Lesson 3 - Light is Energy

We know light when we see it but it is hard to explain to someone what light is. Theories about the nature of light have been discussed and debated for centuries. Some scholars were completely in the dark about the nature of light when they proposed objects appeared to us only after particles streamed from our eyes and landed on that object. In this section, you will read about how light is created and how fast it travels. As you read, think about how light and sound are different and how they are similar.

Light is Both Electric and Magnetic

Ancient Greek philosophers believed light streamed from our eyes as tiny particles. They were wrong about particles of light shooting from your eyes but they were on the right track about particles causing light. We now know tiny charged particles vibrating within atoms create light. The tiny charged particles are usually negatively charged electrons inside an atom. If electrons are forced to vibrate very fast they create a light wave. Since vibrating electric particles, usually electrons, creates light waves a unique wave is created that is both electric and magnetic. These waves are electromagnetic waves (EM waves).

A light wave is an EM wave that is vibrating between 430 trillion to 700 trillion times in one second. The sensors in the retina of your eye are activated by this range of energy and allow you to see light in all the colors of the rainbow.

Comparing Light Waves and Sound Waves - How They are Alike

Like sound and all other waves, light waves carry energy from one place to another. And like sound waves, light and all EM waves have a wavelength and a frequency. For example, red light has a wavelength about 100 times smaller than the thickness of a human hair (0.000000630 meters or 630 nanometers). The frequencies (rates of vibrations) for EM waves can be very high. Violet light has the highest frequency of light we can see. Waves of violet light vibrate 700 trillion times in one second (7 x 1014 Hertz).

How They are Different

What makes light waves different from sound waves is their ability to transfer energy without traveling through matter, like air, water, or wood. Unlike sound, which needs a medium to transfer energy, light and all other EM waves can travel through completely empty space (often called a vacuum).

They can travel through empty space because each wave is caused by a vibrating electron that creates vibrating magnetic and electric fields that reinforce each other's movement. The strengths of the fields are perfectly balanced and are at right angles -- or perpendicular-- to each other. Since the electric and magnetic fields of all EM waves are perpendicular to each other they are classified as transverse waves.

Speed of Light
Have you ever watched a fireworks show and seen the explosion before you heard it? This is because light and sound are two different types of waves. Light waves travel about one million times faster than sound waves. Light, and all other electromagnetic waves, travel at the same speed, about 300 million meters per second in the vacuum of outer space. This is as about 670 million miles per hour!

Speed Limit of the Universe
Even though all electromagnetic waves travel at this same speed , it is often called the "speed of light." Since nothing is known to travel faster than the "the speed of light," it is often called the universe's ultimate speed limit. As quickly as you can blink your eye, light can travel from New York to Los Angeles and back to New York again. If a light beam could circle the Earth, it would go around the Earth 7.5 times in one second. Light from the sun travels the 150 million kilometers to Earth in about 8 minutes.

Slowing Down Light
Light slows down when it has to move through matter like air, water, or glass. In air, light moves at about 99 percent of its speed in space. In water, light slows to about 74 percent of its top speed. Optical fiber, used in computer and communication cables, reduces light's speed to 70 percent of its speed in space. This is still fast enough to circle the Earth five times in a second.

SIMULATION ACTIVITY: Waves Interference
(Adapted from PhET teacher lesson idea by Kristi Goodwin [link to http://phet.colorado.edu/teacher_ideas/view-contribution.php?contribution_id=418&referrer=)

- Load the simulation located at:
- http://phet.colorado.edu/simulations/sims.php?sim=Wave_Interference
- Click on **Run Now!**
- Modify the java applet as instructed and answer the questions below.

Wave Interference Simulator: Light Wave Simulator

1. Click on the tab at the top of the page titled "Light."
2. Click "Show graph" and "Add detector."
3. What happens when you vary the amplitude? What happens if you put the amplitude at 0?
4. Increase the amplitude to midpoint. Find the pentagon-shaped color slider above the Amplitude slider. Move the slider along the color bar. What happens to the wavelength and frequency in the graphs and on the screen as you change the color?
5. What can you say about the difference in colors?
6. Click on measuring tape. Measure the wavelength red light on the screen and on the graph. Record the measurement. Are they the same? Measure the wavelength of blue light on the screen and on the graph. How do these measurements compare to the red light measurements?

7. Now add a slit. Move the slit back and forth. What happens as the slit gets closer and farther from the source? Does changing the color affect this?
8. Now set the slit width at 1050 and the barrier location at 2590. Use the target on the detector to compare the amplitudes on each side of the barrier. Compare red light to blue light. Be sure to move the detector around on the front side of the barrier and then move it around the backside of the barrier.

Diffraction
We often think of light traveling in a straight line and usually it does. That is why shadows are created when something blocks light. Or why you normally cannot see around corners unless the light is reflected or refracted by some means. But there is another way to bend light.

Diffraction [link to http://en.wikipedia.org/wiki/Diffraction]is the bending of light and other waves around barriers or through openings. The amount of diffraction depends on the wavelength of the wave compared to the size of the barrier or opening.

The size of the opening compared to the wave's wavelength is very important in diffraction. A shorter wavelength diffracts less through a big opening. Even the sharpest shadows are fuzzy around the edges because of the interference patterns created by diffraction. Figure 2 shows the diffraction caused interference patterns when light passes through a pinhole.

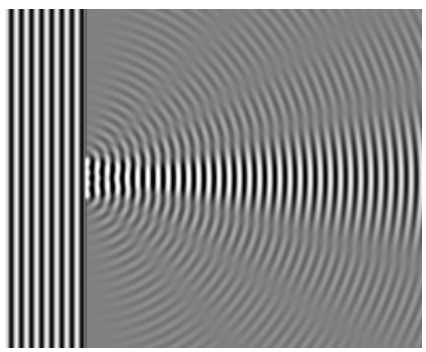

Figure 2

The longer the wave compared with the obstruction, the greater the diffraction. AM Radio waves are very long, ranging from 180 meters to 6000 meters. As a result, they bend easily around objects that would block shorter waves. The wavelength of most FM radio waves is from 3 to 4 meters, and therefore they do not bend as much. This is one of the reasons AM radio broadcasts carry over longer distances than FM stations.

Electromagnetic Spectrum
Imagine doing this experiment. You use a prism and sunlight to create a spectrum. Knowing sunlight warms anything it touches; you place a thermometer in each color of the spectrum to see which color warms it the most. While finishing with red and writing your results in your lab book, you accidentally move the thermometer off to the side of

the red band of the spectrum, where there is no visible light. When you glance back at the thermometer, you can't believe your eyes, but the temperature is now at its highest point. What is this invisible "light" next to the red light in the spectrum? How can it produce more heat than the visible light? An astronomer in England, named William Herschel, did this experiment over two hundred years ago.

The invisible "light" rays that Herschel encountered are called infrared rays, and like visible light waves, are one of many different types of electromagnetic waves (EM waves). The entire range of EM waves is called the electromagnetic spectrum. Figure 1of the electromagnetic spectrum shows different electromagnetic waves arranged in order of their wavelength.

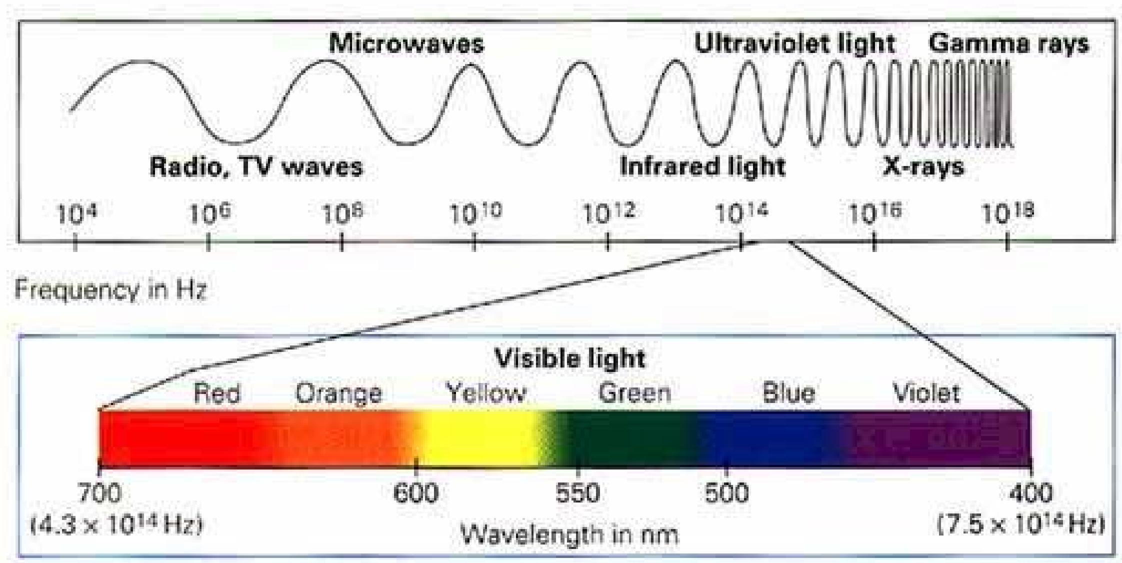

Figure 1

Different Size but Same Speed

All electromagnetic waves are not the same size but they all travel at the same speed in a vacuum, the speed of light or 300 million meters in one second. How can long waves travel as fast as short waves? It is similar to two people of different heights walking the same speed. A shorter person takes smaller steps (shorter wavelengths) but at a faster pace (higher frequency). A taller person takes larger steps (longer wavelength) but at a slower pace (lower frequency). For EM waves to travel at the same speed their wavelength must decrease as their frequency increases. Figure 2of the electromagnetic spectrum shows different electromagnetic waves arranged in order of their wavelength and frequency.

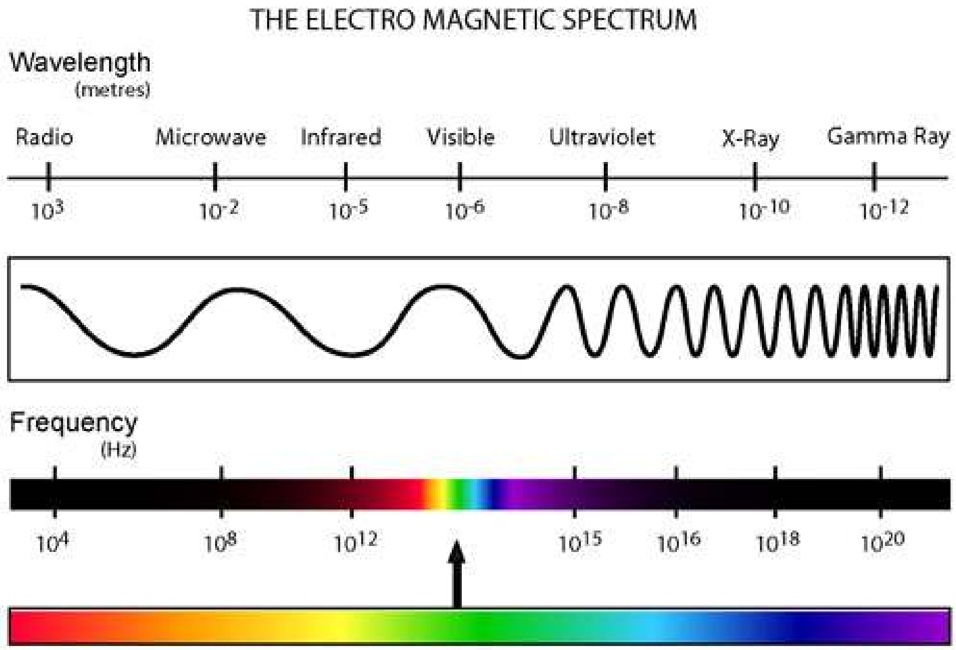

Figure 2

Invisible Spectrum

Electromagnetic waves whose wavelengths are longer than red and shorter than violet are invisible to our eyes. The invisible part of the spectrum makes up about 99 percent of the measured electromagnetic spectrum (visible light is the remaining one percent). Electromagnetic waves can have any frequency or wavelength from zero to infinity but to keep things simple (sort of) we will review regions of the spectrum with the most practical importance.

Radio Waves

Radio waves have some of the longest wavelengths (mostly over one meter) and lowest frequencies (550,000 Hertz) on the electromagnetic spectrum. Even though radio waves carry the music you hear on the radio, they are not sound waves. Radio stations broadcast radio waves that are modulated (modified or changed). This means that the original music, which was first converted to an electrical signal, is superimposed on the radio wave so that the radio wave “carries” the sound signal.

Television and Radio

Television broadcasts are also transmitted by radio waves, but these waves carry picture signals as well as sound. Encoding pictures and sound together is much more complicated so TV stations broadcast over higher frequencies and use a broader range of radio frequencies.

Microwaves

Microwaves have a higher frequency and a shorter wavelength than radio waves. Microwaves are electromagnetic waves with wavelengths from 1 meter to 1 mm. One of their most common uses is in microwave ovens. When you switch on the microwave oven, the microwaves strike molecules of water in the food. The energy from the microwave causes the water molecules to twist back and forth, causing the temperature of the food to increase.

Infrared Waves

Infra- means "below" in Latin. So infrared means "below red." Infrared waves are longer than red light waves but shorter than microwaves. You cannot detect infrared waves with your eyes but you sense them with your skin as heat. Because of their higher frequency, infrared waves carry more energy than radio waves or microwaves. This higher energy causes molecules in your skin and other substances to vibrate more rapidly. The vibrations produce heat and cause the temperature of your skin or other materials to rise.

Ultraviolet Light

Ultra- means beyond in Latin, so ultraviolet (UV) light is beyond violet light on the electromagnetic spectrum. With a higher frequency and shorter wavelength than visible light, ultraviolet light carries more energy than visible light. Overexposure to UV light can cause sunburn, wrinkles, damage to your eyes, and skin cancer. If you apply sun block lotion with a high SPF (Sun Protection Factor) and wear sunglasses that block out UV light, you can limit the damage to your body caused by UV light.

X Rays

X-rays are electromagnetic waves with a higher frequency, shorter wavelength, and more energy than ultraviolet waves. Because of their high frequency and greater energy, X-rays can penetrate most matter. Dense matter, like metal, absorbs and blocks X-rays. The calcium, which is a metal, in bones absorbs X-rays better than skin or muscle. For this reason, X-rays are used to take pictures of your bones. The X-rays that are not absorbed by your bones strike the photographic film and turn it black. Images of your bones appear as bright areas on the film.

Gamma Rays

Gamma rays have some of the shortest wavelengths and highest frequencies of all EM waves. Again, a higher frequency creates a higher energy wave, which can penetrate through more objects. As with X-rays, small amounts of gamma rays are harmless but overexposure can be deadly. Some radioactive substances and certain nuclear reactions produce gamma rays. When used in controlled conditions, some radioactive substances (such as cobalt 60) are used to produce gamma rays for medical treatments. Gamma rays can be used to kill cancer cells in radiation therapy.

Questions:

True or False Questions

1. Energy emitted by vibrating electric charges is carried by electromagnetic waves. [Answer: True]
2. Electromagnetic heat waves are called ultraviolet waves. [Answer: False]
3. Ultraviolet waves are responsible for sunburn. [Answer: True]

Multiple Choice Questions

1. Which of the following is NOT an electromagnetic wave?
   A) Sound
   B) Radio
   C) Infrared
   D) Light
   E) X ray

2. Heat lamps give off mostly
   A) radio waves.
   B) microwaves.
   C) infrared waves.
   D) ultraviolet waves.
   E) X rays.

3. Compared to the speed of light in air, the speed of light in water is
   A) slower.
   B) faster.
   C) the same.

4. What is the ultimate source of electromagnetic waves?
   A) TV antennas
   B) Vibrating charged particles within atoms
   C) Vibrating molecules
   D) Radio sets

5. Compared to the wavelength of ultraviolet waves, the wavelength of infrared waves is
   A) shorter.
   B) longer.
   C) the same.

6. Compared to the velocity of radio waves, the velocity of visible light waves is
   A) slower.
   B) faster.
   C) the same.

7. Which of the following is fundamentally different from the others?

A) sound waves.
B) X rays
C) Gamma rays
D) Light waves
E) Radio waves

8. The main difference between a radio wave and a light wave is its
   A) speed.
   B) wavelength.
   C) Both of the above
   D) None of the above

9. The main difference between a radio wave and a sound wave is its
   A) frequency.
   B) wavelength.
   C) energy.
   D) amplitude.
   E) basic nature.

10. When a wave passes through an opening, some of the wave is bent. This phenomenon is called
   A) reflection.
   B) refraction.
   C) interference.
   D) diffraction.
   E) polarization.

For further study

Explore the American Physical Society webpage on light.
http://www.physicscentral.com/discover/light.cfm