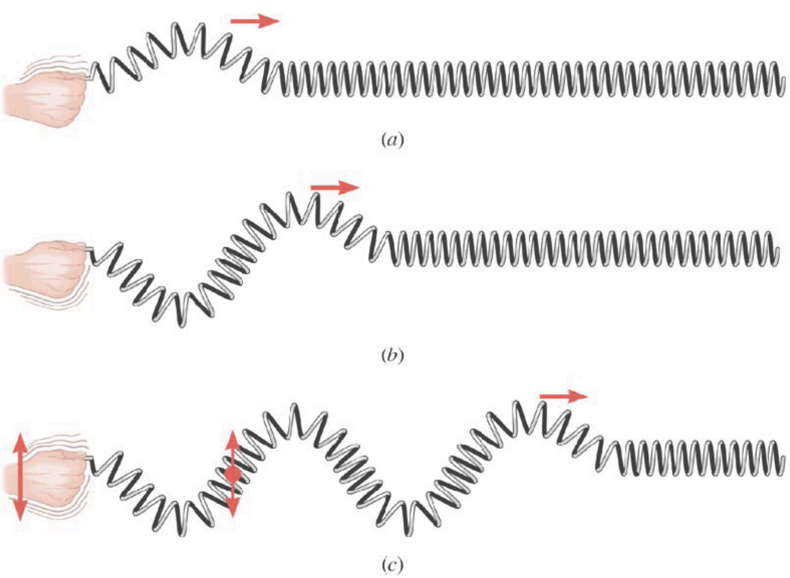
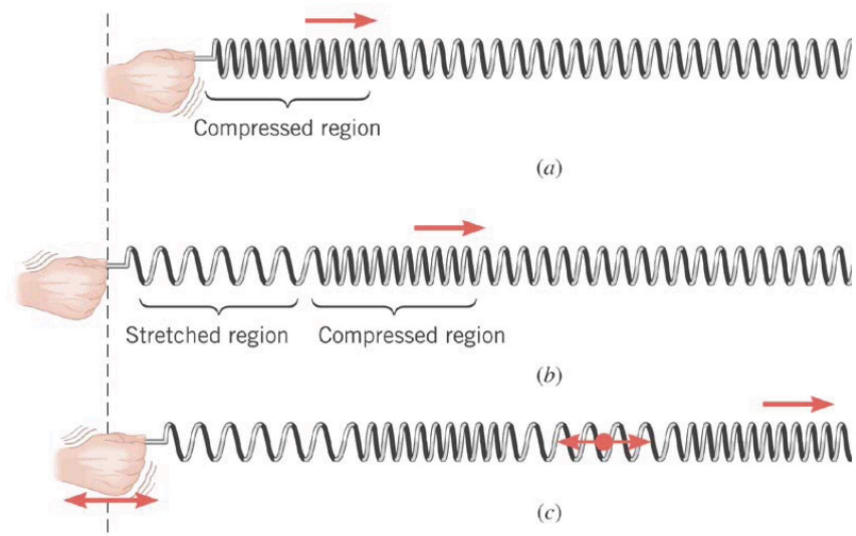
Periodic waves consist of cycles or patterns that are produced over and over again by the source.

In the figures, every segment of the slinky vibrates in simple harmonic motion, provided the end of the slinky is moved in simple harmonic motion.

Transverse Waves



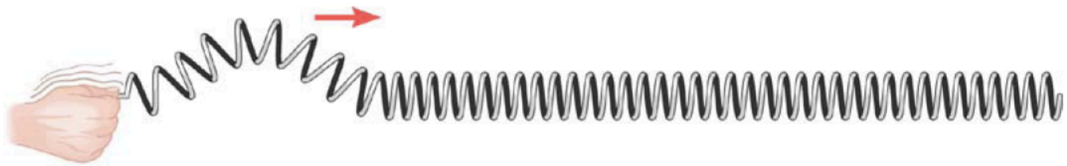
Longitudinal Waves



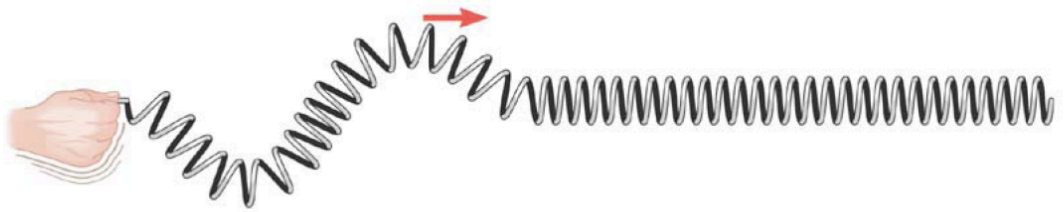
1. A wave is a traveling disturbance.

2. A wave carries energy from place to place.

(A wave does NOT transfer any mass!)



(a)



(b)

(c)

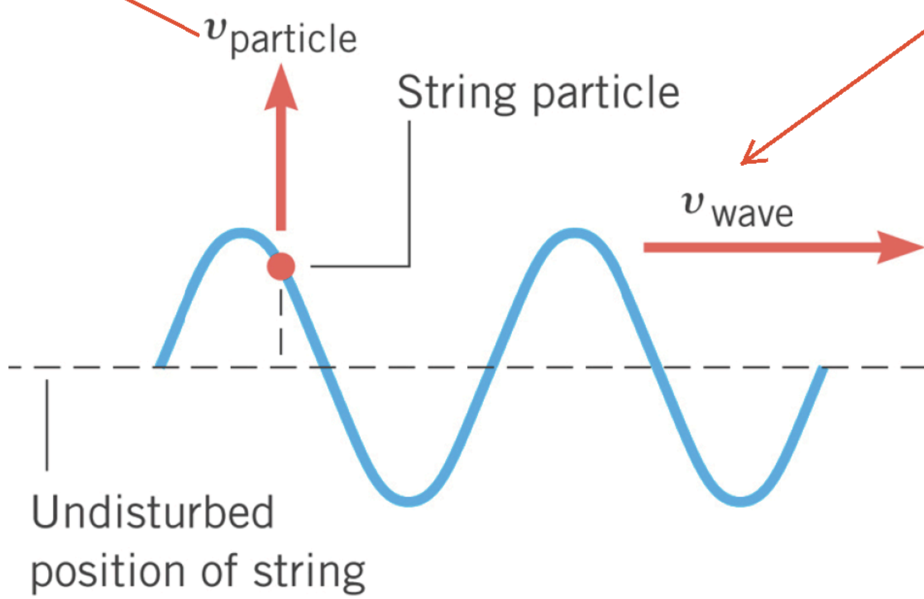
Wave Speed Versus Particle Speed

Is the speed of a transverse wave on a string the same as the speed at which a particle on the string moves?

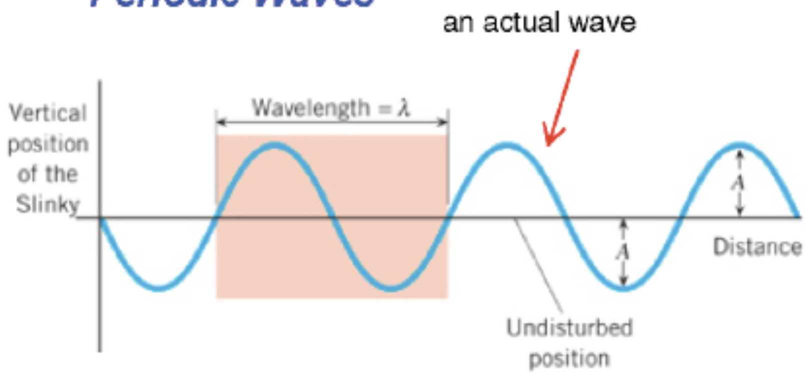
$$v_{max} = A\omega$$

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

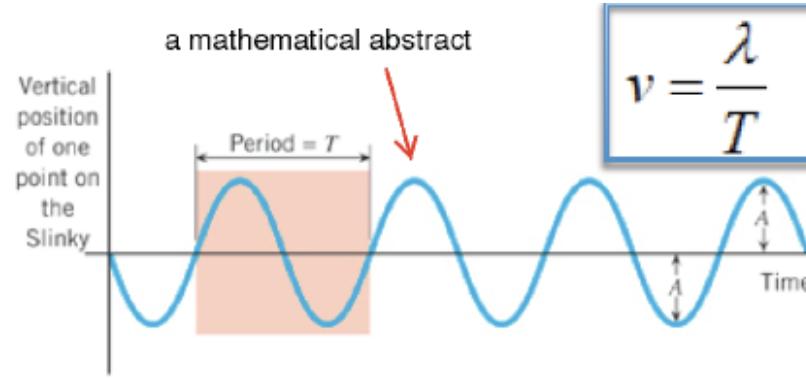
1. yes
2. no
3. it depends on the nature of the wave



Periodic Waves



(a) At a particular time (a snapshot, a photograph)



(b) At a particular location (a graph)

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

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

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

$$Y = A\cos(\omega t \pm k\lambda + \varphi)$$

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

$$\omega = \frac{2\pi}{T}$$

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

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

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

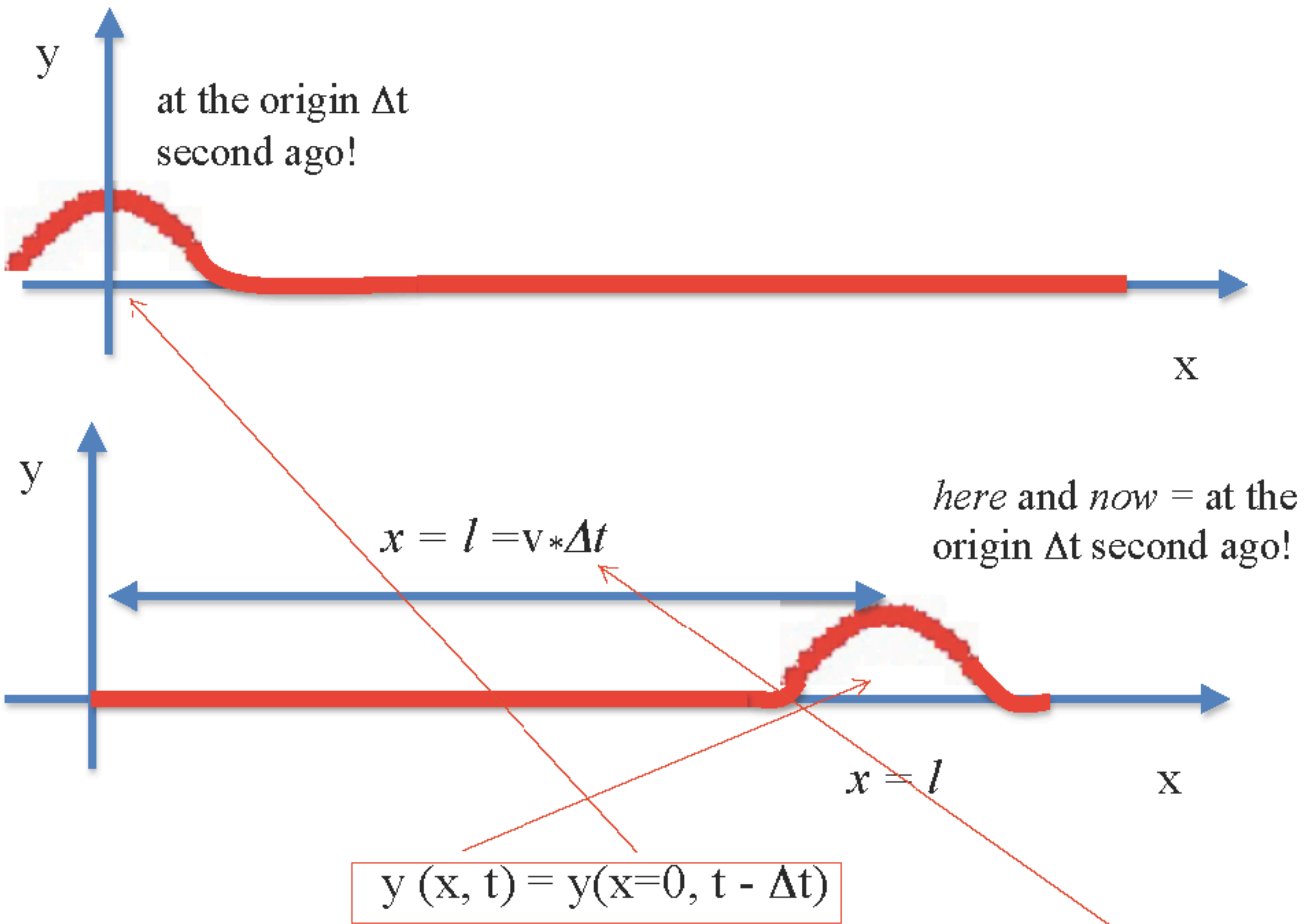
The ***frequency*** is related to the period and has units of Hz, or s^{-1}.

If a certain point on a wave makes 30 oscillations in 1 minute, what are T and f?

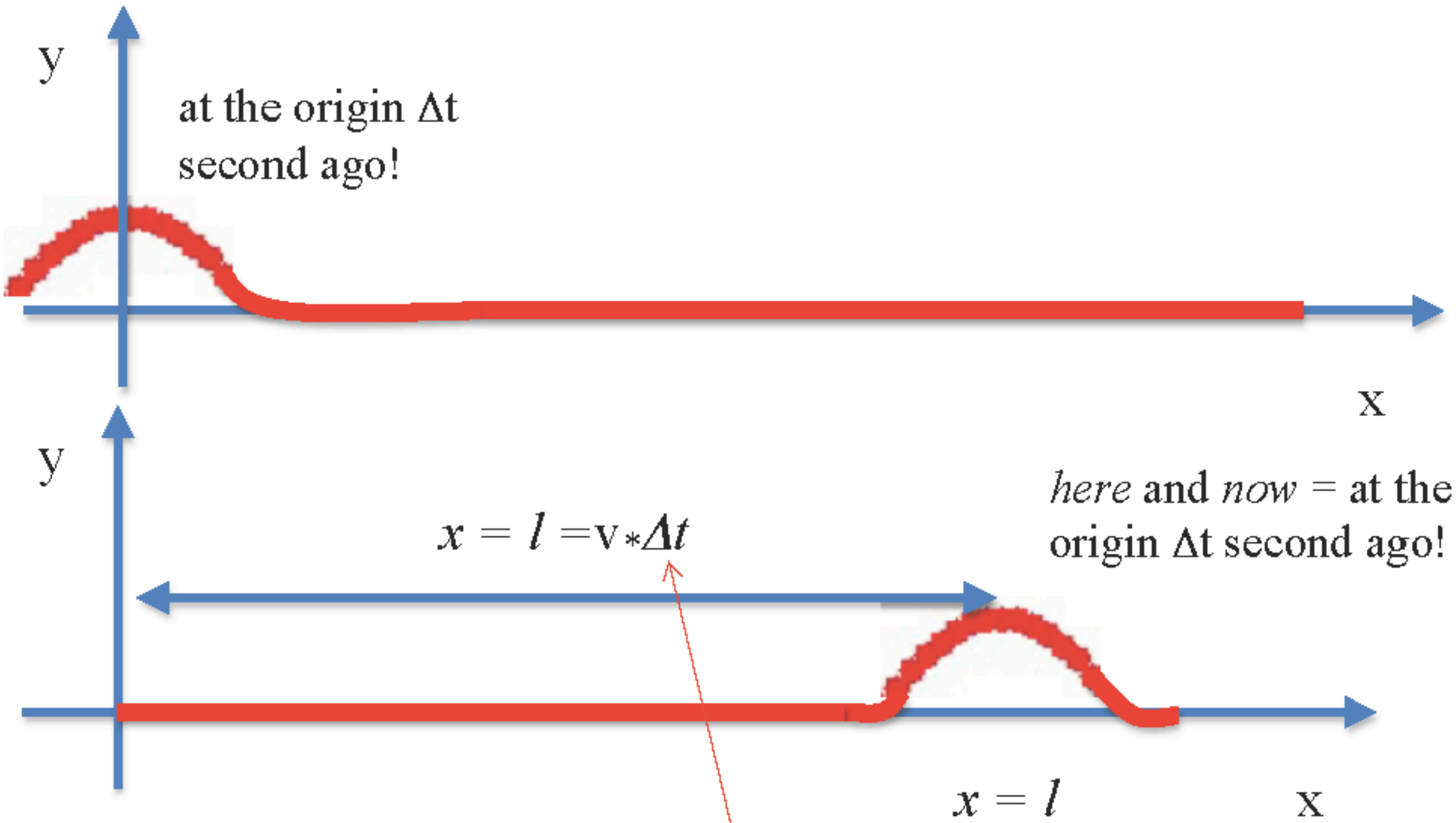
1. 0 2. 0.5 3. 1 4. 1.5 5. 2 6. 2.5 7. 3

What distance does a single point on the wave travel if the amplitude is 1 mm?

1. 30 2. 60 3. 90 4. 120 5. 150 6. 180 7. 210



$$if \quad y(x=0,\ t) = A\cos(\omega t) \quad => \quad y(x,t) = A\cos(\omega(t-\Delta t))$$



$$y(x,t) = A\cos(\omega(t - \Delta t)) = A\cos(\omega(t - x/\mathrm{v})) =$$

$$= A\cos(\omega t \boxed{- x\omega/\mathrm{v}}) = A\cos(\omega t - kx))$$

ϕ

$$k = \frac{\omega}{\mathrm{v}} = \frac{2\pi f}{\mathrm{v}} = \frac{2\pi}{T\mathrm{v}} = \frac{2\pi}{\lambda}$$

$$y(x,t) = (0.9\ \text{cm})\sin\left[(5.0\ \text{s}^{-1})t - (1.2\ \text{m}^{-1})x\right]$$

$$v_{max} = A\omega \qquad \omega = \frac{2\pi}{T} \qquad k = \frac{2\pi}{\lambda} \qquad v = \frac{\lambda}{T}$$

$y = A \cdot \sin(\omega t \pm k \cdot x)$

$A = 0.9\ \text{cm}$ $\qquad k = 1.2\ \text{m}$

$\omega = 5\ \text{rad/s}$

Making use of the mathematical description

$$y(x,t) = (0.9\ \text{cm})\sin\left[(5.0\ \text{s}^{-1})t - (1.2\ \text{m}^{-1})x\right]$$

1) The amplitude is whatever is multiplying the sine.

   $A = 0.9$ cm

2) The wavenumber k is whatever is multiplying the x:

   $k = 1.2\ \text{m}^{-1}$. The wavelength is: $\lambda = \dfrac{2\pi}{k} = 5.2\ \text{m}$

3)

The angular frequency ω is whatever is multiplying the t.

   $\omega = 5.0$ rad/s. The frequency is: $f = \dfrac{\omega}{2\pi} = 0.80\ \text{Hz}$

Making use of the mathematical description

$$y(x,t) = (0.9\text{ cm})\sin\left[(5.0\text{ s}^{-1})t - (1.2\text{ m}^{-1})x\right]$$

4) The wave speed can be found from the frequency and wavelength: $v = f\lambda = (0.80\text{ Hz})(5.2\text{ m}) = 4.2\text{ m/s}$

5) The tension in the string is:

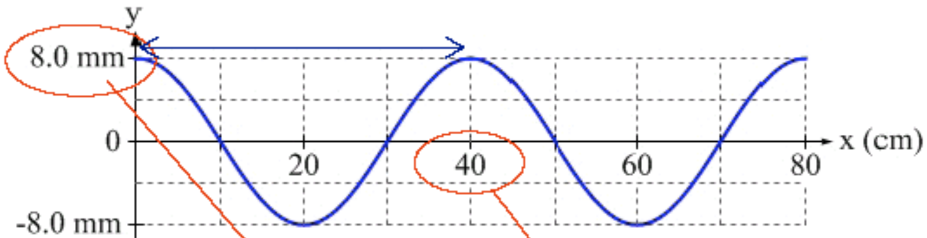
$v = \sqrt{\frac{F_T}{\mu}}$ $F_T = \mu v^2 =$ **(0.012kg/m)(4.2 m/s)²** $= 0.21\text{ N}$

6) The direction of propagation of the wave is: [–] →

7) The maximum transverse speed of the string (from SHM): $v_{\max} = A\omega = (0.9\text{ cm})(5.0\text{ rad/s}) = 4.5\text{ cm/s}$

The wave propagates way faster than its transverse motion!

At a time of $t = 0$, the profile of part of a string is shown in the Figure. The wave on the string is traveling in the $+x$ direction (to the right) at a speed of 20 cm/s. Write out the equation of motion for the wave.



$$y = A*\cos(\omega t \pm kx)$$

Questions to remember: + or -? T or λ?

We can get from the graph: A = λ =

In addition: $v_W = 20$ cm/s = 0.2 m/s

<u>Now we can find:</u>

The period $T = \lambda/v_w$ | the angular frequency $\omega = 2\pi/T$

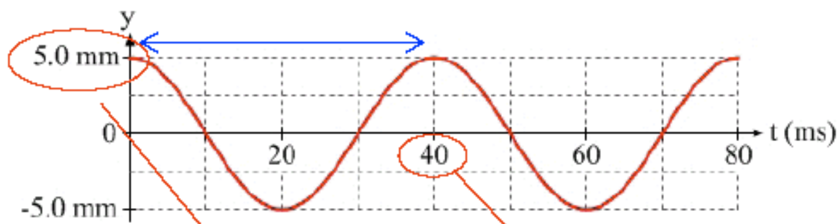
The wave number $k = 2\pi/\lambda$

Now we can write the equation. $$y = A*\cos(\omega t - kx)$$

If we need, we can find more unknowns:

the frequency $f = 1/T$ | the max *transverse* speed $v_p = A\omega$

A graph of the motion of one point on a string (specifically, the point at $x = 0$), as a function of time is shown in the Figure. The wave is traveling in the negative x direction on a string that has a tension of 32 N, and with a mass per unit length of 60 grams per meter. Determine (a) the frequency of the wave, (b) the speed of the wave, (c) the wavelength, and (d) the expression for the wave's equation of motion.



Questions to remember: + or -? T or λ?

We can get from the graph: A = T =

In addition: $F_T = 32$ N | $\mu = 60$ gram/m = 0.06 kg/m

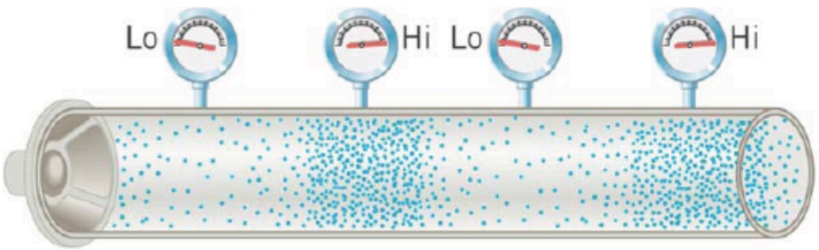
Now we can find:

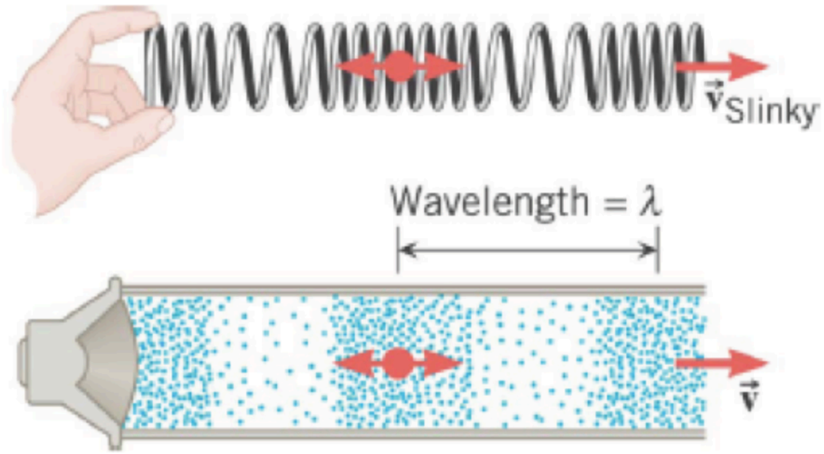
$v_W = \sqrt{\frac{F_T}{\mu}}$ | $f = 1/T$ | $\lambda = T * v_W$

$\omega = 2\pi/T$ | $k = 2\pi/\lambda$

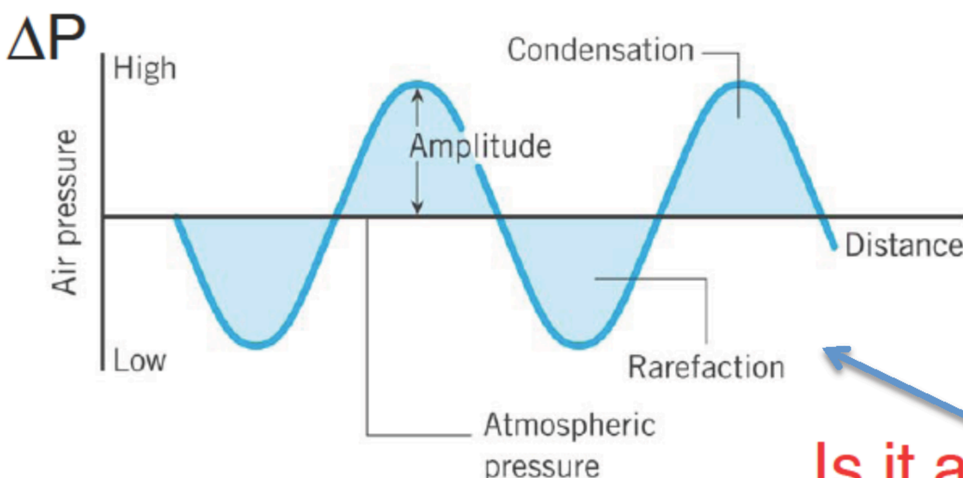
And finally, we can write the equation: $y = A * \cos(\omega t + kx)$

THE PRESSURE AMPLITUDE OF
A SOUND WAVE





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



Is it a graph or a photograph?

1. a graph

2. a photograph

$$\Delta P = P - P_{Atm}$$

Speed of sound

In general, the speed of sound is highest in solids, then liquids, then gases. Sound propagates by molecules passing the wave on to neighboring molecules, and the coupling between molecules is strongest in solids.

Medium	Speed of sound
Air (0°C)	331 m/s
Air (20°C)	343 m/s
Helium	965 m/s
Water	1400 m/s
Steel	5940 m/s
Aluminum	6420 m/s

Speed of sound in air: $v = (331 \text{ m/s}) + (0.6 \text{ m/(s °C)}) \times T_C$

You are observing fishermen illegally catching fish by using a small explosive device to stun the fish. The explosion takes place near the surface of the water, so the sound of the explosion travels through both the air and the water. You record the sound of the explosion using two separate microphones, one in the air above the water and one below the water surface. (a) Which microphone picks up the sound first? (b) If the time delay between the sounds reaching the two microphones is 0.50 seconds, about how far are you from the fishermen?

L = ...

1. 225 m

2. 336 m

3. 447 m

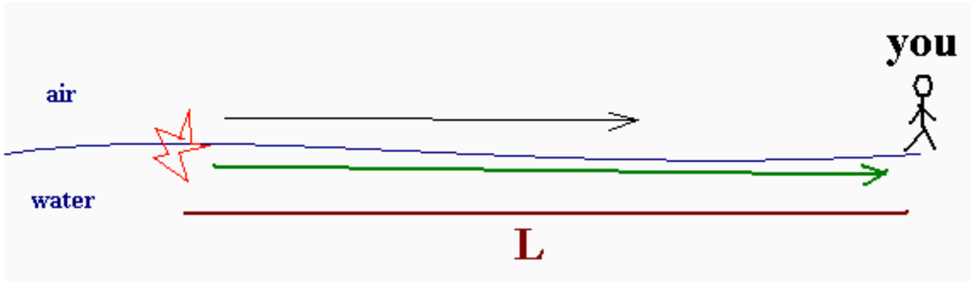
4. 558 m

5. none of the above

Which microphone picks up the sound first?

1:	one that is in the air above the water
2:	one that is in the water
3:	both pick up the sound at the same time
4:	the state policemen is the first
5:	none of the above

You are observing fishermen illegally catching fish by using a small explosive device to stun the fish. The explosion takes place near the surface of the water, so the sound of the explosion travels through both the air and the water. You record the sound of the explosion using two separate microphones, one in the air above the water and one below the water surface. (a) Which microphone picks up the sound first? (b) If the time delay
between the sounds reaching the two microphones is 0.50 seconds, about how far are you from the fishermen?



$$L = v_{in\text{-}air} * t_{in\text{-}air} = v_{in\text{-}water} * t_{in\text{-}water} \qquad \text{and} \qquad \Delta t = t_{in\text{-}water} - t_{in\text{-}air}$$

Medium	Speed of sound
Air (0°C)	331 m/s
Air (20°C)	343 m/s
Helium	965 m/s
Water	1400 m/s
Steel	5940 m/s
Aluminum	6420 m/s

$v_{in\text{-}air} = 343$ m/s

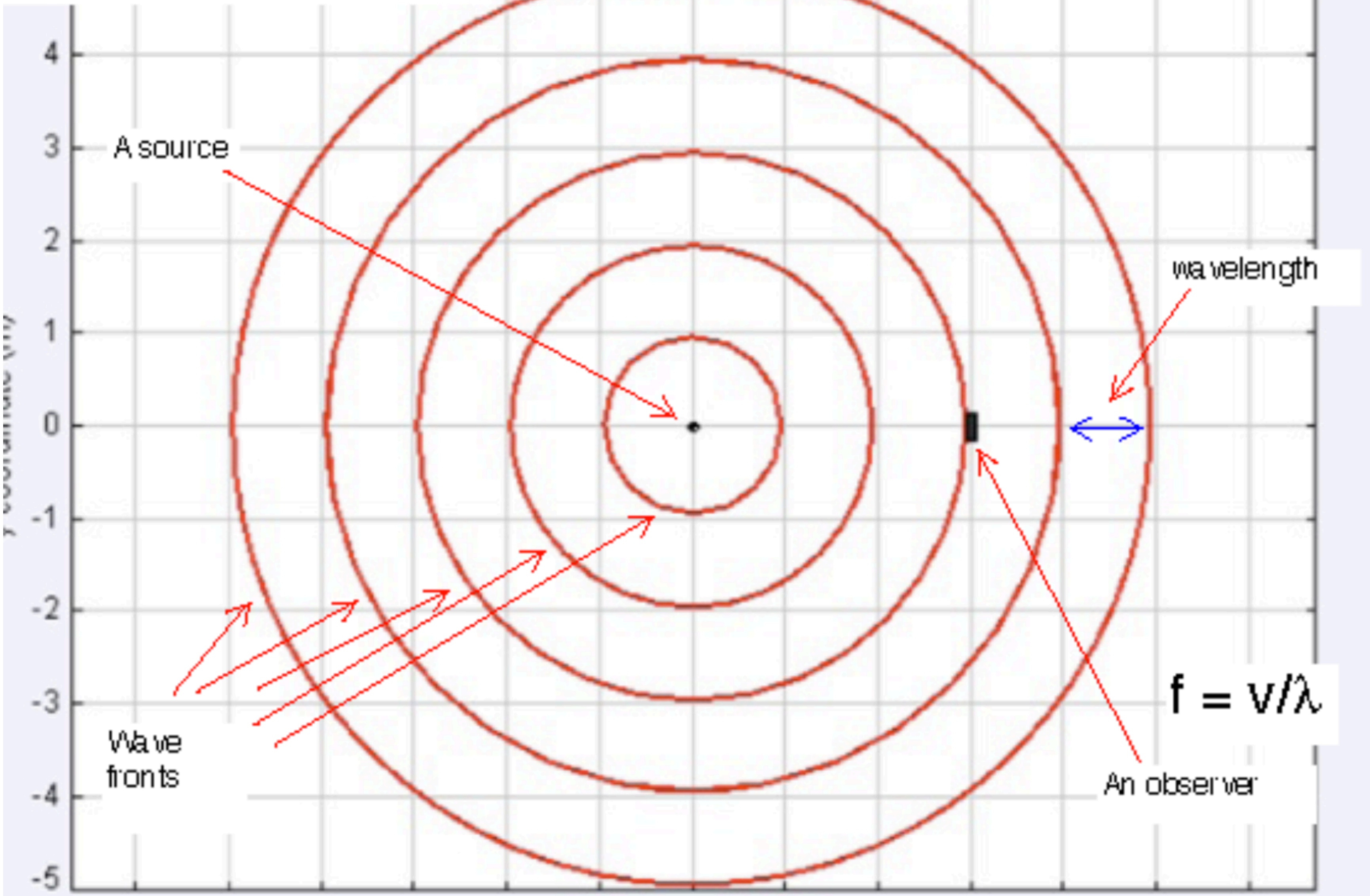
$v_{in\text{-}water} = 1400$ m/s

$\Delta t = 0.50$ s

$$343 * t_a = 1400 * t_W$$
$$t_W - t_a = 0.5$$

This information is enough to set up the needed equations and solve them mathematically.

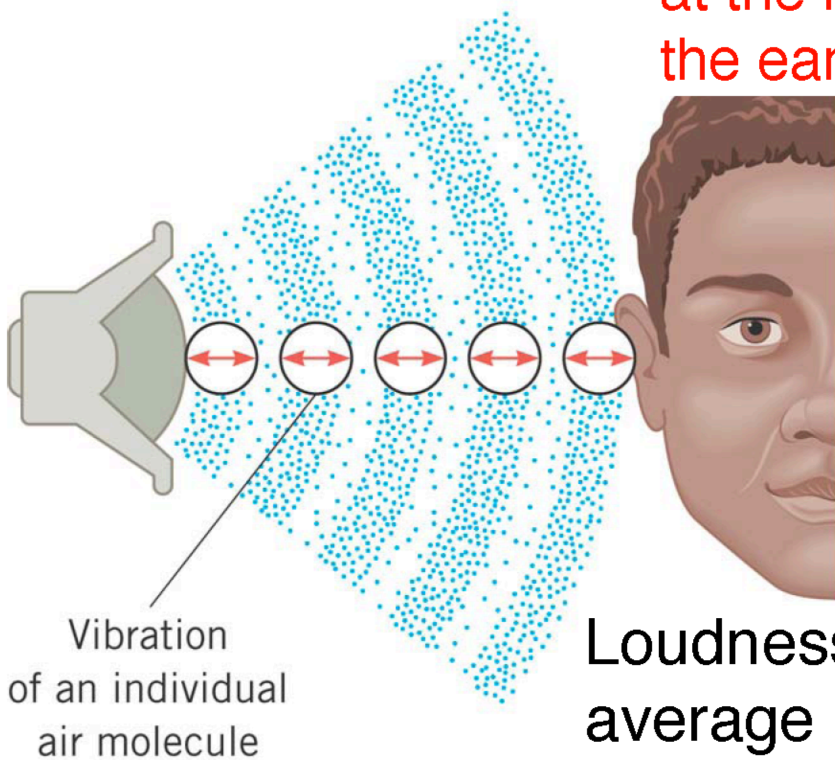
Traveling Sound



Individual air molecules are not carried along with the wave.

P_A is the power at the location of the ear

P is the power of the source



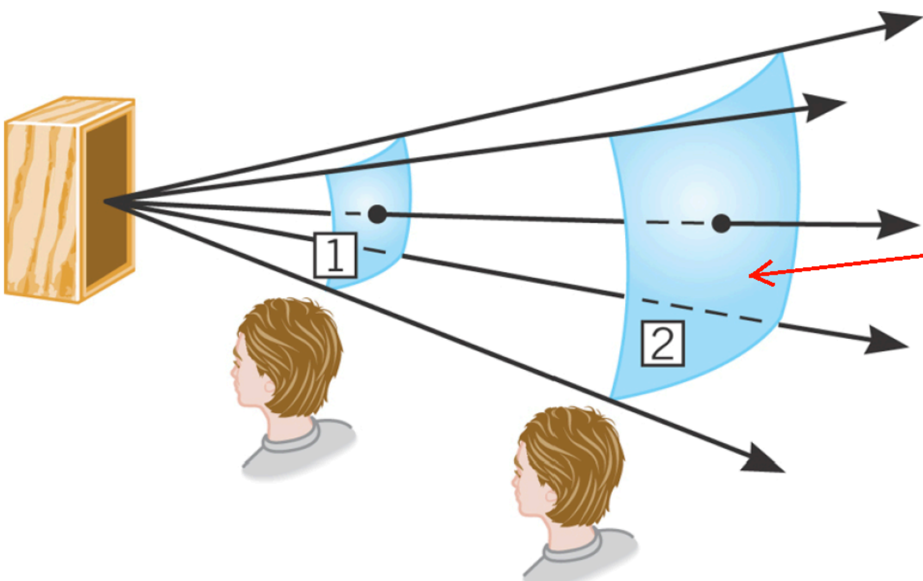
Loudness is an attribute of a sound that depends primarily on the pressure amplitude of the wave.

Loudness is related to the average intensity of the sound, which is related to the power of the source.

Sound waves carry energy that can be used to do work.

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

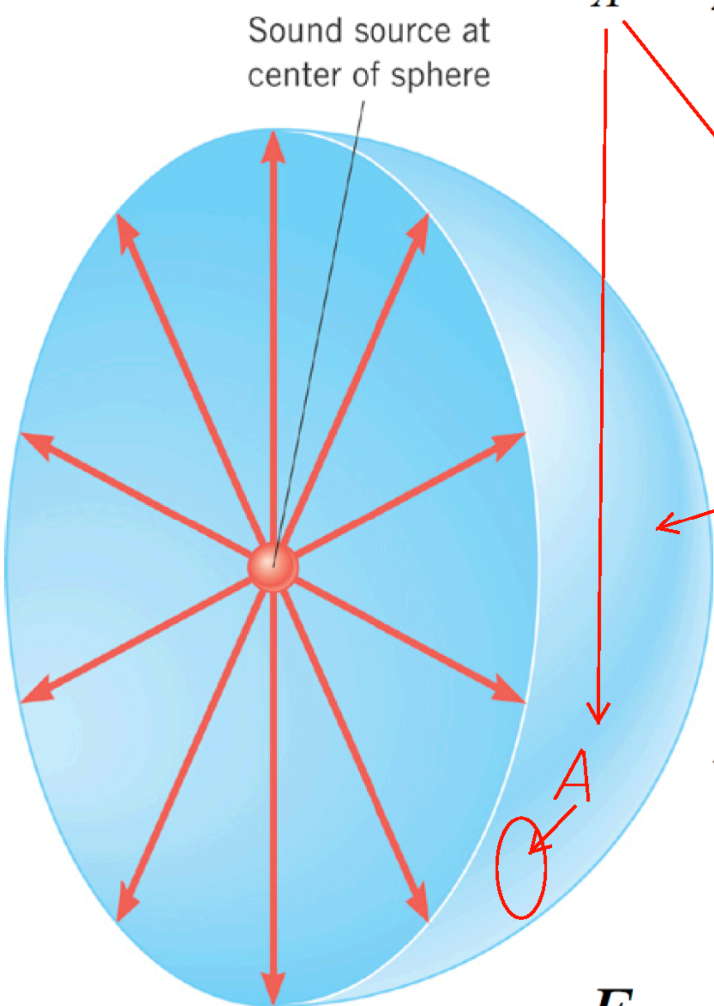
The ***sound intensity*** is defined as the power that passes perpendicularly through a surface divided by the area of that surface.



$$I_A = \frac{P_A}{A} = \frac{E_A/t}{A} = \frac{E_A}{At}$$

Sound Intensity

$$I_A = \frac{P_A}{A} = \frac{E_A/t}{A} = \frac{E_A}{At}$$



For a whole sphere:

power of sound source

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

the same everywhere

area of sphere

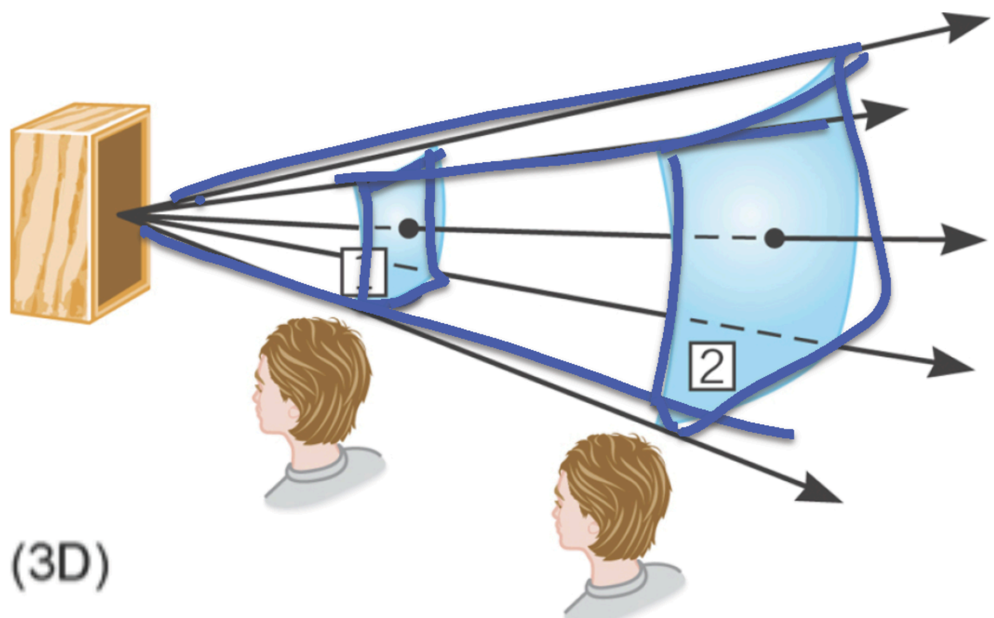
$$I_A = I$$

$$E_A = I_A At = IAt = \frac{P}{4\pi r^2}At = \frac{PAt}{4\pi r^2}$$

Example **Sound Intensities**

$12x10^{-5}$W of sound power passed through the surfaces labeled 1 and 2. The areas of these surfaces are 4.0m^2 and 12m^2. Determine the sound intensity at each surface.

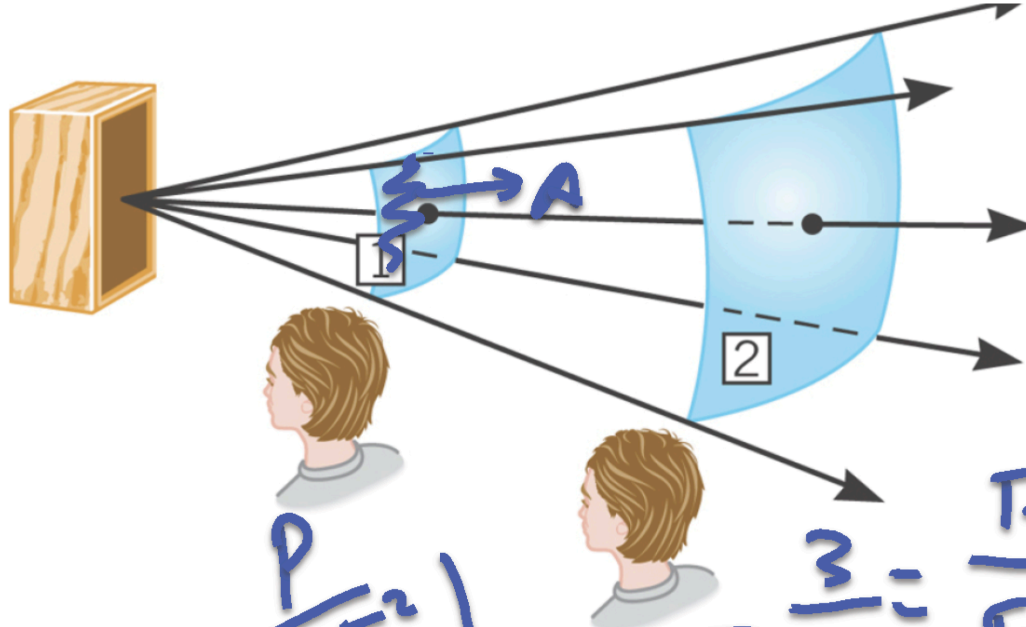
$$I = \frac{P_A}{A}$$



$$I = \frac{P}{4\pi r^2}$$ (3D)

$$I = \frac{P}{4\pi r^2} \quad \text{(3D)}$$

$$I = \frac{P}{A}$$



$$I_1 = \frac{P}{A_1} = \frac{12\times10^{-5}\ \mathrm{W}}{4.0\mathrm{m}^2} = 3.0\times10^{-5}\ \mathrm{W/m^2}$$

$$I_2 = \frac{P}{A_2} = \frac{12\times10^{-5}\ \mathrm{W}}{12\mathrm{m}^2} = 1.0\times10^{-5}\ \mathrm{W/m^2}$$

If the first surface is 2 m from the source, How far is the second one?

For a 1000 Hz tone, the smallest sound intensity that the human ear can detect is about 1×10^{-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.

The decibel scale

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

$I_0 = 1 \times 10^{-12}$ W/m^2

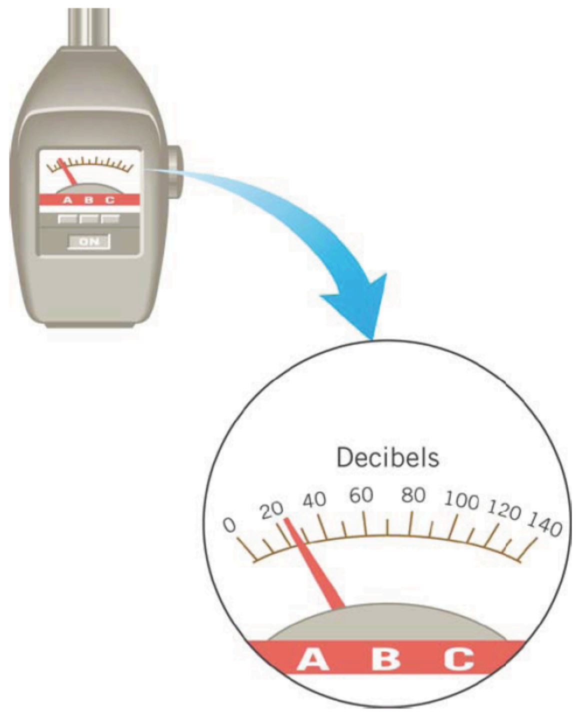
where I is the intensity in W/m^2

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

Because of the way in which the human hearing mechanism responds to intensity, it is appropriate to use a logarithmic scale called the ***intensity level:***

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

$$I_o = 1.00\times10^{-12}\ \text{W/m}^2$$



Note that log(1)=0, so when the intensity of the sound is equal to the threshold of hearing, the intensity level is zero.

Typical Sound Intensities and Intensity Levels Relative to the Threshold of Hearing

	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

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

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

You are listening to the radio when one of your favorite songs comes on, so you turn up the volume. If you managed to increase the sound intensity *by* 15 dB, what is the ratio of the intensities I_2/I_1?

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

$I_2/I_1 = \ldots$

1. 10^0
2. $10^{0.5}$
3. 10
4. $10^{1.5}$
5. 10^2
6. $10^{2.5}$
7. 10^3

You are listening to the radio when one of your favorite songs comes on, so you turn up the volume. If you managed to increase the sound intensity by 15 dB, by what factor did the intensity of the sound, in W/m^2, increase?

"Increasing by" means, we deal with a relative intensity of a sound.

$$\beta_1 = (10\text{ dB})\log_{10}\left(\frac{I_1}{I_0}\right)$$

$$\Delta\beta = (10\text{ dB})\log_{10}\left(\frac{I_f}{I_i}\right)$$

$$\beta_2 = 10\text{ dB}\cdot\log_{10}\left(\frac{I_2}{I_0}\right)$$

For you $\Delta\beta = 15$ dB.

$$\Delta\beta = \beta_2 - \beta_1 = 10\log_{10}\left(\frac{I_2}{I_0}\right) - 10\log\left(\frac{I_1}{I_0}\right)$$

We are looking for $x = I_f/I_i$

This gives us an equation: $15 = 10*\log(x)$

This leads to a logarithmic equation $1.5 = \log x = \log_{10} x$

The solution is $x = 10^{1.5}$

You are listening to the radio when one of your favorite songs comes on, so you turn up the volume. If you managed to increase the sound intensity by 15 dB, by what factor did the intensity of the sound, in W/m^2, increase?

"Increasing by" means, we deal with a relative intensity of a sound.

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

$$\Delta\beta = (10\text{ dB})\log\left(\frac{I_f}{I_i}\right)$$

For you $\Delta\beta = 15$ dB.

We are looking for $x = I_f/I_i$

This gives us an equation: $15 = 10 * \log(x)$

This leads to a logarithmic equation $1.5 = \log x$

The solution is $x = 10^{1.5}$

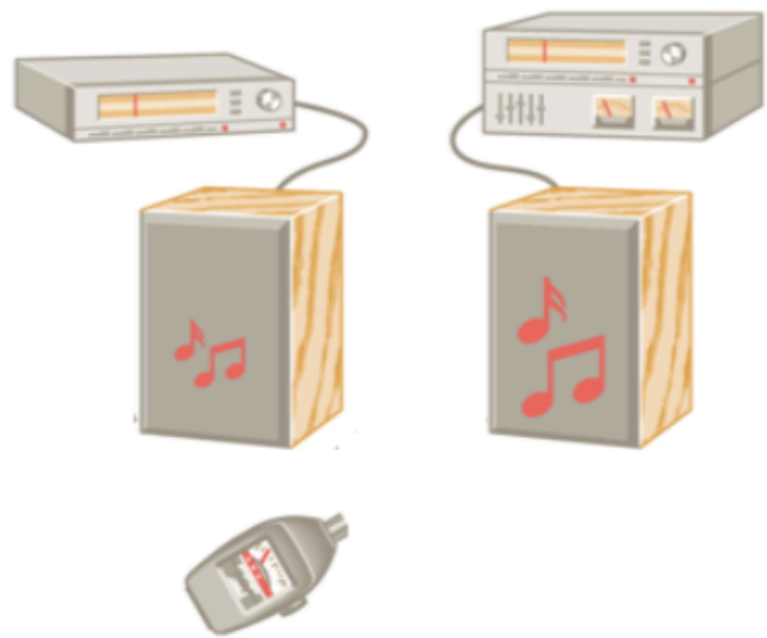
$$\log_{10} x - \log_{10} y = \log_{10} \frac{x}{y}$$

One sound has an intensity level of 10.0 dB while a second has an intensity level of 20.0 dB.

What is the intensity level when the two sounds are combined?

1. 10 dB
2. 15 dB
3. 20 dB
4. 30 dB
5. none of the above

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



$$I_o = 1.00\times10^{-12}\ \text{W/m}^2$$

One sound has an intensity level of 10.0 dB while a second has an intensity level of 20.0 dB.

What is the intensity level when the two sounds are combined?

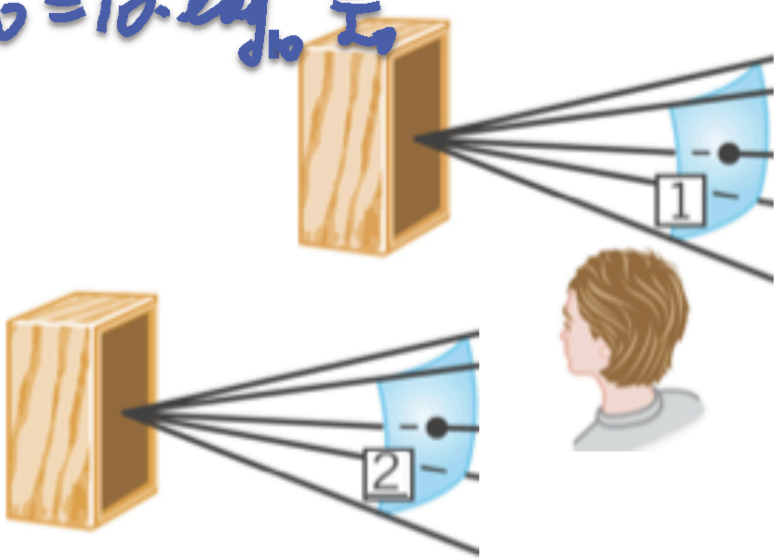
$$10 = \beta_1 = (10\ \text{dB})\log_{10}\left(\frac{I_1}{I_0}\right)$$

$$20 = 10 \cdot \log_{10} \frac{I_2}{I_0}$$

$$\beta_{total} \neq \beta_1 + \beta_2$$

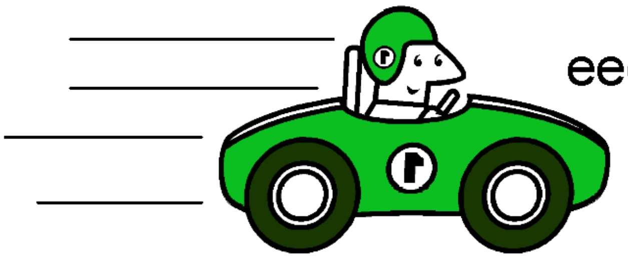
$$I_{total} = I_1 + I_2$$

$$\beta = 10\log\left(\frac{I_t}{I_0}\right)$$



The Doppler Effect

The Doppler effect is the shift in frequency of a wave that occurs when the wave source, or the detector of the wave, is moving.

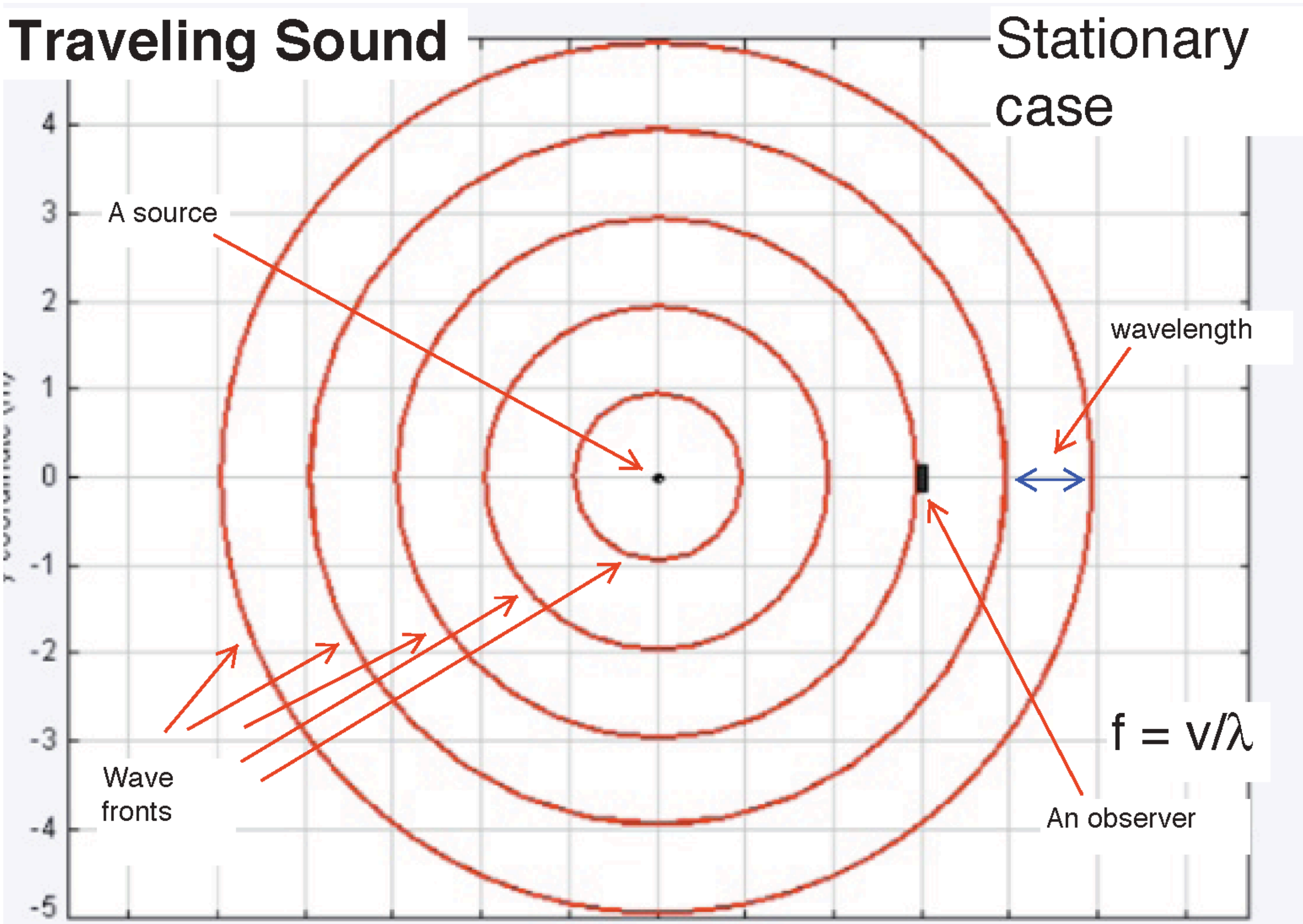


eeeeeeeeee

yyyyyooooowwwwww

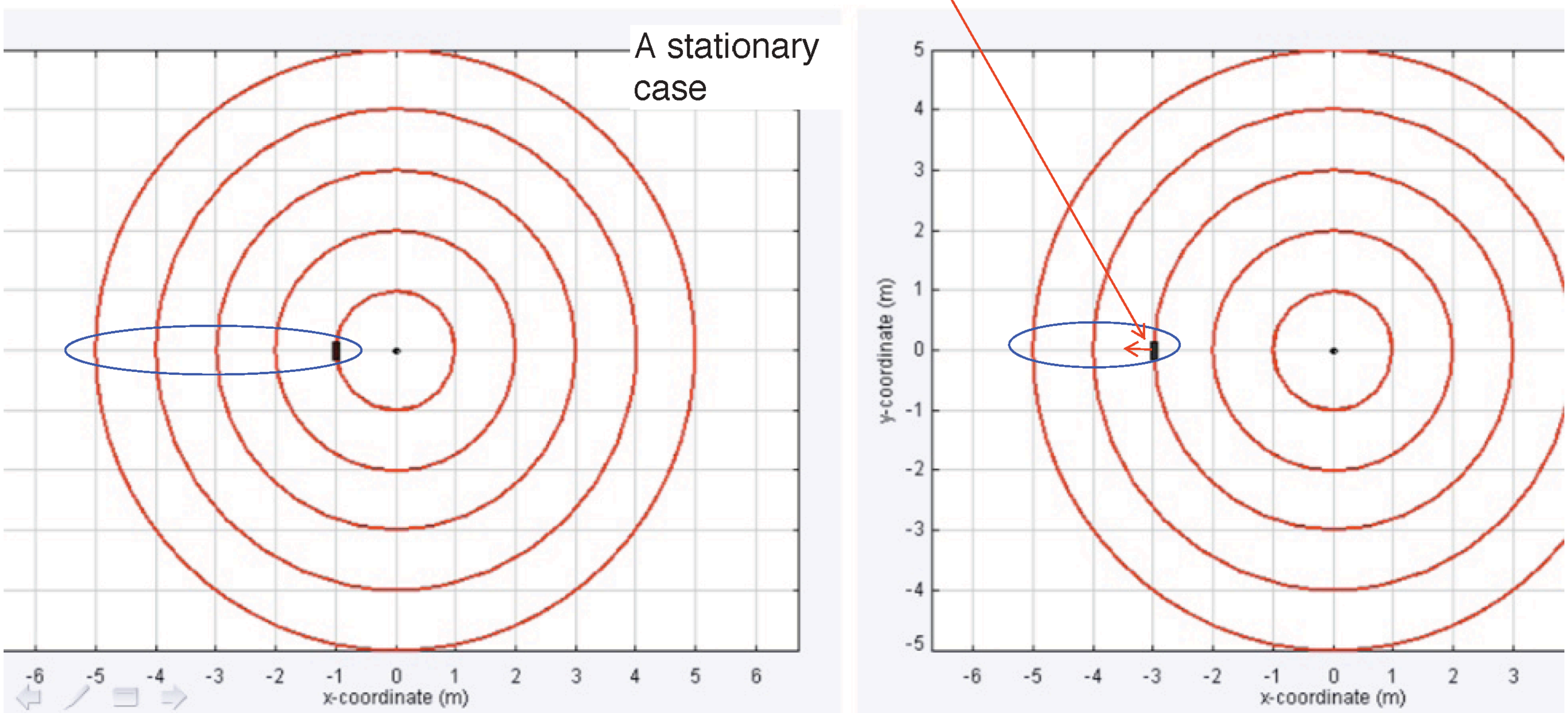
Applications range from medical tests using ultrasound to police speed traps using radar to astronomy (with electromagnetic waves).

Traveling Sound



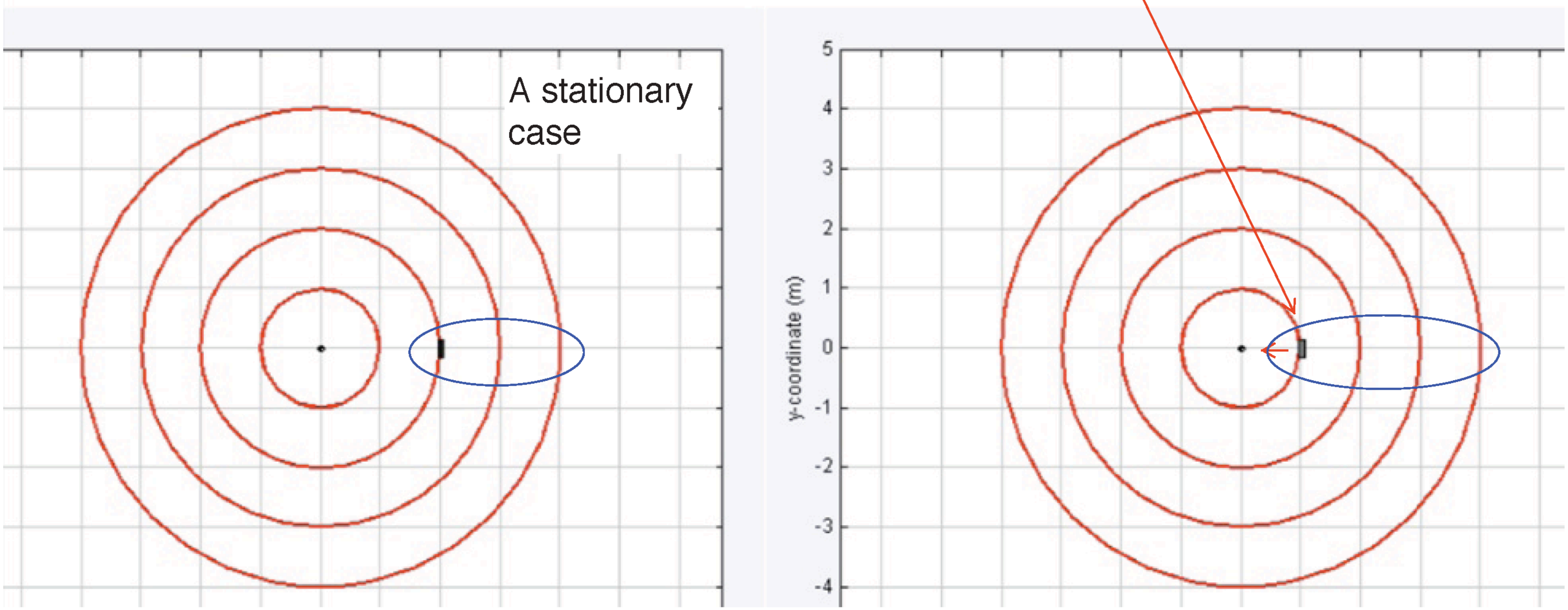
A moving observer

If you move away from the source, the observed frequency is less than the source frequency.



Doppler effect: a moving observer

When you move toward the source, you encounter more waves per unit time than you did before.



From the observer's perspective the wave front pattern travels relative to the observer differently than relative to the ground.

A moving observer

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

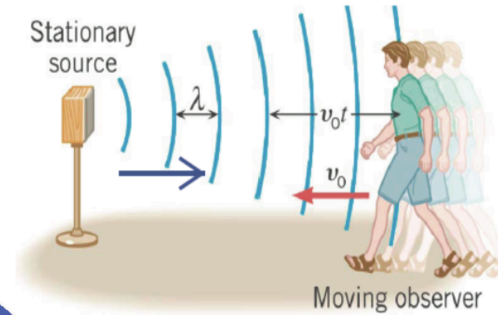
$$v_{sound\_observer} = \lambda_{observer} \bullet f_{observer}$$

$$v_{sound\_ground} = \lambda_{ground} \bullet f_{source}$$

$$\lambda_{observer} = \lambda_{ground}$$

$$v_{sound\_observer} = v_{sound\_ground} \pm v_{observer\_ground}$$

A moving observer (a source is *stationary*)



$$v_{sound\_observer} = v_{sound\_ground} \pm v_{observer\_ground}$$

$$v_{sound\_observer} = \lambda_{observer} \bullet f_{observer}$$

$$\lambda_{observer} = \lambda_{ground} = \lambda$$

$$v_{sound\_ground} = \lambda_{ground} \bullet f_{source}$$

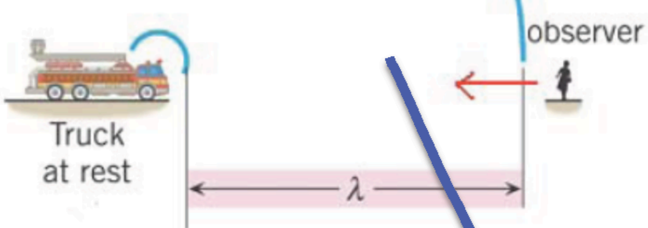
Do the Math

=> $\lambda = \dfrac{v_{sound\_ground}}{f_{source}}$ =>

$$\frac{v_{sound\_observer}}{\lambda} = \frac{v_{sound\_ground} \pm v_{observer\_ground}}{\lambda}$$

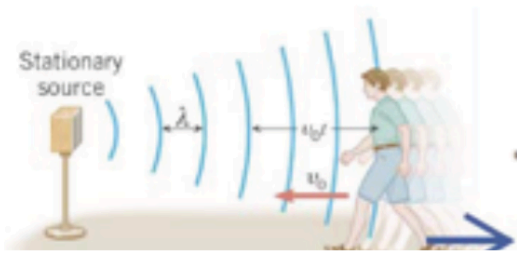
=> $f_{observer} = f_{source} \pm \dfrac{v_{observer\_ground}}{v_{sound\_ground} / f_{source}}$ => $f_o = f_s(1 \pm \dfrac{v_o}{v_s})$

PROBLEM



An observer running at 10 m/s towards the stationary fire truck finds that the truck makes a sound of the wavelength of 0.5 m. What are the wavelength and the frequency for the stationary truck?
The speed of the sound is 340 m/s.

When the truck is 700 m away from the observer the truck blows its horn. How long does it take for the sound to get to the observer after it is emitted? How many wavelengths were emitted during this time?



$$f_o = f_s\left(1 \pm \frac{v_o}{v}\right)$$