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April 16, 2018 9:58 AM

PHYS 11 Introduction to Mechanical Waves

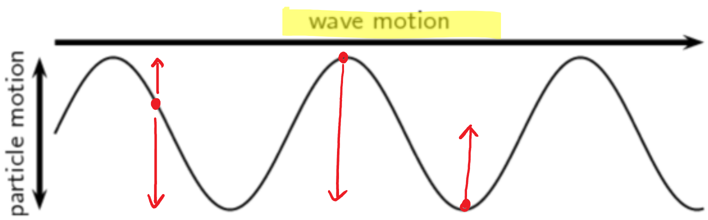
Waves Waves are a _disturbance_ that transfers _Energy_ from one point to another.

Basis on their ability or inability to transmit _Energy_ through a _Vacuum_ (i.e., empty space), we can categorize waves in two main groups

EM Electromagnetic Waves	Mechanical Waves
- Capable of transmitting its energy through a _vacuum_ Ex. Radio, Infrared (Heat) Microwave Visible Light, UV, X-ray gamma	- require a _medium_ in order to transport their energy from one location to another medium Ex. water wave → water (H_2O) Earth Quake → Solid rock Sound wave → air / Liquid / solid. people wave → people.

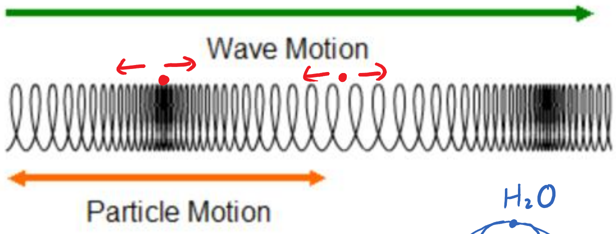
Mechanical waves can occur in two distinct types: _Transverse_ and _Longitudinal_. These are defined based on how the medium _Oscillates_ (moves in a repetitive motion) relative to the motion of the wave itself.

Transverse wave is what we normally think of when we imagine a wave. Here, the particles move _perpendicular_ to the direction that the wave travels in. A wave moving along a rope or string is a good example of a transverse wave.

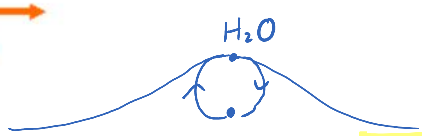


1 - The direction of wave motion (energy travel) and particle motion (oscillation) of a transverse wave.

Longitudinal wave (or **pressure wave** or compression wave) is harder to visualize, but it is also perhaps more common in regular, everyday application: _Sound wave_ are longitudinal waves. In this type of wave, the _particles_ move in the _same direction_ as the motion of the wave.



2 - The direction of wave motion (energy travel) and particle motion (oscillation) in a longitudinal wave.



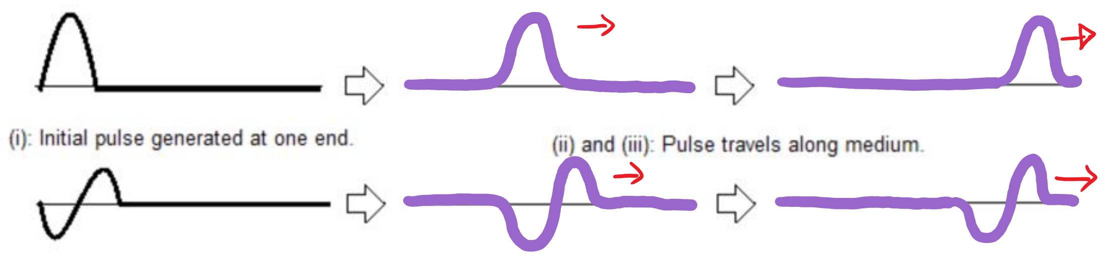
There are other types of mechanical waves, too. For example, water waves are actually a _combination_ of transverse and longitudinal waves: water particles on the surface of a lake actually move in a _circular path_ which has both up/down (transverse) and forward/backward (longitudinal) components of motion.

ANIMATION URL: http://www.acs.psu.edu/drussell/demos/waves/wavemotion.html

Generally speaking, there are two ways that we can produce a wave.

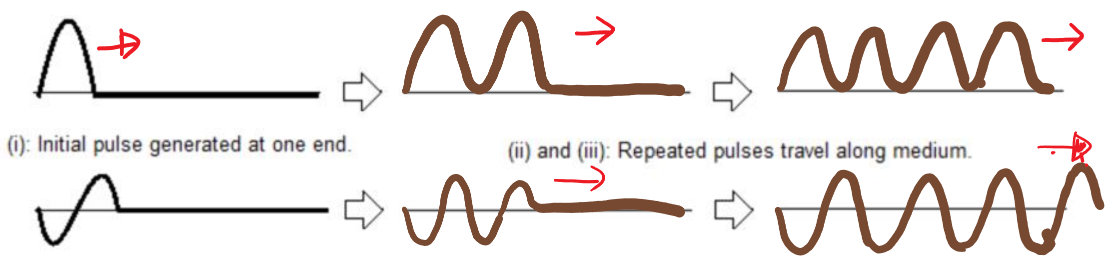
Pulse

A pulse is generated by rapidly _deflecting_ (transverse) or _Compressing_ (longitudinal) the medium and then returning it to normal. The result is a single wave chunk that moves along the medium, which we will draw in below:



Periodic Wave

A periodic wave is generated by repeatedly applying the same pulse



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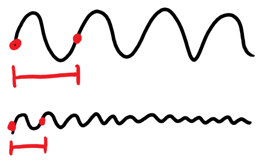
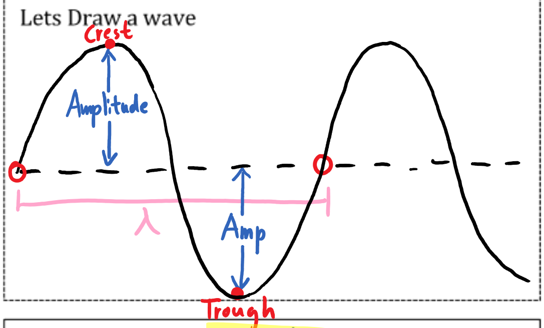


Unit 4 Waves and Optics Day 2

The Universal Wave Equation

Lets Draw a wave



Medium: material that the wave travels in

Crest: high point

Trough: Low point

Amplitude (A): max displacement from rest. (meter)

Waves with higher amplitude have more Energy

λ "Lamda"

Wavelength (λ): (meter)

Waves with shorter wavelength have more Energy

Frequency (f): $f = \frac{cycles}{time}$ unit: Hertz (Hz)

1 Hz = 1 cycle/sec

Ex, 8 waves pass in 2 seconds $f = \frac{8\ cycles}{2\ sec} = 4\ Hz$

Period (T): $T = \frac{time}{cycle}$ unit: (second)

Ex, the wave in last example would have a period of ________ $T = \frac{2\ sec}{8\ cycles} = 0.25\ sec$

Frequency and period are reciprocals, that is:

$f = \frac{1}{T}$ $T = \frac{1}{f}$ not on formula

Ex: Playing middle C on a piano produces a sound with a frequency of 256 Hz. What is the period of the sound wave?

$T = \frac{1}{f} = \frac{1}{256\ Hz} = 0.0039\ sec$

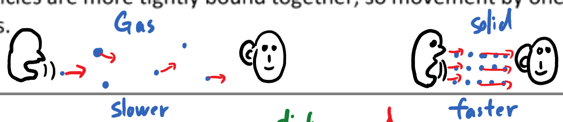
CPU 1.8 GHz → ×10⁹ → 1.8×10^9 Hz

Wave Transmission

In general, the speed of any wave through a medium is fixed regardless of the energy of the wave. For example, a sound wave always travels at 343 m/s in air at sea level and room temperature regardless of its pitch (frequency) or volume (amplitude). In steel, a longitudinal wave always travels at 5790 m/s while a transverse wave always travels at 3100 m/s.

Changes to the composition of a material can change the speed of wave transmission. Here is a general rule:

- All other things being equal, higher rigidity means faster wave travel. Logically, because they are more rigid, the particles are more tightly bound together, so movement by one particle has a significant effect on adjacent particles.

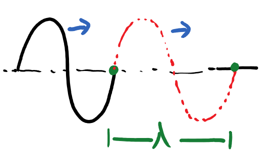


Remember that speed is $V = \frac{dist}{time} = \frac{\lambda}{T}$ $f = \frac{1}{T}$

IF we look at a single wave then:

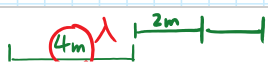
(1) The dist travelled is one wavelength (λ)

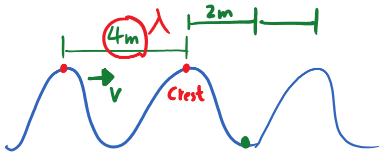
(2) The time is one period (T)



This gives us the Universal Wave Equation: $V = \lambda f$ (m/s) (m) (Hz)

for Light: $c = \lambda f$, c = speed of Light = 3×10^8 m/s





Ex: An air horn sounds at a frequency of 220 Hz. If the speed of sound in air is 330 m/s what is the wavelength of the sound wave?

$V = \lambda f$ (330, 220)

$330 = \lambda (220)$

$\frac{330}{220}$ → $\lambda = 1.5\ m$ (wavelength)

Ex: The distance between successive crests in a series of water waves is 4.0 m, and the crests travel 8.6 m in 5.0 s. Calculate the frequency of a block of wood bobbing up and down on these water waves.

$V \text{ of wave} = \frac{dist}{time} = \frac{8.6m}{5\ sec} = 1.72\ m/s$

$V = f\lambda \quad 1.72 = f(4m)$

$f = 0.43\ Hz$

Wave Worksheet 1-2

1. Suppose that a longitudinal wave moves along a Slinky at a speed of 5 m/s. Does one coil of the Slinky move through a distance of 5 m in one second? Justify your answer.

2. Give one example of a transverse wave and another of a longitudinal wave, being careful to note the relative directions of the disturbance and wave propagation in each.

3. What is the difference between propagation speed and the frequency of a wave? Does one or both affect wavelength? If so, how?

4. What is the period of 60.0 Hz electrical power? **16.7 ms**

5. If your heart rate is 150 beats per minute during strenuous exercise, what is the time per beat in units of seconds? **0.400 s/beat**

6. Find the frequency of a tuning fork that takes 2.50 × 10−3 s to complete one oscillation. **400 Hz**

7. A stroboscope is set to flash every 8.00 × 10−5 s. What is the frequency of the flashes? **12500 Hz**

8. Storms in the South Pacific can create waves that travel all the way to the California coast, which are 12,000 km away. How long in days does it take them if they travel at 15.0 m/s? **9.26 d**

9. Waves on a swimming pool propagate at 0.750 m/s. You splash the water at one end of the pool and observe the wave go to the opposite end, reflect, and return in 30.0 s. How far away is the other end of the pool? 11.3 m

10. Wind gusts create ripples on the ocean that have a wavelength of 5.00 cm and propagate at 2.00 m/s. What is their frequency? **40.0 Hz**

11. How many times a minute does a boat bob up and down on ocean waves that have a wavelength of 40.0 m and a propagation speed of 5.00 m/s? **7.50 times**

12. What is the wavelength of an earthquake that shakes you with a frequency of 10.0 Hz and gets to another city 84.0 km away in 12.0 s? **700 m**

10^8 3×10^8

13. Radio waves transmitted through space at 3.00 × 108 m/s by the Voyager spacecraft have a wavelength of 0.120 m. What is their frequency? **2. 50 × 109** Hz

14. A person lying on an air mattress in the ocean rises and falls through one complete cycle every five seconds. The crests of the wave causing the motion are 20.0 m apart. Determine (a) the frequency and (b) the speed of the wave. **0.200 Hz, 4.00 m/s**

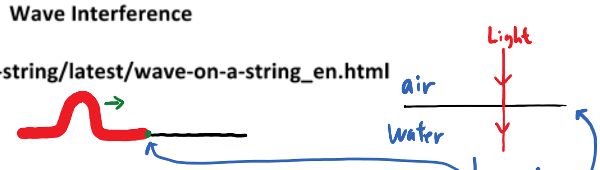
Day 3 Interference

April 18, 2018 9:51 AM

Unit 4 Waves and Optics Day 3

Wave Interference

http://phet.colorado.edu/sims/html/wave-on-a-string/latest/wave-on-a-string_en.html



Boundary Interactions

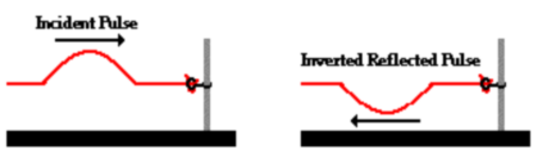
Waves can travel from one medium to another. The interface between the two media is called a boundary. Part of the energy of the wave will transmit through and continue on as a new wave in the medium (transmitted wave), while some of the energy of the wave will reflect back and continue on in the old medium (reflected wave). The amount of transmission/reflection depends on the respective densities of the two media.

Fixed End Reflection

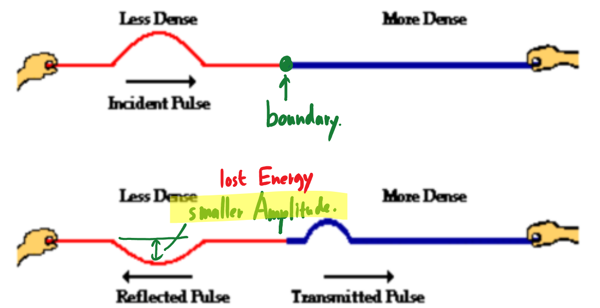
A wave pulse reaching the end of a medium becomes inverted whenever it

- reflects off a fixed end
- moves from a less dense medium into a denser medium

Fixed End Reflection



A wave traveling from a less dense to a more dense medium…



…will be reflected off the boundary and transmitted across the boundary into the new medium. The reflected pulse is inverted.

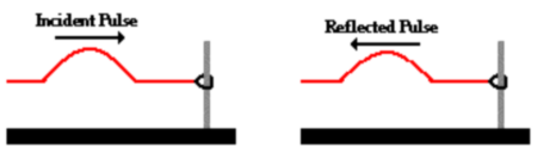
http://www.aplusphysics.com/courses/regents/waves/regents_wave_interference.html

Free End Reflection

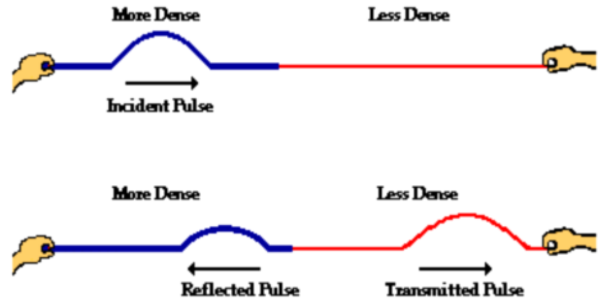
A wave pulse reaching the end of a medium remains upright /erected whenever it

- reflects off a Free end
- moves from a denser medium into less dense medium

Free End Reflection

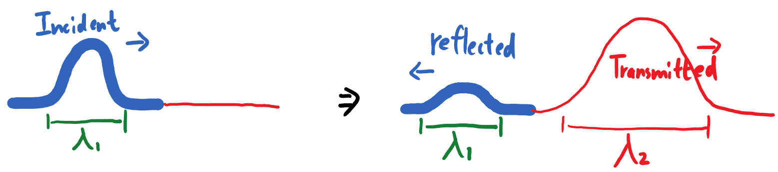


A wave traveling from a more dense to a less dense medium…



…will be reflected off the boundary and transmitted across the boundary into the new medium. There is no inversion.

Example - A wave pulse is sent along a string. The string is attached to a thick rope that is attached to a wall. What happens when the wave reaches the string/rope boundary? Is the reflected wave erect or inverted?

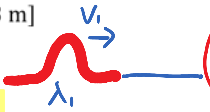


Note: For most boundary interactions:

	Wavelength	Frequency	Speed	Amplitude
Incident Wave	Same	Same	Same	~~[scribbled out]~~
Reflected Wave	Same	Same	Same	smaller
Transmitted Wave	different	Same	faster in the less dense medium	Different.

$V = \lambda f$

Example: A wave travelling along a rope has a speed of 10.0 m/s and a wavelength of 5.00 m. The rope is connected to a light string at the end, and the transmitted wave has a speed of 20.0 m/s. What is the wavelength of the new wave? [13.3 m]



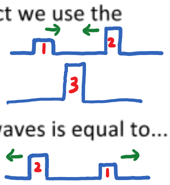
$\lambda_1 = 5m$, $V_1 = 10 m/s$ → $\lambda_2 = ?$, $V_2 = 20 m/s$ → same "f"

$V_1 = \lambda_1 f$
$10 = 5 f$
$f = 2 Hz$

$V_2 = \lambda_2 f$
$20 = \lambda_2 (2)$
$\lambda_2 = 10 m$

Wave Superposition

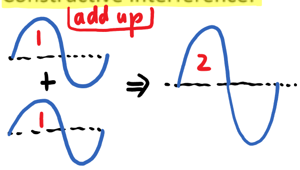
When two waves travel in the same medium they affect the medium independently. To determine their overall effect we use the principle of superposition.



Principle of Superposition:
The total amplitude of the waves is equal to... the sum of the two individule waves.

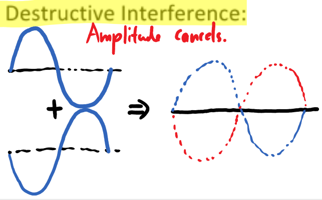
Two waves with the same frequency and **phase**. (same starting point)

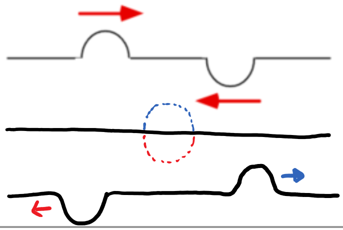
Constructive Interference: (add up)



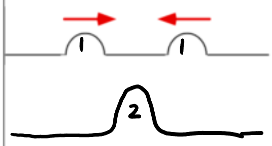
Two waves with the same frequency and opposite phase.

Destructive Interference: Amplitude cancels.

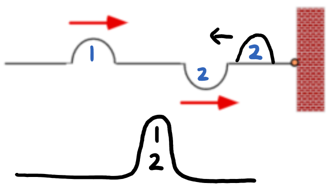




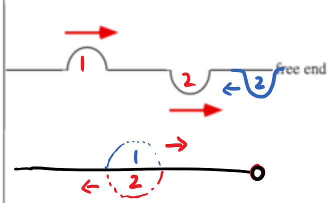
Type Destructive
Pattern:



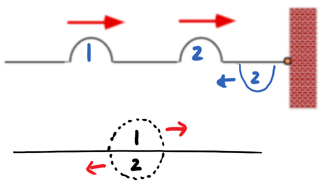
Type Constructive.
Pattern:



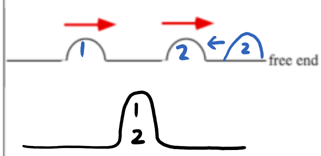
Type C
Pattern:



Type Destructive.
Pattern:



Type Destructive
Pattern:



Type Con
Pattern:

Example - Pulse A is traveling towards pulse B. Pulse A has an amplitude of +2. Pulse B has an amplitude of –3. Draw a diagram of this interaction. What will the amplitude of the resultant wave be? What type of interference is this?

WS#3 Q1–6

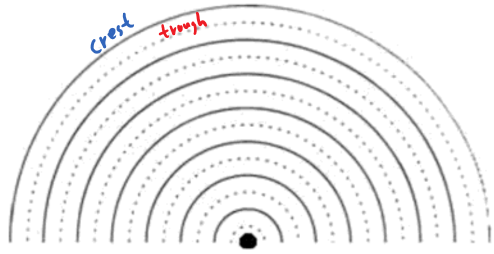
Day 4 Interference

April 23, 2018 8:41 AM

Unit 4 Waves and Optics Day 4

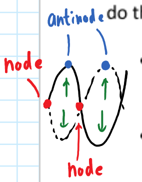
2D Wave Interference

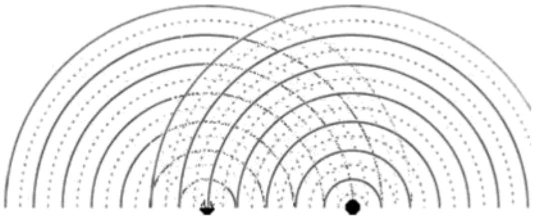
Like 1D waves on a string, a 2D waves on a surface can _interfere_ with one another. This interaction is very complicated and difficult to model for most points, but it can be understood relatively easily using the concept of nodes and antinodes.



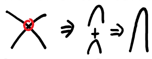
We will generate a two-point-source interference pattern. To do this, we will begin with two point sources like the one shown to the right. Note the _crest_ (solid lines) and _trough_ (dotted lines), with the point source in the center. We are only drawing the upper half of the circular wave; the exact same thing would be found on the lower half of the page.

The interference pattern generated by two such sources side-by-side can be produced by identifying ___________ and __________ where the two waves overlap one another. We will do this in the space below. Use solid dots for antinodes and hollow dots for nodes:

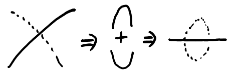




- **ANTINODES**: points where any two wavefronts interfere _constructively_ (crest/crest or trough/trough)



- **NODES**: points where are two wavefronts interfere _destructively_ (crest/trough)



Nodal/Antinodal Lines

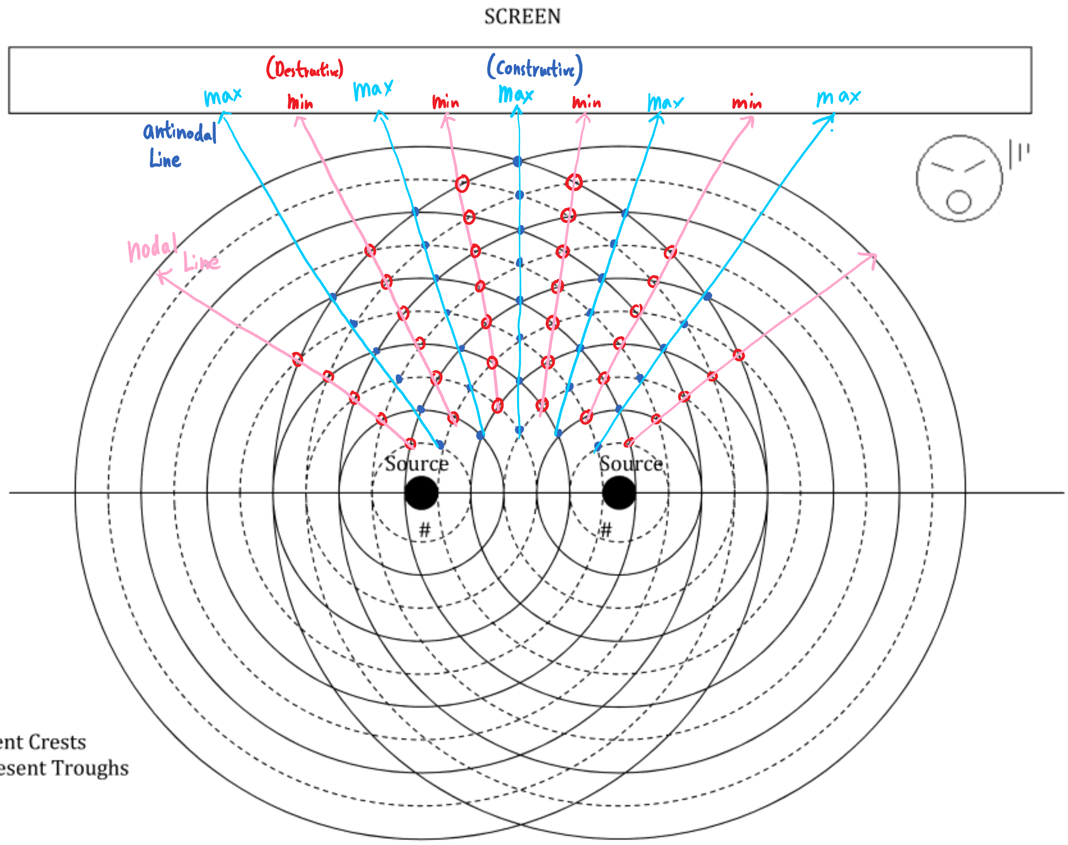
As you fill in the nodes and antinodes, you will observe a pattern where you see lines forming between the two sources. These lines are called nodal and antinodal lines. The density of these lines depends on how _close_ the two sources are:

- If they are far apart relative to their wavelength, there are _many_ lines, but they are small – very distant sources have tiny nodal/antinodal lines that are _dificult_ to see
- If they are close together relative to their wavelength, there are _less_ lines, and they are much _easier_ _to_ _observe_ or pronounced when you look for them

Let's try to build one on the next page

Physics 11 Name:_______________

Two point sources oscillating in Phase: 2D interference Block:______________



Legend:
Solid Circles represent Crests
Dashed Circles represent Troughs

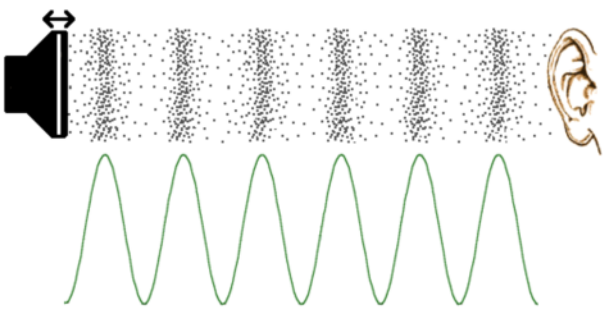
Day 5 Sound

April 24, 2018 9:30 AM

Unit 4 Waves and Optics Day 5

Introduction to Sound

Sound is a longitudinal wave produced by a vibrating object. Imagine a flat surface moving back and forth inside a speaker. The vibrations of the speaker surface result in compressions and rarefactions in the air. Your eardrum, in turn, perceive these vibrations as sound.



Sound Frequency

The pitch of sound is determine by *Frequency*

high-frequency → high-pitch (treble),
low-frequency → Low-pitch (bass).

Determine Max and Min Audible Frequencies (Human)

f_{min}: 20 Hz
f_{max}: 20,000 Hz

Side note: dogs can hear both lower and higher pitched sounds (15 Hz – 50 kHz) than humans, while cats can hear higher pitched sounds than dogs or humans but cannot hear low-pitched sounds that we can hear (60 Hz – 65 kHz).

Speed of Sound

The speed of sound depends on its medium (more dense → faster)

$V_{solid} > V_{liquid} > V_{gas}$

sound travels at 343 m/s in air at room temperature (20°C) or 331 m/s in air at 0 °C.

Sound travels faster in warm air compared to cool air. Speed increases by about 0.6 m/s for 1°C inc of air temperature.

$v_{sound} = 331\ m/s + 0.6\,T$ (T: temperature (°C))

Mach Number

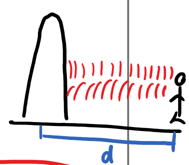
a ratio of the object speed to the speed of sound, so you can calculate it from:

$$Mach\ Number = \frac{v_{object}}{v_{sound}} = \frac{v}{343}$$

ex) What is the speed of a cruise missile travelling at Mach 0.8?

$$0.8 = \frac{V}{343}$$

$$V = 274.4\ m/s$$



WS #5 Sound

Ex) What is the speed of sound at 5 °C air?

$V = 331 + 0.6(5°C) = 334\ m/s$

Ex) A bass guitar produces a 70-Hz sound wave at room (20°C) temperature. Determine the length of the sound wave.

$V_s = 331 + 0.6\,T = 343\ m/s$

$V_{wave} = \lambda f \qquad 343\ m/s = \lambda\,(70\ Hz)$

$\lambda = 4.9\ m$

for everything: $V = \frac{dist}{time}$

for wave: $V = \lambda f$

for sound wave only: $V_s = 331 + 0.6\,T$

Ex) A 250-Hz sound wave is 1.42 m long. Determine the speed of sound in air for this situation and the corresponding air temperature

a) $V_w = \lambda f = 1.42(250) = 355\ m/s$

b) $V_s = 331 + 0.6T$ $\quad 355 = 331 + 0.6T$ $\quad T = 40°C$

Sound Volume

Volume of a sound (or its intensity) is based on the amplitude. of the wave.

Higher amplitude waves → more Energy = louder volume. We use the decibel scale (units decibels, or dB) to measure the intensity of a sound. There is a fancy way to relate decibels to the power delivered to your ear by the sound wave, but the simplest way to think of it is this:

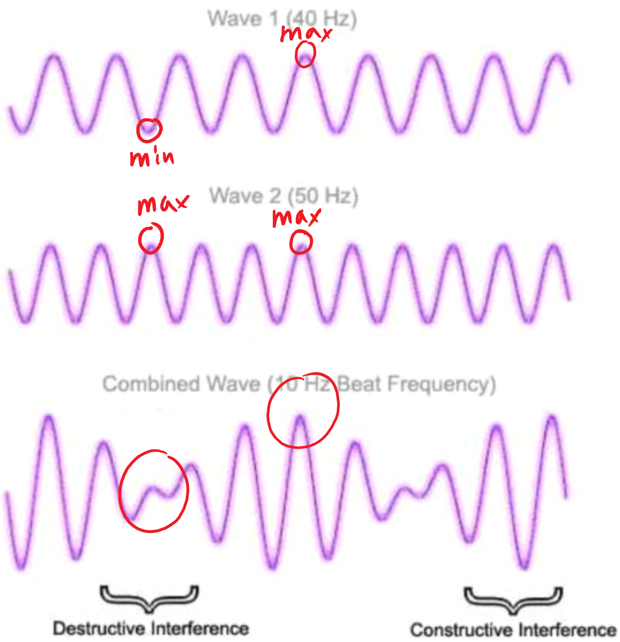
- 0 dB is an arbitrarily defined, incredibly low-intensity sound
- For every increase of 10 dB, the sound is 10x more intense. See the table below:

Sound Intensity (dB)	Intensity Compared to Base Level
0	Base Level
10	10 x
20	100 x
30	1000 x

Beat

An interference pattern between two sounds of slightly different frequency. What you hear is a **beat** with periodic variation in volume.

$$f_{beat} = f_2 - f_1$$



Quiz next day: Day 1, 2, 3, 5

Wave Worksheet #5: Assume the speed of sound in air is 343 m/s unless otherwise noted.

1. The speed of sound, like all waves, depends on the ________________ through which it travels. Sound travels fastest in _____________ (solids, liquids, gases) and slowest in _____________.

2. The speed of sound in air depends on the ____________________ of the air. At 0°C, the speed of sound in air is _____________ m/s. For every degree above 0°C, the speed ____________ by 0.6 m/s. For every degree below 0oC, the speed_________________by 0.6 m/s.
The equation is:

$$v_{sound} = \underline{331}\ \text{m/s} + 0.6\ \underline{T}$$

3. What is the speed of sound at 35°C? _____________
4. What is the speed of sound at -20°C? _____________

5. Other than the velocity/temperature equation, there are two important equation involving the speed of sound:

V= λ x f	V= $\frac{d}{t}$

Rearrange one equation to solve for: f = _________ ; ? =__________
Rearrange the other to solve for: d = __________ ; t = __________

6. A 320 Hz tuning fork will produce a wave of what wavelength in air at 22°C?

7. We see a bolt of lightning and 4 s later we hear the thunderclap. If the speed of sound in air is 343m/s, how far away is the lightning?

8. How many seconds will it take an echo to reach your ears if you yell toward a mountain 82 m away on a day when the air temperature is 0°C?

82m ×2 → $V_s = 331\ m/s$ $V = \frac{d}{t}$ $331 = \frac{164m}{t}$ $t = 0.5\ sec$

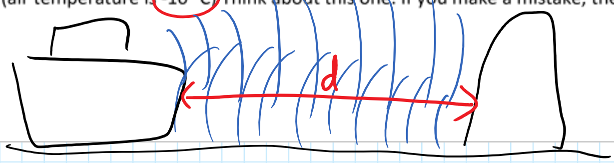
9. You look up and see a helicopter pass directly overhead. 3.10s later you hear the sound of the engine. If the air temperature is 23.0°C, how high was the helicopter flying?

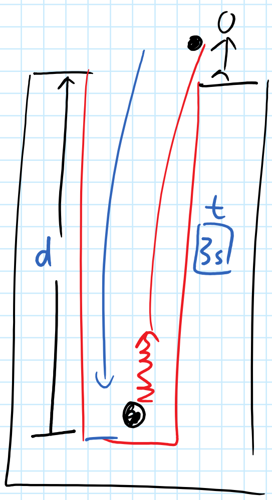
10. Navy ships use sonar (sound navigation and ranging) to detect submarines. A sound pulse sent by the ship reflects off the submarine. If the submarine is 2.2 km away from the ship, and the speed of sound in seawater is 1400 m/s, how long will it take the sound pulse to travel out and back?

11. A person is listening with his ear against the rail for an oncoming train. When the train is 1.65 km away, how long will it take him to hear the sound of the whistle? (The speed of sound in steel is 5200 m/s.)

How long would it take his friend who is standing nearby to hear the same whistle if the air temperature is 0°C?

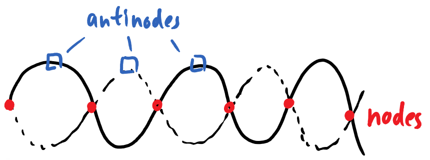
12. If a ship captain sounds a foghorn toward an iceberg and hears the echo 4.6 s later, how far away is the iceberg? (air temperature is -10 °C) Think about this one. If you make a mistake, the ship could run into the iceberg!!!





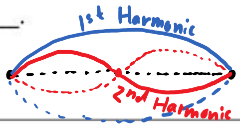
$V_s = 331\ m/s + 0.6(T)(-10) = 325\ m/s$

$V = \frac{dist}{time}$ $325 = \frac{dist}{4.6s}$ $dist = 1495\ m$ $d = \frac{1}{2}(1495) = 748\ m$



Unit 4 Waves and Optics Day 6
Standing Wave and Diffraction

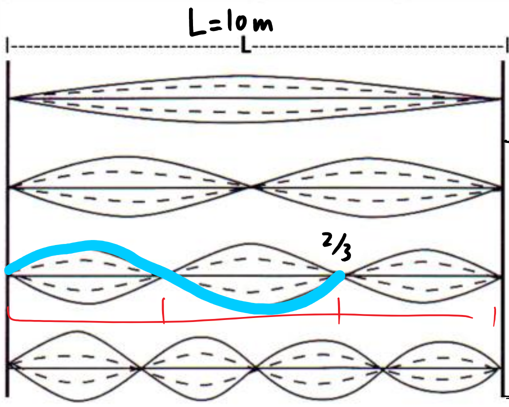
- Standing waves are caused by constructive and destructive interference
- Areas of complete destructive interference have no amplitude and are called nodes
- Areas of complete constructive interference have Large amplitude are called antinodes
- Standing waves have fixed natural frequencies called harmonics.



How to create Standing Waves?

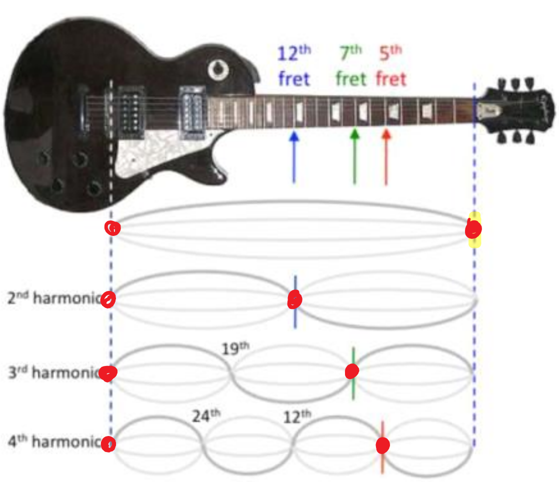
- When a wave hits a fixed boundary it will reflect and invert its amplitude.
- If a series of waves are sent along a string the reflected pulse will...... interfere with itself.
- If the waves are sent at just the right frequencies. we will create a standing wave

Two fixed ends (Standing wave in a rope. Ex, string instruments: guitar, piano or violin)



Harmonic	Wavelength (λ)	
1st	$\lambda_1 = 2L \quad \lambda_1 = \frac{4}{2}L$	fundamental
2nd	$\lambda_2 = \frac{4}{4}L$	1st overtone
3rd	$\lambda_3 = \frac{4}{6}L$	2nd overtone
4th	$\lambda_4 = \frac{4}{8}L$	3rd overtone.

Harmonics on a Guitar

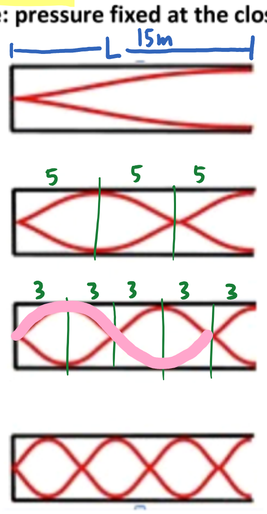


When you pluck a string, you set up a **standing wave**, with stationary nodes at the nut and bridge. **When you fret the string** (i.e. push it down with your finger), you change the length between these nodes, and it changes the note.

Fun fact: **The 12th fret is exactly halfway along the string**, and when fretted there will produce a note **one octave higher** than the unfretted string. (For example, the top string is generally an E, and the note at the 12th fret is a higher E.)

One open End – (standing wave in air columns. Ex. Clarinet, saxophone)

Mouthpiece – pressure varies as you blow (varying pressure = antinodes).
Note: pressure fixed at the closed end = nodes



Harmonic	Wavelength (λ)
1^{st}	$\lambda_1 = \frac{4}{1} L$
2^{nd}	$\lambda_2 = \frac{4}{3} L$
3^{rd}	$\lambda_3 = \frac{4}{5} L$
4^{th}	$\lambda_4 = \frac{4}{7} L$

Open Both end – (standing wave in air column. Ex. Flute, organ)

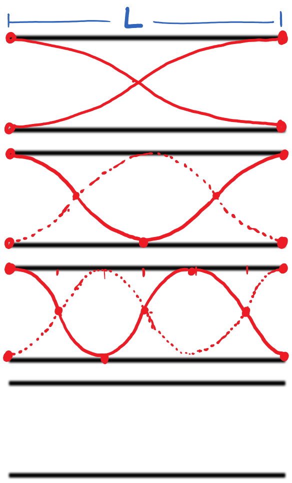
Wavelength (λ)

1st Harmonic $\lambda_1 = 2L = \frac{4}{2} L$

2nd Harmonic $\lambda_2 = \frac{4}{4} L$

3rd Harmonic $\lambda_3 = \frac{4}{6} L$

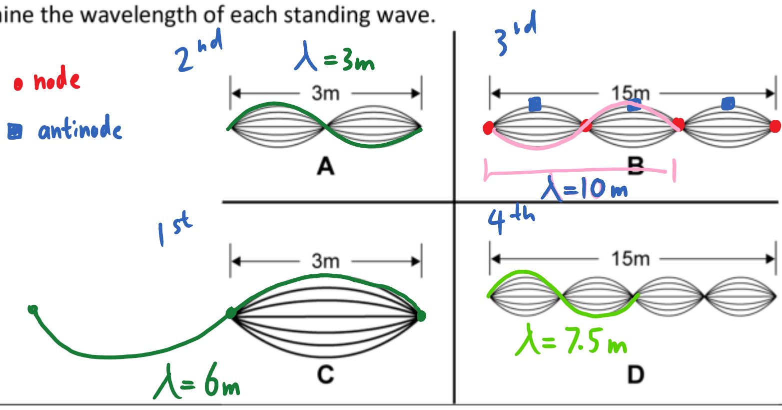
4th Harmonic $\lambda_4 = \frac{4}{8} L$

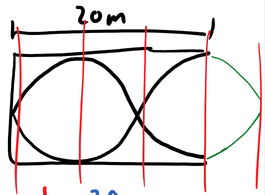


WS # 6

Ex) Use the graphic below to answer these questions

1) Which harmonic is shown in each of the strings below?
2) Label the nodes and antinodes on each of the standing waves shown below.
3) How many wavelengths does each standing wave contain?
4) Determine the wavelength of each standing wave.

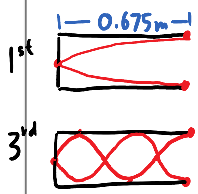




$\lambda = \frac{20}{3} \times 4$

$\lambda = 26.7\,m$

Ex) A clarinet is essentially a tube that is open at only one end. Sketch the wave patterns associated with the first and third harmonic of a clarinet that is 67.5 cm long. What frequencies would these waves have if the clarinet was played at 21.0oC? (128 Hz, 383 Hz)



$\lambda_1 = \frac{4}{1}L = 2.7\,m$ (L = 0.675)

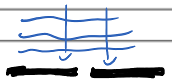
$f_1 = \frac{V}{\lambda_1} = \frac{343.6}{2.7\,m} = 127\ Hz$

$V_s = 331 + 0.6(21\,°C) = 343.6\,m/s$

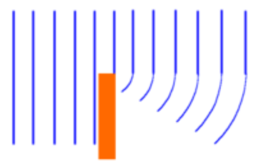
$\lambda_3 = \frac{4}{5}L = 0.54\,m$ (L = 0.675)

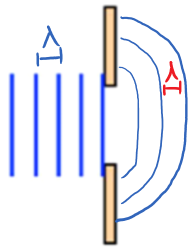
$f_2 = \frac{V}{\lambda_2} = \frac{343.6}{0.54} = 636.3\ Hz$

Diffraction



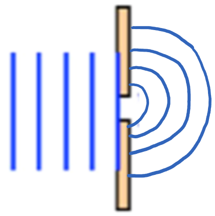
When waves hit a ___slit___ (hole) or a ___boundary___ (like a corner) they bend around. Forming ___circular___ waves that spread out. The ___smaller___ the aperture compared to the wavelength, the more pronounced this effect is (Lets see and sketch some examples).





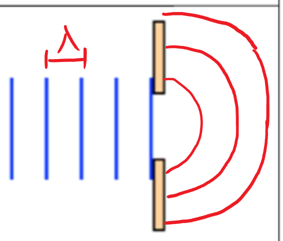
Wide gap →

___weak___ **diffraction effect**



Narrow gap →

___strong___ **diffraction effect**



Large wavelength →

___strong___ **diffraction effect**

Wave Worksheet #6: Standing wave

1) A standing wave in a rope has a frequency of 28 Hz at the second harmonic.

   a. If the wavelength is 0.20 m, what is the distance between nodes? (0.10 m)
   b. What is the speed of the waves that make up the standing wave? (5.6 m/s)
   c. What would the frequency of a rope vibrating at the third harmonic be? (42 Hz)

2) An 85 cm long guitar string is plucked and vibrates at the fourth harmonic. What is the frequency of the sound produced if the speed of sound is 332 m/s? (780 Hz)

3) Two children playing with a 6.0 m long skipping rope produce a standing wave pattern with five “loops”. If the skipping rope is vibrating at 85 vibrations per minute, what is the speed of the vibration producing the standing wave pattern? (3.4 m/s)

4) Hollow wind chimes open at both ends resonate best at their third harmonic. How long should a chime be to produce a sound of 128 Hz when the temperature is 19 °C? (4.0 m)

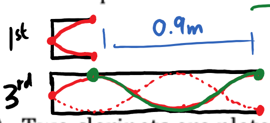
5) A tuba can be considered a tube open at both ends. A tuba with a length of 7.0 m is played at its fundamental note at a temperature of 21 °C. What is the frequency of the fundamental? (25 Hz)

6) A flute is essentially a tube that is open at both ends. Sketch the wave patterns associated with the first and third harmonic of a flute that is 67.5 cm long. What frequencies would these waves have if the flute was played at 21.0 °C? (1020 Hz, 763 Hz)

1st Harmonic 3rd Harmonic

7) A tuning fork was sounded over an adjustable air column open at one end. It was found that the distance between the fundamental and the 2nd overtone was 90.0 cm. What was the frequency of the tuning fork if the air temperature was 0 °C? (370 Hz)

$V_s = 331\,m/s$



$\lambda = 0.9m$

$V = f\lambda$ $331 = f(0.9)$ $f = 368\,Hz$

8) Two clarinets are plated at the same time in a room with a temperature of 21 °C. One clarinet is 1.20 m long and the second is 1.22 m long. What beat frequency would you hear if both were played at their fundamental frequency at the same time? (1.2 Hz)

$\lambda_1 = \frac{4}{1} L_1$ $L_1 = \frac{1}{4}\lambda_1$ $L_3 - L_1 = 0.9$

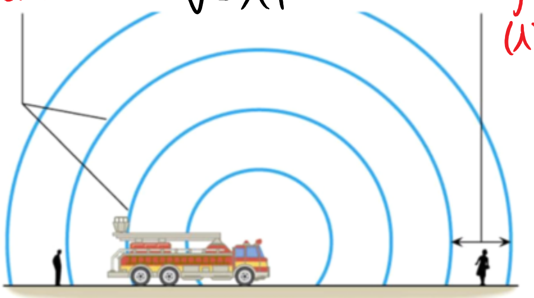
$\lambda_3 = \frac{4}{5} L_3$ $L_3 = \frac{5}{4}\lambda_3$ (same) $\frac{5}{4}\lambda - \frac{1}{4}\lambda = 0.9$

$1\lambda = 0.9\,m$

Unit 4 Waves and Optics Day 7
Doppler Effect

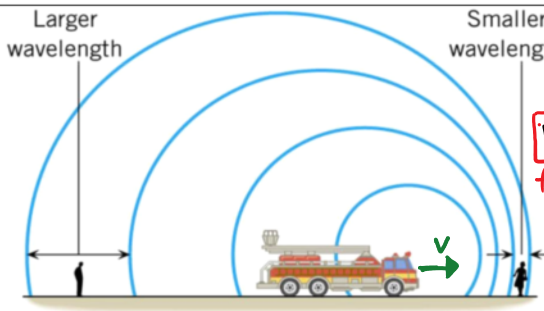
- Have you ever listened to an ambulance drive by quickly with their sirens going? What did it sound like?
- __high__ pitch as the ambulance was coming, __Lower__ pitch as it was leaving
- This phenomenon is called __Doppler Effect__ after Christian Doppler, who first labeled it in 1842.

$V = \lambda f$



Truck at rest

- when the truck is still, the sounds waves move outward in all the directions at the same __speed__ and __frequency__



Truck moving

$V = f\lambda$ (V fixed.)

- when the truck is moving, it produces a sound wave (compression), move, produce another sound wave, etc.
- since it moves between sound production, the air compressions (sound) are __getting closer__ in front of the truck and __getting further apart__ behind the truck

Short __λ__ → **higher** __f__ → __higher__ **pitch**

long __λ__ → **Lower** __f__ → __Lower__ **pitch**

V_{obs} → V_{source}

$f_o = f_s\left(\frac{v_w \pm v_{observer}}{v_w \mp v_{source}}\right)$ (observer, sound wave, source)	f_o= frequency observed f_s= frequency of source	v_s= speed of the source v_o= speed of the observer v_w= speed of wave (sound)	• ±/∓ **Use the top signs when the object is moving** __toward__ **the other object**

both (toward): $\frac{V_w + V_o}{V_w - V_s}$

both (away): $\frac{V_w - V_o}{V_w + V_s}$

Ex) What frequency is received by a mouse just before being dispatched by a hawk flying at it at 25.0 m/s and emitting a screech of frequency 3500 Hz? Take the speed of sound to be 331 m/s.

$V_w = 331\,m/s$, $V_s = 25\,m/s$, $f_s = 3500\,Hz$, $f_o = ?$, $V_o = 0$

$$f_o = f_s\left[\frac{V_w + V_o}{V_w - V_s}\right] = 3500\left[\frac{331}{331-25}\right] = 3786\ Hz$$

higher pitch

Ex) You are driving down the road at 20 m/s when you approach a car going the other direction at 15 m/s with their radio playing loudly. If you hear a certain note at 600 Hz, what is the original frequency? (Assume speed of sound is 343 m/s)

$V_w = 343$ m/s

$f_o = 600$ Hz, V_o 20 m/s

V_s 15 m/s, $f_s = ?$

$$f_o = f_s \left[\frac{V_w + V_o}{V_w - V_s}\right]$$

$$600 = f_s \left[\frac{343+20}{343-15}\right]$$

$$600 = f_s \left[\frac{363}{328}\right]$$

$f_s = 542$ Hz

Ex) A duck is flying overhead while you stand still. As it moves away, you hear its quack at 190 Hz. Because you are a brilliant naturalist, you know that this type of duck quacks at 200 Hz. How fast is the duck flying?

$V = 343$ m/s

$f_s = 200$ Hz

$V_s = ?$

$f_o = 190$ Hz

$V_o = \varnothing$

$$f_o = f_s \left[\frac{V_w}{V_w + V_s}\right]$$

↑ Source away

$$190 = 200 \left[\frac{343}{343 + V_s}\right]$$

÷200 ÷200

$$(0.95) = \frac{343}{(343 + V_s)}$$

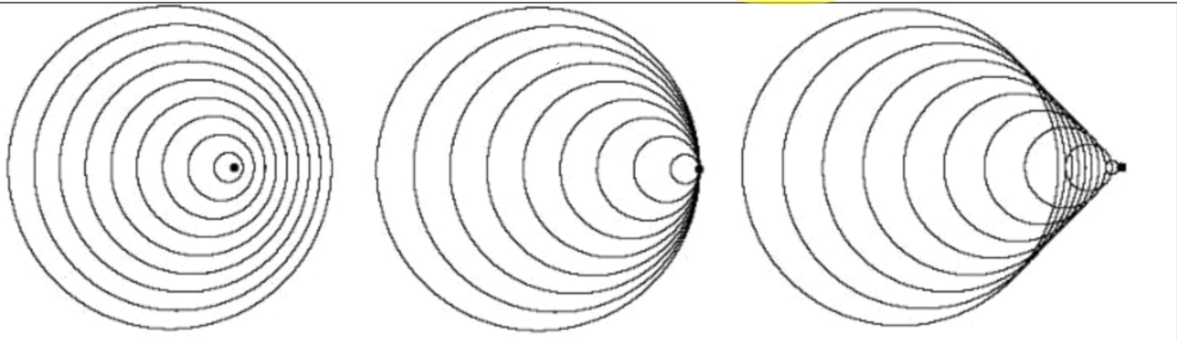
$343 + V_s = 361$

$V_s = 18.1$ m/s

~65 km/hr

Sonic Boom: The image below shows how wavefronts travel for an object traveling slower than the speed of sound, equal to the speed of sound and faster than the speed of sound:

WS # 7



(1) Slower than sound.	(2) At speed of sound.	(3) Faster than sound.
In case (1), the different spacing at the front and behind the object as it moves to the right explains why you hear different pitches as an ambulance gets closer and then drives past you: at the front, the wave fronts are packed closer together, so it sounds high-pitched; the opposite is true at the back	In case (2), at the leading edge all of the wave fronts are stacked up: this createes a VERY high-pressure zone in front of the object.	In case (3), anyone standing on the ground as the line of sound waves hits experiences a Sonic boom: all of those stacked up sound waves make a very loud noise that hits you all at once, sounding like an explosion.

Worksheet 7: Doppler Effect and Sonic Booms

1. The pitch of a sound depends on the ______________ of the sound waves that reach the _____________.

2. In each case, tell whether the pitch rises or drops:
   a. The source of a sound moves away from the observer, who stands still. _____
   b. The source stays still and the observer moves toward the source. ______
   c. The source and observer move toward each other. ___________
   d. The source stays still, and the observer moves away. ___________

3. All the cases above are examples of the ____________ Effect.

Calculation

1. When you hear a sonic boom, you often cannot see the plane that made it. Why is that?

2. When a car is at rest, its horn emits a frequency of 600 Hz. A person standing in the middle of the street hears the horn with a frequency of 580 Hz. Should the person jump out of the way? Account for your answer.

3. (a) What frequency is received by a person watching an oncoming ambulance moving at 110 km/h and emitting a steady 800-Hz sound from its siren? The speed of sound on this day is 345 m/s. (b) What frequency does she receive after the ambulance has passed? (878 Hz, 735 Hz)

4. (a) At an air show a jet flies directly toward the stands at a speed of 1200 km/h, emitting a frequency of 3500 Hz, on a day when the speed of sound is 342 m/s. What frequency is received by the observers? (b) What frequency do they receive as the plane flies directly away from them?

5. What frequency is received by a mouse just before being dispatched by a hawk flying at it at 25.0 m/s and emitting a screech of frequency 3500 Hz? Take the speed of sound to be 331 m/s.

6. A spectator at a parade receives an 888-Hz tone from an oncoming trumpeter who is playing an 880-Hz note. At what speed is the musician approaching if the speed of sound is 338 m/s? (3.05 m/s)

7. A commuter train blows its 200-Hz horn as it approaches a crossing. The speed of sound is 335 m/s. (a) An observer waiting at the crossing receives a frequency of 208 Hz. What is the speed of the train? (b) What frequency does the observer receive as the train moves away? (12.9 m/s, 193 Hz)

8. Suppose you are stopped at a traffic light, and an ambulance approaches you from behind with a speed of 18 m/s. the siren on the ambulance produces sound with a frequency of 955 Hz. The speed of sound I air is 343 m/s. What is the wavelength of the sound reaching your ears? (0.340 m)