WAVE ENERGY

Unit Overview

What is wave energy? Do you think of ocean waves when you think of wave energy? Or do you think of radio waves? Or maybe even sound waves? A disturbance that transfers energy describes a wave. Keep in mind that energy is the ability to do work. Wave energy is energy associated with wave action. Another way to state wave action is to describe it as a traveling disturbance that moves energy from one location to another without transferring matter. In this unit we will discuss the two major classifications of waves, the properties of waves, and the different types of wave energy. Key words will be in bold type.

GLOSSARY OF KEY TERMS	
wave	a traveling disturbance that moves energy from one location to another without transferring matter

crest	the highest point, or peak, of the transverse wave
trough	valley, or lowest point of a transverse wave
compression	area where particles of air are pushed together as a result of being near something that is vibrating
oscillation	up and down, back and forth motion
rarefaction	expanded part of a wave
wavelength	distance between one crest or peak of a sound wave and the next crest or peak
radio waves	longest wavelength, lowest frequency waves on the electromagnetic spectrum
sound waves	movement of sound through the air or other materials in a wave form created by the vibration of some object and detected by causing a sensor to vibrate
amplitude	a measurement of the top (or bottom) half of the wave
frequency	number of vibrations that occur in one second
period	the time it takes for a wave to complete one full vibration
light waves	these waves have both electric and magnetic fields
electromagnetic waves	waves that travel through empty space, a special kind of transverse wave
wavelength	the distance between the point of one wave to the same identical point on the next wave
longitudinal	a wave whose oscillation is parallel to the direction in which the wave travels
transverse	a wave where matter vibrates at right angles to the direction in which the wave travels

For extra practice of your key terms, click on the Key Terms Crossword Puzzle PDF File.

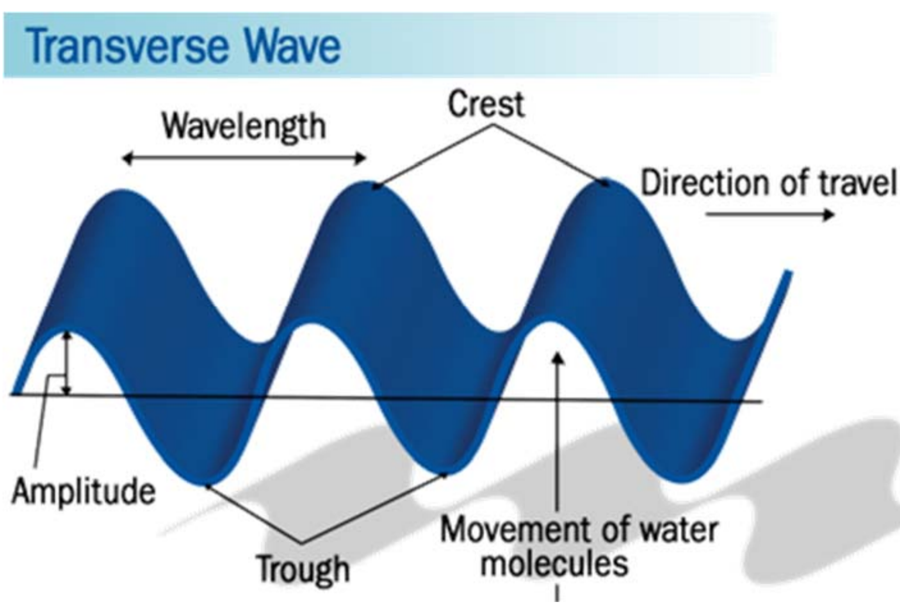
Wave Energy

A **wave** is a traveling disturbance that moves energy from one location to another without transferring matter. A wave does not permanently disturb the medium through which it travels. But keep in mind that as the wave carries energy it causes the particles of the medium to vibrate.

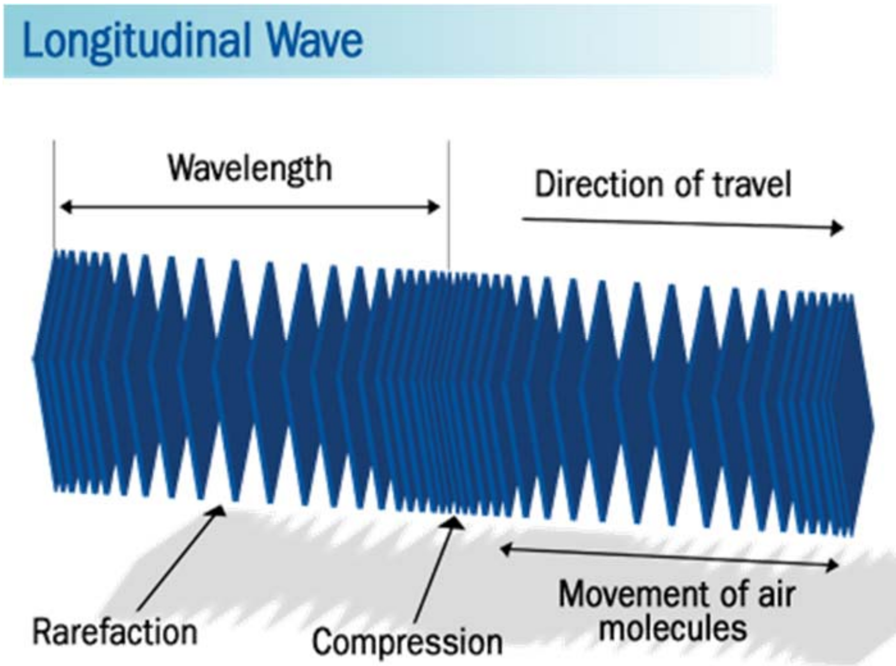
The Nature of Waves (02:20)

There are two major classifications of waves: transverse and longitudinal waves. A **transverse** wave is a wave where matter vibrates at right angles to the direction in which the wave travels. This definition sounds complicated but it is not. An example of a transverse wave would be a water wave with the up-and-down or back-and-forth motion. The up-and-down and back-and-forth motion describes **oscillation.**

Look at the following web site for a demonstration of both transverse and longitudinal waves:
http://www.acs.psu.edu/drussell/Demos/waves/wavemotion.html

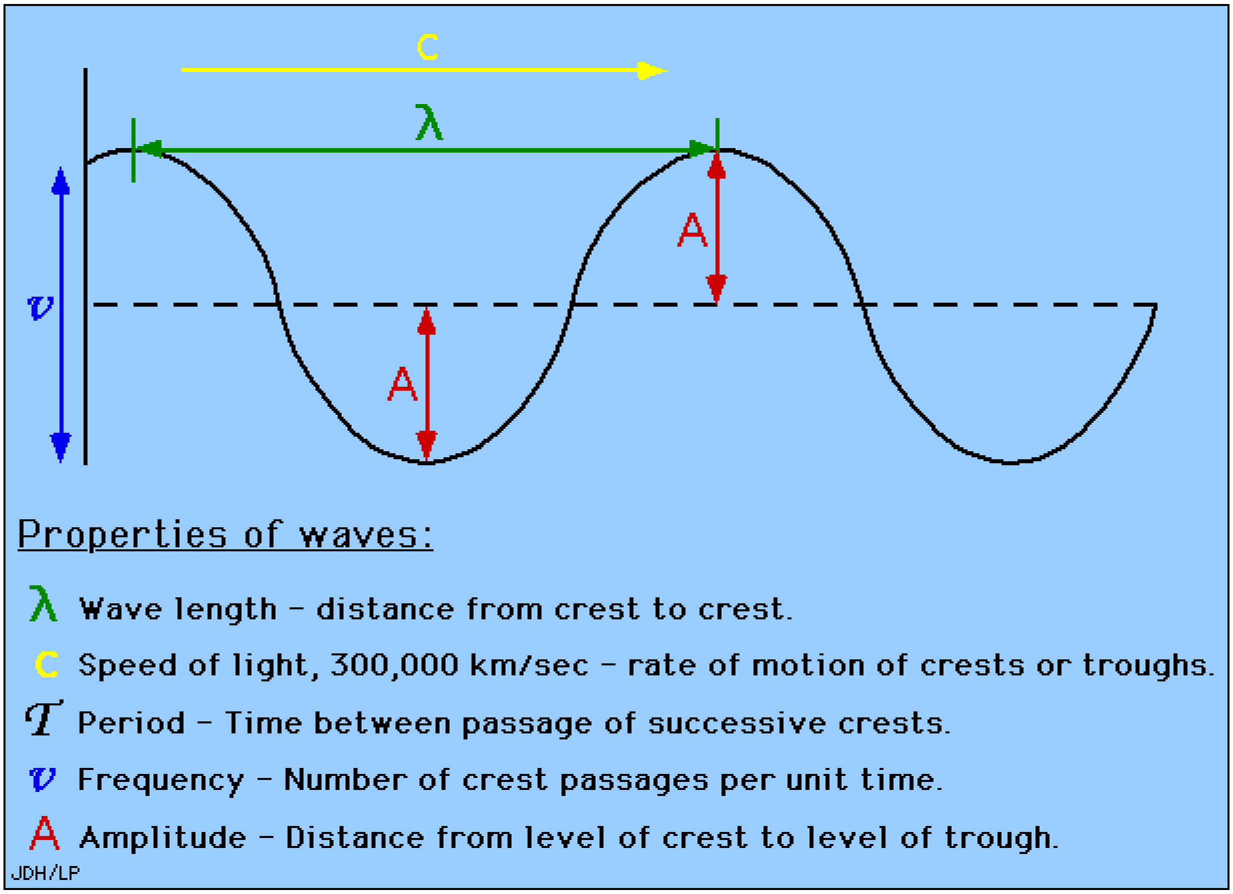


When looking at the above diagram of a transverse wave, you can see that the highest point, or peak, of the transverse is called the **crest**. The valley, or lowest point, is called the **trough**. Other examples of transverse waves might include seismic waves that occur during earthquakes (S-waves or secondary waves) and electromagnetic waves, or light waves.

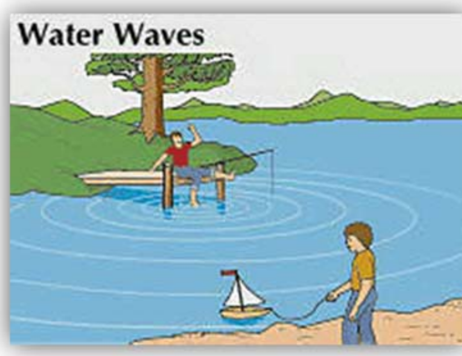


A **longitudinal** wave is a wave whose oscillation is parallel to the direction in which the wave travels. Some examples of longitudinal waves might include sound waves and earthquake seismic waves (primary waves or P-waves). In longitudinal waves, the medium pushes close together at some points (compression) and then separates from each other immediately after (rarefaction). Probably one of the best examples of longitudinal waves would be sound waves. These are a series of back and forth oscillations of air molecules and compress and rarefact in a medium such as water or air. The compressed part of a longitudinal wave, called the **compression**, is the crest. A compression is the area of the medium that is condensed as a result of a force that is being applied to the medium. The **rarefaction**, or expanded part of the wave, is the trough.

In both the transverse and longitudinal wave, we see the wavelength. A **wavelength** is the distance between the point of one wave to the same identical point on the next wave. View the following web link for animated examples of various wavelengths:
http://www.gcse.com/waves/wavelength.htm

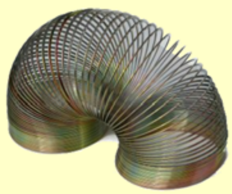


Properties of Waves



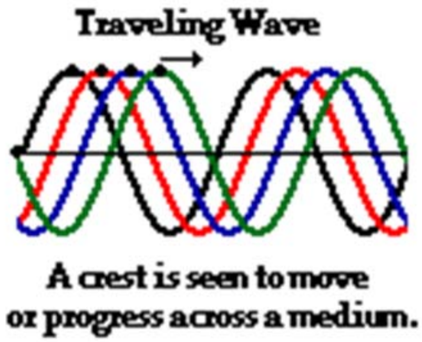
What are the properties of waves? We would use the type of waves, transverse and longitudinal, as well as crest, trough, compression, and rarefaction to describe wave properties. If we are talking about transverse and longitudinal waves we could also discuss amplitude, frequency, period and wavelength. All waves have the characteristics listed previously. **Amplitude** is the distance from the midpoint to the point of maximum displacement (crest or compression). **Frequency** is the number of vibrations that occur in one second; the reciprocal of the period. **Period** is the time it takes for a wave to complete one full vibration; the inverse of the frequency. And you already know the definition of wavelength.

(right) Surface ripples on water, seismic *S* (secondary) **waves**, and electromagnetic (*e.g.*, radio and light) **waves** are examples of **transverse waves**.

Properties of Waves Experiment
 There is an easy experiment you can do to determine the properties of waves. You will need a spring toy (plastic or metal slinky), a meter tape, and safety goggles/glasses, and a partner. Complete the following steps and then answer the questions.
STEP #1: Ask your partner to hold one end of the spring toy without moving it. You will need to hold the other end. Stretch the spring toy to a length of 3 meters along a smooth floor.
STEP #2: Use a side-to-side motion on your end of the spring toy. Observe what happens.
STEP #3: Continue to make a side-to-side motion so that one wave, crest and trough, is formed with the entire spring toy
STEP #4: Move the spring toy twice as fast as before. Observe what happens. Watch the number of waves that are formed and the length of each wave. Repeat.
Next, record your observations from this experiment in questions # 7 - #9.

Wave Velocity

The velocity of a wave is dependent upon the medium or type of material in which it is traveling. Remember that velocity is speed in a given direction. When a wave enters a new medium, the density and elasticity of that medium may cause a change in the velocity of the wave. In most cases, the more elastic and dense the medium, the faster that wave will travel. When the wave is in a particular medium, all of that type of wave will travel at the same speed.



A perfect example of change in the velocity of a wave occurred during the Tsunami of 2004. As reported in Time Magazine on January 10, 2005, the wave spread in all directions, moving as fast as 500 m.p.h. In the deep ocean, the waves were imperceptible (hardly visible), but they slowed down and gained height as they hit shallow water near the shore. In deep water tsunamis are very long, shallow waves, which means they don't lose much energy fighting gravity. Given enough initial force, they will travel vast distances until they are slowed by resistance from the sea floor near shore. Look at the following pictures of the great Tsunami waves as they approached the shore.

How are frequency, wavelength, and velocity related?

We already know the definitions of frequency, wavelength, and velocity, but how are they related? As long as a wave stays in a medium, the wave speed will continue to remain constant. Since the wave velocity does not change, under these conditions, the only variable that might change would be the frequency and the wavelength. If we were to calculate the wave speed we would use the following equation:

velocity = frequency x wavelength.

So, if the frequency of a wave has increased, the wavelength would need to decrease in order for the velocity to remain the same, or constant. So we could say that the frequency of a wave and the wavelength are inversely proportional to each other. Inversely proportional is a mathematical term meaning reciprocal. Sound waves travel at a speed of 331 m/s in air that is at the freezing point (0 degrees Celsius). As the frequency of various sound waves change, the wavelengths change too. Look at the chart below for some examples:

VELOCITY OF SOUND (O DEGREES C)	FREQUENCY (HZ)	WAVELENGTH (M)
331	128	2.59
331	256	1.29
331	512	0.65

In the above chart you can see that the velocity of sound at 0 degrees C is 331. At a frequency of 128, the wavelength would be 2.59 m. If the frequency of 128 is doubled, or increased, the next frequency would be 256. The wavelength would be inversely proportional to the frequency, and would be decreased by dividing by 2. The answer would be 1.29 m. To get a frequency of 512, 128 would be doubled. Again, the wavelength is inversely proportional to the frequency and the answer would be 0.65 m. Use a calculator and calculate these numbers to see if you get the same results. If you performed your calculations correctly, your answers should be the same.

How are frequency and period related?

We already know the definition of frequency, but in other words, it could be described as how many cycles of a vibration occur per second. It is measured in cycles per second of hertz (Hz). Hertz is a unit of frequency. The hertz was named after Heinrich Hertz who proved that electrical signals can be transmitted by electromagnetic waves that travel at the speed of light. The amount of time it takes a wave to vibrate one full cycle is the period of a wave. Again, these two terms, frequency and wavelength, are inversely proportional to each other.

If a wave takes 1 second to vibrate up and down, the period of the wave would be 1 second. That’s pretty easy to understand. So the frequency is the reciprocal of that and is 1 cycle/sec. That is because only one cycle occurred in a second. If a wave took just half a second to again vibrate up and down, the wave period would be 0.5 seconds. The frequency would again be the reciprocal of that wave. The result would be a frequency of 2 cycles per second. Keep this thought in mind: A wave with a very short period (such as 0.5 sec) has a high frequency (2 cycles/sec) and a wave with a long period (such as 1 second) has a low frequency (such as 1 cycle/sec).

Electromagnetic Waves

QuickTime Electromagnetic Waves (03:07)

Waves that travel through empty space are called **electromagnetic waves.** Some examples of electromagnetic waves are light, radio, and x-rays. Electromagnetic waves are a special kind of transverse wave. They consist of two perpendicular transverse waves. Within these two transverse waves, there is one component of the wave being a vibrating electric field and the other is a corresponding magnetic field. Except for the waves that make up light, all other electromagnetic waves are invisible.

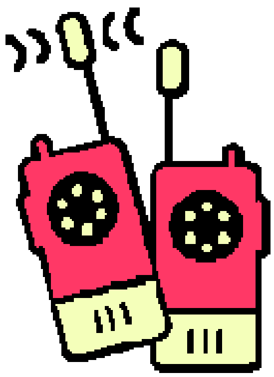
All electromagnetic waves travel at the speed of light, which is 300,000 km/sec or 186,000 miles/sec. A particular type of electromagnetic wave can be defined by its frequency or wavelength. The waves are arranged in order of wavelength and frequency. The electromagnetic wave is arranged with a short wave (gamma rays), then short wavelength and high frequency waves (x-rays and ultraviolet rays), and then a long wavelength and low frequency wave (infrared radiation, microwaves, radio waves).

View the following web site for an animated interactive example of an electromagnetic wave:
http://www.colorado.edu/physics/2000/waves_particles/

Electromagnetic waves differ from other transverse and longitudinal waves in that they don’t need mediums such as water, air, or metal to travel through. Other waves such as radio, gamma, and visible light waves travel easily through the emptiness of space.

Let’s take some time at this point in the unit to introduce the various types of electromagnetic waves. Gamma rays are electromagnetic waves with a short wavelength and an extremely high frequency. Gamma rays are a form of non-visible light. They are given off from a nucleus as radiation during radioactivity. In fact, they are potentially the most dangerous of all radioactive rays. Gamma rays kill living cells since they are radioactive. They are used to sterilize medical equipment by killing any bacteria that may be forming. Gamma rays, with their high frequency and energy, can penetrate almost anything, except lead, which has good absorbing characteristics.

X-rays were discovered in 1895 so they have been around for over 100 years. X-rays can travel through most objects that are soft but not harder, denser substances. X-rays are used in medical facilities to obtain shadow pictures or images of various parts of the body. The use of x-rays is not limited to medical issues, but can also be used in locations such as airports to scan baggage and suitcases for hidden objects.



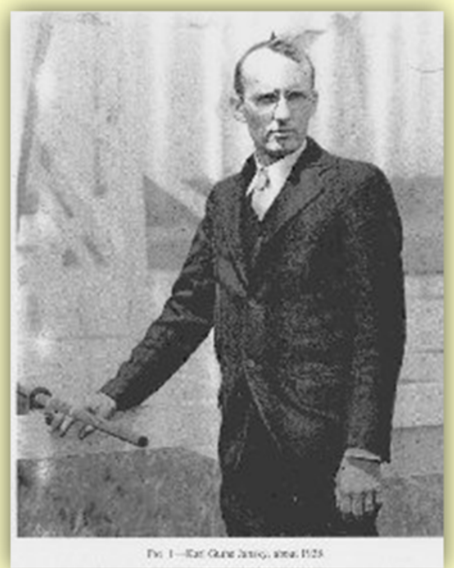
Radio waves are one part of the electromagnetic spectrum. They are the longest of the waves that make up the electromagnetic spectrum. They are made up of a combination of magnetic and electrical fields. They can be reproduced by an electric current that oscillates rapidly. Radio waves are measured by the wavelength or frequency. In order for messages, such as sounds to be carried, the radio waves are altered so that their shape represents messages. Radio waves were first used by Guglielmo Marconi to send messages in 1896. Radio waves today are commonly used to broadcast radio programs. Each radio station uses a specific wavelength that may travel directly to your radio at home, or may be sent to a satellite to be beamed down to another part of the world. Radio waves are quite frequently used in two-way communication with walkie-talkies and mobile (cell) phones.

(1874–1937). The brilliant man who transformed an experiment into the practical invention of radio was Guglielmo Marconi. He shared the 1909 Nobel prize in physics for the development of wireless telegraphy

Radio waves are not just limited to being found on Earth. X-rays are a form of invisible light that is found in space as well. A scientist named Karl Jansky was attempting to find out if static on some radio telephone lines was being caused by thunderstorms. Jansky built a moveable antenna and aimed it at different locations in the sky. This moveable antenna invention was nicknamed “the merry-go-round” because it could be turned around. Jansky discovered that most of the static was coming from radio waves that were produced by thunderstorms. But much to his surprise, the antenna picked up faint hissing sounds that could not be explained. Jansky became curious and pursued the investigation of tracking down the hissing sounds.

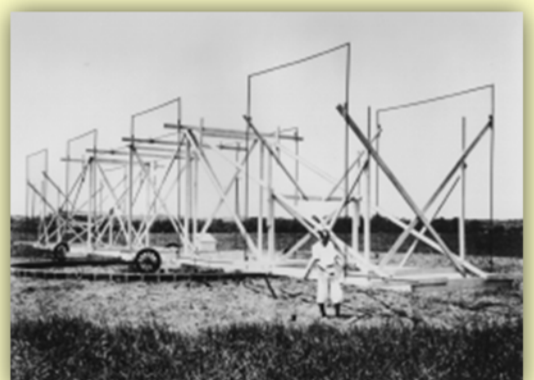
Even today it seems like magic. You turn on your radio and, somehow, sound sent from a distant radio station fills the room. For almost 100 years radio has allowed us to send sounds over the air. How, exactly, is this done? The activity in this link shows you how. Radio Transmission Activity.

To see some of Marconi’s early inventions, click on the following link to take a virtual tour of the Sparkmuseum.
http://www.sparkmuseum.com/MARCONI.HTM



[Karl Guthe Jansky](#) was born in Norman Oklahoma October 22, 1905 (d.Feb.14, 1950), graduated with a degree in physics from the University of Wisconsin, and joined the staff of the Bell Telephone Laboratories in Holmdel, NJ, in 1928.

Bell Labs wanted to investigate using "short waves" (wavelengths of about 10-20 meters) for transatlantic radio telephone service. Jansky was assigned the job of investigating the sources of static that might interfere with radio voice transmissions.



Karl Jansky built an antenna, pictured here, designed to receive radio waves at a frequency of 20.5 MHz (wavelength about 14.5 meters). It was mounted on a turntable that allowed it to rotate in any direction, earning it the name "Jansky's merry-go-round". By rotating the antenna, one could find what the direction was to any radio signal.

Karl Jansky continued to observe for another two years. He eventually discovered that as the stars moved across the sky, so did the hiss. He had discovered that the radio waves, or hissing sound, were coming from space. His discovery of radio waves became quite a sensation. After all the excitement of a new discovery died down, most people seemed to forget about it. Four years later, a man named Grote Reber, an amateur radio operator, played out a hunch that Jansky's discovery was important to the field of science. Reber assembled a dish antenna in his backyard with the intention of capturing these radio waves from space. Reber's dish antenna became the world's very first radio telescope. The discoveries of both Jansky and Reber gave scientists a new and improved way of exploring the sky. Thus, came the discovery of radio astronomy.

Grote Reber was born in Chicago on December 22, 1911 (d.12/20/2002). He was a ham radio operator, studied radio engineering, and worked for various radio manufacturers in Chicago from 1933 to 1947.

He learned about Karl Jansky's discovery (1932) of radio waves from the Galaxy (i.e., the Milky Way), and wanted to follow up this discovery and learn more about cosmic radio waves. Were the waves coming only from the Milky Way, or from other celestial objects? What process produces the radio waves?

(above) The telescope was constructed by Grote Reber in 1937 in his back yard in Wheaton, Illinois (a suburb of Chicago). He built the telescope at his own expense while working full time for a radio company in Chicago. This shows the telescope as it was in Wheaton, Ill.

The mirror, made of sheet metal 31.4 feet in diameter, focuses radio waves to a point 20 feet above the dish. The cylinder contains the radio receiver which amplifies the faint cosmic signals by a factor of many million, making them strong enough to be recorded on a chart. The wooden tower at the left is used for access to the receiver.

Ultraviolet radiation is another form of wave energy that is part of the electromagnetic spectrum. It has more energy than light and can cause chemical reactions to take place. An example of ultraviolet radiation would be the UV rays from the sun. If you were lying out in the sun on the beach, you would be exposed to UV rays, which in high exposures, can be harmful to humans. The sun's UV rays tan the skin by producing a brown chemical called melanin. High levels of melanin have been known to cause skin cancer.

Another wave found in the electromagnetic spectrum is infrared radiation. It is an invisible form of light, just like ultraviolet radiation. Infrared radiation is given out by anything hot, including the Sun. It carries the Sun's heat to Earth, or even the heat from a fire to you. Rattlesnakes have infrared sensors that can help them detect body heat. These sensors help a rattlesnake to catch prey at night. Another way to detect infrared radiation is with an infrared telescope. This type of telescope provides scientists with important information. The telescopes can detect heat waves from newly born stars in clouds of dust and gas. Infrared telescopes even helped discover new comets in our solar system.

Microwaves are short-wave radio waves. They transmit thousands of signals across a narrow band of frequencies that is very narrow. Microwaves are used in the communications and technology fields because they are easy to control and direct. They are difficult to send long distances due to interference from things like mountains, and buildings, etc. They are quite frequently used to send telephone, television, radar, and meteorological communications. Microwave communications are constantly being used for international telephone calls. Microwave beams are directed to satellites and then back down to receivers in other countries. One microwave beam is able to carry more telephone communications than a wire. The most recognizable form of microwave waves is with the kitchen microwave. In order for these ovens to function, food molecules vibrate vigorously. This radiation penetrates through the food, all the way into the middle. All of the molecules vibrate at the same time, so the food heats and cooks evenly and more quickly than a conventional oven.

Radar is a technology that uses microwaves in order to locate distant objects, such as ships and aircraft. A beam of microwaves is sent out from a transmitter. This beam of microwaves is reflected off a solid object and picked up again by a receiver. This information is then transferred into an image on a screen. The image shows where an object is located and how fast it is moving. Radar is also an important tool for weather forecasters. Microwaves bounce off drops of rain. Forecasters are then able to use this information to track bands of rain in large storms.

Radio waves are not sound waves, yet they do carry information. They can travel through air, objects, and even empty space at the speed of light. They can do this without wires or cables. Today radio waves are used to carry signals for television and radio programming, telephone calls, and to communicate into space. In fact, radio waves have even been sent into space to alert any alien life forms (if there are any out there) about human existence on Earth.

Radio waves are one part of the electromagnetic spectrum. Electrical and magnetic field combine to make up radio signals. They can be reproduced by an electric current that oscillates (changes direction) rapidly. Radio waves are the longest of the waves that make up the electromagnetic spectrum. They are measured by their wavelength and frequency. These waves are also measured in hertz (Hz).

Wave Interference

What is wave interference? We already know that waves carry energy. If the crest of a wave passes a given point at the same time as the trough of another wave, they can become weakened. They are considered to be "out of phase" and "interfere" with each other. This results in a lesser wave height. If the crests of many waves are coming together at the same time, they are considered to be "in phase" which results in even more wave height. Waves of water that are "in phase" can quite suddenly produce a huge wave called a "rogue" wave. A rogue wave has been known to reach heights of 30 meters. These waves are considered to be freaks of the sea. They appear all of a sudden out of nowhere and can disappear just as suddenly. This addition and subtraction of wave crests and troughs is known as wave interference.

Wave interference can also be helpful. Scientists and engineers have taken what they know about wave interference and applied it to modern-day technology. Today engineers are using wave interference to make earthquake-prone buildings safer. Buildings that utilize this type of technology are commonly called "smart buildings." This building technology was developed in response to buildings being damaged by earthquake waves. Engineers in the United States and Japan are incorporating control systems into the designs of some buildings that are located in potential earthquake zones. The "smart buildings" are capable of detecting and suppressing their own vibrations to minimize quake damage. During an earthquake, buildings can sway back and forth with the same frequency of the earthquake waves traveling through the Earth. A different approach is being applied today by architects and engineers by developing systems that are included in the structures of buildings. This technology will be discussed further in the next unit.

Unit Extensions

Suggested topics for further research:

- Radio Broadcasting
- Radio Communication
- Computer Technology
- Earthquake Waves
- Earthquake-Proof buildings
- Karl Jansky
- Grote Reber

Careers to explore

- Seismologist
- Radio Broadcaster
- Astronomer

Unit Conclusion

All waves carry energy, from water waves, and sound waves, to electromagnetic waves. The types of electromagnetic include radio waves, microwaves, and other forms. All types of electromagnetic waves are able to travel through space where there is no air or matter. The only type of electromagnetic wave that is visible is light. During this unit, how waves form and how they carry energy has been discussed. Different types of waves share some common characteristics, such as wavelength and frequency. Wave energy is important because it enables us to see light and hear sounds. However, wave energy can be destructive such as with storms and earthquakes. The future of wave interference is a promising technology and will help make lives safer.

Now answer questions 1 through 28.