



# Light

## Waves in Empty Space

On a clear night you might see the Moon shining brightly, as in **Figure 16**. Like other waves, light waves can travel through matter, but light waves are different from water waves and sound waves. Light from the Moon has traveled through space that contains almost no matter. You can see light from the moon, distant stars, and galaxies because light is an electromagnetic wave. **Electromagnetic waves** are waves that can travel through matter or through empty space.

**The Speed of Light** Have you ever seen a movie where a spaceship travels faster than the speed of light? In reality, nothing travels faster than the speed of light. In empty space, light travels at a speed of about 300,000 km/s. Light travels so fast that light emitted from the Sun travels 150 million km to Earth in only about eight and a half minutes.

However, when light travels in matter, it interacts with the atoms and molecules in the material and slows down. As a result, light travels fastest in empty space, and travels slowest in solids. In glass, for example, light travels about 197,000 km/s.

**Wavelength and Frequency of Light** Can you guess how long a wavelength of light is? Wavelengths of light are usually expressed in units of nanometers (nm). One nanometer is equal to one billionth of a meter. For example, green light has a wavelength of about 500 nm, or 500 billionths of a meter. A light wave with this wavelength has a frequency of 600 trillion Hz.

### as you read

#### What You'll Learn

- **Identify** the properties of light waves.
- **Describe** the electromagnetic spectrum.
- **Describe** the types of electromagnetic waves that travel from the Sun to Earth.
- **Explain** human vision and color perception.

#### Why It's Important

Light is necessary for vision. Other electromagnetic waves are used in devices such as cell phones and microwave ovens.

#### Review Vocabulary

**spectrum:** a range of values or properties

#### New Vocabulary

- electromagnetic waves
- electromagnetic spectrum
- infrared waves
- ultraviolet waves

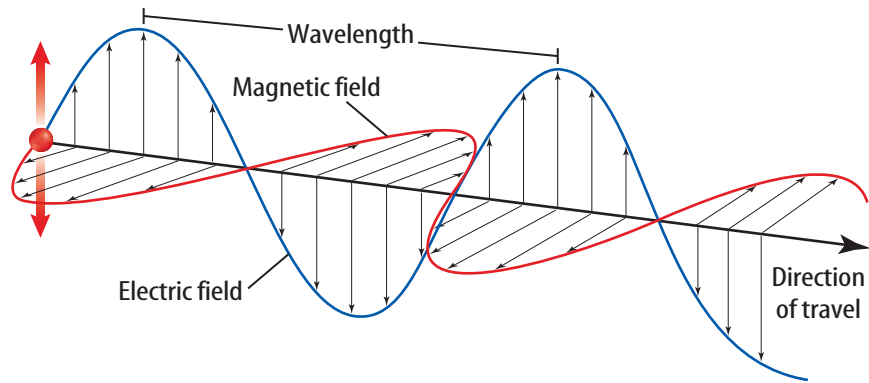


**Figure 16** The Moon reflects light from the Sun. These light waves travel through space to reach your eyes.

**Infer** whether a sound wave could travel from the Moon to Earth.



**Figure 17** A light wave is a transverse wave that contains vibrating electric and magnetic fields. The fields vibrate at right angles to the direction the wave travels.



## Properties of Light Waves

Light waves, and all electromagnetic waves, are transverse waves. Recall that a wave on a rope is a transverse wave that causes the rope to move at right angles to the direction the wave is traveling. An electromagnetic wave traveling through matter also can cause matter to move at right angles to the direction the wave is moving.

An electromagnetic wave contains an electric part and a magnetic part, as shown in **Figure 17**. Both parts are called fields and vibrate at right angles to the wave motion. The number of times the electric and magnetic parts vibrate each second is the frequency of the wave. The wavelength is the distance between the crests or troughs of the vibrating electric or magnetic parts.

**Intensity of Light Waves** The intensity of waves is a measure of the amount of energy that the waves carry. For light waves, the intensity determines the brightness of the light. A dim light has lower intensity because the waves carry less energy. However, as you move away from a light source, the energy spreads out and the intensity decreases.

**Reading Check** What determines the intensity of light waves?

## The Electromagnetic Spectrum

Light waves aren't the only kind of electromagnetic waves. In fact, there is an entire spectrum of electromagnetic waves, as shown in **Figure 18**. The **electromagnetic spectrum** is the complete range of electromagnetic wave frequencies and wavelengths. At one end of the spectrum the waves have low frequency, long wavelength, and low energy. At the other end of the spectrum the waves have high frequency, short wavelength, and high energy. All of the waves—from radio waves to visible light to gamma rays—are the same kind of waves. They differ from each other only by their frequencies, wavelengths, and energy.



### Topic: Lasers

Visit [in7.msscience.com](http://in7.msscience.com) for Web links to information about why the intensity of light emitted by lasers makes them useful.

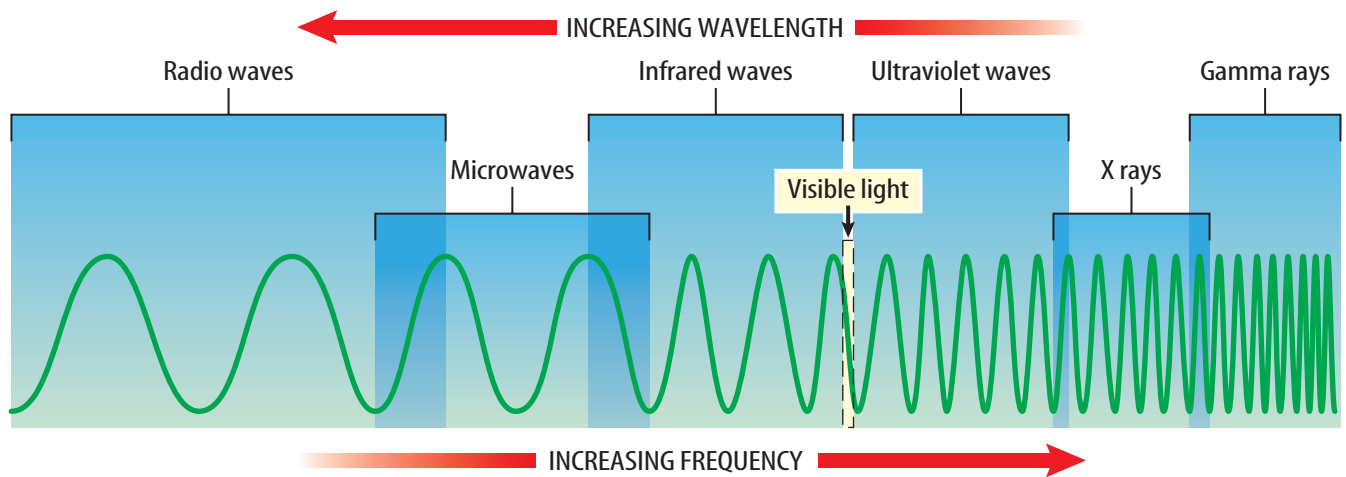
**Activity** Write a short paragraph describing three uses for lasers.



### Indiana Academic Standard Check

**7.3.19:** Explain that human eyes respond to a narrow range of wavelengths of the electromagnetic spectrum.

What range of wavelengths in the electromagnetic spectrum does the human eye detect?



**Radio Waves and Microwaves** The waves that carry radio and television signals to your home are radio waves. The wavelengths of radio waves are greater than about 0.3 meters. Some are even thousands of meters long. The shortest radio waves are called microwaves. These waves have a wavelength between about 0.3 meters and 0.001 meters. You use these waves when you cook food in a microwave oven. Microwaves are also used to transmit information to and from cell phones.

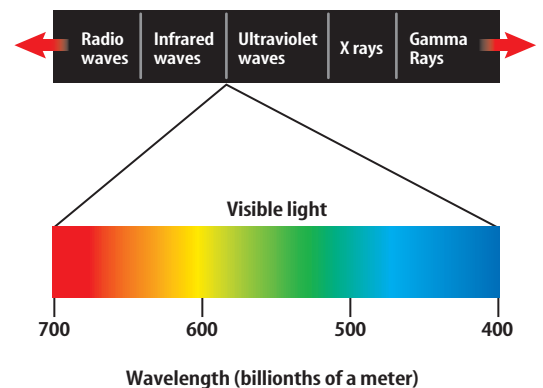
**Infrared Waves** When you use a remote control, infrared waves travel from the remote to a receiver on your television. **Infrared waves** have wavelengths between 0.001 meters and 700 billionths of a meter. All warm bodies emit infrared waves. Because of this, law enforcement officials and military personnel sometimes use special night goggles that are sensitive to infrared waves. These goggles can be used to help locate people in the dark.

**Visible Light and Color** The range of electromagnetic waves between 700 and 400 billionths of a meter is special, because that is the range of wavelengths people can see. Electromagnetic waves in this range are called visible light. **Figure 19** shows how different wavelengths correspond to different colors of light. White light, like the light from the Sun or a flashlight, is really a combination of different colors. You can see this by using a prism to separate white light into different colors. When the light passes through the prism, the different wavelengths of light are bent different amounts. Violet light is bent the most because it has the shortest wavelength. Red light is bent the least.

**Reading Check** What range of wavelengths of electromagnetic waves can people see?

**Figure 18** Electromagnetic waves have a range of frequencies and wavelengths called the electromagnetic spectrum. **Infer** how the frequency of electromagnetic waves change as their wavelength decreases.

**Figure 19** Visible light waves are electromagnetic waves with a narrow range of wavelengths from about 700 to 400 billionths of a meter. The color of visible light waves depends on their wavelength. **Determine** the color of the visible light waves with the highest frequency.





## Mini LAB

### Separating Wavelengths

#### Procedure

1. Place a **prism** in sunlight. Adjust its position until a color spectrum is produced.
2. Place the prism on a **desk-top**. Dim the lights and shine a **flashlight** on the prism.
3. Shine a **laser pointer** on the prism.

**WARNING:** Do not shine the laser pointer into anyone's eyes.


#### Analysis

1. Determine whether sunlight and the light emitted from the flashlight contain more than one wavelength.
2. Determine whether the light emitted from the laser pointer contains more than one wavelength.



### Indiana Academic Standard Check

**7.3.11:** Explain that . . . only a tiny fraction of . . . the Sun's energy arrives as light . . . consisting of . . . ultraviolet radiation.

 Which waves from the Sun are blocked by Earth's atmosphere?

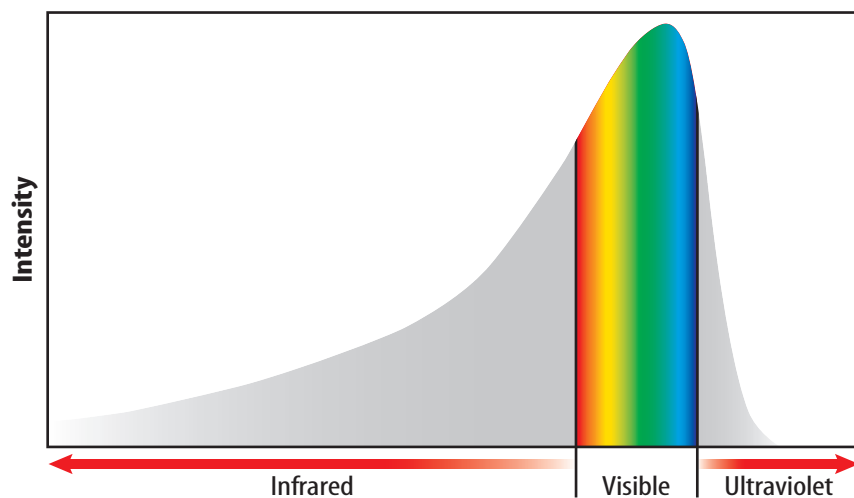
**Figure 20** Almost all of the electromagnetic waves emitted by the Sun are infrared waves, visible light, and ultraviolet waves.

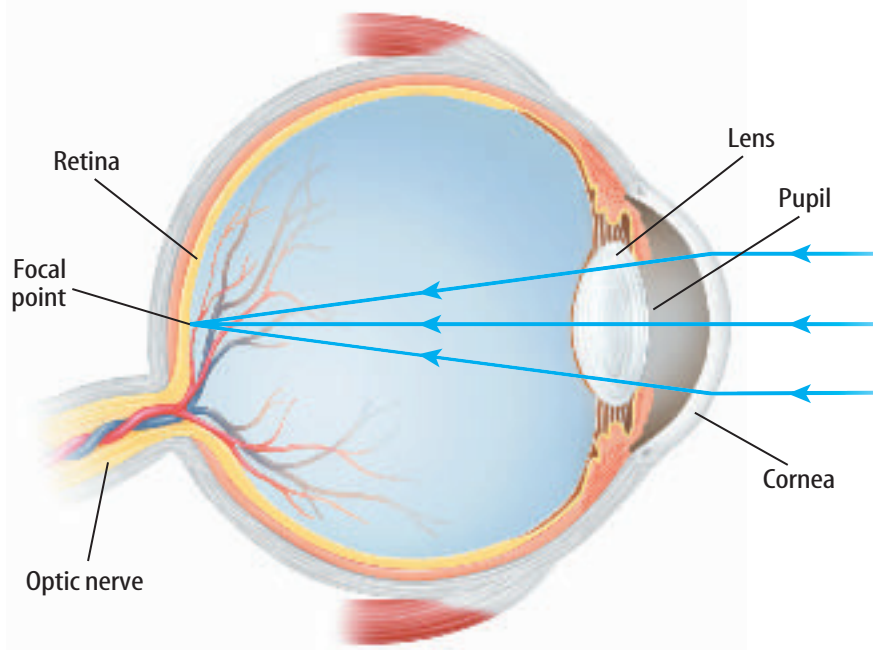
**Ultraviolet Waves** Electromagnetic waves with wavelengths between about 400 billionths and 10 billionths of a meter are **ultraviolet waves**. These wavelengths are shorter than those of visible light. Ultraviolet waves carry more energy than visible light waves. Sunlight that reaches Earth's surface contains a small fraction of ultraviolet waves. These waves can cause sunburn if skin is exposed to sunlight for too long. Excessive exposure to ultraviolet waves can permanently damage skin, and in some cases cause skin cancer. However, some exposure to ultraviolet waves is needed for your body to make vitamin D, which helps form healthy bones and teeth.

**X Rays and Gamma Rays** The electromagnetic waves with the highest energy, highest frequency, and shortest wavelengths are X rays and gamma rays. If you've ever broken a bone, the doctor probably took an X ray to examine the injured area. X rays are energetic enough to pass through the body. X rays pass through soft tissues, but are blocked by denser body parts, such as bones. This enables images to be made of internal body parts. Gamma rays are even more energetic than X rays. One use of gamma rays is in the food industry to kill bacteria that might increase the rate of spoilage of food.

**Electromagnetic Waves from the Sun** Most of the energy emitted by the Sun is in the form of ultraviolet, visible, and infrared waves, as shown in **Figure 20**. These waves carry energy away from the Sun and spread out in all directions. Only a tiny fraction of this energy reaches Earth. Most of the ultraviolet waves from the Sun are blocked by Earth's atmosphere. As a result, almost all energy from the Sun that reaches Earth's surface is carried by infrared and visible electromagnetic waves.

**Electromagnetic Waves from the Sun**





**Figure 21** The cornea and the lens focus light waves that enter your eye so that a sharp image is formed on the retina. Special cells in the retina cause signals to be sent to the brain when they are struck by light.

## The Eye and Seeing Light

You see an object when light emitted or reflected from the object enters your eye, as shown in **Figure 21**. Light waves first pass through a transparent layer called the cornea (KOR nee uh), and then the transparent lens. The lens is flexible and changes shape to enable you to focus on objects that are nearby and far away, as shown in **Figure 22**. However, sometimes the eye is unable to form sharp images of both nearby and distant objects, as shown in **Figure 23** on the next page.

**Why do objects have color?** When light waves strike an object, some of the light waves are reflected. The wavelengths of the light waves that are reflected determine the object's color. For example, a red rose reflects light waves that have wavelengths in the red part of the visible spectrum. The color of objects that emit light is determined by the wavelengths of light that they emit. A neon sign appears to be red because it emits red light waves.

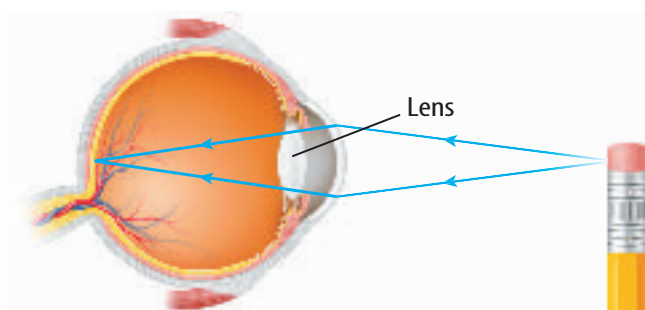


### Indiana Academic Standard Check

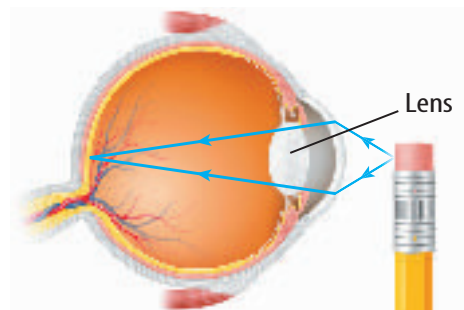
**7.3.20:** Describe something that can be "seen" when light waves emitted or reflected by it enter the eye . . .

✓ Which parts of the eye focus the light waves that enter the eye?

**Figure 22** The shape of the lens changes when you focus on nearby and distant objects.



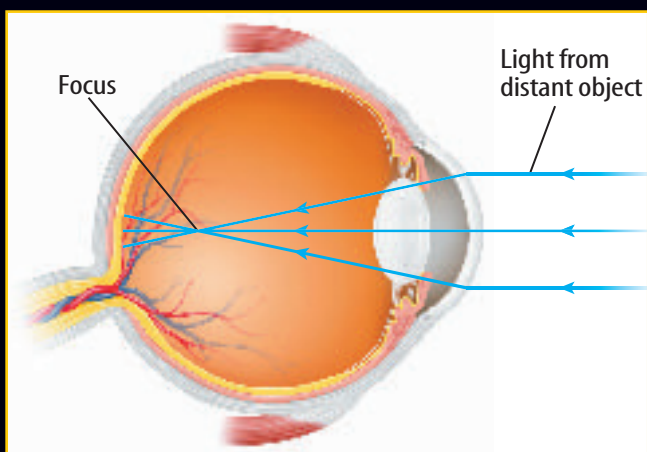
The lens becomes flatter when you focus on a distant object.



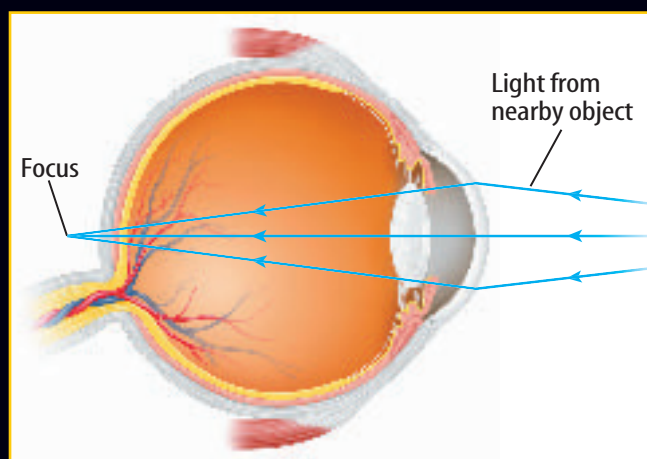
The lens becomes more curved when you focus on an object nearby.

**Figure 23**

In a human eye, light waves pass through the transparent cornea and the lens of the eye. The cornea and the lens cause light waves from an object to be focused on the retina, forming a sharp image. However, vision problems result when a sharp image is not formed on the retina. The two most common vision problems are farsightedness and nearsightedness.



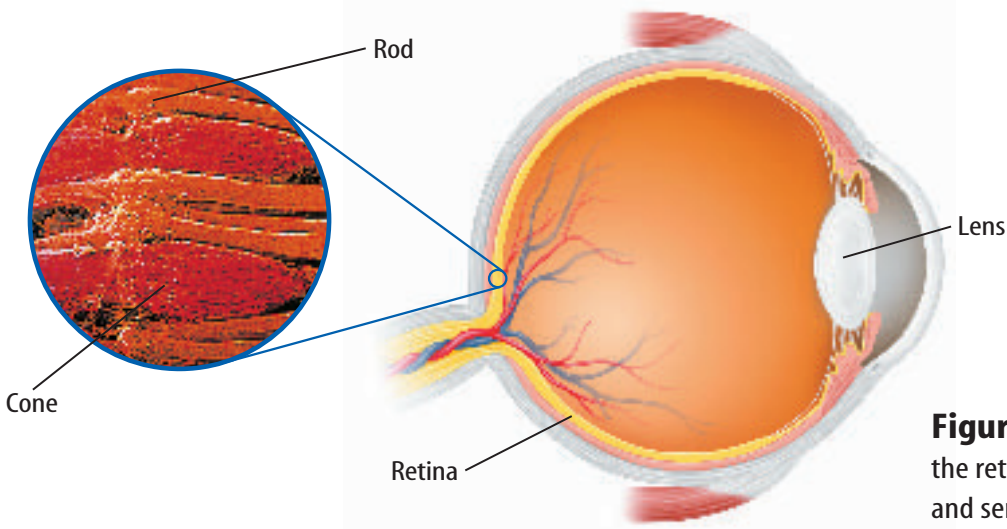
◀ **Nearsightedness** A person that is nearsighted can see nearby objects clearly, but distant objects seem blurry. Nearsightedness results if the eyeball is too long, so that light waves from far away objects are brought to a focus before they reach the retina. This vision problem usually is corrected by wearing glasses or contact lenses. Laser surgery also is used to correct nearsightedness by reshaping the cornea.



◀ **Farsightedness** A farsighted person can see distant objects clearly, but cannot focus clearly on nearby objects. Farsightedness results if the eyeball is too short, so light waves from nearby objects have not been brought to a focus when they strike the retina.

▶ Farsightedness also can be corrected by wearing glasses. People commonly become farsighted as they get older because of changes in the lens of the eye. Laser surgery sometimes is used to correct farsightedness.





**Figure 24** Rod and cone cells in the retina of the eye detect light and send signals to the brain.

**Rod and Cone Cells** The retina contains over a hundred million light-sensitive cells called rods and cones, shown in **Figure 24**. Rod cells are sensitive to dim light, and cone cells enable you to see colors. There are three types of cone cells. One type is sensitive to red and yellow light, another type is sensitive to green and yellow light, and the third type is sensitive to blue and violet light. The combination of the signals sent to the brain by all three types of cone cells forms the color image that you see.

## section 3 review

### Summary

#### Light and Electromagnetic Waves

- Light waves are electromagnetic waves. These waves travel through empty space at a speed of 300,000 km/s.
- Electromagnetic waves are transverse waves made of vibrating electric and magnetic fields.
- Radio waves, infrared waves, visible light, ultraviolet waves, X rays, and gamma rays form the electromagnetic spectrum.
- Most of the electromagnetic waves emitted by the Sun are infrared waves, visible light, and ultraviolet waves.

#### Color and Vision

- The color of an object is the color of the light the object emits or reflects.
- You see an object when light waves emitted or reflected by the object enter your eye and strike the retina.
- Rod cells and cone cells in the retina of the eye are light-sensitive cells that send signals to the brain when light strikes them.

### Self Check

1. **Identify** the electromagnetic waves with the longest wavelengths and the electromagnetic waves with the shortest wavelengths.
2. **Describe** the difference between radio waves, visible light and gamma rays.
3. **Compare and contrast** the rod cells and the cone cells in the retina of the human eye.
4. **Explain** why most of the electromagnetic waves emitted by the Sun that strike Earth's surface are infrared and visible light waves.
5. **Think Critically** Explain why the brightness of the light emitted by a flashlight decreases as the flashlight moves farther away from you.

### Applying Skills

6. **Make a Concept Map** Design a concept map to show the sequence of events that occurs when you see a blue object.
7. **Recognize Cause and Effect** Why does light travel faster through empty space than it does through matter?