Waves
Properties of Waves

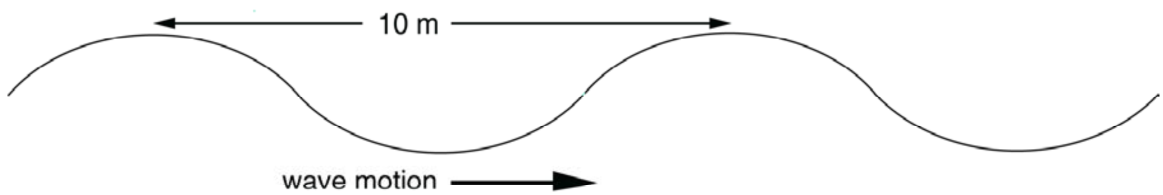
CONCEPT EXPLORATION

Wave theory is an important part of classical physics that enables us to understand how certain kinds of energy are transported from one point to another. When somebody hears the word “wave” they might picture an ocean wave or a wave of people at a sporting event performed by the fans seated around a stadium.
In this unit we will investigate waves in general as well as sound and electromagnetic waves.

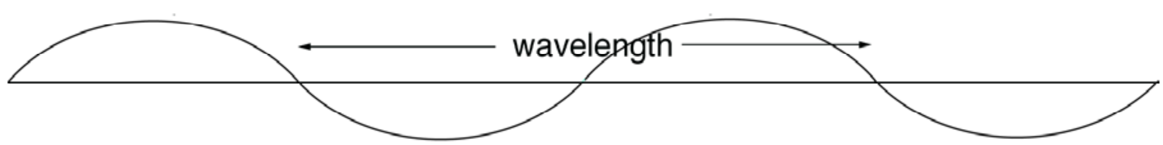
The picture below represents cross sections of ocean waves that are moving to the right. The distance from the top of one wave to the top of the next wave is 10 meters.

Engagement Question

1. If the waves, seen below, take 2 seconds to travel the distance from the top of one wave to the next, how fast are these waves moving?



The distance from the top of one wave to the top of the next wave is called the **wavelength**. Therefore the wavelength for the wave shown above is 10 meters. A wavelength is actually the distance from any point on a wave to the next corresponding point on the wave. For example, another way to identify the wavelength of a wave can be seen below.



2. On the diagram, seen above, label another example of a wavelength.

The time that it takes a wave to travel one wavelength, or the time for the wave to complete one cycle, is called the **period** of the wave. The period for the wave described in the first question is 2 seconds. The period of a wave is the number of seconds it takes to complete one cycle.

Another way to describe waves is to describe the number of cycles that the waves complete in one second. The number of cycles that a wave completes in one second is called the **frequency** of a wave.

3. What would be the frequency of a wave that has a period of 2 seconds? Hint: the wave described takes 2 seconds to complete one cycle. How many cycles does it do in one second?

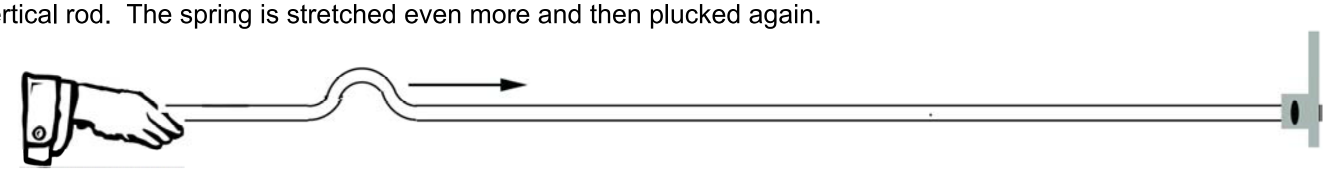
The units that you could use to measure frequency turn out to be cycles per second. A cycle per second is called a **hertz** (Hz) in honor of Heinrich Rudolf Hertz who experimented with electromagnetic waves during the 19th century. A frequency of 1/2 cycle per second would be referred to as 1/2 Hz.
Since period is the number of seconds per cycle and frequency is the number of cycles per second, the period and frequency of a waveform are reciprocals of one another.

The Challenge

You will manipulate a giant spring in order to see what is required to produce different wavelengths in the same medium. You should be able to determine the number of wavelengths that are represented by a picture of a vibrating string or column of air.

Your Ideas about the Challenge

One end of a giant spring is attached to a vertical rod. The other end is then pulled so that the spring is stretched horizontally. This spring is then "plucked" at one end so that a single wave pulse travels to the end that is fixed to the vertical rod. The spring is stretched even more and then plucked again.



3. How will the speed of the second wave pulse compare to the first wave pulse? Will it be faster, slower, or the same speed?

At each lab station you will find the following:
a long spring attached to a vertical support

The Investigation

a. Pull the spring so that it is stretched horizontal. Stretch the spring just a slight amount.
b. While continuing to hold the stretched spring horizontal, grab a part of the spring approximately 20 cm away from your hand and "pluck" the spring so that a wave pulse is produced that travels the length of the spring. Take note of the speed of the wave pulse as it travels down the spring. Watch to see what happens to the wave pulse when it reaches the fixed end of the spring.
c. Stretch the spring a little more and repeat step "b".

4. Which wave pulse seemed to travel the fastest, the first pulse or the second pulse? In general, how does the tension in a spring seem to affect the speed of a wave pulse?

5. What actually moved down the length of the spring when you "plucked" it? Did a part of the spring move or was it something else?

6. Describe what happened when the wave pulse reached the fixed end of the spring.

7. Evaluate the following student statements about the questions that you have just answered. Identify ideas that are consistent with your ideas and others that are not consistent with your ideas.

<u>Student A</u>
"What actually moved in the spring was a disturbance that traveled from one end of the spring and was then reflected back at the fixed end."

<u>Student B</u>
"The spring was just the thing that the disturbance moved through. The spring didn't actually go anywhere itself."

Check your work with your teacher ☐

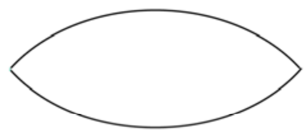
The material substance that a wave passes through is called the **medium of transmission**. Each molecule of the medium of transmission vibrates momentarily as the energy of the wave passes through. It is energy that is actually transported with wave phenomena.

8. What is the medium of transmission for the sound of our voices in this room?

The Investigation (continued)

a. Pull the spring once again so that it is lightly stretched horizontal.

b. Continuously move the spring up and down until you see the spring vibrate in the pattern that you see below. Try to take note of how fast you have to move your hand up and down.



c. While trying to maintain the same amount of tension in the spring, move the spring up and down once again until you get the spring to appear as you see below. Again, take note of the rate at which you are moving your hand up and down.

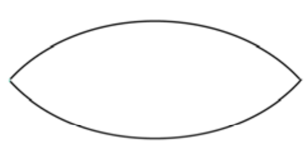
9. When did you have to move your hand the fastest, for the first spring pattern or for the second one?

What you have been creating is what is known as a **standing wave**. Whenever you moved your hand you generated a wave pulse that traveled to the fixed end and was then reflected back towards you. As you continued to generate waves, these waves were reflected back upon one another. If you created the waves at just the right rate (frequency) you were able to produce each of the patterns that you saw. If you increased the frequency of your disturbance even more you could have created more complex standing waves.

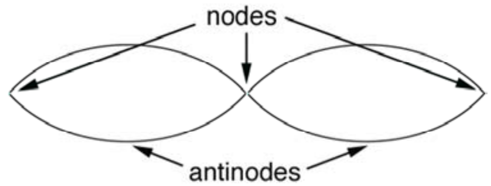
Standing waves are one example of an interference pattern. Interference occurs when you have two waves in the same place at the same time. An **interference pattern** is the resulting waveform that you get when you add two waves together.

The second standing wave that you created represents a full wavelength. This can be seen if half of the waveform is highlighted.

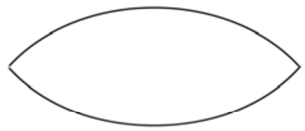
10. What fraction of a wavelength was the first standing waveform that you created with your spring?



The positions on a standing wave where there is very little displacement from the center are called nodes. The positions on a standing wave where there is maximum displacement from the center of the wave are called antinodes. These are labeled below.



11. How many nodes and how many antinodes do you see on the waveform pictured below?



12. What fraction of a wavelength is represented by the distance between successive nodes on a standing wave? . . . between successive antinodes?

13. How many wavelengths are represented by the standing waveform that you see below?

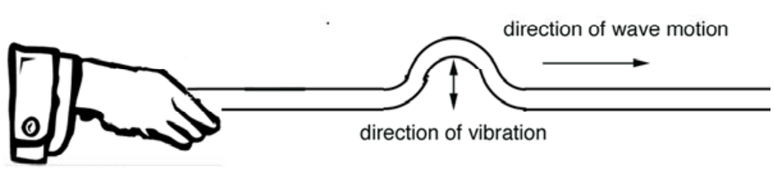
Standing waves are just one example of wave interference. Another example of wave interference occurs when two sound waves with slightly different frequencies are in the same location at the same time.

Your teacher will produce two different pure-tone sounds with slightly different frequencies.

14. Describe the resulting sound that you hear. Do you hear one consistent tone or do you hear a sound that varies in some way?

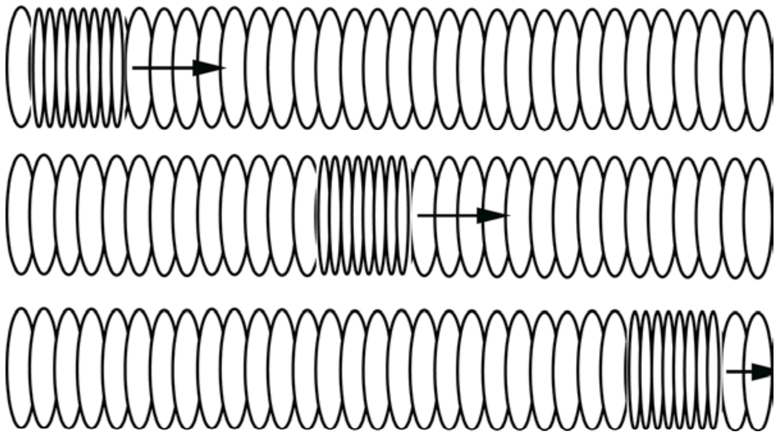
The phenomenon that your teacher just demonstrated for you is known as beats. **Beats** is the resulting variation in the loudness of sound that is produced by two tones played simultaneously with slightly different frequencies.

The disturbances that travel through the medium of transmission can vibrate (oscillate) in several ways. One way that the medium can move is in a direction that is perpendicular to the direction of motion of the wave. This is the kind of wave that you have been producing with your spring.



This kind of a wave is called a **transverse** wave.

A wave in which the disturbance is parallel to the direction of motion is called a **longitudinal** wave. A longitudinal wave can be demonstrated with a larger spring. If you take a large spring and compress the spring in a direction that is the same as the length of the spring you can get an idea of what this would look like. The compression will also travel the length of the spring and be reflected at the fixed end.



Are sound waves transverse waves or longitudinal waves?

One way to generate sound waves is to use a loudspeaker. When a loudspeaker produces sound, the active part of the speaker (the cone) moves back and forth so that the air molecules, that are in direct contact with the speaker, are alternately compressed together and then spread out. This results in alternating pressure variations in the air, moving at the speed of sound.

Our brains, with the help of our ears, perceive these pressure waves as sound.

15. Are sound waves transverse waves or longitudinal waves? Explain how you know.

Check your work with your teacher

Light can also be considered to be another wave phenomena.

The Challenge

You will determine whether light waves are longitudinal waves or if they are transverse waves.

Your Ideas about the Challenge

16. Do you think that light waves are transverse waves or are they longitudinal waves? Explain how you know.

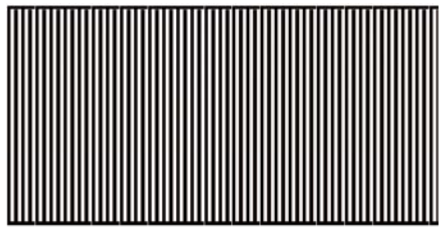
At each lab station you will find two polarizing filters.

The Investigation

a. Hold the two polarizing filters so that they are flush with one another.
b. Hold these two filters together and look through both of these at a light in the classroom.
c. While holding both of the filters together, slowly rotate one of the filters while continuing to look through these two filters.
d. Answer the following questions about what you observe.

17. Describe what happened to the intensity of the light that passed through the two filters as you rotated one of them with respect to the other. Did the intensity of the transmitted light change as you rotated one of the filters? Why do you think that this happened?

Each polarizing filter can be thought of as a plastic grating in which tiny chemical lines are etched onto the surface of this grating.



18. How do you think the two polarizing filters were oriented when they blocked out the most light? Were the lines in the gratings parallel or perpendicular to one another?

19. Would light waves have to be longitudinal waves or transverse waves in order to be blocked by two polarizing filters?

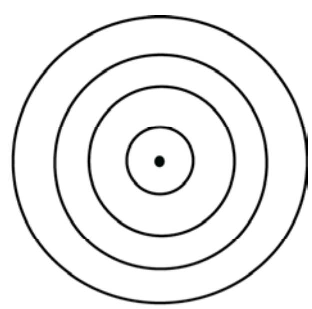
20. Evaluate the following student statement about the question that you have just answered. Identify ideas that are consistent with your ideas and others that are not consistent with your ideas.

"Light waves would have to be transverse waves. Only waves that vibrated up and down in a plane could be blocked by overlapping-perpendicular barriers. Longitudinal waves simply vibrate back and forth and would not be blocked by perpendicular gratings."

Check your work with your teacher

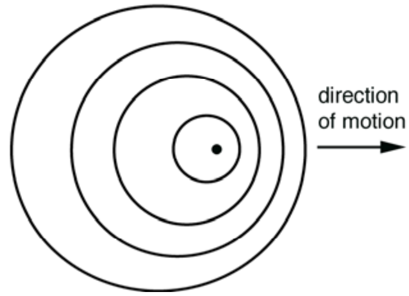
Polarized light consists of light waves traveling in the same direction that also vibrate in the same direction. Since light waves are transverse waves, polarized light waves vibrate in parallel planes. Light that reflects off of a smooth reflective surface, such as still water, can be polarized. This is why "polarized" sunglasses reduce the glare of the light that is reflected from the surface of the water.

If you drop a pebble into still water you can create a pattern of circular waves that spread out evenly from the point where the pebble entered the water.



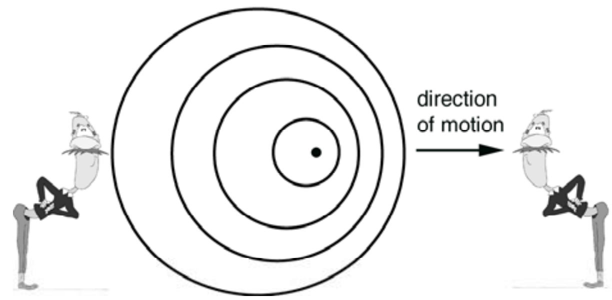
Sound waves, generated by a non-moving source of sound, can also be represented by the diagram seen above. Each of the dark borders of the circles would represent the high point or **crest** of a wave that is spreading out evenly from this source of sound.

If this source of sound began to move to the right it would "catch up" to the waves that are in front of it. It would also be moving farther away from the waves that went in the opposite direction of motion.



A person who was in front of the approaching source of sound would receive more cycles per second than somebody who was behind the source of sound.

The perceived high or low shift in frequency that a listener would receive is called the **Doppler Effect**.



21. Would the person in front of the approaching source of sound hear a higher frequency, lower frequency, or the same frequency as the person behind the moving source of sound? Explain your answer.

22. Evaluate the following student statement about the question that you have just answered. Identify ideas that are consistent with your ideas and others that are not consistent with your ideas.

"I think that the person in front of the approaching source of sound will get more waves per second than the person behind the source of sound. The waves are closer together in front of the moving source of sound and more of them will pass by the person standing in front than the person standing behind the receding source of sound."

Check your work with your teacher ☐

Waves
Properties of Waves

CONCEPT DEVELOPMENT

Waves are a mechanism for the transport of energy from one location to another. Characteristics of any wave phenomena include wavelength, frequency, and period.

Engagement Question

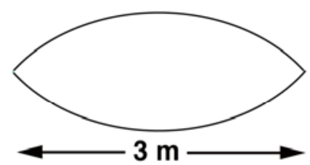
1. A girl and a boy talk at the same time in the classroom. The boy speaks with a low frequency tone and the girl speaks with a high frequency tone. Which sound travels the fastest to the teacher on the far side of the room? Explain your answer.

The Challenge

You will manipulate a giant spring in order to see what is required to produce two different wavelengths in the same medium. You should be able to determine the period of the vibrations as well as the wavelength of the vibrations. Using this information you should be able to determine the speed of the waves.

Your Ideas about the Challenge

Two students standing three meters apart vibrate a giant spring so that the spring looks like the diagram seen to the right.

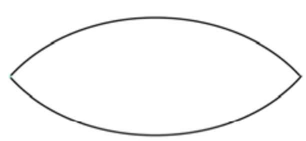


2. What is the wavelength for this vibrating spring?

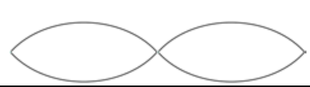
At each lab station you should find the following materials:
A giant spring, a stopwatch, two meter sticks.

The Investigation

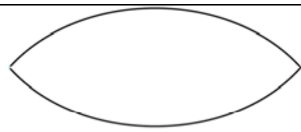
a. Two students should stand approximately 3 meters apart and vibrate the spring in the mode seen below.



b. Another student should measure the distance between the two outside nodes (where the two students hands are) while the other two students maintain this mode of vibration. Record this distance in the data table that follows.
c. Another student should use a stopwatch to time the length of time for the two students to complete 10 vibrations. The vibrating students should count out loud the number of times that they move their hands up and down. Record this time in the data table that follows.
d. Repeat steps a – c for the mode of vibration seen below.



Data Tables

Mode of Vibration		
Distance between the outside nodes		
Time for 10 vibrations (s)		

3. What was the wavelength for the first mode of vibration?

4. What was the wavelength for the second mode of vibration?

5. What fraction of the wavelength of the first mode of vibration was the wavelength for the second mode of vibration? Was is half, one-third, one-fourth, . . . the wavelength of the first mode of vibration?

The wavelengths determined above would be the distance that the generated standing waves traveled during each vibration.

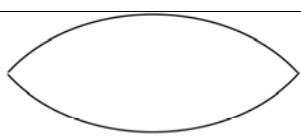
6. What was the time for one vibration for the first mode of vibration?

7. What was the time for one vibration for the second mode of vibration?

8. What fraction of the time of the first mode of vibration was the time for the second mode of vibration? Was is half, one-third, one-fourth, . . . the time of the first mode of vibration?

The time for one vibration would be the time for each of your generated standing waves to move one wavelength. The time for one vibration is the period (T) of the wave.
You can use the distance-rate-time equation (d = rt) to calculate the velocity of your generated standing waves (r = d/t). In this case the distance is the wavelength (λ) and the time is the period of vibration (T). The equation that you can use is: $v = \frac{\lambda}{T}$.

9. Calculate the velocity for both modes of vibration. Be sure to show all of your work and to carry through with the units.

Mode of Vibration	$v = \frac{\lambda}{T}$
	
	

10. Were the velocities for the two different modes of vibration considerably different or were they roughly the same value?

11. Evaluate the following student statements about the question that you have just answered. Identify ideas that are consistent with your ideas and others that are not consistent with your ideas.

<u>Student A</u>

"The velocities for the two different modes of vibration were pretty much the same. It is not the wavelength or the period of a wave that affects its speed. It is the medium of transmission that determines how fast the waves will move. Since we used the same spring under the same tension the speeds should have been about the same."

<u>Student B</u>

Since the frequency for a wave is just the reciprocal value of the period, frequency probably doesn't affect the speed of the waves either."

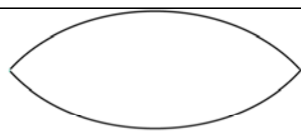
Check your work with your teacher

The classic wave-velocity equation can be derived from the distance-rate-time equation for waves ($v = \frac{\lambda}{T}$). Since the period and the frequency for a wave are reciprocals for each other (f = 1/T), frequency (f) can be substituted for 1/T in the original equation.

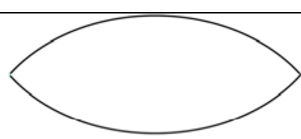
$$v = \frac{\lambda}{T} = \frac{1}{T} \cdot \lambda = f \cdot \lambda$$

$$v = f\lambda$$

12. Calculate the frequency for each of your waveforms that you produced during the investigation. Be sure to include the units with each of your calculations and to label your answers appropriately.

Mode of Vibration		
Period of Vibration (T)		
Frequency for Vibration (f = 1/T)		

13. Recalculate the speed of your generated waves using the new equation ($v = f\lambda$). Be sure to include the units with each of your calculations and to label your answers appropriately.

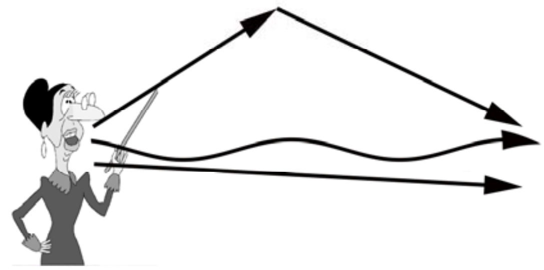
Mode of Vibration		
Wavelength for this mode (λ)		
Speed of waveform ($v = f\lambda$)		

The Challenge

You will be able to identify three different ways in which waveforms can change direction.

Your Ideas about the Challenge

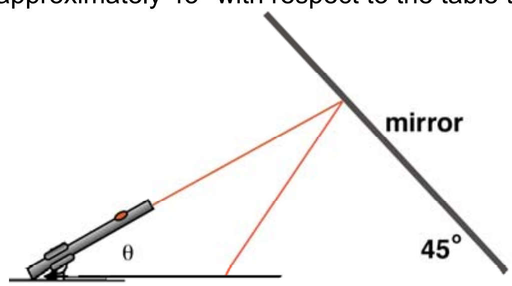
14. You are listening to your teacher speak in front of the class. What kind of path does the sound of your teacher's voice take as it travels to you?



At each lab station you will find the following:
a laser pointer, a mirror, a container of "cloudy" water, a diffraction grating.

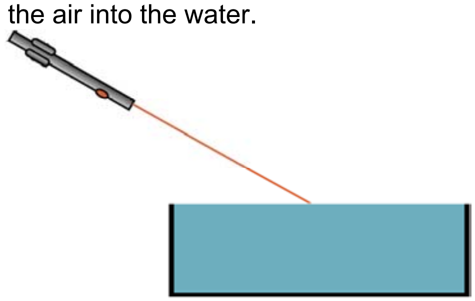
The Investigation

a. Hold the mirror at an angle that is approximately 45^0 with respect to the table top.

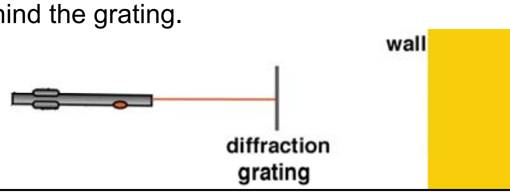


b. Point the laser at the underside of the mirror and push the button to turn the laser on. Take note of how the beam of the laser moves as you change the direction that you point the laser at the mirror. **Be sure to not point the laser in such a way that the beam enters your eye or anyone else's eye.**

c. Point the laser at the surface of the "cloudy water". Adjust the direction that you point the laser and take note of how the beam behaves as it goes from the air into the water.



d. Point the laser at the diffraction grating. Switch the laser on and allow the beam to strike the grating so that the transmitted beam strikes the wall behind the grating.



15. Describe what happened to the laser beam when you projected the laser beam in each of the prescribed methods described in the preceding investigation.

Situation	Description of beam path
Shine beam at mirror	
Shine beam into cloudy liquid	
Shine beam through diffraction grating	

16. What did the path of the laser beams have in common in each of the three situations described above? Did the beam continue to go in a straight line in each case or did the beam change direction?

17. Evaluate the following student statements about the question that you have just answered. Identify ideas that are consistent with your ideas and others that are not consistent with your ideas.

Student A

"The laser beam changed direction when we bounced it off of the mirror and when we pointed it into the cloudy liquid. When we passed it through the diffraction grating the light just spread out into little tiny dots. It didn't really change direction."

Student B

"I think that the light did change direction when it passed through the diffraction grating. The light did spread out and it had to change direction if it made all of those little dots."

Check your work with your teacher

The three situations that you experimented with in the last investigation involve three different ways that waves can change direction. These phenomena occur with all kinds of waves whether they are sound waves or light waves. The names of these phenomena are identified and defined in the chart seen below.

Situation	Name of the phenomena	Definition
Light bounces off of a mirror	**Reflection**	The rebounding of waves that strike a surface of a substance.
Light bends when it enters a liquid	**Refraction**	The change in the direction of a wave as it goes from one substance to another.
Light spreads out when it passes through a grating	**Diffraction**	The bending of a wave when it encounters an obstacle or a barrier.

Waves
Properties of Waves

CONCEPT REFINEMENT

You have been introduced to a variety of vocabulary terms, equations, and phenomena that all relate to wave theory. If a phenomenon is a wave phenomenon, then it must have a wavelength, a frequency, and a velocity. These three characteristics of waves are related by the equation $v = f\lambda$. If you know any two of these three characteristics, for a waveform, you can solve for the third characteristic.

The speed of sound is dependent on the medium of transmission through which the sound moves. Sound goes faster in water than in air. Sound also goes faster through air when the air is warm than when the air is cold.

A good typical value for the speed of sound in air is approximately 340 m/s.
1. Use this value to calculate the missing characteristics for the sound waves described in the table seen below. Assume that these sound waves are traveling through air. Be sure to show all of your calculations and to use appropriate units.

Wave	Frequency (f)	Wavelength (λ)
1	**500 Hz**	
2		**0.2 m**

The speed of light in vacuum is approximately 3×10^8 m/s. This value for the "speed of light" applies to the entire electromagnetic spectrum. Your teacher will discuss the electromagnetic spectrum with you.
2. Use this value to calculate the missing characteristics for the electromagnetic waves described in the table that follows. Assume that the light is traveling through a vacuum. Be sure to show all of your calculations and to use appropriate units.

Wave	Frequency (f)	Wavelength (λ)
1	**7.6×10^5 Hz**	
2		**4×10^{-7} m**

The next set of problems deals with seismic (earthquake) waves. Seismic waves can travel at a variety of speeds depending on the kind of material that they travel through as well as what kind of wave they are.

3. Calculate the missing wave characteristic in the table that follows. Be sure to show all of your calculations and to use the appropriate units.

Wave	Velocity (v)	Frequency (f)	Wavelength (λ)
1		10 Hz	300 m
2	3,000 m/s		60 m
3	5,000 m/s	25 Hz	

4. Assuming that the waves described in the preceding table were seismic waves, traveling through the same material, indicate whether they were "P" waves or "S" waves. P waves (primary waves) travel faster that S waves (secondary waves).

Wave	P or S wave?
1	
2	
3	

P waves are longitudinal-seismic waves and **S waves** are transverse-seismic waves.

You have been introduced to a variety of topics that relate to all waveforms. These include the **Doppler effect**, interference patterns (**beats**), **reflection**, **refraction**, **diffraction**, and **polarization**. Each item, in the table below, is an example of one of these topics.

5. Indicate what each situation describes by writing the appropriate term in the blank provided in the table.

Description of wave behavior	Name of the wave phenomenon
An ocean wave bends around the edges of a small opening in a seawall as the waves strike the seawall.	
You yell across a canyon and hear the sound of your voice return a moment later when you hear the echo.	
A twin-engine airplane flies overhead and you hear an alternating loud and soft sound caused by the droning of the two engines of the airplane.	
The sound of the engines of the airplane seems to drop in tone as the airplane flies past you.	
The transverse waves that make up sunlight, reflected off of a window, all vibrate in the same direction.	
Light waves change direction as they enter the hot air directly above the surface of the hot asphalt of a road. This makes the air appear to "shimmer" above the surface of the road.	