Activity 2 Solutions: Electromagnetic Waves – Radiant Energy I

2.1 How Do Electromagnetic Waves and Other Waves Transmit Energy?

Your instructor will discuss the properties of waves.

1) Transferring energy with waves

a) Stretch a slinky along the length of your table with a student holding each end. Vibrate one end of the slinky to send sine waves along it. What can you do to increase the frequency of the waves?

Vibrating the slinky faster increases the frequency of the waves (how often one of the wave crests passes a given point on the table).

b) What does increasing the frequency of the waves do to the wavelength?

The wavelength becomes shorter.

c) Place a Styrofoam ball near the slinky. Send one pulse wave along the slinky to knock the ball off of the table. Is it possible to transfer energy without a transfer of matter?

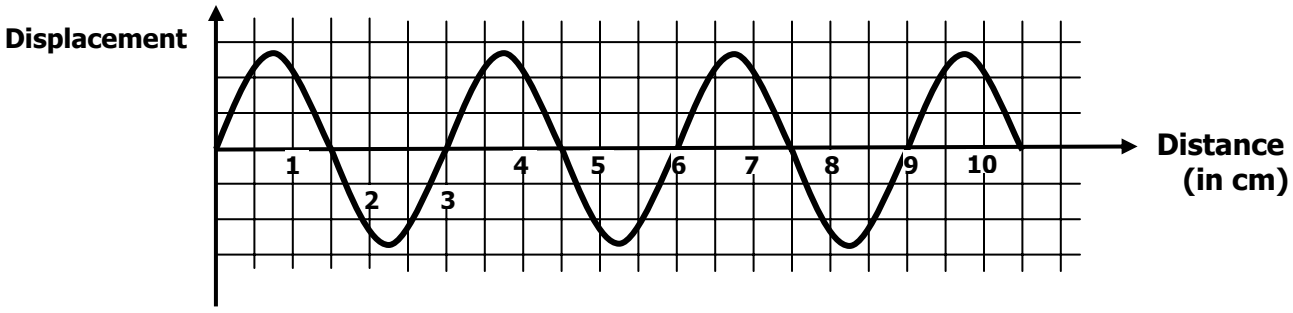
Some of the energy of the wave is converted into the kinetic energy of the ball. This is an example of transferring energy with no transfer of matter (no matter was transferred down the slinky, and no matter was transferred to the ball).

d) Group Discussion Question: List examples of transfer of energy without a transfer of matter.

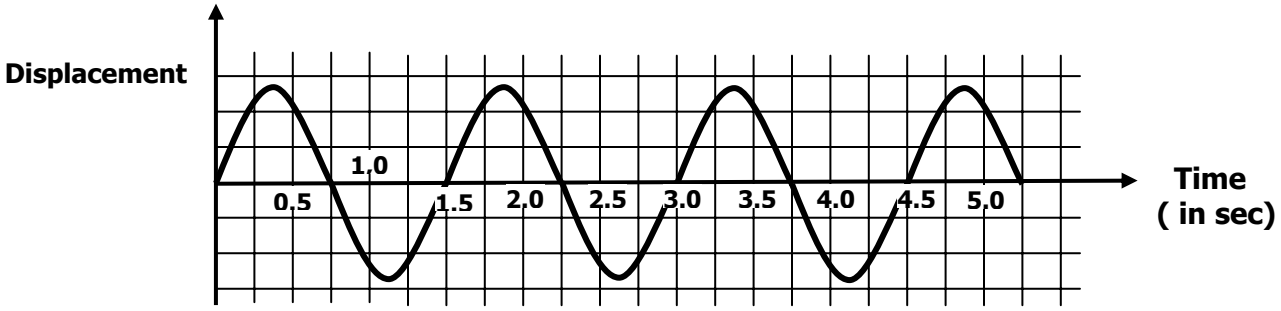
2) Wave Speed and Frequency

Your instructor will discuss wave periods and frequencies. Use this information to find the speed of the wave illustrated in the diagrams below.

a) Find the wavelength (in meters) of the wave in the diagram. **3 cm = 0.03 m**



b) The diagram below shows the displacement of a wave over time, at a fixed point along the path of the wave. Find the period of the wave in the diagram. **_1.5 seconds_**



c) Calculate the frequency of the wave (in cycles/second, or Hertz).

frequency = 1/period = 1/1.5 sec = 0.67 cycles/sec = 0.67 Hz

d) Calculate the speed of this wave.

$$S = f L = 0.67\ \text{Hz} \times 0.03\ \text{m} = 0.02\ \text{m/s} = 2 \times 10^{-2}\ \text{m/s}$$

e) Based on the speed you calculated, could these diagrams represent a wave of electromagnetic radiation? Why or why not?

This could not be a wave of electromagnetic radiation because it is traveling too slowly. All waves of electromagnetic radiation travel at the speed of 3×10^8 m/s (in a vacuum). When traveling in other media, such as air or water, the speed of electromagnetic waves is only slightly slower.

f) Find the wavelength of a wave of electromagnetic radiation that has a frequency of 6×10^{14} Hz.

$$S = f L, \text{ or } L = \frac{S}{f} = \frac{3 \times 10^8\ \text{m/s}}{6 \times 10^{14}\ 1/\text{s}} = 0.5 \times 10^{-6}\ \text{m} = 5 \times 10^{-7}\ \text{m}$$

3) Light and sound in a vacuum Your instructor will demonstrate a vacuum jar that contains a buzzer and a light bulb.

a) Describe the differences you observe between sound waves and waves of electromagnetic radiation.

Sound waves cannot move through a vacuum, as in the bell jar, but waves of electromagnetic radiation can.

b) A sound wave has a wavelength of 0.5 meters and a frequency of 680 Hz. What is the speed of this wave?

$$S = f L = 680\ \text{Hz} \times 0.5\ \text{m} = 340\ \text{m/s}$$

c) How many times greater is the speed of light than the speed of sound?

Sound waves travel at varying speeds, always much slower than electromagnetic waves, which travel at 3 x 10^8 m/s (186,000 miles/s in a vacuum). A typical sound wave travels at approximately 300 m/s in dry air.

$\frac{\text{speed of light}}{\text{speed of sound}} = \frac{3 \times 10^8 \text{ m/s}}{3 \times 10^2 \text{ m/s}} = 1 \times 10^6$ times faster

d) Group Discussion Question: Scaling Quantities. Try to answer the following questions without using your calculator.

1) If the distances in graph 2.a were in meters, what would be the speed of the wave? _____

2) If the times in graph 2.b were in minutes, rather than seconds, what would be the speed of the wave? _____

2.2 Refraction of Radiant Energy

4) Refraction of light

a) Look sideways at a pencil in a cup of water. Does the pencil appear to bend? **Yes** What is it that actually bends?

Light waves traveling from the pencil to your eyes bend as they pass through the surface of the water. The light waves bend because the index of refraction of light in water is greater than the index of refraction of air.

b) Why is the light beam bent?

When light enters a transparent medium such as glass, plastic, or water, the speed of the light wave changes. If the light enters the medium at an angle to the surface, the change in speed causes the light to be refracted, or bent away from the surface of the medium as it passes into the medium.

c) Shine a light through a slit and then through a prism and onto a sheet of paper. What happens to the beam of light?

The beam of light is split into colors by the prism. The effect is similar to what happens to white light that passes through a diffraction grating.

d) Why is the light split into colors?

Different frequencies of light are bent by slightly different amounts.

e) List the colors of visible light from longest to shortest wavelength.

Red, orange, yellow, green, blue, violet

f) Which color of light is bent the most?

The light with the shortest wavelength and highest frequency, violet light, is bent the most.

g) Observe the color wheel. What color do you see when the wheel spins? Why?

When the wheel spins rapidly, the separate colors appear to combine and you observe white light.

h) Group Discussion Question: Why is the light beam bent as it travels through the prism?

2.3 Focusing Radiant Energy

5) Light reflected from mirrors

Your instructor will show you how to use the light box and a plane mirror to determine the angle of reflection of light from a mirror.

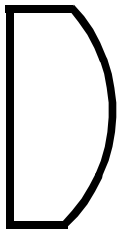
a) Draw a diagram showing light beams striking and reflecting off of a plane mirror.

b) How does the angle that light strikes a mirror (the angle of incidence) compare to the angle that light is reflected from the mirror (the angle of reflection)?

The angle of incidence equals the angle of reflection.

c) Shine light from the light box onto the surface of a curved mirror. Draw light beams on the diagrams below showing the path of the light reflected from the mirror. Which type of mirror focuses light? _**Concave**_

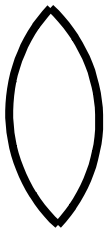
Concave Mirror



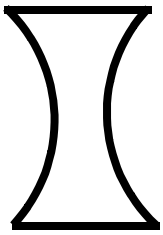
Convex Mirror

6) Light passing through lenses

a) Shine light from the light box onto the surface of a concave and a convex lens. Draw light beams on the diagrams below showing the path of the light traveling through the lens. Which type of lens focuses light? _**Convex**_



Convex Lens



Concave Lens

b) Group Discussion Question: Light that passes through a prism is split into colors. Why is light that passes through a lens not split into colors?

2.4 What is the Quantum Model of Electromagnetic Radiation?

7) Energy of a photon: Your instructor will discuss the quantum (photon model) of radiant energy

a) Find the energy of a photon with a frequency of 5×10^{12} Hz.

$$E = hf = (6.63 \times 10^{-34}\ \text{J s}) \times (5 \times 10^{12}\ 1/\text{s}) = 33.2 \times 10^{-22}\ \text{J} = 3.32 \times 10^{-21}\ \text{J}$$

b) What is energy of a photon with a wavelength of 2×10^{-6} meters?

$$E = \frac{hc}{L} = \frac{(6.63 \times 10^{-34}\ \text{J s}) \times (3 \times 10^{8}\ \text{m/s})}{2 \times 10^{-6}\ \text{m}} = 9.95 \times 10^{-20}\ \text{J}$$

8) Solar Powered Toys Observe the demonstration of a toy that operates with power from a solar cell.

Does the solar toy work when an incandescent bulb shines on its solar cell? Does it work when a glow coil shines on its solar cell? Explain your observations.

The solar toy runs when photons of visible light are absorbed by the solar cell. The absorbed photons eject electrons from atoms in the cell. These electrons generate an electric current. However, the photons of infrared light from the glow coil do not have enough energy per photon to eject an electron from an atom.

9) Solar Cells Try to operate the solar-powered toy by shining different radiant light sources onto the solar cells.

a) First, predict which light sources will operate the solar cells. Then check your predictions by shining each light source onto the solar cells.

	Prediction	Answer
1) microwaves	_____	**__No__**
2) visible light	_____	**__Yes__**
3) ultraviolet light	_____	**__Yes__**

b) Why do some light sources operate the solar cells, while other sources do not?

Microwaves do not have enough energy per photon to operate the solar cells. Waves of visible light and ultraviolet light have shorter wavelengths and higher frequencies than microwaves. Visible light photons and ultraviolet light photons have enough energy per photon to produce a flow of electrons. Certain solar cells have been manufactured to be capable of responding to infrared radiation.

c) Explain why solar cells are also called photoelectric cells.

Solar cells produce an electric current when their atoms absorb photons of energy equal to or greater than the frequency required to eject electrons from their atoms in the cell. The electrons form an electric current. Photons produce electric current, thus the name "photoelectric."

d) Suppose that a solar cell produces an electric current only when it absorbs photons with at least 3.0×10^{-19} joules of energy per photon.

What is the maximum wavelength of electromagnetic radiation that will make the solar cell work? What type of electromagnetic radiation is this?

$$E = \frac{hc}{L} \qquad L = \frac{hc}{E}$$

$$= \frac{(6.63 \times 10^{-34}\ \text{J s}) \times (3 \times 10^{8}\ \text{m/s})}{3.0 \times 10^{-19}\ \text{J}} = 6.63 \times 10^{-7}\ \text{m}$$

This is a photon of visible red light.

e) Group Discussion Question: If visible light has enough energy per photon to make the solar cell operate, which other forms of electromagnetic radiation do you think would operate the solar cell? Which forms of electromagnetic radiation would not work?