Section 1 Electric Charge: Review

1. **MAIN IDEA** In the investigations with tape described in this section, how could you find out which strip of tape, B or T, is positively charged?

   SOLUTION:

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

2. **Charged Objects** After you rub a comb on a wool sweater, you can use the comb to pick up small pieces of paper. Why does the comb lose this ability after a few minutes?

   SOLUTION:

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

3. **Types of Charge** A pith ball is a small sphere made of a light material, such as plastic foam, that is 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, charged positively, or charged negatively?

   SOLUTION:

   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** You can give a rubber rod a negative charge by rubbing the rod with wool. What happens to the charge of the wool? Why?

   SOLUTION:

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

5. **Net Charge** An apple contains on the order of 10^{26} charged particles. Why don’t two apples repel each other when they are brought together?

   SOLUTION:

   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 electrically isolated. You then touch a charged glass rod to one end of the metal rod. Describe the charges on the metal rod.

   SOLUTION:

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

7. **Charging by Friction** You can charge a rubber rod negatively by rubbing it with wool. What happens when you rub a copper rod with wool?

   SOLUTION:

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

8. **Critical Thinking** Some scientists once proposed that electric charge is a type of fluid that flows from objects with an excess of the fluid to objects with a deficit. How is the current two-charge model more accurate than the single-fluid model?

SOLUTION:

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.

Section 2 Electrostatic Force: Practice Problems

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

SOLUTION:

$$F = \frac{Kq_Aq_B}{{r_{AB}}^2}$$
$$= \frac{(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(2.0\times10^{-4}\ \text{C})(8.0\times10^{-4}\ \text{C})}{(0.30\ \text{m})^2}$$
$$= 1.6\times10^4\ \text{N}$$

The forces are attracted to each other.

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

SOLUTION:

$$F = \frac{Kq_Aq_B}{{r_{AB}}^2}$$
$$q_B = \frac{F{r_{AB}}^2}{Kq_A}$$
$$= \frac{(65\ \text{N})(0.050\ \text{m})^2}{(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(6.0\times10^{-6}\ \text{C})}$$
$$= 3.0\times10^{-6}\ \text{C}$$

11. Suppose you replace the charge on B in Example Problem 1 with a charge of $+3.00\,\mu$C. Diagram the new situation, and find the net force on A.

SOLUTION:

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

SOLUTION:

The electrostatic force between two charges is proportional to the inverse square of the distance between those charges. Therefore, the electrostatic force between the two charges decreases by a factor of 3^2 = 9.

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

SOLUTION:

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

$$= \left(9.0\times10^9\ \text{N•m}^2/\text{C}^2\right) \times \frac{\left(2.0\times10^{-6}\ \text{C}\right)\left(3.6\times10^{-6}\ \text{C}\right)}{\left(0.60\ \text{m}\right)^2}$$

= 0.18 N

direction: toward the right

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

$$= \left(9.0\times10^9\ \text{N•m}^2/\text{C}^2\right) \times \frac{\left(2.0\times10^{-6}\ \text{C}\right)\left(4.0\times10^{-6}\ \text{C}\right)}{\left(0.80\ \text{m}\right)^2}$$

= 0.1125 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 N toward the right

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

SOLUTION:

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

$$F_{\text{C on B}} = K\frac{q_C q_B}{{r_{CB}}^2}$$

$$\begin{aligned} F_{\text{net}} &= F_{\text{C on B}} - F_{\text{A on B}} \\ &= K\frac{q_B q_C}{{r_{BC}}^2} - K\frac{q_A q_B}{{r_{AB}}^2} \\ &= \left(9.0\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right) \times \frac{\left(3.6\times10^{-6}\ \text{C}\right)\left(4.0\times10^{-6}\text{C}\right)}{\left(0.20\ \text{m}\right)^2} \\ &\quad -\left(9.0\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right) \times \frac{\left(2.0\times10^{-6}\ \text{C}\right)\left(3.6\times10^{-6}\text{C}\right)}{\left(0.60\ \text{m}\right)^2} \end{aligned}$$

= 3.1 N toward the right

Section 2 Electrostatic Force: Review

15. **MAIN IDEA** Describe the relationship between the magnitude of the electrostatic force, the charge on two objects, and the distance between the objects. What is the equation for this relationship?

SOLUTION:

The Electrostatic force is proportional to the product of the two charges and inversely proportional to the square of the distance between them.

The equation for this relationship is:

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

16. **Force and Charge** How are electrostatic force and charge related? Describe the force when the charges are like charges and the force when the charges are opposite.

SOLUTION:

Electrostatic force is directly related to each charge. It is repulsive between like charges and attractive between opposite charges.

17. **Force and Distance** How are electrostatic force and distance related? How would the force change if the distance between two charges were tripled?

SOLUTION:

Electrostatic 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.

18. **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?

SOLUTION:

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

19. **Electroscopes** Why do the leaves of a charged electroscope rise to a certain angle and no farther?

SOLUTION:

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

20. **Attraction of Neutral Objects** What properties explain how both positively charged objects and negatively charged objects can attract neutral objects?

SOLUTION:

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.

21. **Charging an Electroscope** How can you charge an electroscope positively using a positively charged rod? Using a negatively charged rod?

SOLUTION:

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

22. **Electrostatic Forces** Two charged spheres are held a distance *r* apart, as shown in **Figure 15.** Compare the force of sphere A on sphere B with the force of sphere B on sphere A.

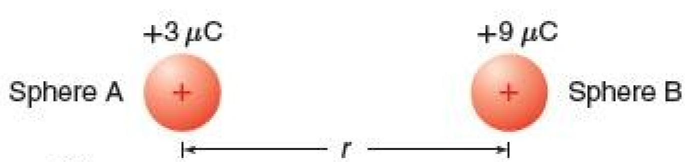


Figure 15

SOLUTION:

The forces are equal in magnitude and opposite in direction.

23. **Critical Thinking** Suppose 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 you bring spheres close together, the force is smaller than expected from Coulomb's law. Explain.

SOLUTION:

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
Section 1 Electric Charge: Mastering Concepts

24. **BIG IDEA** If you comb your hair on a dry day, the comb can become negatively charged. Can your hair remain neutral? Explain.

SOLUTION:

No. Your hair must become positively charged in order to repel a negative charge. Charge is conserved.

25. If you bring a charged comb near tiny pieces of paper, the pieces will first be attracted to the comb, but after touching they will fly away. Why do they fly away?

SOLUTION:

The paper is initially attracted to the comb because the comb causes separation of charge in the paper. The part of the paper pieces with positive charge is attracted to the comb. When the paper touches the comb, some of the excess negative charge in the comb is transferred to the paper. Because their charges are like, the paper is then repelled.

26. List some insulators and conductors.

SOLUTION:

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.

27. What makes metal a good conductor and rubber a good insulator?

SOLUTION:

Metals contain free electrons; rubber has bound electrons.

Chapter Assessment
Section 2 Electrostatic Force: Mastering Concepts

28. **Laundry** Why do socks taken from a clothes dryer sometimes cling to other clothes?

SOLUTION:

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.

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

SOLUTION:

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

30. **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.

SOLUTION:

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

31. 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?

SOLUTION:

Electrostatic 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.

32. Explain how to charge a conductor negatively if you have only a positively charged rod.

SOLUTION:

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.

33. Bernoulli's experiments to measure the strength of the electrostatic force used metal disks about 3 cm in diameter. When the disks were close together, would he have found a $1/r^2$ dependence? Explain.

SOLUTION:

The $1/r^2$ dependence is only valid for point charges. The two disks could be viewed as a collection of point charges, but in order to calculate the *r* dependence, one would have to integrate over all point charges. This is only a problem for small separations. If the disks were much further apart, they would behave like point charges.

Chapter Assessment
Section 2 Electrostatic Force: Mastering Problems

34. **Atoms** Two electrons in an atom are separated by 1.5×10^{-10} m, the typical size of an atom. What is the electrostatic force between them? (Level 1).

SOLUTION:

$$F = \frac{Kq_Aq_B}{r^2}$$
$$= \frac{(9.0\times10^9\ \text{N•m}^2/\text{C}^2)(1.60\times10^{-19}\ \text{C})(1.60\times10^{-19}\ \text{C})}{(1.5\times10^{-10}\ \text{m})^2}$$
$$= 1.0\times10^{-8}\ \text{N, away from each other}$$

35. A positive and a negative charge, each of magnitude 2.5×10^{-5} C, are separated by a distance of 15 cm. Find the force on each of the particles. (Level 1).

SOLUTION:

$$F = \frac{Kq_Aq_B}{r^2}$$
$$= \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(2.5\times10^{-5}\ \text{C})(2.5\times10^{-5}\ \text{C})}{(1.5\times10^{-1}\ \text{m})^2}$$
$$= 2.5\times10^2\ \text{N, toward the other charge}$$

36. Two identical positive charges exert a repulsive force of 6.4×10^{-9} N when separated by a distance of 3.8×10^{-10} m. Calculate the charge of each. (Level 1).

SOLUTION:

$$F = \frac{Kq_Aq_B}{r^2} = \frac{Kq^2}{r^2}$$
$$q = \sqrt{\frac{Fr^2}{K}}$$
$$= \sqrt{\frac{(6.4\times10^{-9}\ \text{N})(3.8\times10^{-10}\ \text{m})^2}{9.0\times9^9\ \text{N·m}^2/\text{C}^2}}$$
$$= 3.2\times10^{-19}\ \text{C}$$

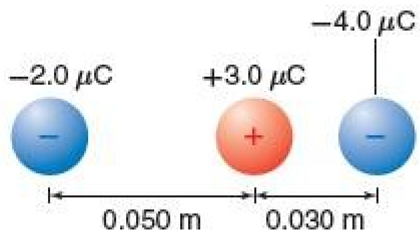
37. **Lightning** A strong lightning bolt transfers about 25 C to Earth. How many electrons are transferred? (Level 1).

SOLUTION:

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

38. A positive charge of 3.0 μC is pulled on by two negative charges. As shown in **Figure 16**, one negative charge, −2.0 μC, is 0.050 m to the west, and the other, −4.0 μC, is 0.030 m to the east. What net force is exerted on the positive charge? (Level 2).

Figure 16



SOLUTION:

West will be designated as the negative direction.

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

= 22 N west

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

= 120 N west

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

= 98 N, east

39. **Figure 17** 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? (Level 2).

Figure 17

SOLUTION:

$$F = K\frac{q_A q_B}{r^2} = K\frac{q_A 3q_A}{r^2}$$

$$q_A = \sqrt{\frac{Fr^2}{3K}}$$

$$= \sqrt{\frac{(0.28\ \text{N})(0.16\ \text{m})^2}{3(9.0\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2)}}$$

$$= 5.2\times10^{-7}\ \text{C}$$

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

40. 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 18.** (Level 2).

a. Find the net force on the middle particle.
b. Find the net force on the right particle.

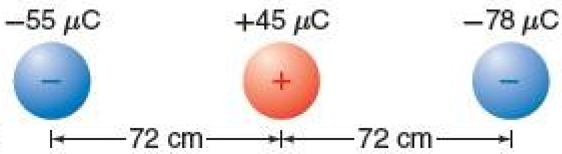


Figure 18

SOLUTION:
Let left be the negative direction

a.

$$F_{net} = -F_l + (F_r)$$
$$= -\frac{Kq_m q_l}{r^2} + \frac{Kq_m q_r}{r^2}$$
$$= \frac{-(9.0\times10^9\ \text{N•m}^2/\text{C}^2)(45\times10^{-6}\ \text{C})(55\times10^{-6}\ \text{C})}{(0.72\ \text{m})^2}$$
$$+ \frac{(9.0\times10^9\ \text{N•m}^2/\text{C}^2)(45\times10^{-6}\ \text{C})(78\times10^{-6}\ \text{C})}{(0.72\ \text{m})^2}$$

F_{net} **= 18 N, right**

b.

$$F_{net} = F_l + (-F_m)$$
$$= +\frac{Kq_l q_r}{(2r)^2} - \frac{Kq_m q_r}{r^2}$$
$$= \frac{(9.0\times10^9\ \text{N•m}^2/\text{C}^2)(55\times10^{-6}\ \text{C})(78\times10^{-6}\ \text{C})}{\left(2(0.72\ \text{m})\right)^2}$$
$$- \frac{(9.0\times10^9\ \text{N•m}^2/\text{C}^2)(45\times10^{-6}\ \text{C})(78\times10^{-6}\ \text{C})}{(0.72\ \text{m})^2}$$

= 42 N, left

Chapter 20 Practice Problems, Review, and Assessment

41. **Reverse Problem** Write a physics problem for which the following equation would be part of the solution: (Level 3).

$$F = \left(9.0\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\times\left(\frac{(3.0\times10^{-6}\ \text{C})(2.0\times10^{-6}\ \text{C})}{(0.25\ \text{m})^2}-\frac{(3.0\times10^{-6}\ \text{C})(5.0\times10^{-6}\ \text{C})}{(0.45\ \text{m})^2}\right)$$

SOLUTION:

Answers will vary, but a correct form of the answer is, "A −3.0 μC charge is located between a +2.0 μC charge and a +5.0 μC charge, such that it is 0.25 m from the 2.0 μC charge and 0.45 m from the 5.0 μC charge. What is the net force on the −3.0 μC charge?"

42. **Charge in a Coin** A nickel has a mass of about 5 g and is 75 percent Cu and 25 percent Ni. On average, each mole of a nickel's atoms will have a mass of about 62 g. Each Cu atom has 29 electrons; each Ni atom has 28 electrons. How many coulombs of charge are on the electrons in a nickel? (Level 3).

SOLUTION:

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 $\frac{5\ \text{g}}{62\ \text{g/mol}} = 0.08$ mol.

Thus, it has (0.08 mol)(6.02×10^{23} atoms/mol) = 4.85×10^{22} atoms

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

(4.85×10^{22} atoms)(28.75 electrons/atom) = 1.40×10^{24} electrons

Find the coulombs on the electrons.

(1.6×10^{-19} C/electron)(1.40×10^{24} electrons) = 2×10^{5} C

43. **Problem Posing** Complete this problem so that it must be solved using Coulomb's Law: "A very small sphere is given a charge of 6.25 μC…" (Level 3).

SOLUTION:

Answers will vary. A possible form of the correct answer would be, "… and is placed 3.5 cm from another sphere with a charge of 2.1 μC. What is the magnitude of the electrostatic force they exert on each other?"

44. **Ranking Task** Rank the following pairs of point charges according to the magnitude of electrostatic force they exert on each other. Specifically indicate any ties. (Level 3).

A. two 7.0 nC charges separated by 0.20 m
B. two 5.0 nC charges separated by 0.20 m
C. two 2.5 nC charges separated by 0.10 m
D. a 2.5 nC charge and a 5.0 nC charge separated by 0.20 m
E. 1.0 μC charge and a 2.5 μC charge separated by 0.10 m

SOLUTION:

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

So, A > B = C > D > E

Chapter Assessment: Applying Concepts

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

SOLUTION:

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

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

SOLUTION:

$$F \propto \frac{1}{r^2} \text{ and } F \propto \frac{1}{\left(\frac{1}{4}\right)^2},$$

so F = (16)(0.145 N) = 2.32 N

47. Electrostatic forces between charges are enormous in comparison to gravitational forces. Yet, you normally do not sense electrostatic forces between yourself and your surroundings, while you do sense gravitational interactions with Earth. Explain.

SOLUTION:

Gravitational forces only can be attractive. Electrostatic 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.

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

SOLUTION:

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

49. Using a charged rod and an electroscope, how can you find whether an object is a conductor?

SOLUTION:

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.

50. 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 the spheres touch the rod, they are flung off in different directions. Explain why this happens.

SOLUTION:

The neutral 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.

51. Explain what would happen to the leaves of a positively charged electroscope if a positively charged rod was brought close to, but did not touch, the electroscope. How would the electroscope's leaves behave if the rod were negatively charged?

SOLUTION:

The leaves would move farther apart when a positively charged rod was brought close to the electroscope but would drop slightly when a negatively charged rod was brought near.

52. **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?

SOLUTION:

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.

53. 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.

SOLUTION:

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.

54. As shown in **Figure 19,** Coulomb's law and Newton's law of universal gravitation appear to be similar. In what ways are the electrostatic and gravitational forces similar? How are they different?

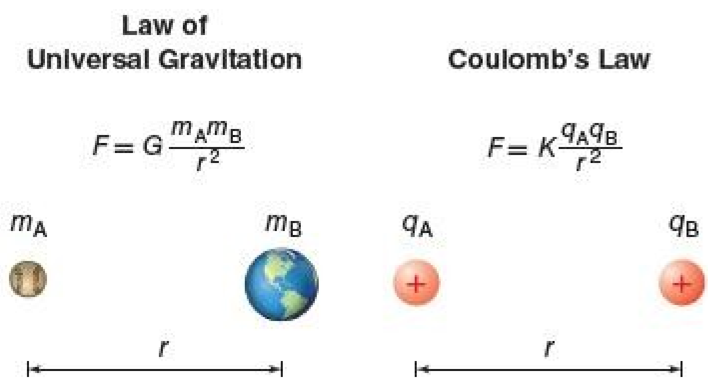


Figure 19

SOLUTION:

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 electrostatic force can be either attractive or repulsive.

Chapter Assessment: Mixed Review

55. A small metal sphere with charge 1.2×10^{-5} C is touched to an identical neutral sphere and then placed 0.15 m from the second sphere. What is the electrostatic force between the two spheres? (Level 1).

SOLUTION:

The two spheres share the charge equally, so

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

$$= (9.0\times10^9\ \text{N·m}^2/\text{C}^2)\times\frac{(6.0\times10^{-6}\ \text{C})(6.0\times10^{-6}\ \text{C})}{(0.15\ \text{m})^2}$$

= 14 N

56. **Atoms** What is the electrostatic force between an electron and a proton placed 5.3×10^{-11} m apart, the approximate radius of a hydrogen atom? (Level 1)

SOLUTION:

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

$$= (9.0\times10^9\ \text{N·m}^2/\text{C}^2)\times\frac{(1.60\times10^{-19}\ \text{C})(1.60\times10^{-19}\ \text{C})}{(5.3\times10^{-11}\ \text{m})^2}$$

$$= 8.2\times10^{-8}\ \text{N}$$

57. A small sphere of charge 2.4 μC experiences a force of 0.36 N when a second sphere of unknown charge is placed 5.5 cm from it. What is the charge of the second sphere? (Level 1).

SOLUTION:

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

$$q_B = \frac{Fr^2}{Kq_A}$$

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

$$= 5.0\times10^{-8}\ \text{C}$$

58. Two identically charged spheres placed 12 cm apart have an electrostatic force of 0.28 N between them. What is the charge on each sphere? (Level 1).

SOLUTION:

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

where $q_A = q_B$

$$q = \sqrt{\frac{Fr^2}{K}}$$
$$= \sqrt{\frac{(0.28\ \text{N})(1.2\times10^{-1}\ \text{m})^2}{(9.0\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2)}}$$
$$= 6.7\times10^{-7}\ \text{C}$$

59. In an investigation using Coulomb’s apparatus, a sphere with a charge of 3.6×10^{-8} C is 1.4 cm from a second sphere of unknown charge. The force between the spheres is 2.7×10^{-2} N. What is the charge of the second sphere? (Level 1).

SOLUTION:

$$F = K\frac{q_A q_B}{r^2}$$
$$q_B = \frac{Fr^2}{Kq_A}$$
$$= \frac{(2.7\times10^{-2}\ \text{N})(1.4\times10^{-2}\ \text{m})^2}{(9.0\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2)(3.6\times10^{-8}\ \text{C})}$$
$$= 1.6\times10^{-8}\ \text{C}$$

Thinking Critically

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

SOLUTION:

$$\frac{F_e}{F_g} = \frac{K\frac{q_e q_p}{r^2}}{G\frac{m_e m_p}{r^2}} = \frac{Kq_e q_p}{Gm_e m_p}$$
$$= (9.0\times10^9\ \text{N}\bullet\text{m}^2/\text{C}^2)(1.60\times10^{-19}\ \text{C})^2 \div$$
$$(6.67\times10^{-11}\ \text{N}\bullet\text{m}^2/\text{kg}^2)(9.11\times10^{-31}\ \text{kg})(1.67\times10^{-27}\ \text{kg})$$
$$= \mathbf{2.3\times10^{39}}$$

61. **Analyze and Conclude** Sphere A, with a charge of +64 μC, is positioned at the origin. A second sphere, B, with a charge of −16 μC, is placed at +1.00 m on the *x*-axis.

a. Where must a third sphere, C, of charge 112 μC be placed so there is no net force on it?
b. If the third sphere had a charge of 16 μC, where should it be placed?

SOLUTION:

a. The attractive and repulsive forces must cancel, so

$$F_{AC} = K\frac{q_A q_C}{{r_{AC}}^2}$$
$$= K\frac{q_B q_C}{{r_{BC}}^2}$$
$$= F_{BC},$$
$$\text{so } \frac{q_A}{{r_{AC}}^2} = \frac{q_B}{{r_{BC}}^2},$$
$$\text{and } 16{r_{AC}}^2 = 64{r_{BC}}^2, \text{ or}$$
$${r_{AC}}^2 = 4{r_{BC}}^2, \text{ so } r_{AC} = 2r_{BC}$$

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. Note that placing sphere C at *x* = 7.33 m would also satisfy $d_{AC} = 2d_{BC}$; however, charge C cannot logically be placed between A and B and experience a net force of zero.

b. The third charge, q_c, cancels from the equation, so it doesn't matter what its magnitude or sign is; it must be placed at
+2.00 m on the *x*-axis.

62. Three charged spheres are at the positions shown in **Figure 20.** Find the net force on sphere B.

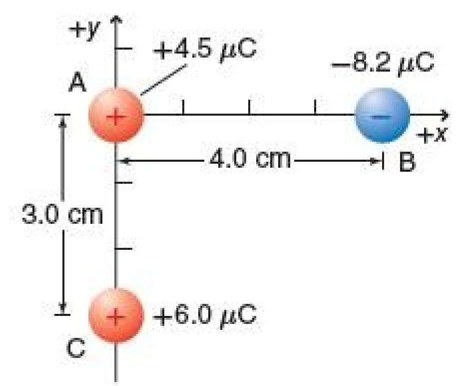


Figure 20

SOLUTION:

$$F_1 = F_{\text{A on B}}$$
$$= \frac{Kq_A q_B}{r^2}$$
$$= \frac{(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(4.5\times10^{-6}\ \text{C})(-8.2\times10^{-6}\ \text{C})}{(0.040\ \text{m})^2}$$

= –208 N

= 208 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.

$$F_2 = F_{\text{C on B}} = \frac{Kq_C q_B}{r^2} = \frac{(9.0\times10^9\text{ N}\cdot\text{m}^2/\text{C})(8.2\times10^{-6}\text{ C})(6.0\times10^{-6}\text{ C})}{(0.050\text{ m})^2}$$

= –177 N
= 177 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 N
= 106 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_{net} = 3.7×10^2 N at 197° counterclockwise from the positive x-axis

63. The two pith balls in **Figure 21** each have a mass of 1.0 g and an equal charge. One pith ball is suspended by an insulating thread. The other is brought to 3.0 cm from the suspended ball. The suspended ball is now hanging, with the thread forming an angle of 30.0° with the vertical. The ball is in equilibrium with F_E, F_g, and F_T. Calculate each of the following.

a. F_g on the suspended ball

b. F_E

c. the charge on the balls

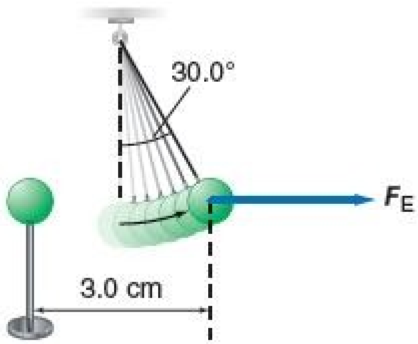


Figure 21

SOLUTION:

a.

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

b.

$$F_T \cos\theta - F_g = 0$$
$$F_E - F_T \sin\theta = 0$$

Substitute for F_T:

$$F_E - F_g\frac{\sin\theta}{\cos\theta} = 0$$
$$F_E = F_g\frac{\sin\theta}{\cos\theta} = F_g\tan\theta$$
$$\tan\theta = \frac{F_E}{F_g}$$
$$\tan 30.0° = \frac{F_E}{F_g}$$
$$F_E = mg\tan 30.0°$$
$$= (1.0\times10^{-3}\ \text{kg})(9.8\ \text{N/kg})(\tan 30.0°)$$
$$= 5.7\times10^{-3}\ \text{N}$$

c.

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

64. A device to trap positively charged ions has four charged rods, equally spaced from the center. The top and bottom rods are charged positively, the left and right rods negatively. Explain why when the ion is at the center of the rods there is no force on it. If the ion moves a small distance up or down, does the net force push it toward or away from the center? What if it moves a small distance to the left or right?

SOLUTION:

When the positive ion is exactly in the center of the rods, the force from the top rod exactly balances the force from the bottom rod. Likewise, the forces from the left and right rods exactly balance each other. If the ion moves up or down the closer rod exerts a stronger repulsive force, pushing the ion back toward the center. When the ion moves left or right the closer rod exerts a stronger attractive force, so the ion is pulled away from the center.

65. Two charges, q_A and q_B, are at rest near a positive charge, q_T, of 7.2 μC. The first charge, q_A, is a positive charge of 3.6 μC located 2.5 cm away from q_T at 35°; q_B is a negative charge of 26.6 μC located 6.8 cm away at 125°.

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

b. Sketch a force diagram.

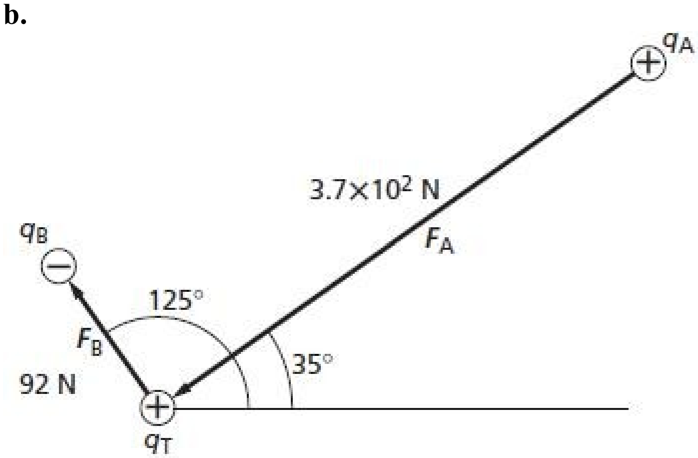
c. Graphically determine the resultant force on q_T.

SOLUTION:

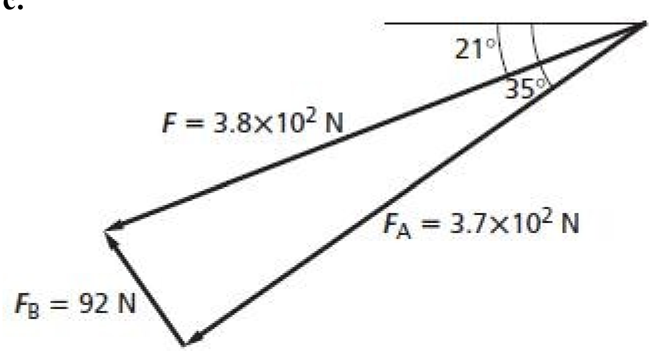
a.

$$F_A = \frac{Kq_Tq_A}{r^2}$$
$$= \frac{(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(7.2\times10^{-6}\ \text{C})(3.6\times10^{-6}\ \text{C})}{(0.025\ \text{m})^2}$$
$$= 3.7\times10^2\ \text{N, away (toward } q_T\text{)}$$
$$F_B = \frac{Kq_Tq_A}{r^2}$$
$$= \frac{(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(7.2\times10^{-6}\ \text{C})(6.6\times10^{-6}\ \text{C})}{(0.068\ \text{m})^2}$$
$$= 92\ \text{N, toward (away from } q_T\text{)}$$

b.



c.



Writing in Physics

66. **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 were used?

SOLUTION:

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.

67. When you studied states of matter, 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.

SOLUTION:

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

68. Explain how a pendulum can be used to determine the acceleration of gravity.

SOLUTION:

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

69. A submarine moving 12.0 m/s sends a sonar ping of frequency 1.50×10^{3} Hz toward a seamount directly in front of it. It receives the echo 1.800 s later.

a. How far is the submarine from the seamount?
b. What is the frequency of the sonar wave that strikes the seamount?
c. What is the frequency of the echo received by the submarine?

SOLUTION:

a. $\mathbf{x = vt = (1533\ m/s)(0.900\ s) = 1380\ m}$

b.

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

c.

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

70. **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?

SOLUTION:

$$m = \frac{-x_i}{x_o}$$
$$x_o = \frac{-x_i}{m}$$
$$= \frac{-(-12.0\ \text{cm})}{\frac{3}{4}}$$
$$= 16.0\ \text{cm}$$
$$\frac{1}{f} = \frac{1}{x_o} + \frac{1}{x_i}$$
$$f = \frac{x_o x_i}{x_o + x_i}$$
$$= \frac{(16.0\ \text{cm})(-12.0\ \text{cm})}{16.0\ \text{cm} + (-12.0\ \text{cm})}$$
$$= -48.0\ \text{cm}$$

71. 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?

SOLUTION:

$$\frac{1}{f}=\frac{1}{x_o}+\frac{1}{x_i}$$

$$x_i=\frac{x_o f}{x_o-f}$$

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

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

$$m=\frac{h_i}{h_o}=\frac{-x_i}{x_o}$$

$$h_i=\frac{-x_i h_o}{x_o}$$

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

$$=1.09\text{ cm}$$

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

72. **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.

SOLUTION:

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

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

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

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

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

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

$$=0.00347°$$