Answers to Multiple-Choice Problems


Solutions to Problems

17.1. Set Up: Unlike charges attract and like charges repel. In a conductor some of the negative charge is free to move. In an insulator the charge can shift position only slightly.

Solve: (a) Aluminum is a conductor and negative charge in the sphere moves away from the rod. The distribution of charge is sketched in Figure 17.1a.
(b) The charges in the nonconducting sphere displace slightly, with negative charge moving away from the rod. The distribution of charge is sketched in Figure 17.1b.

17.2. Set Up: Copper is a conductor, so some of the electrons are free to move. The positive charge on the rod attracts the negative charge in the ball. When the ball is connected to the earth by a conducting wire, charge can flow between the ball and the earth.

Solve: (a) Electrons move toward the rod. The distribution of charge is sketched in Figure 17.2a.
(b) Electrons from the earth are attracted by the region of positive charge on the ball and flow onto the ball, giving it a net negative charge. When the rod is removed, this net charge distributes uniformly over the surface of the ball, as sketched in Figure 17.2b.

17.3. Set Up: For an isolated sphere, the excess charge is uniformly distributed over the surface of the conductor. Unlike charges attract and like charges repel, and in a conductor the excess charge is free to move.

Solve: (a) The uniform distribution of charge over the surface of each sphere is sketched in Figure 17.3a.
(b) When the spheres are close to each other, the negative and positive excess charges are drawn toward each other, as shown in Figure 17.3b.
(e) When the spheres are close to each other, the excess negative charges on each sphere repel, as shown in Figure 17.3c.

![Figure 17.3](image)

**Reflect:** We will learn later in the chapter that the excess charge on a conductor is on the surface of the conductor.

### 17.4. Set Up:
Unlike charges attract and in a conductor the excess charge is free to move.

**Solve:** Negative charge in the earth is pulled to the surface beneath the charged cloud, as sketched in Figure 17.4.

![Figure 17.4](image)

### 17.5. Set Up:
The charge of one electron is \( q_e = -1.60 \times 10^{-19} \text{ C} \). 1 \( \mu \text{C} = 10^{-6} \text{ C} \); 1 nC = \( 10^{-9} \text{ C} \).

**Solve:**
(a) \( N = \frac{|Q|}{e} = \frac{2.50 \times 10^{-6} \text{ C}}{1.60 \times 10^{-19} \text{ C}} = 1.56 \times 10^{13} \) electrons
(b) \( N = \frac{|Q|}{e} = \frac{2.50 \times 10^{-9} \text{ C}}{1.60 \times 10^{-19} \text{ C}} = 1.56 \times 10^{10} \) electrons

### 17.6. Set Up:
The total charge is the number if ions times the charge of each. \( e = 1.60 \times 10^{-19} \text{ C} \).

**Solve:**
\[ N = \left( \frac{5.6 \times 10^{11}/\text{m}}{1.5 \times 10^{-2} \text{ m}} \right)(1.5 \times 10^{-19} \text{ C}) = 8.4 \times 10^{9} \text{ ions} \]
\[ Q = Ne = (8.4 \times 10^{9})(1.60 \times 10^{-19} \text{ C}) = 1.3 \times 10^{-9} \text{ C} = 1.3 \text{ nC} \]

### 17.7. Set Up:
Charge conservation requires that the total charge \( Q \) of the reactants equals the total charge of the products, \( q_a = 0 \), \( q_b = +e \) and \( q_c = -e \). He\(^{2+}\) has charge \(+2e\). X\(^{-1}\) and Y\(^{-1}\) each have charge \(-e\).

**Solve:**
(a) reactants: \( Q = +e \); products \( Q = -e \). Could not occur.
(b) reactants: \( Q = 0 \); products \( Q = +e + (-e) = 0 \). Could occur.
(c) reactants: \( Q = +2e + 2e = +4e \); products \( Q = +2e + e + 0 = +3e \). Could not occur.
(d) reactants: \( Q = +e + 2e = +3e \); products \( Q = +2e + (-e) = +e \). Could not occur.
(e) reactants: \( Q = +e + e + (-e) = +e \); products \( Q = +e + e + (-e) + (-e) = +e \). Could occur.

**Reflect:** Just because the reaction obeys charge conservation doesn’t mean it actually occurs. There could be other reasons why the reaction does not occur.

### 17.8. Set Up:
Like charges repel and unlike charges attract. \( F = \frac{k|q_1q_2|}{r^2} \).

**Solve:** \( q_1 = q_2 = +3.00 \times 10^{-6} \text{ C} \). The force is repulsive. \( F = \left( 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \right) \frac{(3.00 \times 10^{-6} \text{ C})^2}{(0.200 \text{ m})^2} = 2.02 \text{ N} \)

### 17.9. Set Up:
\( F = \frac{k|q_1q_2|}{r^2} \). An electron has charge \(-e\) and a proton has charge \(+e\), where \( e = 1.60 \times 10^{-19} \text{ C} \).

**Solve:** \( r = \sqrt{\frac{k|q_1q_2|}{F}} = \sqrt{\frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(1.60 \times 10^{-19} \text{ C})^2}{2.00 \text{ N}}} = 1.07 \times 10^{-14} \text{ m} \). Since an electron and a proton have the same magnitude of charge the distance is the same for two protons as for two electrons.
17.10. Set Up: $F = k \frac{|q| q_z}{r^2}$. Like charges repel and unlike charges attract.
Solve: (a) The force is attractive so the unknown charge $q_z$ is positive.
\[ |q_z| = \frac{Fr^2}{k|q_1|} = \frac{(0.200 \text{ N})(0.300 \text{ m})^2}{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(0.550 \times 10^{-6} \text{ C})} = 3.64 \times 10^{-6} \text{ C} = 3.64 \mu\text{C} \]
(b) The unknown charge exerts a downward force of 0.200 N on the other charge.

17.11. Set Up: The electrical force is given by Coulomb's law, with $k = 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$. A proton has charge $+e$ and an electron has charge $-e$.
Solve: (a) $F = k \frac{|q| q_z}{r^2} = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(1.60 \times 10^{-19} \text{ C})^2}{(1.00 \times 10^{-15} \text{ m})^2} = 230 \text{ N}$. Yes, this force is about 52 lbs.
(b) The force is smaller than in part (a) by a factor of \( \frac{1.00 \times 10^{-15} \text{ m}}{1.00 \times 10^{-10} \text{ m}} \) so it is $2.30 \times 10^{-8} \text{ N}$. No, this force is very small.

17.12. Set Up: One mole of carbon contains $N_c = 6.02 \times 10^{23}$ atoms. Each electron has charge $-e = -1.60 \times 10^{-19} \text{ C}$. If charge $-q$ is removed from the sphere, the sphere is left with a charge of $+q$.
Solve: (a) The number of moles is $n = \frac{1.00 \text{ g}}{12.0 \text{ g/mol}} = 8.33 \times 10^{-2} \text{ mol}$. The number of atoms is $N = nN_A = (8.33 \times 10^{-2} \text{ mol})(6.02 \times 10^{23} \text{ atoms/mol}) = 5.01 \times 10^{22} \text{ atoms}$. Each atom has 6 electrons, so the number of electrons is $N_e = 6N = 3.01 \times 10^{23} \text{ electrons}$. Each electron has charge $-e$ so the total negative charge of the electrons is $q_e = -eN_e = -(1.60 \times 10^{-19} \text{ C})(3.01 \times 10^{23}) = -4.82 \times 10^4 \text{ C}$.
(b) The sphere would be left with positive charge $q_{\text{sphere}} = +4.82 \times 10^4 \text{ C}$. The force would have magnitude
\[ F = k \frac{|q| q_{\text{sphere}}}{r^2} = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(4.82 \times 10^4 \text{ C})^2}{(1.50 \text{ m})^2} = 9.28 \times 10^{18} \text{ N} \]
This is an immense force. The charges are opposite sign so the force is attractive.

17.13. Set Up: One mole of Ca contains $N_A = 6.02 \times 10^{23}$ atoms. Each proton has charge $e = 1.60 \times 10^{-19} \text{ C}$.
Solve: (a) The mass of one hand is $(0.010 \text{ kg})(75 \text{ kg}) = 0.75 \text{ kg} = 750 \text{ g}$. The number of moles of Ca is
\[ n = \frac{750 \text{ g}}{40.18 \text{ g/mol}} = 18.7 \text{ mol} \]
The number of atoms is
\[ N = nN_A = (18.7 \text{ mol})(6.02 \times 10^{23} \text{ atoms/mol}) = 1.12 \times 10^{25} \text{ atoms}. \]
(b) Each Ca atom contains positive charge $20e$. The total positive charge in each hand is
\[ N_e = (1.12 \times 10^{25})(20)(1.60 \times 10^{-19} \text{ C}) = 3.58 \times 10^7 \text{ C}. \]
If 1.0% is unbalanced by negative charge, the net positive charge of each hand is
\[ q = (0.010)(3.58 \times 10^7 \text{ C}) = 3.6 \times 10^5 \text{ C}. \]
(c) The repulsive force each hand exerts on the other would be
\[ F = k \frac{q^2}{r^2} = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(3.6 \times 10^5 \text{ C})^2}{(1.7 \text{ m})^2} = 4.0 \times 10^{20} \text{ N} \]
This is an immense force; our hands would fly off.
Reflect: Ordinary objects contain a very large amount of charge. But negative and positive charge is present in almost equal amounts and the net charge of a charged object is always a very small fraction of the total magnitude of charge that the object contains.
17.14. Set Up:  \( F = \frac{k|q_1 q_2|}{r^2} \).

Solve: (a) \( q_1 = q_2 = q \).  \( F = k \frac{q^2}{r^2} \) and \( q = r \sqrt{\frac{F}{k}} = (0.150 \text{ m}) \sqrt{\frac{0.220 \text{ N}}{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2}} = 7.42 \times 10^{-7} \text{ C}, \)

(b) \( q_2 = 4q_1 \).  \( F = \frac{k(4q_1)^2}{r^2} \) and \( q_1 = \frac{1}{4} r \sqrt{\frac{F}{k}} = 3.71 \times 10^{-7} \text{ C}. \)  \( q_2 = 1.48 \times 10^{-6} \text{ C}. \)

17.15. Set Up: The mass of a proton is \( 1.67 \times 10^{-27} \text{ kg} \) and the charge of a proton is \( 1.60 \times 10^{-19} \text{ C} \). The distance from the earth to the moon is \( 3.84 \times 10^8 \text{ m} \). The electrical force has magnitude \( F_e = \frac{k|q_1 q_2|}{r^2} \), with \( k = 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \). The gravitational force has magnitude \( F_{\text{grav}} = G \frac{m_1 m_2}{r^2} \), with

\[ G = 6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2. \]

Solve: (a) The number of protons in each box is \( N = \frac{1.0 \times 10^{-3} \text{ kg}}{1.67 \times 10^{-27} \text{ kg}} = 5.99 \times 10^{23}. \) The total charge of each box is \( q = Ne = (5.99 \times 10^{23}) (1.60 \times 10^{-19} \text{ C}) = 9.58 \times 10^4 \text{ C} \).

\[ F_e = \frac{kq^2}{r^2} = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \left( \frac{9.58 \times 10^4 \text{ C}}{3.84 \times 10^8 \text{ m}} \right)^2 = 560 \text{ N} = 130 \text{ lb.} \]

The tension in the string must equal this repulsive electrical force. The weight of the box on earth is \( w = mg = 9.8 \times 10^{-3} \text{ N} \) and the weight of the box on the moon is even less, since \( g \) is less on the moon. The gravitational forces exerted on the boxes by the earth and by the moon are much less than the electrical force and can be neglected.

(b) \( F_{\text{grav}} = G \frac{m_1 m_2}{r^2} = \left( \frac{6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2}{1.0 \times 10^{-3} \text{ kg}} \right) \left( \frac{3.84 \times 10^8 \text{ m}}{1.60 \times 10^{-19} \text{ C}} \right)^2 = 4.5 \times 10^{-34} \text{ N} \)

Reflect: Both the electrical force and the gravitational force are proportional to \( 1/r^2 \). But in SI units the coefficient \( k \) in the electrical force is much greater than the coefficient \( G \) in the gravitational force. And a small mass of protons contains a large amount of charge. It would be impossible to put 1.0 g of protons into a small box, because of the very large repulsive electrical forces the protons would exert on each other.

17.16. Set Up: \( F = k \frac{|q_1 q_2|}{r^2} \). The charge of an electron is \( -e = -1.60 \times 10^{-19} \text{ C} \).

Solve: \( F = \frac{kq^2}{r^2} \). \( |q| = r \sqrt{\frac{F}{k}} = (0.200 \text{ m}) \sqrt{\frac{4.57 \times 10^{-31} \text{ N}}{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2}} = 1.426 \times 10^{-16} \text{ C}. \)

The number of excess electrons is \( \frac{|q|}{e} = 1.426 \times 10^{-16} \text{ C} \). \( 1.60 \times 10^{-19} \text{ C} = 891. \)

17.17. Set Up: An electron has mass \( 9.11 \times 10^{-31} \text{ kg} \) and charge \( q = -e = -1.60 \times 10^{-19} \text{ C} \). The nucleus of a hydrogen atom is a proton, with charge \( +e. F = k \frac{|q_1 q_2|}{r^2} \).

Solve: \( mg = k \frac{e^2}{r} \) gives \( r = \sqrt{\frac{ke^2}{mg}} = \sqrt{\frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) (1.60 \times 10^{-19} \text{ C})^2}{(9.11 \times 10^{-31} \text{ kg}) (9.80 \text{ m/s}^2)}} = 5.08 \text{ m.} \)

Reflect: The electrical force is much stronger than the gravitational force. The electrical binding force within the atom is much larger than the weight of the electron.

17.18. Set Up: A proton has charge \( +e \) and an electron has charge \( -e \), with \( e = 1.60 \times 10^{-19} \text{ C} \). The force between them has magnitude \( F = k \frac{|q_1 q_2|}{r^2} = k \frac{e^2}{r^2} \) and is attractive since the charges have opposite sign. A proton has mass \( m_p = 1.67 \times 10^{-27} \text{ kg} \) and an electron has mass \( 9.11 \times 10^{-31} \text{ kg} \). The acceleration is related to the net force \( \ddot{F} \) by \( \ddot{F} = ma. \)
Solve: \[ F = k \frac{e^2}{r^2} = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \frac{(1.60 \times 10^{-19} \text{ C})^2}{(2.0 \times 10^{-10} \text{ m})^2} = 5.75 \times 10^{-9} \text{ N} \]

proton: \[ a_p = \frac{F}{m_p} = \frac{5.75 \times 10^{-9} \text{ N}}{1.67 \times 10^{-27} \text{ kg}} = 3.4 \times 10^{18} \text{ m/s}^2 \]

electron: \[ a_e = \frac{F}{m_e} = \frac{5.75 \times 10^{-9} \text{ N}}{9.11 \times 10^{-31} \text{ kg}} = 6.3 \times 10^{21} \text{ m/s}^2 \]

The proton has an initial acceleration of \(3.4 \times 10^{18} \text{ m/s}^2\) toward the electron and the electron has an initial acceleration of \(6.3 \times 10^{21} \text{ m/s}^2\) toward the proton. Note that the force the electron exerts on the proton is equal in magnitude to the force the proton exerts on the electron, but the accelerations produced by this force are different because the masses are different.

17.19. Set Up: \(a = 25.0g = 245 \text{ m/s}^2\). \(F = ma\), with \(F = k \frac{|q_1 q_2|}{r^2}\). An electron has charge \(-e = -1.60 \times 10^{-19} \text{ C}\).

Solve: \( F = ma = (8.55 \times 10^{-3} \text{ kg})(245 \text{ m/s}^2) = 2.09 \text{ N}\). The spheres have equal charges \(q\), so \(F = k \frac{q^2}{r^2}\) and \(|q| = r \sqrt{\frac{F}{k}} = (0.150 \text{ m}) \sqrt{\frac{2.09 \text{ N}}{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2}} = 2.29 \times 10^{-6} \text{ C}\).

\(N = \frac{|q|}{e} = \frac{2.29 \times 10^{-6} \text{ C}}{1.60 \times 10^{-19} \text{ C}} = 1.43 \times 10^{13} \text{ electrons}\). The charges on the spheres have the same sign so the electrical force is repulsive and the spheres accelerate away from each other.

Reflect: As the spheres move apart the repulsive force they exert on each other decreases and their acceleration decreases.

17.20. Set Up: \(q_e = -1.60 \times 10^{-19} \text{ C}\). \(q_p = +1.60 \times 10^{-19} \text{ C}\). The net force is the vector sum of the forces exerted by each electron. Each force is attractive so is directed toward the electron that exerts it.

Solve: Each force has magnitude
\[ F_1 = F_2 = k \frac{|q_1 q_2|}{r^2} = k \frac{e^2}{r^2} = \frac{(8.988 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(1.60 \times 10^{-19} \text{ C})^2}{(1.50 \times 10^{-10} \text{ m})^2} = 1.023 \times 10^{-8} \text{ N}\]

The vector force diagram is shown in Figure 17.20.
17.21. Set Up: $F = k \frac{|q_1 q_2|}{r^2}$. Like charges repel and unlike charges attract. The charges and their forces on $q_3$ are shown in Figure 17.21.

![Figure 17.21](image)

Solve: $F_1 = k \frac{|q_1 q_3|}{r_1^2} = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \left( \frac{1.50 \times 10^{-9} \text{ C}}{(0.200 \text{ m})^2} \right) (5.00 \times 10^{-9} \text{ C}) = 1.69 \times 10^{-6} \text{ N}$.

$F_2 = k \frac{|q_2 q_3|}{r_2^2} = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \left( \frac{3.20 \times 10^{-9} \text{ C}}{(0.400 \text{ m})^2} \right) (5.00 \times 10^{-9} \text{ C}) = 8.99 \times 10^{-7} \text{ N}$.

$\vec{F}_1$ and $\vec{F}_2$ are in the same direction so $F = F_1 + F_2 = 2.59 \times 10^{-6} \text{ N}$ and the net force is in the $-y$ direction.

Reflect: The forces are vectors and must be added as vectors. We add the forces by adding their magnitudes only because the two force vectors are in the same direction.

17.22. Set Up: $F = k \frac{|q_1 q_2|}{r^2}$. Like charges repel and unlike charges attract. The charges and their forces on $q_3$ are shown in Figure 17.22.

![Figure 17.22](image)
Solve: \( F_1 = k \frac{|q_1 q_2|}{r_1^2} = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \frac{(4.00 \times 10^{-9} \text{ C})(0.600 \times 10^{-9} \text{ C})}{(0.200 \text{ m})^2} = 5.394 \times 10^{-7} \text{ N}. \)

\( F_2 = k \frac{|q_2 q_3|}{r_2^2} = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \frac{(5.00 \times 10^{-9} \text{ C})(0.600 \times 10^{-9} \text{ C})}{(0.300 \text{ m})^2} = 2.997 \times 10^{-7} \text{ N}. \)

\( F_x = F_{1x} + F_{2x} = +F_1 - F_2 = 2.40 \times 10^{-7} \text{ N}. \) The net force has magnitude \( 2.40 \times 10^{-7} \text{ N} \) and is in the +x direction.

17.23. Set Up: \( F = k \frac{|q q'|}{r^2} \). Like charges repel and unlike charges attract. The charges and the forces on the charges \( q_1 \) and \( q_2 \) in the dipole are shown in Figure 17.23. Use the coordinates shown. \( \sin \theta = \frac{1.50 \text{ cm}}{2.00 \text{ cm}} \) and \( \theta = 48.6^\circ \).

![Figure 17.23](image)

Solve: \( F_1 = F_2 = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \frac{(5.00 \times 10^{-6} \text{ C})(10.0 \times 10^{-6} \text{ C})}{(0.0200 \text{ m})^2} = 1.124 \times 10^3 \text{ N}. \)

\( F_y = F_{1y} = 0, F_y = F_{1y} + F_{2y} = -2F_1 \sin \theta = -2(1.124 \times 10^3 \text{ N}) \frac{1.50 \text{ cm}}{2.00 \text{ cm}} = -1.69 \times 10^3 \text{ N}. \)

The net force has magnitude \( 1.69 \times 10^3 \text{ N} \) and is in the direction from the +5.00 \( \mu \text{C} \) to the −5.00 \( \mu \text{C} \) charge.

(b) \( F_{1z} \) and \( F_{2z} \) each produce clockwise torques and each have a moment arm of 1.50 cm. \( F_{1z} \) and \( F_{2z} \) each have zero moment arm and produce no torque.

\[ \tau = 2F_{1z}(0.0150 \text{ m}) = 2F_1 \cos \theta (0.0150 \text{ m}) = 2(1.124 \times 10^3 \text{ N})(\cos 48.6^\circ)(0.0150 \text{ m}) = 22.3 \text{ N} \cdot \text{m} \]

The torque is clockwise.

Reflect: The \( x \) components of the two forces are in opposite directions so they cancel and the net force has no \( x \) component. But the torques of \( F_{1z} \) and \( F_{2z} \) are in the same direction and therefore produce a net torque.
17.24. **Set Up:** In the O-H-N combination the O\(^-\) is 0.170 nm from the H\(^+\) and 0.280 nm from the N\(^-\). In the N-H-N combination the N\(^-\) is 0.190 nm from the H\(^+\) and 0.300 nm from the other N\(^-\). Like charges repel and unlike charges attract. The net force is the vector sum of the individual forces.

**Solve:** (a) \( F = k \frac{|q_1 q_2|}{r^2} = k \frac{e^2}{r^2} \)

**O-H-N**

\[
\begin{align*}
O^- - H^+ & \quad F = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \left( \frac{1.60 \times 10^{-19} \text{ C}^2}{0.170 \times 10^{-9} \text{ m}^2} \right) = 7.96 \times 10^{-9} \text{ N}, \text{ attractive} \\
O^- - N^- & \quad F = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \left( \frac{1.60 \times 10^{-19} \text{ C}^2}{0.280 \times 10^{-9} \text{ m}^2} \right) = 2.94 \times 10^{-9} \text{ N}, \text{ repulsive}
\end{align*}
\]

**N-H-N**

\[
\begin{align*}
N^- - H^+ & \quad F = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \left( \frac{1.60 \times 10^{-19} \text{ C}^2}{0.190 \times 10^{-9} \text{ m}^2} \right) = 6.38 \times 10^{-9} \text{ N}, \text{ attractive} \\
N^- - N^- & \quad F = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \left( \frac{1.60 \times 10^{-19} \text{ C}^2}{0.300 \times 10^{-9} \text{ m}^2} \right) = 2.56 \times 10^{-9} \text{ N}, \text{ repulsive}
\end{align*}
\]

The total attractive force is \(1.43 \times 10^{-8} \text{ N}\) and the total repulsive force is \(5.50 \times 10^{-9} \text{ N}\). The net force is attractive and has magnitude \(1.43 \times 10^{-8} \text{ N} - 5.50 \times 10^{-9} \text{ N} = 8.80 \times 10^{-9} \text{ N}\).

(b) \( F = k \frac{e^2}{r^2} = \left( 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \right) \left( \frac{1.60 \times 10^{-19} \text{ C}^2}{0.0529 \times 10^{-9} \text{ m}^2} \right) = 8.22 \times 10^{-8} \text{ N} \)

The bonding force of the electron in the hydrogen atom is a factor of 10 larger than the bonding force of the adenine-thymine molecules.

17.25. **Set Up:** In the O-H-O combination the O\(^-\) is 0.180 nm from the H\(^+\) and 0.290 nm from the other O\(^-\). In the N-H-N combination the N\(^-\) is 0.190 nm from the H\(^+\) and 0.300 nm from the other N\(^-\). In the O-H-N combination the O\(^-\) is 0.180 nm from the H\(^+\) and 0.290 nm from the other N\(^-\). Like charges repel and unlike charges attract. The net force is the vector sum of the individual forces.

**Solve:** \( F = k \frac{|q_1 q_2|}{r^2} = k \frac{e^2}{r^2} \). The attractive forces are: O\(^-\) - H\(^+\), \( 7.10 \times 10^{-9} \text{ N} \); N\(^-\) - H\(^+\), \( 6.37 \times 10^{-9} \text{ N} \); O\(^-\) - H\(^+\), \( 7.10 \times 10^{-9} \text{ N} \). The total attractive force is \(2.06 \times 10^{-8} \text{ N}\). The repulsive forces are: O\(^-\) - O\(^-\), \( 2.74 \times 10^{-9} \text{ N} \); N\(^-\) - N\(^-\), \( 2.56 \times 10^{-9} \text{ N} \); O\(^-\) - N\(^-\), \( 2.74 \times 10^{-9} \text{ N} \). The total repulsive force is \(8.04 \times 10^{-9} \text{ N}\). The net force is attractive and has magnitude \(1.26 \times 10^{-8} \text{ N}\).

17.26. **Set Up:** Like charges repel and unlike charges attract. The force increases as the distance between the charges decreases.

**Solve:** The forces on the dipole that is between the slanted dipoles are sketched in Figure 17.26a. The forces are attractive because the + and - charges of the two dipoles are closest. The forces are toward the slanted dipoles so have a net upward component. In Figure 17.26b, in adjacent dipoles charges of opposite sign are closer than charges of the same sign so the attractive forces are larger than the repulsive forces and the dipoles attract.

![Figure 17.26](b)
17.27. **Set Up:** The central charge will be 1.85 nm from the charge on the left and 1.15 nm from the charge on the right. Like charges repel. The force diagram for the central charge is given in Figure 17.27.

\[ \text{Figure 17.27} \]

Solve: \( F_1 = \frac{k(2e)^2}{r_1^2} = \left( 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \right) \left( \frac{4(1.60 \times 10^{-19} \text{ C})^2}{(1.85 \times 10^{-9} \text{ m})^2} \right) = 2.690 \times 10^{-10} \text{ N} \)

\[ F_2 = \frac{k(2e)^2}{r_2^2} = \left( 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \right) \left( \frac{4(1.60 \times 10^{-19} \text{ C})^2}{(1.15 \times 10^{-9} \text{ m})^2} \right) = 6.961 \times 10^{-10} \text{ N} \]

The net force is 4.27 \times 10^{-10} \text{ N}, to the left.

**Reflect:** The electrical forces are vectors and must be added as vectors. At the initial position of the central charge the net force on it is zero. If the central charge is displaced in either direction, the net force on it is in the direction that pushes it back toward the equilibrium position.

17.28. **Set Up:** \( F = \frac{k|q_1q_2|}{r^2} \). The new charges are \( q'_1 = 2q_1 \) and \( q'_2 = 2q_2 \).

Solve: The new force is \( F' = k\frac{|q'_1q'_2|}{r'^2} = k\frac{|2q_12q_2|}{r^2} = 4k\frac{|q_1q_2|}{r^2} = 4F \).

17.29. **Set Up:** \( F = \frac{k|q_1q_2|}{D^2} \). Initially, \( r = D \) and \( F = \frac{k|q_1q_2|}{D^2} \). The new separation is \( r' \). The new force is \( F' = 3F \).

Solve: \( F' = k\frac{|q_1q_2|}{(r')^2} = 3k\frac{|q_1q_2|}{D^2} \), so \( \frac{1}{(r')^2} = \frac{3}{D^2} \) and \( r' = D/\sqrt{3} \).

**Reflect:** The force is proportional to \( 1/r^2 \), so a decrease in \( r \) increases the force.

17.30. **Set Up:** If the new acceleration \( a' \) equals \( a/5 \) then the new force \( F' \) equals \( F/5 \). \( F = \frac{k|q_1q_2|}{r^2} \). Initially, \( r = d \) and \( F = \frac{k|q_1q_2|}{d^2} \). The new separation is \( r' \).

Solve: \( F' = k\frac{|q_1q_2|}{(r')^2} = \frac{1}{5} k\frac{|q_1q_2|}{d^2} \), so \( r' = d/\sqrt{5} \).

17.31. **Set Up:** \( \vec{F} = q\vec{E} \). A proton has charge \( q = +e = +1.60 \times 10^{-19} \text{ C} \).

Solve: (a) \( F = |q|E, E = \frac{F}{|q|} = \frac{20.0 \times 10^{-9} \text{ N}}{8.00 \times 10^{-9} \text{ C}} = 2.50 \text{ N/C} \). Since the charge is negative, the force and electric field are in opposite directions and the electric field is upward.

(b) \( F = |q|E = eE = \left( 1.60 \times 10^{-19} \text{ C} \right) \left( 2.50 \text{ N} \right) = 4.00 \times 10^{-19} \text{ N} \). The charge is positive so the force is in the same direction as the electric field; the force is upward.
17.32. Set Up: \( \mathbf{F} = q \mathbf{E} \). A proton has charge \( q = +e = +1.60 \times 10^{-19} \text{ C} \) and mass \( m = 1.67 \times 10^{-27} \text{ kg} \).

Solve: (a) The gravity force is downward so the electrical force must be upward. An upward force from a downward electric field requires a negative charge. \( \frac{|q| mg}{E} = \frac{(1.45 \times 10^{-3} \text{ kg})(9.80 \text{ m/s}^2)}{650 \text{ N/C}} = 2.19 \times 10^{-5} \text{ C} \).

The charge is \( q = -2.19 \times 10^{-5} \text{ C} \).

(b) \( mg = eE \). \( E = \frac{mg}{e} = \frac{(1.67 \times 10^{-27} \text{ kg})(9.80 \text{ m/s}^2)}{1.60 \times 10^{-19} \text{ C}} = 1.02 \times 10^{-7} \text{ N/C} \)

17.33. Set Up: Use the coordinates shown in Figure 17.33. Since the electric field is uniform, the force is constant and the acceleration is constant. \( \mathbf{F} = q \mathbf{E} \) and \( \mathbf{F} = ma \). \( v_{0y} = 0 \). For an electron, \( q = -e = -1.60 \times 10^{-19} \text{ C} \) and \( m = 9.11 \times 10^{-31} \text{ kg} \).

![Figure 17.33]

Solve: (a) \( y = v_{0y}t + \frac{1}{2}a_y t^2 \). \( a_y = \frac{2y}{t^2} = \frac{2(3.20 \times 10^{-2} \text{ m})}{(1.5 \times 10^{-8} \text{ s})^2} = 2.84 \times 10^{14} \text{ m/s}^2 \).

\( F_y = ma_y = (9.11 \times 10^{-31} \text{ kg})(2.84 \times 10^{14} \text{ m/s}^2) = 2.59 \times 10^{-16} \text{ N} \).

\( E_y = \frac{F_y}{|q|} = \frac{2.59 \times 10^{-16} \text{ N}}{1.60 \times 10^{-19} \text{ C}} = 1.62 \times 10^3 \text{ N/C} \) and \( E = 1.62 \times 10^3 \text{ N/C} \).

(b) \( v_y = v_{0y} + a_y t = 0 + (2.84 \times 10^{14} \text{ m/s}^2)(1.5 \times 10^{-8} \text{ s}) = 4.26 \times 10^6 \text{ m/s} \)

Reflect: We could also use the work-energy theorem and set the work done by the force equal to the gain in kinetic energy of the electron.

17.34. Set Up: For a point charge, \( E = k \frac{|q|}{r^2} \). \( \mathbf{E} \) is toward a negative charge and away from a positive charge.

Solve: (a) The field is toward the negative charge so is downward.

\( E = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \frac{3.00 \times 10^{-9} \text{ C}}{(0.250 \text{ m})^2} = 432 \text{ N/C} \).

(b) \( r = \sqrt{\frac{k|q|}{E}} = \sqrt{\frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(3.00 \times 10^{-9} \text{ C})}{12.0 \text{ N/C}}} = 1.50 \text{ m} \)

17.35. Set Up: For a point charge, \( E = k \frac{|q|}{r^2} \).

Solve: \( |q| = \frac{Er^2}{k} = \frac{(6.50 \times 10^3 \text{ N/C})(0.100 \text{ m})^2}{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2} = 7.23 \times 10^{-9} \text{ C} \)
17.36. Set Up: For a point charge, \( E = \frac{k|q|}{r^2} \).

Solve: \( r = \sqrt[2]{\frac{k|q|}{E}} = \sqrt[2]{\frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) (5.00 \times 10^{-9} \text{ C})}{4.00 \text{ N/C}}} = 3.35 \text{ m} \)

17.37. Set Up: The electric field of a point charge has magnitude \( E = k \frac{|q|}{r^2} \). A proton has charge \( q = e = 1.60 \times 10^{-19} \text{ C} \).

Solve: (a) \( E = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) 1.60 \times 10^{-19} \text{ C}}{(5.0 \times 10^{-13} \text{ m})^2} = 5.8 \times 10^{19} \text{ N/C} \)

(b) \( E = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) 1.60 \times 10^{-19} \text{ C}}{(5.0 \times 10^{-10} \text{ m})^2} = 5.8 \times 10^9 \text{ N/C} \)

Reflect: The electric fields inside atoms are very large.

17.38. Set Up: The weight of an electron is \( w = mg \), with \( m = 9.11 \times 10^{-31} \text{ kg} \). The magnitude of the force on the electron due to the electric field is \( F_e = |q|E = eE \). In part (b), the electric field of a proton at a distance \( r \) from the proton is \( E = k \frac{e}{r^2} \).

Solve: (a) \( w = F_e \) gives \( mg = eE \) and \( E = \frac{mg}{e} = \frac{(9.11 \times 10^{-31} \text{ kg}) (9.80 \text{ m/s}^2)}{1.60 \times 10^{-19} \text{ C}} = 5.58 \times 10^{-11} \text{ N/C} \).

(b) \( E = k \frac{e}{r^2} \) so \( r = \sqrt[2]{\frac{k e}{E}} = \sqrt[2]{\frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) (1.60 \times 10^{-19} \text{ C})}{5.58 \times 10^{-11} \text{ N/C}}} = 5.08 \text{ m} \)

17.39. Set Up: If the axon is modeled as a point charge, its electric field is \( E = k \frac{q}{r^2} \). The electric field of a point charge is directed away from the charge if it is positive.

Solve: (a) \( 5.6 \times 10^{10} \text{ Na}^+ \) ions enter per meter so in a 0.10 mm = 1.0 \( \times \) 10^-4 m section, \( 5.6 \times 10^7 \text{ Na}^+ \) ions enter. This number of ions has charge \( q = (5.6 \times 10^7) (1.60 \times 10^{-19} \text{ C}) = 9.0 \times 10^{-12} \text{ C} \).

(b) \( E = k \frac{q}{r^2} = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) 9.0 \times 10^{-12} \text{ C}}{(5.00 \times 10^{-2} \text{ m})^2} = 32 \text{ N/C}, \text{ directed away from the axon} \).

(c) \( r = \sqrt[2]{\frac{k q}{E}} = \sqrt[2]{\frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) (9.0 \times 10^{-12} \text{ C})}{1.0 \times 10^{-6} \text{ N/C}}} = 280 \text{ m} \)

17.40. Set Up: The electric field of a negative charge is directed toward the charge. \( E = k \frac{|q|}{r^2} \). The net field is the vector sum of the fields produced by each charge. Point A is 0.100 m from \( q_2 \) and 0.150 m from \( q_1 \). Point B is 0.100 m from \( q_1 \) and 0.350 m from \( q_2 \). A charge \( q \) in an electric field \( \vec{E} \) experiences a force \( \vec{F} = q\vec{E} \).

Figure 17.40
Solve: (a) The electric fields due to the charges at point A are shown in Figure 17.40a.

\[ E_1 = k \frac{|q_1|}{r_{1A}^2} = \left( 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \right) \left( 4.00 \times 10^{-9} \text{ C} \right) \left( 0.200 \text{ m} \right)^2 = 899 \text{ N/C} \]

\[ E_2 = k \frac{|q_2|}{r_{2A}^2} = \left( 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \right) \left( 6.00 \times 10^{-9} \text{ C} \right) \left( 0.600 \text{ m} \right)^2 = 150 \text{ N/C} \]

Since the two fields are in opposite directions, we subtract their magnitudes to find the net field. \( E = E_2 - E_1 = 8.74 \times 10^3 \text{ N/C} \), to the right.

(b) The electric fields at points B are shown in Figure 17.40b.

\[ E_1 = k \frac{|q_1|}{r_{1B}^2} = \left( 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \right) \left( 4.00 \times 10^{-9} \text{ C} \right) \left( 0.200 \text{ m} \right)^2 = 899 \text{ N/C} \]

\[ E_2 = k \frac{|q_2|}{r_{2B}^2} = \left( 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \right) \left( 6.00 \times 10^{-9} \text{ C} \right) \left( 0.400 \text{ m} \right)^2 = 337 \text{ N/C} \]

Since the fields are in the same direction, we add their magnitudes to find the net field. \( E = E_1 + E_2 = 6.54 \times 10^3 \text{ N/C} \), to the right.

(c) At A, \( E = 8.74 \times 10^3 \text{ N/C} \), to the right. The force on a proton placed at this point would be \( F = qE = \left( 1.60 \times 10^{-19} \text{ C} \right) \left( 8.74 \times 10^3 \text{ N/C} \right) = 1.40 \times 10^{-15} \text{ N} \), to the right.

17.41. Set Up: For a point charge, \( E = k \frac{|q|}{r^2} \). \( \vec{E} \) is directed toward a negative charge and away from a positive charge. Let the points \( a \), \( b \) and \( c \) be the locations where the field is calculated in parts (a), (b) and (c). The three points and the electric fields produced at those points by each of the two charges are shown in Figure 17.41.

\[ E_1 = \frac{k|q|}{r_{1A}^2} = \frac{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \left( 4.00 \times 10^{-9} \text{ C} \right)}{(0.200 \text{ m})^2} = 899 \text{ N/C} \]

\[ E_2 = \frac{k|q|}{r_{2A}^2} = \frac{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \left( 6.00 \times 10^{-9} \text{ C} \right)}{(0.600 \text{ m})^2} = 150 \text{ N/C} \]

\( E_x = E_{1x} + E_{2x} = -899 \text{ N/C} + (-150 \text{ N/C}) = -1049 \text{ N/C} \). The field is 1050 N/C, in the \(-x\) direction.

\[ E_1 = \frac{k|q|}{r_{1B}^2} = \frac{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \left( 4.00 \times 10^{-9} \text{ C} \right)}{(1.20 \text{ m})^2} = 25.0 \text{ N/C} \]

\[ E_2 = \frac{k|q|}{r_{2B}^2} = \frac{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \left( 6.00 \times 10^{-9} \text{ C} \right)}{(0.400 \text{ m})^2} = 337 \text{ N/C} \]

\( E_x = E_{1x} + E_{2x} = -250.0 \text{ N/C} + 337 \text{ N/C} = 312 \text{ N/C} \). The field is 312 N/C, in the \(+x\) direction.

\[ E_1 = \frac{k|q|}{r_{1C}^2} = \frac{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \left( 4.00 \times 10^{-9} \text{ C} \right)}{(0.200 \text{ m})^2} = 899 \text{ N/C} \]

\[ E_2 = \frac{k|q|}{r_{2C}^2} = \frac{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \left( 6.00 \times 10^{-9} \text{ C} \right)}{(1.00 \text{ m})^2} = 53.9 \text{ N/C} \]

\( E_x = E_{1x} + E_{2x} = 899 \text{ N/C} + (-53.9 \text{ N/C}) = 845 \text{ N/C} \). The field is 845 N/C, in the \(+x\) direction.

Reflect: In each case the two electric fields must be added as vectors.
17.42. **Set Up:** For a point charge, $E = k\frac{|q|}{r^2}$ is toward a negative charge and away from a positive charge. The two charges and their fields at each point are shown in Figures 17.42a-d.

**Figure 17.42**

(a) $E_1$ and $E_2$ are in opposite directions, so the resultant electric field is zero. $E_x = E_y = E = 0$.

(b) $E_1 = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \frac{6.00 \times 10^{-9} \text{ C}}{(0.150 \text{ m})^2} = 2397 \text{ N/C}$

$$E_x = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \frac{6.00 \times 10^{-9} \text{ C}}{(0.450 \text{ m})^2} = 266 \text{ N/C}$$

$c$ $d$

(c) $E_1 = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \frac{6.00 \times 10^{-9} \text{ C}}{(0.400 \text{ m})^2} = 337 \text{ N/C}$. $E_{1x} = 0$, $E_{1y} = -337 \text{ N/C}$.

$E_2 = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \frac{6.00 \times 10^{-9} \text{ C}}{(0.500 \text{ m})^2} = 216 \text{ N/C}$. $\theta = 53.1^\circ$. $E_{2x} = E_2 \cos \theta = 130 \text{ N/C}$.

$E_{2y} = -E_2 \sin \theta = -173 \text{ N/C}$.

$E_y = E_{1y} + E_{2y} = 0 + 130 \text{ N/C} = +130 \text{ N/C}$.

$E_y = E_{1y} + E_{2y} = -337 \text{ N/C} - 173 \text{ N/C} = -510 \text{ N/C}$.

$E = \sqrt{E_x^2 + E_y^2} = 526 \text{ N/C}$.

(d) $\theta = 53.1^\circ$. $E_1 = E_2 = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \frac{6.00 \times 10^{-9} \text{ C}}{(0.250 \text{ m})^2} = 863 \text{ N/C}$.

$E = E_{1y} + E_{2y} = 0$. $E_y = E_{1y} + E_{2y} = 2E_1 \sin \theta = 2(863 \text{ N/C}) \sin 53.1^\circ = 1380 \text{ N/C}$. $\vec{E}$ has magnitude 1380 N/C and is in the $+y$ direction.
17.43. **Set Up:** For a point charge, \( E = k \frac{|q|}{r^2} \). \( \vec{E} \) is toward a negative charge and away from a positive charge. Let \( q_1 = +0.500 \text{ nC} \) and \( q_2 = +8.00 \text{ nC} \). For the net electric field to be zero, \( \vec{E}_1 \) and \( \vec{E}_2 \) must have equal magnitudes and opposite directions.

**Figure 17.43**

**Solve:** The two charges and the directions of their electric fields in three regions are shown in Figure 17.43a. Only in region II are the two electric fields in opposite directions. Consider a point a distance \( x \) from \( q_1 \) so a distance \( 1.20 \text{ m} - x \) from \( q_2 \). \( E_1 = E_2 \) gives \( k \frac{0.500 \text{ nC}}{x^2} = k \frac{8.00 \text{ nC}}{(1.20 - x)^2} \). \( 16x^2 = (1.20 m - x)^2 \). \( 4x = \pm (1.20 m - x) \) and \( x = 0.24 \text{ m} \) is the positive solution. The electric field is zero at a point between the two charges, 0.24 m from the 0.500 nC charge.

(b) Let \( q_2 = -8.00 \text{ nC} \) be the negative charge. The two charges and the directions of their electric fields in three regions are shown in Figure 17.43b. \( \vec{E}_1 \) and \( \vec{E}_2 \) are in opposite directions in regions I and III. But for the magnitudes of the fields to be equal the point must be closer to the charge \( q_1 \) that has smaller magnitude, and that occurs only for region I. Consider a point a distance \( x \) to the left of \( q_1 \) so \( 1.20 m + x \) from \( q_2 \). \( E_1 = E_2 \) gives \( k \frac{0.500 \text{ nC}}{x^2} = k \frac{8.00 \text{ nC}}{(1.20 + x)^2} \). \( 16x^2 = (1.20 m + x)^2 \). \( 4x = \pm (1.20 m + x) \) and \( x = 0.40 \text{ m} \) is the positive solution. The electric field is zero at a point 0.40 m from \( q_1 \) and 1.60 m from \( q_2 \).

**Reflect:** In each case there is only one point along the line connecting the two charges where the net electric field is zero.

17.44. **Set Up:** The electric field of a negative charge is directed toward the charge. \( E = k \frac{|q|}{r^2} \). The net field is the vector sum of the fields due to each charge. Label the charges \( q_1 \), \( q_2 \) and \( q_3 \), as shown in Figure 17.44a. This figure also shows additional distances and angles. The electric fields at point \( P \) are shown in Figure 17.44b. This figure also shows the \( xy \) coordinates we will use and the \( x \) and \( y \) components of the fields \( \vec{E}_1 \), \( \vec{E}_2 \) and \( \vec{E}_3 \).

**Figure 17.44**
Solve: \( E_1 = E_3 = \frac{5.00 \times 10^{-6} \text{C}}{(0.100 \text{ m})^2} = 4.49 \times 10^6 \text{N/C} \)

\[ E_2 = \frac{2.00 \times 10^{-6} \text{C}}{(0.0600 \text{ m})^2} = 4.99 \times 10^6 \text{N/C} \]

\[ E_1 = E_{2y} + E_{3y} = 0 \text{ and } E_3 = E_1 x + E_{2x} + E_{3x} = E_2 + 2E_1 \cos 53.1^\circ = 1.04 \times 10^7 \text{N/C} \]

\[ E = 1.04 \times 10^7 \text{N/C}, \text{ toward the } -2.00 \mu \text{C charge.} \]

17.45. Set Up: The force on a charge \( q \) that is in an electric field \( \vec{E} \) is \( \vec{F} = q \vec{E} \).

Solve: (a) The force on \( +q \) is \( F_+ = qE \), to the right. The force on \( -q \) is \( F_- = qE \), to the left. The net force on the dipole is zero.

(b) The axis is at the midpoint of the line connecting the charges, and perpendicular to the plane of the figure. The torque is zero when each force, \( F_+ \) and \( F_- \), has zero moment arm. This is the case for \( \theta = 0^\circ \) and \( \theta = 180^\circ \), as shown in Figure 17.45a and b.

![Figure 17.45](image)

(c) For \( \theta \) slightly greater than zero, as shown in Figure 17.45c, the torque on the dipole is clockwise and is directed so as to return the dipole to the equilibrium position. For \( \theta \) slightly less than zero the torque is counterclockwise and again tends to rotate the dipole back to its equilibrium position. The \( \theta = 0^\circ \) position of Figure 17.45a is a stable orientation.

For \( \theta \) slightly less than \( 180^\circ \) (Figure 17.45d), the net torque on the dipole rotates it away from the \( \theta = 180^\circ \) equilibrium position. The same is true for \( \theta \) slightly greater than \( 180^\circ \). The \( \theta = 180^\circ \) position of Figure 17.45b is an unstable orientation.

(d) The electric field of the dipole is directed from the positive charge and toward the negative charge. Thus, in Figure 17.45a the electric field of the dipole is to the left, opposite to the direction of the external field.

Reflect: For any orientation of the dipole the net force on the dipole is zero. But only for \( \theta = 0^\circ \) and \( \theta = 180^\circ \) is the net torque zero.
17.46. **Set Up:** \( \vec{F} = q \vec{E} \), \( \tau = Fl \), where \( l \) is the moment arm. The forces and moment arms are shown in Figure 17.46. The axis is at the midpoint of the line connecting the charges, and perpendicular to the page.

![Figure 17.46](image)

**Solve:** \( F_+ = F_- = |q|E = (2.50 \times 10^{-6} \text{ C})(7800 \text{ N/C}) = 1.95 \times 10^{-2} \text{ N} \)

\( I_+ = I_- = (1.75 \text{ nm}) \sin 30^\circ = 8.75 \times 10^{-10} \text{ m} \)

Each force produces a clockwise torque, so the net torque is

\[ \tau = \tau_+ + \tau_- = 2\tau_+ = 2(1.95 \times 10^{-2} \text{ N})(8.75 \times 10^{-10} \text{ m}) = 3.4 \times 10^{-11} \text{ N \cdot m} \]

The net torque is \( 3.4 \times 10^{-11} \text{ N \cdot m}, \) clockwise.

17.47. **Set Up:** \( E = \frac{k|q|}{r^2} \)

**Solve:** (a) For \( r_1 = 1.0 \text{ cm}, \) \( E_1 = E = \frac{k|q|}{r_1^2}, \) \( r_2 = 2r_1, \) \( E_2 = \frac{k|q|}{(2r_1)^2} = \frac{1}{4} \frac{k|q|}{r_1^2} = E/4 \)

(b) Now \( r_3 = 3r_1, \) \( E_3 = \frac{k|q|}{(3r_1)^2} = \frac{1}{9} \frac{k|q|}{r_1^2} = E/9 \)

17.48. **Set Up:** \( E = \frac{k|Q|}{R^2} \)

**Solve:** For \( r = R, \) \( E = \frac{k|Q|}{R^2}, \) \( E_2 = \frac{k|Q|}{r_2^2}, \) \( E_2 = E/10, \) so \( r_2 = \sqrt{\frac{k|Q|}{E_2}} = \sqrt{\frac{k|Q|}{E/10}} = \sqrt{10} \sqrt{\frac{k|Q|}{R^2}} = \sqrt{10}R \)

17.49. **Set Up:** Electric fields come out of positive charge and go into negative charge. The electric field is stronger where the electric field lines are closer together.

**Solve:** (a) The field lines go from \( B \) to \( A, \) so \( B \) must be positive and \( A \) must be negative.

(b) The field lines are closer together near \( A, \) so the electric field has greater magnitude near \( A. \)
17.50. Set Up: The proton has charge $+e$ and the electron has charge $-e$. The electric field of a point charge is directed away from the charge if it is positive and toward the point charge if it is negative. Use coordinates where the $x$ axis is along line $ABC$ and the $+x$ direction is toward $C$ and where the $+y$ direction is toward the proton. The electric fields due to each charge at $A$, $B$ and $C$ are sketched in Figure 17.50.

![Figure 17.50](image)

Solve: (a) At point $A$ the $x$ components of the fields cancel and the net field is in the $-y$ direction. 
(b) At $B$ both fields are in the $-y$ direction and the net field is in the $-y$ direction. 
(c) At $C$, as at $A$, the $x$ component of the fields cancel and the net field is in the $-y$ direction.

17.51. Set Up: Electric field is away from positive charge and toward negative charge.

![Figure 17.51](image)

Solve: (a) The electric fields $\vec{E}_1$ and $\vec{E}_2$ and their vector sum, the net field $\vec{E}$, are shown for each point in Figure 17.51a. The electric field is toward $A$ at points $B$ and $C$ and the field is zero at $A$.
(b) The electric fields are shown in Figure 17.51b. The electric field is away from $A$ at $B$ and $C$. The field is zero at $A$.
(c) The electric fields are shown in Figure 17.51c. The field is horizontal and to the right at points $A$, $B$ and $C$.

Reflect: Compare your results to the field lines shown in Figure 17.24a and b in the textbook.
17.52. **Set Up:** Electric field points toward negative charge and away from positive charge.

![Diagram](a) ![Diagram](b)

**Figure 17.52**

**Solve:** (a) Figure 17.52a shows $\vec{E}_Q$ and $\vec{E}_{-q}$ at point $P$. $\vec{E}_Q$ must have the direction shown, to produce a resultant field in the specified direction. $\vec{E}_Q$ is toward $Q$, so $Q$ is negative. In order for the horizontal components of the two fields to cancel, $Q$ and $q$ must have the same magnitude.

(b) No. If the lower charge were negative, its field would be in the direction shown in Figure 17.52b. The two possible directions for the field of the upper charge, when it is positive ($\vec{E}_+$) or negative ($\vec{E}_-$), are shown. In neither case is the resultant field in the direction shown in the figure in the problem.

17.53. **Set Up:** Electric field is directed away from positive charge and toward negative charge. By symmetry, far from the edges of the sheets the field lines are perpendicular to the sheets; there is no reason to prefer to the left or to the right for a component of electric field.

![Diagram](a) ![Diagram](b) ![Diagram](c) ![Diagram](d) ![Diagram](e)

**Figure 17.53**

**Solve:** (a) The fields of each sheet are sketched in Figure 17.53a. The solid lines are the field due to the upper positive sheet and the dashed lines are the field due to the lower negative sheet. Between the two sheets the fields are in the same direction and add. Outside the two sheets the fields are in opposite directions and cancel. The net electric field is sketched in Figure 17.53b. This result is consistent with the field in the similar case described in Example 17.5.

(b) The fields of each sheet are sketched in Figure 17.53c. The solid lines are the field due to the upper sheet and the dashed lines are the field due to the lower sheet. Since both sheets are positive, the field of each sheet is directed away from that sheet. Between the two sheets the fields are in opposite directions and cancel. Outside the two sheets the fields are in the same direction and add. The net field is sketched in Figure 17.53d.

(c) The fields are the same as in part (b), except they are toward each sheet. The net field of the two sheets is sketched in Figure 17.53e.

**Reflect:** More advanced treatments show that the electric field of an infinite sheet is uniform and does not depend on the distance from the sheet.
17.54. Set Up: Gauss’s law says \( \Phi_E = \frac{Q_{\text{encl}}}{\varepsilon_0} \), \( \varepsilon_0 = 8.854 \times 10^{-12} \text{C}^2/(\text{N}\cdot\text{m}^2) \).

Solve: (a) \( \Phi_E = \frac{2.50 \times 10^{-6} \text{C}}{8.854 \times 10^{-12} \text{C}^2/(\text{N}\cdot\text{m}^2)} = 2.82 \times 10^5 \text{N}\cdot\text{m}^2/\text{C} \)

(b) \( Q_{\text{encl}} = \varepsilon_0 \Phi_E = (8.854 \times 10^{-12} \text{C}^2/(\text{N}\cdot\text{m}^2))(1.40 \text{N}\cdot\text{m}^2/\text{C}) = 1.24 \times 10^{-11} \text{C} \)

17.55. Set Up: Gauss’s law says that the net electric flux \( \Phi_E \) through any closed surface equals \( Q_{\text{encl}}/\varepsilon_0 \), where \( Q_{\text{encl}} \) is the net charge enclosed by the surface.

Solve: (a) \( Q_{\text{encl}} = 0 \) so \( \Phi_E = 0 \)

(b) \( Q_{\text{encl}} = +5.0 \mu\text{C} + 9.0 \mu\text{C} + (-7.0 \mu\text{C}) = +7.0 \mu\text{C} \) and \( \Phi_E = +7.0 \mu\text{C}/\varepsilon_0 = 7.9 \times 10^5 \text{N}\cdot\text{m}^2/\text{C} \).

(c) \( Q_{\text{encl}} = 0 \) and \( \Phi_E = 0 \).

(d) \( Q_{\text{encl}} = +8.0 \mu\text{C} + (-7.0 \mu\text{C}) = +1.0 \mu\text{C} \) and \( \Phi_E = +1.0 \mu\text{C}/\varepsilon_0 = 1.1 \times 10^5 \text{N}\cdot\text{m}^2/\text{C} \).

(e) \( Q_{\text{encl}} = 8.0 \mu\text{C} + (-7.0 \mu\text{C}) + 5.0 \mu\text{C} + 9.0 \mu\text{C} + 1.0 \mu\text{C} + (-10.0 \mu\text{C}) = +6.0 \mu\text{C} \) and \( \Phi_E = +6.0 \mu\text{C}/\varepsilon_0 = 6.8 \times 10^5 \text{N}\cdot\text{m}^2/\text{C} \).

Reflect: The electric field varies in a complicated way, in both magnitude and direction, for each of the surfaces and direct calculation of the flux as \( \sum E \cdot \Delta A \) would be very difficult. Gauss’s law gives us a very simple way of calculating the net flux.

17.56. Set Up: The cube is a closed surface so we can apply Gauss’s law to it: \( \Phi_E = \frac{Q_{\text{encl}}}{\varepsilon_0} \). By symmetry the flux is the same through each of the 6 faces of the cube.

Solve: (a) The total flux through the cube is \( \Phi_E = \frac{Q_{\text{encl}}}{\varepsilon_0} = \frac{8.00 \times 10^{-9} \text{C}}{8.854 \times 10^{-12} \text{C}^2/(\text{N}\cdot\text{m}^2)} = 904 \text{N}\cdot\text{m}^2/\text{C} \).

(b) The flux through each face is \( \frac{\Phi_E}{6} = \frac{904 \text{N}\cdot\text{m}^2/\text{C}}{6} = 151 \text{N}\cdot\text{m}^2/\text{C} \).

17.57. Set Up: Example 17.10 shows that \( E = 0 \) inside a uniform spherical shell and that \( E = \frac{|q|}{r^2} \) outside the shell.

Solve: (a) \( E = 0 \)

(b) \( r = 0.060 \text{m} \) and \( E = \frac{(8.99 \times 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(15.0 \times 10^{-6} \text{C})}{(0.060 \text{m})^2} = 3.75 \times 10^7 \text{N}/\text{C} \)

(c) \( r = 0.110 \text{m} \) and \( E = \frac{(8.99 \times 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(15.0 \times 10^{-6} \text{C})}{(0.110 \text{m})^2} = 1.11 \times 10^7 \text{N}/\text{C} \)

Reflect: Outside the shell the electric field is the same as if all the charge were concentrated at the center of the shell. But inside the shell the field is not the same as for a point charge at the center of the shell; inside the shell the electric field is zero.

17.58. Set Up: A spherically symmetric uniform sphere of charge can be modeled as a series of concentric shells, so \( E = \frac{|q|}{r^2} \) outside the sphere. A proton has charge \(+e\).

Solve: (a) \( E = \frac{|q|}{r^2} = \frac{(8.99 \times 10^9 \text{N}\cdot\text{m}^2/\text{C}^2)(92(1.60 \times 10^{-19} \text{C})}{(7.4 \times 10^{-13} \text{m})^2} = 2.4 \times 10^{21} \text{N}/\text{C} \)

(b) For \( r = 1.0 \times 10^{-10} \text{m} \), \( E = \frac{(7.4 \times 10^{-15} \text{m})^2}{1.0 \times 10^{-10} \text{m}} = 1.3 \times 10^{13} \text{N}/\text{C} \)

(c) \( E = 0 \), inside a spherical shell.
17.59. **Set Up:** The method of Example 17.10 shows that the electric field outside the sphere is the same as for a point charge of the same charge located at the center of the sphere. The charge of an electron has magnitude $e = 1.60 \times 10^{-19}$ C.

**Solve:** (a) $E = k \frac{|q|}{r^2}$. For $r = R = 0.150$ m, $E = 1150$ N/C so $|q| = \frac{E r^2}{k} = \frac{(1150 \text{ N/C}) (0.150 \text{ m})^2}{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2} = 2.88 \times 10^{-9}$ C.

The number of excess electrons is $\frac{2.88 \times 10^{-9} \text{ C}}{1.60 \times 10^{-19} \text{ C/ electron}} = 1.80 \times 10^{10}$ electrons.

(b) $r = R + 0.100$ m = 0.250 m. $E = k \frac{|q|}{r^2} = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) 2.88 \times 10^{-9} \text{ C}}{(0.250 \text{ m})^2} = 414$ N/C.

17.60. **Set Up:** The charge distribution has spherical symmetry, so the electric field is radial and depends only on the distance from the center of the charged sphere. The surface area of a sphere is $A = 4\pi r^2$.

**Solve:** (a) Apply Gauss’s law to a spherical surface of radius $r \geq R$, concentric with the sphere of charge. The electric field is constant over the Gaussian surface and perpendicular to it, so $\Phi_E = EA = E(4\pi r^2)$. The charge enclosed is $Q$, so Gauss’s law gives $E(4\pi r^2) = \frac{Q}{\epsilon_0}$ and $E = \frac{Q}{4\pi \epsilon_0 r^2}$. This is the same $E$ as for a point charge $Q$ at the center of the sphere.

(b) No direction is preferred, so $E = 0$.

17.61. **Set Up:** The charge distribution has spherical symmetry, so the electric field, if nonzero, is radial and depends only on the distance from the center of the shell.

**Solve:** (a) Apply Gauss’s law to a sphere of radius $r < a$ and concentric with the shell. The electric field, if nonzero, is constant over the Gaussian surface and perpendicular to it, so $\Phi_E = E A = E(4\pi r^2)$. But no charge is enclosed by the Gaussian surface, so $Q_{encl} = 0$. Gauss’s law gives $E(4\pi r^2) = 0$ and $E = 0$.

(b) Apply Gauss’s law to a sphere of radius $r > b$. $\Phi_E = E(4\pi r^2)$. $Q_{encl} = Q$. Gauss’s law gives $E(4\pi r^2) = \frac{Q}{\epsilon_0}$ and $E = \frac{Q}{4\pi \epsilon_0 r^2}$.

(c) The thick shell can be constructed from a series of concentric thin shells. $E = 0$ inside each of these thin shells, so $E = 0$ inside the thick shell.

**Reflect:** In using Gauss’s law it is very helpful to select a Gaussian surface of appropriate symmetry, so it is simple to express the flux in terms of the electric field at the surface.

17.62. **Set Up:** Section 17.9 shows that the net charge of a charged conductor is entirely on its outer surface.

**Solve:** (a) $q = 0$ on the surface of the inner cavity of the conducting car.

(b) All the net charge is on the outer surface, $-850 \mu$C.

17.63. **Set Up:** $E = 0$ everywhere within the conductor. Any net charge must be on the inner and outer surfaces of the conductor.

![Gaussian surface](image17.63)
Solve: (a) and (b) Apply Gauss’s law to a surface that is within the conductor, just outside the cavity, as shown in Figure 17.63. \( E = 0 \) everywhere on the Gaussian surface so \( \Phi_E = 0 \) for that surface. Gauss’s law then says that \( Q_{\text{enc}} \) for this surface is zero. The conductor is neutral, so if the outer surface has charge \(-12 \mu \text{C}\) the inner surface must have charge \(+12 \mu \text{C}\). To make \( Q_{\text{enc}} = 0 \) there must be \(-12 \mu \text{C}\) within the hole.

Reflect: The charge in the hole creates the charge separation in the conductor. It pulls \(+12 \mu \text{C}\) to the inner surface and that leaves \(-12 \mu \text{C}\) on the outer surface.

17.64. Set Up: \( E = 0 \) everywhere within the conductor. Any net charge must be on the inner and outer surfaces of the conductor.

Solve: Apply Gauss’s law to a surface that is within the conductor, just outside the cavity, as shown in Figure 17.64. \( E = 0 \) everywhere on the Gaussian surface so \( \Phi_E = 0 \) for that surface.

\begin{figure}
\centering
\includegraphics{17.64.png}
\caption{Figure 17.64}
\end{figure}

(a) \( Q_{\text{enc}} = 0 \) for the Gaussian surface means that \( q = 0 \) on the inner surface, so the \(+16 \mu \text{C}\) of net charge is on the outer surface of the conductor.

(b) \( Q_{\text{enc}} = 0 \) for the Gaussian surface means that there must be \(+11 \text{nC}\) on the inner surface of the conductor. Since the total net charge of the conductor is \(+16 \text{nC}\), if there is \(+11 \text{nC}\) on the inner surface there must be \(+5 \text{nC}\) on the outer surface.

17.65. Set Up: \( F = k \frac{|qq'|}{r^2} \). Like charges repel and unlike charges attract. Charges \( q_1 \) and \( q_2 \) and the forces they exert on \( q_3 \) at the origin are sketched in Figure 17.65a. For the net force on \( q_3 \) to be zero, \( \vec{F}_1 \) and \( \vec{F}_2 \) from \( q_1 \) and \( q_2 \) must be equal in magnitude and opposite in direction.

\begin{figure}
\centering
\includegraphics{17.65.png}
\caption{Figure 17.65}
\end{figure}
Solve: (a) Since \( \vec{F}_1, \vec{F}_2 \) and \( \vec{F}_{\text{net}} \) are all in the +x direction, \( F = F_1 + F_2 \). This gives
\[
4.00 \times 10^{-6} \text{ N} = k \left| \frac{q_1 q_2}{r_1^2} \right| + k \left| \frac{q_2 q_3}{r_2^2} \right|
\]
and \( q_3 = 3.17 \times 10^{-9} \text{ C} = 3.17 \text{ nC} \).
(b) Both \( \vec{F}_1 \) and \( \vec{F}_2 \) are in the +x direction, so \( \vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2 \) is in the +x direction.
(c) The forces \( \vec{F}_1 \) and \( \vec{F}_2 \) on \( q_1 \) in each of the three regions are sketched in Figure 17.65b. Only in regions I (to the left of \( q_2 \)) and III (to the right of \( q_1 \)) are \( \vec{F}_1 \) and \( \vec{F}_2 \) in opposite directions. But since \( |q_2| < |q_1| \), \( q_1 \) must be closer to \( q_2 \) than to \( q_3 \). For \( F_1 = F_2 \), and this is the case only in region I. Let \( d \) be a distance to the left of \( q_2 \), so it is a distance \( d + 0.500 \text{ m} \) from \( q_1 \). \( F_1 = F_2 \) gives
\[
k = \frac{4.50 \text{ nC}}{(d + 0.500 \text{ m})^2} = \frac{2.50 \text{ nC}}{d^2}.
\]
The positive solution is \( d = 1.46 \text{ m} \). This point is at \( x = -0.300 \text{ m} - 1.46 \text{ m} = -1.76 \text{ m} \).
Reflect: At the point found in part (c) the electric field is zero. The force on any charge placed at this point will be zero.

17.66. Set Up: Let \( q_1 \) and \( q_2 \) be the charges on the spheres. \( F = k \left| \frac{q_1 q_2}{r^2} \right| \) and \( q_1 + q_2 = 60.0 \text{ nC} \).

Solve: \( q_1 q_2 = \frac{Fr^2}{k} = \left( \frac{0.270 \times 10^{-3} \text{ N}}{8.99 \times 10^9 \text{ N \cdot m}^2/\text{C}^2} \right) = 3.00 \times 10^{-16} \text{ C}^2 \). \( q_2 = 60.0 \times 10^{-9} \text{ C} - q_1 \) so
\[
q_1 \left( 60.0 \times 10^{-9} \text{ C} - q_1 \right) = 3.00 \times 10^{-16} \text{ C}^2, q_1^2 - (60.0 \times 10^{-9} \text{ C})q_1 + 3.00 \times 10^{-16} \text{ C}^2 = 0.
\]
The quadratic formula gives \( q_1 = \frac{1}{2}(6.00 \times 10^{-8} \pm \sqrt{(6.00 \times 10^{-8})^2 - 4(3.00 \times 10^{-16})}) \text{ C} = 0.55 \times 10^{-8} \text{ C} 
\) or \( 5.45 \times 10^{-8} \text{ C} \). For \( q_1 = 0.55 \times 10^{-8} \text{ C}, q_2 = 5.45 \times 10^{-8} \text{ C} \) and for \( q_1 = 5.45 \times 10^{-8} \text{ C}, q_2 = 0.55 \times 10^{-8} \text{ C} \).

One sphere has charge \( 0.55 \times 10^{-8} \text{ C} \) and the other has charge \( 5.45 \times 10^{-8} \text{ C} \).

17.67. Set Up: \( F = k \left| \frac{|q q'|}{r^2} \right| \). Like charges repel and unlike charges attract. The three charges and the forces on \( q_3 \) are shown in Figure 17.67.
Solve: (a) \( F_1 = k \frac{|q_1 q_3|}{r_1^2} = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) (5.00 \times 10^{-9} \text{ C}) (6.00 \times 10^{-9} \text{ C})}{(0.0500 \text{ m})^2} = 1.079 \times 10^{-4} \text{ C}. \)
\( \theta = 36.9^\circ \). \( F_{1x} = +F_1 \cos \theta = 8.63 \times 10^{-5} \text{ N}, \) \( F_{1y} = +F_1 \sin \theta = 6.48 \times 10^{-5} \text{ N}. \)
\( F_2 = k \frac{|q_2 q_3|}{r_2^2} = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) (2.00 \times 10^{-9} \text{ C}) (6.00 \times 10^{-9} \text{ C})}{(0.0300 \text{ m})^2} = 1.20 \times 10^{-4} \text{ C}. \)
\( F_{2x} = 0, F_{2y} = -F_2 = -1.20 \times 10^{-4} \text{ N}, \) \( F_3 = F_{1x} + F_{2x} = 8.63 \times 10^{-5} \text{ N} \)
\( F_y = F_{1y} + F_{2y} = 6.48 \times 10^{-5} \text{ N} + (-1.20 \times 10^{-4} \text{ N}) = -5.52 \times 10^{-5} \text{ N}. \)
\( (b) F = \sqrt{F_x^2 + F_y^2} = 1.02 \times 10^{-4} \text{ N} \). \( \tan \phi = \frac{F_y}{F_x} = 0.640, \phi = 32.6^\circ, \) below the +x axis.

Reflect: The individual forces on \( q_3 \) are computed from Coulomb’s law and then added as vectors, using components.

17.68. Set Up: \( F = k \frac{|q_1 q_3|}{r^2} \). Like charges repel and unlike charges attract. The positions of the three charges are sketched in Figure 17.68a and each force on \( q_3 \) is shown. The distance between \( q_1 \) and \( q_3 \) is 5.00 cm.

\[
\begin{align*}
\text{Solve: (a) } F_1 &= k \frac{|q_1 q_3|}{r_1^2} = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) (3.00 \times 10^{-9} \text{ C}) (5.00 \times 10^{-9} \text{ C})}{(5.00 \times 10^{-2} \text{ m})^2} = 5.394 \times 10^{-5} \text{ N} \\
F_{1x} &= -F_1 \cos \theta = -\left(5.394 \times 10^{-5} \text{ N}\right)(0.600) = -3.236 \times 10^{-5} \text{ N} \;
F_{1y} &= -F_1 \sin \theta = -\left(5.394 \times 10^{-5} \text{ N}\right)(0.800) = -4.315 \times 10^{-5} \text{ N} \\
F_2 &= k \frac{|q_2 q_3|}{r_2^2} = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) (2.00 \times 10^{-9} \text{ C}) (5.00 \times 10^{-9} \text{ C})}{(3.00 \times 10^{-2} \text{ m})^2} = 9.989 \times 10^{-5} \text{ N} \\
F_{2x} &= 9.989 \times 10^{-5} \text{ N}; \; F_{2y} = 0 \\
F_3 &= F_{1x} + F_{2x} = 9.989 \times 10^{-5} \text{ N} + (-3.236 \times 10^{-5} \text{ N}) = 6.75 \times 10^{-5} \text{ N} \; F_y = F_{1y} + F_{2y} = -4.32 \times 10^{-5} \text{ N} \\
\end{align*}
\]
F\text{ and its components are shown in Figure 17.68b. } F = \sqrt{F_x^2 + F_y^2} = 8.01 \times 10^{-5} \text{ N}, \tan\theta = \frac{F_y}{F_x} = 0.640 \text{ and } \theta = 32.6^\circ. \text{ F is } 327^\circ \text{ counterclockwise from the +x axis.}

17.69. Set Up: } F = k\frac{|q_1q_4|}{r_{14}^2}. \text{ Like charges repel and unlike charges attract.}

![Diagram](a)\quad \text{Figure 17.69}

Solve: (a) The charges and the forces on the $-1.00 \mu\text{C}$ charge are shown in Figure 17.69a. The distance $r_{14}$ between $q_1$ and $q_4$ is $r = \left(\frac{1}{2}\right)\sqrt{2} (0.200 \text{ m}) = 0.1414 \text{ m}. \text{ F}_2 \text{ and } \text{F}_3 \text{ are equal in magnitude and opposite in direction, so } \text{F}_2 + \text{F}_3 = 0 \text{ and } \text{F}_{\text{net}} = \text{F}_1.

\begin{align*}
\text{F}_1 &= k\frac{|q_1q_4|}{r_{14}^2} = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)\left(\frac{3.00 \times 10^{-9} \text{ C}}{1000 \text{ C}}\right) \left(\frac{3.00 \times 10^{-6} \text{ C}}{1000 \text{ C}}\right) = 1.35 \times 10^{-3} \text{ N}.
\end{align*}

The resultant force has magnitude $1.35 \times 10^{-3} \text{ N}$ and is directed away from the vacant corner.

(b) The charges and the forces on the $-1.00 \mu\text{C}$ charge are shown in Figure 17.69b. The distance $r_{14}$ between $q_1$ and $q_4$ is $\sqrt{2} (0.200 \text{ m}) = 0.2828 \text{ m}. \text{ Use coordinates as shown in the figure. } \text{F}_{2x} = -\text{F}_{3y}, \text{ and } \text{F}_{1x} = 0, \text{ so } \text{F}_x = 0. \text{ F}_y = \text{F}_{1y} + \text{F}_{2y} + \text{F}_{3y} = \text{F}_1 + 2\text{F}_2\cos45^\circ.$

\begin{align*}
\text{F}_1 &= k\frac{|q_1q_4|}{r_{14}^2} = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)\left(\frac{3.00 \times 10^{-9} \text{ C}}{1000 \text{ C}}\right) \left(\frac{3.00 \times 10^{-6} \text{ C}}{1000 \text{ C}}\right) = 3.372 \times 10^{-4} \text{ N}.
\end{align*}

\begin{align*}
\text{F}_2 &= k\frac{|q_1q_4|}{r_{24}^2} = (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)\left(\frac{3.00 \times 10^{-9} \text{ C}}{1000 \text{ C}}\right) \left(\frac{3.00 \times 10^{-6} \text{ C}}{1000 \text{ C}}\right) = 6.742 \times 10^{-4} \text{ N}
\end{align*}

\begin{align*}
F_y &= 3.372 \times 10^{-4} \text{ N} + 2(6.742 \times 10^{-4} \text{ N})\cos45^\circ = 1.29 \times 10^{-3} \text{ N}.
\end{align*}

The resultant force has magnitude $1.29 \times 10^{-3} \text{ N}$ and is directed toward the center of the square.

17.70. Set Up: The force on the negatively charged electron is opposite to the direction of the field. Since the field is uniform, the force and acceleration are constant. Use coordinates with +y upward and +x to the right. The electron is at $x = +0.0200 \text{ m}$ when $y = +0.00500 \text{ m}. \ a_x = 0, \ v_{0y} = +5.00 \times 10^6 \text{ m/s}, \ v_{0x} = 0. \ \text{For an electron, } q = -e = -1.60 \times 10^{-19} \text{ C \text{ and } m = 9.11 \times 10^{-31} \text{ kg. } x = v_{0x}t + \frac{1}{2}a_xt^2.}$

\begin{align*}
\frac{x}{v_{0x}} &= \frac{0.0200 \text{ m}}{5.00 \times 10^6 \text{ m/s}} = 4.00 \times 10^{-9} \text{ s}.
\end{align*}

\begin{align*}
y = v_{0y}t + \frac{1}{2}a_yt^2 \text{ gives } a_y = \frac{2y}{t^2} &= \frac{2(0.00500 \text{ m})}{(4.00 \times 10^{-9} \text{ s})^2} = 6.25 \times 10^{14} \text{ m/s}^2.
\end{align*}

\begin{align*}
F_y &= ma_y \text{ and } F_y = \frac{F_e}{e} = \frac{-ma_y}{e} = -\frac{(9.11 \times 10^{-31} \text{ kg})(6.25 \times 10^{14} \text{ m/s}^2)}{1.60 \times 10^{-19} \text{ C}} = -3.56 \times 10^3 \text{ N/C}.
\end{align*}

The electric field has magnitude $3.56 \times 10^3 \text{ N/C}.$
17.71. **Set Up:** The ball is in equilibrium, so for it \( \sum F_x = 0 \) and \( \sum F_y = 0 \). The force diagram for the ball is given in Figure 17.71. \( F_E \) is the force exerted by the electric field. \( \vec{F} = q\vec{E} \). Since the electric field is horizontal, \( \vec{F}_E \) is horizontal. Use the coordinates shown in the figure. The tension in the string has been replaced by its \( x \) and \( y \) components.

![Figure 17.71](image)

**Solve:** \( \sum F_y = 0 \) gives \( T_y - mg = 0 \). \( T \cos \theta - mg = 0 \) and \( T = \frac{mg}{\cos \theta} \)

\[ \sum F_x = 0 \text{ gives } F_E - T_x = 0. F_E - T \sin \theta = 0. \]

\[ F_E = \left( \frac{mg}{\cos \theta} \right) \sin \theta = mg \tan \theta = (12.3 \times 10^{-3} \text{ kg}) \left(9.80 \text{ m/s}^2\right) \tan 17.4^\circ = 3.78 \times 10^{-2} \text{ N} \]

\[ F_E = \frac{|q|E}{q} \text{ so } E = \frac{F_E}{|q|} = \frac{3.78 \times 10^{-2} \text{ N}}{1.11 \times 10^{-6} \text{ C}} = 3.41 \times 10^4 \text{ N/C} \]

\( q \) is negative and \( \vec{F}_E \) is to the right, so \( \vec{E} \) is to the left in the figure.

**Reflect:** The larger the electric field \( E \) the greater the angle the string makes with the wall.

17.72. **Set Up:** \( E = k \frac{|q|}{r^2} \). \( \vec{E} \) is toward a negative charge and away from a positive charge. At the origin, \( \vec{E}_1 \) due to the \(-5.00 \text{ nC} \) charge is in the \(+x\) direction, toward the charge.

**Solve:** (a) \( E_1 = \left(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2\right) \left(5.00 \times 10^{-9} \text{ C}\right) = 31.2 \text{ N/C} \). \( E_{1x} = +31.2 \text{ N/C} \).

\( E_x = E_{1x} + E_{2x} \), \( E_x = +45.0 \text{ N/C} \), so \( E_{2x} = E_x - E_{1x} = +45.0 \text{ N/C} - 31.2 \text{ N/C} = 13.8 \text{ N/C}. \)

\( \vec{E} \) is away from \( Q \) so \( Q \) is positive. \( E_z = k \frac{|Q|}{r^2} \) gives \( |Q| = \frac{E_z r^2}{k} = \frac{(13.8 \text{ N/C})(0.600 \text{ m})^2}{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2} = 5.53 \times 10^{-10} \text{ C}. \)

(b) \( E_z = -45.0 \text{ N/C} \), so \( E_{2z} = E_z - E_{1z} = -45.0 \text{ N/C} - 31.2 \text{ N/C} = -76.2 \text{ N/C}. \)

\( \vec{E} \) is toward \( Q \) so \( Q \) is negative. \( |Q| = \frac{E_z r^2}{k} = \frac{(76.2 \text{ N/C})(0.600 \text{ m})^2}{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2} = 3.05 \times 10^{-9} \text{ C}. \)

17.73. **Set Up:** The gravity force (weight) has magnitude \( w = mg \) and is downward. The electric force is \( \vec{F} = q\vec{E} \).

**Solve:** (a) To balance the weight the electric force must be upward. The electric field is downward, so for an upward force the charge \( q \) of the person must be negative. \( w = F \) gives \( mg = |q|E \) and

\[ |q| = \frac{mg}{E} = \frac{(60 \text{ kg})(9.80 \text{ m/s}^2)}{150 \text{ N/C}} = 3.9 \text{ C}. \]

(b) \( F = k \frac{|qq'|}{r^2} = \left(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2\right) \left(\frac{(3.9 \text{ C})^2}{(100 \text{ m})^2}\right) = 1.4 \times 10^7 \text{ N}. \) The repulsive force is immense and this is not a feasible means of flight.
17.74. Set Up: The force diagram for the $-6.50 \mu C$ charge is given in Figure 17.74. $F_E$ is the force exerted on the charge by the uniform electric field. The charge is negative and the field is to the right, so the force exerted by the field is to the left. $F_q$ is the force exerted by the other point charge. The two charges have opposite signs, so the force is attractive. Take the $+x$ axis to be to the right, as shown in the figure.

![Figure 17.74](image)

Solve: (a) $F = |q|E = (6.50 \times 10^{-6} \text{C})(1.85 \times 10^8 \text{N/C}) = 1.20 \times 10^1 \text{N}$

$$F_q = k \frac{|q_1 q_2|}{r^2} = (8.99 \times 10^9 \text{N} \cdot \text{m}^2/\text{C}^2) \left( \frac{6.50 \times 10^{-6} \text{C}}{0.0250 \text{m}} \right)^2 = 8.18 \times 10^2 \text{N}$$

$\sum F_i = 0$ gives $T + F_q - F_E = 0$ and $T = F_E - F_q = 382 \text{ N}.

(b) Now $F_q$ is to the left, since like charges repel.

$\sum F_i = 0$ gives $T - F_q - F_E = 0$ and $T = F_E + F_q = 2.02 \times 10^3 \text{ N}.$

17.75. Set Up: The force on the electron is upward in the figure so the electric field must be downward. To produce a net electric field that is downward, it must be that $q_1$ is positive, $q_2$ is negative and $|q_1| = |q_2|.$ The field due to $q_1$ and $q_2$ at the location of the electron are sketched in Figure 17.75. The electron is $r = 3.61 \text{ cm}$ from each charge. $\tan \theta = \frac{3.00 \text{ cm}}{2.00 \text{ cm}}$ and $\theta = 56.3^\circ.$

![Figure 17.75](image)

Solve: The net electric field is $E = 2E_{1y} = 2 \frac{k q_1}{r^2} \cos \theta.$ $F = eE = \frac{2k q_1}{r^2} \cos \theta.$ $F = ma$ so $\frac{2k q_1}{r^2} \cos \theta = ma$ and

$$q_1 = \frac{r^2 ma}{2k \cos \theta} = \frac{(3.61 \times 10^{-2} \text{ m})^2 (9.11 \times 10^{-31} \text{ kg}) (8.25 \times 10^{18} \text{ m/s}^2)}{2 (8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) (1.60 \times 10^{-19} \text{ C}) \cos 56.3^\circ} = 6.14 \times 10^{-6} \text{ C}.$$ $q_2 = -6.14 \times 10^{-6} \text{ C}.$

Reflect: The force that an electric field exerts on a negative charge is opposite to the direction of the electric field. We could also do this problem by considering the force that each charge exerts on the electron.
17.76. **Set Up:** When the forces balance, \( a = 0 \) and the molecule moves with constant velocity.

**Solve:**

(a) \( F = F_D \) so \( qE = Krv \) and \( \frac{q}{R} = \frac{Kv}{E} \)

(b) \( v = \frac{E_R}{KR} \) and is constant. \( x = vt = \left( \frac{E_T}{K} \right) T = \left( \frac{ET}{K} \right) \frac{q}{R} \)

(c) \( x = \left( \frac{ET}{K} \right) \frac{q}{R} \) where \( \frac{ET}{K} \) is constant. \( \frac{q}{R_2} = 2 \left( \frac{q}{R_1} \right) \) and \( \frac{q}{R_3} = 3 \left( \frac{q}{R_1} \right) \)

\[
x_2 = \left( \frac{ET}{K} \right) \frac{q}{R_2} = 2 \left( \frac{ET}{K} \right) \frac{q}{R_1} = 2x_1; \quad x_3 = \left( \frac{ET}{K} \right) \frac{q}{R_3} = 3 \left( \frac{ET}{K} \right) \frac{q}{R_1} = 3x_1
\]

17.77. **Set Up:** \( F_{grav} = G \frac{m_s m_e}{r^2} \). For a circular orbit, \( a = \frac{v^2}{r} \). The period \( T \) is \( \frac{2\pi r}{v} \). The mass of the sun is \( m_s = 1.99 \times 10^{30} \text{ kg} \) and the orbit radius of the earth is \( 1.50 \times 10^{11} \text{ m} \).

**Solve:** \( F = ma \) gives \( G \frac{m_s m_e}{r^2} = m_e \frac{v^2}{r} \), so \( v = \frac{\sqrt{G m_s}}{r} \).

\[
T = 2\pi \sqrt{\frac{r}{G m_s}} = 2\pi \frac{r^{3/2}}{\sqrt{G m_s}} = 2\pi \frac{\left(1.50 \times 10^{11} \text{ m}\right)^{3/2}}{\sqrt{(9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{kg}^2) (1.99 \times 10^{30} \text{ kg})}} = 2.73 \times 10^{-3} \text{ s}
\]

A present year is \( 3.146 \times 10^7 \text{ s} \), so the year in the parallel universe would be \( 8.7 \times 10^{-11} \) of a present year.

**Reflect:** \( v = \frac{\sqrt{G m_s}}{r} = \sqrt{\frac{(9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{kg}^2)(1.99 \times 10^{30} \text{ kg})}{1.50 \times 10^{11} \text{ m}}} = 3.5 \times 10^{14} \text{ m/s} \). This exceeds by a large factor the speed of light in our universe, so the parallel universe must have a much larger speed of light than ours, in order for this speed to be possible.