Chapter 20 Organizer

Section/Objectives	Standards: National	Standards: State/Local	Lab and Demo Planning
Chapter Opener	See page 14T for a key to the standards.		
Section 20.1 1. **Demonstrate** that charged objects exert forces, both attractive and repulsive. 2. **Recognize** that charging is the separation, not the creation, of electric charges. 3. **Describe** the differences between conductors and insulators.	UCP.1, UCP.2, UCP.3, A.1, A.2, B.2, B.4, B.6		**Student Lab:** **Launch Lab,** p. 541: plastic ruler, piece of wool, 15–20 scraps of paper from a hole punch
Section 20.2 4. **Summarize** the relationships between electric forces, charges, and distance. 5. **Explain** how to charge objects by conduction and induction. 6. **Develop** a model of how charged objects can attract a neutral object. 7. **Apply** Coulomb's law to problems in one and two dimensions.	UCP.1, UCP.2, UCP.3, A.1, A.2, B.4, B.6, E.1, G.2, G.3		**Student Lab:** **Mini Lab,** p. 549: balloon, wool, electroscope **Additional Mini Lab,** p. 552: Van de Graaff generator, stack of light aluminum pie pans (small ones), crispy cereal that has become stale **Design Your Own Physics Lab,** pp. 554–555: 15-cm plastic ruler; thread; ring stand with ring; masking tape; materials to be charged such as rubber rods, plastic rods, glass rods, PVC pipe, copper pipe, steel pipe, pencils, pens, wool, silk, plastic wrap, plastic sandwich bags, waxed paper, and aluminum foil **Teacher Demonstration:** **Quick Demo,** p. 547: electroscope, computer monitor or television with CRT **Quick Demo,** p. 551: one metal cup, one intact polystyrene cup, one polystyrene cup broken into small pieces, a Van de Graaff generator

Differentiated Instruction

L1 Level 1 activities should be appropriate for students with learning difficulties.

L2 Level 2 activities should be within the ability range of all students.

L3 Level 3 activities are designed for above-average students.

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Assessment Resources

FAST FILE Chapters 16–20 Resources, Chapter 20
Chapter Assessment, pp. 165–170

Additional Challenge Problems, p. 20
Physics Test Prep, pp. 39–40
Pre-AP/Critical Thinking, pp. 39–40
Supplemental Problems, pp. 39–40

Technology

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Chapter 20

Static Electricity

Chapter Overview

This chapter introduces the electrostatic force through simple experiments with everyday objects. Because both attraction and repulsion between charged surfaces are observed, it can be concluded that there are two distinct kinds of charge, called negative and positive. Coulomb's law states that the strength of the electrostatic force between point charges depends directly on the magnitude of the charges and on the inverse square of the distance separating them.

Think About This

The mechanisms that cause lightning are not completely understood and are an area of active research. It is known that lightning plays a critical role in maintaining the electrical characteristics of Earth. See page 545 and the Discussion topic on page 548 for more details.

▶ Key Terms

Chapter 20

Static Electricity

What You'll Learn

- You will observe the behavior of electric charges and analyze how these charges interact with matter.
- You will examine the forces that act between electric charges.

Why It's Important

Static electricity enables the operation of devices such as printers and copiers, but it has harmful effects on electronic components and in the form of lightning.

Lightning The tiny spark that you experience when you touch a doorknob and the dazzling display of lightning in a storm are both examples of the discharge of static electricity. The charging processes and the means of discharging are vastly different in scale, but they are similar in their fundamental nature.

Think About This ▶

What causes charge to build up in a thundercloud, and how does it discharge in the form of a spectacular lightning bolt?

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Kent Wood/Photo Researchers

LAUNCH Lab

Purpose to introduce the forces of attraction and repulsion between static charges

Materials plastic ruler, piece of wool, 15 to 20 scraps of paper from a hole punch

Teaching Strategies ***CAUTION: All students should wear eye protection. Also, make sure that students who are allergic to wool do not handle it.***

- For the lab to work well, students should adequately charge their rulers.
- Don't discuss the resulting activity of the paper until students have had time to form their own hypotheses.

Expected Results At first, a few scraps jump up and stick to the ruler; some of these scraps will collect the same charge as the ruler and then be flung from it. This effect will not be the same for all the scraps; some might cling and then simply drop.

LAUNCH Lab

Which forces act over a distance?

Question

What happens when a plastic ruler is rubbed with wool and then brought near a pile of paper scraps?

Procedure

1. Place 15-20 scraps of paper from a hole punch on the table.
2. Take a plastic ruler and rub it with a piece of wool.
3. Bring the ruler close to the pieces of paper. Observe the effect the ruler has on the scraps of paper.

Analysis

What happens to the pieces of paper when the ruler is brought close to them? What happens to the pieces of paper that come in contact with the ruler? Did you observe any unexpected results when the ruler was brought close to the paper scraps? If so, describe these results.

Critical Thinking

What forces are acting on the pieces of paper before the ruler is brought close to them? What can you infer about the forces on the paper after the ruler is brought near?

Based on your answers to the previous questions, form a hypothesis that explains the effect the ruler has on the scraps of paper.

20.1 Electric Charge

You may have had the experience of rubbing your shoes on a carpet to create a spark when you touched someone. In 1752, Benjamin Franklin set off a flurry of research in the field of electricity when his famous kite experiment showed that lightning is similar to the sparks caused by friction. In his experiment, Franklin flew a kite with a key attached to the string. As a thunderstorm approached, the loose threads of the kite string began to stand up and repel one another, and when Franklin brought his knuckle close to the key, he experienced a spark. Electric effects produced in this way are called static electricity.

In this chapter, you will investigate **electrostatics,** the study of electric charges that can be collected and held in one place. The effects of electrostatics are observable over a vast scale, from huge displays of lightning to the submicroscopic world of atoms and molecules. Current electricity, which is produced by batteries and generators, will be explored in later chapters.

▶ **Objectives**

- **Demonstrate** that charged objects exert forces, both attractive and repulsive.
- **Recognize** that charging is the separation, not the creation, of electric charges.
- **Describe** the differences between conductors and insulators.

▶ **Vocabulary**

electrostatics
neutral
insulator
conductor

Analysis When the charged ruler is brought close to the scraps of paper, it attracts them. The pieces of paper that come in contact with the ruler are then repelled. Some students may not expect the ruler to attract the pieces of paper only to fling them off upon actual contact.

Critical Thinking Initially, the force of gravity and the normal force of the table pushing upward are the only forces acting on the scraps of paper. Because these forces are in balance, the scraps do not move. When the charged ruler is brought near the scraps, introducing an electric force, the forces acting on the scraps are no longer in balance. Opposite charges attract, so the scraps move toward the ruler. When a scrap of paper touches the charged ruler, however, some of the charge on the ruler is transferred to that scrap of paper. The result is that the ruler and the scrap of paper have like charges, hence they repel, and the scrap is flung off the ruler.

1 FOCUS

Bellringer Activity

Squirrelly Tape Before proceeding, please note that most static electric charge demonstrations work best when the indoor atmosphere is very dry. Obtain a dispenser containing a roll of wide transparent tape. Cut a 25-cm strip from the roll. Dangle the strip with one end stuck to a finger in such a way that everyone can see how the strip moves. Ask students what happens when the strip comes near a surface. The strip bends toward an uncharged surface. This happens because it acquires charge as it is removed from the roll and induces an opposite charge when it comes near an uncharged surface. **L1 Visual-Spatial**

Tie to Prior Knowledge

Force The acceleration of the tape is evidence of the presence of a force. The effect of an applied net force on the motion of an object is explored in Chapter 6. The acceleration of a charged object indicates that static electricity is able to produce a net force.

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2 TEACH

Concept Development

Comparison with Gravity Help students further investigate fundamental forces of nature that act at a distance without contact. They now will be familiar with two such forces: electric force and gravitation. The two have important differences. The relative strength of the electric force between common objects can be much, much larger than the gravitational force. In fact, only celestial bodies, including the Sun, the Moon, and Earth, are of a scale sufficient to produce easily observable gravitational attraction. The force of gravity between ordinary-sized objects is very small, and can be detected only by extremely sensitive equipment. Electric force can be either attractive or repulsive. In contrast, gravitation always appears to be attractive to the ordinary observer.

Identifying Misconceptions

How Charging Occurs The idea that friction between objects is required to give them static charges is not true. What is required is that two different kinds of electric insulators come into contact and then separate. Some of the materials used in this chapter never need to be rubbed to become charged. For example, charge separates when the adhesive backing of transparent tape is peeled away from the nonadhesive surface on the roll. The details of how objects become charged are still an area of active inquiry; most answers are unknown.

Charged Objects

Have you ever noticed the way that your hair is attracted to the comb when you comb your hair on a dry day or the way that your hair stands on end after it is rubbed with a balloon? Perhaps you also have found that socks sometimes stick together when you take them out of a clothes dryer. If so, you will recognize the attraction of the bits of paper to a plastic ruler demonstrated by the Launch Lab and shown in **Figure 20-1.** You might have noticed the way the paper pieces jumped up to the ruler as you worked through the Launch Lab. There must be a new, relatively strong force causing this upward acceleration because it is larger than the downward acceleration caused by the gravitational force of Earth.

There are other differences between this new force and gravity. Paper is attracted to a plastic ruler only after the ruler has been rubbed; if you wait a while, the attractive property of the ruler disappears. Gravity, on the other hand, does not require rubbing and does not disappear. The ancient Greeks noticed effects similar to that of the ruler when they rubbed amber. The Greek word for amber is *elektron*, and today this attractive property is called electric. An object that exhibits electric interaction after rubbing is said to be charged.

Like charges You can explore electric interactions with simple objects, such as transparent tape. Fold over about 5 mm of the end of a strip of tape for a handle, and then stick the remaining 8- to 12-cm-long part of the tape strip on a dry, smooth surface, such as your desktop. Stick a second, similar piece of tape next to the first. Quickly pull both strips off the desk and bring them near each other. A new property causes the strips to repel each other: they are electrically charged. Because they were prepared in the same way, they must have the same type of charge. Thus, you have demonstrated that two objects with the same type of charge repel each other.

Figure 20-1 Rubbing a plastic ruler with wool produces a new force of attraction between the ruler and bits of paper. When the ruler is brought close to bits of paper, the attractive electric force accelerates the paper bits upward against the force of gravity.

You can learn more about this charge by doing some simple experiments. You may have found that the tape is attracted to your hand. Are both sides attracted, or just one? If you wait a while, especially in humid weather, you will find that the electric charge disappears. You can restore it by again sticking the tape to the desk and pulling it off. You also can remove its charge by gently rubbing your fingers down both sides of the tape.

Opposite charges Now, stick one strip of tape on the desk and place the second strip on top of the first. As shown in **Figure 20-2a,** use the handle of the bottom strip of tape to pull the two off the desk together. Rub them with your fingers until they are no longer attracted to your hand. You now have removed all the electric charge. With one hand on the handle of one strip and the other on the handle of the second strip, quickly pull the two strips apart. You will find that they are now both charged. They once again are attracted to your hands. Do they still repel each other? No, they now attract each other. They are charged, but they are no longer charged alike. They have opposite charges and therefore attract each other.

StudiOhio

20.1 Resource MANAGER

FAST FILE Chapters 16–20 Resources
- Transparency 20–1 Master, p. 157
- Study Guide, pp. 146–147
- Reinforcement, p. 153
- Section 20–1 Quiz, p. 151

Teaching Transparency 20-1
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Is tape the only object that you can charge? Once again, stick one strip of tape to the desk and the second strip on top. Label the bottom strip *B* and the top strip *T*. Pull the pair off together. Discharge them, then pull them apart. Stick the handle end of each strip to the edge of a table, the bottom of a lamp shade, or some similar object. The two should hang down a short distance apart. Finally, rub a comb or pen on your clothing and bring it near one strip of tape and then the other. You will find that one strip will be attracted to the comb, while the other will be repelled by it, as shown in **Figure 20-2b.** You now can explore the interactions of charged objects with the strips of tape.

■ **Figure 20-2** Strips of tape can be given opposite charges **(a)** and then be used to demonstrate the interactions of like and opposite charges **(b).**

Experimenting with charge Try to charge other objects, such as glasses and plastic bags. Rub them with different materials, such as silk, wool, and plastic wrap. If the air is dry, scuff your shoes on carpet and bring your finger near the strips of tape. To test silk or wool, slip a plastic bag over your hand before holding the cloth. After rubbing, take your hand out of the bag and bring both the bag and cloth near the strips of tape.

Most charged objects will attract one strip and repel the other. You will never find an object that repels both strips of tape, although you might find some that attract both. For example, your finger will attract both strips. You will explore this effect later in this chapter.

Types of charge From your experiments, you can make a list of objects labeled *B*, for bottom, which have the same charge as the tape stuck on the desk. Another list can be made of objects labeled *T*, which have the same charge as the top strip of tape. There are only two lists, because there are only two types of charge. Benjamin Franklin called them positive and negative charges. Using Franklin's convention, when hard rubber and plastic are rubbed, they become negatively charged. When materials such as glass and wool are rubbed, they become positively charged.

Just as you showed that an uncharged pair of tape strips became oppositely charged, you probably were able to show that if you rubbed plastic with wool, the plastic became negatively charged and the wool positively charged. The two kinds of charges were not created alone, but in pairs. These experiments suggest that matter normally contains both charges, positive and negative. Contact in some way separates the two. To explore this further, you must consider the microscopic picture of matter.

Color Convention

- Positive charges are shown in **red.**
- Negative charges are shown in **blue.**

A Microscopic View of Charge

Electric charges exist within atoms. In 1897, J.J. Thomson discovered that all materials contain light, negatively charged particles that he called electrons. Between 1909 and 1911, Ernest Rutherford, a student of Thomson from New Zealand, discovered that the atom has a massive, positively charged nucleus. When the positive charge of the nucleus equals the negative charge of the surrounding electrons, then the atom is **neutral.**

Tom Pantages

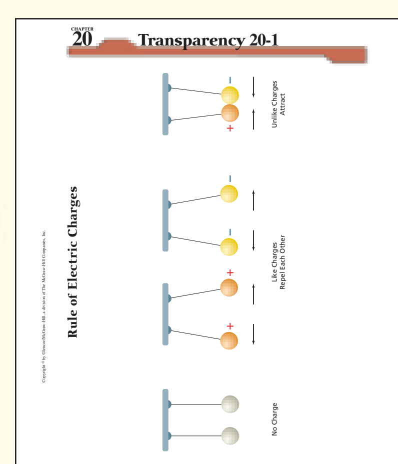
Reinforcement

Summary Table Have students create a table summarizing their observations with charged strips of transparent tape. The table should relate the behavior of the bottom strip, *B*, and top strip, *T*, to any tests performed and with positive and negative charge conventions. A check mark is placed in the column under either *B* or *T* for each tested object depending on which is repelled by the object. A plastic comb becomes negatively charged when rubbed. Use this example to establish the +/− convention. **L2 Linguistic**

Critical Thinking

Forces on Protons The positively charged protons in the nucleus of a multi-proton atom balance its negatively charged electrons so that the atom is neutral. But the protons are packed together inside the nucleus, and like charges have been shown to repel each other. Ask students what must be true of the net interproton forces within a nucleus that prevent the protons from flying apart. An attractive force strong enough to overcome repulsion must exist within the nucleus. This attractive force can operate only at very small distances. (This internucleon attraction is called the *strong force*.) **L2**

Page 157, FAST FILE Chapters 16–20 Resources



Teacher F.Y.I. **CONTENT BACKGROUND**

Elementary Charge Rutherford was the first to propose the concept of atomic structure we hold today—that atoms have a tiny central structure with positive charge surrounded by orbital electrons with negative charge. Robert Millikan, a contemporary of Rutherford's, showed in a clever experiment with oil drops that charge comes in integral units. In other words, charge is quantized. By definition, an electron carries a charge of −1, while a proton carries a charge of +1. Later in this chapter, the value of the elementary charge in Coulombs (C, the SI unit of charge) is given as 1.60×10^{-19} C. Millikan was the first to obtain a measurement of this value. Chapter 21 includes an extended discussion of Millikan's experiment.

Using an Analogy

Separation of Painted Surfaces Ask students to imagine two pieces of cardboard, one with a thin coat of wet paint and the other with no paint. Now suppose that the painted surface contacts the unpainted one, and then the two pieces of cardboard are again separated. Ask what would happen. Some of the paint would stick to the previously unpainted surface, while the original painted surface would lose some paint. If the original conditions were considered to be a balanced situation for both surfaces, the new conditions leave both surfaces in an unbalanced situation. This is similar to the way electrons shift to create unbalanced charge through contact and separation of two different insulating surfaces. L2

APPLYING PHYSICS

There are many other examples of substances that act as either electric conductors or insulators, depending upon the conditions. Air is a poor conductor until it is ionized by a strong electric field. Then it becomes a plasma, a gaslike state that easily conducts electricity (see Chapter 13). In another example, the addition of dissolved salt to water increases the conductivity of the solution, even though neither substance is a good conductor on its own.

ACTIVITY

Insulators and Conductors Bring in a variety of small electric parts, such as a piece of cable, plug adaptor, computer connectors, and a circuit board with ceramic pieces for the students to observe. Have them identify which aspects of the assemblies are the conductors and which are the insulators. Have them think of additional applications, such as a metal pan with plastic handle.
L2 **Visual-Spatial**

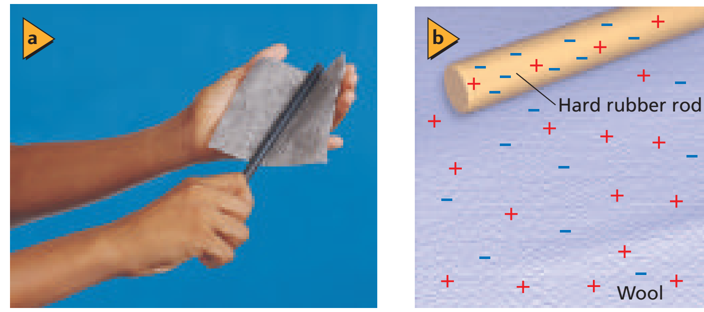


Figure 20-3 When wool is used to charge a rubber rod, electrons are removed from the wool atoms and cling to the rubber atoms. In this way, both objects become charged.

Horizons Companies

With the addition of energy, the outer electrons can be removed from atoms. An atom missing electrons has an overall positive charge, and consequently, any matter made of these electron-deficient atoms is positively charged. The freed electrons can remain unattached or become attached to other atoms, resulting in negatively charged particles. From a microscopic viewpoint, acquiring charge is a process of transferring electrons.

Separation of charge If two neutral objects are rubbed together, each can become charged. For instance, when rubber and wool are rubbed together, electrons from atoms on the wool are transferred to the rubber, as shown in **Figure 20-3.** The extra electrons on the rubber result in a net negative charge. The electrons missing from the wool result in a net positive charge. The combined total charge of the two objects remains the same. Charge is conserved, which is one way of saying that individual charges never are created or destroyed. All that happens is that the positive and negative charges are separated through a transfer of electrons.

Complex processes that affect the tires of a moving car or truck can cause the tires to become charged. Processes inside a thundercloud can cause the cloud bottom to become negatively charged and the cloud top to become positively charged. In both these cases, charge is not created, but separated.

APPLYING PHYSICS

Conductor or Insulator? It might be tempting to classify an element as solely a conductor or solely an insulator, but the classification can change depending on the form the element takes. For example, carbon in the form of diamond is an insulator, but carbon in the form of graphite can conduct charge. This is because the carbon atoms in diamonds are tightly bonded to four other carbons, while the carbon atoms in graphite form three stronger bonds and a fourth, weaker bond that allows electrons a limited amount of movement. As a result, graphite is a much better conductor than diamond, even though both are simply carbon atoms.

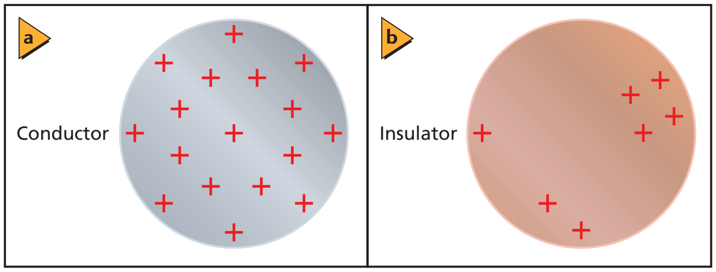
Conductors and Insulators

Hold a plastic rod or comb at its midpoint and rub only one end. You will find that only the rubbed end becomes charged. In other words, the charges that you transferred to the plastic stayed where they were put; they did not move. A material through which a charge will not move easily is called an electric **insulator.** The strips of tape that you charged earlier in this chapter acted in this way. Glass, dry wood, most plastics, cloth, and dry air are all good insulators.

Suppose that you support a metal rod on an insulator so that it is isolated, or completely surrounded by insulators. If you then touch the charged comb to one end of the metal rod, you will find that the charge spreads very quickly over the entire rod. A material that allows charges to move about easily is called an electric **conductor.** Electrons carry, or conduct, electric charge through the metal. Metals are good conductors because at least one electron on each atom of the metal can be removed easily. These electrons act as if they no longer belong to any one atom, but to the metal as a whole; consequently, they move freely throughout the piece of metal. **Figure 20-4** contrasts how charges behave when they are

DIFFERENTIATED INSTRUCTION — Activity

Physically Challenged If a student is challenged by tasks requiring fine motor skills, manipulation of strips of transparent tape could be difficult. In this case, it is possible to make a charge tester with two inflated balloons. Tie each balloon to one end of a 20- to 25-cm-long piece of string. Fasten the other end of the string to a stick. Keep balloons near each other but not touching. The student charges each balloon by rubbing it with a piece of plastic wrap and observes that the balloons repel each other. Before proceeding, the student should touch the balloon all over to remove the charge. The student then rubs one balloon with plastic wrap and the other with a piece of wool and observes that the balloons attract. L1



■ **Figure 20-4** Charges placed on a conductor will spread over the entire surface **(a).** Charges placed on an insulator will remain where they are placed **(b).**

placed on a conductor with how they behave on an insulator. Copper and aluminum are both excellent conductors and are used commercially to carry electricity. Plasma, a highly ionized gas, and graphite also are good conductors of electric charge.

When air becomes a conductor Air is an insulator; however, under certain conditions, charges move through air as if it were a conductor. The spark that jumps between your finger and a doorknob after you have rubbed your feet on a carpet discharges you. In other words, you have become neutral because the excess charges have left you. Similarly, lightning discharges a thundercloud. In both of these cases, air became a conductor for a brief moment. Recall that conductors must have charges that are free to move. For a spark or lightning to occur, freely moving charged particles must be formed in the normally neutral air. In the case of lightning, excess charges in the cloud and on the ground are great enough to remove electrons from the molecules in the air. The electrons and positively or negatively charged atoms form a plasma, which is a conductor. The discharge of Earth and the thundercloud by means of this conductor forms a luminous arc called lightning. In the case of your finger and the doorknob, the discharge is called a spark.

20.1 Section Review

1. **Charged Objects** After a comb is rubbed on a wool sweater, it is able to pick up small pieces of paper. Why does the comb lose that ability after a few minutes?
2. **Types of Charge** In the experiments described earlier in this section, how could you find out which strip of tape, B or T, is positively charged?
3. **Types of Charge** A pith ball is a small sphere made of a light material, such as plastic foam, often coated with a layer of graphite or aluminum paint. How could you determine whether a pith ball that is suspended from an insulating thread is neutral, is charged positively, or is charged negatively?
4. **Charge Separation** A rubber rod can be charged negatively when it is rubbed with wool. What happens to the charge of the wool? Why?
5. **Conservation of Charge** An apple contains trillions of charged particles. Why don't two apples repel each other when they are brought together?
6. **Charging a Conductor** Suppose you hang a long metal rod from silk threads so that the rod is isolated. You then touch a charged glass rod to one end of the metal rod. Describe the charges on the metal rod.
7. **Charging by Friction** You can charge a rubber rod negatively by rubbing it with wool. What happens when you rub a copper rod with wool?
8. **Critical Thinking** It once was proposed that electric charge is a type of fluid that flows from objects with an excess of the fluid to objects with a deficit. Why is the current two-charge model better than the single-fluid model?

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■ **Using Figure 20-4**

Explain that the even distribution of charge on the conductor could be disturbed if another charged object is brought nearby. Positive and negative charges separate if an external charge approaches because electrons move very easily. On an insulating surface, even though charges are much less free to move, molecules near the surface of the material can become polarized. L2

3 ASSESS

Check for Understanding

Type of Charge Ask students whether or not two uncharged objects can acquire the same type of charge when rubbed together. How could you do a simple experiment to verify your answer? The objects always acquire different types of charge. One object gains negative charge, the other loses it. The charge on each object may be tested with a strip of transparent tape freshly removed from a roll. It should be attracted to one of the objects but repelled by the other. L2

Extension

Conductors and Insulators Under certain conditions, charges can move through a substance that is ordinarily an insulator. What is one such example? lightning During a lightning storm, what is it about staying inside a car that makes it safe? It is not the rubber tires on a car that protect you, but the fact that charges added to a conductor quickly spread over the surface of the object; charges do not come inside the car. L2

20.1 Section Review

1. It loses its charge to its surroundings.
2. Bring a positively charged glass rod near the strips. The one repelled is positive.
3. Bring an object of known negative charge near the pith ball. If the ball is repelled, it has the same charge as the rod. If it is attracted, it may have the opposite charge or be neutral. Then bring a positively charged glass rod near the pith ball. If they repel, the pith ball is positive; if they attract, the pith ball is neutral.
4. The wool becomes positively charged.
5. Each apple contains equal numbers of positive and negative charges.
6. The glass rod attracts electrons from the metal rod, so the metal becomes positively charged. The charge is distributed uniformly along the rod.
7. Copper is a conductor, it stays neutral as long as it is contacting your hand.
8. The two-charge model can better explain attraction and repulsion. It also explains how objects can become charged when they are rubbed together.

Section 20.2

1 FOCUS

Bellringer Activity

Electric Torque Suspend a wooden ruler by a string and make it still. Bring a neutral rod near the ruler. Then bring a charged rod near the ruler. Students should observe that the charged rod makes the ruler rotate. Have students discuss why a charged rod might cause the neutral ruler to turn.
L1 Visual-Spatial

Tie to Prior Knowledge

Force and Gravitation Electrostatic force is described as long-range in Chapter 6 because it operates over a distance without contact. Bodies subject to electric force obey Newton's laws. Coulomb's law for the electrostatic force between point charges is similar in mathematical form to the law of universal gravitation studied in Chapter 7. Both are inverse square laws because the magnitude of force decreases with the square of separation distance.

2 TEACH

Concept Development

- **Net Force** Because the attractive and repulsive forces are vectors, when more than one charge exerts a force on another charge, the net force on that charge is the vector sum of the individual forces.
- **Storing Charge** A Leyden jar, the precursor of the capacitor (and a topic for student research) can store electric charges. A Leyden jar may be used to carry charges from one material to another.

20.2 Electric Force

Objectives

- **Summarize** the relationships between electric forces, charges, and distance.
- **Explain** how to charge objects by conduction and induction.
- **Develop** a model of how charged objects can attract a neutral object.
- **Apply** Coulomb's law to problems in one and two dimensions.

Vocabulary

electroscope
charging by conduction
charging by induction
grounding
Coulomb's law
coulomb
elementary charge

Electric forces must be strong because they can easily produce accelerations larger than the acceleration caused by gravity. You also have learned that they can be either repulsive or attractive, while gravitational forces always are attractive. Over the years, many scientists made attempts to measure electric forces. Daniel Bernoulli, best known for his work with fluids, made some crude measurements in 1760. In the 1770s, Henry Cavendish showed that electric forces must obey an inverse square force law, but being extremely shy, he did not publish his work. His manuscripts were discovered over a century later, after all his work had been duplicated by others.

Forces on Charged Bodies

The forces that you observed on tape strips also can be demonstrated by suspending a negatively charged, hard rubber rod so that it turns easily, as shown in **Figure 20-5.** If you bring another negatively charged rod near the suspended rod, the suspended rod will turn away. The negative charges on the rods repel each other. It is not necessary for the rods to make contact. The force, called the electric force, acts at a distance. If a positively charged glass rod is suspended and a similarly charged glass rod is brought close, the two positively charged rods also will repel each other. If a negatively charged rod is brought near a positively charged rod, however, the two will attract each other, and the suspended rod will turn toward the oppositely charged rod. The results of your tape experiments and these actions of charged rods can be summarized in the following way:

- There are two kinds of electric charges: positive and negative.
- Charges exert forces on other charges at a distance.
- The force is stronger when the charges are closer together.
- Like charges repel; opposite charges attract.

Neither a strip of tape nor a large rod that is hanging in open air is a very sensitive or convenient way of determining charge. Instead, a device called an electroscope is used. An **electroscope** consists of a metal knob connected by a metal stem to two thin, lightweight pieces of metal foil, called leaves. **Figure 20-6** shows a neutral electroscope. Note that the leaves hang loosely and are enclosed to eliminate stray air currents.

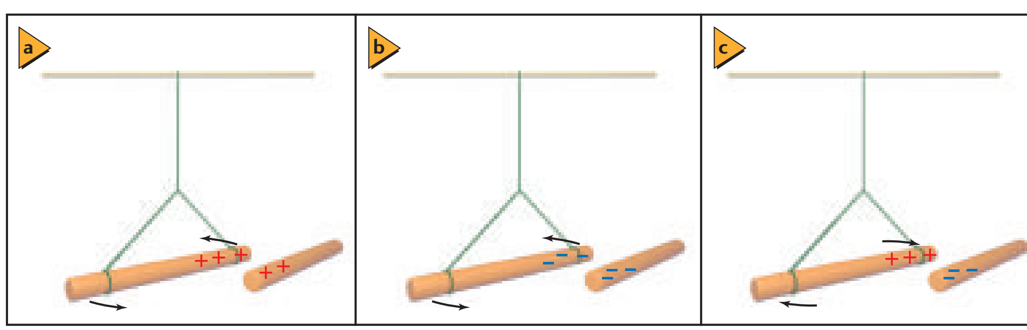

Figure 20-5 A charged rod, when brought close to another charged and suspended rod, will attract or repel the suspended rod.

20.2 Resource MANAGER

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physicspp.com/vocabulary_puzzlemaker

Charging by conduction When a negatively charged rod is touched to the knob of an electroscope, electrons are added to the knob. These charges spread over all the metal surfaces. As shown in **Figure 20-7a,** the two leaves are charged negatively and repel each other; therefore, they spread apart. The electroscope has been given a net charge. Charging a neutral body by touching it with a charged body is called **charging by conduction.** The leaves also will spread apart if the electroscope is charged positively. How, then, can you find out whether the electroscope is charged positively or negatively? The type of charge can be determined by observing the leaves when a rod of known charge is brought close to the knob. The leaves will spread farther apart if the rod and the electroscope have the same charge, as shown in **Figure 20-7b.** The leaves will fall slightly if the electroscope's charge is opposite that of the rod, as in **Figure 20-7c.**

Separation of charge on neutral objects Earlier in this chapter, when you brought your finger near either charged strip of tape, the tape was attracted to your finger. Your finger, however, was neutral—it had equal amounts of positive and negative charge. You know that in conductors, charges can move easily, and that in the case of sparks, electric forces can change insulators into conductors. Given this information, you can develop a plausible model for the force that your finger exerted on the strips of tape.

Suppose you move your finger, or any uncharged object, close to a positively charged object. The negative charges in your finger will be attracted to the positively charged object, and the positive charges in your finger will be repelled. Your finger will remain neutral, but the positive and negative charges will be separated. The electric force is stronger for charges that are closer together; therefore, the separation results in an attractive force between your finger and the charged object. The force that a charged ruler exerts on neutral pieces of paper is the result of the same process, the separation of charges.

The negative charges at the bottom of thunderclouds also can cause charge separation in Earth. Positive charges in the ground are attracted to Earth's surface under the cloud. The forces of the charges in the cloud and those on Earth's surface can break molecules into positively and negatively charged particles. These charged particles are free to move, and they establish a conducting path from the ground to the cloud. The lightning that you observe occurs when a bolt travels at speeds on the order of 500,000 km/h along the conducting path and discharges the cloud.

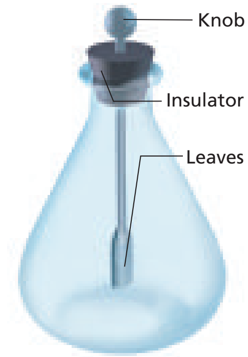


Figure 20-6 An electroscope is a device used for detecting charges. In a neutral electroscope, the leaves hang loosely, almost touching one another.

Figure 20-7 A negatively charged electroscope will have its leaves spread apart **(a).** A negatively charged rod pushes electrons down to the leaves, causing them to spread farther apart **(b).** A positively charged rod attracts some of the electrons, causing the leaves to spread apart less **(c).**

QUICK DEMO

Electroscope and CRT

Estimated Time 5 minutes

Materials electroscope, computer monitor or television with CRT

Procedure

1. Touch a rubber or plastic rod to transfer negative charge onto an electroscope. The leaves should spread.

2. Bring the charged electroscope near the screen of a television that is turned on. What happens?

3. Repeat the procedure but use a charged glass rod. What happens? Why?

In step 2, the leaves should contract slightly. In step 3, they should spread more. The screen should exhibit a positive charge because the front end of a cathode ray tube has a positive charge in order to attract the electrons that are fired at it.

Critical Thinking

Separating Bound Charge

Charge is bound on an insulating surface. Recognizing that even the atoms and molecules of insulating materials are surrounded by negative charge, ask students to propose an explanation for how charge might separate near the surface of such a material. The hint in the question is that atoms and molecules have charge surrounding their fixed positions. Even if electrons in insulators cannot move easily across the material, their positions near their fixed sites could be disturbed by the presence of a nearby external charge. One side of each atom or molecule near the surface of the material could become more negative or more positive than the other. The result would be an effective net charge on the material. (This phenomenon is known as *polarization.*) **L2 Logical-Mathematical**

Teacher F.Y.I. — REAL-LIFE PHYSICS

Controlling Electrostatic Discharge (ESD) Electronic components, especially those that are computer-related, are vulnerable to damage from discharge of static electricity. People may not be aware that they carry a charge sufficient to damage equipment. Technicians who work with sensitive components or explosives use anti-static mats and wear special metal wrist straps that provide a path for charge to flow quickly to ground. This prevents charge from accumulating on the body. To ensure that a person grounded with a wrist strap won't accidentally be electrocuted, a high-value current resistor is placed between the wrist and ground.

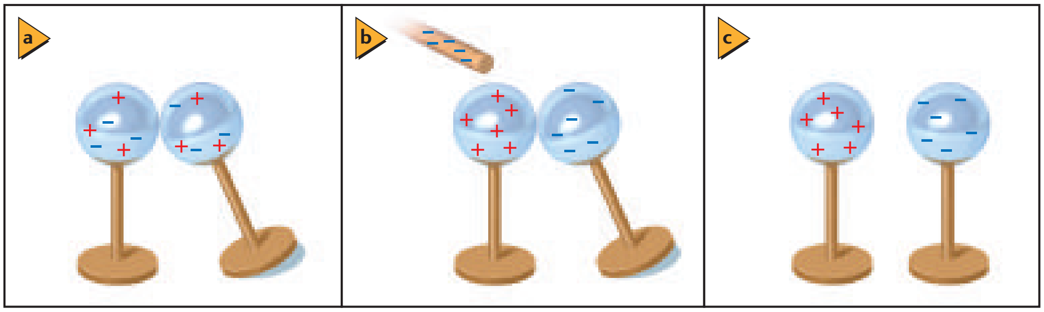
Discussion

Question Earth and its atmosphere act as a giant charge separator. The ground (Earth's surface) carries a negative charge while the conductive layer of the upper atmosphere is positive. What mechanism in the atmosphere maintains this global charge separation?

Answer The answer to this question is counterintuitive. It seems like lightning should discharge Earth because its local effect is usually the discharge of particular clouds where charge imbalance has built up. But it is the worldwide action of lightning in thousands of daily thunderstorms that carries net negative charge to ground, leaving net positive charge in the atmosphere as a whole. Without lightning, this global charge imbalance would not be maintained. Air is not a perfect insulator, so it allows charge to drain off slowly. L2

Using Models

Grounding Activity Ground is a vast supply of charge, usually connected by a conductor to Earth, that is hardly disturbed by nearly any flow of charge. The amount in the flow will be tiny compared to the supply. Use a box full of foam packing peanuts and a charged rod to visualize the nature of ground. A box about 200 cm long by 100 cm wide filled to the top with a few hundred foam peanuts should be enough. When the charged object is brought near the opening of the box, a few of the peanuts will jump up and stick to the object. But this will be a very small number compared to the total number of foam peanuts in the box. The box still looks full. Likewise, shaking a few peanuts (representing charges) back into the box is a negligible change to the total in the box. L1 Visual-Spatial



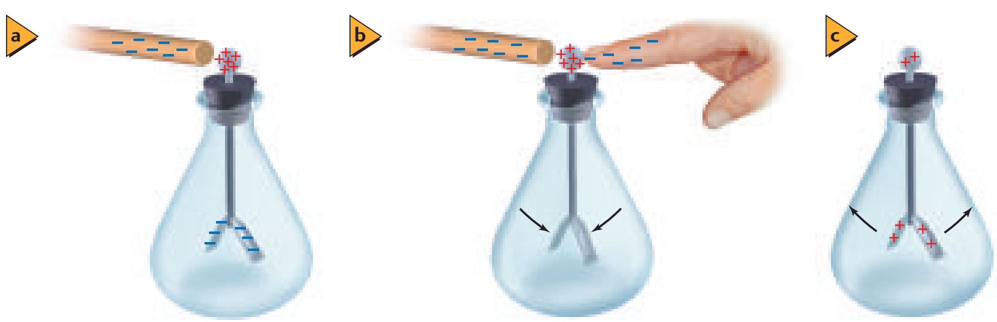
■ **Figure 20-8** One method of charging by induction begins with neutral spheres that are touching **(a).** A charged rod is brought near them **(b),** then the spheres are separated and the charged rod is removed **(c).** The charges on the separated spheres are equal in magnitude, but opposite in sign.

Charging by induction Suppose that two identical, insulated metal spheres are touching, as shown in **Figure 20-8a.** When a negatively charged rod is brought close to one, as in **Figure 20-8b,** electrons from the first sphere will be forced onto the sphere farther from the rod and will make it negatively charged. The closer sphere is now positively charged. If the spheres are separated while the rod is nearby, each sphere will have a charge, and the charges will be equal but opposite, as shown in **Figure 20-8c.** This process of charging an object without touching it is called **charging by induction.**

A single object can be charged by induction through **grounding,** which is the process of connecting a body to Earth to eliminate excess charge. Earth is a very large sphere, and it can absorb great amounts of charge without becoming noticeably charged itself. If a charged body is touched to Earth, almost any amount of charge can flow to Earth.

If a negatively charged rod is brought close to the knob of an electroscope, as in **Figure 20-9a,** electrons are repelled onto the leaves. If the knob is then grounded on the side opposite the charged rod, electrons will be pushed from the electroscope into the ground until the leaves are neutral, as in **Figure 20-9b.** Removing the ground before the rod leaves the electroscope with a deficit of electrons, and it will be positively charged, as in **Figure 20-9c.** Grounding also can be used as a source of electrons. If a positive rod is brought near the knob of a grounded electroscope, electrons will be attracted from the ground, and the electroscope will obtain a negative charge. When this process is employed, the charge induced on the electroscope is opposite that of the object used to charge it. Because the rod never touches the electroscope, its charge is not transferred, and it can be used many times to charge objects by induction.

■ **Figure 20-9** A negatively charged rod induces a separation of charges in an electroscope **(a).** The electroscope is grounded, and negative charges are pushed from the electroscope to the ground **(b).** The ground is removed before the rod, and the electroscope is left with a positive charge **(c).**



Teacher F.Y.I. — CONTENT BACKGROUND

Accumulated Charges Your body can become electrically charged from the friction between your shoes and carpet. If you walk across the floor to greet someone, you may end up giving a small shock instead of a handshake. Static electricity is worse in winter because the air tends to be drier. There are ways to reduce static charge. Avoid wearing the sort of fabrics that readily accumulate charges, such as wool and nylon. Before grasping a metal door handle with your bare hand, touch a key to the metal first to conduct the charge away from their body. You can also reduce shock sensation by tapping the metal handle with your knuckles first. There is still a spark, but not as shocking a one.

Coulomb's Law

You have seen that a force acts between two or more charged objects. In your experiments with tape, you found that the force depends on distance. The closer you brought the charged comb to the tape, the stronger the force was. You also found that the more you charged the comb, the stronger the force was. How can you vary the quantity of charge in a controlled way? This problem was solved in 1785 by French physicist Charles Coulomb. The type of apparatus used by Coulomb is shown in **Figure 20-10.** An insulating rod with small conducting spheres, A and A′, at each end was suspended by a thin wire. A similar sphere, B, was placed in contact with sphere A. When they were touched with a charged object, the charge spread evenly over the two spheres. Because they were the same size, they received equal amounts of charge. The symbol for charge is q. Therefore, the amount of charge on the spheres can be represented by the notation q_A and q_B.

Force depends on distance Coulomb found how the force between the two charged spheres depended on the distance. First, he carefully measured the amount of force needed to twist the suspending wire through a given angle. He then placed equal charges on spheres A and B and varied the distance, r, between them. The force moved A, which twisted the suspending wire. By measuring the deflection of A, Coulomb could calculate the force of repulsion. He showed that the force, F, varied inversely with the square of the distance between the centers of the spheres.

$$F \propto \frac{1}{r^2}$$

Force depends on charge To investigate the way in which the force depended on the amount of charge, Coulomb had to change the charges on the spheres in a measured way. He first charged spheres A and B equally, as before. Then he selected an uncharged sphere, C, of the same size as sphere B. When C was placed in contact with B, the spheres shared the charge that had been on B alone. Because the two were the same size, B then had only half of its original charge. Therefore, the charge on B was only one-half the charge on A. After Coulomb adjusted the position of B so that the distance, r, between A and B was the same as before, he found that the force between A and B was half of its former value. That is, he found that the force varied directly with the charge of the bodies.

$$F \propto q_A q_B$$

After many similar measurements, Coulomb summarized the results in a law now known as **Coulomb's law:** the magnitude of the force between charge q_A and charge q_B, separated by a distance r, is proportional to the magnitude of the charges and inversely proportional to the square of the distance between them.

$$F \propto \frac{q_A q_B}{r^2}$$

The unit of charge: the coulomb The amount of charge that an object has is difficult to measure directly. Coulomb's experiments, however, showed that the quantity of charge could be related to force. Thus, Coulomb could define a standard quantity of charge in terms of the amount of force that it produces. The SI standard unit of charge is called the **coulomb** (C).

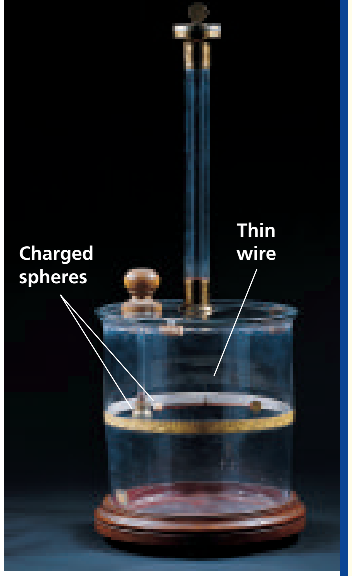


Figure 20-10 Coulomb used a similar type of apparatus to measure the force between two spheres, A and B. He observed the deflection of A while varying the distance between A and B.

MINI LAB

Investigating Induction and Conduction

Use a balloon and an electroscope to investigate charging by induction and charging by conduction.

1. Predict what will happen if you charge a balloon by rubbing it with wool and bring it near a neutral electroscope.

2. Predict what will happen if you touch the balloon to the electroscope.

3. Test your predictions.

Analyze and Conclude

4. Describe your results.

5. Explain the movements of the leaves in each step of the experiment. Include diagrams.

6. Describe the results if the wool had been used to charge the electroscope.

Jose Pessoa-Divisao de Documentacao fotografica do Instituto Portugues de Museus

MINI LAB

Investigating Induction and Conduction

See page 139 of **FAST FILE Chapters 16–20 Resources** *for the accompanying Mini Lab Worksheet.*

CAUTION: Students allergic to latex should use caution if rubber-based balloons are used.

Purpose Students will investigate inducing a charge on a neutral object and transferring charges by contact.

Materials balloon, wool, electroscope

Expected Results Students should observe that the leaves of the electroscope spread when the charged balloon is brought near the knob and when the charged balloon is touched to the knob. After charging, the wool will also cause the leaves of the electroscope to spread.

Analyze and Conclude

4. Students should indicate that the leaves of the electroscope spread apart when a charged object is brought near the electroscope and when the charged object is touched to the knob of the electroscope. Verify that the students' diagrams reflect these observations.

5. In the first part (balloon near a neutral electroscope), the negative charges on the balloon repel electrons onto the leaves of the electroscope. The electroscope hasn't gained or lost charges, but a negative charge has been induced in the leaves. When the balloon is touched to the electroscope, negative charges transfer from the balloon to the electroscope, giving the electroscope a net negative charge.

6. If the wool had been used, electrons would have been attracted to the knob of the electroscope, and the leaves would have spread because of an induced positive charge in the leaves. If the wool were touched to the electroscope, electrons would have been attracted, leaving the electroscope with a net positive charge.

PHYSICS PROJECT — Activity

Humidity and Electrostatic Discharge (ESD) Which atmospheric conditions are worst for electronic devices that are vulnerable to damage from electrostatic discharge (ESD)? First, have students study the mechanisms by which equipment can be damaged by ESD. Then have them devise a procedure for evaluating the daily ESD threat to equipment. One approach may be to keep an electroscope in a certain location along with a consistent procedure for charging a particular object and bringing it near the uncharged electroscope. The degree of the electroscope's response each day could be categorized, along with the relative humidity at that time. Student reports could discuss any possible correlations. **L2 Kinesthetic**

Using Figure 20-11

Coulomb force always acts along a line joining two point charges. Note that the subscripts on the force vectors denote which charge is considered to be producing the Coulomb force. The force on charge A is subscripted "B on A," and the force on charge B is subscripted "A on B." L2

Reinforcement

Inverse Square Law How does electrostatic force vary as distance changes? Coulomb's law provides a method of direct calculation. However, as long as the charge quantities remain equal, ratios may be used to compute force at new positions. Have students do a series of these quick calculations. If the force between two charges is 90.0 N at a distance of 4.0 cm, ask students what the force is between them if the distance is 12.0 cm. The distance is tripled, so the force is reduced by a factor of 9, to 10 N. Ask what the force would be if the distance between the same charges is 2.0 cm. The force will quadruple, to 360 N. L2

Discussion

Question Ask students why it seems that most often lightweight objects like bits of paper, small strips of transparent tape, and balloons are the ones affected by electrostatic force.

Answer Coulomb's law provides a clue. If we consider that only a very small portion near the surface of all the atoms or molecules in an object can be involved in providing the charge imbalance that leads to electrostatic force. As the mass of an object becomes large with respect to its surface area, the effect of electrostatic force with respect to the total possible charge on that surface becomes less noticeable. L2

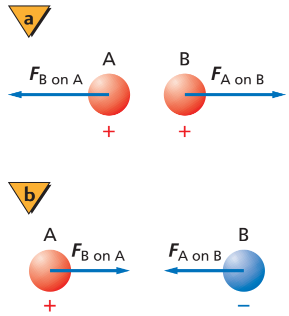


Figure 20-11 The rule for determining the direction of force is: like charges repel; unlike charges attract.

One coulomb is the charge of 6.24×10^{18} electrons or protons. A typical lightning bolt can carry 5 C to 25 C of charge. The charge on a single electron is 1.60×10^{-19} C. The magnitude of the charge of an electron is called the **elementary charge.** Even small pieces of matter, such as coins, contain up to 10^6 C of negative charge. This enormous amount of negative charge produces almost no external effects because it is balanced by an equal amount of positive charge. If the charge is unbalanced, even as small a charge as 10^{-9} C can result in large forces.

According to Coulomb's law, the magnitude of the force on charge q_A caused by charge q_B a distance r away can be written as follows.

Coulomb's Law $F = K\dfrac{q_A q_B}{r^2}$

The force between two charges is equal to Coulomb's constant, times the product of the two charges, divided by the square of the distance between them.

When the charges are measured in coulombs, the distance in meters, and the force in newtons, the constant, K, is 9.0×10^9 N·m²/C².

The Coulomb's law equation gives the magnitude of the force that charge q_A exerts on q_B and also the force that q_B exerts on q_A. These two forces are equal in magnitude but opposite in direction. You can observe this example of Newton's third law of motion in action when you bring two strips of tape with like charges together. Each exerts forces on the other. If you bring a charged comb near either strip of tape, the strip, with its small mass, moves readily. The acceleration of the comb and you is, of course, much less because of the much greater mass.

The electric force, like all other forces, is a vector quantity. Force vectors need both a magnitude and a direction. However, the Coulomb's law equation above gives only the magnitude of the force. To determine the direction, you need to draw a diagram and interpret charge relations carefully. If two positively charged objects, A and B, are brought near, the forces they exert on each other are repulsive, as shown in **Figure 20-11a.** If, instead, B is negatively charged, the forces are attractive, as shown in **Figure 20-11b.**

PROBLEM-SOLVING Strategies

Electric Force Problems

Use these steps to find the magnitude and direction of the force between charges.

1. Sketch the system showing all distances and angles to scale.
2. Diagram the vectors of the system.
3. Use Coulomb's law to find the magnitude of the force.
4. Use your diagram along with trigonometric relations to find the direction of the force.
5. Perform all algebraic operations on both the numbers and the units. Make sure that the units match the variables in question.
6. Consider the magnitude of your answer. Is it reasonable?

HELPING STRUGGLING STUDENTS Activity

Make a Scale Drawing In order to better visualize the force exerted by two fixed point charges on a third point charge, students should make the scale drawing suggested by the Problem-Solving Strategies on this page for Example Problem 1. Have them map out on graph paper the positions of each charge in the problem. Then they should sketch the lines of action due to each pair of forces by joining these with a straightedge. Finally, have them carefully add arrows of length proportional to the Coulomb force calculated for that pair. Review how the Pythagorean theorem may be used to find the resultant force. L2 **Visual-Spatial**

▶ EXAMPLE Problem 1

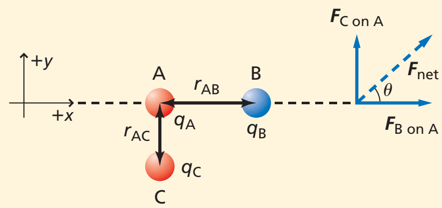
Coulomb's Law in Two Dimensions Sphere A, with a charge of $+6.0\ \mu C$, is located near another charged sphere, B. Sphere B has a charge of $-3.0\ \mu C$ and is located 4.0 cm to the right of A.

a. What is the force of sphere B on sphere A?

b. A third sphere, C, with a $+1.5\text{-}\mu C$ charge, is added to the configuration. If it is located 3.0 cm directly beneath A, what is the new net force on sphere A?

1 Analyze and Sketch the Problem

- Establish coordinate axes and sketch the spheres.
- Show and label the distances between the spheres.
- Diagram and label the force vectors.



Known:		Unknown:
$q_A = +6.0\ \mu C$	$r_{AB} = 4.0$ cm	$\boldsymbol{F}_{B\text{ on }A} = ?$
$q_B = -3.0\ \mu C$	$r_{AC} = 3.0$ cm	$\boldsymbol{F}_{C\text{ on }A} = ?$
$q_C = +1.5\ \mu C$		$\boldsymbol{F}_{net} = ?$

2 Solve for the Unknown

a. Find the force of sphere B on sphere A.

$$F_{B\text{ on }A} = K\frac{q_Aq_B}{r_{AB}^2}$$

$$= (9.0\times10^9\ N\cdot m^2/C^2)\frac{(6.0\times10^{-6}\ C)(3.0\times10^{-6}\ C)}{(4.0\times10^{-2}\ m)^2}$$ **Substitute $q_A = 6.0\ \mu C$, $q_B = 3.0\ \mu C$, $r_{AB} = 4.0$ cm**

$$= 1.0\times10^2\ N$$

Because spheres A and B have unlike charges, the force of B on A is to the right.

b. Find the force of sphere C on sphere A.

$$F_{C\text{ on }A} = K\frac{q_Aq_C}{r_{AC}^2}$$

$$= (9.0\times10^9\ N\cdot m^2/C^2)\frac{(6.0\times10^{-6}\ C)(1.5\times10^{-6}\ C)}{(3.0\times10^{-2}\ m)^2}$$ **Substitute $q_A = 6.0\ \mu C$, $q_C = 1.5\ \mu C$, $r_{AC} = 3.0$ cm**

$$= 9.0\times10^1\ N$$

Spheres A and C have like charges, which repel. The force of C on A is upward.

Find the vector sum of $\boldsymbol{F}_{B\text{ on }A}$ and $\boldsymbol{F}_{C\text{ on }A}$ to find $\boldsymbol{F}_{net}$ on sphere A.

$$F_{net} = \sqrt{F_{B\text{ on }A}{}^2 + F_{C\text{ on }A}{}^2}$$

$$= \sqrt{(1.0\times10^2\ N)^2 + (9.0\times10^1\ N)^2}$$ **Substitute $F_{B\text{ on }A} = 1.0\times10^2$ N, $F_{C\text{ on }A} = 9.0\times10^1$ N**

$$= 130\ N$$

$$\tan\theta = \frac{F_{C\text{ on }A}}{F_{B\text{ on }A}}$$

$$\theta = \tan^{-1}\left(\frac{F_{C\text{ on }A}}{F_{B\text{ on }A}}\right)$$

$$= \tan^{-1}\left(\frac{9.0\times10^1\ N}{1.0\times10^2\ N}\right)$$ **Substitute $F_{C\text{ on }A} = 9.0\times10^1$ N, $F_{B\text{ on }A} = 1.0\times10^2$ N**

$$= 42°$$

$$F_{net} = 130\ N,\ 42°\text{ above the }x\text{-axis}$$

Math Handbook
Inverses of Sine, Cosine, and Tangent
page 856

3 Evaluate the Answer

- **Are the units correct?** $(N\cdot m^2/C^2)(C)(C)/m^2 = N$. The units work out to be newtons.
- **Does the direction make sense?** Like charges repel; unlike charges attract.
- **Is the magnitude realistic?** The magnitude of the net force is in agreement with the magnitudes of the component forces.

QUICK DEMO

Cup of Charge

Estimated Time 5 minutes

Materials one metal cup, one intact polystyrene cup, one polystyrene cup broken into small pieces, a Van de Graaff generator

Procedure Place equal amount of polystyrene pieces in each cup. Ask students to predict what will happen when you place the cups on top of the generator. Ask them to explain the differences observed. The pieces remain in the metal cup but fly out of the polystyrene cup. With a metal cup, a conductor, charge is repelled to the outside. The polystyrene cup, an insulator, has charge induced on both inside and outside so the polystyrene pieces develop like charges and repel.

▶ IN-CLASS Example

Question Using Example Problem 1, assume that the third sphere C, charge, $+2.0\ \mu C$ is located 5.00 cm directly below sphere B. What is the net force on sphere B?

Answer Determine the force of sphere C on sphere B. $F_{C\text{ on }B} = (K)(q_Bq_C)/r_{BC}^2 = (9.0\times10^9\ N\cdot m^2/C^2)[(3.0\times10^{-6}\ C)(2.0\times10^{-6}\ C)/(5.00\times10^{-2}\ m)^2] = 2.2\times10^1$ N. Spheres C and B have charges that attract. The force of C on B is downward. F_{net} on sphere B = vector sum of $F_{A\text{ on }B}$ and $F_{C\text{ on }B}$. $F_{net} = \sqrt{(1.0\times10^2\ N)^2 + (2.2\times10^1\ N)^2} = 1.0\times10^2$ N. To determine the angle of the force

$$\tan\theta = \frac{F_{C\text{ on }B}}{F_{A\text{ on }B}}$$

$$= \tan^{-1}\left(\frac{2.2\times10^1\ N}{1.0\times10^2\ N}\right)$$

$$= 12°$$

$F_{net} = 1.0\times10^2$ N, 12° below the x-axis.

CHALLENGE Activity

Calculate Charge Have students suspend and charge two balloons from strings in the manner of the Extension activity on page 545. Have them make careful measurements of their separation distance, r, and separation angle, θ. Assuming the balloons carry equal charge, q, ask students to calculate this value. The force components of the tension in each string, F_T, are

$$F_T\cos\left(\frac{\theta}{2}\right) = mg \text{ and } F_T\sin\left(\frac{\theta}{2}\right) = \frac{kq^2}{r^2}\text{, so } q = \sqrt{\frac{mgr^2}{k}\tan\left(\frac{\theta}{2}\right)}.$$ Use $K = 9.0\times10^9\ N\cdot m^2/C^2$.

The result may be order-of-magnitude accurate. **L3 Kinesthetic**

Identifying Misconceptions

Coulomb's Law Ask students to describe the circumstances when Coulomb's Law applies. In general, it applies to point charges where the size of the charge is small compared to the distance between them; it also holds for the force between point charges at rest. Explain that if the distribution of charge is not spherically symmetric, or if it is farther from the test point than the size of the distribution itself, then Coulomb's law is inaccurate.

PRACTICE Problems

9. 1.6×10^{4} N

10. 3.0×10^{-6} C

11. Magnitudes of all forces remain the same. The direction changes to 42° above the −x axis, or 138°.

12. 0.068 N toward the right

13. 3.1 N toward the right

CHALLENGE PROBLEM

1.

$$q = m\sqrt{\frac{G}{K}}$$

$$= m\sqrt{\left(\frac{6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2}{9.0\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2}\right)}$$

$$= (8.61\times10^{-11}\ \text{C/kg})m$$

2. The distance does not affect the value of q because both forces are inversely related to the square of the distance, and the distance cancels out.

3. $q = (8.61\times10^{-11}\ \text{C/kg})(1.50\ \text{kg}) = 1.29\times10^{-10}$ C

THE MECHANICAL UNIVERSE

HIGH SCHOOL ADAPTATION

Videotape

Electric Fields and Forces

PRACTICE Problems

Additional Problems, Appendix B

9. A negative charge of -2.0×10^{-4} C and a positive charge of 8.0×10^{-4} C are separated by 0.30 m. What is the force between the two charges?

10. A negative charge of -6.0×10^{-6} C exerts an attractive force of 65 N on a second charge that is 0.050 m away. What is the magnitude of the second charge?

11. The charge on B in Example Problem 1 is replaced by a charge of $+3.00\ \mu$C. Diagram the new situation and find the net force on A.

12. Sphere A is located at the origin and has a charge of $+2.0\times10^{-6}$ C. Sphere B is located at +0.60 m on the x-axis and has a charge of -3.6×10^{-6} C. Sphere C is located at +0.80 m on the x-axis and has a charge of $+4.0\times10^{-6}$ C. Determine the net force on sphere A.

13. Determine the net force on sphere B in the previous problem.

As you use the Coulomb's law equation, keep in mind that Coulomb's law is valid only for point charges or uniform spherical charge distributions. That is, a charged sphere may be treated as if all the charge were located at its center if the charge is spread evenly across its entire surface or throughout its volume. If a sphere is a conductor and another charge is brought near it, the charges on the sphere will be attracted or repelled, and the charge no longer will act as if it were at the sphere's center. Therefore, it is important to consider how large and how far apart two charged spheres are before applying Coulomb's law. The problems in this textbook assume that charged spheres are small enough and far enough apart to be considered point charges unless otherwise noted. When shapes such as long wires or flat plates are considered, Coulomb's law must be modified to account for the nonpoint charge distributions.

Application of Electrostatic Forces

There are many applications of electric forces on particles. For example, these forces can collect soot in smokestacks, thereby reducing air pollution, as shown in **Figure 20-12.** Tiny paint droplets, charged by

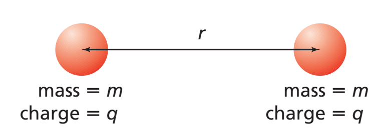
CHALLENGE PROBLEM

As shown in the figure on the right, two spheres of equal mass, m, and equal positive charge, q, are a distance, r, apart.

1. Derive an expression for the charge, q, that must be on each sphere so that the spheres are in equilibrium; that is, so that the attractive and repulsive forces between them are balanced.

2. If the distance between the spheres is doubled, how will that affect the expression for the value of q that you determined in the previous problem? Explain.

3. If the mass of each sphere is 1.50 kg, determine the charge on each sphere needed to maintain the equilibrium.



Additional MINI LAB

Flying Objects

Purpose to observe the behavior of objects charged with a Van de Graaff generator

Materials Van de Graaff generator; small light aluminum pie pans; crispy cereal that is stale

Procedure

1. Place one pie pan upside down on dome of generator. Ask students to observe what happens.

2. Place an entire stack of pie pans on the generator. Turn it on as students observe.

3. Stand on an insulating surface while touching the generator's terminal. Have some cereal closed in your free hand. Open your palm.

Assessment The pan flies off because it acquires like charge with the dome. The upside-down stack of pans repel, one after the other. The cereal also flies off a hand.

■ **Figure 20-12** The fly ash being released by these smokestacks is a by-product of burning coal. Static-electricity precipitators can be used to reduce fly ash emissions.

induction, can be used to paint automobiles and other objects very uniformly. Photocopy machines use static electricity to place black toner on a page so that a precise reproduction of the original document is made. In other instances, applications are concerned with the control of static charge. For example, static charge can ruin film if it attracts dust, and electronic equipment can be damaged by the discharge of static charge. In these cases, applications are designed to avoid the buildup of static charge and to safely eliminate any charge that does build up.

20.2 Section Review

14. Force and Charge How are electric force and charge related? Describe the force when the charges are like charges and the force when the charges are opposite charges.

15. Force and Distance How are electric force and distance related? How would the force change if the distance between two charges were tripled?

16. Electroscopes When an electroscope is charged, the leaves rise to a certain angle and remain at that angle. Why do they not rise farther?

17. Charging an Electroscope Explain how to charge an electroscope positively using

a. a positive rod.

b. a negative rod.

18. Attraction of Neutral Objects What two properties explain why a neutral object is attracted to both positively and negatively charged objects?

19. Charging by Induction In an electroscope being charged by induction, what happens when the charging rod is moved away before the ground is removed from the knob?

20. Electric Forces Two charged spheres are held a distance, r, apart. One sphere has a charge of $+3\mu$C, and the other sphere has a charge of $+9\mu$C. Compare the force of the $+3\mu$C sphere on the $+9\mu$C sphere with the force of the $+9\mu$C sphere on the $+3\mu$C sphere.

21. Critical Thinking Suppose that you are testing Coulomb's law using a small, positively charged plastic sphere and a large, positively charged metal sphere. According to Coulomb's law, the force depends on $1/r^2$, where r is the distance between the centers of the spheres. As the spheres get close together, the force is smaller than expected from Coulomb's law. Explain.

Physics Online physicspp.com/self_check_quiz

Mike McClure/Maxximages

3 ASSESS

Reteach

Test Charge Have students use charge and distance ratios to determine the point at which the net force on a $+1\ \mu$C test charge equals zero, when it is attracted to a $-2\ \mu$C charge and a $-8\ \mu$C charge that are 6.0 m apart. The attractive force on the test charge due to the $-2\ \mu$C charge must be equal and opposite to that due to the $-8\ \mu$C. This happens on the line connecting the two charges. Because the charge ratio is 4, the distance to the $-2\ \mu$C charge will be 1/2 of that to the $-8\ \mu$C charge, or 2.0 m from the $-2\ \mu$C charge. L2

Extension

Electric Force and Newton's Law A proton has approximately 2000 times more mass than an electron. Ask students what Coulomb's and Newton's laws suggest would happen if it were possible to release a free proton and a free electron in a region without the presence of other charges. The particles experience equal and opposite attractive forces. According to Coulomb's law, this force is $-Ke^2/r^2$ where e is the elementary charge. Because an electron's acceleration is about 2000 times greater than that of a proton, the particles collide much nearer to the proton's original position. L3

20.2 Section Review

14. Electric force is directly related to each charge. Like charges repel, opposite charges attract.

15. It is inversely related to the square of the distance between charges. The force will be one-ninth as great.

16. As the leaves move farther apart, the electric force decreases until it is balanced by the gravitational force.

17. a. Touch the rod to the electroscope.

b. Bring the rod near the electroscope. Ground the electroscope; remove the ground and then remove the rod.

18. The nearer, opposite charges will attract more than the more distant, like charges will repel.

19. The electroscope remains neutral.

20. The forces are equal in magnitude and opposite in direction.

21. Some charge on the metal sphere will be repelled to the opposite side from the plastic sphere, making the effective distance between the charges greater than the distance between the sphere's centers.

PHYSICSLAB • Design Your Own

Time Allotment
one laboratory period

Process Skills use scientific explanations, observe and infer, compare and contrast, formulate models, think critically, collect and organize data, interpret data, draw conclusions

Safety Precautions Wear safety goggles and protective clothing. Students allergic to wool should be advised not to handle it.

Alternative Materials Encourage students to test a variety of materials. Cotton and paper are examples of common materials that students might not think to test. Students may want to compare various types of plastics, such as polyvinyl chloride (PVC) and polyethylene terephthalate (PETE).

Teaching Strategies
- **Keep the room as dry as possible. If it is humid, you may need to increase the heat in the room to minimize the effect of humidity draining charge from the rubbed materials.**
- **Have students select their materials and systematically test the possible combinations.**
- **Remind students to be aware that the charge on the suspended ruler will dissipate over time, so they will need to recharge it periodically.**

PHYSICSLAB • Design Your Own

Charged Objects

In this chapter, you observed and studied phenomena that result from the separation of electric charges. You learned that hard rubber and plastic tend to become negatively charged when they are rubbed, while glass and wool tend to become positively charged. But what happens if two objects that tend to become negatively charged are rubbed together? Will electrons be transferred? If so, which material will gain electrons, and which will lose them? In this physics lab, you will design a procedure to further your investigations of positive and negative charges.

QUESTION

How can you test materials for their ability to hold positive and negative charges?

Objectives

- **Observe** that different materials tend to become positively or negatively charged.
- **Compare and contrast** the ability of materials to acquire and hold positive and negative charges.
- **Interpret data** to order a list of materials from strongest tendency to be negatively charged to strongest tendency to be positively charged.

Safety Precautions

Horizons Companies

Materials

15-cm plastic ruler
thread
ring stand with ring
masking tape
materials to be charged, such as rubber rods, plastic rods, glass rods, PVC pipe, copper pipe, steel pipe, pencils, pens, wool, silk, plastic wrap, plastic sandwich bags, waxed paper, and aluminum foil

Procedure

1. Use the lab photo as a guide to suspend a 15-cm plastic ruler. It is advisable to wash the ruler in soapy water, then rinse and dry it thoroughly before each use, especially if it is a humid day. The thread should be attached at the midpoint of the ruler with two or three wraps of masking tape between the thread and ruler.
2. Use the following situations as a reference for types of charges a material can have: 1) a plastic ruler rubbed with wool gives the plastic ruler an excess negative charge and the wool an excess positive charge, and 2) a plastic ruler rubbed with plastic wrap gives the plastic ruler an excess positive charge and the plastic wrap an excess negative charge.

Sample Data Answers will vary, depending on materials used.

Material 1	Material 2	Charge on Ruler (+, −, 0)	Observation of Ruler's Movements	Charge on Material 1 (+, −, 0)	Charge on Material 2 (+, −, 0)
wool	rubber	−	repulsed by rubber rod	+	−
plastic sandwich bag	rubber	−	attracted to rubber	−	+
PVC	wool	−	repulsed by PVC	−	+

Data Table

Material 1	Material 2	Charge on Ruler (+, −, 0)	Observation of Ruler's Movements	Charge on Material 1 (+, −, 0)	Charge on Material 2 (+, −, 0)

3. Design a procedure to test which objects tend to become negatively charged and which tend to become positively charged. Try various combinations of materials and record your observations in the data table.
4. Develop a test to see if an object is neutral. Remember that a charged ruler may be attracted to a neutral object if it induces a separation of charge in the neutral object.
5. Be sure to check with your teacher and have your procedure approved before you proceed with your lab.

Analyze

1. **Observe and Infer** As you brought charged materials together, could you detect a force between the charged materials? Describe this force.
2. **Formulate Models** Make a drawing of the charge distribution on the two materials for one of your trials. Use this drawing to explain why the materials acted the way they did during your experiments with them.
3. **Draw Conclusions** Which materials hold an excess charge? Which materials do not hold a charge very well?
4. **Draw Conclusions** Which materials tend to become negatively charged? Which tend to become positively charged?
5. **Interpret Data** Use your data table to list the relative tendencies of materials to be positively or negatively charged.

Conclude and Apply

1. Explain what is meant by the phrases *excess charge* and *charge imbalance* when referring to static electricity.
2. Does excess charge remain on a material or does it dissipate over time?
3. Could you complete this physics lab using a metal rod in place of the suspended plastic ruler? Explain.
4. Clear plastic wrap seals containers of food. Why does plastic wrap cling to itself after it is pulled from its container?

Going Further

Review the information in your textbook about electroscopes. Redesign the lab using an electroscope, rather than a suspended ruler, to test for the type of charge on an object.

Real-World Physics

Trucks often have a rubber strap or a chain that drags along the road. Why are they used?

Physics Online

To find out more about static charge, visit the Web site: **physicspp.com**

ALTERNATIVE INQUIRY LAB

To Make this Lab an Inquiry Lab: Let students choose the materials they will test and design their own procedures. Challenge students to develop a way to quantify the deflection of the suspended ruler. For example, they could mark degrees on a circle on a piece of paper beneath the suspended ruler.

Analyze

1. Yes, it is strong enough to move the ruler.
2. A sample drawing could show a suspended ruler with negative charges drawn on it being repelled by a rubber rod that also has negative charges drawn on it.
3. Good insulators, such as plastic and rubber, hold a charge. Good conductors, such as most metals, do not.
4. Wool, glass, nylon, and silk tend to become positively charged. Polystyrene, rubber, and plastics tend to become negatively charged.
5. A sample list, arranged from negative to positive, might be ordered PVC, plastic wrap, plastic ruler, rubber, cotton, silk, wool, glass.

Conclude and Apply

1. There are positively charged particles in objects with a net negative charge and negatively charged particles in objects with a net positive charge. If an object or area of an object carries a net charge, it has more of one kind of charge than of the other.
2. Even though air is a good insulator of electric charge, water vapor in the air can help pull electric charge off a material. Thus, materials in the lab lose their charge over time.
3. No. A conductor such as a metal rod will not hold a charge in one place. Because a separation of charges can easily be induced in a neutral conductor, the metal rod will be attracted to any charged object, positive or negative.
4. When plastic wrap is pulled from its roll, the result is a charge imbalance that is similar to the situation when you pulled two strips of tape apart. This results in an attractive force between different parts of the plastic wrap.

Going Further

Students should know how to charge an electroscope. Once it has a known charge, they should describe the movement of the leaves that will be caused by objects with like charges compared to movements caused by objects with unlike charges.

Real-World Physics

It helps drain charge that can build up while the tires roll along the road.

Background

We can discharge earthbound objects by touching them to the ground because Earth acts as a source, or sink, for electric charge. Though very thin, the plasma cloud around a spacecraft serves the same function—it is a source for the charges that can accumulate on the spacecraft. Electric arcs in space occur at much lower voltages than arcs on Earth. A high voltage (~20kV/cm) is required to produce an electric arc on Earth because the air particles are so close together. A free electron accelerated by an electric field cannot gain much velocity before it strikes an air particle and stops. In space, gas particles are far apart, so electrons can gain high speeds. When these strike other gas particles, more electrons are liberated, which then accelerate and liberate even more electrons. This avalanche of charge ultimately produces an electric arc.

Teaching Strategies

- Remind students that plasmas are highly conductive.
- Discuss how contact with Earth can discharge either a positively or negatively charged object. Point out that the grounding that we take for granted on Earth is impossible in space.

Activity

Model an Arc Have students produce and observe sparks with a spark coil or from static electricity. Ask them to note any evidence of heat and the quick voltage and current changes. If students use static electricity to produce sparks, ask them how they can alter the materials to discharge the potential difference.

Future Technology

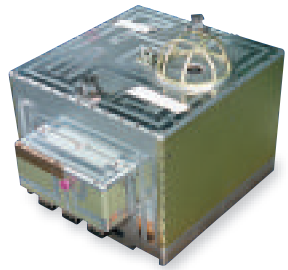
Spacecraft and Static Electricity

Most objects on Earth do not build up substantial static-electric charges because a layer of moisture clings to surfaces, allowing charges to migrate to or from the ground. As you learned in this chapter, Earth can absorb almost any amount of charge. However, there is no moisture in space, and Earth is far away. Charged particles ejected from the Sun, or in the ionosphere, strike and cling to spacecraft, charging their surfaces to thousands of volts.

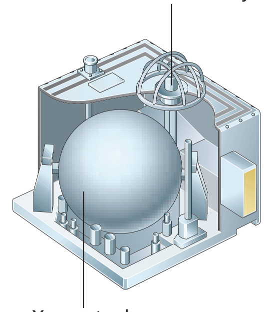
Plasma and Charging

In Chapter 13, you learned that plasma consists of free electrons and positive ions. Orbiting spacecraft are surrounded by a thin cloud of this plasma. The electrons in plasma can move far more easily than more massive positive ions. Thus, spacecraft surfaces tend to attract electrons and develop a negative charge. This negative charge eventually attracts some heavy positive ions, which strike the spacecraft and can damage its surface.

On the *International Space Station,* an additional difficulty stems from the array of solar panels that convert energy from the Sun into electricity. When the arrays are powering the space station, the voltage on the surface of the craft tends to be close to the voltage of the solar array. As a result, it is possible that an electric arc could form between the space station and the plasma that surrounds it.



Plasma Contactor Unit (PCU)



This is a cutaway drawing of the PCU.

Consequences of an Arc

Arcs are extremely hot and carry a great deal of current. They can prematurely ignite retro-rockets or explosive bolts and interfere with the operation of the spacecraft's electronic equipment. The solar panels are particularly susceptible to arc damage. In addition to damage to the spacecraft's components, there is a remote chance that the buildup of charge might endanger astronauts on space walks.

To discharge the potential difference and protect craft and crew, the space station's skin must be connected by a conductor, called a plasma contactor, to the plasma cloud surrounding it. The connection begins on board the station, where a stream of xenon gas from a tank in the Plasma Contactor Unit (PCU) is ionized by an electric current. This ionization takes place in the cathode assembly. The ionized xenon, now in the plasma state, passes out of the craft through the cathode assembly. It is this stream of conductive plasma that connects the craft to the surrounding plasma cloud, thereby reducing the potential difference to safe levels.

Future Applications

Future spacecraft might integrate the plasma contactor into the propulsion system. For example, the Variable Specific Impulse Magnetoplasma Rocket (VASIMR) could use the plasma exhaust that it produces to provide an electric connection between the spacecraft and the surrounding plasma. Scientists think that this type of rocket could be used in the future to travel between planets.

Going Further

1. **Apply** What is the purpose of a plasma contactor? How is it similar to using your finger to ground an electroscope?
2. **Research** How could scientists assess the charge on the surface of the *International Space Station?*

NASA

Going Further

1. The plasma contactor provides a conducting path for charges. A potential difference can be neutralized by charges flowing along this path. When you touch an electroscope with your finger, you provide a path for electrons to flow on or off the electroscope.
2. Students' research will vary. One method scientists have used is to deploy a Floating Potential Probe (FPP). This device can assess the potential difference between the surface of the space station and the surrounding plasma.

Chapter 20

Study Guide

20.1 Electric Charge

Vocabulary

- electrostatics (p. 541)
- neutral (p. 543)
- insulator (p. 544)
- conductor (p. 544)

Key Concepts

- There are two kinds of electric charge, positive and negative. Interactions of these charges explain the attraction and repulsion that you observed in the strips of tape.
- Electric charge is not created or destroyed; it is conserved. Charging is the separation, not creation, of electric charges.
- Objects can be charged by the transfer of electrons. An area with excess electrons has a net negative charge; an area with a deficit of electrons has a net positive charge.
- Charges added to one part of an insulator remain on that part. Insulators include glass, dry wood, plastics, and dry air.
- Charges added to a conductor quickly spread over the surface of the object. In general, examples of conductors include graphite, metals, and matter in the plasma state.
- Under certain conditions, charges can move through a substance that is ordinarily an insulator. Lightning moving through air is one example.

20.2 Electric Force

Vocabulary

- electroscope (p. 546)
- charging by conduction (p. 547)
- charging by induction (p. 548)
- grounding (p. 548)
- Coulomb's law (p. 549)
- coulomb (p. 549)
- elementary charge (p. 550)

Key Concepts

- When an electroscope is charged, electric forces cause its thin metal leaves to spread apart.
- An object can be charged by conduction by touching it with a charged object.
- A charged object will induce a separation of charges within a neutral conductor. This process will result in an attractive force between the charged object and the neutral conductor.
- To charge a conductor by induction, a charged object is first brought near it, causing a separation of charges. Then, the conductor to be charged is separated, trapping opposite charges on the two halves.
- Grounding is the removal of excess charge by touching an object to Earth. Grounding can be used in the process of charging an electroscope by induction.
- Coulomb's law states that the force between two charged particles varies directly with the product of their charges and inversely with the square of the distance between them.

$$F = K\frac{q_A q_B}{r^2}$$

  To determine the direction of the force, remember the following rule: like charges repel; unlike charges attract.
- The SI unit of charge is the coulomb. One coulomb (C) is the magnitude of the charge of 6.24×10^{18} electrons or protons. The elementary charge, the charge of a proton or electron, is 1.60×10^{-19} C.

Chapter 20

Study Guide

Key Concepts
Summary statements can be used by students to review the major concepts of the chapter.

Physics Online
Visit physicspp.com
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/chapter_test
/standardized_test

VOCABULARY PuzzleMaker

For additional help with vocabulary, have students access the Vocabulary PuzzleMaker online.
physicspp.com/vocabulary_puzzlemaker

Concept Mapping

22. See Solutions Manual.

Mastering Concepts

23. No. By conservation of charge, your hair must become negatively charged.

24. Student answers will vary but may include dry air, wood, plastic, glass, cloth, and deionized water as insulators; and metals, tap water, and your body as conductors.

25. Metals contain free electrons; rubber has bound electrons.

26. They have been charged by contact as they rub against other clothes and thus are attracted to clothing that is neutral or has an opposite charge.

27. Rubbing the CD charges it. Neutral particles such as dust are attracted.

28. No. Net charge is the difference between positive and negative charges. The coin can still have a net charge of zero.

29. Electric force is inversely proportional to the distance squared. As distance decreases and charges remain the same, the force increases as the square of the distance.

30. Bring the conductor close to, but not touching, the rod. Ground the conductor in the presence of the charged rod; then, remove the ground before removing the charged rod. The conductor will have a net negative charge.

Applying Concepts

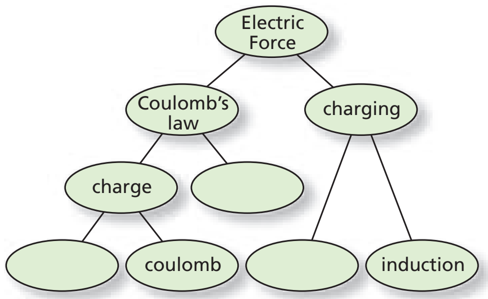
31. The charge of the proton is exactly the same size as that of the electron but has the opposite sign.

32. Use a known insulator to hold one end of the object against the electroscope. Touch the other end with the charged rod. If the electroscope indicates a charge, the object is a conductor.

Chapter 20 Assessment

Concept Mapping

22. Complete the concept map below using the following terms: *conduction, distance, elementary charge.*



Mastering Concepts

23. If you comb your hair on a dry day, the comb can become positively charged. Can your hair remain neutral? Explain. (20.1)

24. List some insulators and conductors. (20.1)

25. What property makes metal a good conductor and rubber a good insulator? (20.1)

26. **Laundry** Why do socks taken from a clothes dryer sometimes cling to other clothes? (20.2)

27. **Compact Discs** If you wipe a compact disc with a clean cloth, why does the CD then attract dust? (20.2)

28. **Coins** The combined charge of all electrons in a nickel is hundreds of thousands of coulombs. Does this imply anything about the net charge on the coin? Explain. (20.2)

29. How does the distance between two charges impact the force between them? If the distance is decreased while the charges remain the same, what happens to the force? (20.2)

30. Explain how to charge a conductor negatively if you have only a positively charged rod. (20.2)

Applying Concepts

31. How does the charge of an electron differ from the charge of a proton? How are they similar?

32. Using a charged rod and an electroscope, how can you find whether or not an object is a conductor?

33. A charged rod is brought near a pile of tiny plastic spheres. Some of the spheres are attracted to the rod, but as soon as they touch the rod, they are flung off in different directions. Explain.

34. **Lightning** Lightning usually occurs when a negative charge in a cloud is transported to Earth. If Earth is neutral, what provides the attractive force that pulls the electrons toward Earth?

35. Explain what happens to the leaves of a positively charged electroscope when rods with the following charges are brought close to, but not touching, the electroscope.
a. positive
b. negative

36. As shown in **Figure 20-13,** Coulomb's law and Newton's law of universal gravitation appear to be similar. In what ways are the electric and gravitational forces similar? How are they different?

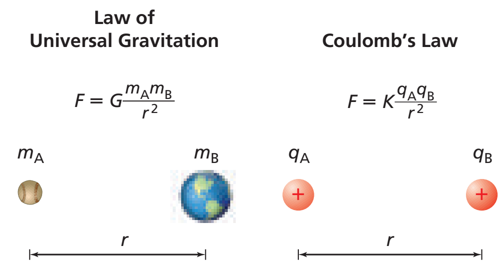


Figure 20-13 (Not to scale)

37. The constant, K, in Coulomb's equation is much larger than the constant, G, in the universal gravitation equation. Of what significance is this?

38. The text describes Coulomb's method for charging two spheres, A and B, so that the charge on B was exactly half the charge on A. Suggest a way that Coulomb could have placed a charge on sphere B that was exactly one-third the charge on sphere A.

39. Coulomb measured the deflection of sphere A when spheres A and B had equal charges and were a distance, r, apart. He then made the charge on B one-third the charge on A. How far apart would the two spheres then have had to be for A to have had the same deflection that it had before?

40. Two charged bodies exert a force of 0.145 N on each other. If they are moved so that they are one-fourth as far apart, what force is exerted?

41. Electric forces between charges are enormous in comparison to gravitational forces. Yet, we normally do not sense electric forces between us and our surroundings, while we do sense gravitational interactions with Earth. Explain.

 For more problems, go to Additional Problems, Appendix B.

33. The natural spheres are initially attracted to the charged rod, but they acquire the same charge as the rod when they touch it. As a result, they are repelled from the rod.

34. The charge in the cloud repels electrons on Earth, causing a charge separation. The side of Earth closest to the cloud is positive, resulting in an attractive force.

35. **a.** The leaves will move farther apart.
b. The leaves will drop slightly.

36. Similar: inverse-square dependence on distance, force proportional to product of two masses or two charges; different: only one sign of mass, so gravitational force is always attractive; two signs of charge, so electric force can be either attractive or repulsive

Mastering Problems

20.2 Electric Force

42. Two charges, q_A and q_B, are separated by a distance, r, and exert a force, F, on each other. Analyze Coulomb's law and identify what new force would exist under the following conditions.
  a. q_A is doubled
  b. q_A and q_B are cut in half
  c. r is tripled
  d. r is cut in half
  e. q_A is tripled and r is doubled

43. Lightning A strong lightning bolt transfers about 25 C to Earth. How many electrons are transferred?

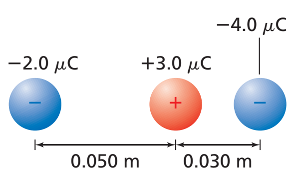
44. Atoms Two electrons in an atom are separated by 1.5×10^{-10} m, the typical size of an atom. What is the electric force between them?

45. A positive and a negative charge, each of magnitude 2.5×10^{-5} C, are separated by a distance of 15 cm. Find the force on each of the particles.

46. A force of 2.4×10^{2} N exists between a positive charge of 8.0×10^{-5} C and a positive charge of 3.0×10^{-5} C. What distance separates the charges?

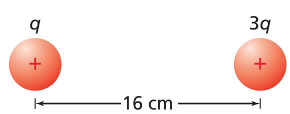
47. Two identical positive charges exert a repulsive force of 6.4×10^{-9} N when separated by a distance of 3.8×10^{-10} m. Calculate the charge of each.

48. A positive charge of 3.0 μC is pulled on by two negative charges. As shown in **Figure 20-14,** one negative charge, -2.0 μC, is 0.050 m to the west, and the other, -4.0 μC, is 0.030 m to the east. What total force is exerted on the positive charge?



■ Figure 20-14

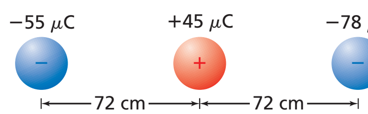
49. Figure 20-15 shows two positively charged spheres, one with three times the charge of the other. The spheres are 16 cm apart, and the force between them is 0.28 N. What are the charges on the two spheres?



■ Figure 20-15

50. Charge in a Coin How many coulombs of charge are on the electrons in a nickel? Use the following method to find the answer.
  a. Find the number of atoms in a nickel. A nickel has a mass of about 5 g. A nickel is 75 percent Cu and 25 percent Ni, so each mole of the coin's atoms will have a mass of about 62 g.
  b. Find the number of electrons in the coin. On average, each atom has 28.75 electrons.
  c. Find the coulombs on the electrons.

51. Three particles are placed in a line. The left particle has a charge of -55 μC, the middle one has a charge of $+45$ μC, and the right one has a charge of -78 μC. The middle particle is 72 cm from each of the others, as shown in **Figure 20-16.**
  a. Find the net force on the middle particle.
  b. Find the net force on the right particle.



■ Figure 20-16

Mixed Review

52. A small metal sphere with charge 1.2×10^{-5} C is touched to an identical neutral sphere and then placed 0.15 m from the second sphere. What is the electric force between the two spheres?

53. Atoms What is the electric force between an electron and a proton placed 5.3×10^{-11} m apart, the approximate radius of a hydrogen atom?

54. A small sphere of charge 2.4 μC experiences a force of 0.36 N when a second sphere of unknown charge is placed 5.5 cm from it. What is the charge of the second sphere?

55. Two identically charged spheres placed 12 cm apart have an electric force of 0.28 N between them. What is the charge of each sphere?

56. In an experiment using Coulomb's apparatus, a sphere with a charge of 3.6×10^{-8} C is 1.4 cm from a second sphere of unknown charge. The force between the spheres is 2.7×10^{-2} N. What is the charge of the second sphere?

57. The force between a proton and an electron is 3.5×10^{-10} N. What is the distance between these two particles?

37. The electrical force is much larger.

38. After charging spheres A and B equally, sphere B is touched to two other equally sized balls that are touching each other. The charge on B will be divided equally among all three balls, leaving one-third the total charge on it.

39. To have the same force with one-third the charge, the distance would have to be decreased such that $d^2 = \frac{1}{3}$, or 0.58 times as far apart.

40. 16 times the original force

41. Gravitational forces can only be attractive. Electrical forces can either be attractive or repulsive, and we can only sense their vector sum, which is small.

Mastering Problems

20.2 Electric Force

Level 1

42. a. $2F$ **b.** $\frac{1}{4}F$
c. $\frac{1}{9}F$ **d.** $4F$
e. $\frac{3}{4}F$

43. 1.6×10^{20} electrons

44. 1.0×10^{-8} N, away from each other

45. 2.5×10^{2} N, toward the other charge

46. 0.30 m

47. 3.2×10^{-19} C

Level 2

48. 98 N, east

49. $q_A = 5.2\times10^{-7}$ C; $q_B = 1.5\times10^{-6}$ C

50. a. 5×10^{22} atoms
b. 1×10^{24} electrons
c. 2×10^{5} C

51. a. 18 N, right **b.** 42 N, left

Mixed review

52. 14 N

53. 8.2×10^{-8} N

54. 5.0×10^{-8} C

55. 6.7×10^{-7} C

56. 1.6×10^{-8} C

57. 8.1×10^{-10} m

Thinking Critically

58. 2.3×10^{39}

59. a. $+2.00$ m on the x-axis
b. The third charge, q_c, cancels from the equation, so it doesn't matter what its magnitude or sign is.
c. As in part b, the magnitude and sign of the third charge, q_c, do not matter.

60. $\boldsymbol{F}$ = 3.7×10^2 N, 197° from the positive x-axis

61. a. 9.8×10^{-3} N
b. 5.7×10^{-3} N
c. 2.4×10^{-8} C

62. a. $\boldsymbol{F}_A$ = 3.7×10^2 N, away (toward q_T); $\boldsymbol{F}_B$ = 92 N, toward (away from q_T)
b. See Solutions Manual.
c. See Solutions Manual.

Writing in Physics

63. Answers should include information such as the following. The Leyden jar, invented in the mid-1740s, was the earliest capacitor. It was used throughout the 18th and 19th centuries to store charges for electricity-related experiments and demonstrations. The Wimshurst machine was used in the 19th and early 20th centuries to produce and discharge static charges. It was replaced by the Van de Graff generator in the 20th century.

64. Students should describe the interactions between positive and negative charges at the molecular level. They should note that the strength of these forces accounts for differences in melting and boiling points and for the unusual behavior of water between 0°C and 4°C.

Cumulative Review

65. Measure the length and period of the pendulum, and use the equation for the period of a pendulum to solve for g.

66. a. 1380 m **b.** 1510 Hz
c. 1520 Hz

67. −48.0 cm

68. position: −10.9 cm; height: 1.09 cm; virtual and upright relative to the object

69. 0.00347°

Thinking Critically

58. Apply Concepts Calculate the ratio of the electric force to the gravitational force between the electron and the proton in a hydrogen atom.

59. Analyze and Conclude Sphere A, with a charge of +64 μC, is positioned at the origin. A second sphere, B, with a charge of −16 μC, is placed at +1.00 m on the x-axis.
a. Where must a third sphere, C, of charge +12 μC be placed so there is no net force on it?
b. If the third sphere had a charge of +6 μC, where should it be placed?
c. If the third sphere had a charge of −12 μC, where should it be placed?

60. Three charged spheres are located at the positions shown in **Figure 20-17.** Find the total force on sphere B.

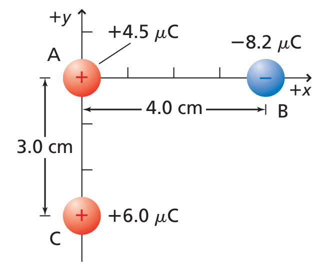


Figure 20-17

61. The two pith balls in **Figure 20-18** each have a mass of 1.0 g and an equal charge. One pith ball is suspended by an insulating thread. The other is brought to 3.0 cm from the suspended ball. The suspended ball is now hanging with the thread forming an angle of 30.0° with the vertical. The ball is in equilibrium with F_E, F_g, and F_T. Calculate each of the following.
a. F_g on the suspended ball
b. F_E
c. the charge on the balls

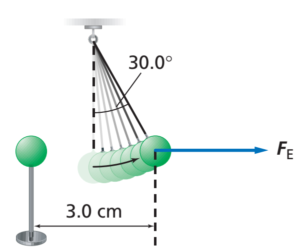


Figure 20-18

62. Two charges, q_A and q_B, are at rest near a positive test charge, q_T, of 7.2 μC. The first charge, q_A, is a positive charge of 3.6 μC located 2.5 cm away from q_T at 35°; q_B is a negative charge of −6.6 μC located 6.8 cm away at 125°.
a. Determine the magnitude of each of the forces acting on q_T.
b. Sketch a force diagram.
c. Graphically determine the resultant force acting on q_T.

Writing in Physics

63. History of Science Research several devices that were used in the seventeenth and eighteenth centuries to study static electricity. Examples that you might consider include the Leyden jar and the Wimshurst machine. Discuss how they were constructed and how they worked.

64. In Chapter 13, you learned that forces exist between water molecules that cause water to be denser as a liquid between 0°C and 4°C than as a solid at 0°C. These forces are electrostatic in nature. Research electrostatic intermolecular forces, such as van der Waals forces and dipole-dipole forces, and describe their effects on matter.

Cumulative Review

65. Explain how a pendulum can be used to determine the acceleration of gravity. (Chapter 14)

66. A submarine that is moving 12.0 m/s sends a sonar ping of frequency 1.50×10^3 Hz toward a seamount that is directly in front of the submarine. It receives the echo 1.800 s later. (Chapter 15)
a. How far is the submarine from the seamount?
b. What is the frequency of the sonar wave that strikes the seamount?
c. What is the frequency of the echo received by the submarine?

67. Security Mirror A security mirror is used to produce an image that is three-fourths the size of an object and is located 12.0 cm behind the mirror. What is the focal length of the mirror? (Chapter 17)

68. A 2.00-cm-tall object is located 20.0 cm away from a diverging lens with a focal length of 24.0 cm. What are the image position, height, and orientation? Is this a real or a virtual image? (Chapter 18)

69. Spectrometer A spectrometer contains a grating of 11,500 slits/cm. Find the angle at which light of wavelength 527 nm has a first-order bright band. (Chapter 19)

 For more problems, go to Additional Problems, Appendix B.

Standardized Test Practice

Multiple Choice

1. How many electrons have been removed from a positively charged electroscope if it has a net charge of 7.5×10^{-11} C?

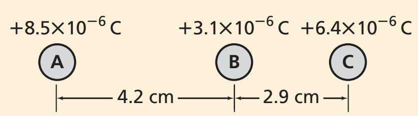
- (A) 7.5×10^{-11} electrons
- (B) 2.1×10^{-9} electrons
- (C) 1.2×10^{8} electrons
- (D) 4.7×10^{8} electrons

2. The force exerted on a particle with a charge of 5.0×10^{-9} C by a second particle that is 4 cm away is 8.4×10^{-5} N. What is the charge of the second particle?

- (A) 4.2×10^{-13} C
- (B) 2.0×10^{-9} C
- (C) 3.0×10^{-9} C
- (D) 6.0×10^{-5} C

3. Three charges, A, B, and C, are located in a line, as shown below. What is the net force on charge B?

- (A) 78 N toward A
- (B) 78 N toward C
- (C) 130 N toward A
- (D) 210 N toward C



4. What is the charge on an electroscope that has an excess of 4.8×10^{10} electrons?

- (A) 3.3×10^{-30} C
- (B) 4.8×10^{-10} C
- (C) 7.7×10^{-9} C
- (D) 4.8×10^{10} C

5. Two charged bodies exert a force of 86 N on each other. If they are moved so that they are six times farther apart, what is the new force that they will exert on each other?

- (A) 2.4 N
- (B) 14 N
- (C) 86 N
- (D) 5.2×10^{2} N

6. Two equally charged bodies exert a force of 90 N on each other. If one of the bodies is exchanged for a body of the same size, but three times as much charge, what is the new force that they will exert on each other?

- (A) 10 N
- (B) 30 N
- (C) 2.7×10^{2} N
- (D) 8.1×10^{2} N

7. An alpha particle has a mass of 6.68×10^{-27} kg and a charge of 3.2×10^{-19} C. What is the ratio of the electrostatic force to the gravitational force between two alpha particles?

- (A) 1
- (B) 4.8×10^{7}
- (C) 2.3×10^{15}
- (D) 3.1×10^{35}

8. Charging a neutral body by touching it with a charged body is called charging by ________ .

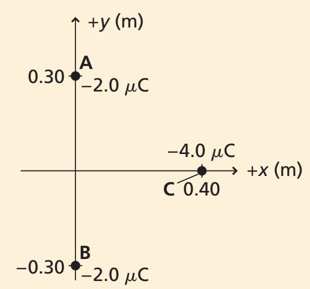
- (A) conduction
- (B) induction
- (C) grounding
- (D) discharging

9. Macy rubs a balloon with wool, giving the balloon a charge of -8.9×10^{-14} C. What is the force between the balloon and a metal sphere that is charged to 25 C and is 2 km away?

- (A) 8.9×10^{-15} N
- (B) 5.0×10^{-9} N
- (C) 2.2×10^{-12} N
- (D) 5.6×10^{4} N

Extended Answer

10. According to the diagram, what is the net force exerted by charges A and B on charge C? In your answer, include a diagram showing the force vectors $\boldsymbol{F}_{\text{A on C}}$, $\boldsymbol{F}_{\text{B on C}}$, and $\boldsymbol{F}_{\text{net}}$.



✓ Test-Taking TIP

Slow Down

Check to make sure you are answering the question that each problem is posing. Read the questions and answer choices very carefully. Remember that doing most of the problems and getting them right is always preferable to doing all of the problems and getting a lot of them wrong.

Physics Online physicspp.com/standardized_test

Standardized Test Practice

Rubric

The following rubric is a sample scoring device for extended response questions.

Extended Response

Points	Description
4	The student demonstrates a thorough understanding of the physics involved. The response may contain minor flaws that do not detract from the demonstration of a thorough understanding.
3	The student demonstrates an understanding of the physics involved. The response is essentially correct and demonstrates an essential but less than thorough understanding of the physics.
2	The student demonstrates only a partial understanding of the physics involved. Although the student may have used the correct approach to a solution or may have provided a correct solution, the work lacks an essential understanding of the underlying physical concepts.
1	The student demonstrates a very limited understanding of the physics involved. The response is incomplete and exhibits many flaws.
0	The student provides a completely incorrect solution or no response at all.

Multiple Choice

1. D **2.** C **3.** A
4. C **5.** A **6.** C
7. D **8.** A **9.** B

Extended Answer

10. F_{net} = 0.46 N in the positive x direction