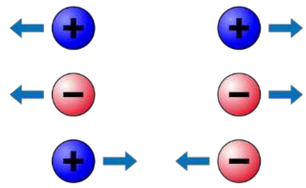
# Static Electricity

## SECTION 1 Electric Charge

**Electrostatics:**
is the study of static electricity due to charges

**Law of electrostatic**
Like charges repel, unlike charges attract.



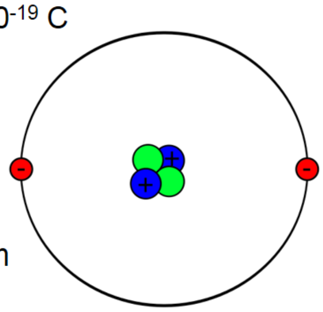
**A discharge:**
the movement of static electricity from one object to another

Two uncharged particles have no effect on each other

Charges are *quantized* (come in units of e= $1.6\text{x}10^{-19}$ C).

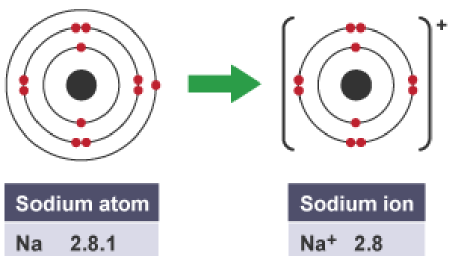
**Elementary particles that make up atoms:**

- Protons  charge +e = $+1.6\text{x}10^{-19}$ C
- Neutrons  uncharged
- Electrons charge –e = $-1.6\text{x}10^{-19}$ C



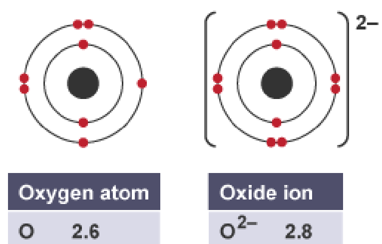
Helium atom

**Positive charge**

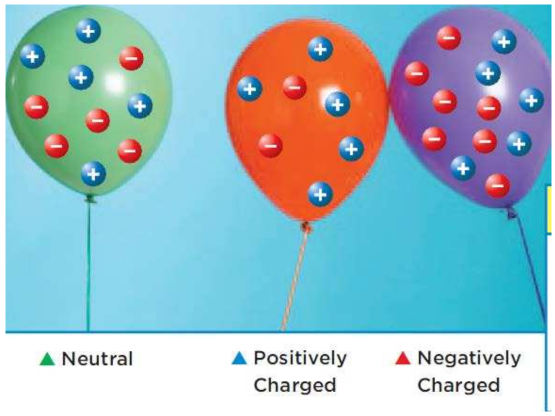



**Atom loses electrons**

**Negative charge**

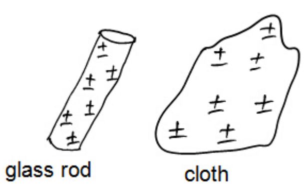
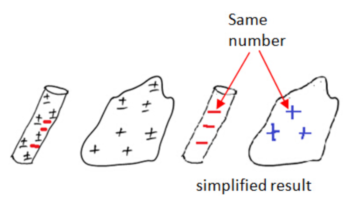



**Atom gains electrons**




| Types | Insulators | Conductors |
|---|---|---|
| Definition | Materials where electrons remain on the surface of it and do not move about freely within the material. | Materials that allow electrons to move freely within the material. |
| What happen when adding or removing electrons? | When electrons are gained or lost in an insulator, the electron remains at the region where it was transferred. i.e it is "localized". | When electrons are gained or lost in a conductor, the electrons will be redistributed. |
| Example | Non-metals like plastic, paper, wood | Metals like copper, iron, steel, graphite |
| Charging method | Charging by Friction (Rubbing) | Charging by Contact, Charging by Induction |
| Discharging Method | Heating, Humid conditions | Earthing |

## Charging Insulators by Friction / Rubbing

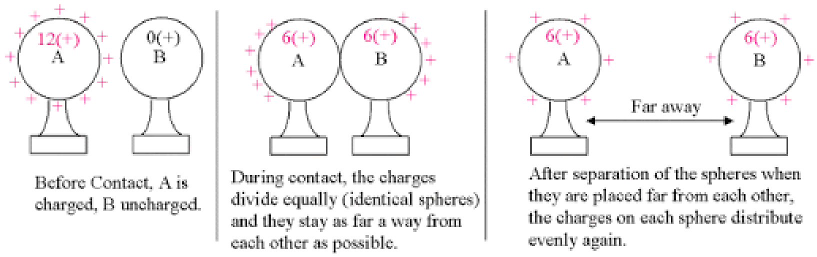
| Before rubbing | Rubbing | After rubbing |
|---|---|---|
|  |  |  |
| Both are electrically neutral. i.e same number of electrons and positive charges. | Electrons are transferred from cloth to glass rod | Glass rod has excess electrons => negatively charged, Cloth has excess positive charges => positively charged |

Notes

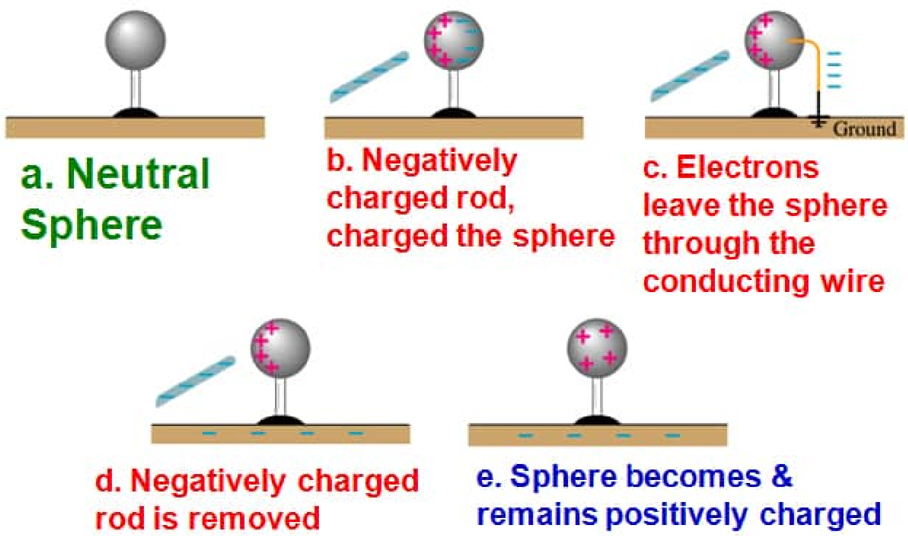
- Charge is conserved, which is one way of saying that **individual charges never are created or destroyed**.
- A net positive or negative charge means that electrons have been transferred.

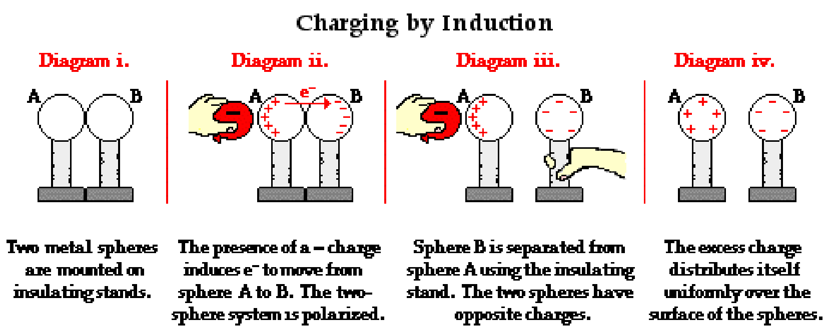
- Processes inside a thundercloud can cause the cloud bottom to become negatively charged and the cloud top to become positively charged. Electric charge can be transferred from a road to the car traveling on it

## Charging by conduction



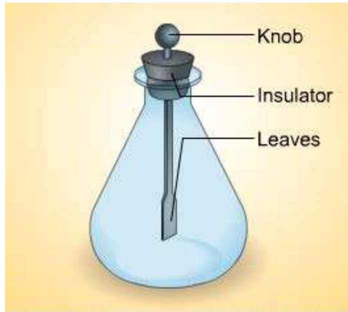

## Charging by Induction



# SECTION 2 Electrostatic Force

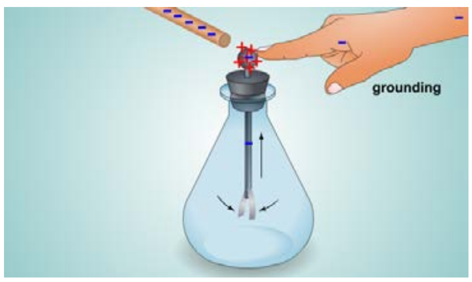
An **electroscope** consists of a metal knob connected by a metal stem to two thin, lightweight pieces of metal foil, called leaves




Charging a neutral body by touching it with a charged body is called **charging by conduction**

Bringing a negatively charged rod near a negatively charged electroscope causes the leaves to spread apart farther
**charging by Induction**

**Grounding**
is the process of removing excess charge by connecting an object to Earth




## Coulomb's Law

**COULOMB'S LAW**
The force between two charges is equal to a constant times the product of the two charges, divided by the square of the distance between them.

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

## EXAMPLE PROBLEM 1

Get help with **Coulomb's law in two dimensions.**

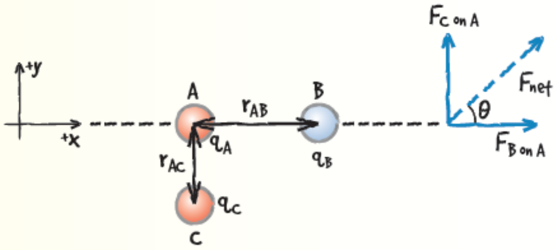
**COULOMB'S LAW IN TWO DIMENSIONS** Sphere A, with a charge of $+6.0\ \mu C$, is located near another charged sphere, B. Sphere B has a charge of $-3.0\ \mu C$ and is located 4.0 cm to the right of A.

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

**b.** A third sphere, C, with a $+1.5$-$\mu C$ charge, is added. 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 | $F_{B \text{ on } A} = ?$ |
| $q_B = -3.0\ \mu C$ | $r_{AC} = 3.0$ cm | $F_{C \text{ on } A} = ?$ |
| $q_C = +1.5\ \mu C$ | $K = 9.0\times 10^9\ N{\cdot}m^2/C^2$ | $\boldsymbol{F}_{net} = ?$ |

### 2 SOLVE FOR THE FORCES ON SPHERE A

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

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

$$= (9.0\times 10^9\ N{\cdot}m^2/C^2)\frac{(6.0\times 10^{-6}\ C)(3.0\times 10^{-6}\ C)}{(4.0\times 10^{-2}\ m)^2}$$

◀ Substitute $q_A = 6.0\ \mu C$, $q_B = 3.0\ \mu C$, $r_{AB} = 4.0$ cm

$$= 1.0\times 10^2\ N$$

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

**b.** Find the net force on sphere A.

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

$$= (9.0\times 10^9\ N{\cdot}m^2/C^2)\frac{(6.0\times 10^{-6}\ C)(1.5\times 10^{-6}\ C)}{(3.0\times 10^{-2}\ m)^2}$$

◀ Substitute $q_A = 6.0\ \mu C$, $q_C = 1.5\ \mu C$, $r_{AC} = 3.0$ cm

$$= 9.0\times 10^1\ N$$

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.

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

$$= \sqrt{(1.0\times 10^2\ N)^2 + (9.0\times 10^1\ N)^2}$$

◀ Substitute $F_{B \text{ on } A} = 1.0\times 10^2$ N, $F_{C \text{ on } A} = 9.0\times 10^1$ N

$$= 130\ N$$

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

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

$$= \tan^{-1}\left(\frac{9.0\times 10^1\ N}{1.0\times 10^2\ N}\right)$$

◀ Substitute $F_{C \text{ on } A} = 9.0\times 10^1$ N, $F_{B \text{ on } A} = 1.0\times 10^2$ N

$$= 42°$$

$\boldsymbol{F}_{net} = 1.3\times 10^2$ N, 42° above the $x$-axis

## PRACTICE PROBLEMS

Do additional problems. Online Practice

**9.** A negative charge of $-2.0\times10^{-4}$ C and a positive charge of $8.0\times10^{-4}$ C are separated by 0.30 m. What is the force between the two charges?

**10.** A negative charge of $-6.0\times10^{-6}$ 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.** Suppose you replace the charge on B in Example Problem 1 with a charge of $+3.00$ μC. Diagram the new situation, and find the net force on A.

**12.** Describe how the electrostatic force between two charges changes when the distance between those two charges is tripled.

**13.** 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 $-3.6\times10^{-6}$ 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.

**14.** **CHALLENGE** Determine the net force on sphere B in the previous problem.

**Practice Problems**

**9.** 1.6×1 0 4 N attractive

**10.** 3.0× 10 −6 C

**11.** The force diagram is refl ected about the y-axis with respect to the diagram shown in Example **Problem**

1. Magnitudes of all forces remain the same. The direction changes to 42° above the negative x-axis, or 138° counterclockwise from the positive x-axis.

**12.** The electrostatic force between the two charges decreases by a factor of $3^2 = 9$.

**13.** 0.068 N toward the right

**14.** 3.1 N toward the right

## 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 the figure.

Section 20.2-45

1. Two electric charges with the same sign ____.
   - a. attract each other
   - b. repel each other
   - c. have no effect on each other
   - d. annihilate each other
2. For two particles such as protons with both electrostatic and gravitational forces, the ____.
   - a. electrostatic forces will be stronger
   - b. gravitational forces will be stronger
   - c. electrostatic and gravitational forces will be the same
   - d. strength of the forces depends on the object
3. All electric charges are multiples of the charge on a(n) ____.
   - a. coulomb
   - b. neutron
   - c. electron
   - d. atom
4. The charge on a rubber rod that has been rubbed with wool is ____.
   - a. positive
   - b. negative
   - c. neutral
   - d. unchanged by the wool
5. The electrostatic force between two charges is ____ to the square of the distance between them.
   - a. not related
   - b. equal
   - c. directly proportional
   - d. inversely proportional
6. While many properties are similar, one important difference between electrostatic and gravitational forces is that unlike gravity, electric charge ____.
   - a. can be transferred
   - b. operates at a distance
   - c. obeys an inverse-square law
   - d. remains constant over time
7. When wool and plastic are rubbed together, the plastic becomes ____.
   - a. positively charged because it loses electrons to the wool
   - b. negatively charged because it loses electrons to the wool
   - c. positively charged because it gains electrons from the wool
   - d. negatively charged because it gains electrons from the wool
8. Transferring charge by touching one object to another is called ____.
   - a. charging by induction
   - b. charging by conduction
   - c. charging by friction
   - d. charging by transfer
9. The SI unit of electric charge is the ____.
   - a. volt
   - b. watt
   - c. coulomb
   - d. ampere
10. Air can become a conductor when it becomes ____.
    - a. dry
    - b. a plasma
    - c. discharged
    - d. wet

**11.** An important difference between gravitational and electrostatic force is that gravitational force is always ____.

**a.** attractive
**c.** stronger
**b.** repulsive
**d.** downward

**12.** Charging by induction ____.

**a.** transfers charges from one object to another
**b.** results in a negative charge
**c.** creates charges within an object
**d.** separates charges within an object

**13.** When an electroscope is charged, its leaves separate because ____.

**a.** unlike charges repel
**b.** similar charges exert force on each other over a distance
**c.** positive charges spread over the metal leaves
**d.** magnetic forces spread the metal leaves apart

**14.** If a negatively charged rod is brought near a negatively charged electroscope, ____.

**a.** there will be no effect
**b.** the leaves will fall
**c.** the leaves will spread farther apart
**d.** the electroscope will become positively charged

**15.** The force that charge $q_A$ exerts on charge $q_B$ is ____ the force that charge $q_B$ exerts on charge $q_A$.

**a.** opposite and equal to
**b.** opposite and greater than
**c.** opposite and less than
**d.** the same as

CHAPTER

# 20 Static Electricity

## Section Review

### 20.1 Electric Charge pages 541–545

**page 545**

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?

   **The comb loses its charge to its surroundings and becomes neutral once again.**

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?

   **Bring a positively charged glass rod near the two strips of tape. The one that is repelled by the rod is positive.**

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?

   **Bring an object of known charge, such as a negatively charged hard rubber rod, near the pith ball. If the pith ball is repelled, it has the same charge as the rod. If it is attracted, it may have the opposite charge or be neutral. To find out which, bring a positively charged glass rod near the pith ball. If they repel, the pith ball is positive; if they attract, the pith ball must be neutral.**

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?

   **The wool becomes positively charged because it gives up electrons to the rubber rod.**

5. **Conservation of Charge** An apple contains trillions of charged particles. Why don't two apples repel each other when they are brought together?

   **Each apple contains equal numbers of positive and negative charges, so they appear neutral to each other.**

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.

   **The glass rod attracts electrons off the metal rod, so the metal becomes positively charged. The charge is distributed uniformly along the 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?

   **Because the copper is a conductor, it remains neutral as long as it is in contact with your hand.**

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?

   **The two-charge model can better explain the phenomena of attraction and repulsion. It also explains how objects can become charged when they are rubbed together. The single-fluid model indicated that the charge should be equalized on objects that are in contact with each other.**

# Practice Problems

## 20.2 Electric Force pages 546–553

**page 552**

**9.** A negative charge of $-2.0\times10^{-4}$ C and a positive charge of $8.0\times10^{-4}$ C are separated by 0.30 m. What is the force between the two charges?

$$F = \frac{Kq_Aq_B}{{d_{AB}}^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(2.0\times10^{-4}\ \text{C})(8.0\times10^{-4}\ \text{C})}{(0.30\ \text{m})^2}$$

$$= 1.6\times10^4\ \text{N}$$

**10.** A negative charge of $-6.0\times10^{-6}$ 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?

$$F = \frac{Kq_Aq_B}{{d_{AB}}^2}$$

$$q_B = \frac{F{d_{AB}}^2}{Kq_A} = \frac{(65\ \text{N})(0.050\ \text{m})^2}{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(6.0\times10^{-6}\ \text{C})}$$

$$= 3.0\times10^{-6}\ \text{C}$$

**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.

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

**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 $-3.6\times10^{-6}$ 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.

$$F_{\text{B on A}} = K\frac{q_Aq_B}{{d_{AB}}^2} = (9.0\times10^9\ \text{N·m}^2/\text{C}^2)\frac{(2.0\times10^{-6}\ \text{C})(3.6\times10^{-6}\ \text{C})}{(0.60\ \text{m})^2} = 0.18\ \text{N}$$

**direction: toward the right**

$$F_{\text{C on A}} = K\frac{q_Aq_C}{{d_{AC}}^2} = (9.0\times10^9\ \text{N·m}^2/\text{C}^2)\frac{(2.0\times10^{-6}\ \text{C})(4.0\times10^{-6}\ \text{C})}{(0.80\ \text{m})^2} = 0.1125 = \text{N}$$

**direction: toward the left**

$$F_{\text{net}} = F_{\text{B on A}} - F_{\text{C on A}} = (0.18\ \text{N}) - (0.1125\ \text{N}) = 0.068\ \text{N toward the right}$$

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

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

$$F_{\text{C on B}} = K\frac{q_Aq_B}{{d_{AB}}^2}$$

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

$$= K\frac{q_Bq_C}{{d_{BC}}^2} - K\frac{q_Aq_B}{{d_{AB}}^2}$$

$$= (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)\frac{(3.6\times10^{-6}\ \text{C})(4.0\times10^{-6}\ \text{C})}{(0.20\ \text{m})^2} - (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)\frac{(2.0\times10^{-6}\ \text{C})(3.6\times10^{-6}\ \text{C})}{(0.60\ \text{m})^2}$$

**= 3.1 N toward the right**

# Section Review

## 20.2 Electric Force pages 546–553

**page 553**

**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.

**Electric force is directly related to each charge. It is repulsive between like charges and attractive between 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?

**Electric force is inversely related to the square of the distance between charges. If the distance is tripled, the force will be one-ninth as great.**

**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?

**As the leaves move farther apart, the electric force between them decreases until it is balanced by the gravitational force pulling down on the leaves.**

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

**a.** a positive rod.

**Touch the positive rod to the electroscope. Negative charges will move to the rod, leaving the electroscope positively charged.**

**b.** a negative rod.

**Bring the negative rod near, but not touching the electroscope. Touch (ground) the electroscope with your finger, allowing electrons to be repelled off of the electroscope into your finger. Remove your finger and then remove the rod.**

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

**Charge separation, caused by the attraction of opposite charges and the repulsion of like charges, moves the opposite charges in the neutral body closer to the charged object and the like charges farther away. The inverse relation between force and distance means that the nearer, opposite charges will attract more than the more distant, like charges will repel. The overall effect is attraction.**

**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?

**Charge that had been pushed into the ground by the rod would return to the electroscope from the ground, leaving the electroscope neutral.**

**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.

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

**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.

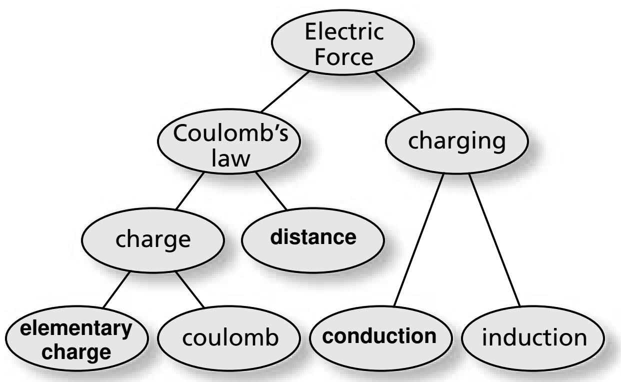
**Some charges on the metal sphere will be repelled to the opposite side from the plastic sphere, making the effective distance between the charges greater than the distance between the spheres' centers.**

# Chapter Assessment

## Concept Mapping

**page 558**

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




## Mastering Concepts

**page 558**

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

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

**24.** List some insulators and conductors. (20.1)

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

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

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

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

**Rubbing the CD charges it. Neutral particles, such as dust, are attracted to a charged object.**

**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)

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

**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)

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

**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

**page 558**

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

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

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

**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.**

**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.

**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. 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?

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

**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.

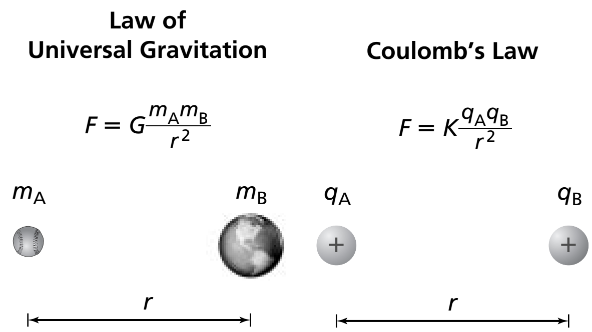
**a.** positive

**The leaves will move farther apart.**

**b.** negative

**The leaves will drop slightly.**

**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)

**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.**

**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?

**The electric force is much larger than the gravitational force.**

**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.

**After changing 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.** 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?

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

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?

**$F \propto \frac{1}{d^2}$ and $F \propto \frac{1}{\left(\frac{1}{4}\right)^2}$, so $F = 16$ times the original force.**

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.

**Gravitational forces only can be attractive. Electric forces can be either attractive or repulsive, and we can sense only their vector sums, which are generally small. The gravitational attraction to Earth is larger and more noticeable because of Earth's large mass.**

## Mastering Problems

### 20.2 Electric Force

**page 559**

**Level 1**

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

**$2q_A$, then new force $= 2F$**

**b.** $q_A$ and $q_B$ are cut in half

**$\frac{1}{2}q_A$ and $\frac{1}{2}q_B$, then new force $= \left(\frac{1}{2}\right)\left(\frac{1}{2}\right)F = \frac{1}{4}F$**

**c.** $r$ is tripled

**$3d$, then new force $= \frac{F}{(3)^2} = \frac{1}{9}F$**

**d.** $r$ is cut in half

**$\frac{1}{2}d$, then new force $= \frac{F}{\left(\frac{1}{2}\right)^2} = \frac{3}{4}F = 4F$**

**e.** $q_A$ is tripled and $r$ is doubled

**$3q_A$ and $2d$, then new force $= \frac{(3)F}{(2)^2} = \frac{3}{4}F$**

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

$$(-25\text{ C})\left(\frac{1\text{ electron}}{-1.60\times10^{-19}\text{ C}}\right) = 1.6\times10^{20}\text{ electrons}$$

44. **Atoms** Two electrons in an atom are separated by $1.5\times10^{-10}$ m, the typical size of an atom. What is the electric force between them?

$$F = \frac{Kq_Aq_B}{d^2} = \frac{(9.0\times10^{9}\text{ N·m}^2/\text{C}^2)(1.60\times10^{-19}\text{ C})(1.60\times10^{-19}\text{ C})}{(1.5\times10^{-10}\text{ m})^2}$$

$$= 1.0\times10^{-8}\text{ N, away from each other}$$

**45.** A positive and a negative charge, each of magnitude $2.5\times10^{-5}$ C, are separated by a distance of 15 cm. Find the force on each of the particles.

$$F = \frac{Kq_Aq_B}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(2.5\times10^{-5}\ \text{C})(2.5\times10^{-5}\ \text{C})}{(1.5\times10^{-1}\ \text{m})^2}$$

$= 2.5\times10^2$ **N, toward the other charge**

**46.** A force of $2.4\times10^2$ N exists between a positive charge of $8.0\times10^{-5}$ C and a positive charge of $3.0\times10^{-5}$ C. What distance separates the charges?

$$F = \frac{Kq_Aq_B}{d^2}$$

$$d = \sqrt{\frac{Kq_Aq_B}{F}} = \sqrt{\frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(8.0\times10^{-5}\ \text{C})(3.0\times10^{-5}\ \text{C})}{2.4\times10^2\ \text{N}}}$$

$= 0.30$ **m**

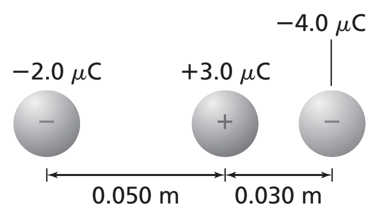
**47.** Two identical positive charges exert a repulsive force of $6.4\times10^{-9}$ N when separated by a distance of $3.8\times10^{-10}$ m. Calculate the charge of each.

$$F = \frac{Kq_Aq_B}{d^2} = \frac{Kq^2}{d^2}$$

$$q = \sqrt{\frac{Fd^2}{K}} = \sqrt{\frac{(6.4\times10^{-9}\ \text{N})(3.8\times10^{-10}\ \text{m})^2}{9.0\times10^9\ \text{N·m}^2/\text{C}^2}} = 3.2\times10^{-19}\ \text{C}$$

**Level 2**

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




■ **Figure 20-14**

$$F_1 = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(3.0\times10^{-6}\ \text{C})(2.0\times10^{-6}\ \text{C})}{(0.050\ \text{m})^2}$$

$= 22$ **N west**

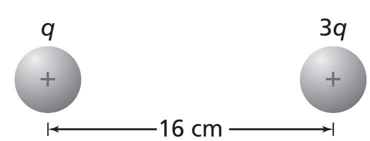
$$F_2 = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(3.0\times10^{-6}\ \text{C})(4.0\times10^{-6}\ \text{C})}{(0.030\ \text{m})^2}$$

$= 120$ **N east**

$$F_{net} = F_2 + F_1 = (1.2\times10^2\ \text{N}) - (2.2\times10^1\ \text{N})$$

$= 98$ **N, east**

**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**

$$F = K\frac{q_Aq_B}{d^2} = K\frac{q_A3q_A}{d^2}$$

$$q_A = \sqrt{\frac{Fd^2}{3K}} = \sqrt{\frac{(0.28\ \text{N})(0.16\ \text{m})^2}{3(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)}} = 5.2\times10^{-7}\ \text{C}$$

$$q_B = 3q_A = 1.5\times10^{-6}\ \text{C}$$

**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.

**A coin is $\frac{5\ \text{g}}{62\ \text{g}} = 0.08$ mole.**

**Thus, it has $(0.08)(6.02\times10^{23}) = 5\times10^{22}$ atoms**

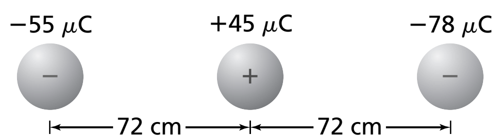
**b.** Find the number of electrons in the coin. On average, each atom has 28.75 electrons.

**$(5\times10^{22}$ atoms)(28.75 electrons/atom) $= 1\times10^{24}$ electrons**

**c.** Find the coulombs on the electrons.

**$(1.6\times10^{-19}$ coulombs/electron)$(1\times10^{24}$ electrons) $= 2\times10^{5}$ coulombs**

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




■ **Figure 20-16**

**a.** Find the net force on the middle particle.

**Let left be the negative direction**

$$F_{net} = -F_l + (F_r) = -\frac{Kq_mq_l}{d^2} + \frac{Kq_mq_r}{d^2}$$

$$= \frac{-(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(45\times10^{-6}\ \text{C})(55\times10^{-6}\ \text{C})}{(0.72\ \text{m})^2} + \frac{(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(45\times10^{-6}\ \text{C})(78\times10^{-6}\ \text{C})}{(0.72\ \text{m})^2}$$

$$= 18\ \text{N, right}$$

**b.** Find the net force on the right particle.

$$F_{net} = F_l + (-F_m) = +\frac{Kq_lq_r}{(2d)^2} - \frac{Kq_mq_r}{d^2}$$

$$= \frac{(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(55\times10^{-6}\ \text{C})(78\times10^{-6}\ \text{C})}{(2(0.72\ \text{m}))^2} + \frac{(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(45\times10^{-6}\ \text{C})(78\times10^{-6}\ \text{C})}{(0.72\ \text{m})^2}$$

$$= -42\ \text{N, left}$$

# Mixed Review

**page 559**

**Level 1**

**52.** A small metal sphere with charge $1.2\times10^{-5}$ 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?

**The two spheres share the charge equally, so**

$$F = K\frac{q_A q_B}{d^2} = (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)\frac{(6.0\times10^{-6}\ \text{C})(6.0\times10^{-6}\ \text{C})}{(0.15\ \text{m})^2} = 14\ \text{N}$$

**53.** **Atoms** What is the electric force between an electron and a proton placed $5.3\times10^{-11}$ m apart, the approximate radius of a hydrogen atom?

$$F = K\frac{q_A q_B}{d^2} = (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)\frac{(1.60\times10^{-19}\ \text{C})(1.60\times10^{-19}\ \text{C})}{(5.3\times10^{-11}\ \text{m})^2} = 8.2\times10^{-8}\ \text{N}$$

**54.** A small sphere of charge 2.4 $\mu$C 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?

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

$$q_B = \frac{Fd^2}{Kq_A} = \frac{(0.36\ \text{N})(5.5\times10^{-2}\ \text{m})^2}{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)(2.4\times10^{-6}\ \text{C})} = 5.0\times10^{-8}\ \text{C}$$

**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?

$$F = K\frac{q_A q_B}{d^2}\text{, where } q_A = q_B$$

$$q = \sqrt{\frac{Fd^2}{K}} = \sqrt{\frac{(0.28\ \text{N})(1.2\times10^{-1}\ \text{m})^2}{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)}}$$

$$= 6.7\times10^{-7}\ \text{C}$$

**56.** In an experiment using Coulomb's apparatus, a sphere with a charge of $3.6\times10^{-8}$ C is 1.4 cm from a second sphere of unknown charge. The force between the spheres is $2.7\times10^{-2}$ N. What is the charge of the second sphere?

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

$$q_B = \frac{Fd^2}{Kq_A} = \sqrt{\frac{(2.7\times10^{-2}\ \text{N})(1.4\times10^{-2}\ \text{m})^2}{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)(3.6\times10^{-8}\ \text{C})}}$$

$$= 1.6\times10^{-8}\ \text{C}$$

**57.** The force between a proton and an electron is $3.5\times10^{-10}$ N. What is the distance between these two particles?

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

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

$$= \sqrt{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)\frac{(1.60\times10^{-19}\ \text{C})(1.6\times10^{-19}\ \text{C})}{3.5\times10^{-10}\ \text{N}}} = 8.1\times10^{-10}\ \text{m}$$

## Thinking Critically

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

$$\frac{F_e}{F_g} = \frac{K\frac{q_e q_p}{d^2}}{G\frac{m_e m_p}{d^2}} = \frac{Kq_e q_p}{Gm_e m_p}$$

$$= \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(1.60\times10^{-19}\ \text{C})^2}{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(9.11\times10^{-31}\ \text{kg})(1.67\times10^{-27}\ \text{kg})} = 2.3\times10^{39}$$

**59. Analyze and Conclude** Sphere A, with a charge of $+64\ \mu$C, is positioned at the origin. A second sphere, B, with a charge of $-16\ \mu$C, is placed at 11.00 m on the *x*-axis.

**a.** Where must a third sphere, C, of charge $+12\ \mu$C be placed so there is no net force on it?

**The attractive and repulsive forces must cancel, so**

$$F_{AC} = K\frac{q_A q_C}{d_{AC}^2} = K\frac{q_B q_C}{d_{BC}^2} = F_{BC}, \text{ so}$$

$$\frac{q_A}{d_{AC}^2} = \frac{q_B}{d_{BC}^2}, \text{ and } 16d_{AC}^2 = 64d_{BC}^2, \text{ or}$$

$$d_{AC}^2 = 4d_{BC}^2, \text{ so } d_{AC} = 2d_{BC}$$

**The third sphere must be placed at +2.00 m on the *x*-axis so it is twice as far from the first sphere as from the second sphere.**

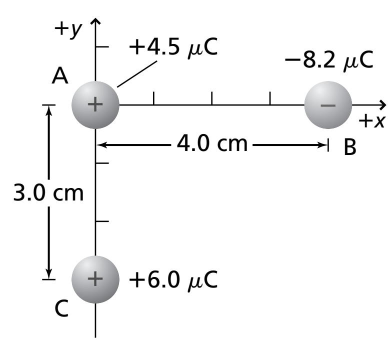
**b.** If the third sphere had a charge of $+6\ \mu$C, where should it be placed?

**The third charge, $q_C$, cancels from the equation, so it doesn't matter what its magnitude or sign is.**

**c.** If the third sphere had a charge of $-12\ \mu$C, where should it be placed?

**As in part b, the magnitude and sign of the third charge, $q_C$, do not matter.**

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




■ **Figure 20-17**

$$F_1 = F_{\text{A on B}}$$

$$= \frac{Kq_A q_B}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(4.5\times10^{-6}\ \text{C})(-8.2\times10^{-6}\ \text{C})}{(0.040\ \text{m})^2}$$

$= -208\ \text{N} = 208\ \text{N, to left}$

**The distance between the other two charges is**

$\sqrt{(0.040\ \text{m})^2 + (0.030\ \text{m})^2} = 0.050\ \text{m}$

$\theta_1 = \tan^{-1}\left(\frac{0.030\ \text{m}}{0.040\ \text{m}}\right)$

$= 37°$ **below the negative** $x$**-axis, or 217° from the positive** $x$**-axis.**

$F_2 = F_{\text{C on B}}$

$= \frac{Kq_Cq_B}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C})(8.2\times10^{-6}\ \text{C})(6.0\times10^{-6}\ \text{C})}{(0.050\ \text{m})^2}$

$= -177\ \text{N} = 177\ \text{N}$ **at 217° from the positive** $x$**-axis** $(37° + 180°)$

**The components of** $F_2$ **are:**

$F_{2x} = F_2 \cos\theta = (177\ \text{N})(\cos 217°) = -142\ \text{N} = 142\ \text{N}$ **to the left**

$F_{2y} = F_2 \sin\theta = (177\ \text{N})(\sin 217°) = -106\ \text{N} = 106\ \text{N}$ **down**

**The components of the net (resultant) force are:**

$F_{\text{net},\ x} = -208\ \text{N} - 142\ \text{N} = -350\ \text{N} = 350\ \text{N, to left}$

$F_{\text{net},\ y} = 106\ \text{N, down}$

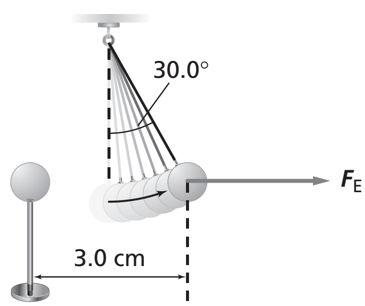
$F_{\text{net}} = \sqrt{(350\ \text{N})^2 + (106\ \text{N})^2} = 366\ \text{N} = 3.7\times10^2\ \text{N}$

$\theta_2 = \tan^{-1}\left(\frac{106\ \text{N}}{350\ \text{N}}\right)$

$= 17°$ **below the negative** $x$**-axis**

$F_{\text{net}} = 3.7\times10^2\ \text{N}$ **at 197° from the positive** $x$**-axis**

**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 $\boldsymbol{F}_E$, $\boldsymbol{F}_g$, and $\boldsymbol{F}_T$. Calculate each of the following.




■ **Figure 20-18**

**a.** $\boldsymbol{F}_g$ on the suspended ball

$F_g = mg = (1.0\times10^{-3}\ \text{kg})(9.80\ \text{m/s}^2) = 9.8\times10^{-3}\ \text{N}$

**b.** $\boldsymbol{F}_E$

$\tan 30.0° = \frac{F_E}{F_g}$

$$F_E = mg \tan 30.0°$$
$$= (1.0\times10^{-3}\ \text{kg})(9.80\ \text{m/s}^2)(\tan 30.0°)$$
$$= 5.7\times10^{-3}\ \text{N}$$

**c.** the charge on the balls

$$F = \frac{Kq_A q_B}{d^2}$$

$$F = \frac{Kq^2}{d^2}$$

$$q = \sqrt{\frac{Fd^2}{K}} = \sqrt{\frac{(5.7\times10^{-3}\ \text{N})(3.0\times10^{-2}\ \text{m}^2)}{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)}} = 2.4\times10^{-8}\ \text{C}$$

**62.** Two charges, $q_A$ and $q_B$, are at rest near a positive test charge, $q_T$, of 7.2 $\mu$C. The first charge, $q_A$, is a positive charge of 3.6 $\mu$C located 2.5 cm away from $q_T$ at 35°; $q_B$ is a negative charge of −6.6 $\mu$C located 6.8 cm away at 125°.

**a.** Determine the magnitude of each of the forces acting on $q_T$.

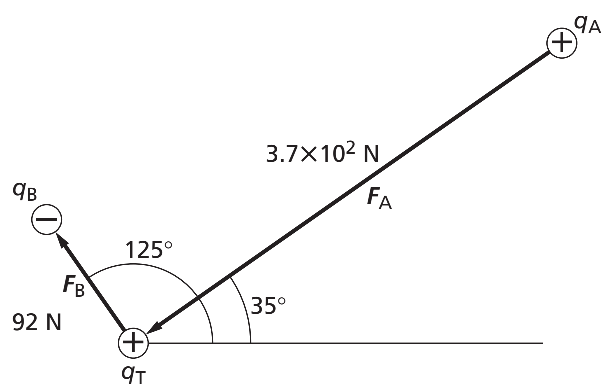
$$F_A = \frac{Kq_T q_A}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(7.2\times10^{-6}\ \text{C})(3.6\times10^{-6}\ \text{C})}{(0.025\ \text{m})^2}$$

$$= 3.7\times10^2\ \text{N, away (toward } q_T)$$

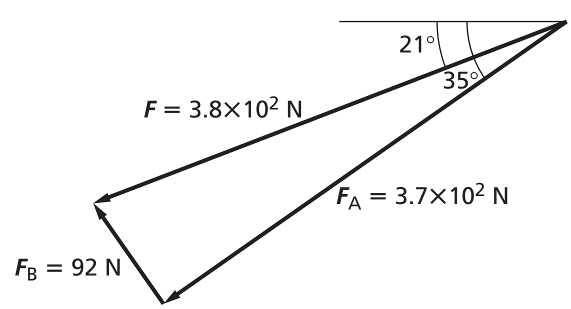
$$F_B = \frac{Kq_T q_A}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(7.2\times10^{-6}\ \text{C})(6.6\times10^{-6}\ \text{C})}{(0.068\ \text{m})^2}$$

$$= 92\ \text{N, toward (away from } q_T)$$

**b.** Sketch a force diagram.




**c.** Graphically determine the resultant force acting on $q_T$.



## Writing in Physics

**page 560**

**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.

**Student answers will vary, but should include information such as the following. The Leyden jar, invented in the mid-1740s, was the earliest capacitor. It was used throughout the eighteenth and nineteenth centuries to store charges for electricity-related experiments and demonstrations. The Wimshurst machine was a device used in the nineteenth and early twentieth centuries to produce and discharge static charges. Wimshurst machines, which were replaced by the Van de Graaff generator in the twentieth century, used Leyden jars to store the charges prior to discharge.**

**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.

**Answers will vary, but students should describe the interactions between positive and negative charges at the molecular level. Students 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

**page 560**

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

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

**66.** A submarine that is moving 12.0 m/s sends a sonar ping of frequency $1.50\times10^3$ 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?

$$d = vt = (1533\text{ m/s})(0.900\text{ s}) = 1380\text{ m}$$

**b.** What is the frequency of the sonar wave that strikes the seamount?

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right) = (1.50\times10^3\text{ Hz})\left(\frac{1533\text{ m/s} - 0.0\text{ m/s}}{1533\text{ m/s} - 12.0\text{ m/s}}\right)$$
$$= 1510\text{ Hz}$$

**c.** What is the frequency of the echo received by the submarine?

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right) = (1510\text{ Hz})\left(\frac{1533\text{ m/s} - (-12.0\text{ m/s})}{1533\text{ m/s} - 0.0\text{ m/s}}\right)$$
$$= 1520\text{ Hz}$$

**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)

$$m = \frac{-d_i}{d_o}$$

$$d_o = \frac{-d_i}{m} = \frac{-(-12.0\text{ cm})}{\frac{3}{4}} = 16.0\text{ cm}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i}$$

$$= \frac{(16.0 \text{ cm})(-12.0 \text{ cm})}{16.0 \text{ cm} + (-12.0 \text{ cm})}$$

$$= -48.0 \text{ cm}$$

**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)

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(20.0 \text{ cm})(-24.0 \text{ cm})}{20.0 \text{ cm} - (-24.0 \text{ cm})}$$

$$= -10.9 \text{ cm}$$

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(-10.9 \text{ cm})(2.00 \text{ cm})}{20.0 \text{ cm}}$$

$$= 1.09 \text{ cm}$$

**This is a virtual image that is upright in orientation, relative to the object.**

**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)

**The number of centimeters per slit is the slit separation distance, *d*.**

$$\frac{1 \text{ slit}}{d} = 11{,}500 \text{ slits/cm}$$

$$d = 8.70\times10^{-5} \text{ cm}$$

$$\lambda = d \sin\theta$$

$$\theta = \sin^{-1}\left(\frac{\lambda}{d}\right)$$

$$= \sin^{-1}\left(\frac{527\times10^{-9} \text{ m}}{8.70\times10^{-3} \text{ m}}\right)$$

$$= 0.00347°$$

# Challenge Problem

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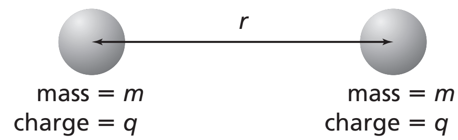
As shown in the figure below, two spheres of equal mass, *m*, and equal positive charge, *q*, are a distance, *r*, apart.




■ **Figure 20-11**

**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.

**The attractive force is gravitation, and the repulsive force is electrostatic, so their expressions may be set equal.**

$$F_g = G\frac{m_A m_B}{d^2} = K\frac{q_A q_B}{d^2} = F_e$$

**The masses and charges are equal, and the distance cancels, so**

$Gm^2 = Kq^2$, **and**

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

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

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

**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.

**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 of the expression.**

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

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

$$= 1.29\times10^{-10} \text{ C}$$