Waves

- A traveling _______________
- Carries _______________ from place to place

When a boat makes a wave,

- the water itself does not get up and move
- the water _______________ a little, then moves _______________
- energy is _______________ in the wave and is what you _______________

Transverse

- _______________ and _______________ disturbance
- Wave travels _______________ or _______________
- Disturbance is _______________ to direction of travel
- Examples:
    - _______________ waves, _______________ waves, _______________waves, _______________ instruments

Longitudinal Waves

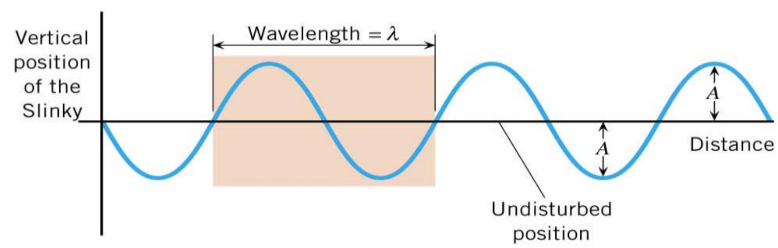
- Disturbance is _______________ and _______________
- Direction of travel is _______________ or _______________
- Disturbance and direction of travel are _______________
- Series of _______________ and _______________ regions
- Example:
    - _______________

Other

- Water waves are a _______________
- Water at the surface of a water wave travels in small _______________

Parts of a Wave at a Particular Time

- Periodic → pattern is regularly _____________
- Cycle → one unit of _______________
- Wavelength (λ) → ______________ of one cycle
- Amplitude (A) → _______________ from equilibrium to crest



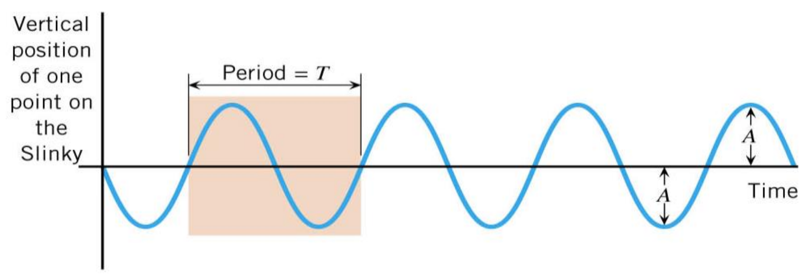
(*a*) At a particular time

Parts of a Wave at a Particular Location

- Period (T) → time it takes for one _________
- Unit: s
- Frequency (f) → number of ______________ per _______________
- Unit: 1/s = 1 hertz (Hz)

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

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



(*b*) At a particular location

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?

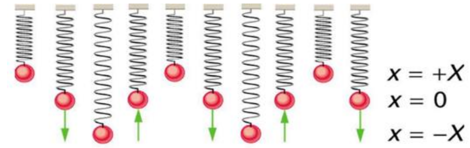
You are sitting on the beach and notice that a seagull floating on the water moves up and down 15 times in 1 minute. What is the frequency of the water waves?

Homework

1. "Domino Toppling" is one entry in the *Guinness Book of World Records*. The event consists of lining up an incredible number of dominoes and then letting them topple, one after another. Is the disturbance that propagates along the line of dominoes transverse, longitudinal, or partly both? Explain.
2. 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.
3. 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.
4. What is the difference between propagation speed and the frequency of a wave? Does one or both affect wavelength? If so, how?
5. What is the period of 60.0 Hz electrical power? (OpenStax 16.7) **16.7 ms**
6. If your heart rate is 150 beats per minute during strenuous exercise, what is the time per beat in units of seconds? (OpenStax 16.8) **0.400 s/beat**
7. Find the frequency of a tuning fork that takes 2.50×10^{-3} s to complete one oscillation. (OpenStax 16.9) **400 Hz**
8. A stroboscope is set to flash every 8.00×10^{-5} s. What is the frequency of the flashes? (OpenStax 16.10) **12500 Hz**
9. 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 does it take them if they travel at 15.0 m/s? (OpenStax 16.47) **9.26 d**
10. 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? (OpenStax 16.48) **11.3 m**
11. 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? (OpenStax 16.49) **40.0 Hz**
12. 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? (OpenStax 16.50) **7.50 times**
13. 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? (OpenStax 16.53) **700 m**
14. Radio waves transmitted through space at 3.00×10^8 m/s by the Voyager spacecraft have a wavelength of 0.120 m. What is their frequency? (OpenStax 16.54) $\mathbf{2.50 \times 10^9}$ **Hz**
15. 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. (Cutnell 16.6) **0.200 Hz, 4.00 m/s**

 Name: ________________

Hooke's Law



$$F = -kx$$

- F = restoring __________, x = __________ displaced, k = spring __________
- Force will __________ the mass back toward _____________
- As mass gets to _____________, it has ______________, so it continues past

Energy in Hooke's Law

- Since a force acts over a distance, _____________ is done

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

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?

Speed of a Wave on a String

- On a string, if one part of the string is pulled up (__________________________),
  - Then the next piece of the string is _____________________
  - Then the next piece of the string is _____________________, etc.
  - After the pulse passed the string moves back down to the ____________________ position due to ______________
  - The more _____________, the quicker the string ______________________ back and the __________ the wave travels.
- Speed of a wave depends on the _____________
- For a string, the speed depends on
  - _____________
  - Linear _____________ (m/L)

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

Simple harmonic motion

- Motion that regularly _____________
- Frequency ________________ of amplitude

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

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

- Think of a point on a string some _____________ (x) from the _____________
- We want to know the vertical _______________ (y) of the particle at any given _____________
- If the wave repeats, then it will look like a ___________ (or _____________) graph

$$y = A\cos\left(\frac{2\pi t}{T}\right)$$

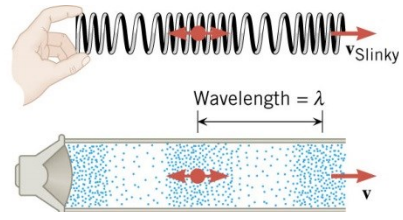
A wave has an amplitude of 1.5 cm, a speed of 20 m/s, and a frequency of 100 Hz. Write the equation of the wave position of the wave.

Homework

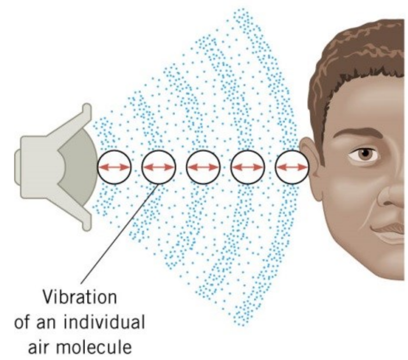
1. A wire is strung tightly between two immovable posts. Discuss how an increase in temperature affects the speed of a transverse wave on this wire. Give your reasoning, ignoring any change in the mass per unit length of the wire.
2. A rope of mass *m* is hanging down from the ceiling. Nothing is attached to the loose end of the rope. A transverse wave is traveling on the rope. As the wave travels up the rope, does the speed of the wave increase, decrease, or remain the same? Give a reason for your choice.
3. Explain why you expect an object made of a stiff material to vibrate at a higher frequency than a similar object made of a spongy material.
4. As you pass a freight truck with a trailer on a highway, you notice that its trailer is bouncing up and down slowly. Is it more likely that the trailer is heavily loaded or nearly empty? Explain your answer.
5. Fish are hung on a spring scale to determine their mass (most fishermen feel no obligation to truthfully report the mass). (a) What is the force constant of the spring in such a scale if it the spring stretches 8.00 cm for a 10.0 kg load? (b) What is the mass of a fish that stretches the spring 5.50 cm? (c) How far apart are the half-kilogram marks on the scale? (OpenStax 16.1) **1.23×10^3 N/m, 6.88 kg, 4.00 mm**
6. It is weigh-in time for the local under-85-kg rugby team. The bathroom scale used to assess eligibility can be described by Hooke's law and is depressed 0.75 cm by its maximum load of 120 kg. (a) What is the spring's effective spring constant? (b) A player stands on the scales and depresses it by 0.48 cm. Is he eligible to play on this under-85 kg team? (OpenStax 16.2) **1.57×10^5 N/m, 77 kg, yes**
7. One type of BB gun uses a spring-driven plunger to blow the BB from its barrel. (a) Calculate the force constant of its plunger's spring if you must compress it 0.150 m to drive the 0.0500-kg plunger to a top speed of 20.0 m/s. (b) What force must be exerted to compress the spring? (OpenStax 16.3) **889 N/m, 133 N**
8. The mass of a string is 5.0×10^{-3} kg, and it is stretched so that the tension in it is 180 N. A transverse wave traveling on this string has a frequency of 260 Hz and a wavelength of 0.60 m. What is the length of the string? (Cutnell 16.12) **0.68 m**
9. The linear density of the A string on a violin is 7.8×10^{-4} kg/m. A wave on the string has a frequency of 440 Hz and a wavelength of 65 cm. What is the tension in the string? (Cutnell 16.13) **64 N**
10. A transverse wave is traveling with a speed of 300 m/s on a horizontal string. If the tension in the string is increased by a factor of four, what is the speed of the wave? (Cutnell 16.15) **600 m/s**
11. A type of cuckoo clock keeps time by having a mass bouncing on a spring, usually something cute like a cherub in a chair. What force constant is needed to produce a period of 0.500 s for a 0.0150-kg mass? (OpenStax 16.13) **2.37 N/m**
12. If the spring constant of a simple harmonic oscillator is doubled, by what factor will the mass of the system need to change in order for the frequency of the motion to remain the same? (OpenStax 16.14) **M = 2m**
13. A 0.500-kg mass suspended from a spring oscillates with a period of 1.50 s. How much mass must be added to the object to change the period to 2.00 s? (OpenStax 16.15) **0.389 kg**
14. A diver on a diving board is undergoing simple harmonic motion. Her mass is 55.0 kg and the period of her motion is 0.800 s. The next diver is a male whose period of simple harmonic oscillation is 1.05 s. What is his mass if the mass of the board is negligible? (OpenStax 16.18) **94.7 kg**
15. Suppose a diving board with no one on it bounces up and down in a simple harmonic motion with a frequency of 4.00 Hz. The board has an effective mass of 10.0 kg. What is the frequency of the simple harmonic motion of a 75.0-kg diver on the board? (OpenStax 16.19) **1.37 Hz**

 Name: ____________________

How Sound Is Made



- Some ____________ object like a speaker moves and ____________ the air
- Air pressure rises called ____________
- Condensation moves ____________ at speed of ____________
- Object moves back creating ____________ air pressure called ____________
- Rarefaction moves ____________ at speed of ____________
- Particles move ____________ and ____________
- Distance between consecutive condensations or rarefactions is ____________



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

Pitch

- 1 cycle = 1 ________________ + 1 ____________

$$Frequency = \frac{cycles}{second}$$

- Each frequency has own ____________
  - Sounds with 1 frequency called ____________
- Healthy ____________ people can hear frequencies of ____________ to ____________ Hz
- Brain can interpret frequency as ____________
  - High freq = ____________ pitch
  - ____________ because most people don't have ____________ pitch

Loudness

- The condensations have more ____________ than the rarefactions
- Amplitude = ____________ pressure
- Typical conversation, Amp = ____________ Pa
- Atmospheric air pressure = ____________ Pa
- ____________ is ear's interpretation of ____________ amplitude

Speed of Sound

- For ____________ waves

$$v_w = f\lambda$$

- Sound travels slowest in ____________, faster in ____________, and fastest in ____________
- Air at 20 °C → 343 m/s
- Speed of sound depends on properties of ____________
- In gases
  - Sound is transmitted only when molecules ____________
  - So we derive formula from speed of ____________
  - And speed changes with ____________

For air

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

- where T is in ____________

Table 17.1 Speed of Sound in Various Media

Medium	v_w(m/s)
Gases at 0°C	
Air	331
Carbon dioxide	259
Oxygen	316
Helium	965
Hydrogen	1290
Liquids at 20°C	
Ethanol	1160
Mercury	1450
Water, fresh	1480
Sea water	1540
Human tissue	1540
Solids (longitudinal or bulk)	
Vulcanized rubber	54
Polyethylene	920
Marble	3810
Glass, Pyrex	5640
Lead	1960
Aluminum	5120
Steel	5960

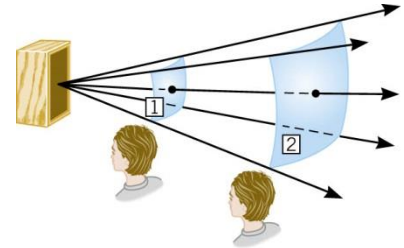
What wavelength corresponds to a frequency of concert A which is 440 Hz if the air is 25 °C?

How far away is a ship if it takes 3.4 s to receive a return signal in seawater?

Homework

1. How do sound vibrations of atoms differ from thermal motion?
2. When sound passes from one medium to another where its propagation speed is different, does its frequency or wavelength change? Explain your answer briefly.
3. A loudspeaker produces a sound wave. Does the wavelength of the sound increase, decrease, or remain the same, when the wave travels from air into water? Justify your answer.
4. When poked by a spear, an operatic soprano lets out a 1200-Hz shriek. What is its wavelength if the speed of sound is 345 m/s? (OpenStax 17.1) **0.288 m**
5. What frequency sound has a 0.10-m wavelength when the speed of sound is 340 m/s? (OpenStax 17.2) **3400 Hz**
6. Calculate the speed of sound on a day when a 1500 Hz frequency has a wavelength of 0.221 m. (OpenStax 17.3) **332 m/s**
7. (a) What is the speed of sound in a medium where a 100-kHz frequency produces a 5.96-cm wavelength? (b) Which substance in the table is this likely to be? (OpenStax 17.4) $\mathbf{5.96 \times 10^3}$ **m/s, steel**
8. Show that the speed of sound in 20.0 °C air is 343 m/s, as claimed in the text. (OpenStax 17.5) **343 m/s**
9. Air temperature in the Sahara Desert can reach 56.0 °C (about 134 °F). What is the speed of sound in air at that temperature? (OpenStax 17.6) **363 m/s**
10. Dolphins make sounds in air and water. What is the ratio of the wavelength of a sound in air to its wavelength in seawater? Assume air temperature is 20.0 °C. (OpenStax 17.7) **0.223**
11. A sonar echo returns to a submarine 1.20 s after being emitted. What is the distance to the object creating the echo? (Assume that the submarine is in the ocean, not in fresh water.) (OpenStax 17.8) **924 m**
12. (a) If a submarine's sonar can measure echo times with a precision of 0.0100 s, what is the smallest difference in distances it can detect? (Assume that the submarine is in the ocean, not in fresh water.) (b) Discuss the limits this time resolution imposes on the ability of the sonar system to detect the size and shape of the object creating the echo. (OpenStax 17.9) **7.70 m**
13. For research purposes a sonic buoy is tethered to the ocean floor and emits an infrasonic pulse of sound. The period of this sound is 71 ms. Determine the wavelength of the sound. (Cutnell 16.30) **110 m**
14. The distance between a loudspeaker and the left ear of a listener is 2.70 m. (a) Calculate the time required for sound to travel this distance if the air temperature is 20 °C. (b) Assuming that the sound frequency is 523 Hz, how many wavelengths of sound are contained in this distance? (Cutnell 16.31) $\mathbf{7.87 \times 10^{-3}}$ **s, 4.12**

Sound Intensity



- Sound waves carry ____________ that can do ____________
- Amount of ____________ transported per ____________ = ____________
- As sound moves away from a ____________, it spreads out over a ____________ and larger ____________
- As the areas get ____________, intensity at any 1 point is ____________

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

  - Units: W/m²
- If sound is transmitted ____________ in all directions, the areas are the surfaces of ____________.

$$A_{sphere} = 4\pi r^2$$

- Intensity is proportional to ____________

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

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

You and a friend are watching fireworks that are launching from the observatory. You are standing right in front of Berman Hall (150 m) and your friend is across campus at AA (700 m). The sound intensity at AA is 0.2 W/m². What is the sound intensity at your location, and how much power is the firework emitting?

Sound Level and Decibels

- Unit of measure to ____________ two sound ____________.
- Based on how human ear perceives ____________.
- If you ____________ the intensity, I, the sound is ____________ twice as loud.
- Use a ________________ scale
- 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 ____________ W/m²
  - Unit: dB (decibel)
- An intensity level of ____________ only means that $I = I_0$ since log (1) = 0
- Intensity can be ____________
- Loudness is simply how ear ____________
- Doubling ____________ does not double ____________

Table 17.2 Sound Intensity Levels and Intensities

Sound intensity level β (dB)	Intensity I (W/m²)	Example/effect
0	1×10^{-12}	Threshold of hearing at 1000 Hz
10	1×10^{-11}	Rustle of leaves
20	1×10^{-10}	Whisper at 1 m distance
30	1×10^{-9}	Quiet home
40	1×10^{-8}	Average home
50	1×10^{-7}	Average office, soft music
60	1×10^{-6}	Normal conversation
70	1×10^{-5}	Noisy office, busy traffic
80	1×10^{-4}	Loud radio, classroom lecture
90	1×10^{-3}	Inside a heavy truck; damage from prolonged exposure[1]
100	1×10^{-2}	Noisy factory, siren at 30 m; damage from 8 h per day exposure
110	1×10^{-1}	Damage from 30 min per day exposure
120	1	Loud rock concert, pneumatic chipper at 2 m; threshold of pain
140	1×10^{2}	Jet airplane at 30 m; severe pain, damage in seconds
160	1×10^{4}	Bursting of eardrums

You double the intensity of sound coming from a stereo. What is the change in loudness?

- Experiment shows that if the intensity level increases by ____________, the sound will seem ____________ as loud.

See Table 17.2

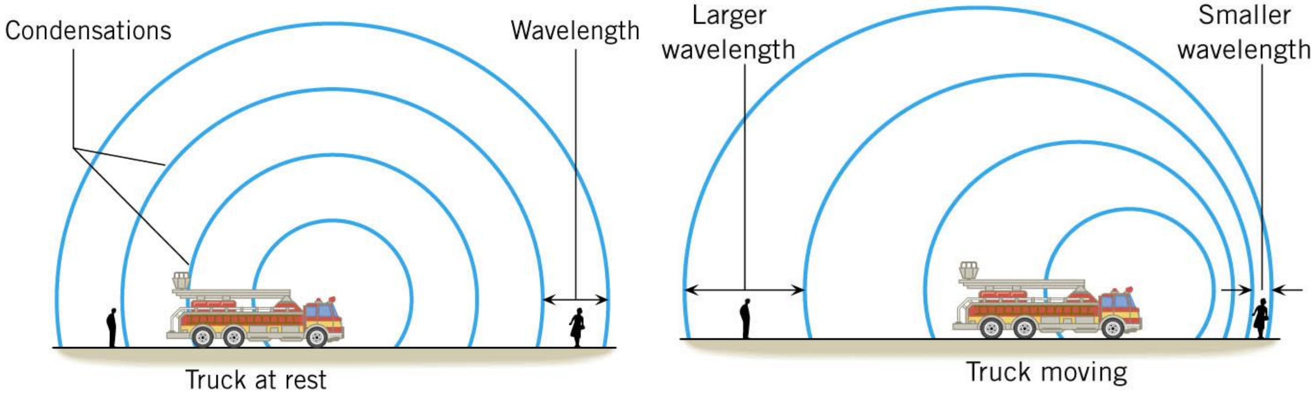
What is the intensity of a 20 dB sound?

Homework

1. A source is emitting sound uniformly in all directions. There are no reflections anywhere. A *flat* surface faces the source. Is the sound intensity the same at all points on the surface? Give our reasoning.
2. If two people talk simultaneously and each creates an intensity level of 65 dB at a certain point, does the total intensity level at this point equal 130 dB? Account for your answer.
3. A typical adult ear has a surface area of 2.1×10^{-3} m². The sound intensity during a normal conversation is about 3.2×10^{-6} W/m² at the listener's ear. Assume that the sound strikes the surface of the ear perpendicularly. How much power is intercepted by the ear? (Cutnell 16.48) $\mathbf{6.7 \times 10^{-9}}$ **W**
4. What is the intensity in watts per meter squared of 85.0-dB sound? (OpenStax 17.12) $\mathbf{3.16 \times 10^{-4}}$ **W/m²**
5. The warning tag on a lawn mower states that it produces noise at a level of 91.0 dB. What is this in watts per meter squared? (OpenStax 17.13) $\mathbf{1.26 \times 10^{-3}}$ **W/m²**
6. A sound wave traveling in 20 °C air has a pressure amplitude of 0.5 Pa. What is the intensity of the wave? (OpenStax 17.14) $\mathbf{3.04 \times 10^{-4}}$ **W/m²**
7. What intensity level does the sound in the preceding problem correspond to? (OpenStax 17.15) **85 dB**
8. What sound intensity level in dB is produced by earphones that create an intensity of 4.00×10^{-2} W/m²? (OpenStax 17.16) **106 dB**
9. (a) What is the intensity of a sound that has a level 7.00 dB lower than a 4.00×10^{-9} W/m² sound? (b) What is the intensity of a sound that is 3.00 dB higher than a 4.00×10^{-9} W/m² sound? (OpenStax 17.19) $\mathbf{8.00 \times 10^{-10}}$ **W/m²,** $\mathbf{8.00 \times 10^{-9}}$ **W/m²**
10. People with good hearing can perceive sounds as low in level as –8.00 dB at a frequency of 3000 Hz. What is the intensity of this sound in watts per meter squared? (OpenStax 17.21) $\mathbf{1.58 \times 10^{-13}}$ **W/m²**
11. If a large housefly 3.0 m away from you makes a noise of 40.0 dB, what is the noise level of 1000 flies at that distance, assuming interference has a negligible effect? (OpenStax 17.22) **70.0 dB**
12. An 8-hour exposure to a sound intensity level of 90.0 dB may cause hearing damage. What energy in joules falls on a 0.800-cm-diameter eardrum so exposed? (OpenStax 17.26) $\mathbf{1.45 \times 10^{-3}}$ **J**
13. The bellow of a territorial bull hippopotamus has been measured at 115 dB above the threshold of hearing. What is the sound intensity? (Cutnell 16.59) **0.316 W/m²**
14. Humans can detect a difference in sound intensity levels as small as 1.0 dB. What is the ratio of the sound intensities? (Cutnell 16.61) **1.3**

Doppler Effect

- As a source of a sound moves by a listener
- ____________ pitch as they were ____________, ____________ pitch as they were ____________.



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

- v_w, v_s, and v_o are ____________
- Use the top signs when that object is moving ____________ the other ____________

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)

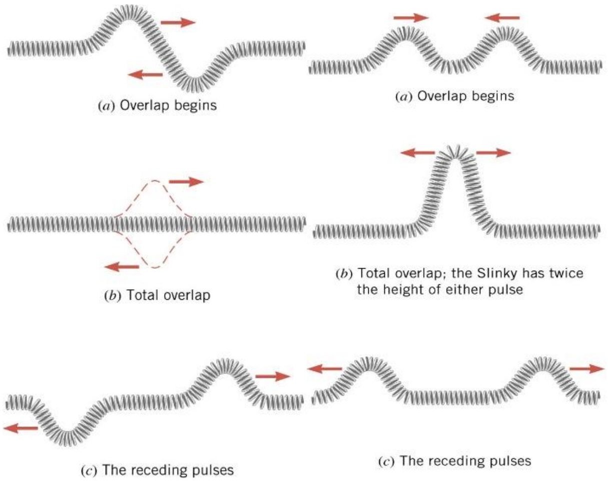
A duck is flying overhead while you stand still. As it moves away, you hear its quack at 190 Hz. Because you are a brilliant naturalist, you know that this type of duck quacks at 200 Hz. How fast is the duck flying?

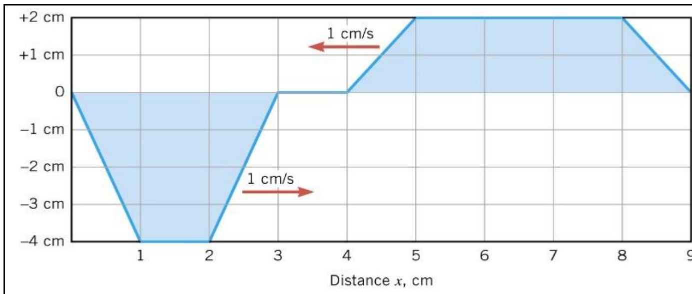
Homework

1. Is the Doppler shift real or just a sensory illusion?
2. When you hear a sonic boom, you often cannot see the plane that made it. Why is that?
3. Two cars, one behind the other, are traveling in the same direction at the same speed. Does either driver hear the other's horn at a frequency that is different from that heard when both cars are at rest? Justify your answer.
4. 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.
5. (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? (OpenStax 17.30) **878 Hz, 735 Hz**
6. (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? (OpenStax 17.31) $\mathbf{1.38 \times 10^5}$ **Hz,** $\mathbf{1.77 \times 10^3}$ **Hz**
7. 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. (OpenStax 17.32) $\mathbf{3.79 \times 10^3}$ **Hz**
8. 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? (OpenStax 17.33) **3.05 m/s**
9. 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? (OpenStax 17.34) **12.9 m/s, 193 Hz**
10. Can you perceive the shift in frequency produced when you pull a tuning fork toward you at 10.0 m/s on a day when the speed of sound is 344 m/s? To answer this question, calculate the factor by which the frequency shifts and see if it is greater than 0.300%. (OpenStax 17.35) **1.030**
11. The security alarm on a parked car goes off and produces a frequency of 960 Hz. The speed of sound is 343 m/s. As you drive toward this parked car, pass it, and drive away, you observe the frequency to change by 95 Hz. At what speed are you driving? (Cutnell 16.71) **17 m/s**
12. 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? (Cutnell 16.72) **0.340 m**
13. A speeder looks in his rearview mirror. He notices that a police car has pulled behind him and is matching his speed of 38 m/s. The siren on the police car has a frequency of 860 Hz when the police car and the listener are stationary. The speed of sound is 343 m/s. What frequency does the speeder hear when the siren is turned on in the moving police car? (Cutnell 16.73) **860 Hz**
14. A bird is flying directly toward a stationary bird-watcher and emits a frequency of 1250 Hz. The bird-watcher, however, hears a frequency of 1290 Hz. What is the speed of the bird, expressed as a percentage of the speed of sound? (Cutnell 16.74) **3.1%**

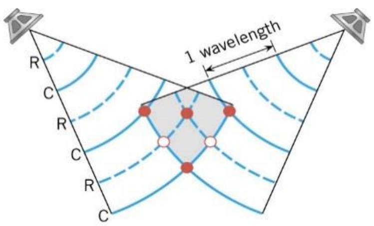
Superposition

- Often ______________ or more wave ______________ move through the same ______________ at once
- When two or more waves are present ____________________ at the same place, the ______________ disturbance is the ______________ of the disturbances from ______________ waves



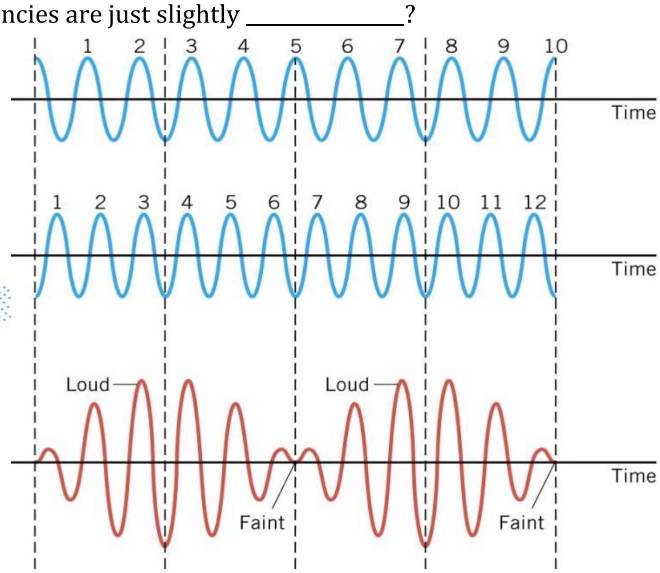


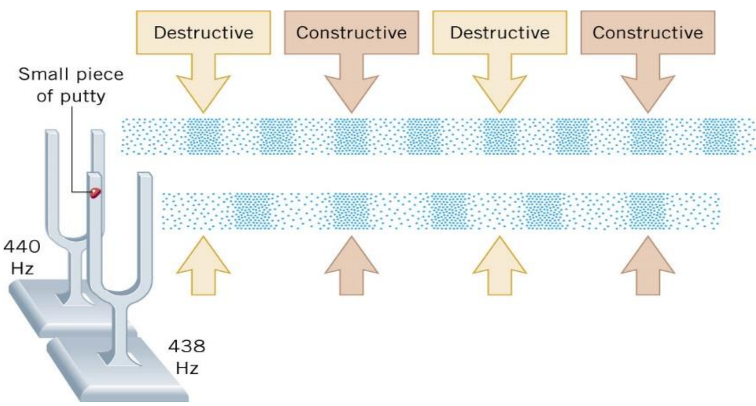
After 2 seconds, what is the height of the resultant pulse at x = 2, 4, and 6 cm?



Beats

- When two ______________ are the ______________
- Constructive and Destructive Interference give ______________ the amplitude or ______________ amplitude
- What if the two frequencies are just slightly ______________?





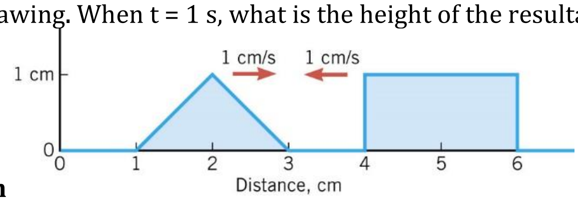
- Beat Frequency = ______________ of the two ______________ frequencies

$$Beats = |f_1 - f_2|$$

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

Homework

1. Speakers in stereo systems have two color-coded terminals to indicate how to hook up the wires. If the wires are reversed, the speaker moves in a direction opposite that of a properly connected speaker. Explain why it is important to have both speakers connected the same way.
2. Does the principle of linear superposition imply that two sound waves, passing through the same place at the same time, always create a louder sound than either wave alone? Explain.
3. A tuning fork has a frequency of 440 Hz. The string of a violin and this tuning fork, when sounded together, produce a beat frequency of 1 Hz. From these two pieces of information alone, is it possible to determine the exact frequency of the violin string? Explain.
4. A car has two horns, one emitting a frequency of 199 Hz and the other emitting a frequency of 203 Hz. What beat frequency do they produce? (OpenStax 16.57) **4 hz**
5. The middle-C hammer of a piano hits two strings, producing beats of 1.50 Hz. One of the strings is tuned to 260.00 Hz. What frequencies could the other string have? (OpenStax 16.58) **261.50 Hz, 258.50 Hz**
6. Two tuning forks having frequencies of 460 and 464 Hz are struck simultaneously. What average frequency will you hear, and what will the beat frequency be? (OpenStax 16.59) **462 Hz, 4 Hz**
7. Twin jet engines on an airplane are producing an average sound frequency of 4100 Hz with a beat frequency of 0.500 Hz. What are their individual frequencies? (OpenStax 16.60) **4099.750 Hz, 4100.250 Hz**
8. Three adjacent keys on a piano (F, F-sharp, and G) are struck simultaneously, producing frequencies of 349, 370, and 392 Hz. What beat frequencies are produced by this discordant combination? (OpenStax 16.62) **21 Hz, 22 Hz, 43 Hz**
9. Two pulses are traveling toward each other, each having a speed of 1 cm/s. At t = 0 s, their positions are shown in the drawing. When t = 1 s, what is the height of the resultant pulse at (a) x = 3 cm and at (b) x = 4 cm? (Cutnell 17.1) **2 cm, 1**

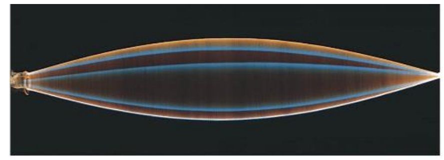


cm

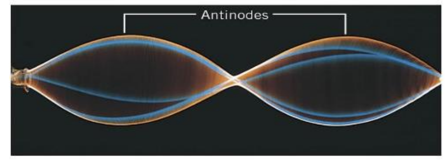
10. Two speakers, one directly behind the other, are each generating a 245-Hz sound wave. What is the smallest separation distance between the speakers that will produce destructive interference at a listener standing in front of them? The speed of sound is 343 m/s. (Cutnell 17.2) **0.700 m**
11. Two out-of-tune flutes play the same note. One produces a tone that has a frequency of 262 Hz, while the other produces 266 Hz. When a tuning fork is sounded together with the 262-Hz tone, a beat frequency of 1 Hz is produced. When the same tuning fork is sounded together with the 266-Hz tone, a beat frequency of 3 Hz is produced. What is the frequency of the tuning fork? (Cutnell 17.16) **263 Hz**
12. A 440-Hz tuning fork is sounded together with an out-of-tune guitar string, and a beat frequency of 3 Hz is heard. When the string is tightened, the frequency at which it vibrates increases, and the beat frequency is heard to decrease. What was the original frequency of the guitar string? (Cutnell 17.18) **437 Hz**
13. A tuning fork vibrates at a frequency of 524 Hz. An out-of-tune piano string vibrates at 529 Hz. How much time separates successive beats? (Cutnell 17.20) **0.2 s**

String Attached at Both Ends

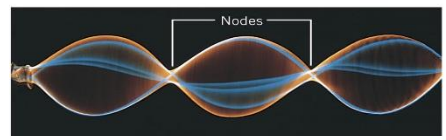
- The ________ wave is formed.
- Nodes – ________
- Antinodes – ________



- The wave ________ along the string until it hits the other ________
- The wave ________ off the other end and travels in the ________ direction, but ________
- The returning wave hits the ________ end and ________ again (this side the wave is ____________)
- Unless the timing is just right the reflecting wave and the new wave will not ________



- When they do coincide, the waves add due to ________ interference
- When they don't coincide; ________ interference



Harmonics

- When you vibrate the string faster, you can get standing waves with ________ nodes and antinodes
- Standing waves are named by number of ________
- 1 antinode → 1st harmonic (fundamental frequency)
- 2 antinodes → 2nd harmonic (1st overtone)
- 3 antinodes → 3rd harmonic (2nd overtone)
- f_1 = fundamental frequency (1st harmonic)
- $f_2 = 2f_1$ (2nd harmonic)
- $f_3 = 3f_1$ (3rd harmonic)

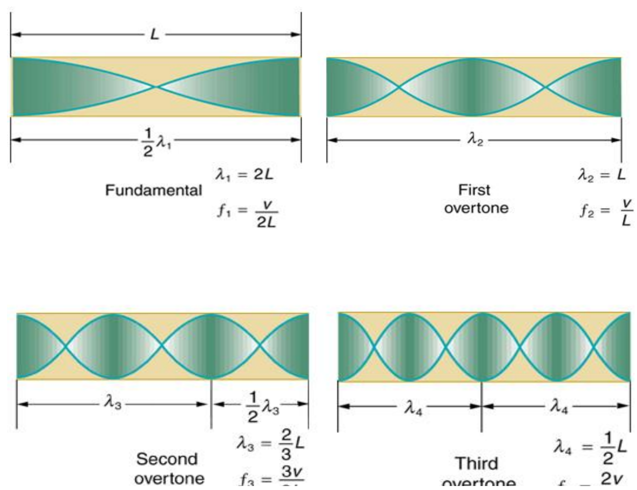
- To find the fundamental frequencies and harmonics of a string fixed at ________ ends

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

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

Tube open at both ends

- Wind instruments rely on standing ________ sound waves in ________
- The waves ________ off the open ends of tubes
- One difference at the ends are ________ instead of nodes



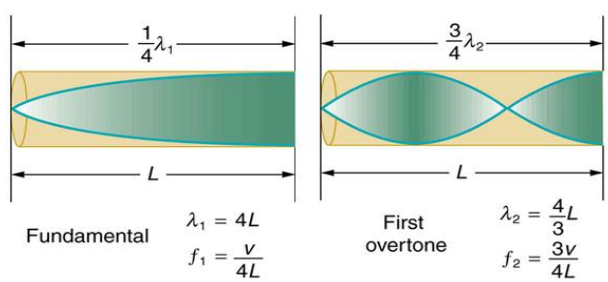
Formula for Tube Open at Both Ends

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

What is the lowest frequency playable by a flute that is 0.60 m long if that air is 20 °C.

Tube open at one end

- Node at the ________ end

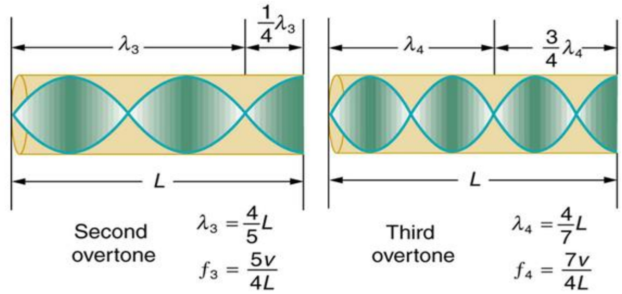


Physics 07-07 Sound Interference and Resonance

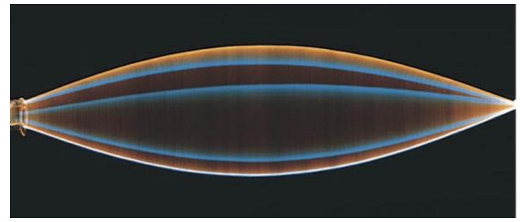
- Antinode at the ________________ end
- Lengths are *odd integer* multiples of ¼ λ

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

- Only ________________ harmonics

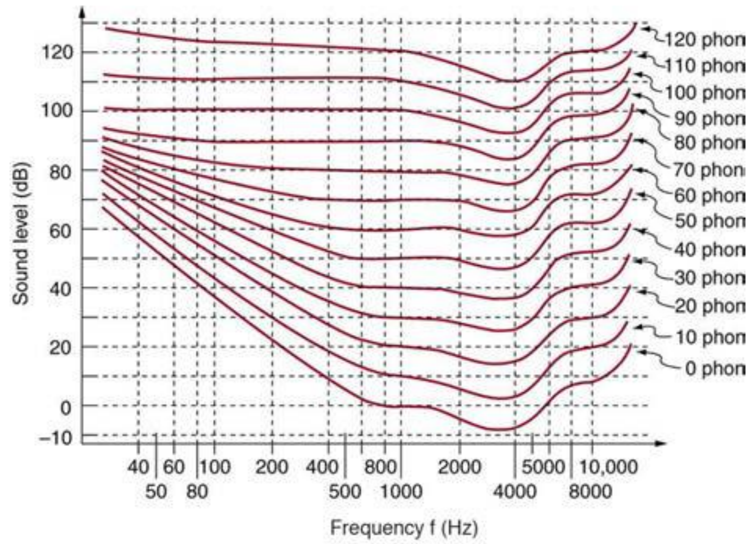


Homework



1. A string is vibrating back and forth as in the figure. The tension in the string is decreased by a factor of four, with the frequency and the length of the string remaining the same. Draw the new standing wave pattern that develops on the string. Give your reasoning.
2. A rope is hanging vertically straight down. The top end is being vibrated back and forth. Standing waves can develop on the rope analogous to those on a horizontal rope. (a) There is a node at the top end. Is there a node or an antinode at the bottom end? Try it. (b) The separation between successive nodes is not the same everywhere on the rope, as it would be if the rope were horizontal. Is the separation greater near the top or near the bottom? Try it. Taking into account the mass of the rope, give your reasoning.
3. How does an unamplified guitar produce sounds so much more intense than those of a plucked string held taut by a simple stick?
4. What is the difference between an overtone and a harmonic? Are all harmonics overtones? Are all overtones harmonics?
5. (a) What is the fundamental frequency of a 0.672-m-long tube, open at both ends, on a day when the speed of sound is 344 m/s? (b) What is the frequency of its second harmonic? (OpenStax 17.42) **256 Hz, 512 Hz**
6. If a wind instrument, such as a tuba, has a fundamental frequency of 32.0 Hz, what are its first three overtones? It is closed at one end. (The overtones of a real tuba are more complex than this example, because it is a tapered tube.) (OpenStax 17.43) **96.0 Hz, 160 Hz, 224 Hz**
7. What are the first three overtones of a bassoon that has a fundamental frequency of 90.0 Hz? It is open at both ends. (The overtones of a real bassoon are more complex than this example, because its double reed makes it act more like a tube closed at one end.) (OpenStax 17.44) **180 Hz, 270 H, 360 Hz**
8. How long must a flute be in order to have a fundamental frequency of 262 Hz (this frequency corresponds to middle C on the evenly tempered chromatic scale) on a day when air temperature is 20.0 °C? It is open at both ends. (OpenStax 17.45) **65.4 cm**
9. What length should an oboe have to produce a fundamental frequency of 110 Hz on a day when the speed of sound is 343 m/s? It is open at both ends. (OpenStax 17.46) **1.56 m**
10. What is the length of a tube that has a fundamental frequency of 176 Hz and a first overtone of 352 Hz if the speed of sound is 343 m/s? (OpenStax 17.47) **0.974 m**
11. (a) Find the length of an organ pipe closed at one end that produces a fundamental frequency of 256 Hz when air temperature is 18.0 °C. (b) What is its fundamental frequency at 25.0 °C? (OpenStax 17.48) **0.334 m, 259 Hz**
12. The A string on a string bass is tuned to vibrate at a fundamental frequency of 55.0 Hz. If the tension in the string were increased by a factor of four, what would be the new fundamental frequency? (Cutnell 17.23) $\mathbf{1.1 \times 10^2}$ **Hz**
13. The G string on a guitar has a fundamental frequency of 196 Hz and a length of 0.62 m. This string is pressed against the proper fret to produce the note C, whose fundamental frequency is 262 Hz. What is the distance L between the fret and the end of the string at the bridge of the guitar? (Cutnell 17.25) **0.46 m**
14. On a cello, the string with the largest linear density (1.56×10^{-2} kg/m) is the C string. This string produces a fundamental frequency of 65.4 Hz and has a length of 0.800 m between the two fixed ends. Find the tension in the string. (Cutnell 17.27) **171 N**
15. Sound enters the ear, travels through the auditory canal, and reaches the eardrum. The auditory canal is approximately a tube open at only one end. The other end is closed by the eardrum. A typical length for the auditory canal in an adult is about 2.9 cm. The speed of sound is 343 m/s. What is the fundamental frequency of the canal? (Interestingly, the fundamental frequency is in the frequency range where human hearing is most sensitive.)(Cutnell 17.36) **3000 Hz**

Hearing



- Pitch
  - Perception of ______________
  - 20 Hz – 20000 Hz
  - Most sensitive to ______________ Hz
  - Can distinguish between pitches that vary by at least ______________
- Loudness
  - Perception of ______________
  - Range 10^{-12} W/m^2 – 10^{12} W/m^2
  - Most people can discern an intensity level difference of ______________

Ultrasound

- Used in ______________ to examine a fetus, used to examine some ______________, and ______________ flow
- High ______________ sound aimed at target
- Sound reflects at ______________ of tissues with different ______________ impedances
- ______________compiles picture from where ______________ come from
- Acoustic impedance
  $Z = \rho v$
  - See table
- Intensity reflection coefficient
  $$a = \frac{(Z_2 - Z_1)^2}{(Z_1 + Z_2)^2}$$
  - Higher coefficient, more reflection

Table 17.5 The Ultrasound Properties of Various Media, Including Soft Tissue Found in the Body

Medium	Density (kg/m^3)	Speed of Ultrasound (m/s)	Acoustic Impedance $(\text{kg}/(\text{m}^2 \cdot \text{s}))$
Air	1.3	330	429
Water	1000	1500	1.5×10^6
Blood	1060	1570	1.66×10^6
Fat	925	1450	1.34×10^6
Muscle (average)	1075	1590	1.70×10^6
Bone (varies)	1400–1900	4080	5.7×10^6 to 7.8×10^6
Barium titanate (transducer material)	5600	5500	30.8×10^6

- Can't see detail smaller than ______________
- Can only penetrate to depth of ______________

Calculate the intensity reflection coefficient of ultrasound when going from water to fat tissue (like a baby in the womb)

Cavitron Ultra Surgical Aspirator

- Used to remove inoperable ______________ tumors
- Tip of instrument vibrates at ______________kHz
- Shatters ______________ tissue that comes in contact
- Better ______________ than a knife

High-Intensity Focused Ultrasound

- Sound is ______________ on a region of the body.

- The waves entering the body don't do ______________
- Only damage done where ______________ (like sun and magnifying glass)
- The focused energy at target causes ______________ which kills abnormal cells

Doppler Flow Meter

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

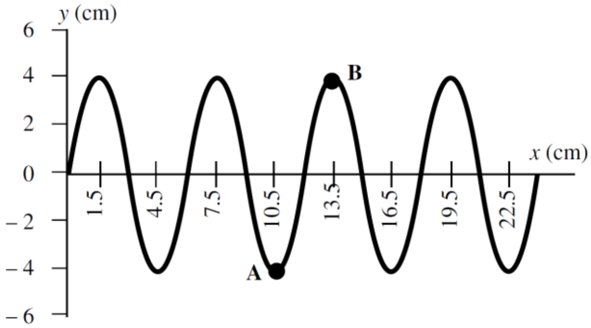
Homework

1. Why can a hearing test show that your threshold of hearing is 0 dB at 250 Hz, when the figure on the front side implies that no one can hear such a frequency at less than 20 dB?
2. If audible sound follows a rule of thumb similar to that for ultrasound, in terms of its absorption, would you expect the high or low frequencies from your neighbor's stereo to penetrate into your house? How does this expectation compare with your experience?
3. Elephants and whales are known to use infrasound to communicate over very large distances. What are the advantages of infrasound for long distance communication?
4. Suppose you read that 210-dB ultrasound is being used to pulverize cancerous tumors. You calculate the intensity in watts per centimeter squared and find it is unreasonably high (10^5 W/cm^2). What is a possible explanation?
5. What are the closest frequencies to 500 Hz that an average person can clearly distinguish as being different in frequency from 500 Hz? The sounds are not present simultaneously. (OpenStax 17.57) **498.5 Hz and 501.5 Hz**
6. Can the average person tell that a 2002-Hz sound has a different frequency than a 1999-Hz sound without playing them simultaneously? (OpenStax 17.58) **No**
7. If your radio is producing an average sound intensity level of 85 dB, what is the next lowest sound intensity level that is clearly less intense? (OpenStax 17.59) **82 dB**
8. Can you tell that your roommate turned up the sound on the TV if its average sound intensity level goes from 70 to 73 dB? (OpenStax 17.60) **Yes**
9. Based on the graph on the front side, what is the threshold of hearing in decibels for frequencies of 60, 400, 1000, 4000, and 15,000 Hz? *Note that many AC electrical appliances produce 60 Hz, music is commonly 400 Hz, a reference frequency is 1000 Hz, your maximum sensitivity is near 4000 Hz, and many older TVs produce a 15,750 Hz whine.* (OpenStax 17.61) **48 dB, 9 dB, 0 dB, -7 dB, 20 dB**
10. What is the sound intensity level in decibels of ultrasound of intensity 10^5 W/m^2, used to pulverize tissue during surgery? (OpenStax 17.72) **170 dB**
11. Find the sound intensity level in decibels of 2.00×10^{-2} W/m^2 ultrasound used in medical diagnostics. (OpenStax 17.74) **103 dB**
12. The time delay between transmission and the arrival of the reflected wave of a signal using ultrasound traveling through a piece of fat tissue was 0.13 ms. At what depth did this reflection occur? (OpenStax 17.75) **10 cm**
13. In the clinical use of ultrasound, transducers are always coupled to the skin by a thin layer of gel or oil, replacing the air that would otherwise exist between the transducer and the skin. (a) Using the values of acoustic impedance given in Table 17.5 calculate the intensity reflection coefficient between transducer material and air. (b) Calculate the intensity reflection coefficient between transducer material and gel (assuming for this problem that its acoustic impedance is identical to that of water). (c) Based on the results of your calculations, explain why the gel is used. (OpenStax 17.76) **1.00, 0.823**
14. (a) How far apart are two layers of tissue that produce echoes having round-trip times (used to measure distances) that differ by 0.750 μs? (b) What minimum frequency must the ultrasound have to see detail this small? (OpenStax 17.80) $\mathbf{5.78 \times 10^{-4}}$ **m,** $\mathbf{2.67 \times 10^{6}}$ **Hz**
15. A diagnostic ultrasound echo is reflected from moving blood and returns with a frequency 500 Hz higher than its original 2.00 MHz. What is the velocity of the blood? (Assume that the frequency of 2.00 MHz is accurate to seven significant figures and 500 Hz is accurate to three significant figures.) (OpenStax 17.83) **0.192 m/s**

Physics

Unit 7: Waves and Sound

1. Know meanings of reflect, interference, beats, constructive, destructive, frequency, superposition, wavelength, standing wave, fundamental frequency, harmonics (i.e. 1st harmonic, 2nd harmonic), overtones (i.e. 1st overtone, 2nd overtone), resonate.
2. Be able to classify waves by type (longitudinal, transverse, or both).
3. Know the value of the threshold of hearing.
4. Know how frequency and pitch are related.
5. Know how decibels and loudness are related.
6. Know what affects the speed of a wave ($v = f\lambda$ and all the speed formulas)
7. Know some drawings to represent standing waves in open and closed tubes.
8. How are standing waves produced?
9. How are beats produced?
10. What happens when two wave pulses traveling opposite directions meet?
11. Do waves: move energy? Move matter from place to place? Have a traveling disturbance?
12. What is the λ for a wave with a speed of 10 m/s and a period of 40 s?
13. A wave has a frequency of 30 Hz and a speed of 60 m/s. What is the wavelength of the wave?
14. In the following graph, what is the amplitude, wavelength and frequency of wave A is its speed is 5 cm/s?



15. A submarine sends out a sonar ping. The return echo is heard 20 s later. If the speed of sound is 1522 m/s, how far away is the reflecting surface?
16. The intensity of a spherical wave 5 m from the source is 200 W/m^2. What is the intensity at a point 10 m away from the source?
17. The decibel level of rock concert is 120 dB relative to the threshold of hearing. Determine the sound intensity produced by the concert.
18. A car moving at constant speed passes a boy playing a concert A (440 Hz) on an instrument. After the car has passed the driver hears the note as a concert E (330 Hz). How fast was the car going (speed of sound = 343 m/s)?
19. A car moving at 50 m/s approaches a train whistling. The train is moving towards the car at a speed of 10 m/s. The whistle is set at 200 Hz. What is the frequency heard by the driver of the car?
20. A guitar string produces 10 beats/s when sounded with a 440 Hz tuning fork and 5 beats/s when sounded with a 445 Hz tuning fork. What is vibrational frequency of the string?
21. A 2-m long string vibrates in 4 segments. The wave speed is 40 m/s. What is the frequency of vibration?
22. A 2-m long string vibrates in 4 segments. The wave speed is 40 m/s. What is the lowest possible frequency for standing waves on this string?
23. Determine the shortest length of pipe, open at both ends, which will resonate at 440 Hz. The speed of sound is 343 m/s.
24. A spring is used on a jumping toy. The bottom of the toy has a suction cup that keeps the spring compressed. If the suction cup supplies 15 N of force to keep the spring compressed 3 cm, what is the spring constant?
25. The -string on a certain guitar is under 100 N of tension. If the frequency is 200 Hz and the wavelength is 2.0 m, find the linear density of the string.

11. a. **Yes** b. **No** c. **Yes**

12. $v = 10\frac{m}{s}, 40\ s$

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

$10\frac{m}{s} = \frac{\lambda}{40\ s}$

$\lambda = 10\frac{m}{s}(40\ s) = \mathbf{400\ m}$

13. $f = 30\ Hz, v = 60\frac{m}{s}$

$v = f\lambda$

$60\frac{m}{s} = 30\ Hz\ \lambda$

$\lambda = \mathbf{2\ m}$

14. $A = \mathbf{4\ cm}, \boldsymbol{\lambda} = \mathbf{6\ cm}, \boldsymbol{f} = \mathbf{0.83\ Hz}$

$v = f\lambda = f \cdot 6\ cm = 5\frac{cm}{s}$

15. $t = 20\ s(t = 10\ s\ for\ one\ way), v = 1522\frac{m}{s}$

$x = vt$

$x = 1522\frac{m}{s}(10\ s) = \mathbf{15220\ m}$

16. $5\ m, I = 200\frac{W}{m^2}$

$10\ m, I = ?$

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

$200\frac{W}{m^2} = \frac{P}{4\pi(5\ m)^2} \rightarrow P = 62832\ W$

$I = \frac{62832\ W}{4\pi(10\ m)^2} = \mathbf{50\ W/m^2}$

17. $\beta = 120\ dB, I_0 = 10^{-12}\frac{W}{m^2}$

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

$120\ dB = (10dB)\ log\left(\frac{I}{10^{-12}\frac{W}{m^2}}\right)$

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

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

$\boldsymbol{I} = \mathbf{1.0\ W/m^2}$

18. $f_s = 440\ Hz, f_0 = 330\ Hz, v = 343\frac{m}{s}$

$f_0 = f_s\left(\frac{v_w \pm v_o}{v_w \mp v_s}\right)$

$330\ Hz = 440\ Hz\ \left(\frac{343\frac{m}{s} - v_o}{343\frac{m}{s} + 0}\right)$

$0.75 = \frac{343\frac{m}{s} - v_o}{343\frac{m}{s}}$

$257.25\frac{m}{s} = 343\frac{m}{s} - v_o$

$\boldsymbol{v_0} = \mathbf{85.8\frac{m}{s}}$

19. $v_0 = 50\frac{m}{s}, v_s = 10\frac{m}{s}, f_s = 200\ Hz$

$f_0 = f_s\left(\frac{v_w \pm v_o}{v_w \mp v_s}\right)$

$f_0 = 200\ Hz\ \left(\frac{343\frac{m}{s} + 50\frac{m}{s}}{343\frac{m}{s} - 10\frac{m}{s}}\right) = \mathbf{236\ Hz}$

20. $|f_g - 440\ Hz| = 10\ Hz$

$f_g = \mathbf{450\ Hz}\ or\ 430\ Hz$

$|f_g - 445\ Hz| = 5\ Hz$

$f_g = \mathbf{450\ Hz}\ or\ 440\ Hz$

21. $L = 2\ m, n = 4, v = 40\frac{m}{s}, f = ?$

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

$f_4 = 4\left(\frac{40\frac{m}{s}}{2(2\ m)}\right) = \mathbf{40\ Hz}$

22. $L = 2\ m, n = 1, v = 40\frac{m}{s}$

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

$f_1 = 1\left(\frac{40\frac{m}{s}}{2(2\ m)}\right) = \mathbf{10\ Hz}$

23. $f_1 = 440\ Hz, n = 1, v = 343\frac{m}{s}$

$f = n\left(\frac{v}{2L}\right)$

$440\ Hz = 1\left(\frac{343\frac{m}{s}}{2L}\right)$

$440\ Hz = \frac{171.5\frac{m}{s}}{L}$

$L = \frac{171.5\frac{m}{s}}{440\ Hz} = \mathbf{0.390\ m}$

24. $F = 15\ N, x = -0.03\ m$

$F = -kx$

$15\ N = -k(-0.03\ m)$

$\mathbf{500\ \frac{N}{m}} = k$

25. $F = 100\ N, f = 200\ Hzs, \lambda = 2.0\ m$

$v = f\lambda$

$v = (200\ Hz)(2.0\ m) = 400\frac{m}{s}$

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

$400\frac{m}{s} = \sqrt{\frac{100\ N}{m/L}}$

$160000\frac{m^2}{s^2} = \frac{100\ N}{m/L}$

$m/L = \frac{100\ N}{160000\frac{m^2}{s^2}} = \mathbf{6.25 \times 10^{-4}\ kg/m}$