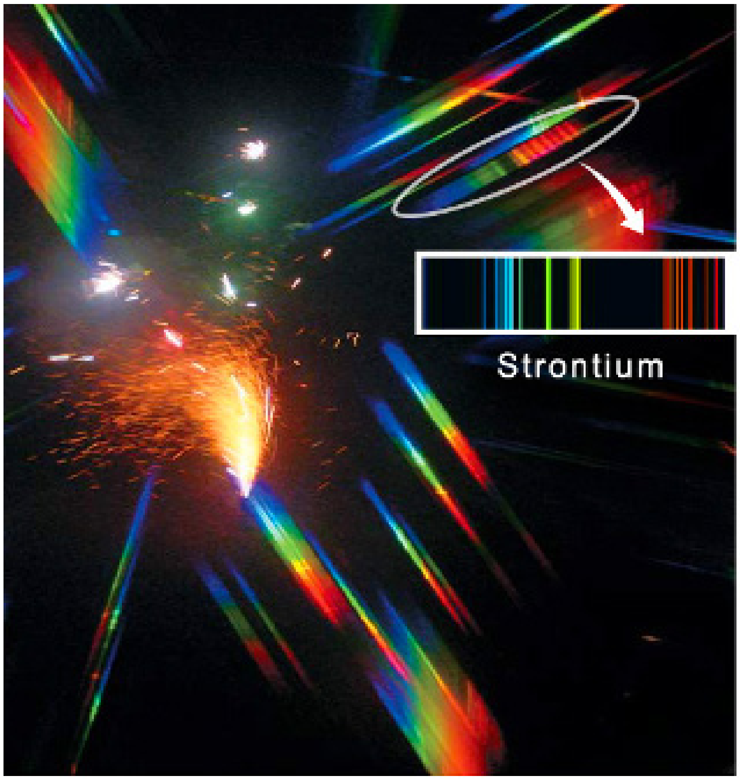


Chapter 4

Subatomic Particles

THE MAIN IDEA

Atoms are made of electrons, protons, and neutrons

4.5 Light Is a Form of Energy

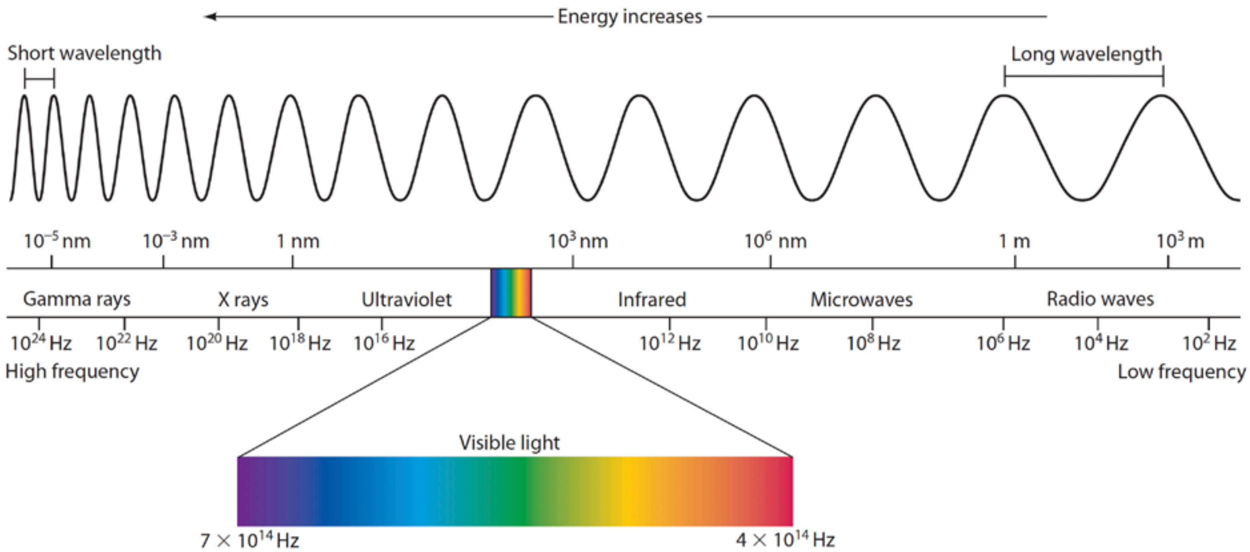
Modern models of the atom were developed by scientists to explain how atoms emit light. To help you understand and appreciate these models, it is good to review the basic concepts regarding the nature of light.

From physics we learn that surrounding every charged particle is an *electric field*, which is a region of space through which the electric force of that charged particle may act. If an electron were to start vibrating, the electric field surrounding that electron would also start to vibrate and at the same frequency. Interestingly, such a vibrating electric field generates a complementary vibrating magnetic field, which in turn reinforces the vibrating electric field. The net result is a series of self-reinforcing electric and magnetic waves that propagate away from the vibrating electron.

By analogy, you know that if you shake the end of a stick back and forth in still water, you create waves that travel outward on the water's surface. If you similarly shake an electrically charged rod in empty space, you create electromagnetic waves in space that also travel outward. Electromagnetic waves, however, are oscillations (vibrations) of electric and magnetic fields, not oscillations of a material medium such as water. These waves are called *electromagnetic radiation*. Most of the electromagnetic radiation we encounter is generated by electrons, which can oscillate at exceedingly high rates because of their small size.

READING CHECK

What are electromagnetic waves?



Λ Figure 4.15
The electromagnetic spectrum is a continuous band of wave frequencies extending from high- energy gamma rays, which have short wavelengths and high frequencies, to low-energy radio waves, which have long wavelengths and low frequencies. The descriptive names of these regions are merely a historical classification, for all waves are the same in nature, differing only in wavelength and frequency. Interestingly, the speed at which they travel is also the same. This is the speed of light, which is about 3 x 10^{8} meters per second.

FOR YOUR INFORMATION

Tap the end of a stick on the surface of some still water. Do this repeatedly and you will generate waves that emanate outward. The faster you tap your stick, the closer together the waves are to one another, but the speed at which they travel outward remains the same. Try it and see! Similarly, as electrons oscillate back and forth in an atom, they generate electromagnetic waves that emanate from the atom. All electromagnetic waves travel at the same speed, which is the speed of light.

The distance between two crests of an electromagnetic wave is called the *wavelength* of the wave. **Figure 4.15** labels two wavelengths—one very long, the other very short—on a fictitious wave drawn for illustration only. Electromagnetic waves can also be characterized by their *wave frequency*, a measure of how rapidly they oscillate. The basic unit of wave frequency is the hertz (abbreviated Hz), where 1 hertz equals 1 cycle per second. The higher the frequency of a wave, the shorter its wavelength and the greater its energy.

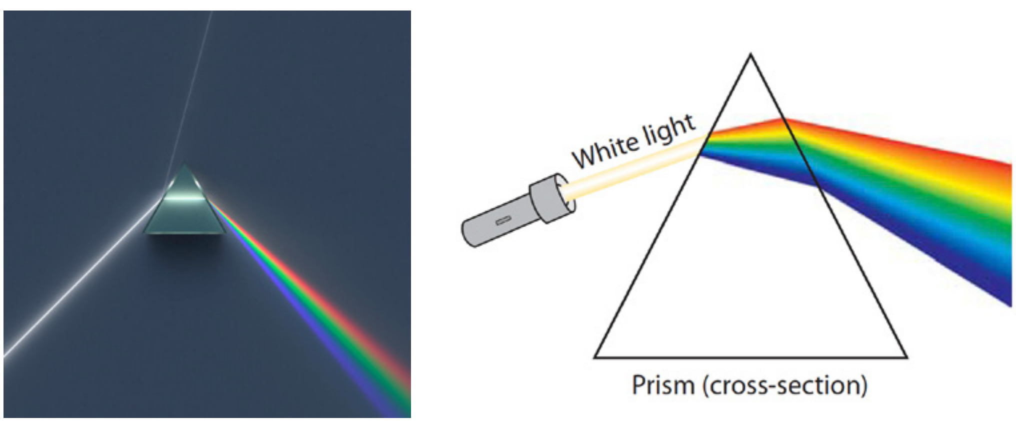
Figure 4.15 shows a full range of frequencies and wave-lengths of electro- magnetic radiation in a display known as the **electromagnetic spectrum**. The most energetic region of the electromagnetic spectrum consists of gamma rays. Next is the region of slightly lower energy, where we find X rays, and following that is the electromagnetic radiation we call ultraviolet light. Within a narrow region from about 7 x 10^{14} (700 trillion) hertz to about 4 x 10^{14} (400 trillion) hertz are the frequencies of electromagnetic radiation known as visible light. This region includes the rainbow of colors our eyes are able to detect, from violet at 700 trillion hertz to red at 400 trillion hertz. Lower in energy than visible light are infrared waves (detected by our skin as "heat waves"), then microwaves (used to cook foods), and finally radio waves (through which radio signals are sent)—the waves of lowest energy

CONCEPT **CHECK**
Can you see radio waves? Can you hear them?

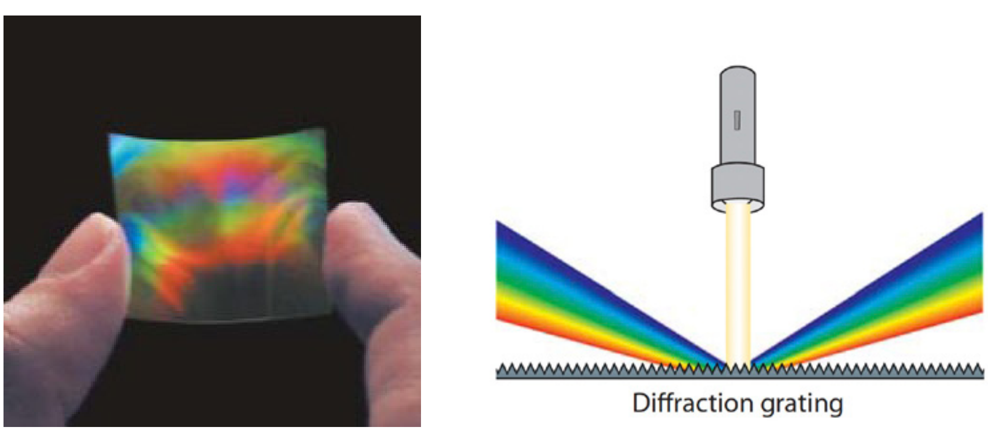
CHECK YOUR ANSWER Your eyes are equipped to see only the narrow range of frequencies of electromagnetic radiation from about 700 trillion to 400 trillion hertz—the range of visible light. Radio waves are one type of electromagnetic radiation, but their frequency is much lower than what your eyes can detect. Thus, you can't see radio waves. Neither can you hear them. You can, however, turn on an electronic gizmo called a radio. The radio translates radio waves into signals that drive a speaker to push air molecules around in the form of sound waves your ears can detect.

We see white light when all frequencies of visible light reach our eye at the same time. By passing white light through a prism or through a diffraction grating, which is a glass plate or plastic sheet with microscopic lines etched into it, the color components of the light can be separated, as shown in **Figure 4.16**. Remember—each color of visible light corresponds to a unique frequency.

A spectroscope, shown in **Figure 4.17**, is an instrument used to observe the color components of any light source. As we discuss in the following section, a spectroscope allows us to analyze the frequencies of light emitted by elements as they are made to glow.

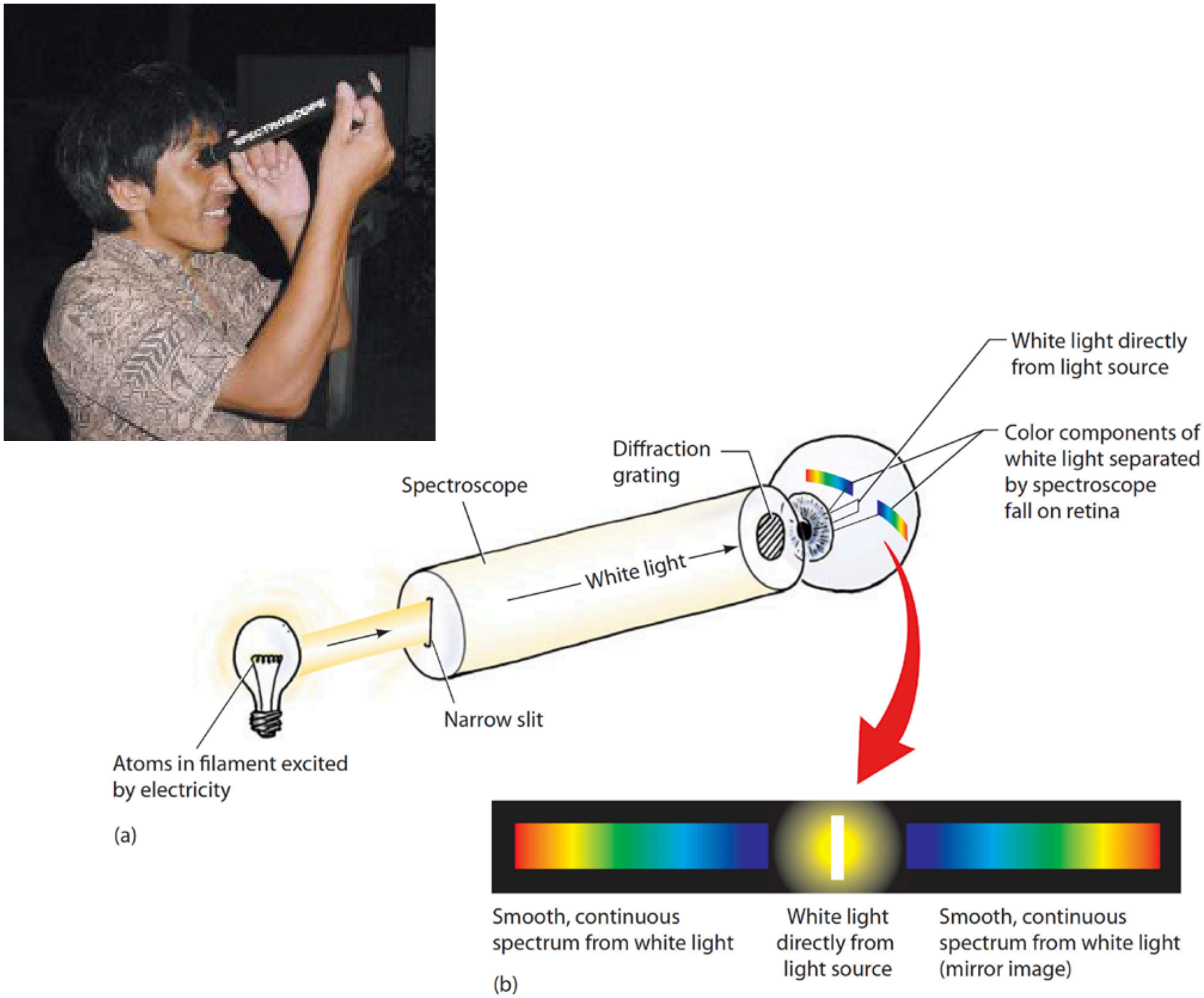


(a)



(b)

< Figure 4.16
White light is separated into its color components by (a) a prism and (b) a diffraction grating.



Λ Figure 4.17

(a) In a spectroscope, light emitted by atoms passes through a narrow slit before being separated into particular frequencies by a prism or (as shown here) a diffraction grating. (b) This is what the eye sees when the slit of a diffraction-grating spectroscope is pointed toward a white-light source. Spectra of colors appear to the left and right of the slit.