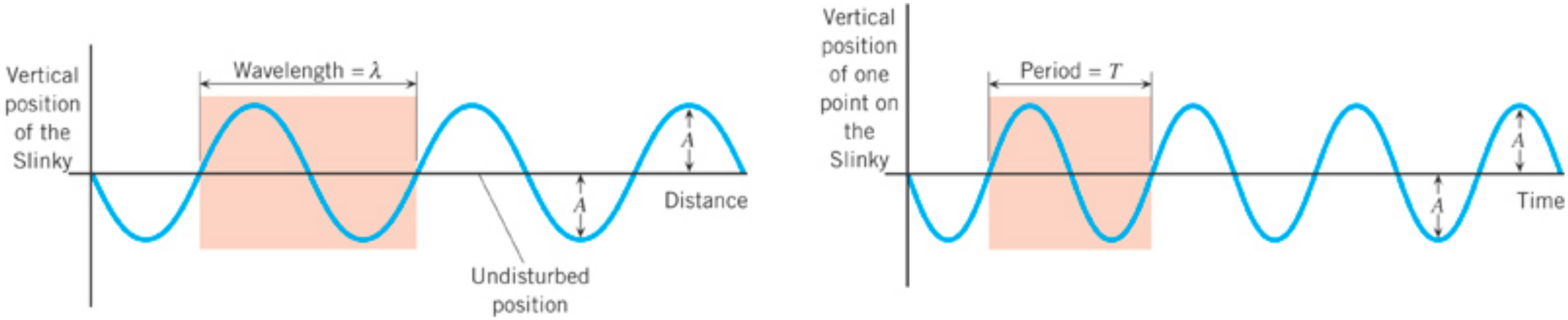
Chapter 11

Waves & Sound

11.2 Periodic Waves



(a) At a particular time

(b) At a particular location

In the drawing, one ***cycle*** is shaded in color.

The ***amplitude*** A is the maximum excursion of a particle of the medium from the particles undisturbed position.

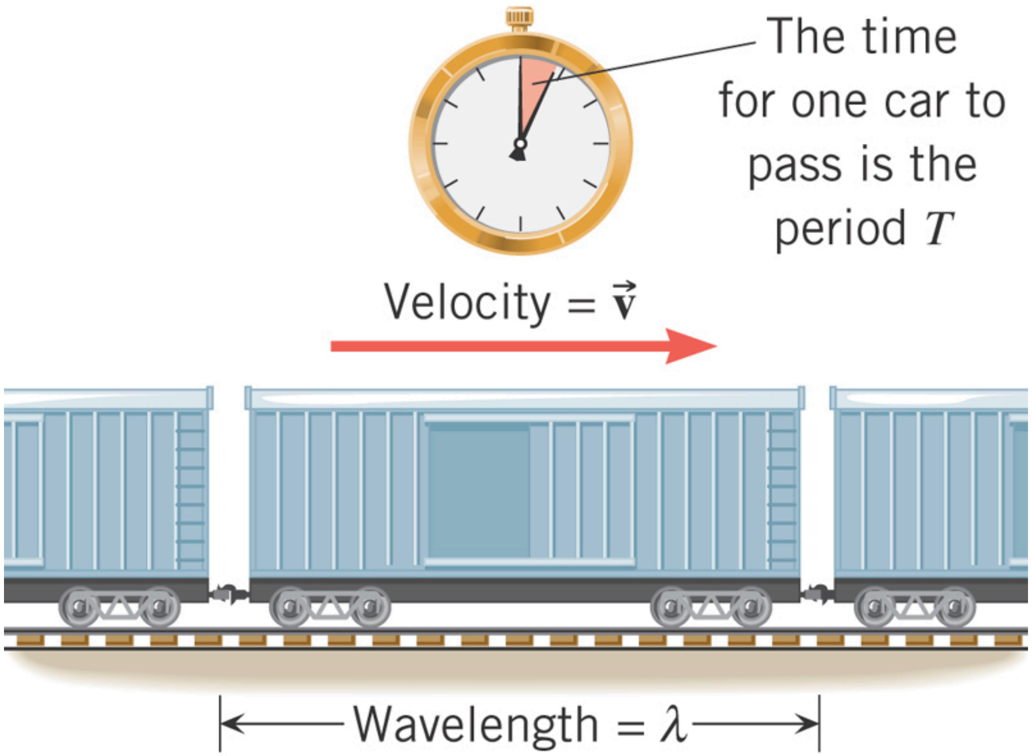
The ***wavelength*** is the horizontal length of one cycle of the wave.

The ***period*** is the time required for one complete cycle.

The ***frequency*** is related to the period and has units of Hz, or s^{-1}.

$$f = \frac{1}{T}$$

11.2 Periodic Waves



$$\boxed{vT = \lambda; \quad f = \frac{1}{T}}$$

$$\boxed{v = \frac{\lambda}{T} = f\lambda \quad \Rightarrow \quad \lambda = \frac{v}{f}}$$

Example: The Wavelengths of Radio Waves

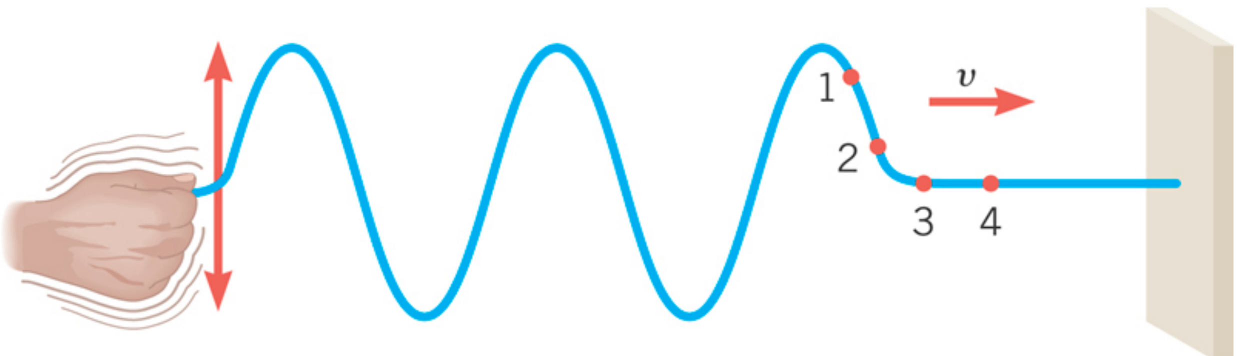
AM and FM radio waves are transverse waves consisting of electric and magnetic field disturbances traveling at a speed of 3.00x10^{8}m/s. A station broadcasts AM radio waves whose frequency is 1230x10^{3}Hz and an FM radio wave whose frequency is 91.9x10^{6}Hz. Find the distance between adjacent crests in each wave.

$$\lambda_{\mathrm{AM}} = \frac{v}{f} = \frac{3.00\times 10^{8}\ \mathrm{m/s}}{1230\times 10^{3}\mathrm{Hz}} = 244\ \mathrm{m}$$

$$\lambda_{\mathrm{FM}} = \frac{v}{f} = \frac{3.00\times 10^{8}\ \mathrm{m/s}}{91.9\times 10^{6}\mathrm{Hz}} = 3.26\ \mathrm{m}$$

11.3 The Speed of a Wave on a String

The speed at which the wave moves to the right depends on how quickly one particle of the string is accelerated upward in response to the net pulling force.



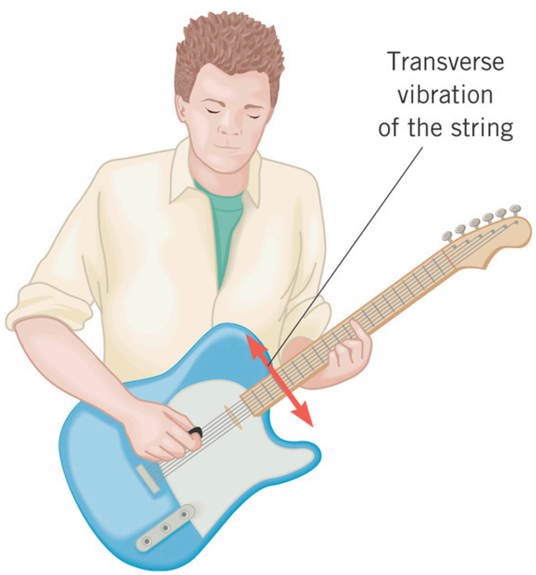
$$\boxed{v = \sqrt{\frac{T}{\mu}}}$$

Tension: T

Linear mass density: $\mu = m/L$

Example: Waves Traveling on Guitar Strings

Transverse waves travel on each string of an electric guitar after the string is plucked. The length of each string between its two fixed ends is 0.628 m, and the mass is 0.208 g for the highest pitched E string and 3.32 g for the lowest pitched E string. Each string is under a tension of 226 N. Find the speeds of the waves on the two strings.



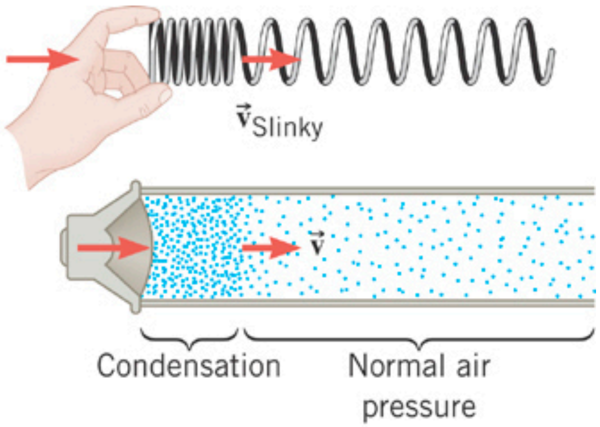
High E

$$v = \sqrt{\frac{T}{m/L}} = \sqrt{\frac{226\text{ N}}{\left(0.208\times10^{-3}\text{kg}\right)/\left(0.628\text{ m}\right)}} = 826\,\text{m/s}$$

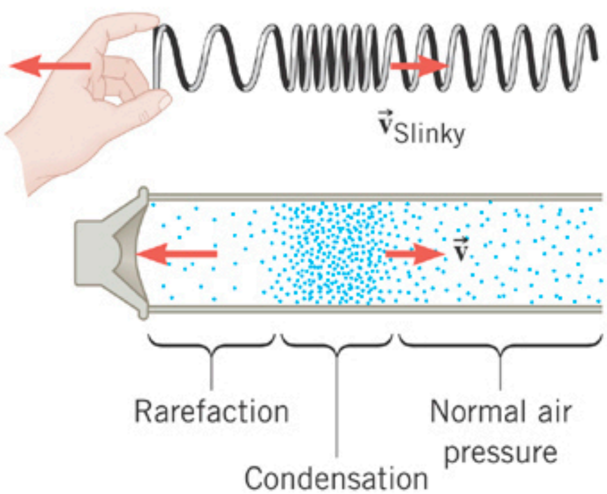
Low E

$$v = \sqrt{\frac{T}{m/L}} = \sqrt{\frac{226\text{ N}}{\left(3.32\times10^{-3}\text{kg}\right)/\left(0.628\text{ m}\right)}} = 207\,\text{m/s}$$

LONGITUDINAL SOUND WAVES

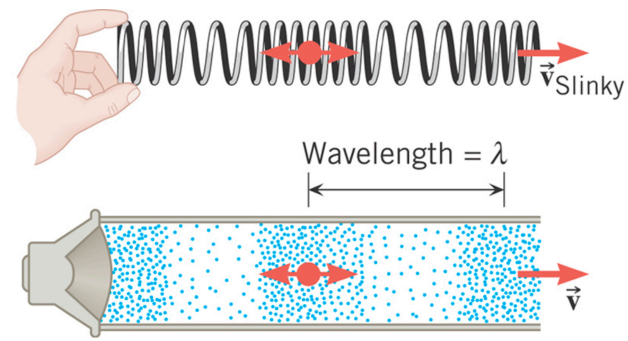


(*a*)



(*b*)

The distance between adjacent condensations is equal to the wavelength of the sound wave.



THE FREQUENCY OF A SOUND WAVE

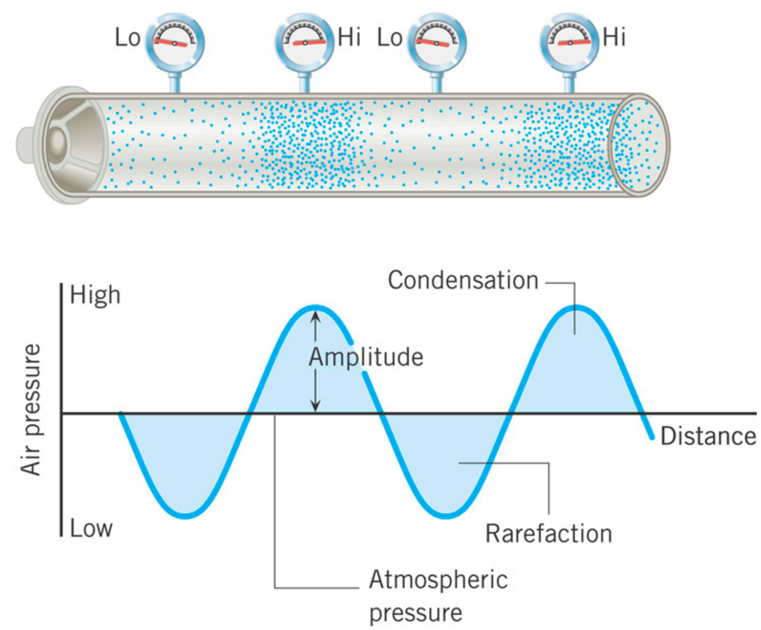
The ***frequency*** is the number of cycles per second.

A sound with a single frequency is called a ***pure tone***.

The brain interprets the frequency in terms of the subjective quality called ***pitch***.

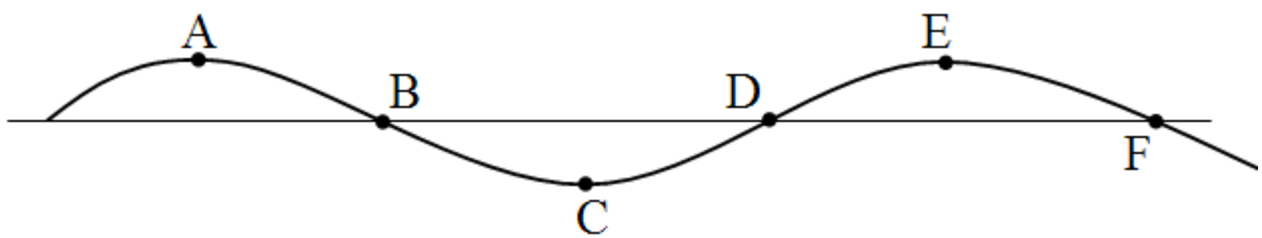
THE AMPLITUDE OF A SOUND WAVE

Loudness is an attribute of a sound that depends primarily on the pressure amplitude of the wave.



Clicker Question 11.1

The drawing shows the vertical position of points along a string versus distance as a wave travels along the string. Six points on the wave are labeled A, B, C, D, E, and F. Between which two points is the length of the segment equal to one wavelength



a) A to E

b) B to D

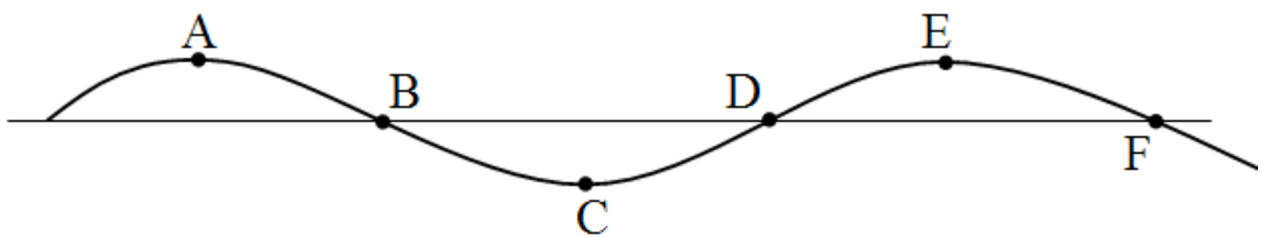
c) A to C

d) A to F

e) C to F

Clicker Question 11.1

The drawing shows the vertical position of points along a string versus distance as a wave travels along the string. Six points on the wave are labeled A, B, C, D, E, and F. Between which two points is the length of the segment equal to one wavelength



a) A to E

b) B to D

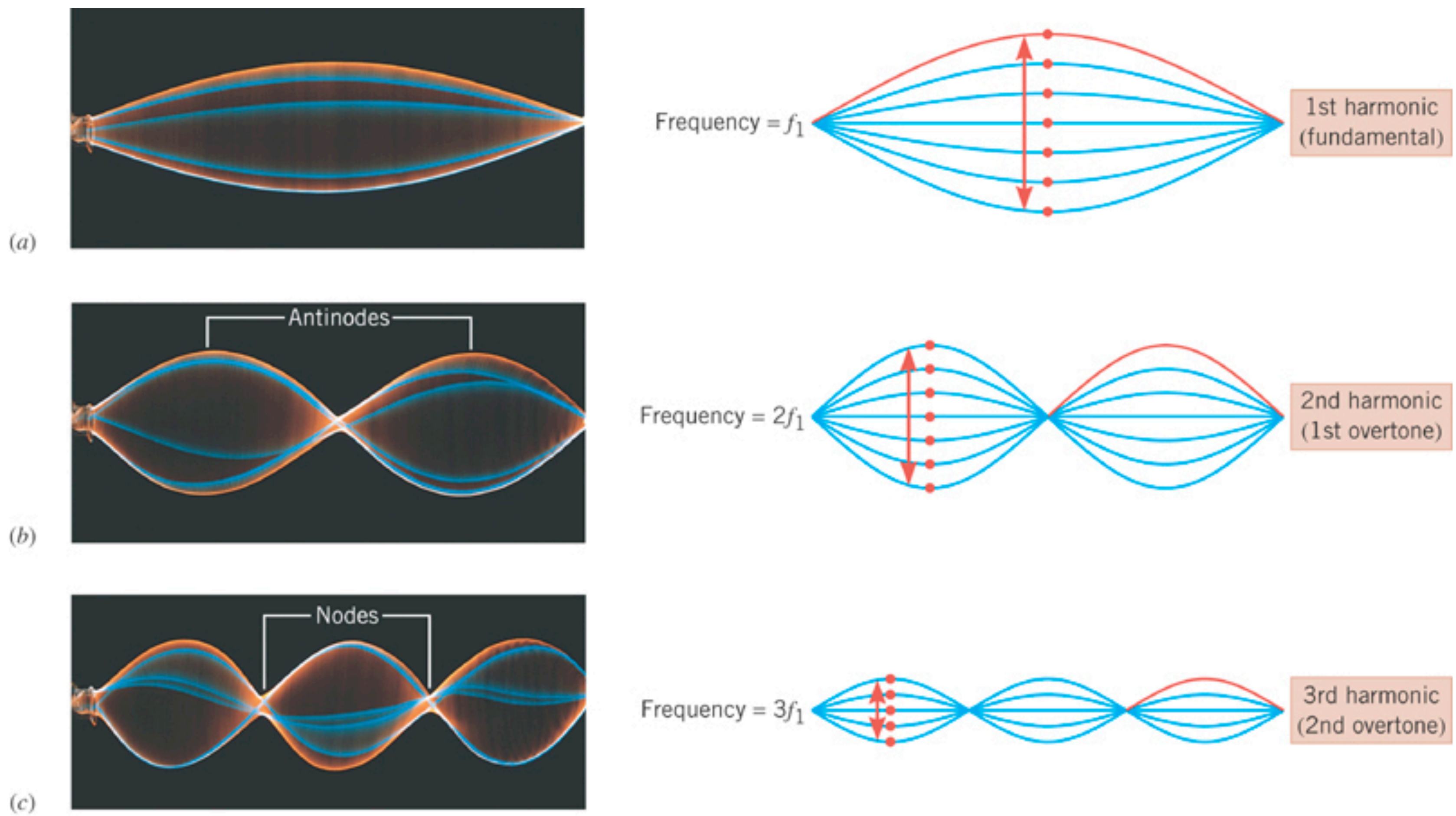
c) A to C

d) A to F

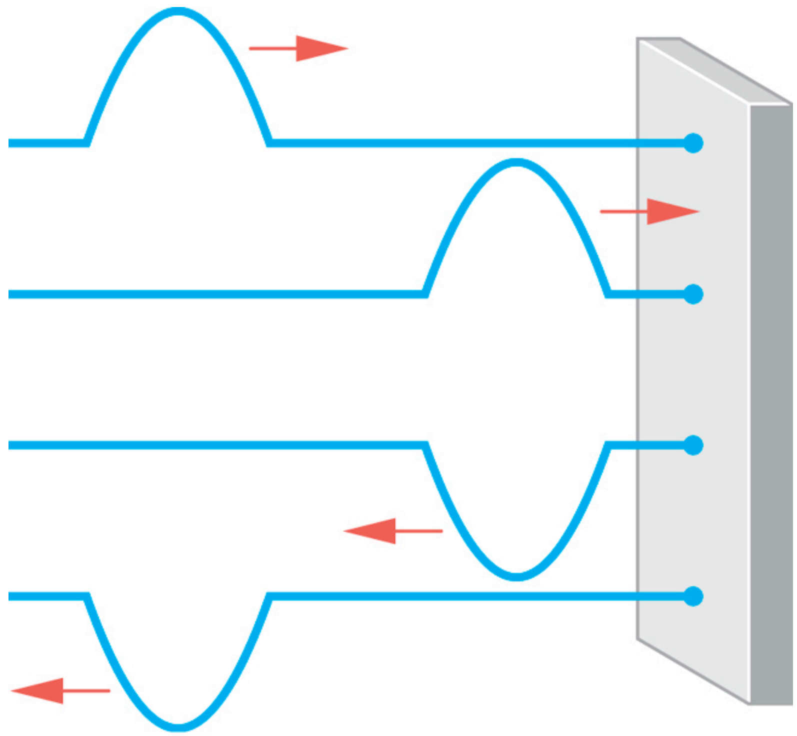
e) C to F

11.3 Transverse Standing Waves

Transverse standing wave patters.



11.3 Transverse Standing Waves

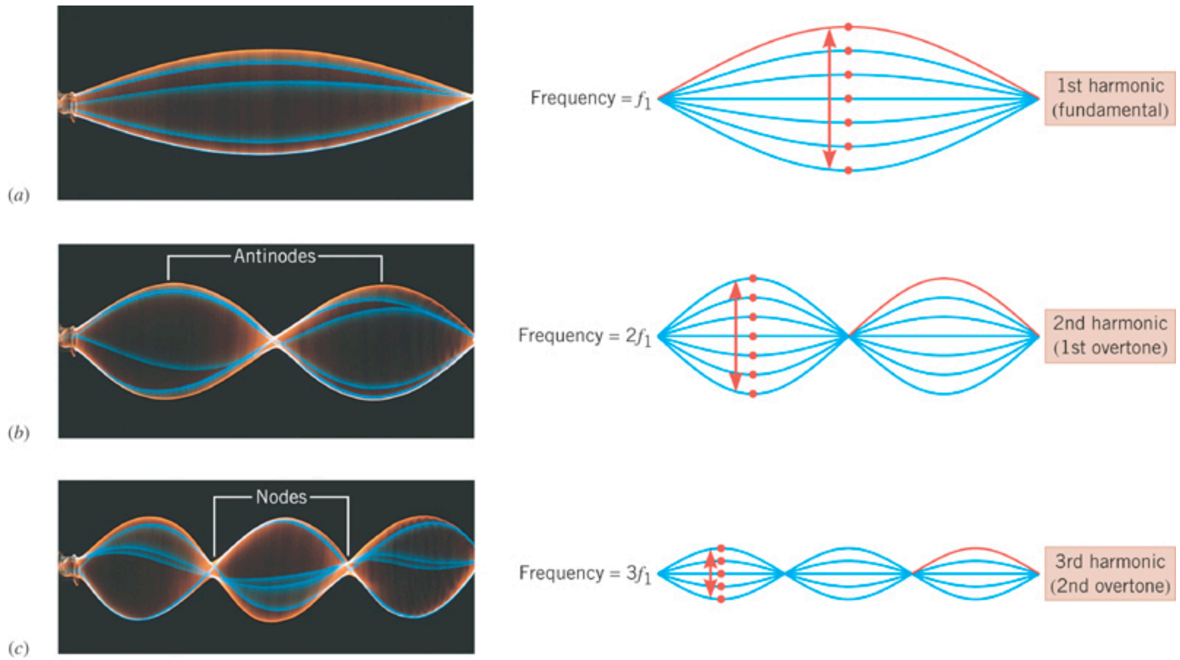


In reflecting from the wall, a forward-traveling half-cycle becomes a backward-traveling half-cycle that is inverted.

Unless the timing is right, the newly formed and reflected cycles tend to offset one another.

Repeated reinforcement between newly created and reflected cycles causes a large amplitude standing wave to develop.

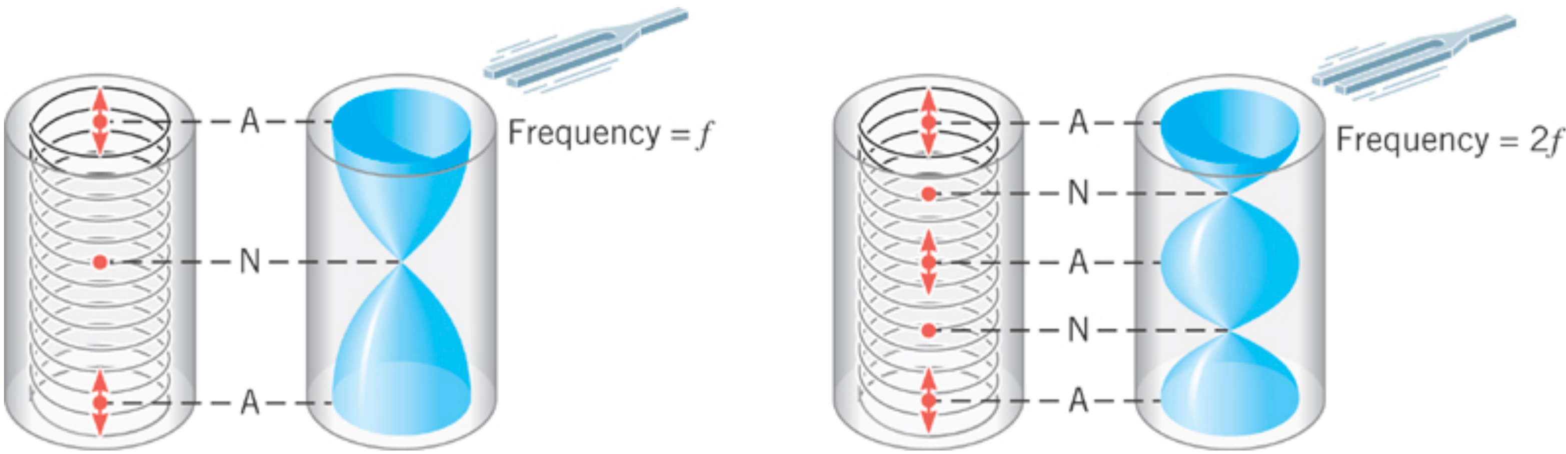
11.3 Transverse Standing Waves



String fixed at both ends

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

11.3 Longitudinal Standing Waves



Tube open at both ends

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

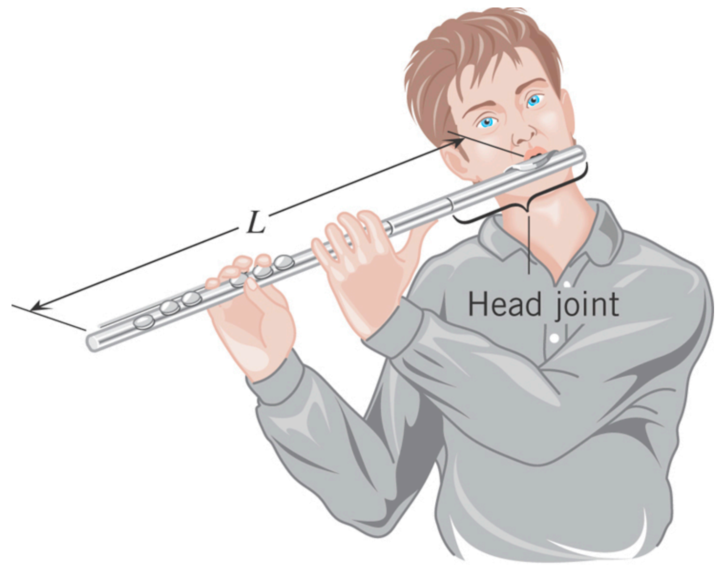
\# of Nodes

Example: Playing a Flute

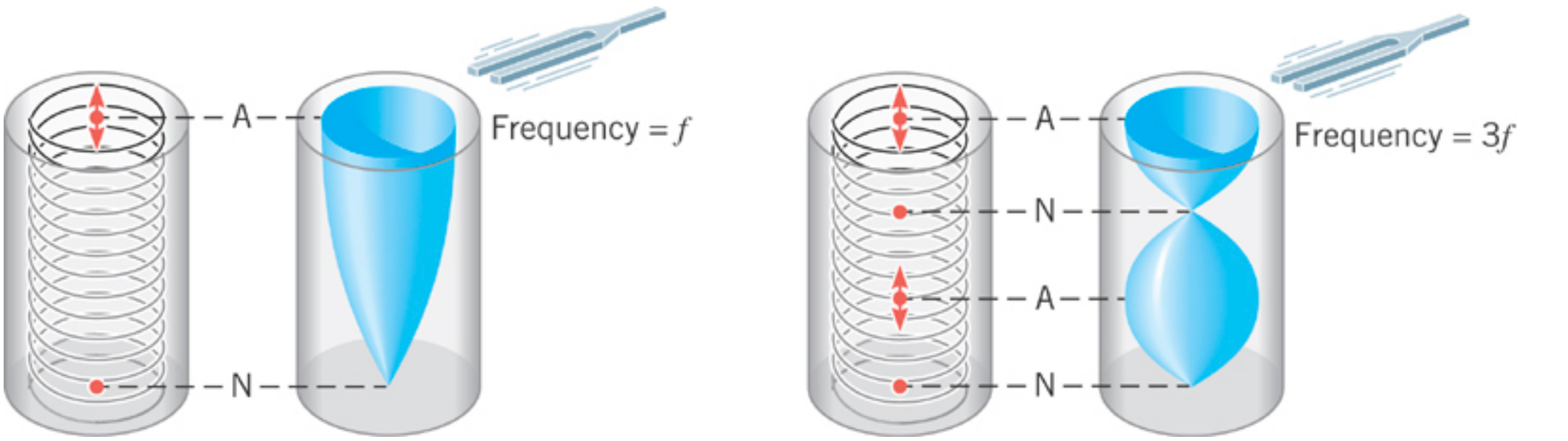
When all the holes are closed on one type of flute, the lowest note it can sound is middle C (261.6 Hz). If the speed of sound is 343 m/s, and the flute is assumed to be a cylinder open at both ends, determine the distance L.

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

$$L = \frac{nv}{2f_n} = \frac{1(343\,\mathrm{m/s})}{2(261.6\,\mathrm{Hz})} = 0.656\,\mathrm{m}$$



11.3 Longitudinal Standing Waves



Tube open at one end

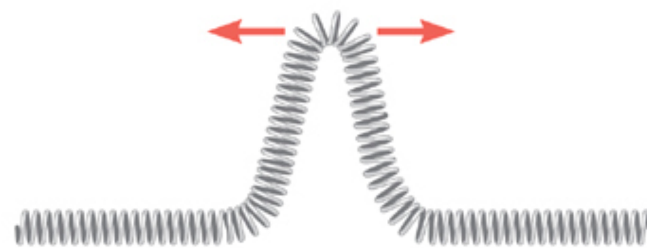
$$f_n = n\left(\frac{v}{4L}\right) \qquad n = 1,3,5,\ldots$$

$$n \text{ is } 2\times\text{Nodes} - 1$$

11.3 The Principle of Linear Superposition

When the pulses merge, the Slinky assumes a shape that is the sum of the shapes of the individual pulses.

(*a*) Overlap begins

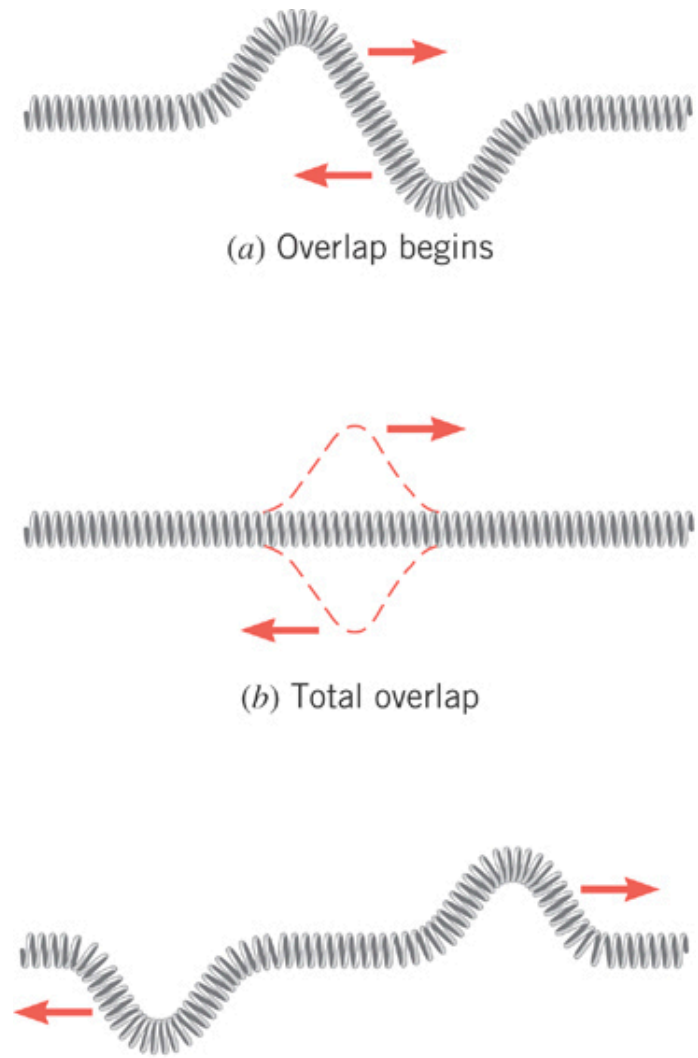


(*b*) Total overlap; the Slinky has twice the height of either pulse

(*c*) The receding pulses

11.3 The Principle of Linear Superposition

When the pulses merge, the Slinky assumes a shape that is the sum of the shapes of the individual pulses.



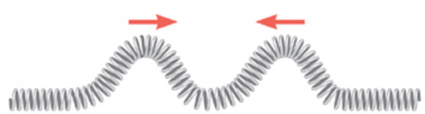
(*a*) Overlap begins

(*b*) Total overlap

(*c*) The receding pulses

THE PRINCIPLE OF LINEAR SUPERPOSITION

When two or more waves are present simultaneously at the same place, the resultant disturbance is the sum of the disturbances from the individual waves.



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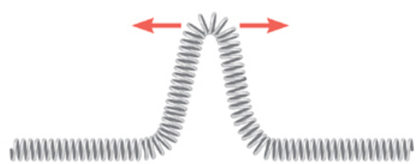
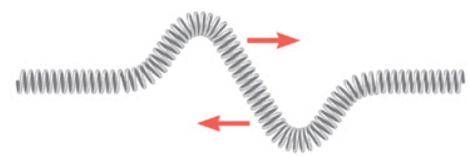
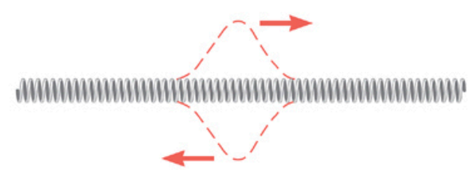


(*b*) Total overlap; the Slinky has twice the height of either pulse

(*c*) The receding pulses



(*a*) Overlap begins

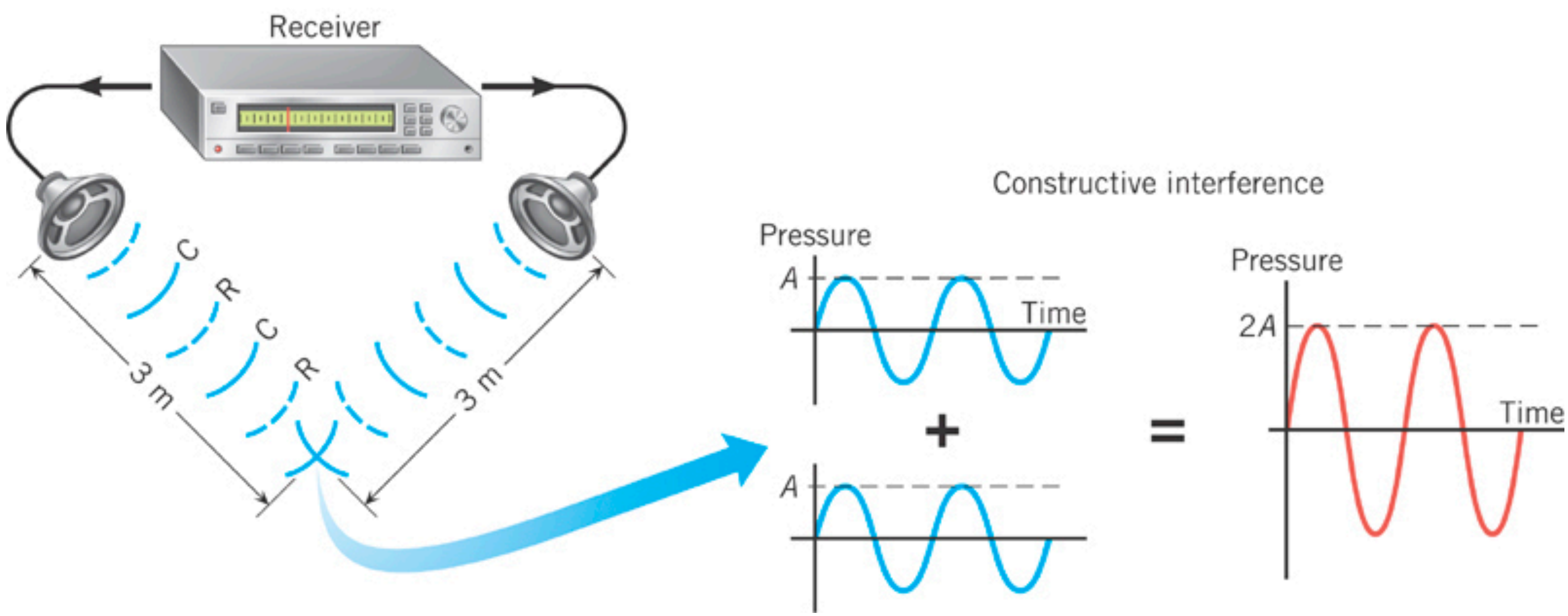


(*b*) Total overlap

(*c*) The receding pulses

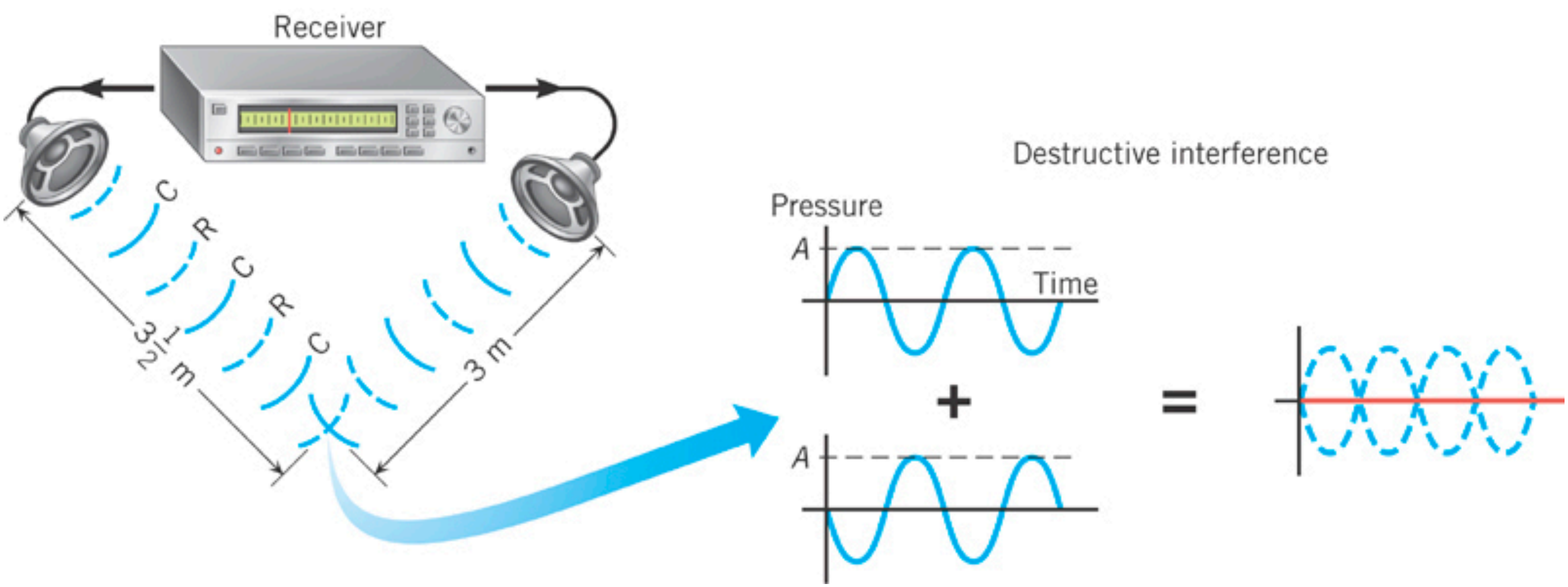
11.3 Constructive and Destructive Interference of Sound Waves

When two waves always meet condensation-to-condensation and rarefaction-to-rarefaction, they are said to be ***exactly in phase*** and to exhibit ***constructive interference.***

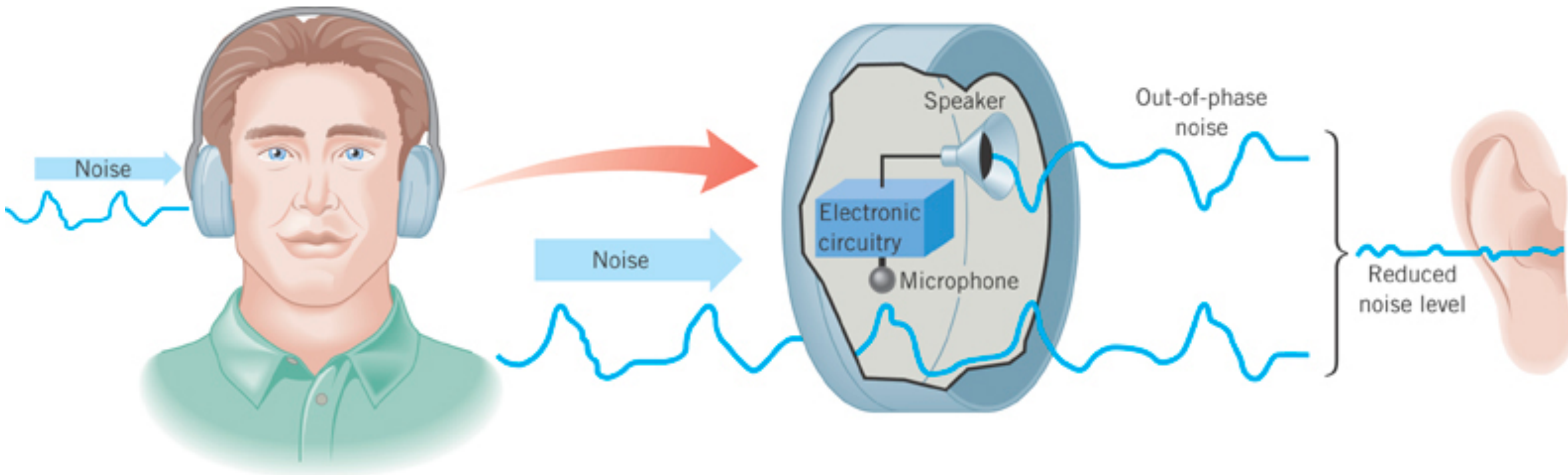


11.3 Constructive and Destructive Interference of Sound Waves

When two waves always meet condensation-to-rarefaction, they are said to be ***exactly out of phase*** and to exhibit ***destructive interference.***



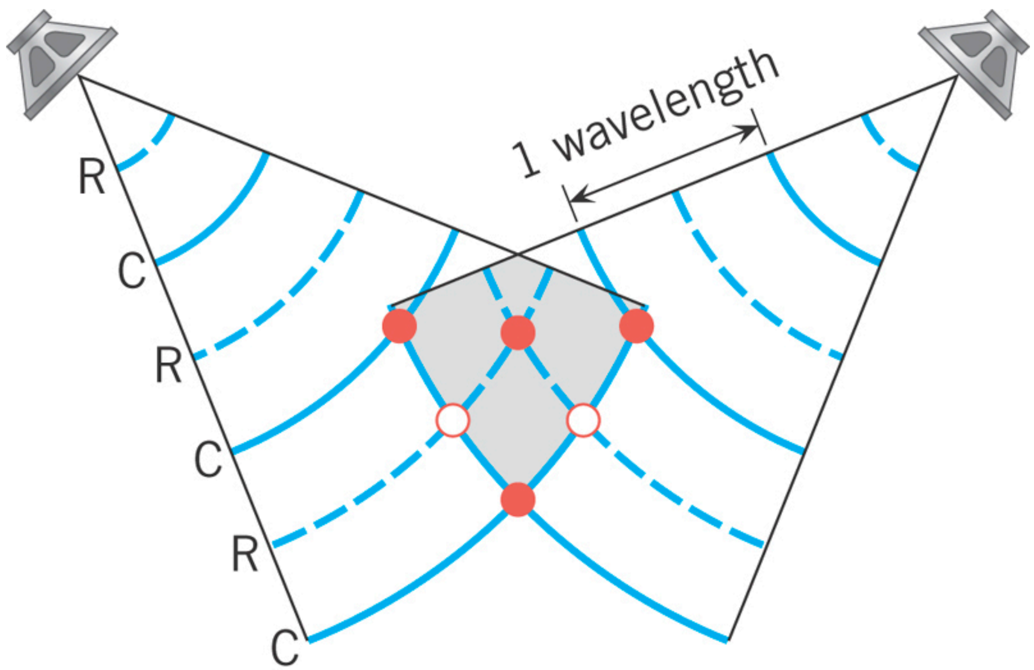
11.3 Constructive and Destructive Interference of Sound Waves



11.3 Constructive and Destructive Interference of Sound Waves

If the wave patters do not shift relative to one another as time passes, the sources are said to be ***coherent***.

For two wave sources vibrating in phase, a difference in path lengths that is zero or an integer number (1, 2, 3, . .) of wavelengths leads to constructive interference; a difference in path lengths that is a half-integer number (½ , 1 ½, 2 ½, . .) of wavelengths leads to destructive interference.



11.3 Sound Intensity

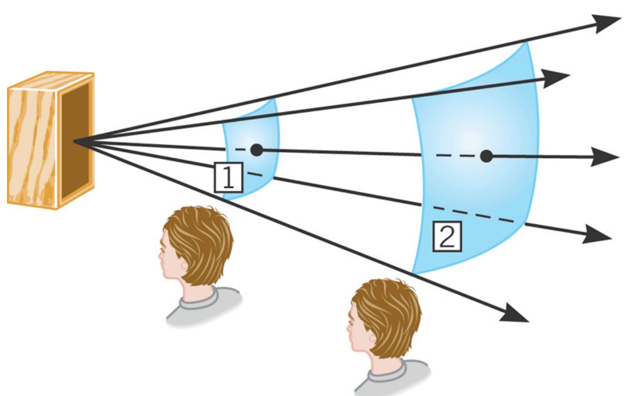
The amount of energy transported per second is called the ***power*** of the wave.

The ***sound intensity*** is defined as the power that passes perpendicularly through a surface divided by the area of that surface.

$$\boxed{I = P/A; \quad \text{power: } P \quad (\text{watts})}$$

Example: **Sound Intensities**

12×10^{-5} W of sound power passed through the surfaces labeled 1 and 2. The areas of these surfaces are $4.0 m^2$ and $12 m^2$. Determine the sound intensity at each surface.



$$I_1 = \frac{P}{A_1} = \frac{12 \times 10^{-5}\,\text{W}}{4.0\text{m}^2} = 3.0 \times 10^{-5}\,\text{W/m}^2$$

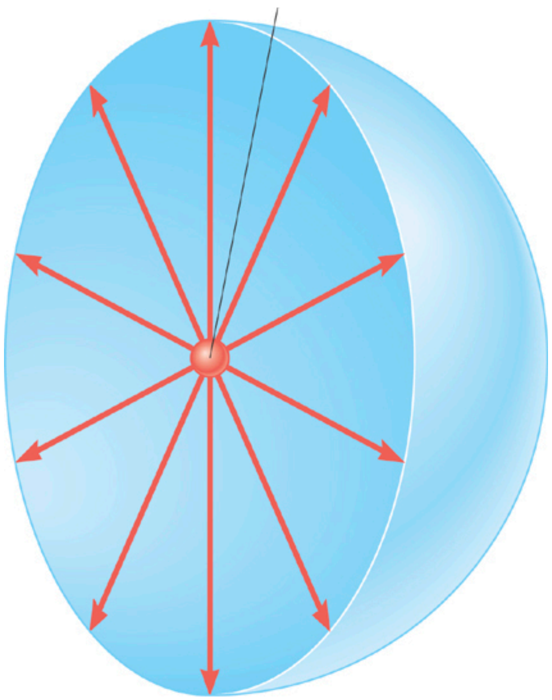
$$I_2 = \frac{P}{A_2} = \frac{12 \times 10^{-5}\,\text{W}}{12\text{m}^2} = 1.0 \times 10^{-5}\,\text{W/m}^2$$

11.3 Sound Intensity

For a 1000 Hz tone, the smallest sound intensity that the human ear can detect is about $1 \times 10^{-12}\ W/m^2$. This intensity is called the ***threshold of hearing***.

On the other extreme, continuous exposure to intensities greater than $1 W/m^2$ can be painful.

If the source emits sound *uniformly in all directions,* the intensity depends on the distance from the source in a simple way.



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

Intensity depends inversely on the square of the distance from the source.

11.3 Decibels

The ***decibel*** (dB) is a measurement unit used when comparing two sound Intensities.

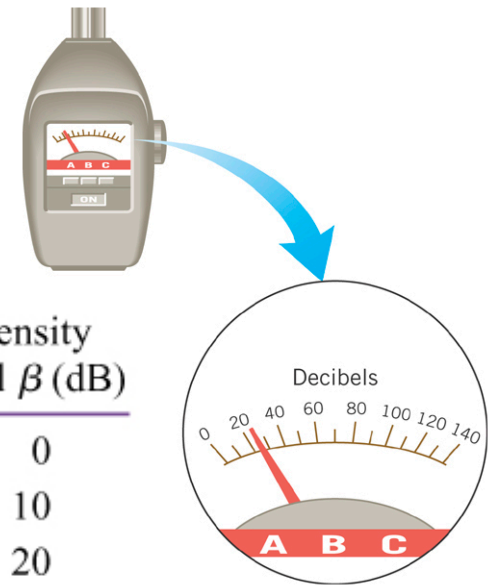
Human hearing mechanism responds to sound ***intensity level*** , logarithmically.

$$\boxed{\beta = (10\ \text{dB})\log\left(\frac{I}{I_o}\right)}$$

$$\boxed{\text{dB}\ \ (\text{decibel})}$$

$$\boxed{I_o = 1.00\times 10^{-12}\ \text{W/m}^2}$$

Note that log(1) = 0

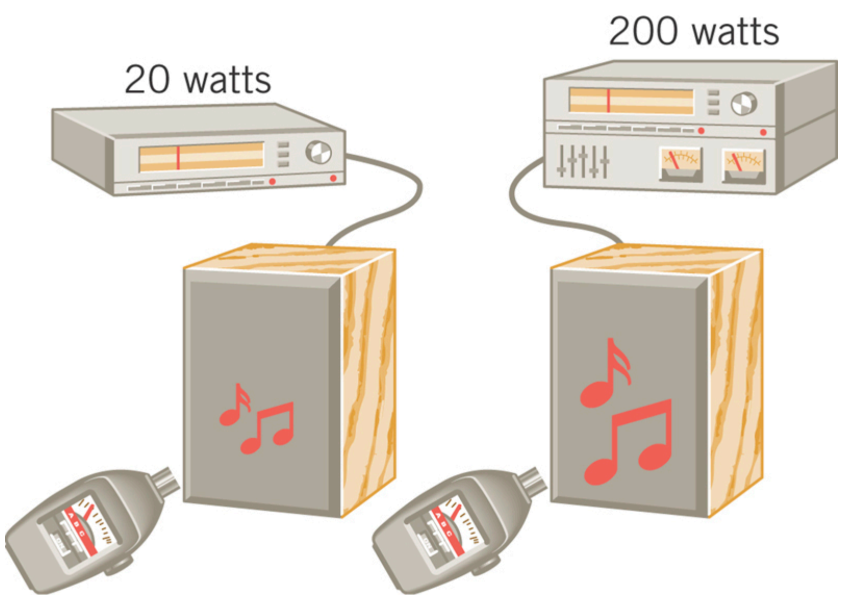


	Intensity I (W/m^2)	Intensity Level β (dB)
Threshold of hearing	1.0×10^{-12}	0
Rustling leaves	1.0×10^{-11}	10
Whisper	1.0×10^{-10}	20
Normal conversation (1 meter)	3.2×10^{-6}	65
Inside car in city traffic	1.0×10^{-4}	80
Car without muffler	1.0×10^{-2}	100
Live rock concert	1.0	120
Threshold of pain	10	130

Example: **Comparing Sound Intensities**

Audio system 1 produces a sound intensity level of 90.0 dB, and system 2 produces an intensity level of 93.0 dB. Determine the ratio of intensities.

$$\beta = (10\text{ dB})\log\left(\frac{I}{I_o}\right)$$



$$90\text{ dB} = (10\text{ dB})\log(I/I_o)$$
$$\log(I/I_o) = 9;$$
$$I = I_o \times 10^9 = (1\times10^{-12}\text{ W/m}^2)\times10^9$$
$$= 1\times10^{-3}\text{ W/m}^2$$

$$93\text{ dB} = (10\text{ dB})\log(I/I_o)$$
$$\log(I/I_o) = 9.3;$$
$$I = I_o \times 10^{9.3} = (1\times10^{-12}\text{ W/m}^2)\times10^{9.3}$$
$$= 1\times10^{-2.7}\text{ W/m}^2 = 1\times10^{-3}(10^{0.3})\text{W/m}^2$$
$$= 1\times10^{-3}(2)\text{W/m}^2 = 2\times10^{-3}\text{W/m}^2$$

$$93\text{dB} = 90\text{dB} + 3\text{dB}$$

Adding 3dB results in a factor of 2

$$3\text{ dB} = (10\text{dB})\log(I_2/I_1)$$
$$0.3 = \log(I_2/I_1);$$
$$I_2 = 10^{0.3} I_1 = 2I_1$$

Clicker Question 11.2

Software is used to amplify a digital sound file on a computer by 20 dB. By what factor has the intensity of the sound been increased as compared to the original sound file?

$$\boxed{\beta = (10\ \text{dB})\log\left(\frac{I}{I_o}\right)}$$

a) 2

b) 5

c) 10

d) 20

e) 100

Take the dB increase and divide by 10.

The intensity increase factor is 10 to that power.

Clicker Question 11.2

Software is used to amplify a digital sound file on a computer by 20 dB. By what factor has the intensity of the sound been increased as compared to the original sound file?

a) 2

b) 5

c) 10

d) 20

e) $\boxed{100}$

$$\beta_2 = \beta_1 + 20\text{ dB}$$

$$(10\text{ dB})\log\left(\frac{I_2}{I_o}\right) = (10\text{ dB})\log\left(\frac{I_1}{I_o}\right) + 20\text{ dB}$$

$$\log I_2 = \log I_1 + 2$$

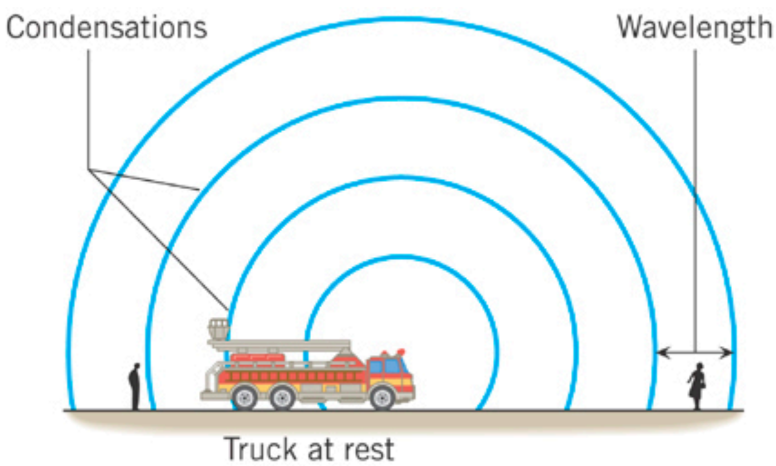
$$I_2 = 10^{\log I_1 + 2} = 10^{\log I_1}\cdot 10^2$$

$$= \underline{10^2} I_1$$

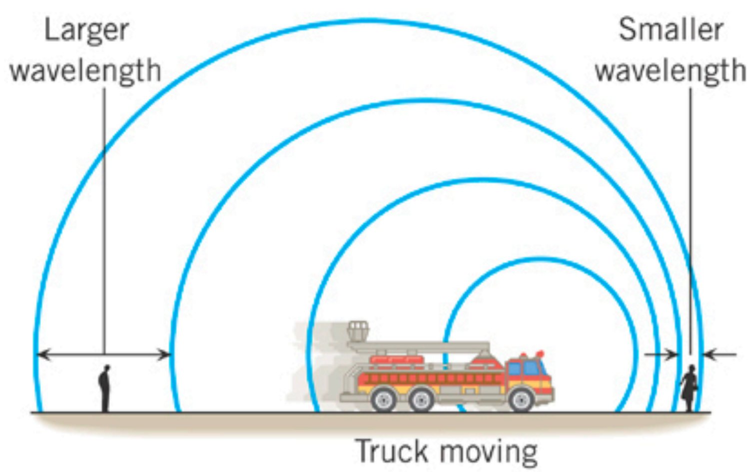
Take the dB increase and divide by 10.

The intensity increase factor is 10 to that power.

11.5 The Doppler Effect



(*a*)



(*b*)

The ***Doppler effect*** is the change in frequency or pitch of the sound detected by an observer because the sound source and the observer have different velocities with respect to the medium of sound propagation.

SOURCE (*s*) MOVING AT v_s TOWARD A STATIONARY OBSERVER (*obs*)

$$f_{obs} = f_s \left(\frac{1}{1 - v_s / v} \right)$$

SOURCE (*s*) MOVING AT v_s AWAY A FROM STATIONARY OBSERVER (*obs*)

$$f_{obs} = f_s \left(\frac{1}{1 + v_s / v} \right)$$

Summary: Waves and Sound

Periodic Waves $\boxed{v = \lambda f}$

v : velocity of wave

λ : wavelength

f : frequency

Standing Waves $\boxed{\lambda = \frac{2L}{n} \quad (n \text{ anti-nodes})}$

String wave speed $\boxed{v = \sqrt{T/\mu}}$

T : Tension

μ : lin. mass density

Sound Intensity

$$I = \frac{P}{A}; \quad \beta = (10\text{dB})\log\frac{I}{I_0} \quad (I_0 = 1.0\times10^{-12}\ \text{W/m}^2)$$

β units are decibels (dB)

Doppler Effect

(Observer at rest)

$$f_{obs} = f_s\left(\frac{1}{1 \mp v_s/v}\right)$$

− source approaching

+ source receding