Waves

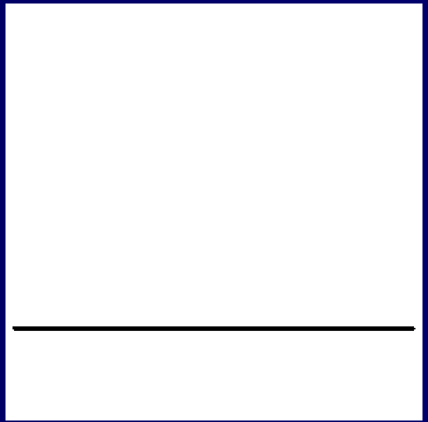
Auburn Mountainview
Karl Steffin, 2008
8/7/2024

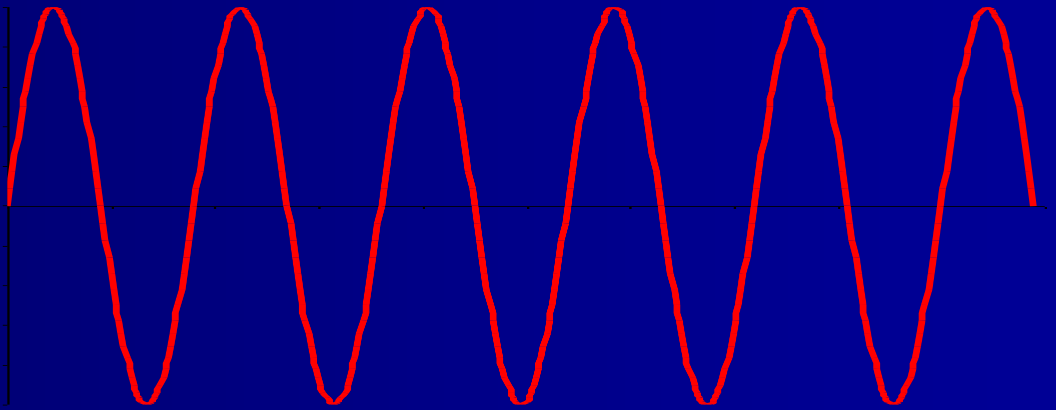
Waves and Energy

- Waves…
  - Are traveling disturbances.
  - Carry energy from place to place.
- There are three types of waves:
  - Transverse (Mechanical)
  - Longitudinal/Surface (Mechanical)
  - Complex Transverse (Electro-magnetic)

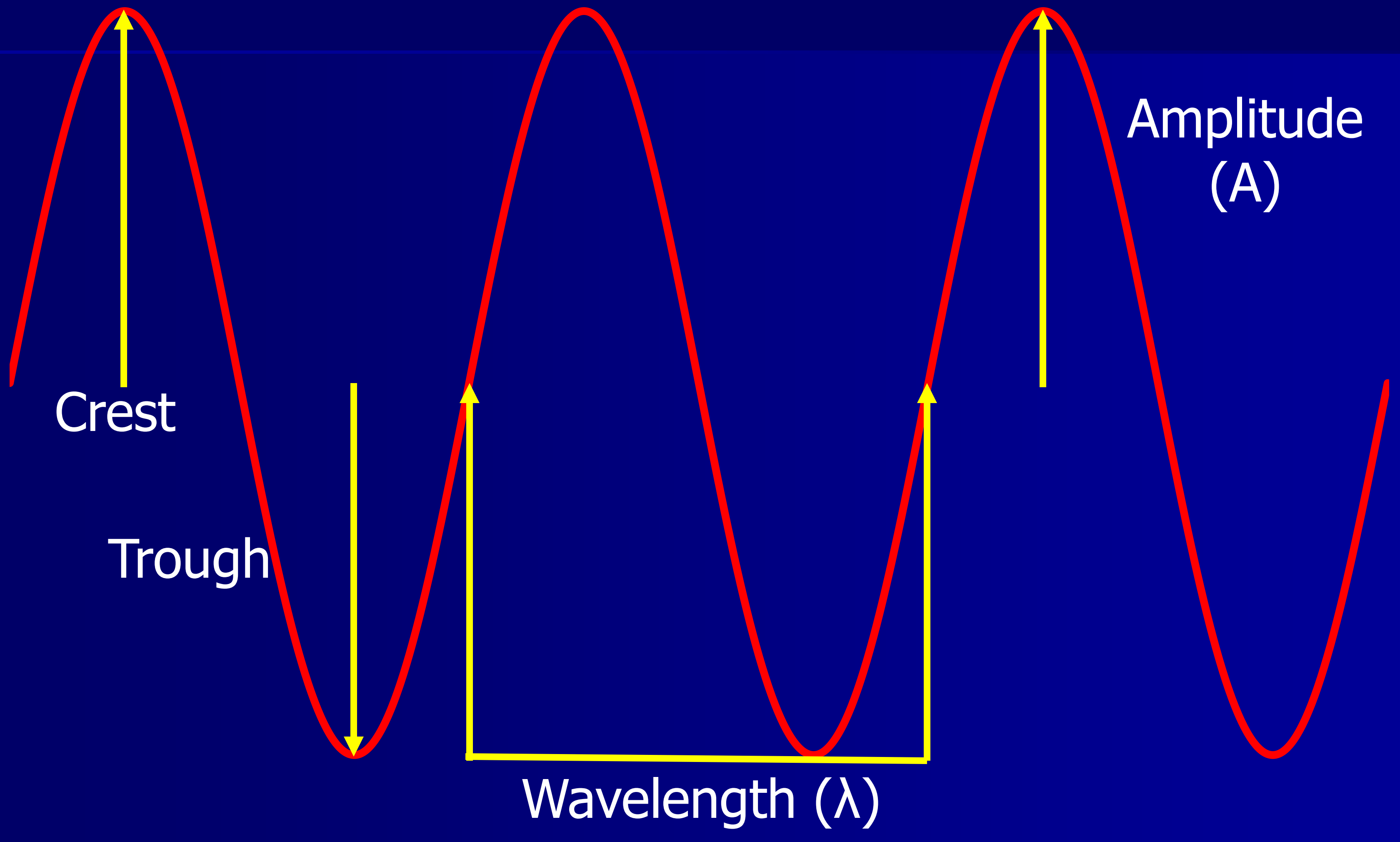
Transverse Wave

- A wave that vibrates perpendicular to the direction of travel.
  - A wave pulse: One disturbance that travels through a medium
  - Continuous waves: A series of wave pulses.





Anatomy of a Trans. Wave

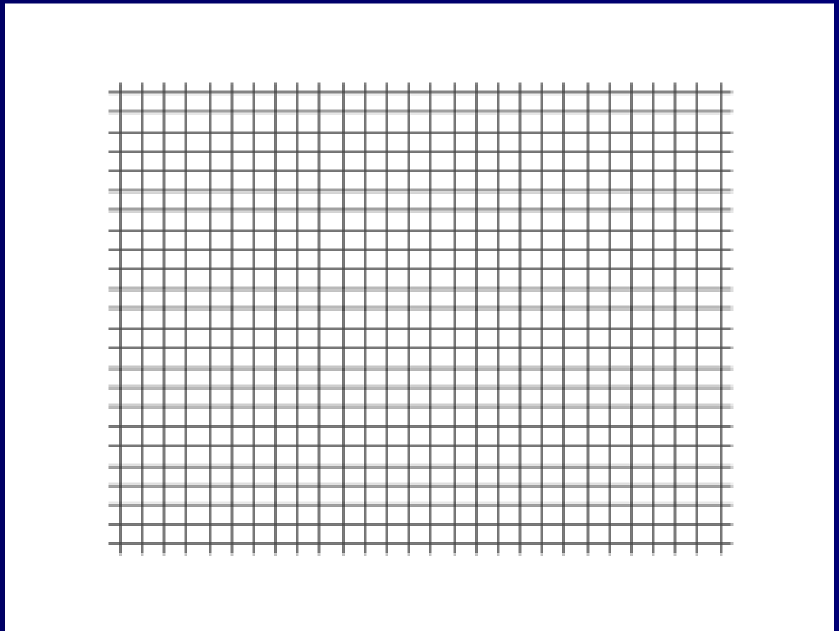


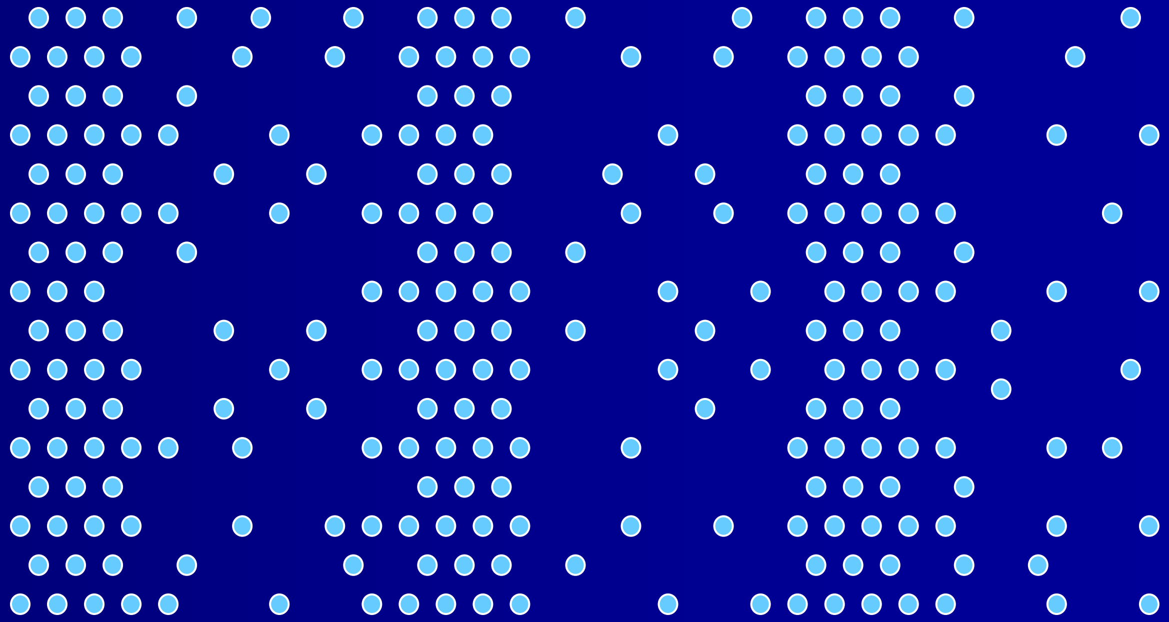
Trans. Wave Defined:

- Crest: Highest point of a wave's displacement.
- Trough: Lowest point of a wave's displacement.
- Amplitude (A): The maximum displacement from center to either crest or trough.
- Wavelength (λ): The length of one full wave.
- Frequency (f): The number of waves that pass through a point in one second. (cycles/second or Hertz Hz)
- Period (T) : The time it takes for one part of a wave to return to the same point. ($T=f^{-1}$ or $T=1/f$)
- Velocity: Speed that a wave travels ($v=f\lambda$)

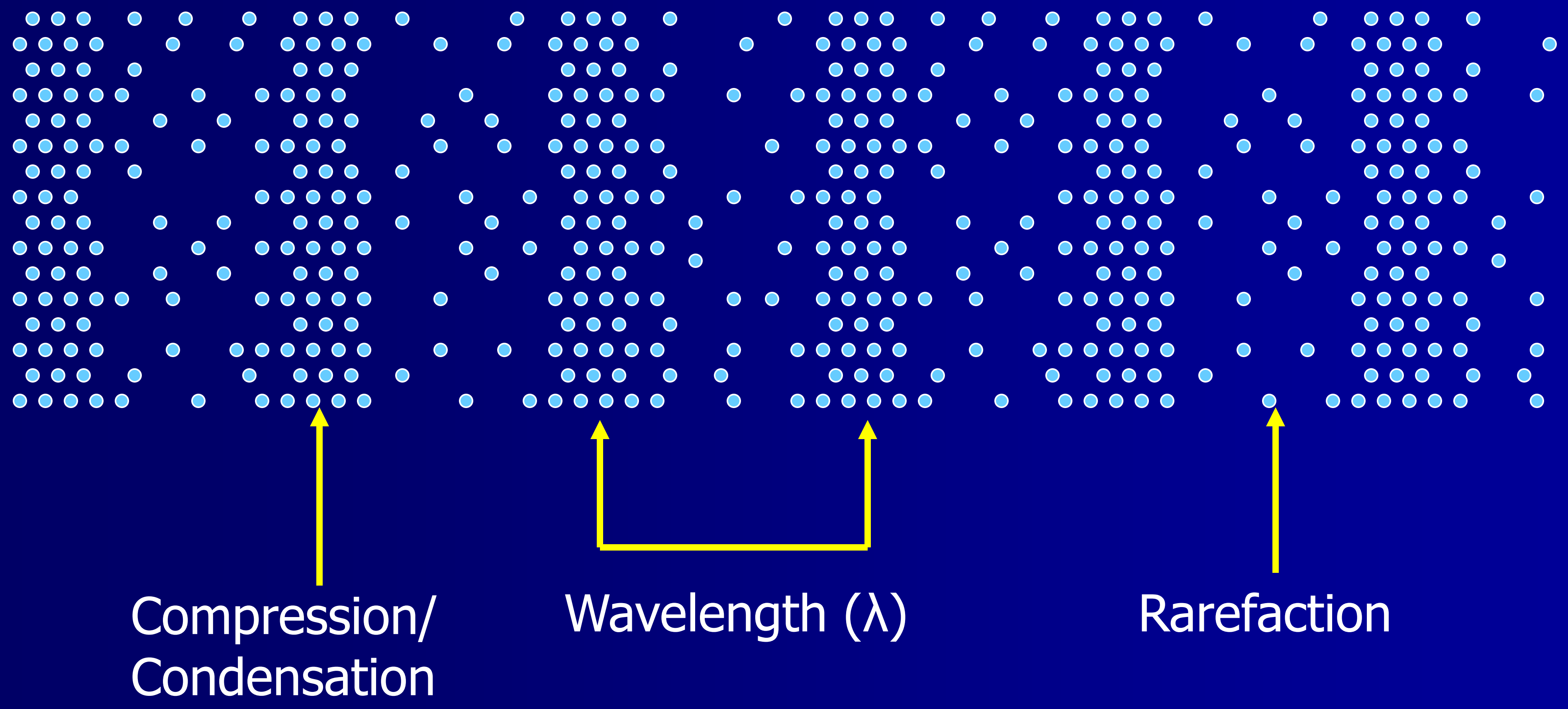
Longitudinal

- Also called a compression wave.
- Energy travels with the direction of motion. (Sound).



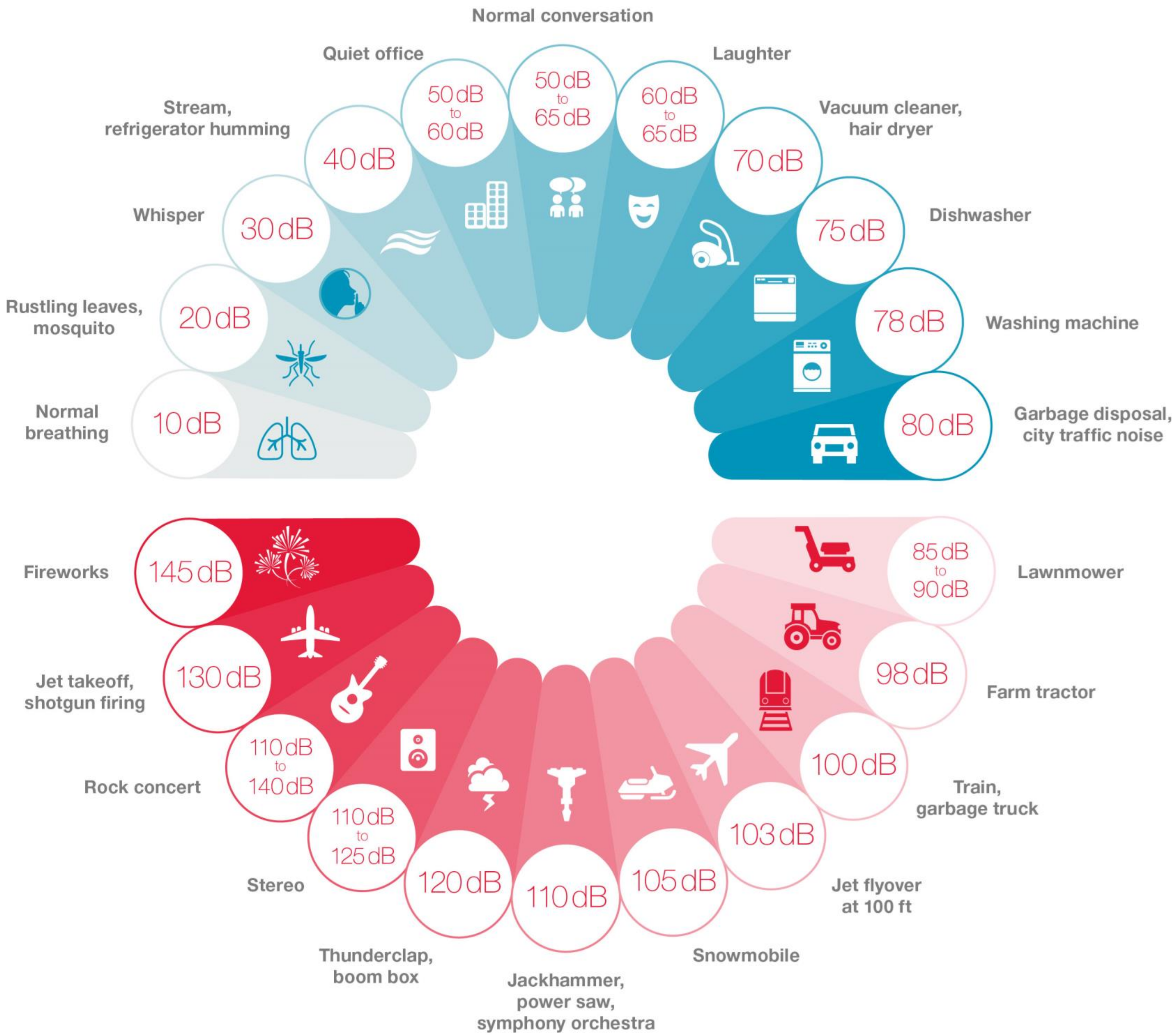


Anatomy of a Long. Wave



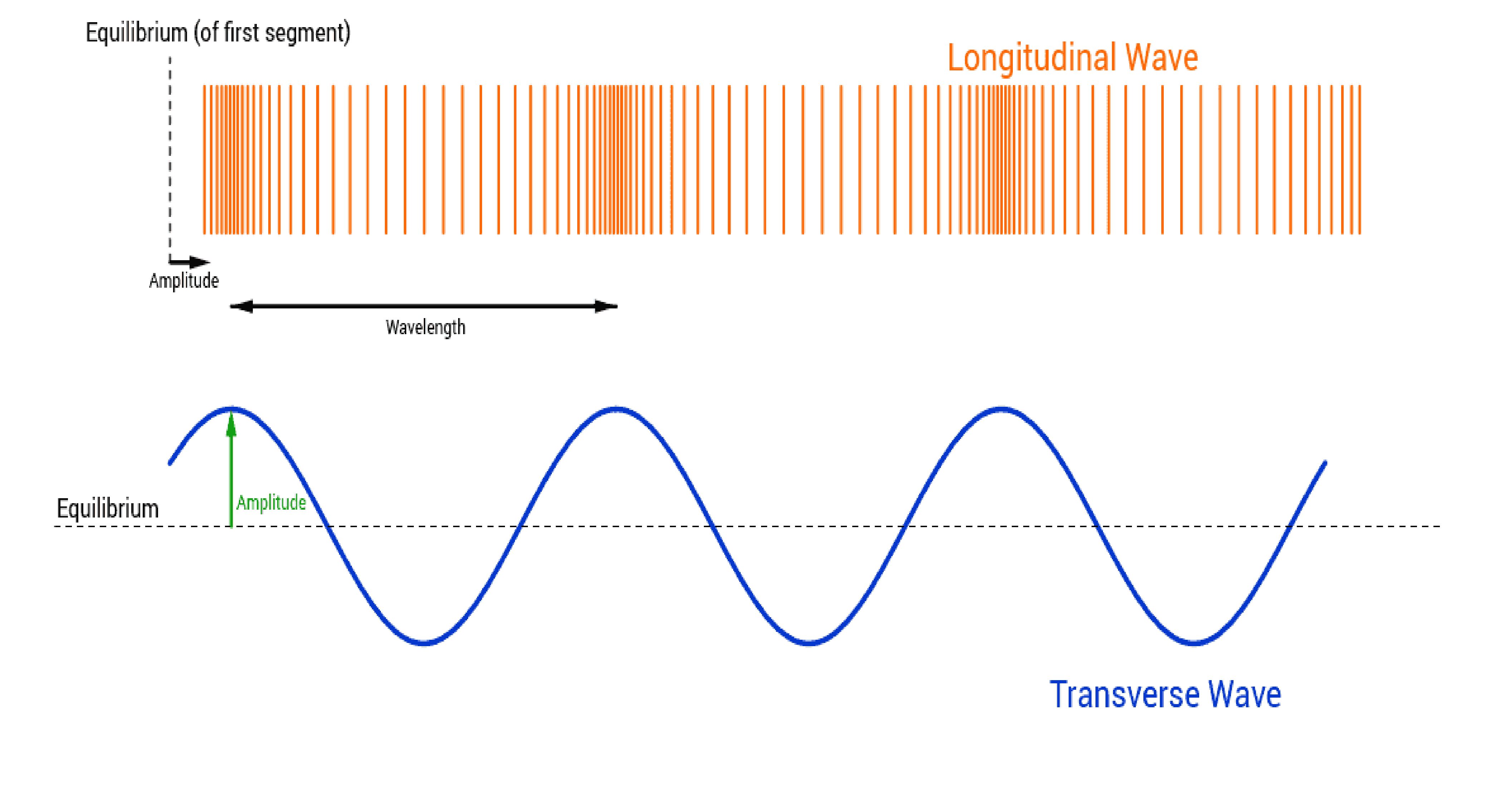
Long. Wave Defined:

- Compression/Condensation: Area of increased particle density.
- Rarefaction: Area of decreased particle density.
- For Sound:
  - Velocity: 343-m/s at 293.15-K (20-°C)
  - Frequency (f): Pitch (The audible range for people: 20 Hz-20kHz)
  - Amplitude (A): How loud sound is (~dB).



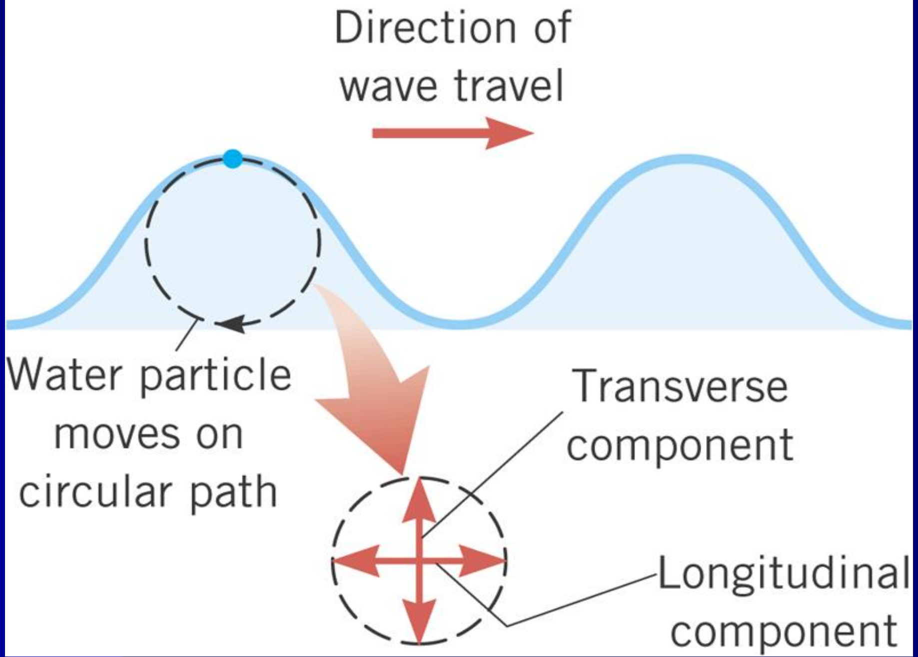
Normal breathing
10 dB
Rustling leaves, mosquito
20 dB
Whisper
30 dB
Stream, refrigerator humming
40 dB
Quiet office
50 dB to 60 dB
Normal conversation
50 dB to 65 dB
Laughter
60 dB to 65 dB
Vacuum cleaner, hair dryer
70 dB
Dishwasher
75 dB
Washing machine
78 dB
Garbage disposal, city traffic noise
80 dB
Lawnmower
85 dB to 90 dB
Farm tractor
98 dB
Train, garbage truck
100 dB
Jet flyover at 100 ft
103 dB
Snowmobile
105 dB
Jackhammer, power saw, symphony orchestra
110 dB
Thunderclap, boom box
120 dB
Stereo
110 dB to 125 dB
Rock concert
110 dB to 140 dB
Jet takeoff, shotgun firing
130 dB
Fireworks
145 dB

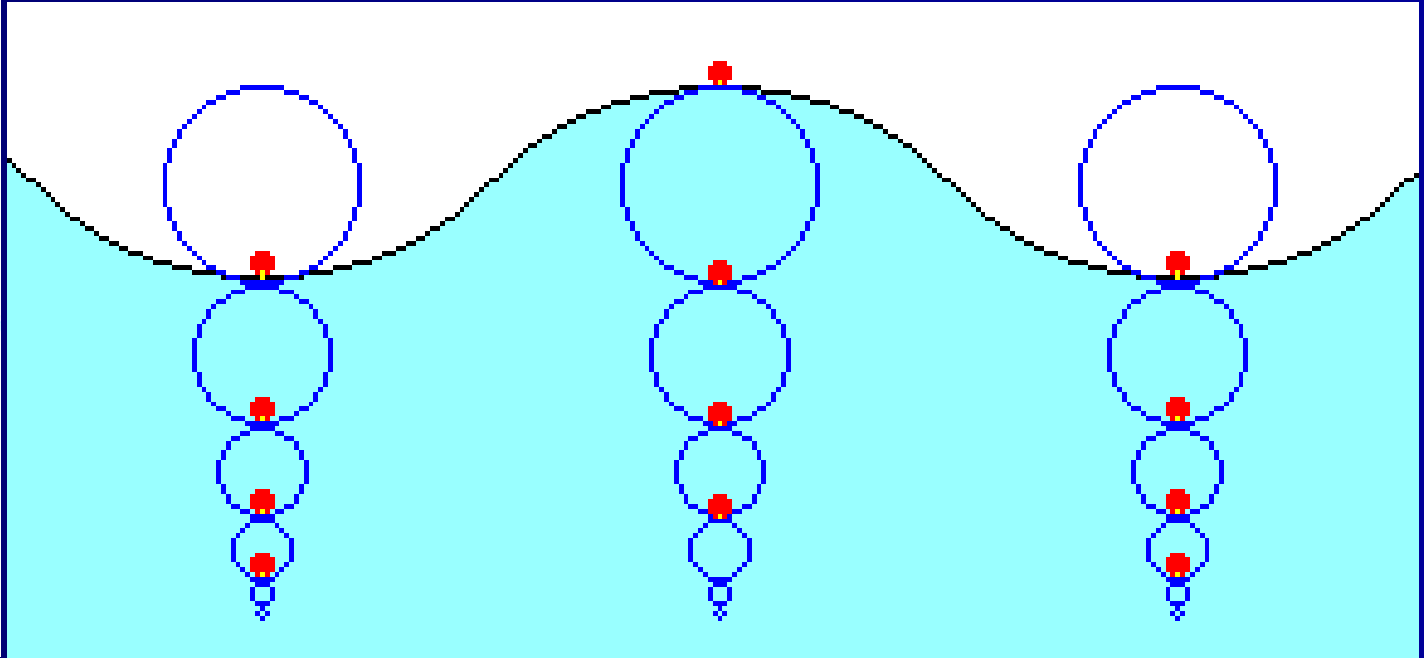
Comparing TW vs LW



Mechanical: Surface

- Type of wave with properties of both transverse and longitudinal.
- The path of a particle is circular.





Example 1

- A tuning fork produces a sound wave that has a frequency of 262.00-Hz and a wavelength of 1.29-m.
  A. What is the speed of the wave?
  B. How long will it take the wave to travel the length of a football field (91.40-m)?
  C. What is the period of the wave?

Example 1 Cont.

A. What is the speed of the wave?

$v = f\lambda$

$v = 262 - Hz \cdot 1.29 - m$

$v =$
f = 262.00-Hz
λ = 1.29-m

$$v = 338.00 - \frac{m}{s}$$

Example 1 Cont.

B. How long will it take the wave to travel the length of a football field (91.40-m)?

$$v = \frac{\Delta p}{\Delta t}$$

v = 338.00-m/s
p = 91.40-m
t =

$$338 - \frac{m}{s} = \frac{91.4 - m}{\Delta t}$$

$$\Delta t = 2.70x10^{-1} - s$$

Example 1 Cont.

C. What is the period of the wave?

f = 262.00-Hz
T =

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

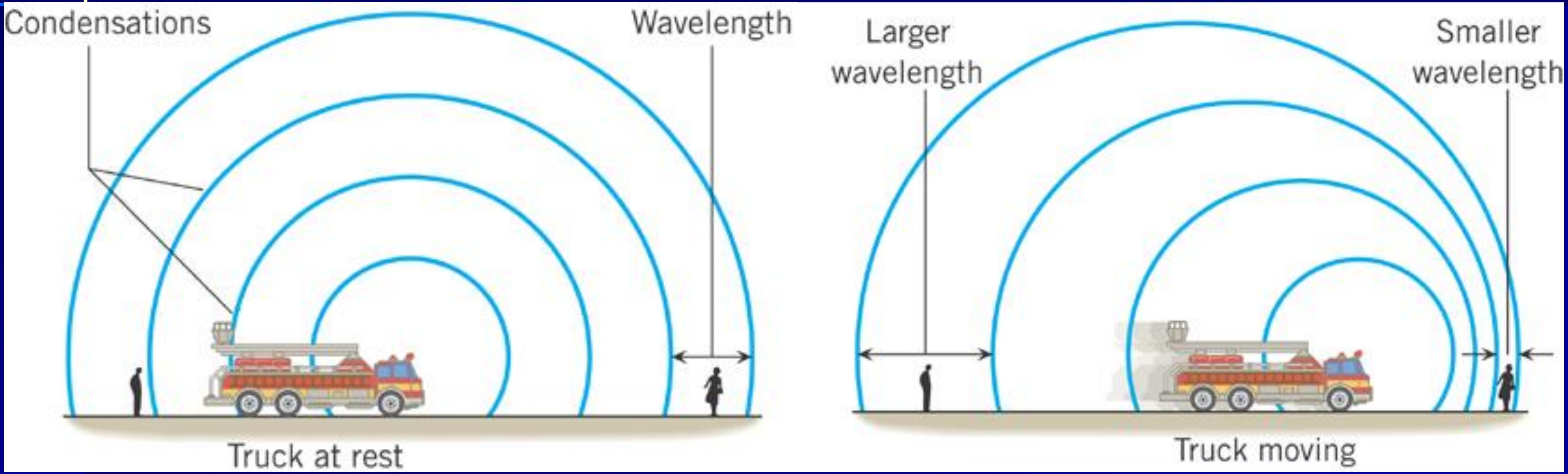
$$T = \frac{1}{262.00 - Hz}$$

$$T = 3.82x10^{-3} - s$$

The Doppler Effect

- When a moving object emits sound the compression waves can pile up or spread apart (depending on the movement).
- This piling/spreading creates a change in frequency called the Doppler effect
  - This is why sirens sound higher when approaching and lower once they pass.

The Doppler Effect Visual



From the front the sound's frequency is higher, from behind it is lower.

The Doppler Effect

To measure the change of frequency:

$$f_o = f_s \frac{1}{1 - \frac{v_s}{v}}$$

Sound moving toward observer

$$f_o = f_s \frac{1}{1 + \frac{v_s}{v}}$$

Sound moving away from observer

f_o = Frequency observed

f_s = Frequency of source

v_s = velocity of source

v = speed of sound

Example 2

The Shinkansen, traveling 44.70-m/s, sounds a warning siren (f=415.00-Hz). What is the perceived frequency of the siren for a person standing at the crossing as the train is both going towards and away from the crossing?

Example 2: Moving Towards (-)

$$f_o = 415-Hz \frac{1}{1 - \frac{44.70-\frac{m}{s}}{343-\frac{m}{s}}}$$

$$f_o = \frac{415-Hz}{1-.1303}$$

$$f_o = \frac{415-Hz}{.8696}$$

f_o =

v = 343.00-m/s

f_s = 415.00 Hz

v_s = 44.70-m/s

$$f_o = 477.19-\text{Hz}$$

Example 2: Moving Away (+)

$$f_o = 415\text{-}Hz \frac{1}{1 + \frac{44.70\text{-}\frac{m}{s}}{343\text{-}\frac{m}{s}}}$$

$$f_o = \frac{415\text{-}Hz}{1+.1303}$$

$$f_o = \frac{415\text{-}Hz}{1.1303}$$

f_o =

v = 343.00-m/s

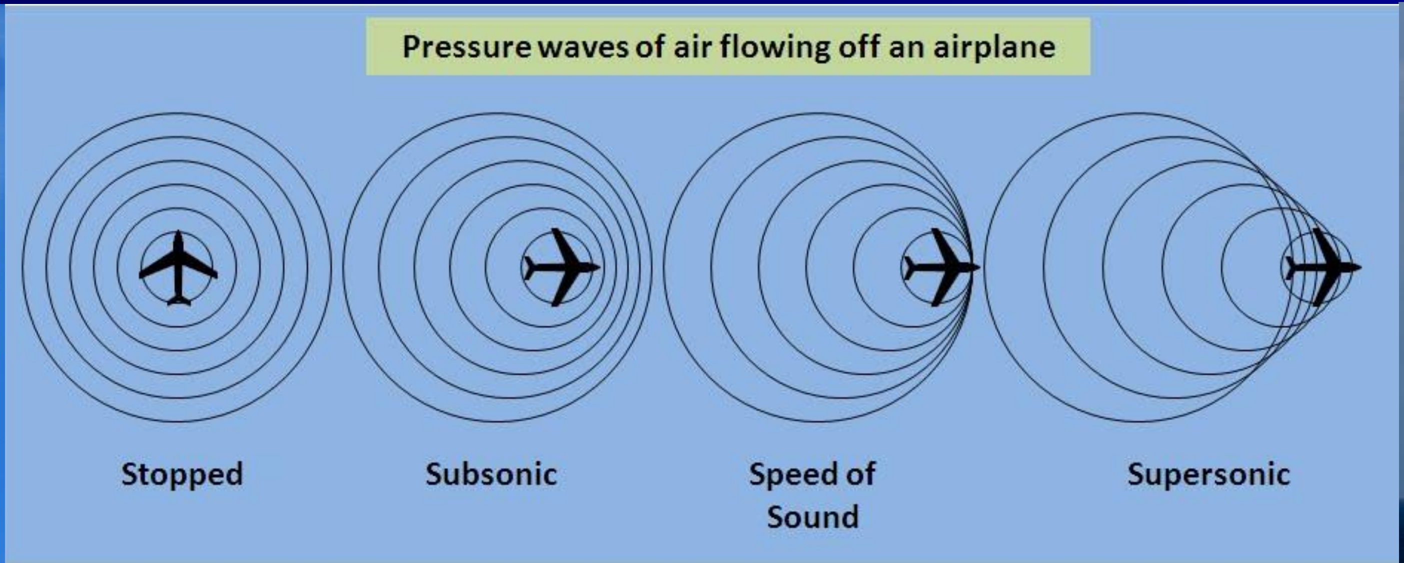
f_s = 415.00 Hz

v_s = 44.70-m/s

$$f_o = 367.15\text{-}\mathrm{Hz}$$

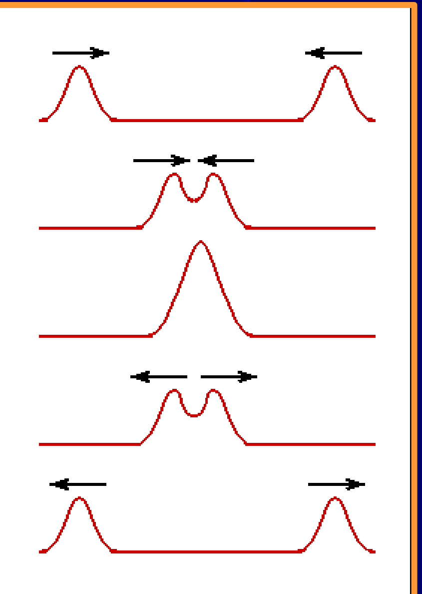
A Final Thought on Sound

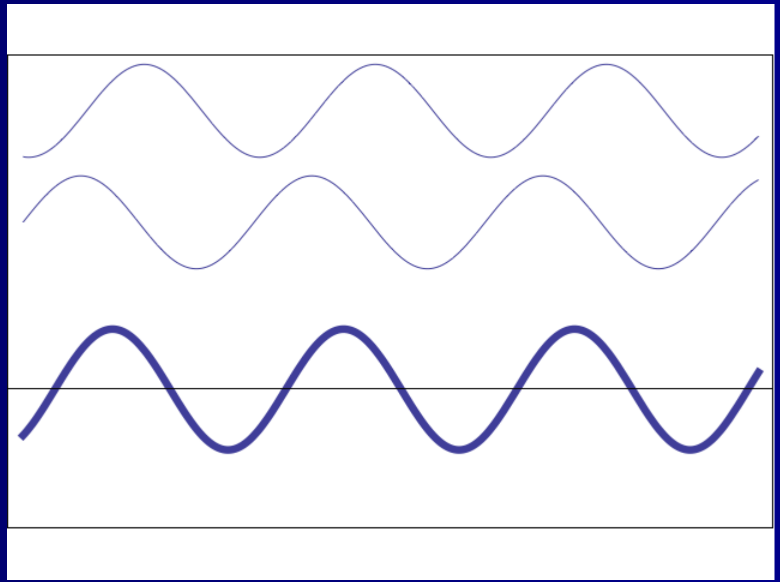
- When an object travels the compression waves in front bunch up.
- Since the maximum speed these waves can travel is 343-m/s eventually as a plane passes this speed, the collective waves form one singular shock wave.
- This is a sonic boom and can normally be upwards of 200-dB.

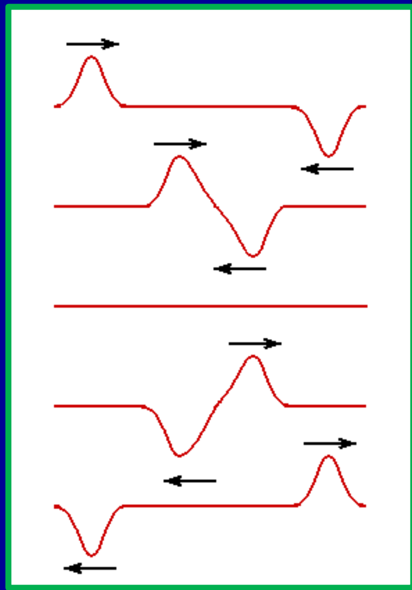


Wave Behaviors: Superposition

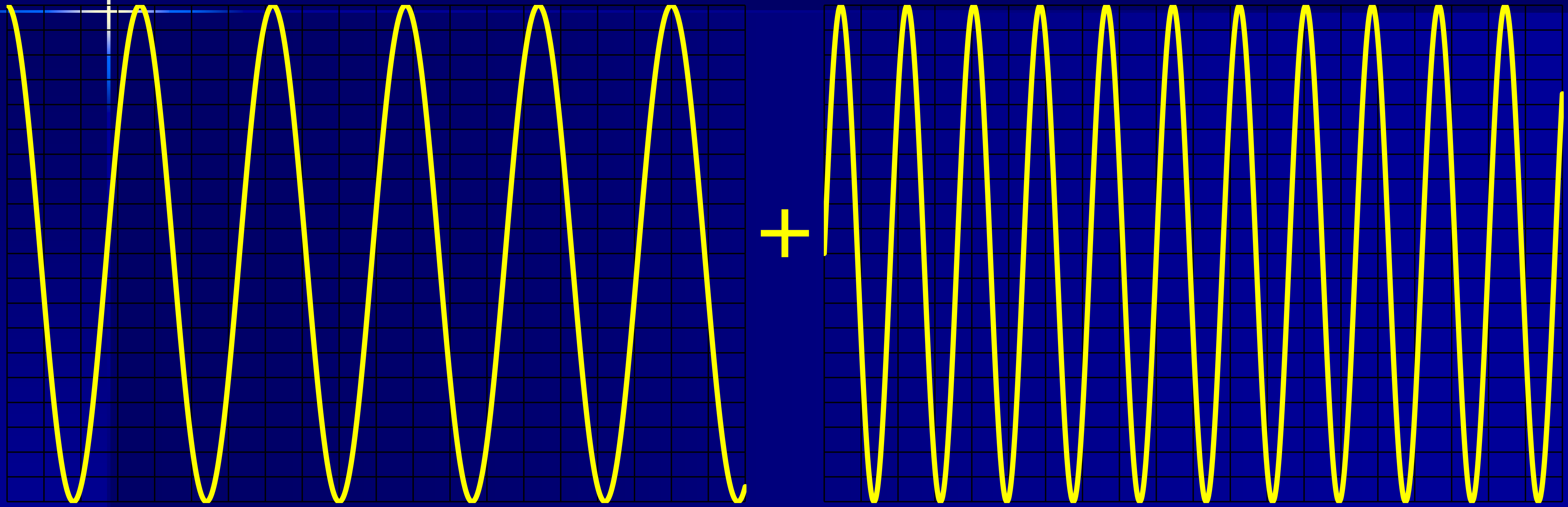
- waves passing through each other combine.
  - Constructive interference: Maxima of two waves meet in phase.
  - Destructive interference: Maxima of two waves meet 180° out of phase.





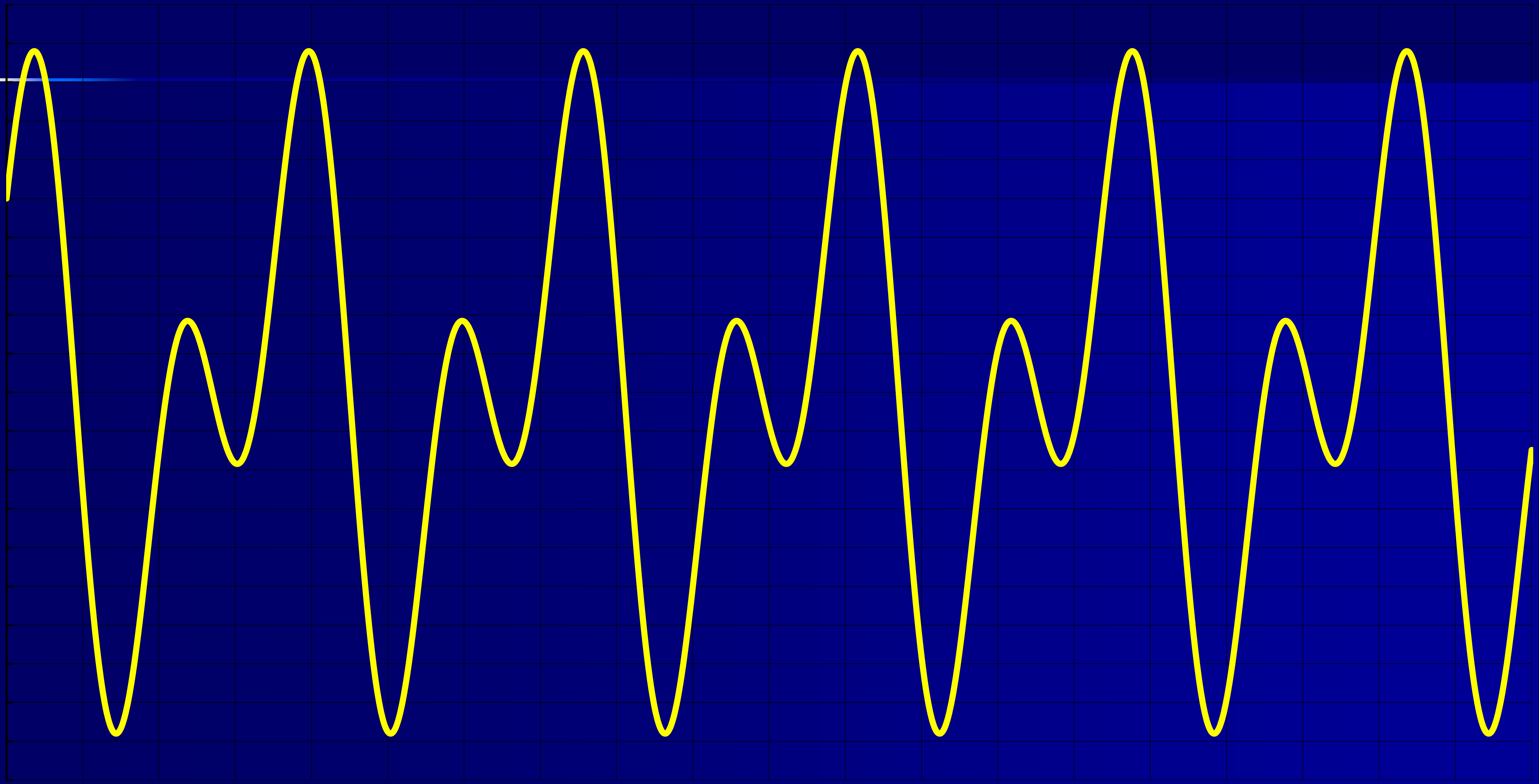


Waves: Superposition Visual



- Wave 1 (left) added to wave 2 (right) will form:

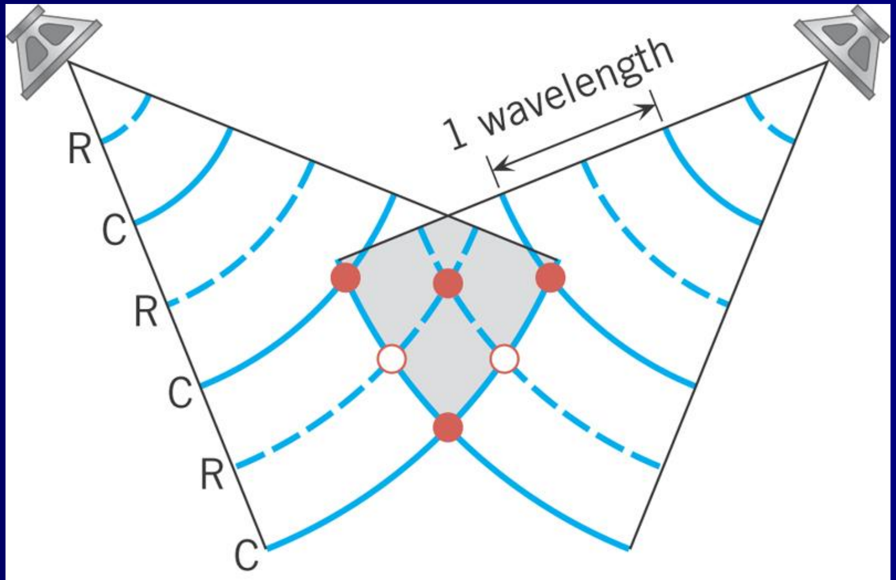
Waves: Superposition Visual

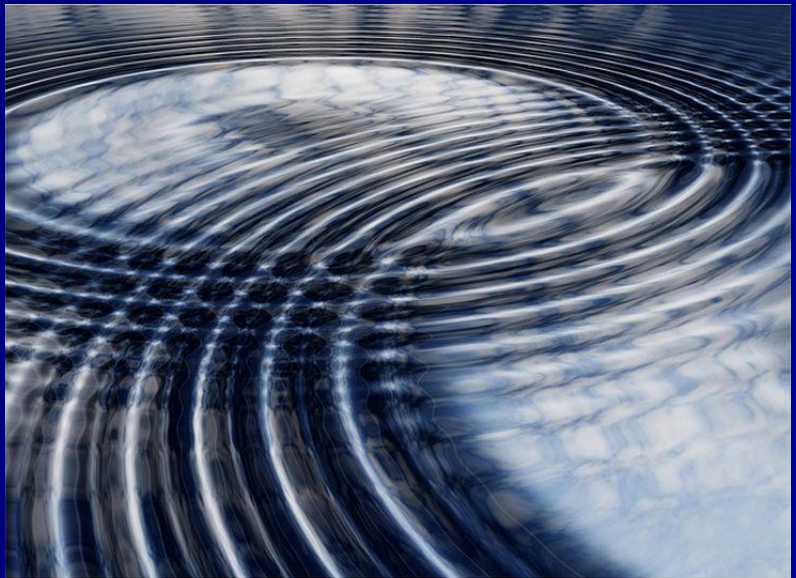


This works for sound waves too. If a sound is captured and inverted an exact opposite wave can be created and the sound will be canceled: Noise reducing/canceling headphones.

Waves Behaviors : Interference

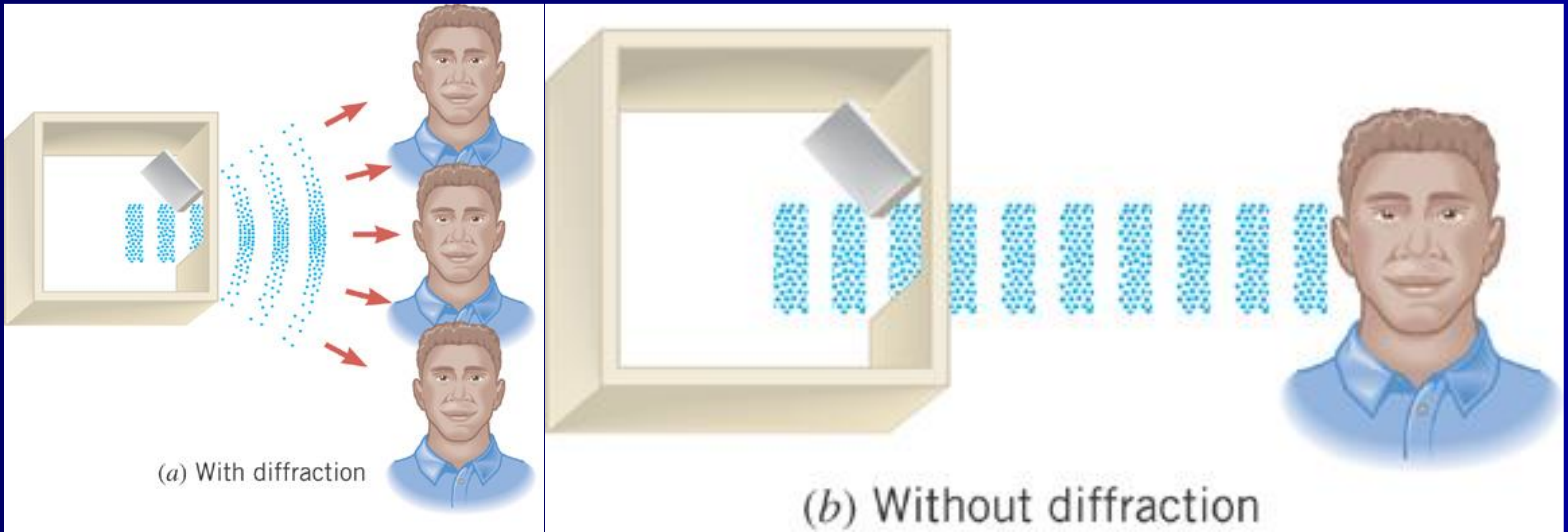
- Sound wave interference may lead to loud and quiet areas.
  - Depending on the frequency (high), these points are normally smaller than the size of a human eardrum.





Wave Behaviors: Diffraction

- When a wave passes through a small opening it will spread out.
  - The bending around the edges is called diffraction.



Wave Behaviors: Diffraction

- The sound is most intense in a straight line out the opening.
  - Moving away from this smaller intensities (m) will also appear.

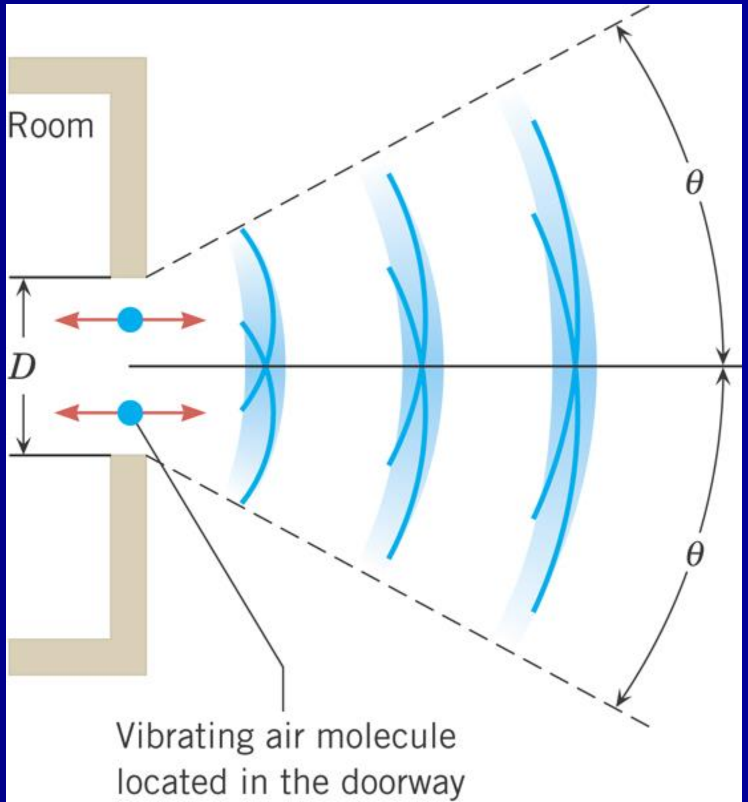
$D \bullet \sin \theta_m = m\lambda$

D=Distance of slit/opening

θ = (Degrees)

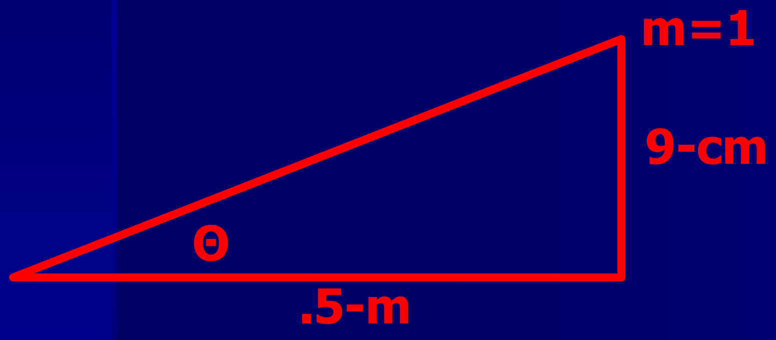
m = integer (1, 2, 3…)

λ = wavelength



Example 3

When a laser passes through a 6.00-nm opening the second brightest spot appears 9.00-cm away from the center of the wall. What is the lasers wavelength if the opening is .50-m from the wall.



$$\theta = tan^{-1}\frac{9x10^{-2}}{.5}$$

$$\theta = 10.2040°$$

D = $6x10^{-9}$-m

Θ = 10.2040°

m = 1

λ =

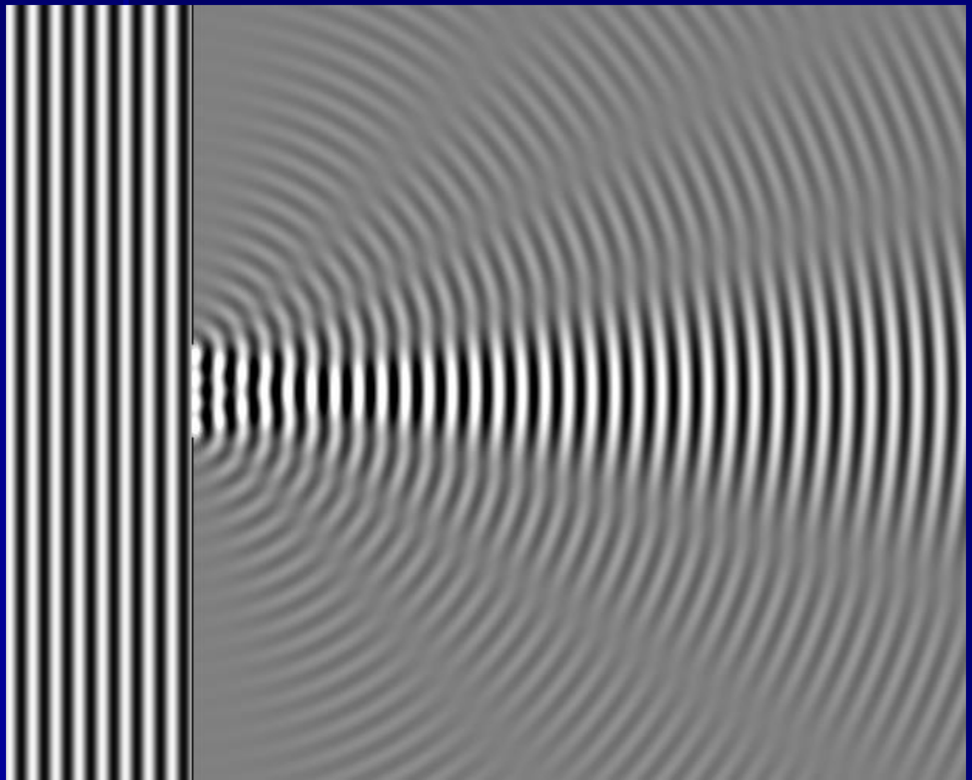
$$Dsin\theta = m\lambda$$

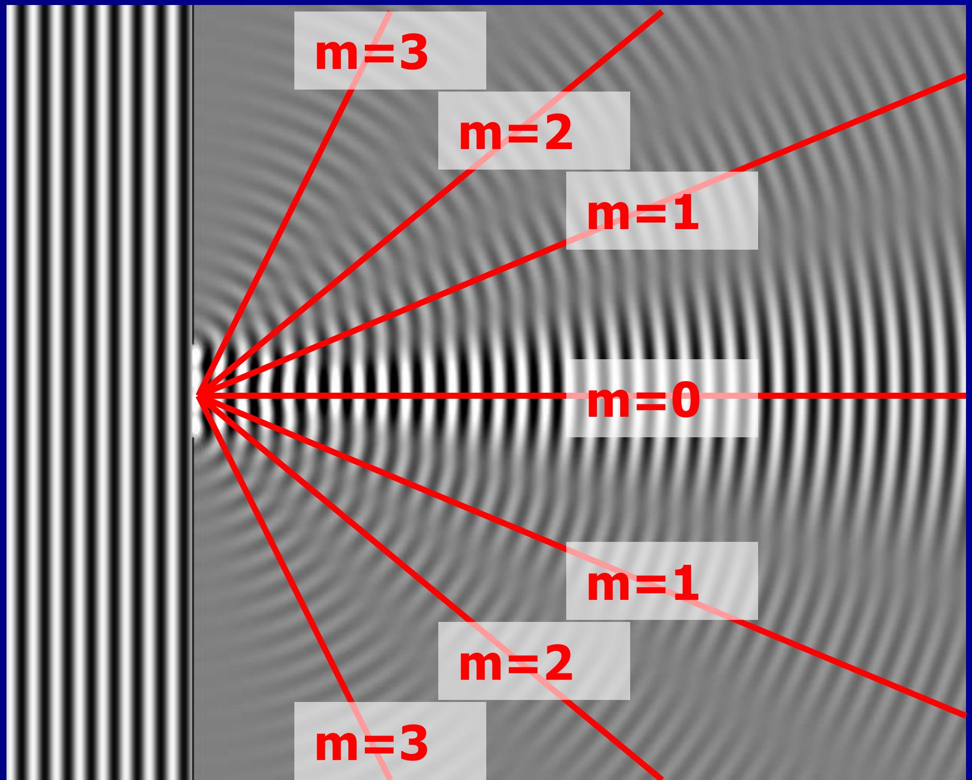
$$6x10^{-9}m \cdot sin10 = 1 \cdot \lambda$$

$$\lambda = 1.06x10^{-9} - m$$

Wave Behaviors: Diffraction

- Physicist Thomas Young presented these findings in 1803 to the Royal Society, UK.

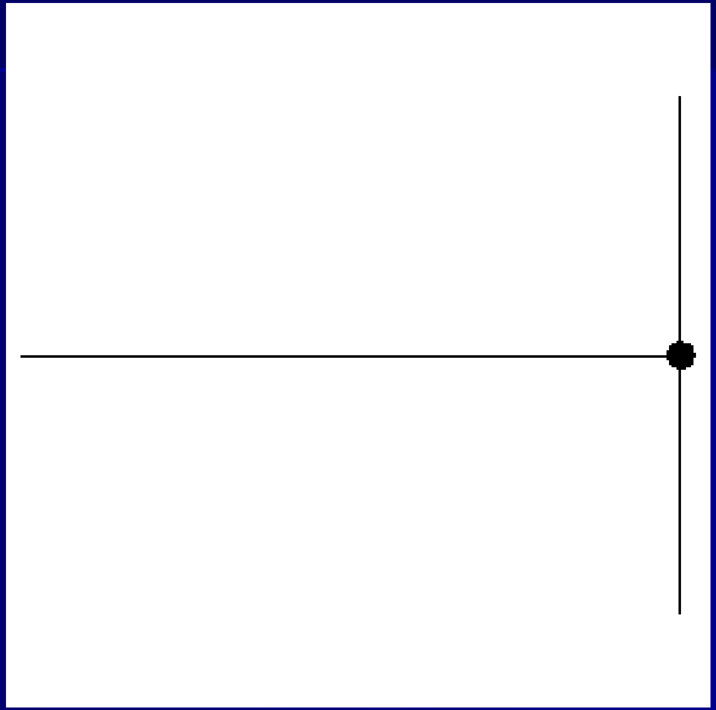


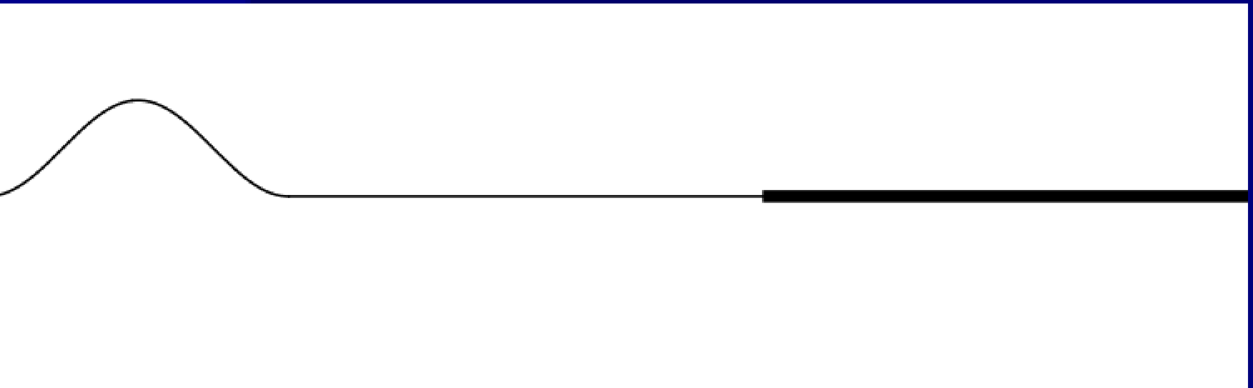


Speed versus Amplitude

- The speed of a wave is determined by the medium that the wave travels through.
  - Higher Density → Higher Speed
- The Amplitude of the wave is determined by how the wave was generated.
  - More Energy → More Amplitude

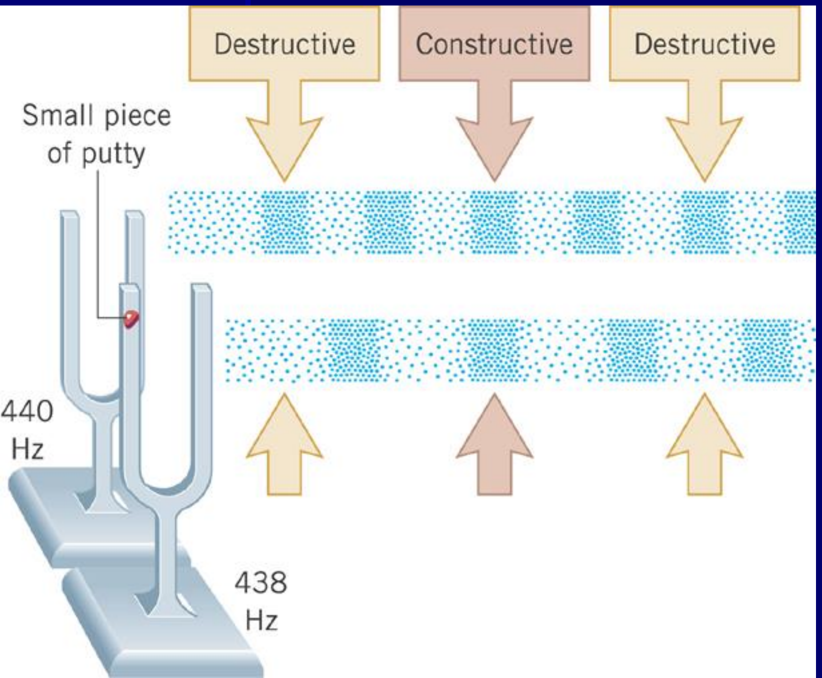
Waves Hitting Barriers/Interfaces

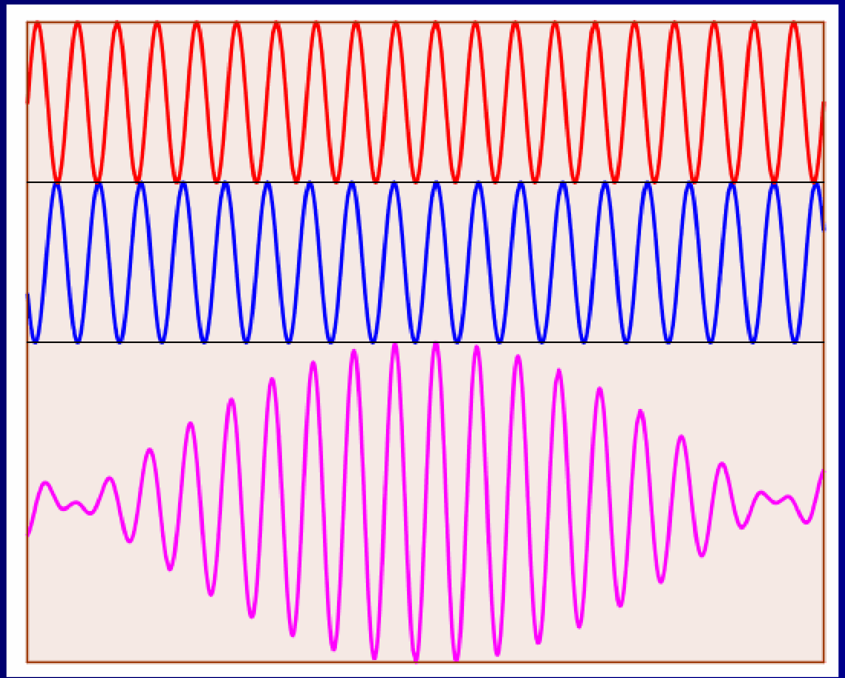


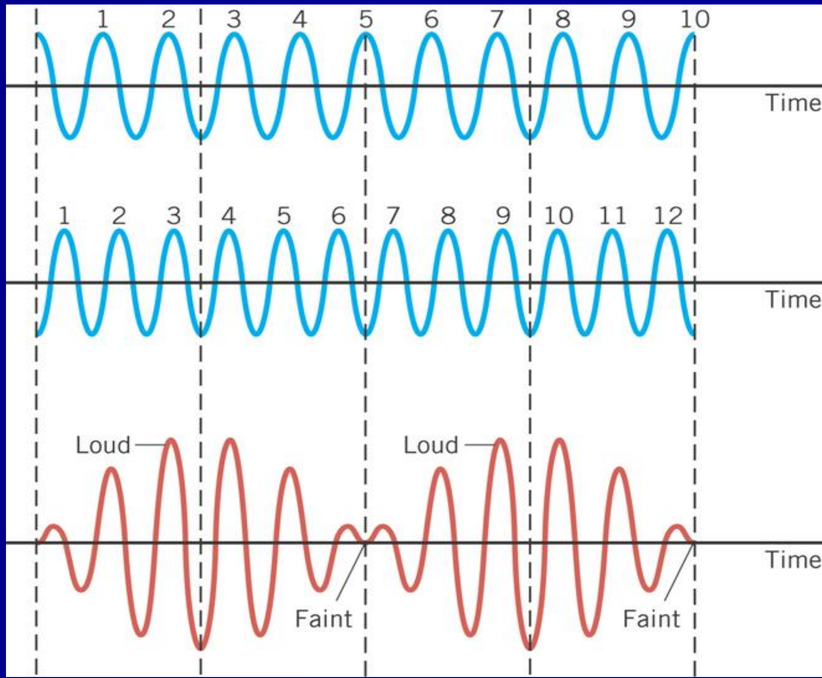


Wave Behaviors: Beats

- Two similar frequencies will create a beat frequency.
  - Beats: Pulse of the waves interference. ($f_B = |f_1 - f_2|$

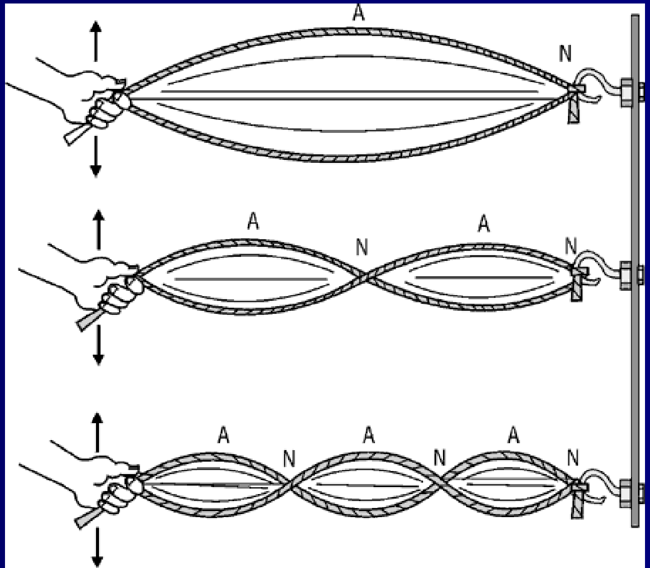


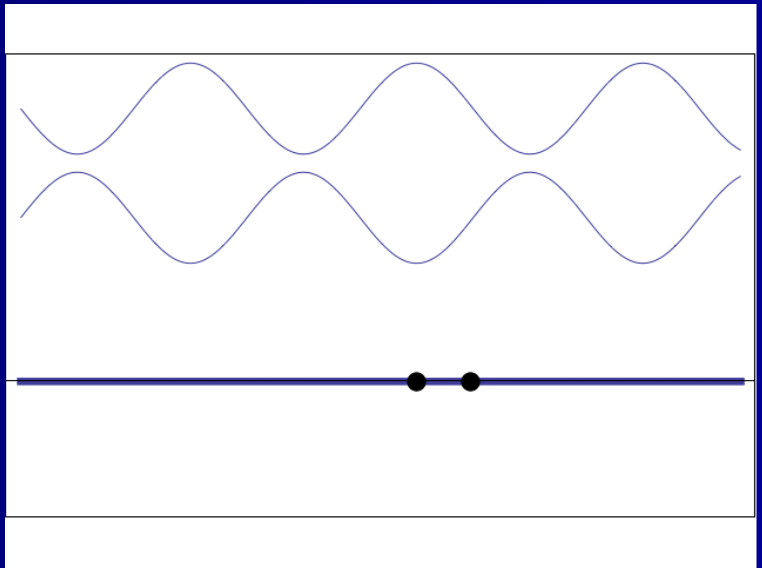




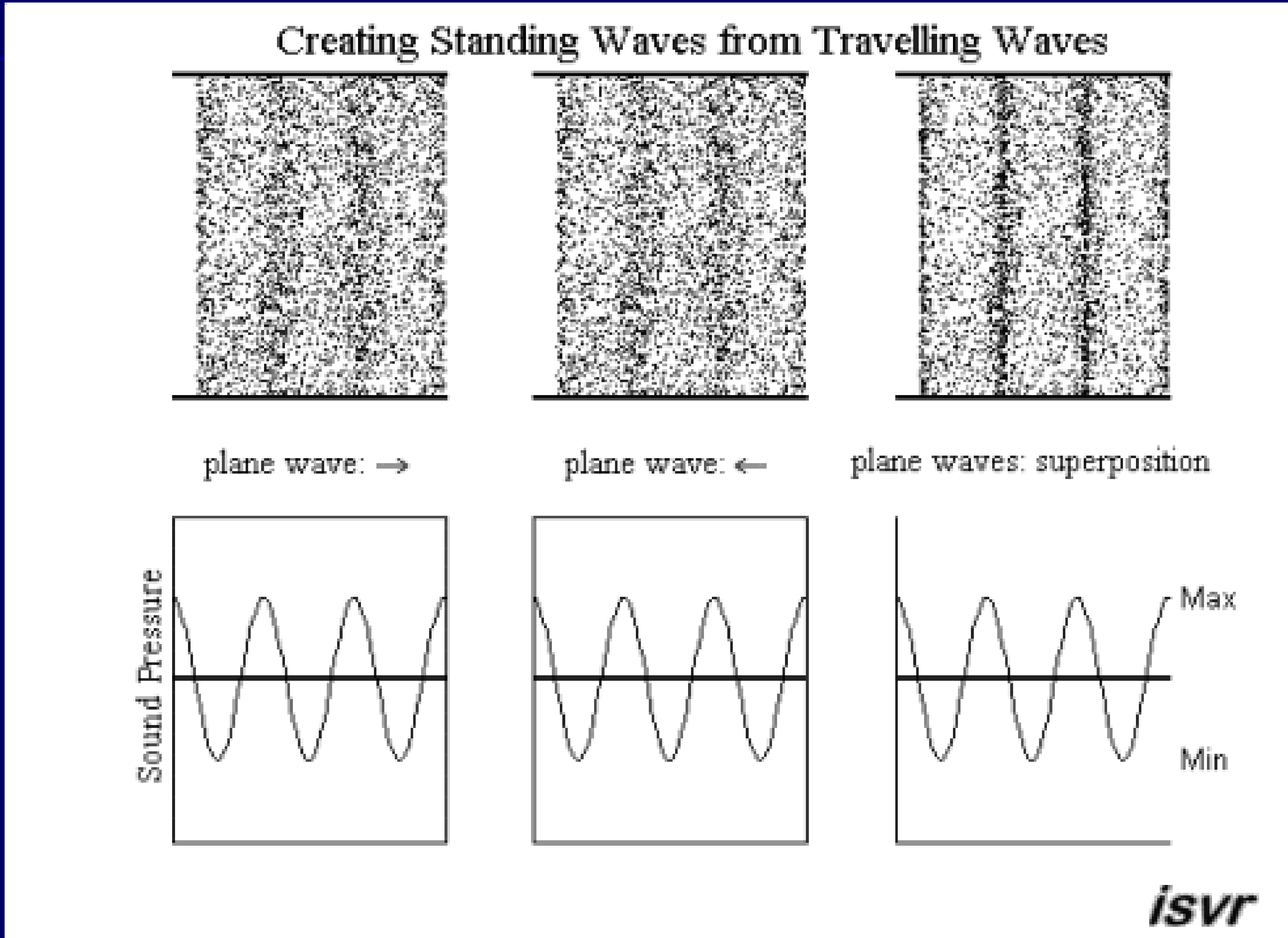
Wave Behavior: Standing Waves

- Standing wave: Two waves traveling towards each other in phase.
  - Node: Area of no displacement.
  - Antinode: Area of maximum displacement





Wave Behaviors: Longitudinal



Longitudinal: Standing Waves Tubes

- In music the woodwind family depends on standing waves setting up in a tube:
  - Both ends open: Flute, Recorder, *Organ*
  - One end open: Clarinet, Saxophone



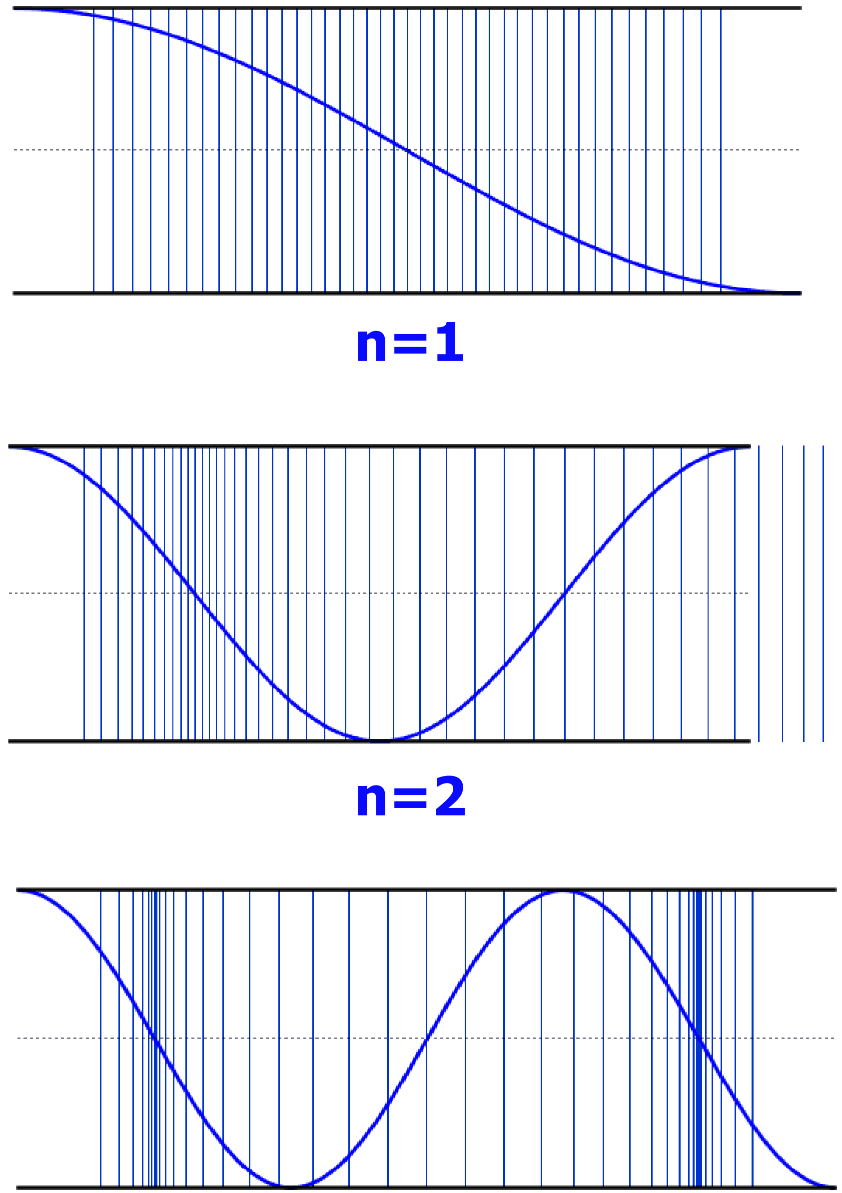

Open Tubes

- Antinodes are set up at the ends.
- To find the frequency of the sound:

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

L= Length

n^{th} (harmonic) = all positive integers



Closed Tubes

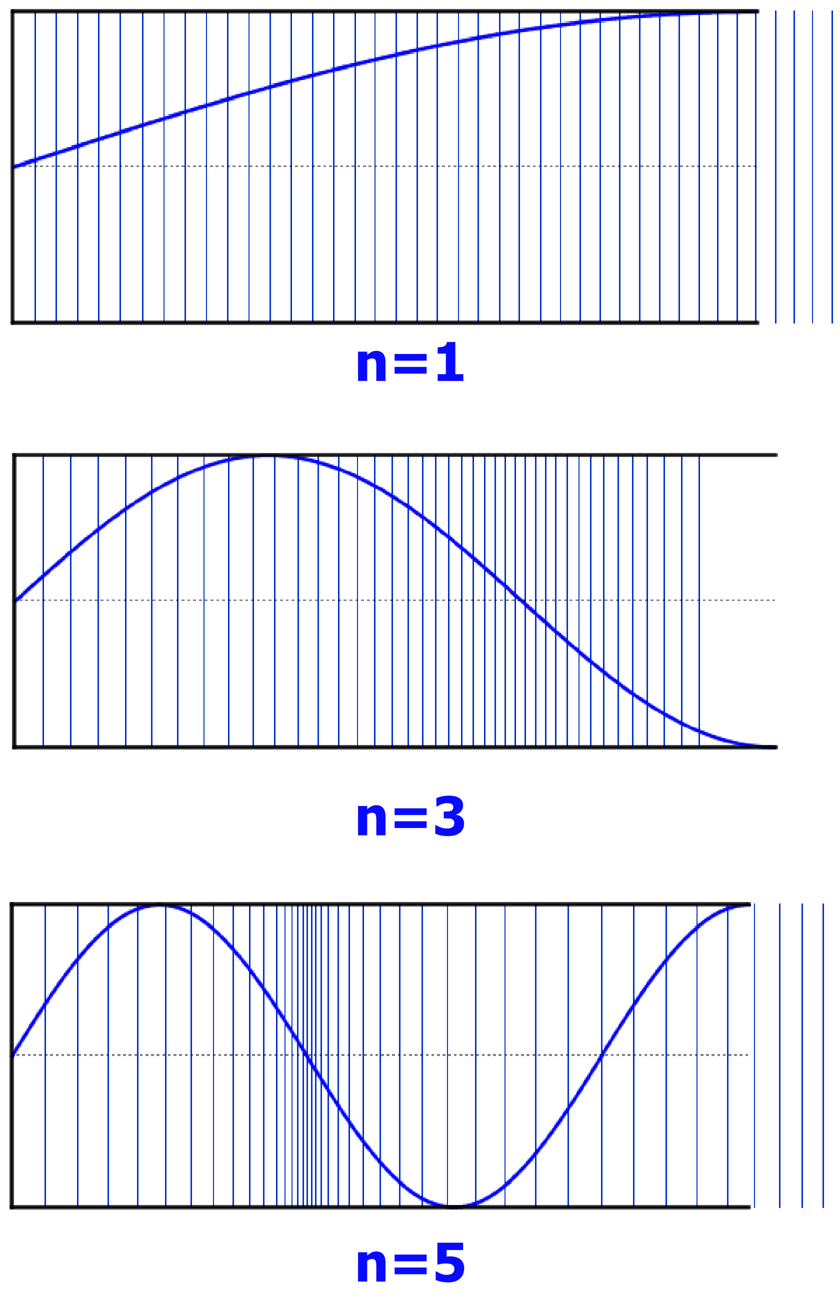
- Antinode is set up at one end.
- To find the frequency of the sound:

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

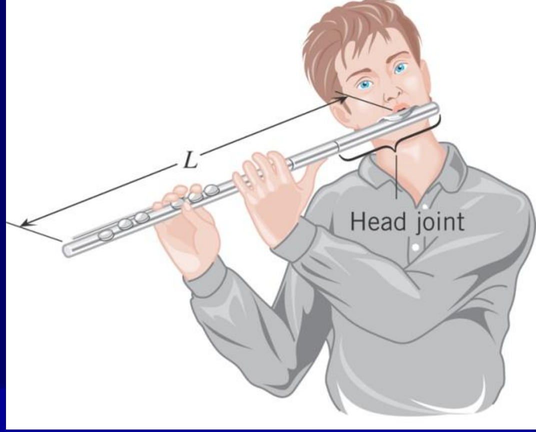
L= Length

n^{th} (harmonic) = all odd integers.

There are no even harmonics.



Example 4



Find the length of the flute above if the fundamental (first) harmonic frequency is 261.6-Hz.

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

$$261.6 - Hz = 1\frac{343 - \frac{m}{s}}{2L}$$

$$L = \frac{343 - m}{523.2}$$

f_1= 261.6-Hz
n= 1
v= 343-m/s
L=

$L = 6.55x10^{-1}$-m