Section 7.1: Properties of Electric Charge

Mini Investigation: Observing Electric Charge, page 325

A. Each charged object attracts the pieces of paper differently because different objects accept different amounts of extra electrons. Therefore, they vary in their total charge. Objects with greater charge have a stronger attraction to the pieces of paper.
B. Some pieces of paper fall off the charged object after a short while because the charged object polarizes the nearby pieces of paper. The side of the paper attracted to the charged object has a charge opposite to that of the charged object. When the two are in contact, electrons move from the charged object to the paper, causing it to have a neutral charge. Without the attraction to the charged object, the pieces of paper fall away from the object.
C. Paper in contact with the charged conductor can take on some of the excess charge of the conductor. The conductor has enough charge to neutralize the opposite charge on the side of the paper next to the conductor and to place extra charge onto the paper. The paper thus acquires the same kind of charge as the conductor. The like charges repel each other, causing the paper to "jump" from the conductor.

Section 7.1 Questions, page 326

1. To determine the sign of the charge on an unknown object using a glass rod and a piece of silk, I would first rub the glass rod with the piece of silk, giving it a negative charge. Then I would place the silk close to the charged object. If the silk is pulled toward the object, then the object has a positive charge. If the silk is pushed away from the object, the object has a negative charge.
2. The electric force between two like charges is repulsive, and the electric force between unlike charges is attractive. The object that has a charge attracts unlike charges and repels like charges in the object with zero charge. Induced charge separation creates a slight charge on the ends of the object; because the unlike charge is closest to the inducing charge, the two objects are attracted to one another.
3. The negative charge on the balloons repels the electrons in the material on the wall, so that the electrons are repelled from the wall's surface. This resulting positive charge in that area holds the negative charge on the balloons, causing the balloons to attach to the wall.
4. When the pellets of foam plastic touch the rod, the pellets become negatively charged. The negatively charged pellets are repelled by the negatively charged rod, causing the pellets to jump away from the rod. When they jump, they spark.
5. When two objects, such as a glass rod and a silk cloth, are rubbed together, protons cannot move from one object to the other. Protons cannot move from one object to another because they are tightly bound to the nucleus of the atom.
6. (a) The charge on my body and the charge on the carpet are equal and opposite. After walking across the carpet, my body now has an excess of electrons because the electrons moved from the carpet to me. Therefore, the charge on my body is negative, and the charge on the carpet is positive.
(b) Walking across a carpet on a cold, dry day illustrates charging by friction.
7. It is a good precaution to touch the metal casing before handling the memory chip because sparks from charge build-up on the student can damage the circuitry of the chip. Touching the casing acts as an electrical ground.

8. To give a neutral object a positive charge using only a negatively charged object, I would use the process of charging by induction. By bringing the negatively charged object near the neutral object, the object becomes polarized. Using a ground connection on the far side of the neutral object removes electrons, so that when the negatively charged object is pulled away, the formerly neutral object has a net positive charge.

9. (a) When a glass rod is rubbed with a wool rag, electrons move from the glass to the wool. The glass rod becomes negatively charged, and the wool rag becomes positively charged.

(b) When a plastic rod is rubbed with a silk scarf, electrons move from the scarf to the rod. The plastic rod becomes positively charged, and the silk scarf becomes negatively charged.

(c) When a platinum rod with a negative charge is touched with a similar rod with a positive charge, electrons move from the negatively charged rod to the other rod until the charge on one rod is balanced. One rod will become neutral. The charge of the other rod will have the same charge as the rod with the greater charge at the beginning.

(d) When a small metal rod touches a large positively charged metal sphere, electrons move from the rod to the sphere, balancing only some positive charge on the sphere. Both the metal rod and sphere are positively charged.

10. Friction between the father's skin and the wool sweater he is wearing gave a net charge to the father. When the student and his father shook hands, the charge transferred to the student.

11. (a) Clothes rubbing against each other in the dryer transfer electrons, so that some clothes have negative charge and others have positive charge. These unlike charges attract each other, causing the clothes to cling together.

(b) Compounds in a fabric softener sheet break into negative and positive ions, which interact with the charges on the clothes. This process easily removes the built-up charge.

Section 7.2: Coulomb's Law

Tutorial 1 Practice, page 332

1. Given: $q_1 = 1.00 \times 10^{-4}$ C; $q_2 = 1.00 \times 10^{-5}$ C; $r = 2.00$ m; $k = 8.99 \times 10^9$ N·m²/C²

Required: F_E

Analysis: $F_E = \frac{kq_1q_2}{r^2}$

Solution: $F_E = \frac{kq_1q_2}{r^2}$

$$= \frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)(1.00\times10^{-4}\ \cancel{\text{C}})(1.00\times10^{-5}\ \cancel{\text{C}})}{(2.00\ \cancel{\text{m}})^2}$$

$F_E = 2.25$ N

Statement: The magnitude of the electric force between the two charges is 2.25 N.

2. Given: $q_1 = q$; $q_2 = -2q$; $r_{12} = 1.000$ m; $F_{E13} + F_{E23} = 0$; $k = 8.99 \times 10^9$ N·m²/C²

Required: r_{13}

Analysis: Use $F_E = \frac{kq_1q_2}{r^2}$ to develop a quadratic equation to solve for r_{13}.

Solution: $F_{E13} + F_{E23} = 0$

$$F_{E13} = -F_{E23}$$

$$\frac{\cancel{k}q_1\cancel{q_3}}{r_{13}^2} = -\frac{\cancel{k}q_2\cancel{q_3}}{r_{23}^2}$$

$$\frac{q_1}{r_{13}^2} = -\frac{q_2}{r_{23}^2}$$

$$\frac{q}{r_{13}^2} = -\frac{-2q}{\left(1.000 + r_{13}\right)^2}$$

$$\left(1 + r_{13}\right)^2 = 2r_{13}^2$$

$$1 + 2r_{13} + r_{13}^2 = 2r_{13}^2$$

$$0 = r_{13}^2 - 2r_{13} - 1$$

Solve the quadratic equation:

$$0 = r_{13}^2 - 2r_{13} - 1$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$r_{13} = \frac{-(-2) \pm \sqrt{(-2)^2 - 4(1)(-1)}}{2(1)}$$

$$r_{13} = \frac{2 \pm \sqrt{4+4}}{2}$$

$$r_{13} = \frac{2 \pm 2\sqrt{2}}{2}$$

$$r_{13} = 1 \pm \sqrt{2}$$

Only the positive distance is necessary:

$$r_{13} = 1 + \sqrt{2} \text{ m}$$

$$r_{13} = 2.414 \text{ m}$$

Statement: The third charge is 2.414 m to the left of q.

3. Given: q_1 = +2.0 μC = +2.0 × 10^{-6} C; d_1 = 0 m; q_2 = –3.0 μC = –3.0 × 10^{-6} C; d_2 = 40.0 cm = 0.40 m; q_3 = –5.0 μC = –5.0 × 10^{-6} C; d_3 = 120.0 cm = 1.20 m; $k = 8.99 \times 10^9$ N·m²/C²

Required: F_{Enet} at q_2

Analysis: $F_\text{E} = \dfrac{kq_1q_2}{r^2}$

Solution:

Determine the electric force due to q_1:

$$F_\text{E12} = \frac{kq_1q_2}{r^2}$$

$$= \frac{\left(8.99\times10^9 \ \frac{\text{N}\cdot\cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)(2.0\times10^{-6}\ \cancel{\text{C}})(-3.0\times10^{-6}\ \cancel{\text{C}})}{(0.40\ \cancel{\text{m}})^2}$$

$$F_\text{E12} = -0.3371 \text{ N} \quad \text{(two extra digits carried)}$$

Determine the electric force due to q_3:

$$F_{E23} = \frac{kq_3q_2}{r^2}$$

$$= \frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\cancel{\text{m}}^2}{\cancel{\text{C}}^2}\right)(-5.0\times10^{-6}\ \cancel{\text{C}})(-3.0\times10^{-6}\ \cancel{\text{C}})}{(1.20\ \cancel{\text{m}} - 0.40\ \cancel{\text{m}})^2}$$

$F_{E23} = 0.2107\ \text{N}$ (two extra digits carried)

Determine the net force:

$$\vec{F}_{Enet} = \vec{F}_{E12} + \vec{F}_{E23}$$
$$= 0.3371\ \text{N [left]} + 0.2107\ \text{N [left]}$$
$$\vec{F}_{Enet} = 0.55\ \text{N [left]}$$

Statement: The force on the –3.0 μC charge is 0.55 N [left].

Section 7.2 Questions, page 333

1. Given: $F_{E1} = 0.080$ N; $r_2 = 3r_1$

Required: F_{E2}

Analysis: Determine how the force changes when the distance is tripled, then substitute for the original force, $F_E = \frac{kq_1q_2}{r^2}$.

Solution:

$$F_{E2} = \frac{kq_1q_2}{r_2^2}$$
$$= \frac{kq_1q_2}{(3r_1)^2}$$
$$= \frac{kq_1q_2}{9r_1^2}$$
$$= \frac{1}{9}\left(\frac{kq_1q_2}{r_1^2}\right)$$
$$= \frac{1}{9}F_{E1}$$
$$= \frac{1}{9}(0.080\ \text{N})$$
$$F_{E2} = 8.9\times10^{-3}\ \text{N}$$

Statement: The new force is 8.9×10^{-3} N.

2. Given: F_{E1} = 0.080 N; $r_2 = 3r_1$; $q_{1B} = 3q_{1A}$
Required: F_{E2}
Analysis: Determine how the force changes when the distance and the charge are tripled, then substitute for the original force; $F_E = \dfrac{kq_1q_2}{r^2}$.

Solution:
$$\begin{aligned}F_{E2} &= \frac{kq_{1B}q_2}{r_2^2}\\ &= \frac{k(3q_{1A})q_2}{(3r_1)^2}\\ &= \frac{3kq_{1A}q_2}{9r_1^2}\\ &= \frac{1}{3}\left(\frac{kq_{1A}q_2}{r_1^2}\right)\\ &= \frac{1}{3}F_{E1}\\ &= \frac{1}{3}(0.080\text{ N})\\ F_{E2} &= 2.7\times10^{-2}\text{ N}\end{aligned}$$

Statement: The new force is 2.7×10^{-2} N.
3. Given: $q_1 = 1.6 \times 10^{-19}$ C; $q_2 = 1.6 \times 10^{-19}$ C; r = 0.10 nm = 1.0×10^{-10} m;
$k = 8.99 \times 10^9$ N·m^2/C^2
Required: F_E
Analysis: $F_E = \dfrac{kq_1q_2}{r^2}$

Solution:
$$\begin{aligned}F_E &= \frac{kq_1q_2}{r^2}\\ &= \frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)(1.6\times10^{-19}\ \cancel{\text{C}})(1.6\times10^{-19}\ \cancel{\text{C}})}{(1.0\times10^{-10}\ \cancel{\text{m}})^2}\\ F_E &= 2.3\times10^{-8}\text{ N}\end{aligned}$$

Statement: The magnitude of the electric force between the two electrons is 2.3×10^{-8} N.

4. Given: $r_2 = \dfrac{1}{1.50}r_1$
Required: F_{E2}
Analysis: $F_E = \dfrac{kq_1q_2}{r^2}$

Solution: $F_{E2} = \dfrac{kq_1q_2}{r_2^2}$

$$= \frac{kq_1q_2}{\left(\dfrac{r_1}{1.50}\right)^2}$$

$$F_{E2} = 2.25\left(\frac{kq_1q_2}{r_1^2}\right)$$

$$F_{E2} = 2.25F_{E1}$$

Statement: The magnitude of the electric force will increase by a factor of 2.25.

5. Given: q_1 = 1.00 μC = 1.00 × 10^{-6} C; q_2 = 1.00 μC = 1.00 × 10^{-6} C; m = 1.00 kg; g = 9.8 m/s^2; $F_E = F_g$; k = 8.99 × 10^9 N·m^2/C^2

Required: F_g; r

Analysis: Rearrange the equation $F_E = \dfrac{kq_1q_2}{r^2}$ to solve for r. Then determine F_g.

$$F_E = \frac{kq_1q_2}{r^2}$$

$$r = \sqrt{\frac{kq_1q_2}{F_E}}$$

$$F_g = mg$$

$$= (1.00 \text{ kg})(9.8 \text{ m/s}^2)$$

$$F_g = 9.8 \text{ N}$$

Solution:

$$r = \sqrt{\frac{kq_1q_2}{F_E}}$$

$$= \sqrt{\frac{\left(8.99\times10^9 \; \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(1.00\times10^{-6}\text{ C})(1.00\times10^{-6}\text{ C})}{9.8 \text{ N}}}$$

$$r = 0.030 \text{ m}$$

Statement: The distance between the charges is 0.030 m.

6. (a) Given: m_1 = 9.11 × 10^{-31} kg; m_2 = 1.67 × 10^{-27} kg; r = 1.0 nm = 1.0 × 10^{-9} m; G = 6.67 × 10^{-11} N·m^2/kg^2

Required: F_g

Analysis: $F_g = \dfrac{Gm_1m_2}{r^2}$

Solution: $F_g = \dfrac{Gm_1m_2}{r^2}$

$$= \frac{\left(6.67\times10^{-11}\ \frac{\text{N}\cdot\cancel{\text{m}^2}}{\cancel{\text{kg}^2}}\right)(9.11\times10^{-31}\ \cancel{\text{kg}})(1.67\times10^{-27}\ \cancel{\text{kg}})}{(1.0\times10^{-9}\ \cancel{\text{m}})^2}$$

$$F_g = 1.0\times10^{-49}\ \text{N}$$

Statement: The magnitude of the gravitational force between the electron and the proton is 1.0×10^{-49} N.

(b) Given: $q_1 = 1.6 \times 10^{-19}$ C; $q_2 = 1.6 \times 10^{-19}$ C; $r = 1.0 \times 10^{-9}$ m; $k = 8.99 \times 10^9$ N·m^2/C^2

Required: F_E

Analysis: $F_E = \dfrac{kq_1q_2}{r^2}$

Solution:

$$F_E = \frac{kq_1q_2}{r^2}$$

$$= \frac{\left(8.99\times10^{9}\ \frac{\text{N}\cdot\cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)(1.6\times10^{-19}\ \cancel{\text{C}})(1.6\times10^{-19}\ \cancel{\text{C}})}{(1.0\times10^{-9}\ \cancel{\text{m}})^2}$$

$$F_E = 2.3\times10^{-10}\ \text{N}$$

Statement: The magnitude of the electric force between the electron and proton is 2.3×10^{-10} N.

(c) If the distance were increased to 1.0 m, there would be no change because the ratios of the forces are independent of the separation distance.

7. Given: $q_1 = q$; $q_2 = 3q$; $r_1 = 50$; $r_2 = -40$; $F_{E13} = F_{E23}$

Required: r_{13}

Analysis: Use $F_E = \dfrac{kq_1q_2}{r^2}$ to develop a quadratic equation to solve for r_{13}. First determine r_{12}:

$r_{12} = 50 - (-40) = 90$

Solution:

$$F_{E13} = F_{E23}$$

$$\frac{\cancel{k}q_1\cancel{q_3}}{r_{13}^2} = \frac{\cancel{k}q_2\cancel{q_3}}{r_{23}^2}$$

$$\frac{q_1}{r_{13}^2} = \frac{q_2}{r_{23}^2}$$

$$\frac{\cancel{q}}{r_{13}^2} = \frac{3\cancel{q}}{(90 - r_{13})^2}$$

$$\left(90-r_{13}\right)^2 = 3r_{13}^2$$
$$8100-180r_{13}+r_{13}^2 = 3r_{13}^2$$
$$0 = 2r_{13}^2+180r_{13}-8100$$
$$0 = r_{13}^2+90r_{13}-4050$$

Solve the quadratic equation:

$$x = \frac{-b \pm \sqrt{b^2-4ac}}{2a}$$
$$0 = r_{13}^2+90r_{13}-4050$$
$$r_{13} = \frac{-(90) \pm \sqrt{(90)^2-4(1)(-4050)}}{2(1)}$$
$$= \frac{-90 \pm \sqrt{24\,300}}{2}$$
$$= \frac{-90 \pm 90\sqrt{3}}{2}$$
$$r_{13} = -45 \pm 45\sqrt{3}$$

Only the positive distance is necessary:

$$r_{13} = 45-45\sqrt{3}$$
$$r_{13} = 33$$
$x = –40 + 33$

$x = –7$

Statement: The third charge is at $x = –7$.

8. Given: $q_1 = 2.0 \times 10^{-6}$ C; $q_2 = –1.0 \times 10^{-6}$ C; $r_{12} = 10$ cm = 0.10 m; $F_{E13} + F_{E23} = 0$

Required: r_{13}

Analysis: Use $F_E = \dfrac{kq_1q_2}{r^2}$ to develop a quadratic equation to solve for r_{13}.

Solution: $F_{E13}+F_{E23} = 0$

$$F_{E13} = -F_{E23}$$
$$\frac{\cancel{k}q_1\cancel{q_3}}{r_{13}^2} = -\frac{\cancel{k}q_2\cancel{q_3}}{r_{23}^2}$$
$$\frac{q_1}{r_{13}^2} = -\frac{q_2}{r_{23}^2}$$

$$\frac{2.0\times10^{-6}\ \text{C}}{r_{13}^2} = -\frac{-1.0\times10^{-6}\ \text{C}}{\left(0.10+r_{13}\right)^2}$$

$$\frac{2}{r_{13}^2} = \frac{1}{\left(0.10+r_{13}\right)^2}$$

$$2\left(0.10+r_{13}\right)^2 = r_{13}^2$$

$$0.01+0.2r_{13}+2r_{13}^2 = r_{13}^2$$

$$r_{13}^2+0.2r_{13}-0.01=0$$

Solve the quadratic equation:

$$x = \frac{-b\pm\sqrt{b^2-4ac}}{2a}$$

$$r_{13}^2+0.2r_{13}-0.01=0$$

$$r_{13} = \frac{-(-0.2)\pm\sqrt{(-0.2)^2-4(1)(-0.01)}}{2(1)}$$

$$r_{13} = \frac{0.2\pm\sqrt{0.04+0.04}}{2}$$

$$r_{13} = \frac{0.2\pm0.2\sqrt{2}}{2}$$

$$r_{13} = 0.1\pm\sqrt{2}$$

Only the positive distance is necessary:

$$r_{13} = 0.1\ \text{m}+0.1\sqrt{2}\ \text{m}$$

$$r_{13} = 0.24\ \text{m}$$

Statement: The third charge is 0.24 m, or 24 cm, beyond the smaller charge.

9. (a) Given: $q = 7.5 \times 10^{-6}$ C; L = 25 cm = 0.25 m; $k = 8.99 \times 10^9$ N·m^2/C^2

Required: F_{Enet} at q_3

Analysis: Determine the distance between particles using the Pythagorean theorem. Then use $F_{\text{E}} = \frac{kq_1q_2}{r^2}$ to determine the magnitude of the electric force between two particles.

Solution: Determine the distance:

$$r = \sqrt{(0.25\ \text{m})^2+(0.25\ \text{m})^2}$$

$$= \sqrt{0.125\ \text{m}^2}$$

$r = 0.3536$ m (two extra digits carried)

Determine the magnitude of the electric force:

$$F_E = \frac{kq_1q_2}{r^2}$$

$$= \frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)(7.5\times10^{-6}\ \cancel{\text{C}})(7.5\times10^{-6}\ \cancel{\text{C}})}{(0.3536\ \cancel{\text{m}})^2}$$

$F_E = 4.044$ N (two extra digits carried)

The x-components of the forces will add to zero, so calculate the y-components of the forces.

$$F_{\text{Enet}} = 2F_E \sin 45°$$

$$= 2(4.044\ \text{N})\sin 45°$$

$F_{\text{Enet}} = 5.7$ N [down]

Statement: The net force on the charge at the bottom is 5.7 N [down].

(b) Given: $q = 7.5 \times 10^{-6}$ C; $L = 0.25$ m; $k = 8.99 \times 10^9$ N·m^2/C^2; $F_E = 4.044$ N

Required: F_{Enet} at q_2

Analysis: $F_E = \frac{kq_1q_2}{r^2}$

Solution: Determine the magnitude of the force between the two particles on the x-axis:

$$F_E = \frac{kq_1q_2}{r^2}$$

$$= \frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)(7.5\times10^{-6}\ \cancel{\text{C}})(7.5\times10^{-6}\ \cancel{\text{C}})}{(0.25\ \cancel{\text{m}}+0.25\ \cancel{\text{m}})^2}$$

$= 2.023$ N (two extra digits carried)

$F_E = 2.0$ N

Determine the x- and y-components of the diagonal force:

$$F_{Ex} = F_E \sin 45°$$
$$= (4.044\ \text{N})\sin 45°$$
$$F_{Ex} = 2.860\ \text{N}$$

$$F_{Ey} = F_E \cos 45°$$
$$= (4.044\ \text{N})\cos 45°$$
$$F_{Ey} = 2.860\ \text{N}$$

Add the horizontal forces:

2.860 N + 2.023 N = 4.883 N [to the right]

The vertical force is 2.860 N [up].

Determine the magnitude of the net force:

$$F_{\text{Enet}} = \sqrt{(4.883\ \text{N})^2 + (2.860\ \text{N})^2}$$

$$= \sqrt{32.02\ \text{N}^2}$$

$= 5.659$ N (two extra digits carried)

$F_{\text{Enet}} = 5.7$ N

Determine the direction of the net force:

$$\tan\theta = \frac{2.860\ \text{N}}{4.883\ \text{N}}$$

$$\theta = \tan^{-1}\left(\frac{2.860\ \cancel{\text{N}}}{4.883\ \cancel{\text{N}}}\right)$$

$$\theta = 30°$$

Statement: The net force on the charge on the right is 5.7 N [E 30° N].

(c) Given: $q = 7.5 \times 10^{-6}$ C; $L = 0.25$ m; $q_e = 1.6 \times 10^{-19}$ C; $k = 8.99 \times 10^9$ N·m^2/C^2

Required: F_{Enet} at origin

Analysis: $F_E = \dfrac{kq_1q_2}{r^2}$; the two charges on the x-axis have a net force of zero, so the only force is an attractive force from the charge at the bottom.

Solution: $F_E = \dfrac{kq_1q_2}{r^2}$

$$= \frac{\left(8.99\times 10^9\ \frac{\text{N}\cdot\cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)(7.5\times 10^{-6}\ \cancel{\text{C}})(1.6\times 10^{-19}\ \cancel{\text{C}})}{(0.25\ \cancel{\text{m}})^2}$$

$$= 1.726\ \times 10^{-13}\ \text{N (two extra digits carried)}$$

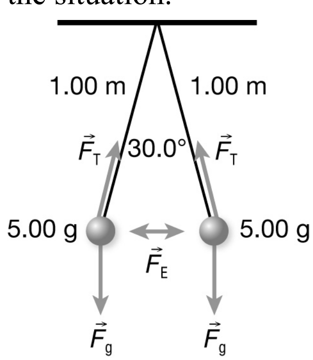
$$F_E = 1.7\ \times 10^{-13}\ \text{N}$$

Statement: The net force on the electron is 1.7×10^{-13} N [down].

10. Given: $m = 5.00$ g $= 5.00 \times 10^{-3}$ kg; $L = 1.00$ m; $\theta = 30.0°$; g = 9.8 m/s^2;
$k = 8.99 \times 10^9$ N·m^2/C^2

Required: q

Analysis: The electric, gravitational, and tension forces on the pith balls give a net force of zero. Since the electric force is entirely horizontal and the gravitational force is entirely vertical, first determine the gravitational force, $F_g = mg$. Then use trigonometry to determine the tension force and the electric force. Use $F_E = \dfrac{kq_1q_2}{r^2}$ to determine the charge on each pith ball. Draw a sketch of the situation.



Solution: Determine the gravitational force on one pith ball:

$$F_g = mg$$
$$= (5.00 \times 10^{-3}\ \text{kg})(9.8\ \text{m/s}^2)$$
$$F_g = 0.490\ \text{N}$$

Determine the force of tension on one pith ball:

$$F_g = F_T \cos\left(\frac{30.0^\circ}{2}\right)$$
$$F_T = \frac{F_g}{\cos 15.0^\circ}$$
$$= \frac{0.490\ \text{N}}{\cos 15.0^\circ}$$
$$F_T = 0.5073\ \text{N}$$

Determine the electric force on one pith ball:

$$F_E = F_T \sin\left(\frac{30.0^\circ}{2}\right)$$
$$= (0.5073\ \text{N})\sin 15.0^\circ$$
$$F_E = 1.313 \times 10^{-2}\ \text{N}$$

Determine the distance between pith balls:

$$r = 2L\sin\left(\frac{30.0^\circ}{2}\right)$$
$$= 2(1.00\ \text{m})\sin 15.0^\circ$$
$$r = 0.5176\ \text{m}$$

Determine the charge on the pith balls:

$$F_E = \frac{kq_1q_2}{r^2}$$
$$F_E = \frac{kq^2}{r^2}$$
$$q^2 = \frac{F_E r^2}{k}$$
$$q = \sqrt{\frac{F_E r^2}{k}}$$
$$= \sqrt{\frac{(1.313 \times 10^{-2}\ \cancel{\text{N}})(0.5176\ \cancel{\text{m}})^2}{\left(8.99 \times 10^9\ \frac{\cancel{\text{N}} \cdot \cancel{\text{m}^2}}{\text{C}^2}\right)}}$$
$$q = 6.26 \times 10^{-7}\ \text{C}$$

Statement: The charge on each pith ball is 6.26×10^{-7} C.

Section 7.3: Electric Fields

Tutorial 1 Practice, page 337

1. (a) Given: $\vec{F}_E$ = 2.5 N [left]; q = –5.0 C

Required: $\vec{\varepsilon}$

Analysis: $\vec{F}_E = q\vec{\varepsilon}$

Solution: $\vec{F}_E = q\vec{\varepsilon}$

$$\vec{\varepsilon} = \frac{\vec{F}_E}{q}$$
$$= \frac{2.5 \text{ N [left]}}{-5.0 \text{ C}}$$
$$= -0.50 \text{ N/C [left]}$$
$$\vec{\varepsilon} = 0.50 \text{ N/C [right]}$$

Statement: The electric field in which the charge is located is 0.50 N/C [toward the right].

(b) Given: $\vec{F}_E$ = 2.5 N [left]; q = –0.75 C

Required: $\vec{\varepsilon}$

Analysis: $\vec{F}_E = q\vec{\varepsilon}$

Solution: $\vec{F}_E = q\vec{\varepsilon}$

$$\vec{\varepsilon} = \frac{\vec{F}_E}{q}$$
$$= \frac{2.5 \text{ N [left]}}{-0.75 \text{ C}}$$
$$= -3.3 \text{ N/C [left]}$$
$$\vec{\varepsilon} = 3.3 \text{ N/C [right]}$$

Statement: The electric field in which the charge is located is 3.3 N/C [toward the right].

2. Given: r = 2.50 m; $q = 6.25 \times 10^{-6}$ C; $k = 8.99 \times 10^9$ N·m^2/C^2

Required: $\vec{\varepsilon}$

Analysis: $\varepsilon = \dfrac{kq}{r^2}$

Solution: $\varepsilon = \dfrac{kq}{r^2}$

$$= \frac{\left(8.99 \times 10^9 \ \frac{\text{N} \cdot \cancel{\text{m}^2}}{\text{C}^{\cancel{2}}}\right)(6.25 \times 10^{-6} \ \cancel{\text{C}})}{(2.50 \ \cancel{\text{m}})^2}$$
$$\varepsilon = 8.99 \times 10^3 \text{ N/C}$$

Since the charge is positive, the direction of the electric field is toward the point, right.

Statement: The electric field at the point is 8.99×10^3 N/C [toward the right].

3. Given: r_1 = 0.668 m; r_2 = 0.332 m; $q_1 = 5.56 \times 10^{-9}$ C; $q_2 = -1.23 \times 10^{-9}$ C; $k = 8.99 \times 10^9\ \text{N·m}^2/\text{C}^2$

Required: $\vec{\varepsilon}_{\text{net}}$

Analysis: The direction of the electric field is to the right, toward point Z. Determine the magnitude of the electric field at point Z; $\varepsilon = \dfrac{kq}{r^2}$; first, calculate r:

$$
\begin{aligned}
r &= r_1 + r_2 \\
&= 0.668\ \text{m} + 0.332\ \text{m} \\
r &= 1.000\ \text{m}
\end{aligned}
$$

Solution:

$$
\begin{aligned}
\varepsilon_1 &= \frac{kq_1}{r^2} \\
&= \frac{\left(8.99\times10^9\ \dfrac{\text{N}\cdot\cancel{\text{m}^2}}{\text{C}^{\cancel{2}}}\right)(5.56\times10^{-9}\ \cancel{\text{C}})}{(1.000\ \cancel{\text{m}})^2} \\
\varepsilon_1 &= 49.984\ \text{N/C (two extra digits carried)}
\end{aligned}
$$

$$
\begin{aligned}
\varepsilon_2 &= \frac{kq_2}{r_2^2} \\
&= \frac{\left(8.99\times10^9\ \dfrac{\text{N}\cdot\cancel{\text{m}^2}}{\text{C}^{\cancel{2}}}\right)(-1.23\times10^{-9}\ \cancel{\text{C}})}{(0.332\ \cancel{\text{m}})^2} \\
\varepsilon_2 &= -1.0032\times10^2\ \text{N/C (two extra digits carried)}
\end{aligned}
$$

$$
\begin{aligned}
\vec{\varepsilon}_{\text{net}} &= \vec{\varepsilon}_1 + \vec{\varepsilon}_2 \\
&= \left(49.984\ \text{N/C [right]}\right) + \left(-1.0032\times10^2\ \text{N/C [right]}\right) \\
&= -50.336\ \text{N/C [right]} \\
\vec{\varepsilon}_{\text{net}} &= 50.3\ \text{N/C [left]}
\end{aligned}
$$

Statement: The electric field at the point Z is –50.3 N/C, or 50.3 N/C [toward the left].

Research This: Fish and Electric Fields, page 344

A. Answers may vary. Sample answers: I chose electric eels. Electric eels produce electric fields for self-defence; they also use electric fields to stun prey.

B. Answers may vary. Sample answers: Fish that stun prey with electric fields are typically freshwater species because salt water conducts electricity. Therefore, a fish that produces a strong enough field in salt water to stun prey can also injure itself in the salt water.

C. Answers may vary. Sample answers: Low light levels and poor visibility in certain rivers would make it difficult for fish to detect prey visually. Since the transmission of electric fields is not affected by the amount of soil and silt in the water, the ability to detect electric fields is a beneficial adaptation for fish living in these rivers.

Section 7.3 Questions, page 345

1. For a proton and an electron placed in a uniform electric field, the magnitudes of the forces will be equal.

2. Given: r = 1.5 m; q = 3.5 C; $k = 8.99 \times 10^9$ N·m²/C²

Required: ε

Analysis: $\varepsilon = \dfrac{kq}{r^2}$

Solution: $\varepsilon = \dfrac{kq}{r^2}$

$$= \frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\cancel{\text{m}^2}}{\text{C}^{\cancel{2}}}\right)(3.5\ \cancel{\text{C}})}{(1.5\ \cancel{\text{m}})^2}$$

$$\varepsilon = 1.4\times10^{10}\ \text{N/C}$$

Statement: The magnitude of the electric field at the point is 1.4×10^{10} N/C.

3. Given: r_1 = 10 cm = 0.10 m; r_2 = 25 cm = 0.25 m; $q_1 = 4.5 \times 10^{-6}$ C; $\vec{\varepsilon}_{\text{net}}$ = 0 N/C; $k = 8.99 \times 10^9$ N·m²/C²

Required: q_2

Analysis: $\varepsilon_1 = \dfrac{kq_1}{r_1^2}$; $\varepsilon_2 = \dfrac{kq_2}{r_2^2}$; $q_2 = \dfrac{\varepsilon_2 r_2^2}{k}$

Solution: Determine the magnitude of the electric field from q_1 at the origin.

$$\varepsilon_1 = \frac{kq_1}{r_1^2}$$

$$= \frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\cancel{\text{m}^2}}{\text{C}^{\cancel{2}}}\right)(4.5\times10^{-6}\ \cancel{\text{C}})}{(0.10\ \cancel{\text{m}})^2}$$

$$= 4.046\times10^6\ \text{N/C (two extra digits carried)}$$

The second charge's electric field must have the same magnitude at the origin:

$$q_2 = \frac{\varepsilon_2 r_2^2}{k}$$

$$= \frac{\left(4.046\times10^6\ \frac{\cancel{\text{N}}}{\cancel{\text{C}}}\right)(0.25\ \cancel{\text{m}})^2}{\left(8.99\times10^9\ \frac{\cancel{\text{N}}\cdot\cancel{\text{m}^2}}{\text{C}^{\cancel{2}}}\right)}$$

$$q_2 = 2.8\times10^{-5}\ \text{C}$$

Statement: The charge on q_2 is 2.8×10^{-5} C.

4. The origin is centred in the ring, so for every position on the ring, there is an equal and opposite charge on the other side of the ring. Therefore, the net electric field at the origin is 0 N/C.

5. When drawing electric field lines, the number of lines originating from a charge is determined by the relative strength of the charge from which the lines originate to the other charges in the sketch.

6. Given: $r_1 = \frac{L}{4}$; $r_2 = \frac{3L}{4}$; $\vec{\varepsilon}_{\text{net}} = 0$ N/C

Required: $q_1 : q_2$

Analysis: Since the electric field is zero at A, the components from each charge must be equal.

Use $\varepsilon = \frac{kq}{r^2}$ to determine the ratio.

Solution:

$$\varepsilon_1 = \varepsilon_2$$

$$\frac{\cancel{k} q_1}{r_1^2} = \frac{\cancel{k} q_2}{r_2^2}$$

$$\frac{q_1}{\left(\frac{L}{4}\right)^2} = \frac{q_2}{\left(\frac{3L}{4}\right)^2}$$

$$\frac{q_1}{\frac{L^2}{16}} = \frac{q_2}{\frac{9L^2}{16}}$$

$$\frac{q_1}{1} = \frac{q_2}{9}$$

$$\frac{q_1}{q_2} = \frac{1}{9}$$

Statement: The ratio between the charges, $q_1 : q_2$, is 1:9.

7. Given: $q = 7.5$ C; $r = 2.3$ m; $k = 8.99 \times 10^9$ N·m^2/C^2

Required: $\vec{\varepsilon}_{\text{net}}$

Analysis: The point charges on the *x*-axis result in a zero electric field because they have equal charges and are on opposite sides of the origin. Likewise, the two point charges not on an axis will only contribute a vertical component. The direction of the electric field will be down.

Determine the magnitude of the electric field from a point charge at the origin, $\varepsilon = \frac{kq}{r^2}$. Then determine the total electric field at the origin.

Solution: The magnitude of the electric field from a point charge at the origin:

$$\begin{aligned}\varepsilon &= \frac{kq}{r^2} \\ &= \frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\cancel{\text{m}^2}}{\text{C}^{\cancel{2}}}\right)(7.5\ \cancel{\text{C}})}{(2.3\ \cancel{\text{m}})^2}\end{aligned}$$

$\varepsilon = 1.275\times10^{10}$ N/C (two extra digits carried)

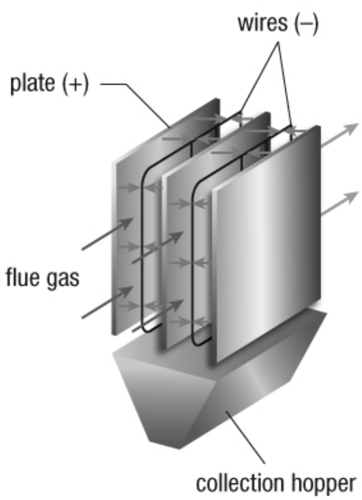
The total electric field at the origin:

$$\begin{aligned}\varepsilon_{\text{net}} &= \varepsilon + \varepsilon\sin45^\circ + \varepsilon\sin45^\circ \\ &= \varepsilon + \frac{2\varepsilon}{\sqrt{2}} \\ &= \varepsilon + \sqrt{2}\varepsilon \\ &= 1.275\times10^{10}\ \text{N/C} + \sqrt{2}(1.275\times10^{10}\ \text{N/C})\end{aligned}$$

$\varepsilon_{\text{net}} = 3.1\times10^{10}$ N/C [down]

Statement: The electric field at the origin is 3.1×10^{10} N/C [down].

8.



Section 7.4: Potential Difference and Electric Potential

Tutorial 1 Practice, page 349

1. (a) Given: $\vec{\varepsilon}$ = 145 N/C [right]; $q = -1.6 \times 10^{-19}$ C; d_i = 1.5 m; d_f = 4.6 m

Required: ΔE_E

Analysis: $\Delta E_E = -q\varepsilon \Delta d$

Solution:
$$\begin{aligned}\Delta E_E &= -q\varepsilon \Delta d \\ &= -q\varepsilon(d_f - d_i) \\ &= -(-1.6\times10^{-19}\ \text{C})\left(145\ \frac{\text{N}}{\text{C}}\right)(4.6\ \text{m} - 1.5\ \text{m}) \\ &= (1.6\times10^{-19}\ \cancel{\text{C}})\left(145\ \frac{\text{N}}{\cancel{\text{C}}}\right)(3.1\ \text{m}) \\ &= 7.192\times10^{-17}\ \text{N}\cdot\text{m}\ \ \text{(two extra digits carried)} \\ \Delta E_E &= 7.2\times10^{-17}\ \text{J}\end{aligned}$$

Statement: The change in the electric potential energy of the electron is 7.2×10^{-17} J.

(b) Given: $v_i = 1.7 \times 10^7$ m/s; $\Delta E_E = 7.192 \times 10^{-17}$ J; $m = -9.11 \times 10^{-31}$ kg

Required: v_f

Analysis: $\Delta E_E + \Delta E_k = 0$; $\Delta E_k = \frac{1}{2}mv_f^{\ 2} - \frac{1}{2}mv_i^{\ 2}$

Solution:
$$\begin{aligned}\Delta E_E + \Delta E_k &= 0 \\ \Delta E_E + \left(\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2\right) &= 0 \\ \frac{1}{2}mv_f^2 &= \frac{1}{2}mv_i^2 - \Delta E_E \\ v_f &= \sqrt{\frac{2}{m}\left(\frac{1}{2}mv_i^2 - \Delta E_E\right)} \\ &= \sqrt{v_i^2 - \frac{2\Delta E_E}{m}} \\ &= \sqrt{(1.7\times10^7\ \text{m/s})^2 - \frac{2(7.192\times10^{-17}\ \text{J})}{(9.11\times10^{-31}\ \text{kg})}} \\ &= \sqrt{(1.7\times10^7\ \text{m/s})^2 - \frac{1.4384\times10^{-16}\ \cancel{\text{kg}}\cdot\frac{\text{m}}{\text{s}^2}\cdot\text{m}}{9.11\times10^{-31}\ \cancel{\text{kg}}}} \\ v_f &= 1.1\times10^7\ \text{m/s}\end{aligned}$$

Statement: The final speed of the electron is 1.1×10^7 m/s.

2. Given: $q = 1.6 \times 10^{-19}$ C; $\Delta d = 0.75$ m; $\varepsilon = 23$ N/C
Required: W
Analysis: $W = q\varepsilon\Delta d$
Solution:
$$\begin{aligned} W &= q\varepsilon\Delta d \\ &= \left(1.6\times10^{-19}\ \text{C}\right)\left(23\ \frac{\text{N}}{\text{C}}\right)\left(0.75\ \text{m}\right) \\ &= 2.76\times10^{-18}\ \text{N}\cdot\text{m} \\ W &= 2.8\times10^{-18}\ \text{J} \end{aligned}$$
Statement: The work done in moving the proton 0.75 m is 2.8×10^{-18} J.

3. Given: $q = -1.6 \times 10^{-19}$ C; $\Delta E_k = +4.2 \times 10^{-16}$ J; $\Delta\vec{d} = 0.18$ m [right]
Required: $\vec{\varepsilon}$
Analysis: $\Delta E_E + \Delta E_k = 0$; $\Delta E_E = -q\varepsilon\Delta d$
Solution:
$$\begin{aligned} \Delta E_E + \Delta E_k &= 0 \\ -q\varepsilon\Delta d + \Delta E_k &= 0 \\ \Delta E_k &= q\varepsilon\Delta d \\ \varepsilon &= \frac{\Delta E_k}{q\Delta d} \\ &= \frac{4.2\times10^{-16}\ \text{N}\cdot\text{m}}{\left(-1.6\times10^{-19}\ \text{C}\right)\left(0.18\ \text{m}\right)} \\ \varepsilon &= -1.5\times10^{4}\ \text{N/C} \end{aligned}$$
Since the magnitude of the electric field is negative, the direction of the electric field is in the opposite direction of the displacement.
Statement: The magnitude and direction of the electric field are as follows:
1.5×10^4 N/C [toward the left].

Tutorial 2 Practice, page 353

1. (a) Given: $\Delta V = 1.6 \times 10^4$ V; $\Delta d = 12$ cm $= 0.12$ m; $q = -1.6 \times 10^{-19}$ C; $m = 9.11 \times 10^{-31}$ kg
Required: v_f
Analysis: $\Delta E_E + \Delta E_k = 0$; $\Delta E_E = q\Delta V$; $\Delta E_k = \frac{1}{2}m{v_f}^2$
$$\begin{aligned} \Delta E_E + \Delta E_k &= 0 \\ \left(q\Delta V\right) + \left(\frac{1}{2}mv_f^2\right) &= 0 \\ \frac{1}{2}mv_f^2 &= -q\Delta V \\ v_f &= \sqrt{\frac{-2q\Delta V}{m}} \end{aligned}$$

Solution:

$$v_f = \sqrt{\frac{-2q\Delta V}{m}}$$
$$= \sqrt{\frac{-2(-1.6\times10^{-19}\ \text{C})(1.6\times10^{4}\ \text{V})}{9.11\times10^{-31}\ \text{kg}}}$$
$$= \sqrt{\frac{(3.2\times10^{-19}\ \cancel{\text{C}})\left(1.6\times10^{4}\ \cancel{\text{kg}}\cdot\frac{\text{m}}{\text{s}^2}\cdot\frac{\text{m}}{\cancel{\text{C}}}\right)}{9.11\times10^{-31}\ \cancel{\text{kg}}}}$$
$$v_f = 7.5\times10^{7}\ \text{m/s}$$

Statement: The electrons strike the screen at a speed of 7.5×10^7 m/s.

(b) Given: $\Delta V = 1.6 \times 10^4$ V; $\Delta d = 0.12$ m

Required: ε

Analysis: $\varepsilon = \frac{\Delta V}{\Delta d}$

Solution:

$$\varepsilon = \frac{\Delta V}{\Delta d}$$
$$= \frac{1.6\times10^{4}\ \text{N}\cdot\frac{\cancel{\text{m}}}{\text{C}}}{0.12\ \cancel{\text{m}}}$$
$$\varepsilon = 1.3\times10^{5}\ \text{N/C}$$

Statement: The magnitude of the electric field is 1.3×10^5 N/C.

2. (a) Given: $\Delta d_{XW} = 6.0$ cm = 0.060 m; $v_i = 0$ m/s; $\Delta V = 4.0 \times 10^2$ V; $q = -1.6 \times 10^{-19}$ C; $m = 9.11 \times 10^{-31}$ kg

Required: v_f

Analysis: Determine the final speed of the electron using the equation $v_f^2 = v_i^2 + 2a\Delta d$. But first calculate the acceleration of the electron using the equations $a = \frac{F_E}{m} = \frac{q\varepsilon}{m}$ and $\varepsilon = \frac{\Delta V}{\Delta d}$:

$$a = \frac{q\varepsilon}{m}$$
$$a = \frac{q}{m}\left(\frac{\Delta V}{\Delta d}\right)$$

Solution:

$$a = \frac{q}{m}\left(\frac{\Delta V}{\Delta d}\right)$$

$$= \frac{\left(1.6\times10^{-19}\ \not{C}\right)\left(4.0\times10^{2}\ \not{kg}\cdot\frac{m}{s^2}\cdot\frac{\not{m}}{\not{C}}\right)}{\left(9.11\times10^{-31}\ \not{kg}\right)\left(0.060\ \not{m}\right)}$$

$a = 1.171\times10^{15}\ \text{m/s}^2$ (two extra digits carried)

Determine the final speed of the electron as it reaches hole W:

$$v_{\text{f}} = \sqrt{v_{\text{i}}^2 + 2a\Delta d}$$

$$= \sqrt{0^2 + 2\left(1.171\times10^{15}\ \frac{\text{m}}{\text{s}^2}\right)\left(0.060\ \text{m}\right)}$$

$= 1.185\times10^{7}$ m/s (two extra digits carried)

$v_{\text{f}} = 1.2\times10^{7}$ m/s

Solution: The speed of the electron at hole W is 1.2×10^7 m/s.

(b) Given: Δd_{YZ} = 6.0 cm = 0.060 m; v_{i} = 0 m/s; $v_{\text{f}} = 1.185 \times 10^7$ m/s; $\Delta V = 7.0 \times 10^3$ V; $q = -1.6 \times 10^{-19}$ C; $m = 9.11 \times 10^{-31}$ kg

Required: Δd_{Z0}, the distance from Z at which the speed of the electron is 0 m/s

Analysis: $a = \frac{q}{m}\left(\frac{\Delta V}{\Delta d}\right)$;

$$v_{\text{f}}^2 = v_{\text{i}}^2 + 2a\Delta d$$

$$\Delta d = \frac{v_{\text{f}}^2 - v_{\text{i}}^2}{2a}$$

Solution:

$$a = \frac{q}{m}\left(\frac{\Delta V}{\Delta d}\right)$$

$$= \frac{\left(1.6\times10^{-19}\ \not{C}\right)\left(7.0\times10^{3}\ \not{kg}\cdot\frac{m}{s^2}\cdot\frac{\not{m}}{\not{C}}\right)}{\left(9.11\times10^{-31}\ \not{kg}\right)\left(0.060\ \not{m}\right)}$$

$a = 2.049\times10^{16}\ \text{m/s}^2$ (two extra digits carried)

Determine the distance the electron travels from Y before its speed becomes 0:

$$\Delta d = \frac{v_f^2 - v_i^2}{2a}$$

$$= \frac{\left(1.185 \times 10^7 \text{ m/}\cancel{s}\right)^{\cancel{2}} - 0^2}{2\left(2.049 \times 10^{16} \cancel{\text{m}}/\cancel{s^2}\right)}$$

$\Delta d = 0.0034$ m

Determine the distance the from Z:

$\Delta d_{Z0} = 0.060 \text{ m} - 0.0034 \text{ m}$

$\Delta d_{Z0} = 0.057$ m, or 5.7 cm

Statement: The electron changes direction 5.7 cm to the left of Z.

3. Given: $L = 8.0 \text{ cm} = 0.080 \text{ m}$; $\Delta d = 4.0 \text{ cm} = 0.040 \text{ m}$; $\vec{v}_i = 6.0 \times 10^7$ m/s [E];

$\Delta V = 6.0 \times 10^2$ V; $q = -1.6 \times 10^{-19}$ C; $m = 9.11 \times 10^{-31}$ kg

Required: $\vec{v}_f$

Analysis: There is an upward force on the electron because the negative plate is below the negatively charged electron. First, determine the magnitude of the electric field, $\varepsilon = \frac{\Delta V}{\Delta d}$. Then calculate the amount of time it takes the electron to pass through the plates, $v = \frac{\Delta d}{\Delta t}$; $v_i = \frac{L}{\Delta t}$; $\Delta t = \frac{L}{v_i}$. Then calculate the resultant velocity using the equation $v_f = \sqrt{{v_{xf}}^2 + {v_{yf}}^2}$, where the components of the final velocity are the initial velocity for v_{xf} and $v_{yf} = a_y \Delta t$, where $a_y = \frac{F_E}{m} = \frac{q\varepsilon}{m}$. Finally, calculate the angle using the inverse tangent function.

Solution:

$$\varepsilon = \frac{\Delta V}{\Delta d}$$

$$= \frac{6.0 \times 10^2 \text{ N} \cdot \frac{\cancel{\text{m}}}{\text{C}}}{0.040 \cancel{\text{m}}}$$

$\varepsilon = 1.500 \times 10^4$ N/C (two extra digits carried)

Determine the amount of time it takes the electron to pass through the plates:

$$\Delta t = \frac{L}{v_i}$$

$$= \frac{(0.080 \cancel{\text{m}})}{\left(6.0 \times 10^7 \frac{\cancel{\text{m}}}{\text{s}}\right)}$$

$\Delta t = 1.333 \times 10^{-9}$ s (two extra digits carried)

Determine the upward velocity of the electron:

$$v_{yf} = \frac{q\varepsilon}{m}\Delta t$$

$$= \frac{\left(1.6\times10^{-19}\ \cancel{\text{C}}\right)\left(1.500\times10^{4}\ \frac{\text{N}}{\cancel{\text{C}}}\right)}{9.11\times10^{-31}\ \text{kg}}\left(1.333\times10^{-9}\ \text{s}\right)$$

$$= \frac{2.400\times10^{-15}\ \cancel{\text{kg}}\cdot\frac{\text{m}}{\text{s}^{\cancel{2}}}}{9.11\times10^{-31}\ \cancel{\text{kg}}}\left(1.333\times10^{-9}\ \cancel{\text{s}}\right)$$

$$v_{yf} = 3.504\times10^{6}\ \text{m/s (two extra digits carried)}$$

Determine the magnitude of the final velocity:

$$v_{\text{f}} = \sqrt{v_{xf}^2 + v_{yf}^2}$$

$$= \sqrt{\left(6.0\times10^{7}\ \text{m/s}\right)^2 + \left(3.504\times10^{6}\ \text{m/s}\right)^2}$$

$$v_{\text{f}} = 6.0\times10^{7}\ \text{m/s}$$

Determine the direction of the final velocity (the angle north of east):

$$\tan\theta = \left(\frac{v_{yf}}{v_{xf}}\right)$$

$$\theta = \tan^{-1}\left(\frac{v_{yf}}{v_{xf}}\right)$$

$$= \tan^{-1}\left(\frac{3.504\times10^{6}\ \cancel{\text{m/s}}}{6.0\times10^{7}\ \cancel{\text{m/s}}}\right)$$

$$\theta = 3.3°$$

Statement: The final velocity of the electron is 6.0×10^7 m/s [E 3.3° N].

Section 7.4 Questions, page 354

1. (a) Given: $q = -1.6 \times 10^{-19}$ C; $V_{\text{i}} = 30$ V; $V_{\text{f}} = 150$ V

Required: ΔE_{E}

Analysis: $\Delta V = \frac{\Delta E_{\text{E}}}{q}$

$$\Delta E_{\text{E}} = q\Delta V$$

$$\Delta E_{\text{E}} = q(V_{\text{f}} - V_{\text{i}})$$

Solution: $\Delta E_{\text{E}} = q\left(V_{\text{f}} - V_{\text{i}}\right)$

$$= \left(-1.6\times10^{-19}\ \text{C}\right)\left(150\ \text{V} - 30\ \text{V}\right)$$

$$= -1.92\times10^{-17}\ \text{J (one extra digit carried)}$$

$$\Delta E_{\text{E}} = -1.9\times10^{-17}\ \text{J}$$

Statement: The change in the electron's potential energy is a decrease of 1.9×10^{-17} J.
(b) Given: $q = -1.6 \times 10^{-19}$ C; Δd = 10 cm = 0.10 m; $\Delta E_E = -1.92 \times 10^{-17}$ J
Required: $\vec{\varepsilon}$

Analysis: $\Delta E_E = -q\varepsilon\Delta d$; $\varepsilon = -\frac{\Delta E_E}{q\Delta d}$. Since electrons travel from regions of low potential to regions of high potential, and electrons move against the direction of an electric field, the direction of the field will be opposite the direction of the electron.

Solution:
$$\varepsilon = -\frac{\Delta E_E}{q\Delta d}$$
$$= -\frac{-1.92\times10^{-17}\ \text{N}\cdot\cancel{\text{m}}}{(1.6\times10^{-19}\ \text{C})(0.10\ \cancel{\text{m}})}$$
$$\varepsilon = 1.2\times10^{3}\ \text{N/C}$$

Statement: The average electric field along the electron's path is -1.2×10^3 N/C.
2. Given: Δd = 3.0 mm = 3.0×10^{-3} m; ε = 250 V/m
Required: ΔV

Analysis: $\varepsilon = -\frac{\Delta V}{\Delta d}$; $\Delta V = -\varepsilon\Delta d$

Solution:
$$\Delta V = -\varepsilon\Delta d$$
$$= -\left(250\ \frac{\text{V}}{\cancel{\text{m}}}\right)(3.0\times10^{-3}\ \cancel{\text{m}})$$
$$\Delta V = -0.75\ \text{V}$$

Statement: The magnitude of the electric potential difference is 0.75 V.
3. (a) Given: $q = 1.6 \times 10^{-19}$ C; V_i = 75.0 V; V_f = –20.0 V
Required: ΔE_k

Analysis:
$$\Delta V = \frac{-\Delta E_k}{q}$$
$$\Delta E_k = -q\Delta V$$
$$\Delta E_k = -q(V_f - V_i)$$

Solution:
$$\Delta E_k = -q(V_f - V_i)$$
$$= -(1.6\times10^{-19}\ \text{C})(-20.0\ \text{V} - 75.0\ \text{V})$$
$$\Delta E_k = 1.52\times10^{-17}\ \text{J}$$

Statement: The change in the proton's kinetic energy is 1.52×10^{-17} J.
(b) Given: $q = -1.6 \times 10^{-19}$ C; V_i = 75.0 V; V_f = –20.0 V
Required: ΔE_k
Analysis: $\Delta E_k = -q(V_f - V_i)$

Solution: $\Delta E_k = -q(V_f - V_i)$

$$= -(-1.6\times10^{-19}\ \text{C})(-20.0\ \text{V} - 75.0\ \text{V})$$

$$\Delta E_k = -1.52\times10^{-17}\ \text{J}$$

Statement: The change in the electron's kinetic energy is -1.52×10^{-17} J.

4. (a) Given: $q = -1.6 \times 10^{-19}$ C; $\Delta V = 45$ V

Required: W

Analysis:

$$\Delta V = \frac{\Delta E_E}{q}$$

$$\Delta E_E = q\,\Delta V$$

$$W = -\Delta E_E$$

$$W = -q\Delta V$$

Solution: $W = -q\,\Delta V$

$$= -(-1.6\times10^{-19}\ \text{C})(45\ \text{V})$$

$$W = 7.2\times10^{-18}\ \text{J}$$

Statement: The work done to push the electron is 7.2×10^{-18} J against the electric field.

(b) The electric field is doing the work.

5. (a) Electrons move from a region of low potential energy to a region of high potential energy.

(b) Given: $q = -1.6 \times 10^{-19}$ C; $\Delta V = 2.5 \times 10^4$ V

Required: ΔE_k

Analysis: $\Delta E_k + \Delta E_E = 0$; $\Delta E_E = -\Delta E_k$

$$\Delta V = \frac{\Delta E_E}{q}$$

$$\Delta V = \frac{-\Delta E_k}{q}$$

$$\Delta E_k = -q\,\Delta V$$

Solution:

$$\Delta E_k = -q\,\Delta V$$

$$= -(-1.6\times10^{-19}\ \text{C})(2.5\times10^{4}\ \text{V})$$

$$\Delta E_k = 4.0\times10^{-15}\ \text{J}$$

Statement: The change in one of the electron's kinetic energy is 4.0×10^{-15} J.

(c) Given: $v_i = 0$ m/s; $\Delta E_k = 4.0 \times 10^{-15}$ J; $m = 9.11 \times 10^{-31}$ kg
Required: v_f
Analysis:

$$\Delta E_k = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$
$$= \frac{1}{2}mv_f^2 - 0$$
$$v_f = \sqrt{\frac{2\Delta E_k}{m}}$$

Solution:

$$v_f = \sqrt{\frac{2\Delta E_k}{m}}$$
$$= \sqrt{\frac{2\left(4.0\times10^{-15}\ \cancel{\text{kg}}\cdot\frac{\text{m}}{\text{s}^2}\cdot\text{m}\right)}{\left(9.11\times10^{-31}\ \cancel{\text{kg}}\right)}}$$
$$v_f = 9.4\times10^{7}\ \text{m/s}$$

Solution: The final speed of the electron is 9.4×10^7 m/s.
6. Given: $\varepsilon = 2.26 \times 10^5$ N/C; $d_i = 2.55$ m; $d_f = 4.55$ m
Required: ΔV
Analysis:

$$\varepsilon = \frac{\Delta V}{\Delta d}$$
$$\Delta V = \varepsilon\Delta d$$

Solution: $\Delta V = \varepsilon\,\Delta d$

$$= \varepsilon\left(d_f - d_i\right)$$
$$= \left(2.26\times10^5\ \text{N/C}\right)\left(4.55\ \text{m} - 2.55\ \text{m}\right)$$
$$\Delta V = 4.52\times10^5\ \text{V}$$

Statement: The change in the electric potential between the points is 4.52×10^5 V.
7. (a) Given: $\varepsilon = 150$ N/C; $L = 6.0$ cm = 0.060 m; $v_i = 4.0 \times 10^6$ m/s; $q = -1.6 \times 10^{-19}$ C; $m = 9.11 \times 10^{-31}$ kg
Required: $\vec{v}_{yf}$
Analysis: There is an upward force on the electron because the negative plate is below the negatively charged electron. First, calculate the amount of time the electron takes to pass through the plates, $v = \frac{\Delta d}{\Delta t}$; $v_i = \frac{L}{\Delta t}$; $\Delta t = \frac{L}{v_i}$. Then determine the vertical component of the final velocity using $v_{yf} = a_y\Delta t$, where $a_y = \frac{F_E}{m} = \frac{q\varepsilon}{m}$.

Solution: Determine the amount of time it takes the electron to pass through the plates:

$$\Delta t = \frac{L}{v_\text{i}}$$
$$= \frac{(0.060\ \cancel{\text{m}})}{\left(4.0\times 10^{6}\ \frac{\cancel{\text{m}}}{\text{s}}\right)}$$
$$\Delta t = 1.5\times 10^{-8}\ \text{s}$$

Determine the upward velocity of the electron:

$$v_{y\text{f}} = \frac{q\varepsilon}{m}\Delta t$$
$$= \frac{(1.6\times 10^{-19}\ \cancel{\text{C}})\left(150\ \frac{\text{N}}{\cancel{\text{C}}}\right)}{9.11\times 10^{-31}\ \text{kg}}(1.5\times 10^{-8}\ \text{s})$$
$$= \frac{2.400\times 10^{-17}\ \cancel{\text{kg}}\cdot\frac{\text{m}}{\text{s}^{\cancel{2}}}}{9.11\times 10^{-31}\ \cancel{\text{kg}}}(1.5\times 10^{-8}\ \cancel{\text{s}})$$
$$= 3.952\times 10^{5}\ \text{m/s (two extra digits carried)}$$
$$v_{y\text{f}} = 4.0\times 10^{5}\ \text{m/s}$$

Statement: The vertical component of the electron's final velocity is 4.0×10^5 m/s [up].

(b) Given: $\varepsilon = 150$ N/C; $L = 0.060$ m; $v_\text{i} = 4.0 \times 10^6$ m/s; $v_{y\text{f}} = 3.952 \times 10^5$ m/s; $q = -1.6 \times 10^{-19}$ C; $m = 9.11 \times 10^{-31}$ kg

Required: v_f

Analysis: Determine the magnitude of the final velocity using the equation $v_\text{f} = \sqrt{v_{x\text{f}}^2 + v_{y\text{f}}^2}$. Then use the inverse tangent ratio to determine the angle.

Solution: $v_\text{f} = \sqrt{v_{x\text{f}}^2 + v_{y\text{f}}^2}$

$$= \sqrt{(4.0\times 10^{6}\ \text{m/s})^2 + (3.952\times 10^{5}\ \text{m/s})^2}$$
$$v_\text{f} = 4.0\times 10^{6}\ \text{m/s}$$

$$\tan\theta = \left(\frac{v_{y\text{f}}}{v_{x\text{f}}}\right)$$
$$\theta = \tan^{-1}\left(\frac{v_{y\text{f}}}{v_{x\text{f}}}\right)$$
$$= \tan^{-1}\left(\frac{3.952\times 10^{5}\ \cancel{\text{m/s}}}{4.0\times 10^{6}\ \cancel{\text{m/s}}}\right)$$
$$\theta = 5.6°$$

Statement: The final velocity of the electron is 4.0×10^6 m/s [5.6° from the *x*-axis].

8. (a) Given: $\varepsilon = 20$ N/C; $d_A = 0$ m; $d_B = 4$ m
Required: ΔV
Analysis: $\varepsilon = -\dfrac{\Delta V}{\Delta d}$; $\Delta V = -\varepsilon \Delta d$
Solution: $\Delta V = -\varepsilon \Delta d$

$$\Delta V = -\varepsilon (d_B - d_A)$$
$$= -\left(20\ \frac{\text{V}}{\cancel{\text{m}}}\right)(4\ \cancel{\text{m}} - 0\ \cancel{\text{m}})$$
$$\Delta V = -80\ \text{V}$$

Statement: The potential difference is –80 V.
(b) Given: $\varepsilon = 20$ N/C; $d_A = 4$ m; $d_B = 6$ m
Required: ΔV
Analysis: $\Delta V = -\varepsilon \Delta d$
Solution: $\Delta V = -\varepsilon \Delta d$

$$\Delta V = -\varepsilon (d_B - d_A)$$
$$= -\left(20\ \frac{\text{V}}{\cancel{\text{m}}}\right)(6\ \cancel{\text{m}} - 4\ \cancel{\text{m}})$$
$$\Delta V = -40\ \text{V}$$

Statement: The potential difference is –40 V.
9. The net work done is 0 J because the points are at the same potential.
10. Given: $V = 20$ V; $q = 0.5$ C
Required: W
Analysis:

$$\Delta V = \frac{-W}{q}$$
$$W = -q\Delta V$$

Solution: $W = -q\Delta V$

$$= -(0.5\ \text{C})(20\ \text{V})$$
$$W = -10\ \text{J}$$

Statement: The amount of work done in bringing the charge to the point was 10 J.

Section 7.5: Electric Potential and Electric Potential Energy Due to Point Charges

Tutorial 1 Practice, page 360

1. (a) Given: $q_1 = +6.0 \times 10^{-6}$ C; $q_2 = -3.0 \times 10^{-6}$ C; $q_3 = -3.0 \times 10^{-6}$ C; $r = 3.0$ m; $k = 8.99 \times 10^9$ N·m^2/C^2

Required: V_1; V_2; V_3

Analysis: The potential at each midpoint is the sum of the potentials due to the three charges. Use $V = \frac{kq}{r}$ to calculate the potential due to each charge. The distance from a midpoint to an endpoint is $0.5r$, and the distance from a midpoint to an opposite vertex is $0.5\sqrt{3}r$.

Solution: Calculate the potential between q_1 and q_2, V_1:

$$V_1 = \frac{kq_1}{0.5r} + \frac{kq_2}{0.5r} + \frac{kq_3}{0.5\sqrt{3}r}$$

$$= \frac{k}{r}\left(2q_1 + 2q_2 + \frac{2}{\sqrt{3}}q_3\right)$$

$$= \frac{8.99\times 10^9 \ \frac{\text{J}\cdot\cancel{\text{m}}}{\text{C}^{\cancel{2}}}}{3.0\ \cancel{\text{m}}}\left(2\left(6.0\times 10^{-6}\ \cancel{\text{C}}\right) + 2\left(-3.0\times 10^{-6}\ \cancel{\text{C}}\right) + \frac{2}{\sqrt{3}}\left(-3.0\times 10^{-6}\ \cancel{\text{C}}\right)\right)$$

$$V_1 = 7.6\times 10^3 \text{ J/C}$$

Calculate the potential between q_1 and q_3, V_2:

$$V_2 = \frac{kq_1}{0.5r} + \frac{kq_2}{0.5\sqrt{3}r} + \frac{kq_3}{0.5r}$$

$$= \frac{k}{r}\left(2q_1 + \frac{2}{\sqrt{3}}q_2 + 2q_2\right)$$

$$= \frac{8.99\times 10^9 \ \frac{\text{J}\cdot\cancel{\text{m}}}{\text{C}^{\cancel{2}}}}{3.0\ \cancel{\text{m}}}\left(2\left(6.0\times 10^{-6}\ \cancel{\text{C}}\right) + \frac{2}{\sqrt{3}}\left(-3.0\times 10^{-6}\ \cancel{\text{C}}\right) + 2\left(-3.0\times 10^{-6}\ \cancel{\text{C}}\right)\right)$$

$$V_2 = 7.6\times 10^3 \text{ J/C}$$

Calculate the potential between q_2 and q_3, V_3:

$$V_3 = \frac{kq_1}{0.5\sqrt{3}r} + \frac{kq_2}{0.5r} + \frac{kq_3}{0.5r}$$

$$= \frac{k}{r}\left(\frac{2}{\sqrt{3}}q_1 + 2q_2 + 2q_3\right)$$

$$= \frac{8.99\times 10^9 \ \frac{\text{J}\cdot\cancel{\text{m}}}{\text{C}^{\cancel{2}}}}{3.0\ \cancel{\text{m}}}\left(\frac{2}{\sqrt{3}}\left(6.0\times 10^{-6}\ \cancel{\text{C}}\right) + 2\left(-3.0\times 10^{-6}\ \cancel{\text{C}}\right) + 2\left(-3.0\times 10^{-6}\ \cancel{\text{C}}\right)\right)$$

$$V_3 = -1.5\times 10^4 \text{ J/C}$$

Statement: The potential between q_1 and q_2, V_1, is 7.6×10^3 J/C. The potential between q_1 and q_3, V_2, is 7.6×10^3 J/C. The potential between q_2 and q_3, V_3, is -1.5×10^4 J/C.
(b) Given: $q_1 = +6.0 \times 10^{-6}$ C; $q_2 = -3.0 \times 10^{-6}$ C; $q_3 = -3.0 \times 10^{-6}$ C; $r = 3.0$ m; $k = 8.99 \times 10^9$ N·m^2/C^2
Required: E_E
Analysis: The total electric potential energy is the sum of the three electric potential energies of a pair of charges. Use $E_E = \frac{kq_1q_2}{r}$ to calculate the electric potential energy for each pair of charges.
Solution: Calculate the electric potential energy between q_1 and q_2, E_{E1}:

$$E_{E1} = \frac{kq_1q_2}{r}$$
$$= \frac{\left(8.99 \times 10^9 \ \frac{\text{J} \cdot \cancel{\text{m}}}{\cancel{\text{C}^2}}\right)\left(6.0 \times 10^{-6} \ \cancel{\text{C}}\right)\left(-3.0 \times 10^{-6} \ \cancel{\text{C}}\right)}{3.0 \ \cancel{\text{m}}}$$
$$E_{E1} = -5.394 \times 10^{-2} \text{ J (two extra digits carried)}$$

The electric potential energy between q_1 and q_3, E_{E2}, is equal to E_{E1} because $q_2 = q_3$.
Calculate the electric potential energy between q_2 and q_3, E_{E3}:

$$E_{E3} = \frac{kq_2q_3}{r}$$
$$= \frac{\left(8.99 \times 10^9 \ \frac{\text{J} \cdot \cancel{\text{m}}}{\cancel{\text{C}^2}}\right)\left(-3.0 \times 10^{-6} \ \cancel{\text{C}}\right)\left(-3.0 \times 10^{-6} \ \cancel{\text{C}}\right)}{3.0 \ \cancel{\text{m}}}$$
$$E_{E3} = 2.697 \times 10^{-2} \text{ J (two extra digits carried)}$$

Calculate the total electric potential energy, E_E:

$$E_E = E_{E1} + E_{E2} + E_{E3}$$
$$= (-5.394 \times 10^{-2} \text{ J}) + (-5.394 \times 10^{-2} \text{ J}) + (2.697 \times 10^{-2} \text{ J})$$
$$E_E = -8.1 \times 10^{-2} \text{ J}$$

Statement: The total electric potential energy of the group of charges is -8.1×10^{-2} J.
2. Given: $q = 4.5 \times 10^{-6}$ C; $s = 1.5$ m; $k = 8.99 \times 10^9$ N·m^2/C^2
Required: V at the centre of the square
Analysis: The potential at the centre is the sum of the potentials due to the four charges. Use $V = \frac{kq}{r}$ to calculate the potential due to each charge. The distance from a vertex to the centre is $\frac{1}{2}\sqrt{2}s$, or $\frac{s}{\sqrt{2}}$.

Solution: $V = 4\dfrac{kq}{r}$

$$= \frac{4kq}{\dfrac{s}{\sqrt{2}}}$$

$$= \frac{4\sqrt{2}\left(8.99\times10^{9}\ \dfrac{\text{J}\cdot\cancel{\text{m}}}{\text{C}^{\cancel{2}}}\right)(4.5\times10^{-6}\ \cancel{\text{C}})}{1.5\ \cancel{\text{m}}}$$

$$V = 1.5\times10^{5}\ \text{J/C}$$

Statement: The electric potential at the centre of the square is 1.5×10^5 J/C.

3. Given: $q = -1.6 \times 10^{-19}$ C; $r_i = 5.0 \times 10^{-12}$ m; $m = 9.11 \times 10^{-31}$ kg; $k = 8.99 \times 10^9$ N·m^2/C^2

Required: v_f

Analysis: Determine the initial electric potential energy using the equation $E_{Ei} = \dfrac{kq_1q_2}{r_i}$. The final kinetic energy of each electron is $\dfrac{1}{2}mv_f^2$. The initial kinetic energy and final potential energy are both 0. Use the conservation of energy to determine the final speed of each electron.

$$E_{Ei} + E_{ki} = E_{Ef} + E_{kf}$$

$$\frac{kq_1q_2}{r_i} + 0 = 0 + \frac{1}{2}mv_f^2 + \frac{1}{2}mv_f^2$$

$$\frac{kq^2}{r_i} = mv_f^2$$

$$v_f = \sqrt{\frac{kq^2}{mr_i}}$$

Solution: $v_f = \sqrt{\dfrac{kq^2}{mr_i}}$

$$= \sqrt{\frac{\left(8.99\times10^{9}\ \dfrac{\cancel{\text{kg}}\cdot\dfrac{\text{m}}{\text{s}^2}\cdot\text{m}^{\cancel{2}}}{\cancel{\text{C}^2}}\right)\left(-1.6\times10^{-19}\ \cancel{\text{C}}\right)^2}{\left(9.11\times10^{-31}\ \cancel{\text{kg}}\right)\left(5.0\times10^{-12}\ \cancel{\text{m}}\right)}}$$

$$v_f = 7.1\times10^{6}\ \text{m/s}$$

Statement: The final speed of each electron is 7.1×10^6 m/s.

4. Given: $q = 1.6 \times 10^{-19}$ C; $v_1 = 2.3 \times 10^6$ m/s; $v_2 = 1.2 \times 10^6$ m/s; $m = 1.673 \times 10^{-27}$ kg; $k = 8.99 \times 10^9$ N·m^2/C^2

Required: r_f

Analysis: Calculate the final electric potential energy using the equation $E_{Ei} = \dfrac{kq_1q_2}{r_f}$. The initial kinetic energy of each proton is $\dfrac{1}{2}mv^2$, and the initial potential energy and final kinetic energy are both 0. Use the conservation of energy to determine the final separation of the protons.

$$E_{Ei} + E_{ki} = E_{Ef} + E_{kf}$$

$$0 + \frac{1}{2}m_1v_{i1}^2 + \frac{1}{2}m_2v_{i2}^2 = \frac{kq_1q_2}{r_f} + 0$$

$$mv_{i1}^2 + mv_{i2}^2 = \frac{2kq^2}{r_f}$$

$$r_f = \frac{2kq^2}{mv_{i1}^2 + mv_{i2}^2}$$

Solution:

$$r_f = \frac{2kq^2}{mv_{i1}^2 + mv_{i2}^2}$$

$$= \frac{2\left(8.99 \times 10^9 \ \dfrac{\cancel{\text{kg}} \cdot \dfrac{\text{m}}{\cancel{\text{s}^2}} \cdot \cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)\left(1.6 \times 10^{-19} \ \cancel{\text{C}}\right)^2}{\left(1.673 \times 10^{-27} \ \cancel{\text{kg}}\right)\left(2.3 \times 10^6 \ \dfrac{\cancel{\text{m}}}{\cancel{\text{s}}}\right)^2 + \left(1.673 \times 10^{-27} \ \cancel{\text{kg}}\right)\left(1.2 \times 10^6 \ \dfrac{\cancel{\text{m}}}{\cancel{\text{s}}}\right)^2}$$

$$r_f = 4.1 \times 10^{-14} \text{ m}$$

Statement: The separation of the protons when they are closest to each other is 4.1×10^{-14} m.

Section 7.5 Questions, page 361

1. (a) The proton moves to a region of lower potential energy and lower electric potential.
(b) The electron moves to a region of lower potential energy and higher electric potential.

2. Two particles that are at locations where the electric potential is the same do not necessarily have the same electric potential energy. The potential energy equals the product of the charge and the electric potential. If the particles have different charges, then they have different potential energies.

3. No work, or 0 J, is required to move a charge from one spot to another with the same electric potential. The work done equals the change in kinetic energy, and the change in kinetic energy equals the negative change in potential energy if energy is conserved. If the electric potential does not change, then the electric potential energy does not change. Therefore, the kinetic energy does not change, and no work is done.

4. Given: $q_1 = 4.5 \times 10^{-5}$ C; $q_2 = 8.5 \times 10^{-5}$ C; $E_E = 40.0$ J; $k = 8.99 \times 10^9$ N·m²/C²
Required: r

Analysis: $E_E = \dfrac{kq_1q_2}{r}$

$$r = \frac{kq_1q_2}{E_E}$$

Solution: $r = \dfrac{kq_1q_2}{E_E}$

$$= \frac{\left(8.99\times10^9\ \frac{\cancel{N}}{\cancel{C^2}}\right)\left(4.5\times10^{-5}\ \cancel{C}\right)\left(8.5\times10^{-5}\ \cancel{C}\right)}{40.0\ \cancel{N}\cdot\text{m}}$$

$$= 0.86\text{ m}$$

$$r = 86\text{ cm}$$

Statement: The distance between the charges is 86 cm.

5. Given: $q_1 = 4.5 \times 10^{-5}$ C; $q_2 = 8.5 \times 10^{-5}$ C; $r_i = 2.5$ m; $r_f = 1.5$ m; $k = 8.99 \times 10^9$ N·m²/C²
Required: ΔE_E
Analysis:

$$\Delta E_E = \frac{kq_1q_2}{r_f} - \frac{kq_1q_2}{r_i}$$

$$\Delta E_E = kq_1q_2\left(\frac{1}{r_f} - \frac{1}{r_i}\right)$$

Solution: $\Delta E_E = kq_1q_2\left(\dfrac{1}{r_f} - \dfrac{1}{r_i}\right)$

$$= \left(8.99\times10^9\ \frac{\text{J}\cdot\cancel{m}}{\cancel{C^2}}\right)\left(4.5\times10^{-5}\ \cancel{C}\right)\left(8.5\times10^{-5}\ \cancel{C}\right)\left(\frac{1}{1.5\ \cancel{m}} - \frac{1}{2.5\ \cancel{m}}\right)$$

$$\Delta E_E = 9.2\text{ J}$$

Statement: The electric potential energy increases by +9.2 J.

6. Given: $q_1 = 3.5 \times 10^{-6}$ C; $q_2 = 7.5 \times 10^{-6}$ C; $r_i \to \infty$; $r_f = 2.5$ m; $k = 8.99 \times 10^9$ N·m²/C²
Required: W
Analysis:

$$W = \frac{kq_1q_2}{r_f} - \frac{kq_1q_2}{r_i}$$

$$= \frac{kq_1q_2}{r_f} - 0$$

$$W = \frac{kq_1q_2}{r_f}$$

Solution: $W = \dfrac{kq_1q_2}{r_f}$

$$= \frac{\left(8.99\times10^9\ \frac{\text{J}\cdot\cancel{\text{m}}}{\cancel{\text{C}^2}}\right)\left(3.5\times10^{-6}\ \cancel{\text{C}}\right)\left(7.5\times10^{-6}\ \cancel{\text{C}}\right)}{2.5\ \cancel{\text{m}}}$$

$W = 9.4\times10^{-2}$ J

Statement: The work required to bring the point charges together is 9.4×10^{-2} J.

7. Given: $q_1 = -1.6 \times 10^{-19}$ C; $q_2 = 1.6 \times 10^{-19}$ C; $r_i = 5.00 \times 10^{-11}$ m; $r_f \to \infty$; $k = 8.99 \times 10^9$ N·m^2/C^2

Required: W

Analysis:

$$W = \frac{kq_1q_2}{r_f} - \frac{kq_1q_2}{r_i}$$

$$= 0 - \frac{kq_1q_2}{r_i}$$

$$W = -\frac{kq_1q_2}{r_i}$$

Solution: $W = -\dfrac{kq_1q_2}{r_i}$

$$= -\frac{\left(8.99\times10^9\ \frac{\text{J}\cdot\cancel{\text{m}}}{\cancel{\text{C}^2}}\right)\left(-1.6\times10^{-19}\ \cancel{\text{C}}\right)\left(1.6\times10^{-19}\ \cancel{\text{C}}\right)}{5.00\times10^{-11}\ \cancel{\text{m}}}$$

$W = 4.6\times10^{-18}$ J

Statement: The work required to separate the electron and the proton is 4.6×10^{-18} J.

8. (a) Given: r_f = 15 cm = 0.15 m; $V = -8.5 \times 10^4$ V; $k = 8.99 \times 10^9$ N·m^2/C^2

Required: q

Analysis: $V = \dfrac{kq}{r}$; $q = \dfrac{Vr}{k}$

Solution: $q = \dfrac{Vr}{k}$

$$= \frac{\left(-8.5\times10^4\ \frac{\cancel{\text{J}}}{\cancel{\text{C}}}\right)\left(0.15\ \cancel{\text{m}}\right)}{\left(8.99\times10^9\ \frac{\cancel{\text{J}}\cdot\cancel{\text{m}}}{\text{C}^{\cancel{2}}}\right)}$$

$q = -1.4\times10^{-6}$ C

Statement: The charge on the sphere is -1.4×10^{-6} C.

(b) Given: $r_f = 0.15$ m; $V = -8.5 \times 10^4$ V
Required: ε
Analysis:

$$\varepsilon = \frac{kq}{r^2}$$

$$\varepsilon = \frac{V}{r}$$

Solution: $\varepsilon = \dfrac{V}{r}$

$$= \frac{\left(-8.5\times10^4 \ \frac{\text{N}\cdot\cancel{\text{m}}}{\text{C}}\right)}{\left(0.15\ \cancel{\text{m}}\right)}$$

$$\varepsilon = -5.7\times10^5 \text{ N/C}$$

Statement: The magnitude of the electric field near the surface of the sphere is -5.7×10^5 N/C.
(c) By convention, the electric field points radially inward from the surface of a negatively charged sphere.

Section 7.6: The Millikan Oil Drop Experiment

Tutorial 1 Practice, page 364

1. Given: r = 110 cm = 1.10 m; $N = 1.2 \times 10^8$; $e = 1.602 \times 10^{-19}$ C; $k = 8.99 \times 10^9$ N·m²/C²

Required: F_E

Analysis: Determine the magnitude of the charge on each sphere using $q = Ne$. The charges will be positive because the spheres have a deficit of electrons. Then calculate the force of repulsion, $F_E = \dfrac{kq_1q_2}{r^2}$.

Solution:

$$q = Ne$$
$$= (1.2 \times 10^8)(1.602 \times 10^{-19}\ \text{C})$$
$$q = 1.92 \times 10^{-11}\ \text{C (one extra digit carried)}$$

$$F_E = \frac{kq_1q_2}{r^2}$$
$$= \frac{\left(8.99 \times 10^9\ \dfrac{\text{N} \cdot \text{m}^2}{\text{C}^2}\right)(1.92 \times 10^{-11}\ \text{C})(1.92 \times 10^{-11}\ \text{C})}{(1.10\ \text{m})^2}$$
$$F_E = 2.7 \times 10^{-12}\ \text{N}$$

Statement: The force of repulsion between the two plastic spheres is 2.7×10^{-12} N.

2. Given: $m = 2.48 \times 10^{-15}$ kg; Δd = 1.7 cm = 0.017 m; ΔV_b = 260 V; $e = 1.602 \times 10^{-19}$ C; g = 9.8 m/s²

Required: q; N

Analysis: Determine the charge on the oil drop, $q = \dfrac{mg\Delta d}{\Delta V_b}$. Then calculate the number of excess electrons, $q = Ne$; $N = \dfrac{q}{e}$. The top plate is positively charged, so the field between the plates points downward. However, the electric force is balancing the gravitational force, so the particle is moving against the electric field. Therefore the charge will be negative.

Solution: Determine the charge on the oil drop:

$$q = \frac{mg\Delta d}{\Delta V_b}$$
$$= \frac{(2.48 \times 10^{-15}\ \text{kg})\left(9.8\ \dfrac{\text{m}}{\text{s}^2}\right)(0.017\ \text{m})}{260\ \text{kg} \cdot \dfrac{\text{m}}{\text{s}^2} \cdot \dfrac{\text{m}}{\text{C}}}$$
$$q = 1.589 \times 10^{-18}\ \text{C (two extra digits carried)}$$
$$q = 1.6 \times 10^{-18}\ \text{C}$$

The charge on the oil drop is -1.6×10^{-18} C.

Determine the excess of electrons:

$$N = \frac{q}{e}$$
$$= \frac{1.589 \times 10^{-18}\ \cancel{C}}{1.602 \times 10^{-19}\ \cancel{C}}$$
$$N = 10$$

Statement: The charge on the oil drop is –1.6 × 10^{-18} C. The oil drop has an excess of 10 electrons, or –10*e*.

3. Given: ε = 1.0 × 10^2 N/C; *m* = 2.4 × 10^{-15} kg; *e* = 1.602 × 10^{-19} C; *g* = 9.8 m/s^2

Required: *q*

Analysis: $q = \frac{mg}{\varepsilon}$. The ionosphere is positively charged, so Earth's electric field points toward Earth's surface. The electric force is balancing the gravitational force, so the particle is moving against the electric field. Therefore the charge will be negative.

Solution: Determine the charge on the object:

$$q = \frac{mg}{\varepsilon}$$
$$= \frac{\left(2.4 \times 10^{-15}\ \cancel{\text{kg}}\right)\left(9.8\ \frac{\cancel{\text{m}}}{\cancel{\text{s}^2}}\right)}{\left(1.0 \times 10^{2}\ \frac{\cancel{\text{N}}}{\text{C}}\right)}$$
$$= 2.352 \times 10^{-16}\ \text{C (two extra digits carried)}$$
$$q = 2.4 \times 10^{-16}\ \text{C}$$

Determine the charge as a multiple of the elementary charge:

$$q = \frac{qe}{e}$$
$$= \frac{\left(2.352 \times 10^{-16}\ \cancel{C}\right)e}{\left(1.602 \times 10^{-19}\ \cancel{C}\right)}$$
$$q = 1.5 \times 10^{3} e$$

Statement: The oil drop has a charge of –2.4 × 10^{-16} C, or –1.5 × 10^3*e*.

Section 7.6 Questions, page 365

1. Given: *q* = 3.8 × 10^{-14} C; *e* = 1.602 × 10^{-19} C

Required: *N*

Analysis:

$$q = Ne$$
$$N = \frac{q}{e}$$

Solution: $N = \frac{q}{e}$

$$= \frac{3.8 \times 10^{-14} \cancel{C}}{1.602 \times 10^{-19} \cancel{C}}$$

$N = 2.4 \times 10^5$

Statement: To give the object a positive charge of 3.8×10^{-14} C, 2.4×10^5 C electrons must be removed.

2. Given: $r = 0.35$ m; $N = 6.1 \times 10^6$ C; $e = -1.602 \times 10^{-19}$ C; $k = 8.99 \times 10^9$ N·m^2/C^2

Required: ε; V

Analysis: Determine the charge on the object using $q = Ne$. Then calculate the magnitude of the electric field using $\varepsilon = \frac{kq}{r^2}$ and the magnitude of the electric potential using $V = -\varepsilon d$.

Solution: Determine the charge on the object:

$q = Ne$

$= (6.1 \times 10^6)(-1.602 \times 10^{-19} \text{ C})$

$q = -9.77 \times 10^{-13}$ C (one extra digit carried)

Determine the magnitude of the electric field:

$$\varepsilon = \frac{kq}{r^2}$$

$$= \frac{\left(8.99 \times 10^9 \ \frac{\text{N} \cdot \cancel{\text{m}^2}}{\text{C}^{\cancel{2}}}\right)\left(-9.77 \times 10^{-13} \cancel{\text{C}}\right)}{\left(0.35 \cancel{\text{m}}\right)^2}$$

$= -7.172 \times 10^{-2}$ N/C (two extra digits carried)

$\varepsilon = -7.2 \times 10^{-2}$ N/C

Determine the magnitude of the electric potential:

$V = -\varepsilon d$

$= -(-7.172 \times 10^{-2} \text{ N/C})(0.35 \text{ m})$

$V = 2.5 \times 10^{-2}$ V

Statement: At a distance of 0.35 m, the magnitude of the electric field is 7.2×10^{-2} N/C and the magnitude of the electric potential is 2.5×10^{-2} V.

3. Given: $\Delta d = 2.00$ mm $= 2.00 \times 10^{-3}$ m; $\Delta V = 240$ V; $m = 5.88 \times 10^{-10}$ kg; $e = 1.602 \times 10^{-19}$ C; $g = 9.8$ m/s^2

Required: q; N

Analysis: Determine the charge on the oil droplet using $q = \frac{mg\,\Delta d}{\Delta V_b}$. Then determine the excess number of electrons using $q = Ne$; $N = \frac{q}{e}$. The top plate is positively charged, so the field between the plates points downward. However, the electric force is balancing the gravitational force, so the particle is moving against the electric field. Therefore the charge will be negative.

Solution: Determine the charge on the oil droplet:

$$q = \frac{mg\,\Delta d}{\Delta V_{\text{b}}}$$

$$= \frac{\left(5.88\times10^{-10}\ \cancel{\text{kg}}\right)\left(9.8\ \frac{\cancel{\text{m}}}{\cancel{\text{s}^2}}\right)\left(2.00\times10^{-3}\ \cancel{\text{m}}\right)}{240\ \cancel{\text{kg}}\cdot\frac{\cancel{\text{m}}}{\cancel{\text{s}^2}}\cdot\frac{\cancel{\text{m}}}{\text{C}}}$$

$= 4.802\times10^{-14}$ C (two extra digits carried)

$q = 4.8\times10^{-14}$ C

Determine the excess of electrons:

$$N = \frac{q}{e}$$

$$= \frac{4.802\times10^{-14}\ \cancel{\text{C}}}{1.602\times10^{-19}\ \cancel{\text{C}}}$$

$N = 3.0\times10^{5}$

Statement: The charge on the oil droplet is -4.8×10^{-14} C. The oil droplet has an excess of 3.0×10^{5} electrons.

4. (a) The charge on the drop is positive because the force needed to suspend the drop is in the same direction as the field.

(b) Given: $m = 3.3 \times 10^{-7}$ kg; $\varepsilon = 8.4 \times 10^{3}$ N/C; $e = 1.602 \times 10^{-19}$ C; $g = 9.8$ m/s^2

Required: N

Analysis: $q = \frac{mg}{\varepsilon}$; $q = Ne$; $N = \frac{q}{e}$

Solution: Determine the charge on the object:

$$q = \frac{mg}{\varepsilon}$$

$$= \frac{\left(3.3\times10^{-7}\ \cancel{\text{kg}}\right)\left(9.8\ \frac{\cancel{\text{m}}}{\cancel{\text{s}^2}}\right)}{\left(8.4\times10^{3}\ \frac{\cancel{\text{N}}}{\text{C}}\right)}$$

$q = 3.85\times10^{-10}$ C (one extra digit carried)

Determine the deficit of electrons:

$$N = \frac{q}{e}$$

$$= \frac{3.85\times10^{-10}\ \cancel{\text{C}}}{1.602\times10^{-19}\ \cancel{\text{C}}}$$

$N = 2.4\times10^{9}$

Statement: The drop of water has a deficit of 2.4×10^{9} electrons.

5. (a) Given: $m = 5.2 \times 10^{-15}$ kg; $\Delta d = 0.21$ cm $= 2.1 \times 10^{-3}$ m; $\Delta V = 220$ V; $g = 9.8$ m/s^2
Required: q

Analysis: $q = \dfrac{mg\,\Delta d}{\Delta V_\text{b}}$. The bottom plate is positively charged, so the field between the plates points upward. However, the electric force is balancing the gravitational force, so the particle is moving against the electric field. Therefore the charge will be positive.

Solution:
$$q = \frac{mg\,\Delta d}{\Delta V_\text{b}}$$
$$= \frac{\left(5.2\times10^{-15}\ \cancel{\text{kg}}\right)\left(9.8\ \dfrac{\cancel{\text{m}}}{\cancel{\text{s}^2}}\right)\left(2.1\times10^{-3}\ \cancel{\text{m}}\right)}{220\ \cancel{\text{kg}}\cdot\dfrac{\cancel{\text{m}}}{\cancel{\text{s}^2}}\cdot\dfrac{\cancel{\text{m}}}{\text{C}}}$$
$$= 4.864\times10^{-19}\ \text{C (two extra digits carried)}$$
$$q = 4.9\times10^{-19}\ \text{C}$$

Statement: The charge on the oil drop is 4.9×10^{-19} C.

(b) Given: $q = 4.864 \times 10^{-19}$ C; $e = 1.602 \times 10^{-19}$ C
Required: N

Analysis: $q = Ne$; $N = \dfrac{q}{e}$

Solution:
$$N = \frac{q}{e}$$
$$= \frac{4.864\times10^{-19}\ \cancel{\text{C}}}{1.602\times10^{-19}\ \cancel{\text{C}}}$$
$$N = 3$$

Statement: The oil drop has a deficit of 3 electrons.

6. Given: $m_\text{A} = 4.2 \times 10^{-2}$ kg; $N_\text{A} = 1.2 \times 10^{12}$; $N_\text{B} = 3.5 \times 10^{12}$; $r = 0.23$ m; $e = 1.602 \times 10^{-19}$ C; $k = 8.99 \times 10^9$ N·m^2/C^2; $g = 9.8$ m/s^2
Required: θ

Analysis: The angle between the wall and the thread is also the angle of the tension force on sphere A. The only other forces on sphere A are due to gravity and electric attraction. Use $q = Ne$ to determine the charges, $F_\text{E} = \dfrac{kq_1q_2}{r^2}$ to determine the electric force, and $F_\text{g} = mg$ to determine the gravitational force. Use the tangent ratio to determine the angle of the tension force.

Solution: Determine the charge on each sphere:

$$q_\text{A} = N_\text{A}e$$
$$= (1.2\times10^{12})(1.602\times10^{-19}\ \text{C})$$
$$q_\text{A} = 1.92\times10^{-7}\ \text{C (one extra digit carried)}$$

$$q_\text{B} = N_\text{B}e$$
$$= (3.5\times10^{12})(1.602\times10^{-19}\ \text{C})$$
$$q_\text{B} = 5.61\times10^{-7}\ \text{C (one extra digit carried)}$$

Determine the electric force:

$$F_E = \frac{kq_1q_2}{r^2}$$

$$= \frac{\left(8.99 \times 10^9 \frac{\text{N} \cdot \cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)\left(1.92 \times 10^{-7} \cancel{\text{C}}\right)\left(5.61 \times 10^{-7} \cancel{\text{C}}\right)}{\left(0.23 \cancel{\text{m}}\right)^2}$$

$F_E = 1.830 \times 10^{-2}$ N (two extra digits carried)

Determine the force of gravity:

$$F_g = m_A g$$

$$= \left(4.2 \times 10^{-2} \text{ kg}\right)\left(9.8 \text{ m/s}^2\right)$$

$F_g = 4.116 \times 10^{-1}$ N (two extra digits carried)

Use the tangent ratio to determine the angle of the tension force:

$$\tan\theta = \left(\frac{F_E}{F_g}\right)$$

$$\theta = \tan^{-1}\left(\frac{F_E}{F_g}\right)$$

$$= \tan^{-1}\left(\frac{1.830 \times 10^{-2} \cancel{\text{N}}}{4.116 \times 10^{-1} \cancel{\text{N}}}\right)$$

$= 2.544°$ (two extra digits carried)

$\theta = 2.5°$

Statement: The thread is at an angle of 2.5° from the wall.

(b) Given: $\theta = 2.544°$; $F_g = 4.116 \times 10^{-1}$ N

Required: F_T

Analysis: $\cos\theta = \frac{F_g}{F_T}$

$$F_T = \frac{F_g}{\cos\theta}$$

Solution: $F_T = \frac{F_g}{\cos\theta}$

$$= \frac{4.116 \times 10^{-1} \text{ N}}{\cos 2.544°}$$

$F_T = 0.41$ N

Statement: The tension in the thread is 0.41 N [up the thread].

7. (a) Both Earth’s electric field and gravitational field point in the same direction and have approximately the same shape. The change in Earth’s electric field and gravitational field is the same as the altitude increases, because both follow the inverse-square law.

(b) Given: $\varepsilon = 1.0 \times 10^2$ N/C; $q = 1.602 \times 10^{-19}$ C; $g = 9.8$ m/s^2
Required: m

Analysis: $q = \dfrac{mg}{\varepsilon}$

$$m = \frac{q\varepsilon}{g}$$

Solution: $m = \dfrac{q\varepsilon}{g}$

$$= \frac{\left(1.602 \times 10^{-19}\ \cancel{\text{C}}\right)\left(1.0 \times 10^{2}\ \dfrac{\text{kg}}{\cancel{\text{C}}} \cdot \dfrac{\cancel{\text{m}}}{\cancel{\text{s}^2}}\right)}{\left(9.8\ \dfrac{\cancel{\text{m}}}{\cancel{\text{s}^2}}\right)}$$

$$m = 1.6 \times 10^{-18}\ \text{kg}$$

Statement: The mass of a particle with an elementary charge on it that can be suspended by Earth's electric field is 1.6×10^{-18} kg.

8. The tiny dust particles observed in a beam of sunlight may have become charged by friction and are now suspended by Earth's electric field or some other nearby electric field. I could test the answer by charging another object, such as a balloon or a piece of fabric, and testing whether the particles are attracted or repelled by the object without coming into contact. If so, then the particles have a charge.

Chapter 7 Review, pages 370–375

Knowledge

1. (b)
2. (b)
3. (a)
4. (a)
5. (c)
6. (d)
7. (a)
8. (d)
9. (d)
10. (a)
11. (a)
12. (a)
13. (d)
14. (a)
15. (b)
16. (b)
17. (b)
18. False. *Insulators and conductors* can hold a net positive charge.
19. False. A balloon will attract a thin stream of water *if the balloon is positively or negatively* charged.
20. True
21. False. A positively charged particle will create an electric field that repels *positively* charged particles *and attracts negatively charged particles*.
22. True
23. True
24. True
25. False. When a metal plate is given a negative charge, the excess electrons accumulate *around the edge* of the metal plate.
26. False. In Coulomb's law, the denominator *r* represents the *distance between the centres of the two charges*.
27. True
28. False. The value of the proportionality constant *k* in Coulomb's law *is independent of* the distance between charges.
29. False. The *square of the* magnitude of the force on charge A due to charges B and C equals *the sum of the squares of the magnitudes due to B and C.*
30. True
31. False. It is *possible* for an electric field to exist in empty space.
32. True
33. False. There is an electric field created around any charge. Electric fields can superimpose when there are multiple charges.
34. True
35. False. An electron will experience a force in the *opposite* direction as an electric field line.
36. True

37. False. The electric field between two parallel plates is *of uniform magnitude throughout the entire region between the plates.*
38. False. Volt per metre and newton per coulomb are two ways to measure electric *field*.
39. False. If the electric field at a certain point is zero, then the electric potential at that same point *may be positive, negative, or zero*.
40. True
41. False. The electric potential due to a point charge is *inversely* proportional to the distance from the charge and *directly* proportional to the amount of charge.
42. False. Millikan measured the charge on an electron by suspending *oil droplets* with an electric field.
43. True

Understanding
44. A person's hair sometimes stands on end when the person's hand is on a continuously charged conductor, such as a Van de Graaff generator, because the person's hair obtains a net charge. The charge forces each individual strand of hair to exert a repulsive force on the surrounding strands of hair.
45. Excess charge can never stay on an insulator because insulators attract stray positive ions, which are usually part of the surrounding air. Therefore, there is no net charge on the insulator.
46. To place a positive charge on an isolated metal sphere using a negatively charged plastic rod, I would charge the metal sphere through induction. First, I would bring the negatively charged rod close to the sphere. Then I would touch the sphere to a ground (someone's finger) and move the rod away.
47. (a) The balloon that has been rubbed on the student's hair sticks to the wall because atoms in the wall become polarized and show slight attraction to the charged balloon.
(b) If the balloon is turned around, it will not stick to the wall. The balloon is an insulator; only the part that is rubbed will have a charge.
48. Both the electric force and the gravitational force have similar equations: the magnitude of each force is related to the inverse square of distance. However, the electrostatic force can be attractive or repulsive, and the gravitational force is only attractive. Electric forces dominate over gravitational forces on the atomic scale.
49. To verify that the unit V/m is equivalent to the unit N/C, use the definitions 1 V = 1 J/C and 1 J = 1 N·m:

$$\begin{aligned} 1\text{ V/m} &= 1\ \frac{\text{V}}{\text{m}} \\ &= 1\ \frac{\left(\frac{\text{J}}{\text{C}}\right)}{\text{m}} \\ &= 1\ \frac{\text{J}}{\text{C}\cdot\text{m}} \\ &= 1\ \frac{\text{N}\cdot\cancel{\text{m}}}{\text{C}\cdot\cancel{\text{m}}} \end{aligned}$$

$$1\text{ V/m} = 1\text{ N/C}$$

50. When a 5 C charge and a 50 C charge are placed, one at a time, at 1.0 m from a –1 C point charge, both the 5 C and the 50 C charges will experience the same electric potential. This happens because the electric potential depends only on the central charge and the distance from the central charge.
51. The work done on the charge moving in a surrounding electric field is equal to the displacement along the field lines. Therefore, no work is done; $W = 0$ J. The electric potential does not change either.
52. Given: $r = 0.25$ m; $q = 1.2$ C; $k = 8.99 \times 10^9$ N·m²/C²
Required: V

Analysis: $V = \dfrac{kq}{r}$

Solution: $V = \dfrac{kq}{r}$

$$= \frac{\left(8.99\times10^9\ \frac{\text{J}\cdot\cancel{\text{m}}}{\text{C}^{\cancel{2}}}\right)\left(1.2\ \cancel{\text{C}}\right)}{0.25\ \cancel{\text{m}}}$$

$$V = 4.3\times10^{10}\ \text{J/C}$$

Statement: The electric potential at the point is 4.3×10^{10} V.
53. A Van de Graaff generator is a device that produces a high potential difference using friction. The device can be used to accelerate charged particles.
54. Three different forces play a part in Millikan's oil drop experiment: The force of gravity pulls the drops downward. The electric force on the oil drops resists the force of gravity and allows the oil drops to float between the plates. The force of air friction affects the speed and acceleration of the drops as they fall.

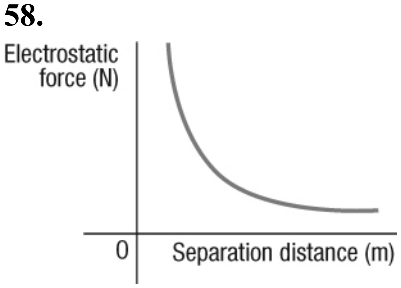
Analysis and Application

55. An oxygen ion has an excess of two electrons, each with a charge of -1.6×10^{-19} C. Therefore, the charge of the ion is two times the charge of an electron, or -3.2×10^{-19} C.
56. After contact is made, the charge on each pith ball is half the original charge of –6.8 nC, or –3.4 nC.
57. (a) The charge on each sphere is half the sum of the two original charges, –2 μC:

$$q = \frac{6\ \mu\text{C} + (-10\ \mu\text{C})}{2}$$

$$q = -2\ \mu\text{C}$$

(b) The charge becomes 0 C when the sphere is grounded.
58.



59. Given: r = 25 cm = 0.25 m; $q_1 = 2.3 \times 10^{-10}$ C; $q_2 = 2.3 \times 10^{-10}$ C; $k = 8.99 \times 10^9$ N·m²/C²
Required: F_E

Analysis: $F_E = \dfrac{kq_1q_2}{r^2}$

Solution: $F_E = \dfrac{kq_1q_2}{r^2}$

$$= \frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)\left(2.3\times10^{-10}\ \cancel{\text{C}}\right)\left(2.3\times10^{-10}\ \cancel{\text{C}}\right)}{\left(0.25\ \cancel{\text{m}}\right)^2}$$

$$F_E = 7.6\times10^{-9}\ \text{N}$$

Statement: The magnitude of the electric force between the spheres is 7.6×10^{-9} N.

60. Given: q_1 = 4.2 μC = 4.2×10^{-6} C; q_2 = 4.2 μC = 4.2×10^{-6} C; F_E = 0.25 N;
$k = 8.99 \times 10^9$ N·m²/C²
Required: r

Analysis: $F_E = \dfrac{kq_1q_2}{r^2}$

$$r = \sqrt{\frac{kq_1q_2}{F_E}}$$

Solution: $r = \sqrt{\dfrac{kq_1q_2}{F_E}}$

$$= \sqrt{\frac{\left(8.99\times10^9\ \frac{\cancel{\text{N}}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)\left(4.2\times10^{-6}\ \cancel{\text{C}}\right)\left(4.2\times10^{-6}\ \cancel{\text{C}}\right)}{\left(0.25\ \cancel{\text{N}}\right)}}$$

$$r = 0.80\ \text{m}$$

Statement: The distance that separates the charges is 0.80 m.

61. Given: r = 60 cm = 0.60 m; F_E = 1.8 N; q_1 = –83 μC = -8.3×10^{-5} C; $k = 8.99 \times 10^9$ N·m²/C²
Required: q_2

Analysis: The charge of q_2 will be positive because the charges attract each other and the charge on q_1 is negative;

$$F_E = \frac{kq_1q_2}{r^2}$$

$$q_2 = \frac{F_E r^2}{kq_1}$$

Solution: $q_2 = \dfrac{F_E r^2}{kq_1}$

$$= \frac{(1.8\ \text{N})(0.60\ \text{m})^2}{\left(8.99 \times 10^9\ \dfrac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(8.3 \times 10^{-5}\ \text{C})}$$

$q_2 = 8.7 \times 10^{-7}\ \text{C}$

Statement: The other charge, q_2, is $+8.7 \times 10^{-7}$ C, or +0.87 μC.

62. Given: $e = 1.602 \times 10^{-19}$ C; $q_1 = 2e = 2(1.602 \times 10^{-19}\ \text{C})$; $q_2 = 79(1.602 \times 10^{-19}\ \text{C})$; $r = 6.2 \times 10^{-14}$ m; $k = 8.99 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2$

Required: F_E

Analysis: $F_E = \dfrac{kq_1q_2}{r^2}$

Solution: $F_E = \dfrac{kq_1q_2}{r^2}$

$$= \frac{\left(8.99 \times 10^9\ \dfrac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(2)(1.602 \times 10^{-19}\ \text{C})(79)(1.602 \times 10^{-19}\ \text{C})}{(6.2 \times 10^{-14}\ \text{m})^2}$$

$F_E = 9.5\ \text{N}$

Statement: The magnitude of the electrostatic repulsive force between the alpha particle and the gold nucleus is 9.5 N.

63. Given: $q_1 = q$; $q_2 = 3q$; $r_{12} = 12$ cm = 0.12 m; $F_{E13} = F_{E23}$

Required: r_{13}

Analysis: Use $F_E = \dfrac{kq_1q_2}{r^2}$ to develop a quadratic equation to solve for r_{13}.

Solution:

$$F_{E13} = F_{E23}$$

$$\frac{kq_1q_3}{r_{13}^2} = \frac{kq_2q_3}{r_{23}^2}$$

$$\frac{q_1}{r_{13}^2} = \frac{q_2}{r_{23}^2}$$

$$\frac{q}{r_{13}^2} = \frac{3q}{(12 - r_{13})^2}$$

$$(12 - r_{13})^2 = 3r_{13}^2$$

$$144 - 24r_{13} + r_{13}^2 = 3r_{13}^2$$

$$0 = 2r_{13}^2 + 24r_{13} - 144$$

$$0 = r_{13}^2 + 12r_{13} - 72$$

Solve the quadratic equation:

$$0 = r_{13}^2 + 12r_{13} - 72$$
$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$r_{13} = \frac{-(12) \pm \sqrt{(12)^2 - 4(1)(-72)}}{2(1)}$$
$$r_{13} = \frac{-12 \pm \sqrt{432}}{2}$$
$$r_{13} = \frac{-12 \pm 12\sqrt{3}}{2}$$
$$r_{13} = -6 \pm 6\sqrt{3}$$

Only the positive distance is necessary:

$$r_{13} = -6 + 6\sqrt{3} \text{ cm}$$
$$r_{13} = 4.4 \text{ cm}$$

Statement: The position at which $+q$ experiences a net force of zero is 4.4 cm from the origin.

64. Given: $q = -8.5\ \mu\text{C} = -8.5 \times 10^{-6}\ \text{C}$; $\theta = 60°$; $r = 30\ \text{cm} = 0.30\ \text{m}$

Required: F_E

Analysis: The charges all have the same sign and magnitude, so the force will be repulsive and equal. Determine the net force on one pair of particles and it applies to the other two particles;

$$F_E = \frac{kq_1q_2}{r^2}$$

Solution:

$$F_E = \frac{kq_1q_2}{r^2}$$
$$= \frac{\left(8.99 \times 10^9\ \frac{\text{N} \cdot \cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)\left(-8.5 \times 10^{-6}\ \cancel{\text{C}}\right)\left(-8.5 \times 10^{-6}\ \cancel{\text{C}}\right)}{\left(0.30\ \cancel{\text{m}}\right)^2}$$
$$F_E = 7.217\ \text{N (two extra digits carried)}$$

For the top charge, the net horizontal components of the forces will equal zero. Determine the total force in the y-direction:

$$F_{net} = 2F_E \cos\left(\frac{60°}{2}\right)$$
$$= 2(7.217\ \text{N})\cos 30°$$
$$F_{net} = 13\ \text{N}$$

Statement: The magnitude and direction of the net force on each particle are as follows: 13 N [away from the centre].

65. Given: q_1 = +41 nC = 4.1 × 10^{-8} C; x_1 = 0.0 cm = 0.0 m; q_2 = –19 nC = –1.9 × 10^{-8} C; x_2 = 6.0 cm = 0.60 m; q_3 = –28 nC = –2.8 × 10^{-8} C; x_3 = –4.0 cm = –0.040 m; $k = 8.99 \times 10^9$ N·m²/C²

Required: F_{net} at each particle

Analysis: $F_{\text{E}} = \dfrac{kq_1q_2}{r^2}$; determine the force between each pair of particles, then calculate the sum at each particle.

Solution: Determine the attractive force between q_1 and q_2:

$$F_{\text{E}} = \frac{kq_1q_2}{r^2}$$

$$F_{12} = \frac{kq_1q_2}{(x_2 - x_1)^2}$$

$$= \frac{\left(8.99 \times 10^9 \ \frac{\text{N} \cdot \cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)(4.1 \times 10^{-8} \ \cancel{\text{C}})(1.9 \times 10^{-8} \ \cancel{\text{C}})}{(0.06 \ \cancel{\text{m}} - 0.0 \ \cancel{\text{m}})^2}$$

$F_{12} = 1.945 \times 10^{-3}$ N (two extra digits carried)

Determine the attractive force between q_1 and q_3:

$$F_{13} = \frac{kq_1q_3}{(x_3 - x_1)^2}$$

$$= \frac{\left(8.99 \times 10^9 \ \frac{\text{N} \cdot \cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)(4.1 \times 10^{-8} \ \cancel{\text{C}})(2.8 \times 10^{-8} \ \cancel{\text{C}})}{(-0.04 \ \cancel{\text{m}} - 0.0 \ \cancel{\text{m}})^2}$$

$F_{13} = 6.450 \times 10^{-3}$ N (two extra digits carried)

Determine the repulsive force between q_2 and q_3:

$$F_{23} = \frac{kq_2q_3}{(x_3 - x_2)^2}$$

$$= \frac{\left(8.99 \times 10^9 \ \frac{\text{N} \cdot \cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)(1.9 \times 10^{-8} \ \cancel{\text{C}})(2.8 \times 10^{-8} \ \cancel{\text{C}})}{(-0.04 \ \cancel{\text{m}} - 0.06 \ \cancel{\text{m}})^2}$$

$F_{23} = 4.783 \times 10^{-4}$ N (two extra digits carried)

Determine the net force at q_1, where attractive force F_{12} is to the right and attractive force F_{13} is to the left:

$$\begin{aligned} F_{\text{net}, q1} &= F_{12} + F_{13} \\ &= \left(1.945\times10^{-3} \text{ N [right]}\right) + \left(6.450\times10^{-3} \text{ N [left]}\right) \\ &= -1.945\times10^{-3} \text{ N [left]} + 6.450\times10^{-3} \text{ N [left]} \\ F_{\text{net}, q1} &= 4.5\times10^{-3} \text{ N [left]} \end{aligned}$$

Determine the net force at q_2, where attractive force F_{12} is to the left and repulsive force F_{23} is to the right:

$$\begin{aligned} F_{\text{net}, q2} &= F_{12} + F_{23} \\ &= \left(1.945\times10^{-3} \text{ N [left]}\right) + \left(4.783\times10^{-4} \text{ N [right]}\right) \\ &= 1.945\times10^{-3} \text{ N [left]} - 4.783\times10^{-4} \text{ N [left]} \\ F_{\text{net}, q2} &= 1.5\times10^{-3} \text{ N [left]} \end{aligned}$$

Determine the net force at q_3, where attractive force F_{13} is to the right and repulsive force F_{23} is to the left:

$$\begin{aligned} F_{\text{net}, q3} &= F_{13} + F_{23} \\ &= \left(6.450\times10^{-3} \text{ N [right]}\right) + \left(4.783\times10^{-4} \text{ N [left]}\right) \\ &= 6.450\times10^{-3} \text{ N [right]} - 4.783\times10^{-4} \text{ N [right]} \\ F_{\text{net}, q3} &= 6.0\times10^{-3} \text{ N [right]} \end{aligned}$$

Statement: The net force at q_1 is 4.5×10^{-3} N [left]. The net force at q_2 is 1.5×10^{-3} N [left]. The net force at q_3 is 6.0×10^{-3} N [right].

66. The sharp piece of copper sticking up from the highest point on the roofs of tall buildings serves as a lightning rod. In the electric field between the ground and the clouds, charge is concentrated along the sharp conductor. When lightning strikes the copper, the charge is safely conducted to the ground, avoiding damage to buildings.

67. Given: q_1 = +76 μC = 7.6×10^{-5} C; q_2 = +76 μC = 7.6×10^{-5} C; s = 15 cm = 0.15 m; q_3 = –24 μC = -2.4×10^{-5} C; $k = 8.99 \times 10^9$ N·m²/C²

Required: ε_{net} at the fourth corner

Analysis: The electric field at the fourth corner results from the electric fields of the three charges. Use the equation $\varepsilon = \dfrac{kq}{r^2}$ to calculate the magnitudes of the electric fields. The distances are either the side length of the square, s, or the diagonal length, $\sqrt{2}s$. Then use the equation $\varepsilon_{12} = \sqrt{\varepsilon_1^2 + \varepsilon_2^2}$ for the electric field in the same direction as the third electric field before calculating the net electric field.

Solution: Determine the electric fields of q_1 and q_2:

$$\varepsilon = \frac{kq}{r^2}$$

$$\varepsilon_1 = \frac{kq_1}{s^2}$$

$$= \frac{\left(8.99 \times 10^9 \ \frac{\text{N} \cdot \text{m}^2}{\text{C}^2}\right)\left(7.6 \times 10^{-5} \ \text{C}\right)}{\left(0.15 \ \text{m}\right)^2}$$

$\varepsilon_1 = 3.037 \times 10^7$ N/C (two extra digits carried)

Determine the electric field of q_3:

$$\varepsilon_3 = \frac{kq_3}{\left(\sqrt{2}s\right)^2}$$

$$= \frac{\left(8.99 \times 10^9 \ \frac{\text{N} \cdot \text{m}^2}{\text{C}^2}\right)\left(-2.4 \times 10^{-5} \ \text{C}\right)}{2\left(0.15 \ \text{m}\right)^2}$$

$\varepsilon_3 = -4.795 \times 10^6$ N/C (two extra digits carried)

Determine the net electric force:

$$\varepsilon_{\text{net}} = \varepsilon_{12} + \varepsilon_3$$

$$= \sqrt{\varepsilon_1^2 + \varepsilon_2^2} + \varepsilon_3$$

$$= \sqrt{\left(3.037 \times 10^7 \ \text{N/C}\right)^2 + \left(3.037 \times 10^7 \ \text{N/C}\right)^2} + \left(-4.795 \times 10^6 \ \text{N/C}\right)$$

$$\varepsilon_{\text{net}} = 3.8 \times 10^7 \ \text{N/C}$$

Statement: The magnitude of the electric field at the empty corner of the square is 3.8×10^7 N/C.

68. Given: $r = 0.040$ m; $q = 1.2 \times 10^{-8}$ C

Required: ε

Analysis: $\varepsilon = \frac{kq}{r^2}$

Solution: $\varepsilon = \frac{kq}{r^2}$

$$= \frac{\left(8.99 \times 10^9 \ \frac{\text{N} \cdot \text{m}^2}{\text{C}^2}\right)\left(1.2 \times 10^{-8} \ \text{C}\right)}{\left(0.040 \ \text{m}\right)^2}$$

$$\varepsilon = 6.7 \times 10^4 \ \text{N/C}$$

Statement: The magnitude of the electric field is 6.7×10^4 N/C.

69. (a) Given: $q = –56\text{ nC} = –5.6 \times 10^{–8}\text{ C}$; $\varepsilon = 3000\text{ N/C}$
Required: r

Analysis: $\varepsilon = \dfrac{kq}{r^2}$

$$r = \sqrt{\frac{kq}{\varepsilon}}$$

Solution: $r = \sqrt{\dfrac{kq}{\varepsilon}}$

$$= \sqrt{\frac{\left(8.99\times10^{9}\ \frac{\cancel{\text{N}}\cdot\text{m}^2}{\text{C}^{\cancel{2}}}\right)\left(5.6\times10^{-8}\ \cancel{\text{C}}\right)}{\left(3000\ \frac{\cancel{\text{N}}}{\cancel{\text{C}}}\right)}}$$

$$= 0.41\text{ m}$$

$$r = 41\text{ cm}$$

Statement: When the electric field is 3000 N/C, the distance from the centre of the sphere is 41 cm.

(b) Given: $q = –5.6 \times 10^{–8}\text{ C}$; $\varepsilon = 1500\text{ N/C}$
Required: r
Analysis:

$$r = \sqrt{\frac{kq}{\varepsilon}}$$

Solution: $r = \sqrt{\dfrac{kq}{\varepsilon}}$

$$= \sqrt{\frac{\left(8.99\times10^{9}\ \frac{\cancel{\text{N}}\cdot\text{m}^2}{\text{C}^{\cancel{2}}}\right)\left(5.6\times10^{-8}\ \cancel{\text{C}}\right)}{\left(1500\ \frac{\cancel{\text{N}}}{\cancel{\text{C}}}\right)}}$$

$$= 0.58\text{ m}$$

$$r = 58\text{ cm}$$

Statement: When the electric field is 1500 N/C, the distance from the centre of the sphere is 58 cm.

(c) Given: $q = –5.6 \times 10^{–8}\text{ C}$; $\varepsilon = 400\text{ N/C}$; $k = 8.99 \times 10^{9}\text{ N·m}^2/\text{C}^2$
Required: r

Analysis: $r = \sqrt{\dfrac{kq}{\varepsilon}}$

Solution: $r = \sqrt{\frac{kq}{\varepsilon}}$

$$= \sqrt{\frac{\left(8.99\times10^9 \ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left(5.6\times10^{-8}\ \text{C}\right)}{\left(400\ \frac{\text{N}}{\text{C}}\right)}}$$

$r = 1.1$ m

Statement: When the electric field is 400 N/C, the distance from the centre of the sphere is 1.1 m.

70. Given: q_1 = +4.0 μC = 4.0 × 10^{-6} C; x_1 = 0.0 cm = 0.0 m; x_2 = 18 cm = 0.18 m; ε_{net} = 0 N/C at x = 36 cm = 0.36 m

Required: q_2

Analysis: $\varepsilon = \frac{kq}{r^2}$; since ε_{net} = 0 N/C, $\varepsilon_1 + \varepsilon_2 = 0$

Solution:

$$\varepsilon_1 + \varepsilon_2 = 0$$

$$\frac{kq_1}{r_1^2} + \frac{kq_2}{r_2^2} = 0$$

$$\frac{q_1}{r_1^2} + \frac{q_2}{r_2^2} = 0$$

$$\frac{q_2}{r_2^2} = -\frac{q_1}{r_1^2}$$

$$q_2 = -\frac{q_1 r_2^2}{r_1^2}$$

$$= \frac{\left(4.0\times10^{-6}\ \text{C}\right)\left(0.18\ \text{m}\right)^2}{\left(0.36\ \text{m}\right)^2}$$

$$q_2 = -1.0\times10^{-6}\ \text{C}$$

Statement: The magnitude and sign of charge q_2 are as follows: –1.0 × 10^{-6} C, or –1.0 μC.

71. Given: q = 1.8 μC = 1.8 × 10^{-6} C; ε = 6700 N/C

Required: F_E

Analysis: $F_E = q\varepsilon$

Solution: $F_E = q\varepsilon$

$$= (1.8\times10^{-6}\ \text{C})(6700\ \text{N/C})$$

$$F_E = 0.012\ \text{N}$$

Statement: The electrostatic force on the particle is 0.012 N.

72. (a) Given: $F_E = 0.063$ N; $\varepsilon = 4200$ N/C
Required: q

Analysis: $F_E = q\varepsilon$; $q = \dfrac{F_E}{\varepsilon}$

Solution:
$$q = \frac{F_E}{\varepsilon} = \frac{0.063\ \cancel{\text{N}}}{4200\ \frac{\cancel{\text{N}}}{\text{C}}} = 1.5\times10^{-5}\ \text{C}$$
$$q = 15\ \mu\text{C}$$

Statement: The magnitude of the charge on the particle is 15 μC.
(b) If the force is opposite the direction of the electric field, then the charge is negative.
73. Given: $F_E = 2.3 \times 10^{-5}$ N; $q = 4.5 \times 10^{-11}$ C
Required: ε

Analysis: $F_E = q\varepsilon$; $\varepsilon = \dfrac{F_E}{q}$

Solution:
$$\varepsilon = \frac{F_E}{q} = \frac{2.3\times10^{-5}\ \text{N}}{4.5\times10^{-11}\ \text{C}}$$
$$\varepsilon = 5.1\times10^{5}\ \text{N/C}$$

Statement: The electric field strength of the precipitator is 5.1×10^5 N/C.
74. Given: $m = 2.4 \times 10^{-26}$ kg; $e = 1.602 \times 10^{-19}$ C; $q = -2e = -2(1.602 \times 10^{-19}\ \text{C})$; $\varepsilon = 200.0$ N/C
Required: a
Analysis: $F_{net} = ma$; $F_E = q\varepsilon$
$$a = \frac{F_E}{m}$$
$$a = \frac{q\varepsilon}{m}$$
Solution:
$$a = \frac{q\varepsilon}{m} = \frac{-2\left(1.602\times10^{-19}\ \cancel{\text{C}}\right)\left(200.0\ \frac{\cancel{\text{kg}}\cdot\frac{\text{m}}{\text{s}^2}}{\cancel{\text{C}}}\right)}{\left(2.4\times10^{-26}\ \cancel{\text{kg}}\right)}$$
$$a = -2.7\times10^{9}\ \text{m/s}^2$$
Statement: The magnitude of the initial acceleration of the ion is 2.7×10^9 m/s^2.

75. Given: q = 0.6 C; W = 3.0 J
Required: ΔV
Analysis: Work is done on the positive charge, so the charge must be moving to a point of greater electric potential. Therefore, the electric potential difference is positive;

$$\Delta V = \frac{\Delta E_{\text{E}}}{q}$$
$$\Delta E_{\text{E}} = q\Delta V$$
$$W = -\Delta E_{\text{E}}$$
$$W = -q\Delta V$$
$$\Delta V = -\frac{W}{q}$$

Solution: $\Delta V = -\frac{W}{q}$

$$= -\frac{3.0\text{ J}}{0.6\text{ C}}$$
$$\Delta V = -5\text{ V, or }-5\text{ J/C}$$

Statement: The electric potential difference between points A and B is 5 V, or 5 J/C.
76. Given: ΔE_{k} = 0.042 J; V_{A} = 700.0 V; V_{B} = 200.0 V
Required: q
Analysis: The particle loses potential energy as it moves to a lower electric potential, so the particle is a positive charge;

$$\Delta E_{\text{k}} = -\Delta E_{\text{E}}$$
$$\Delta V = \frac{\Delta E_{\text{E}}}{q}$$
$$V_{\text{B}} - V_{\text{A}} = \frac{-\Delta E_{\text{k}}}{q}$$
$$q = \frac{-\Delta E_{\text{k}}}{V_{\text{B}} - V_{\text{A}}}$$

Solution: $q = \frac{-\Delta E_{\text{k}}}{V_{\text{B}} - V_{\text{A}}}$

$$= \frac{-(0.042\text{ J})}{200.0\text{ V} - 700.0\text{ V}}$$
$$= \frac{-0.042\ \cancel{\text{J}}}{-500.0\ \frac{\cancel{\text{J}}}{\text{C}}}$$
$$q = 8.4 \times 10^{-5}\text{ C}$$

Statement: The charge is $+8.4 \times 10^{-5}$ C.

77. (a) Given: $\Delta V = 5.3 \times 10^5$ V; $q = 1.6 \times 10^{-19}$ C
Required: ΔE_k
Analysis:

$$\Delta E_k = -\Delta E_E$$

$$\Delta V = \frac{\Delta E_E}{q}$$

$$\Delta V = \frac{-\Delta E_k}{q}$$

$$\Delta E_k = -q\Delta V$$

Solution: $\Delta E_k = -q\Delta V$

$$= -\left(1.6 \times 10^{-19}\ \cancel{\text{C}}\right)\left(5.3 \times 10^5\ \frac{\text{J}}{\cancel{\text{C}}}\right)$$

$$= -8.48 \times 10^{-14}\ \text{J (one extra digit carried)}$$

$$\Delta E_k = -8.5 \times 10^{-14}\ \text{J}$$

Statement: The kinetic energy gained by the proton is 8.5×10^{-14} J.
(b) Given: $m = 1.67 \times 10^{-27}$ kg; $\Delta E_k = 8.48 \times 10^{-14}$ J
Required: v

Analysis: $\Delta E_k = \frac{1}{2}mv^2$

$$v = \sqrt{\frac{2\Delta E_k}{m}}$$

Solution: $v = \sqrt{\frac{2\Delta E_k}{m}}$

$$= \sqrt{\frac{2\left(8.48 \times 10^{-14}\ \cancel{\text{kg}} \cdot \frac{\text{m}}{\text{s}^2} \cdot \text{m}\right)}{\left(1.67 \times 10^{-27}\ \cancel{\text{kg}}\right)}}$$

$$v = 1.0 \times 10^7\ \text{m/s}$$

Statement: The final speed of the proton is 1.0×10^7 m/s.
78. (a) Given: $m = 9.11 \times 10^{-31}$ kg; $q = -1.6 \times 10^{-19}$ C; $\Delta V = 150$ V
Required: E_k

Analysis: $\Delta E_k = -\Delta E_E$

$$\Delta V = \frac{\Delta E_E}{q}$$

$$\Delta V = \frac{-\Delta E_k}{q}$$

$$\Delta E_k = -q\Delta V$$

Solution: $\Delta E_k = -q\Delta V$

$$= -\left(-1.6\times10^{-19}\ \cancel{C}\right)\left(150\ \frac{J}{\cancel{C}}\right)$$

$$\Delta E_k = 2.4\times10^{-17}\ J$$

Statement: The kinetic energy of the electron after it crosses between the plates is 2.4×10^{-17} J.

(b) Given: $m = 9.11 \times 10^{-31}$ kg; $\Delta E_k = 2.4 \times 10^{-17}$ J

Required: v_f

Analysis: $\Delta E_k = \frac{1}{2}mv_f^2$

$$v_f = \sqrt{\frac{2\Delta E_k}{m}}$$

Solution: $v_f = \sqrt{\frac{2\Delta E_k}{m}}$

$$= \sqrt{\frac{2\left(2.4\times10^{-17}\ \cancel{kg}\cdot\frac{m}{s^2}\cdot m\right)}{\left(9.11\times10^{-31}\ \cancel{kg}\right)}}$$

$$= 7.259\times10^{6}\ m/s\ \text{(two extra digits carried)}$$

$$v_f = 7.3\times10^{6}\ m/s$$

Statement: The final speed of the electron is 7.3×10^6 m/s.

(c) Given: $v_i = 0$ m/s; $v_f = 7.259 \times 10^6$ m/s; $\Delta d = 0.80$ cm = 0.0080 m

Required: a

Analysis: $v_f^2 = v_i^2 + 2a\Delta d$

$$v_f^2 = 2a\Delta d$$

$$a = \frac{v_f^2}{2\Delta d}$$

Solution: $a = \frac{v_f^2}{2\Delta d}$

$$= \frac{\left(7.259\times10^{6}\ m/s\right)^2}{2\left(0.0080\ m\right)}$$

$$a = 3.3\times10^{15}\ m/s^2$$

Statement: The acceleration of the electron while it is between the plates is 3.3×10^{15} m/s^2.

(d) Given: $v_i = 0$ m/s; $v_f = 7.259 \times 10^6$ m/s; $\Delta d = 0.0080$ m
Required: Δt

Analysis: $\Delta d = \dfrac{v_f + v_i}{2}\Delta t$

$$\Delta d = \frac{v_f}{2}\Delta t$$

$$\Delta t = \frac{2\Delta d}{v_f}$$

Solution: $\Delta t = \dfrac{2\Delta d}{v_f}$

$$= \frac{2(0.0080\ \text{m})}{\left(7.259\times 10^6\ \frac{\text{m}}{\text{s}}\right)}$$

$$\Delta t = 2.2\times 10^{-9}\ \text{s}$$

Statement: The time required for the electron to travel across the plates in 2.2×10^{-9} s.

79. (a) Given: $\varepsilon = 3.0 \times 10^4$ V/cm $= 3.0 \times 10^6$ V/m; $\Delta d = 6$ mm $= 0.006$ m
Required: ΔV

Analysis: $\varepsilon = -\dfrac{\Delta V}{\Delta d}$

$$\Delta V = -\varepsilon\Delta d$$

Solution: $\Delta V = -\varepsilon\Delta d$

$$= -\left(3.0\times 10^6\ \frac{\text{V}}{\text{m}}\right)(0.006\ \text{m})$$

$$\Delta V = -18\ 000\ \text{V}$$

Statement: The magnitude of the potential difference is 18 000 V.

(b) Given: $\varepsilon = 3.0 \times 10^4$ V/cm; $\Delta d = 12$ cm
Required: ΔV
Analysis: $\Delta V = -\varepsilon\Delta d$
Solution: $\Delta V = -\varepsilon\Delta d$

$$= -\left(3.0\times 10^4\ \frac{\text{V}}{\text{cm}}\right)(12\ \text{cm})$$

$$\Delta V = -3.6\times 10^5\ \text{V}$$

Statement: The magnitude of the potential difference is 3.6×10^5 V.

(c) Given: $\varepsilon = 3.0 \times 10^6$ V/m; $\Delta d = 950$ m
Required: ΔV
Analysis: $\Delta V = -\varepsilon \Delta d$
Solution: $\Delta V = -\varepsilon \Delta d$

$$= -\left(3.0 \times 10^6 \ \frac{\text{V}}{\cancel{\text{m}}}\right)(950 \ \cancel{\text{m}})$$

$$\Delta V = -2.8 \times 10^9 \text{ V}$$

Statement: The magnitude of the potential difference is 2.8×10^9 V.

80. Given: $\Delta d = 4.9$ cm = 0.049 m; $\Delta V = 85$ V
Required: ε
Analysis: $\varepsilon = -\dfrac{\Delta V}{\Delta d}$
Solution: $\varepsilon = -\dfrac{\Delta V}{\Delta d}$

$$= -\frac{85 \text{ V}}{0.049 \text{ m}}$$

$$\varepsilon = -1.7 \times 10^3 \text{ V/m}$$

Statement: The magnitude of the electric field is 1.7×10^3 V/m.

81. Given: $\varepsilon = 5400$ N/C; $\Delta d = 2.5$ cm = 0.025 m
Required: ΔV
Analysis: $\varepsilon = -\dfrac{\Delta V}{\Delta d}$

$$\Delta V = -\varepsilon \Delta d$$

Solution: $\Delta V = -\varepsilon \Delta d$

$$= -\left(5400 \ \frac{\text{V}}{\cancel{\text{m}}}\right)(0.025 \ \cancel{\text{m}})$$

$$\Delta V = -140 \text{ V}$$

Statement: The magnitude of the electric potential difference to which the plates should be set is 140 V.

82. Given: $\Delta d = 12$ cm = 0.12 m; $V = 98$ V; $k = 8.99 \times 10^9$ N·m^2/C^2
Required: q
Analysis: $V = \dfrac{kq}{r}$

$$q = \frac{Vr}{k}$$

Solution: $q = \frac{Vr}{k}$

$$= \frac{\left(98\ \frac{\text{N}\cdot\text{m}}{\text{C}}\right)(0.12\ \text{m})}{\left(8.99\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)}$$

$$q = 1.3\times10^{-9}\ \text{C}$$

Statement: The point charge for which the electric potential is at 12 cm is 1.3×10^{-9} C.

83. The work done on a 1.0 C charge as it moves in a circle around a –1.0 C charge is 0 J because the charge is constant.

84. Given: $q_1 = 1.6 \times 10^{-19}$ C; $q_2 = 1.6 \times 10^{-19}$ C; $r = 3.0 \times 10^{-15}$ m; $k = 8.99 \times 10^9$ N·m²/C²

Required: E_E

Analysis: $E_\text{E} = \frac{kq_1q_2}{r}$

Solution: $E_\text{E} = \frac{kq_1q_2}{r}$

$$= \frac{\left(8.99\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(1.6\times10^{-19}\ \text{C})(1.6\times10^{-19}\ \text{C})}{(3.0\times10^{-15}\ \text{m})}$$

$$E_\text{E} = 7.7\times10^{-14}\ \text{J}$$

Statement: The protons' mutual potential energy is 7.7×10^{-14} J.

85. Given: $q_1 = 1.3 \times 10^{-6}$ C; $q_2 = 3.3 \times 10^{-3}$ C; $r_\text{i} = 1.4$ m; $r_\text{f} = 0.45$ m; $k = 8.99 \times 10^9$ N·m²/C²

Required: ΔE_E

Analysis: $\Delta E_\text{E} = \frac{kq_1q_2}{r_\text{f}} - \frac{kq_1q_2}{r_\text{i}}$

Solution:

$$\Delta E_\text{E} = \frac{kq_1q_2}{r_\text{f}} - \frac{kq_1q_2}{r_\text{i}}$$

$$= \frac{\left(8.99\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(1.3\times10^{-6}\ \text{C})(3.3\times10^{-3}\ \text{C})}{(0.45\ \text{m})} - \frac{\left(8.99\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(1.3\times10^{-6}\ \text{C})(3.3\times10^{-3}\ \text{C})}{(1.4\ \text{m})}$$

$$\Delta E_\text{E} = 58\ \text{J}$$

Statement: The work required to move the point charge is 58 J.

86. Given: $N = 1.5 \times 10^{12}$; $r = 1.2$ m; $k = 8.99 \times 10^9$ N·m²/C²

Required: V; ε

Analysis: Determine the charge on the sphere using $q = Ne$. Then determine the magnitude of the electric field using $\varepsilon = \frac{kq}{r^2}$. Finally, calculate the electric potential, $\varepsilon = -\frac{\Delta V}{\Delta d}$; $\Delta V = -\varepsilon\Delta d$

Solution: Charge on the sphere:

$$q = Ne$$
$$= \left(1.5\times10^{12}\right)\left(-1.6\times10^{-19}\ \text{C}\right)$$
$$q = -2.4\times10^{-7}\ \text{C}$$

Magnitude of the electric field:

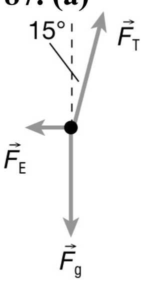
$$\varepsilon = \frac{kq}{r^2}$$
$$= \frac{\left(8.99\times10^{9}\ \frac{\text{N}\cdot\cancel{\text{m}^2}}{\text{C}^{\cancel{2}}}\right)\left(-2.4\times10^{-7}\ \cancel{\text{C}}\right)}{\left(1.2\ \cancel{\text{m}}\right)^2}$$
$$\varepsilon = -1.5\times10^{3}\ \text{N/C}$$

Electric potential:

$$\Delta V = -\varepsilon\,\Delta d$$
$$= -\left(-1.5\times10^{3}\ \text{N/C}\right)\left(1.2\ \text{m}\right)$$
$$\varepsilon = 1.8\times10^{3}\ \text{V}$$

Statement: At a point 1.2 m from the sphere, the electric potential is 1.8×10^3 V, and the magnitude of the electric field is 1.5×10^3 N/C.

87. (a)



(b) Given: m = 2.1 g = 2.1×10^{-3} kg; r = 5.0 cm = 0.0050 m; θ = 15°; $k = 8.99 \times 10^9$ N·m²/C²; g = 9.8 m/s²

Required: q

Analysis: Use $F_g = mg$ to determine the force of gravity. Then use the tangent ratio to determine the electric force. To calculate the charge, rearrange the equation $F_E = \frac{kq_1q_2}{r^2}$:

$$F_E = \frac{kq_1q_2}{r^2}$$
$$= \frac{kq^2}{r^2}$$
$$q^2 = \frac{F_E r^2}{k}$$
$$q = \sqrt{\frac{F_E r^2}{k}}$$

Solution: Force of gravity:

$$F_g = mg$$
$$= (2.1 \times 10^{-3}\ \text{kg})(9.8\ \text{m/s}^2)$$
$$F_g = 2.058 \times 10^{-2}\ \text{N (two extra digits carried)}$$

Electric force:

$$\tan\theta = \frac{F_E}{F_g}$$
$$F_E = F_g \tan\theta$$
$$= (2.058 \times 10^{-2}\ \text{N})\tan 15°$$
$$F_E = 5.514 \times 10^{-3}\ \text{N (two extra digits carried)}$$

Charge on the table tennis balls:

$$q = \sqrt{\frac{F_E r^2}{k}}$$
$$= \sqrt{\frac{(5.514 \times 10^{-3}\ \cancel{\text{N}})(0.050\ \cancel{\text{m}})^2}{\left(8.99 \times 10^9\ \frac{\cancel{\text{N}} \cdot \cancel{\text{m}^2}}{\text{C}^2}\right)}}$$
$$= 3.916 \times 10^{-8}\ \text{C (two extra digits carried)}$$
$$q = 3.9 \times 10^{-8}\ \text{C}$$

Statement: The charge is negative, so each table tennis ball has a charge of –3.9 × 10^{-8} C.
(c) Given: q = –3.916 × 10^{-8} C; e = 1.602 × 10^{-19} C
Required: N
Analysis: $q = Ne$

$$N = \frac{q}{e}$$

Solution: $N = \frac{q}{e}$

$$= \frac{-3.916 \times 10^{-8}\ \cancel{\text{C}}}{1.602 \times 10^{-19}\ \cancel{\text{C}}}$$
$$N = 2.4 \times 10^{11}$$

Statement: Each table tennis ball has an excess of 2.4 × 10^{11} electrons.
88. (a) Given: m = 0.04 g = 4 × 10^{-5} kg; ε = 370 N/C; g = 9.8 m/s^2
Required: q
Analysis: The electric field points downward and the electric force is balancing the gravitational force, so the particle is moving against the electric field. Therefore, the charge will be negative;

$$q = \frac{mg}{\varepsilon}$$

Solution: Determine the charge on the oil drop:

$$q = \frac{mg}{\varepsilon}$$

$$= \frac{\left(4\times10^{-5}\ \text{kg}\right)\left(9.8\ \frac{\text{m}}{\text{s}^2}\right)}{370\ \frac{\text{m}}{\text{s}^2}\cdot\frac{\text{kg}}{\text{C}}}$$

$$= 1.059\times10^{-6}\ \text{C (two extra digits carried)}$$

$$q = 1.1\ \mu\text{C}$$

Statement: The charge on the oil droplet is –1.1 μC.

(b) Given: $q = -1.059 \times 10^{-6}$ C; $e = -1.602 \times 10^{-19}$ C

Required: N

Analysis: $q = Ne$

$$N = \frac{q}{e}$$

Solution: $N = \frac{q}{e}$

$$= \frac{\left(-1.059\times10^{-6}\ \text{C}\right)}{\left(-1.602\times10^{-19}\ \text{C}\right)}$$

$$N = 6.6\times10^{12}$$

Statement: The oil droplet has an excess of 6.6×10^{12} electrons.

89. Given: $q = -0.50$ μC $= -5.0 \times 10^{-7}$ C; $e = -1.602 \times 10^{-19}$ C

Required: N

Analysis: $q = Ne$

$$N = \frac{q}{e}$$

Solution: $N = \frac{q}{e}$

$$= \frac{\left(-5.0\times10^{-7}\ \text{C}\right)}{\left(-1.602\times10^{-19}\ \text{C}\right)}$$

$$N = 3.1\times10^{12}$$

Statement: The plastic rod has an excess of 3.1×10^{12} electrons.

90. Given: $N = 7.6 \times 10^9$; $e = 1.602 \times 10^{-19}$ C

Required: q

Analysis: $q = Ne$

Solution: $q = Ne$

$$= (7.6\times10^{9})(1.602\times10^{-19}\ \text{C})$$

$$= 1.2\times10^{-9}\ \text{C}$$

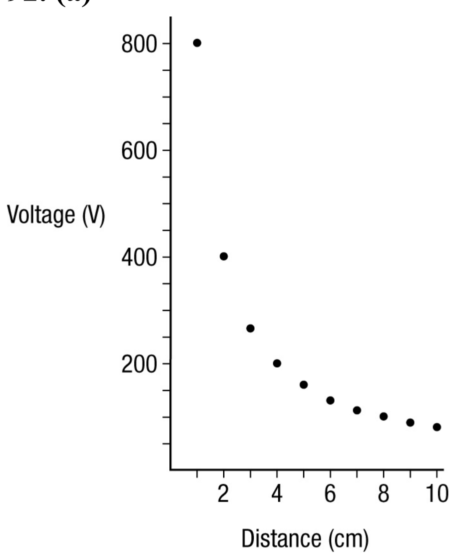
$$q = 1.2\ \text{nC}$$

Statement: The magnitude of the charge is 1.2 nC.

Evaluation

91. Answers may vary. Sample answer: To determine the average charge held on a small rubber balloon after the balloon has been rubbed with another type of material, I would do the following: I would calculate the mass of two identical and neutral balloons. Then I would charge them using the same number of rubs (assume equal charge). I would then tie the balloons together with string and hold the centre of the string. The balloons will repel each other, making an inverted "V" shape. I would then measure the separation distance between the balloons. To calculate the charge of each balloon, I would use force vectors. The vertical component of the string tension is equal to the weight of the balloon, and the horizontal component of tension is equal to the electrical force on the balloon.

92. (a)



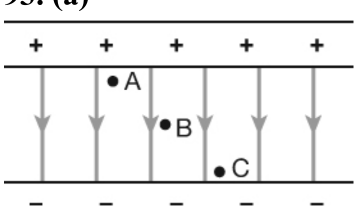
(b) At x = 2.5 cm, the electric field is about $\dfrac{320\text{ V}}{0.025\text{ m}} = 1.3 \times 10^4\text{ V/m}$.

At x = 5.5 cm, the electric field is about $\dfrac{145\text{ V}}{0.055\text{ m}} = 2.6 \times 10^3\text{ V/m}$.

At x = 8.5 cm, the electric field is about $\dfrac{95\text{ V}}{0.085\text{ m}} = 1.1 \times 10^3\text{ V/m}$.

(c) Information regarding electric field strength is useful to protect people and electronics from strong electric fields. Another real-world situation is to use electric fields to generate motion. The magnitude of the electric field is equal to the electric potential difference divided by the distance, so the graph should be of the *difference* between voltages at 1 cm intervals.

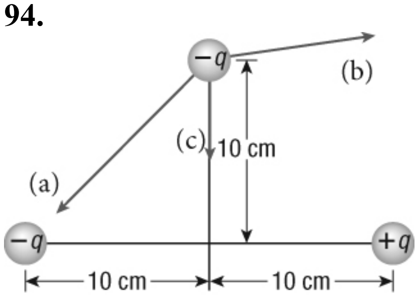
93. (a)



(b) The electrical potential energy is greatest near the positive plate at point A.

(c) The electrical potential energy is least near the negative plate at point C.

(d) The force on $+q$ is equal at all places because the electric field is uniform.
(e) Answers may vary. Sample answer: The diagram could emphasize the amount of electrical potential energy a charge would have at each distance from the top plate. This could be shown with coloured lines or with lines of different thicknesses.
94.



(a) Any pathway to the left would increase the electrical potential energy because it would be toward the other negative charge.
(b) Any pathway to the right would decrease the electrical potential energy because it would be toward the positive charge.
(c) Any pathway straight up or straight down would keep the electrical potential energy constant because it would maintain equal distances from the two charged particles.
(d) Answers may vary. Sample answer: To illustrate this concept to another student, I could use gravity. If an object takes any path such that its position is higher, the object's potential energy increases. If an object takes any path such that its position is lower, the object's potential energy decreases. Any path in which the height is constant will maintain the same potential energy.
95. Answers may vary. Sample answer: Millikan could not have been sure that the fundamental charge was the smallest value he measured. Therefore, his method was not ideal, even though he calculated the correct result.
Alternative answer: Millikan performed his experiment many times and did not calculate a smaller value for the charge, so I consider his method to be successful.

Reflect on Your Learning

96. Answers may vary. Students should discuss the topic they found most interesting, for example, how Millikan effectively counted the excess or deficiency of electrons on tiny drops of oil to calculate the fundamental charge.
97. Answers may vary. Sample answer: To explain the concept of electric fields to a friend who has not taken physics, I would relate electric fields to something more common, such as gravity. Both the electric field and the gravitational field are similar in that they radiate from a point and decrease in strength as distance increases. However, an electric field can attract as well as repel charges, depending on the signs of the charges. Gravity can only attract objects.
98. Answers may vary. Students should pick a topic relevant to them, for example, static charges or application of electric fields in everyday technology. Students should explain its importance and list methods of learning more, such as research (books or Internet) and further study in physics.

Research

99. Students should discuss the physics of the charge separation that leads to the formation of lightning: The friction between rising ice crystals and falling hail causes the hail to gain electrons from the ice crystals. The negatively charged particles collect at the bottom of the cloud while the positive particles accumulate at the top. This creates a difference in charge within the cloud and between the bottom of the cloud and the ground.

Students' answers should include a discussion of safety measures. For example, avoid being outdoors during thunderstorms when possible, avoid open water and areas of high elevation, avoid conductors such as fences and open vehicles (tractors, bicycles, etc.), avoid tall trees, and stay inside or in a car. An example of a safety precaution when inside the home is to disconnect appliances.

100. (a) Electroreception is better suited to sea creatures because seawater is a much better conductor than air. Seawater is a better conductor of electricity than air because of the dissolved salts it contains. Salt is a compound made up of sodium and chlorine atoms. When salt is dissolved in solution, the compound dissolves to form sodium and chlorine ions. These ions are charged (positive for sodium, negative for chlorine). It is these ions that allow for the conduction of electricity.

(b) Ampullae are long, jelly-filled canals on the snout of a fish that can detect electric fields in the water.

(c) Answers may vary. Students' answers will likely include the need for a controlled body of water and the difficulty of keeping a large fish in captivity while researching.

101. Students should describe the atmosphere's layers (from the Earth's surface up, they are the troposphere, stratosphere, mesosphere, thermosphere, and exosphere) and identify a technology that uses the electrical properties. For example, within the thermosphere is a layer of ionized gas (the ionosphere). This layer reflects some radio signals headed into space back to Earth. This property allows radio signals to be received beyond the horizon. Another technology that uses the electrical property of the ionosphere is the open system electrodynamic tether. The tether is usually a long and very strong cable attached to any object in space. The tether is conductive, carrying a current that can cause the object to be propelled forward or dragged, from the magnetic field of a planet or Earth. It acts like an electric motor.

102. Students should describe some of the effects of long-term exposure and identify examples of at-risk people, such as power line workers and others who work near power stations. Some possible long-term effects due to exposure to high voltage lines is an increased risk for cancer, particularly leukemia and brain cancer, and Alzheimer's.

103. Students should describe the basic workings of an ECG in terms of electrical properties. For example, an ECG is a non-invasive medical device that uses electrodes placed around the body to monitor the electric impulses around the heart. Since these impulses cause the pump action of the heart, the ECG monitors the functioning of the system that keeps your heart pumping.

104. Students should discuss how photocopiers use electrostatics to duplicate an image. For example, the photoreceptor drum is a cylinder coated with selenium or some other photoconductive material. To begin, the drum is given a positive charge. Then, a bright light is reflected off the original sheet of paper. The light then hits the rotating drum, freeing electrons. The electrons neutralize the positive charge, leaving only the areas where light was not reflected off the original (because it was dark) charged. Toner particles are attracted to the charged regions of the drum and are rolled across a blank sheet of paper, creating the photocopier image.