Physics

Aley

Week 3 & 4

April 13th – April 24th

Epting, William

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Attachments: Waves 20.pdf; Physics Wave Diagrams.docx; Wave WS PW1.docx

Leon Physics
Mark Aley
Quarter 4
WEEK 3 & 4

Leon Physics week 3 and 4 schedule.

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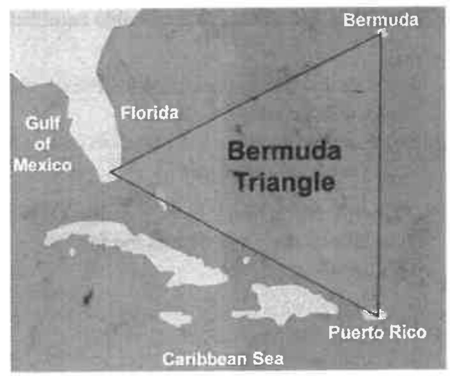
Textbook assignments are from the Essential Physics Pasco Edition textbook. Textbooks are available in room 123 on the counter in the far back right corner of the room.
Italicized assignments in the schedule are attached.
Please only do one assignment per page (don't cram all assignments on one paper).

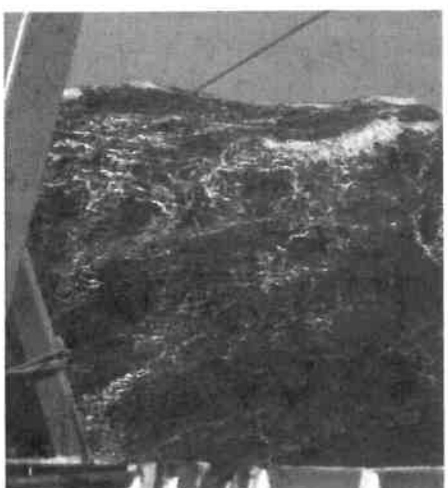
Mark Aley
Leon Physics
Distance Learning Instructor

Chapter 15 Waves

In 1952, a magazine writer claimed that supernatural forces were causing ships and planes to disappear in a place the writer named the *Bermuda Triangle*—a triangle bracketed by Miami, Puerto Rico, and the island of Bermuda. Subsequent investigations showed that the losses, while tragic, were statistically unremarkable. Nevertheless, ships at sea *can* disappear suddenly with hardly a trace. The culprit, in many cases, is a *rogue wave:* a mountain of water that can break a ship apart in a single blow.



"Most people don't survive encounters with such waves," according to Sebastian Junger, author of *The Perfect Storm.* One sailor who did survive was English adventurer Beryl Smeeton. Recalling a rogue wave off of Cape Horn, she wrote, "The whole horizon was blotted out by a huge grey wall... a wall of water with a completely vertical face, down which ran white ripples, like a waterfall." The wave flipped her 46-ft (14-m) boat and stripped it of its masts, but the crew survived. Others have not been so lucky. In 1976, the oil tanker *Cretan Star* reported being "struck by a huge wave that went over the deck." The ship was never heard from again.



To those who have survived to tell the tale, the appearance of a rogue wave seemingly violates natural law. But in fact rogue waves are the result of a basic physics concept called *constructive interference.* When the crests of several unrelated waves arrive in one place simultaneously, their heights are added—even if they may have largely canceled one another out in other nearby locations. Research suggests that these waves can also be amplified by ocean currents that crowd their crests together. Such currents frequent Africa's Cape Horn and the Gulf Stream, an immense flow of warm water that crosses the Atlantic Ocean from the Caribbean Sea to Western Europe. Fortunately, rogue waves are rare!

Chapter study guide

Chapter summary

In the previous chapter, you learned about many different kinds of oscillators: pendulums, masses on springs, and so on. What is the difference between an oscillator and a *wave*? A wave is an oscillation that *travels through space*. Waves are found all around us in nature, musical instruments, technology, and medical and industrial applications. Waves can reflect, refract, diffract, resonate, and interfere with each other. In this chapter, you will learn about the physical characteristics of waves and the behaviors associated with wave propagation.

Learning objectives

By the end of this chapter you should be able to

- describe waves and wave pulses and provide examples;
- define amplitude, frequency, wavelength, speed, and phase for a wave and identify each graphically;
- solve problems involving the speed, frequency, and wavelength of a wave;
- distinguish between transverse and longitudinal waves and provide examples of each;
- describe wave propagation in various types of media;
- describe wave behaviors of reflection, refraction, diffraction, and resonance and provide examples of each;
- describe constructive and destructive interference of waves and provide examples of each;
- describe standing waves and resonance and provide examples of each; and
- describe medical applications of waves.

Investigations

15A: Waves
15B: Wave interactions
15C: Interference
15D: Wavelength and standing waves

Chapter index

Important relationships

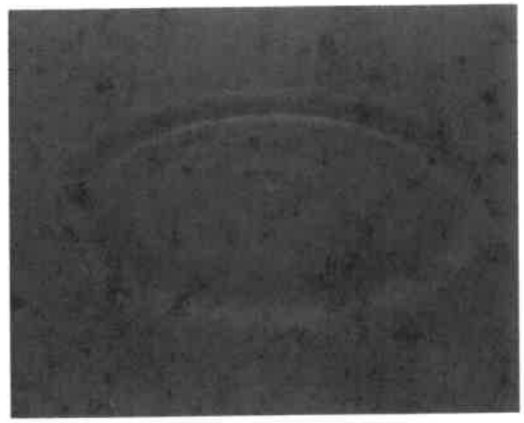
$$v = f\lambda$$

Vocabulary

wave	**wavelength**	**transverse**
polarization	**longitudinal**	**crest**
trough	**wavefront**	**reflection**
concave	**convex**	**refraction**
diffraction	**absorption**	**superposition principle**
constructive interference	**destructive interference**	**node**
antinode	**mode**	**standing wave**

15.1 - Waves

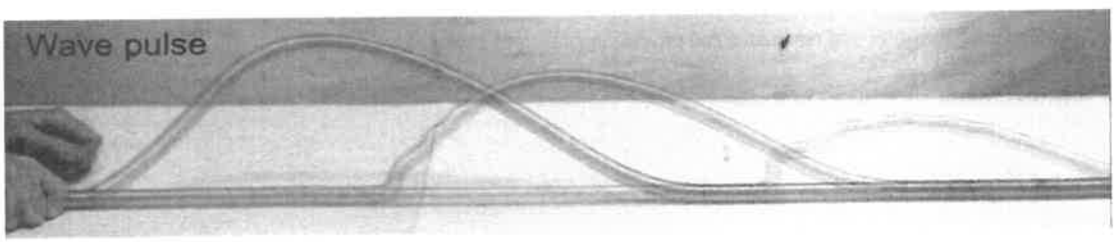
Think about dropping a stone into a pond on a very calm day. As the stone breaks the surface of the water, the surface oscillates up and down—in harmonic motion. But something else happens to the water surface: *Ripples form and spread out.* Everything the ripples touch also oscillates up and down with the same frequency. An oscillation that travels is a **wave**, and waves are the subject of this section. Both sound and light are waves. There are even gravity waves created when black holes crash into each other.



The importance of waves

Why are waves important?

Waves are an essential way by which energy travels. Think about the example of a stone falling into a pond. The ripple causes the water and objects floating in it to move up and down some distance away. Where did their energy of motion come from? The answer is that *it came from the stone and was carried by the wave.* When the stone hit the water surface some of its kinetic energy was converted to waves. The waves spread out over the surface of the pond, dispersing the kinetic energy of the stone over a much broader area of space than was directly touched by the stone itself.



Wave pulses

A fundamental reason for why waves are important is that any disturbance that releases energy often produces waves. The waves spread the energy out and propagate the disturbance through space, affecting other regions, which may be quite far away. A *wave pulse* on a long spring is a good example. To make a wave pulse on a spring, disturb one end by rapidly jerking it up and down once. The disturbance quickly moves away from your hand and travels along the spring. Areas of the spring far away from your hand are affected as the wave pulse reaches them. As the pulse moves, the energy of the disturbance is spread along the spring and also dissipates through friction. The wave pulse gets smaller until the spring is at rest again.

Earthquakes

This aspect of waves is frighteningly displayed by earthquakes. In an earthquake a tremendous amount of elastic potential energy is released when stressed rock deep underground suddenly slips and realigns itself. That energy is largely released as seismic waves that oscillate the ground up, down, and sideways. Just as a wave pulse moves along a spring, seismic waves race away from the earthquake epicenter at the speed of sound. When the seismic waves interact with matter, energy can be released—which can topple buildings 100 miles away during a powerful earthquake! Architects must design buildings to withstand the energy from oscillations (or shaking) caused by earthquakes.

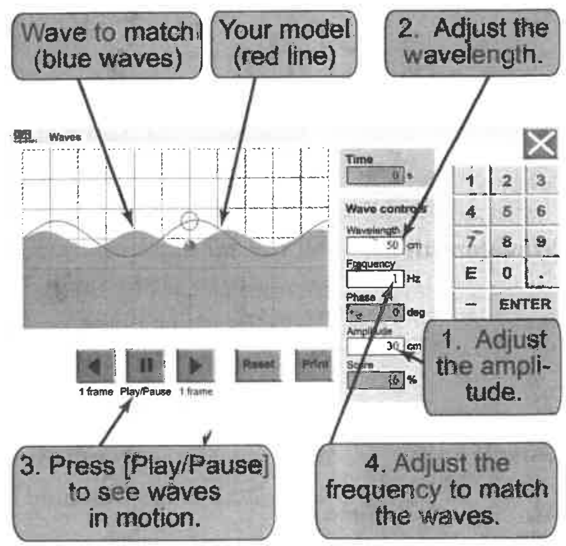
Investigation 15A Waves

Essential questions *What is a wave and what are the properties of waves?*

Interactive simulation

A wave is a traveling form of energy that carries oscillations from one place in space to another. Sound and light are both waves and share characteristics of frequency and wavelength with familiar water waves. This investigation will use a simulation of water waves to characterize the properties of frequency, amplitude, and wavelength.

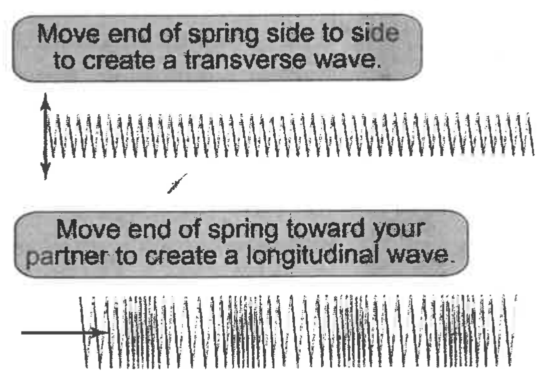
Part 1: Match a wave's properties



1. Open the interactive simulation. You will create a mathematical model of a wave (red line) to match the blue waves representing water.
2. Adjust the amplitude and wavelength to match the blue wave.
3. Run and Pause the waves. Adjust the frequency until the red circle bobbing in your model matches the bobbing of the floating ball.

a. Describe how changing the amplitude changes the wave.
b. Describe the effect of changing the wavelength.
c. Describe the effect of changing the frequency.
d. What are the frequency, amplitude, and wavelength of the blue wave?
e. Draw a graph showing the amplitude and wavelength of this wave.
f. Calculate the speed of the wave. Show your work.

Part 2: Transverse and longitudinal waves



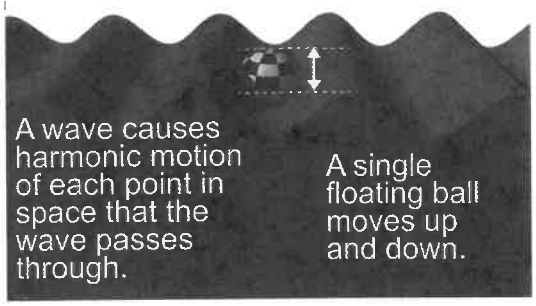
1. Hold one end of a Slinky® spring (or other long spring) and have your partner hold the other end. Stretch the spring a little bit so that it is not slack.
2. Create *transverse* waves by moving your hand side to side.
3. Create *longitudinal* waves by moving your hand sharply toward your partner.
4. Repeat the above steps, but this time using a wave motion rope or other heavy string.

a. What are the differences between these two types of waves? Describe the characteristics of each in words.
b. Can you make both types of waves on both pieces of equipment? Why or why not?
c. Can you create waves of different velocities with the spring or rope? If so, how?

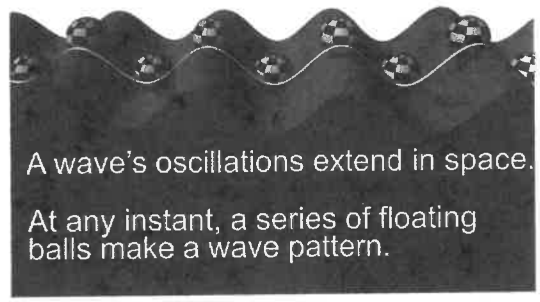
Waves in time and space

Oscillations have cycles and so do waves. Waves spread out and move, so their cycles extend over both *time* and *space*. Consider a water wave on the surface of a pond. If you watch one single location in space as *time* goes by, the water oscillates up and down at the frequency of the wave. A ball floating at this location oscillates up and down over time. Next, consider freezing the entire surface of the pond at a single instant of time. In the frozen surface there is also an up–down repeating pattern that repeats in *space*.

A point in *space*



An instant in *time*



Wavelength

At any moment of time, the cycles of a single wave are described by its *wavelength*. The **wavelength** is the spatial length of one complete cycle of the wave at one instant of time. Wavelength is a new property of waves that does not exist for a stationary oscillator such as a pendulum.

Measuring wavelength

If you could "freeze" a wave in place, you could measure the wavelength as the distance between two successive crests (or peaks) of the wave. Alternatively, wavelength can be described as the distance between two successive *troughs* (or lowest points) of the wave.

Frequency

The frequency of a wave is just like the frequency of an oscillator. A wave with a frequency of 10 Hz repeats itself 10 times per second *at every place in space the wave reaches*. This allows waves to carry *information* over great distances. When you listen to a guitar, the sound wave carries information about the vibration of the string from the instrument to your ear. A light wave carries information about color and space to your eyes. Electrical waves in wires and light waves in optical fiber cables carry Internet and television information. A microwave carries cellphone conversations. In nature and in human technology, waves carry energy and information from one place to another. The information could be sound, color, pictures, commands, or virtually anything else.

Amplitude

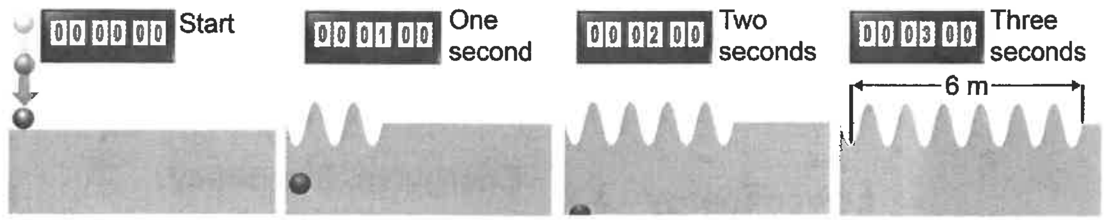
The amplitude of a water wave is the maximum amount the wave causes the water to rise (or fall) compared to its average resting level. While the amplitude of a water wave is measured as a height in meters, the amplitudes of other waves may have different units. For example, a sound wave is a pressure oscillation and therefore its amplitude is measured in force per unit area, not distance. Most waves become smaller with increasing distance from the source, just as ripples decrease far from the splash of a pebble. Even though the *amplitude* of the wave decreases, the *frequency* remains the same.

Mechanical waves

Sound and water waves are *mechanical waves*, which means that they propagate via the oscillation of matter in a medium. The medium can be a solid, liquid, or gas. As you will learn in Chapter 22, light is an *electromagnetic wave* that can propagate in a vacuum —without any medium whatsoever.

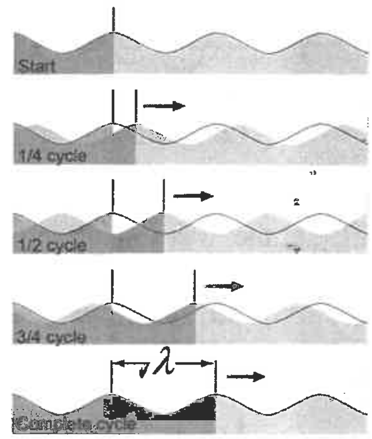
Speed of a wave

The speed of a wave is not quite the same as the speed of a moving object. Think about dropping a stone into a pond in which a ball is floating a few meters away. When the ripples reach the ball, the ball oscillates up and down. The speed of the wave is the speed at which the ripples spread out from where the stone fell. Physicists use the word *propagate*, which means to "spread out and grow." The speed of a wave is the speed at which the *wave* propagates, or spreads itself out.



Speed, frequency, and wavelength

As a wave moves forward, it advances one wavelength with each complete cycle. Speed is distance divided by time, and therefore the speed of a wave is its wavelength λ divided by the period T of its cycle. Since the frequency is the inverse of the period ($f = 1 / T$) we usually write the speed of a wave in terms of frequency and wavelength. The result is true for sound waves, light waves, and even gravity waves. Frequency multiplied by wavelength is the speed of the wave.



$$v = \frac{d}{t} = \frac{\lambda}{T} = \lambda f$$

Interactive equation

Speed, frequency, and wavelength of a wave

(15.1) $$v = f\lambda$$

v = speed of the wave (m/s)
f = frequency (Hz)
λ = wavelength (m)

Waves have a wide range of speeds

Waves have a wide range of speeds. Lab-sized water waves are fairly slow; a few miles per hour, or 0–5 m/s, is typical. Deep ocean waves, such as tsunamis, can be much faster, reaching 600 mph (268 m/s) or more—as fast as a jet airliner! Light waves are extremely fast—300,000 kilometers *per second,* which is 3×10^8 m/s or 671,000,000 mph. Sound waves travel at about 343 m/s in air—faster than water waves but much slower than light.

Calculating the speed of a wave

Two men use a long spring to create a wave. The wavelength is 2 m and the frequency is 2 Hz. How fast is the wave traveling along the spring?

Asked: speed v of the wave ("how fast")
Given: wavelength $\lambda = 2$ m, frequency $f = 2$ Hz
Relationships: $v = f\lambda$
Solution: Insert the values into the equation:

$$v = f\lambda = 2 \text{ Hz} \times 2 \text{ m} = 4 \text{ m/s}$$

Answer: The wave travels at 4 m/s.

Sound waves in solids

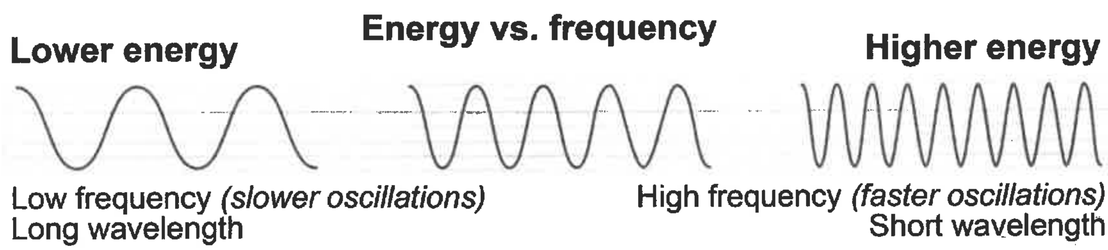
Sound waves travel faster through water (1,500 m/s) than they do through air (343 m/s). Sound waves also generally travel faster through solids than through liquids. A seismic wave may travel at 2,000 to 8,000 m/s through the Earth's crust.

Waves are a form of energy

Waves are a form of moving energy. Waves may move *through* matter, but a wave is not matter itself. For example, a water wave is *not* the water, which exists independently of the wave. A water wave is a form of pure energy. When a water wave moves across a pond surface, the wave's energy causes the matter to respond—by moving up and down. Once the wave passes, the matter returns to equilibrium again. Waves transfer energy from one location to another.

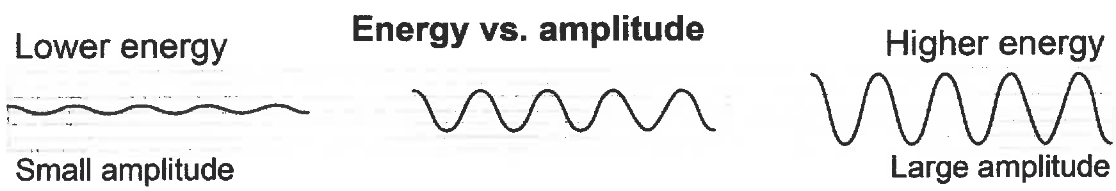
Energy and frequency

The energy of a wave increases with frequency. The three waves in the diagram below have the same amplitude and different frequencies. The wave with the higher frequency transfers more energy. This is true for almost all waves, including water waves, sound, and light.



Energy and amplitude

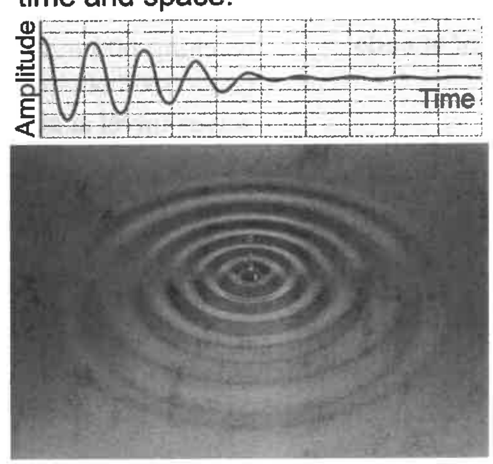
The energy of a wave also increases with amplitude. If two waves have the same frequency, the wave with the larger amplitude transfers more energy. With water waves, larger amplitude means that the wave lifts the water a greater distance above its equilibrium level. With sound waves, larger amplitude means louder sound. With light waves, larger amplitude means brighter light.



Amplitude decreases over space

As a wave spreads out, its amplitude decreases. This can happen for two reasons. One is damping, a process in which friction reduces the wave energy over time. But there is also a second reason that amplitude decreases. As a wave propagates, its energy may spread out over a larger area. That leaves less energy in any given portion of the wave. This is the main reason why ripples get smaller and smaller as they spread. It is also the reason why light gets dimmer as you get far from a bulb and sound gets fainter far from its source.

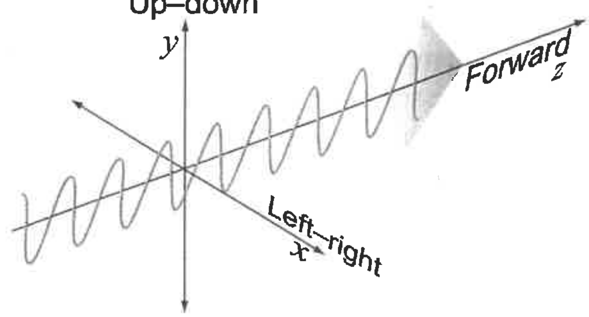
Amplitude tends to decrease over time and space.



Waves in three dimensions

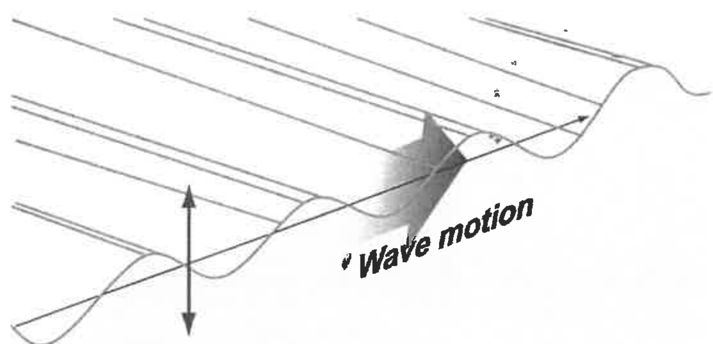
Space is three dimensional and waves can cause oscillations in all three dimensions as well as *scalar* oscillations that have no direction. How a wave oscillates relative to its direction of motion is one important way to classify waves. To explain this we define the forward dimension as the direction the wave moves. The other two dimensions—up–down and left–right—are both perpendicular to the direction the wave moves.

Describing waves in three dimensions



Transverse waves

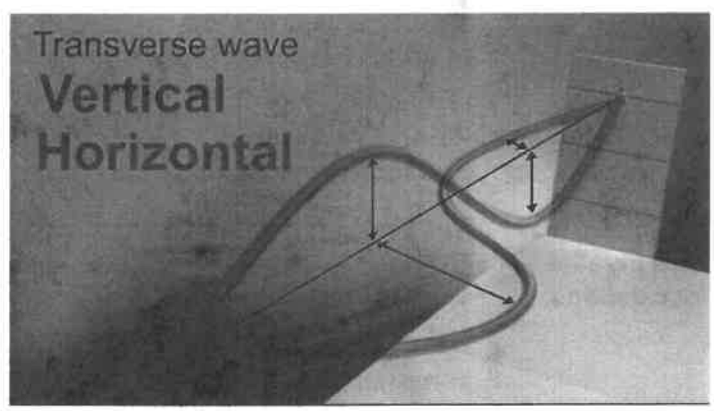
A **transverse** wave causes oscillations perpendicular to the forward direction the wave moves. Waves in a stretched string are transverse waves because the wave moves along the string and the oscillations are up and down, perpendicular to the line of the string. Light is also a transverse wave, although the explanation for *why* will have to wait until Chapter 22 when we discuss electric and magnetic fields.



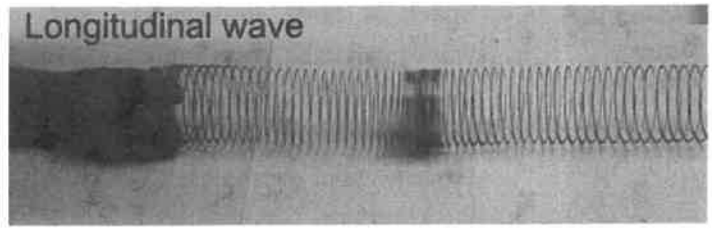
Transverse waves

Polarization

A spring can be used to create transverse waves. Shaking a long spring up and down versus side to side demonstrates the property of *polarization* that is common to all transverse waves. **Polarization** describes the direction of the oscillation in a plane perpendicular to the direction the wave moves. A transverse wave has a *polarization* because there are two directions perpendicular to the motion of the wave. For example, a wave on a spring moving in the *z*-direction could be polarized in the horizontal *x*-direction, the vertical *y*-direction, or any other direction in between.

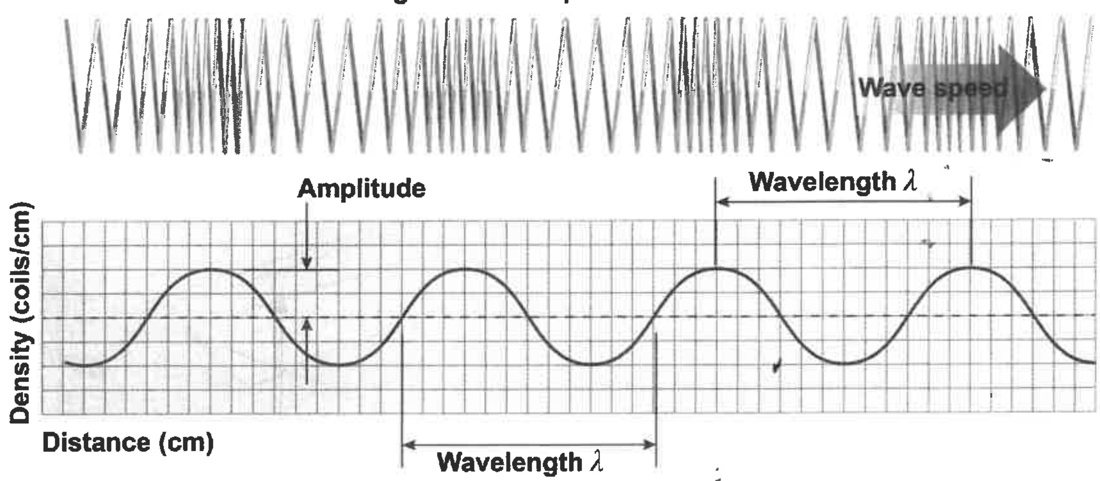


Longitudinal waves



If you rapidly move the end of a Slinky® spring forward and backward again, a *longitudinal* compression wave moves along the spring. A **longitudinal** wave is either a *scalar* oscillation or an oscillation of the medium that moves back and forth in the same direction as the wave travels. The compression wave on the Slinky® moves along the length of the slinky. The oscillations are the "bunching" and "stretching" that move along through the spring as the wave travels. Sound is another example of a longitudinal wave.

Longitudinal compression wave



Amplitude and wavelength

The *amplitude* of the compression wave is the difference between the maximum "bunching" and the average, resting spacing of the spring. The amplitude of any longitudinal wave is the difference between the average and the maximum displacement away from average of the parameter that is oscillating. For the Slinky® spring the oscillation is in the density of coils per centimeter. For a sound wave the oscillation will be of air pressure. The *wavelength* of a longitudinal wave is the length of one complete cycle of the amplitude oscillation. The graph shows the wavelength as related to the motion of the spring. This is the same as the distance between one maximum compression and the next maximum compression.

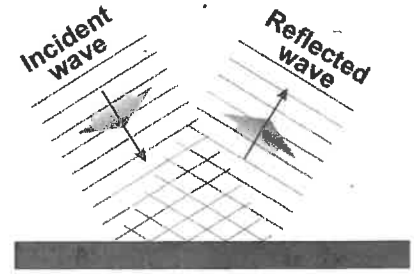
Perpendicular and parallel oscillations

The key distinction between transverse waves (such as *light*, which you will learn about in Chapter 22) and longitudinal waves (such as sound, which you will learn about in Chapter 16) is the relationship between the direction of the oscillation and the direction the wave travels. Oscillations in transverse waves are *perpendicular* to the direction the wave travels —meaning that they are rotated 90° away from the wave's direction of motion. Oscillations in longitudinal waves are either *parallel* to the direction the wave travels—such as the compression wave on the Slinky®—or they are oscillations of a scalar variable, such as pressure.

Reflection

Reflection causes a wave to change direction and may also change the shape of its wavefront. Reflection occurs for both transverse and longitudinal waves. A plane wave encountering a straight boundary reflects in a new direction while keeping the same waveform. The same is true of a circular wave. A circular wave reflecting from a straight boundary will still be a circular wave.

Reflection from a fixed boundary



Boundaries

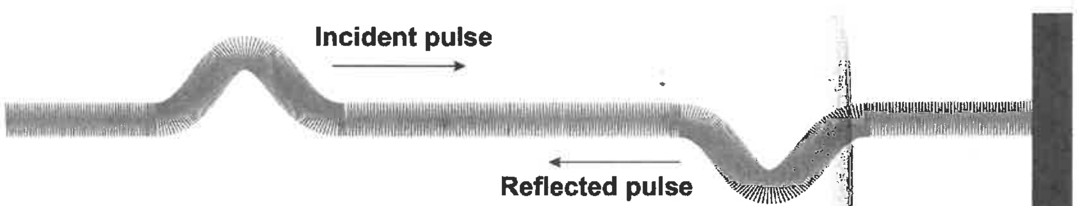
Reflection occurs at *boundaries* where conditions change, such as the edge of a pool or the wall of a room. The end of a long, snaky spring can also be considered a boundary for waves on the spring since it represents a change of conditions.

Fixed boundary for a spring

Open boundary for a spring

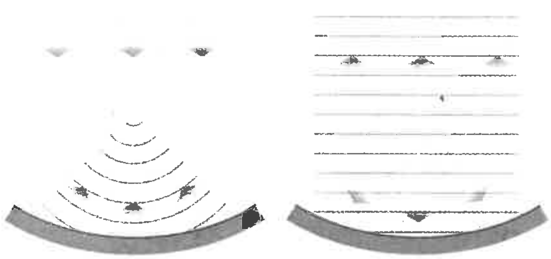
Boundary types

The kind of reflection that occurs at a boundary depends on whether the boundary is *fixed* or *open*. A fixed boundary does not move in response to the wave. A transverse wave pulse on a spring reflects onto the opposite side of the spring when encountering a fixed boundary. The free end of a spring is an open boundary. The end moves in response to a wave traveling along the spring. A wave pulse reflects back on the same side of the spring when encountering an open boundary.

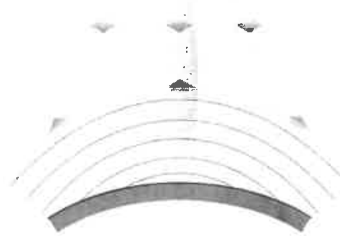


Curved boundaries

Curved boundaries can change the shape of a wave, altering its direction. A **concave** reflector can turn a plane wave into a circular wave that converges to a point. A circular wave reflecting off the same shape can turn into a plane wave. A **convex** reflector can turn a plane wave into a circular wave that diverges from a point. The convex shape can also turn a circular wave into another circular wave with a different curvature. Curved boundaries are extensively used in communications technology such as satellite dish receivers.



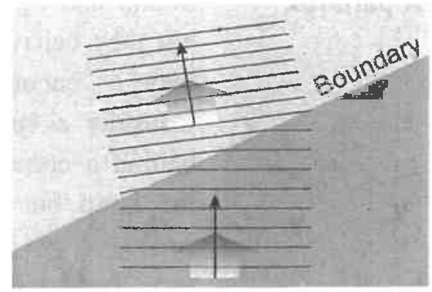
Concave reflector



Convex reflector

Refraction

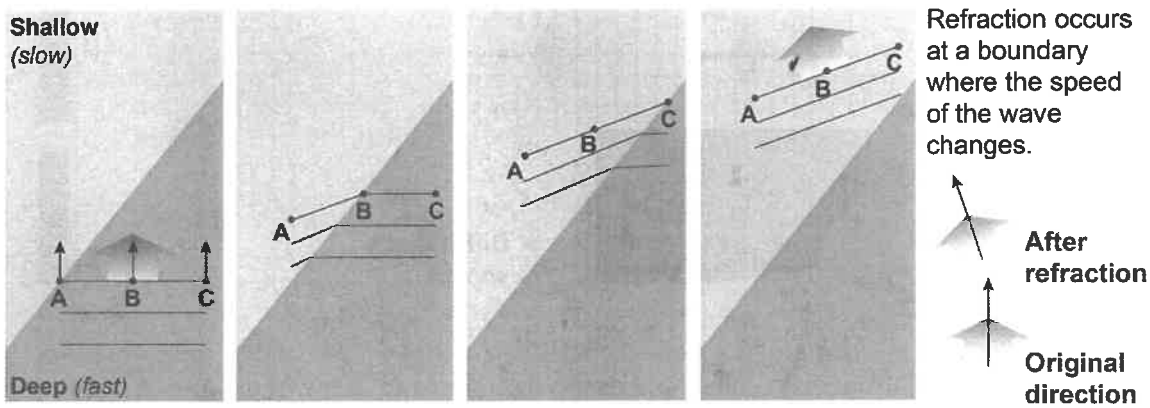
Some boundaries divide regions where conditions change, such as the depth of water. A plane wave in water that crosses a depth boundary changes its direction. This process is called **refraction**. Refraction is the process by which a wave changes direction as its wavefront is altered by passing *through* a boundary. A plane wave passing through a straight boundary remains a plane wave but changes direction as shown in the diagram.



Refraction
occurs when a wave changes direction crossing a boundary.

What causes refraction?

Refraction occurs when the speed of the wave is different on the two sides of a boundary. Consider three points on the crest of a plane wave crossing a boundary between deep and shallow water. Water waves travel slower in shallow water compared to deep water. Point A reaches the boundary first and starts to move slower. Point B hits next and point C hits last. The wavefront over the shallow section has a different angle than the original wave. A wave moves in the direction perpendicular to the wavefront, and therefore the change in the wavefront causes a corresponding change in direction of the wave as it crosses the boundary.



Refraction occurs at a boundary where the speed of the wave changes.

Do the wavelength or the frequency change?

Refraction usually changes the wavelength as well as the direction. Note in the diagram that the wavefronts get closer together on the slow side of the boundary. This occurs because the frequency of the wave does *not* change. The same number of crests per second must enter the boundary as leave. If the speed v gets slower and the frequency f stays the same, then, according to the equation $v = f\lambda$, the wavelength λ must decrease.

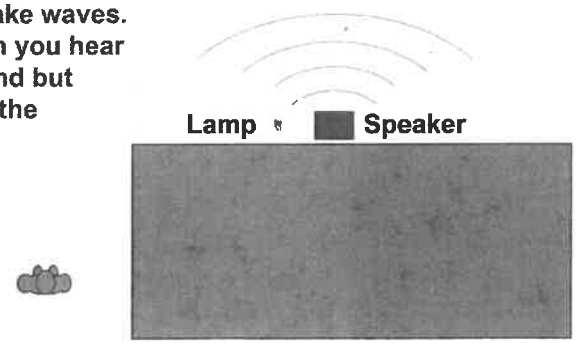
Is refraction useful?

Refraction occurs with all types of waves, including transverse and longitudinal waves, and is important in many technologies. In optical systems, such as in cameras and telescopes, curved refracting surfaces bend light waves to create images. Ultrasound imaging detects the changes in tissue density within the human body by measuring the refraction of very high frequency sound waves.

A paradox

Sound and light are both waves, but they behave differently when they encounter obstacles. Consider a speaker and a lamp behind a corner. You cannot see the lamp but you can hear the sound! Why? Why does a sound wave bend around a corner but a light wave does not!

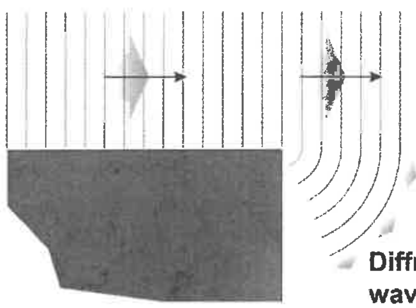
Both make waves. Why can you hear the sound but not see the light?



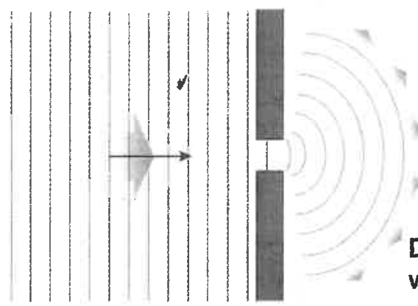
The answer to the paradox

The answer is *diffraction*. **Diffraction** is a property of waves that allows a wave to bend around an obstacle, such as a corner. Sound waves diffract around the corner because the wavelength of sound is typically a few centimeters. This wavelength is comparable to the size of the corner itself. Light waves also diffract *slightly* around the corner but the typical wavelength of a light wave is on the order of 10^{-5} cm. This is far smaller than the scale of the corner itself, and the amount of diffraction is imperceptible.

Diffraction around a corner



Diffraction through an opening



What does diffraction do?

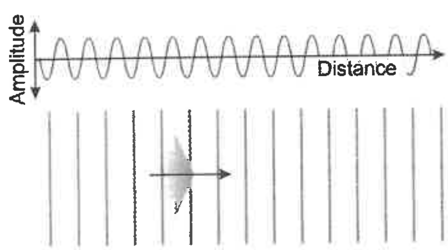
Diffraction often changes the direction and shape of a wave. A plane wave passing a corner is diffracted so that its wavefronts become nearly circular at the edges. The same plane wave passing through a slot spreads out into a circular wave on the other side of the slot. Diffraction of sound explains why you can hear someone in another room even if the door is open only a crack. Diffraction causes a sound wave to spread out from the crack. This also occurs for light waves but you typically have to look at fairly small systems or very fine details to see the effects of diffraction of light.

Is diffraction important?

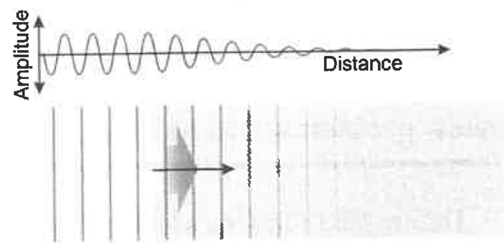
Diffraction has many implications for technology. Radio waves have wavelengths that can be tens of meters to kilometers long. This allows radio signals to bend around obstacles such as mountains. Cellphone transmissions, in contrast, use much shorter wavelengths, typically 6–12 cm. As a result, cellphone waves diffract (spread) less, which is why good reception typically requires a direct line of sight from the phone to the nearest tower.

How do waves change as they move?

When a wave travels through matter some of the wave's energy is dissipated through processes we loosely call "friction." This loss of energy is more properly called *absorption*. **Absorption** describes the transformation of wave energy into other forms of energy that occurs when a wave travels through matter. Absorption at some level affects virtually all waves, including sound, light, water, and even seismic waves. One of the few exceptions is an electromagnetic wave, such as visible light, traveling through a pure vacuum. Light waves can travel through the vacuum of space across the known universe without significant absorption.



Wave traveling with no absorption



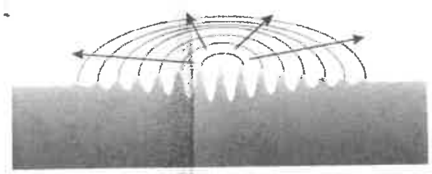
Wave traveling *with* absorption

What changes in absorption?

As a wave is absorbed, the amplitude of the wave decreases. Except in special cases *the frequency remains the same.* How quickly the amplitude decreases depends on both the type of wave and the medium the wave is moving through. For example, a sponge absorbs water waves within a fraction of a wavelength, but it transmits sound waves through several centimeters. Theaters often use thick heavy curtains to absorb sound waves so that the audience cannot hear backstage noise. The tinted glass in sunglasses absorbs some energy from light but still passes enough to see by.

Can amplitude decrease for other reasons?

Wave amplitude may decrease for reasons other than absorption. For example, when a circular ripple spreads out, the amplitude of the ripple decreases with increasing distance from the center. This decrease mostly results from the wave's energy being distributed over a larger area as the wave expands. Circular and spherical waves share this characteristic because both distribute wave energy over an increasing area as they spread.

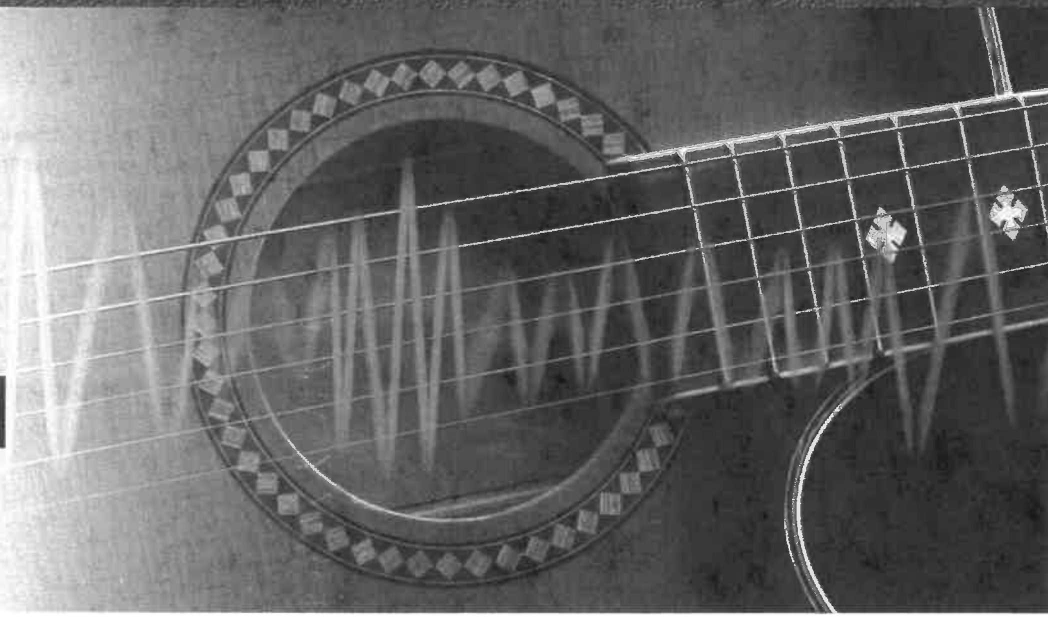


Ripples decrease in amplitude because wave energy is spread out over a larger and larger circle as the wave expands.

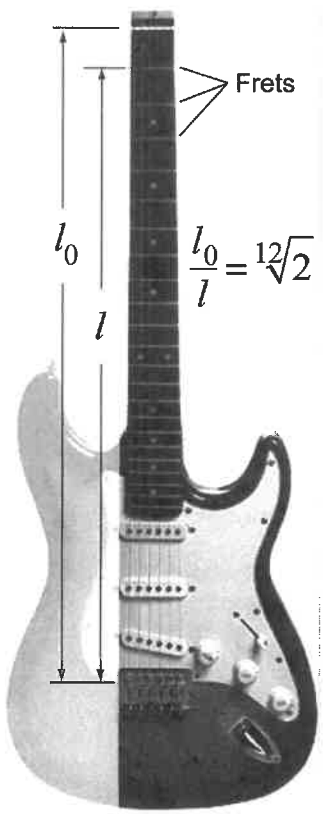
What happens to absorbed energy?

The energy of a wave is transferred to the material that absorbs the wave. With water waves this effect is dramatically illustrated by the power of hurricanes. When a large wave hits the shore, all of its energy is released quickly. This energy may be enough to move cars and trucks and demolish roads and houses. With other types of waves the absorbed energy is often converted to heat.

Chapter 16 Sound



Musical instruments are among the very earliest technologies invented by humans. From the brass pots of the traditional Indonesian *gamelan* to the most ragged-edged electric guitar, all music is created from sounds using patterns of rhythm and pitch. Rhythm is created easily by tapping or plucking in time with the beat. Musical instruments create different pitches using objects that are shaped to *vibrate* at specific frequencies of sound. The fundamental frequency determines the pitch and the mix of overtones determines the quality or *timbre* of the sound.



Stringed instruments such as the guitar control the pitch in three ways. The neck has a series of raised metal *frets* that provide a precise way to control the vibrating length of each string. By placing a finger just behind different frets the player changes the string's vibrating length, thereby changing the pitch. The shorter the vibrating length, the higher the pitch. Each successive fret in a modern guitar decreases the length of the vibrating string by the 12th root of two (approximately 1.059). The number 12 comes from the 12 half-steps in the western musical scale—A, A#, B, C, C#, D, D#, E, F, F#, G, and G#. The number 2 arises because the pitch of a note has twice the frequency of a note one octave below it.

The second method of changing pitch is to change the mass of the strings. The six strings of a guitar each have a different thickness. The low-E string has the greatest mass, and it vibrates 82 times per second (a frequency of 82 Hz) for its lowest note. The high-E string is the thinnest, and its highest playable note (22nd fret) has a frequency of 1,174 Hz.

The third method of controlling pitch is by changing the string tension, such as when a guitar is tuned. The string's frequency is proportional to the square root of its tension. Tightening a string's tension by a factor of 4 will raise its frequency by a factor of 2.

Chapter study guide

Chapter summary

Hearing is one of our five senses, which makes sound an important part of how we interact with the world. Sound is a longitudinal wave that travels to our ears as variations in pressure in the air. Pitch and loudness are commonly used to describe the sounds we hear, and both are related to physical properties of the sound waves themselves. We can distinguish different voices and musical instruments because the sound produced by each has a different *timbre*—a unique set of higher frequency overtones that make up the sounds. In this chapter, you will learn about the basic properties of sound and apply those concepts to understand why an approaching train has a higher pitch than a receding one, why jets produce a supersonic boom, and how a musical instrument works.

Learning objectives

By the end of this chapter you should be able to

- describe how sound propagates;
- describe pitch and loudness for sound and how they relate to amplitude, frequency, and wavelength;
- solve problems involving frequency, wavelength, and the speed of sound;
- describe subsonic and supersonic motion;
- describe the Doppler effect, provide examples, and calculate the frequency shift;
- describe how sounds can include more than one frequency, interpret spectrograms, and explain how to distinguish different musical instruments;
- describe echoes and calculate the distance to a reflecting surface; and
- describe the concepts of reverberation, beats, and resonance in a pipe and provide examples of each.

Investigations

16A: Sound waves
16B: Doppler effect
16C: How sound carries information
16D: Resonance and sound
Design project: Musical instrument

Chapter index

Important relationships

$$v = f\lambda$$

$$f = f_0 \frac{v_s}{v_s - v}$$

Vocabulary

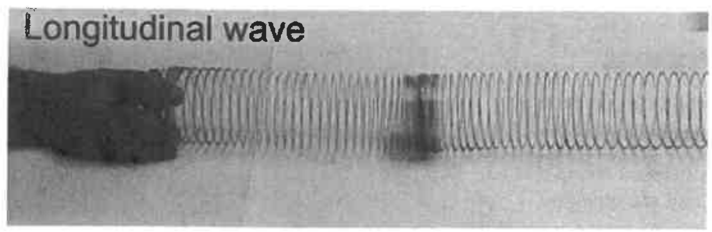
pitch
supersonic
frequency spectrum
echo
harmonic
speed of sound
Doppler effect
Fourier's theorem
phase
decibel (dB)
microphone
spectrogram
beats

Along with light, *sound* is one of the most important ways in which we experience the world. For most people, sound is a fundamental part of every moment. You might not hear the terms *frequency* and *amplitude* in everyday conversation but almost everyone knows these same properties by the names *low* and *high pitch* and *loudness*. For example, musical notes are different frequencies of sound. This section describes the basic properties of sound and how we perceive and understand voices and music.

Basic properties of sound

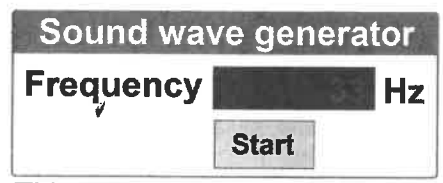
What are sound waves?

Sound is a longitudinal wave, like the compression wave on a Slinky™ spring. Sound waves are similar except that they are much higher frequency and it is air that is being alternately compressed and expanded rather than the coils of a spring.



The range of sounds we can hear

We perceive different frequencies as having different **pitch**. The lowest frequency humans can ordinarily hear is a deep hum at a frequency around 20 Hz. Even this frequency is so fast that you cannot see the vibration with your eye; instead, you can only see a slight blur. The highest frequency that a young, healthy human ear can ordinarily perceive is a high-pitched whine at a frequency near 20,000 Hz.



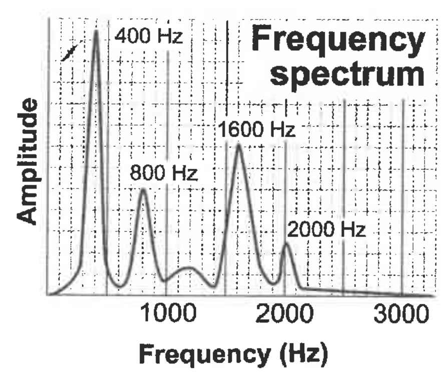
This will play a sound that increases in frequency from 20 to 20,000 Hz over 20 s.

Loudness and pitch

We also perceive sound to have a *loudness*. The loudness of a sound depends on the amplitude of the wave. A loud sound has a larger amplitude than a soft sound of the same frequency. A stereo's speaker moves back and forth a greater distance when producing a loud sound than when producing a soft sound. The larger amplitude of the speaker's motion causes larger amplitude pressure variations in the air.

Multiple frequencies

Almost all sound you hear contains many simultaneous frequencies at once. Even a "clean" musical instrument sound contains a dominant frequency, called the fundamental, and many *overtones*, which are additional frequencies that give the sound its characteristic "piano-ness" or "guitar-ness." The fundamental frequency is also called the first harmonic; the higher frequency overtones are called the second harmonic, third harmonic, and so on. The graph on the right is a *frequency spectrum*, which shows a range of frequencies up to around 2,500 Hz with the loudest peaks at 400, 800, 1,600, and 2,000 Hz.



Investigation 16A Sound waves

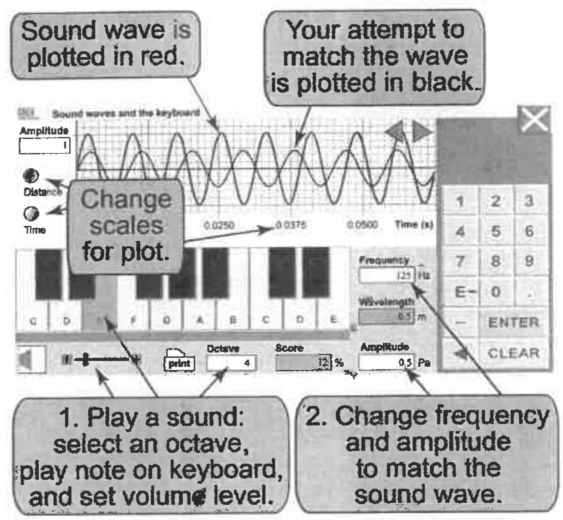
Essential questions *What is a sound wave?*
What are the properties of sound waves?

Interactive simulation

Sound waves are traveling oscillations of air pressure. This interactive simulation allows you to determine the amplitude, wavelength, and frequency of some typical musical notes by matching the waveform in both time and space.

Part 1: Matching the parameters of a sound wave

The red wave is the sound you are hearing, which you select with the piano keyboard keys. The black wave corresponds to the frequency, wavelength, and amplitude you set in the data boxes. The score is a percentage similarity between the red sound wave and the black wave with which you are trying to match it. The volume slider adjusts the volume of the sound (red wave). You will have to change the horizontal axis between time and length to determine both the frequency and the wavelength.



1. Choose a note and adjust your computer speakers so you can hear it.
2. Set the time and amplitude values on the graph until you can see at least a few cycles of the sound wave.
3. While time *t* is plotted on the horizontal axis, see whether you can make the black wave match the red sound wave by adjusting the frequency and amplitude.
4. Switch to distance for the horizontal axis. Match your black wave to the red sound wave by adjusting the wavelength and amplitude. A good match has a score of greater than 95%. *You must match both frequency and wavelength to score 100%.*

a. What is the frequency and wavelength of the note "C" on the left-hand side of the keyboard?
b. Describe how the observed wave varies with loudness.
c. Determine the frequency and wavelength for at least four different sounds.
d. From your data, discuss possible relationships between frequency and wavelength with your lab partners. Propose and test an equation that expresses your hypothetical relationship.
e. Using authoritative print or digital resources, research the value for the frequency of the note "A" in orchestral tuning. What is its accepted value and variation? Explain the origin of any variations.

Part 2: Going further with octaves

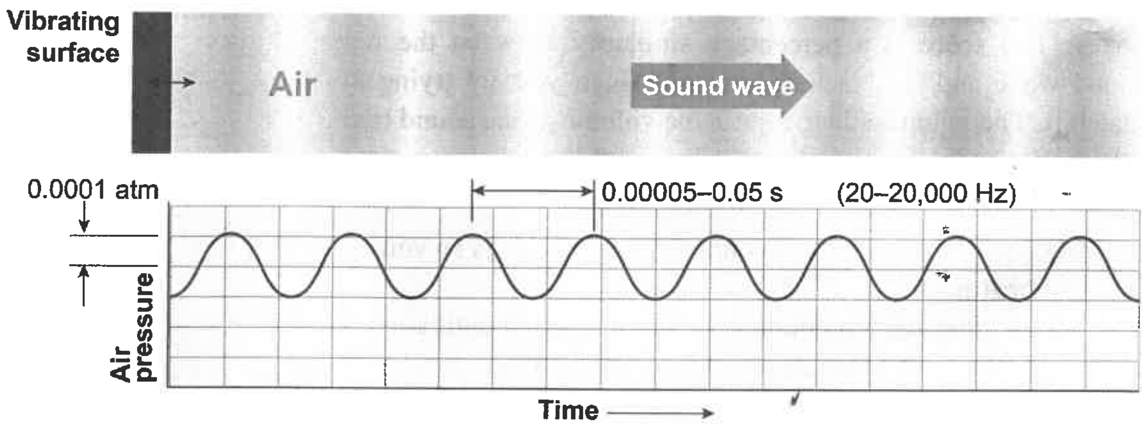
1. Devise and conduct an experiment to determine what happens to the frequency and wavelength of sound when you set the octave to different values. Note that the octave can only be set to positive integers.

a. What do you conclude occurs by setting different octaves?
b. How does this fit with your prior knowledge of music?

The nature of sound waves

What is sound?

Sound is a very tiny oscillation of *pressure.* Imagine moving a metal cymbal up and down. When the surface moves upward, the air above is slightly compressed, which means the pressure is raised a little. When the surface moves downward, the air is drawn out, slightly lowering the pressure. Tapping the cymbal with a drumstick creates a much more *rapid* up-and-down oscillation of the metal surface. The result is a traveling oscillation of air pressure—a sound wave. Anything that vibrates in contact with matter makes sound waves.



How are sound waves different from other waves?

Sound waves are rapid oscillations compared to waves in springs or in water. The period of oscillations in sounds that humans can hear is less than 0.05 s. This corresponds to a frequency of 20 Hz, which is the low-frequency limit to an average human ear. The high-frequency limit is about 20,000 Hz for a young person, but this declines to around 12,000 Hz by middle age.

Can we feel the pressure of sound waves?

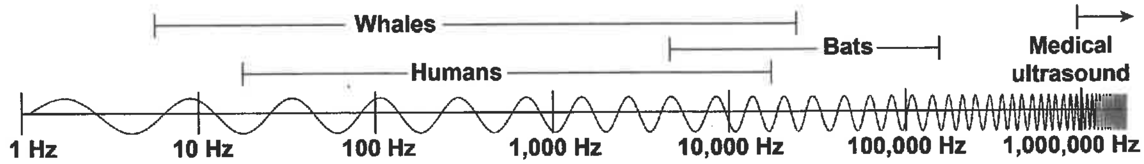
Sound waves have a wide range of amplitudes. Typically the variation in pressure is around one part in 10,000 or 0.0001 atmospheres. This kind of pressure variation is far below the detection threshold of our sense of *touch.* Nonetheless, sound is such a rich environmental factor that virtually all higher animals have evolved a sense of hearing that is well adapted to detecting sound. The human ear is extremely sensitive and can easily detect pressure oscillations of less than one part in a million.

How fast do sound waves travel?

Sound waves travel faster than familiar objects in your everyday environment. For example, if someone across a 5 m room talks to you, the sound wave reaches your ear in 0.015 s. In air at room temperature (21°C) and one atmosphere of pressure, the **speed of sound** is 343 m/s (767 mph). The speed of sound is not constant but varies with temperature and pressure. The highest speed people normally attain, about 500 mph on a passenger jet, never exceeds the speed of sound.

Frequencies of sound

The frequencies of sound that the average human ear can perceive range from a low of around 20 Hz to a high of around 20,000 Hz. Most of the information contained in the human voice, however, is limited to the range between about 100 and 2,000 Hz. The physical range of frequencies of sound is much greater than what humans can hear. Whales can sense sounds in water at frequencies below 10 Hz. Bats can sense sound frequencies in air higher than 100,000 Hz.



Frequencies of sound and average range of hearing

What is ultrasound?

Medical *ultrasound* technology uses sound waves at frequencies of 10^6 Hz and higher. These frequencies are inaudible to the ear but pass readily through living tissue. Differences in tissue density reflect ultrasound waves back to a detector and allow sophisticated imaging without harm to the patient. The figure on the right is an ultrasound image of a 22-week old baby still in the womb.

Wavelengths of sound

The wavelength of sound in air is comparable to the size of everyday objects. For example, a 1,000 Hz sound wave in air has a wavelength of 34 cm, or about the length of your forearm. The wavelength of sound is important in many technologies, including musical instruments. To design a vibrating object to make a certain frequency of sound, the size of the object must be comparable to the corresponding wavelength of the sound. A trombone is a good example. Pulling in the slide on a trombone results in a shorter wavelength vibration and a higher frequency sound.

Wavelength and frequency of sound in air (at standard temperature and pressure)

λ (cm)	f (Hz)	Typical source
840	41	Low E, bass guitar
420	82	Low E, male bass voice
70	500	Average voice tone
34	1,000	Female soprano voice
17	2,000	Siren
7	5,000	Highest note on a piano
3.4	10,000	Whine of a turbine
1.7	20,000	Limit of human hearing

Wavelength varies with material

The wavelength of sound varies depending on the properties of the material through which the sound is traveling. A 1 kHz (1,000 Hz) sound in air at 20°C and 1 atmosphere has a wavelength of 34 cm. A 1 kHz sound wave in water has a wavelength of 150 cm, almost five times longer than in air. In general, the more resistant to compression a medium is, the longer the wavelength for a given frequency of sound. Steel is even more resistant to being compressed than water and the wavelength of a 1 kHz sound in steel is 5 m!

Loudness and amplitude

Loudness describes the perception of sound by your ear and brain. The loudness of sound is mostly determined by the amplitude of a sound wave. We say *mostly* because, to a human ear, the frequency also matters. A high-amplitude sound at a frequency of 40,000 Hz is *silent* to a human ear but quite loud to a bat! We use the **decibel (dB)** scale to measure noise levels because the human ear can respond to such a wide range of pressure changes. Zero decibels corresponds to the smallest pressure change that a healthy young listener can detect. Most sounds fall between 0 and 100 on the decibel scale, making it a very convenient set of numbers to understand and use.

Loudness and the decibel scale

10 dB	A whisper, 1 m away
30 dB	Background sound, country
40 dB	Background sound, city
50 dB	Noise, average restaurant
65 dB	Conversation, 1 m away
70 dB	City traffic
90 dB	Jackhammer, 3 m away
120 dB	Physical pain

Decibel scale

The decibel scale is *logarithmic.* In a logarithmic scale, equal intervals correspond to multiplying by 10 instead of adding equal amounts. For sound, every increase of 20 decibels (dB) means that the wave has 10 times greater amplitude. This is different from the linear scales you are familiar with. On a linear scale, going from 100 to 120 means that the amplitude increases by 20%. On a logarithmic scale, going from 100 to 120 dB means that the amplitude increases by a factor of 10—for example, from 100 to 1,000! Logarithmic scales are useful because they allow us to represent large ranges with convenient numbers. For example, sound waves with amplitudes from 0.00002 N/m^2 to 20 N/m^2 (also called *pascals* or Pa) can be represented by values from 0 to 120 on the decibel scale. The Richter scale for earthquake magnitude is also a logarithmic scale.

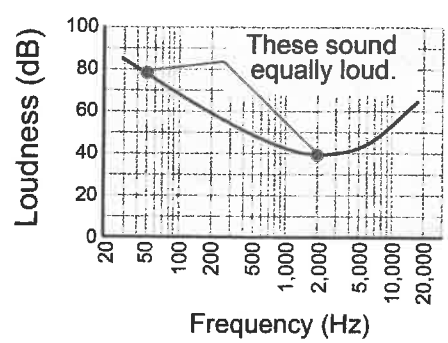
Loudness and frequency

The perception of loudness depends on frequency as well as amplitude. Sounds below 20 Hz or above 20,000 Hz are not perceived at all by the average human ear. A large amplitude sound wave at a frequency of 30,000 Hz is totally inaudible to a person. Of course, other animals have different sensitivities and this sound would be quite loud to a bat, which can hear frequencies past 100,000 Hz.

Equal loudness curve

Even within the range of hearing, the perceived loudness is affected by frequency. The equal loudness curve shows how sounds of different frequencies compare in perceived loudness to an average human ear. Sounds near 2,000 Hz seem louder than sounds of other frequencies, even at the same decibel level. For example, the equal loudness curve shows that a 40 dB sound at 2,000 Hz sounds just as loud as an 80 dB sound at 50 Hz. The human ear is most sensitive to sounds between 300 and 3,000 Hz. The ear is less sensitive to sounds outside this range. Not coincidentally, most of the frequencies that make up speech lie between 300 and 3,000 Hz.

Equal loudness curve



What is the speed of sound?

Sound travels at 343 m/s (767 mph) in air at 20°C and atmospheric pressure. Sound travels faster than most water waves but far slower than light waves. By comparison, sound is faster than all forms of human transportation except a few high-performance aircraft and rockets. Passenger jets typically travel at speeds of 550 mph or less.

Speed, frequency, and wavelength

The speed of sound is the product of frequency and wavelength, similar to other waves. With sound, this equations is most often applied to calculate frequency or wavelength of sound in air by assuming that the speed is 343 m/s.

Interactive equation

Speed of sound

$$(16.1) \quad v = f\lambda$$

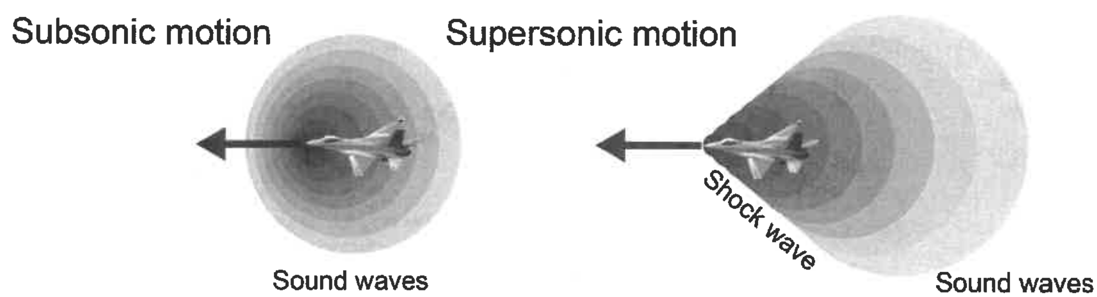
v = speed of sound = 343 m/s at sea level and 21°C
f = frequency (Hz)
λ = wavelength (m)

What is the frequency of sound that has a wavelength of 0.5 m?

Asked: frequency f
Given: $\lambda = 0.5$ m; assume $v = 343$ m/s
Relationships: $v = f\lambda$
Solution: $v = f\lambda \rightarrow f = v/\lambda = (343 \text{ m/s}) \div (0.5 \text{ m}) = 686 \text{ Hz}$
Answer: The frequency is 686 Hz.

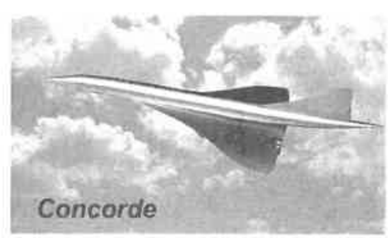
Supersonic flight

Supersonic describes motion at speeds greater than the speed of sound. Many military jets are capable of supersonic flight, as are most rockets. No passenger jets currently flying, however, are capable of supersonic flight. This is because the aerodynamics required for stable supersonic flight is different from that required for subsonic flight. The reason has to do with the *shock wave* that forms at the nose and leading edges of a supersonic aircraft.



The last supersonic passenger jet

The pressure change across the shock wave causes a very loud sound known as a sonic boom. The shock wave can create severe turbulence that may make an aircraft unstable. It also takes a great deal of power to push through the atmosphere at supersonic speeds. Air travelers have been unwilling to pay the price, and the last supersonic passenger jet, the *Concorde*, was retired in 2003.

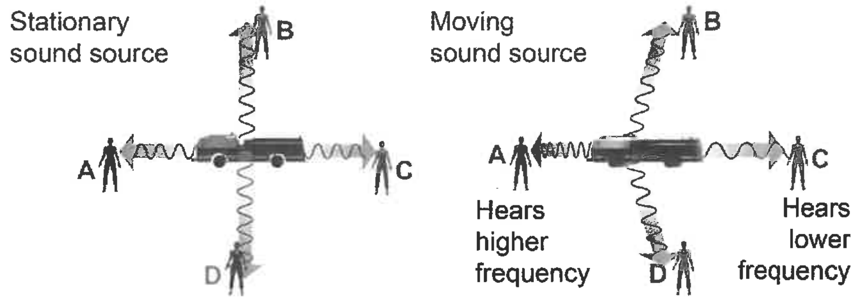


What is the Doppler effect?

Consider a speaker that is moving forward. People in front of the moving speaker hear a higher frequency sound. People behind the moving speaker hear a lower frequency sound. The shift in frequency caused by motion is called the **Doppler effect** and it occurs when a source of emitted or reflected sound is moving at speeds less than the speed of sound.

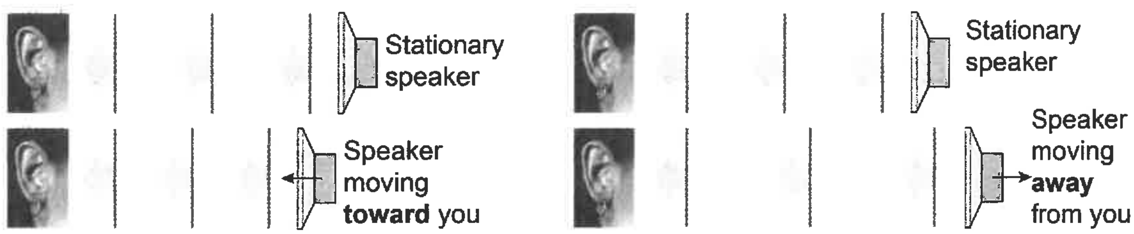
The Doppler effect

The frequency of sound heard from a moving source depends on the observer's position.



Why does the frequency change?

The Doppler effect is caused by relative motion along the line of sight between a source of sound and an observer. Consider yourself as the observer of a sound source moving toward you. Your ear "hears" the frequency at which wavefronts reach you. Between one wave and the next the source gets closer, so the second wave reaches you sooner. You hear a *higher* frequency. The opposite happens if the source is moving *away*. Successive waves reaching your ear are farther apart because the source is farther away with each wave. You hear a *lower* frequency.



How much does the frequency change?

Equation (16.2) gives the observed frequency f when the source is emitting the sound at frequency f_0. In the equation it is assumed that the observer is at rest, and the source is moving *toward* the observer with velocity v. If the source is moving *away* from the observer the velocity should be *negative*. Equation (16.2) only holds for speeds below the speed of sound.

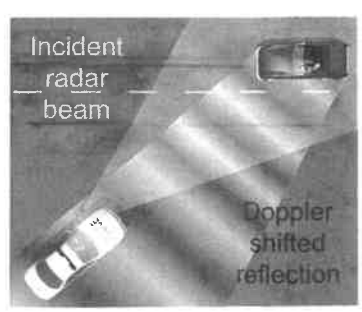
Doppler effect

$$f = f_0 \frac{v_s}{v_s - v} \qquad (16.2)$$

f = observed frequency (Hz)
f_0 = frequency of source (Hz)
v = relative velocity of source to observer (m/s) [positive toward observer]
v_s = speed of sound (m/s)

How is the Doppler effect used?

The Doppler effect occurs for waves reflected from moving objects. The acronym RADAR originally stood for RAdio Detection And Ranging, in which reflected radio waves are analyzed for Doppler shift (speed) and time delay (range). Modern highway patrols use a laser form of Doppler radar to measure the speed of a car from a distance. The amount of the frequency shift is proportional to the speed of the car.

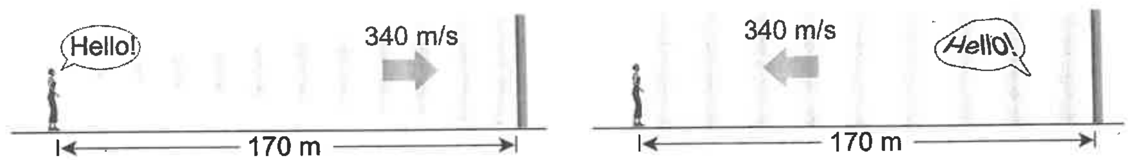


Virtually every sound you hear is affected by interference and resonance. In this context, the term *interference* does not mean anything *bad.* Interference just means that more than one frequency is present in the sound and that the overall wave form is the sum of multiple frequencies. Resonance in sound maximizes certain frequencies and eliminates or weakens others. Resonance occurs when you blow air across the top of a bottle, strike a tuning fork, or run a bow across a violin string. The distinctive frequency balance that makes a person's voice unique and recognizable comes from complex resonances involving your vocal cords, larynx, mouth, tongue, and even your nasal passages!

Echoes and reverberation

What causes echoes?

If you yell "hello!" 170 m away from a large wall, the sound will reflect back to you one second later as a distinct *echo.* An **echo** is a reflected sound wave. One second is the round-trip time for the sound wave traveling at 340 m/s. But what will happen when the wall is much closer, say 10 m away? The round-trip echo time is 0.06 s. What will you hear?

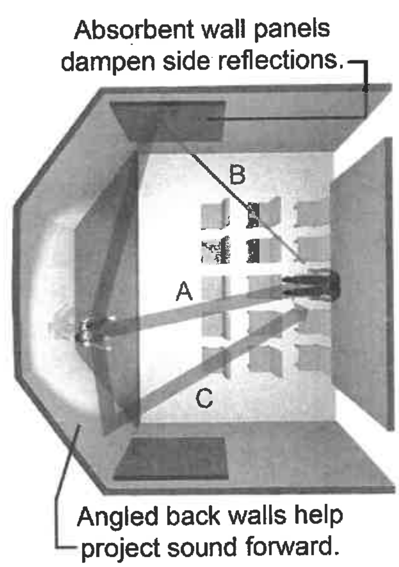


What is reverberation?

In a good concert hall you hear music directly from the stage but you also hear a multiple echo called *reverberation.* Reverberation is the addition of multiple reflections of a sound to the original sound. Each reflection is slightly delayed but not so much that the echo is distinctly recognizable. Reverberation adds liveliness, depth, and richness to sound and concert halls are specifically designed to created the right amount of "reverb." Many musicians use reverb effects that electronically add layers of echoes to their sound.

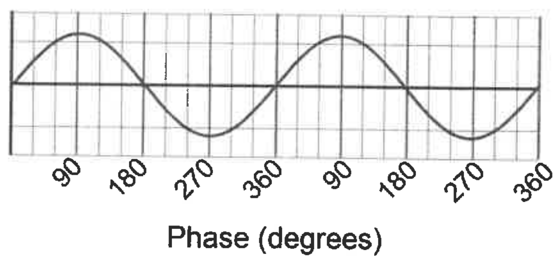
Acoustical engineering

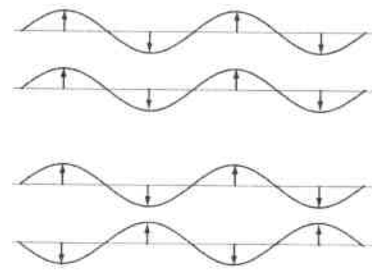
Think about sitting in the middle of an auditorium. You hear sound directly along path A but also reflected sound (along path B, C, and others). The shape of the room and the wall surfaces are designed so that there is enough reverberation to be pleasant but not too much, which would "muddy" the sound. Furthermore, a good design avoids creating locations where indirect, reflected sounds interfere destructively with direct sound waves; in those "dead spots," certain frequency ranges will lose clarity or volume. Many auditoriums have movable ceiling panels ("clouds") that can be rearranged to balance the reverberation for different performances and instruments.



Constructive and destructive interference

Interference can result from a *phase* difference between two or more sound waves. The **phase** of a wave describes a place in the wave's cycle with respect to the full cycle. A full wave is usually assigned a phase of 360°. That means a phase of 180° is one-half of a cycle. Two waves are *in phase* when both begin at the same point in their cycle. Two waves are 180° *out of phase* when one wave begins one-half cycle ahead of or behind the other wave. Sound waves that are the same frequency add up constructively when they are in phase, or destructively when they are out of phase.

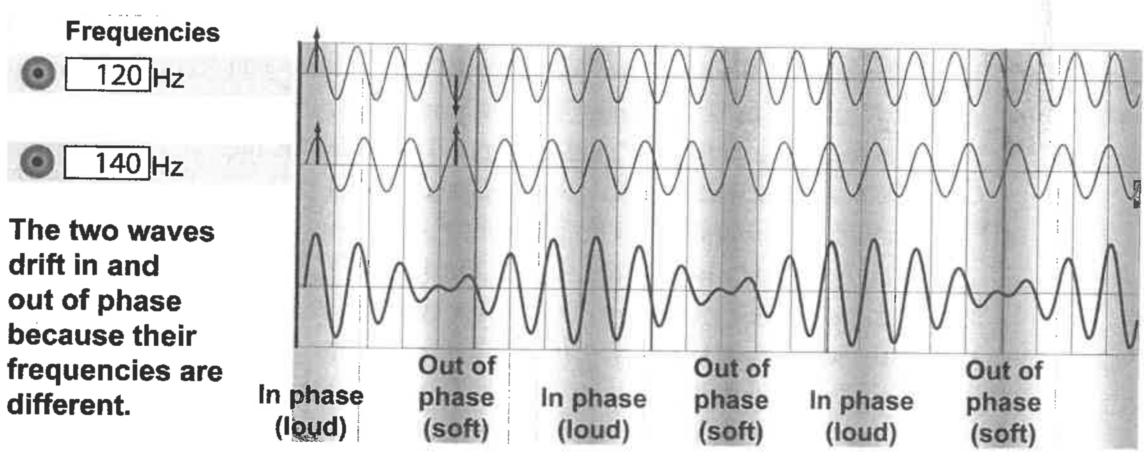




Beats

Interactive simulation

When two frequencies of sound are close, but not identical, the sound waves drift in and out of phase and make **beats**. Sometimes the two waves are in phase, and the total is louder than either wave separately. Other times the waves are out of phase and they cancel each other out, making the sound quieter. The term *beats* refers to the rapid alternation in amplitude caused by this interference. The alternation in loudness occurs at the *beat frequency*, which is the difference between the two single frequencies. For example, a 120 Hz sound and a 140 Hz sound interfere to make beats at 20 Hz. The overall loudness of the combined sound would go up and down 20 times per second. In the e-Book, use the interactive tool on the left to investigate beats!

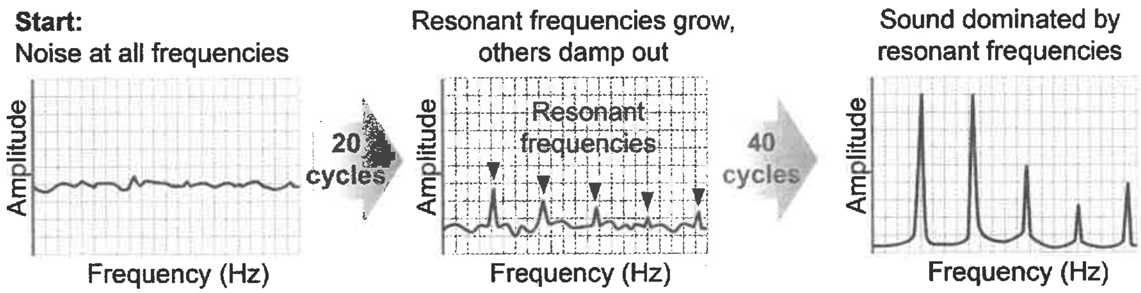


What do beats sound like?

Instruments that are out of tune make beats. Many people find beat frequencies between 1 Hz and about 30 Hz unpleasant to listen to. Sounds that create beats are *dissonant* and may evoke tension and unrest. The frequencies in the musical scale are specifically chosen to reduce the occurrence of beats. The word *harmony* technically means a combination of sounds that do not make unpleasant beats.

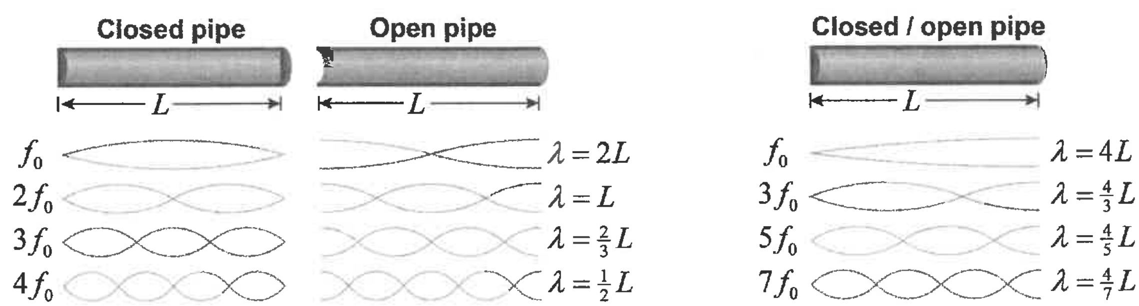
Resonance amplifies certain frequencies

Musical instruments produce sound through *resonance*. Woodwind and brass instruments use a volume of air as a resonant *cavity.* In acoustics, a cavity is a volume of space enclosed by boundaries that contain and reflect sound. When many frequencies are present in a sound, frequencies that are resonant absorb and hold energy far more effectively than other frequencies. Within a few dozen oscillations—fractions of a second!—the energy in noise at all frequencies has been channeled into the amplitudes of only the resonant frequencies, which then dominate the sound.



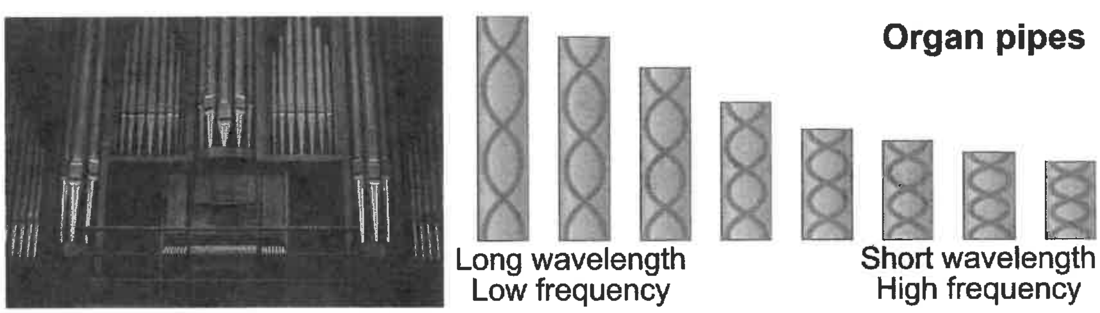
Resonant modes of pipes

The resonant *modes* of a cavity correspond to standing waves of air pressure that occur at specific frequencies. For a pipe that is closed at both ends, the resonant modes have *nodes* at the boundaries. For an open pipe, the resonant modes have *antinodes* at the ends. In both cases, the resonant frequencies are integer multiples of the fundamental. For a pipe that is closed at one end and open at the other the boundaries are a node and an antinode, respectively. An open/closed pipe has resonances that are *only odd-integer multiples* of the fundamental. The frequencies and wavelengths of the first four harmonics are shown below.



Pipe organs

The size of a vibrating object affects its natural frequency through resonance. For example, the pipes in a pipe organ are made in all different sizes, each designed to produce a specific wavelength and frequency of sound.

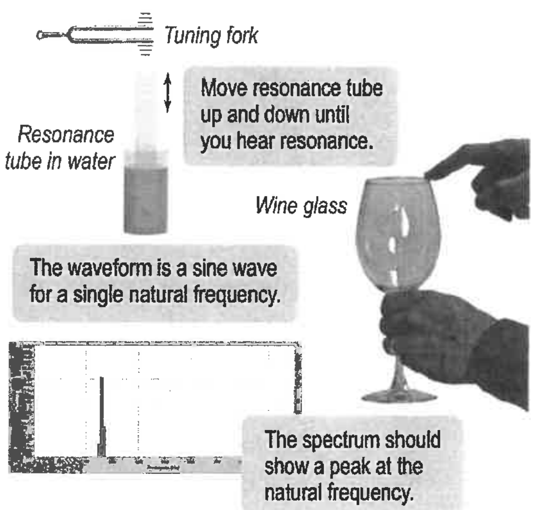


Investigation 16D Resonance and sound

Essential questions *How do we create specific frequencies of sound, such as in music?*

A guitar string vibrates at its natural frequencies. Other objects, such as wine glasses and tuning forks, also vibrate at their natural frequencies. The frequencies are controlled by properties such as size, mass, and tension.

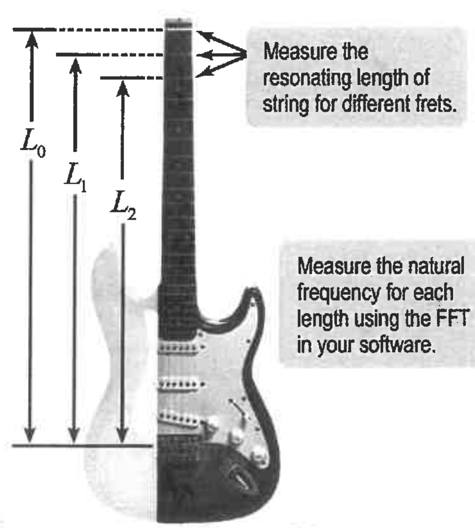
Part 1: Measuring the natural frequency



1. Open the **16D_ResonanceAndSound** experiment file.
2. Strike a tuning fork with a rubber mallet and hold it next to the microphone on your computer. Using the FFT in your software, confirm that its natural frequency matches the marked value.
3. Strike the tuning fork again and hold it over the resonance tube, partially immersed in water.
4. Raise and lower the tube until you hear the loudest amplification of the tuning fork note. Measure and record the height of the tube above the waterline. Repeat for two other tuning forks.
5. Firmly hold the stem of the wine glass while running a wet finger lightly around its rim. The glass should ring in a clear tone. Measure its natural frequency.
6. Add water to the glass in small increments and repeat the measurements.

a. *Why did the tube resonate at a particular position? What characteristics of a resonance tube determine its natural frequency?*
b. *Calculate the wavelength and then the product of wavelength and frequency for each tuning fork you tested, and record the data in a table.*
c. *Does the product of wavelength and frequency vary among tuning forks. Why or why not?*
d. *Propose a hypothesis that explains the variation in resonance frequency with the height of water in the wine glass. How is your hypothesis supported by your observations?*

Part 2: Controlling the natural frequency through resonance

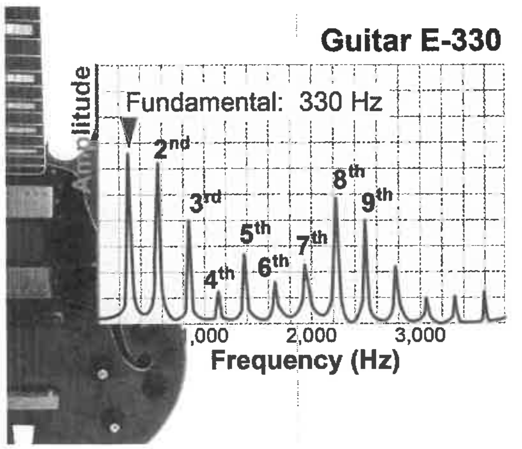


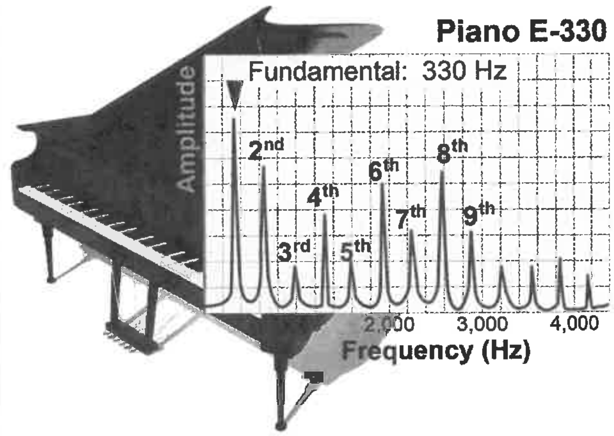
1. Measure the length of string for your instrument at each of its different frets, or fingerboard positions.
2. Use the FFT in your software to determine the natural frequency for each different string length.
3. Repeat the procedure for at least two additional strings.

a. *Graph frequency versus length of a single string. Explain why the graph has the shape that it does.*
b. *On the same graph, plot frequency versus length for a different string. Explain the difference between the two curves using Newton's laws.*
c. *Explain how resonance controls which frequencies persist in a vibrating system.*

Why do instruments sound different?

Different instruments have characteristic sounds just as different people have characteristic voices. As an example, the note E-330 Hz played on a guitar is recognizable as the same note when played on a piano. This note, however, sounds quite different when played on the two instruments. What is different and what is the same? The answer involves the properties of resonant objects and cavities.





Are notes a single frequency?

The sound from a musical instrument is not a single pure frequency but contains many frequencies. The most important are *harmonics*. A **harmonic** is a frequency that is an integer multiple of the fundamental. Strings and air columns can vibrate at many harmonics. A real resonant oscillation in an instrument contains many harmonics at once. There are more than 40 distinct harmonics present in the note from a piano! The distinctive sound of an instrument results from:

1. the relative amplitude of each harmonic compared to the fundamental and
2. how quickly each harmonic grows and decays after a note is struck.

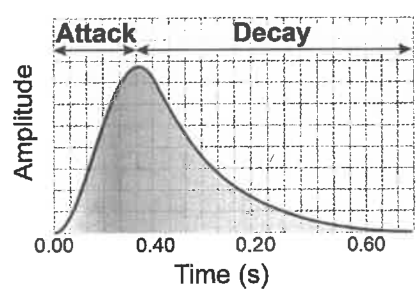
Explaining the spectra

In the guitar and piano spectra above, the fundamental frequency is the same but the third and fourth harmonics have different amplitudes. The guitar has a strong third and weak 4th and the piano has a weak third and strong fourth. The same 330 Hz fundamental is the reason why both notes sound like "E," and the difference in harmonics explains why the guitar sounds like a guitar and the piano sounds like a piano.

Attack and decay times

The *rate* at which the loudness of each harmonic rises and falls is another characteristic that makes an instrument's sound distinctive. The *attack* time is the time it takes to reach maximum loudness. The *decay* time is the time over which the sound dies away. Attack and decay times differ for each harmonic, and higher harmonics tend to attack and decay faster. Attack and decay depend on both resonance and damping, and they are very different for each instrument.

Each harmonic may have different attack and decay times.



Design a musical instrument

Musical instruments

A musical instrument creates frequencies of sound that match a musical scale. The beauty and richness of the sound come from the harmonics that are produced along with the fundamental frequencies.

Design challenge

Create a musical instrument that

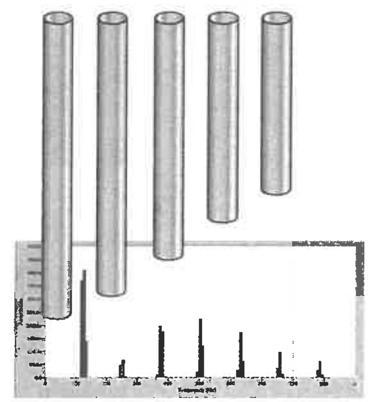
1. plays the frequencies (within 5%) of all eight notes of a major scale,
2. has working parts consisting of a metal bar (or tube) with lengths less than 1 m, and
3. has a total mass of less than 5 kg.

Based on the above instructions, identify the *design criteria* and *design constraints* and include them in your written report.

Modeling the system

1. Measure the resonance frequencies of different lengths of your tube or bar material using the **DC_MusicalSound** experiment file.
2. Use your data to create a graphical and/or algebraic model that allows you to predict what length of tubing you need to produce each frequency in the scale.
3. Identify and record the variables that should be controlled. Describe how you designed your testing procedure to control for these variables.
4. Determine what changes can make small frequency corrections.
5. Explore how different methods of mounting the chime affect its sound. Consult additional resources (e.g., the library, a textbook, or the Internet) to obtain design ideas.

Chimes of different length and/or mass



The spectrum shows a fundamental and several harmonics.

Design

Use your model to determine the design lengths you need to make your instrument. You will also need to design a way to support your resonant elements without dampening their vibration too much.

Prototype

Use appropriate tools, such as a pipe cutter, to create the resonant elements of your instrument. Assemble your prototype.

Test

Test your prototype by using the **MusicalSound** experiment file to measure the resonance frequency of each chime. Also look at the frequency spectrum for the harmonic content of each chime.

Evaluate

Compare the actual frequencies to the design criteria. Identify the strengths and weaknesses of your prototype's performance and document them in your written report. Determine any frequency adjustments that need to be made to the chimes and any changes that need to be made to your model.

Revise

Use your model to implement the design changes, such as removing material to raise a frequency. Implement the changes and test your revised design again. When you are ready, demonstrate the performance of your musical instrument by measuring the frequency of each chime.

Pitch and rhythm

The most basic elements of music are *pitch* and *rhythm.* The *pitch* of a sound is how high or low we hear its frequency. Pitch corresponds closely to frequency, but pitch is also a matter of *perception.* The way you hear a pitch can be affected by the sounds you hear immediately preceding, along with, and just after a note. Rhythm is the repeating time pattern in a sound. Rhythm can be loud or soft: tap-tap-TAP-tap-tap-TAP-tap-tap-TAP. Rhythm can be made with sound and silence or with different pitches.

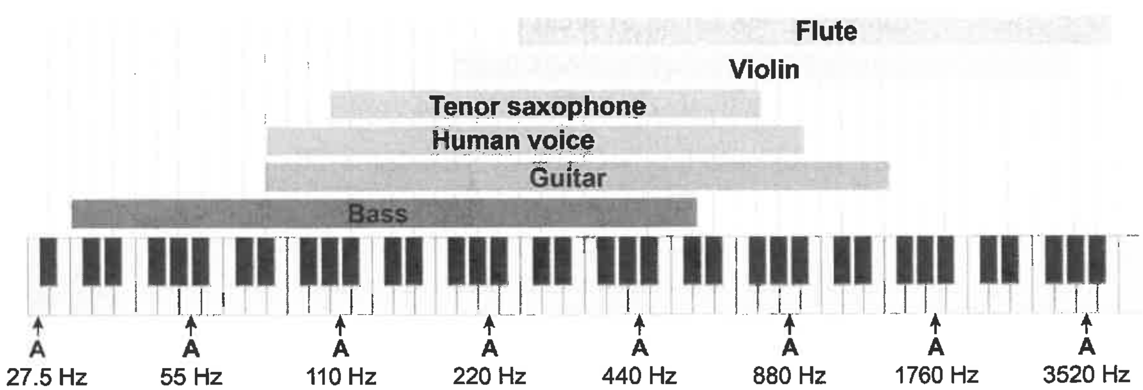
What is a musical scale?

Although styles vary, all music is created from carefully chosen patterns of frequencies of sound called *musical scales.* Each frequency in a scale is called a *note.* The diagram below shows some of the notes on a piano along with their frequencies. There are eight primary notes in the Western musical scale, which correspond to the white keys on the piano.

C major scale	C	D	E	F	G	A	B	C
Frequency (Hz) (just tempered)	264	297	330	352	396	440	495	528
Frequency ratio f/f_0	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Example (C-264)	$\frac{264}{264}$	$\frac{297}{264}$	$\frac{330}{264}$	$\frac{352}{264}$	$\frac{396}{264}$	$\frac{440}{264}$	$\frac{495}{264}$	$\frac{528}{264}$
Wavelength ratio λ/λ_0	1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$
Frequency (Hz) (equal tempered)	261.6	293.7	329.6	349.2	392.0	440.0	493.9	523.2

Why do note names repeat?

The range between a frequency and twice that frequency is called an *octave.* Notes that are an octave apart in frequency share the same name because they sound similar. An 88-key piano can play notes across a little more than seven full octaves, corresponding to a frequency range from A-27.5 Hz to high C-4186 Hz.



Where does this scale come from?

The ratios of the scale were discovered in the sixth century BC by Pythagoras, whose mathematical analysis of sound forms the basis of Western music. Look at the frequencies in the top figure: All of the frequencies are spaced apart such that none make unpleasant beats with another and *none of their harmonics make beats with the harmonics of other notes!* Since the mid-18th century, however, Western music has adopted the *equal tempered* scale, containing frequencies that deviate slightly from these perfect ratios.

Noise cancellation

Need for noise reduction

Have you ever been in a place that was so noisy that ordinary conversation was impossible? Imagine being the pilot of a plane or the engineer on a locomotive where loud engine noise is a constant, irritating presence. Over the past few decades advances in electronics and miniaturization have made it possible to eliminate constant background noise *while allowing voices and other sounds to pass through!* This technology is called *active noise cancellation* and it is based on the destructive interference of sound waves.

Everyday sounds

The sounds of everyday life are made up of hundreds or thousands of different frequencies all superposed on top of each other. Although the human ear can separate out different frequencies, sometimes background noises become so loud that it is impossible to hear the desired sounds—such as someone's voice or music.

Which sounds are canceled?

In many cases the information you want to hear, such as a voice, has the following characteristics:

1. The amplitude changes relatively quickly, on time scales of a second or less and
2. most of the *information* is carried in frequencies higher than a few hundred hertz.

A background noise, such as a loud hum from an engine, has different characteristics:

1. The amplitude is relatively constant over time scales of 10 s or so and
2. the frequencies are low, typically less than a few hundred hertz.

Active noise cancellation uses the differences between these two kinds of sounds to interfere destructively with one while leaving the other unchanged.

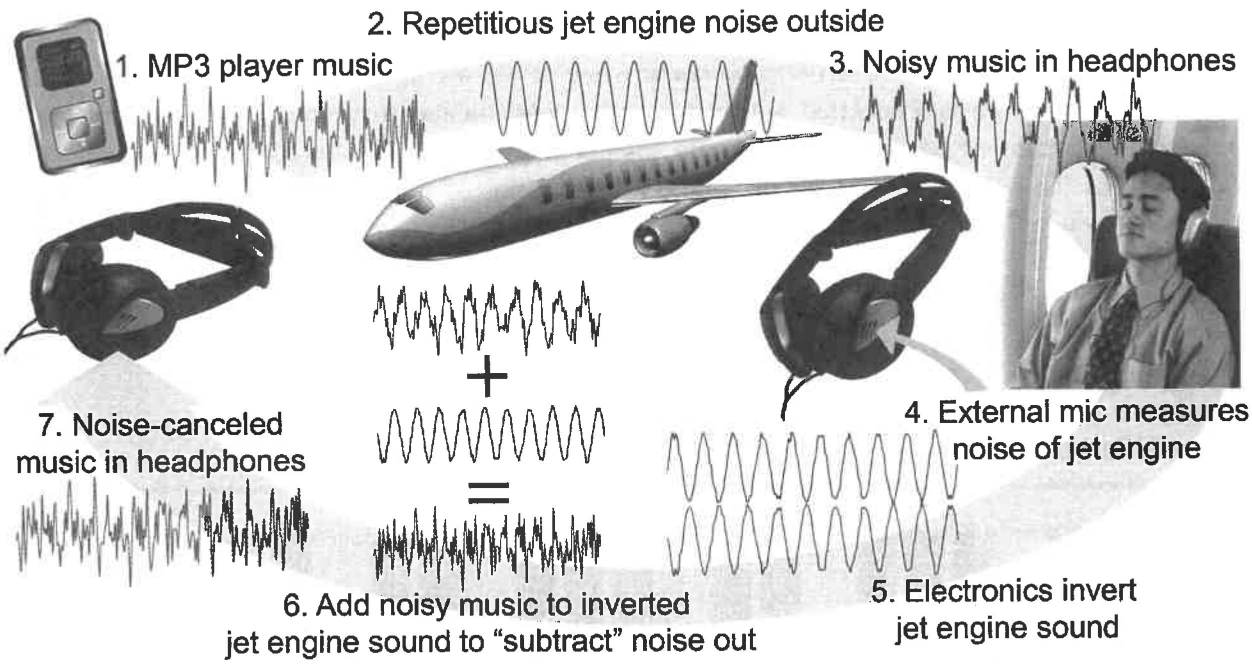
Applications of active noise cancellation

Active noise cancellation technology is now used to improve safety for pilots, train conductors, and workers in noisy areas, but it has also appeared in cellphones, cars, and home stereo headphones. You may not even know that your cellphone uses antinoise to cancel out the sound of wind or other low-frequency noise from your phone calls. Many high-end cars include a "black noise" system, which uses internal microphones and special speakers to actively cancel tire and road noise from the interior of the car.

Noise-canceling headphones

Any noise-canceling technology includes a microphone that samples the external noises that you want to cancel out. In noise-canceling headphones, each earphone contains one or more small microphones located on the outside. The microphones are connected to a powerful computer chip that drives a miniature amplifier. The amplifier drives a speaker *inside* the headphones. This internal speaker can send sound directly into your ear.

Noise-canceling headphones



Listening to music on an airplane

Do you want to listen to music on headphones while on an airplane trip? If so, you might have to turn the headphone volume very high to hear the music over the regular whirring sound of the engines and air circulation system. Inside the headphones, your ear is hearing both the music and the jet noises superposed on top of each other. Noise-canceling headphones can reduce those external sounds so that you hear the music more clearly—and at a lower volume level!

How the headphones work

On the outside of noise-canceling headphones is a microphone that samples the sounds of the air and engine. Those signals are sent to a specialized computer chip called a *digital signal processor* that separates out the low frequencies. This chip then inverts the low-frequency sound—changes the sign from positive to negative or vice versa—and sends it to the amplifier. The amplifier plays this *antinoise* back into you ear at just the right amplitude to cancel with the low-frequency part of the sounds from the jet, but without affecting the sounds from your music. Thus

noise + antinoise = quiet!

Voices can still be heard

Even though the headphones cancel the jet noises, you can still hear the voice of the person next to you. Why? The antinoise signal does not cancel voices because these are mostly composed of higher frequencies and they do not repeat over periods of a few seconds. Repeated, low-frequency noises are canceled; nonrepeated, high-frequency sounds are not.

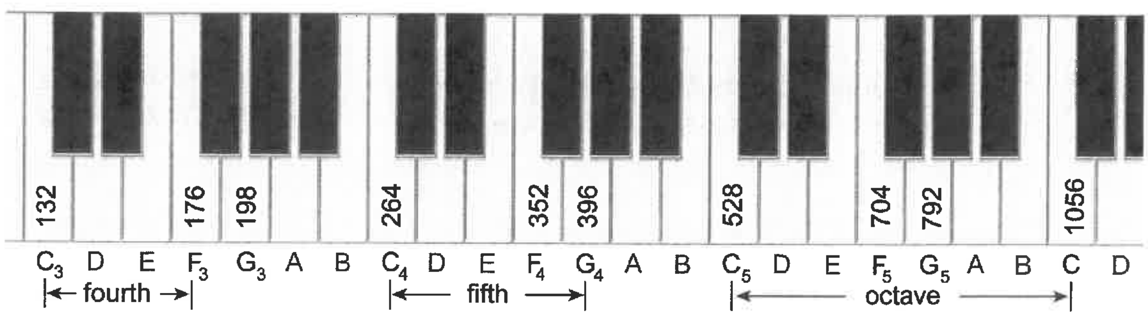
Technology trade-offs

Like all technologies, active noise cancellation has trade-offs. The headphones require additional power for both the chip and the internal amplifiers. There is also a degradation of audio quality, particularly for low-frequency (bass) sounds, and sometimes also an audible, high-frequency hiss.

Wave phenomena such as reflection, interference, and superposition are responsible for many acoustical and musical phenomena. *Echoes* and *reverberation* occur when sound waves are reflected. Although each musical note on a piano keyboard is associated with a particular fundamental frequency, most musical instruments create a wide spectrum of *harmonics*, which are integer multiples of the fundamental frequency. Musical intervals, such as the octave, correspond to simple integer ratios of frequencies. Interference of waves with two different frequencies produces *beats* and determines whether two or more notes sound pleasant when played together.

Vocabulary words **echo, phase, beats, harmonic**

Review problems and questions



1. This depiction of a piano keyboard gives the letter names for notes in the C-major scale, along with their frequencies in hertz. *Intervals* such as the fourth, the fifth, and the octave refer to *ratios* of frequencies. For example, to go one *octave* to the right means *doubling* the frequency.
   a. What is the frequency ratio corresponding to the interval known as a *fifth*? (Express your answer as a ratio of integers and in decimal format.)
   b. What is the frequency ratio corresponding to the interval known as a *fourth*? (Express your answer as a ratio of integers and in decimal format.)
   c. What is the product of the two ratios you just computed?
   d. State a general relationship between the fourth, the fifth, and the octave.

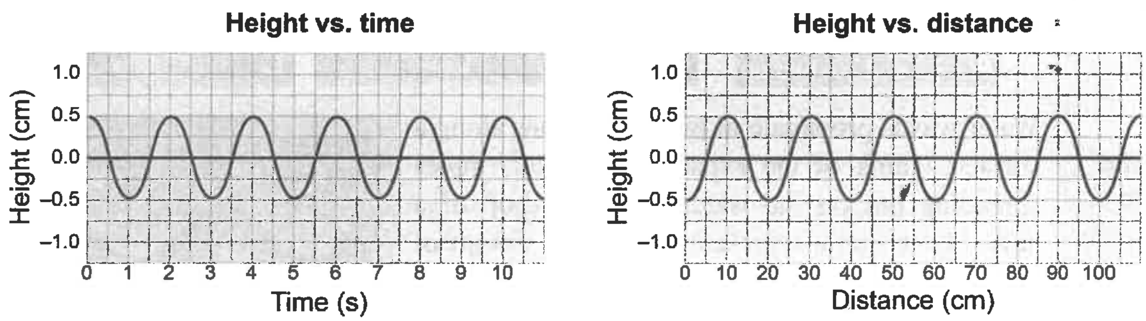
2. *Beats* are heard when two tones of different frequencies occur. The beat frequency equals the difference of the two original frequencies.
   a. What is the beat frequency if C_4 and C_5 are played at the same time?
   b. Does that beat frequency correspond to one of the marked notes? If so, which?
   c. What is the beat frequency if C_4 and G_4 are played simultaneously?
   d. Does that beat frequency correspond to one of the marked notes? If so, which?
   e. What beat frequency results if C_5 and F_5 are played together?
   f. Does that beat frequency correspond to one of the marked notes? If so, which?
   g. The fourth, the fifth, and the octave are among the most pleasant-sounding and important intervals in Western music. Can you speculate why?

Section 1 review

Waves are oscillations that travel. Waves have amplitude and frequency just like oscillators, but waves have the additional property of *wavelength.* A wave moves one wavelength forward in each cycle, so the speed of a wave is its wavelength divided by its period. This is equivalent to frequency times wavelength. A wave carries energy that is proportional to both amplitude and frequency. The higher the amplitude, the higher the energy at a given frequency. At equal amplitudes low-frequency waves have less energy than high-frequency waves. Transverse waves cause oscillations that are perpendicular to the direction of the wave's motion, whereas longitudinal waves cause oscillations that are parallel to the wave's motion.

Vocabulary words	**wave, wavelength, transverse, polarization, longitudinal**
Key equations	$v = f\lambda$

Review problems and questions



1. The figure above shows a graph of the oscillation of a single point on a transverse wave as a function of time and a second graph of the waveform at a given instant as a function of distance. Use the graphs to answer the following questions.
   a. What is the frequency of the wave?
   b. What is the wavelength of the wave?
   c. What is the amplitude of the wave?
   d. What is the speed at which the wave propagates?

2. A water wave has a frequency of 2 Hz and a wavelength of 1.5 m. What is the speed at which this wave travels?
   a. 0.75 m/s
   b. 1.5 m/s
   c. 2.0 m/s
   d. 3.0 m/s

3. a. If you are using a water tank in an investigation into waves, is a still image or a video a better choice for measuring wavelength?
   b. How about for measuring frequency?
   c. Amplitude?
   d. Velocity of the wave?

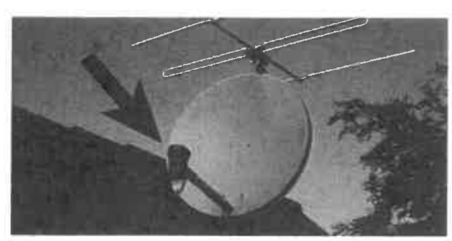
Section 2 review

Wave propagation is the passage of wave energy from one location to another. As waves propagate, they can change amplitude, direction, or wavelength, depending on the kind of wave and the material through which it travels. Wavefronts are extended wave crests, such as ripples on a pond. Waves always travel at right angles to wavefronts. Waves can be reflected, refracted, diffracted, or absorbed at a boundary or when encountering an obstacle. Absorption can rob a wave of its energy, but a wave's amplitude can also decrease simply because the wave is spreading out over an ever-larger area (as when ripples spread from a pebble dropped into water).

Vocabulary words **crest, trough, wavefront, reflection, concave, convex, refraction, diffraction, absorption**

Review problems and questions

1. Define the following as one of the wave–boundary interactions, using *reflection, refraction, absorption,* and *diffraction* each once.
   a. Tarmac heats up on a sunny day.
   b. A magnifying glass enlarges an image.
   c. Waves curve around a boulder in the water.
   d. A shout echoes off of a building.
2. How is it that you can hear people inside another room even when the door is only opened very slightly?
3. A dozen classmates line up shoulder to shoulder, hold hands, and walk forward at a steady pace. They walk on pavement, but then three students at the left hit mud and slow down. The other students keep going forward and the line bends toward the muddy field. What wave-propagation effect does this imitate, and why?
4. Waves passing from a slow medium into a faster medium undergo refraction.
   a. Does the frequency of the waves increase, decrease, or remain the same?
   b. Does the wavelength of the waves increase, decrease, or remain the same?
5. The horizontal distance from one crest to the next crest of a water wave is the wavelength of the wave. The *vertical* distance from crest to trough of a water wave is equal to
   a. the amplitude.
   b. half the wavelength.
   c. twice the amplitude .
   d. twice the wavelength.
6. This satellite TV dish reflects radio signals that arrive in parallel wave fronts from a great distance. To provide good reception, it must bring those wavefronts to a focus at the position of the arrowed antenna. Is the side of the dish seen here convex, or is it concave?



Section 3 review

The *superposition principle* describes what happens when multiple waves overlap. It states that the wave amplitude at any place and time is the sum of the amplitudes from each individual wave. *Interference* is one possible result of superposition. When the combined amplitude of two waves is larger than either of the individual waves, the interference is *constructive*. If the combined amplitude decreases, the interference is *destructive*. A *standing wave* occurs when a wave interferes with its own reflection; it is characterized by *nodes* (places where the amplitude remains zero) and *antinodes* (where the amplitude is largest). In wave physics, *resonance* refers to the fact that certain physical systems will only sustain standing waves with certain frequencies. Resonance allows objects such as guitar strings and organ pipes to produce distinct musical notes.

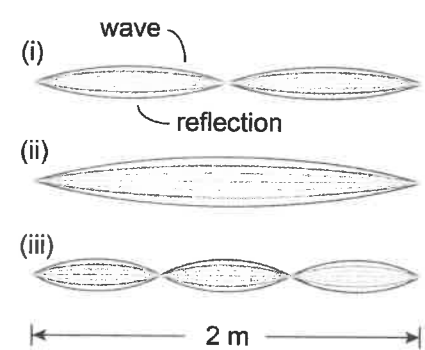
Vocabulary words	**superposition principle, constructive interference, destructive interference, node, antinode, mode, standing wave**

Review problems and questions

1. Is it possible for two waves to have individual amplitudes that are not zero while the *sum* of the two waves has an amplitude of zero? Explain.

2. Give three examples in which wave behaviors such as reflection, refraction, and absorption help doctors diagnose their patients' medical conditions.

3. Two friends stand on either end of a rope of length 2 m. One friend repeatedly shakes her end of the rope up and down by a few centimeters. By shaking the rope at different rates (frequencies), she generates all three of the standing-wave patterns shown here.



   a. In Pattern (i), what is the wavelength of the wave?
   b. Suppose that she completes one up-and-down hand motion in half a second (0.5 s) to generate Pattern (i). What are the period, frequency, and wave speed?
   c. Next, she generates Pattern (ii). What has doubled, the wavelength or the frequency?
   d. In Pattern (iii), how many wavelengths fit between the two ends of the rope?
   e. Which pattern represents the rope's fundamental mode of vibration?

4. For each standing wave pattern shown in the figure above, how many nodes are present? How many antinodes?

5. For a standing wave on a stretched string, what is the relationship between the number of nodes and the number of antinodes?

Chapter review

Standardized test practice

78. Which waves have the most energy?

A. low frequency, small amplitude
B. high frequency, small amplitude
C. low frequency, large amplitude
D. high frequency, large amplitude

79. You and a friend create a standing wave with a rope. You both hold your hands still. In total, there are 5 nodes in this wave. How many antinodes are there?

A. 3
B. 4
C. 5
D. 6

80. A sound wave has a frequency of 500 Hz. What is the period of this wave?

A. 2×10^{-3} s
B. 1 s
C. 5 s
D. 5×10^{2} s

81. Which of the following terms are used to describe waves?

I. wavelength
II. mass
III. velocity
IV. force
V. amplitude

A. I and II only
B. III, IV, and V only
C. I and III only
D. I, III, and V only
E. all of the above

82. Which of the following is an example of a longitudinal wave?

A. a plucked guitar string
B. sound from a tractor
C. a long spring when one end is moved side to side
D. an airplane traveling north to south through Greenwich, England

83. An ocean buoy moves up and down once every 4 s because of passing water waves. What is the wavelength of the waves if their speed is 3 m/s?

A. 0.75 m
B. 1.33 m
C. 7 m
D. 12 m

84. When two waves overlap each other such that the combined amplitude is smaller than the amplitude of either wave, this is an example of

A. constructive interference.
B. destructive interference.
C. diffractive interference.
D. rarefactive interference.

85. What light–boundary interaction do eyeglasses use to correct vision?

A. reflection
B. refraction
C. absorption
D. diffraction

86. Two sound waves combine to create a wave with greater amplitude than either of them individually. What is this an example of?

A. damping
B. destructive interference
C. wave–boundary interaction
D. constructive interference

87. Which is *not* an example of wave phenomena at a boundary?

A. Light is reflected off the surface of a mirror.
B. Light is refracted into a rainbow by passing through a glass prism.
C. Water waves are diffracted by passing through a small hole.
D. Sound waves travel through the air.

88. A sound wave has an amplitude of 10 mm and a speed of 343 m/s. Which of the following could be the period of this wave?

A. 500 Hz
B. 10 m
C. $0.1\ m^{-1}$
D. 15 s

89. An electromagnetic wave traveling at 3×10^{8} m/s has a 3 m wavelength. What is the frequency of this wave?

A. 100 MHz
B. 10 GHz
C. 10,000,000 Hz
D. 100 μHz

90. If a wave in the ocean has a frequency of 143 Hz and a wavelength of 2 m, what is the speed of this wave?

A. 71.5 m/s
B. 145 m/s
C. 286 m/s
D. 1,430 m/s

Chapter review

Vocabulary

Match each word to the sentence where it best fits.

Section 16.1

Doppler effect	**decibel (dB)**
pitch	**speed of sound**
supersonic	

1. A sound that is 90 _______ is louder than an 80 _______ sound.
2. An airplane that is moving at 600 m/s is undergoing _______ motion.
3. When the sound of an approaching train is higher in pitch than the sound of a receding train, this is an example of the _______.
4. A musical note "B" differs in _______ from the note "C."

Section 16.2

Fourier's theorem	**frequency spectrum**
microphone	**spectrogram**

5. A device for converting sound waves in air into electrical signals is called a _______.
6. A graphical tool for showing what oscillations are present in a wave is called a _______.
7. A graphical representation of sound and its various frequency contributions is called a _______.
8. When applying _______ to analyze the same note played by a piano and a flute, you can see that each has different contributions from higher frequency sounds.

Section 16.3

beats	**echo**
harmonic	**phase**

9. When two sounds of nearly the same frequency are played at the same time, the sound waves drift in and out of _____, causing beats.
10. A piano and guitar playing the same fundamental tone will have different relative contributions of each _______ in their sound.
11. Sound reflected off the other side of the canyon, allowing Rosabella to hear a/an _______.
12. When you hear two sound waves at the same time, but they have slightly different frequencies, you might hear a slow pulsation of sound called _______.

Conceptual questions

Section 16.1

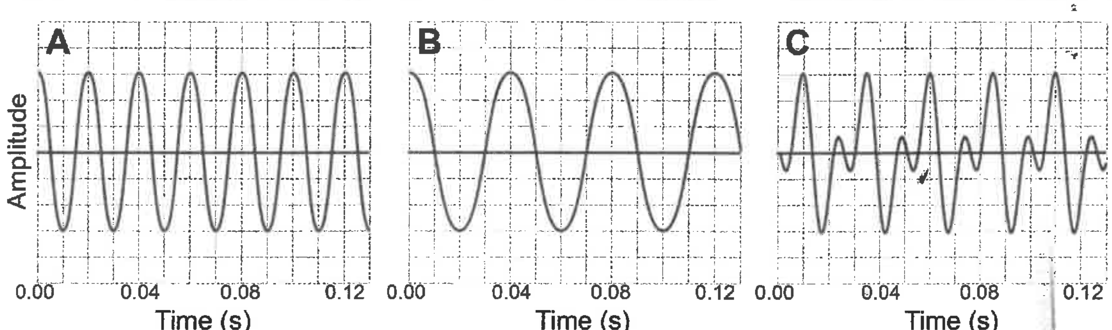
13. Describe the difference between loudness and pitch in musical sounds.
14. When conducting Investigation 16B on page 888, two students disagreed over a point. One of them said that the frequency of the sound would be higher if the *source* producing the sound were moving toward the observer. The other students said that the frequency of the sound would be higher if the *observer* were moving toward the source producing the sound. Which student is correct?
15. How does the amplitude of a sound wave affect how you hear a sound wave?
16. Which of the following *two* statements are *not* true of sound?
    a. Sound is a transverse wave.
    b. Sound is a small traveling oscillation of pressure.
    c. The amplitude of audible sound waves may be less than one millionth of an atmosphere.
    d. Ordinary sound contains at most one or two different frequencies at a time.
17. ❬ When we talk of the "highest" or "lowest" notes on a piano, they are highest and lowest in what physical property of sound?
18. ❬ Is a high-frequency sound higher or lower in pitch? What is the relationship between pitch and frequency?
19. ❬ Which has a longer period, a musical note with a high pitch or one with a low pitch?
20. ❬ A violinist presses her finger down in the middle of a string she is playing. How does this change the wavelength of the sound produced by the string?
21. ❬❬ Why do sound waves typically oscillate at higher frequencies than water waves?
22. ❬❬ Estimate the loudness in decibels for the sound at a concert of (a) classical music with a solo piano, (b) a full orchestra, (c) an African drumming ensemble, and (d) a rock band.
23. ❬❬ There is a pipe in a church pipe organ that you want to sound a higher pitch. What can you do to the pipe to raise its pitch?

Section 1 review

Sound is a longitudinal pressure wave that can travel through many substances, though humans normally hear it through air. The human sense of hearing responds to sound waves with frequencies that range from about 20 Hz up to 20,000 Hz. High frequencies are perceived as high *pitch* and large-amplitude sound waves are perceived as *loud.* The amplitude of a sound wave is measured using the logarithmic *decibel* scale: An increase of 20 dB means that the amplitude of a sound wave has been multiplied by a factor of 10. The Doppler effect describes how a sound wave's pitch is altered when its source moves toward or away from the listener. Supersonic (faster-than-sound) motion through a substance creates a *shock wave* in that substance.

Vocabulary words	**pitch, speed of sound, decibel (dB), supersonic, Doppler effect**
Key equations	$v = f\lambda$ $\qquad f = f_0 \dfrac{v_s}{v_s - v}$

Review problems and questions



1. These three graphs show the relative amplitudes of three different sound waves, each as a function of time.
   a. Which of the three sound waves has the lowest pitch?
   b. Is that pitch high enough for the typical human to hear?

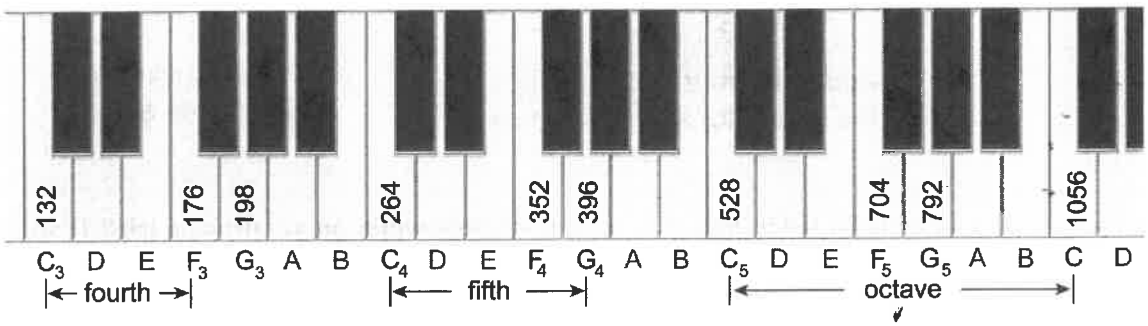
2. One valuable assistive technology is the *hearing aid*, an electronic device that contains a small amplifier to boost sound strength.
   a. Suppose that one hearing aid multiplies the *amplitude* of sound waves by a factor of 10. How many decibels will the hearing aid add to the sounds it detects?
   b. Another hearing aid adds 40 dB to the sounds it detects. By what factor does *it* multiply sound amplitude?

3. Return to the graphs near the top of this page. Suppose that Sound A and Sound B both came from the same source and had the same original frequency f_0. Now consider that one of the sounds was heard as the source approached you, while the other was heard after the source passed you and receded into the distance.
   a. Which sound (A or B) was from the source when *approaching*?
   b. The source was moving at a speed of 114 m/s. What was the source's actual sound frequency, f_0? (Assume a sound speed v_s of 343 m/s.)

Wave phenomena such as reflection, interference, and superposition are responsible for many acoustical and musical phenomena. *Echoes* and *reverberation* occur when sound waves are reflected. Although each musical note on a piano keyboard is associated with a particular fundamental frequency, most musical instruments create a wide spectrum of *harmonics*, which are integer multiples of the fundamental frequency. Musical intervals, such as the octave, correspond to simple integer ratios of frequencies. Interference of waves with two different frequencies produces *beats* and determines whether two or more notes sound pleasant when played together.

Vocabulary words **echo, phase, beats, harmonic**

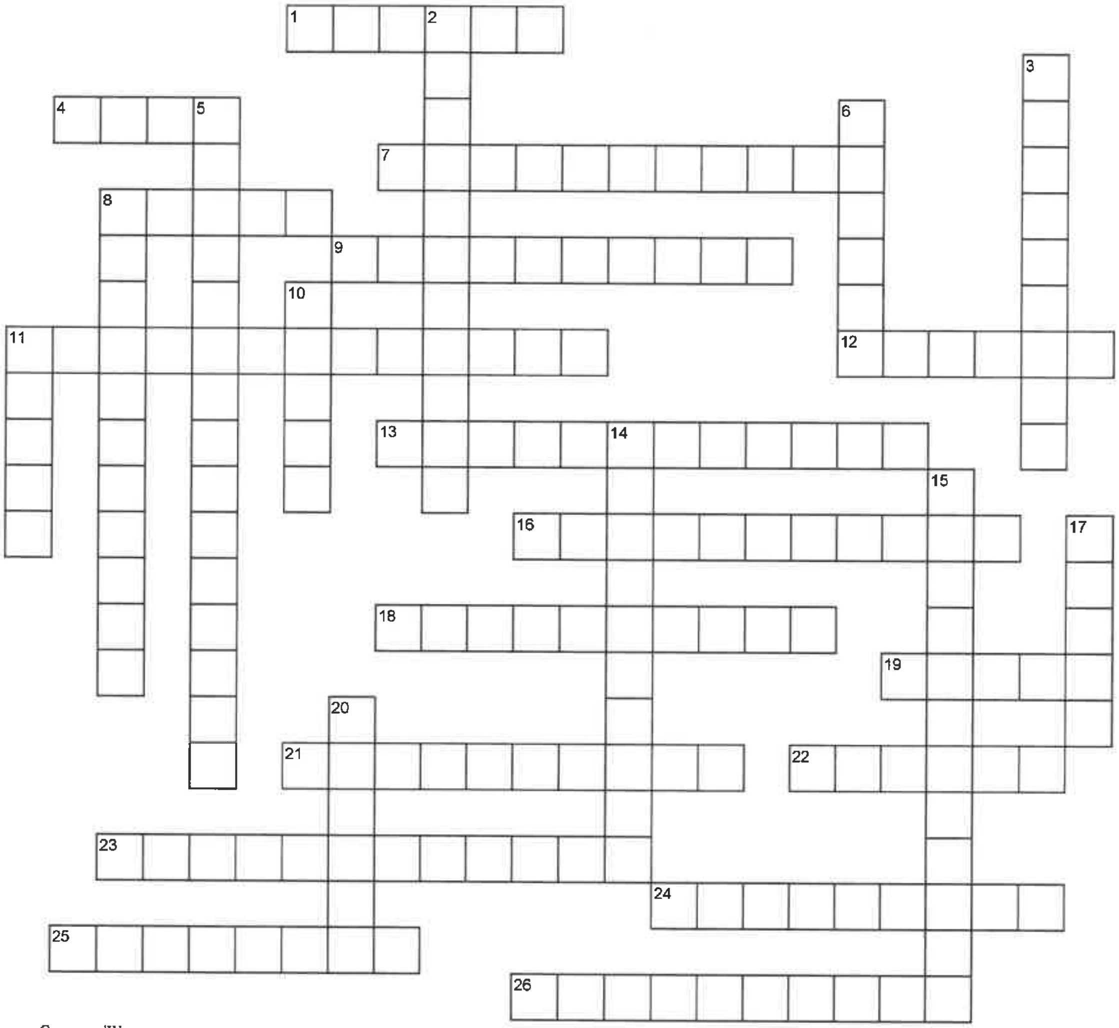
Review problems and questions



1. This depiction of a piano keyboard gives the letter names for notes in the C-major scale, along with their frequencies in hertz. *Intervals* such as the fourth, the fifth, and the octave refer to *ratios* of frequencies. For example, to go one *octave* to the right means *doubling* the frequency.
   a. What is the frequency ratio corresponding to the interval known as a *fifth*? (Express your answer as a ratio of integers and in decimal format.)
   b. What is the frequency ratio corresponding to the interval known as a *fourth*? (Express your answer as a ratio of integers and in decimal format.)
   c. What is the product of the two ratios you just computed?
   d. State a general relationship between the fourth, the fifth, and the octave.

2. *Beats* are heard when two tones of different frequencies occur. The beat frequency equals the difference of the two original frequencies.
   a. What is the beat frequency if C_4 and C_5 are played at the same time?
   b. Does that beat frequency correspond to one of the marked notes? If so, which?
   c. What is the beat frequency if C_4 and G_4 are played simultaneously?
   d. Does that beat frequency correspond to one of the marked notes? If so, which?
   e. What beat frequency results if C_5 and F_5 are played together?
   f. Does that beat frequency correspond to one of the marked notes? If so, which?
   g. The fourth, the fifth, and the octave are among the most pleasant-sounding and important intervals in Western music. Can you speculate why?

Waves



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ACROSS

1 Waves transfer this from place to place.
4 A part of a wave with no motion
7 Type of wave interference when a trough and a crest meet.
8 The top of a wave.
9 Type of wave where the particles of the medium move at right angles to the wave.
11 The principle that the combined amplitudes of two waves meeting is the sum of the amplitude of the two waves.
12 This is not needed for electromagnetic waves.
13 Type of wave interference where two crests meet.
16 Bending waves around barriers
18 The distance from crest to crest
19 An example of an electromagnetic wave
21 Bending waves that pass through different mediums.
22 The bottom of a wave
23 When a wave oscilates in only one direction
24 The number of waves per second
25 A part of a standing wave with a large amplitude
26 Type of wave that requires a medium

DOWN

2 Part of a longitudinal wave where that particles of the medium are few and far between.
3 The maximum displacement of a wave
5 Type of wave that does not require a medium.
6 Material that carries mechanical waves.
8 A crest in a longitudinal wave.
10 An example of a mechanical wave
11 Multiplying the wavelength and the frequency of a wave.
14 Bouncing a wave off a surface.
15 Type of wave where particles of the medium move parallel to the wave motion.
17 The unit for wave frequency
20 The reciprical of the frequency.

Physics – Waves Diagrams Name ______________________

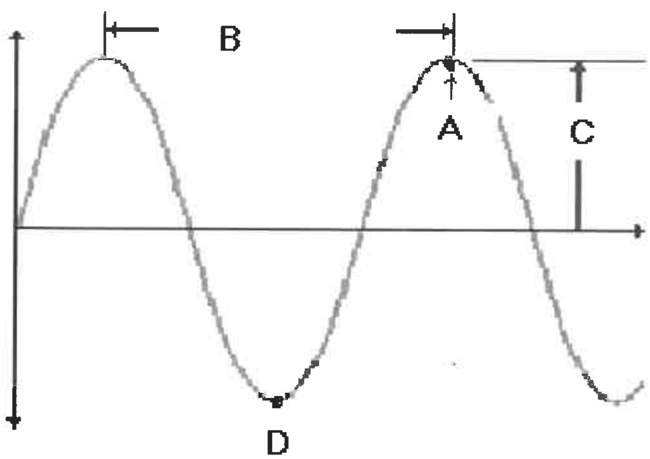
Identify the following parts of the transverse wave in the diagram below.

A. ____________________

B. ____________________

C. ____________________

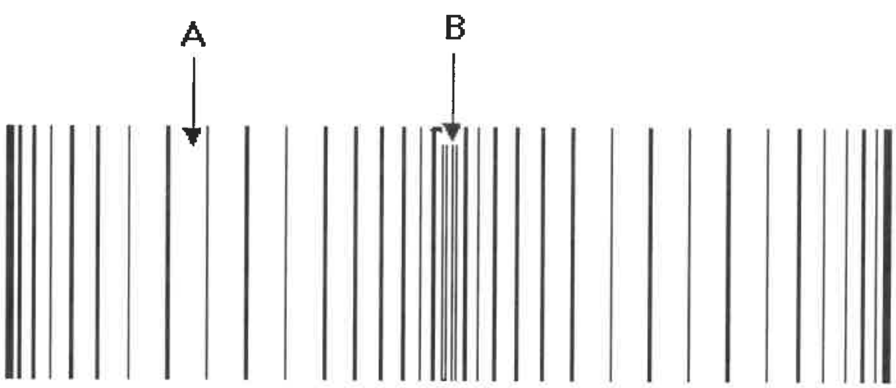
D. ____________________



Identify the parts of the longitudinal wave in the diagram below.

A. ____________________

B. ____________________



Physics – Waves Diagrams Name ______________________

In the space provided draw two transverse waves. Draw one wave with twice the wavelength of the other

In the space provided draw two transverse waves. Draw one wave with twice the wavelength of the other

List three examples of transverse waves in nature

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List three examples of transverse waves in nature

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Waves Worksheet P1HA Name ______________________

Solve the following problems. Show all work for full credit (list givens, identify required equations, solve for unknown, plug in values and solve. Remember to use your significant digits). Enclose your final answer.

1) Determine the period of a wave with a frequency of 23 Hz.

2) You measure the time between crashing waves on a beach to be 8.5 seconds. What is the frequency of the waves at that location?

3) A wave takes 22 seconds to travel 15 meters. What is the speed of the wave?

4) Light waves from the sun take 8.3 minutes to reach the earth. Light travels at 3.0×10^8 m/s. How many kilometers are between the earth and the sun?

5) A 440 Hz sound wave travels at 320 m/s. What is the wavelength of the sound wave?

6) A microwave has a wavelength of 3.2 cm and a speed of 3.0×10^8 m/s. Calculate the frequency.

7) A wave generator produces a wave every 0.25 seconds. The wave travels 12 meters in 3.0 seconds. What is the wavelength?

8) If a wave on a lake has a frequency of 57 Hz and a wavelength of 3.0 meters, what is the speed of the wave?

9) A wave has a frequency of 15 HZ and a wavelength of 2.3 meters. How long would it take th wave to travel 95 meters?

10) A crest with amplitude of 15 meters meets a trough with amplitude of – 8.0 meters. What is the amplitude of the combined wave?