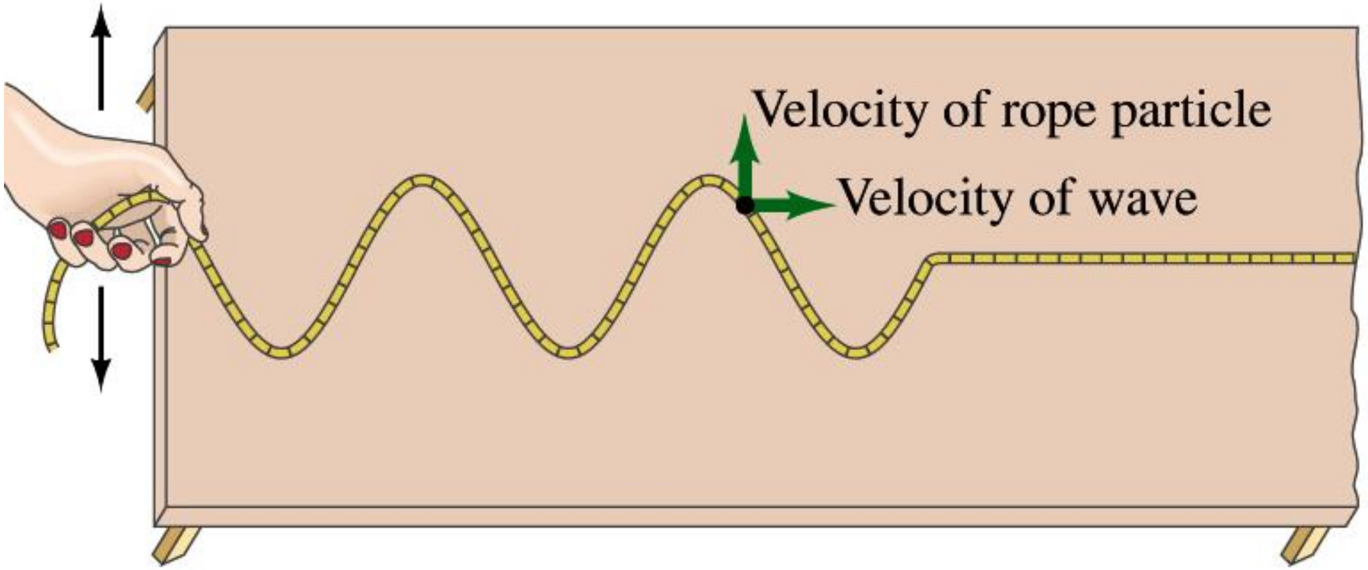
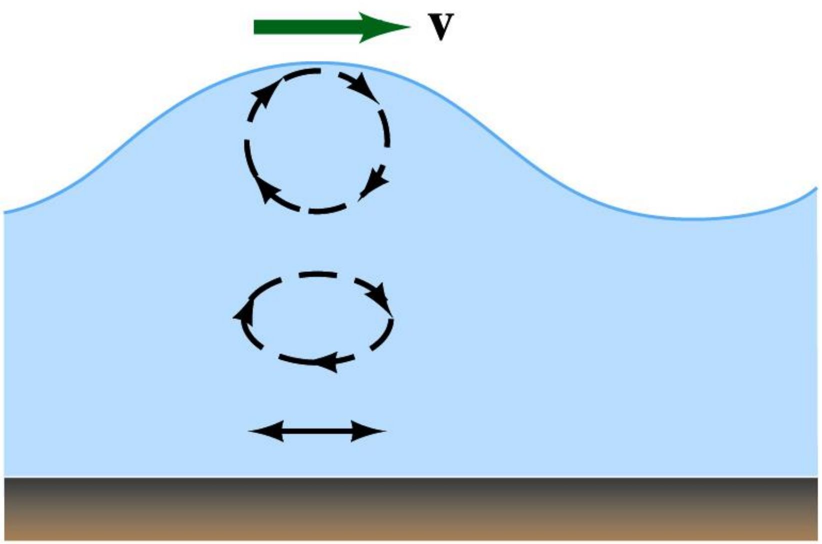
Chapter 12: Mechanical Waves and Sound





$y(x,t) = A\,sin\,2\pi f\left(\frac{t}{T} - \frac{x}{\lambda}\right)$ and $v = \lambda \cdot f$

Mechanical Waves – Figure 12.1

- Waves in a fluid are the result of a mechanical disturbance.
- At right, a stone disturbs water and creates visually observable traveling waves.

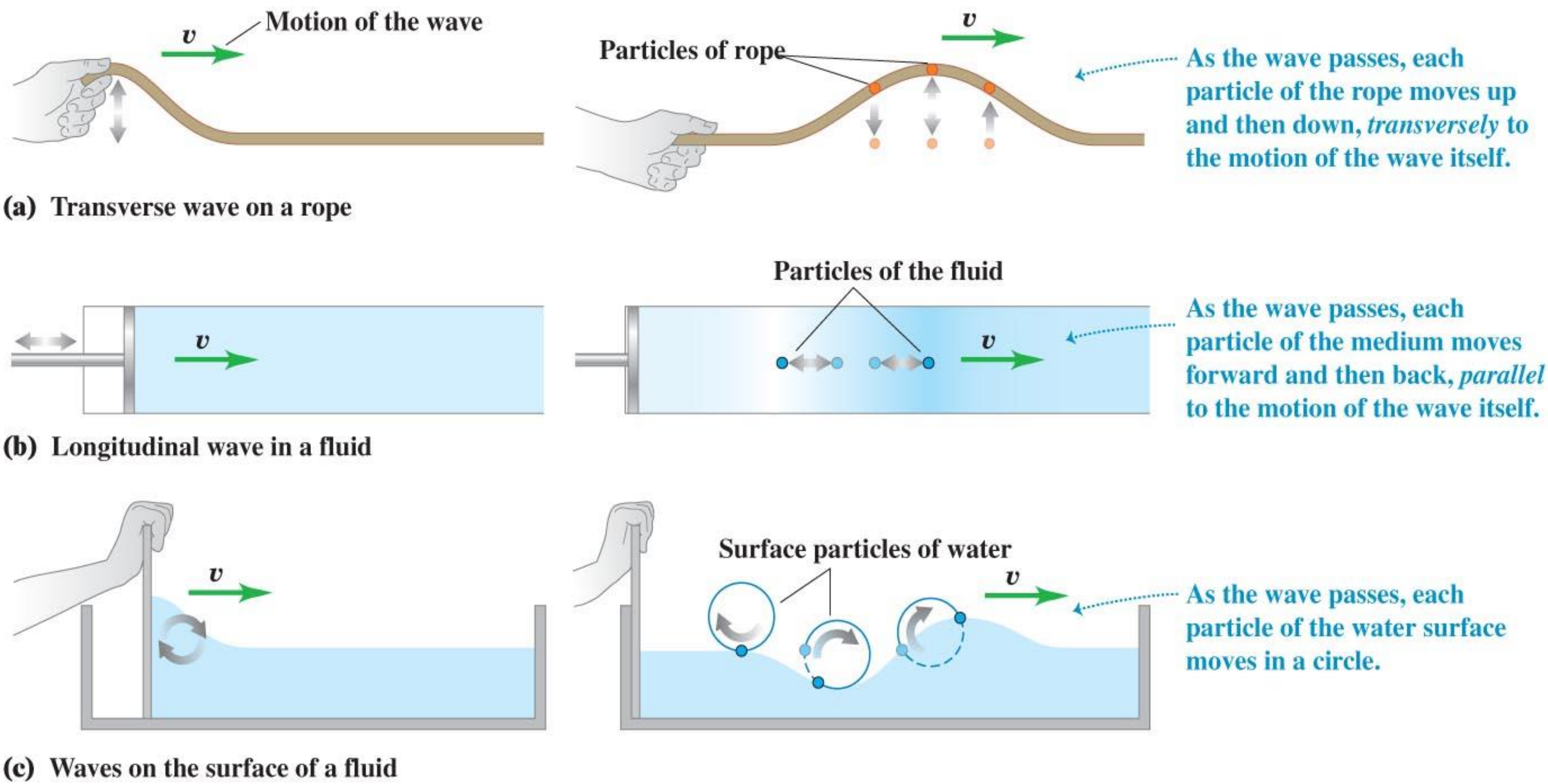
Chapter 12 Mechanical Waves and Sound

- To describe mechanical waves.
- To study superposition, standing waves, and interference.
- To understand sound as a longitudinal wave.
- To study sound intensity and beats.
- To understand the Doppler effect and frequency shifts.

To examine applications of acoustics and musical tones

Making waves

There are transverse, longitudinal, combined transverse longitudinal waves



note: differentiate between particle motion (SHM) and waveform motion (v)

Waves transport energy, but not matter from one point to another

Clicker – Questions 1

This airplane has remote sensing equipment based on a) laser, b)microwave, and c)sound waves.

Which radar has the highest resolution?

a) Visible Light - Laser

b) Microwave

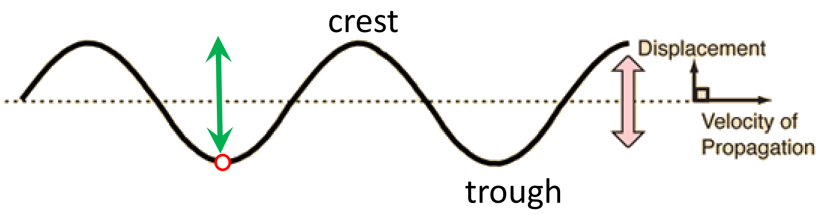
c) Sound wave

12.1 Mechanical Wave

Mechanical waves are produced by mechanical disturbance and there are two types.

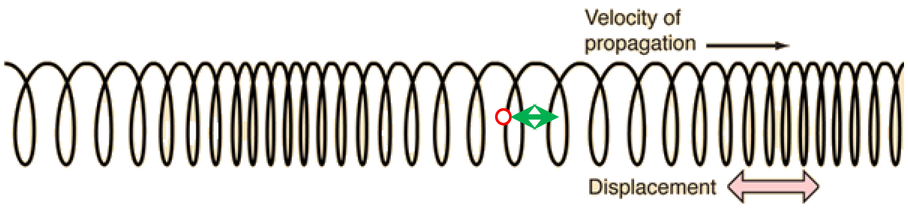
- Transverse Waves

  The wave disturbance is perpendicular
  to the direction of wave propagation.

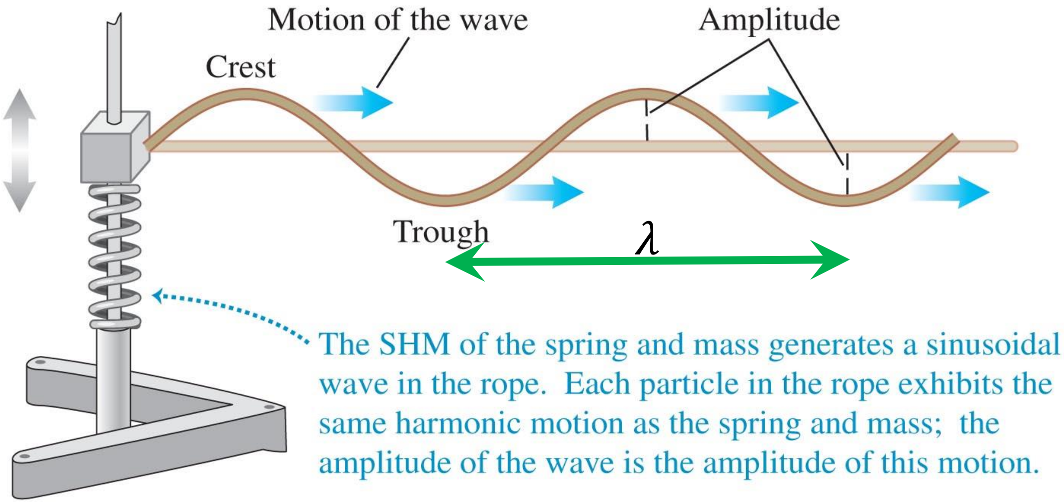


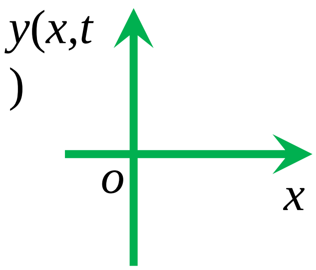
- Longitudinal Waves

  The wave disturbance is parallel to the
  direction of wave propagation.



12.2 Periodic Mechanical Wave





Wave speed

$$v = \frac{\lambda}{T} = \lambda f$$

Periodic in time----At a given x, the displacement from equilibrium changes periodically in a time period T, which is $1/f$ where f is the frequency of the oscillations.

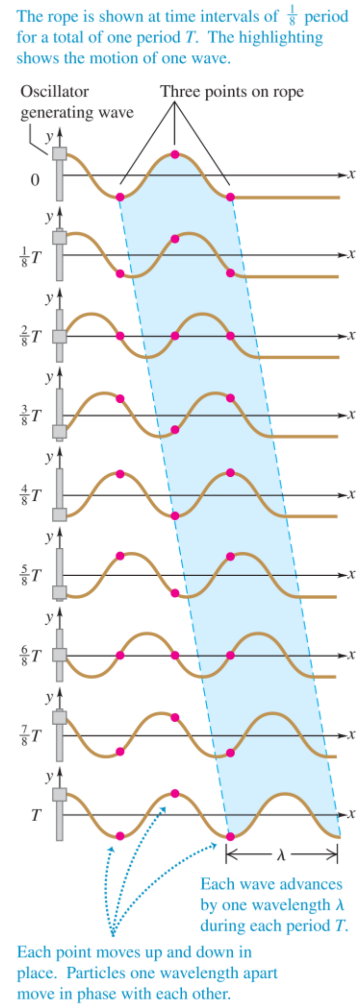
Periodic in space---At a given time (taking a snap shot), the displacement from equilibrium repeats itself after a certain distance known as the wavelength λ.

Periodic in propagation---In a time period T, the wave appears to propagate forward by a distance that is equal to the wavelength λ.

“Time Lapse” Snapshot of a Traveling Wave – Figure12.4

The wave advances one wavelength during one periodT

- If you follow the original set of markers (3 red dots at top of the figure), you can see the movement as time passes going down from top to bottom.
- Each fresh sketch as you go downward elapses 1/8 of the period.
- Recall that 8/8*T* (all the way from top to bottom) is one period, the time for one complete oscillation to pass.



$$v = distance/time = \lambda/Tv = \lambda f$$

$$f = 1/T$$

$$v = \lambda f$$

Pearson

$\lambda f = v_{wave}$ – Example 12.1

- We know that for any wave, the wavelength (in meters) times the frequency (in 1/s or Hz) will multiply to give the velocity of the wave (in m/s).
- Sound in air, sound in water, sound in metal, light … this relationship will guide us.
- Refer to the worked example for sound in air at 20°C.

Q15.1

Clicker question 2

If you double the wavelength λ of a wave on a string, what happens to the wave speed v and the wave frequency f?

A. v is doubled and f is doubled.

B. v is doubled and f is unchanged.

C. v is unchanged and f is halved.

D. v is unchanged and f is doubled.

E. v is halved and f is unchanged.

TABLE 12.1 Speed of sound in various materials

Material	Speed of sound (m/s)
Gases	
Air (20°C)	344
(25°C)	347
(30°C)	350
Helium (20°C)	999
Hydrogen (20°C)	1330
Liquids	
Liquid helium	
(4 K)	211
Water (0°C)	1402
Water (100°C)	1543
Mercury (20°C)	1451
Solids	
Polystyrene	1840
Bone	3445
Brass	3480
Pyrex™ glass	5170
Steel	5000
Beryllium	12,870

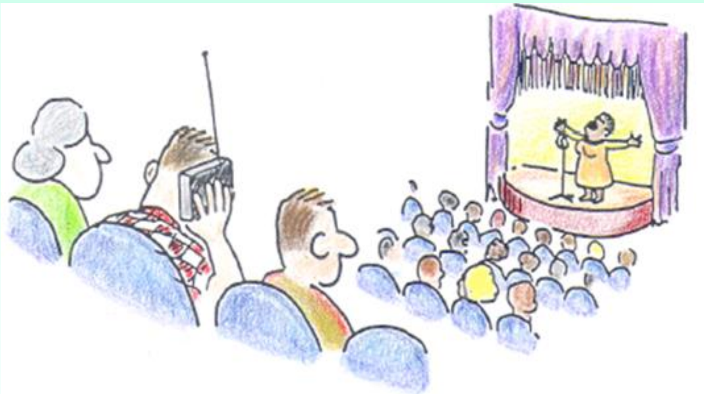
Example 12.1 What is the wave-length of sound in air at 20°C if the frequency $f = 262$ Hz?

$$\lambda = \frac{v}{f} = \frac{344 \text{ m/s}}{262 \text{ s}^{-1}} = 1.31 \text{ m}$$

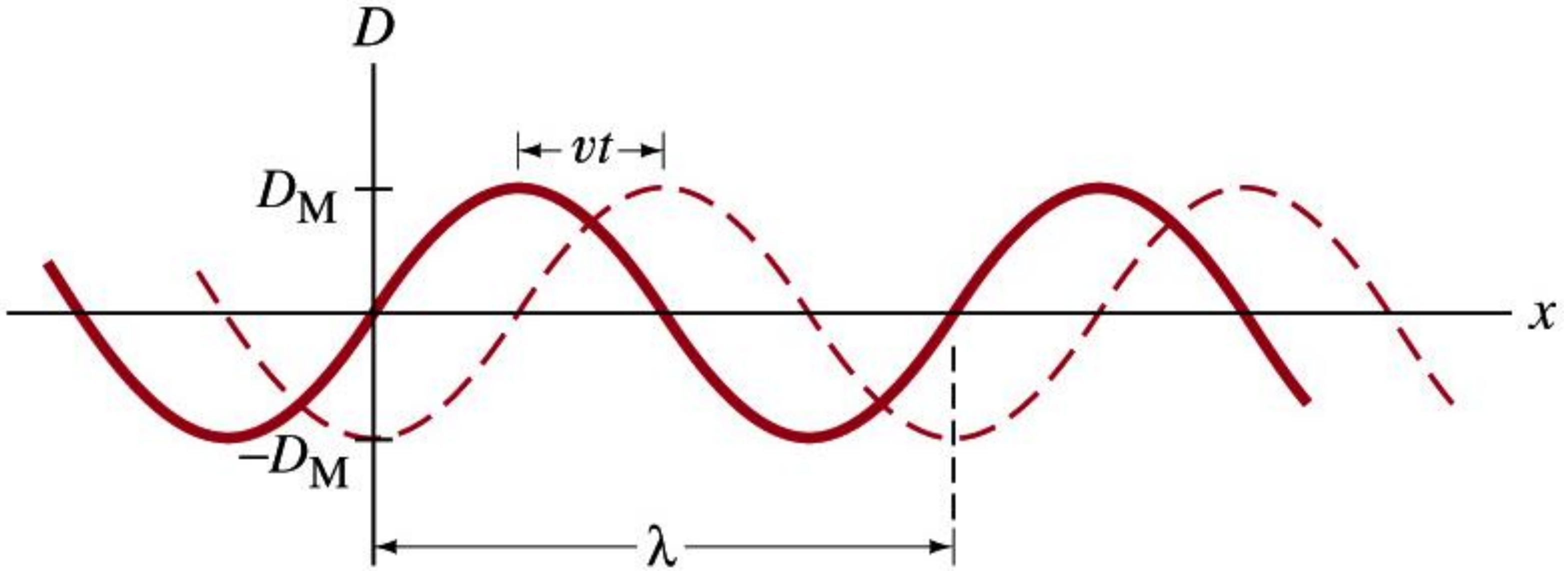
Clicker – Questions 3

Suppose at a concert a singer's voice is radio broadcast all the way around the world before reaching the radio you hold to your ear. This takes 1/8 seconds. If you are close, you hear her voice in air before you hear it from the radio. But if you are far enough away, both signals will reach you at the same time. How many meters distant must you be for this to occur?

$\boldsymbol{a)\,42.5\,m \quad b)\,1km \quad c)\,5m \quad d)\,10m}$



Mathematical description of a wave



velocity : $v = f\lambda$

period : $T = \frac{1}{f} = \frac{\lambda}{v}$

wave number : $k = \frac{2\pi}{\lambda}$

$$y(x,t) = A \sin 2\pi f\left(\frac{t}{T} - \frac{x}{\lambda}\right)$$

and $v = \lambda \cdot f$

$$v = \lambda f = \left(\frac{2\pi}{k}\right)\left(\frac{\omega}{2\pi}\right) = \frac{\omega}{k}$$

Dispersion relation

12.9 A certain transverse wave is described by the equation;

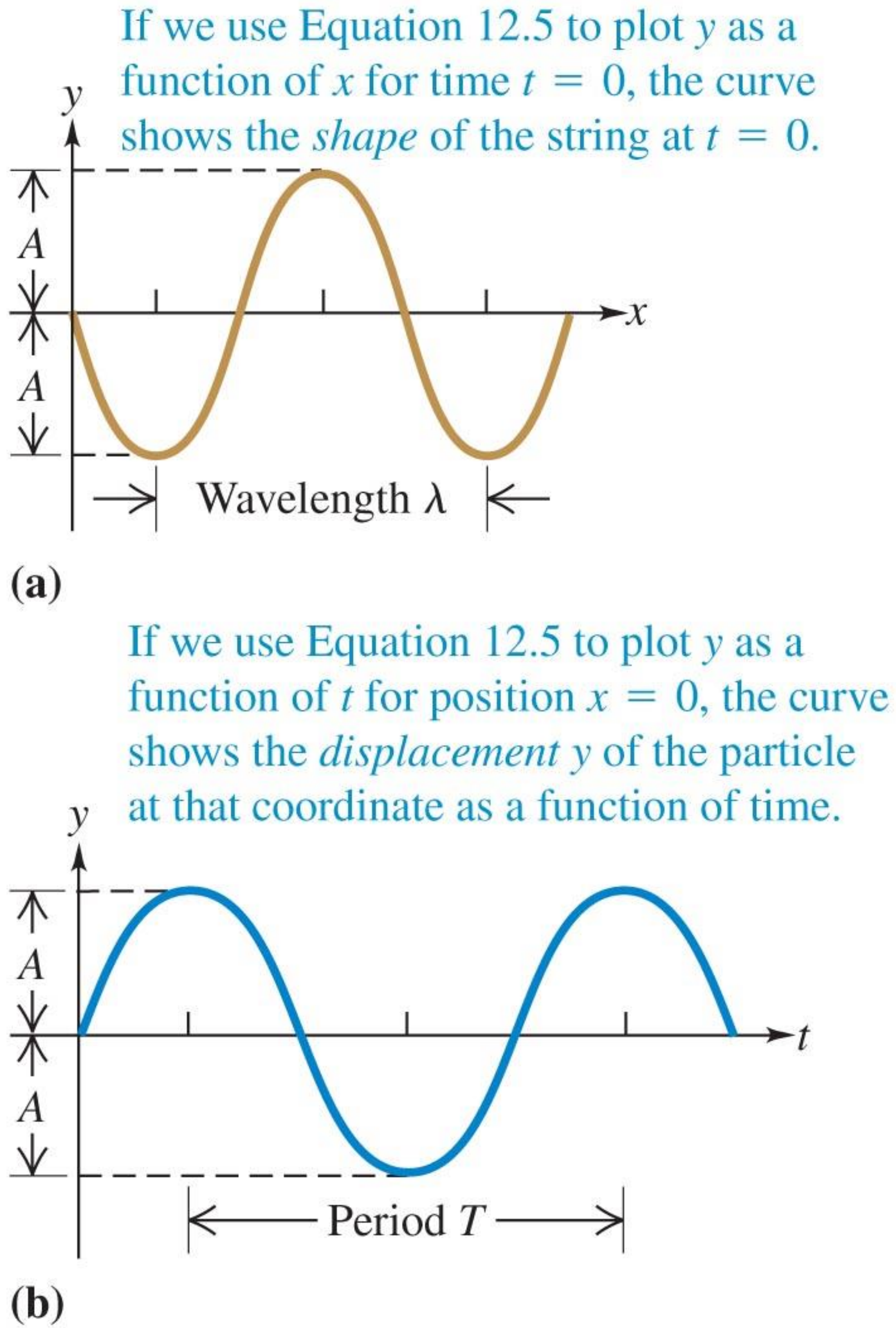
$$y(x,t) = (6.5mm)\, sin\, 2\pi\left(\frac{t}{0.036\ s} - \frac{x}{0.280\ m}\right)$$

$$y(x,t) = A\, sin\, 2\pi f\left(\frac{t}{T} - \frac{x}{\lambda}\right) \text{ and } v = \lambda \cdot f$$

Determine the wave's (a) amplitude, (b) wavelength, (c) frequency, (d) speed of propagation, and (e) direction of propagation?

(a) Amplitude $A = 6.5\ mm$
(b) Wavelength $\lambda = 0.280\ m$
(c) Frequency $f = \frac{1}{T} = \frac{1}{0.036} = 27.8\ Hz$
(d) Speed of propagation $v = \lambda \cdot f = 0.28 * 27.8 = 7.78 \frac{m}{s}$
(e) The wave propagates in the +***x*** direction.

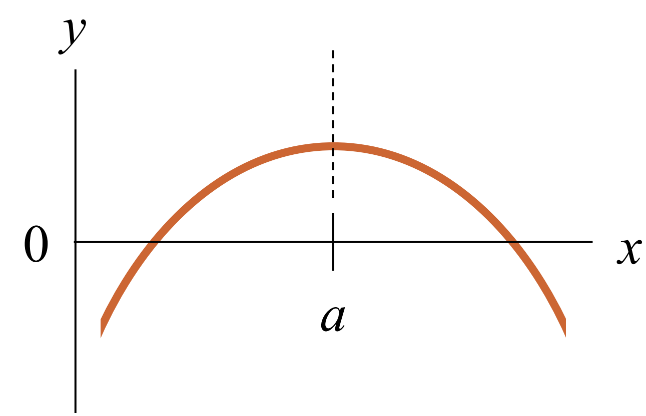
Two ways to graph a wave



Q15.3

Clicker question 4

A wave on a string is moving to the right. This graph of $y(x, t)$ versus coordinate x for a specific time t shows the shape of part of the string at that time. At this time, what is the *velocity* of a particle of the string at $x = a$?



A. The velocity is upward.

B. The velocity is downward.

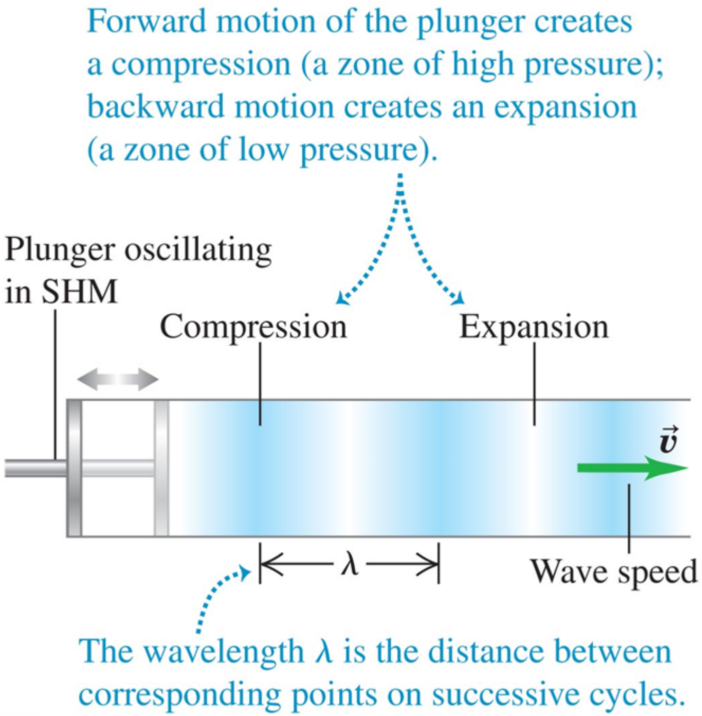
C. The velocity is zero.

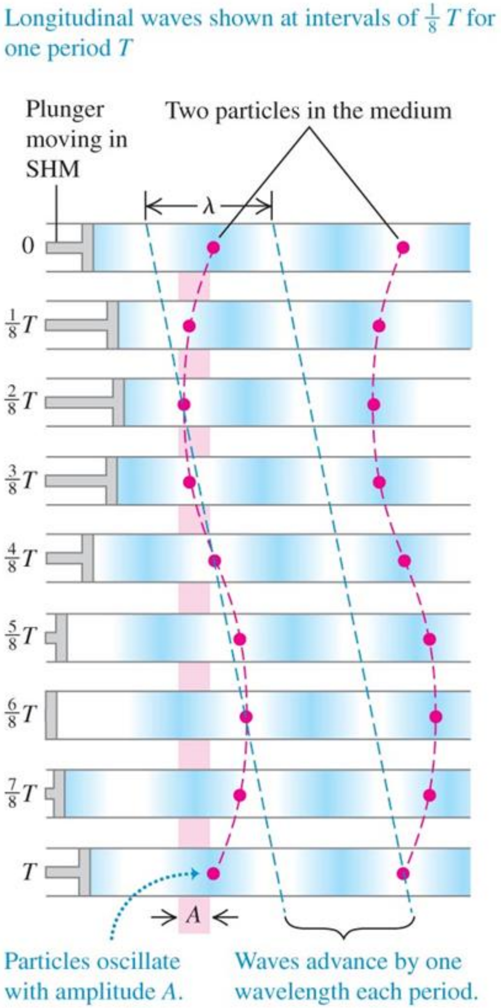
D. Either A or B is possible.

E. Any of A, B, or C is possible.

Longitudinal and Transverse Waves

- Figures 12.5 and 12.6 help us to see the sinusoidal waveform.





12.3 Waves Speed

Speed of a Transverse Wave (in a rope or string) is $v = \sqrt{\frac{F_T}{\mu}}$

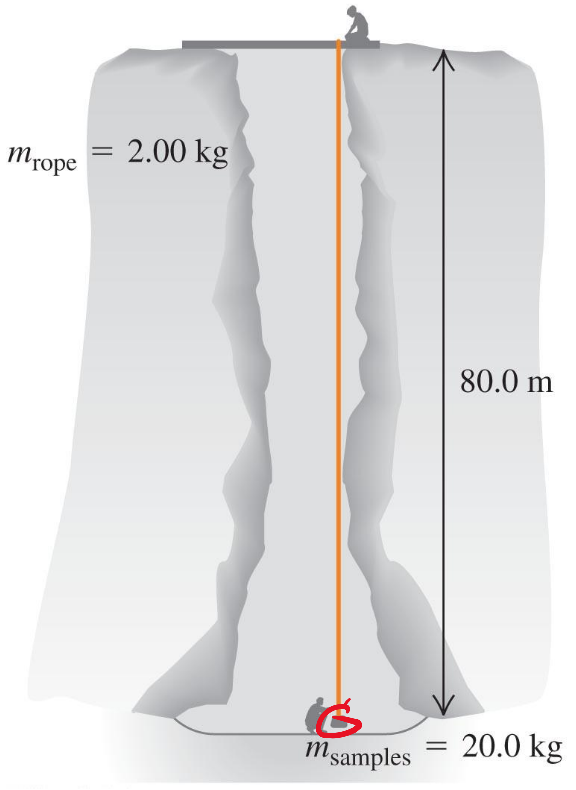
F_T: Tension force in N,
μ: The linear mass density, mass per unit length, in kg/m.

Example 12.2
Waves on a Long Rope Under Tension

Given: See the diagram. Ignore the weight of the rope for F_T.
Find: (a) the speed of the wave.
(b) if f = 20 Hz, what is λ?

Solution:
(a) $F_T = m_{sample}g = (20\text{ kg})(9.8\text{ m/s}^2) = 196\text{ N}$
$\mu = m/L = (2.00\text{ kg})/(80.0\text{ m}) = 0.0250\text{ kg/m}$
$v = \sqrt{F_T/\mu} = 88.5\text{ m/s}$

(b) $\lambda = v/f = 4.43\text{ m}$



The velocity of the wave will depend on the type and size of rope as well as the tension we add with our geological sample.

12.4 Mathematical Description of a Wave

How is the displacement from equilibrium related to position and time? $y = f(x, t)$

- Consider *x* = 0 where the wave is generated:

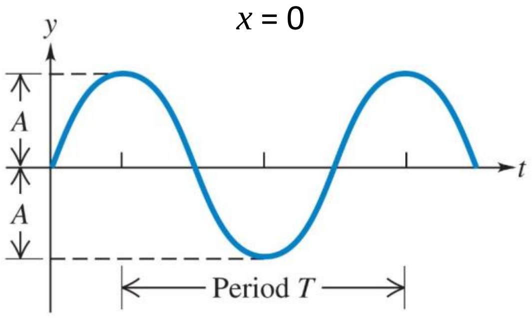
$$y = A\sin(\omega t) = A\sin(2\pi f t)$$

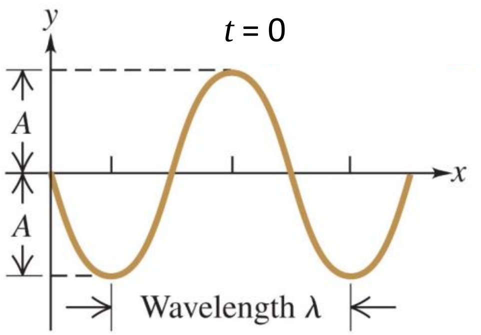
- Now, consider $x \neq 0$.

It takes a time $t = \frac{x}{v}$ for the wave generated at $x = 0$ to propagate to *x*. Or, the oscillations at x is delayed by a time $t = \frac{x}{v}$ compared with the oscillations at $x = 0$. Therefore, the oscillations at x is given by

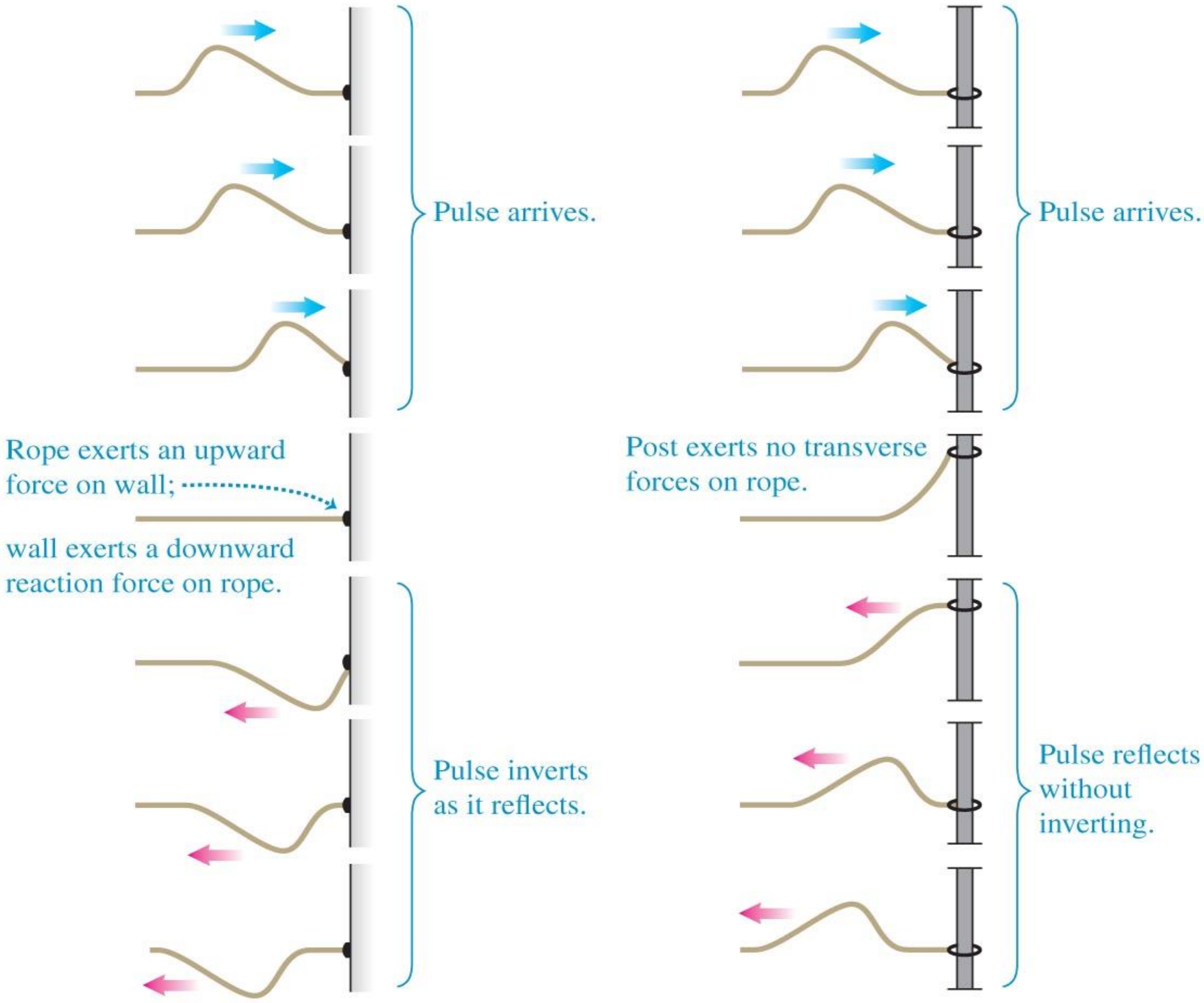
$$y(x,t) = A\sin\omega\left(t - \frac{x}{v}\right) = A\sin 2\pi f\left(t - \frac{x}{v}\right)$$

$$= A\sin 2\pi\left(\frac{t}{T} - \frac{fx}{v}\right) = A\sin 2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)$$





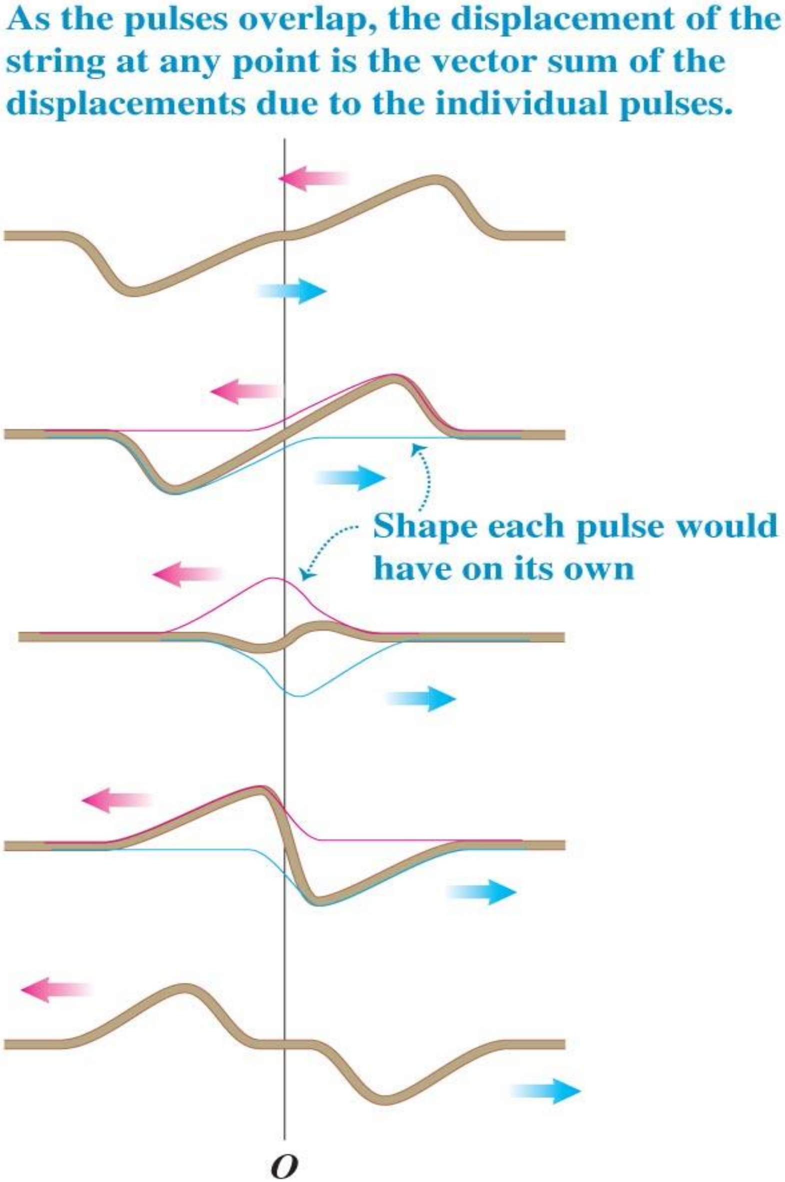
12.5 Reflection and Superposition

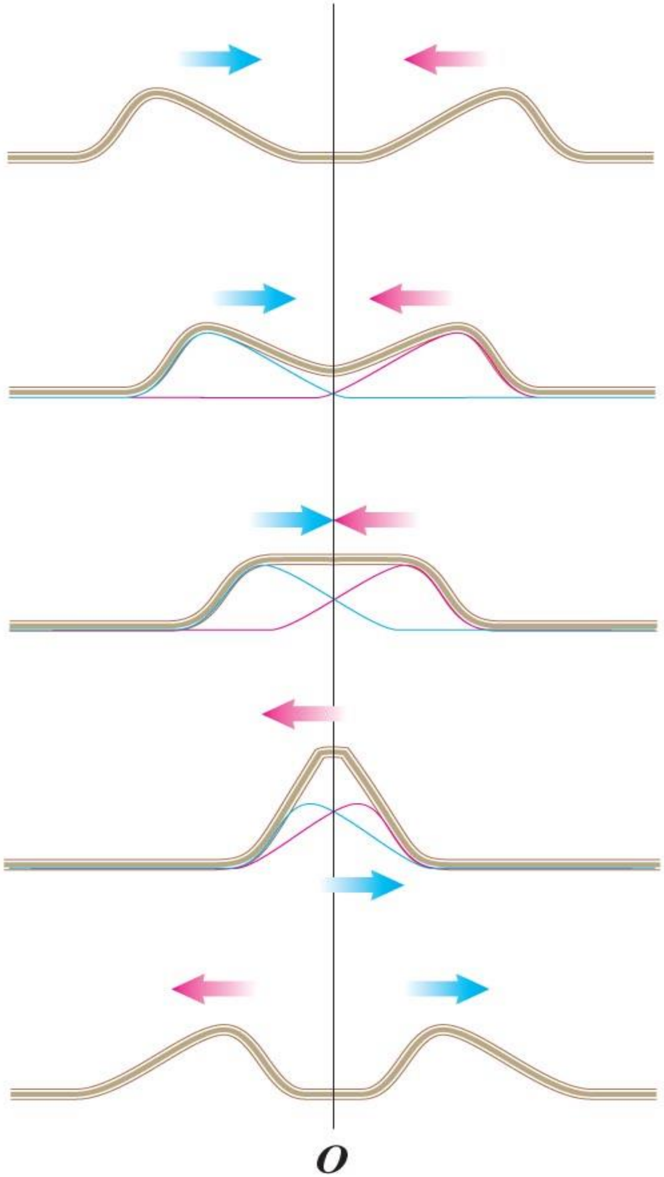


(a) Wave reflects from a fixed end.

(b) Wave reflects from a free end.

Encounter between waves travelling in opposite directions

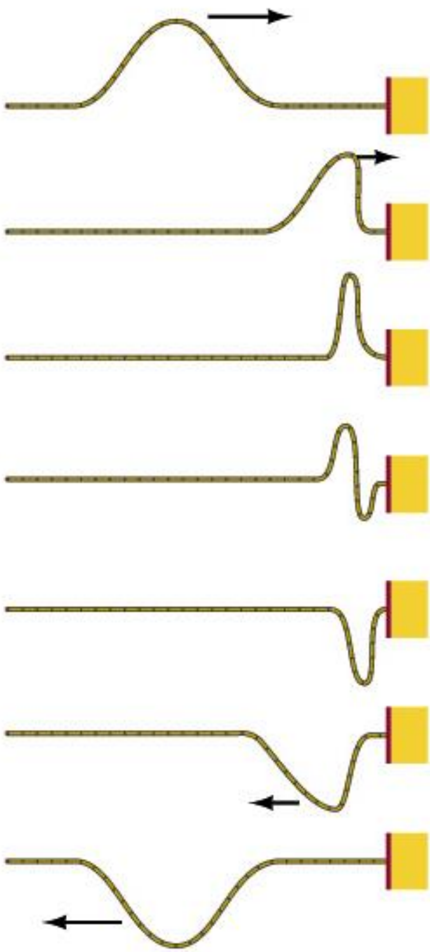




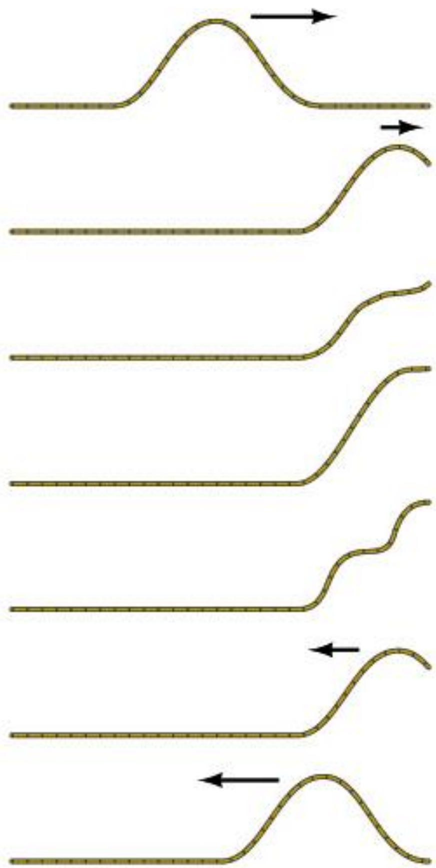
Inverted
At point 0 amplitude = 0

Identical
At point 0 slope = 0

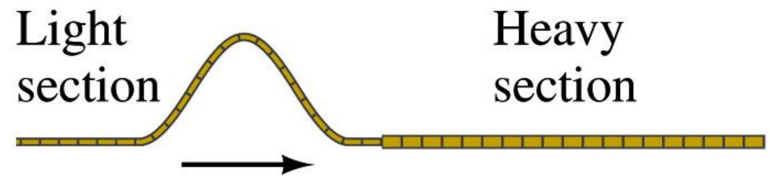
Reflection and Transmission



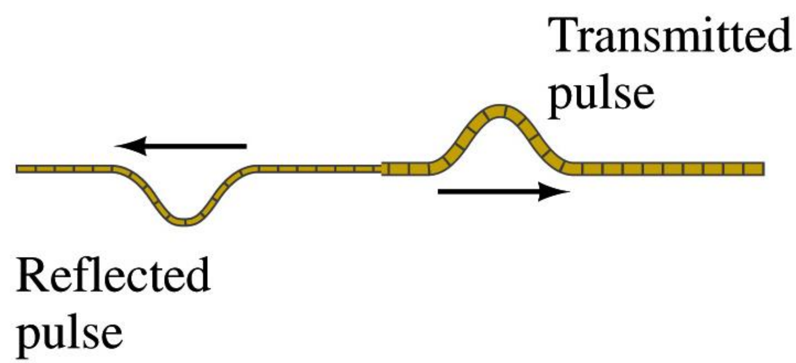
End of rope is fixed



End of rope is free

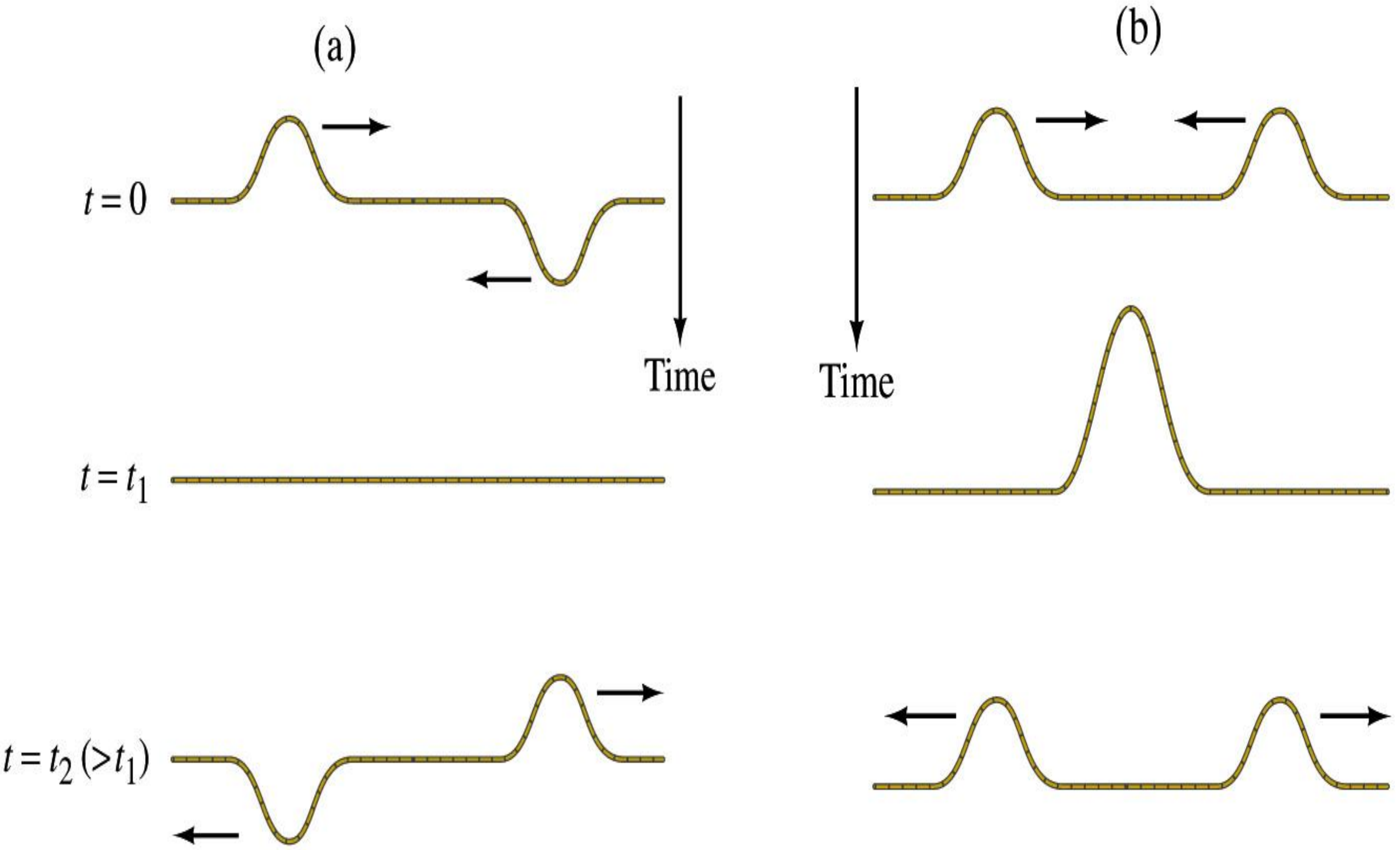


Wave pulse reaches a discontinuity



Wave pulse is partly reflected and transmitted

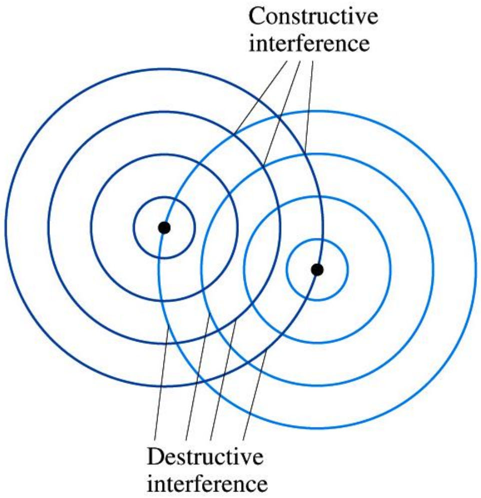
Two waves pulses pass each other

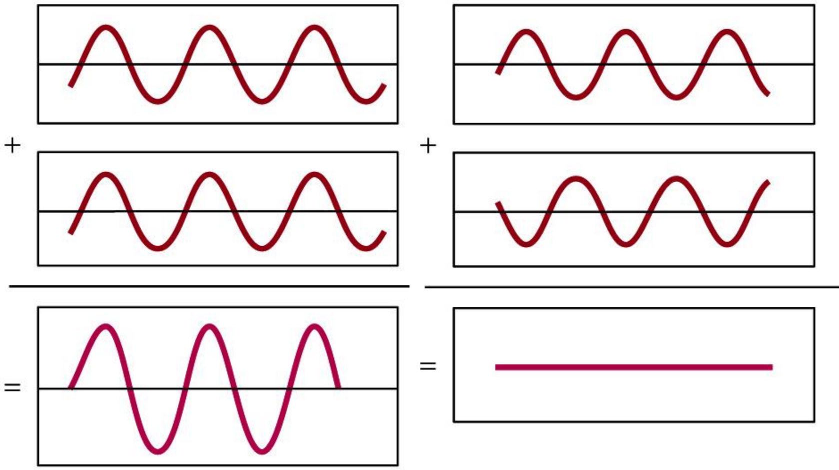


destructive

constructive

Interference of Waves

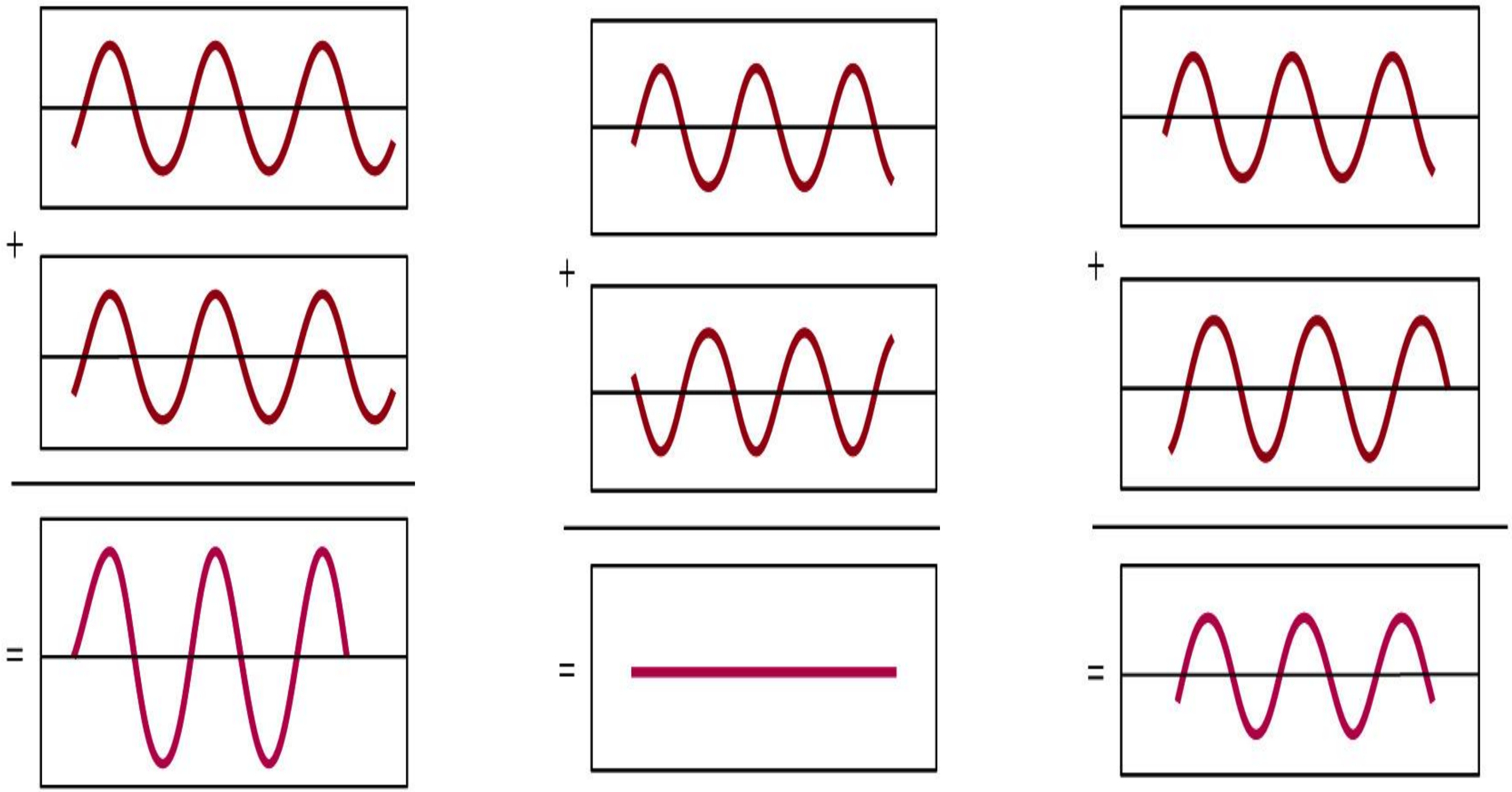




Constructive **Destructive**

Light plus light gives darkness when Φ=180

Two waves interfere

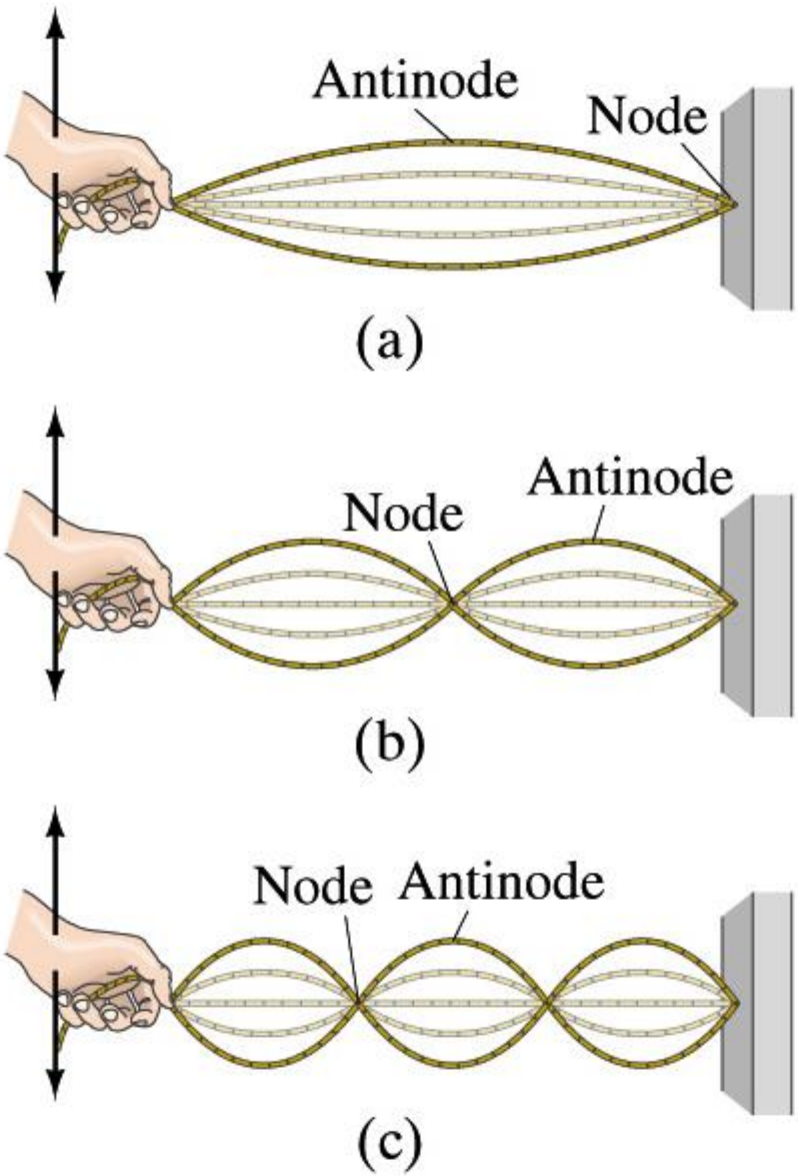


(a) constructively

(b) destructively

(c) partially destructively

Standing Waves



The frequency at which standing waves are produced are the natural frequencies or resonant frequencies

Standing Wave (mathematical derivation)

→ ←

$y_1(x,t) = -A\cos(kx+\omega t)$

$y_2 = A\cos(kx-\omega t)$

} wave travel in opposite directions and are 180° out of phase

$$y(x,t) = y_1(x,t) + y_2(x,t) = A\left(-\cos(kx+\omega t) + \cos(kx-\omega t)\right)$$

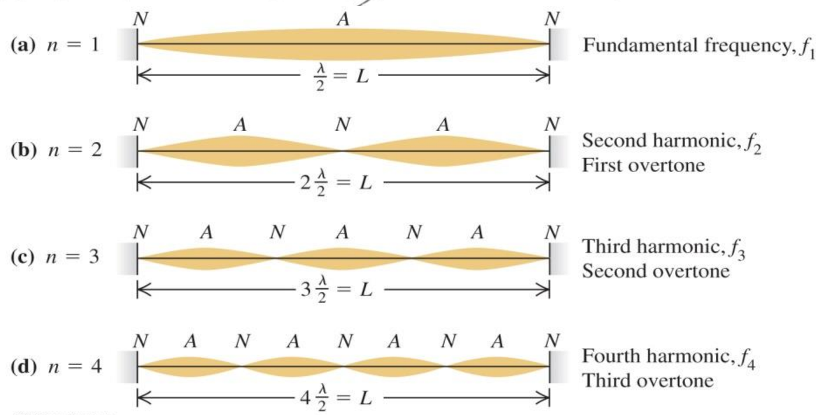
use: $\cos(a \pm b) = \cos a \cos b \mp \sin a \sin b$

$a = kx$

$b = \omega t$

$$y(x,t) = A\cos(a-b) - A\cos(a+b) = A(\cos a\cos b + \sin a \sin b - \cos a \cos b + \sin a \sin b)$$

$$= 2A \sin kx \sin \omega t \rightarrow \boxed{A_{SW} = 2A}$$



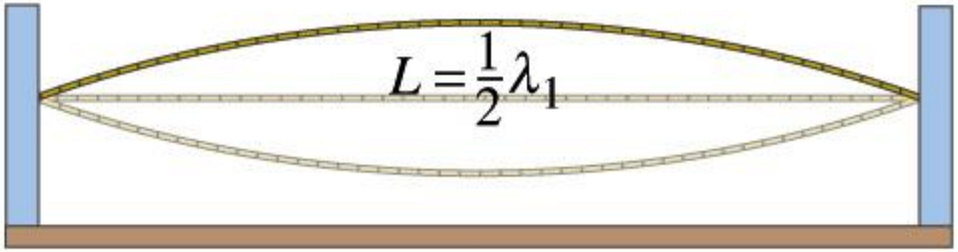
for $kx = 0$: $0, \pi, 2\pi, 3\pi$

$k = \frac{2\pi}{\lambda}$

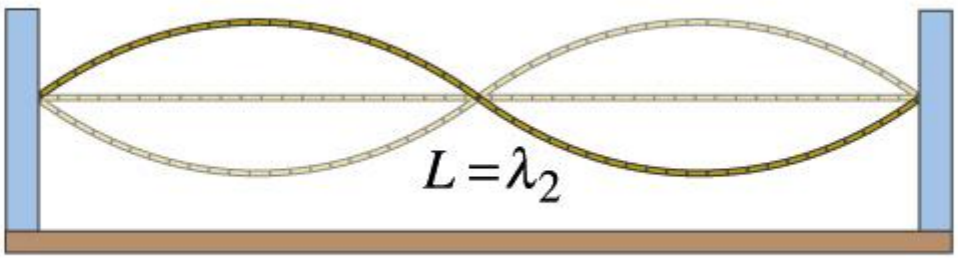
$$x = 0, \frac{\pi}{k}, \frac{2\pi}{k}, \frac{3\pi}{k} \ldots = 0, \frac{\lambda}{2}, \frac{2\lambda}{2}, \frac{3\lambda}{2} \ldots$$

fundamental ($\frac{\lambda}{2}$), first overtone ($\frac{2\lambda}{2}$), second overtone ($\frac{3\lambda}{2}$)

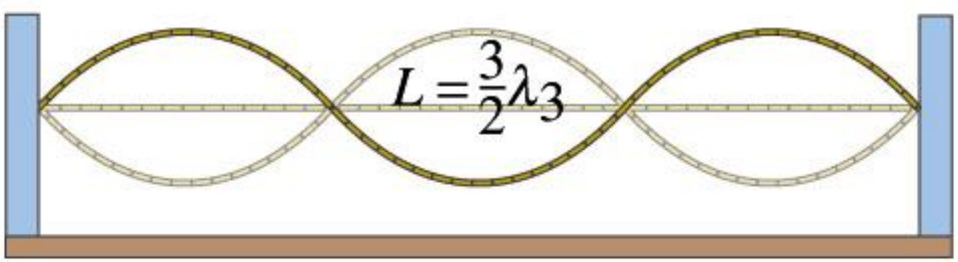
Resonant waves in a cavity



Fundamental or first harmonic, f_1



First overtone or second harmonic, $f_2 = 2f_1$



Second overtone or third harmonic, $f_3 = 3f_1$

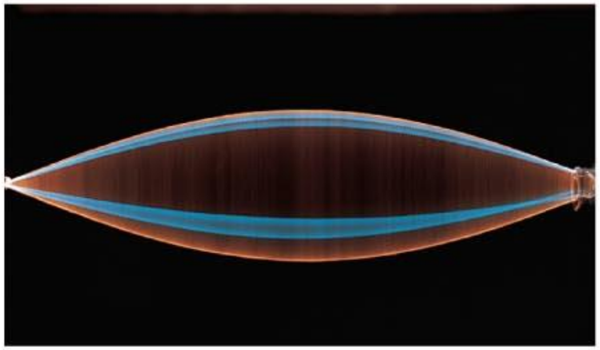
$$L = \frac{n\lambda_n}{2} \qquad n = 1, 2, 3 \text{ ------}$$

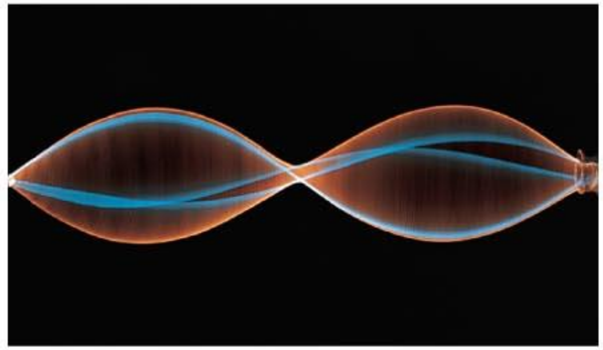
$$\lambda_n = \frac{2L}{n} \qquad n = 1, 2, 3 \text{ ------}$$

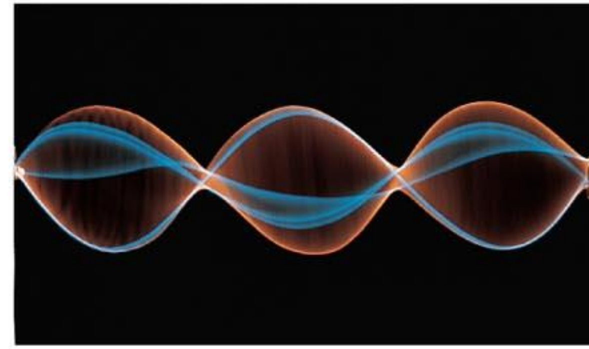
$$f_n = \frac{v}{\lambda_n} = \frac{nv}{2L} = nf_1 \qquad n = 1, 2, 3 \text{ ------}$$

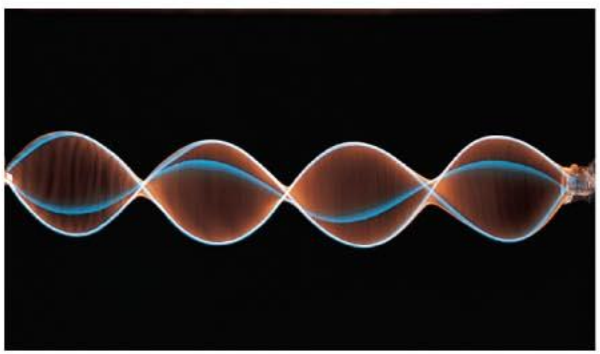
$$f_1 = \frac{v}{\lambda_1} = \frac{v}{2L} = \text{fundamental frequency}$$

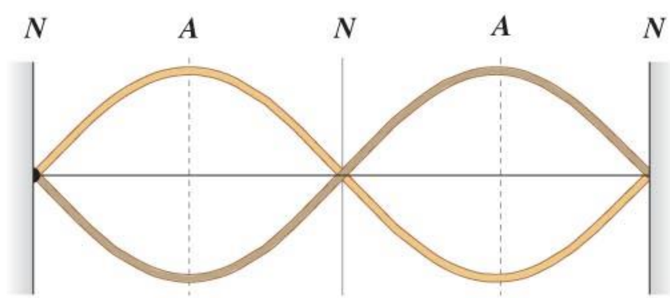
Standing waves and normal modes


(a) String is one-half wavelength long.


(b) String is one wavelength long.


(c) String is one and a half wavelengths long.

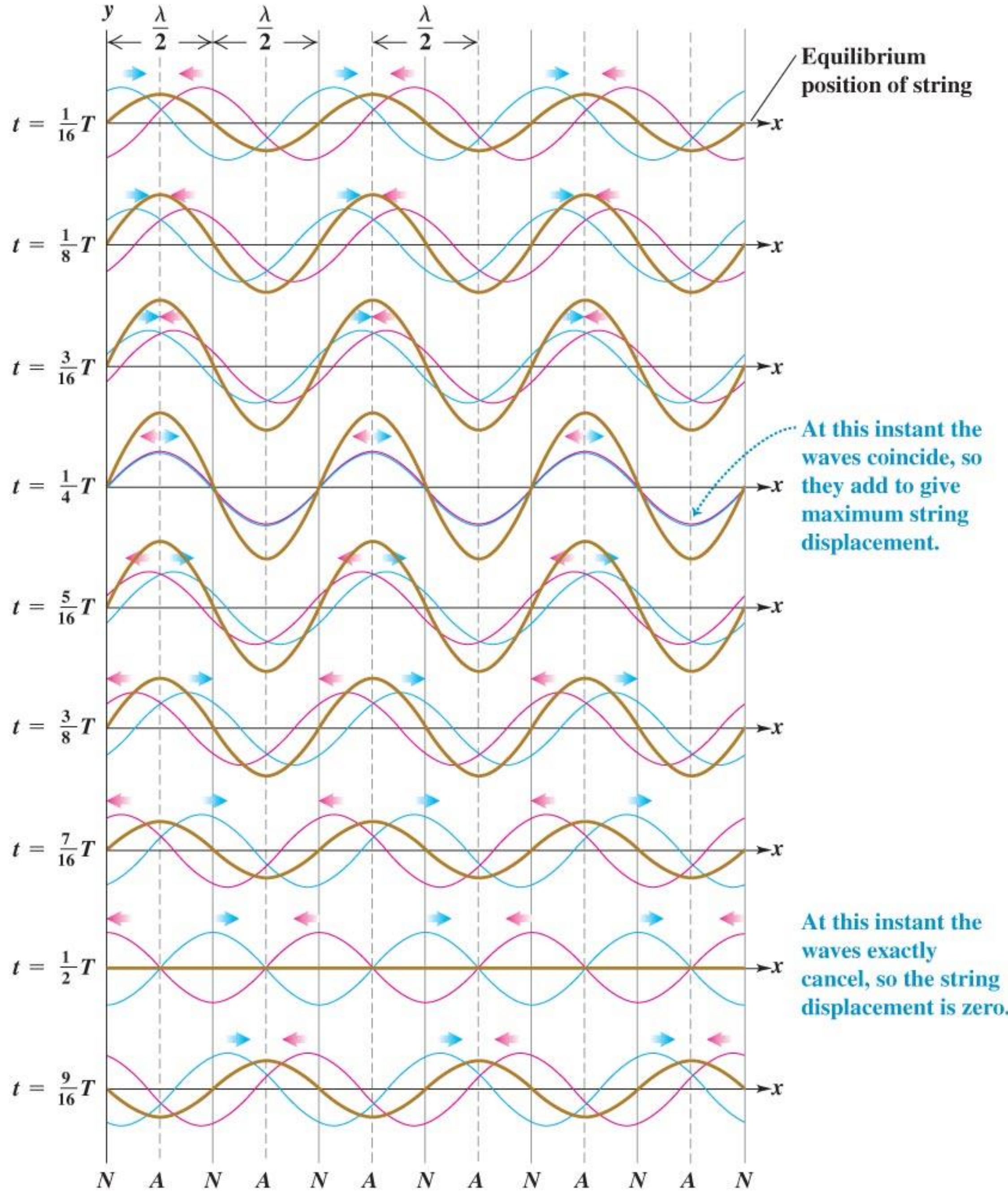

(d) String is two wavelengths long.



N = **nodes:** points at which the string never moves.

A = **antinodes:** points at which the amplitude of string motion is greatest.

(e) The shape of the string in (b) at two different instants.



y
λ/2
λ/2
λ/2
Equilibrium position of string
$t = \frac{1}{16}T$
$t = \frac{1}{8}T$
$t = \frac{3}{16}T$
$t = \frac{1}{4}T$
$t = \frac{5}{16}T$
$t = \frac{3}{8}T$
$t = \frac{7}{16}T$
$t = \frac{1}{2}T$
$t = \frac{9}{16}T$
x
At this instant the waves coincide, so they add to give maximum string displacement.
At this instant the waves exactly cancel, so the string displacement is zero.
N A N A N A N A N A N A N

Standing waves and normal modes

A string of length **L** is rigidly fixed on both ends and integer half wavelength appear as standing waves

$$L = n\frac{\lambda}{2} \text{ (n=1,2,3.............)}$$

$$\text{Wavelengths } \lambda = 2\frac{L}{n} \text{ (n=1,2,3.............)}$$

$f_1 = \frac{v}{2L}$ fundamental frequency; (Use; $f_n = \frac{v}{\lambda_n} = \frac{nv}{2L}$)

$$\text{Frequency; } f_n = n\frac{v}{2L} = nf_1 \text{ (n=1,2,3.............)}$$

These frequencies are harmonics or overtones

Application: tuning a string instrument.

$$v = \sqrt{\frac{F_T\ (tension\ force)}{\mu\ (mass\ per\ unit\ length)}}$$

$$f_1 = \frac{v}{2L} = \frac{1}{2L}\sqrt{\frac{F_T}{\mu}}\ (\mu = \frac{m}{L})$$

Q15.8

Clicker question 5

The four strings of a musical instrument are all made of the same material and are under the same tension, but have different thicknesses. Waves travel…

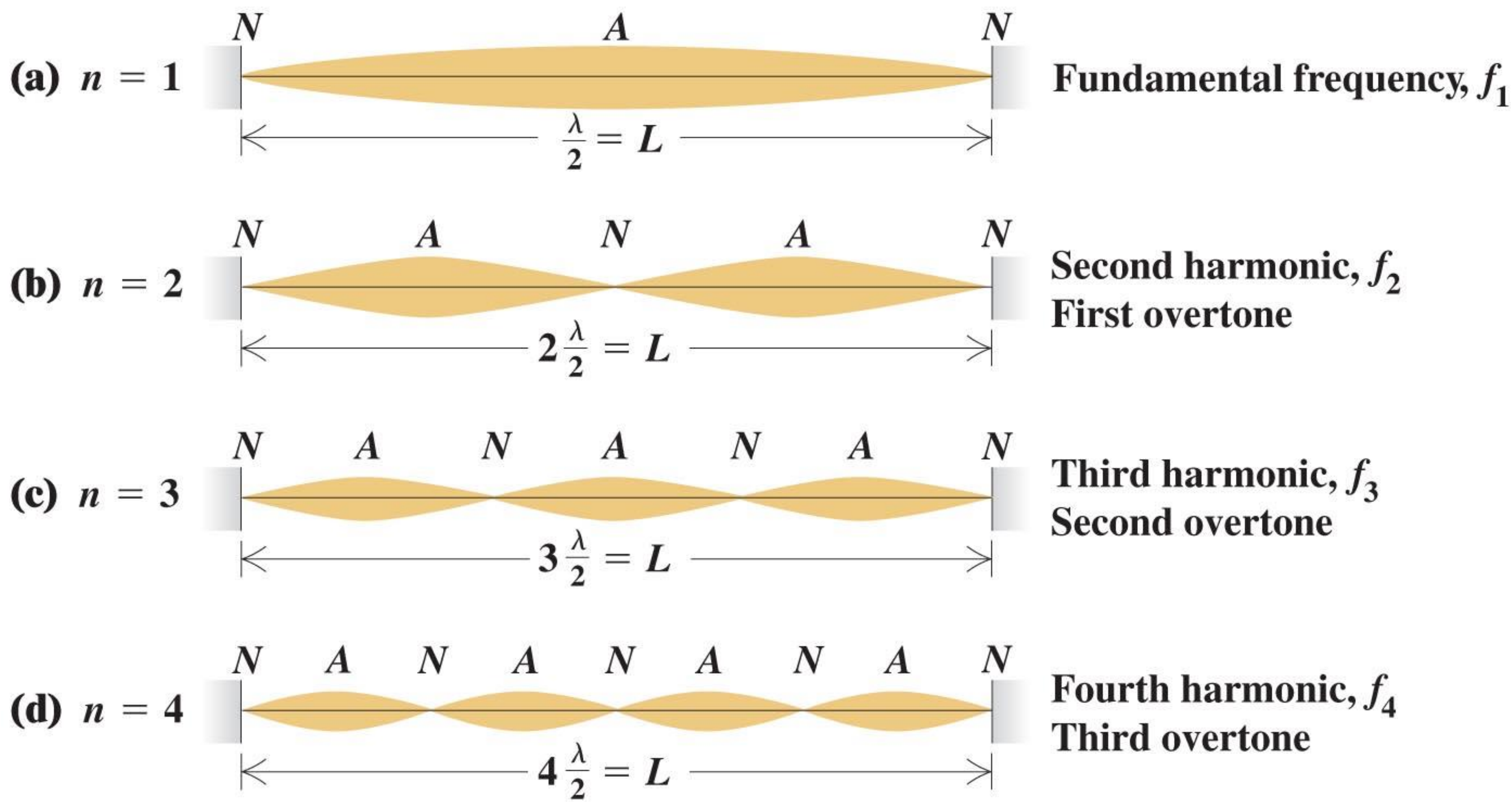
A. fastest on the thickest string.

B. fastest on the thinnest string.

C. at the same speed on all strings.

D. Either A or B is possible.

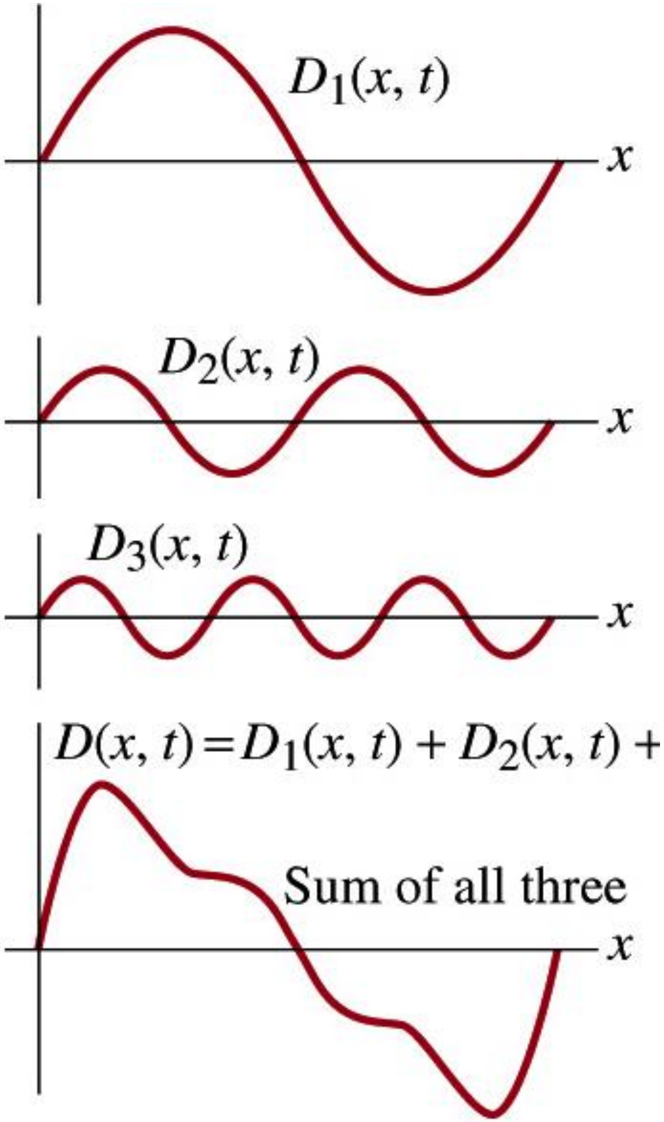
E. Any of A, B, or C is possible.



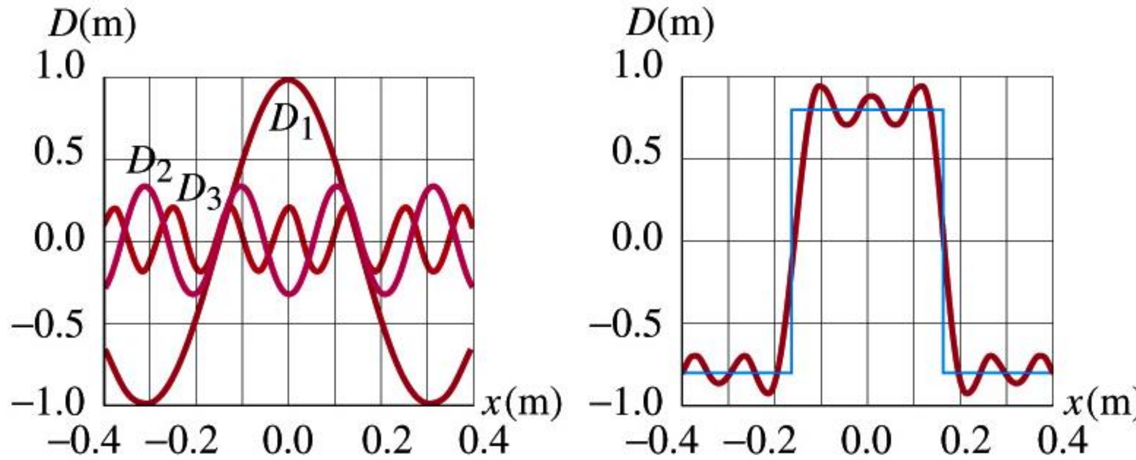
(a) $n = 1$
N A N
$\frac{\lambda}{2} = L$
Fundamental frequency, f_1
(b) $n = 2$
N A N A N
$2\frac{\lambda}{2} = L$
Second harmonic, f_2
First overtone
(c) $n = 3$
N A N A N A N
$3\frac{\lambda}{2} = L$
Third harmonic, f_3
Second overtone
(d) $n = 4$
N A N A N A N A N
$4\frac{\lambda}{2} = L$
Fourth harmonic, f_4
Third overtone

The principle of superposition

General case



Making a square wave



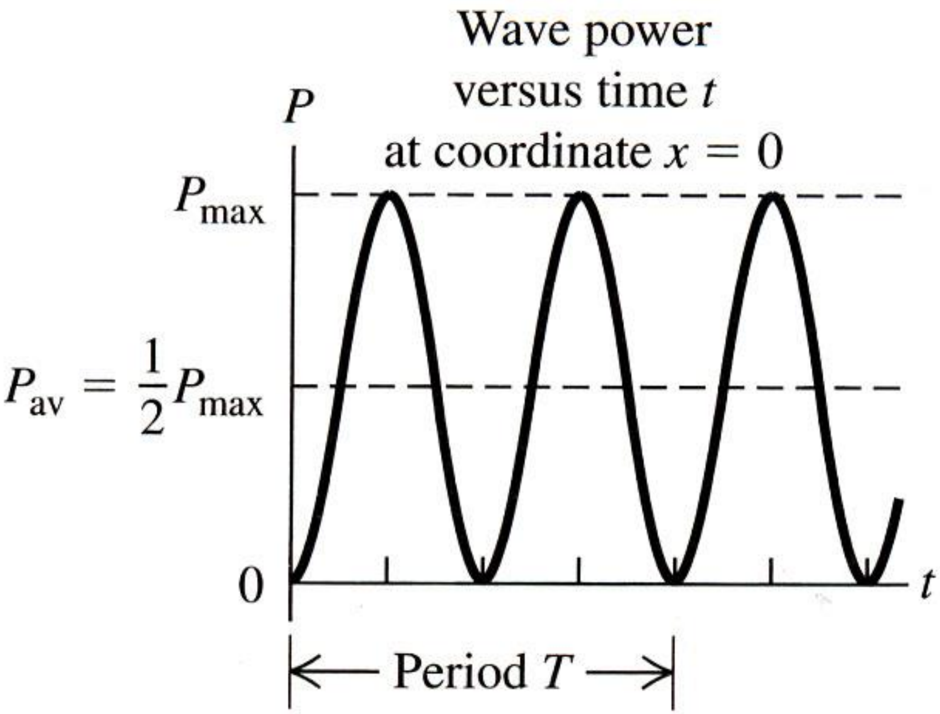
At t=0 we have

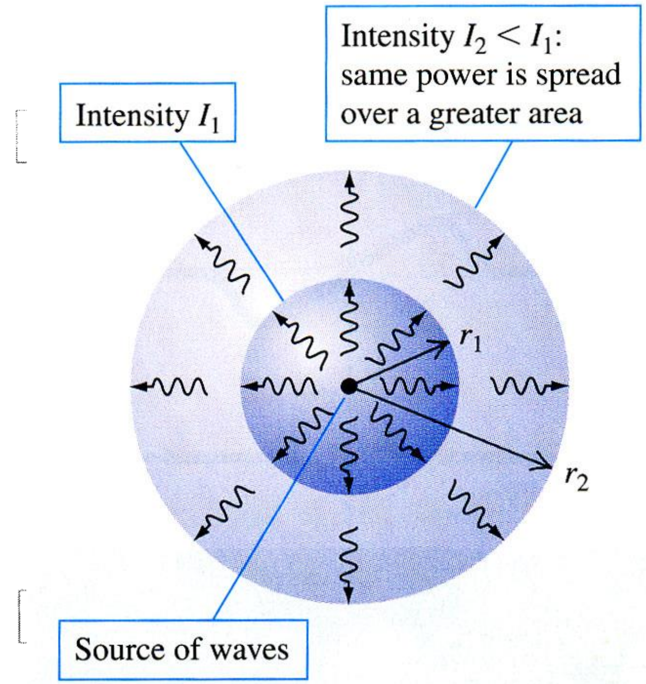
$$D1 = D_m \mathrm{Cos}[kx]$$

$$D2 = \frac{1}{3} D_m \mathrm{Cos}[3kx]$$

$$D2 = \frac{1}{5} D_m \mathrm{Cos}[5kx]$$

$$D_M = 1.0\mathrm{m} \quad k = 10\mathrm{m}^{-1}$$





$E \propto A^2 \sin^2 \omega t$

E: energy; A: amplitude

$E \propto A^2$

$P = \frac{E}{t}$

$I = \frac{\overline{P}}{Area} = \frac{\overline{P}}{4\pi r^2} \propto \frac{1}{r^2}$

$4\pi r^2$: spherical wave

Towards the wave equation

particle velocity

$$y(x,t) = A\sin(\omega t - kx) \quad \text{wave function}$$

at fixed location x

$$v_y = \frac{\partial y}{\partial t} = \omega A\cos(\omega t - kx)$$

particle acceleration

$$a_y = \frac{\partial^2 y}{\partial t^2} = -\omega^2 A\sin(\omega t - kx) = -\omega^2 y(x,t) \quad \text{SHM } a_y = -\omega^2 y$$

at fixed time t

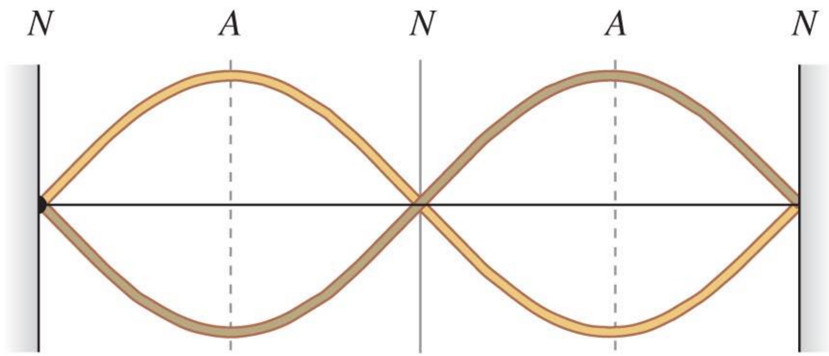
$$\frac{d^2 y(x,t)}{dx^2} = \frac{1}{v^2}\frac{d^2 y(x,t)}{dt^2}$$

slope: $\frac{dy}{dx} = -kA\cos(\omega t - kx)$

curvature: $\frac{d^2 y}{dx^2} = -k^2 A\sin(\omega t - kx) = -k^2 y(x,t)$

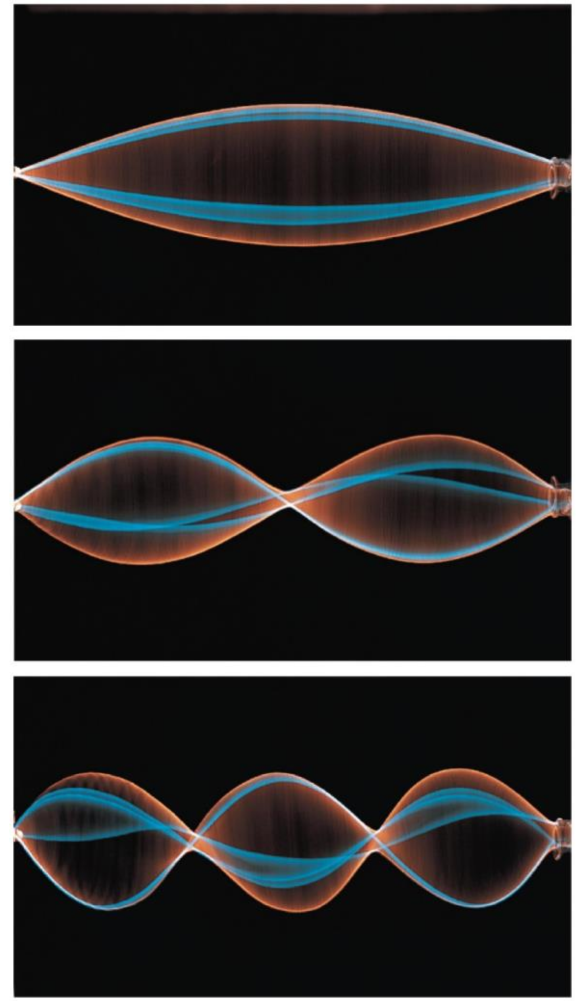
$$\frac{\frac{d^2 y}{dt^2}}{\frac{d^2 y}{dx^2}} = \frac{-\omega^2 y(x,t)}{-k^2 y(x,t)} = v^2$$

12.6 Standing Waves and Normal Modes



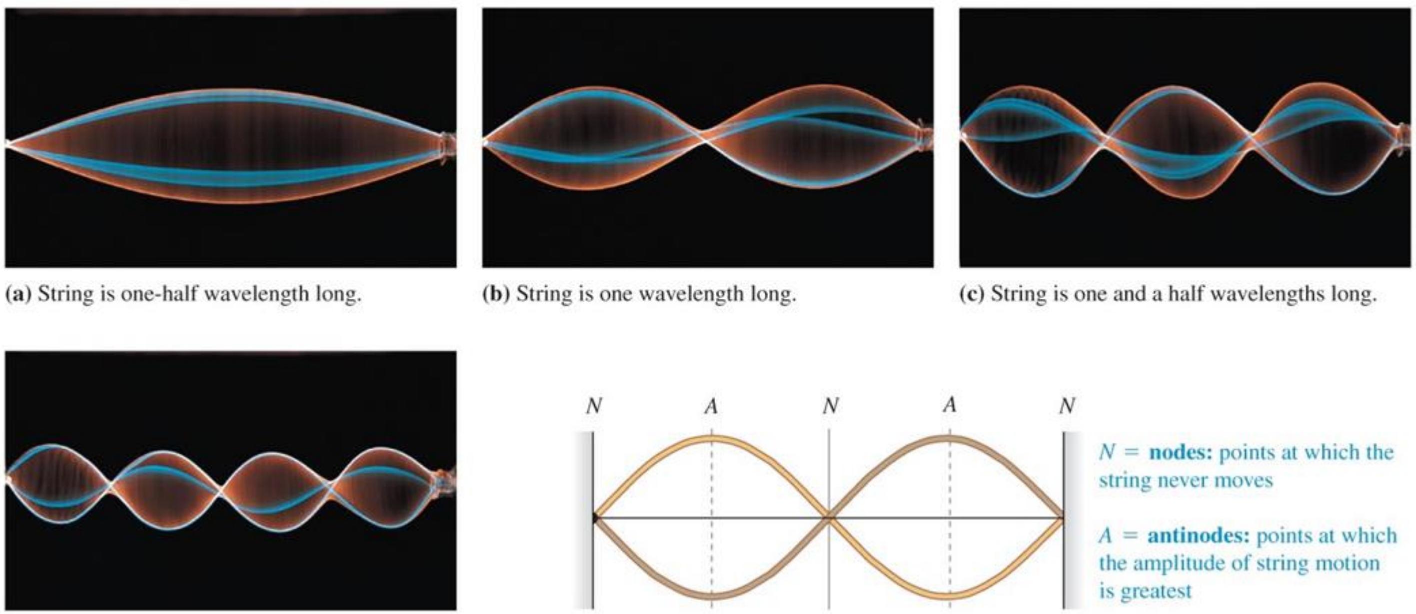
N: Nodes, points at which the string does not move, or, displacement is zero.

A: Antinodes, points at which the string has the largest displacements.



Waves Become Coherent (Standing) – Figure 12.14

- When nodes and antinodes align, there is no destructive interference and a steady-state condition is established.
- Depending on the shape and size of the medium transmitting the wave, different standing wave patterns are established as a function of energy.



(a) String is one-half wavelength long.

(b) String is one wavelength long.

(c) String is one and a half wavelengths long.

(d) String is two wavelengths long.

(e) The shape of the string in **(b)** at two different instants

Normal Modes: Allowed modes of wave oscillation

The resonator is fixed at both ends.

$$L = n\frac{\lambda}{2} \quad (n = 1, 2, 3, \ldots.)$$

Allowed wavelengths:

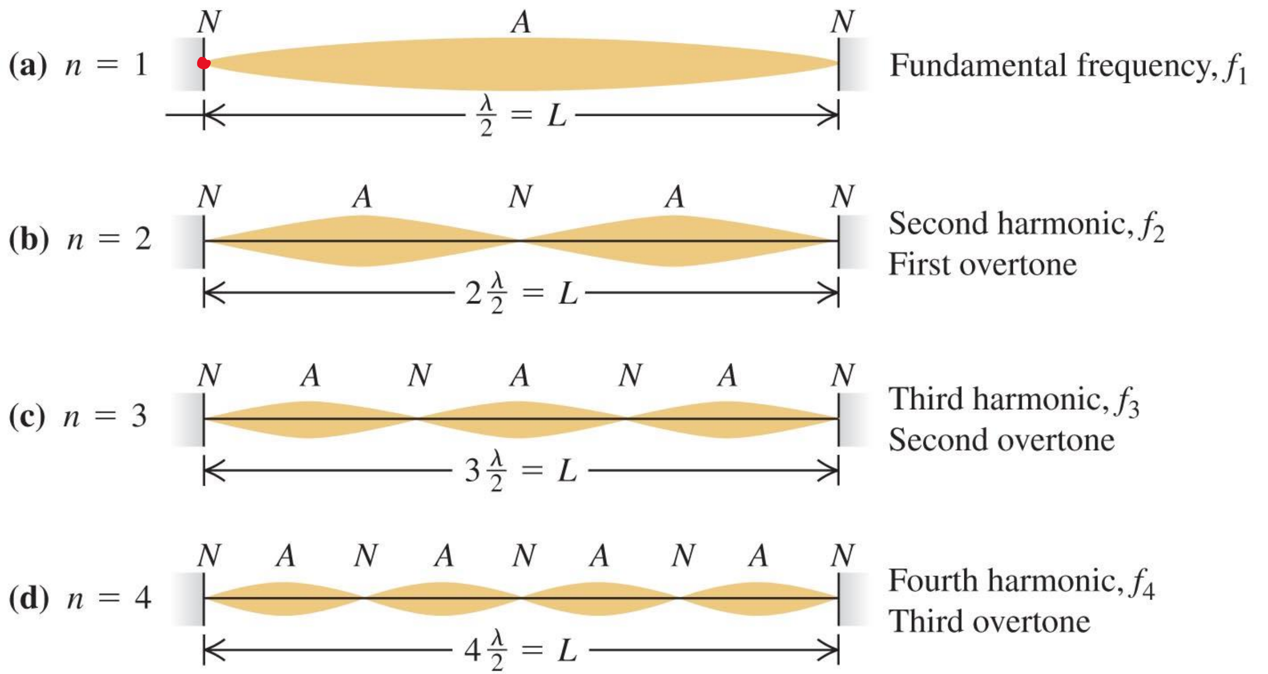
$$\lambda_n = \frac{2L}{n} \quad (n = 1, 2, 3, \ldots)$$

Allowed frequencies:

$$f_n = \frac{v}{\lambda_n} = n\frac{v}{2L} = nf_1$$
$$(n = 1, 2, 3, \ldots)$$

Fundamental frequency:

$$f_1 = \frac{v}{2L}$$



The fundamental frequency of a vibrating string of length L, fixed at both ends, is

$$f_1 = \frac{v}{2L} = \frac{1}{2L}\sqrt{\frac{F_T}{\mu}}$$

Example 12.3, a bass string

Given: $f_1 = 41.0$ Hz, $L = 0.86$ m, $\mu = 0.015$ kg/m

Find: (a) F_T

(b) f_2 and λ_2 (second harmonic)

(c) f_3 and λ_3 (third harmonic)

Solution:

(a) Since $f_1 = \frac{v}{2L} = \frac{1}{2L}\sqrt{\frac{F_T}{\mu}}$

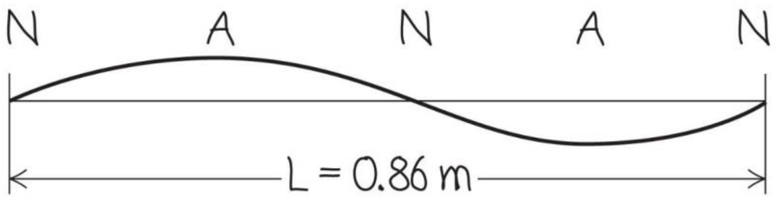
$$F_T = 4\mu L^2 f_1^2 = 76 \text{ N}$$

(b) $f_2 = 2f_1 = 82.0$ Hz

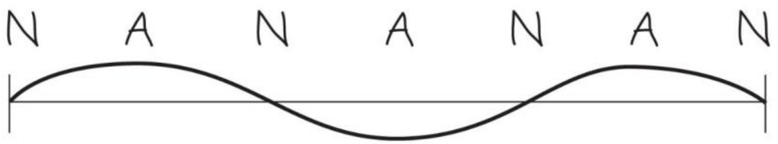
$$\lambda_2 = \frac{2L}{2} = 0.86 \text{ m}$$

(a) $f_3 = 3f_1 = 123$ Hz

$$\lambda_3 = \frac{2L}{3} = 0.57 \text{ m}$$

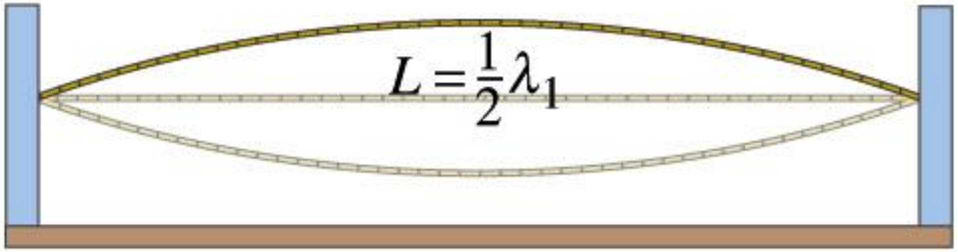


Second harmonic (n = 2)

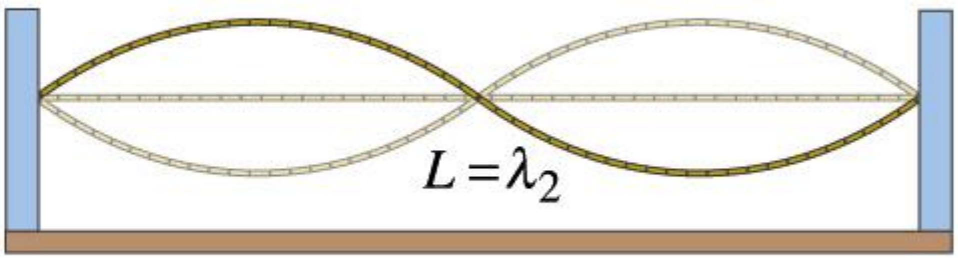


Third harmonic (n = 3)

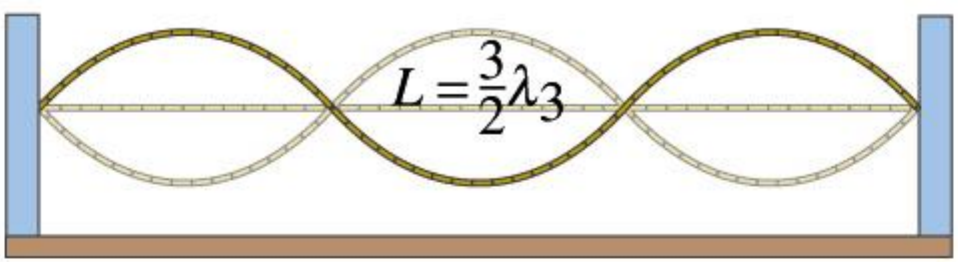
Resonant waves in a cavity



Fundamental or first harmonic, f_1



First overtone or second harmonic, $f_2 = 2f_1$



Second overtone or third harmonic, $f_3 = 3f_1$

$$L = \frac{n\lambda_n}{2} \qquad n = 1, 2, 3 \text{ ------}$$

$$\lambda_n = \frac{2L}{n} \qquad n = 1, 2, 3 \text{ ------}$$

$$f_n = \frac{v}{\lambda_n} = \frac{nv}{2L} = nf_1 \qquad n = 1, 2, 3 \text{ ------}$$

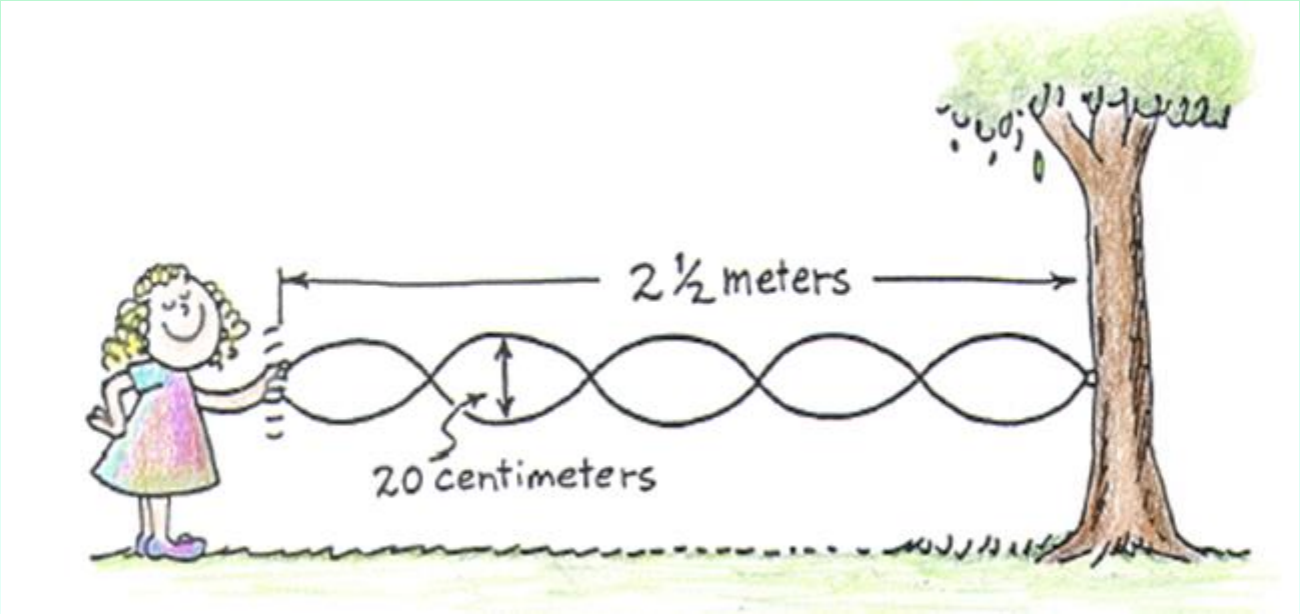
$$f_1 = \frac{v}{\lambda_1} = \frac{v}{2L} = \text{fundamental frequency}$$

Clicker – Questions 6.I

In the standing wave shown.

1) What is its wavelength?

a)1m
b)2m
c)2.5m
d)1.5m

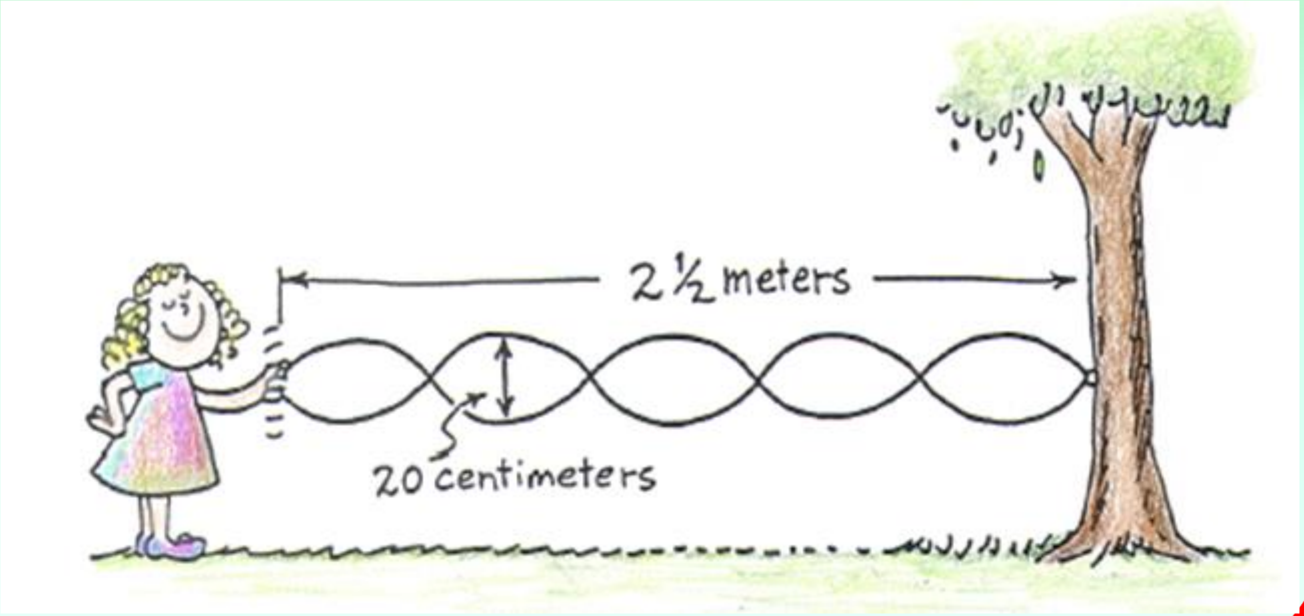


Clicker – Questions 6.II

In the standing wave shown.

1) What is its amplitude?

a) 2m
b)1m
c)10 cm
d) 20cm

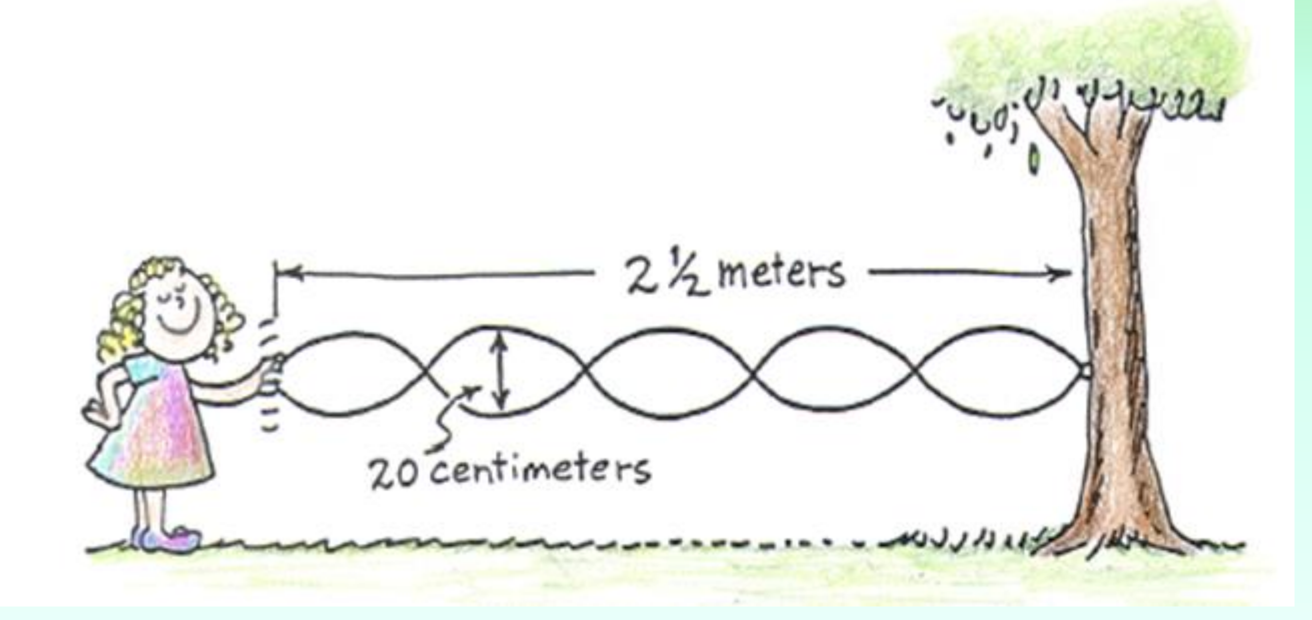


Clicker – Questions 6.III

In the standing wave shown.

1) **How many nodes are there?**

a) **5**
b) **6**
c) **7**
d) **4**



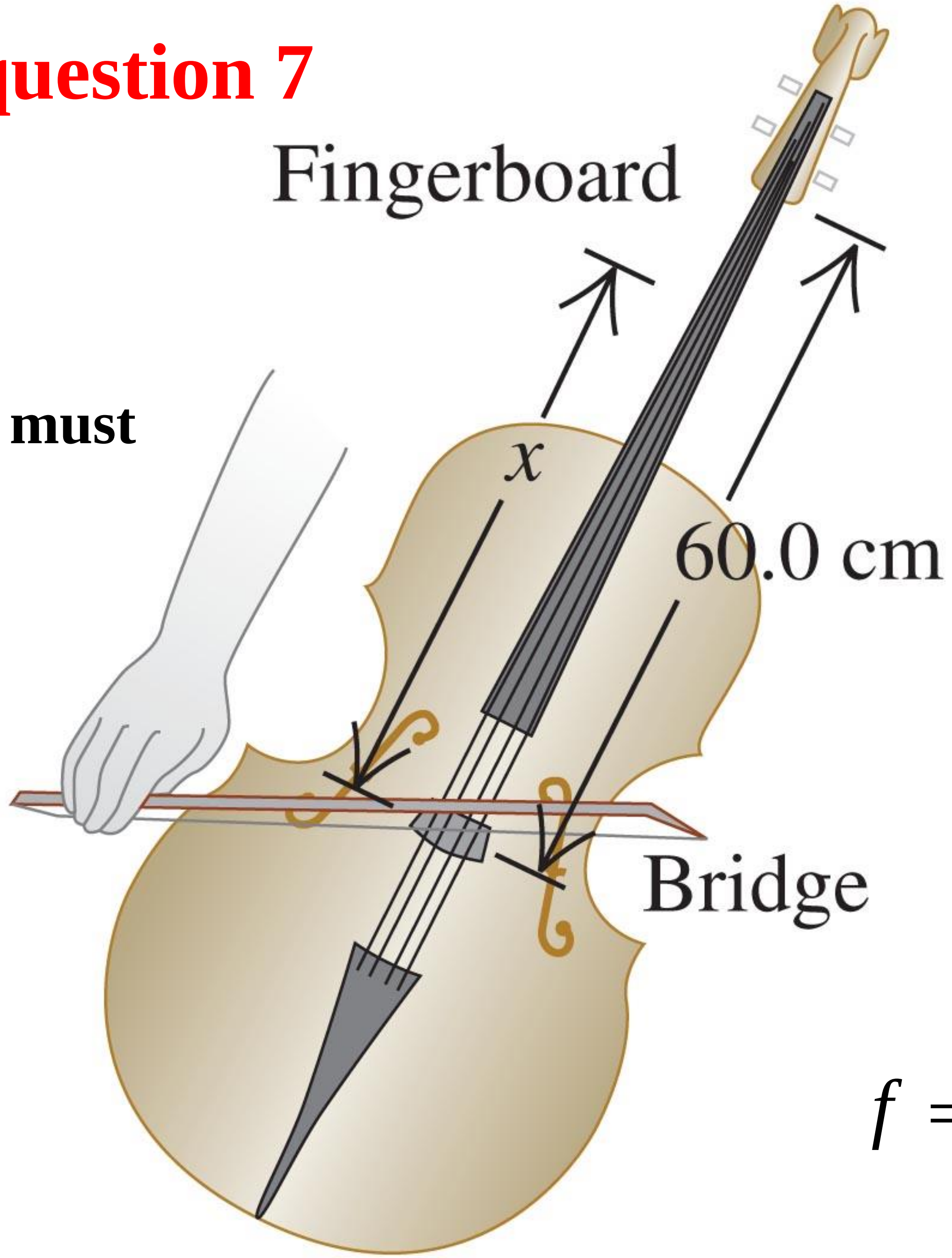
Clicker question 7

For larger frequency x must be…

a)shorter

b) longer

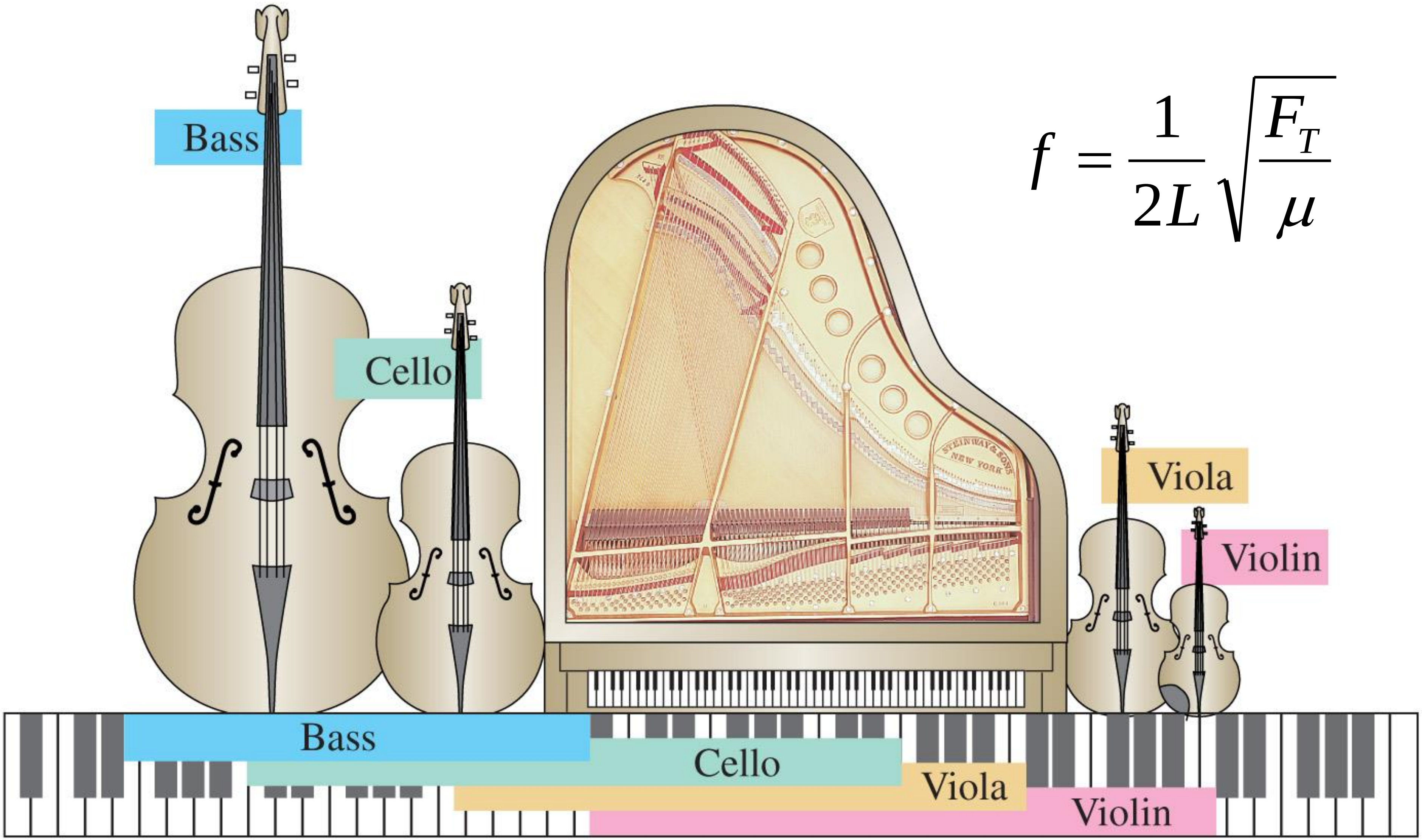
c) the same



$$f = \frac{1}{2L}\sqrt{\frac{F_T}{\mu}}$$

Frequency of a vibrating string

$$f = \frac{1}{2L}\sqrt{\frac{F_T}{\mu}}$$

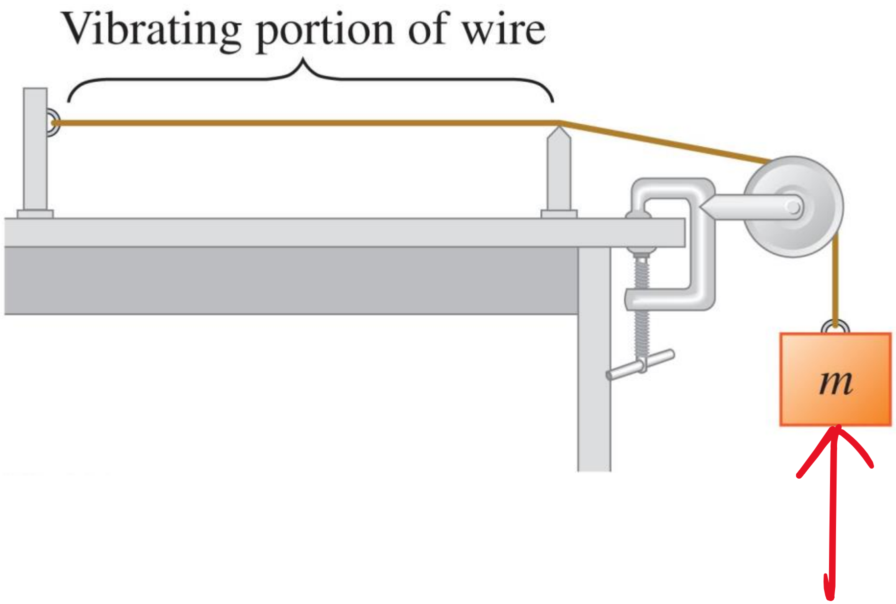


Quantitative Analysis 12.4

Given: The vibrating string has fundamental frequency *f* when a block of mass *m* is hung as shown.

Find: To increase the fundamental frequency of the vibration to 2f, what mass should be hung on the string?

(A) $\sqrt{2}m$
(B) $2m$
(C) $4m$



$$f_1 = \frac{v}{2L} = \frac{1}{2L}\sqrt{\frac{F_T}{\mu}}$$

1. A wire 1.80 m long is stretched between two supports. The wire is vibrating with a standing wave that has frequency 600 Hz. This frequency is three times the frequency of the fundamental standing wave. What is the speed v of the transverse waves on the wire?

(a) 2160 m/s
(b) 1080 m/s
(c) 720 m/s
(d) 540 m/s
(e) none of these answers

From the Formula Sheet

$v = f\lambda$ $\quad v = \sqrt{\frac{F_T}{\mu}}$ $\quad y(x,t) = A\sin\left[2\pi f\left(t - \frac{x}{v}\right)\right] = A\sin\left[2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)\right]$

$f_n = n\left(\frac{v}{2L}\right),\ n = 1,2,3,\ldots$ $\quad f_n = n\left(\frac{v}{4L}\right),\ n = 1,3,5,\ldots$

$I = \frac{P}{4\pi r^2}$ $\quad \beta = (10\text{ dB})\log\left(\frac{I}{I_0}\right)$ $\quad f_{\text{beat}} = f_1 - f_2$ $\quad f_L = \left(\frac{v + v_L}{v + v_S}\right) f_S$

(5 pts) 1. A light string held fixed at both ends has standing waves of wavelength 0.200 m when it vibrates in its 3rd harmonic. What is the length of the string?

(a) 0.100 m
(b) 0.200 m
(c) 0.300 m
(d) 0.400 m
(e) none of the above answers

From the Formula Sheet

$v = f\lambda$ $\quad v = \sqrt{\frac{F_T}{\mu}}$ $\quad y(x,t) = A\sin\left[2\pi f\left(t - \frac{x}{v}\right)\right] = A\sin\left[2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)\right]$

$f_n = n\left(\frac{v}{2L}\right),\ n = 1,2,3,\ldots$ $\quad f_n = n\left(\frac{v}{4L}\right),\ n = 1,3,5,\ldots$

$I = \frac{P}{4\pi r^2}$ $\quad \beta = (10\text{ dB})\log\left(\frac{I}{I_0}\right)$ $\quad f_{\text{beat}} = f_1 - f_2$ $\quad f_L = \left(\frac{v + v_L}{v + v_S}\right)f_S$

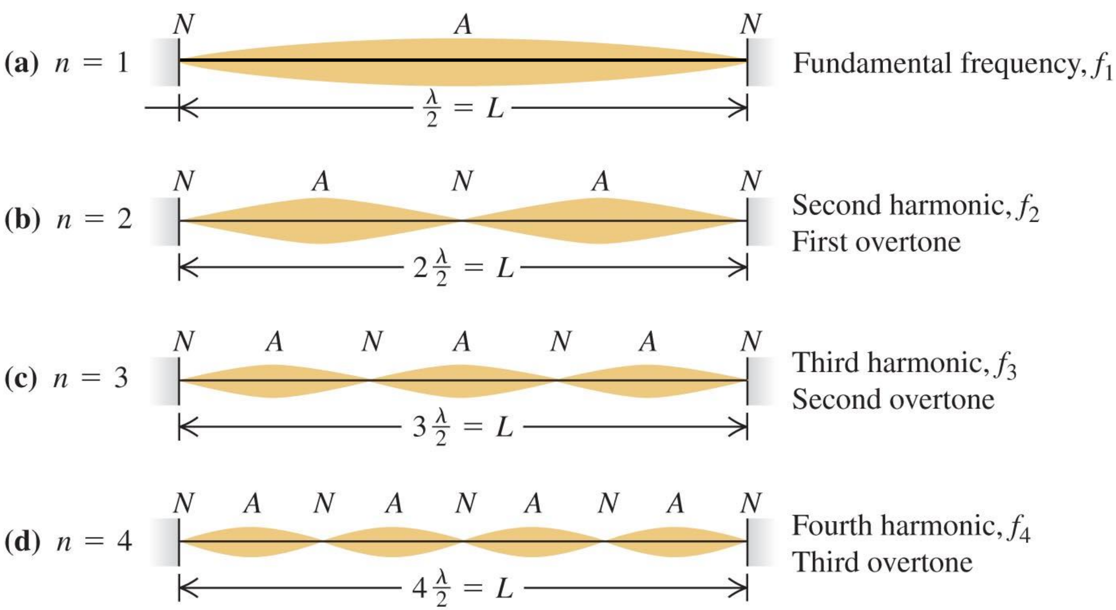
From the Formula Sheet

$v = f\lambda$ $\qquad v = \sqrt{\frac{F_T}{\mu}}$ $\qquad y(x,t) = A\sin\left[2\pi f\left(t - \frac{x}{v}\right)\right] = A\sin\left[2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)\right]$

$f_n = n\left(\frac{v}{2L}\right),\ n = 1,2,3,\ldots$ $\qquad f_n = n\left(\frac{v}{4L}\right),\ n = 1,3,5,\ldots$

$I = \frac{P}{4\pi r^2}$ $\qquad \beta = (10\ \text{dB})\log\left(\frac{I}{I_0}\right)$ $\qquad f_{\text{beat}} = f_1 - f_2$ $\qquad f_L = \left(\frac{v + v_L}{v + v_S}\right) f_S$

Standing Waves in Rope with Two Fixed Ends



$L = n\frac{\lambda}{2} \quad (n = 1, 2, 3, \ldots.)$

Allowed wavelengths:

$$\lambda_n = \frac{2L}{n} \quad (n = 1, 2, 3, \ldots)$$

Allowed frequencies:

$$f_n = \frac{v}{\lambda_n} = n\frac{v}{2L} = nf_1$$

$$(n = 1, 2, 3, \ldots)$$

Fundamental frequency:

$$f_1 = \frac{v}{2L}$$

(5 pts) 2. A wire with mass 0.500 kg is stretched so that its two ends are tied down at points 1.25 m apart. The wire vibrates in its fundamental mode with frequency 40.0 Hz. What is the speed of propagation of the transverse waves on the wire?

(a) 50 m/s
(b) 100 m/s
(c) 200 m/s
(d) 300 m/s
(e) 400 m/s
(f) none of the above answers

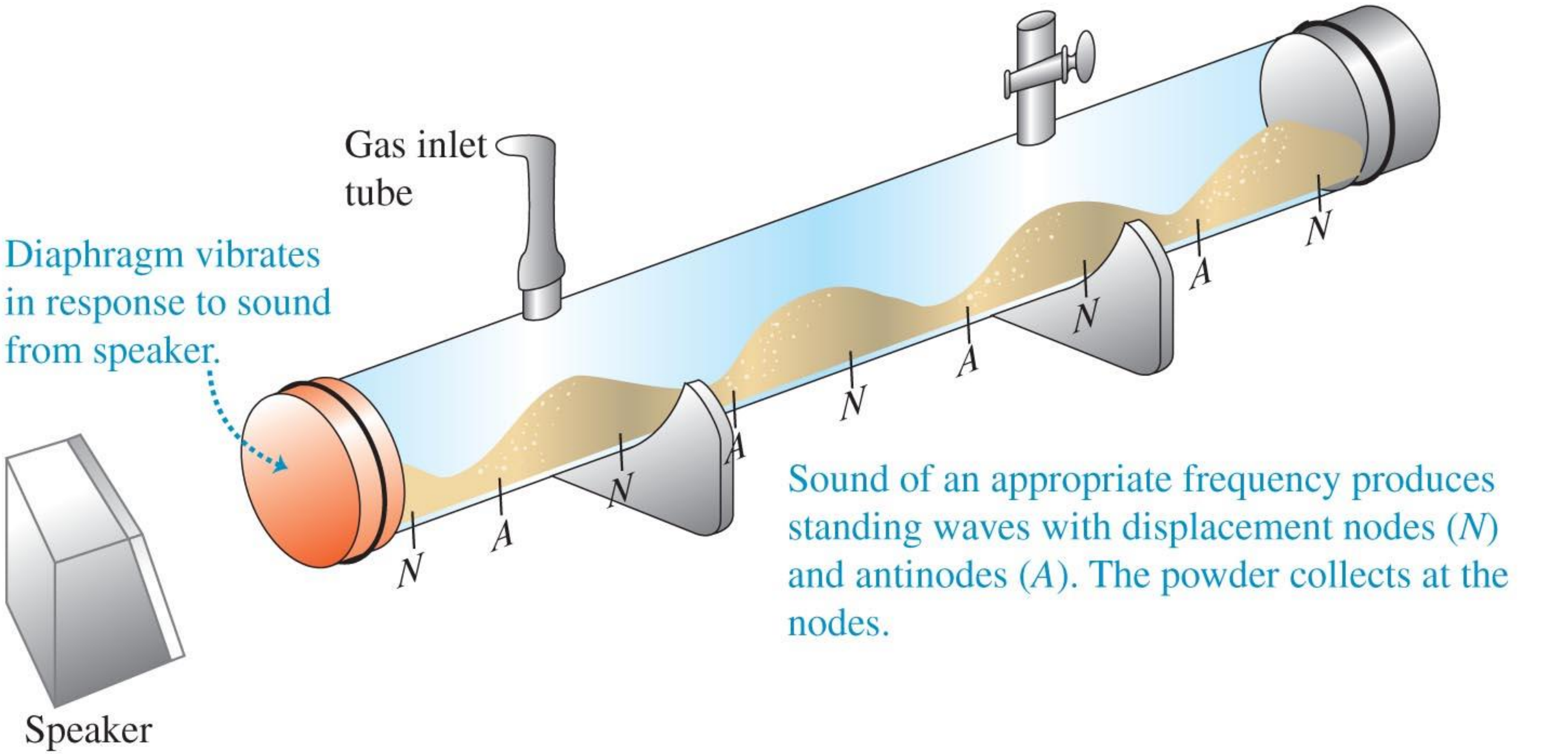
From the Formula Sheet

$v = f\lambda \qquad v = \sqrt{\frac{F_T}{\mu}} \qquad y(x,t) = A\sin\left[2\pi f\left(t - \frac{x}{v}\right)\right] = A\sin\left[2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)\right]$

$f_n = n\left(\frac{v}{2L}\right),\ n = 1,2,3,\ldots \qquad f_n = n\left(\frac{v}{4L}\right),\ n = 1,3,5,\ldots$

$I = \frac{P}{4\pi r^2} \qquad \beta = (10\ \text{dB})\log\left(\frac{I}{I_0}\right) \qquad f_{\text{beat}} = f_1 - f_2 \qquad f_L = \left(\frac{v + v_L}{v + v_S}\right)f_S$

12.7 Longitudinal Standing Waves



Longitudinal standing waves

displacement

open end = displacement antinode (point were displacement is maximal)
closed end = displacement node (" " " " minimal)

The pressure variations have an also an alternating pattern.

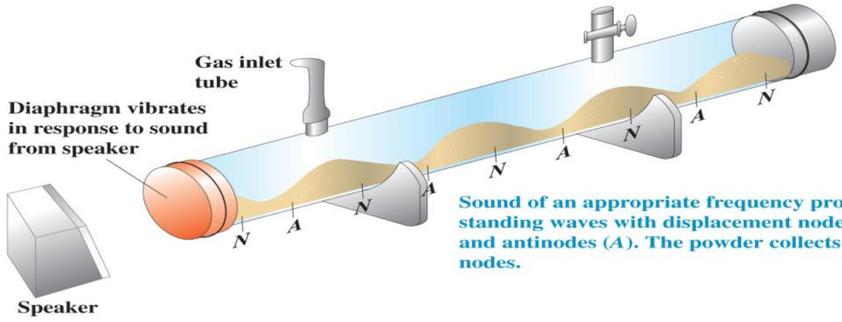
pressure and displacement are opposite = maximum pressure are minimum displacement

pressure antinode = displacement node
pressure node = displacement antinode

Kundt's tube powder collects in the displacement nodes (where gas does no move)

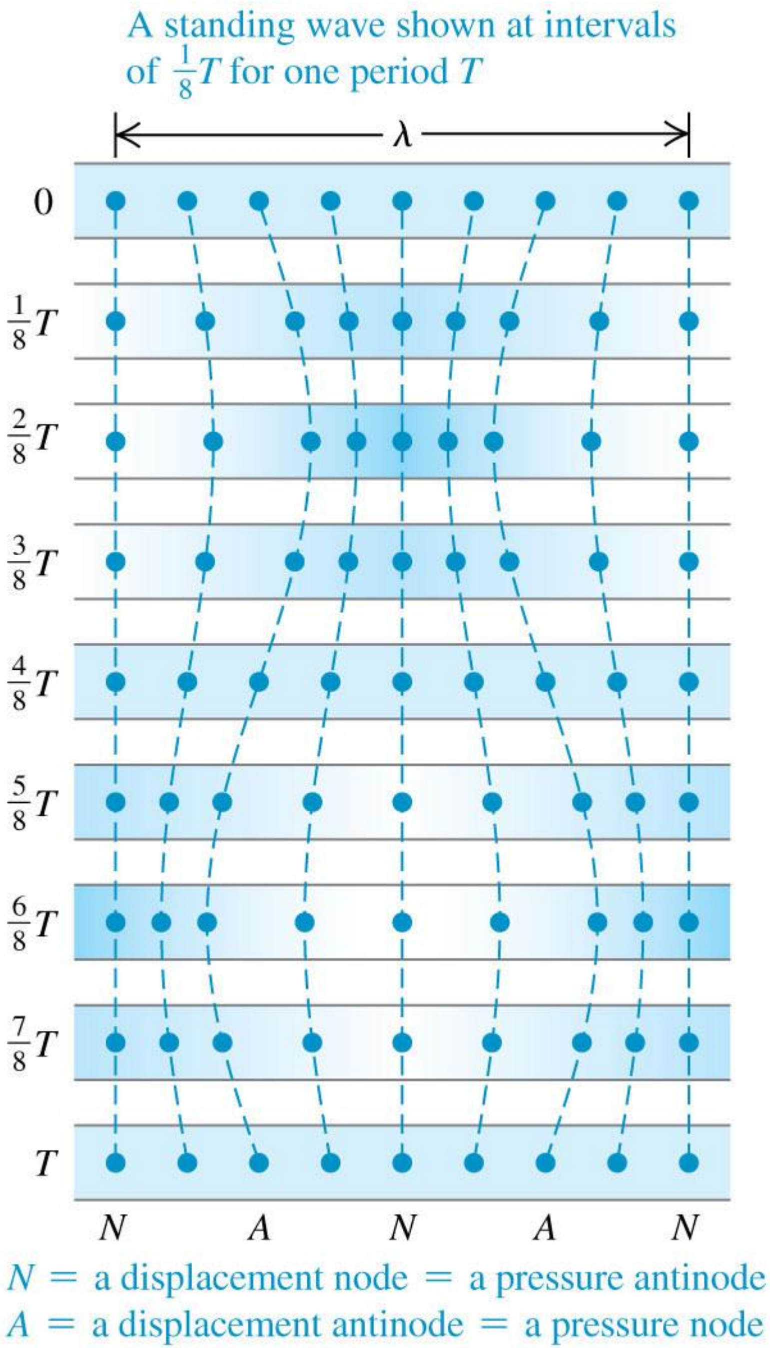
$v = \lambda f$

Adjacent nodes are separated by $\frac{\lambda}{2}$
We read frequency from sound source which drives the ~~load~~ speaker



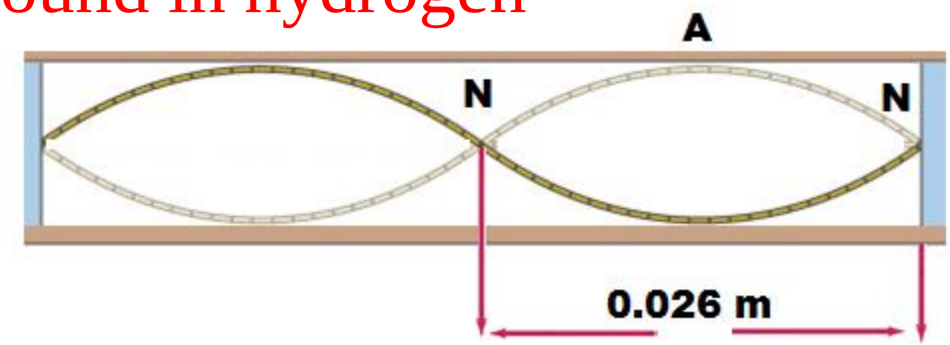
Sound of an appropriate frequency produces standing waves with displacement nodes (N) and antinodes (A). The powder collects at the nodes.

Figure 16.13



A standing wave shown at intervals of $\frac{1}{8}T$ for one period T
λ
0
$\frac{1}{8}T$
$\frac{2}{8}T$
$\frac{3}{8}T$
$\frac{4}{8}T$
$\frac{5}{8}T$
$\frac{6}{8}T$
$\frac{7}{8}T$
T
N A N A N
N = a displacement node = a pressure antinode
A = a displacement antinode = a pressure node

Speed of sound in hydrogen



At a frequency of 25 kHz the distance from either one of the closed ends of a tube of a hydrogen gas to the nearest displacement node of a standing wave is 0.026m.

(a) Calculate the wave speed.

$$\frac{\lambda}{2} = 0.026m \quad and \quad v = f \cdot \lambda = 0.052m * 25x10^3 s^{-1} = 1300\frac{m}{s}$$

(b) Replace hydrogen by air; where v is about 4 times less than hydrogen, what frequency of sound is needed to get the same standing wave wavelength?

$$f = \frac{v}{\lambda} = \frac{\frac{1300}{4}}{0.052} = 6250\, Hz = 6.25\, kHz$$

9000 year old bone flutes from china

Open Pipe and Normal Modes

$$L = n\frac{\lambda_n}{2} \quad (n = 1, 2, 3, \ldots.)$$

Allowed wavelengths:

$$\lambda_n = \frac{2L}{n} \quad (n = 1, 2, 3, \ldots)$$

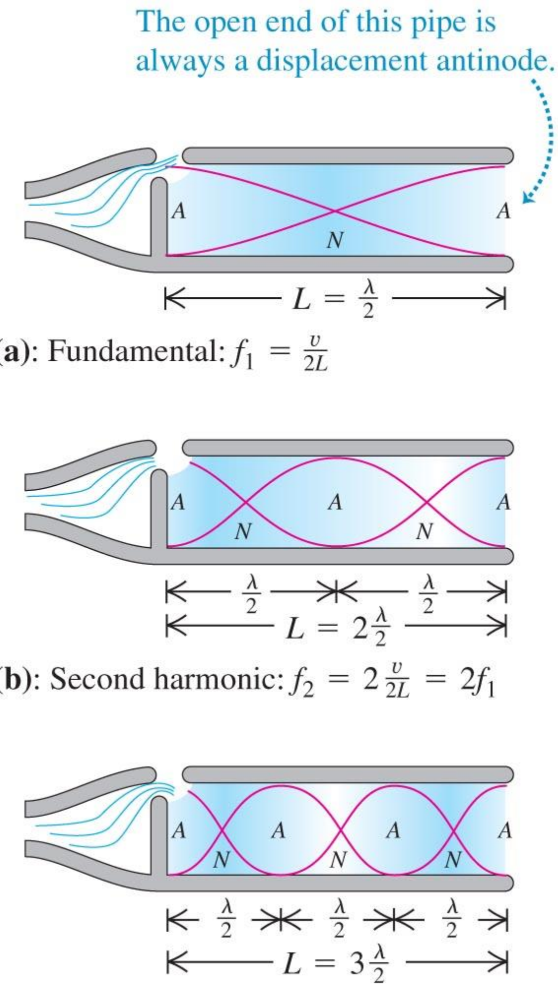
Allowed frequencies:

$$f_n = \frac{v}{\lambda_n} = n\frac{v}{2L} = nf_1$$

$$(n = 1, 2, 3, \ldots)$$

Fundamental frequency:

$$f_1 = \frac{v}{2L}$$



(a): Fundamental: $f_1 = \frac{v}{2L}$

(b): Second harmonic: $f_2 = 2\frac{v}{2L} = 2f_1$

(c): Third harmonic: $f_3 = 3\frac{v}{2L} = 3f_1$

Stopped Pipe and Normal Modes

$$L = n\frac{\lambda_n}{4} \quad (n = 1, 3, 5, 7 \ldots.)$$

Allowed wavelengths:

$$\lambda_n = \frac{4L}{n} \quad (n = 1, 3, 5, 7 \ldots)$$

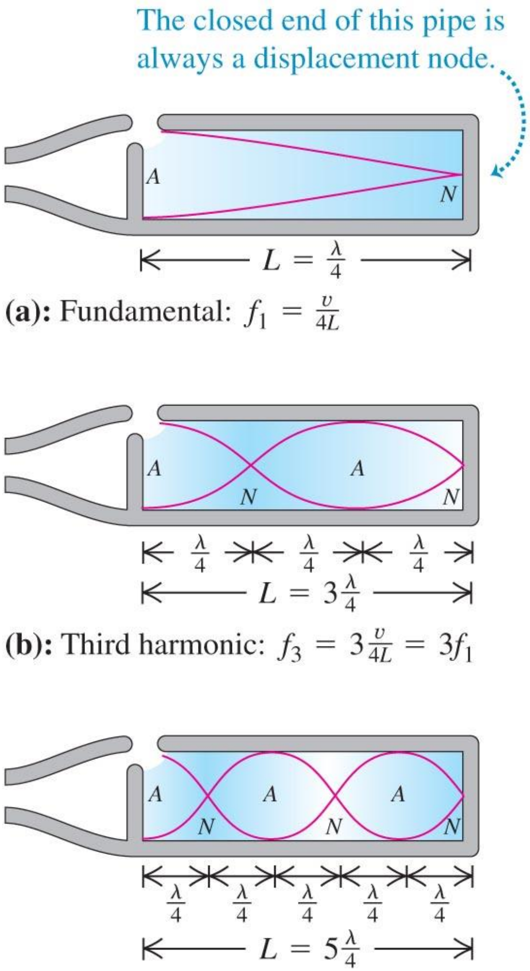
Allowed frequencies:

$$f_n = \frac{v}{\lambda_n} = n\frac{v}{4L} = nf_1$$

$$(n = 1, 3, 5, 7 \ldots)$$

Fundamental frequency:

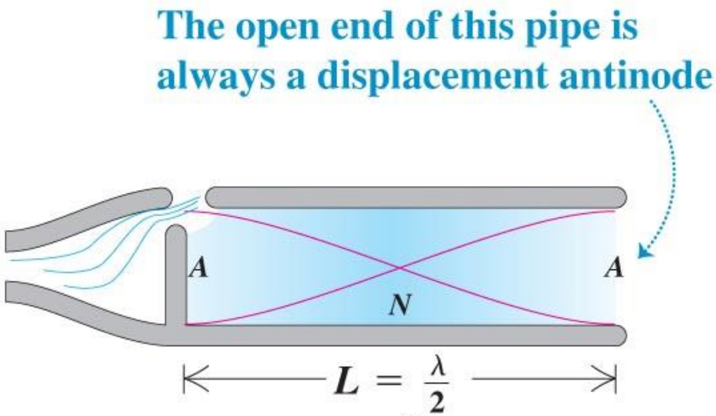
$$f_1 = \frac{v}{4L}$$



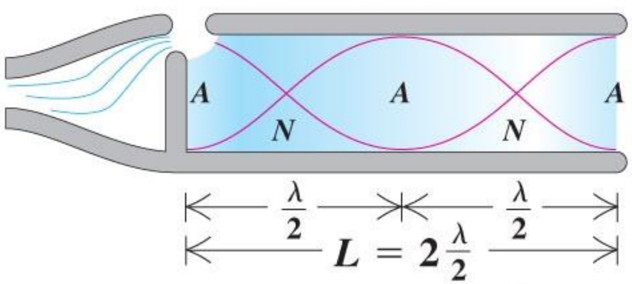
(a): Fundamental: $f_1 = \frac{v}{4L}$

(b): Third harmonic: $f_3 = 3\frac{v}{4L} = 3f_1$

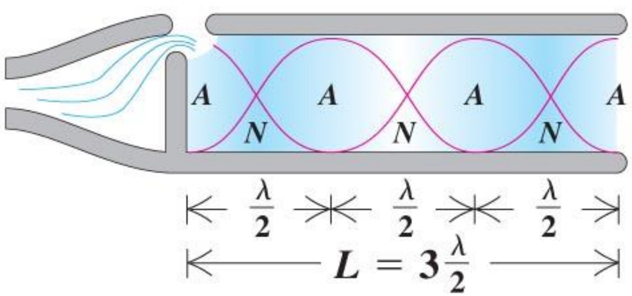
(c): Fifth harmonic: $f_5 = 5\frac{v}{4L} = 5f_1$



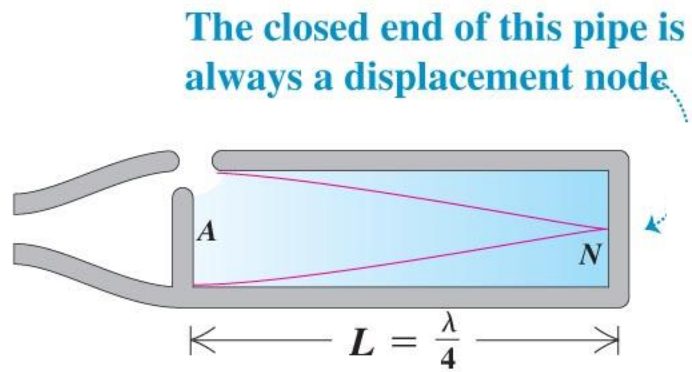
(a): Fundamental: $f_1 = \frac{v}{2L}$



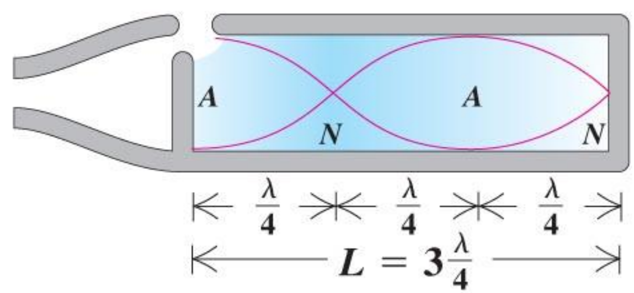
(b): Second harmonic: $f_2 = 2\frac{v}{2L} = 2f_1$



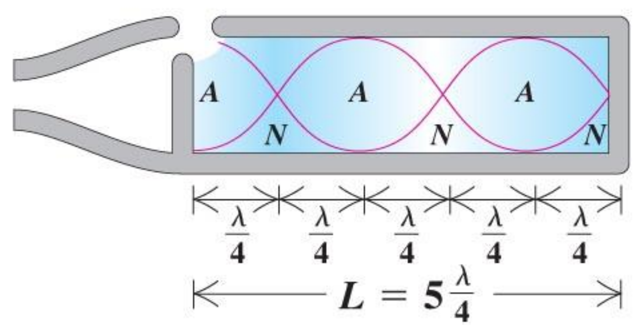
(c): Third harmonic: $f_3 = 3\frac{v}{2L} = 3f_1$



(a): Fundamental: $f_1 = \frac{v}{4L}$



(b): Third harmonic: $f_3 = 3\frac{v}{4L} = 3f_1$



(c): Fifth harmonic: $f_5 = 5\frac{v}{4L} = 5f_1$

<u>open pipe</u>: $L = \frac{\lambda_1}{2}$

$f_1 = \frac{v}{2L}$

$L = n\frac{\lambda_n}{2}$ $\quad \lambda_n = \frac{2L}{n}$

$f_n = n\frac{v}{2L} = n f_1$

$(n = 1, 2, 3 \ldots$

<u>stopped pipe</u>: $L = \frac{\lambda_1}{4}$

$f_1 = \frac{v}{\lambda_1} = \frac{v}{4L}$

$L = n\frac{\lambda_n}{4}$ $\quad \lambda_n = \frac{4L}{n}$

$f_n = n\frac{v}{4L} = n f_1$

$(n = 1, 3, 5)$

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12.24 The fundamental frequency of a pipe that is open at both ends is594 Hz.
a) How long is this pipe?
b) If one end is now closed find the wavelength c)find the frequency of the new fundamental

12.24. Set Up: For an open pipe, $f_1 = \frac{v}{2L}$. For a stopped pipe, $f_1 = \frac{v}{4L}$. $v = f\lambda$. $v = 344$ m/s. For a pipe, there must be a displacement node at a closed end and an antinode at the open end.

Solve: (a) $L = \frac{v}{2f_1} = \frac{344 \text{ m/s}}{2(594 \text{ Hz})} = 0.290 \text{ m}.$

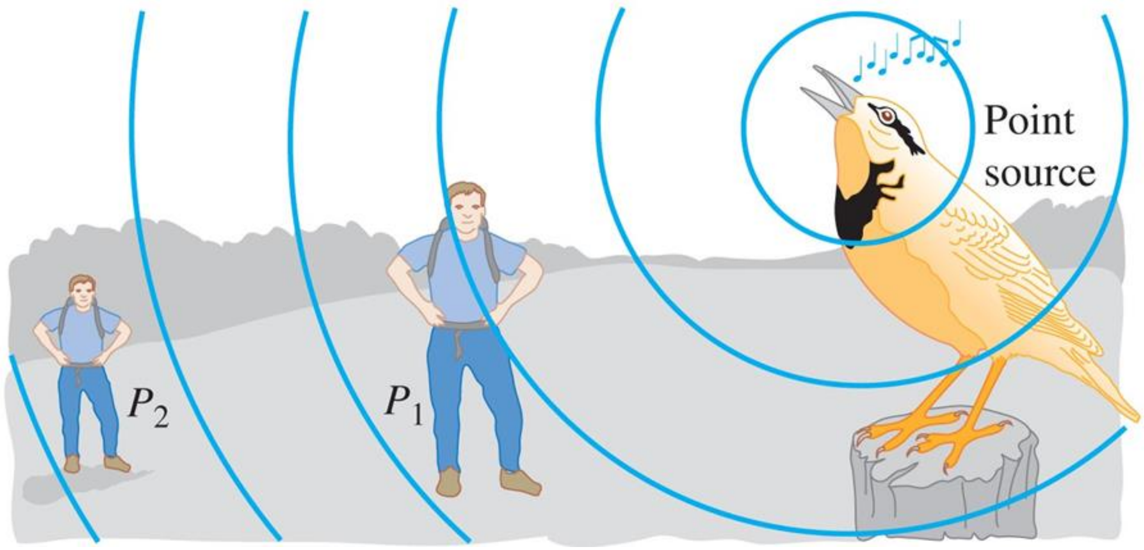
(b) There is a node at one end, an antinode at the other end and no other nodes or antinodes in between, so $\frac{\lambda_1}{4} = L$ and $\lambda_1 = 4L = 4(0.290 \text{ m}) = 1.16 \text{ m}.$

(c) $f_1 = \frac{v}{4L} = \frac{1}{2}\left(\frac{v}{2L}\right) = \frac{1}{2}(594 \text{ Hz}) = 297 \text{ Hz}.$

Reflect: We could also calculate f_1 for the stopped pipe as $f_1 = \frac{v}{\lambda_1} = \frac{344 \text{ m/s}}{1.16 \text{ m}} = 297 \text{ Hz}$, which agrees with our result in part (c).

Sound Intensity and the Decibel Scale – Figure 12.30

- Use Table 12.2 to see logarithmic dB examples of common sounds.
- Refer to Examples 12.8 and 12.9 (see figure below).



Pearson

An auditorium sound system

A sound system is designed to produce a 1.0W/m^2 sound intensity over the surface of a hemisphere 20 m in radius. What acoustic power is needed from an array of speakers at the center of the sphere?

r=20 m, P=1.0 W/m^2

Area of the hemispherical surface:

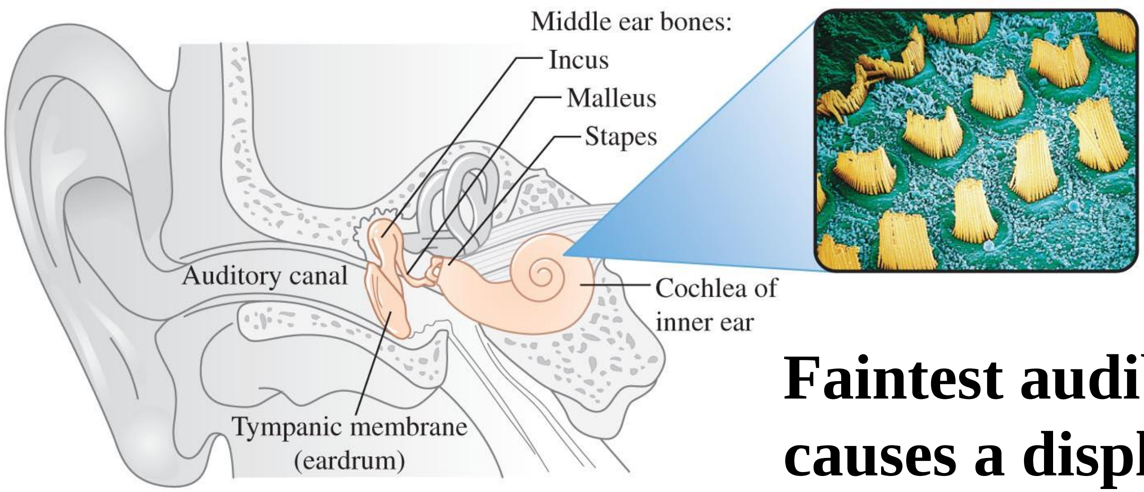
$$\frac{1}{2}(4\pi r^2) = \frac{1}{2}(4\pi)(20\text{ m})^2 = 2500\text{ m}^2$$

Total acoustic power needed:

$$\left(1.0\,\frac{\text{W}}{\text{m}^2}\right)(2500\text{ m}^2) = 2500\text{ W} = 2.5\text{ kW}$$

Human Hearing

- 20–20,0000 Hz is the approximate range of human hearing. Below that is infrasonic and above …. ultrasonic.
- Note, there are slight variations between animal species and effects on any hearing due to pressure changes.



Hair cells send nerve pulses to brain

Faintest audible sound causes a displacement amplitude of 10^-11m

Sound intensity

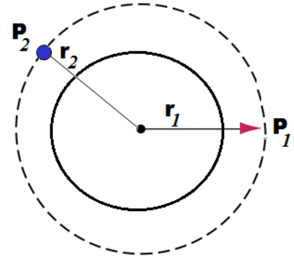


TABLE 12.2 Noise levels due to various sources (representative values)

Type of noise	Sound level, dB	Intensity, W/m²
Rock concert	140	100
Threshold of pain	120	1
Riveter	95	3.2×10^{-3}
Elevated train	90	10^{-3}
Busy street traffic	70	10^{-5}
Ordinary conversation	65	3.2×10^{-6}
Quiet automobile	50	10^{-7}
Quiet radio in home	40	10^{-8}
Average whisper	20	10^{-10}
Rustle of leaves	10	10^{-11}
Threshold of hearing	0	10^{-12}

For a point source:

$$I_1 = \frac{P}{4\pi r_1^2} \text{ and } I_2 = \frac{P}{4\pi r_2^2}$$

The power is the same, since nothing is absorbed between the spheres;

$$4\pi r_1^2 I_1 = 4\pi r_2^2 I_2 \text{ and } \frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}$$

The intensity is inversely proportional to the square of the distance

Decibels:

logarithmic scale to cover a broad range of intensities

$$\textbf{Intensity level } \boldsymbol{\beta = 10dB\, log\frac{I}{I_o}}$$

$$I_o = reference\ intensity = 10^{-12}\frac{W}{m^2}$$

The logarithm of a number to a given base is the exponent to which the base is raised to produce the number.

Example:
$\boldsymbol{log_{10}1000 = 3}$ **and** $\boldsymbol{10^3 = 1000}$

Note:
$\boldsymbol{log\ x \cdot y = logx + logy}$
and $\boldsymbol{logx^P = P\ logx}$

Special cases:

$$I = I_o, \qquad \beta = 10dB\ log1 = 10dB * 0 = 0$$

$$I = 1\frac{W}{cm^2} = 10dB\ log\frac{1\frac{W}{cm^2}}{10^{-12}\frac{W}{m^2}} = 10dB\ log10^{12} = 10 * 12 = 120\ dB$$

Example 12.9 A bird sings

By how many dB does the sound intensity level drop, when you move to a point twice as far away from the bird?

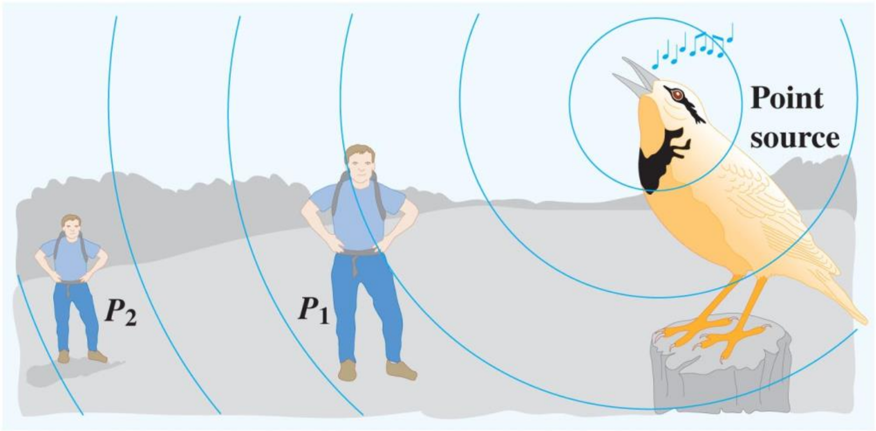
$$\beta_2 - \beta_1 = 10\ dB\left(log\left(\frac{I_2}{I_o} - \frac{I_1}{I_o}\right)\right)$$

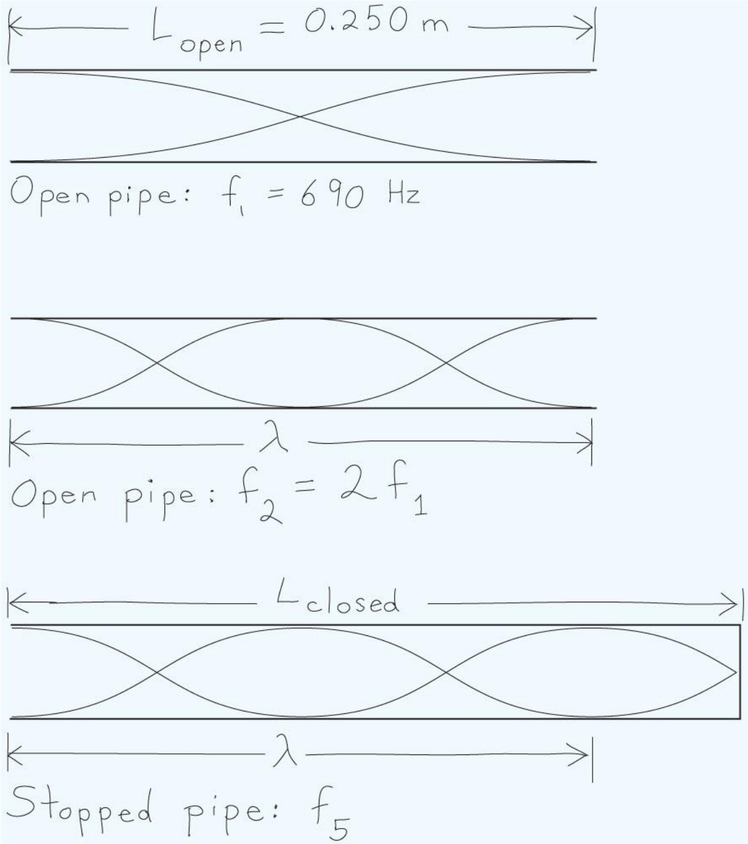
$$= 10\ dB[(logI_2 - logI_o) - (logI_1 - logI_o)] = 10\text{ dB log}\frac{I_2}{I_1}$$

$$\frac{I_2}{I_1} = \frac{r_1^2}{r_2^2} \text{ and } \beta_2 - \beta_1 = 10\ dB\ log\frac{r_1^2}{r_2^2}\Big\}\ \beta_2 - \beta_1 = 10\ dB\ log\frac{1}{4} = -6.0\ dB$$

Note:

The decibel scale is logarithmic.
factor 2 is 3 dB
factor 4 is 6 dB
factor 8 is 9 dB
……………………
……………………
factor 16 is 12 dB





Example 12.5 Harmonics on an organ pipe

On a day when the speed of sound is 345 m/s the fundamental frequency of an open pipe is 690 Hz

If the second harmonic of this pipe has the same wavelength as the second overtone of the stopped pipe. What is the length of each pipe?

open: $f_1 = \frac{v}{2L} \rightarrow L_{open} = \frac{v}{2f_1} = \frac{345}{2 \times 690} = \boxed{0.25\,m}$

$f_2 = 2f_1 = 2\,(690\,Hz) = 1380\,Hz$

stopped: frequency of second overtone must be 1380

first overtone is $3f_1$

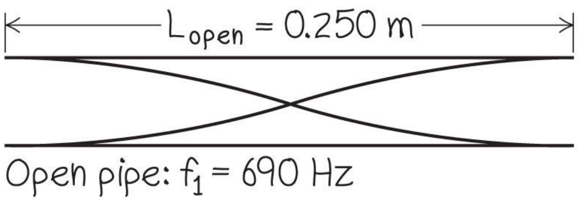
Second overtone is $5f_1 = 5\left(\frac{v}{4L}\right)$

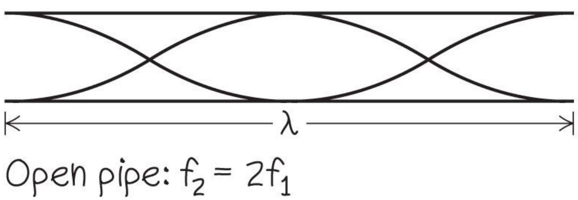
$1380 = \frac{345}{4L_{stopped}} \rightarrow \boxed{L = 0.313\,m}$

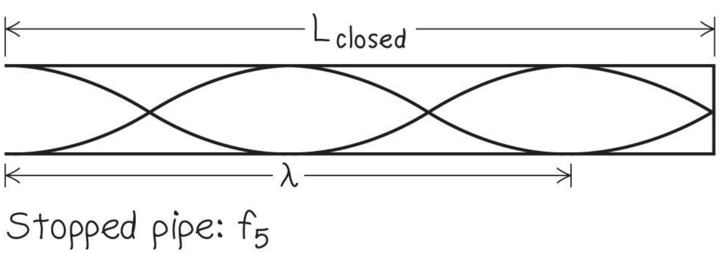
Example 12.5 on page 374: Harmonics of an organ pipe

Given: Speed of sound v = 345 m/s; Open pipe f_1 = 690 Hz

Question: If the n = 2 mode of the open pipe has the same wavelength as the n = 5 mode of a stopped pipe, what is the length of each pipe?







Solution:

(a) For the open pipe $f_1 = \dfrac{v}{2L_{open}}$

Therefore, $L_{\text{open}} = \dfrac{v}{2f_1} = \dfrac{345\ m/s}{2(690\ Hz)} = 0.250$ m

(b) $\lambda_2^{open} = \lambda_5^{stopped}$

Given $\lambda_n^{open} = \dfrac{2L_{open}}{n}$ and $\lambda_n^{stopped} = \dfrac{4L_{stopped}}{n}$,

we have $\dfrac{2L_{open}}{2} = \dfrac{4L_{stopped}}{5}$

Therefore, $L_{stopped} = \dfrac{5L_{open}}{4} = 0.313$ m

(5 pts) 3. A pipe has length 1.20 m and is open at one end and closed at the other. What is the wavelength of the fundamental standing wave for the air column that is in the pipe?

(a) 0.30 m
(b) 0.60 m
(c) 1.2 m
(d) 1.8 m
(e) 2.4 m
(f) 4.8 m
(g) none of the above answers

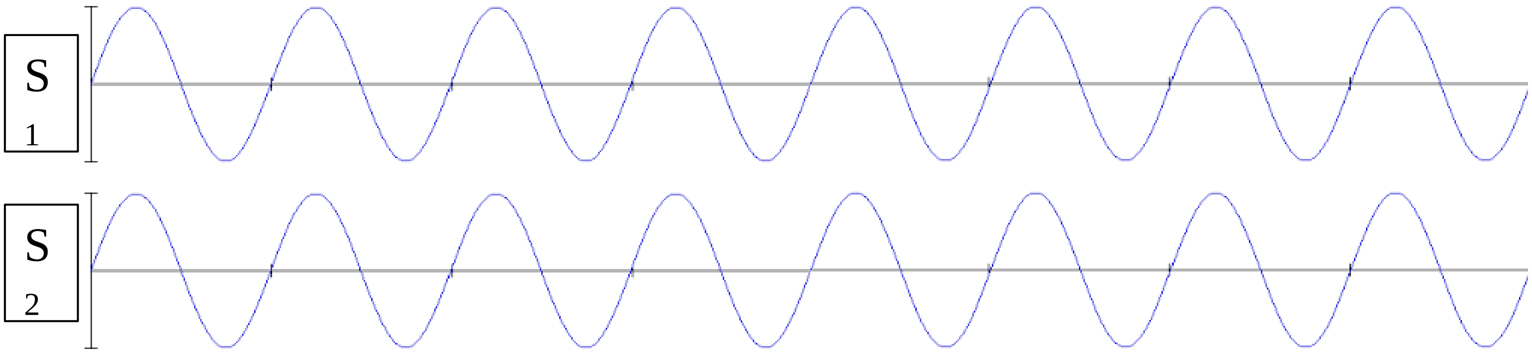
From the Formula Sheet

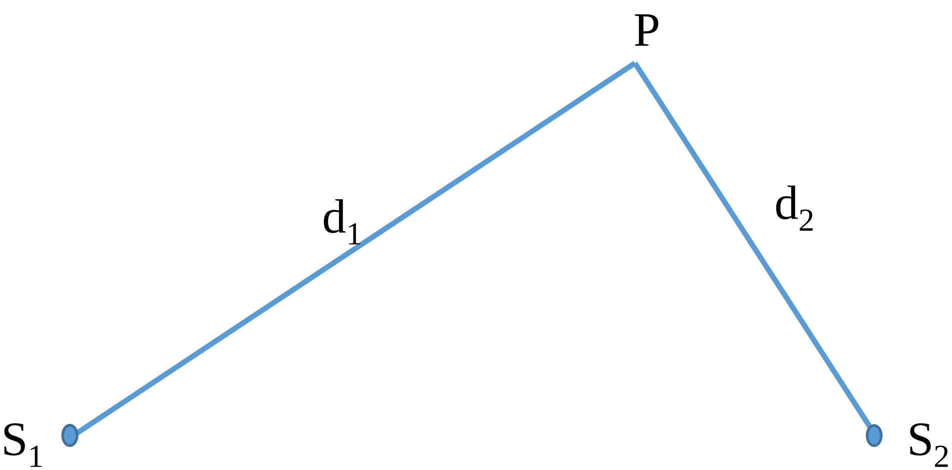
$$v = f\lambda \qquad v = \sqrt{\frac{F_T}{\mu}} \qquad y(x,t) = A\sin\left[2\pi f\left(t - \frac{x}{v}\right)\right] = A\sin\left[2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)\right]$$

$$f_n = n\left(\frac{v}{2L}\right),\ n = 1,2,3,\ldots \qquad f_n = n\left(\frac{v}{4L}\right),\ n = 1,3,5,\ldots$$

$$I = \frac{P}{4\pi r^2} \qquad \beta = (10\text{ dB})\log\left(\frac{I}{I_0}\right) \qquad f_{\text{beat}} = f_1 - f_2 \qquad f_{\text{L}} = \left(\frac{v + v_{\text{L}}}{v + v_{\text{S}}}\right)f_{\text{S}}$$

12.8 Interference





Constructive Interference:

$$d = d_1 - d_2 = n\lambda = n\frac{v}{f}$$

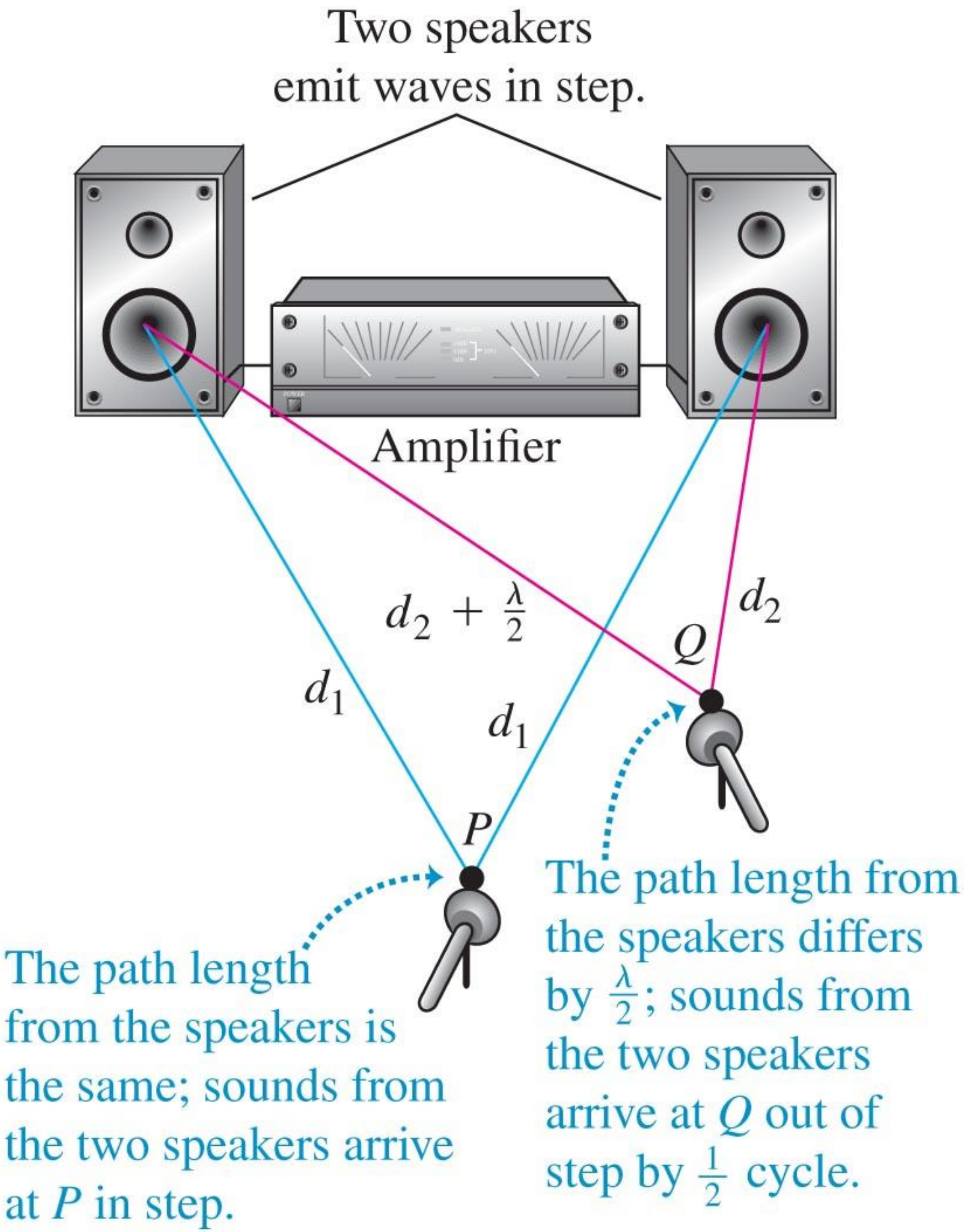
(n = 0, 1, 2, 3,…)

Destructive Interference:

$$d = d_1 - d_2 = \left(n + \frac{1}{2}\right)\lambda = \left(n + \frac{1}{2}\right)\frac{v}{f}$$

(n = 0, 1, 2, 3,…)

Destructive Interference: light + light = darkness


Two speakers
emit waves in step.
Amplifier
d_1
$d_2 + \frac{\lambda}{2}$
d_1
d_2
Q
P
The path length
from the speakers is
the same; sounds from
the two speakers arrive
at P in step.
The path length from
the speakers differs
by $\frac{\lambda}{2}$; sounds from
the two speakers
arrive at Q out of
step by $\frac{1}{2}$ cycle.

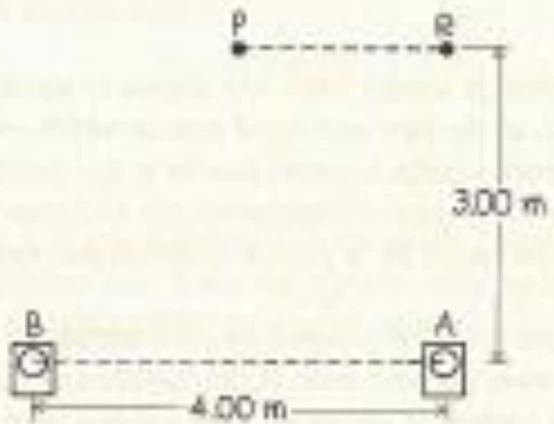
Interference from two loudspeakers

CONCEPTUAL ANALYSIS 12.5

Interference revisited

Suppose you take the two small speakers *A* and *B* from Example 12.6 and rearrange them so that they are separated by 4.00 m, as shown in Figure 12.28. You set up the sound system so that both speakers simultaneously emit sinusoidal waves with a frequency of 700 Hz. When you initially stand at point *P*, which is located 3.00 m above the midpoint of the line connecting the two speakers, you find that the sound waves from the two speakers are interfering constructively. If you then move along the horizontal line from point *P* to point *R*, how many times will you cross a point where the sound waves from the two speakers cancel out?

A. 1 B. 2 C. 3 D. 4



▲ **FIGURE 12.28**

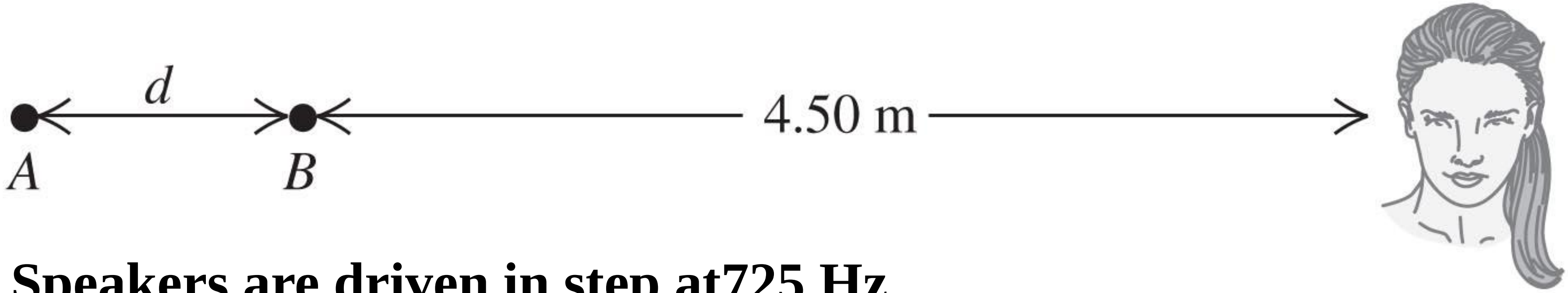
SOLUTION What matters in an interference problem is how the path difference between the two waves compares to the wavelength of the waves. Because point *P* lies along the center line between the two speakers, the sound wave from speaker *A* travels the same distance as the sound wave from speaker *B*, and the path difference is zero. To reach point *R*, the sound from speaker *A* needs to travel 3.00 m to reach that point, but the sound from speaker *B* needs to travel $[(4.00\ \text{m})^2 + (3.00\ \text{m})^2]^{1/2} = 5.00\ \text{m}$. Therefore, the path difference is $d = 5.00\ \text{m} - 3.00\ \text{m} = 2.00\ \text{m}$. If the frequency of the sounds emitted from the speakers is 700 Hz, then the wavelength of the sound waves is

$$\lambda = \frac{v}{f} = \frac{350\ \text{m/s}}{700\ \text{Hz}} = 0.500\ \text{m},$$

and the path difference is

$$d = \frac{2.00\ \text{m}}{0.500\ \text{m}/\lambda} = 4\lambda.$$

As you move from point *P* to point *R*, you will cross through three points of maximum constructive interference (where $d = 1\lambda$, 2λ, and 3λ) and four points of destructive interference (where $d = \lambda/2$, $3\lambda/2$, $5\lambda/2$, and $7\lambda/2$). So D is the correct answer.



Speakers are driven in step at725 Hz

***12.30. Set Up:** The path difference for the two sources is d. For destructive interference, the path difference is a half-integer number of wavelengths. For constructive interference, the path difference is an integer number of wavelengths. $\lambda = v/f$

Solve: $\lambda = \frac{v}{f} = \frac{344 \text{ m/s}}{725 \text{ Hz}} = 0.474 \text{ m}$

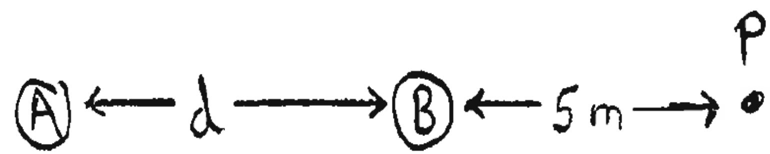
(a) Will first produce destructive interference when $d = \lambda/2 = 0.237$ m.

(b) Will next produce destructive interference when $d = 3\lambda/2 = 0.711$ m.

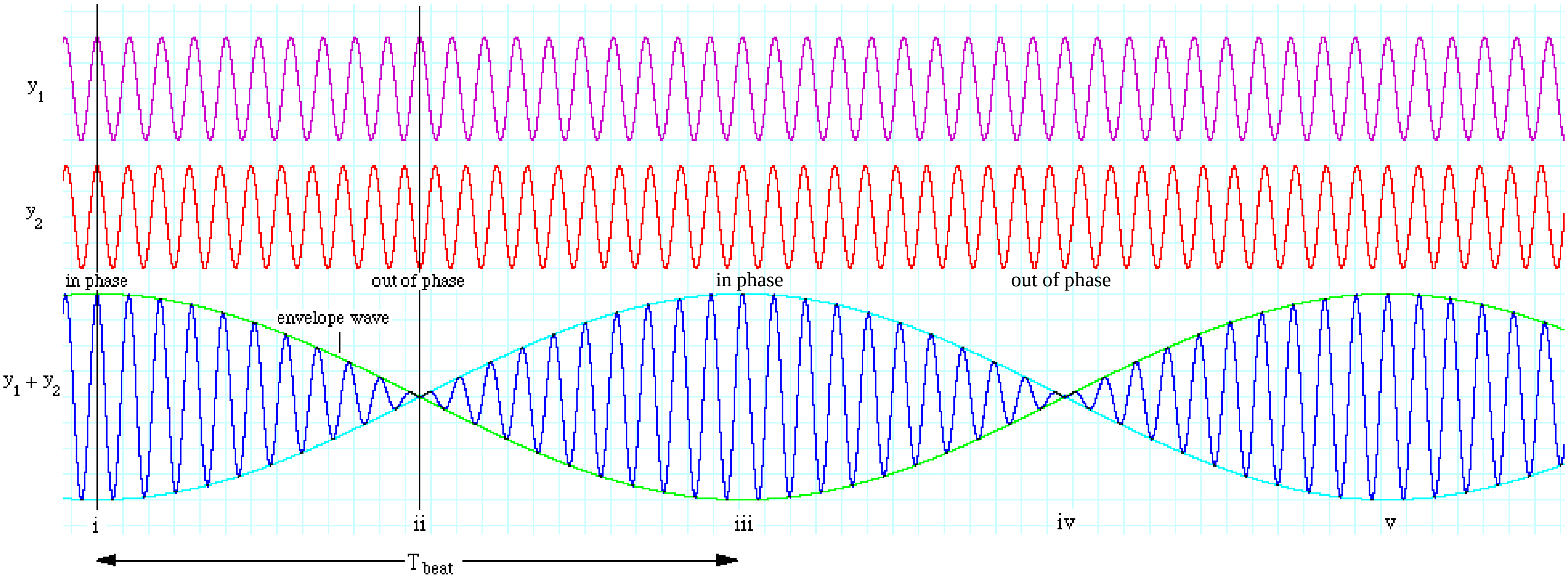
(c) Will first produce constructive interference again when $d = \lambda = 0.474$ m.

6. Two speakers *A* and *B* are driven by the same amplifier emit sound waves that are in phase and that have frequency 85 Hz. Speaker *A* is a distance *d* to the left of speaker *B* and the waves are observed at point *P*, a distance of 5.0 m to the right of speaker *B*. The speed of sound in air is 340 m/s. What is the smallest value of *d* for which there is destructive interference at *P*?

(a) 1.0 m
(b) 2.0 m
(c) 4.0 m
(d) 8.0 m
(e) none of these answers



12.11 Beats



Let $T_1 < T_2$.

Beat occurs when $nT_1 = T_{beat} = (n - 1)T_2$

Or, $T_{beat} = \frac{T_1 T_2}{T_2 - T_1}$, $f_{beat} = \frac{1}{T_{beat}} = \frac{T_2 - T_1}{T_1 T_2} = \frac{1}{T_1} - \frac{1}{T_2} = f_1 - f_2$

12.9 Sound and Hearing

12.10 Sound Intensity

Intensity: amount of energy falling on a surface of unit area (1 m^2) in a unit of time (1 s).

$$I = \frac{P}{4\pi r^2}$$

Decibels: $\beta = (10\ dB) log \frac{I}{I_0}$

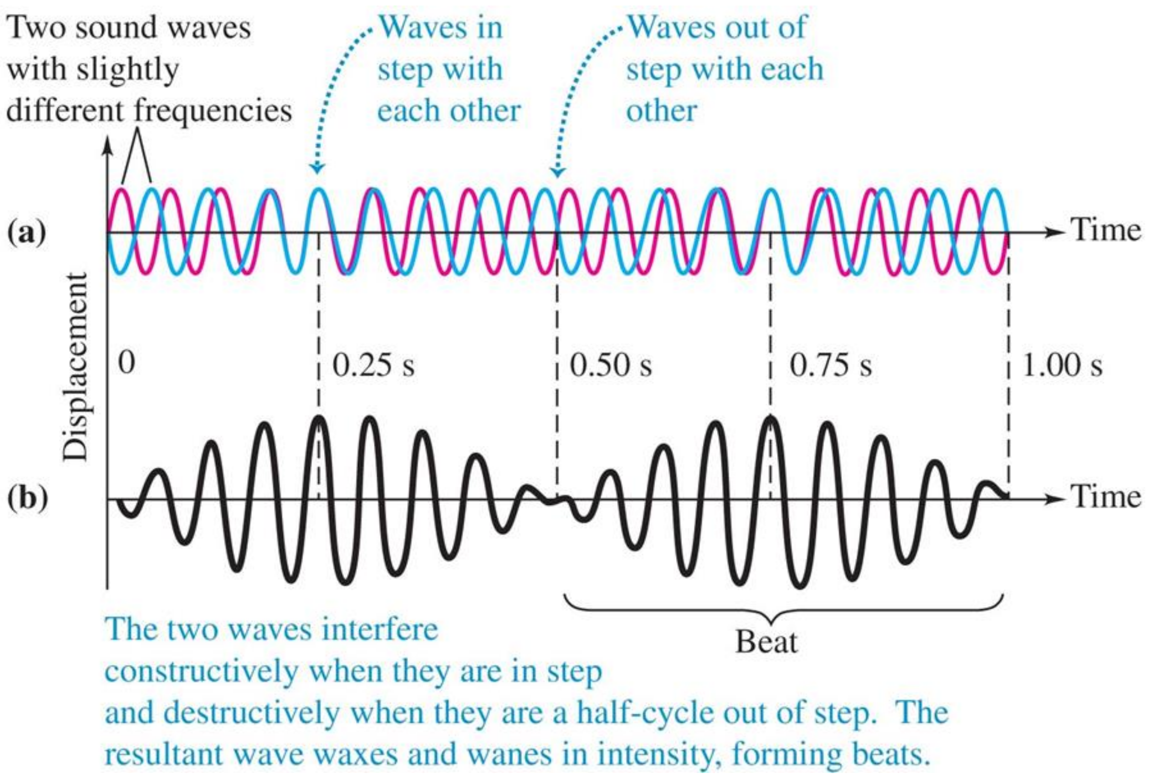
with $I_0 = 10^{-12}$ W/m^2.

5. A point source of sound waves emits uniformly in all directions. The sound intensity *I* at a distance of 8.0 m from the source is 2.0×10^{-6} W/m^2. What is the sound intensity at a distance of 2.0 m from the source?

(a) 1.2×10^{-7} W/m^2
(b) 5.0×10^{-7} W/m^2
(c) 3.2×10^{-5} W/m^2
(d) 8.0×10^{-4} W/m^2
(e) none of these answers

Beats and the Beat Frequency – Figure 12.31

- Two slightly different tuning forks will ring more loudly at the difference of the frequencies.



Q16.8

Clicker question 9

You hear a sound with a frequency of 256 Hz. The amplitude of the sound increases and decreases periodically: It takes 2 seconds for the sound to go from loud to soft and back to loud. This sound can be thought of as a sum of two waves with frequencies…

A. 256 Hz and 2 Hz.

B. 254 Hz and 258 Hz.

C. 255 Hz and 257 Hz.

D. 255.5 Hz and 256.5 Hz.

E. 255.75 Hz and 256.25 Hz.

12.12 The Doppler Effect

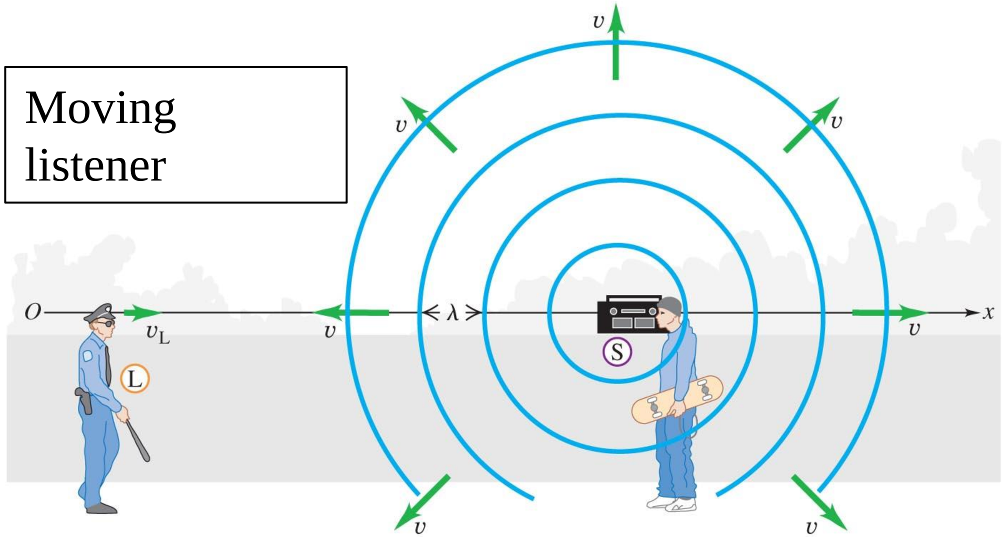
Consider a stationary source: emitting sound at frequency f_s and wavelength $\lambda = v/f_s$, where v is the speed of sound in air.

What is the frequency of the sound that a moving listener hear?

To a listener moving at a speed v_L toward the stationary sound source, the speed of sound is $v + v_L$.

Therefore, $f_L = \frac{v+v_L}{\lambda} = \frac{v+v_L}{v} f_s$.

Moving listener



The Doppler Effect of sound in air

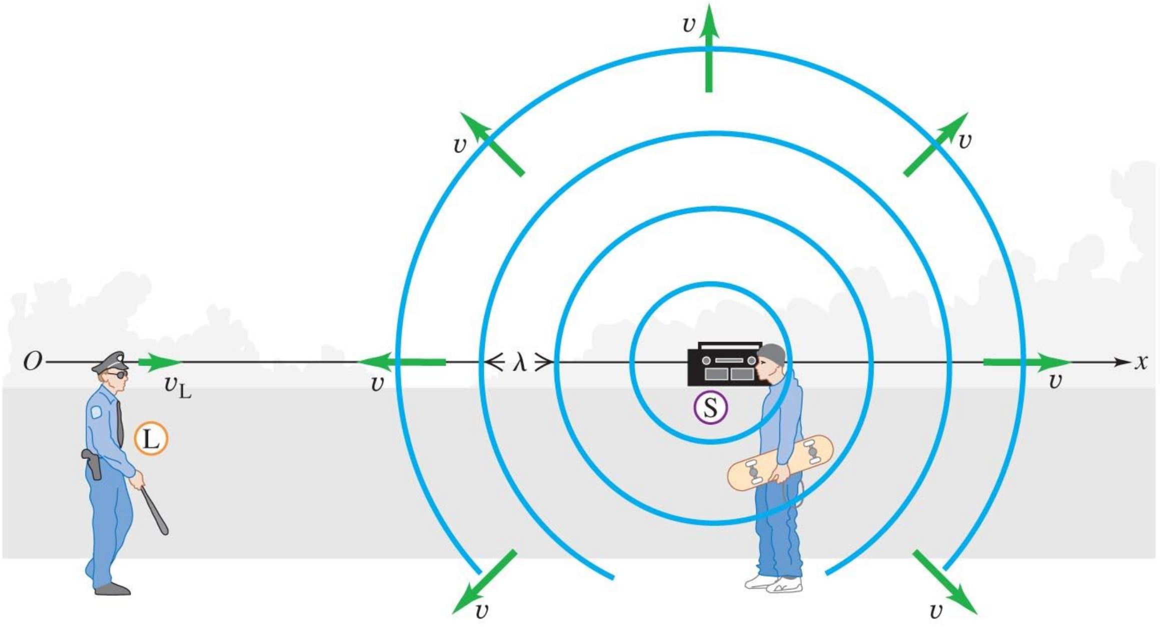
- Shifts in observed frequency can be caused by motion of the source, the listener, or both. Consider only the special case in which the velocities of both source and listener are along the line joining them.

Stationary source

$$f_L = \frac{v + v_L}{\lambda} = \frac{v + v_L}{\frac{v}{f_S}} = \frac{v + v_L}{v} f_S$$

v_L **>0 move toward the right**

v_L <0 move toward the left



The Doppler Effect Continued

Consider a source moving at a speed v_S, emitting sound wave at a frequency f_s.

What is the frequency of the sound that a stationary listener hear?

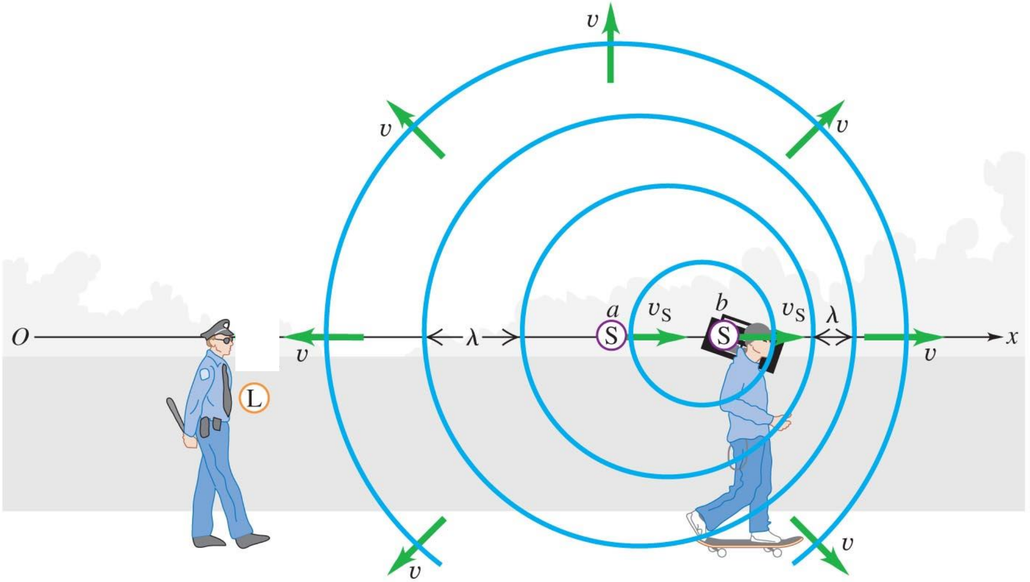
To a listener, the speed of the sound is not affected by the motion of the source. It is the speed of sound in air, v. However, the wavelength of the sound is affected by the speed of the source:

$$\lambda = \frac{v}{f_s} + v_S T = \frac{v}{f_s} + \frac{v_S}{f_s} = \frac{v+v_S}{f_s}.$$

Therefore, the frequency the listener hears is:

$$f_L = \frac{v}{\lambda} = \frac{v}{v+v_S} f_s$$

Moving Source



moving source

before source

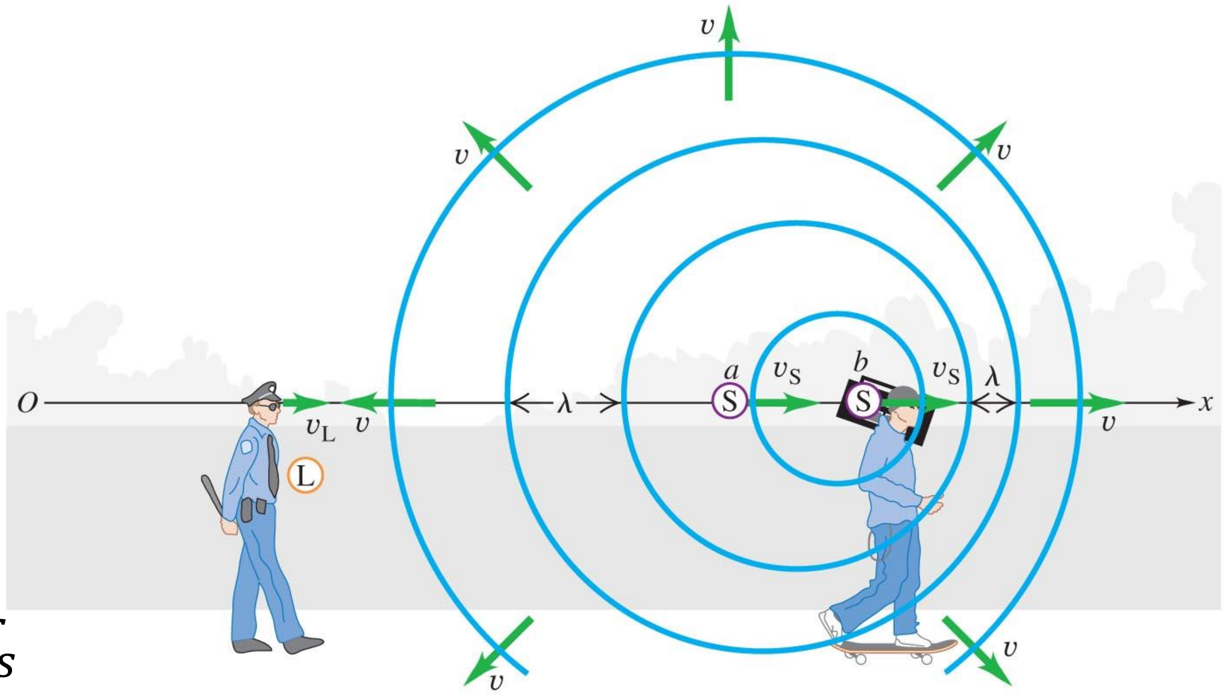
$$\lambda = \frac{v}{f_s} - \frac{v_s}{f_s} = \frac{v - v_s}{f_s}$$

During 1cycle the wave travels $\frac{v}{f_s}$ and the displacement of the source is $\frac{v_s}{f_s}$

Wavelength= distance between crests

behind source

$$\lambda = \frac{v + v_s}{f_s}$$



$$f_L == \frac{v + v_L}{\lambda} = \frac{v + v_L}{v \pm v_s} f_s$$

The Doppler Effect Continued

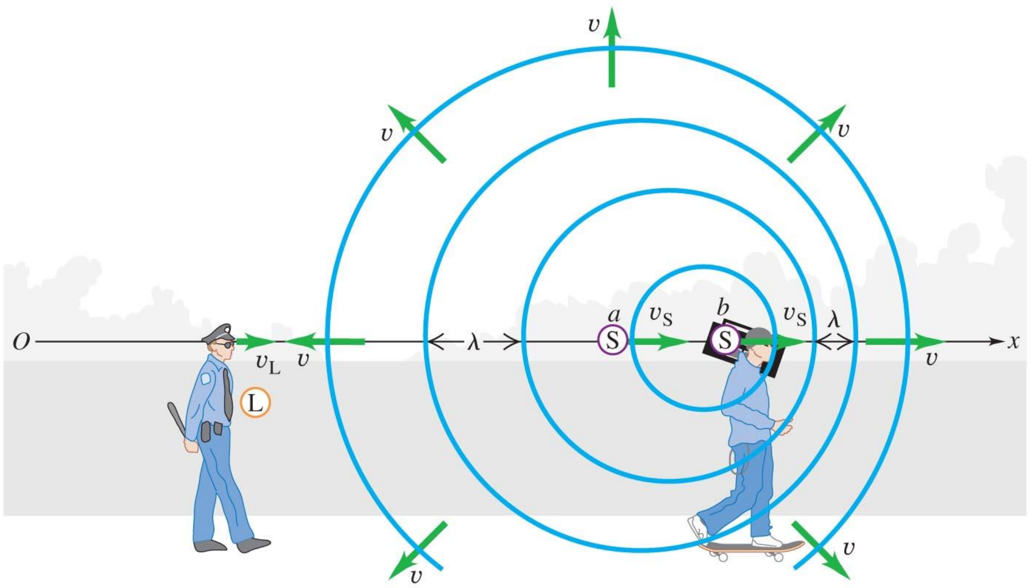
What if both the source and the listener are moving?

What is the frequency of the sound that the listener hear?

$$f_L = \frac{v+v_L}{\lambda} = \frac{v+v_L}{v+v_S} f_s,$$

since $\lambda = \frac{v+v_S}{f_s}$.

Moving source and moving listener



How to determine the signs of v_L and v_S?
General rule: moving closer leads to an increasing frequency, vice versa.

Therefore: If listener moving toward source, v_L is positive, and, vice versa.
If source moving toward listener, v_S is negative, and, vice versa.

4. You are standing at rest. A siren on a stationary firetruck emits sound waves that have wavelength 0.800 m. The firetruck then drives rapidly away from you. While the firetruck is moving away from you the wavelength of the sound that you observe will be

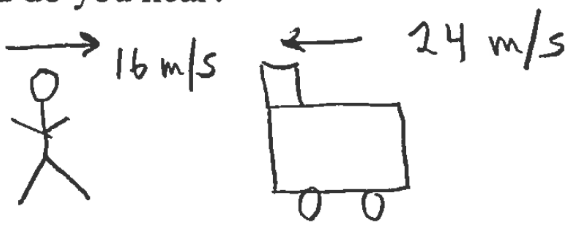
(a) greater than 0.800 m
(b) 0.800 m
(c) less than 0.800 m

Therefore, the frequency the listener hears is:

$$f_L = \frac{v}{\lambda} = \frac{v}{v+v_S} f_S$$

(5 pts) 5. A train is moving due west at a constant speed of 24.0 m/s. You are due west of the train and you are traveling due east toward the train with a constant speed of 16.0 m/s. The train whistle is emitting sound waves with a frequency of 640 Hz. The speed of sound in air is 344 m/s. What frequency of the sound do you hear?

(a) 446 Hz
(b) 626 Hz
(c) 656 Hz
(d) 720 Hz
(e) none of the above answers



General rule: moving closer leads to an increasing frequency, vice versa.

Doppler effect

EXAMPLE 12.13 Following the police car

Video Tutor Solution

Finally, let's consider an example in which both the source and listener are moving. If the siren is moving in the $+x$ direction with a speed of 45.0 m/s relative to the air, and the listener is moving in the same direction with a speed of 15.0 m/s relative to the air, what frequency does the listener hear?

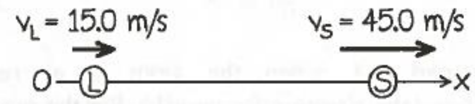
SOLUTION

SET UP Figure 12.37 shows our sketch. In this case, $v_L = 15.0$ m/s and $v_S = 45.0$ m/s. (Both velocities are positive because both velocity vectors point in the $+x$ direction, from listener to source.)

SOLVE From Equation 12.19,

$$f_L = \frac{v + v_L}{v + v_S} f_S = \frac{340 \text{ m/s} + 15.0 \text{ m/s}}{340 \text{ m/s} + 45.0 \text{ m/s}} (300 \text{ Hz}) = 277 \text{ Hz}.$$

REFLECT When the source and listener are moving apart, the frequency f_L heard by the listener is always *lower than* the frequency f_S emitted by the source. This is the case in all of the last three examples. Note that the *relative velocity* of source and listener (30.0 m/s) is the same in all three, but the Doppler shifts are all different because the velocities relative to the air are different.

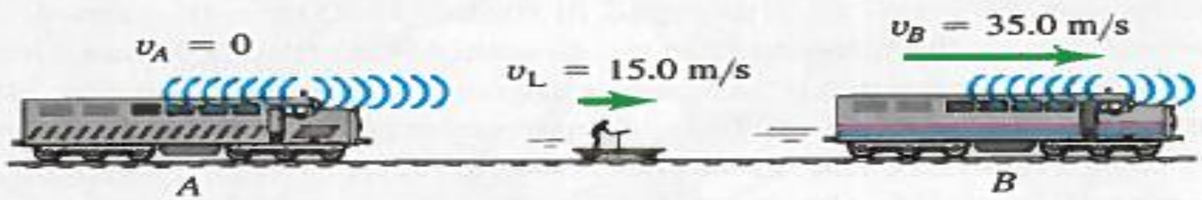


▲ **FIGURE 12.37** Our sketch for this problem.

If v_s goes in the negative(-x) direction

v_s is negative in the denominator and f_L **is higher than** f_s

50. | Two train whistles, A and B, each have a frequency of 392 Hz. A is stationary and B is moving toward the right (away from A) at a speed of 35.0 m/s. A listener is between the two whistles and is moving toward the right with a speed of 15.0 m/s. (See Figure 12.43.) (a) What is the frequency from A as heard by the listener? (b) What is the frequency from B as heard by the listener? (c) What is the beat frequency detected by the listener?



***12.50. Set Up:** The positive direction is from listener to source. $f_S = 392$ Hz.

(a) $v_S = 0$. $v_L = -15.0$ m/s.

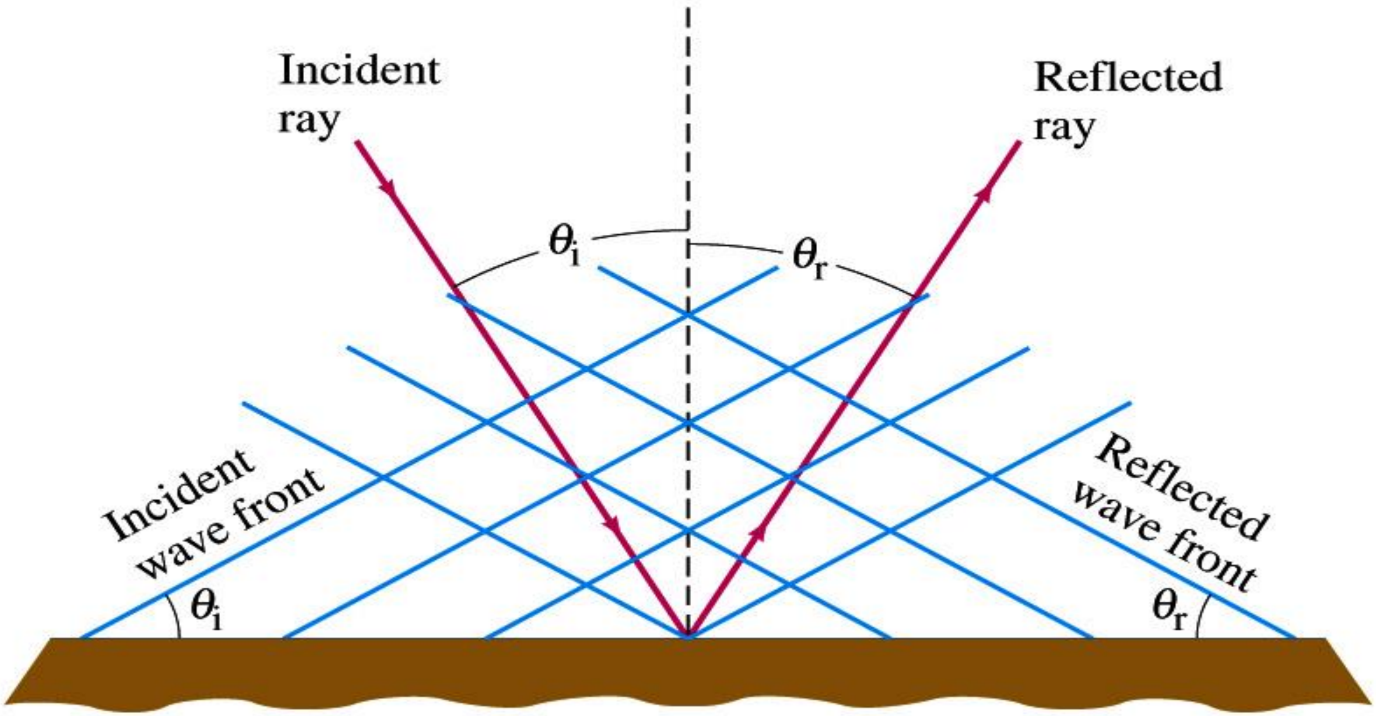
$$f_L = \left(\frac{v + v_L}{v + v_S}\right) f_S = \left(\frac{344 \text{ m/s} - 15.0 \text{ m/s}}{344 \text{ m/s}}\right)(392 \text{ Hz}) = 375 \text{ Hz}$$

(b) $v_S = +35.0$ m/s. $v_L = +15.0$ m/s.

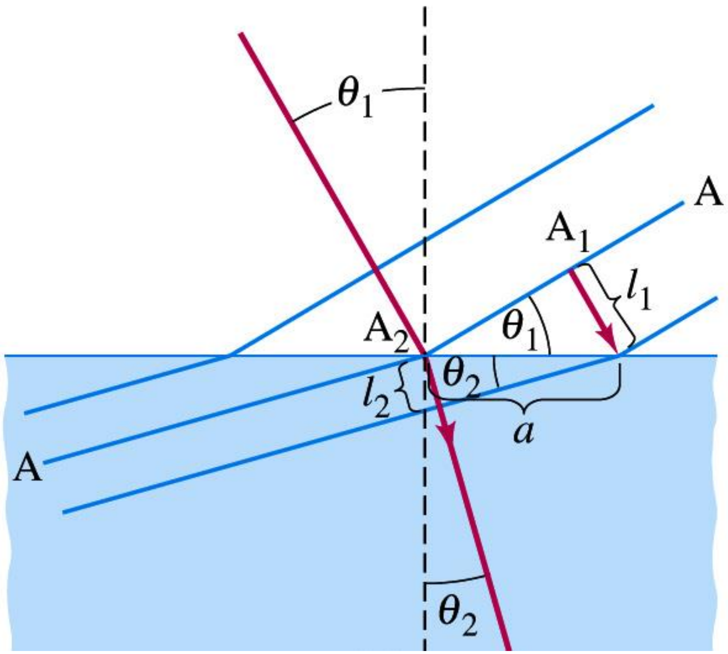
$$f_L = \left(\frac{v + v_L}{v + v_S}\right) f_S = \left(\frac{344 \text{ m/s} + 15.0 \text{ m/s}}{344 \text{ m/s} + 35.0 \text{ m/s}}\right)(392 \text{ Hz}) = 371 \text{ Hz}$$

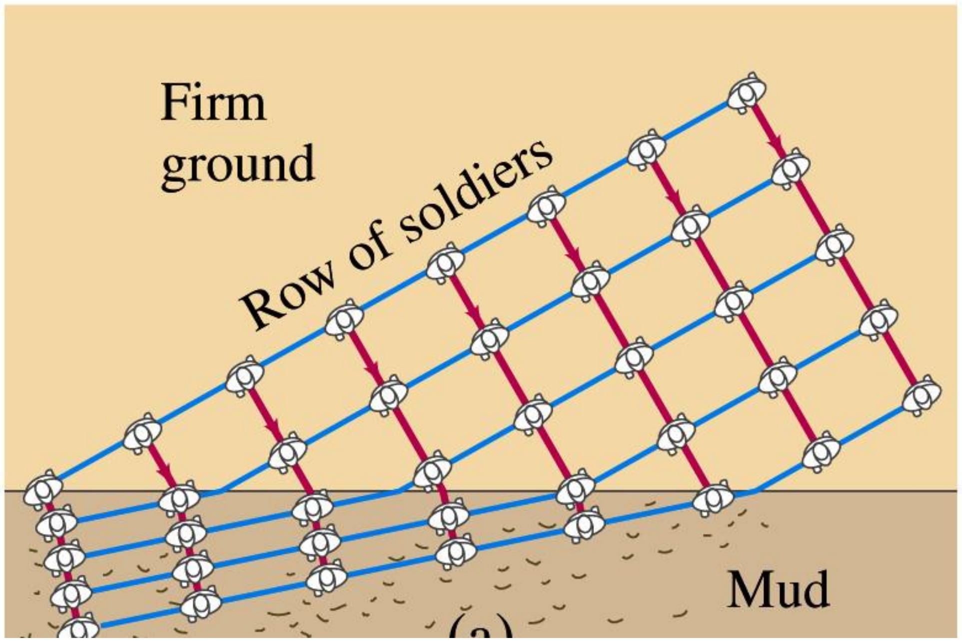
(c) $f_{beat} = f_1 - f_2 = 4$ Hz

Law of reflection



Refraction





Wave s

$$\text{Sin}\Theta_1 = \frac{l1}{a} = \frac{v1t}{a}$$

$$\text{Sin}\Theta_2 = \frac{l2}{a} = \frac{v2t}{a}$$

Soldiers

$$v1\ \text{Sin}\Theta_1 = v2\ \text{Sin}\Theta_2$$

Temporary deafness

Studies have shown that, on average, 10 years of exposure to 92 dB sound causes your threshold of hearing to permanently shift from 0 dB to 28 dB. What intensities correspond to 28 dB and 92 dB?

$$I = I_0 10^{\left(\frac{\beta}{10} dB\right)}$$

When $\beta = 28$ B

$$I = \left(10^{-12} \frac{\mathrm{W}}{\mathrm{m}^2}\right) 10^{(28\, dB\, /10\, dB)} = \left(10^{-12} \frac{\mathrm{W}}{\mathrm{m}^2}\right)(10^{2.8}) = 6.3 \times 10^{-10} \mathrm{W/m^2}$$

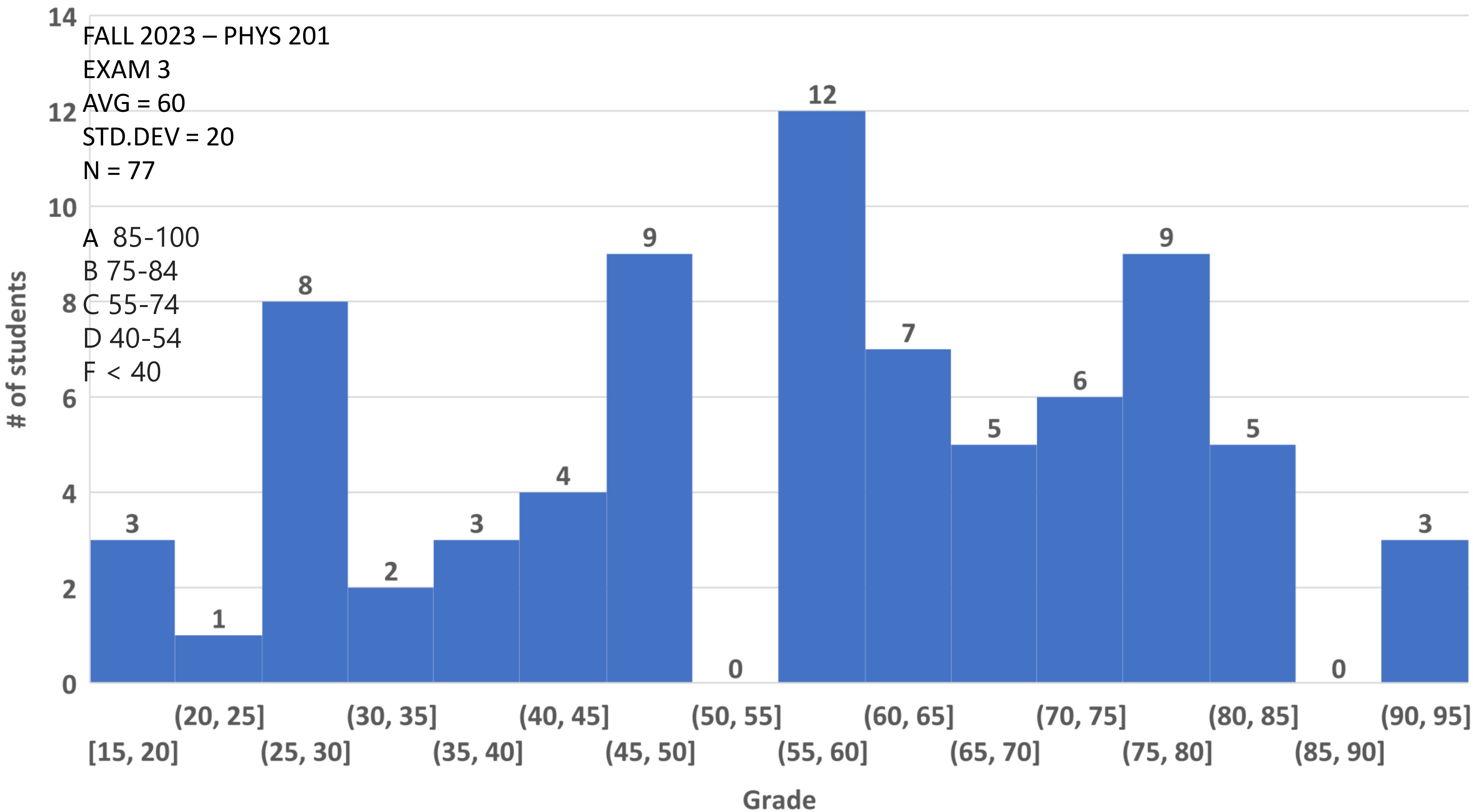
When $\beta = 92$ dB,

$$I = \left(10^{-12} \frac{\mathrm{W}}{\mathrm{m}^2}\right) 10^{(92\, dB\, /10\, dB)} = \left(10^{-12} \frac{\mathrm{W}}{\mathrm{m}^2}\right)(10^{9.2}) = 1.6 \times 10^{-3} \mathrm{W/m^2}$$

Clicker – Questions 10

You create waves on a pond surface by pushing up and down on it with your hand. Which aspect of the wave can you NOT affect by changing how you move your hand?

A. Frequency
B. Speed
C. Wavelength


FALL 2023 – PHYS 201
EXAM 3
AVG = 60
STD.DEV = 20
N = 77
A 85-100
B 75-84
C 55-74
D 40-54
F < 40
# of students
Grade
0
2
4
6
8
10
12
14
3
1
8
2
3
4
9
0
12
7
5
6
9
5
0
3
[15, 20]
(20, 25]
(25, 30]
(30, 35]
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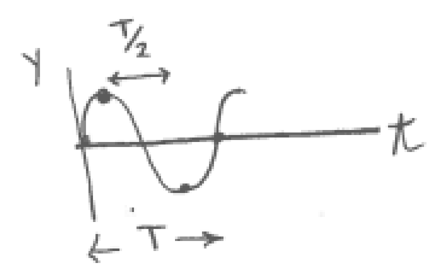
(45, 50]
(50, 55]
(55, 60]
(60, 65]
(65, 70]
(70, 75]
(75, 80]
(80, 85]
(85, 90]
(90, 95]


MPHY
203

12.4

a) $v = f\lambda = \frac{\lambda}{T}$

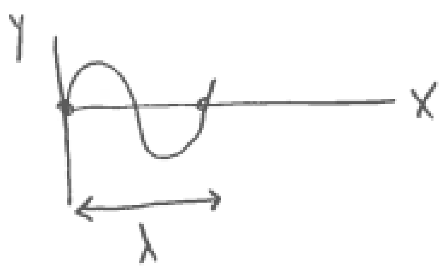


period T is time for 1 cycle

highest to lowest takes $t = \frac{T}{2}$

so T = 5.0 s

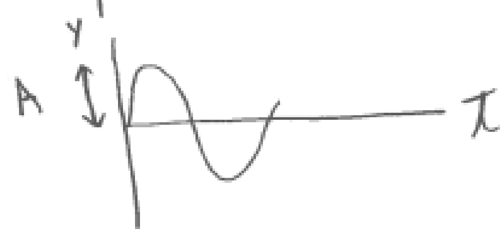
wavelength λ is distance for one cycle



$\lambda = 6.0\ m$

$$V = \frac{\lambda}{T} = \frac{6.0\ m}{5.0\ s} = 1.2\ m/s$$

b) amplitude is maximum displacement from equilibrium



$$A = \frac{0.62\ m}{2} = 0.31\ m$$

c) amplitude would be $\frac{0.30\ m}{2} = 0.15\ m$

λ, T and therefore v unchanged

12.12

Compare the specific equation given in the problem to the general equation $y(x,t) = A\sin\left[2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)\right]$ in order to obtain numerical values for T and λ. Then the wave speed is $v = \frac{\lambda}{T}$. For part (b) use $v = \sqrt{\frac{F_T}{\mu}}$.

a) $y(x,t) = (1.25\,\text{cm})\sin\left[(415\,s^{-1})t - (44.9\,m^{-1})x\right]$

$$\frac{2\pi}{T} = 415\,s^{-1} \quad \text{so} \quad T = \frac{2\pi}{415\,s^{-1}} = 0.01514\,s$$

$$\frac{2\pi}{\lambda} = 44.9\,m^{-1} \quad \text{so} \quad \lambda = \frac{2\pi}{44.9\,m^{-1}} = 0.1399\,m$$

$$v = f\lambda = \frac{\lambda}{T} = \frac{0.1399\,m}{0.01514\,s} = 9.24\,m/s$$

b) $$v = \sqrt{\frac{F_T}{\mu}} \quad \text{so} \quad \mu = \frac{F_T}{v^2} = \frac{4.00\,N}{(9.24\,m/s)^2} = 0.0469\,kg/m$$

12.18

N A N

fundamental
$f = 60.0\text{ Hz}$

a) $\frac{\lambda}{2} = L$ so $\lambda = 2L = 2(0.800\text{ m}) = 1.60\text{ m}$

$v = f\lambda = (60.0\text{ Hz})(1.60\text{ m}) = 96\text{ m/s}$

b) $v = \sqrt{\frac{F_T}{\mu}}$ $\quad F_T = \mu v^2$

$\mu = \frac{m}{L} = \frac{0.040\text{ kg}}{0.80\text{ m}} = 0.050\text{ kg/m}$

$F_T = (0.050\text{ kg/m})(96\text{ m/s})^2 = 461\text{ N}$

12.30

a) path difference is $4.5m + d - 4.5m = d$

$$\lambda = \frac{v}{f} = \frac{344\,m/s}{725\,Hz} = 0.474\,m$$

destructive interference for path difference $= (m+\frac{1}{2})\lambda$, $m = 0, 1, 2, \ldots$

$d = (m + \frac{1}{2})\lambda$ smallest d for $m = 0$ and $d = \frac{\lambda}{2} = 0.237\,m$

b) $m = 1$ so $d = \frac{3}{2}\lambda = 0.712\,m$

c) constructive interference for $d = m\lambda$, $m = 0, 1, 2, \ldots$

$m = 1$ $d = \lambda = 0.474\,m$

12.40

$$\beta = (10\,dB)\log\left(\frac{I}{I_0}\right)$$

for $r_1 = 15.0\,m$ $\quad 20.0\,dB = (10\,dB)\log\frac{I_1}{I_0}$

$\log\left(\frac{I_1}{I_0}\right) = 2$ and $\frac{I_1}{I_0} = 10^2$ $\quad I_1 = (10^{-12}\,W/m^2)(10^2) = 10^{-10}\,W/m^2$

for r_2, $\quad 60.0\,dB = (10\,dB)\log\frac{I_2}{I_0}$

$\log\left(\frac{I_2}{I_0}\right) = 6$ and $\frac{I_2}{I_0} = 10^6$ $\quad I_2 = (10^{-12}\,W/m^2)(10^6) = 10^{-6}\,W/m^2$

$$\frac{I_2}{I_1} = \frac{r_1^2}{r_2^2}$$

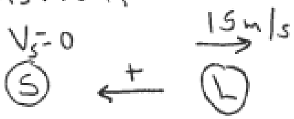
$$\frac{10^{-6}}{10^{-10}} = \frac{(15.0\,m)^2}{r_2^2} \qquad r_2 = (15.0\,m)\sqrt{\frac{10^{-10}}{10^{-6}}} = (15.0\,m)(10^{-2}) = 0.150\,m$$

$r_2 = 15.0\,cm$

12.50

Apply $f_L = \left(\frac{v+v_L}{v+v_S}\right) f_s$ to each source. At the start of the problems it says to use $v = 344$ m/s if no other value is given. The equation is based on the sign convention that the positive direction for v_L and v_s is from listener to source.

a) whistle A



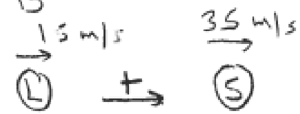
$v = 344$ m/s $\quad v_L = -15$ m/s

$v_s = 0 \quad f_s = 392$ Hz

$$f_L = \left(\frac{344\text{ m/s} - 15\text{ m/s}}{344\text{ m/s} + 0}\right)(392\text{ Hz}) = 375\text{ Hz}$$

Listener is moving away from the source and $f_L < f_s$

b) whistle B



$v = 344$ m/s $\quad v_L = 15$ m/s

$v_s = +35$ m/s $\quad f_s = 392$ Hz

$$f_L = \left(\frac{344\text{ m/s} + 15\text{ m/s}}{344\text{ m/s} + 35\text{ m/s}}\right)(392\text{ Hz}) = 371\text{ Hz}$$

Net effect of the motion is for listener and source to be moving apart and $f_L < f_s$.

c) beat frequency = $f_A - f_B$ = 375 Hz − 371 Hz = 4 Hz

For Mastering Physics keep extra significant figures to avoid round off error when calculate the difference in the two frequencies.