

10.1 Properties of Light

Every time you “see,” you are using **light**. You can’t see *anything* in complete darkness! Whether you are looking at a light bulb, or a car, or this book, light brings information to your eyes. In fact, the very act of “seeing” means receiving light and forming images in your mind from the light received by your eyes. This chapter is about light—where it comes from, its many and useful properties, and how it is related to color.

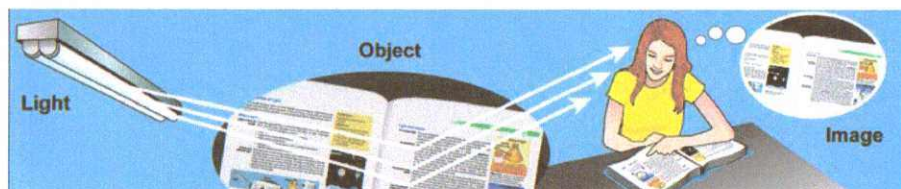
What is light?

Light is a form of energy Light, like sound and heat, is a form of energy. Our understanding of light starts with what light does and what its properties are (Figure 10.1). We know that:

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

Seeing with reflected light

What happens when you “see” this page? Light in the room reflects off the page and into your eyes. The reflected light carries information about the page that your brain uses to make a mental picture of the page. You see because light in the room *reflects* from the page into your eyes. If you were sitting in a perfectly dark room with no light, you would not be able to see this page at all because the page does not give off its own light. *We see most of the world by reflected light.*



VOCABULARY

light - a form of energy that travels at 300,000 km/s and includes all the colors that can be seen by the human eye.

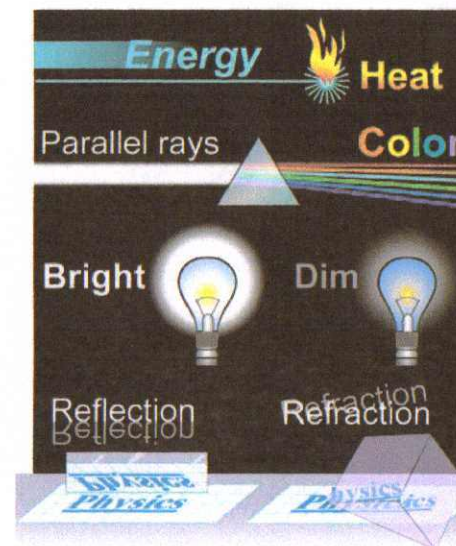


Figure 10.1: Some words and properties that are associated with light. What words do you use to describe light?



Most light comes from atoms

The electric light For most of human history, people relied on the Sun, Moon, and fire to provide light. Thomas Edison's electric light bulb (1879) changed our dependence on fire and daylight forever. The electric light is one of the most important inventions in the progress of human development.

Light is produced by atoms Whether in an electric bulb or in the Sun, light is mostly produced by atoms. Here's an analogy. When you stretch a rubber band you give the rubber band elastic energy. You can use that energy to launch a paper airplane. In this case, the energy is released as kinetic energy of the flying airplane. In this same way, *atoms release energy by giving off light.*

Incandescent light bulbs In order to get light *out* of an atom, you must put some energy *into* the atom first. One way to do this is with heat. Making light with heat is called **incandescence**. Incandescent bulbs use electric current to heat a thin wire (filament). Atoms in the filament convert electrical energy to heat and then to light. Unfortunately, incandescent bulbs are not very efficient. Only a fraction of the energy of electricity is converted into light. Most of the energy becomes heat (Figure 10.2). Some incandescent bulbs are actually designed to make heat.

Fluorescent light bulbs A better kind of electric light is from a fluorescent bulb (Figure 10.3). Fluorescent bulbs are used in schools, businesses, and homes because they are much more efficient than incandescent bulbs. Compared with a standard incandescent bulb, you get four times as much light from a fluorescent bulb for the same amount of electrical energy.

How fluorescent bulbs make light To make light, fluorescent bulbs use high-voltage electricity to energize atoms of gas in the bulb. These atoms release the electrical energy directly as light (not heat), in a process called **fluorescence**. The atoms in a fluorescent bulb give off high-energy ultraviolet light, 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 as white light that we can see. Even with the two-step process, fluorescent bulbs are still four times more efficient at producing light than incandescent bulbs.

VOCABULARY

incandescence - a process that makes light with heat.

fluorescence - a process that makes light directly from electricity.

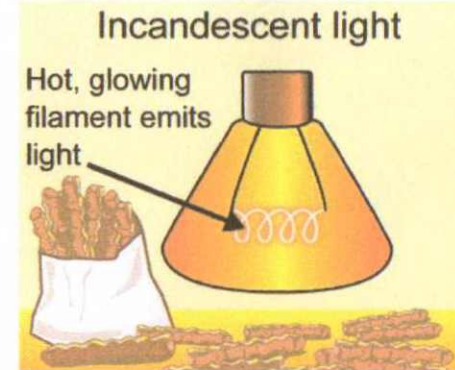


Figure 10.2: An incandescent bulb makes light by heating a metal filament.

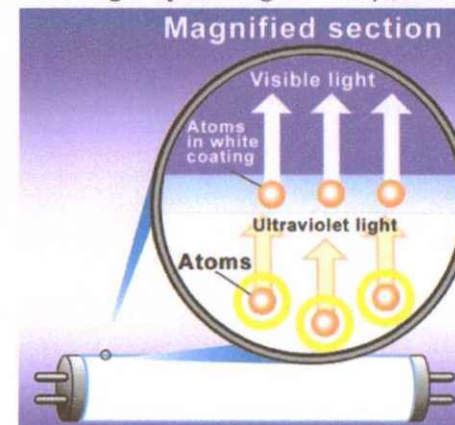
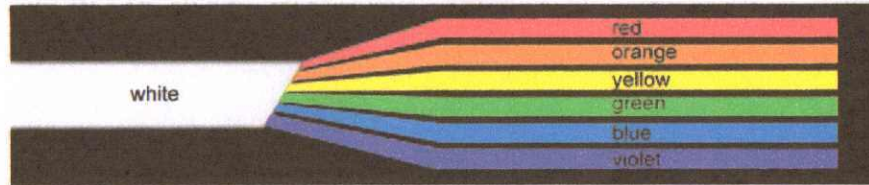


Figure 10.3: How fluorescent bulbs generate light.

Color and energy

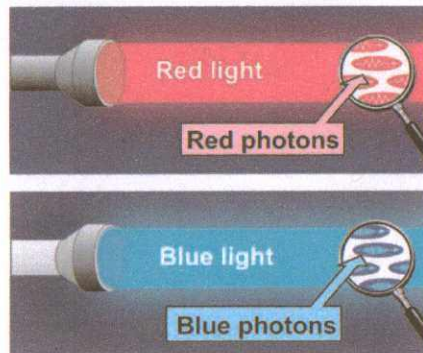
White light When all the colors of the rainbow are combined, we see light without *any* color. We call the combination of all colors **white light**. The light that is all around us most of the time is white light. The light from the Sun and the light from most electric lights is white light.



What is color? Not all light has the same energy. **Color** is how we perceive the energy of light. This definition of color was proposed by Albert Einstein. All of the colors in the rainbow are light of different energies. Red light has the lowest energy we can see, and violet light the highest energy. As we move through the rainbow from red to yellow to blue to violet, the energy of the light increases.

Color and energy What do we mean when we talk about the energy of light? Think about the hot, blue flame from a gas stove compared to the orange flame of a match. The hot gas flame has more energy than the cooler flame of the match. The light from a gas flame is blue (high energy) and the light from a match is red-orange (low energy) (Figure 10.4).

Photons



Just as matter is made of atoms, light energy comes in tiny wave-bundles called **photons**. In some ways, photons act like jellybeans of different colors. Each photon has its own color (energy), no matter how you mix them up. The lowest-energy photons we can see are dull red and the highest-energy photons are blue-violet.

VOCABULARY

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

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

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

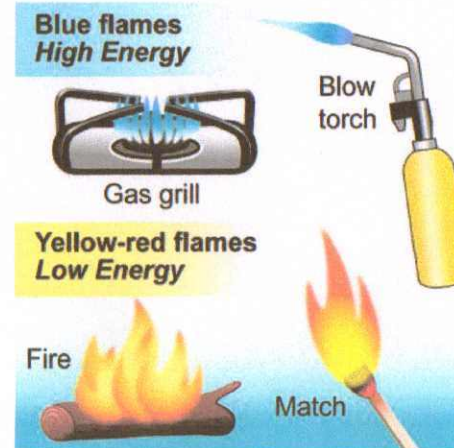


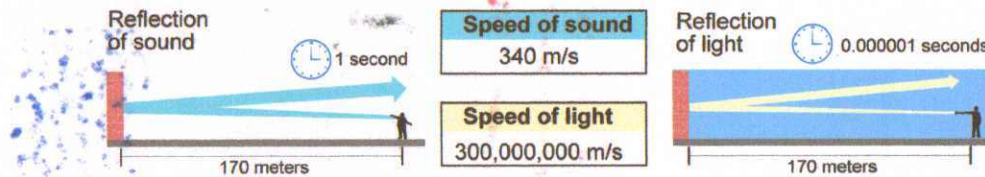
Figure 10.4: High-energy flames such as the ones from a gas grill produce blue light. Fire flames are lower energy and produce reddish-yellow light.



The speed of light

Comparing the speeds of sound and light

Think about what happens when you shine a flashlight on a wall that is far away. You don't see a time delay as the light leaves your flashlight, travels to the wall, bounces off, and comes back to your eyes. But that is exactly what happens. You don't notice because it happens so *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 a 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 1/2 times in 1 second. The *speed of light* is so important in physics that it is given its own symbol, a lower case *c*. When you see this symbol in a formula, remember that it means the speed of light ($c = 300,000,000$ m/s.)

Why you hear thunder after you see lightning

The speed of light is so fast that when lightning strikes a few miles away, we hear the thunder several seconds after we see the lightning. At the point of the lightning strike, the thunder and lightning are simultaneous. But just a mile away from the lightning strike, the sound of the thunder is already about 5 seconds behind the flash of the lightning. You can use this information to calculate how far you are away from a thunderstorm (see the sidebar at right).

Light is faster than sound

The speed of light is about 300 million meters per second or 186,000 miles per second. At 15 °C, the speed of sound is about 340 meters per second or one mile every five seconds. You can use the speed of sound to determine how far away a lightning strike has occurred.

When you see lightning, begin counting seconds until you hear thunder. Divide the number of seconds you count by 5. The result is the distance in miles between where you are and where the lightning struck.



The wavelength and frequency of light

Wavelength of light The wavelength of visible light is very small. For example, waves of orange light have a length of only 0.0000006 meter. Because the wavelength of light is so small, scientists use **nanometers**. One nanometer (nm) is one billionth of a meter (0.000000001 m). Figure 10.5 shows the size of a light wave relative to other small things. Thousands of wavelengths of red light would fit in the width of a single hair on your head!

Frequency of light The frequency of light waves is very high. For example, red light has a frequency of 460 trillion, or 460,000,000,000,000 cycles per second. To manage these large numbers, scientists use units of terahertz (THz) to measure light waves. One THz is a trillion Hz (1,000,000,000,000 Hz).

Wavelength, frequency, color, and energy Like other waves, the wavelength and frequency of light are inversely related. As frequency increases, wavelength decreases. Red light has a lower frequency and longer wavelength than blue light. Blue light has a higher frequency and shorter wavelength than red light.

Energy	Color	Wavelength (nanometers)	Frequency (THz)
Low  High	Red	650	462
	Orange	600	500
	Yellow	580	517
	Green	530	566
	Blue	470	638
	Violet	400	750

As you can see from the table above, energy and frequency are directly related. The higher the frequency, the higher the energy. Since color is related to energy, the table also shows the relationships between color, frequency, and wavelength.

VOCABULARY

nanometer - a unit of length equal to one billionth of a meter (0.000000001 m).

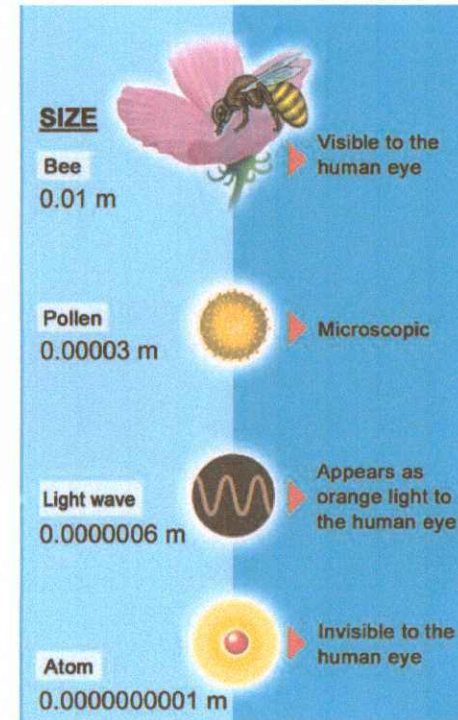
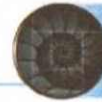


Figure 10.5: The sizes of some objects compared to the wavelength of a light wave.



What kind of wave is light?

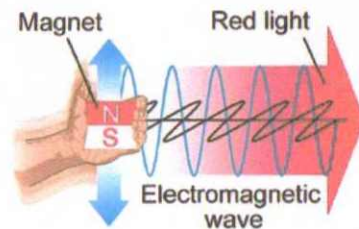
Light comes from electricity and magnetism

A sound wave is an oscillation of air. A water wave is an oscillation of the surface of water. 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 wave the magnet in your hand back and forth, you can make the magnet on the string sway back and forth (Figure 10.6). How does the oscillation of one magnet get to the other one? In Chapter 8 you learned that magnets create an invisible magnetic field around them. When you move a magnet in your hand back and forth, you make a change in the magnetic field. The changing magnetic field makes the other magnet move. In a similar way, the force between two electric charges is carried by an *electric field*.

Electromagnetic waves

Any change in the electric or magnetic field travels at the speed of light. If you could shake your magnet (or 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 field.

The hard way to make red light



If you could shake the magnet up and down 450 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 450 THz.

Oscillations of electricity or magnetism create light waves

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

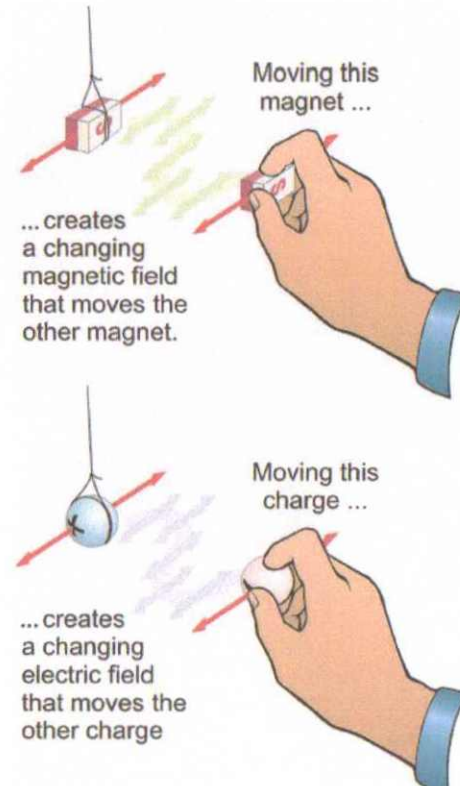
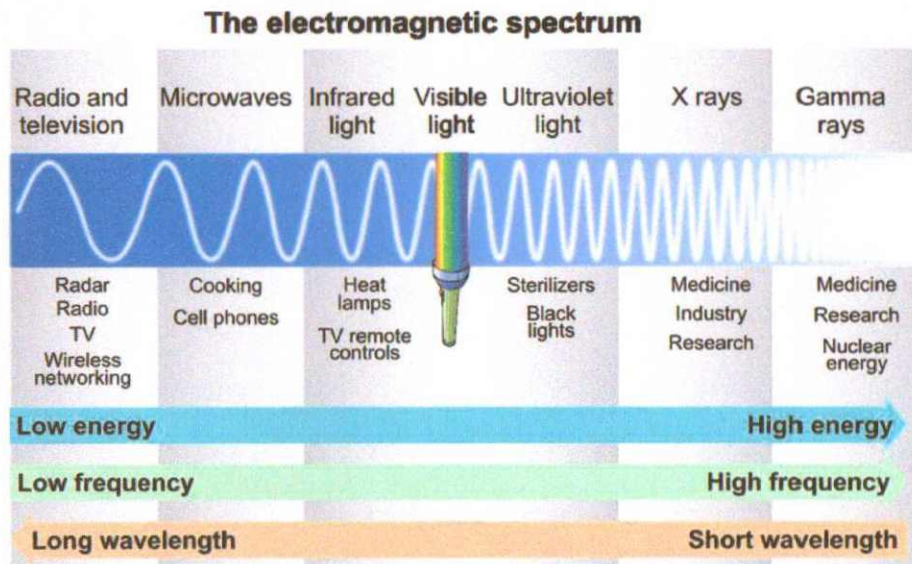


Figure 10.6: Magnets influence each other through the magnetic field. Charges influence each other through the electric field.

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 all kinds of human technologies.



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. 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 other frequencies, including some infrared and some ultraviolet light.

VOCABULARY

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

TECHNOLOGY

X-rays

X-rays are high-energy electromagnetic waves used in medicine and industry.



The wavelength range is from about 10 nanometers to about 0.001 nm (or 10-trillionths of a meter). When you get a medical X-ray, the film darkens where bones are because calcium and other elements in your bones absorb the X-rays before they reach the film. X-rays show the extent of an injury such as a broken bone.