SECTION 1

Static Electricity and Coulomb's Law: Opposites Attract

Section Overview

Students investigate the behavior of electrically charged objects by bringing two strips of charged tapes near each other and observing the forces of attraction and repulsion between them. They charge the tapes by folding and labeling the ends, then pressing them together and pulling off the top tape. Students also charge a plastic rod or styrene foam with wool and bring it near the charged tapes to observe what happens to the tapes. They also describe how charged objects are neutralized by adding or removing electrons and investigate the force of attraction due to charge redistribution between charged and neutral objects. Subsequently, students read about the principle for conservation of charge, calculate the electrical force using Coulomb's law, and compare Coulomb's law to Newton's law of universal gravitation.

Background Information

Understanding the electrostatic force between charges is crucial for explaining how atoms are held together. It is also the basis of chemical bonding. There are two types of charges, positive and negative. Like charges repel and unlike charges attract. In the everyday interaction of objects, it is the electrons—the negative charges—that get exchanged between objects. An excess of electrons accounts for a negative charge, while a deficiency of electrons accounts for a positive charge.

There are few conserved quantities in nature. The conservation of electric charge is one of these. The total charge in a closed system remains the same. The charges can be exchanged, but the total charge before an interaction must equal the total charge after the interaction.

In 1784, Charles Augustus Coulomb experimentally determined the equation for electric forces. Coulomb's law describes the forces between charges. The force is proportional to the charges and inversely proportional to the square of the distance between the charges.

$F = kq_1q_2/d^2$

where F is the force in newtons (N),

q_1 and q_2 are charges in coulombs (C),

d is the distance between the centers of the charges in meters, and

k is Coulomb's constant and always equal to $9 \times 10^9\ \text{N} \cdot \text{m}^2 / \text{C}^2$.

The similarity between Coulomb's law and Newton's law of gravitation hints at an underlying symmetry of nature. The investigation of symmetries like this (often on a more subtle mathematical level) drives much physics research.

Crucial Physics

- Atoms are composed of smaller particles that may have an electric charge. The electric charge on the electron is defined as being negative, while the charge on the proton is said to be positive.
- The magnitude of the charge on electrons and protons is equal.
- Static electric charge comes in two forms. An object gains a negative charge by having an excess of electrons and gains a positive charge from a deficiency of electrons.
- Charges that have the same sign (positive or negative) repel one another, while charges of opposite signs attract.
- Coulomb's law describes the force between charged particles. The force between two charged objects (F) depends upon the product of the charges (q_1 and q_2), and is inversely proportional to the square of the distance between the charges (d). This is expressed mathematically as $F = kq_1q_2/d^2$. Coulomb's law for the force between two charges is very similar to the law of universal gravitation, which describes the gravitational force between two masses; however, gravitation is only attractive.
- When charge is passed from one object to another, the total amount of charge on the two bodies is conserved.
- Objects may be charged either by passing charge from one object to another, or by inducing charge redistribution on another body when a charged object is brought near by (induction).

Learning Outcomes	Location in the Section	Evidence of Understanding
Produce electrically charged objects.	***Investigate*** Steps 1 and 4	Students press two strips of invisible tape together, and then separate them to create oppositely charged objects. They also rub a rod or a piece of styrene foam with wool to produce a net charge on each object.
Describe the behavior of like charges, and the behavior of unlike charges.	***Investigate*** Steps 2–8 ***Physics Talk*** ***Physics to Go*** Questions 1–20	Students bring the electrically charged objects near each other and describe the charges as like or unlike, depending on whether they attract or repel each other. Students read how charged objects behave and solve problems that explain how like and unlike charges behave when brought near each other.
Discover the factors that determine the force between two charged objects.	***Investigate*** Steps 2–8 ***Physics Talk***	Students compare and contrast forces of attraction and repulsion between charged objects and how the magnitude of charges and the distance between them affects the strength of those forces.
Calculate the electrical forces using Coulomb's law.	***Physics Talk*** ***Physics to Go*** Questions 5, 6, 11, and 12	Students calculate electrical force by solving problems using Coulomb's law.
Implement the organizing principle of conservation of charge.	***Physics Talk*** ***Physics to Go*** Questions 1–4, and 18–19	Student read how charge is conserved between two electrically charged spheres that are brought in contact and then separated using the overall net charge before and after contact as a constant.
Recognize the similarities and differences between Coulomb's law and Newton's law of gravitation.	***Physics Talk***	Students recognize that electrical forces can be attractive or repulsive since charges are either positive or negative. Gravitational forces are only attractive since mass only comes in one variety. The constants that determine the magnitude of the forces is much larger for electrical forces than gravity.
Explain how Coulomb was able to measure the electrostatic constant using a torsion balance.	***Physics Talk***	Students read how Cavendish measured the gravitational constant and about how Coulomb used a similar experiment to measure the electric force constant.

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Section 1 Materials, Preparation, and Safety

Materials and Equipment

PLAN A and PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Rod, friction, plastic	1 per group	
Pad, wool	1 per group	
Tape, transparent, adhesive	1 per group	
Paper, single sheet*	1 per group	

*Additional items needed not supplied

Time Requirements

- Allow one class period or 45 minutes for the *Investigate*.

Teacher Preparation

- If not already available, obtain one roll of "transparent" cellophane tape for each lab group.
- One pack of styrene-foam plates (available from a supermarket) should be sufficient for all the groups, and can be reused for other classes.
- Test the cloth you are using to charge the styrene-foam plates to ensure that it is able to develop a charge. If an electroscope is available, it would serve as a charge detector. If other charging apparatus is to be used, try it out first with the tapes to ensure that it functions in the desired manner.
- Search the Internet to find a Web site that has an animation of electrostatics and charged objects that can be shown to the students.

Safety Requirements

- A careful examination of the voltages developed in even small static experiments would indicate that high voltages are being generated. In this experiment, however, the voltages are both small, and the total energy available is so low that it does not present a hazard of students receiving an electric shock.

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Following written directions	***Investigate*** Step 1 ***Investigate*** Steps 3, 4, 6, and 8	**Augmentation** • Students who struggle with reading, visual processing, and/or maintaining attention to a task often have a difficult time following written directions, especially those written in paragraph form. An alternate way to present these directions in written form is to provide a numbered list. This allows students to complete one simple step at a time and to check off steps as they proceed. • When preparing the strips of tape, it may also be helpful to ask a student to read the directions aloud while the teacher models the process once for the whole group. Students have a difficult time understanding how to make a tab and label the tape. They often press the entire piece of tape onto the table and find it difficult to remove it. Having a visual model paired with auditory directions helps many students. **Accommodation** • For students who struggle to follow a set of directions and may take a long time to set up the tape, provide ready-made sets of tape for them to pull off of the table. This will allow students to focus on the investigation and the concepts instead of wasting a lot of time playing with tape.
Understanding vocabulary	***Investigate*** Steps 2.c) and 5	**Augmentation** • Some students will not know the meanings of the words "attractive" and "repulsive." There are a number of ways to help students understand these two words. Ask them to find the words in their science text or a dictionary. Show them two objects that are attracted or repelled and ask them to describe the action of the objects. • Ask students to show their hands repelling and attracting. Pairing auditory, visual, and kinesthetic cues helps all students remember these words.
Estimating distances	***Investigate*** Step 3.b)	**Augmentation** • Students who struggle with visual/spatial tasks have a difficult time estimating measurements. Ask students to find common objects that they could measure and use to help them estimate. For example, a paper clip may be three centimeters long or a penny may be two centimeters wide. Students can also create their own cardboard squares for a few different measurements and use those tabs to help with estimation. • It may also help these students to actually use a ruler and measure the distance, knowing that the measurements may not be extremely accurate but more accurate than a poor estimation. • Pair students strategically to help students who struggle with estimation. **Accommodation** • Seeing this part of the investigation as a demonstration in a smaller group may help some students focus on the distances as opposed to focusing on maneuvering the tape.

Learning Issue	Reference	Augmentation and Accommodations
Understanding the transfer of electrons	***Investigate*** Steps 6, 8, and 9 ***Physics Talk*** ***Physics to Go*** Questions 1, 2, 18, and 19	**Augmentation** • Because students are unable to see electrons, they may not have an idea how the negative charges are transferred. Some students may need to see a visual representation of an atom to be able to make sense of charge transfer. Though the structure of an atom will be discussed further in later sections, it is important that deductive learners have the big picture in their mind. • Ask students to draw pictures to represent the transfer of negative charges from the wool to the foam. This visual representation will make clear some misconceptions students may have about the transfer of charges. **Accommodation** • Provide drawings of the transfer of charges to make an object positively or negatively charged. As students show increased understanding of this concept, require increased independence in making charge transfer drawings and describing the process of transferring charges.
Solving problems to find electric force	***Physics Talk*** ***Active Physics Plus*** ***Physics to Go*** Questions 5 and 6.	**Augmentation** • Students who struggle with mathematical calculation have a difficult time with the formula for electric force because it contains a constant with a challenging SI unit, distance is squared, multiplication and division are required, and scientific notation is used. One strategy that is used to help students practice a new skill is to show them how to do one problem from start to finish. Next, ask them to guide the teacher through doing a second problem and clarify any misunderstandings. Then require that all students complete a third problem independently. • Students may need to learn or review scientific notation. They may also need to learn how to do calculations with exponents on their calculators. Taking the time to review these skills will build confidence and allow more students to successfully solve for electric force. **Accommodation** • There are students who may be unable to solve problems for electric force. For example, if a student is still struggling to multiply and divide, these problems will be very challenging. For these students, focus on the conceptual ideas of attractive and repulsive forces and how they are affected by charge and distance.
Conceptually understanding Coulomb's law	***Physics Talk*** ***Physics to Go*** Questions 9, 10, 14, 15, and 17	**Augmentation** • Students who struggle with mathematical relationships and number sense will need help understanding the direct relationship between electrical force and charge and the inverse square relationship between electrical force and distance. One method to help students understand these concepts is to use a kinesthetic model. Two or three students hold signs with a positive or negative number to represent their relative charges and use meter sticks to represent the distances between them. Then a small group or the whole class decides which direction the charges will move based on the effects of charge and distance. It is helpful if the students who are struggling to understand the concept are the students who represent the charges. • Help students see the direct and inverse mathematical relationships by using small whole numbers to represent the charges and the distance and solve for electrical force in terms of k. This allows students to make more sense of what will happen if charge is doubled or what will happen if distance is doubled.

Strategies for Students with Limited English-Language Proficiency

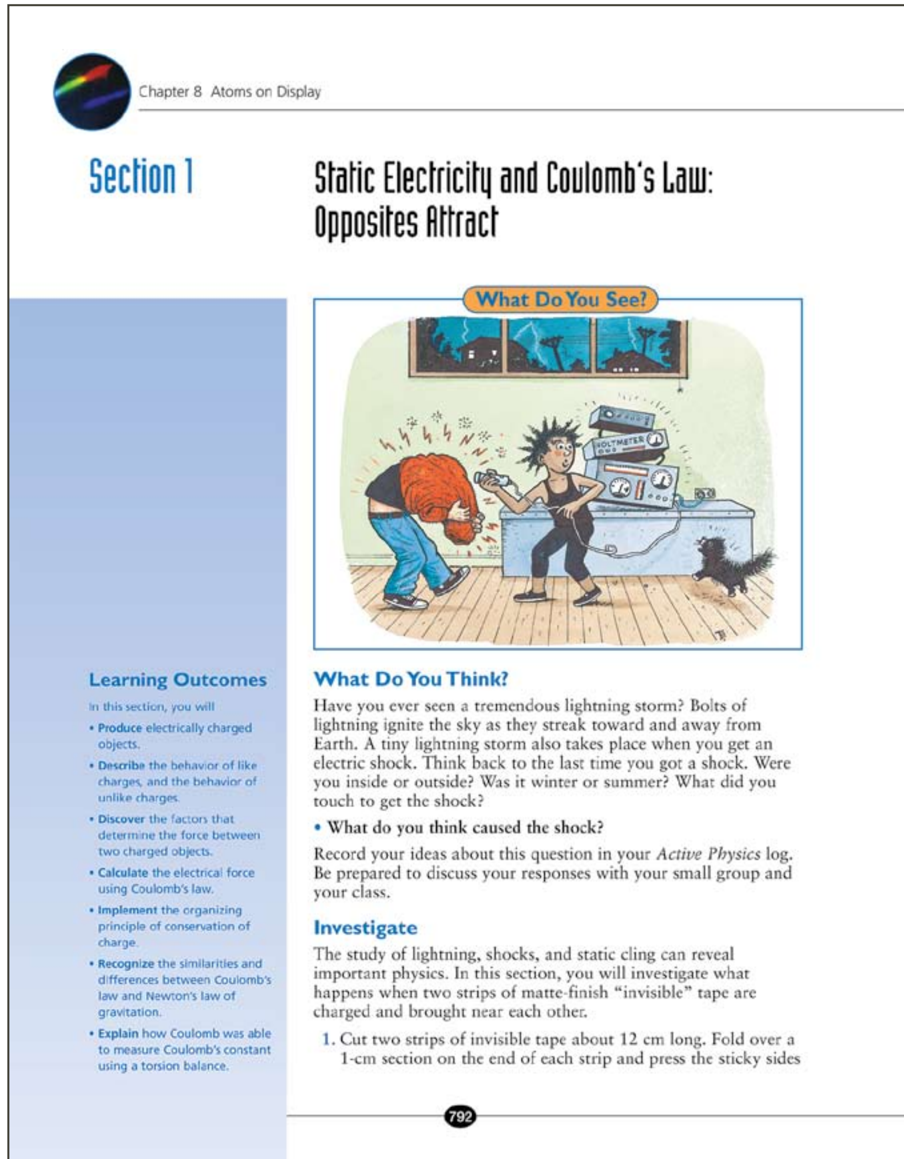
Learning Issue	Reference	Augmentation
Vocabulary comprehension	***Investigate*** Step 1	Learning to use context to figure out the meaning of unfamiliar words and phrases is an important skill for all readers, including ELL students. Notice how students deal with the phrase "smooth out the creases." Other words in the sentence, "rubbing your finger over the strips a few times," should be sufficient to help students determine the meaning of both "smooth out" and "creases."
Comprehension	***Investigate*** Step 2.b)	Students may benefit from a quick review of Newton's second law. Discuss what it means to be "in agreement" with a law. Make it clear that the agreement is between the observations and the interactions predicted by Newton's second law, rather than the more familiar context of an agreement between two people.
Identifying parts of speech	***Investigate*** Step 2.c)	Students have previously encountered the terms "attract" and "repel," most recently when dealing with magnets. Here, check that they understand the adjectival forms "attractive" and "repulsive."
Understanding concepts Vocabulary comprehension	***Investigate*** Step 5.a)	Making inferences is a higher-level reading skill. When learning a new language, ELL students may not pick up on subtleties that indicate a connection between two bits of information. Be sure students understand that "this law of electrostatics" refers to "opposite charges attract and like charges repel." Students may be familiar with the term "static," but most likely have not seen it used as a word root in a term like "electrostatics." Help students deconstruct the meaning of this term.
Vocabulary comprehension Identifying parts of speech	***Investigate*** Step 9.b)	Students will likely recognize the word "sink" but may not have encountered the meaning found here. Tell students that in English, many words have more than one meaning. Students may have heard of a "heat sink," which is used, for example, to draw heat away from electronic components. The terms "ground," "grounding," and "grounded" may have syntax that seems odd for students. Students may be puzzled about the active voice in a phrase like "when the ground removes electrons." Most people do not think of the ground as a noun that initiates action. The verb form can also be confusing. You can ground an object by just touching it or by touching it to a ground. Also, an object can "be grounded." Because so many different variations occur with this verb, the meaning may need to be discussed at length.
Understanding concepts	***Physics Talk*** Static Charges and Forces	Hold a class discussion about "visible and measurable effects." Be sure students understand that scientists frequently use such effects to prove the existence of and explain the behavior of various unseen phenomena. Remind students that they have already learned about two such phenomena in their studies this year: gravity and magnetism.
Vocabulary comprehension	***Physics Talk*** Conservation of Charge	Work through the idea of conservation of charge with the class. To help students understand the concept, you may wish to review the law of conservation of energy. But unlike energy, which can change form, charge does not change form. The total amount of negative charge remains constant, and the total amount of positive charge remains constant. Also, be sure students do not think that matter with a neutral charge has no charge. Neutral matter can be loaded with charge, but as long as the amount of positive charge equals the amount of negative charge, matter has a neutral charge. Finally, challenge students to use context to determine the meanings of "excess" and "deficiency."

SECTION 1

Teaching Suggestions and Sample Answers

What Do You See?

The images in this illustration are likely to elicit an immediate reaction from students. The bolts of lightning outside and the obvious effects of the electric discharge detected by the person holding the microphone provides interesting points of discussion. You might want to prompt students to notice that the lightning streaks are toward the ground, rather than from cloud to cloud. Encourage them to relate their impressions of what the artist is trying to convey and suggest that they return to the *What Do You Think?* question once they have advanced further in this section. Use an overhead of this illustration to highlight different aspects of the visual.



Chapter 8 Atoms on Display

Section 1 — Static Electricity and Coulomb's Law: Opposites Attract

What Do You See?

Learning Outcomes

In this section, you will

- **Produce** electrically charged objects.
- **Describe** the behavior of like charges, and the behavior of unlike charges.
- **Discover** the factors that determine the force between two charged objects.
- **Calculate** the electrical force using Coulomb's law.
- **Implement** the organizing principle of conservation of charge.
- **Recognize** the similarities and differences between Coulomb's law and Newton's law of gravitation.
- **Explain** how Coulomb was able to measure Coulomb's constant using a torsion balance.

What Do You Think?

Have you ever seen a tremendous lightning storm? Bolts of lightning ignite the sky as they streak toward and away from Earth. A tiny lightning storm also takes place when you get an electric shock. Think back to the last time you got a shock. Were you inside or outside? Was it winter or summer? What did you touch to get the shock?

- What do you think caused the shock?

Record your ideas about this question in your *Active Physics* log. Be prepared to discuss your responses with your small group and your class.

Investigate

The study of lightning, shocks, and static cling can reveal important physics. In this section, you will investigate what happens when two strips of matte-finish "invisible" tape are charged and brought near each other.

1. Cut two strips of invisible tape about 12 cm long. Fold over a 1-cm section on the end of each strip and press the sticky sides

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Students' Prior Conceptions

This section reviews what students think they understand about the nature of matter and how charges are created or transferred among various objects. You should look for students to seek consistent explanations dealing with the production of electrically charged objects and how the forces between two objects make them behave. Attending to the following prior conceptions sets the stage for eradicating misconceptions in other sections of this chapter.

1. **Friction is necessary to create static electricity.** This belief is erroneous because static charges appear whenever two dissimilar insulating objects touch each other. Chemical bonds form between the two surfaces and if atoms in one of the objects hold electrons more tightly than the second object then the first object takes charged particles from the second object upon immediately touching each other. You can emphasize this phenomenon between dissimilar objects, such as sticky tape and table tops. You may also emphasize that merely standing on a rug in stocking feet is sufficient for the existence of an imbalance in charge between the stockings and the rug. Students need not slide across a rug to touch a metal doorknob and receive a "static shock."
2. **Neutral objects have no charge.** It is essential for you to review the structure of atoms to reinforce that all atoms contain both positive and negative charges. Atoms are electrically neutral because these charges are balanced—the number of electrons in the atomic orbits equals the number of protons in the nucleus.
3. **Protons are mobile like electrons.** As you focus on the structure of the atom, emphasize that the electrons are the mobile constituents of atoms; only under extreme nuclear reactions are protons involved in reactions that transfer charge.

Consider reading the title aloud and asking students to make connections between the title and the stormy scenes depicted in the visual.

What Do You Think?

The introductory paragraph of this section has several questions that prompt students to think about what caused them to feel a shock. The questions provide you an opportunity to start a discussion that should help students to respond with confidence. Emphasize that at this stage it doesn't matter whether an answer is accurate, the purpose of *What Do You Think?* is to set the stage for the *Investigate* that follows after they have recorded their answers in their logs. Given the freedom to express their ideas without being concerned about a grade reveals the prior conceptions students might have and will help you address these conceptions at appropriate times during the lesson. Encourage students to connect the *What Do You Think?* question to why people sometimes feel a shock when they touch something.

Teaching Tip

If students' hands are oily, cleaning them with a few drops of commercial alcohol-based hand sanitizer will allow for better results with the tapes.

Investigate

1.

Students cut the two 12-cm long strips of invisible tape, fold the ends, label them, and press them together. They peel off the top strip by pulling up its tab.

What Do You Think?

A Physicist's Response

The lightning outside caused the shock by transferring a large charge from cloud to the ground. Flashes of lightning and small shocks one gets from shuffling across a carpet differ only in scale. Students probably received electric shocks from carpets when they were indoors—more likely in the winter when the air was dry. Rubbing shoes against a dry carpet often builds up a charge on the walker, who may then touch a doorknob, a light switch, or another person.

4. **A positively charged object gains protons.** The key idea for you to emphasize is that only the electrons are mobile during ordinary chemical interactions and reactions. It is the loss and gain of electrons that makes an object carry a positive charge or a negative charge.
5. **Static electricity is the build-up of electrons.** This prior conception is false because it is the imbalance of charge between two objects that leads to a static build-up and the discharge of an electric "jolt," such as the discharge depicted in the picture in the *Physics Talk*. The central concept for teachers to emphasize is the imbalance of charge.
6. **Students fail to recognize that charge is conserved.** When students are explaining what happens with the strips of tape, and what happens when charge is shared between objects that are able to conduct electricity, be sure that students are considering the total charge on an isolated system. The distribution of charge may change but the total charge is conserved.
7. **As students compare Newton's law of gravitation with Coulomb's law, they might believe that the electrical force is the same as the gravitational force. A corollary to this misconception is that the gravitational force is stronger than the electrical force.** Have students observe the reaction between small bits of paper and one of the charged strips of tape. The paper bits will "jump up" to the charged tape, demonstrating that the force of gravity is the weaker force. Emphasize that the Coulomb force is both an attractive and a repulsive force whereas the force of gravity is only an attractive force. You should also emphasize that the value for the gravitational constant, *G*, is a small number, whereas the value for Coulomb's constant, *k*, is a large number.

2.a)

The two strips will attract each other.

2.b)

The two strips did not hang straight down but accelerated toward each other. The fact that they accelerated toward each other at first and then were stationary once equilibrium of forces was attained is in agreement with Newton's second law.

2.c)

The force was attractive.

3.

Students should set up an experiment to see what occurs when two top strips, two bottom strips, and combinations of top and bottom strips are brought near one another. T_1 should be brought near B_1, B_2, and T_2. Then B_1 brought near T_1, B_2, and T_2 and so forth until all combinations have been tried.

3.a)

Students should record their observations in a table. The table may look like the one shown below:

	T_1	B_1
T_2	Repel	Attract
B_2	Attract	Repel

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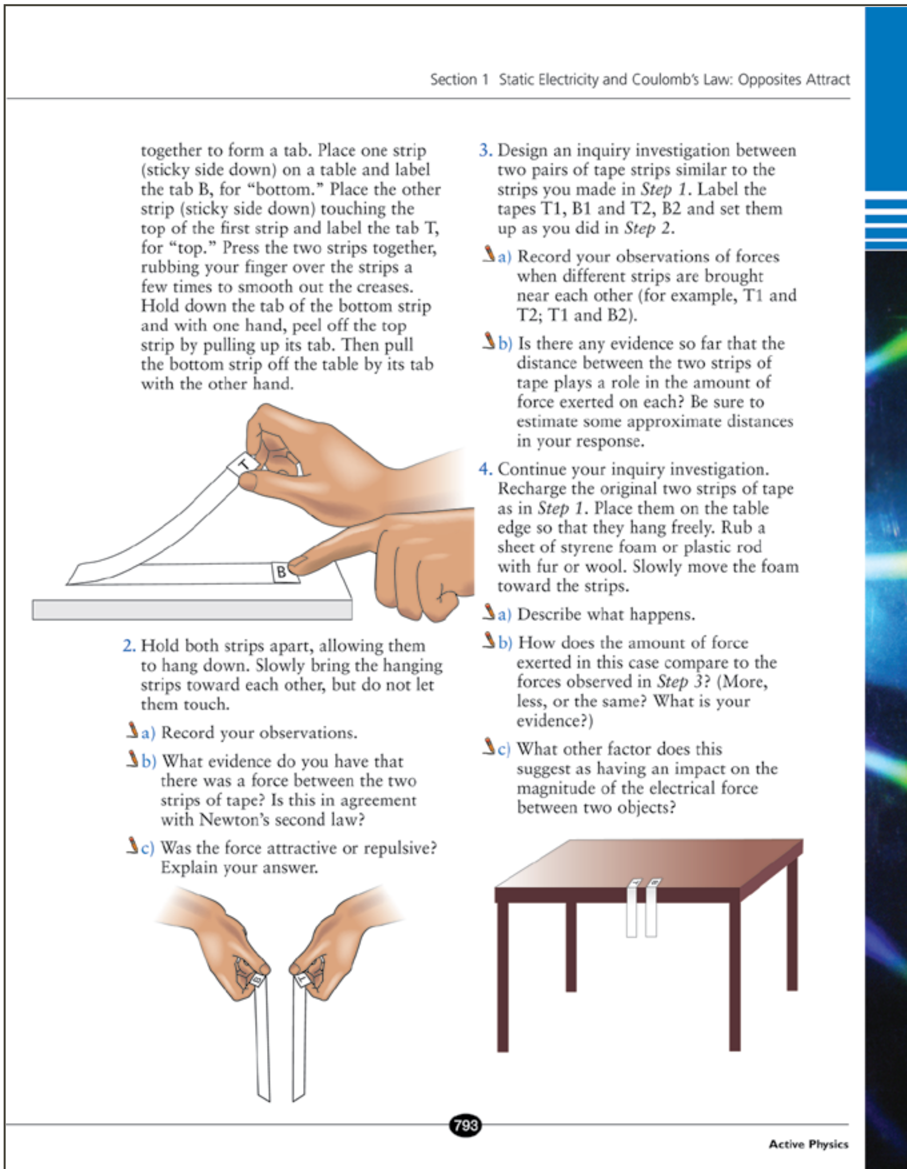


together to form a tab. Place one strip (sticky side down) on a table and label the tab B, for "bottom." Place the other strip (sticky side down) touching the top of the first strip and label the tab T, for "top." Press the two strips together, rubbing your finger over the strips a few times to smooth out the creases. Hold down the tab of the bottom strip and with one hand, peel off the top strip by pulling up its tab. Then pull the bottom strip off the table by its tab with the other hand.

2. Hold both strips apart, allowing them to hang down. Slowly bring the hanging strips toward each other, but do not let them touch.
   a) Record your observations.
   b) What evidence do you have that there was a force between the two strips of tape? Is this in agreement with Newton's second law?
   c) Was the force attractive or repulsive? Explain your answer.

3. Design an inquiry investigation between two pairs of tape strips similar to the strips you made in *Step 1*. Label the tapes T1, B1 and T2, B2 and set them up as you did in *Step 2*.
   a) Record your observations of forces when different strips are brought near each other (for example, T1 and T2; T1 and B2).
   b) Is there any evidence so far that the distance between the two strips of tape plays a role in the amount of force exerted on each? Be sure to estimate some approximate distances in your response.

4. Continue your inquiry investigation. Recharge the original two strips of tape as in *Step 1*. Place them on the table edge so that they hang freely. Rub a sheet of styrene foam or plastic rod with fur or wool. Slowly move the foam toward the strips.
   a) Describe what happens.
   b) How does the amount of force exerted in this case compare to the forces observed in *Step 3*? (More, less, or the same? What is your evidence?)
   c) What other factor does this suggest as having an impact on the magnitude of the electrical force between two objects?

3.b)

Distance affects the magnitude of the force. The closer the strips, the more they will attract or repel. Estimates of distance measurements will vary with the students doing the investigation, the weather conditions, the tape used, etc.

4.a)

Students record their observations. The styrene foam will also attract the top tapes and repel the bottom tapes.

Teaching Tip

Many materials will reliably develop static charges for testing. PVC pipe rubbed with wool is a long lasting and inexpensive alternative to the styrene-foam plates, as well as things such as the golf tubes that are inside golf bags, and the plastic covers that fit over fluorescent lights. For additional material that develops both positive and negative charges, consult the triboelectric series, a list that ranks various materials according to their tendency to gain or lose electrons. This can be found on the Web.

4.b)

To compare the forces, students will have to ensure that the distances between a charged tape and the styrene foam or plastic rod are the same as the previous distances between tapes. The forces between the styrene foam or plastic and the tape should be greater than the force between tapes due to the larger charge on the styrene foam or plastic rod.

4.c)

The magnitude of the charge on the plate compared to the tape will also affect the size of the force.

CHAPTER 8

5.a)

Using the concept that opposite charges attract and like charges repel, students should conclude that when pairs of strips (T_1 and B_1) attract, they must have opposite charges. When top or bottom pairs of strips are brought together (T_1 and T_2 or B_1 and B_2), they repel. This implies they have like charges.

5.b)

Students should conclude that the styrene foam has the same charge as the bottom tapes, since it repels them.

6.a)

The positives on the T tapes came from transferring electrons to the B tapes.

6.b)

Because the B tapes gained electrons, they must have a net negative charge.

6.c)

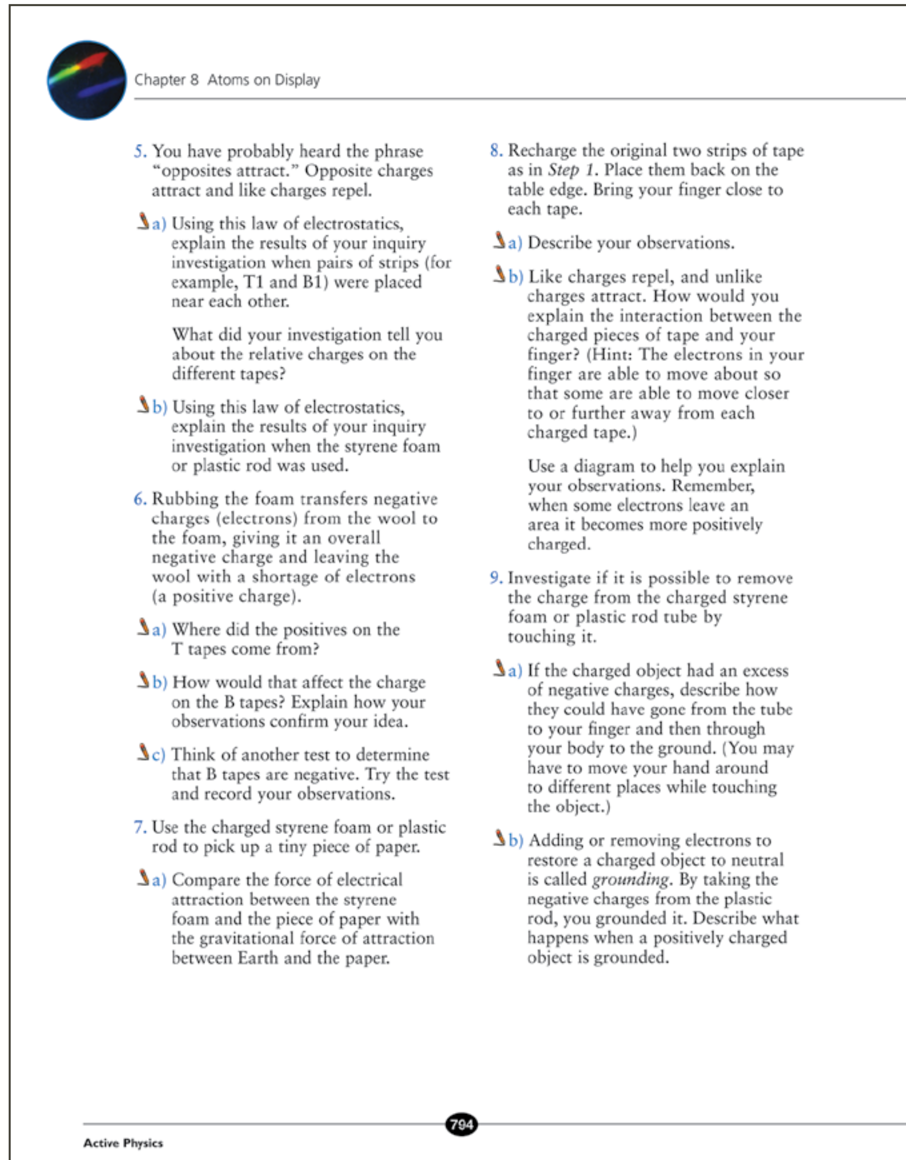
One possible test is to use the wool, which transferred electrons to the styrene foam, leaving it with a net positive charge. When the wool is brought near the bottom tape, it should attract the tape with negative charge.

7.a)

The force of attraction between the styrene foam and the pieces of paper must be stronger than the force of gravity between the paper and Earth.

8.a)

Students should find that their finger attracts both tapes by induction.



Chapter 8 Atoms on Display

5. You have probably heard the phrase "opposites attract." Opposite charges attract and like charges repel.

a) Using this law of electrostatics, explain the results of your inquiry investigation when pairs of strips (for example, T1 and B1) were placed near each other.

What did your investigation tell you about the relative charges on the different tapes?

b) Using this law of electrostatics, explain the results of your inquiry investigation when the styrene foam or plastic rod was used.

6. Rubbing the foam transfers negative charges (electrons) from the wool to the foam, giving it an overall negative charge and leaving the wool with a shortage of electrons (a positive charge).

a) Where did the positives on the T tapes come from?

b) How would that affect the charge on the B tapes? Explain how your observations confirm your idea.

c) Think of another test to determine that B tapes are negative. Try the test and record your observations.

7. Use the charged styrene foam or plastic rod to pick up a tiny piece of paper.

a) Compare the force of electrical attraction between the styrene foam and the piece of paper with the gravitational force of attraction between Earth and the paper.

8. Recharge the original two strips of tape as in *Step 1*. Place them back on the table edge. Bring your finger close to each tape.

a) Describe your observations.

b) Like charges repel, and unlike charges attract. How would you explain the interaction between the charged pieces of tape and your finger? (Hint: The electrons in your finger are able to move about so that some are able to move closer to or further away from each charged tape.)

Use a diagram to help you explain your observations. Remember, when some electrons leave an area it becomes more positively charged.

9. Investigate if it is possible to remove the charge from the charged styrene foam or plastic rod tube by touching it.

a) If the charged object had an excess of negative charges, describe how they could have gone from the tube to your finger and then through your body to the ground. (You may have to move your hand around to different places while touching the object.)

b) Adding or removing electrons to restore a charged object to neutral is called *grounding*. By taking the negative charges from the plastic rod, you grounded it. Describe what happens when a positively charged object is grounded.

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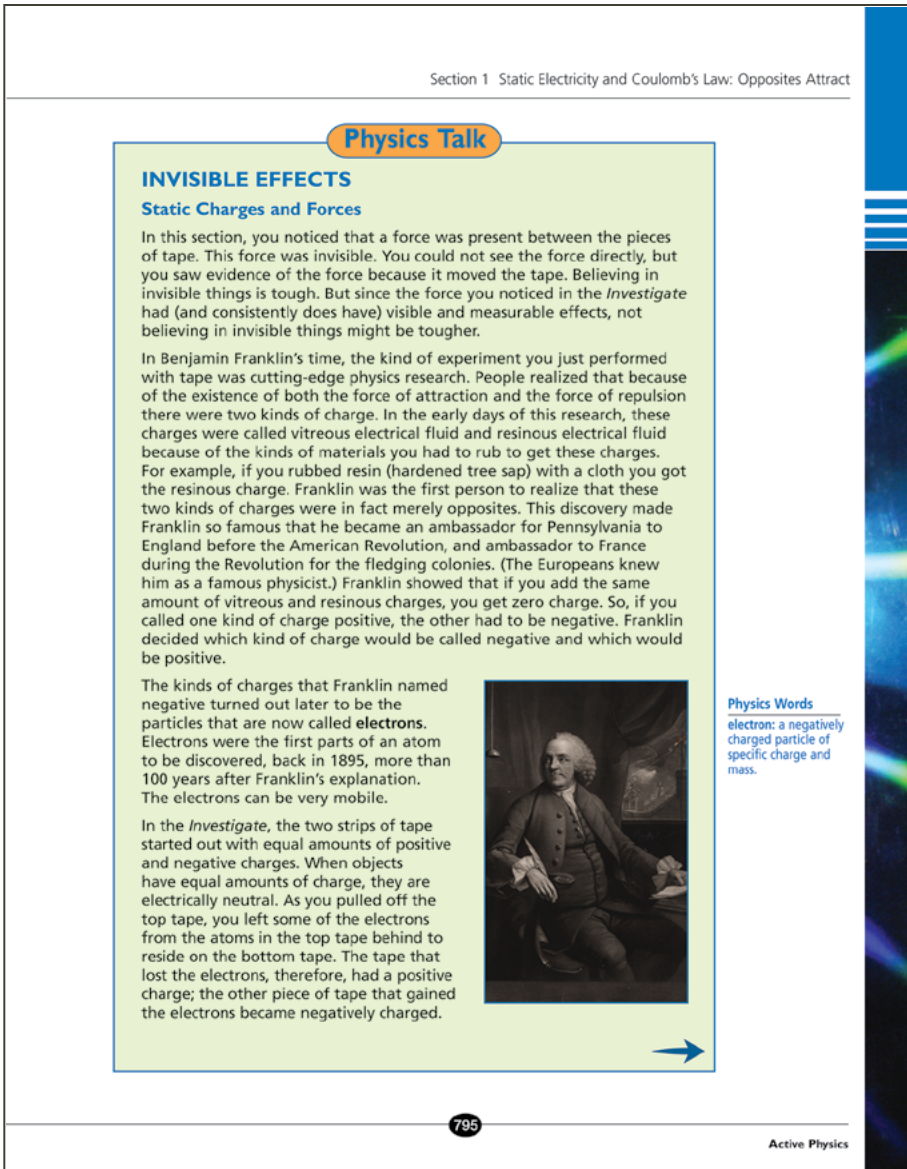
8.b)

Because a finger attracts both the top (positive) tape and the bottom (negative) tape, the finger must have the charge opposite to each tape. Electrons in the finger are able to move, so when the finger is brought near the top tape, the electrons are drawn toward the positive charges in the tape. This makes the fingertip negative, leaving the back of the hand positive. Because the negative fingertip is closer than the positive back of the hand there is a net attractive force, which attracts the positive tape. The electrons in the fingertip are drawn from further back in the finger, leaving that part positive. The first diagram on the next page shows what the charges would look like.



Physics Talk

INVISIBLE EFFECTS

Static Charges and Forces

In this section, you noticed that a force was present between the pieces of tape. This force was invisible. You could not see the force directly, but you saw evidence of the force because it moved the tape. Believing in invisible things is tough. But since the force you noticed in the *Investigate* had (and consistently does have) visible and measurable effects, not believing in invisible things might be tougher.

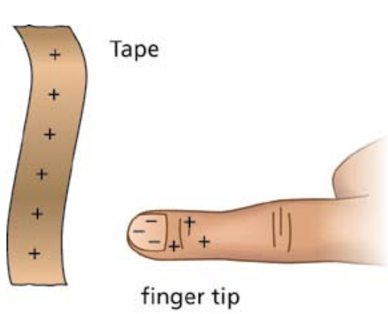
In Benjamin Franklin's time, the kind of experiment you just performed with tape was cutting-edge physics research. People realized that because of the existence of both the force of attraction and the force of repulsion there were two kinds of charge. In the early days of this research, these charges were called vitreous electrical fluid and resinous electrical fluid because of the kinds of materials you had to rub to get these charges. For example, if you rubbed resin (hardened tree sap) with a cloth you got the resinous charge. Franklin was the first person to realize that these two kinds of charges were in fact merely opposites. This discovery made Franklin so famous that he became an ambassador for Pennsylvania to England before the American Revolution, and ambassador to France during the Revolution for the fledging colonies. (The Europeans knew him as a famous physicist.) Franklin showed that if you add the same amount of vitreous and resinous charges, you get zero charge. So, if you called one kind of charge positive, the other had to be negative. Franklin decided which kind of charge would be called negative and which would be positive.

The kinds of charges that Franklin named negative turned out later to be the particles that are now called **electrons**. Electrons were the first parts of an atom to be discovered, back in 1895, more than 100 years after Franklin's explanation. The electrons can be very mobile.

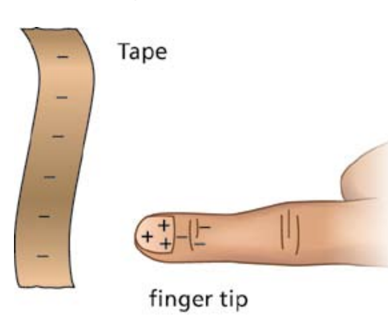
In the *Investigate*, the two strips of tape started out with equal amounts of positive and negative charges. When objects have equal amounts of charge, they are electrically neutral. As you pulled off the top tape, you left some of the electrons from the atoms in the top tape behind to reside on the bottom tape. The tape that lost the electrons, therefore, had a positive charge; the other piece of tape that gained the electrons became negatively charged.

Physics Words

electron: a negatively charged particle of specific charge and mass.



When the finger is brought near a negative (bottom) tape, the opposite process occurs, as shown in the diagram below:



9.a)

For the negatively charged styrene foam, the electrons would repel each other, and pass through the hand and arm down to the ground (which is able to store large numbers of electrons), leaving the styrene foam with almost no charge. Because styrene is an insulator, students will probably have to rub the foam with their hand to get all the charge to move from the styrene to their hand.

9.b)

When a positively charged object is grounded, the positive charges draw electrons up from the ground through your arm, to neutralize the positive object.

Physics Talk

Students understand the presence of invisible forces on different objects. They correlate their findings in the *Investigate* with the evidence of visible and measurable effects. They read how electrons were discovered. The *Physics Talk* also explains the process of grounding and how charge is conserved. Students further relate the behavior of charged objects to Coulomb's law and compare Coulomb's law to Newton's law of universal gravitation.

The idea of invisible forces may present prior conceptions that you could address during this *Physics Talk*. Ask students to summarize Benjamin Franklin's discovery of opposite charges and explain how he decided which kind of charge would be called positive and which kind of charge would be negative.

CHAPTER 8

Using the example of the investigations with tapes, determine if students know that the tapes were electrically neutral before they pulled the top tape off the bottom tape. Consider asking students why their finger removed the excess electrons from the charged object and have them describe the process of grounding. Encourage them to draw diagrams while explaining the transfer of charges.

While discussing the conservation of charge, check to see if students understand how charge is distributed after spheres of different charges touch and then separate. You might want to ask student volunteers to come up to the board and explain how charges becomes identical after the two spheres of different charges come in contact with each other. Point out that the charges are only equally distributed when the spheres are identical. Ask students to write a brief description of the law of conservation of charge.

As students are introduced to Coulomb's law, have them describe how Charles Augustin de Coulomb was able to verify that the attractive or repulsive force between charged objects decreases as the distance between them increases, and that the strength of the force is directly proportional to the magnitude of the charges. Ask students to explore how enormous amounts of electric charge are transferred to person inside his or her house when a bolt of lightning hits the ground nearby. Have them compare the results of Cavendish's experiment to Coulomb's experiment. Discuss the similarities between the equations describing the gravitational and electric forces and how both depend upon the inverse square of the distance between the objects.

Physics Words

grounding: the process of adding or removing electrons to restore a charged object to neutral.

conservation of charge: the total charge of an isolated system before an event equals the total electric charge after the event.

The top tape and the bottom tape attracted each other because positively and negatively charged objects attract (unlike charges attract). In other experiments you performed, you found that positively-charged objects repel positively charged objects and negatively-charged objects repel negatively charged objects (like charges repel). You also found that by touching a charged object with your finger you removed the excess charge from the object. This process of adding or removing excess electrons to achieve electrical neutrality is called **grounding**.

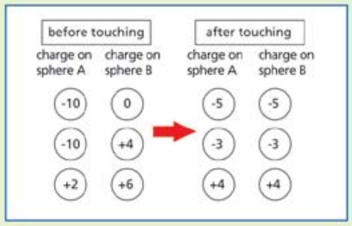
In all these cases, however, only a very little mass has been transferred. Electrons are parts of the atom, but account for only a very tiny part of the mass compared to the rest of the atom. Evidently, the positives (positive charges) that are left behind are very heavy compared to the electrons. You will learn more about the electrons, and about the positives, later in this chapter.

Conservation of Charge

When the top strip of tape is pulled from the bottom strip of tape, the top strip loses electrons, while the bottom strip gains electrons. This situation is a good example of one of the major organizing principles of physics—the **conservation of charge**. In any isolated system, the total amount of charge must remain constant. If a negative charge is removed from one object, that negative charge must go somewhere. For example, if 15 bits of negative charge are removed from the top strip of tape in the *Investigate*, then 15 bits of negative charge are transferred to the bottom strip. There are only a few quantities discovered that nature conserves—charge is one of them.

Perhaps without being aware of it, you used the concept of conservation of charge in your analysis of what you observed. A few simple problems illustrate this conservation law. When two identical metal spheres touch and then separate, they will end up with identical charges. If they did not end up with identical charges, there would be a way to distinguish the metal spheres. One sphere with a charge of –10 touches a neutral, identical sphere. After touching and separating, each sphere has a net charge of –5. The charge was transferred, but the total charge remained the same. Keep in mind that neutral matter already contains enormous amounts of positives and negatives (positive and negative charges), but in equal amounts. Thus, the excess and deficiency are relative to a baseline of starting out neutral.

Section 1 Static Electricity and Coulomb's Law: Opposites Attract



The conservation of charge between identical metal spheres that touch and then separate can be summarized as follows:

1. The total charge of the two spheres before touching is equal to the total charge after touching.
2. The charges on the identical spheres must be identical after they touch.
3. In solving problems like this, find the total charge before contact. Distribute that total charge of the two spheres equally to both spheres after contact.

Coulomb's Law

You have seen that in physics, scientists often search for an equation that can provide a clearer, more precise description of what they observe. In your experiments, you found that the force between two charged objects could be attractive or repulsive, and the force decreased when the objects moved farther apart. You also found that larger amounts of charge exerted a greater force between the objects. In 1784, Charles Augustin de Coulomb experimentally determined and used precise measurements to show that the force of attraction between two charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them. This is called **Coulomb's law.**

Physics Words

Coulomb's law of electrical attraction or repulsion: the force of attraction between two charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them.

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Active Physics

Chapter 8 Atoms on Display

This law can be written using an equation:

$$F = k\frac{q_1 q_2}{d^2}$$

where F is the force in newtons (N),

q_1 and q_2 are charges in coulombs (C),

d is the distance between the centers of the charges in meters (m), and

k is Coulomb's constant, always equal to 9×10^9 N·m²/C².

In every problem you solve, k will be $9 \times 10^9 \text{N}\cdot\text{m}^2/\text{C}^2$. That is why it is called a constant. Note that the unit of charge was named a coulomb, in honor of Charles de Coulomb.

Sample Problem

Two small charged spheres are placed 0.2 m apart. The first sphere has a charge of $+3.0 \times 10^{-6}\text{C}$ and the second sphere has a charge of $-4.0 \times 10^{-6}\text{C}$. Calculate the force between them.

Strategy: You can use the equation for electric forces to calculate the force between the spheres.

Given:

$q_1 = +3.0 \times 10^{-6}\text{C}$

$q_2 = -4.0 \times 10^{-6}\text{C}$

$d = 0.2$ m

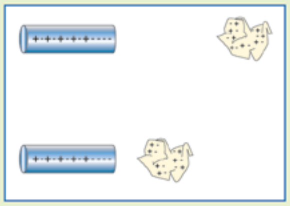
Solution:

$$F = k\frac{q_1 q_2}{d^2}$$

$$F = \frac{(9 \times 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(+3.0 \times 10^{-6}\text{C})(-4.0 \times 10^{-6}\text{C})}{(0.2\text{m})^2} = -2.7\text{ N}$$

The negative sign indicates that the force is attractive.

One coulomb of charge is an enormous amount of charge. A lightning bolt may transfer a coulomb of charge. That is why, in solving problems that have to do with realistic charges, you must use numbers and units like $1 \times 10^{-6}\text{C}$. Many calculators allow calculations with exponents to be completed with ease.



How does a negatively charged rod pick up a neutral piece of paper? The rod is negatively charged. In the diagram to the right, there are more negatives than positives in the rod. The piece of paper is neutral. There are an equal number of positives and negatives. When the rod is brought close to the paper, the excess negatives on the rod repel the negatives of the paper. The excess negatives of the rod are attracted to the positives in the paper and repelled by the negatives in the paper. Because the positives are closer, the force of attraction is larger. Coulomb's law informs you that the force gets weaker as the distance gets larger. With a stronger force of attraction on the positive charges and the weaker force of repulsion on the negative charges, the rod can pick up the paper.

Comparing Coulomb's Law and Newton's Law of Universal Gravitation

You found you could actually calculate the force of attraction or repulsion of charges by using Coulomb's law:

$$F = k\frac{q_1 q_2}{d^2}$$

Coulomb's law for electrostatic attraction and repulsion is very similar to **Newton's law of universal gravitation**. Newton's law gives the relationship among gravitational force, masses, and the distance between the masses. This relationship can be summarized by the following equation:

$$F = G\frac{m_1 m_2}{d^2}$$

Where F is the force in newtons (N),

m_1 and m_2 are masses in kilograms (kg),

d is the distance between the centers of the masses in meters (m),

and G is the gravitational constant, always equal to 6.67×10^{-11} N·m²/kg².

Look at the similarities:

- Both laws show forces that decrease in strength with the square of the distance between two objects.
- Both laws show forces that depend on the product of the masses or charges.

Physics Words

Newton's law of universal gravitation: the relationship among gravitational force, masses, and the distance between the masses.

CHAPTER 8

Checking Up

1.

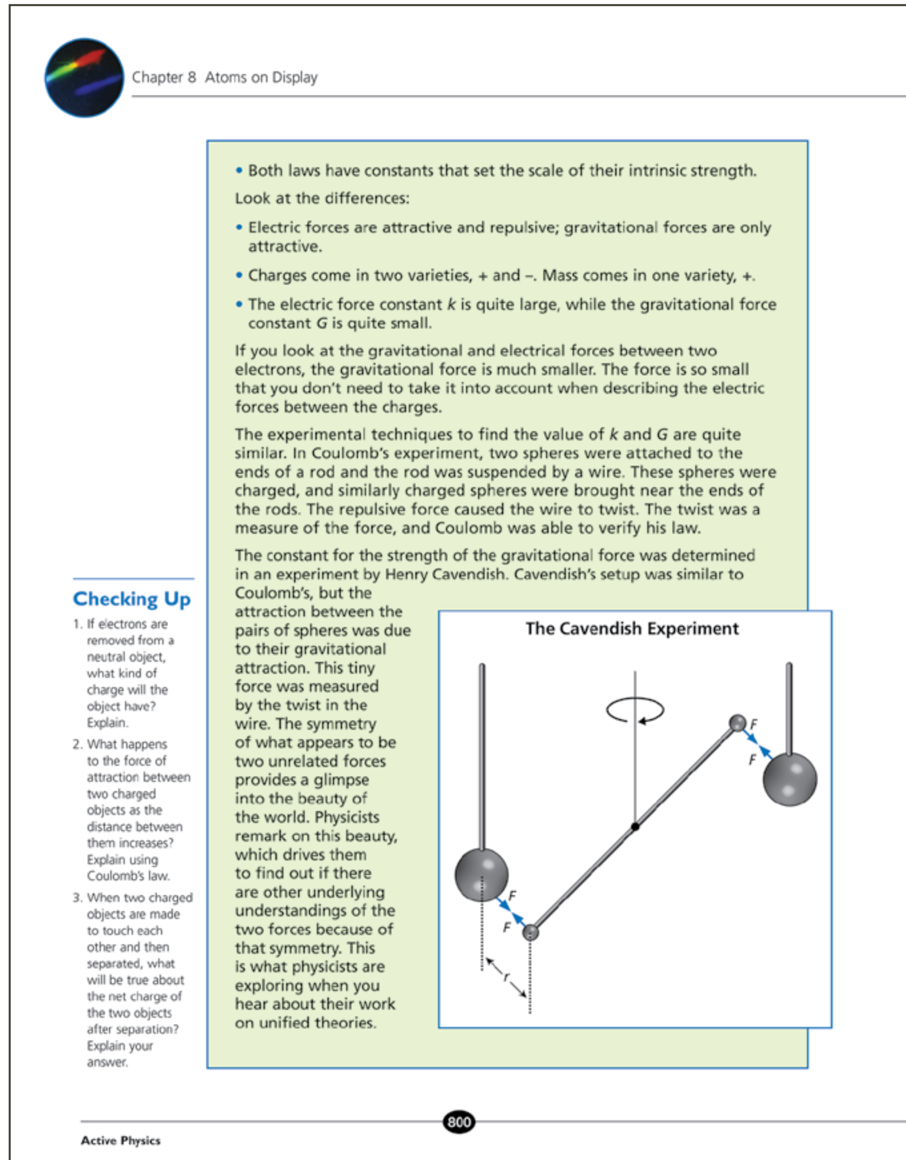
Removing electrons from a neutral object leaves the object with a net positive charge. Because a neutral material has an equal number of positive and negative charges, taking away some of the negatives leaves some of the positives unbalanced, and thus the net positive charge.

2.

As the distance between two charged objects increases, the force of attraction between the objects decreases. According to Coulomb's law, the force between charged objects varies according to the equation $F = kq_1q_2/d^2$ so that if the distance between the objects is doubled, the force between them will decrease by a factor of four.

3.

When two charged conducting objects touch each other and are then separated, the charges between the objects will be shared. (Note: The objects will achieve the same potential—i.e., voltage—not necessarily equal charges.) The total net charge before contact will be the same after contact due to conservation of charge. If the two objects are conducting spheres of equal size, each object will have the same net charge.


Chapter 8 Atoms on Display

- Both laws have constants that set the scale of their intrinsic strength.

Look at the differences:

- Electric forces are attractive and repulsive; gravitational forces are only attractive.
- Charges come in two varieties, + and –. Mass comes in one variety, +.
- The electric force constant k is quite large, while the gravitational force constant G is quite small.

If you look at the gravitational and electrical forces between two electrons, the gravitational force is much smaller. The force is so small that you don't need to take it into account when describing the electric forces between the charges.

The experimental techniques to find the value of k and G are quite similar. In Coulomb's experiment, two spheres were attached to the ends of a rod and the rod was suspended by a wire. These spheres were charged, and similarly charged spheres were brought near the ends of the rods. The repulsive force caused the wire to twist. The twist was a measure of the force, and Coulomb was able to verify his law.

The constant for the strength of the gravitational force was determined in an experiment by Henry Cavendish. Cavendish's setup was similar to Coulomb's, but the attraction between the pairs of spheres was due to their gravitational attraction. This tiny force was measured by the twist in the wire. The symmetry of what appears to be two unrelated forces provides a glimpse into the beauty of the world. Physicists remark on this beauty, which drives them to find out if there are other underlying understandings of the two forces because of that symmetry. This is what physicists are exploring when you hear about their work on unified theories.

The Cavendish Experiment

Checking Up

1. If electrons are removed from a neutral object, what kind of charge will the object have? Explain.
2. What happens to the force of attraction between two charged objects as the distance between them increases? Explain using Coulomb's law.
3. When two charged objects are made to touch each other and then separated, what will be true about the net charge of the two objects after separation? Explain your answer.

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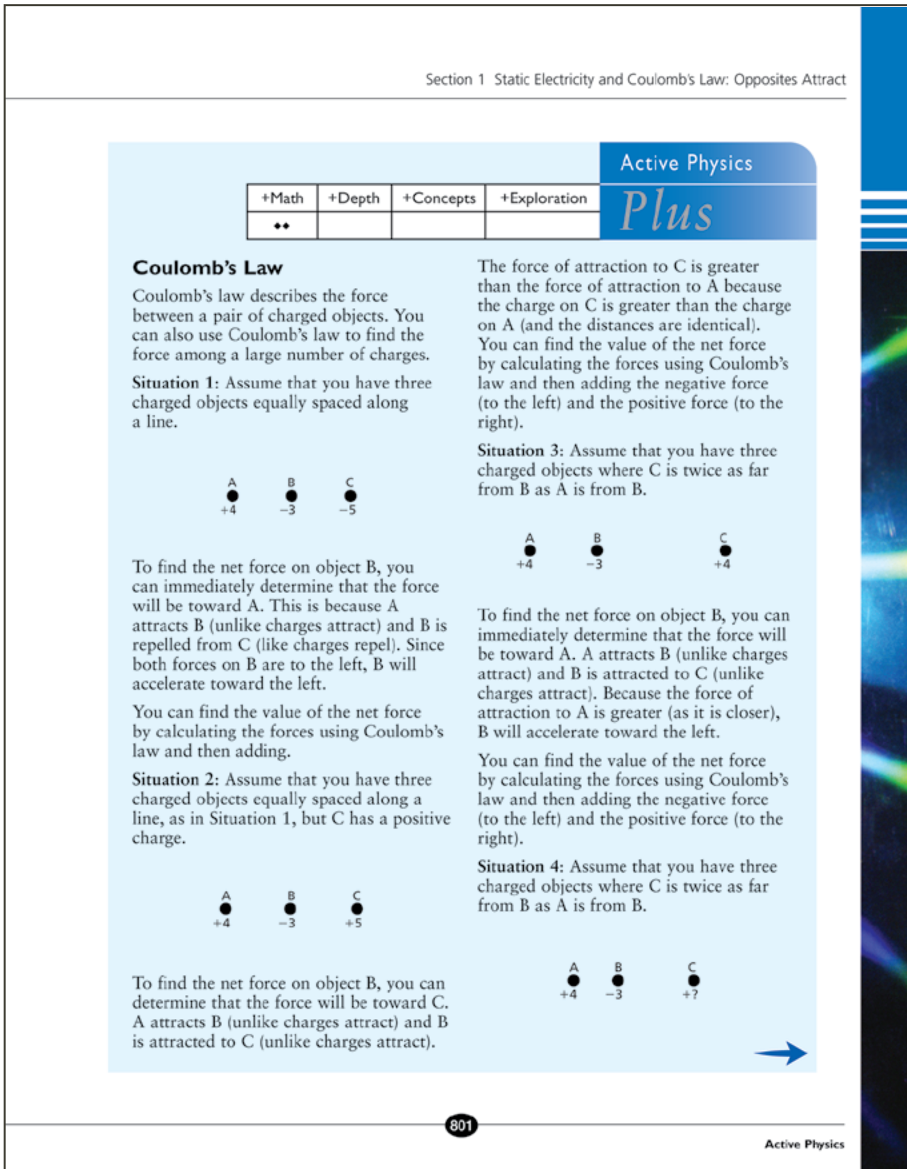

Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
••			

Coulomb's Law

Coulomb's law describes the force between a pair of charged objects. You can also use Coulomb's law to find the force among a large number of charges.

Situation 1: Assume that you have three charged objects equally spaced along a line.

To find the net force on object B, you can immediately determine that the force will be toward A. This is because A attracts B (unlike charges attract) and B is repelled from C (like charges repel). Since both forces on B are to the left, B will accelerate toward the left.

You can find the value of the net force by calculating the forces using Coulomb's law and then adding.

Situation 2: Assume that you have three charged objects equally spaced along a line, as in Situation 1, but C has a positive charge.

To find the net force on object B, you can determine that the force will be toward C. A attracts B (unlike charges attract) and B is attracted to C (unlike charges attract).

The force of attraction to C is greater than the force of attraction to A because the charge on C is greater than the charge on A (and the distances are identical). You can find the value of the net force by calculating the forces using Coulomb's law and then adding the negative force (to the left) and the positive force (to the right).

Situation 3: Assume that you have three charged objects where C is twice as far from B as A is from B.

To find the net force on object B, you can immediately determine that the force will be toward A. A attracts B (unlike charges attract) and B is attracted to C (unlike charges attract). Because the force of attraction to A is greater (as it is closer), B will accelerate toward the left.

You can find the value of the net force by calculating the forces using Coulomb's law and then adding the negative force (to the left) and the positive force (to the right).

Situation 4: Assume that you have three charged objects where C is twice as far from B as A is from B.

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Students use Coulomb's law to determine that the force among charges depends upon the magnitude and vector nature of the forces. They then use this principle in different situations to explain the direction in which the charges will accelerate under the influence of attractive or repulsive forces.

CHAPTER 8

1.a)

45 units to the right where each unit $F = kq_1q_2/d^2$.

1.b)

20 units to the left

1.c)

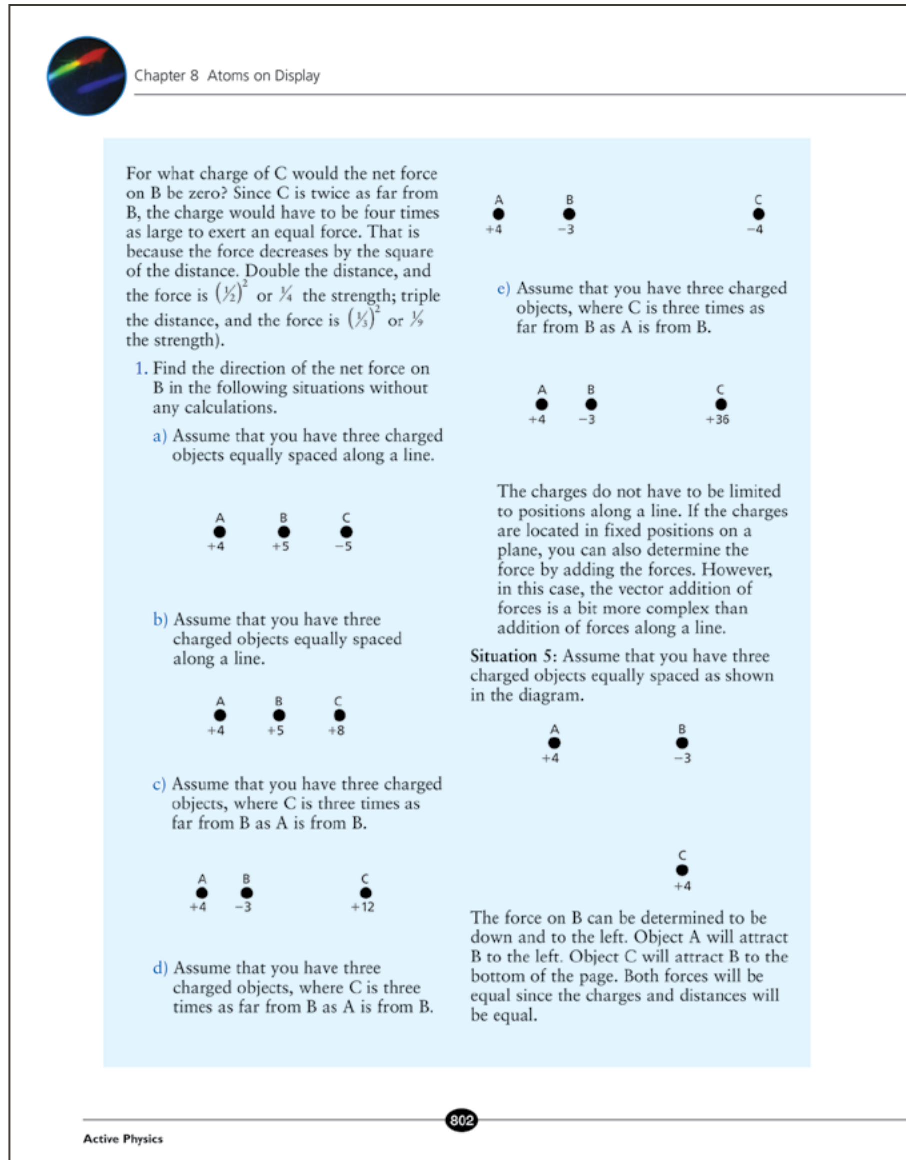
8 units to the left

1.d)

$120/9$ units to the left

1.e)

0 units in any direction



For what charge of C would the net force on B be zero? Since C is twice as far from B, the charge would have to be four times as large to exert an equal force. That is because the force decreases by the square of the distance. Double the distance, and the force is $(\frac{1}{2})^2$ or $\frac{1}{4}$ the strength; triple the distance, and the force is $(\frac{1}{3})^2$ or $\frac{1}{9}$ the strength).

1. Find the direction of the net force on B in the following situations without any calculations.

a) Assume that you have three charged objects equally spaced along a line.

A +4   B +5   C −5

b) Assume that you have three charged objects equally spaced along a line.

A +4   B +5   C +8

c) Assume that you have three charged objects, where C is three times as far from B as A is from B.

A +4   B −3   C +12

d) Assume that you have three charged objects, where C is three times as far from B as A is from B.

A +4   B −3   C −4

e) Assume that you have three charged objects, where C is three times as far from B as A is from B.

A +4   B −3   C +36

The charges do not have to be limited to positions along a line. If the charges are located in fixed positions on a plane, you can also determine the force by adding the forces. However, in this case, the vector addition of forces is a bit more complex than addition of forces along a line.

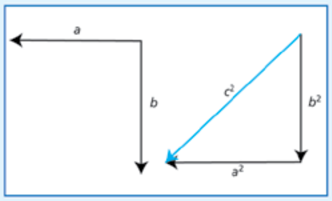
Situation 5: Assume that you have three charged objects equally spaced as shown in the diagram.

A +4   B −3

C +4

The force on B can be determined to be down and to the left. Object A will attract B to the left. Object C will attract B to the bottom of the page. Both forces will be equal since the charges and distances will be equal.

The vector sum of these forces can be determined by the vector addition in the diagram below.



You can find the value of the force by calculating each force using Coulomb's law and then adding the forces using the Pythagorean theorem $(a^2 + b^2 = c^2)$.

The problems can get more complex if the charges and distances are no longer equal.

2. Determine the force (both magnitude and direction) on object B for each of the following charges and distances. Assume that the configuration is that A is to the left of B, and C is below B as shown in Situation 5.

Case Number	Charge on A	Charge on B	Charge on C	Distance Between A and B	Distance Between B and C
1	$+5 \times 10^{-6}$C	$+5 \times 10^{-6}$C	$+5 \times 10^{-6}$C	2 m	2 m
2	$+5 \times 10^{-6}$C	$+5 \times 10^{-6}$C	-5×10^{-6}C	2 m	2 m
3	$+5 \times 10^{-6}$C	$+5 \times 10^{-6}$C	-10×10^{-6}C	2 m	2 m
4	-5×10^{-6}C	-5×10^{-6}C	-5×10^{-6}C	2 m	2 m
5	$+5 \times 10^{-6}$C	$+5 \times 10^{-6}$C	-15×10^{-6}C	2 m	2 m

What Do You Think Now?

At the beginning of this section you were asked the following about getting a shock:

- What do you think caused the shock?

Now that you know about electrons, what happens when they are transferred from one object to another object? What is the law of conservation of charge? How is this law related to the transfer of charge between two objects?

2.

Let each unit of force be $F = kq_1q_2/d^2$ with the coordinate system being the standard cardinal directions.

Case 1

$F_{\text{A on B}} = 0.0563\text{ N}$
$F_{\text{C on B}} = 0.0563\text{ N}$

$|F_B| = \sqrt{(F_{\text{A on B}})^2 + (F_{\text{C on B}})^2} =$
$\sqrt{(0.0563\text{ N})^2 + (0.0563\text{ N})^2} =$
0.0796 N at $45°$ North of East

Case 2

$F_{\text{A on B}} = 0.0563\text{ N}$
$F_{\text{C on B}} = -0.0563\text{ N}$

$|F_B| = \sqrt{(F_{\text{A on B}})^2 + (F_{\text{C on B}})^2} =$
$\sqrt{(0.0563\text{ N})^2 + (-0.0563\text{ N})^2} =$
0.0796 N at $45°$ South of East

Case 3

$F_{\text{A on B}} = 0.0563\text{ N}$
$F_{\text{C on B}} = -0.1125\text{ N}$

$|F_B| = \sqrt{(F_{\text{A on B}})^2 + (F_{\text{C on B}})^2} =$
$\sqrt{(0.0563\text{ N})^2 + (-0.1125\text{ N})^2} =$
0.1258 N at $63°$ South of East

Case 4

$F_{\text{A on B}} = 0.0563\text{ N}$
$F_{\text{C on B}} = 0.0563\text{ N}$

$|F_B| = \sqrt{(F_{\text{A on B}})^2 + (F_{\text{C on B}})^2} =$
$\sqrt{(0.0563\text{ N})^2 + (0.0563\text{ N})^2} =$
0.0796 N at $45°$ North of East

Case 5

$F_{\text{A on B}} = 0.0563\text{ N}$
$F_{\text{C on B}} = -0.1688\text{ N}$

$|F_B| = \sqrt{(F_{\text{A on B}})^2 + (F_{\text{C on B}})^2} =$
$\sqrt{(0.0563\text{ N})^2 + (-0.1688\text{ N})^2} =$
0.1779 N at $71°$ South of East

What Do You Think Now?

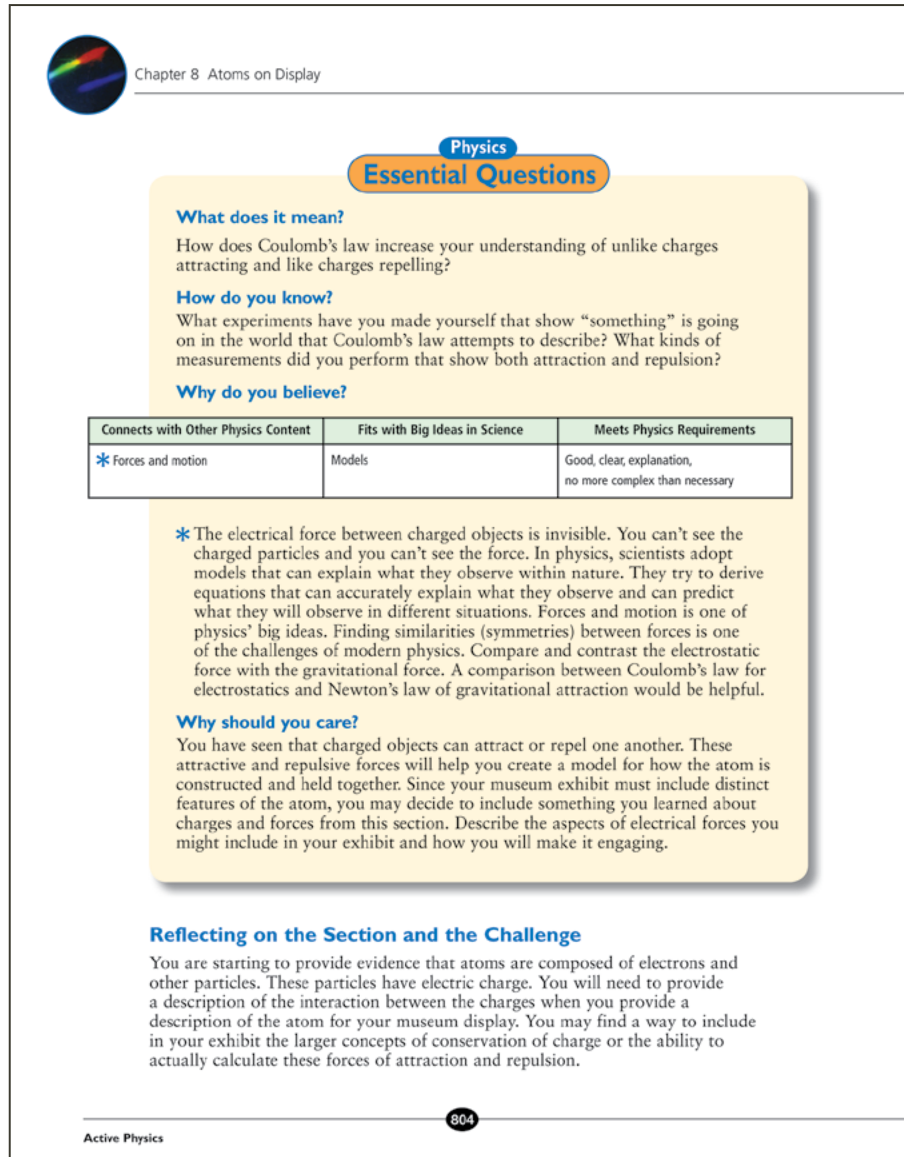
Students should know how the transfer of charges leaves an object with a net positive or negative charge, and should be able to answer why they felt a shock on touching something. Share *A Physicist's Response* with them and ask them to include the law of conservation of charge in their responses. Point out that they now have the opportunity to update their previous answers and also realize how their understanding of charges has evolved gradually and prior conceptions modified or changed to accommodate knew concepts.

CHAPTER 8

Encourage them to revisit *What Do You See?* and explain how the lightning strike might have transferred an electric charge of 1 C.

Reflecting on the Section and the Challenge

Students should reflect on what they have learned from this section and how they can connect the interaction between charges to their *Chapter Challenge*. Encourage them to begin planning their museum display based on what evidence they have on the particles comprising an atom. Ask students to reflect attractive and repulsive forces between like and unlike charges and how an electrostatic force is similar to and different from a gravitational force.



Chapter 8 Atoms on Display

Physics
Essential Questions

What does it mean?

How does Coulomb's law increase your understanding of unlike charges attracting and like charges repelling?

How do you know?

What experiments have you made yourself that show "something" is going on in the world that Coulomb's law attempts to describe? What kinds of measurements did you perform that show both attraction and repulsion?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
* Forces and motion	Models	Good, clear, explanation, no more complex than necessary

* The electrical force between charged objects is invisible. You can't see the charged particles and you can't see the force. In physics, scientists adopt models that can explain what they observe within nature. They try to derive equations that can accurately explain what they observe and can predict what they will observe in different situations. Forces and motion is one of physics' big ideas. Finding similarities (symmetries) between forces is one of the challenges of modern physics. Compare and contrast the electrostatic force with the gravitational force. A comparison between Coulomb's law for electrostatics and Newton's law of gravitational attraction would be helpful.

Why should you care?

You have seen that charged objects can attract or repel one another. These attractive and repulsive forces will help you create a model for how the atom is constructed and held together. Since your museum exhibit must include distinct features of the atom, you may decide to include something you learned about charges and forces from this section. Describe the aspects of electrical forces you might include in your exhibit and how you will make it engaging.

Reflecting on the Section and the Challenge

You are starting to provide evidence that atoms are composed of electrons and other particles. These particles have electric charge. You will need to provide a description of the interaction between the charges when you provide a description of the atom for your museum display. You may find a way to include in your exhibit the larger concepts of conservation of charge or the ability to actually calculate these forces of attraction and repulsion.

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Active Physics

Physics Essential Questions

What does it mean?

Coulomb's law provides an equation by which you can calculate the strength of the force. The force is proportional to the quantity of charge and inversely proportional to the square of the distance between charges.

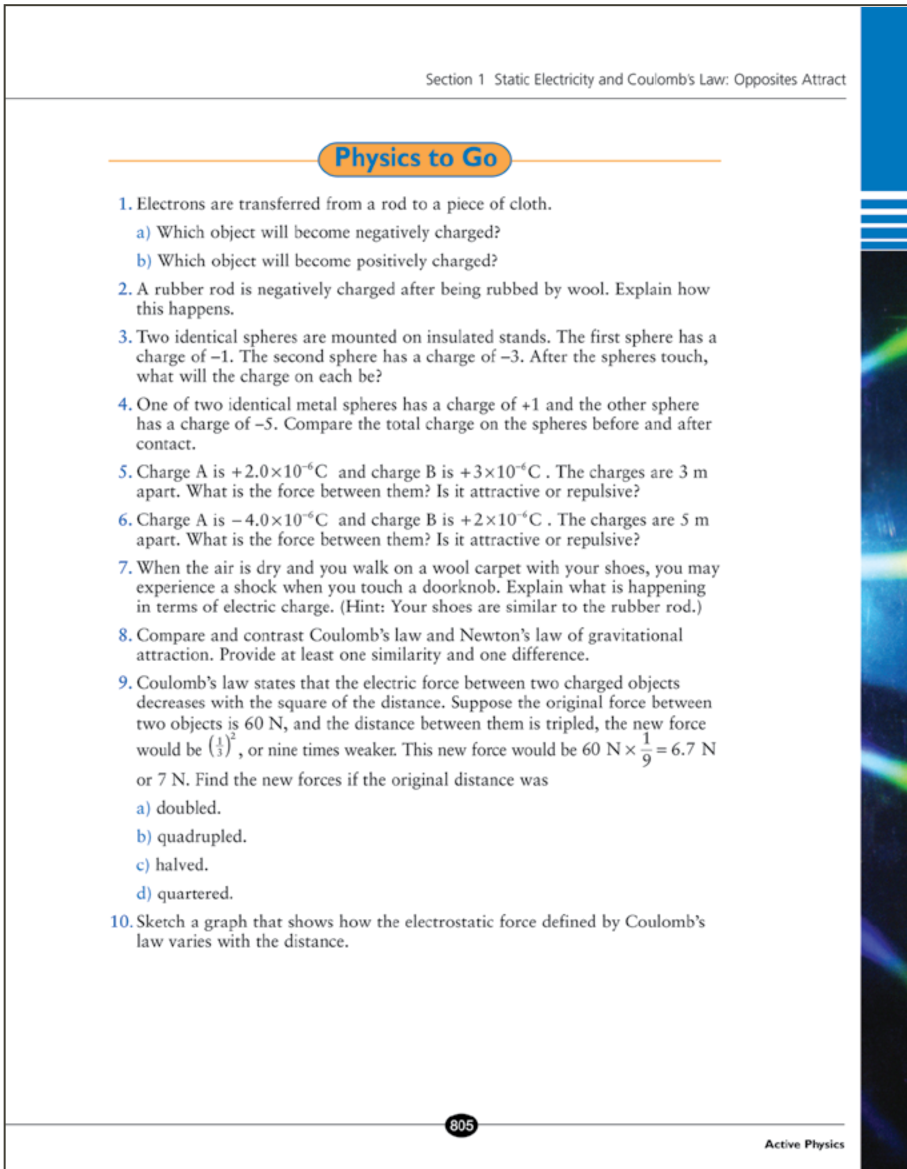
How do you know?

Strips of tape were able to attract while other strips of tape repelled each other.

Why do you believe?

Both the gravitational force and the electrostatic force are "inverse square" laws. The force gets weaker by the square of the distance between masses or charges. The forces are also similar because the gravitational force depends on mass and the electrical force depends on charge. The gravitational force is always attractive (i.e., there is only one type of mass) and the electrostatic force can be attractive or repulsive (i.e., there are both positive and negative charges). Electrostatic force is expressed in the following equation:

$$F = kq_1q_2/d^2$$


Section 1 Static Electricity and Coulomb's Law: Opposites Attract

Physics to Go

1. Electrons are transferred from a rod to a piece of cloth.
   a) Which object will become negatively charged?
   b) Which object will become positively charged?
2. A rubber rod is negatively charged after being rubbed by wool. Explain how this happens.
3. Two identical spheres are mounted on insulated stands. The first sphere has a charge of −1. The second sphere has a charge of −3. After the spheres touch, what will the charge on each be?
4. One of two identical metal spheres has a charge of +1 and the other sphere has a charge of −5. Compare the total charge on the spheres before and after contact.
5. Charge A is $+2.0\times10^{-6}$ C and charge B is $+3\times10^{-6}$ C. The charges are 3 m apart. What is the force between them? Is it attractive or repulsive?
6. Charge A is -4.0×10^{-6} C and charge B is $+2\times10^{-6}$ C. The charges are 5 m apart. What is the force between them? Is it attractive or repulsive?
7. When the air is dry and you walk on a wool carpet with your shoes, you may experience a shock when you touch a doorknob. Explain what is happening in terms of electric charge. (Hint: Your shoes are similar to the rubber rod.)
8. Compare and contrast Coulomb's law and Newton's law of gravitational attraction. Provide at least one similarity and one difference.
9. Coulomb's law states that the electric force between two charged objects decreases with the square of the distance. Suppose the original force between two objects is 60 N, and the distance between them is tripled, the new force would be $\left(\frac{1}{3}\right)^2$, or nine times weaker. This new force would be $60\text{ N}\times\frac{1}{9}=6.7\text{ N}$ or 7 N. Find the new forces if the original distance was
   a) doubled.
   b) quadrupled.
   c) halved.
   d) quartered.
10. Sketch a graph that shows how the electrostatic force defined by Coulomb's law varies with the distance.

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Active Physics

Gravitational force is expressed in the following equation:

$$F_G = Gm_1m_2/r^2$$

Why should you care?

You can include the attractive and repulsive forces. You can let people try the experiment with pieces of tape. You can have two pieces of tape repelling each other to capture people's attention.

Physics to Go

1.a)

the cloth

1.b)

the rod

2.

Electrons were stripped off the wool and attached to the rubber rod.

3.

−2 on each

4.

−2 on each

5.

6×10^{-3} N, repulsive

6.

2.9×10^{-3} N, attractive

7.

The rubber soles of your shoes pick up electrons from the wool carpet. This makes your shoes negative. Since you are a good conductor of electric charge, this excess negative charge spreads throughout your body (you are at a higher voltage). When you touch the doorknob, you are grounded (you have touched a point of zero voltage) and the charge leaves your body at once, producing a shock (electric current is driven by a voltage difference).

8.

They are similar because: They both decrease with the square of the distance between the objects. They both have constants.
They are different because: The Coulomb constant is much greater than the gravitational constant. Electrical forces are attractive

CHAPTER 8

and repulsive while gravitational forces are only attractive. Masses come in one variety (+) while charges come in two varieties (+/–).

9.a)

If distance is doubled, the force is decreased by a factor of four.

9.b)

If distance is quadrupled, the force is 1/16 its magnitude.

9.c)

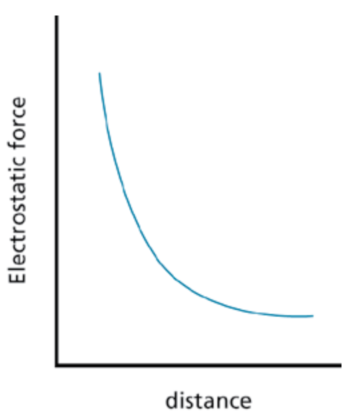
If the distance is halved, the force is four times as large.

9.d)

If the distance is quartered, the force is 16 times as large.

10.

The student's graph should look similar to the one shown below.



11.a)

Let N = number of electrons sought. Then $1\ \text{C} = N \times 1.6 \times 10^{-19}\ \text{C}$. Therefore $N = 1/\left(1.6 \times 10^{-19}\right) = 6.25 \times 10^{18}$.

11.b)

Because current = charge/time, we have charge = current × time = (5 amps) × (1 min) = (5 C/s)(60 s) = 300 C. Because each Coulomb equals 6.25×10^{18} electrons, the total number of electrons is $(300\ \text{C})(6.25 \times 10^{18}\ \text{electrons/C}) = 1.875 \times 10^{21}$ electrons.

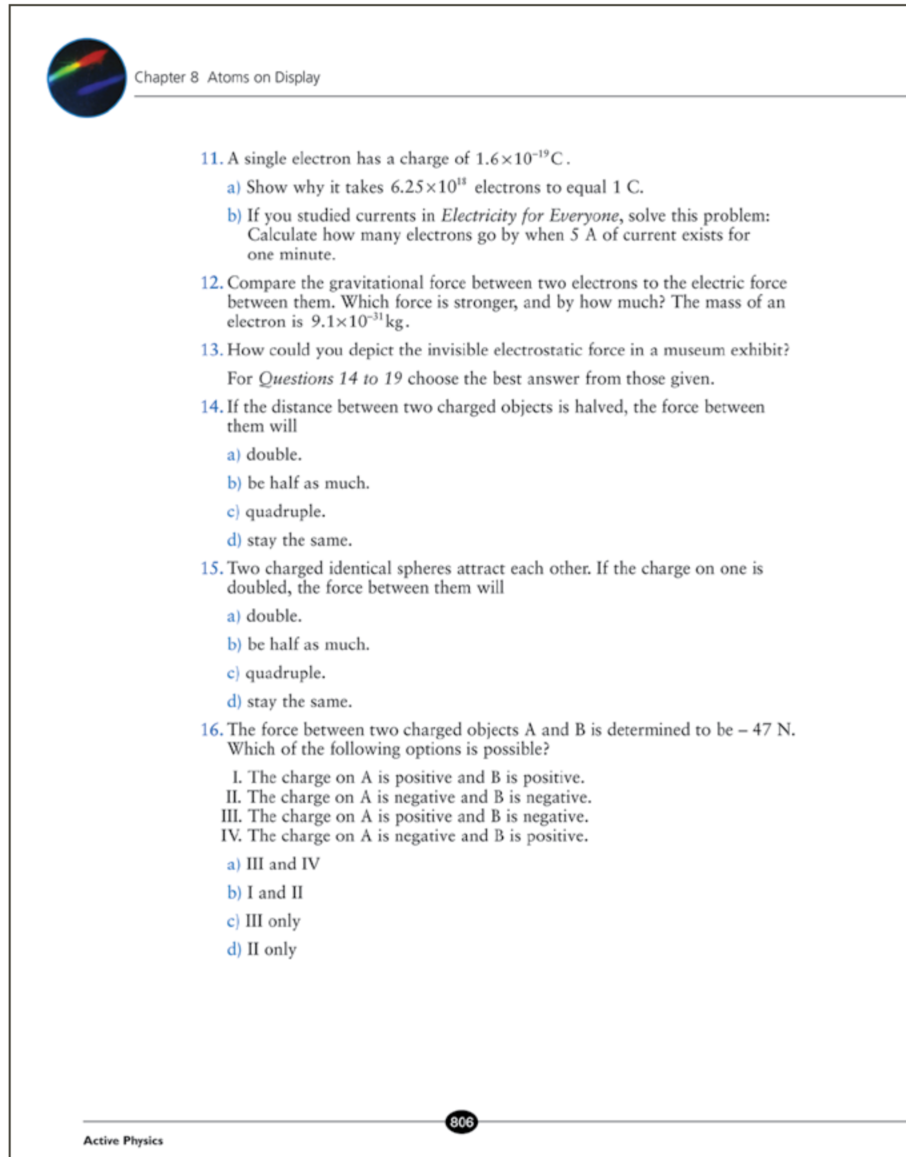
12.

$$F_{\text{gravity}}/F_{\text{electric}} = \frac{Gm^2/r^2}{ke^2/r^2} = \quad \text{(the } r\text{'s cancel)}$$

$$\frac{\left[\left(6.67 \times 10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2\right) \times \left(9.11 \times 10^{-31}\ \text{kg}\right)^2\right]}{\left[\left(9 \times 10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2\right) \times \left(1.6 \times 10^{-19}\ \text{C}\right)^2\right]} =$$

2.4×10^{-43} =

0. 000 000 000 000 000 000 000 000 000 000 000 000 000 000 24.



Chapter 8 Atoms on Display

11. A single electron has a charge of 1.6×10^{-19} C.
   a) Show why it takes 6.25×10^{18} electrons to equal 1 C.
   b) If you studied currents in *Electricity for Everyone*, solve this problem: Calculate how many electrons go by when 5 A of current exists for one minute.
12. Compare the gravitational force between two electrons to the electric force between them. Which force is stronger, and by how much? The mass of an electron is 9.1×10^{-31} kg.
13. How could you depict the invisible electrostatic force in a museum exhibit?

For *Questions 14 to 19* choose the best answer from those given.

14. If the distance between two charged objects is halved, the force between them will
   a) double.
   b) be half as much.
   c) quadruple.
   d) stay the same.
15. Two charged identical spheres attract each other. If the charge on one is doubled, the force between them will
   a) double.
   b) be half as much.
   c) quadruple.
   d) stay the same.
16. The force between two charged objects A and B is determined to be – 47 N. Which of the following options is possible?
   I. The charge on A is positive and B is positive.
   II. The charge on A is negative and B is negative.
   III. The charge on A is positive and B is negative.
   IV. The charge on A is negative and B is positive.
   a) III and IV
   b) I and II
   c) III only
   d) II only

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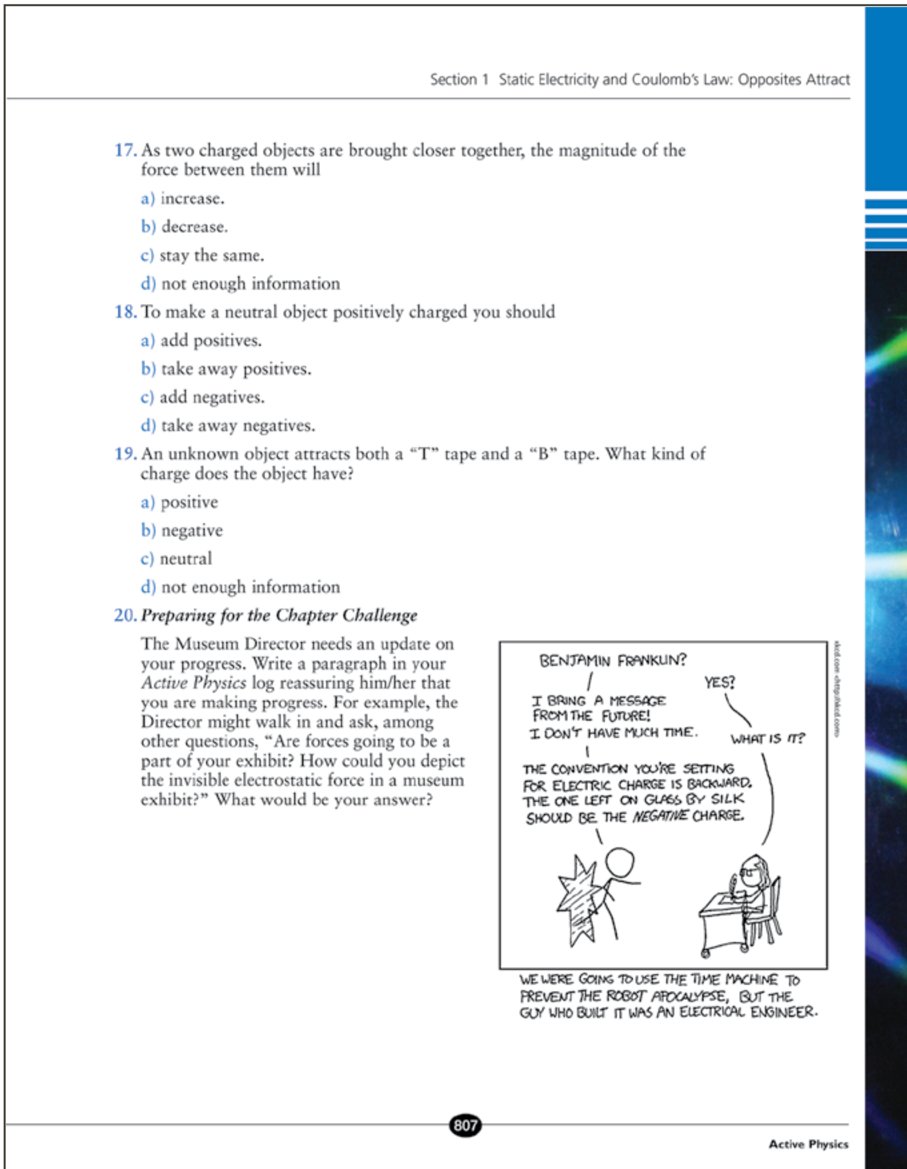
Active Physics


Section 1 Static Electricity and Coulomb's Law: Opposites Attract

17. As two charged objects are brought closer together, the magnitude of the force between them will
   a) increase.
   b) decrease.
   c) stay the same.
   d) not enough information

18. To make a neutral object positively charged you should
   a) add positives.
   b) take away positives.
   c) add negatives.
   d) take away negatives.

19. An unknown object attracts both a "T" tape and a "B" tape. What kind of charge does the object have?
   a) positive
   b) negative
   c) neutral
   d) not enough information

20. *Preparing for the Chapter Challenge*

The Museum Director needs an update on your progress. Write a paragraph in your *Active Physics* log reassuring him/her that you are making progress. For example, the Director might walk in and ask, among other questions, "Are forces going to be a part of your exhibit? How could you depict the invisible electrostatic force in a museum exhibit?" What would be your answer?

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Therefore, gravity is negligible compared to the electric force between two electrons.

13.

Magnetism is also an invisible force, so substituting magnetism for electricity might be a possibility. Alternatively, magicians' tricks using mirrors to make things seem to be invisible might be used to hide one object exerting a force.

14.c)

quadruple. If the distance between two charged objects is doubled, the force between them will be one quarter the original.

15.a)

double. If the charge on one is doubled, the force between them will double.

16.a)

III and IV. A negative force means a force of attraction, so the charges must be of opposite signs.

17.a)

increase. Since the force is inverse square with distance, decreasing the distance increases the force.

18.d)

take away negatives. Electrons are the mobile charges, and removing some from neutral objects which have equal numbers of positive and negative charges makes neutral objects positive.

19.c)

neutral. A neutral object will attract both a positive and a negative object by induction.

20.

Preparing for the Chapter Challenge

Student answers will vary, but should make some mention of the electric force associated with charges such as electrons.

CHAPTER 8

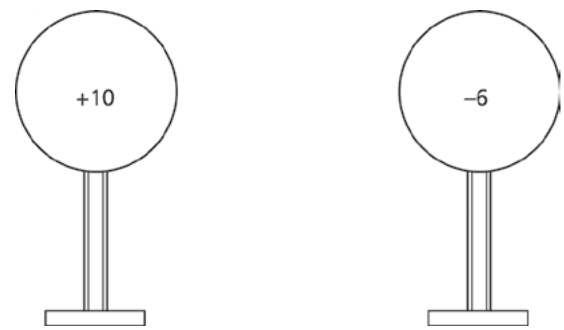
SECTION 1 QUIZ

8-1a Blackline Master

1. To charge an object positively, a student should

   a) add positive charges.
   b) add negative charges.
   c) remove positive charges.
   d) remove negative charges.

2. Two identical conducting spheres on insulating stands are charged as shown at right. The two spheres touch and then are separated. After the spheres are separated the charge on each sphere will be



   a) + 4.
   b) + 2.
   c) + 16.
   d) – 4.

3. For *Question 2*, when the spheres touch, the total charge on the two spheres will

   a) decrease by 6.
   b) increase by 6.
   c) decrease by 4.
   d) remain the same.

4. Two small charges are a distance of 10 meters apart. Charge A is 4.0×10^{-5} C and charge B is 2.0×10^{-6} C. What is the size of the force between the charges?

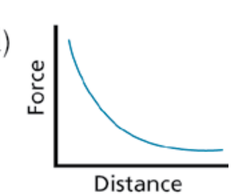
   a) 8.0×10^{-30} N
   b) 8.0×10^{-11} N
   c) 7.2×10^{-3} N
   d) 7.2×10^{-17} N

5. Which graph below correctly represents how the force between two charged objects varies with distance?

a)


b)


c)


d)


SECTION 1 QUIZ ANSWERS

1. d) remove negative charges. Electrons are the mobile parts of the atom. The positively charged protons are firmly held in the nucleus and are difficult to remove. To affect the balance of the charge, it is easier to remove the negatively charged electrons, leaving a net positive charge. Adding positive charges to the nucleus would be extremely difficult, and not doable under ordinary circumstances.

2. b) By conservation of charge, the total charge on the two spheres before contact the sum of +10 and −6, or +4. That is, there are 6 extra electrons on one sphere, while the other is 10 electrons short. When the spheres touch, the 6 electrons will migrate to the sphere that is missing the 10 electrons. In addition, the remaining positive charge of +4 will then attract an additional 2 electrons from the now neutral sphere to leave a charge of +2 on each. Thus the charge is equally distributed between the two identical spheres giving each one a charge of +2 for a total of +4.

3. d) By conservation of charge, the total charge must remain the same.

4. c) Using the Coulomb's law formula $F = kq_1q_2/d^2$ gives

   $$F = \left(9\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(4\times10^{-5}\ \text{C}\right)\left(2\times10^{-6}\ \text{C}\right)/\left(10\ \text{m}\right)^2 = 7.2\times10^{-3}\ \text{N}.$$

5. d) The force falls off as the inverse square of the distance and only graph d shows this type of relationship.