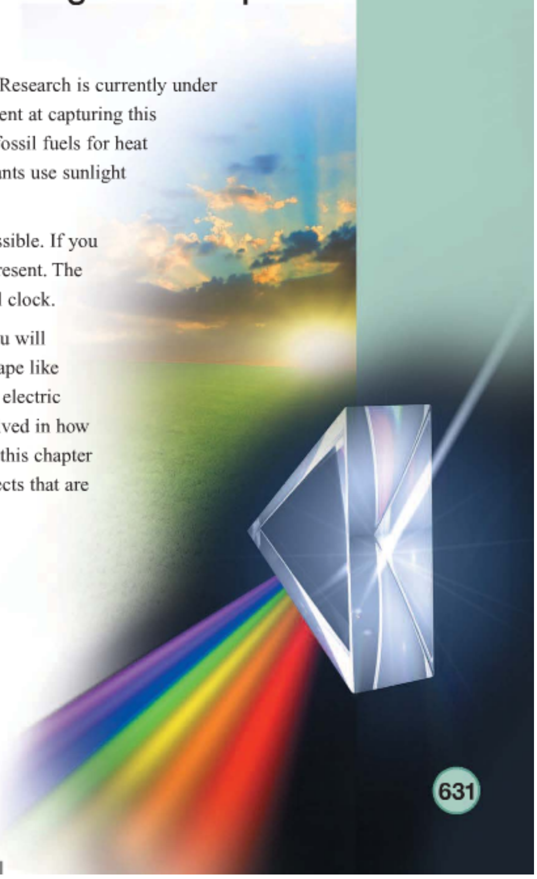
Chapter 25

Light and Optics

Earth's most important source of energy is the Sun. Research is currently under way to develop technologies that will be more efficient at capturing this renewable energy resource. In time, we might not need to depend on fossil fuels for heat and electricity. The Sun is also our most important source of light. Plants use sunlight to grow. How do humans use light?

For starters, we need light to see. In complete darkness, sight is impossible. If you can see at all in a dark room, it's because a small amount of light is present. The light might be coming from under a door or from the glow of a digital clock.

In this chapter, you will learn about light's properties. As you read, you will discover that light is unusual. For example, it doesn't have mass or shape like matter. Light is produced as a result of a disturbance in a magnetic or electric field. Fortunately, the complex topic of light is colorful! Light is involved in how you see color, and how color is produced on paper or a TV screen. In this chapter you will also learn how light is used to enhance vision and to see objects that are miniscule or astronomically far away!



Key Questions

- ✔ *What makes a color of light unique but also similar to an X-ray?*
- ✔ *How do printers and TV screens produce color?*
- ✔ *How do lenses take advantage of the properties of light?*

631

Next

25.1 Properties of Light

Whether you are looking at the flame of a candle, a car, or this book, light brings information to your eyes. In fact, *seeing* means forming images in your mind from the light received by your eyes (Figure 25.1). What are the properties of this amazing thing called light?

Light is fast-moving energy

How fast is light? When you shine a flashlight on a wall, the light leaves your flashlight, travels to the wall, bounces off, and comes back to your eyes. You don't notice this happening because it happens very *fast*. Suppose the wall is 170 meters away. The light travels to the wall and back in about one-millionth of a second (0.000001 s). Sound travels much slower than light. If you shout, you will hear an echo one full second later from the sound bouncing off the wall and back to your ears. Light travels almost one million times faster than sound!

The speed of light, $c = 3 \times 10^8$ m/s The speed at which light travels through air is about 300 million meters per second. Light is so fast, it can travel around the entire Earth 7.5 times in one second. The *speed of light* is so important in physics that it is given its own symbol, a lowercase *c*. When you see this symbol in a formula, remember that it means the speed of light (c = 300,000,000 m/s).

What are the other properties of light? **Light** is a form of electromagnetic energy. The properties of light are that it:

- travels extremely fast and over long distances;
- carries energy and information;
- has color;
- varies in intensity, which means it can be bright or dim;
- travels in straight lines; and
- bounces and bends when it comes in contact with objects.

VOCABULARY

light - a form of electromagnetic energy.

Figure 25.1: *This girl sees a page in her book when reflected light carries information about the page to her brain.*

SCIENCE FACT

Light Is Faster than Sound

You can use the speed of sound to estimate how far away a lightning strike has occurred.

When you see lightning, begin counting the seconds until you hear thunder. Divide the number of seconds you count by five. The result is an estimate of the distance in miles between where you are and where the lightning struck.

Most light comes from atoms

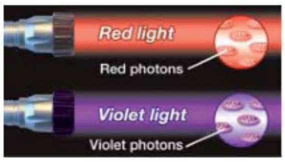
Light is produced by atoms Light is mostly produced by atoms when they release energy. For example, when you stretch a rubber band, you give the rubber band elastic energy. This energy, once released, could become the kinetic energy of a launched paper airplane. An atom's released energy produces light.

Incandescent light bulbs Atoms release light when they have extra energy. Adding heat is one way to give atoms extra energy. Making light with heat is called **incandescence**. Incandescent bulbs use electric current to heat a thin wire, or filament. Atoms in the filament convert electrical energy to heat and then to light. However, incandescent bulbs are not very efficient. Only a fraction of the energy of electricity is converted into light, and the rest becomes heat. But, some incandescent bulbs are designed and used to make heat (Figure 25.2).

Compact fluorescent light bulbs A more efficient type of electric light comes from compact fluorescent lamps, or CFLs (Figure 25.3). A CFL uses about 75 percent less energy, produces 75 percent less heat, and lasts 10 times longer than a standard incandescent bulb. For this reason, the U.S. Department of Energy recommends replacing incandescent bulbs with CFLs in schools, businesses, and homes.

Making light with fluorescence To make light, CFLs use high-voltage electricity to energize atoms of gas in the lamp. These atoms release the electrical energy directly as high-energy ultraviolet light (not heat), the same kind of light that causes sunburn. The ultraviolet light is absorbed by other atoms in a white coating on the inside surface of the bulb. This coating re-emits the energy (fluoresces) as white light that we can see in a process called **fluorescence**. Even with this two-step process, fluorescent lamps are still more efficient at producing light than incandescent bulbs.

Photons



Light energy comes in tiny wave bundles called **photons**. Each photon has its own energy. The energy of photons is seen as color. The lowest-energy photons we can see are dull red and the highest-energy photons are violet.

VOCABULARY

incandescence - a process that makes light with heat.

fluorescence - a process that makes light when the energy is supplied by electromagnetic radiation, often ultraviolet light.

photon - the smallest possible amount of light, in the form of a wave bundle.

Figure 25.2: *An incandescent bulb makes light by heating a metal filament.*

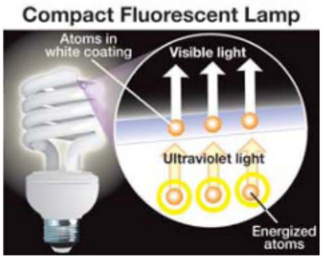


Figure 25.3: *How fluorescent light is produced.*

Color and energy

What is color?

Color is how we perceive the energy of light. All of the colors in the rainbow are light of different energies. As you learned on the previous page, red light has the lowest energy we can see, and violet light has the highest energy. As we move through the rainbow from red to yellow to blue to violet, the energy of the light increases. You can use this information to identify that the blue light from a gas flame has higher energy than the yellow-red light from a match (Figure 25.4).

White light

When all the colors of the rainbow are combined, we see light without *any* color. We call the combination of all colors **white light**. The light that is all around us most of the time is white light. Sunlight and the electric light in your home and school are examples of white light.

Energy, frequency, wavelength, and color

Energy and frequency are directly related properties of light. As with other waves, wavelength and frequency of light are inversely related (see the table below). Where wavelength is very small, frequency is extremely high. In fact, the wavelength of light is so small, it is measured in nanometers. One nanometer (nm) is one-billionth of a meter (1.0×10^{-9} m). And the frequency of light waves is so high that scientists use units of terahertz (THz) to measure light waves. One THz is a trillion Hz (1,000,000,000,000 Hz). Now, look at the table to see how color corresponds to the energy, frequency, and wavelength of light. Note: Frequency and wavelength are often given as ranges rather than the single values shown here.

Table 25.1: Wavelengths and frequencies of light

Energy	Color	1×10^{-6} m	Wavelength (nanometers)	Frequency (THz)
Low	Red		650	462
	Orange		600	500
	Yellow		580	517
	Green		530	566
	Blue		470	638
High	Violet		400	750

VOCABULARY

color - the sensation created by the different energies of light falling on your eye.

white light - visible light containing an equal mix of all colors.

Figure 25.4: *High-energy flames such as the ones from a gas stove produce blue light. Fire flames are lower energy and produce yellow-red light.*

What kind of wave is light?

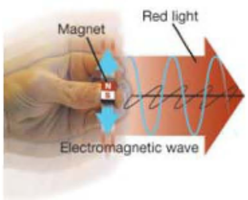
Light comes from electricity and magnetism

A water wave is an oscillation of the surface of water. A sound wave is an oscillation of air. What is oscillating in a light wave? The answer is electricity and magnetism. Imagine you have two magnets. One hangs from a string and the other is in your hand. If you move the magnet in your hand back and forth, you can make the magnet on the string sway back and forth, too (Figure 25.5). How does the oscillation of one magnet get to the other one? In Chapter 17 you learned that magnets create an invisible magnetic field around themselves. When you move a magnet in your hand back and forth, you make a change in the magnetic field. The changing magnetic field causes the other magnet to move. In a similar way, the force between two electric charges is carried by an *electric field*.

Electromagnetic waves

Any change in an electric or magnetic field travels at the speed of light. If you could shake your magnet (or electric charge) back and forth *100 million times per second*, you would make an electromagnetic wave. In fact, it would be an FM radio wave at 100 million Hz (100 MHz). An **electromagnetic wave** is a traveling oscillation in the electric and magnetic fields.

The hard way to make red light



If you could shake the magnet up and down *462 trillion times per second*, you would make waves of red light. Red light is a traveling oscillation (wave) in the electric and magnetic fields with a frequency of about 462 THz. From the previous page, what else do you know about red light?

Oscillations of electricity or magnetism create light waves

Anything that creates an oscillation of electricity or magnetism also creates electromagnetic waves. If you repeatedly switch electricity on and off in a wire, the oscillating electricity makes an electromagnetic wave. This is how radio towers make radio waves. Electric currents oscillate up and down the metal towers and create electromagnetic waves of the correct frequency to carry radio signals.

VOCABULARY

electromagnetic wave - a wave of electricity and magnetism that travels at the speed of light. Light is an electromagnetic wave.

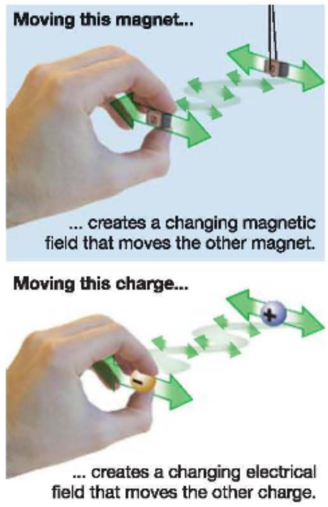
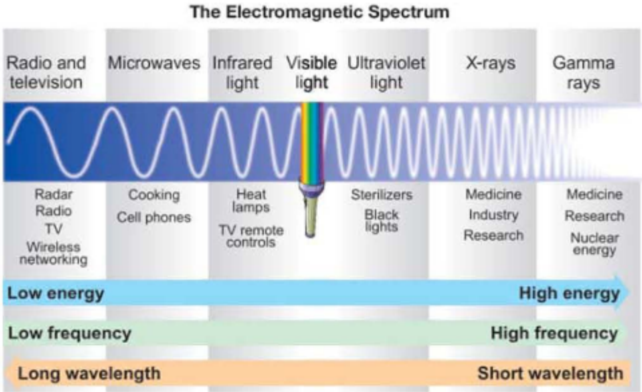


Figure 25.5: *Magnets influence each other through the magnetic field. Charges influence each other through the electric field.*

The electromagnetic spectrum

Waves in the electromagnetic spectrum The entire range of electromagnetic waves, including all possible frequencies, is called the **electromagnetic spectrum**. The electromagnetic spectrum includes radio waves, microwaves, infrared light, ultraviolet light, X-rays, and gamma rays. As you can see from the chart below, we use electromagnetic waves for many technologies.

The Electromagnetic Spectrum



Properties of electromagnetic waves You can see that visible light is a small group of frequencies in the middle of the spectrum between infrared and ultraviolet light. The rest of the spectrum is invisible for the same reason you cannot see the magnetic field between two magnets. The energies are either too low or too high for the human eye to detect. Visible light includes only the electromagnetic waves with the range of energy that can be detected by the human eye. Some insects and animals can see or detect other frequencies, including infrared (snakes) and ultraviolet light (bees and birds).

VOCABULARY

electromagnetic spectrum - the entire range of electromagnetic waves, including all possible frequencies, such as radio waves, microwaves, X-rays, and gamma rays.

CHALLENGE

Who discovered that white light contains all colors? How was the discovery made? When was it made? This famous scientist is mentioned in this book but not in connection with light!

25.1 Section Review

1. Which of the following is NOT a property of light?
   a. Light is a form of matter less dense than air.
   b. Light travels in straight lines.
   c. Light can be different colors.
   d. Light has different intensities and can be bright or dim.
2. If a room were completely dark, could you see your hand? Explain.
3. What is the source of most light?
4. What is white light?
5. The highest pitch sound you can hear has a wavelength of 1.7 centimeters. How does the wavelength of this sound compare to the size of the items shown in Figure 25.6?
6. Waves of orange light have a length of only 0.0000006 meter.
   a. What is this wavelength in nanometers?
   b. How does the size of this wavelength compare to the wavelength of green light?
7. One hertz equals one cycle per second. Write the frequency of red light (462 THz) in units of cycles per second.
8. The range of wavelengths for one color of light is 570 to 590 nm. What is the color of this light?
9. Which electromagnetic wave has less energy than visible light and more energy than radio waves?
   a. microwaves
   b. ultraviolet light
   c. gamma rays
   d. X-rays
10. How are all electromagnetic waves similar? How are they different?
11. How does infrared light compare to a gamma ray in terms of energy, frequency, wavelength, and use in technology?

SOLVE IT!

The speed of light is calculated as frequency multiplied by wavelength (the same as for other waves). Suppose you make light with a frequency of 600 THz.

a) What is the wavelength of this light?

b) Describe what color the light would appear to your eye.

You will have to use scientific notation to solve this problem with your calculator. If necessary, ask your teacher or a friend for help.

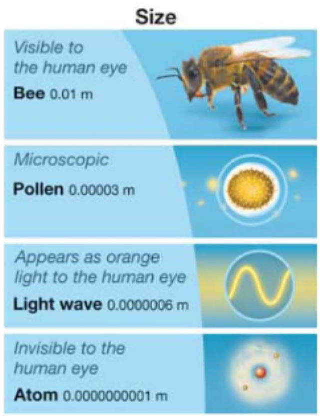


Figure 25.6: *Question 5.*