Physics 122 – Class #5

Questions?
Announcements/reminders

MP HW02 and written HW02 are due next Tuesday, September 9.

Read actively the rest of Ch.20

Always check the class website to make sure of assignments and due dates.
(http://www.physics.nmt.edu/~saska/phys122.html)

I-Clickers. Starting today?
Last class: we derived the equation for sinusoidal wave:

\[ D(x,t) = A \sin \left( kx - \omega t + \phi_0 \right) \]

And we started looking at a wave on a string.

\[ V = ? \]
Wave on a String

\[ Y(x,t) = A \sin(kx - \omega t + \phi_0) \]

\[ V_y(x,t) = \frac{dy}{dt} = -A \omega \cos(kx - \omega t + \phi_0) \]

\[ V_{y_{max}} = A \omega \]

\[ a_y = \frac{dV_y}{dt} = -A \omega^2 \sin(kx - \omega t + \phi_0) \]

\[ a_{y_{max}} = -A \omega^2 \]

- on the crest, \(-\) \(1^\ast\)
Wave on a String

\[ F = 2 T_s \sin \theta \]

\[ \sin \theta = \frac{T_{sy}}{T_s} \Rightarrow T_{sy} = T_s \sin \theta \]

\[ F = 2 T_s \sin \theta \approx 2 T_s \theta \]

\[ \Delta x \ll \lambda \]

\[ \theta \text{ is small} \]

\[ y = A \cos(kx) \]

Slope at \( \frac{\Delta x}{2} \):

\[ \tan \theta = \frac{dy}{dx} \bigg|_{\frac{\Delta x}{2}} = -Ak \sin \left( k \cdot \frac{\Delta x}{2} \right) \]
Wave on a String

\[ k \frac{\Delta x}{2} = \frac{k \Delta x}{2} \frac{\Delta x}{2} = k \left( \frac{\Delta x}{2} \right) \Rightarrow \frac{k \Delta x}{2} < 1 \]

\[ \Rightarrow \Theta \approx \tan \Theta = -\lambda k \frac{k \Delta x}{2} \Rightarrow \]

\[ \Theta \approx -\frac{k^2 A \Delta x}{2} \]  \hspace{1cm} (3)

Subsit (3) in (2):

\[ F = -2T_s k^2 A \frac{\Delta x}{2} = -k^2 T_s A \Delta x \]  \hspace{1cm} (4)

**Newton's 11 Laws**

\[ F = ma \]

\[ m = \max \]

\[ a = a_{\text{max}} = -A \left( k^2 v^2 \right) \]
Wave on a String

\[ \Rightarrow -k^2 T_s A \Delta x = -M \Delta x A \Rightarrow k^2 V^2 \]

\[ T_s = MV^2 \Rightarrow V = \sqrt{\frac{T_s}{M}} \]
Wave on a String
Example 1

A 43 meters long rope of mass 5.0 kg joins two climbers. One climber strikes the rope and 1.4 seconds later the second climber feels the effect. What is the rope tension?

\[ L = 43 \text{ m} \]
\[ m = 5.0 \text{ kg} \]
\[ \Delta t = 1.4 \text{ s} \]

\[ T_s = ? \]

\[ v = \sqrt{\frac{T_s}{m}} \quad \rightarrow \quad T_s = \mu v^2 \]

\[ m = ? \quad v = ? \]

\[ M = \frac{m}{L} \quad ; \quad v = \frac{L}{\Delta t} \]

\[ T_s = \frac{m}{L} \frac{L^2}{\Delta t^2} = \frac{mL}{\Delta t^2} = 110 \text{ N} \]
Example 1

A 43 meters long rope of mass 5.0 kg joins two climbers. One climber strikes the rope and 1.4 seconds later the second climber feels the effect. What is the rope tension?
2-D and 3-D Waves

wave fronts

circular wave

\[ D(r, t) = A(r) \sin(kr - wt + \phi) \]
2-D and 3-D Waves

Very far from the source, small segments of spherical wave fronts appear to be planes. The wave is creasing at every point in these planes.
\[ \sin \phi = \sin (kx - \omega t + \phi_0) \]

\[ \phi_1 = kx_1 - \omega t + \phi_0 \]

\[ \phi_2 = kx_2 - \omega t + \phi_0 \]

\[ \Delta \phi = \phi_2 - \phi_1 = k (x_2 - x_1) = k \Delta x = \frac{2\pi}{\lambda} \Delta x = 2\pi \frac{\Delta x}{\lambda} \]

\[ \Delta \phi_{\text{neighb. crest}} = 2\pi \text{ rad} \]
**Example 20.4 (phase)**

**Example 20.5**  
**The phase difference between two points on a sound wave**

A 100 Hz sound wave travels with a wave speed of 343 m/s.

a. What is the phase difference between two points 60.0 cm apart along the direction the wave is traveling?

b. How far apart are two points whose phase differs by 90°?

**Model** Treat the wave as a plane wave traveling in the positive x-direction.

\[ f = 100 \, \text{Hz} \]
\[ v = 343 \, \text{m/s} \]

\[ \Delta \phi = \frac{2\pi f}{v} \Delta x = 0.350 \, \text{rad} \]

\[ k = \frac{2\pi f}{v} = \frac{2\pi}{\lambda} \]

\[ \Delta \phi = k \Delta x \]

\[ \Delta x = 600 \, \text{cm} = 0.6 \, \text{m} \]
Example 20.4 (phase)

\[ \phi_2 = 63^\circ \]

6) \[ \Delta \phi = 90^\circ = 90^\circ \frac{\pi}{180^\circ} = \frac{\pi}{2} \text{ rad.} \]

\[ \Delta \phi = k \Delta x \quad \Rightarrow \quad \Delta x = \frac{\Delta \phi}{k} = \frac{\phi_2 - \phi_1}{2 \pi f} \]

\[ = 0.858 \text{ m} = 85.8 \text{ cm} \]
Sound Waves

Compression \rightarrow \text{density } \uparrow

Rarefaction \rightarrow \text{density } \downarrow

20 \text{ Hz} \quad 20 \text{ kHz}

Human range of hearing

\[ V_{\text{air}} = 340 \text{ m/s} \quad \text{(depends on the temperature)} \]

\[ V_{\text{water}} \approx 1480 \text{ m/s} \]
Electromagnetic Waves

Increasing frequency (Hz) →

10^6 10^8 10^10 10^12 10^14 10^16 10^18
AM radio FM radio/TV Microwaves Infrared Ultraviolet X rays
300 3 0.03 3 \times 10^{-4} 3 \times 10^{-6} 3 \times 10^{-8} 3 \times 10^{-10}

Increasing wavelength (m)

Visible light

700 nm 600 nm 500 nm 400 nm
Electromagnetic Waves

\[ n \text{- index of refraction} \]
\[ C \text{- speed of light in vacuum} \approx 3 \times 10^8 \text{ m/s} \]

\[ V_{\text{med}} = \frac{C}{n} \]

\[ f \text{ stays the same!} \]
\[ v = \Omega f \]
\[ \lambda \text{- must change} \]
\[ V_{\text{med}} \uparrow \Rightarrow \lambda \downarrow \]

Plane of incidence

\[ n = 1 \quad n > 1 \]
Example 20.8

Orange light with a wavelength of 600 nm is incident upon a 1.00 mm thick glass microscope slide.

a. What is the light speed in the glass?
b. How many wavelengths of light are inside the slide?
Power

\[ P = \frac{\text{Energy}}{\text{time}} \]

units = \[ J \text{ (joule)} \div S \text{ (second)} = W \text{ (watt)} \]
Intensity

\[ I = \frac{P}{a} \]

@ \( R_1 \) => \( q_1 = 4\pi R_1^2 \)

@ \( R_2 \) => \( q_2 = 4\pi R_2^2 \)

\[ I_1 = \frac{P}{4\pi R_1^2} ; \quad I_2 = \frac{P}{4\pi R_2^2} \]

\[ \frac{I_1}{I_2} = \frac{R_2^2}{R_1^2} \]

units = \( \frac{W}{m^2} = \frac{J}{m^2s} \)
Intensity

$I \propto P \propto E \propto A^2$

$E = \frac{m v^2}{2} + \frac{1}{2} k x^2$

$E = 0 + \frac{1}{2} k A^2$

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Intensity

\[ I_0 = I_{\text{min}} = 10^{12} \frac{W}{m^2} - \text{threshold of hearing} \]

\[ I_{\text{max}} = 10 \frac{W}{m^2} - \text{threshold of pain} \]

\[ \beta = (10 \text{ dB}) \log_{10} \left( \frac{I}{I_0} \right) \]

\( \beta = 0 \text{ dB} \) for \( I = I_0 \)

\( \beta = 130 \text{ dB} \) for \( I = I_{\text{max}} \)
Example 20.10 (Blender noise)

The blender making a smoothie produces a sound intensity level of 83 dB. What is the intensity of the sound? What would the sound intensity level be if a second blender is turned on?
Example 20.10 (Blender noise)

The blender making a smoothie produces a sound intensity level of 83 dB. What is the intensity of the sound? What would the sound intensity level be if a second blender is turned on?
Doppler Effect

Snapshot at time $3T$

Behind the source, the wavelength is expanded to $\lambda_{-}$.

In front of the source, the wavelength is compressed to $\lambda_{+}$.

Pablo detects frequency $f_{-}$.

Nancy detects frequency $f_{+}$.

Crest 0 was emitted at $t = 0$. The wave front is a circle centered on point 0.

Crest 1 was emitted at $t = T$. The wave front is a circle centered on point 1.

Crest 2 was emitted at $t = 2T$. The wave front is a circle centered on point 2.

\[ v - \text{speed of sound} \]
\[ v_{s} - \text{source} \]

\[ t = 3T \]

\[ \lambda_{+} = \frac{d}{3} = \frac{\Delta x_{\text{wave}} - \Delta x_{\text{source}}}{3} \]

\[ = \frac{3Tv - 3Tv_{s}}{3} \Rightarrow \lambda_{+} = T(v - v_{s}) \]

\[ \lambda_{-} = \frac{\Delta x_{\text{wave}} + \Delta x_{\text{source}}}{3} \Rightarrow \]

\[ \Rightarrow \lambda_{-} = T(v + v_{s}) \]
Doppler Effect

\[(20, 39)\]

\[\mathcal{S}_+ = \quad \mathcal{S}_- = \]
Doppler Effect

\[ \lambda_- = \sqrt{\frac{1 + \frac{v_3}{c}}{1 - \frac{v_3}{c}}} \lambda_0 \quad \text{receding} \]

\[ \lambda_+ = \sqrt{\frac{1 - \frac{v_3}{c}}{1 + \frac{v_3}{c}}} \lambda_0 \quad \text{approaching source} \]

Light wave