_0 = m\lambda$$

$$\theta_0 = \frac{m\lambda}{a} = \frac{4(500 * 10^{-9})}{0.1 * 10^{-3}} = 0.02 \text{ rad}$$

Example Problem - Diffraction (Cont.)

$$a \sin(\theta_0) = m\lambda$$

$$y_4 = L\theta_0 = 2 * 0.02 = 0.04 \text{ m}$$

$$a\theta_0 = m\lambda$$

$$\theta_0 = \frac{m\lambda}{a} = \frac{4(500 * 10^{-9})}{0.1 * 10^{-3}} = 0.02 \text{ rad}$$

Example Problem - Diffraction (Cont.)

$$a \sin(\theta_0) = m\lambda$$

$$y_4 = L\theta_0 = 2 * 0.02 = 0.04 \text{ m}$$

$$a\theta_0 = m\lambda$$

$$y_4 = 0.04 \text{ m} = 4 \text{ cm}$$

$$\theta_0 = \frac{m\lambda}{a} = \frac{4(500 * 10^{-9})}{0.1 * 10^{-3}} = 0.02 \text{ rad}$$

Good luck!

Feel free to ask any
questions you may have.

You got this!

