What Is Light?
Most of us see and feel light almost every moment of our lives. We even feel the warmth of the sun on our skin, which is an effect of infrared light. We are very familiar with light, but how much do we understand about what light really is?

Like sound, light is a type of energy. Experiments with light show that it sometimes behaves in unexpected ways. Therefore, it is difficult to describe all of the properties of light with a single model. The two most common models describe light either as a wave or as a stream of particles.

EXPERIMENTING WITH LIGHT
In 1801, the English scientist Thomas Young devised an experiment to test the nature of light. He passed a narrow beam of red light through two small openings. The light was focused onto a screen on the other side of the openings. He found that the light produced a striped pattern of light and dark bands on the screen. This striped pattern is an interference pattern. Interference patterns form when waves interfere with each other.

1. Red light of a single wavelength passes through two tiny slits.
2. The light waves diffract as they pass through the slits.
3. The diffracted light waves interfere both constructively and destructively.
4. An interference pattern is created. The constructive interference results in the bright bands of light, and the destructive interference results in the dark bands.

KEY IDEAS
As you read this section, keep these questions in mind:
• What two models do scientists use to describe light?
• What is the electromagnetic spectrum?
• How can electromagnetic waves be used?
THE WAVE MODEL OF LIGHT

Because the light in Young’s experiment produced interference patterns, Young concluded that light consists of waves. This model, called the wave model, describes light as transverse waves. 

Light waves, like all transverse waves, can be described by their amplitude, wavelength, and frequency. Light waves are also called electromagnetic waves because they consist of changing electric and magnetic fields.

The wave model of light explains how light waves interfere with one another. It also explains other behaviors of light, such as reflection, refraction, and diffraction. The wave model of light is still used to explain many of the basic properties of light and light’s behavior. However, the wave model cannot explain all of light’s behavior.

By the early 1900s, physicists were making observations that could not be explained with the wave model of light. For example, when light strikes a piece of metal, electrons may fly off the metal’s surface. Scientists found that in some experiments, dim blue light could cause electrons to fly off the metal plate. Scientists also found that very bright red light could not cause electrons to leave the plate.

According to the wave model, bright light has more energy than dim light. This is because the waves in bright light have greater amplitude than the waves in dim light. Therefore, dim light should not be able to knock electrons off the plate, but bright light should. The wave model cannot explain the observations in the metal plate experiment.

2. Identify According to the wave model of light, what does light consist of?

3. Describe What are three behaviors of light that the wave model can explain?

4. Describe According to the wave model of light, which of the lights should cause electrons to fly off the plate?
PARTICLE MODEL OF LIGHT

Scientists proposed a new model of light to explain the effects of light striking a metal plate. According to this model, the energy in light is contained in individual particles called photons. This model of light is called the particle model.

Photons of different colors of light have different amounts of energy. A photon of blue light carries more energy than a photon of red light. Therefore, blue light can cause electrons to fly off a metal plate, but red light cannot.

Photons are considered particles, but they are not like particles of matter. Photons do not have mass. Instead, they contain only energy. Unlike the energy in a wave, the energy in a photon is located in a specific area. A beam of light is a stream of photons. The more photons in the beam, the brighter the light appears.

Which Model of Light Is Correct?

Some scientists think that light has a dual nature. This means that light can behave both as waves and as particles. Some effects, such as the interference of light, are more easily explained with the wave model. In contrast, the particle model better explains how light can knock electrons off metal plates. It also explains why light can travel across empty space without a medium.

Most scientists currently accept both the wave model and the particle model of light. The model they use depends on the situation they are studying. In many cases, using either the wave model or the particle model of light gives good results.

<table>
<thead>
<tr>
<th>Property of light</th>
<th>Model that best explains the property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light can reflect, refract, and diffract when it interacts with matter.</td>
<td></td>
</tr>
<tr>
<td>Light can travel through a vacuum.</td>
<td></td>
</tr>
<tr>
<td>Light produces interference patterns.</td>
<td></td>
</tr>
<tr>
<td>Light can cause electrons to fly off of pieces of metal.</td>
<td></td>
</tr>
</tbody>
</table>

Reading Check

5. Describe According to the particle model, what does light consist of?

Critical Thinking

6. Infer Which beam of light contains more photons, a dim blue beam or a bright red beam? Explain your answer.

7. Identify Fill in the blank spaces in the table.
How Can We Describe the Properties of Light?

Whether modeled as a particle or as a wave, light is a form of energy. Like all waves, light waves carry energy. In the particle model of light, each photon of light carries a specific, small amount of energy. The amount of energy in a photon of light is related to the frequency of the light waves.

For example, ultraviolet photons have about twice as much energy as red light photons. Therefore, the frequency of ultraviolet waves is about twice the frequency of red light waves. The table below gives examples of the wavelengths, wave frequencies, and photon energies of different types of electromagnetic waves.

<table>
<thead>
<tr>
<th>Type of electromagnetic wave</th>
<th>Wavelength (m)</th>
<th>Wave frequency (Hz)</th>
<th>Photon energy (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrared</td>
<td>$1.33 \times 10^{-6}$</td>
<td>$2.25 \times 10^{14}$</td>
<td>$1.5 \times 10^{-19}$</td>
</tr>
<tr>
<td>Visible light</td>
<td>$6.67 \times 10^{-7}$</td>
<td>$4.5 \times 10^{14}$</td>
<td>$3.0 \times 10^{-19}$</td>
</tr>
<tr>
<td>Ultraviolet</td>
<td>$3.33 \times 10^{-7}$</td>
<td>$9.0 \times 10^{14}$</td>
<td>$6.0 \times 10^{-19}$</td>
</tr>
</tbody>
</table>

Remember that all forms of electromagnetic radiation, including visible light, travel at the same speed in a vacuum. This speed, the speed of light, is represented by the letter $c$. The speed of light is about $3 \times 10^{8}$ m/s.

Light can travel through a vacuum, but it can also travel through mediums such as air, water, and glass. However, light travels more slowly in a medium than in a vacuum. The table below shows the approximate speed of light in different mediums.

<table>
<thead>
<tr>
<th>Medium</th>
<th>Speed of light (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>$2.997047 \times 10^8$</td>
</tr>
<tr>
<td>Ice</td>
<td>$2.29 \times 10^8$</td>
</tr>
<tr>
<td>Water</td>
<td>$2.25 \times 10^8$</td>
</tr>
<tr>
<td>Glass</td>
<td>$1.97 \times 10^8$</td>
</tr>
<tr>
<td>Diamond</td>
<td>$1.24 \times 10^8$</td>
</tr>
</tbody>
</table>

BRIGHTNESS AND INTENSITY

Remember that intensity is the rate at which the energy in a wave travels through a specific area of space. For sound waves, the intensity of the wave affects how loud a sound is. For visible light waves, the intensity of the wave affects how bright a light looks. The higher the intensity, the brighter the light.
INTENSITY AND DISTANCE

Intensity depends on the number of photons per second that pass through a certain area of space. The intensity of light decreases as distance from the light source increases. This is because the light spreads out as it travels. □

The image below shows why intensity decreases as distance increases. The light from a light bulb travels outward in all directions. The light waves spread out into spheres that move away from the bulb. Each sphere is called a wave front. The total amount of energy in each wave front is the same. However, as the wave front gets bigger, that energy is spread out over a larger area. As a result, the intensity decreases.

What Is the Electromagnetic Spectrum?

There are many different types of electromagnetic radiation. Each type has a different set of wavelengths. Humans eyes can detect only visible light, which has wavelengths between about $4 \times 10^{-7}$ and $7 \times 10^{-7}$ m. Visible light is only one kind of electromagnetic radiation.

The electromagnetic spectrum is all of the different wavelengths of electromagnetic radiation. Although all electromagnetic waves have some similarities, each type of radiation also has unique properties.

**Electromagnetic Spectrum**

Shorter wavelengths  |  Longer wavelengths

Gamma rays | X rays | Ultraviolet rays | Visible light | Infrared waves | Microwaves | Radio waves

Looking Closer

11. Explain Why does the intensity of a light decrease as the distance to the light increases?

12. Identify On the figure, circle the area at which intensity is lowest.

13. Compare Which type of electromagnetic radiation has the shortest wavelengths?
RADIO WAVES

Radio waves have the longest wavelengths of any kind of electromagnetic radiation. The wavelength of a radio wave may be several kilometers. This part of the electromagnetic spectrum includes TV signals and AM and FM radio signals.

Radar is a system that uses radio waves to find the locations of objects. Police use radar to monitor the speed of vehicles. Air traffic control towers at airports use radar to find the locations of aircraft. Antennas at the control tower emit radio waves. The waves bounce off the aircraft and return to a receiver at the tower.

Airports use radar to track the locations of airplanes.

MICROWAVES

Electromagnetic waves that have wavelengths in the range of centimeters are known as microwaves. Microwaves are used to carry communication signals over long distances. Space probes use microwaves to transmit signals back to Earth.

Microwaves are also used in cooking. Microwaves are easily transmitted through air, glass, paper, and plastic. However, the water, fat, and sugar molecules in food all absorb microwaves. The absorbed microwaves can cook food. The energy from the absorbed waves causes water and other molecules to vibrate. The energy of these vibrations spreads throughout the food and warms it.

The signals from cellular phones are microwaves.

READING CHECK

14. Identify Which kind of electromagnetic radiation has the longest wavelengths?

15. Define What is radar?

16. Describe How long are the wavelengths of microwaves?

17. Compare Which type of signal has a shorter wavelength, a phone signal or a radio signal?
INFRARED AND ULTRAVIOLET LIGHT

Electromagnetic waves that have wavelengths slightly longer than wavelengths of red visible light are infrared waves. You cannot see it, but infrared light from the sun warms you. Devices that are sensitive to infrared light can produce images of objects that emit infrared waves. For example, remote infrared sensors on weather satellites can record temperature changes in the atmosphere and track cloud movements.

The invisible light that lies just beyond violet light makes up the ultraviolet (UV) part of the spectrum. Nine percent of the energy emitted by the sun is ultraviolet light. UV light has higher energy and shorter wavelengths than visible light does. It has enough energy to pass through clouds and give you a sunburn. Sunscreens absorb or block UV light and can prevent sunburns. UV light also kills germs and can be used to disinfect objects.

X RAYS AND GAMMA RAYS

Beyond the ultraviolet part of the spectrum are waves called X rays and gamma rays. X rays have wavelengths less than $10^{-8}$ m. Gamma rays have the highest energies and have wavelengths as short as $10^{-14}$ m.

Passing X rays through the body makes an X-ray image of bones. Most X rays pass right through, but bones and other tissues absorb a few. The X rays that pass through the body to a photographic plate produce an image.

X rays are useful tools for doctors, but they can also be dangerous. Both X rays and gamma rays have very high energies. Exposure to X rays and gamma rays may kill or damage living cells, which can cause cancer. However, gamma rays can also be used to treat cancer by killing the diseased cells.
**Section 2 Review**

**SECTION VOCABULARY**

<table>
<thead>
<tr>
<th><strong>intensity</strong></th>
<th>in physical science, the rate at which energy flows through a given area of space</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>photon</strong></td>
<td>a unit or quantum of light; a particle of electromagnetic radiation that has zero rest mass and carries a quantum of energy</td>
</tr>
<tr>
<td><strong>radar</strong></td>
<td>radio detection and ranging, a system that uses reflected radio waves to determine the velocity and location of objects</td>
</tr>
</tbody>
</table>

1. **List**  Give two examples of how radar is used.

   ________________________________________________________________

   ________________________________________________________________

2. **Explain**  Why do scientists use two different models of light?

   ________________________________________________________________

   ________________________________________________________________

3. **Describe**  Give one observation that supports the wave model of light and one observation that supports the particle model of light.

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   ________________________________________________________________

   ________________________________________________________________

4. **Identify**  Which photons have more energy, photons of radio waves or photons of visible light? Explain your answer.

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

5. **Apply Concepts**  Why should you use sunscreen even on cloudy days?

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

6. **Identify**  List the seven main kinds of electromagnetic radiation in order from highest frequency to lowest frequency.

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________