8

LIGHT AND ELECTROMAGNETISM

Light is all around us, yet it is not easy to say what light is. How are you able to see this page? Are invisible rays emitted by your eyes that move from your eyes toward the page, as the ancient Greek thinkers Plato and Euclid thought? Or does the page send out or reflect a stream of particles that is received by your eyes, as the Pythagoreans (Section 1.3) and Isaac Newton thought? Or is light, as the Greek thinker Empedocles and Newton's contemporary Christian Huygens thought, a high-speed wave?

What is light? It is one of science's oldest questions, and it is the focus of this and the following chapter. Pursuit of this question led to both of the great post-Newtonian theories, relativity theory and quantum theory. Light and its near relatives are also important to understanding societal topics like solar energy, ozone depletion, and global warming.

This chapter presents two topics that are essential to understanding the nature of light: waves (Sections 8.1 through 8.3) and the electromagnetic force (Sections 8.4 and 8.5). Sections 8.6 and 8.7 discuss the planetary atom, a model that incorporates electromagnetic forces and helps explain light. Chapter 9 then presents the electromagnetic wave theory of light and explores the human impacts of these ideas.

8.1 Waves: *something else that travels*

You are probably familiar with some kinds of waves (Figure 8.1). Stretch a few meters of flexible rope along the floor, fix one end (perhaps under a friend's foot), and give the free end a single shake. Something travels down the rope. Figure 8.2 is a series of pictures taken with a movie camera, showing a similar

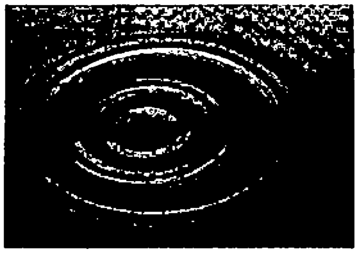


FIGURE 8.1
Water waves.

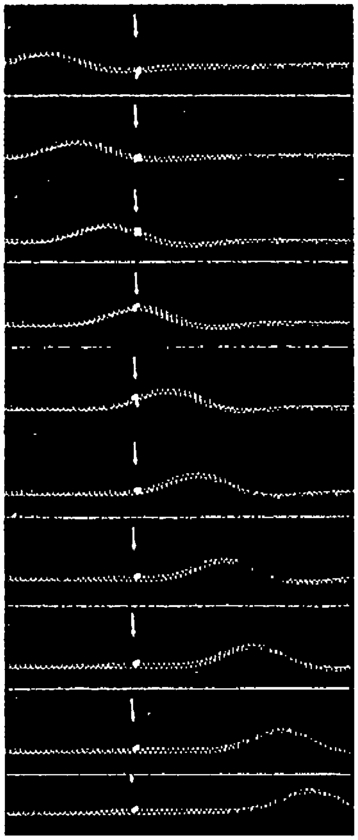


FIGURE 8.2
A series of pictures taken with a movie camera, showing a wave moving along a spring. A ribbon is tied to the spring at the point marked by the arrow. The ribbon moves up and down as the wave goes by but does not move in the direction of the wave.

"something" traveling down a long spring that has been given a single up-and-down shake at the right-hand end. As another example, imagine (better yet, try it!) stretching a Slinky toy between your two hands along a tabletop. Quickly move the left end a short distance toward the right and then back to the left, holding the right end fixed. Something travels along the Slinky from your left to your right hand (Figure 8.3).

This "something" that travels across the water, along the rope, and along the Slinky, is called a **wave**. As another example, the continued shaking of one end of a rope causes a long, continuous wave to travel along the rope (Figure 8.4). But *wave* is just a word that names the behavior without telling us what it really is. What actually happens here?

Observe the motion carefully. In Figure 8.2, how do the individual parts of the spring actually move? As you can see from the motion of the small ribbon tied to the spring, each loop just moves up and then back down.

How does a particular part of the water move in Figure 8.1? Fill a bowl with water, float a small cork in it, and drop a small pebble in, several centimeters from the cork, to create ripples. Observe the cork as ripples pass by. If the ripples are small, the cork will move up and down, not outward along with the ripples. Each portion of the water just moves up and down, shaking or **vibrating** up and down, but they do not travel along the water surface. The Slinky wave is similar, except that the vibrations are parallel instead of perpendicular to the Slinky.

One thing that is traveling along with each of these waves is energy. You can verify this for yourself by holding the fixed end of a rope while a friend shakes the other end. Your hand vibrates as the pulse arrives. It takes work to force your hand back and forth this way, and we know that work requires energy. So waves transfer energy.

On the other hand, no material substance is transferred by waves: No water is transferred outward in Figure 8.1; no part of the spring is transferred from left to right in Figure 8.2; and no part of the Slinky is transferred from the left to the right hand in Figure 8.3. This type of motion is unlike any motion we have examined before. Previously we studied balls, books, molecules, and other material objects actually moving from one place to another. We call such cases **projectile motion**, because a material object is actually projected (thrown or transferred) from one place to another.

In discussing waves, it is important to distinguish between the small vibrational motions of the substance through which the wave travels and the nonvibrational motion of the wave itself.

What do we see traveling down the spring in Figure 8.2? Very simply, we see a bump in the otherwise straight spring. In Figure 8.3, we see a compression, a squeezed region (followed by a stretched region), traveling down the otherwise evenly stretched Slinky. We could describe both as *disturbances* that travel down the otherwise undisturbed rope or Slinky. The situation is similar for water waves. The material through which the disturbance travels—the spring or Slinky or water—is called the **medium** for the wave.

So we have a useful definition: A **wave** is a disturbance that travels throug a medium, and that transfers energy without transferring matter. Such **wav motion** is different from projectile motion.

FIGURE 8.3
With the right-hand end of the Slinky held fixed, a quick motion of the left-hand end to the right and back again to the left creates a pulse that travels down the Slinky.

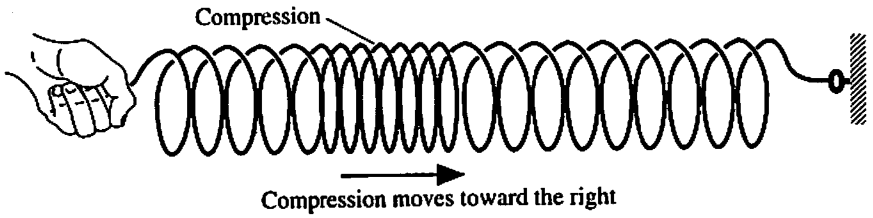


FIGURE 8.4
Continued shaking of the end of a rope creates a continuous wave that travels down the rope.

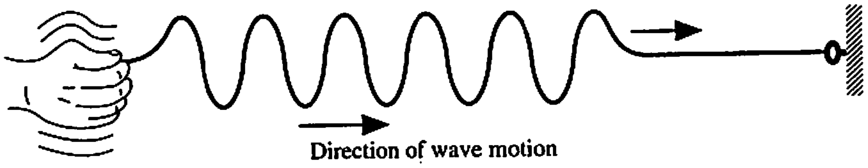
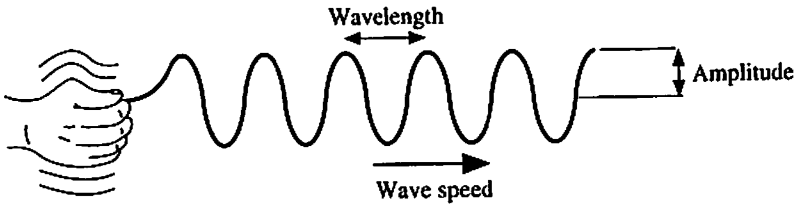


FIGURE 8.5
The meaning of wavelength and amplitude. The wave speed is the speed at which a crest or a trough moves down the rope.



We need some quantitative terms. The **wavelength** of a continuous, repeated wave is the distance from any point along the wave to the next similar point, for example, from crest to crest or from trough to trough in Figure 8.5.

A wave's **frequency** is the number of vibrations that any particular part of the medium completes in each second. Waves are usually sent out by a vibrating source of some kind, in which case the wave's frequency must be the same as the source's frequency. The frequency could also be defined as the number of waves that the source sends out during each second. The unit for measuring frequency is the "vibration per second," also called a **hertz** (Hz).

A wave's **amplitude** refers to its width of vibration, the distance that each part moves back and forth during that part's vibrations. The amplitude is measured quantitively from the midpoint of vibration to the farthest point, so it is just half of the overall vibration width.

The **wavespeed** of a wave is the speed at which the disturbance moves through the medium, for example, the speed at which a compression moves along a Slinky or the speed at which a crest moves along the rope in Figure 8.5.

Disturbances are able to travel through a medium because of the connections between the parts of the medium. For example, when you shake one end of a rope, this disturbance is transferred down the rope because the different parts of the rope are connected, so that when one part is lifted, its neighbor soon is lifted also. So it is reasonable to suppose that the wavespeed is determined mainly by the medium and is roughly the same for different disturbances within the same medium. Experiments confirm this notion that all disturbances travel through any particular medium at roughly the same wavespeed.

DIALOGUE 1 Surfers are able to ride large water waves coming into a beach. Are these really waves as we defined them? What about a row of falling dominoes, in which each domino knocks over its neighbor as it falls—is this a wave? If either answer is yes, then what is the medium?

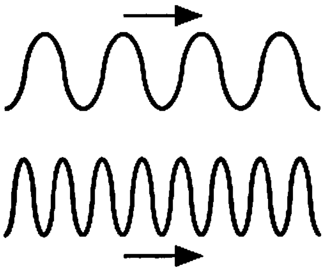


Figure 8.6
Which wave has the higher (larger) frequency, assuming that both have the same wavespeed?

DIALOGUE 2 Which wave has the larger or "higher" frequency: a long-wavelength wave moving along a rope or a short-wavelength wave moving along the same rope (Figure 8.6), assuming that both have the same wavespeed? Which carries more energy, assuming their amplitudes are the same? Note these useful rules: Short wavelength means high frequency,* and high frequency means high energy.

8.2 Interference: *a behavior unique to waves*

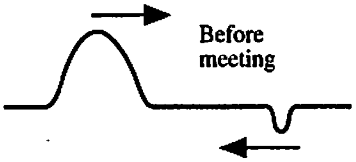


Figure 8.7
Two waves travel in opposite directions along a rope. What happens when they meet?

How do different waves in the same medium interact with one another? For example, what happens when the large upward wave and the small downward wave shown in Figure 8.7 meet? If we do an experiment like this, we will find that the two waves just pass through each other without distortion (Figure 8.8). This is what we might have expected, because each wave just lifts or lowers the rope as it travels along the rope, so when the two waves meet, the rope is raised a lot by the large wave at the same time that it is lowered a little by the small wave. Experiments like this show that when different waves move through the same medium, they pass through each other without disturbing each other and continue on their way as though nothing had happened.

The effects that occur when two waves are present at the same time and place are called **wave interference** (or just interference) effects.

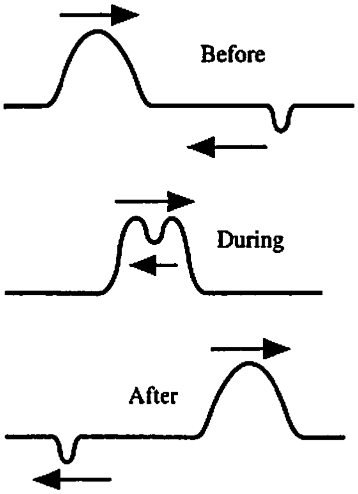


Figure 8.8
Two waves meeting: interference.

DIALOGUE 3 What would be the interference effect if the two waves of Figure 8.7 had identical heights, one upward and one downward? What if both were upward?

Two equal waves of opposite orientation interfere by canceling each other (Figure 8.9). Two equal waves of the same orientation interfere by adding up to a disturbance that is twice the size of either wave (Figure 8.10). These two cases, cancellation and reinforcement, are called **destructive interference and constructive interference.**

---

1. Breaking waves carry water into the beach (and then back out again as an undercurrent). This is projectile motion, not wave motion. A row of falling dominoes is a true wave, because the dominoes don't go anywhere. The medium is the row of dominoes.
2. The short-wavelength wave had to be sent out more frequently; the rope must vibrate more frequently as this wave passes through it; and the short-wavelength wave must carry the most energy. For instance, it could vibrate any "receiver" twice as often, which would take more work.

* Quantitatively, a wave's wavelength λ, frequency f, and wavespeed v are related by $v = f\lambda$. For example, if three waves are sent out by the wave source every second ($f = 3$ vib/s) and each wave has a length of 2 meters ($\lambda = 2$ m), then the speed at which the wave moves is $3 \times 2 = 6$ m/s.

3. See Figures 8.9 and 8.10.

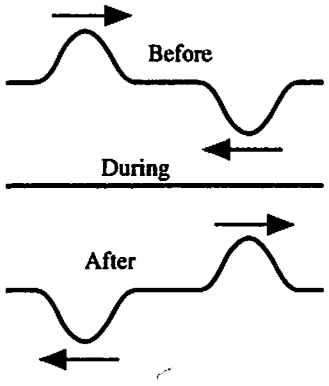


FIGURE 8.9
Two waves meet and interfere destructively.

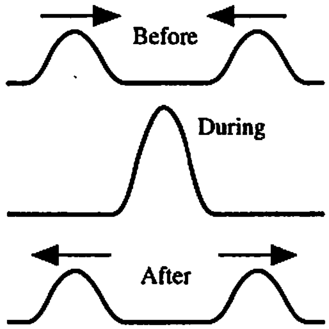


FIGURE 8.10
Two waves meet and interfere constructively.

Wave interference shows, once again, the stark difference between projectile motion and wave motion. Two moving material objects—say two freight trains moving toward each other on the same track—do not interfere in the way that waves do. Two trains certainly don't pass through each other undisturbed!

Interference effects become more interesting when they happen in two or three dimensions. An undisturbed rope or a Slinky has only one significant "dimension," length. The surface of a lake is "two dimensional" because it has length and width. And the space in a room is "three dimensional" because it has length, width, and height.

In a two- or three-dimensional medium, the waves created by a small source spread out into circles or spheres. If you send out a continuous water wave from a small vibrating source such as your finger tapping on the water surface, waves will spread out into circles, as in Figure 8.1, and eventually cover the entire surface.

Suppose you fill a rectangular pan with water and tap your fingers at the same steady rate on the surface at two points along one side of the pan. Continuous waves will soon cover the water surface, spreading out from each of the two sources. What will the interference effects look like? The wave crests spreading out from each individual source form circles (Figure 8.1), as do the wave troughs (the low points). The two waves from the two sources have the same frequencies because the tapping rates are identical, and so the two wavelengths also must be identical. In Figure 8.11, these waves are drawn looking down from above. The two sources are marked A and B. The colored circles represent the crests from source A acting alone, and the black circles represent the crests of the waves from source B. The troughs, not drawn, lie midway between the crests.

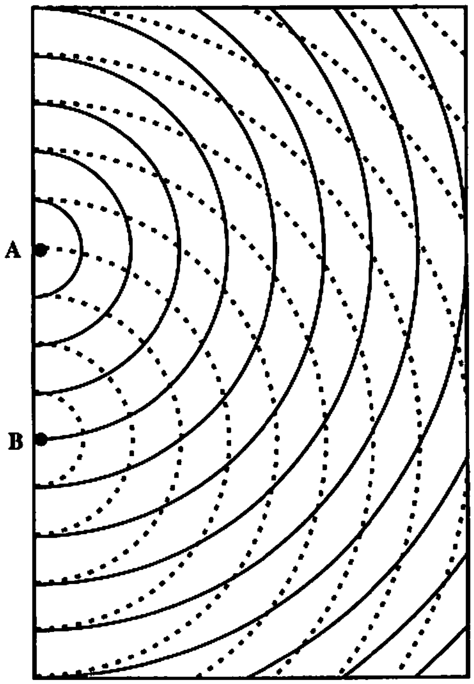


FIGURE 8.11
Continuous surface waves spreading out from two sources. What will the interference effects look like?

DIALOGUE 4 But the sources do not act alone. Predict the appearance of the water's surface as it would look in a snapshot. Draw an x (a color enhances the effect) at every point of constructive interference, in other words, at points where crest meet crest and at points where trough meets trough. Can you see a pattern? Next, draw a small o (in a different color) at every point of destructive interference. Now can you see a pattern?

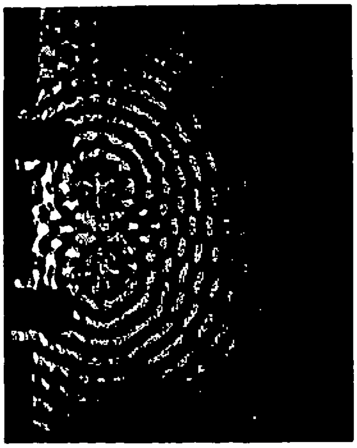


Figure 8.12
Interference between continuous surface waves spreading out from two sources: experimental results.

Figure 8.12 is a photograph of this experiment, looking down onto the water's surface. The photographic technique causes crests to appear bright and troughs to appear dark. As you can see, the interference pattern has lines of undisturbed water radiating outward as though they came from a point somewhere between the two sources. The interference is destructive along these lines. Between these undisturbed lines are other lines of constructive interference, with large crests and troughs. This is just what Dialogue 4 predicted.

All of our analysis so far has been at one instant in time. Now "turn on time" by imagining a moving picture that begins with the snapshot in Figure 8.12. Since the individual circular waves move outward from A and B, the entire interference pattern must move outward also. The rays of destructive and constructive interference remain fixed in place, and the large waves within the constructive rays move outward, as shown by the arrows in Figure 8.13.

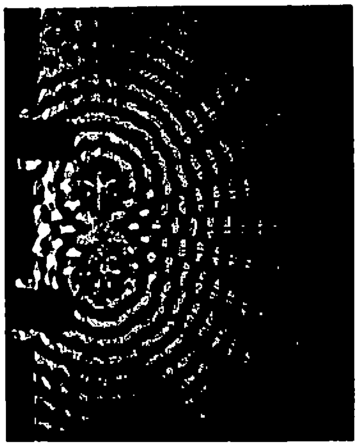


Figure 8.13
Lines of constructive and destructive interference remain fixed in place, and constructive (large) waves move outward within the constructive regions in the directions indicated by the arrows.

Finally, think about how all this would appear to an observer who could only see these waves roll in to the far right border of Figure 8.13. Imagine that the body of water is a rectangular swimming pool. How does water-wave interference appear to an observer who examines the waves arriving along the right-hand wall but who for some reason cannot see any appreciable portion of the pool's surface?

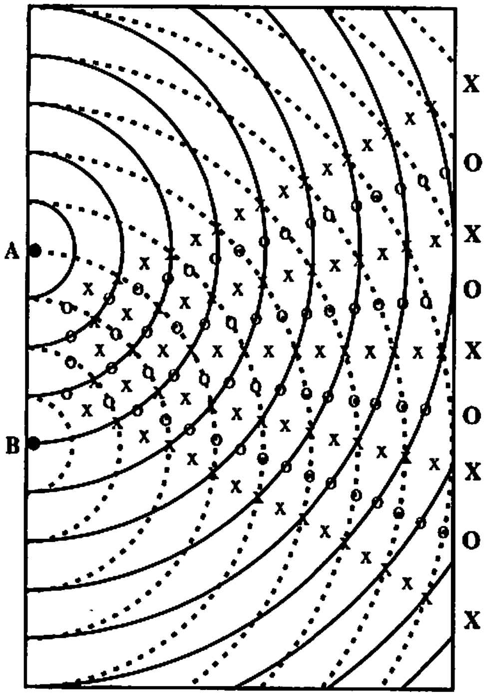
We can predict the answer using Figure 8.13. The observer should find some points where large waves pound against the wall and other points where no waves roll in. These are the points of constructive and destructive interference along the wall, as diagrammed in Figure 8.14. An observer examining waves arriving at the right-hand wall would find alternating points (marked X) where large waves roll in and points (O) where no waves roll in.

The difference here between the pattern from a single source of water waves and the pattern from two sources is especially striking. Waves from a single source, say source A, spread out in circles that cover the entire surface. These waves roll into all parts of the bordering wall (Figure 8.15). If we now also turn on the second source, B, the pattern along the wall will shift to an interference pattern. The most dramatic change is that now no waves come into the points marked O, even though they did come into these points when only one source was operating. It seems paradoxical: We added a second source and got a reduced (in fact, zero) effect at the points marked O. Interference effects such as these give us a good way to identify wave behavior.

Now let's look at light.

---

4. See the small x's and o's in Figure 8.14.



Observer stands here and looks down at pool, observing large waves rolling into points marked X at side of pool, and no waves rolling into points marked O. Small x's and o's are places on surface of pool where interference is constructive (x's) and destructive (o's).

Figure 8.14
An observer scanning a wall at the far border of the pool finds points where large waves come into the wall, interspersed with points where no waves come in.

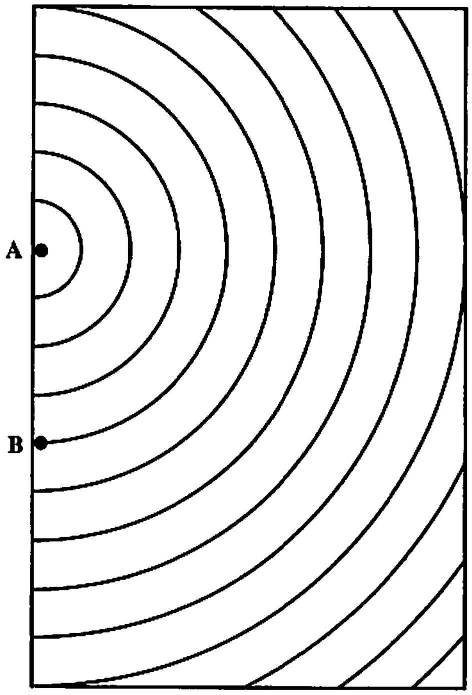


Figure 8.15
If one of the two wave sources shuts off, an observer scanning the wall will find that waves arrive at all points. Since waves now spread out from only a single source, there is no longer any interference.

8.3 Light: *particles or wave?*

When you turn off the light at night, it gets dark. So the light in your room must have come from the lightbulb. It couldn't, for example, have come from your eyes, because even though your eyes were still open after you turned off the lightbulb, you could not see. So light is something that enters your eyes from the outside. When you look at a luminous (light-emitting) object like a lightbulb, light goes from the bulb to your eyes. In order for you to see a nonluminous object such as the wall of your room, light from the lightbulb must bounce (*reflect* is the official word) off the wall and then into your eyes. The light reflecting from the wall does not give you a nice mirror reflection, however, as light does when it reflects from a glass mirror, because the rough surface of most walls scatters the incoming light in many different directions.

But what enters your eyes when you see light? The question has been debated for centuries. Most of the suggested answers fall into one of two different categories: particles and waves. Perhaps luminous objects send out tiny particles that enter our eyes. Or perhaps light is a wave emitted by some kind of vibrations within the luminous object. Experiment is the ultimate judge.

We need an experimental test that distinguishes between the projectile and wave models of light. The preceding section of this chapter suggests a good candidate: wave interference. When waves meet, they exhibit wave interference. Particles might interact in other ways, but they do not interfere in the way that waves do. What does light do? To answer this, we need an experiment like the water-wave interference experiment, but with light.

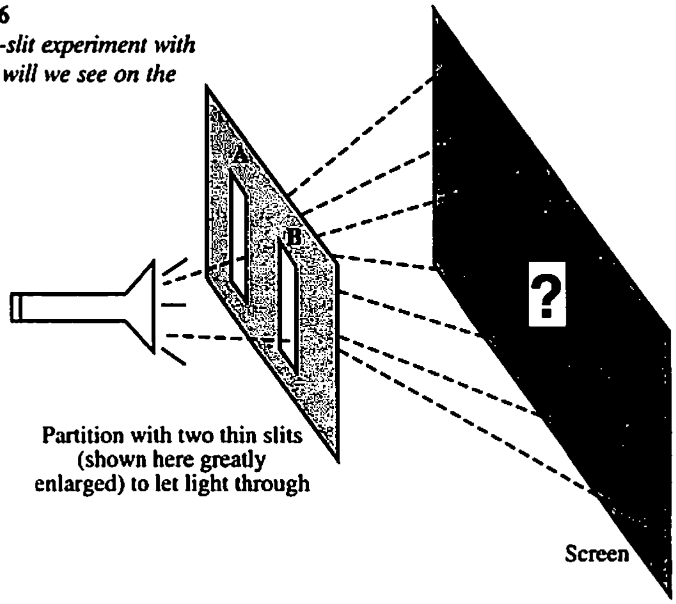
The first experiment you might think of is just to shine two flashlights on a movie screen. This gives no observable interference effects, as you can see by trying it yourself. So maybe light is a stream of particles.

But recall that in order to observe water-wave interference, we assumed that the two wave sources had identical and synchronized vibrations. For example, if both sources A and B in Figure 8.12 were changing their frequency all the time and in different ways, we would not expect to see any recognizable interference pattern. It is possible that light is a wave but that the waves from the two flashlights are not synchronized. A flashlight bulb's light is produced by heating up the bulb's thin wire, or "filament," until it glows. The microscopic thermal motions that make the filament hot enough to glow are mixed up and random, so we would not expect two different bulbs to have synchronized vibrations.

HOW DO WE KNOW? THE DOUBLE-SLIT EXPERIMENT WITH LIGHT.

In 1801, Thomas Young solved the problem of finding two synchronized light sources. Young's trick was to use a single light source but to split its light into two parts that should then have identical vibrations. He then recombined these parts to see whether they interfered.

FIGURE 8.16
The double-slit experiment with light. What will we see on the screen?



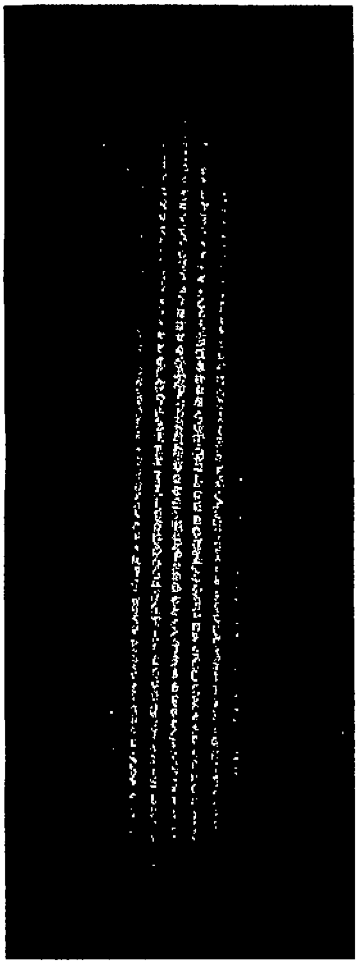


Figure 8.17
The double-slit experiment with light: experimental results.

Figure 8.16 shows one way to do this. A light source sends light to two very narrow parallel slits in a partition that blocks all the light except that going through the slits. The two slits then act as the two sources of light, like sources A and B in Figure 8.12. With this arrangement, if light is a wave, these two sources should have synchronized vibrations, because the light from each slit originated in the same filament.

Using this arrangement, Young found an experimental result like that shown in Figure 8.17. This photograph was made by placing photographic film at the position of the receiving screen in Figure 8.16. Figure 8.18 depicts the experimental arrangement and its outcome. As we will soon see, this outcome is excellent evidence that light is a wave.

In order to interpret Figure 8.17, let us return to water-wave interference. Figure 8.14 shows the interference pattern observed along a wall placed in the path of water waves from two synchronized sources. The receiving screen of Figure 8.16 is just like this wall: The screen is placed in the path of the light from the two sources. But water waves occur on the two-dimensional surface of water, whereas light fills up three-dimensional space. The two sources of light are not tiny points like A and B in Figure 8.14 but instead are slits that extend into the third dimension. If these sources send out light waves, we would expect the interference pattern seen on the receiving screen to be alternating lines of constructive and destructive interference running parallel to the slits, not small points like the points marked X and O along the right-hand border in Figure 8.14. In other words, we would expect alternating bright (lit) and dark lines. We would, in fact, expect precisely the outcome seen in Figure 8.17.

What would we expect if we closed one of the slits, leaving only one slit open? If light is a wave, we would expect that waves would spread out from

Figure 8.18
The double-slit experiment with light: the experimental setup and results.

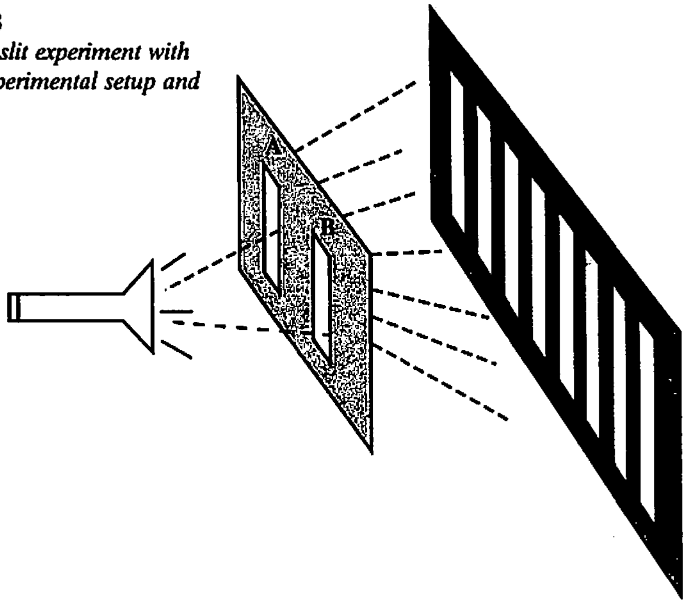
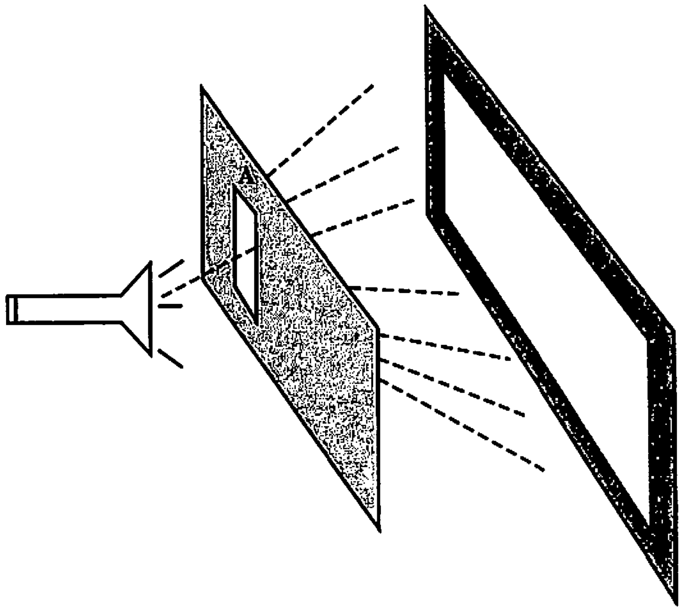


Figure 8.19
If one of the two slits is closed, light will arrive at all points along the receiving screen. Compare Figures 8.18 and 8.19 with Figures 8.14 and 8.15.



the open slit, without interference, just as water waves spread out from a single source without interference in Figure 8.15. A broad band of light should then cover a large area of the receiving screen (Figure 8.19). This is, in fact, what happens.

The clearest evidence that the flashlight is sending out waves and not particles can be found at the positions of the dark lines in the double-slit experiment, the points where no light arrives. With only slit A open, light spreads out over the entire receiving screen (Figure 8.19). How is it, then, that if we simply open slit B, no light will arrive at these particular positions? It is difficult to see how particles coming through the two slits could cancel one another out in this way, but it is just what we expect of waves. We conclude that light is a wave.

By measuring the distance from one bright constructive-interference line to the next such line in a pattern such as Figure 8.17 and using a little geometry, it is possible to calculate the wavelength of the light that created the pattern. Measurements of interference patterns like this are the usual method of measuring the wavelength of light. This wavelength turns out to be very small. Light sources have wavelengths ranging from about 0.4×10^{-6} m to 0.7×10^{-6} m (0.4 to 0.7 millionths of a meter).

HOW DO WE KNOW?
You can demonstrate light-wave interference yourself, using a single-slit wave-interference effect that occurs when the slit is much wider than the wavelength of the light. In order to get the spread-out, noninterfering result shown in Figure 8.19, the single slit must be very narrow—comparable in width to the wavelength of the light being used. In the following demonstration, we use a slit whose width is hundreds of times larger than the wavelength of the light. With such a wide slit, the light coming through

the slit does not behave as though it came from a single tiny source. Instead, the slit acts like hundreds of tiny sources. If light is a wave, then all the individual waves from these hundreds of sources should interfere with one another to form an interference pattern.

Here's the experiment: Focus your eyes on a well-lit wall or other surface. Make a slit by holding your thumb and forefinger close together but not touching, about a millimeter apart and several centimeters in front of your eye. Focus on the source, and not on your fingers, because you want to learn about the light from this source. Your fingers should look blurred, and where the blurs overlap, you should be able to see narrow bright and dark lines running parallel to your fingers.

These light and dark lines are constructive and destructive interference regions, formed at the position of your eye, created by the light coming through the single slit. A half-millimeter-wide slit between your thumb and forefinger is about 1000 times larger than the wavelength of light, so as explained earlier, the observed pattern is just what we would expect if light is a wave.

Figure 8.20
Light beams cannot be seen from the side. What invisible medium is carrying the light waves?

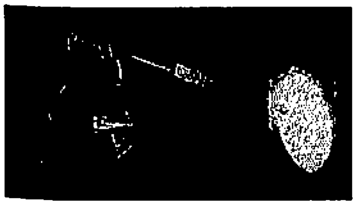


Figure 8.21
You can see a light beam by allowing it to reflect off dust particles in the air.

Since light is a wave, what kind of wave is it? What is it a wave in? Water waves, rope waves, and Slinky waves are waves in water, ropes, and Slinkies. What medium vibrates when light waves travel? It's not an easy question. We don't see light beams directly the way we see water waves (Figure 8.20). It is as though we could see the impact of water waves against a bordering wall, but without being able to see the water. We can see light beams in dusty air (Figure 8.21), but only because the light is reflected off the dust particles. The medium for light waves is itself invisible.

Could the medium be air? This sounds plausible because you cannot see air, and air does fill up space, at least near Earth. But what about light traveling far from Earth? In any appreciable amounts, air extends only a few miles above Earth's surface, yet light arrives here from distant stars, across great reaches of nearly empty space. So air cannot be the medium for light waves.*

The odd thing about light is that it moves through empty space where there is essentially no matter at all. But something must be out there, in so-called empty space, because you can't have a wave without having a medium to do the waving. After all, we began our study of waves with the idea that a wave is a disturbance in a medium. You can't have a disturbance without having something to disturb. The medium for light, then, must be nonmaterial, not made of atoms or other forms of matter.

Nineteenth-century scientists devoted a lot of time and effort to learning what kind of wave light is. It turned out that the answer is bound up with a new phenomenon that was beginning to be understood during that century: electricity. The answer, briefly, to the question about light waves is that light is an "electromagnetic wave." In order to understand this important idea, we will devote the rest of this chapter to electricity. Then we will see, in the following chapter, what electricity has to do with light.

---

* Air is the medium for sound waves, not light waves. Since sound does not bear directly on the major purposes of this book, we won't discuss it further here.

DIALOGUE 5 If we compared two water-wave interference experiments, one using a short wavelength and the other using a long wavelength, how would the interference patterns observed along the right-hand wall in Figure 8.14 differ? How would the use of longer-wavelength light waves affect the interference pattern in Figure 8.17?

DIALOGUE 6 MAKING ESTIMATES Roughly, how does a typical light wavelength compare with the thickness of a piece of paper?

8.4 Electric force: *part of the electromagnetic force*

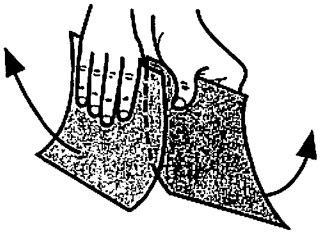


Figure 8.22
Two rubbed transparencies exert electric forces on each other.

Figure 8.23
An extremely bad hair day: electric hair. The source of this effect is the "charged" metal sphere that the woman is touching.

Find a couple of plastic transparencies, the kind that teachers use on overhead projectors. Rub them vigorously with tissue paper and hold them from one edge in separate hands (Figure 8.22). If you hold them parallel and just a few centimeters apart but not touching, they should repel each other. At short separations, they repel each other strongly enough to stand noticeably apart. The force weakens at larger separations. Now spread out the tissue on a level surface, and hold one transparency directly above it. The tissue is pulled upward and clings to the transparency. You may experience similar forces when you take a synthetic shirt from a clothes dryer or when you brush your hair. Figure 8.23 shows an extreme example.

What is the source of these forces? This force can act across a distance such as that between the transparencies. The only force acting at a distance that we have encountered so far in this book is gravity. This force has other similarities with gravity. For example, the force acting between the two transparencies weakens as the separation widens, just as gravity does.*

Can this force actually be gravity? There are several reasons that it cannot be. First, the transparencies repel each other, whereas gravity attracts. Second, this new force is far stronger than gravity could possibly be between relatively low-mass objects such as transparencies and tissues. The force by the transparency on the tissue is so strong that it easily lifts the tissue against the downward gravitational pull on the tissue by the entire Earth. Third, the existence and size of this force depend on whether the transparencies are rubbed, and it is hard to see how rubbing could affect the gravitational force.

---

5. Longer-wavelength water waves would create a more spread-out pattern, with more distance between the X's and O's in Figure 8.14. Longer-wavelength light would produce broader, more spread-out lines in Figure 8.17.

6. Choose a typical wavelength of light, say 5×10^{-7} m (in making estimates, choose simple but reasonable numbers). To estimate the thickness of a sheet of paper, estimate the thickness of, say, 500 sheets (about 5 cm) and divide by 500 (5 cm / 500 = .01 cm = 10^{-4} m). The number of wavelengths in this thickness is $10^{-4}/5 \times 10^{-7} = 10^{-4+7}/5 = 10^3/5 = 1000/5 = 200$.

* In fact, this force even turns out to be inversely proportional to the square of the separation distance between the two objects experiencing this force, precisely like gravity. This similarity between gravity and this new type of force has always fascinated physicists. Nature seems to favor "inverse square" force laws.

This force has properties that are different from those considered so far in this book. We call it the **electric force**. An "electrified" object such as the transparency or the tissue (after rubbing) is said to be **electrically charged**, or "charged," and any process that produces this state is called **charging**.

The experiments show that when we electrically charge two identical objects in identical ways, they repel each other. But the charged transparency and the charged tissue attract each other. So the transparency must be charged differently from the tissue. After experimenting with all sorts of other charged objects, one finds that every charged object falls into just two categories: those that repel the transparency but attract the tissue, and those that attract the transparency but repel the tissue.

We name these two categories of charged objects **positive** and **negative**. Do not attach much significance to the names—we could just as well call them red and blue, or charming and revolting.

Our experiments demonstrate:

> THE ELECTRIC FORCE LAW
> Electrically charged objects exert forces on each other at a distance. Objects may be charged in either of two ways, known as positive and negative. Two objects possessing like charges repel each other, and two objects possessing unlike charges attract each other.*

8.5 Magnetic force: *the other part*

Have you ever played with magnets? Everybody should have the opportunity to experience the intriguing forces of attraction and repulsion that magnets exert on each other. You can buy inexpensive magnets at a toy store.

If you bring two bar magnets near each other, you will discover that the ends of two magnets either attract or repel each other even when they are separated by a distance. The ends are called **magnetic poles**. The two ends are called the "north" and "south" pole of the magnet and might be indicated by "N" and "S" printed on the ends. Experiment shows that similar poles repel each other and dissimilar poles (north and south) attract each other. This reminds us of the forces between electric charges: Likes repel, and unlikes attract.

It seems plausible to hypothesize that the force acting between the magnets actually is the electric force. This hypothesis is easy to check, for it predicts that magnets should exert forces on electrically charged objects such as a rubbed transparency or tissue. If you try this, you will find that the magnets

---

* The electric force is quantitively proportional to the product of the "strengths" (or magnitudes) of the charge of each of the two objects and inversely proportional to the square of the separation distance: $F \propto q_1q_2/d^2$. Note the similarity with the gravitational force law: $F \propto m_1m_2/d^2$.

do not exert forces on a rubbed transparency or tissue.* So our hypothesis is wrong. Despite the similarity to electricity, the force between bar magnets is not the electric force, and the two ends of a bar magnet are not electrically charged.

There are other important differences between magnetism and electricity. First, a bar magnet's magnetism is permanent and has nothing to do with rubbing. Second, every magnet has both a north and a south pole—magnetic poles always come in pairs. Nobody has ever found an object that possessed either kind of pole without the other kind, although many experiments have looked for evidence of such "monopoles." On the other hand, it is easy to find objects that are entirely positively charged or entirely negatively charged.

This new kind of force is called the **magnetic force**. Despite their differences, the similarities between the electric force and the magnetic force suggest that they might be related. One of the great triumphs of nineteenth-century physics was the demonstration that electricity and magnetism are in fact related. The most concrete evidence was an experiment, first conducted in 1820, in which electrically charged particles that were in motion exerted a measurable force on a magnet.

Note that only charged objects that are *moving* exert forces on magnets. The experiment involving a magnet and *stationary* charged objects such as a transparency or tissue shows that charged objects *at rest* do not exert forces on magnets.

Further experiments during the nineteenth century showed that *all* magnetic forces can be traced to the motion of charged objects. Moving charged objects exert and feel magnetic forces over and above whatever purely electric forces they would feel if they were at rest. This additional force, due solely to the motion of charged objects, is the magnetic force.

For example, the forces observed with bar magnets are due to subatomic charged particles moving inside each magnet (Section 8.7). For another example, Earth's magnetic effects are due to electrically charged material flowing inside Earth.

We summarize this idea as:

THE MAGNETIC FORCE LAW

Charged objects that are moving exert and feel an additional force beyond the electric force that exists when they are at rest. This additional force is called the **magnetic force**. All magnetic forces are caused by the motion of charged objects.

---

* A small attractive force is sometimes obtained with the transparency, an electric effect called *electrical polarization*. This force, if it does occur, is attractive at both the north and south poles of the magnet, and it occurs equally strongly even if an unmagnetized piece of metal is used in place of the magnet, so it is not caused by the presence of the magnetic poles. Rather, it is caused by the redistribution of electric charge that occurs in a metal when a charged object like the transparency is brought near it. A similar electric polarization occurs quite dramatically when a charged transparency is brought near an empty aluminum can that is free to roll. Try this!

One day, Sir, you may tax it.
Michael Faraday, codiscoverer of electromagnetism, when asked by the chancellor of the exchequer about the practical worth of electricity

This means that the separate concept of magnetic poles is not needed, that we can drop the idea of magnetic poles and just think of moving charges instead.

A goal of science is to find connections between apparently different phenomena. For example, Newton united the heavens and Earth by finding similarities between a falling apple and the moon. Similarly, nineteenth-century scientists found that both electricity and magnetism are due to the existence of electrically charged objects and that these two forces can be united into a single **electromagnetic force** between charged objects.

DIALOGUE 7 Could the force between two bar magnets be due to gravity? Defend your answer.

DIALOGUE 8 If you charge two transparencies by rubbing and then hold them at rest several meters apart, will they exert an electrical force on each other? Will they also exert a magnetic force? What if you shake both of them back and forth?

DIALOGUE 9 What will you have if you saw off one end of a magnet?

8.6 The electric atom: *the planetary model*

One outgrowth of the nineteenth-century developments surrounding electricity and magnetism was a new model of the atom, an atom made of electrically charged subatomic parts. Because light is created by the motions of these subatomic parts, as part of our effort to understand light, we will devote the rest of this chapter to the electric atom.

Physicists have always sought microscopic explanations of macroscopic events. So far in this book, we have discussed, from a microscopic point of view, chemical reactions, thermal energy, and much more. All of these phenomena are comprehensible on the basis of the **Greek model of the atom** (Chapter 2). According to this theory, all matter is made of small unchangeable particles, *atoms* (Greek for "uncutable"), which come in many varieties or "elements" and move and combine in various ways. This model of the microscopic world, conceived by the ancient Greeks, formed the background for Newtonian physics. During the nineteenth century, this model was developed into the theory of chemical elements, compounds, and reactions.

It is difficult to fit electromagnetic phenomena into this indivisible-particle picture of the atom. Where does electric charge come from? How can

---

7. Although the magnetic force can be repulsive, gravity cannot. Also, the force between bar magnets is far too strong to be caused by gravity acting between the small bars.
8. With both at rest, you will get only an electric force. With both in motion, you will get not only an electric force but also a magnetic force. However, if you try an experiment like this, the magnetic part of the overall electromagnetic force will be immeasurably small.
9. Two magnets. Each piece will have its own north and south poles. It is impossible to isolate a north or south pole.

rubbing produce it? Why are there two kinds of charge? These and other electromagnetic phenomena led, early in the twentieth century, to the **planetary model of the atom.*** According to this theory, the atom is not an unchangeable, solid, indivisible particle. To the contrary: The planetary atom is continually changing, is almost entirely empty, is divisible, and is made of many parts.

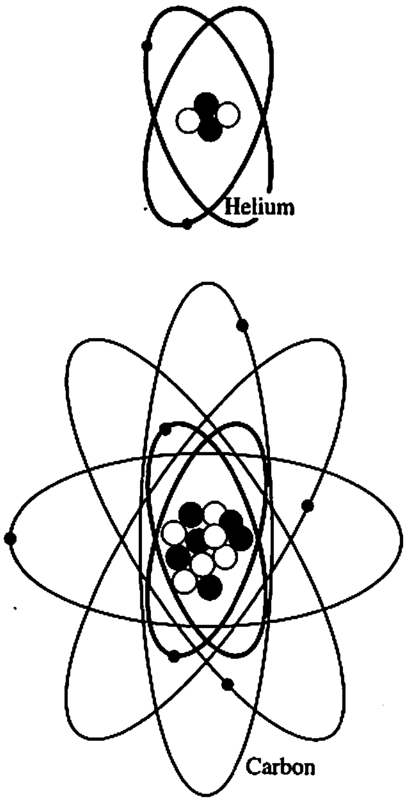


FIGURE 8.24
Two examples of the planetary model of the atom. Color code: Protons are green, neutrons are white, and electrons are black. The diagrams are not drawn to scale! If it were drawn to scale on the page, the nuclei would be too small to be seen.

As its name implies, the planetary model resembles a miniature solar system. Figure 8.24 portrays single atoms of two different elements, helium and carbon. The defining feature of the planetary atom is the tiny **nucleus** at the center, surrounded by a number of even tinier **electrons** ("electrified ones") that orbit the nucleus at a relatively great distance, much greater than the size of the nucleus itself. The overall size of an atom, the distance across its electron orbits, is typically about 10^{-10} m. This is the typical size of an atom as it is visualized in the single-particle model, and it is roughly the distance between neighboring atoms in solid materials. But a typical nucleus is 10,000 times smaller, on the order of 10^{-14} m. To put this into perspective, if we built a scaled-up model of an atom in which the nucleus were represented by a soccer ball, the orbiting electrons would be dust specks several kilometers away! Atoms are nearly totally empty. Despite the fact that the nucleus is far smaller than the atom, more than 99.9% of an atom's mass resides in its nucleus.

Electrons always repel negatively charged objects and attract positive ones. You cannot remove the charge from an electron—it is permanently negatively charged, and the electron has a mass that is about two thousand times smaller than the mass of even the least massive atom. Nobody has any inkling of why either fact is so.

The nucleus is itself made of several subatomic particles, of two different types: protons and neutrons. A **proton** ("positive one") is another permanently charged particle, like an electron. It is charged precisely as strongly as the electron, but positively instead of negatively. When we say that electrons and protons are charged "equally strongly," we mean that when they are placed near some other charged object, both exert the same amount of force (but in opposite directions) at the same distance away. Although the electron and proton have equally strong charges, they do not have equal masses. The proton is about two thousand times more massive. The **neutron** ("neutral one") is an uncharged, or neutral, particle whose mass is nearly the same as the proton's mass. Between one and a few hundred protons and neutrons form the nucleus of any atom.

The "glue" that holds electrons in their orbits around the nucleus is the electric attraction between the electrons and the protons in the nucleus. The glue that holds the nucleus together, however, must be some nonelectric force, because the electric force between the positively charged protons is repulsive and neutrons do not exert an electric force (Chapter 15).

---

* The term *planetary atom* is self-contradictory. *A-tom* means "indivisible," and *planetary* refers to the parts into which the atom can be divided! The old Greek name, *atom*, has stuck, but not its essence.

Since an atom's electrons are relatively distant (compared with the size of the nucleus) from the nucleus, it is not surprising to learn that the forces binding them to atoms are rather weak, and that it is not difficult to remove electrons from atoms. On Earth, unattached atoms (atoms that are not combined into molecules) usually have just as many electrons as protons. The reason is that any atom having fewer electrons than protons carries a net positive charge and so tends to attract electrons from its environment, while any atom having more electrons than protons carries a net negative charge and tends to lose its outermost electrons to its surroundings. This is why it took so long to discover many electrical phenomena: Most individual atoms are normally uncharged and exhibit no obvious electrical effects. Any atom having an excess or deficiency of electrons is called an **ion**.

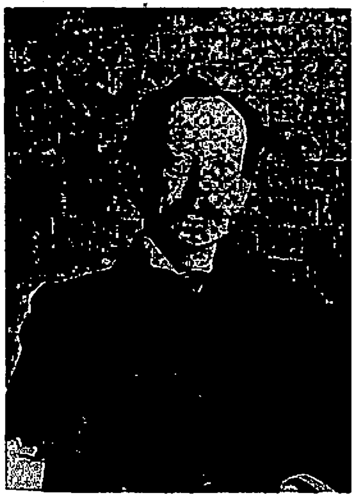


FIGURE 8.25
J. J. Thomson.

HOW DO WE KNOW? THE DISCOVERY OF THE ELECTRON

One key experiment leading to the planetary atom was by the English physicist J. J. Thomson (Figure 8.25). In 1897, Thomson was investigating a type of invisible beam known as a *cathode ray*. Cathode rays were produced in a nearly evacuated (emptied of air and other gases) glass tube whose two ends were attached by metal wires to a source of electric power. When the power was switched on, rays of unknown composition streamed along the length of the tube, as could be observed by the flashes of light where they hit one end of the tube.

Suspecting that these rays were electrically charged, Thomson placed electric charges and magnets around them. The flashes of light shifted in position. Because the charges and magnets deflected the rays, the rays themselves had to be electrically charged. The only charged microscopic objects then known were ions, observed in certain chemical experiments. Thomson hypothesized that the electrically charged cathode rays were streams of such ions.

He then measured the deflections of the rays. Using the known electric and magnetic force laws, he deduced from these measurements that these rays were streams of charged particles whose charge was the same as the charge of typical ions but whose mass was some two thousand times smaller.* These, then, were not ions.

This was revolutionary. It established that atoms had parts. According to Thomson, "At first there were very few who believed in the existence of these bodies smaller than atoms. . . .It was only after I was convinced that the experiments left no escape from it that I published my belief in the existence of bodies smaller than atoms."

Thomson had discovered the electron. Cathode rays are now also called *electron beams*. Today, electron-beam tubes are in wide use as TV tubes, fluorescent bulbs, computer screens, and many other devices.

---

* More precisely, he found that the *ratio* of the mass to the charge was two thousand times smaller than it was for any known ion.

Figure 8.26
Ernest Rutherford, one of the greatest experimental physicists of the twentieth century, talks with a colleague. Rutherford had a booming voice that could upset delicate experimental instruments, and the sign overhead was playfully aimed at him. His research on radioactivity and nuclear physics influenced a generation of experimental physicists early in this century.

HOW DO WE KNOW? THE DISCOVERY OF THE NUCLEUS

New Zealander Ernest Rutherford's work was at least as revolutionary as Thomson's (Figure 8.26). Like others around 1910, Rutherford was trying to determine the atom's internal structure. He knew that atoms contained electrons and that a positive charge must be present too. It was known that atoms are pressed right up against one another in solid materials and that huge forces are required to compress solids into smaller volumes. This means that it is difficult to squeeze atoms into other atoms. So Rutherford and others hypothesized that atoms were filled with matter throughout most of their volume.

To probe the atom's structure and test this hypothesis, Rutherford and his coworkers used what has become a traditional physics technique: He threw tiny things at other tiny things in order to see what would happen. He threw a recently discovered ray known as an alpha ray at the atoms in pieces of thin metal foil, similar to aluminum foil. The alpha ray was a high-energy stream of positively charged and fairly massive (about four times the proton's mass) "alpha particles" that emerged from certain substances (Chapter 15).

The idea was to observe how far the foil deflected the fast-moving alpha particles from their original directions and, from this, to deduce how matter must be distributed within the foil's atoms (Figure 8.27). The deflection was measured by observing flashes of light where the alpha particles hit a screen placed partially around the foil. Similar experiments had been done before, and it had been found that the foil had surprisingly little effect on the motion of the alpha particles. Most deflections were less than one angular degree. Since even the thinnest foils were about 500 atoms thick, alpha particles apparently passed straight through most atoms without deflection. Apparently, atoms were fairly porous, open structures.

Then in 1911, Rutherford decided to see whether any alpha particles were deflected through very large angles, perhaps greater than 90 degrees. His coworkers studied this by surrounding the foil with the detection screen (with a gap to allow the alpha ray to enter). Rutherford expected to see no large deflections, because a fast-moving and massive alpha particle was thought to pass through an atom somewhat like a high-velocity cannonball through pudding. An alpha particle would have to experience an enormous force to be deflected by very much.

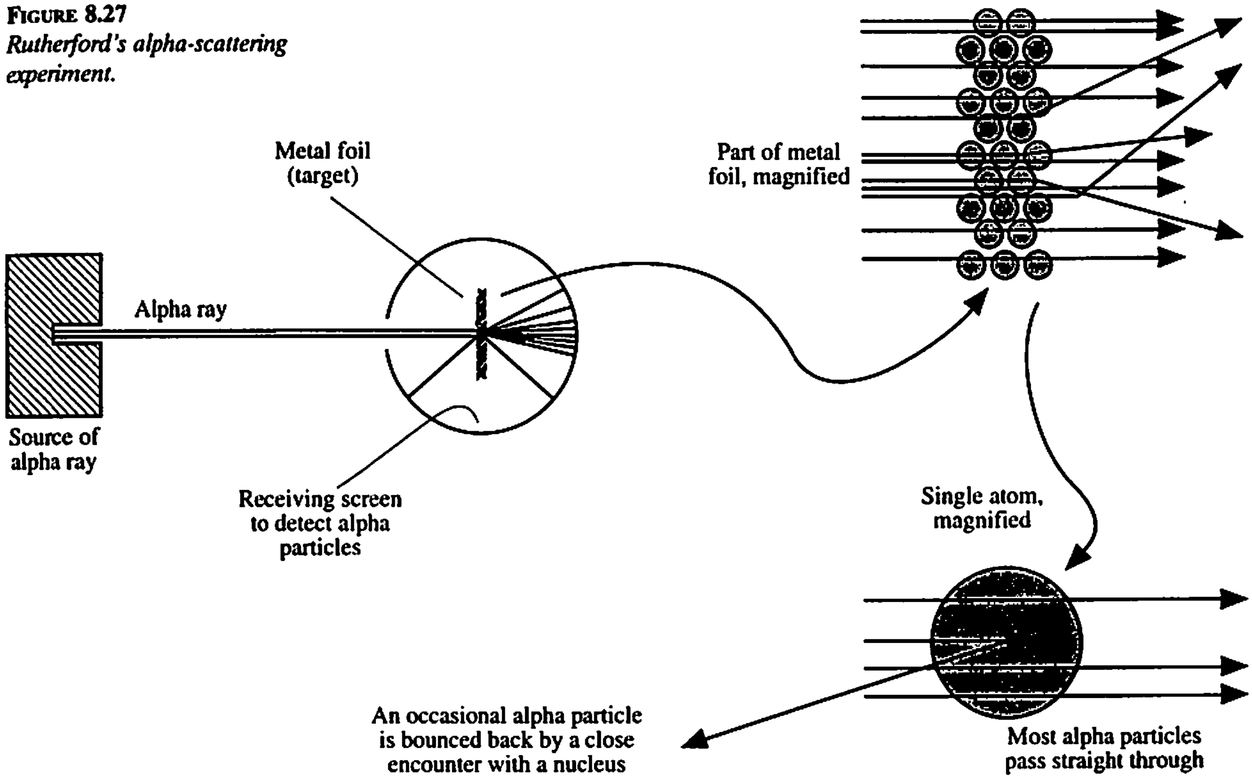
His coworkers came to Rutherford a few days later with the news that a few alpha particles had been deflected backward. In Rutherford's words, "It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you."

The reason was, apparently, that nearly all of the matter and all of the positive charge of the atom were concentrated in a tiny, dense region in the center. The cannonball had struck an even more massive cannonball and bounced back. Rutherford had discovered the atomic nucleus.

The energy produced by the breaking down of the atom is a very poor kind of thing. Anyone who expects a source of power from the transformation of these atoms is talking moonshine.

Ernest Rutherford, discoverer of the atomic nucleus, made this famous wrong prediction in 1933, while addressing the British Association for the Advancement of Science in the same hall where physicist Lord Kelvin had asserted, in 1907, that the atom was indestructible. The *New York Herald Tribune* article, dated September 12, 1933, carried the headline "ATOM-POWERED WORLD ABSURD, SCIENTISTS TOLD. Lord Rutherford Scoffs at Theory of Harnessing Energy in Laboratories"

FIGURE 8.27
Rutherford's alpha-scattering experiment.



Not exist—not exist! Why I can see the little beggars there in front of me as plainly as I can see that spoon!
Rutherford, when asked over a dinner table whether he believed that atomic nuclei really existed

8.7 The planetary atom: *a useful theory*

Like all good theories, the planetary atom explains many things.

It explains the experiments with charged objects. When you rub a transparency with tissue, some of the loosely attached outermost electrons in the transparency's atoms are rubbed off and transferred to the tissue's atoms, charging the transparency positively and the tissue negatively. That is why the two attract each other after rubbing. The two rubbed transparencies repel each other because both are positively charged.

When the ends of a copper wire are attached to the positive and negative attachments (called *electrodes*) of a battery, electric forces are suddenly exerted on every charged particle in the wire (Figure 8.28). Chemical processes in the battery cause its electrodes to be permanently charged, positively and negatively, and these charged electrodes exert electric forces on every charged particle in the wire. These forces produce practically no disturbance of the positively charged copper nuclei, which are fixed in position. But in copper or any other metal, each atom's outermost electrons are nearly free of their parent atom. As soon as these electrons feel the electric forces established by a battery, they all begin to move along the wire. Such a flow of charged particles is called an **electric current.**

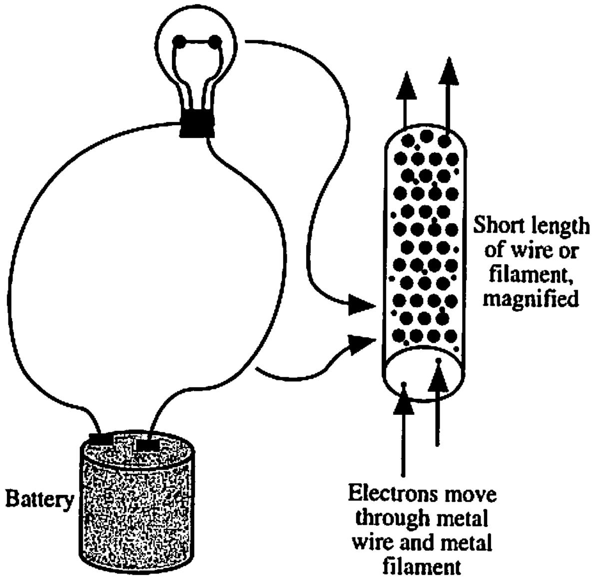


Figure 8.28
A battery produces electrical forces that cause electrons to move through the metal wire.

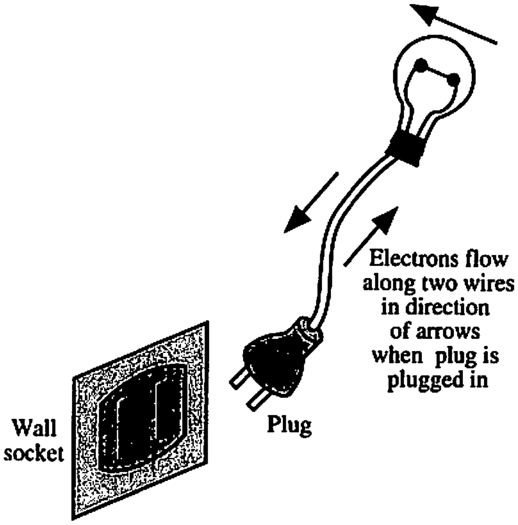


Figure 8.29
Electrical appliances are based on the motion of unseen, microscopic, charged particles called electrons that move through appliances. A wall socket (more precisely, a generating station connected by wires to a wall socket) is the electrical equivalent of a water pump. It "pumps" (energizes) the electrons so that they can flow around the circuit.

If this "electric circuit," from one electrode around to the other electrode, also includes a lightbulb filament (Figure 8.28), electrons will flow through the thin filament and heat it by simply bumping into lots of atoms. The filament becomes so hot that it creates light. All of the standard electrical appliances—toasters, lightbulbs, electric motors, and so forth—are based on the flow of the unseen, microscopic electrons that ordinarily orbit in atoms. Figure 8.28 shows how the process works when a battery is the source of the electric force. Electrical outlets in your home work in a similar way (Figure 8.29).

The magnetic force law says that all magnetic effects come from electric charges in motion, in other words, from electric currents. Where, then, are the electric currents responsible for permanent magnets? The answer is that they are found at the subatomic level, in the motions of electrons in atoms.* Each moving electron in a bar magnet causes its own tiny magnetic force on each moving electron in another bar magnet. In most materials, these tiny magnetic forces cancel one another because the electrons all are oriented differently. But the treatment of the iron when a magnet is made locks many electron orbits into similar orientations. This causes the many atomic-level magnetic forces to add up to a large macroscopic effect, creating the forces you see between permanent magnets.

---

* More precisely, in orbiting and spinning electrons. Electrons not only orbit around a nucleus, but they also spin on their own axis. This spin is a kind of electric current also, with magnetic effects. Electron spin, rather than orbital motion, causes the large effects seen in ordinary magnets.

Permanent magnets can temporarily magnetize objects such as nails by forcing many of the nail's electrons to orient themselves in similar directions. This is why nails are attracted to permanent magnets.

Earth's magnetism is thought to be caused by molten iron and electric currents flowing in Earth's hot interior. Its magnetism is, in turn, responsible for the behavior of compass needles, which are small permanent magnets, and for Earth's other magnetic effects.

The planetary model explains many chemical phenomena. Chemical reactions and other properties of the elements occur because of the behavior of the orbital electrons of the atoms of that element. Table salt, NaCl, makes a good example. Sodium (Na) combines readily with chlorine (Cl) because the Cl atom has a stronger attraction for electrons than does Na, so one electron from Na is attracted to Cl, leaving an overall positive charge on the Na and a negative charge on the Cl. The electric force between opposite charges then attracts and holds the Na and the Cl atoms together.

The property that really defines an "element" is the structure of the electron orbits in the atoms of that element. Two neutral atoms with the same number of electrons have the same chemical properties because their electron orbits have the same structure. The different elements are in fact numbered according to their number of electrons or, what is the same thing, their number of protons. This number is called the element's **atomic number**.

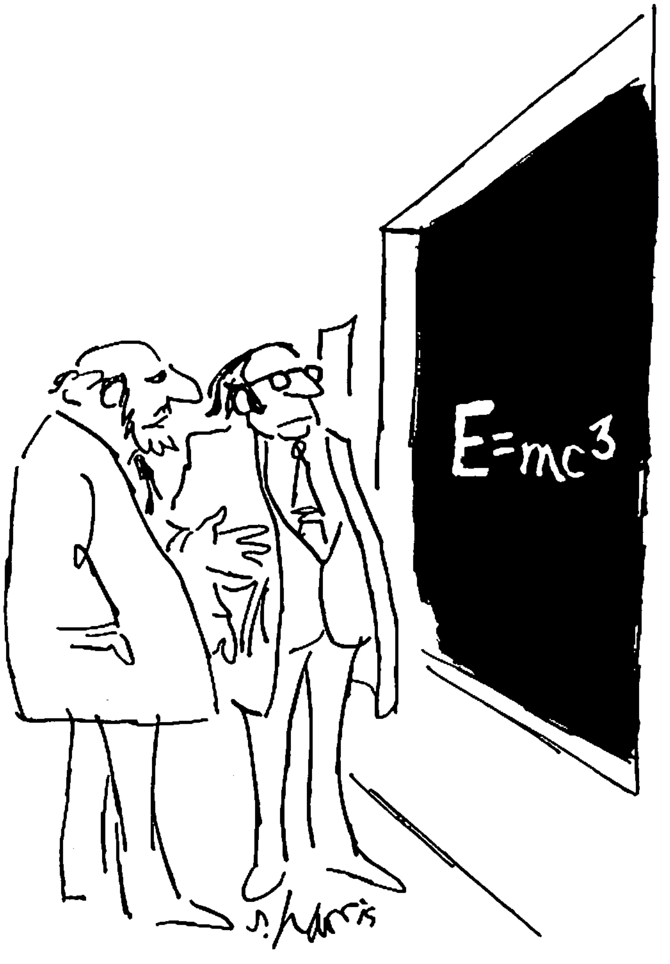
Since an atom is mostly empty space, what keeps solid matter solid? Why don't you fall through the floor, for instance? The planetary model's answer is that the repulsion of electrons by electrons keeps atoms from penetrating one another. Although an atom itself is mostly empty space, it occupies a considerable amount of space because of the forces that its electrons exert on surrounding objects. All contact forces can be interpreted at the microscopic level as forces by the orbital electrons in atoms on the orbital electrons in other atoms. Every time you touch or feel something, you are experiencing the electric force between orbiting electrons! In fact, all the forces in your daily environment come down to just two kinds of forces. The gravitational force explains weight, and the electromagnetic force explains all the contact forces and also the forces between charged or magnetized objects. Just two fundamental forces underlying all ordinary phenomena. This is quite a unification!

Despite the many successes of the planetary model, more recent experiments require it to be replaced with yet another model, the *quantum atom*. Today, the quantum atom is regarded as the correct theory, and the planetary model and the Greek model are regarded as approximations that are useful for many purposes.

DIALOGUE 10 The magnetic north pole of a compass needle points roughly toward Earth's geographic North Pole. What type of magnetic pole must be at Earth's northern end?

---

10. A magnetic *south* pole.



"THESE DAYS EVERYTHING IS HIGHER."

Summary of Ideas and Terms

Wave motion A transfer of energy without a transfer of matter. A disturbance that travels through a **medium.**

Projectile motion or particle motion An actual transfer of matter.

Wavelength The distance from any point to the next similar point along a continuous wave.

Wave frequency The number of vibrations that any part of the medium completes in each second. Also the number of complete wavelengths sent out in each second. Higher-frequency waves have shorter wavelengths and (assuming equal amplitudes) higher energies. Unit: vib/s = **hertz** (Hz).

Amplitude The half-width of vibration of each part of a wave's medium.

Wave speed The speed at which a disturbance (a wave) moves through a medium.

Wave interference The effects that occur when two waves of the same type are present at the same time and place. Interference can be either **constructive** or **destructive,** depending on whether the two waves reinforce or cancel each other.

Double-slit experiment with light The interference of light coming from two synchronized sources is observed on a screen, demonstrating that light is a wave.

Electrically charged object Any object that can exert or feel the electric force. There are two types of charge, **positive** and **negative.**

Electric force law Electrically charged objects exert forces on each other at a distance. Like charges repel each other, and unlike charges attract each other.

Electric current A flow or motion of charged particles. Electric currents in wires are due to electrons moving along the wire.

Magnetic poles The ends of a permanent magnet. There are two types, north and south. Like poles repel, and unlike poles attract.

Magnetic force law Charged objects that are moving exert and feel an additional force, called the **magnetic force**, beyond the electric force that exists when they are at rest.

Electromagnetic force The total (electric and magnetic) force between charges.

Planetary model of the atom Atoms are made of negative **electrons**, positive **protons**, and uncharged **neutrons**. From one to a few hundred protons and neutrons form a tiny central **nucleus**, which the electrons orbit.

Ion Any atom having an excess or deficiency of electrons.

Atomic number The number of protons in an atom. Also the number of electrons in a neutral atom. An atom's atomic number determines its chemical properties and the **element** to which it belongs.

Review Questions

WAVES

1. Describe the motion of the parts of the medium when a wave travels along a rope, along a Slinky, and across the water.
2. What is the difference between wave and projectile motions?
3. What does "hertz" mean?
4. Waves A and B have the same wave speed, but A's wavelength is longer. Which has the larger frequency, or are they the same?
5. Choose the correct answer(s): Two different continuous waves on the surface of a pond would be expected to have roughly the same (wave speeds, wavelengths, frequencies, energies, amplitudes, none of these).

INTERFERENCE

6. Two continuous water waves each have a 2 cm amplitude. What is the water surface's displacement (a) when a crest meets a trough? (b) When crest meets crest? (c) When trough meets trough?
7. Give an example of (a) a one-dimensional medium. (b) A two-dimensional medium. (c) A three-dimensional medium.
8. You tap one finger on the water's surface, on one side of a rectangular pan of water. Describe the waves rolling into the far side. How will the wave pattern at the far side change if you now begin tapping, at the same rate, at two different points, using one tapping finger at each point?

LIGHT

9. Describe the experimental evidence supporting the claim that light is a wave.
10. How would the pattern on the screen in Figure 8.18 change if one of the slits were closed?
11. How do we know that the medium for light waves is not air?

ELECTRIC FORCE, MAGNETIC FORCE

12. When you rub two transparencies with tissue and hold them close together, they stand apart. Give two reasons that the force causing this cannot be gravity.
13. Cite the evidence supporting the claim that there are two, and only two, types of electric charge.
14. Give two reasons that the force between bar magnets cannot be the electric force.
15. What is meant by an "electric current"?
16. Magnetic forces are always caused by what types of objects?

THE PLANETARY ATOM

17. List several phenomena that require the planetary atom, rather than the Greek atom, for their explanation.
18. Name and briefly describe the three kinds of subatomic particles found in atoms.
19. Give evidence supporting the claim that most of an atom's mass is concentrated in a tiny nucleus at the center.
20. Explain what happens at the microscopic level when a battery creates an electric current in a wire.
21. What is an "atomic number," and how is it related to the chemical elements?

Home Projects

1. Float a cork at one end of a tub of water. Drop a pebble into the other end to make a wave that reaches the cork. Observe the cork's motion. Does it vibrate back and forth? Up and down? Try it with larger pebbles. Is there some point at which the water's motion is no longer a true wave?
2. In a tub of still water, drop two small pebbles in at different places. Observe the interference effects as the two spreading circular waves cross. Do they appear to pass through each other without distortion? Try a tiny pebble and a larger pebble. Try tapping one finger at the water's edge to produce a continuous wave.
3. Use a razor blade to cut a thin slit in an index card, a millimeter or less in width and a few centimeters long. Look at a well-lit wall or other surface through the slit, focusing on the wall. Hold the card at an angle to narrow the width through which light can come. You should see rather striking light and dark lines running parallel to the long dimension of the slit. What causes these lines?
4. Ask a friend to stand at the far end of a carpeted room. Scuff your way across the rug until your noses are close together. What happens? Do you get a stronger effect when either of you are barefoot or when wearing shoes? Would the weather make any difference? Try touching wood, metal, and plaster. Explain any differences.

Exercises

WAVES

1. Is a mountain stream rushing downhill an example of wave motion? Defend your answer.
2. A gust of wind moves across a wheat field, causing a noticeable ripple that crosses the field. Is this ripple a wave? If not, why not? If so, then what is the medium?
3. When you send a brief wave down a rope or Slinky, it eventually dies out. What has become of the energy?
4. A cork floats on the water as a water wave passes by. What happens to the cork? Will the cork's vibrational frequency be related to the water wave's frequency, and if so, how?
5.*If you doubled the wavelength of a wave without changing its wave speed, what would happen to the frequency? What if you halved the wavelength?

INTERFERENCE

6. The two waves shown in Figure 8.30 are moving toward each other along a string. Sketch the string during the interference of the two waves.

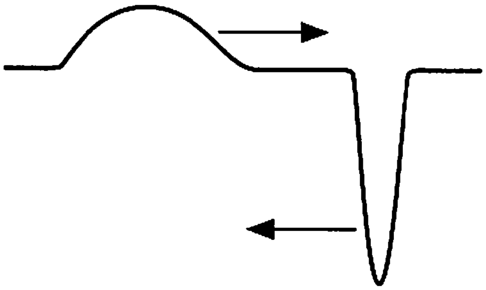


Figure 8.30
How will the two waves interfere?

7. Suppose the frequency of the waves in Figure 8.12 is 1 Hz. Describe the appearance of the water surface one-half second later (one-half second after the snapshot was taken). One second later.
8. What happens to the energy of the two waves in Figure 8.9 when they interfere destructively, as shown in the second of the three sketches? Did the energy vanish? (*Hint*: What are the parts of the rope doing as the wave moves? Which type of energy is the wave carrying?)
9. Two small sources of water waves send out circular waves. Each source produces waves whose amplitudes are 1.5 cm. What is the water level (relative to the undisturbed level) at the point where crest meets crest? Where trough meets trough? Where trough meets crest?

LIGHT

10. Do waves of any sort travel to Earth from the moon? Explain.
11. How do you know that light is not something that comes out of your eyes?
12. You shine two flashlights on a wall. Why don't you see an interference pattern?
13. Which of these objects are luminous (light sources), during their normal operation: camera, polished chrome, firefly, electric stove heating element, camera flashbulb, mirror, diamond, sun, moon?
14.*Making estimates. Estimate the number of wavelengths of light in 1 millimeter.

ELECTRIC FORCE, MAGNETIC FORCE

15. Since matter is made of electrically charged particles, why don't we and the objects around us feel electric forces all the time?
16. When you remove a wool dress from a garment bag, the sides of the bag might stick together. Explain.

17. Figure 8.31 shows an "electroscope." The leaves (made of metal foil) normally hang down, but they spread apart when the metal sphere on top touches a charged object. Explain.

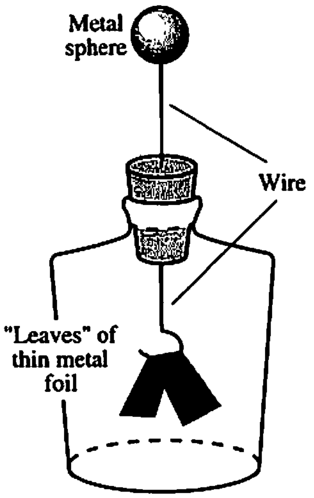


Figure 8.31
Why do the leaves stand apart?

18. How does the operation of the electroscope (previous exercise) demonstrate electrical conduction?
19. You have three iron bars, only two of which are permanent magnets. Because of temporary magnetization (Section 8.7), all three bars at first appear to be magnetized. How can you determine which one is not magnetized, without using any other objects?

THE PLANETARY ATOM

20. While brushing your hair, you find that the hairs tend to stand apart from one another and that they are attracted toward the brush. Explain this in microscopic terms.
21. A covered mystery shoebox is placed on a table. What are a few ways that you could learn something about its contents without directly touching it or having it lifted?
22. After you walk across a rug and scuff electrons off the rug, are you positively or negatively charged?
23. According to Figure 8.24, what are the atomic numbers of carbon and helium? Roughly how much more massive is the carbon atom than the helium atom?
24. Some science fiction stories portray atoms as true miniature solar systems populated by tiny creatures. What are some differences, other than size, between our solar system and the planetary model of an atom?
25. An atom loses its two outermost electrons. How does the resulting ion behave when it is near a positively charged transparency? A negatively charged tissue? Would anything be different if it lost only one electron?

26.*Making estimates. About how many atoms thick is a sheet of paper?

27.*Making estimates. Which is bigger, an atom or a wavelength of light? Roughly how much bigger?