CHAPTER 15

Quick Quizzes

1. (d). Object A could possess a net charge whose sign is opposite that of the excess charge on B. If object A is neutral, B would also attract it by creating an induced charge on the surface of A. This situation is illustrated in Figure 15.5 of the textbook.

2. (b). By Newton's third law, the two objects will exert forces having equal magnitudes but opposite directions on each other.

3. (c). The electric field at point *P* is due to charges *other* than the test charge. Thus, it is unchanged when the test charge is altered. However, the direction of the force this field exerts on the test change is reversed when the sign of the test charge is changed.

4. (b). The magnitude of the upward electrical force must equal the weight of the ball. That is: $qE = mg$, so

$$E = \frac{mg}{q} = \frac{\left(5.0 \times 10^{-3}\ \text{kg}\right)\left(9.80\ \text{m/s}^2\right)}{4.0 \times 10^{-6}\ \text{C}} = 1.2 \times 10^{4}\ \text{N/C}$$

5. (a). If a test charge is at the center of the ring, the force exerted on the test charge by charge on any small segment of the ring will be balanced by the force exerted by charge on the diametrically opposite segment of the ring. The net force on the test charge, and hence the electric field at this location, must then be zero.

6. (c) and (d) The electron and the proton have equal magnitude charges of opposite signs. The forces exerted on these particles by the electric field have equal magnitude and opposite directions. The electron experiences an acceleration of greater magnitude than does the proton because the electron's mass is much smaller than that of the proton.

7. *A, B,* and *C*. The field is greatest at point *A* because this is where the field lines are closest together. The absence of lines at point *C* indicates that the electric field there is zero.

8. Statements (b) and (d) are true and follow from Gauss's law. Statement (a) is not necessarily true because Gauss's law says that the net flux through any closed surface equals the net charge inside the surface divided by ϵ_0. For example, a positive and a negative charge could be inside the surface. Statement (c) is not necessarily true. Although the net flux through the surface is zero, the electric field in that region may not be zero.

Problem Solutions

15.1 Since the charges have opposite signs, the force is one of $\boxed{\text{attraction}}$.
Its magnitude is

$$F = \frac{k_e|q_1q_2|}{r^2} = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(4.5\times10^{-9}\ \text{C}\right)\left(2.8\times10^{-9}\ \text{C}\right)}{\left(3.2\ \text{m}\right)^2} = \boxed{1.1\times10^{-8}\ \text{N}}$$

15.2 (a) The force is

$$F = \frac{k_eq^2}{r^2} = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(1.60\times10^{-14}\ \text{C}\right)^2}{\left(2.5\times10^{-6}\ \text{m}\right)^2} = \boxed{3.7\times10^{-7}\ \text{N}\quad(\text{repulsion})}$$

(b) With r two times larger, r^2 is four times larger and the force is $\boxed{\text{reduced to one fourth of its previous value}}$.

15.3 $$F = \frac{k_e(2e)(79e)}{r^2}$$

$$= \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(158)\left(1.60\times10^{-19}\ \text{C}\right)^2}{\left(2.0\times10^{-14}\ \text{m}\right)^2} = \boxed{91\ \text{N}\quad(\text{repulsion})}$$

15.4 The electrical force is $F_e = \frac{k_ee^2}{r^2}$, and the gravitational force is $F_g = \frac{Gm^2}{r^2}$. Thus, if $F_g = F_e$, the mass would have to be

$$m = e\sqrt{\frac{k_e}{G}} = \left(1.60\times10^{-19}\ \text{C}\right)\sqrt{\frac{8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2}{6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2}} = \boxed{1.86\times10^{-9}\ \text{kg}}$$

This result is 1.11×10^{18} times greater than the actual mass of a proton.

15.5 (a) $$F = \frac{k_e(2e)^2}{r^2} = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left[4\left(1.60\times10^{-19}\ \text{C}\right)^2\right]}{\left(5.00\times10^{-15}\ \text{m}\right)^2} = \boxed{36.8\ \text{N}}$$

(b) The mass of an alpha particle is $m = 4.0026\ \text{u}$, where $\text{u} = 1.66\times 10^{-27}\ \text{kg}$ is the unified mass unit. The acceleration of either alpha particle is then

$$a = \frac{F}{m} = \frac{36.8\ \text{N}}{4.0026\left(1.66\times 10^{-27}\ \text{kg}\right)} = \boxed{5.54\times 10^{27}\ \text{m/s}^2}$$

15.6 The attractive force between the charged ends tends to compress the molecule. Its magnitude is

$$F = \frac{k_e(1e)^2}{r^2} = \left(8.99\times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(1.60\times 10^{-19}\ \text{C}\right)^2}{\left(2.17\times 10^{-6}\ \text{m}\right)^2} = 4.89\times 10^{-17}\ \text{N}\ .$$

The compression of the "spring" is

$$x = (0.0100)\,r = (0.0100)\left(2.17\times 10^{-6}\ \text{m}\right) = 2.17\times 10^{-8}\ \text{m}\ ,$$

so the spring constant is $k = \frac{F}{x} = \frac{4.89\times 10^{-17}\ \text{N}}{2.17\times 10^{-8}\ \text{m}} = \boxed{2.25\times 10^{-9}\ \text{N/m}}$

15.7 1.00 g of hydrogen contains Avogadro's number of atoms, each containing one proton and one electron. Thus, each charge has magnitude $|q| = N_A\, e$. The distance separating these charges is $r = 2R_E$, where R_E is the Earth's radius. Thus,

$$F = \frac{k_e\left(N_A\, e\right)^2}{\left(2R_E\right)^2}$$

$$= \left(8.99\times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left[\left(6.02\times 10^{23}\right)\left(1.60\times 10^{-19}\ \text{C}\right)\right]^2}{4\left(6.38\times 10^6\ \text{m}\right)^2} = \boxed{5.12\times 10^5\ \text{N}}$$

15.8 The magnitude of the repulsive force between electrons must equal the weight of an electron, Thus, $k_e e^2/r^2 = m_e g$

or $$r = \sqrt{\frac{k_e e^2}{m_e g}} = \sqrt{\frac{\left(8.99\times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(1.60\times 10^{-19}\ \text{C}\right)^2}{\left(9.11\times 10^{-31}\ \text{kg}\right)\left(9.80\ \text{m/s}^2\right)}} = \boxed{5.08\ \text{m}}$$

15.9 (a) The spherically symmetric charge distributions behave as if all charge was located at the centers of the spheres. Therefore, the magnitude of the attractive force is

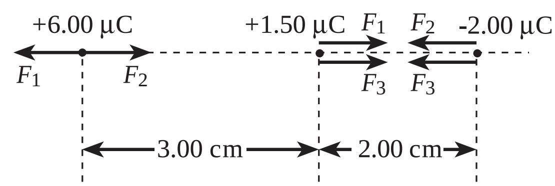
$$F = \frac{k_e q_1 |q_2|}{r^2} = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(12\times10^{-9}\ \text{C}\right)\left(18\times10^{-9}\ \text{C}\right)}{\left(0.30\ \text{m}\right)^2} = \boxed{2.2\times10^{-5}\ \text{N}}$$

(b) When the spheres are connected by a conducting wire, the net charge $q_{net} = q_1 + q_2 = -6.0\times10^{-9}\ \text{C}$ will divide equally between the two identical spheres. Thus, the force is now

$$F = \frac{k_e\left(q_{net}/2\right)^2}{r^2} = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(-6.0\times10^{-9}\ \text{C}\right)^2}{4\left(0.30\ \text{m}\right)^2}$$

or $F = \boxed{9.0\times10^{-7}\ \text{N (repulsion)}}$

15.10 The forces are as shown in the sketch at the right.



$$F_1 = \frac{k_e q_1 q_2}{r_{12}^2} = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(6.00\times10^{-6}\ \text{C}\right)\left(1.50\times10^{-6}\ \text{C}\right)}{\left(3.00\times10^{-2}\ \text{m}\right)^2} = 89.9\ \text{N}$$

$$F_2 = \frac{k_e q_1 |q_3|}{r_{13}^2} = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(6.00\times10^{-6}\ \text{C}\right)\left(2.00\times10^{-6}\ \text{C}\right)}{\left(5.00\times10^{-2}\ \text{m}\right)^2} = 43.2\ \text{N}$$

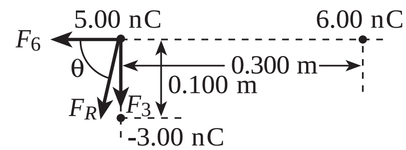
$$F_3 = \frac{k_e q_2 |q_3|}{r_{23}^2} = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(1.50\times10^{-6}\ \text{C}\right)\left(2.00\times10^{-6}\ \text{C}\right)}{\left(2.00\times10^{-2}\ \text{m}\right)^2} = 67.4\ \text{N}$$

The net force on the $6\,\mu\text{C}$ charge is $F_6 = F_1 - F_2 = \boxed{46.7\ \text{N (to the left)}}$.

The net force on the $1.5\,\mu\text{C}$ charge is $F_{1.5} = F_1 + F_3 = \boxed{157\ \text{N (to the right)}}$.

The net force on the $-2\,\mu\text{C}$ charge is $F_{-2} = F_2 + F_3 = \boxed{111\ \text{N (to the left)}}$.

15.11 In the sketch at the right, F_R is the resultant of the forces F_6 and F_3 that are exerted on the charge at the origin by the 6.00 nC and the –3.00 nC charges respectively.



$$F_6 = \left(8.99\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(6.00\times10^{-9}\ \text{C}\right)\left(5.00\times10^{-9}\ \text{C}\right)}{\left(0.300\ \text{m}\right)^2}$$

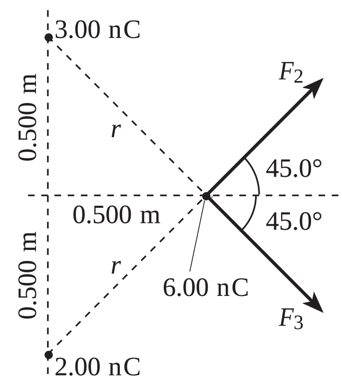
$$= 3.00\times10^{-6}\ \text{N}$$

$$F_3 = \left(8.99\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(3.00\times10^{-9}\ \text{C}\right)\left(5.00\times10^{-9}\ \text{C}\right)}{\left(0.100\ \text{m}\right)^2} = 1.35\times10^{-5}\ \text{N}$$

The resultant is $F_R = \sqrt{\left(F_6\right)^2 + \left(F_3\right)^2} = 1.38\times10^{-5}\ \text{N}$ at $\theta = \tan^{-1}\left(\frac{F_3}{F_6}\right) = 77.5°$,

or $\mathbf{F}_R = \boxed{1.38\times10^{-5}\ \text{N at } 77.5° \text{ below } -x \text{ axis}}$

15.12 Consider the arrangement of charges shown in the sketch at the right. The distance r is



$$r = \sqrt{(0.500\text{ m})^2 + (0.500\text{ m})^2} = 0.707\text{ m}$$

The forces exerted on the 6.00 nC charge are

$$F_2 = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(6.00\times10^{-9}\text{ C})(2.00\times10^{-9}\text{ C})}{(0.707\text{ m})^2}$$
$$= 2.16\times10^{-7}\text{ N}$$

and $F_3 = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(6.00\times10^{-9}\text{ C})(3.00\times10^{-9}\text{ C})}{(0.707\text{ m})^2} = 3.24\times10^{-7}\text{ N}$

Thus, $\Sigma F_x = (F_2 + F_3)\cos 45.0° = 3.81\times10^{-7}\text{ N}$,

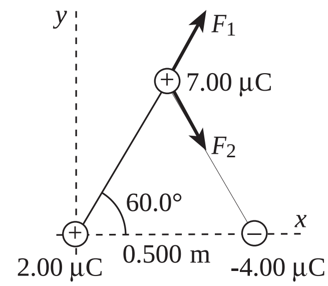
and $\Sigma F_y = (F_2 - F_3)\sin 45.0° = -7.63\times10^{-8}\text{ N}$

The resultant force on the 6.00 nC charge is then

$$F_R = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2} = 3.89\times10^{-7}\text{ N at } \theta = \tan^{-1}\left(\frac{\Sigma F_y}{\Sigma F_x}\right) = -11.3°$$

or $\mathbf{F}_R = \boxed{3.89\times10^{-7}\text{ N at } 11.3° \text{ below } +x \text{ axis}}$

15.13 The forces on the 7.00 μC charge are shown at the right.



$$F_1 = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(7.00\times10^{-6}\ \text{C}\right)\left(2.00\times10^{-6}\ \text{C}\right)}{\left(0.500\ \text{m}\right)^2}$$
$$= 0.503\ \text{N}$$

$$F_2 = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(7.00\times10^{-6}\ \text{C}\right)\left(4.00\times10^{-6}\ \text{C}\right)}{\left(0.500\ \text{m}\right)^2}$$
$$= 1.01\ \text{N}$$

Thus, $\Sigma F_x = \left(F_1 + F_2\right)\cos 60.0° = 0.755\ \text{N}$,

and $\Sigma F_y = \left(F_1 - F_2\right)\sin 60.0° = -0.436\ \text{N}$

The resultant force on the 7.00 μC charge is

$$F_R = \sqrt{\left(\Sigma F_x\right)^2 + \left(\Sigma F_y\right)^2} = 0.872\ \text{N} \quad \text{at } \theta = \tan^{-1}\left(\frac{\Sigma F_y}{\Sigma F_x}\right) = -30.0°\ ,$$

or $\mathbf{F}_R = \boxed{0.872\ \text{N at } 30.0° \text{ below the } +x \text{ axis}}$

15.14 Assume that the third bead has charge Q and is located at $0 < x < d$. Then the forces exerted on it by the +3q charge and by the +1q charge have magnitudes

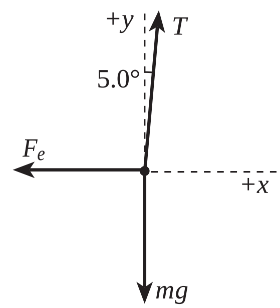
$$F_3 = \frac{k_e Q\left(3q\right)}{x^2} \quad \text{and} \quad F_1 = \frac{k_e Q\left(q\right)}{\left(d - x\right)^2} \quad \text{respectively}$$

These forces are in opposite directions, so charge Q is in equilibrium if $F_3 = F_1$. This gives $3\left(d - x\right)^2 = x^2$, and solving for x, the equilibrium position is seen to be

$$x = \frac{d}{1 + 1/\sqrt{3}} = \boxed{0.634d}$$

This is a position of $\boxed{\text{stable equilibrium if } Q > 0}$. In that case, a small displacement from the equilibrium position produces a net force directed so as to move Q back toward the equilibrium position.

15.15 Consider the free-body diagram of one of the spheres given at the right. Here, T is the tension in the string and F_e is the repulsive electrical force exerted by the other sphere.



$$\Sigma F_y = 0 \Rightarrow T\cos 5.0° = mg\text{, or } T = \frac{mg}{\cos 5.0°}$$

$$\Sigma F_x = 0 \Rightarrow F_e = T\sin 5.0° = mg\tan 5.0°$$

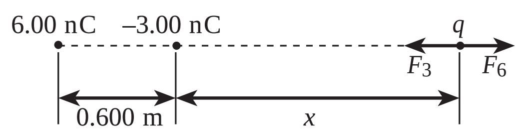
At equilibrium, the distance separating the two spheres is $r = 2L\sin 5.0°$.

Thus, $F_e = mg\tan 5.0°$ becomes $\dfrac{k_e q^2}{(2L\sin 5.0°)^2} = mg\tan 5.0°$ and yields

$$q = (2L\sin 5.0°)\sqrt{\frac{mg\tan 5.0°}{k_e}}$$

$$= [2(0.300\text{ m})\sin 5.0°]\sqrt{\frac{(0.20\times 10^{-3}\text{ kg})(9.80\text{ m/s}^2)\tan 5.0°}{8.99\times 10^9\text{ N}\cdot\text{m}^2/\text{C}^2}} = \boxed{7.2\text{ nC}}$$

15.16 The required position is shown in the sketch at the right. Note that this places q closer to the smaller charge, which will allow the two forces to cancel. Requiring that



$F_6 = F_3$ gives

$$\frac{k_e(6.00\text{ nC})q}{(x+0.600\text{ m})^2} = \frac{k_e(3.00\text{ nC})q}{x^2}\text{, or } 2x^2 = (x+0.600\text{ m})^2$$

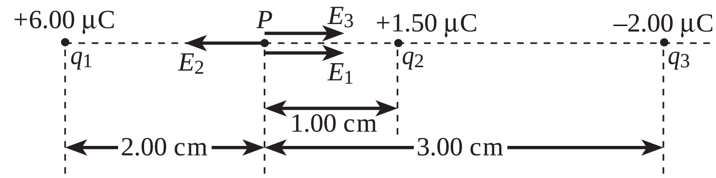
Solving for x gives the equilibrium position as

$$x = \frac{0.600\text{ m}}{\sqrt{2}-1} = \boxed{1.45\text{ m beyond the -3.00 nC charge}}$$

15.17 Since the proton is positively charged, the direction of the electric field is $\boxed{\text{radial outward from the proton}}$. Its magnitude is

$$E = \frac{k_e|q|}{r^2} = \frac{(8.99\times 10^9\text{ N}\cdot\text{m}^2/\text{C}^2)(1.60\times 10^{-19}\text{ C})}{(0.51\times 10^{-10}\text{ m})^2} = \boxed{5.5\times 10^{11}\text{ N/C}}$$

15.18 (a) Taking to the right as positive, the resultant electric field at point P is given by



$$E_R = E_1 + E_3 - E_2$$

$$= \frac{k_e|q_1|}{r_1^2} + \frac{k_e|q_3|}{r_3^2} - \frac{k_e|q_2|}{r_2^2}$$

$$= \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left[\frac{6.00\times10^{-6}\ \text{C}}{(0.0200\ \text{m})^2} + \frac{2.00\times10^{-6}\ \text{C}}{(0.0300\ \text{m})^2} - \frac{1.50\times10^{-6}\ \text{C}}{(0.0100\ \text{m})^2}\right]$$

This gives $E_R = +2.00\times10^7\ \text{N/C}$,

or $\mathbf{E}_R = \boxed{2.00\times10^7\ \text{N/C to the right}}$

(b) $\mathbf{F} = q\mathbf{E}_R = \left(-2.00\times10^{-6}\ \text{C}\right)\left(2.00\times10^7\ \text{N/C}\right) = -40.0\ \text{N}$,

or $\mathbf{F} = \boxed{40.0\ \text{N to the left}}$

15.19 We shall treat the concentrations as point charges. Then, the resultant field consists of two contributions, one due to each concentration.

The contribution due to the positive charge at 3000 m altitude is

$$E_+ = k_e\frac{|q|}{r^2} = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(40.0\ \text{C})}{(1000\ \text{m})^2} = 3.60\times10^5\ \text{N/C}\quad(\text{downward})$$

The contribution due to the negative charge at 1000 m altitude is

$$E_- = k_e\frac{|q|}{r^2} = \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(40.0\ \text{C})}{(1000\ \text{m})^2} = 3.60\times10^5\ \text{N/C}\quad(\text{downward})$$

The resultant field is then

$$\mathbf{E} = \mathbf{E}_+ + \mathbf{E}_- = \boxed{7.20\times10^5\ \text{N/C (downward)}}$$

15.20 (a) The magnitude of the force on the electron is $F = |q|E = eE$, and the acceleration is

$$a = \frac{F}{m_e} = \frac{eE}{m_e} = \frac{\left(1.60\times10^{-19}\text{ C}\right)\left(300\text{ N/C}\right)}{9.11\times10^{-31}\text{ kg}} = \boxed{5.27\times10^{13}\text{ m/s}^2}$$

(b) $v = v_i + at = 0 + \left(5.27\times10^{13}\text{ m/s}^2\right)\left(1.00\times10^{-8}\text{ s}\right) = \boxed{5.27\times10^{5}\text{ m/s}}$

15.21 If there is zero tension in the string, the electrical force supports the entire weight of the foil. Thus,

$$F = |q|E = mg,$$

so $$E = \frac{mg}{|q|} = \frac{\left(5.00\times10^{-2}\text{ kg}\right)\left(9.80\text{ m/s}^2\right)}{3.00\times10^{-6}\text{ C}} = \boxed{1.63\times10^{5}\text{ N/C}}$$

15.22 When the electron enters the electric field, it experiences a retarding force of magnitude $|\mathbf{F}| = eE$, and is given an acceleration of

$$a = \frac{F}{m_e} = \frac{-eE}{m_e} = -\frac{\left(1.60\times10^{-19}\text{ C}\right)\left(1000\text{ N/C}\right)}{9.11\times10^{-31}\text{ kg}} = -1.76\times10^{14}\text{ m/s}^2$$

From $v^2 = v_i^2 + 2a(\Delta x)$, the stopping distance is found to be

$$\Delta x = \frac{v^2 - v_i^2}{2a} = \frac{0 - \left(3.00\times10^{6}\text{ m/s}\right)^2}{2\left(-1.76\times10^{14}\text{ m/s}^2\right)} = 0.0256\text{ m} = \boxed{2.56\text{ cm}}$$

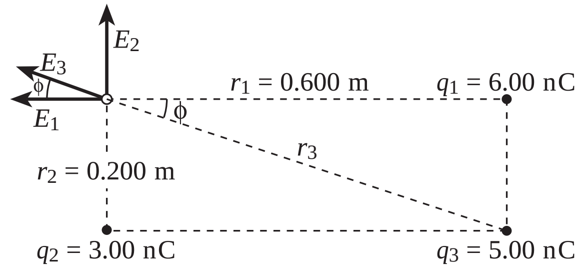
15.23 (a) $a = \dfrac{F}{m} = \dfrac{qE}{m_p} = \dfrac{\left(1.60\times10^{-19}\text{ C}\right)\left(640\text{ N/C}\right)}{1.673\times10^{-27}\text{ kg}} = \boxed{6.12\times10^{10}\text{ m/s}^2}$

(b) $t = \dfrac{\Delta v}{a} = \dfrac{1.20\times10^{6}\text{ m/s}}{6.12\times10^{10}\text{ m/s}^2} = 1.96\times10^{-5}\text{ s} = \boxed{19.6\ \mu\text{s}}$

(c) $\Delta x = \dfrac{v_f^2 - v_i^2}{2a} = \dfrac{\left(1.20\times10^{6}\text{ m/s}\right)^2 - 0}{2\left(6.12\times10^{10}\text{ m/s}^2\right)} = \boxed{11.8\text{ m}}$

(d) $KE_f = \dfrac{1}{2}m_p v_f^2 = \dfrac{1}{2}\left(1.673\times10^{-27}\text{ kg}\right)\left(1.20\times10^{6}\text{ m/s}\right)^2 = \boxed{1.20\times10^{-15}\text{ J}}$

15.24 From the geometry of the rectangle,



$$r_3^2 = (0.600\text{ m})^2 + (0.200\text{ m})^2 = 0.400\text{ m}^2,$$

and

$$\phi = \tan^{-1}\left(\frac{0.200\text{ m}}{0.600\text{ m}}\right) = 18.4°$$

The resultant field at the vacant corner is

$$\mathbf{E}_R = \mathbf{E}_1 + \mathbf{E}_2 + \mathbf{E}_3$$

$$E_x = \Sigma E_x = -\frac{k_e|q_1|}{r_1^2} - \frac{k_e|q_3|}{r_3^2}\cos\phi$$

$$= -\left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left[\frac{6.00\times10^{-9}\text{ C}}{(0.600\text{ m})^2} + \frac{5.00\times10^{-9}\text{ C}}{0.400\text{ m}^2}\cos 18.4°\right] = -256\text{ N/C}$$

$$E_y = \Sigma E_y = \frac{k_e|q_2|}{r_2^2} + \frac{k_e|q_3|}{r_3^2}\sin\phi$$

$$= \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left[\frac{3.00\times10^{-9}\text{ C}}{(0.200\text{ m})^2} + \frac{5.00\times10^{-9}\text{ C}}{0.400\text{ m}^2}\sin 18.4°\right] = 710\text{ N/C}$$

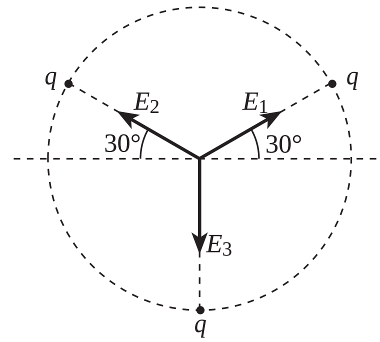
Thus, $E_R = \sqrt{(E_x)^2 + (E_y)^2} = 755\text{ N/C}$. With $E_x < 0$ and $E_y > 0$, the resultant field lies in the second quadrant. Its angle with the +*x* axis is

$$\theta = \tan^{-1}\left(\frac{E_y}{E_x}\right) = \tan^{-1}\left(\frac{710}{-256}\right) = 110°,$$

so $\mathbf{E}_R = \boxed{755\text{ N/C at }110°\text{ counterclockwise from }+x\text{ axis}}$

15.25 From the symmetry of the charge distribution, students should recognize that the resultant electric field at the center is

$$\boxed{\mathbf{E}_R = 0}$$



If one does not recognize this intuitively, consider:

$\mathbf{E}_R = \mathbf{E}_1 + \mathbf{E}_2 + \mathbf{E}_3$, so

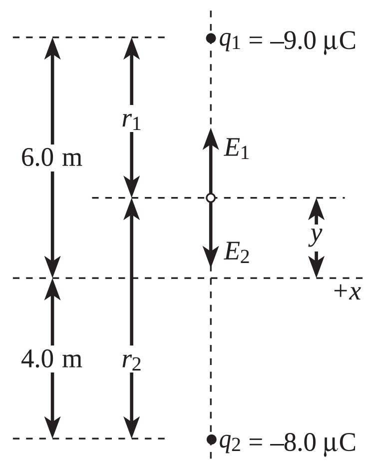
$$E_x = E_{1x} - E_{2x} = \frac{k_e|q|}{r^2}\cos 30° - \frac{k_e|q|}{r^2}\cos 30° = 0$$

and

$$E_y = E_{1y} + E_{2y} - E_3 = \frac{k_e|q|}{r^2}\sin 30° + \frac{k_e|q|}{r^2}\sin 30° - \frac{k_e|q|}{r^2} = 0$$

Thus, $E_R = \sqrt{E_x^2 + E_y^2} = 0$

15.26 If the resultant field is to be zero, the contributions from the two charges must equal in magnitude and must have opposite directions. This is only possible at a point on the line between the two negative charges.

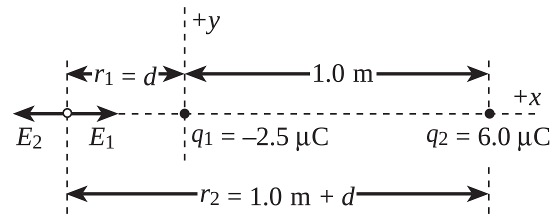


Assume the point of interest is located on the y-axis at $-4.0\text{ m} < y < 6.0\text{ m}$. Then, for equal magnitudes,

$$\frac{k_e|q_1|}{r_1^2} = \frac{k_e|q_2|}{r_2^2} \quad \text{or} \quad \frac{9.0\ \mu\text{C}}{(6.0\text{ m} - y)^2} = \frac{8.0\ \mu\text{C}}{(y + 4.0\text{ m})^2}$$

Solving for y gives $y + 4.0\text{ m} = \sqrt{\frac{8}{9}}(6.0\text{ m} - y)$, or $y = \boxed{+0.85\text{ m}}$

15.27 If the resultant field is zero, the contributions from the two charges must be in opposite directions and also have equal magnitudes. Choose the line connecting the charges as the *x*-axis, with the origin at the –2.5 μC charge. Then, the two contributions will have opposite directions only in the regions $x < 0$ and $x > 1.0\text{ m}$. For the magnitudes to be equal, the point must be nearer the smaller charge. Thus, the point of zero resultant field is on the *x*-axis at $x < 0$.



Requiring equal magnitudes gives $\dfrac{k_e|q_1|}{r_1^2} = \dfrac{k_e|q_2|}{r_2^2}$ or $\dfrac{2.5\ \mu\text{C}}{d^2} = \dfrac{6.0\ \mu\text{C}}{(1.0\text{ m} + d)^2}$.

Thus, $(1.0\text{ m} + d)\sqrt{\dfrac{2.5}{6.0}} = d$

Solving for *d* yields

$d = 1.8\text{ m}$, or $\boxed{1.8\text{ m to the left of the } -2.5\ \mu\text{C charge}}$

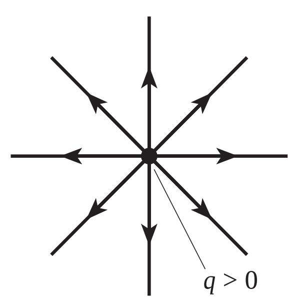
15.28 The magnitude of q_2 is three times the magnitude of q_1 because 3 times as many lines emerge from q_2 as enter q_1. $|q_2| = 3|q_1|$

(a) Then, $\boxed{q_1/q_2 = -1/3}$

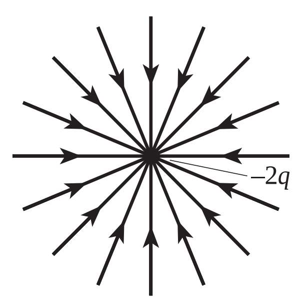
(b) $\boxed{q_2 > 0}$ because lines emerge from it,

and $\boxed{q_1 < 0}$ because lines terminate on it.

15.29 Note in the sketches at the right that electric field lines originate on positive charges and terminate on negative charges. The density of lines is twice as great for the $-2q$ charge in (b) as it is for the $1q$ charge in (a).

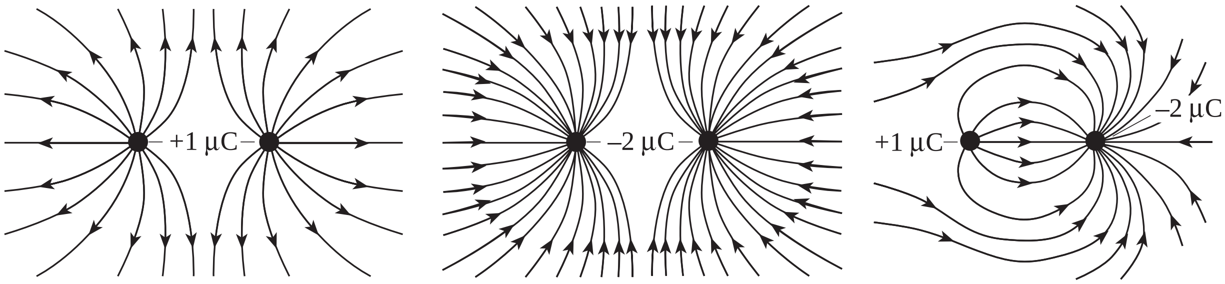


(a)



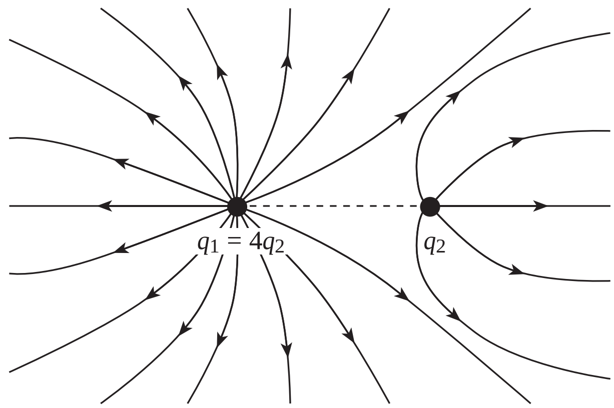
(b)

15.30 Rough sketches for these charge configurations are shown below.



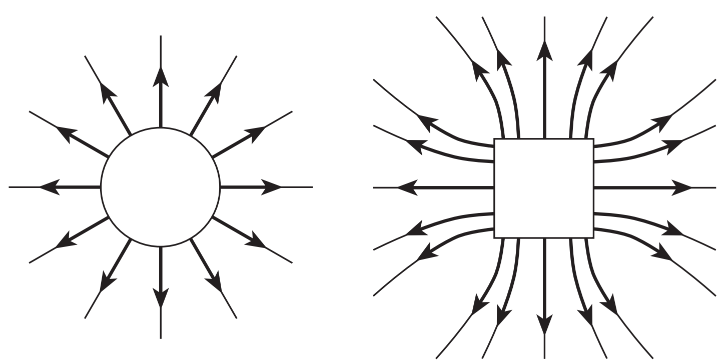
(a) **(b)** **(c)**

15.31 (a) The sketch for (a) is shown at the right. Note that four times as many lines should leave q_1 as emerge from q_2 although, for clarity, this is not shown in this sketch.



(b) The field pattern looks the same here as that shown for (a) with the exception that the arrows are reversed on the field lines.

15.32 (a) In the sketch for (a) at the right, note that there are no lines inside the sphere. On the outside of the sphere, the field lines are uniformly spaced and radially outward.



(a) **(b)**

(b) In the sketch for (b) above, note that the lines are perpendicular to the surface at the points where they emerge. They should also be symmetrical about the symmetry axes of the cube. The field is zero inside the cube.

15.33 (a) $\boxed{\text{Zero}}$ net charge on each surface of the sphere.

(b) The negative charge lowered into the sphere repels $\boxed{-5\,\mu\text{C to the outside}}$ surface, and leaves $\boxed{+5\,\mu\text{C on the inside}}$ surface of the sphere.

(c) The negative charge lowered inside the sphere neutralizes the inner surface, leaving $\boxed{\text{zero charge on the inside}}$. This leaves $\boxed{-5\,\mu\text{C on the outside}}$ surface of the sphere.

(d) When the object is removed, the sphere is left with $\boxed{-5.00\,\mu\text{C on the outside}}$ surface and $\boxed{\text{zero charge on the inside}}$.

15.34 (a) The dome is a closed conducting surface. Therefore, the electric field is $\boxed{\text{zero}}$ everywhere inside it.

At the surface and outside of this spherically symmetric charge distribution, the field is as if all the charge were concentrated at the center of the sphere.

(b) At the surface,

$$E = \frac{k_e q}{R^2} = \frac{\left(8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(2.0\times10^{-4}\ \text{C}\right)}{(1.0\ \text{m})^2} = \boxed{1.8\times10^{6}\ \text{N/C}}$$

(c) Outside the spherical dome, $E = \dfrac{k_e q}{r^2}$. Thus, at $r = 4.0\ \text{m}$,

$$E = \frac{\left(8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(2.0\times10^{-4}\ \text{C}\right)}{(4.0\ \text{m})^2} = \boxed{1.1\times10^{5}\ \text{N/C}}$$

15.35 For a uniformly charged sphere, the field is strongest at the surface.

Thus, $E_{max} = \dfrac{k_e q_{max}}{R^2}$,

or $$q_{max} = \frac{R^2 E_{max}}{k_e} = \frac{(2.0\ \text{m})^2\left(3.0\times10^{6}\ \text{N/C}\right)}{8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2} = \boxed{1.3\times10^{-3}\ \text{C}}$$

15.36 (a) $$a = \frac{F}{m} = \frac{|q|E_{max}}{m_e} = \frac{\left(1.60\times10^{-19}\ \text{C}\right)\left(3.0\times10^{6}\ \text{N/C}\right)}{9.11\times10^{-31}\ \text{N}} = \boxed{5.3\times10^{17}\ \text{m/s}^2}$$

(b) Anticipating that this distance is very small, we assume the field to be uniform and the acceleration constant over the distance involved. Then,

$$\Delta x = \frac{v_f^2 - v_f^2}{2a} = \frac{\left[0.100\left(3.00\times10^{8}\ \text{m/s}\right)\right]^2 - 0}{2\left(5.3\times10^{17}\ \text{m/s}^2\right)} = 8.5\times10^{-4}\ \text{m} = \boxed{0.85\ \text{mm}}$$

15.37 (a) $F = qE = \left(1.60\times10^{-19}\text{ C}\right)\left(3.0\times10^{4}\text{ N/C}\right) = \boxed{4.8\times10^{-15}\text{ N}}$

(b) $a = \dfrac{F}{m_p} = \dfrac{4.8\times10^{-15}\text{ N}}{1.673\times10^{-27}\text{ kg}} = \boxed{2.9\times10^{12}\text{ m/s}^2}$

15.38 The flux through an area is $\Phi_E = EA\cos\theta$, where θ is the angle between the direction of the field *E* and the line perpendicular to the area *A*.

(a) $\Phi_E = EA\cos\theta = \left(6.2\times10^{5}\text{ N/C}\right)\left(3.2\text{ m}^2\right)\cos 0^\circ = \boxed{2.0\times10^{6}\text{ N}\cdot\text{m}^2/\text{C}}$

(b) In this case, $\theta = 90^\circ$ and $\Phi_E = \boxed{0}$

15.39 The area of the rectangular plane is $A = (0.350\text{ m})(0.700\text{ m}) = 0.245\text{ m}^2$.

(a) When the plane is parallel to the *yz* plane, $\theta = 0^\circ$, and the flux is

$$\Phi_E = EA\cos\theta = \left(3.50\times10^{3}\text{ N/C}\right)\left(0.245\text{ m}^2\right)\cos 0^\circ = \boxed{858\text{ N}\cdot\text{m}^2/\text{C}}$$

(b) When the plane is parallel to the *x*-axis, $\theta = 90^\circ$ and $\Phi_E = \boxed{0}$

(c) $\Phi_E = EA\cos\theta = \left(3.50\times10^{3}\text{ N/C}\right)\left(0.245\text{ m}^2\right)\cos 40.0^\circ = \boxed{657\text{ N}\cdot\text{m}^2/\text{C}}$

15.40 In this problem, we consider part (b) first.

(b) Since the field is radial everywhere, the charge distribution generating it must be $\boxed{\text{spherically symmetric}}$. Also, since the field is radially inward, the net charge inside the sphere is $\boxed{\text{negative charge}}$.

(a) Outside a spherically symmetric charge distribution, the field is $E = \dfrac{k_e Q}{r^2}$. Thus, just outside the surface where $r = R$, the magnitude of the field is $E = k_e|Q|/R^2$, so

$$|Q| = \frac{R^2 E}{k_e} = \frac{(0.750\text{ m})^2(890\text{ N/C})}{8.99\times10^{9}\text{ N}\cdot\text{m}^2/\text{C}^2} = 5.57\times10^{-8}\text{ C} = 55.7\text{ nC}$$

Since we have determined that $Q < 0$, we now have $Q = \boxed{-55.7\text{ nC}}$

15.41 $\Phi_E = EA\cos\theta$ and $\Phi_E = \Phi_{E,\max}$ when $\theta = 0°$

Thus, $E = \dfrac{\Phi_{E,\max}}{A} = \dfrac{\Phi_{E,\max}}{\pi d^2/4} = \dfrac{4\left(5.2\times10^5\ \text{N}\cdot\text{m}^2/\text{C}\right)}{\pi\left(0.40\ \text{m}\right)^2} = \boxed{4.1\times10^6\ \text{N/C}}$

15.42 $\Phi_E = EA\cos\theta = \left(\dfrac{k_e q}{R^2}\right)\left(4\pi R^2\right)\cos 0° = 4\pi k_e q$

$\Phi_E = 4\pi\left(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(5.00\times10^{-6}\ \text{C}\right) = \boxed{5.65\times10^5\ \text{N}\cdot\text{m}^2/\text{C}}$

15.43 We choose a spherical gaussian surface, concentric with the charged spherical shell and of radius *r*. Then, $\Sigma EA\cos\theta = E\left(4\pi r^2\right)\cos 0° = 4\pi r^2 E$.

(a) For $r > R$ (i.e., outside the shell), the total charge enclosed by the gaussian surface is $Q = +q - q = 0$. Thus, Gauss's law gives $4\pi r^2 E = 0$, or $E = \boxed{0}$.

(b) Inside the shell, $r < R$, and the enclosed charge is $Q = +q$.

Therefore, from Gauss's law, $4\pi r^2 E = \dfrac{q}{\epsilon_0}$, or $E = \dfrac{q}{4\pi\epsilon_0 r^2} = \dfrac{k_e q}{r^2}$

The field for $r < R$ is $\boxed{\mathbf{E} = \dfrac{k_e q}{r^2}\ \text{directed radially outward}}$.

15.44 Construct a gaussian surface just barely inside the surface of the conductor, where $E = 0$. Since $E = 0$ inside, Gauss' law says $\dfrac{Q}{\epsilon_0} = 0$ inside. Thus, any excess charge residing on the conductor must be outside our gaussian surface (i.e., on the surface of the conductor).

15.45 $E = 0$ at all points inside the conductor, and $\cos\theta = \cos 90° = 0$ on the cylindrical surface. Thus, the only flux through the gaussian surface is on the outside end cap and Gauss's law reduces to $\Sigma EA\cos\theta = EA_{cap} = \dfrac{Q}{\epsilon_o}$.

The charge enclosed by the gaussian surface is $Q = \sigma A$, where A is the cross-sectional area of the cylinder and also the area of the end cap, so Gauss's law becomes

$$EA = \frac{\sigma A}{\epsilon_o}\text{, or } E = \boxed{\frac{\sigma}{\epsilon_o}}$$

15.46 Choose a very small cylindrical gaussian surface with one end inside the conductor. Position the other end parallel to and just outside the surface of the conductor.

Since, in static conditions, $E = 0$ at all points inside a conductor, there is no flux through the inside end cap of the gaussian surface. At all points outside, but very close to, a conductor the electric field is perpendicular to the conducting surface. Thus, it is parallel to the cylindrical side of the gaussian surface and no flux passes through this cylindrical side. The total flux through the gaussian surface is then $\Phi = EA$, where A is the cross-sectional area of the cylinder as well as the area of the end cap.

The total charge enclosed by the cylindrical gaussian surface is $Q = \sigma A$, where σ is the charge density on the conducting surface. Hence, Gauss's law gives

$$EA = \frac{\sigma A}{\epsilon_0} \text{ or } E = \boxed{\frac{\sigma}{\epsilon_o}}$$

15.47 $F = \dfrac{k_e|q_1||q_2|}{r^2} = \dfrac{k_e e^2}{r^2} = \dfrac{\left(8.99\times10^9 \text{ N}\cdot\text{m}^2/\text{C}\right)\left(1.60\times10^{-19}\text{ C}\right)^2}{\left(2.00\times10^{-15}\text{ m}\right)^2} = \boxed{57.5\text{ N}}$

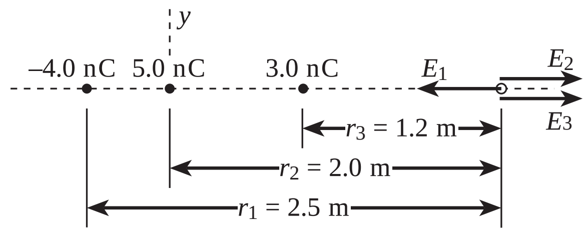
15.48 (a) $F = \dfrac{k_e|q_1||q_2|}{r^2} = \dfrac{k_e e^2}{r^2}$

$$= \frac{\left(8.99\times10^9 \text{ N}\cdot\text{m}^2/\text{C}^2\right)\left(1.60\times10^{-19}\text{ C}\right)^2}{\left(0.53\times10^{-10}\text{ m}\right)^2} = \boxed{8.2\times10^{-8}\text{ N}}$$

(b) $F = m_e a_c = m_e \left(v^2/r\right)$, so

$$v = \sqrt{\frac{r \cdot F}{m_e}} = \sqrt{\frac{\left(0.53 \times 10^{-10}\ \text{m}\right)\left(8.2 \times 10^{-8}\ \text{N}\right)}{9.11 \times 10^{-31}\ \text{kg}}} = \boxed{2.2 \times 10^{6}\ \text{m/s}}$$

15.49 The three contributions to the resultant electric field at the point of interest are shown in the sketch at the right.



The magnitude of the resultant field is

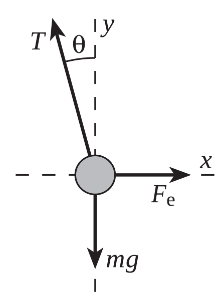
$$E_R = -E_1 + E_2 + E_3$$

$$E_R = -\frac{k_e|q_1|}{r_1^2} + \frac{k_e|q_2|}{r_2^2} + \frac{k_e|q_3|}{r_3^2} = k_e\left[-\frac{|q_1|}{r_1^2} + \frac{|q_2|}{r_2^2} + \frac{|q_3|}{r_3^2}\right]$$

$$E_R = \left(8.99 \times 10^{9}\ \frac{\text{N} \cdot \text{m}^2}{\text{C}^2}\right)\left[-\frac{4.0 \times 10^{-9}\ \text{C}}{(2.5\ \text{m})^2} + \frac{5.0 \times 10^{-9}\ \text{C}}{(2.0\ \text{m})^2} + \frac{3.0 \times 10^{-9}\ \text{C}}{(1.2\ \text{m})^2}\right]$$

$E_R = +24\ \text{N/C}$, or $\mathbf{E}_R = \boxed{24\ \text{N/C in the } +x \text{ direction}}$

15.50 Consider the free-body diagram shown at the right.



$$\Sigma F_y = 0 \Rightarrow T\cos\theta = mg \quad \text{or} \quad T = \frac{mg}{\cos\theta}$$

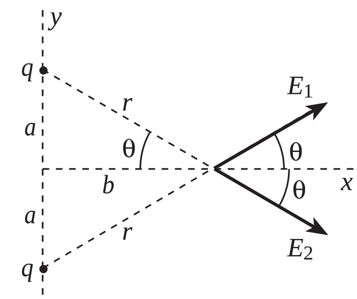
$$\Sigma F_x = 0 \Rightarrow F_e = T\sin\theta = mg\tan\theta$$

Since $F_e = qE$, we have

$qE = mg\tan\theta$, or $q = \dfrac{mg\tan\theta}{E}$

$$q = \frac{\left(2.00 \times 10^{-3}\ \text{kg}\right)\left(9.80\ \text{m/s}^2\right)\tan 15.0^\circ}{1.00 \times 10^{3}\ \text{N/C}} = 5.25 \times 10^{-6}\ \text{C} = \boxed{5.25\ \mu\text{C}}$$

15.51 (a) At a point on the x-axis, the contributions by the two charges to the resultant field have equal magnitudes given by $E_1 = E_2 = \frac{k_e q}{r^2}$.



The components of the resultant field are

$$E_y = E_{1y} - E_{2y} = \left(\frac{k_e q}{r^2}\right)\sin\theta - \left(\frac{k_e q}{r^2}\right)\sin\theta = 0$$

and
$$E_x = E_{1x} + E_{2x} = \left(\frac{k_e q}{r^2}\right)\cos\theta + \left(\frac{k_e q}{r^2}\right)\cos\theta = \left[\frac{k_e(2q)}{r^2}\right]\cos\theta$$

Since $\frac{\cos\theta}{r^2} = \frac{b/r}{r^2} = \frac{b}{r^3} = \frac{b}{\left(a^2+b^2\right)^{3/2}}$, the resultant field is

$$\mathbf{E}_R = \boxed{\frac{k_e(2q)b}{\left(a^2+b^2\right)^{3/2}} \text{ in the } +x \text{ direction}}$$

(b) Note that the result of part (a) may be written as $E_R = \frac{k_e(Q)b}{\left(a^2+b^2\right)^{3/2}}$ where $Q = 2q$ is the total charge in the charge distribution generating the field.

In the case of a uniformly charged circular ring, consider the ring to consist of a very large number of pairs of charges uniformly spaced around the ring. Each pair consists of two identical charges located diametrically opposite each other on the ring. The total charge of pair number i is Q_i. At a point on the axis of the ring, this pair of charges generates an electric field contribution that is parallel to the axis and has magnitude $E_i = \frac{k_e b Q_i}{\left(a^2+b^2\right)^{3/2}}$.

The resultant electric field of the ring is the summation of the contributions by all pairs of charges, or

$$E_R = \Sigma E_i = \left[\frac{k_e b}{\left(a^2+b^2\right)^{3/2}}\right]\Sigma Q_i = \frac{k_e b Q}{\left(a^2+b^2\right)^{3/2}},$$

where $Q = \Sigma Q_i$ is the total charge on the ring.

$$\mathbf{E}_R = \boxed{\frac{k_e Q\, b}{\left(a^2+b^2\right)^{3/2}} \text{ in the } +x \text{ direction}}$$

15.52 (a) $a_y = \dfrac{v_y^2 - v_{0y}^2}{2(\Delta y)} = \dfrac{(21.0 \text{ m/s})^2 - 0}{2(5.00 \text{ m})} = 44.1 \text{ m/s}^2 \text{ (downward)}$

Since $a_y > g$, the electrical force must be directed downward, aiding the gravitational force in accelerating the bead. Because the bead is positively charged, the electrical force acting on it is in the direction of the electric field. Thus, the field is directed $\boxed{\text{downward}}$.

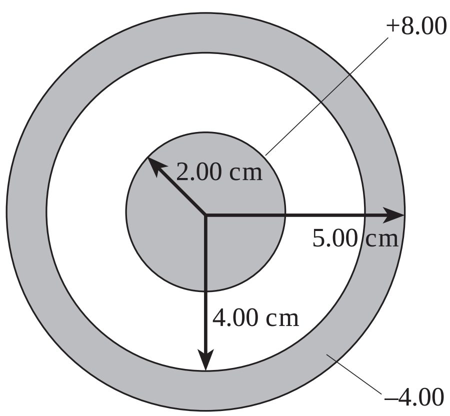
(b) Taking downward as positive, $\Sigma F_y = qE + mg = ma_y$.

Therefore,

$$q = \frac{m(a_y - g)}{E}$$

$$= \frac{(1.00 \times 10^{-3} \text{ kg})\left[(44.1 - 9.80) \text{ m/s}^2\right]}{1.00 \times 10^4 \text{ N/C}} = 3.43 \times 10^{-6} \text{ C} = \boxed{3.43\ \mu\text{C}}$$

15.53 Because of the spherical symmetry of the charge distribution, any electric field present will be radial in direction. If a field does exist at distance R from the center, it is the same as if the net charge located within $r \le R$ were concentrated as a point charge at the center of the inner sphere. Charge located at $r > R$ does not contribute to the field at $r = R$.



(a) At $r = 1.00$ cm, $\boxed{E = 0}$ since static electric fields cannot exist within conducting materials.

(b) The net charge located at $r \le 3.00$ cm is $Q = +8.00\ \mu\text{C}$.

Thus, at $r = 3.00$ cm,

$$E = \frac{k_e Q}{r^2}$$

$$= \frac{(8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(8.00 \times 10^{-6} \text{ C})}{(3.00 \times 10^{-2} \text{ m})^2} = \boxed{7.99 \times 10^7 \text{ N/C (outward)}}$$

(c) At $r = 4.50\ \text{cm}$, $\boxed{E = 0}$ since this is located within conducting materials.

(d) The net charge located at $r \le 7.00\ \text{cm}$ is $Q = +4.00\ \mu\text{C}$.

Thus, at $r = 7.00\ \text{cm}$,

$$E = \frac{k_e Q}{r^2}$$

$$= \frac{\left(8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(4.00\times10^{-6}\ \text{C}\right)}{\left(7.00\times10^{-2}\ \text{m}\right)^2} = \boxed{7.34\times10^{6}\ \text{N/C (outward)}}$$

15.54 The charges on the spheres will be equal in magnitude and opposite in sign. From $F = k_e q^2/r^2$, this charge must be

$$q = \sqrt{\frac{F\cdot r^2}{k_e}} = \sqrt{\frac{\left(1.00\times10^{4}\ \text{N}\right)\left(1.00\ \text{m}\right)^2}{8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2}} = 1.05\times10^{-3}\ \text{C}$$

The number of electrons transferred is

$$n = \frac{q}{e} = \frac{1.05\times10^{-3}\ \text{C}}{1.60\times10^{-19}\ \text{C}} = 6.59\times10^{15}$$

The total number of electrons in 100-g of silver is

$$N = \left(47\ \frac{\text{electrons}}{\text{atom}}\right)\left(6.02\times10^{23}\ \frac{\text{atoms}}{\text{mole}}\right)\left(\frac{1\ \text{mole}}{107.87\ \text{g}}\right)\left(100\ \text{g}\right) = 2.62\times10^{25}$$

Thus, the fraction transferred is

$$\frac{n}{N} = \frac{6.59\times10^{15}}{2.62\times10^{25}} = \boxed{2.51\times10^{-10}}\ \text{(i.e., 2.51 out of every 10 billion).}$$

15.55 $\Phi_E = EA\cos\theta$

$$= \left(2.00\times10^{4}\ \text{N/C}\right)\left[\left(6.00\ \text{m}\right)\left(3.00\ \text{m}\right)\right]\cos 10.0^\circ = \boxed{3.55\times10^{5}\ \text{N}\cdot\text{m}^2/\text{C}}$$

15.56 (a) The downward electrical force acting on the ball is

$$F_e = qE = \left(2.00\times10^{-6}\text{ C}\right)\left(1.00\times10^{5}\text{ N/C}\right) = 0.200\text{ N}\ .$$

The total downward force acting on the ball is then

$$F = F_e + mg = 0.200\text{ N} + \left(1.00\times10^{-3}\text{ kg}\right)\left(9.80\text{ m/s}^2\right) = 0.210\text{ N}\ .$$

Thus, the ball will behave as if it was in a modified gravitational field where the effective acceleration of gravity is

$$"g" = \frac{F}{m} = \frac{0.210\text{ N}}{1.00\times10^{-3}\text{ kg}} = 210\text{ m/s}^2$$

The period of the pendulum will be

$$T = 2\pi\sqrt{\frac{L}{"g"}} = 2\pi\sqrt{\frac{0.500\text{ m}}{210\text{ m/s}^2}} = \boxed{0.307\text{ s}}$$

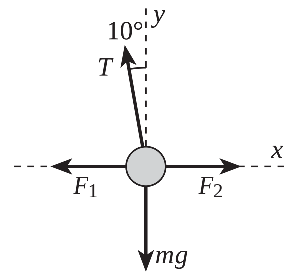
(b) $\boxed{\text{Yes}}$. The force of gravity is a significant portion of the total downward force acting on the ball. Without gravity, the effective acceleration would be

$$"g" = \frac{F_e}{m} = \frac{0.200\text{ N}}{1.00\times10^{-3}\text{ kg}} = 200\text{ m/s}^2,$$

giving $T = 2\pi\sqrt{\frac{0.500\text{ m}}{200\text{ m/s}^2}} = 0.314\text{ s}$,

a 2.28% difference from the correct value with gravity included.

15.57 The sketch at the right gives a free-body diagram of the positively charged sphere. Here, $F_1 = k_e|q|^2/r^2$ is the attractive force exerted by the negatively charged sphere and $F_2 = qE$ is exerted by the electric field.



$$\Sigma F_y = 0 \Rightarrow T\cos 10° = mg \quad \text{or} \quad T = \frac{mg}{\cos 10°}$$

$$\Sigma F_x = 0 \Rightarrow F_2 = F_1 + T\sin 10° \quad \text{or} \quad qE = \frac{k_e|q|^2}{r^2} + mg\tan 10°$$

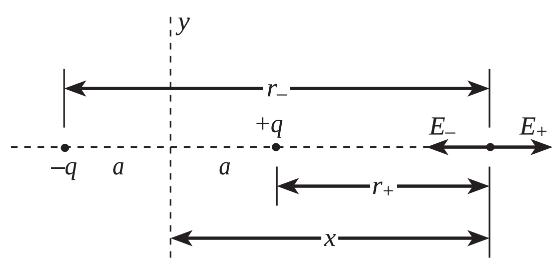
At equilibrium, the distance between the two spheres is $r = 2(L\sin 10°)$. Thus,

$$E = \frac{k_e|q|}{4(L\sin 10°)^2} + \frac{mg\tan 10°}{q}$$

$$= \frac{(8.99\times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(5.0\times 10^{-8}\ \text{C})}{4[(0.100\ \text{m})\sin 10°]^2} + \frac{(2.0\times 10^{-3}\ \text{kg})(9.80\ \text{m/s}^2)\tan 10°}{(5.0\times 10^{-8}\ \text{C})},$$

or the needed electric field strength is $E = \boxed{4.4\times 10^5\ \text{N/C}}$.

15.58 As shown in the sketch, the electric field at any point on the x-axis consists of two parts, one due to each of the charges in the dipole.

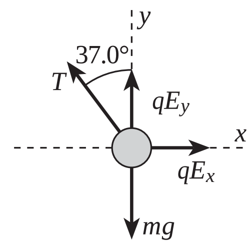


$$E = E_+ - E_- = \frac{k_e|q|}{r_+^2} - \frac{k_e|q|}{r_-^2}$$

$$E = \frac{k_e|q|}{(x-a)^2} - \frac{k_e|q|}{(x+a)^2} = k_e|q|\left[\frac{(x+a)^2-(x-a)^2}{(x-a)^2(x+a)^2}\right] = k_e q\left[\frac{4ax}{(x^2-a^2)^2}\right]$$

Thus, if $x^2 >> a^2$, this gives $E \approx k_e q\left[\frac{4ax}{x^4}\right] = \boxed{\frac{4k_e qa}{x^3}}$

15.59 (a) Consider the free-body diagram for the ball given in the sketch.



$$\Sigma F_x = 0 \Rightarrow T\sin 37.0° = qE_x \quad \text{or} \quad T = \frac{qE_x}{\sin 37.0°}$$

and

$$\Sigma F_y = 0 \Rightarrow qE_y + T\cos 37.0° = mg \quad \text{or} \quad qE_y + qE_x\cot 37.0° = mg$$

Thus, $q = \dfrac{mg}{E_y + E_x\cot 37.0°} = \dfrac{(1.00\times 10^{-3}\text{ kg})(9.80\text{ m/s}^2)}{[5.00 + (3.00)\cot 37.0°]\times 10^5\text{ N/C}}$

$$= 1.09\times 10^{-8}\text{ C} = 10.9\text{ nC}$$

(b) From $\Sigma F_x = 0$, we found that $T = \dfrac{qE_x}{\sin 37.0°}$.

Hence, $T = \dfrac{(1.09\times 10^{-8}\text{ C})(3.00\times 10^5\text{ N/C})}{\sin 37.0°} = \boxed{5.44\times 10^{-3}\text{ N}}$

Answers to Even Numbered Conceptual Questions

2. To avoid making a spark. Rubber-soled shoes acquire a charge by friction with the floor and could discharge with a spark, possibly causing an explosive burning situation, where the burning is enhanced by the oxygen.

4. Electrons are more mobile than protons and are more easily freed from atoms than are protons.

6. The tumbling action of the clothes in the dryer causes them to acquire static charges by friction effects. The hot, dry air in the dryer is a good insulator, so these static charges are not quickly dissipated.

8. So the electric field from the test charge does not distort the electric field you are trying to measure by moving the charges that create it.

10. She is not shocked. She becomes part of the dome of the Van de Graaff, and charges flow onto her body. They do not jump to her body via a spark, however, so she is not shocked.

12. An electric field once established by a positive or negative charge extends in all directions from the charge. Thus, it can exist in empty space if that is what surrounds the charge.

14. No. Life would be no different if electrons were positively charged and protons were negatively charged. Opposite charges would still attract, and like charges would still repel. The designation of charges as positive and negative is merely a definition.

16. The antenna is similar to a lightning rod and can induce a bolt to strike it. A wire from the antenna to the ground provides a pathway for the charges to move away from the house in case a lightning strike does occur.

18. Lightning usually strikes the tallest object in the affected area. If you are under the tree, the charges passing though it and the earth can also cause damage to you.

Answers to Even Numbered Problems

2. (a) 3.7×10^{-7} N (repulsion)
(b) it is reduced to one fourth its previous value

4. 1.86×10^{-9} kg

6. 2.25×10^{-9} N/m

8. 5.08 m

10. $F_6 = 46.7$ N (left), $F_{1.5} = 157$ N (right), $F_{-2} = 111$ N (left)

12. 3.89×10^{-7} N at 11.3° below $+x$ axis

14. $x = 0.634d$, stable if third bead has positive charge

16. 1.45 m beyond the –3.00 nC charge

18. (a) 2.00×10^{7} N/C to the right (b) 40.0 N to the left

20. (a) 5.27×10^{13} m/s^2 (b) 5.27×10^{5} m/s

22. 2.56 cm

24. 755 N/C at 110° CCW from $+x$ axis

26. at $y = +0.85$ m

28. (a) $q_1/q_2 = -1/3$ (b) $q_2 > 0, q_1 < 0$

34. (a) zero (b) 1.8×10^{6} N/C (c) 1.1×10^{5} N/C

36. (a) 5.3×10^{17} m/s^2 (b) 0.85 mm

38. (a) 2.0×10^{6} N·m^2/C (b) 0

40. (a) –55.7 nC
(b) negative, with a spherically symmetric distribution

42. 5.65×10^{5} N·m^2/C

48. (a) 8.2×10^{-8} N (b) 2.2×10^{6} m/s

50. $5.25\ \mu C$

52. (a) downward (b) $3.43\ \mu C$

54. 2.51×10^{-10}

56. (a) 0.307 s
(b) Yes, the absence of gravity produces a 2.28% difference.