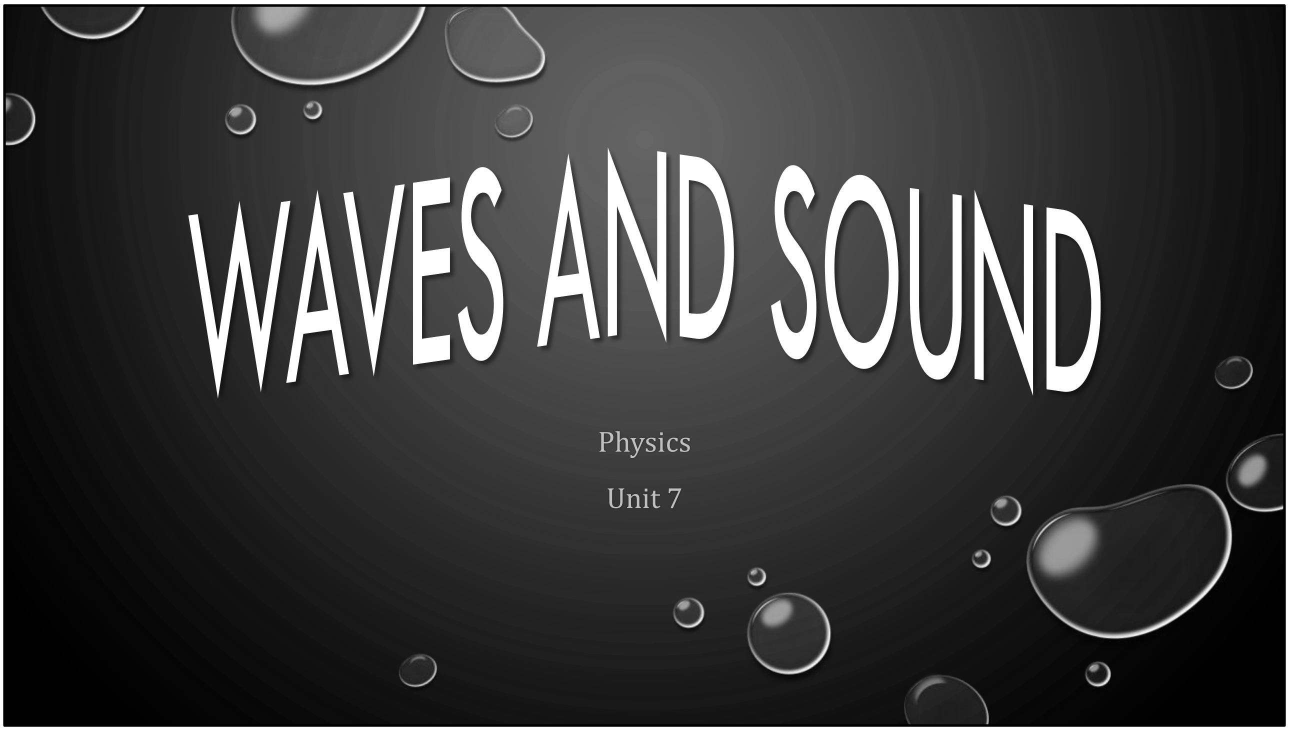

Physics Unit 7

- This Slideshow was developed to accompany the textbook
    - *OpenStax Physics*
        - *Available for free at https://openstaxcollege.org/textbooks/college-physics*
    - *By OpenStax College and Rice University*
    - *2013 edition*
- Some examples and diagrams are taken from the textbook.

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07-01 WAVES

In this lesson you will…

- State the characteristics of a wave.
- Calculate the velocity of wave propagation.
- Observe the vibrations of a guitar string.
- Determine the frequency of oscillations.

07-01 Waves

Waves
- A traveling disturbance
- Carries energy from place to place

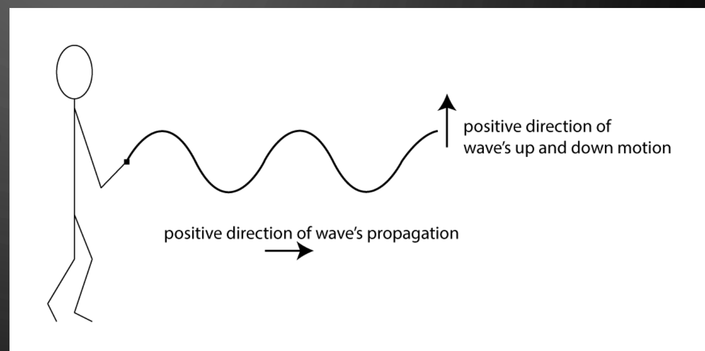
- When a boat makes a wave,
  - the water itself does not get up and move
  - the water pushes a little, then moves back
  - energy is transferred in the wave and is what you feel

If the water moved in bulk, then there would be a hole in the water.

07-01 Waves

- Transverse
  - Up and down disturbance
  - Wave travels left or right
  - Disturbance is perpendicular to direction of travel

  - Examples:
    - Radio waves, light waves, microwaves, stringed instruments

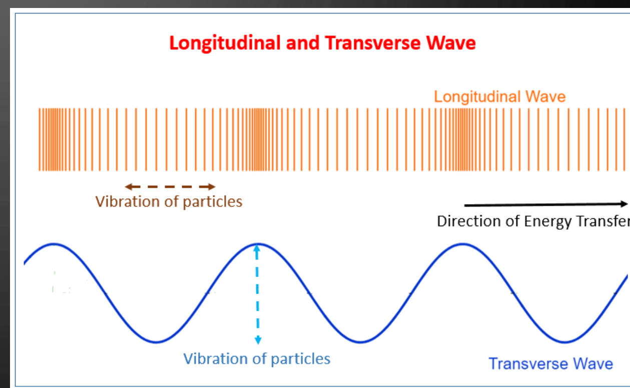


Demonstrate with a slinky

07-01 WAVES

- Longitudinal Waves
  - Disturbance is left and right
  - Direction of travel is left or right
  - Disturbance and direction of travel are parallel
  - Series of compressed and stretched regions

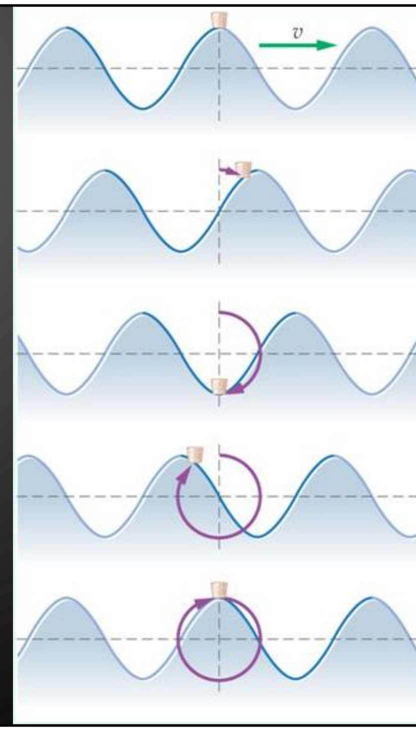
  - Example:
    - Sound



Demonstrate with a slinky

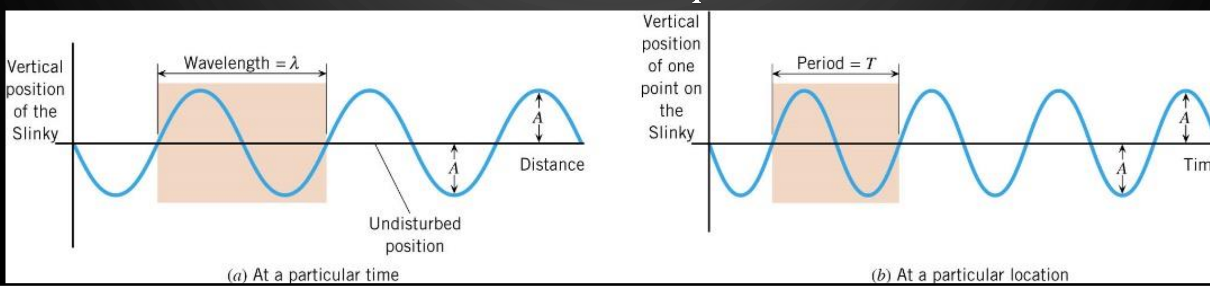
07-01 WAVES

- Other
  - Water waves are a combination
  - Water at the surface of a water wave travels in small circles



07-01 WAVES

- Periodic → pattern is regularly repeated
- Cycle → one unit of pattern
- Wavelength (λ) → Distance of one cycle
- Amplitude (A) → height from equilibrium to crest



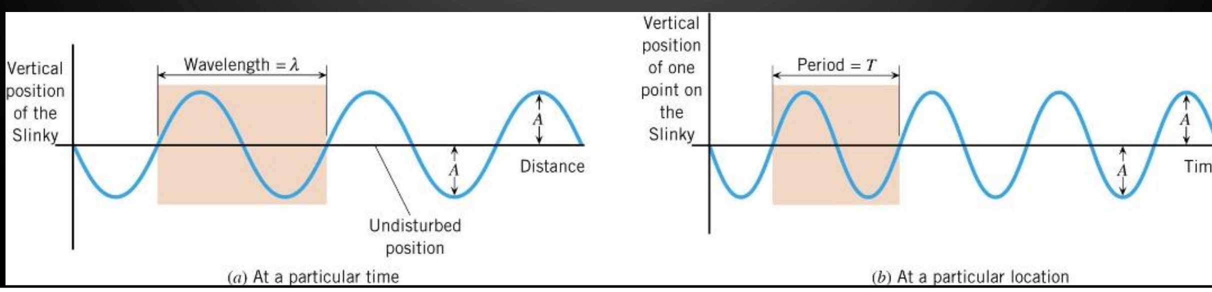
Put drawing on board and label the parts

The amplitude of a longitudinal wave is the amount of compression instead of a height

07-01 WAVES

- Period (T) → time it takes for one cycle
  - Unit: s
- Frequency (f) → # of cycles per second
  - Unit: 1/s = 1 hertz (Hz)

- $f = \frac{1}{T}$
- $v = \frac{\lambda}{T} = f \cdot \lambda$



07-01 WAVES

- WAUS operates at a frequency of 90.7 MHz. These waves travel at 2.99×10^8 m/s. What is the wavelength and period of these radio waves?

- $\lambda = 3.30$ m
- $T = 1.10 \times 10^{-8}$ s

$$v = f\lambda$$
$$2.99 \times 10^8 \frac{m}{s} = 90.7 \times 10^6\ Hz\,\lambda$$
$$\lambda = 3.30\ m$$

$$f = \frac{1}{T} \rightarrow 90.7 \times 10^6\ Hz = \frac{1}{T} \rightarrow T = \frac{1}{90.7 \times 10^6\ Hz} = 1.10 \times 10^{-8}\ s$$

07-01 Waves

- You are sitting on the beach and notice that a seagull floating on the water moves up and down 15 times in 1 minute. What is the frequency of the water waves?

- f = 0.25 Hz

$$Frequency\ is\ \frac{cycles}{seconds}$$
$$f = \frac{15}{60\ s} = 0.25\ Hz$$

07-01 HOMEWORK

- Wave hello to some exercises.

- Read 16.1, 16.3

07-02 HOOKE'S LAW AND SIMPLE HARMONIC MOTION

In this lesson you will…

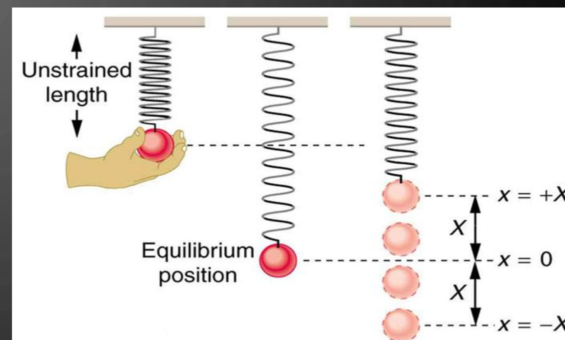
- Explain Newton's third law of motion with respect to stress and deformation.
- Describe the restoration of force and displacement.
- Calculate the energy in Hook's Law of deformation, and the stored energy in a string.
- Describe a simple harmonic oscillator.
- Explain the link between simple harmonic motion and waves.

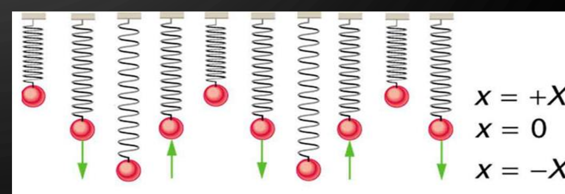
07-02 LAB

- Do the 07-02 Simple Harmonic Motion Lab

07-02 Hooke's Law and Simple Harmonic Motion

- A mass is hung from a spring
- If it just hangs, it is at equilibrium position
- If stretched and released, it bounced up and down



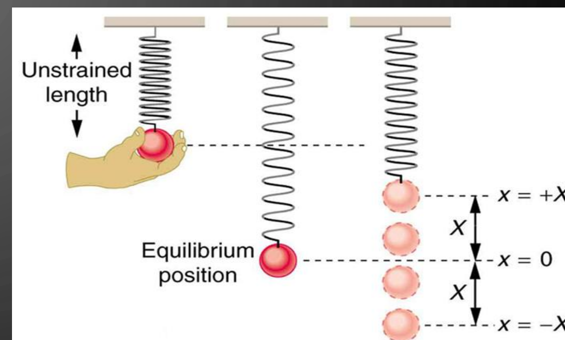


07-02 HOOKE'S LAW AND SIMPLE HARMONIC MOTION

- Hooke's Law

$$F = -kx$$

- F = restoring force
- x = distance displaced
- k = spring constant



- Force will pull the mass back toward equilibrium
- As mass gets to equilibrium, it has momentum, so it continues past

07-02 HOOKE'S LAW AND SIMPLE HARMONIC MOTION

- Energy in Hooke's Law
  - Since a force acts over a distance, work is done

$$PE_{el} = \frac{1}{2}kx^2$$

Called elastic potential energy

07-02 Hooke's Law and Simple Harmonic Motion

- A Nerf dart gun uses a spring to launch a dart. If it takes 24 N of force to compress the spring 6 cm, what is the spring constant? How much potential energy does it contain?

- $PE_{el} = 0.72\ J$

$$F = -kx$$
$$24\ N = -k(-0.06\ m)$$
$$k = 400\frac{N}{m}$$

$$PE_{el} = \frac{1}{2}kx^2$$
$$PE_{el} = \frac{1}{2}\left(400\frac{N}{m}\right)(0.06\ m)^2$$
$$PE_{el} = 0.72\ J$$

07-02 HOOKE'S LAW AND SIMPLE HARMONIC MOTION

- On a string, if one part of the string is pulled up (a wave pulse created),
  - Then the next piece of the string is pulled up
  - Then the next piece of the string is pulled up, etc.
  - After the pulse passed the string moves back down to the equilibrium position due to Hooke's Law
  - The more force, the quicker the string accelerates back and the faster the wave travels.

07-02 HOOKE'S LAW AND SIMPLE HARMONIC MOTION

Speed of a Wave on a String

- Speed of a wave depends on the medium
- For a string, the speed depends on
  - Tension
  - Linear density (m/L)

$$v = \sqrt{\frac{F}{m/L}}$$

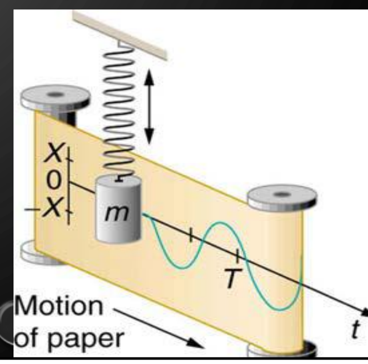
07-02 HOOKE'S LAW AND SIMPLE HARMONIC MOTION

- Simple harmonic motion
  - Motion that regularly repeats
  - Frequency independent of amplitude

$$T = 2\pi\sqrt{\frac{m}{k}}$$

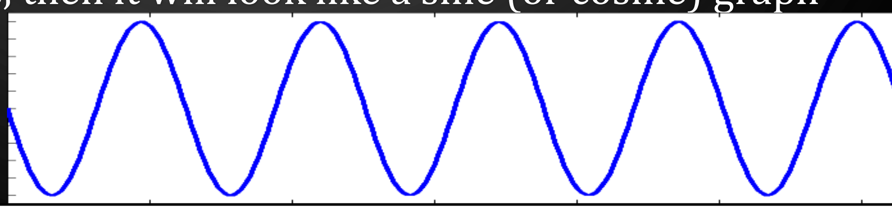
$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

- If a graph of position versus time of simple harmonic motion is made, a wave is formed



07-02 HOOKE'S LAW AND SIMPLE HARMONIC MOTION

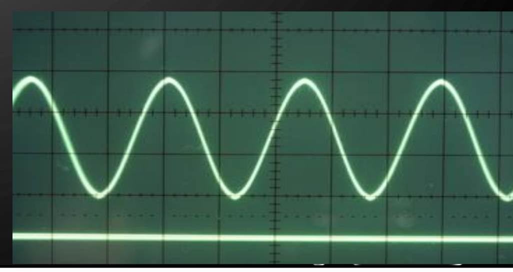
- Think of a point on a string some distance (x) from the origin
- We want to know the vertical displacement (y) of the particle at any given time
- If the wave repeats, then it will look like a sine (or cosine) graph
- $y = A\cos\left(\frac{2\pi t}{T}\right)$



07-02 Hooke's Law and Simple Harmonic Motion

- A wave has an amplitude of 1.5 cm, a speed of 20 m/s, and a frequency of 100 Hz. Write the equation of the wave position of the wave.

- $y = 0.015\cos(200\pi t)$



$$y = \mathrm{A}\cos(2\pi t/T)$$
$$A = 0.015\ m$$
$$f = 100\ Hz \rightarrow T = \frac{1}{100\ Hz} = 0.01\ s$$
$$y = 0.015\cos\left(\frac{2\pi t}{0.01\ s}\right)$$
$$y = 0.015\cos(200\pi t)$$

07-02 HOMEWORK

- These problems harmonize with the lesson
- Read 17.1, 17.2

07-03 SOUND, SPEED, FREQUENCY, AND WAVELENGTH

In this lesson you will…

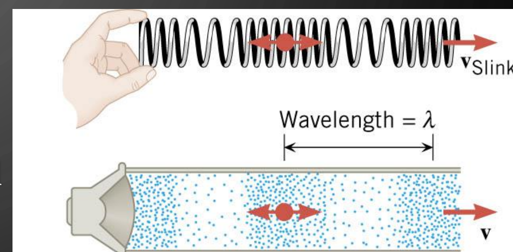
- Define sound and hearing.
- Describe sound as a longitudinal wave.
- Define pitch.
- Describe the relationship between the speed of sound, its frequency, and its wavelength.
- Describe the effects on the speed of sound as it travels through various media.
- Describe the effects of temperature on the speed of sound.

07-03 LAB

- Do the 07-03 Properties of Sound Lab

07-03 SOUND, SPEED, FREQUENCY, AND WAVELENGTH

- How sound is made
  - Some vibrating object like a speaker moves and compresses the air
  - Air pressure rises called ***Condensation***
  - Condensation moves away at speed of sound
  - Object moves back creating less air pressure called ***Rarefaction***
  - Rarefaction moves away at speed of sound
  - Particles move back and forth

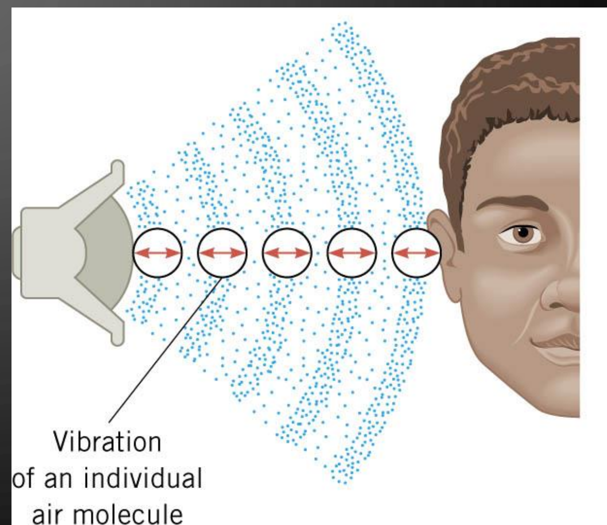


Maybe have big speaker with bouncing something on it

07-03 SOUND, SPEED, FREQUENCY, AND WAVELENGTH

- Distance between consecutive condensations or rarefactions is wavelength

- String or speaker makes air molecule vibrate
- That molecule pushes the next one to vibrate and so on
- When it hits the ear, the vibrations are interpreted as sound



07-03 SOUND, SPEED, FREQUENCY, AND WAVELENGTH

- 1 cycle = 1 condensation + 1 rarefaction
- Frequency = cycles / second
- 1000 Hz = 1000 cycles / second

- Each frequency has own tone
  - Sounds with 1 frequency called ***Pure Tone***

- Healthy young people can hear frequencies of 20 to 20,000 Hz

07-03 SOUND, SPEED, FREQUENCY, AND WAVELENGTH

- Brain can interpret frequency as pitch
  - High freq = high pitch
  - Subjective because most people don't have perfect pitch

- Some electronic devices can produce and detect exact frequencies

07-03 Sound, Speed, Frequency, and Wavelength

- The condensations have more pressure than the rarefactions
- Amplitude = highest pressure

- Typical conversation, Amp = 0.03 Pa
- Atmospheric air pressure = 101,000 Pa

- Loudness is ear's interpretation of pressure amplitude

Loudness is subjective, pressure is not.
Measure pressure to see if damaging

07-03 SOUND, SPEED, FREQUENCY, AND WAVELENGTH

- For all waves

$$v_w = f\lambda$$

- Sound travels slowest in gases, faster in liquids, and fastest in solids

- Air at 20 °C → 343 m/s
- Fresh Water → 1482 m/s
- Steel → 5960 m/s

07-03 SOUND, SPEED, FREQUENCY, AND WAVELENGTH

- Speed of sound depends on properties of medium

- In gases
  - Sound is transmitted only when molecules collide
  - So we derive formula from speed of molecules
    - And speed changes with temperature

07-03 SOUND, SPEED, FREQUENCY, AND WAVELENGTH

- For air

$$v_w = \left(331\frac{m}{s}\right)\sqrt{\frac{T}{273\ K}}$$

  - where T is in Kelvin

07-03 SOUND, SPEED, FREQUENCY, AND WAVELENGTH

- What wavelength corresponds to a frequency of concert A which is 440 Hz if the air is 25 °C?

- $\lambda = 0.786\ m$

$$T = 25\ °C = 298\ K$$

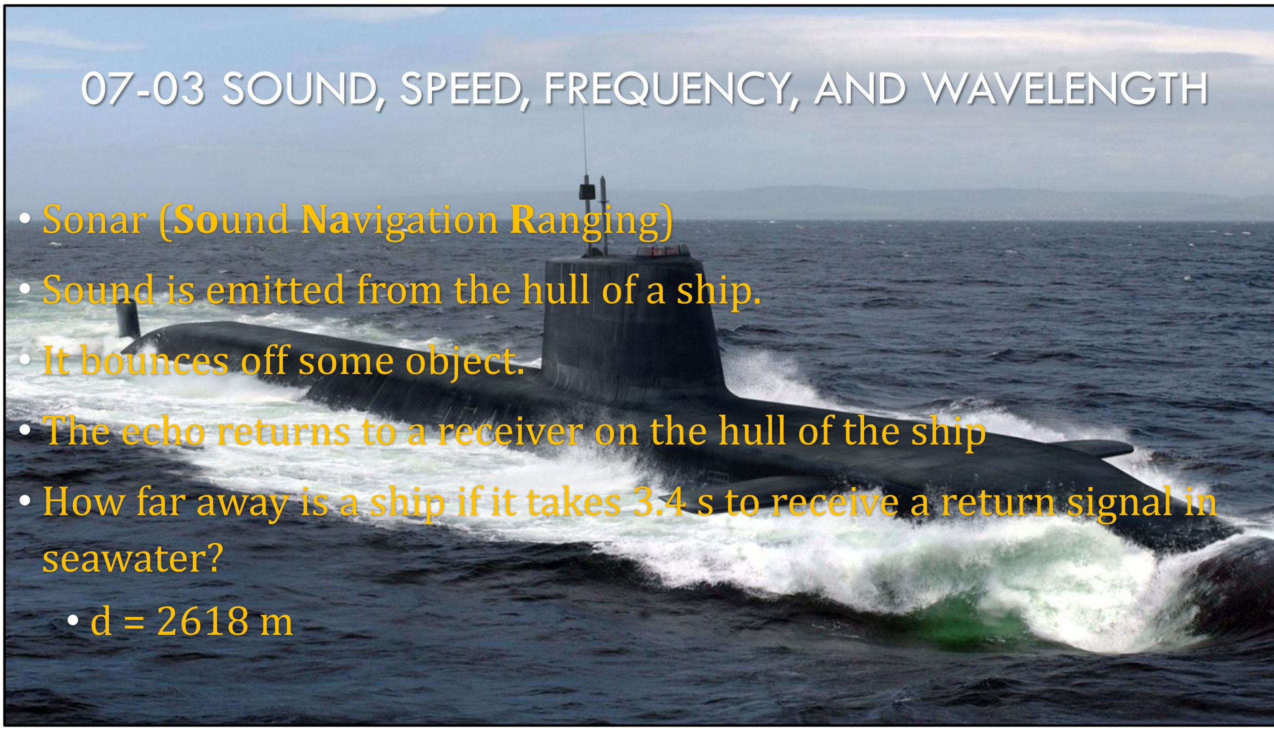
$$v_w = \left(331\,\frac{m}{s}\right)\sqrt{\frac{T}{273\ K}}$$

$$v_w = \left(331\,\frac{m}{s}\right)\sqrt{\frac{298\ K}{273\ K}} = 345.8\,\frac{m}{s}$$

$$v_w = f\lambda$$

$$345.8\,\frac{m}{s} = 440\ Hz\ \lambda$$

$$\lambda = 0.786\ m$$



$$v = 1540\ m/s$$

$$x = vt \rightarrow x = \left(1540\frac{m}{s}\right)(3.4\ s) \rightarrow x = 5236\ m$$

This the distance to the object and back again. So divide it by 2 → $x = 2618\ m$

07-03 HOMEWORK

- These problems sound like you could speed right through them.
- Read 17.3

07-04 Sound Intensity and Sound Level

In this lesson you will…

- Define intensity, sound intensity, and sound pressure level.
- Calculate sound intensity levels in decibels (dB).

07-04 LAB

- Do the 07-04 Intensity vs Distance Lab

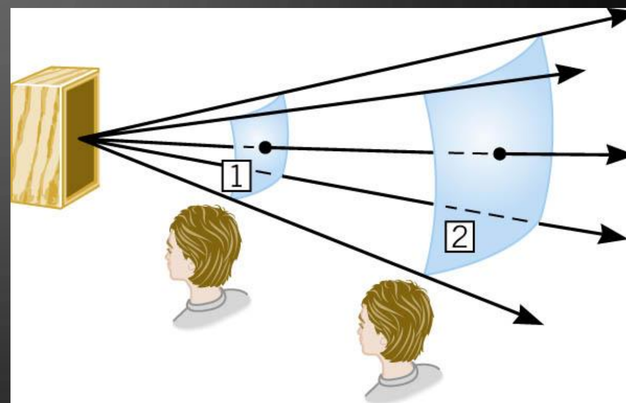
07-04 SOUND INTENSITY AND SOUND LEVEL

- Sound waves carry energy that can do work
- Amount of energy transported per second = power
- Units: J/s = W

Work example causing ear drum to vibrate

07-04 SOUND INTENSITY AND SOUND LEVEL

- As sound moves away from a source, it spreads out over a larger and larger area
- As the areas get bigger, intensity at any 1 point is less
- $I = \frac{P}{A}$
- Units: W/m^2



07-04 SOUND INTENSITY AND SOUND LEVEL

07-04 SOUND INTENSITY AND SOUND LEVEL

- If sound is transmitted uniformly in all directions, the areas are the surfaces of spheres.
- $A_{sphere} = 4\pi \mathrm{r}^2$
- $I_{uniform} = \frac{P}{4\pi \mathrm{r}^2}$

Notice that Intensity $\propto 1 / r^2$
As distance doubles, the intensity is divided by four

07-04 SOUND INTENSITY AND SOUND LEVEL

- Intensity is proportional to amplitude^2

$$I = \frac{(\Delta p)^2}{2\rho v_w}$$

  - where
    - Δp = pressure amplitude
    - ρ = density of the medium
    - v_w = speed of the wave

Used lowercase p for Pressure to keep from confusing with Power

07-04 SOUND INTENSITY AND SOUND LEVEL

- You and a friend are watching fireworks that are launching from the observatory. You are standing right in front of University Towers (150 m) and your friend is across campus at AA (700 m). The sound intensity at AA is 0.2 W/m^2. What is the sound intensity at your location, and how much power is the firework emitting?

- P = 1.23×10^6 W
- I = 4.36 W/m^2

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

$$0.2\frac{W}{m^2} = \frac{P}{4\pi(700\ m)^2} \rightarrow P = 1.231504 \times 10^6\ W$$

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

$$I = \frac{1.23 \times 10^7\ W}{4\pi(150\ m)^2} = 4.36\ W/m^2$$

Sitting out by berman hall during the fireworks at the beginning of the school year. So

07-04 SOUND INTENSITY AND SOUND LEVEL

Sound Level and Decibels

- Unit of measure to compare two sound intensities.
- Based on how human ear perceives loudness.
- If you double the intensity, I, the sound isn't twice as loud.
- Use a logarithmic scale

07-04 SOUND INTENSITY AND SOUND LEVEL

- Intensity Level

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

  - Where
    - β = intensity level β
    - I and I_0 are intensities of two sounds
      - I_0 is usually 1.0×10^{-12} W/m^2
  - Unit: dB (decibel)
- An intensity level of zero only means that $I = I_0$ since log (1) = 0

I_0 is the threshold of hearing

07-04 SOUND INTENSITY AND SOUND LEVEL

- Intensity can be measured
- Loudness is simply how ear perceives

- Doubling intensity does not double loudness

07-04 Sound Intensity and Sound Level

- You double the intensity of sound coming from a stereo. What is the change in loudness?
- β = 3 dB

- Experiment shows that if the intensity level increases by 10 dB, the sound will seem twice as loud.
- See Table 17.2

$$\beta = (10\ dB)\log\left(\frac{I}{I_0}\right)$$
$$\beta = (10\ dB)\log\left(\frac{2I}{I}\right)$$
$$\beta = (10\ dB)\log 2$$
$$\beta \approx 3\ dB$$

Thus a 200 W stereo system will only sound twice as loud as a 20 W system.

07-04 SOUND INTENSITY AND SOUND LEVEL

- What is the intensity of a 20 dB sound?

- $I = 10^{-10}\ W/m^2$

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

$$20\ db = (10\ dB)\log\left(\frac{I}{10^{-12}\ W/m^2}\right)$$

$$2 = \log\left(\frac{I}{10^{-12}\ W/m^2}\right)$$

$$10^2 = \frac{I}{10^{-12}\ W/m^2}$$

$$I = 10^{-10}\ W/m^2$$

07-04 HOMEWORK

- This is intense!
- Read 17.4

07-05 DOPPLER EFFECT

In this lesson you will…

- Define Doppler effect, Doppler shift, and sonic boom.
- Calculate the frequency of a sound heard by someone observing Doppler shift.

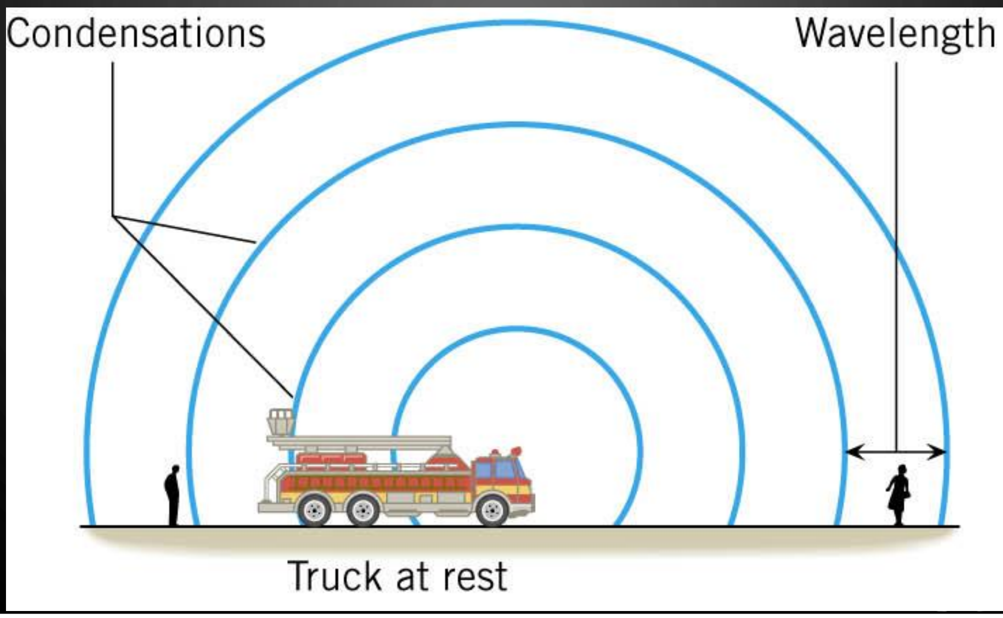
07-05 LAB

- Do the 07-05 Doppler Effect Lab

07-05 DOPPLER EFFECT

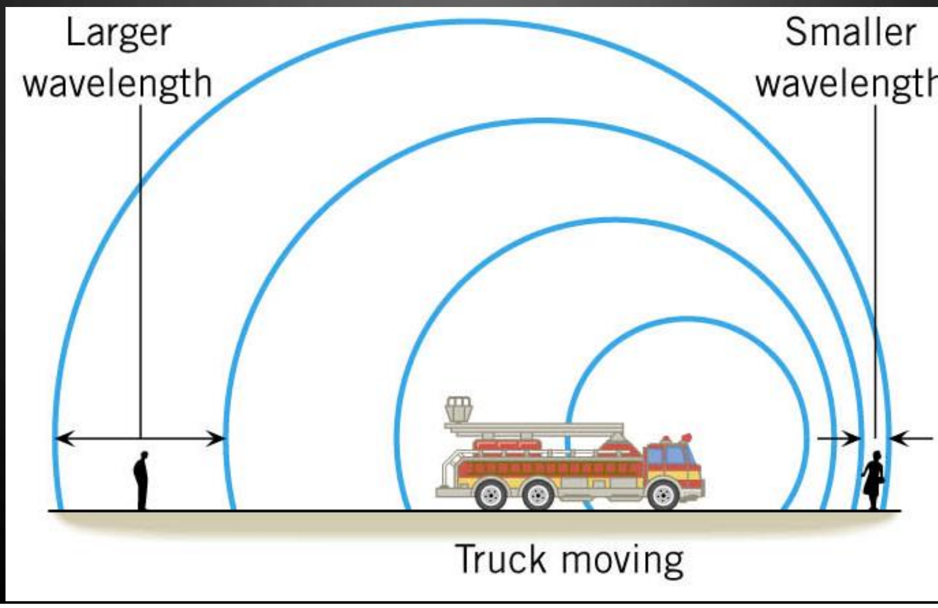
- Have you ever listened to a ambulance drive by quickly with their lights and sirens going?
- What did it sound like?
- High pitch as they were coming, low pitch as they were leaving.
- Called Doppler effect after Christian Doppler who first labeled it.

07-05 DOPPLER EFFECT



When the truck is still, the sounds waves move outward in all the directions, the same speed

07-05 DOPPLER EFFECT



When the truck is moving.
It produces a condensation, moves, produces another condensation, moves, etc.
Since it moves between condensations, they are closer together in front of the truck and farther apart behind the truck.
Higher freq (short λ) = higher pitch
Lower freq (long λ) = lower pitch

07-05 DOPPLER EFFECT

- Deriving the formula
- Moving toward object

- $\lambda' = \lambda - v_s T$

- Where
  - λ = wavelength of wave
  - λ' = perceived wavelength
  - v_s = velocity of ***s***ource
  - T = Period of wave

The perceived wavelength is shorted by the distance the source moves in one period. (Period is time between condensations)

07-05 Doppler Effect

- $f_o = \frac{v_w}{\lambda'} = \frac{v_w}{\lambda - v_s T}$
- $\lambda = \frac{v_w}{f_s}$ $\quad T = \frac{1}{f_s}$
- $f_o = f_s \left(\frac{v_w}{v_w - v_s} \right)$

- λ' = perceived wavelength
- f_o = frequency observed
- f_s = frequency of source
- v_w = speed of wave
- v_s = speed of source

07-05 DOPPLER EFFECT

- Moving Observer
- Encounters more condensations than if standing still

- $f_o = f_s\left(\frac{v_w + v_o}{v_w}\right)$

Notice the differences between the two formulas

07-05 Doppler Effect

- General Case
- Combine the two formulas
- Both observer and source can be moving

- $f_o = f_s\left(\frac{v_w \pm v_o}{v_w \mp v_s}\right)$

- WARNING!
  - v_w, v_s, and v_o are signless
  - Use the top signs when that object is moving ***towards*** the other object

07-05 Doppler Effect

- 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)

- 542 Hz

$$f_o = f_s\left(\frac{v_w \pm v_o}{v_w \mp v_s}\right)$$

$$600\ Hz = f_s\left(\frac{343\frac{m}{s} + 20\frac{m}{s}}{343\frac{m}{s} - 15\frac{m}{s}}\right)$$

$$600\ Hz = f_s(1.1)$$

$$f_s = 542\ Hz$$

07-05 Doppler Effect

- 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?

- 18.1 m/s (40 mph)

$$f_o = f_s\left(\frac{v_w \pm v_o}{v_w \mp v_s}\right)$$

$$190\ Hz = 200\ Hz\left(\frac{343\frac{m}{s} + 0}{343\frac{m}{s} + v_s}\right)$$

$$65170\ \frac{m}{s} + 190\ v_s = 68600\frac{m}{s}$$

$$190\ v_s = 3430\frac{m}{s}$$

$$v_s = 18.1\frac{m}{s}$$

07-05 DOPPLER EFFECT

- NEXRAD
  - NEXt generation weather RADar
  - Sends out radio waves
  - Wave bounce off water drops in storms
  - Radar receives echoes
  - Computer checks to compare the frequencies
  - Can compute to see how fast the clouds are spinning

Water on one side of tornado move away, water on other side move towards radar

07-05 HOMEWORK

- Move yourselves to do these exercises
- Read 16.10

07-06 SUPERPOSITION AND INTERFERENCE

In this lesson you will…

- Explain standing waves.
- Describe the mathematical representation of overtones and beat frequency.

07-06 LAB

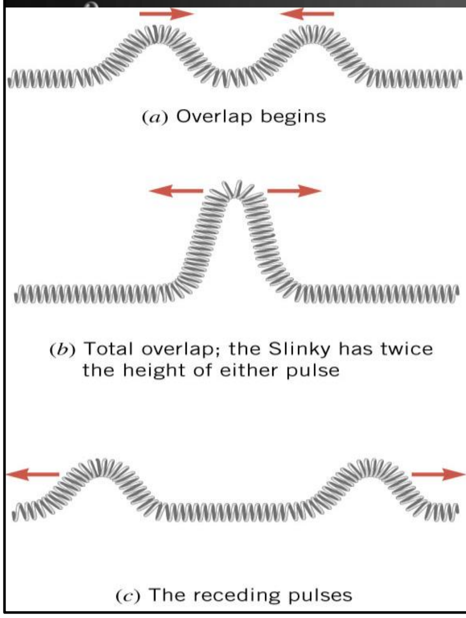
- Do the 07-06 Superposition Lab

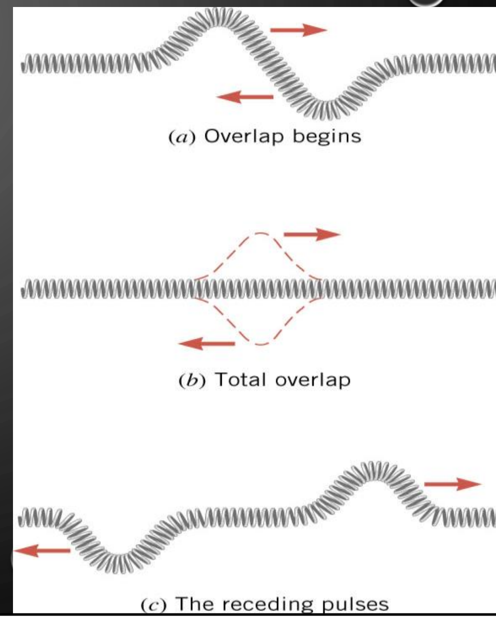
07-06 SUPERPOSITION AND INTERFERENCE

- Often two or more wave pulses move through the same space at once

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

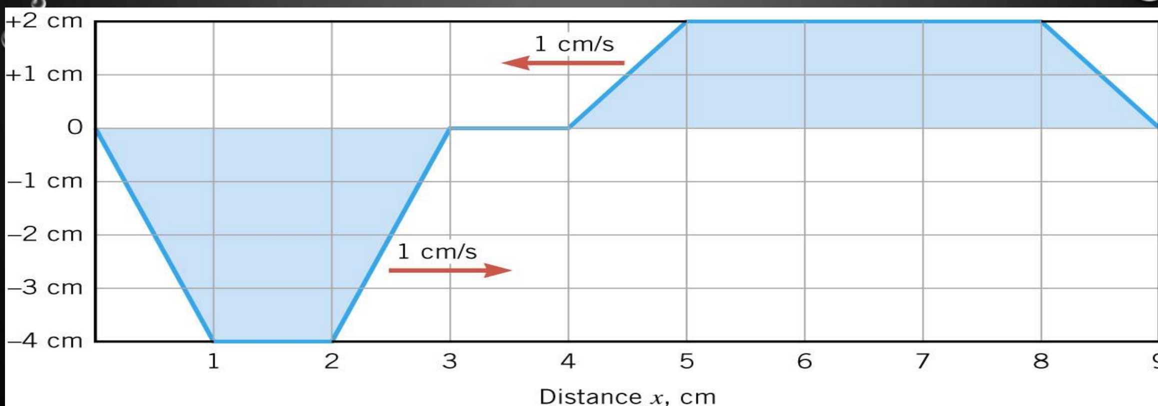
07-06 SUPERPOSITION AND INTERFERENCE





Try to demonstrate with spring or wave tank

07-06 SUPERPOSITION AND INTERFERENCE

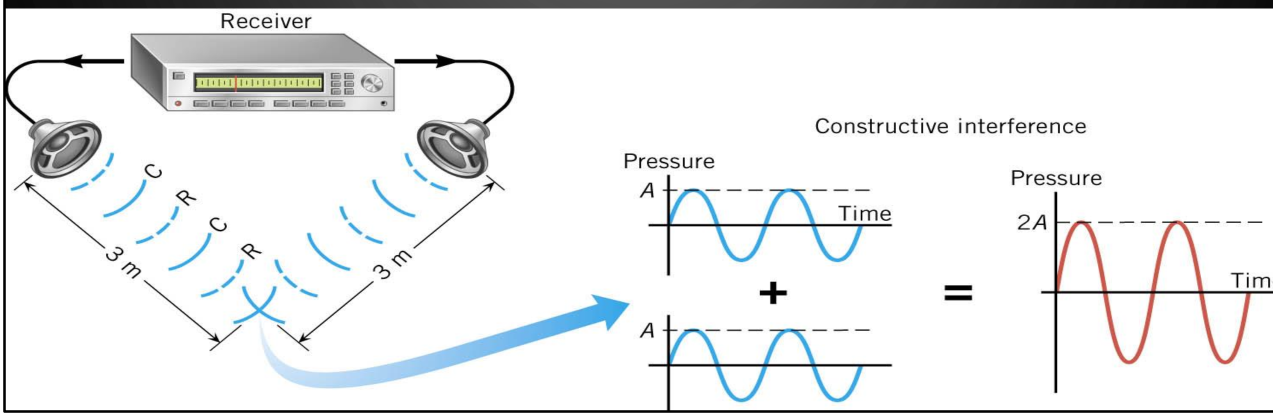


- After 2 seconds, what is the height of the resultant pulse at x = 2, 4, and 6 cm?
- 0, -2, 2

Draw the result on the pull down graph

07-06 SUPERPOSITION AND INTERFERENCE

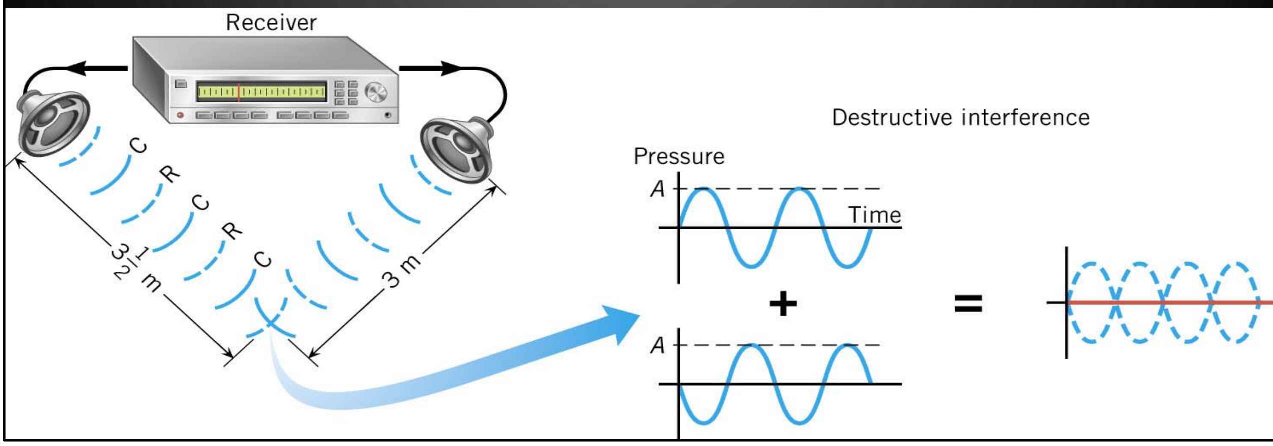
- Imagine that there are 2 speakers facing each other. Both speakers produce the same sound at the same time. $\lambda = 1$ m



At a point between the speakers where each of the sounds have moved full wavelengths
•Condensation meats condensation and rarefaction meets rarefaction all the time
•Linear superposition says the sound is twice as loud
•Called constructive interference (exactly in phase)

07-06 SUPERPOSITION AND INTERFERENCE

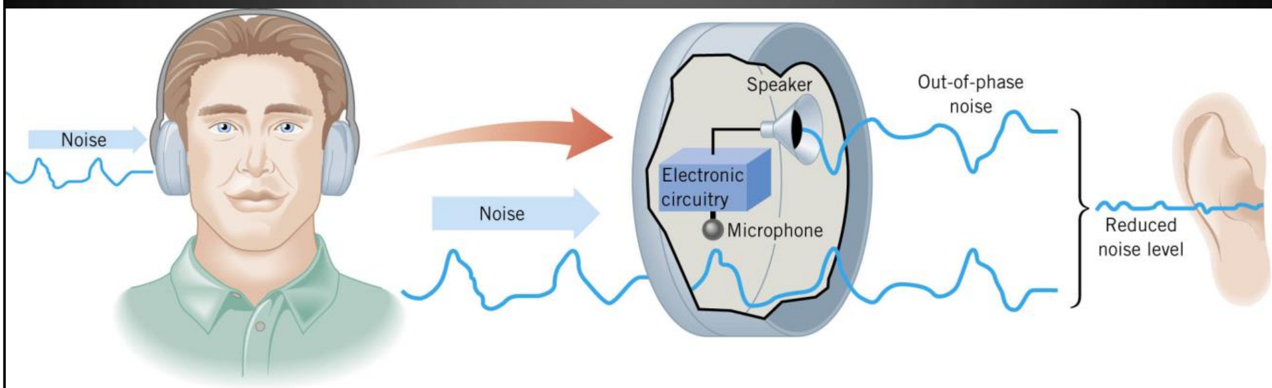
- One of the speakers is moved back half a wavelength



Now a condensation always meets a rarefaction, so cancel into nothing
Called Destructive interference (exactly out of phase)

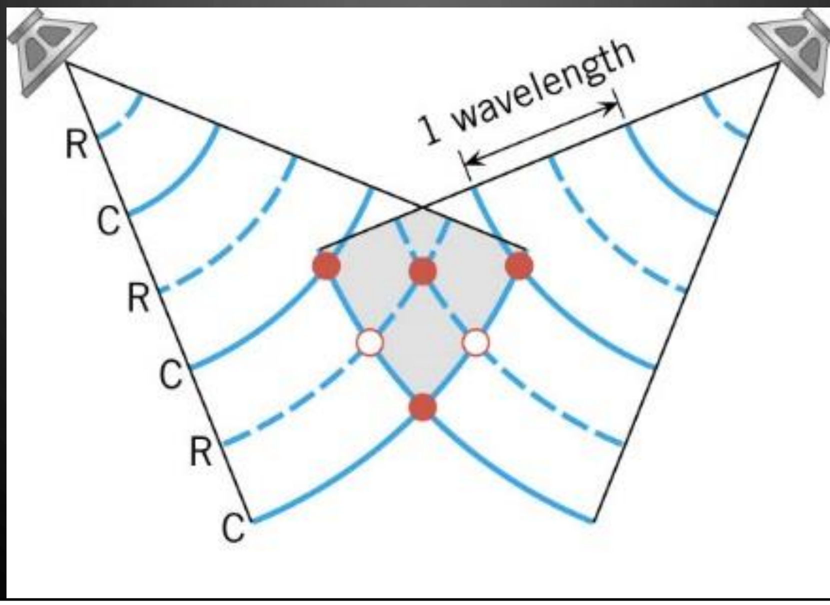
Sound Wave Interference

07-06 SUPERPOSITION AND INTERFERENCE



A microphone hears the noise
The electronics invert the noise
A speaker plays the inverted noise and destructive interference results so you don't hear much

07-06 SUPERPOSITION AND INTERFERENCE



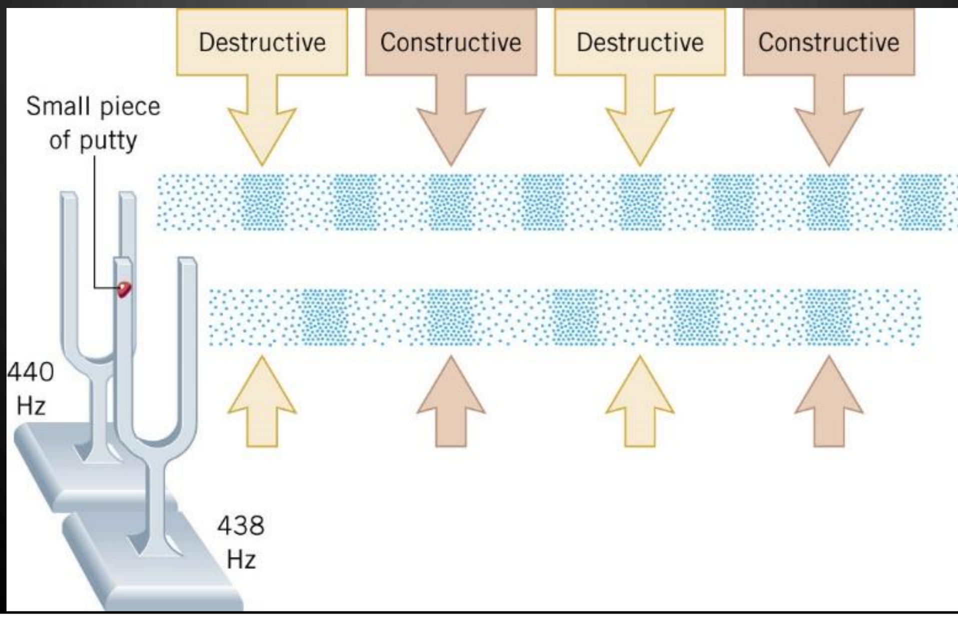
Solid lines are condensations, dashed lines are rarefactions
2 fixed speakers
where two condensations or rarefactions meet = constructive interference (red dots)
Where a condensation and rarefaction meet = destructive interference (white dots)
So as you move throughout the room the noise intensities change depending on your position
Follows law of conservation of energy

- At constructive interference → twice as much energy
- At destructive interference → no energy
- Add it all up and you get constant energy (1 + 1 = 2 + 0)

07-06 SUPERPOSITION AND INTERFERENCE

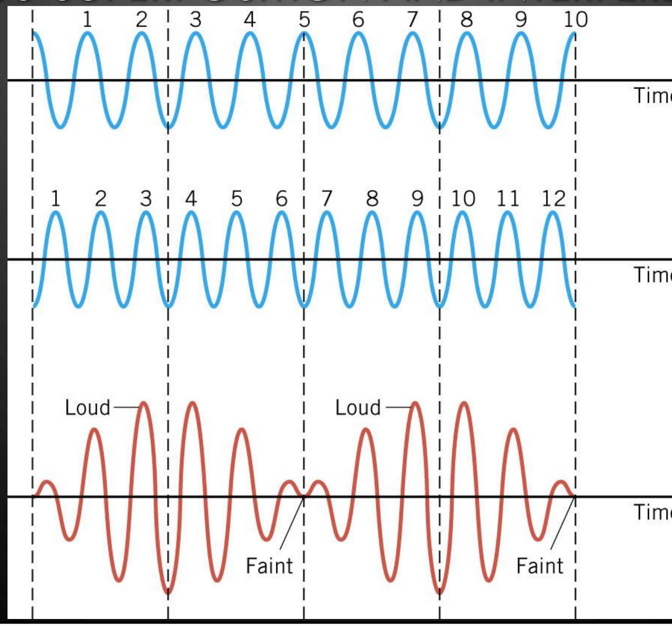
- Beats
  - When two frequencies are the same
  - Constructive and Destructive Interference give twice the amplitude or no amplitude
  - What if the two frequencies are just slightly different?

07-06 SUPERPOSITION AND INTERFERENCE



When the frequencies are slightly different, Constructive and destructive interference still happens
Where two condensations are at the same place, you get louder
Where 1 condensation and 1 rarefaction are at the same place, you get softer
You get some places with loud and some soft and in between

07-06 SUPERPOSITION AND INTERFERENCE



What the ear hears is the rising and falling of volume of the combined frequency
How often the loudness rises and falls is the **beat frequency**
Beat frequency obtained from subtracting the two frequencies of the sounds.
In the picture, the number above each blue wave indicates the number of complete cycles

The top wave is 10 Hz, the bottom is 12 Hz
The beat frequency is 12 – 10 = 2 Hz as seen in the red wave

07-06 SUPERPOSITION AND INTERFERENCE

- Beat Frequency = difference of the two source frequencies

- Beats = $| f_1 - f_2 |$

07-06 SUPERPOSITION AND INTERFERENCE

- A simple way to tune musical instruments is with beats
- If the notes are out of tune, you hear beats
- Adjust the tuning and try again
- If the frequency of the beats is higher, adjust the other way
- Keep adjusting until there are no more beats

07-06 SUPERPOSITION AND INTERFERENCE

- Two car horns have an average frequency of 420 Hz and a beat frequency of 40 Hz. What are the frequencies of both horns?

- 440 Hz, 400 Hz

$$f_{ave} = \frac{f_1 + f_2}{2}$$
$$f_B = f_1 - f_2$$

$$420\ Hz = \frac{f_1 + f_2}{2}$$
$$40\ Hz = f_1 - f_2$$

$$840\ Hz = f_1 + f_2$$
$$\underline{40\ Hz = f_1 - f_2}$$
$$880\ Hz = 2f_1$$
$$f_1 = 440\ Hz$$
$$f_2 = 400\ Hz$$

07-06 HOMEWORK

- Don’t beat around the bush, start the problems now!

- Read 17.5

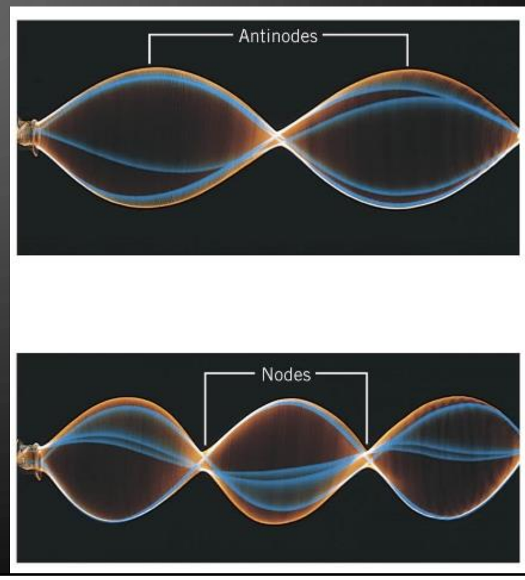
07-07 SOUND INTERFERENCE AND RESONANCE

In this lesson you will…

- Define antinode, node, fundamental, overtones, and harmonics.
- Identify instances of sound interference in everyday situations.
- Describe how sound interference occurring inside open and closed tubes changes the characteristics of the sound, and how this applies to sounds produced by musical instruments.
- Calculate the length of a tube using sound wave measurements.

07-07 SOUND INTERFERENCE AND RESONANCE

- One end of a string is attached to a fixed point.
- The other end is vibrated up and down.
- The standing wave is formed.
- Nodes – No move
- Antinodes – most movement



07-07 SOUND INTERFERENCE AND RESONANCE

- The wave travels along the string until it hits the other end
- The wave reflects off the other end and travels in the opposite direction, but upside down
- The returning wave hits the vibrating end and reflects again (this side the wave is right side up)
- Unless the timing is just right the reflecting wave and the new wave will not coincide
- When they do coincide, the waves add due to constructive interference
- When they don't coincide; destructive interference

Why its reflected upside down. → the string pulls up on the wall, by Newton's reaction force, the wall pulls down on the string

07-07 SOUND INTERFERENCE AND RESONANCE

- Harmonics
  - When you vibrate the string faster, you can get standing waves with more nodes and antinodes
  - Standing waves are named by number of antinodes
    - 1 antinode → 1^{st} harmonic (fundamental freq)
    - 2 antinodes → 2^{nd} harmonic (1^{st} overtone)
    - 3 antinodes → 3^{rd} harmonic (2^{nd} overtone)

07-07 SOUND INTERFERENCE AND RESONANCE

- f_1 = fundamental frequency (1st harmonic)
- $f_2 = 2f_1$ (2nd harmonic)
- $f_3 = 3f_1$ (3rd harmonic)

- Harmonics Example
  - If the fundamental is 440 Hz (concert A)
  - 2nd harmonic = 2(440 Hz) = 880 Hz (High A)
  - 3rd harmonic = 3(440 Hz) = 1320 Hz

Multiply the fundamental frequency by an integer to obtain that integer's harmonic

07-07 Sound Interference and Resonance

- To find the fundamental frequencies and harmonics of a string fixed at both ends

$$f_n = n\left(\frac{v_w}{2L}\right)$$

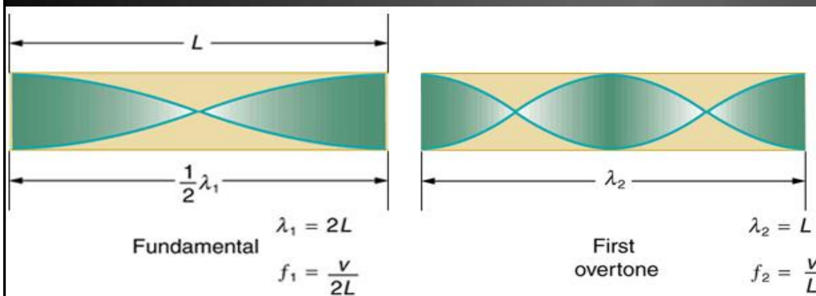
- Where
  - f_n = frequency of the n^{th} harmonic
  - n = integer (harmonic #)
  - v_w = speed of wave
  - L = length of string

07-07 Sound Interference and Resonance

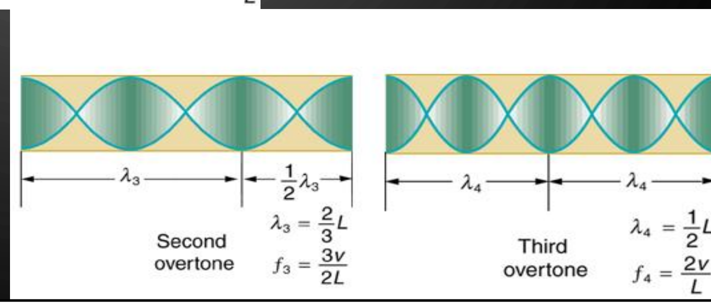
- Just like stringed instruments rely on standing transverse waves on strings
- Wind instruments rely on standing longitudinal sound waves in tubes
- The waves reflect off the open ends of tubes
- One difference at the ends are antinodes instead of nodes

Demonstrate antinodes at the end by making standing waves in a string by dangling a string and shaking it

07-07 SOUND INTERFERENCE AND RESONANCE



Tube open at both ends



07-07 SOUND INTERFERENCE AND RESONANCE

- Formula for Tube Open at Both Ends
  - Distance between antinodes = ½ λ
  - Tube must be integer number of ½ λ
    - $L = n\left(\frac{1}{2}\lambda_n\right)$ or $\lambda_n = \frac{2L}{n}$
  - $f_n = \frac{v_w}{\lambda_n}$

$$f_n = n\left(\frac{v_w}{2L}\right)$$

Demonstrate with tube

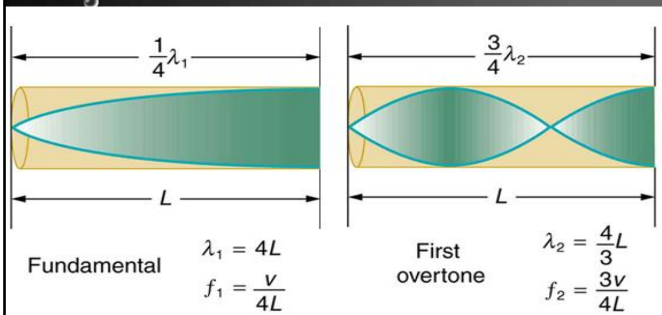
07-07 SOUND INTERFERENCE AND RESONANCE

- What is the lowest frequency playable by a flute that is 0.60 m long if that air is 20 °C.
- f = 285.8 Hz

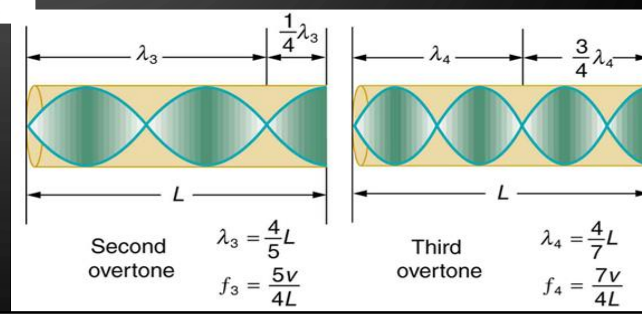
$$n = 1$$

$$f = 1\left(\frac{343\,\frac{m}{s}}{2(.6\,m)}\right) = 285.8\,Hz$$

07-07 SOUND INTERFERENCE AND RESONANCE



Tube open at one end



07-07 SOUND INTERFERENCE AND RESONANCE

- Tube Open at One End
    - Node at the closed end
    - Antinode at the open end
    - At fundamental frequency L = ¼ λ
    - The 2nd harmonic adds one more node or ½ λ
    - Thus the lengths are *odd integer* multiples of ¼ λ

$$f_n = n\left(\frac{v_w}{4L}\right)$$

    - Only odd harmonics

Where n is odd integers

07-07 HOMEWORK

- Try blowing your way through these problems

- Read 17.6, 17.7

07-08 HEARING AND ULTRASOUND

In this lesson you will…

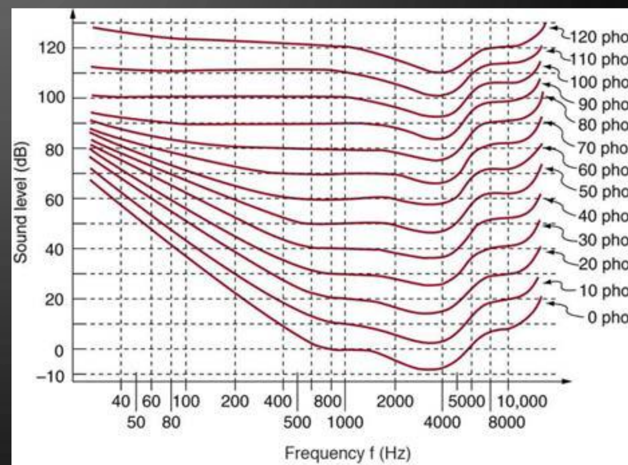
- Define hearing, pitch, loudness, timbre, note, tone, phon, ultrasound, and infrasound.
- Compare loudness to frequency and intensity of a sound.
- Identify structures of the inner ear and explain how they relate to sound perception.
- Define acoustic impedance and intensity reflection coefficient.
- Describe medical and other uses of ultrasound technology.
- Calculate acoustic impedance using density values and the speed of ultrasound.

07-08 HEARING AND ULTRASOUND

- Hearing
  - Pitch
    - Perception of frequency
    - 20 Hz – 20000 Hz
    - Most sensitive to 2000 – 5000 Hz
    - Can distinguish between pitches that vary by at least 0.3 %
- Loudness
  - Perception of intensity
  - Range 10^{-12} W/m^2 – 10^{12} W/m^2
  - Most people can discern a intensity level difference of 3 dB

07-08 HEARING AND ULTRASOUND

- Phons measure loudness
- The graph shows the sensitivity of the average human ear



07-08 HEARING AND ULTRASOUND

Ultrasound

- Used in obstetrics to examine a fetus, used to examine some organs, and blood flow

- High frequency sound aimed at target
- Sound reflects at boundary of tissues with different acoustic impedances
- Computer compiles picture from where echoes come from

- Acoustic impedance

$$Z = \rho v$$

  - See table 17.5

- Intensity reflection coefficient

$$a = \frac{(Z_2 - Z_1)^2}{(Z_1 + Z_2)^2}$$

  - Higher coefficient, more reflection
- Can't see detail smaller than λ
- Can only penetrate to depth of 500λ

07-08 HEARING AND ULTRASOUND

- Calculate the intensity reflection coefficient of ultrasound when going from water to fat tissue (like a baby in the womb).
- a = 0.00317
- This means 0.317% of the sound is reflected.

$$a = \frac{(Z_2 - Z_1)^2}{(Z_1 + Z_2)^2}$$

$$a = \frac{\left(1.5 \times 10^6 \frac{kg}{m^2 \cdot s} - 1.34 \times 10^6 \frac{kg}{m^2 \cdot s}\right)^2}{\left(1.5 \times 10^6 \frac{kg}{m^2 \cdot s} + 1.34 \times 10^6 \frac{kg}{m^2 \cdot s}\right)^2} = 0.00317$$

07-08 HEARING AND ULTRASOUND

Cavitron Ultra Surgical Aspirator

- Used to remove inoperable brain tumors
- Tip of instrument vibrates at 23 kHz
- Shatters tumor tissue that comes in contact
- Better precision than a knife

07-08 HEARING AND ULTRASOUND

High-Intensity Focused Ultrasound

- Sound is focused on a region of the body.
- The waves entering the body don't do damage
- Only damage done where focused (like sun and magnifying glass)
- The focused energy at target causes heating which kills abnormal cells

07-08 HEARING AND ULTRASOUND

Doppler Flow Meter

- Transmitter and receiver placed on skin
- High frequency sound emitted
- Sound reflects off of blood cells
- Since cells are moving, Doppler effect exists
- Computer can find rate of flow by counting the returned frequency
- Used to find areas of narrowed blood vessels
- Narrowest area → fastest flow

07-08 HOMEWORK

- Applying science is called engineering.