

Lesson 7

Waves-Sound

Introduction: Connecting Your Learning

In this lesson, you will learn all about waves. Waves can be classified as either mechanical or electromagnetic. Perhaps the two most familiar types of waves are water waves and sound waves. Both of these wave types carry energy from one location to another without transporting matter along with the energy. These types of waves are referred to as mechanical waves, because they require a medium such as air or water to transport the energy. This lesson examines wave properties and wave applications.

Readings, Resources, and Assignments

Required
Textbook
Readings

Conceptual Physics
Chapter 8

Check Prior Knowledge

See how much of the chart regarding wave concepts you can fill in. Answers are located at the end of the lesson.

Wave Term	Description	Symbol	Units of measure
Crest		None	None
Trough		None	None
Wave height			
Wave amplitude			
Wave frequency			
Wavelength			
Wave speed			
Wave period			

Lesson Objectives

By the end of this lesson, you should be able to:

1. Compare and contrast mechanical and electromagnetic waves.
2. Differentiate between transverse and longitudinal waves.
3. Calculate wave properties in terms of frequency, wavelength, wave speed, and amplitude.
4. Predict how the Doppler Effect will cause an apparent shift in wave properties between a sound source and a sound receiver due the relative motion between them.
5. Compare and contrast wave properties such as interference, diffraction, reflection, and refraction.
6. Discuss wave properties associated with musical sounds such as pitch, quality, and loudness.

Approaching the Objectives

This lesson is comprised of five sections:

Section 1: Fundamentals of Waves

Section 2: Wave Properties

Section 3: The Nature of Sound

Section 4: Sound Wave Properties

Section 1: Fundamentals of Waves

Start this lesson by reading **Chapter 8, Section 8.1, pp. 163 to 165** in the *Conceptual Physics* textbook.

View this video from the Kahn Academy on [Introduction to Waves](#).

Waves provide a means to carry energy from one point in space to another point. One way to classify waves is based on whether or not the waves need a medium (air, water, a piece of rope, etc.) to carry the energy. Electromagnetic waves such as those that transport energy from the Sun do not need such a medium. Solar energy can be transported through empty space and does not need air or water. Mechanical waves differ in that they do require a medium in which to transfer energy.

Mechanical waves can further be categorized into two basic types. Longitudinal waves (e.g., sound waves) require that the particles in the medium (air or water for example) vibrate back and forth in the same direction as the energy transfer. On the other hand, in transverse waves, the particles in the medium vibrate perpendicular to the direction of energy transfer. In nature, both longitudinal and transverse waves play an important role in transferring energy. Most water waves are very close to being ideal transverse waves. Instead of the water particles moving exactly up and down perpendicular to the direction of energy transfer, the actual particles of water move in a more circular or elliptical pattern.

View this video from the Kahn Academy on [Amplitude, Period, Frequency, and Wavelength](#).

One important relationship between wave variables is the relationship between the wave speed, the wave frequency, and the wavelength. The wave speed (S) is equal to the wave frequency multiplied by the wavelength.

$$S = f \cdot L \text{ or } v = \nu \cdot \lambda$$

or

$$S = L / T \text{ or } v = \lambda / T$$

Note: These are not different equations. They are shown with various symbols to emphasize that variables often are represented by different symbols. Most textbooks use v , ν , and λ to represent velocity, frequency, and wavelength respectively.

The wave frequency, ν , and the wave period, T , are reciprocals.

Note: The units of wave speed, S , are m/s. When frequency (1/s) is multiplied by wavelength (m), the result is (m/s), which is consistent. The units of the quantities on each side of the equal sign must be the same.

Another important point is that the speed of electromagnetic waves is the speed of light (3×10^8 m/s) and is essentially constant. The frequency and wavelength are simply reciprocals.

Mechanical wave speed is determined by the source of the wave. The frequency of the wave is also determined by the source of the wave in the medium that transports the energy. The sources that provide the energy for water waves can vary. One primary source is the wind. Underwater volcanoes and earthquakes can also provide energy for a wave. Differences in density between layers in the deep ocean can provide the energy to produce waves. There is no one single source for waves on land or in the ocean.

Practice:

A wave is produced in the ocean by an underwater earthquake. The wave speed is 200 m/s. The wavelength is 100 kilometers (These numbers are reasonable for this type of wave).

- What is the frequency of the wave?
- What is the period of the wave?

Check your answers at the end of the lesson.

The next section focuses on the fundamental wave properties associated with longitudinal and transverse waves.

Section 2: Wave Properties

Start this section by reading **Chapter 8, Sections 8.2 and 8.3, pp. 166 to 172** in the *Conceptual Physics* textbook.

View this video from Kahn Academy on the [Doppler Effect](#)

Interference and Standing Waves:

When two or more waves interact with each other, the result can be either constructive interference or destructive interference. As the names suggest, constructive interference results when the waves add to one another and destructive interference results when the waves cancel each other out. In reality, when interference occurs, it is usually a combination of both types of interference. When waves come in contact with a material of a very different density, (e.g., a water wave striking a cement wall), there will be some reflection. When conditions are just right, the reflected wave can be in phase with the incident wave and a standing wave can be produced. Practical examples of standing waves are often seen in musical instruments (i.e., stringed instruments as well as organ pipes, flutes, etc.).

Another common wave property that applies to all types of waves (i.e., mechanical and electromagnetic) is the Doppler Effect. When the source of the wave or the instrument detecting the wave such as a telescope or a person's eardrum is moving toward or away from the wave's source, there is an apparent shift in the frequency of the wave. A familiar example is the passing of a vehicle emitting the sound of a siren. As the vehicle approaches the observer, the frequency of the wave appears to increase, and as the vehicle goes away from the observer, the frequency appears to decrease. The same phenomenon is seen with light waves as planets approach or move away from the Earth.

Why is this happening? The actual frequency of the source does not depend on who is listening. The image below shows an observer listening to a fire truck approaching and then going away. Wave fronts are shown to represent the distance between the wave maximums. This is also called the wavelength. The frequency of the wave is equal to the wave speed divided by the wavelength.



View these videos from Kahn Academy on the Doppler Effect Formula for [Observed Frequency](#) and the [Formula for When the Source is Moving Away](#)

There are many different scenarios involving the relative motion between the wave source and wave receiver (i.e., the observer could also be moving toward or away in addition to the source moving). Each scenario requires a unique analysis of the wave equations and can become mathematically cumbersome. There is a general rule that the shift in frequency is equal to:

$$F_{\text{apparent}} = F_{\text{normal}} [(v \pm v_{\text{receiver}})/(v \pm v_{\text{source}})]$$

In this equation, v is the velocity of the sound in air. The velocity of the source with respect to the air is v_{source} , and the velocity of the receiver with respect to air is v_{receiver} . The rule for the plus and minus signs is straightforward. When the motion of the receiver or source is toward the other, the sign of the velocity must be negative, which results in an increase in frequency. When the motion of the receiver or source is away from the other, the sign of the velocity is positive, which results in a decrease in frequency.

The simple scenario above shows a stationary observer. The speed of sound in air at 20°C is about 343 m/s, if the observer is stationary and the frequency of the siren is 1000 Hz. If the fire truck is approaching at 120 km/hr (about 75 mph), then the equation above would reduce to:

$$F_{\text{apparent}} = F_{\text{normal}} [(v \pm 0)/(v \pm v_{\text{source}})]$$

Remember to convert 120 km/hr to m/s. So, 120 km/hr = 33.3 m/s.

$$F_{\text{apparent}} = 1000 \text{ Hz} [(343 \text{ m/s} \pm 0)/(343 \text{ m/s} - 33.3 \text{ m/s})]$$

$$F_{\text{apparent}} = 1108 \text{ Hz}$$

Math Challenge:

Use the above equation to find the frequency of the sound heard by the observer while the fire truck is going away. (Check your answer at the end of the lesson.) The general equation for the Doppler Effect can be derived mathematically but is simply given here for reference.

$$f_{\text{apparent}} = f [(v \pm v_o)/(v \pm v_s)]$$

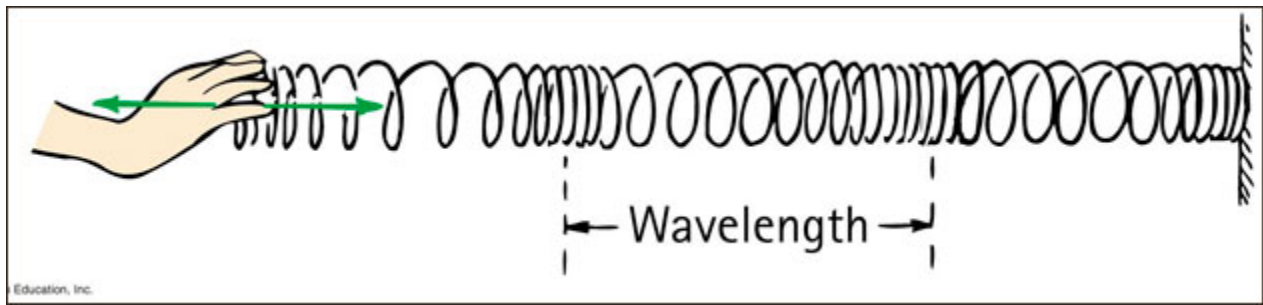
Notes:

1. If the source and/or the observer are moving toward one another, use the + sign in the numerator and the – sign in the denominator.
2. If the source and/or the observer are moving away from one another, use the – sign in the numerator and the + sign in the denominator.
3. v_o is the velocity of the observer and v_s is the velocity of the source.
4. f is the frequency of the source.

The next section examines the nature of sound waves. Sound waves are longitudinal. The energy of the particles in the medium vibrates back and forth in the same direction as the energy transferred.

Section 3: The Nature of Sound

The distinguishing characteristic of a longitudinal wave is that the particles in the medium (i.e., the air, water, solid material, etc.) vibrate back and forth in the same direction as the energy flow of the wave. In the diagram below, observe the regions where the wave is compressed. Between these regions, the wave is more spread out.



Sound waves need a medium to transfer energy. The type of medium determines the speed of the wave. Temperature also influences the speed of the wave. Waves travel much faster in solid material than water. Likewise, they travel faster in water than in air. This is due to the closeness of the molecules that make up the material. The molecules in a solid substance are much closer together and can more easily transfer energy from one molecule to another.

Sound waves travel through the medium creating alternating positions in space referred to as compressions and rarefactions. The compressions and rarefactions correspond to positions of high and low pressure in the medium.

Section 4: Sound Wave Properties

Start this section by reading **Chapter 8, Section 8.4, pp. 172 to 175** in the *Conceptual Physics* textbook.

Sound waves exhibit the same properties seen in all waves: reflection, refraction, diffraction, and interference.

Reflection: Sound waves can be reflected when they strike a material of a different density than the medium. For example, to measure the depth of a water column in the ocean, a sound wave is transmitted down into the water. When the wave reaches the bottom of the ocean, the wave is reflected back to the source. The time it takes for the wave to make the back and forth trip can be measured. If the velocity of sound in that medium is known (i.e., speed of sound in salt water), then the distance can be computed.

Refraction: Refraction refers to the bending of sound waves due to the waves entering a medium of different density. Going back to the water example, the water density depends on the temperature of the water. The water temperature can change abruptly in a column of water. The region where the temperature changes is referred to as a thermocline. Submarines rely on knowing the depth of the thermocline in order to hide from enemy sonar. When the sound waves refract, the waves create a shadow zone where the oncoming waves that would detect the submarine are bent and never come in contact with the submarine.

Diffraction: Diffraction refers to the bending of waves around small obstacles and the spreading out of waves beyond small openings. The fact that you can hear sounds around corners and around barriers involves both diffraction and reflection of sound. Since diffraction is more pronounced with longer wavelengths, this implies that you can hear low frequencies around obstacles better than high frequencies. Diffraction will be discussed in more depth in later lessons dealing with light waves.

Interference: Wave interference was mentioned in an earlier part of the lesson as either constructive or destructive. This is the adding or subtracting of two or more wave trains as they come together. Interference of sound waves has practical application in any situation where waves have an opportunity to combine. For a longitudinal wave, the maximums are referred to as rarefactions (areas where the density of the medium is minimum) and compression rarefactions (areas where the density of the medium is maximum). When these areas line up, constructive interference results, and when the compressions are out of phase with the rarefactions, destructive interference results. From a practical point of view, this produces areas of high sound intensity and dead spots where the sound intensity is zero. This is very important when sound engineers design theaters or auditoriums. Sound wave interference must be taken into account. The shape of the building or stage and the materials used to build it are chosen based on interference patterns. They want every member of the audience to hear loud, clear sounds.

The speed of sound depends on several factors. Most importantly is the density of the medium. Since the molecules or atoms in a solid are more closely packed than liquids or gases, the speed of sound is much faster in a solid because it is easier for the atoms to transfer energy as they vibrate back and forth. By the same argument, the speed of sound is higher in a liquid than in a gas.

Summarizing Your Learning

This lesson focused on various types of waves. Waves are an important means to transport energy from one location to another. There are two primary types of mechanical waves: transverse, and longitudinal. The most common everyday example of a longitudinal wave is a sound wave. The speed of sound varies in different mediums. Wave properties such as reflection, refraction, diffraction, and interference were discussed. The next lesson considers electricity and electric circuits.

Practice Answers

Check Prior Knowledge

Wave vocabulary: Fill in the missing information that accompanies each term and then check your answers.

Wave Term	Description	Symbol	Units of measure
Crest	The highest point in the wave	None	None
Trough	The lowest point in the wave	None	None
Wave height	Vertical distance between a crest and a trough	H	meters
Wave amplitude	The distance measured from the zero point to the crest	A	meters
Wave frequency	Number of wave crests (or troughs) passing a fixed location per unit time	f (Many sources use the Greek letter nu, ν .)	Hertz or 1/s or s^{-1}
Wavelength	The distance from one crest (or trough) to the next crest (or trough)	L (Many sources use the Greek letter lambda, λ .)	meters
Wave speed	Same as <i>celerity</i> Wavelength/Period	S	m/s
Wave period	Complete wave cycle to pass a fixed point in space	T	Seconds

Section 1: Fundamentals of Waves

A wave is produced in the ocean by an underwater earthquake. The wave speed is 200 m/s. The wavelength is 100 kilometers (These numbers are reasonable for this type of wave).

- a. What is the frequency of the wave? 0.002 1/s
- b. What is the period of the wave? 500 s

Section 2: Wave Properties

Use the above equation to find the frequency of the sound heard by the observer while the fire truck is going away. 911.5 Hz