since the spheres have the same mass $m$ and carry charges of the same magnitude $|q|$.
Solving for $|q|$, we find

$$|q| = m\sqrt{\frac{G}{k}} = (2.0 \times 10^{-6}\ \text{kg})\sqrt{\frac{6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2}{8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2}} = \boxed{1.7\times10^{-16}\ \text{C}}$$

---

16. ***REASONING AND SOLUTION*** The electrostatic forces decreases with the square of the distance separating the charges. If this distance is increased by a factor of 5 then the force will decrease by a factor of 25. The new force is, then,

$$F = \frac{3.5\ \text{N}}{25} = \boxed{0.14\ \text{N}}$$

---

17. ***REASONING*** The electrons transferred increase the magnitudes of the positive and negative charges from 2.00 $\mu$C to a greater value. We can calculate the number $N$ of electrons by dividing the change in the magnitude of the charges by the magnitude $e$ of the charge on an electron. The greater charge that exists after the transfer can be obtained from Coulomb's law and the value given for the magnitude of the electrostatic force.

***SOLUTION*** The number $N$ of electrons transferred is

$$N = \frac{|q_{\text{after}}| - |q_{\text{before}}|}{e}$$

where $|q_{\text{after}}|$ and $|q_{\text{before}}|$ are the magnitudes of the charges after and before the transfer of electrons occurs. To obtain $|q_{\text{after}}|$, we apply Coulomb's law with a value of 68.0 N for the electrostatic force:

$$F = k\frac{|q_{\text{after}}|^2}{r^2} \quad \text{or} \quad |q_{\text{after}}| = \sqrt{\frac{Fr^2}{k}}$$

Using this result in the expression for $N$, we find that

$$N = \frac{\sqrt{\dfrac{Fr^2}{k}} - |q_{\text{before}}|}{e} = \frac{\sqrt{\dfrac{(68.0\ \text{N})(0.0300\ \text{m})^2}{8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2}} - 2.00\times10^{-6}\ \text{C}}{1.60\times10^{-19}\ \text{C}} = \boxed{3.8\times10^{12}}$$

---



18. ***REASONING AND SOLUTION*** Calculate the magnitude of each force acting on the center charge. Using Coulomb's law, we can write

$$F_{43} = \frac{k|q_4||q_3|}{r_{43}^2} = \frac{(8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2)(4.00\times10^{-6}\ \text{C})(3.00\times10^{-6}\ \text{C})}{(0.100\ \text{m})^2}$$

$$= 10.8\ \text{N}\ \ \text{(toward the south)}$$

$$F_{53} = \frac{k|q_5||q_3|}{r_{53}^2} = \frac{(8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2)(5.00\times10^{-6}\ \text{C})(3.00\times10^{-6}\ \text{C})}{(0.100\ \text{m})^2}$$

$$= 13.5\ \text{N}\ \ \text{(toward the east)}$$

Adding $F_{43}$ and $F_{53}$ as vectors, we have

$$F = \sqrt{F_{43}^2 + F_{53}^2} = \sqrt{(10.8\ \text{N})^2 + (13.5\ \text{N})^2} = \boxed{17.3\ \text{N}}$$

$$\theta = \tan^{-1}\left(\frac{F_{43}}{F_{53}}\right) = \tan^{-1}\left(\frac{10.8\ \text{N}}{13.5\ \text{N}}\right) = \boxed{38.7^\circ\ \text{S of E}}$$

---

19. ***REASONING*** According to Newton's second law, the centripetal acceleration experienced by the orbiting electron is equal to the centripetal force divided by the electron's mass. Recall from Section 5.3 that the centripetal force $F_c$ is the name given to the net force required to keep an object on a circular path of radius $r$. For an electron orbiting about two protons, the centripetal force is provided almost exclusively by the electrostatic force of attraction between the electron and the protons. This force points toward the center of the circle and its magnitude is given by Coulomb's law.

***SOLUTION*** The magnitude $a_c$ of the centripetal acceleration is equal to the magnitude $F_c$ of the centripetal force divided by the electron's mass: $a_c = F_c/m$ (Equation 5.3). The centripetal force is provided almost entirely by the electrostatic force, so $F_c = F$, where $F$ is the magnitude of the electrostatic force of attraction between the electron and the two protons, Thus, $a_c = F/m$. The magnitude of the electrostatic force is given by Coulomb's law, $F = k|q_1||q_2|/r^2$ (Equation 18.1), where $|q_1| = |-e|$ and $|q_2| = |+2e|$ are the magnitudes of the charges, $r$ is the radius of the orbit, and $k = 8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2$. Substituting this expression for $F$ into $a_c = F/m$, and using $m = 9.11\times10^{-31}$ kg for the mass of the electron, we find that

$$\left(\Sigma F_x\right)_B = -F_{BC}\cos 60.0° - F_{BA}\cos 60.0° = -2F\cos 60.0°$$

$$\left(\Sigma F_y\right)_B = 0$$

where we have used the fact that $F_{BC} = F_{BA} = F$. The Pythagorean theorem indicates that the magnitude of the net force at corner B is

$$(\Sigma F)_B = \sqrt{\left(\Sigma F_x\right)_B^2 + \left(\Sigma F_y\right)_B^2} = \sqrt{(-2F\cos 60.0°)^2 + (0)^2} = 2F\cos 60.0°$$

$$= 2k\frac{|q|^2}{L^2}\cos 60.0° = 2\left(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\frac{\left(5.0\times10^{-6}\ \text{C}\right)^2}{(0.030\ \text{m})^2}\cos 60.0°$$

$$= \boxed{250\ \text{N}}$$

As discussed in the ***REASONING***, the magnitude of the net force acting on the charge at corner C is the same as that acting on the charge at corner B, so $(\Sigma F)_C = \boxed{250\ \text{N}}$.

---

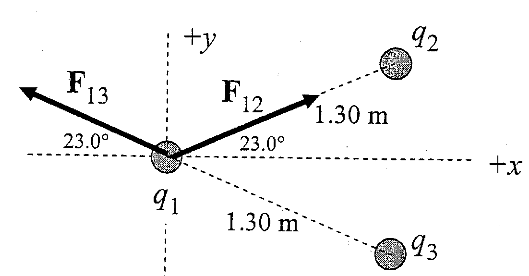
21. ***REASONING***

a. There are two electrostatic forces that act on $q_1$; that due to $q_2$ and that due to $q_3$. The magnitudes of these forces can be found by using Coulomb's law. The magnitude and direction of the net force that acts on $q_1$ can be determined by using the method of vector components.

b. According to Newton's second law, Equation 4.2b, the acceleration of $q_1$ is equal to the net force divided by its mass. However, there is only one force acting on it, so this force is the net force.

***SOLUTION***

a. The magnitude $F_{12}$ of the force exerted on $q_1$ by $q_2$ is given by Coulomb's law, Equation 18.1, where the distance is specified in the drawing:




$$F_{12} = \frac{k|q_1||q_2|}{r_{12}^2} = \frac{\left(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(8.00\times10^{-6}\ \text{C}\right)\left(5.00\times10^{-6}\ \text{C}\right)}{(1.30\ \text{m})^2} = 0.213\ \text{N}$$



Since the magnitudes of the charges and the distances are the same, the magnitude of $\mathbf{F}_{13}$ is the same as the magnitude of $\mathbf{F}_{12}$, or $F_{13} = 0.213$ N. From the drawing it can be seen that the $x$-components of the two forces cancel, so we need only to calculate the $y$ components of the forces.

| Force | $y$ component |
|---|---|
| $\mathbf{F}_{12}$ | $+F_{12}\sin 23.0° = +(0.213\ \text{N})\sin 23.0° = +0.0832\ \text{N}$ |
| $\mathbf{F}_{13}$ | $+F_{13}\sin 23.0° = +(0.213\ \text{N})\sin 23.0° = +0.0832\ \text{N}$ |
| $\mathbf{F}$ | $F_y = +0.166\ \text{N}$ |

Thus, the net force is $\boxed{\mathbf{F} = +0.166\ \text{N (directed along the } +y \text{ axis)}}$.

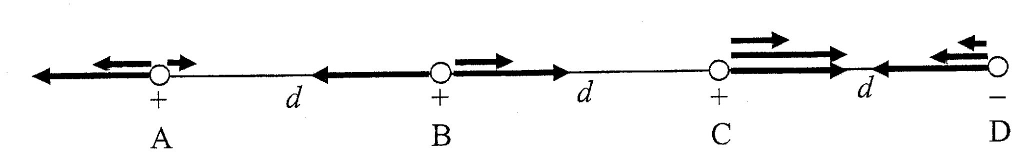
b. According to Newton's second law, Equation 4.2b, the acceleration of $q_1$ is equal to the net force divided by its mass. However, there is only one force acting on it, so this force is the net force:

$$\mathbf{a} = \frac{\mathbf{F}}{m} = \frac{+0.166\ \text{N}}{1.50\times10^{-3}\ \text{kg}} = \boxed{+111\ \text{m/s}^2}$$

where the plus sign indicates that $\boxed{\text{the acceleration is along the +y axis}}$.

---

22. ***REASONING*** We will use Coulomb's law to calculate the force that any one charge exerts on another charge. Note that in such calculations there are three separations to consider. Some of the charges are a distance $d$ apart, some a distance $2d$, and some a distance $3d$. The greater the distance, the smaller the force. The net force acting on any one charge is the vector sum of three forces. In the following drawing we represent each of those forces by an arrow. These arrows are not drawn to scale and are meant only to "symbolize" the three different force magnitudes that result from the three different distances used in Coulomb's law. In the drawing the directions are determined by the facts that like charges repel and unlike charges attract. By examining the drawing we will be able to identify the greatest and the smallest net force.




The greatest net force occurs for charge C, because all three force contributions point in the same direction and two of the three have the greatest magnitude, while the third has the next

$$|q_1| = 5.58\ \mu\text{C} \quad \text{and} \quad |q_2| = 0.957\ \mu\text{C} \qquad (6)$$

Considering Equations (5) and (6) and remembering that $q_1$ is the negative charge, we conclude that the two possible solutions to this problem are

$$\boxed{q_1 = -0.957\ \mu\text{C} \quad \text{and} \quad q_2 = +5.58\ \mu\text{C}} \quad \text{or} \quad \boxed{q_1 = -5.58\ \mu\text{C} \quad \text{and} \quad q_2 = +0.957\ \mu\text{C}}$$

---

29. ***SOLUTION*** Knowing the electric field at a spot allows us to calculate the force that acts on a charge placed at that spot, without knowing the nature of the object producing the field. This is possible because the electric field is defined as $\mathbf{E} = \mathbf{F}/q_0$, according to Equation 18.2. This equation can be solved directly for the force **F**, if the field **E** and charge $q_0$ are known.

***SOLUTION*** Using Equation 18.2, we find that the force has a magnitude of

$$F = E|q_0| = (260\ 000\ \text{N/C})\left(7.0 \times 10^{-6}\ \text{C}\right) = 1.8\ \text{N}$$

If the charge were positive, the direction of the force would be due west, the same as the direction of the field. But the charge is negative, so the force points in the opposite direction or due east. Thus, the force on the charge is $\boxed{1.8\ \text{N due east}}$.

---

30. ***REASONING***

a. The magnitude of the electric field is obtained by dividing the magnitude of the force (obtained from the meter) by the magnitude of the charge. Since the charge is positive, the direction of the electric field is the same as the direction of the force.

b. As in part (a), the magnitude of the electric field is obtained by dividing the magnitude of the force by the magnitude of the charge. Since the charge is negative, however, the direction of the force (as indicated by the meter) is opposite to the direction of the electric field. Thus, the direction of the electric field is opposite to that of the force.

***SOLUTION***

a. According to Equation 18.2, the magnitude of the electric field is

$$E = \frac{F}{|q|} = \frac{40.0\ \mu\text{N}}{20.0\ \mu\text{C}} = \boxed{2.0\ \text{N/C}}$$

As mentioned in the ***REASONING***, the direction of the electric field is the same as the direction of the force, or $\boxed{\text{due east}}$.



b. The magnitude of the electric field is

$$E = \frac{F}{|q|} = \frac{20.0\ \mu\text{N}}{10.0\ \mu\text{C}} = \boxed{2.0\ \text{N/C}}$$

Since the charge is negative, the direction of the electric field is opposite to the direction of the force, or $\boxed{\text{due east}}$. Thus, the electric fields in parts (a) and (b) are the same.

---

31. SSM WWW ***REASONING*** The electric field created by a point charge is inversely proportional to the square of the distance from the charge, according to Equation 18.3. Therefore, we expect the distance $r_2$ to be greater than the distance $r_1$, since the field is smaller at $r_2$ than at $r_1$. The ratio $r_2/r_1$, then, should be greater than one.

***SOLUTION*** Applying Equation 18.3 to each position relative to the charge, we have

$$E_1 = \frac{k|q|}{r_1^2} \quad \text{and} \quad E_2 = \frac{k|q|}{r_2^2}$$

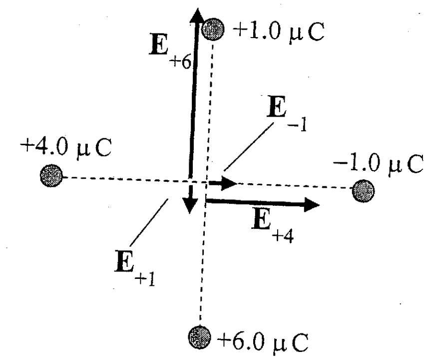
Dividing the expression for $E_1$ by the expression for $E_2$ gives

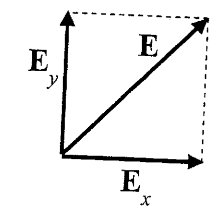
$$\frac{E_1}{E_2} = \frac{k|q|/r_1^2}{k|q|/r_2^2} = \frac{r_2^2}{r_1^2}$$

Solving for the ratio $r_2/r_1$ gives

$$\frac{r_2}{r_1} = \sqrt{\frac{E_1}{E_2}} = \sqrt{\frac{248\ \text{N/C}}{132\ \text{N/C}}} = \boxed{1.37}$$

As expected, this ratio is greater than one.




***SOLUTION***

**Part (*a*) of the drawing given in the text.** The net electric field in the $x$ direction is

$$E_x = \frac{\left(8.99\times10^9\ \mathrm{N\cdot m^2/C^2}\right)\left(2.0\times10^{-6}\ \mathrm{C}\right)}{\left(0.061\ \mathrm{m}\right)^2} + \frac{\left(8.99\times10^9\ \mathrm{N\cdot m^2/C^2}\right)\left(3.0\times10^{-6}\ \mathrm{C}\right)}{\left(0.061\ \mathrm{m}\right)^2}$$

$$= 1.2\times10^7\ \mathrm{N/C}$$

The net electric field in the $y$ direction is

$$E_y = \frac{\left(8.99\times10^9\ \mathrm{N\cdot m^2/C^2}\right)\left(5.0\times10^{-6}\ \mathrm{C}\right)}{\left(0.061\ \mathrm{m}\right)^2} = 1.2\times10^7\ \mathrm{N/C}$$

The magnitude of the net electric field is

$$E = \sqrt{E_x^2+E_y^2} = \sqrt{\left(1.2\times10^7\ \mathrm{N/C}\right)^2+\left(1.2\times10^7\ \mathrm{N/C}\right)^2} = \boxed{1.7\times10^7\ \mathrm{N/C}}$$

**Part (*b*) of the drawing given in the text.** The magnitude of the net electric field is the same as determined for part (a); $E = \boxed{1.7\times10^7\ \mathrm{N/C}}$.

---

35. ***REASONING AND SOLUTION***
a. In order for the field to be zero, the point cannot be between the two charges. Instead, it must be located on the line between the two charges on the side of the positive charge and away from the negative charge. If $x$ is the distance from the positive charge to the point in question, then the negative charge is at a distance (3.0 m + $x$) meters from this point. For the field to be zero here we have

$$\frac{k|q_-|}{(3.0\ \mathrm{m}+x)^2} = \frac{k|q_+|}{x^2} \quad \text{or} \quad \frac{|q_-|}{(3.0\ \mathrm{m}+x)^2} = \frac{|q_+|}{x^2}$$



Solving for the ratio of the charge magnitudes gives

$$\frac{|q_-|}{|q_+|} = \frac{16.0\ \mu\mathrm{C}}{4.0\ \mu\mathrm{C}} = \frac{(3.0\ \mathrm{m}+x)^2}{x^2} \quad \text{or} \quad 4.0 = \frac{(3.0\ \mathrm{m}+x)^2}{x^2}$$

Suppressing the units for convenience and rearranging this result gives

$$4.0x^2 = (3.0+x)^2 \quad \text{or} \quad 4.0x^2 = 9.0+6.0x+x^2 \quad \text{or} \quad 3x^2-6.0x-9.0=0$$

Solving this quadratic equation for $x$ with the aid of the quadratic formula (see Appendix C.4) shows that

$$x = 3.0\ \mathrm{m} \quad \text{or} \quad x = -1.0\ \mathrm{m}$$

We choose the positive value for $x$, since the negative value would locate the zero-field spot between the two charges, where it can not be (see above). Thus, we have $\boxed{x = 3.0\ \mathrm{m}}$.

b. Since the field is zero at this point, the force acting on a charge at that point is $\boxed{0\ \mathrm{N}}$.

---

36. ***REASONING***
a. The magnitude $E$ of the electric field is given by $E = \sigma/\varepsilon_0$ (Equation 18.4), where $\sigma$ is the charge density (or charge per unit area) and $\varepsilon_0$ is the permittivity of free space.

b. The magnitude $F$ of the electric force that would be exerted on a $K^+$ ion placed inside the membrane is the product of the magnitude $|q_0|$ of the charge and the magnitude $E$ of the electric field (see Equation 18.2), or $F = |q_0|E$.

***SOLUTION***
a. The magnitude of the electric field is

$$E = \frac{\sigma}{\varepsilon_0} = \frac{7.1\times10^{-6}\ \mathrm{C/m^2}}{8.85\times10^{-12}\ \mathrm{C^2/\left(N\cdot m^2\right)}} = \boxed{8.0\times10^5\ \mathrm{N/C}}$$

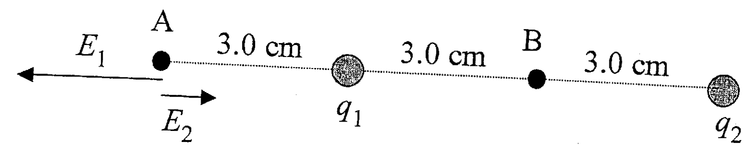
b. The magnitude $F$ of the force exerted on a $K^+$ ion ($q_0 = +e$) is

$$F = |q_0|E = |e|E = |1.60\times10^{-19}\ \mathrm{C}|\left(8.0\times10^5\ \mathrm{N/C}\right) = \boxed{1.3\times10^{-13}\ \mathrm{N}}$$

---

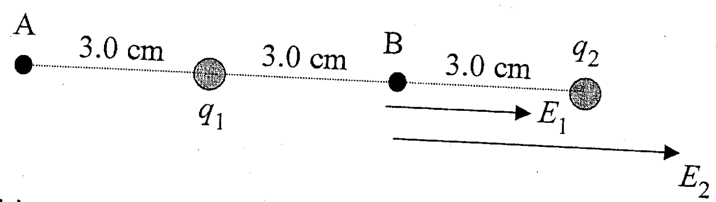
37. SSM **REASONING**

a. The drawing shows the two point charges $q_1$ and $q_2$. Point A is located at $x = 0$ cm, and point B is at $x = +6.0$ cm.




Since $q_1$ is positive, the electric field points away from it. At point A, the electric field $E_1$ points to the left, in the $-x$ direction. Since $q_2$ is negative, the electric field points toward it. At point A, the electric field $E_2$ points to the right, in the $+x$ direction. The net electric field is $E = -E_1 + E_2$. We can use Equation 18.3, $E = k|q|/r^2$, to find the magnitude of the electric field due to each point charge.

b. The drawing shows the electric fields produced by the charges $q_1$ and $q_2$ at point B, which is located at $x = +6.0$ cm.




Since $q_1$ is positive, the electric field points away from it. At point B, the electric field points to the right, in the $+x$ direction. Since $q_2$ is negative, the electric field points toward it. At point B, the electric field points to the right, in the $+x$ direction. The net electric field is $E = +E_1 + E_2$.

**SOLUTION**

a. The net electric field at the origin (point A) is $E = -E_1 + E_2$:

$$E = -E_1 + E_2 = \frac{-k|q_1|}{r_1^2} + \frac{k|q_2|}{r_2^2}$$

$$= \frac{-(8.99\times10^9\ \mathrm{N\cdot m^2/C^2})(8.5\times10^{-6}\ \mathrm{C})}{(3.0\times10^{-2}\ \mathrm{m})^2} + \frac{(8.99\times10^9\ \mathrm{N\cdot m^2/C^2})(21\times10^{-6}\ \mathrm{C})}{(9.0\times10^{-2}\ \mathrm{m})^2}$$

$$= \boxed{-6.2\times10^7\ \mathrm{N/C}}$$



The minus sign tells us that the net electric field points along the $-x$ axis.

b. The net electric field at $x = +6.0$ cm (point B) is $E = E_1 + E_2$:

$$E = E_1 + E_2 = \frac{k|q_1|}{r_1^2} + \frac{k|q_2|}{r_2^2}$$

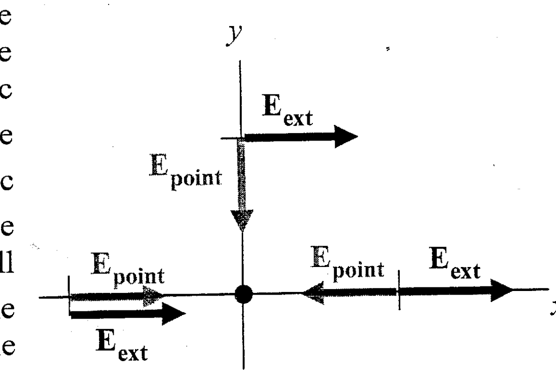
$$= \frac{(8.99\times10^9\ \mathrm{N\cdot m^2/C^2})(8.5\times10^{-6}\ \mathrm{C})}{(3.0\times10^{-2}\ \mathrm{m})^2} + \frac{(8.99\times10^9\ \mathrm{N\cdot m^2/C^2})(21\times10^{-6}\ \mathrm{C})}{(3.0\times10^{-2}\ \mathrm{m})^2}$$

$$= \boxed{+2.9\times10^8\ \mathrm{N/C}}$$

The plus sign tells us that the net electric field points along the $+x$ axis.

---

38. **REASONING** At every position in space, the net electric field $\mathbf{E}$ is the vector sum of the external electric field $\mathbf{E}_{\mathrm{ext}}$ and the electric field $\mathbf{E}_{\mathrm{point}}$ created by the point charge at the origin: $\mathbf{E} = \mathbf{E}_{\mathrm{ext}} + \mathbf{E}_{\mathrm{point}}$. The external electric field is uniform, which means that it has the same magnitude $E_{\mathrm{ext}} = 4500$ N/C at all locations and that it always points in the positive $x$ direction (see the drawing). The magnitude $E_{\mathrm{point}}$ of the electric field due to the point charge at the origin is given by $E_{\mathrm{point}} = \dfrac{k|q|}{r^2}$ (Equation 18.3), where $r$ is the distance between the origin and the location where the electric field is to be evaluated, $q$ is the charge at the origin, and $k = 8.99\times10^9\ \mathrm{N\cdot m^2/C^2}$. All three locations given in the problem are a distance $r = 0.15$ m from the origin, so we have that




$$E_{\mathrm{point}} = \frac{k|q|}{r^2} = \frac{(8.99\times10^9\ \mathrm{N\cdot m^2/C^2})|-8.0\times10^{-9}\ \mathrm{C}|}{(0.15\ \mathrm{m})^2} = 3200\ \mathrm{N/C}$$

The direction of the electric field $\mathbf{E}_{\mathrm{point}}$ varies from location to location, but because the charge $q$ is negative, $\mathbf{E}_{\mathrm{point}}$ is always directed towards the origin (see the drawing).

$$q^2 = \frac{Fr^2}{k} \quad \text{or} \quad q = \sqrt{\frac{Fr^2}{k}} \qquad (4)$$

Substituting Equations (3) into Equations (1) and (2) yields

$$F + T_{max} = \frac{2(\text{KE}_2)}{r} \quad \text{and} \quad T_{max} = \frac{2(\text{KE}_1)}{r} \qquad (5)$$

Substituting the second of Equations (5) into the first of Equations (5), we obtain

$$F + \frac{2(\text{KE}_1)}{r} = \frac{2(\text{KE}_2)}{r} \quad \text{or} \quad F = \frac{2(\text{KE}_2)}{r} - \frac{2(\text{KE}_1)}{r} = \frac{2(\text{KE}_2 - \text{KE}_1)}{r} \qquad (6)$$

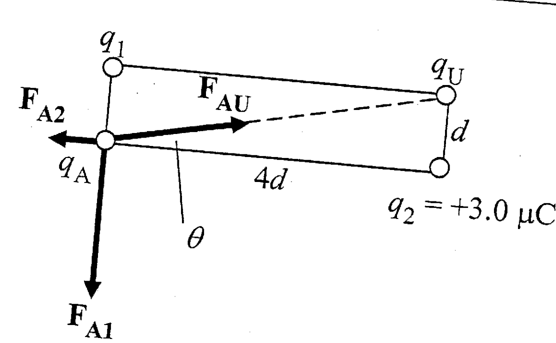
Substituting Equation (6) into Equation (4), we find that

$$q = \sqrt{\frac{Fr^2}{k}} = \sqrt{\frac{2(\text{KE}_2 - \text{KE}_1)}{\cancel{r}}\left(\frac{r^{\cancel{2}}}{k}\right)} = \sqrt{\frac{2(\text{KE}_2 - \text{KE}_1)r}{k}}$$

Therefore, the magnitude $q$ of the charge on the airplane is

$$q = \sqrt{\frac{2(51.8\text{ J} - 50.0\text{ J})(3.0\text{ m})}{8.99\times10^9\text{ N}\cdot\text{m}^2/\text{C}^2}} = \boxed{3.5\times10^{-5}\text{ C}}$$

25. **SSM** ***REASONING*** Consider the drawing at the right. It is given that the charges $q_A$, $q_1$, and $q_2$ are each positive. Therefore, the charges $q_1$ and $q_2$ each exert a repulsive force on the charge $q_A$. As the drawing shows, these forces have magnitudes $F_{A1}$ (vertically downward) and $F_{A2}$ (horizontally to the left). The unknown charge placed at the empty corner of the rectangle is $q_U$, and it exerts a force on $q_A$ that has a magnitude $F_{AU}$. In order that the net force acting on $q_A$ point in the vertical direction, the horizontal component of $\mathbf{F_{AU}}$ must cancel out the horizontal force $\mathbf{F_{A2}}$. Therefore, $\mathbf{F_{AU}}$ must point as shown in the drawing, which means that it is an attractive force and $q_U$ must be negative, since $q_A$ is positive.






***SOLUTION*** The basis for our solution is the fact that the horizontal component of $\mathbf{F_{AU}}$ must cancel out the horizontal force $\mathbf{F_{A2}}$. The magnitudes of these forces can be expressed using Coulomb's law $F = k|q||q'|/r^2$, where $r$ is the distance between the charges $q$ and $q'$. Thus, we have

$$F_{AU} = \frac{k|q_A||q_U|}{(4d)^2 + d^2} \quad \text{and} \quad F_{A2} = \frac{k|q_A||q_2|}{(4d)^2}$$

where we have used the fact that the distance between the charges $q_A$ and $q_U$ is the diagonal of the rectangle, which is $\sqrt{(4d)^2 + d^2}$ according to the Pythagorean theorem, and the fact that the distance between the charges $q_A$ and $q_2$ is $4d$. The horizontal component of $\mathbf{F_{AU}}$ is $F_{AU}\cos\theta$, which must be equal to $F_{A2}$, so that we have

$$\frac{k|q_A||q_U|}{(4d)^2 + d^2}\cos\theta = \frac{k|q_A||q_2|}{(4d)^2} \quad \text{or} \quad \frac{|q_U|}{17}\cos\theta = \frac{|q_2|}{16}$$

The drawing in the ***REASONING***, reveals that $\cos\theta = (4\text{d})/\sqrt{(4d)^2 + d^2} = 4/\sqrt{17}$. Therefore, we find that

$$\frac{|q_U|}{17}\left(\frac{4}{\sqrt{17}}\right) = \frac{|q_2|}{16} \quad \text{or} \quad |q_U| = \frac{17\sqrt{17}}{64}|q_2| = \frac{17\sqrt{17}}{64}\left(3.0\times10^{-6}\text{ C}\right) = \boxed{3.3\times10^{-6}\text{ C}}$$

As discussed in the ***REASONING***, the algebraic sign of the charge $q_U$ is $\boxed{\text{negative}}$.

26. ***REASONING AND SOLUTION***
a. To find the charge on each ball we first need to determine the electric force acting on each ball. This can be done by noting that each thread makes an angle of 18° with respect to the vertical.

$$F_e = mg\tan 18° = (8.0\times10^{-4}\text{ kg})(9.80\text{ m/s}^2)\tan 18° = 2.547\times10^{-3}\text{ N}$$

We also know that

$$F_e = \frac{k|q_1||q_2|}{r^2} = \frac{k|q|^2}{r^2}$$

where $r = 2(0.25\text{ m})\sin 18° = 0.1545$ m. Now

$$Q=\underbrace{\frac{q}{\frac{4}{3}\pi R^3}}_{\substack{\text{Charge}\\ \text{density}}}\times\underbrace{\left(\tfrac{4}{3}\pi r^3\right)}_{\substack{\text{Volume of}\\ \text{Gaussian}\\ \text{surface}}}=\frac{qr^3}{R^3} \qquad (2)$$

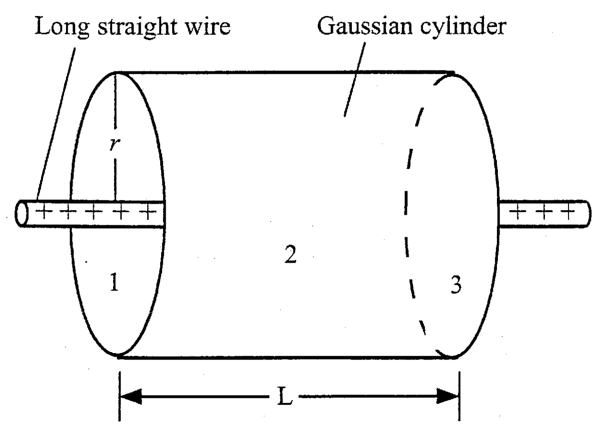
Substituting Equations (1) and (2) into Equation 18.7 gives

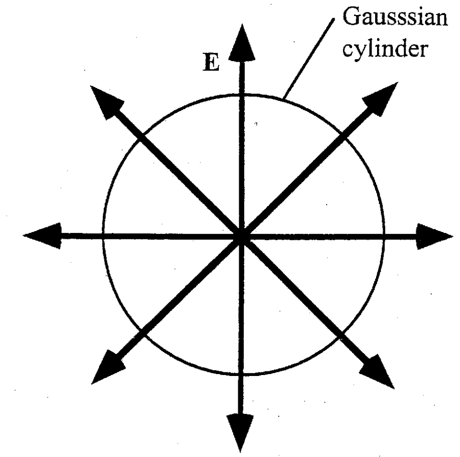
$$E\left(4\pi r^2\right)=\frac{qr^3/R^3}{\varepsilon_0}$$

Rearranging this result shows that

$$E=\frac{qr^3/R^3}{\left(4\pi r^2\right)\varepsilon_0}=\boxed{\frac{qr}{4\pi\varepsilon_0 R^3}}$$

62. ***REASONING*** Because the charge is distributed uniformly along the straight wire, the electric field is directed radially outward, as the following end view of the wire illustrates.



End view

And because of symmetry, the magnitude of the electric field is the same at all points equidistant from the wire. In this situation we will use a Gaussian surface that is a cylinder concentric with the wire. The drawing shows that this cylinder is composed of three parts, the two flat ends (1 and 3) and the curved wall (2). We will evaluate the electric flux for this three-part surface and then set it equal to $Q/\varepsilon_0$ (Gauss' law) to find the magnitude of the electric field.

***SOLUTION*** Surfaces 1 and 3 – the flat ends of the cylinder – are parallel to the electric field, so $\cos\phi=\cos 90°=0$. Thus, there is no flux through these two surfaces: $\Phi_1=\Phi_3=0\ \mathrm{N\cdot m^2/C}$.

Surface 2 – the curved wall – is everywhere perpendicular to the electric field **E**, so $\cos\phi=\cos 0°=1$. Furthermore, the magnitude $E$ of the electric field is the same for all points on this surface, so it can be factored outside the summation in Equation 18.6:



$$\Phi_2=\Sigma\left(E\cos 0°\right)\Delta A=E\Sigma A$$

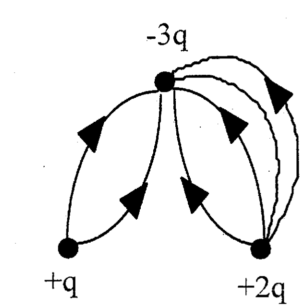
The area $\Sigma A$ of this surface is just the circumference $2\pi r$ of the cylinder times its length $L$: $\Sigma A=(2\pi r)L$. The electric flux through the entire cylinder is, then,

$$\Phi_E=\Phi_1+\Phi_2+\Phi_3=0+E(2\pi rL)+0=E(2\pi rL)$$

Following Gauss' law, we set $\Phi_E$ equal to $Q/\varepsilon_0$, where $Q$ is the net charge inside the Gaussian cylinder: $E(2\pi rL)=Q/\varepsilon_0$. The ratio $Q/L$ is the charge per unit length of the wire and is known as the linear charge density $\lambda$: $\lambda=Q/L$. Solving for $E$, we find that

$$\boxed{E=\frac{Q/L}{2\pi\varepsilon_0 r}=\frac{\lambda}{2\pi\varepsilon_0 r}}$$

63. ***REASONING AND SOLUTION*** The electric field lines must originate on the positive charges and terminate on the negative charge. They cannot cross one another. Furthermore, the number of field lines beginning or terminating on any charge must be proportional to the magnitude of the charge. Thus, for every field line that leaves the charge +q, two field lines must leave the charge +2q. These three lines must terminate on the −3q charge. If the sketch is to have six field lines, two of them must originate on +q, and four of them must originate on the charge +2q.




64. ***REASONING***

a. The magnitude of the electrostatic force that acts on each sphere is given by Coulomb's law as $F=k|q_1||q_2|/r^2$, where $|q_1|$ and $|q_2|$ are the magnitudes of the charges, and $r$ is the distance between the centers of the spheres.

b. When the spheres are brought into contact, the net charge after contact and separation must be equal to the net charge before contact. Since the spheres are identical, the charge on each after being separated is one-half the net charge. Coulomb's law can be applied again to determine the magnitude of the electrostatic force that each sphere experiences.

*SOLUTION*
a. The magnitude of the force that each sphere experiences is given by Coulomb's law as

$$F=\frac{k|q_1||q_2|}{r^2}=\frac{\left(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(20.0\times10^{-6}\ \text{C}\right)\left(50.0\times10^{-6}\ \text{C}\right)}{\left(2.50\times10^{-2}\ \text{m}\right)^2}=\boxed{1.44\times10^4\ \text{N}}$$

Because the charges have opposite signs, the force is $\boxed{\text{attractive}}$.

b. The net charge on the spheres is $-20.0\ \mu\text{C}+50.0\ \mu\text{C}=+30.0\ \mu\text{C}$. When the spheres are brought into contact, the net charge after contact and separation must be equal to the net charge before contact, or $+30.0\ \mu\text{C}$. Since the spheres are identical, the charge on each after being separated is one-half the net charge, so $q_1=q_2=+15.0\ \mu\text{C}$. The electrostatic force that acts on each sphere is now

$$F=\frac{k|q_1||q_2|}{r^2}=\frac{\left(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(15.0\times10^{-6}\ \text{C}\right)\left(15.0\times10^{-6}\ \text{C}\right)}{\left(2.50\times10^{-2}\ \text{m}\right)^2}=\boxed{3.24\times10^3\ \text{N}}$$

Since the charges now have the same signs, the force is $\boxed{\text{repulsive}}$.

65. ***REASONING AND SOLUTION*** The $+2q$ of charge initially on the sphere lies entirely on the outer surface. When the $+q$ charge is placed inside of the sphere, then a $\boxed{-q}$ charge will still be induced on the interior of the sphere. An additional $+q$ will appear on the outer surface, giving a net charge of $\boxed{+3q}$.

66. ***REASONING*** Two forces act on the charged ball (charge $q$); they are the downward force of gravity $m\mathbf{g}$ and the electric force $\mathbf{F}$ due to the presence of the charge $q$ in the electric field $\mathbf{E}$. In order for the ball to float, these two forces must be equal in magnitude and opposite in direction, so that the net force on the ball is zero (Newton's second law). Therefore, $\mathbf{F}$ must point upward, which we will take as the positive direction. According to Equation 18.2, $\mathbf{F}=q\mathbf{E}$. Since the charge $q$ is negative, the electric field $\mathbf{E}$ must point downward, as the product $q\mathbf{E}$ in the expression $\mathbf{F}=q\mathbf{E}$ must be positive, since the force $\mathbf{F}$ points upward. The magnitudes of the two forces must be equal, so that $mg=|q|E$. This expression can be solved for $E$.

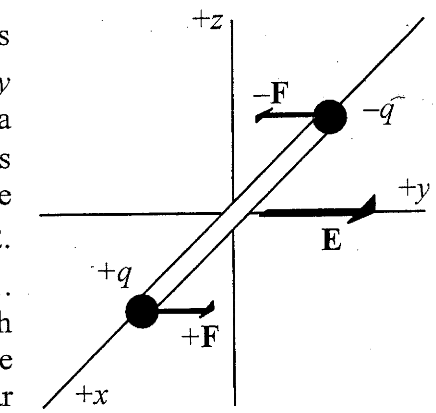
***SOLUTION*** The magnitude of the electric field **E** is

$$E=\frac{mg}{|q|}=\frac{(0.012\ \text{kg})(9.80\ \text{m/s}^2)}{18\times10^{-6}\ \text{C}}=\boxed{6.5\times10^3\ \text{N/C}}$$

As discussed in the reasoning, this electric field points $\boxed{\text{downward}}$.



67. SSM ***REASONING*** The drawing at the right shows the set-up. Here, the electric field **E** points along the $+y$ axis and applies a force of $+\mathbf{F}$ to the $+q$ charge and a force of $-\mathbf{F}$ to the $-q$ charge, where $q=8.0\ \mu\text{C}$ denotes the magnitude of each charge. Each force has the same magnitude of $F=E|q|$, according to Equation 18.2. The torque is measured as discussed in Section 9.1. According to Equation 9.1, the torque produced by each force has a magnitude given by the magnitude of the force times the lever arm, which is the perpendicular distance between the point of application of the force and the axis of rotation. In the drawing the $z$ axis is the axis of rotation and is midway between the ends of the rod. Thus, the lever arm for each force is half the length $L$ of the rod or $L/2$, and the magnitude of the torque produced by each force is $(E|q|)(L/2)$.




***SOLUTION*** The $+\mathbf{F}$ and the $-\mathbf{F}$ force each cause the rod to rotate in the same sense about the $z$ axis. Therefore, the torques from these forces reinforce one another. Using the expression $(E|q|)(L/2)$ for the magnitude of each torque, we find that the magnitude of the net torque is

$$\text{Magnitude of net torque}=E|q|\left(\frac{L}{2}\right)+E|q|\left(\frac{L}{2}\right)=E|q|L$$

$$=\left(5.0\times10^3\ \text{N/C}\right)\left(8.0\times10^{-6}\ \text{C}\right)(4.0\ \text{m})=\boxed{0.16\ \text{N}\cdot\text{m}}$$

68. ***REASONING*** The magnitude of the electrostatic force that acts on particle 1 is given by Coulomb's law as $F=k|q_1||q_2|/r^2$. This equation can be used to find the magnitude $|q_2|$ of the charge.

***SOLUTION*** Solving Coulomb's law for the magnitude $|q_2|$ of the charge gives

$$|q_2|=\frac{Fr^2}{k|q_1|}=\frac{(3.4\ \text{N})(0.26\ \text{m})^2}{\left(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(3.5\times10^{-6}\ \text{C}\right)}=\boxed{7.3\times10^{-6}\ \text{C}} \qquad (18.1)$$

Since $q_1$ is positive and experiences an attractive force, the charge $q_2$ must be $\boxed{\text{negative}}$.

69. SSM WWW ***REASONING*** Each particle will experience an electrostatic force due to the presence of the other charge. According to Coulomb's law (Equation 18.1), the magnitude of the force felt by each particle can be calculated from $F = k|q_1||q_2|/r^2$, where $|q_1|$ and $|q_2|$ are the respective charges on particles 1 and 2 and $r$ is the distance between them. According to Newton's second law, the magnitude of the force experienced by each particle is given by $F = ma$, where $a$ is the acceleration of the particle and we have assumed that the electrostatic force is the only force acting.

***SOLUTION***

a. Since the two particles have identical positive charges, $|q_1| = |q_2| = |q|$, and we have, using the data for particle 1,

$$\frac{k|q|^2}{r^2} = m_1 a_1$$

Solving for $|q|$, we find that

$$|q| = \sqrt{\frac{m_1 a_1 r^2}{k}} = \sqrt{\frac{(6.00\times10^{-6}\text{ kg})\,(4.60\times10^{3}\text{ m/s}^2)\,(2.60\times10^{-2}\text{ m})^2}{8.99\times10^{9}\text{ N}\cdot\text{m}^2/\text{C}^2}} = \boxed{4.56\times10^{-8}\text{ C}}$$

b. Since each particle experiences a force of the same magnitude (From Newton's third law), we can write $F_1 = F_2$, or $m_1 a_1 = m_2 a_2$. Solving this expression for the mass $m_2$ of particle 2, we have

$$m_2 = \frac{m_1 a_1}{a_2} = \frac{(6.00\times10^{-6}\text{ kg})(4.60\times10^{3}\text{ m/s}^2)}{8.50\times10^{3}\text{ m/s}^2} = \boxed{3.25\times10^{-6}\text{ kg}}$$

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70. ***REASONING AND SOLUTION*** The electric field is defined by Equation 18.2: $\mathbf{E} = \mathbf{F}/q_0$. Thus, the magnitude of the force exerted on a charge q in an electric field of magnitude E is given by

$$F = |q|E \qquad (1)$$

The magnitude of the electric field can be determined from its $x$ and $y$ components by using the Pythagorean theorem:

$$E = \sqrt{E_x^2 + E_y^2} = \sqrt{\left(6.00\times10^{3}\text{ N/C}\right)^2 + \left(8.00\times10^{3}\text{ N/C}\right)^2} = 1.00\times10^{4}\text{ N/C}$$

a. From Equation (1) above, the magnitude of the force on the charge is

$$F = (7.50\times10^{-6}\text{ C})(1.00\times10^{4}\text{ N/C}) = \boxed{7.5\times10^{-2}\text{ N}}$$



b. From the defining equation for the electric field, it follows that the direction of the force on a charge is the same as the direction of the field, provided that the charge is positive. Thus, the angle that the force makes with the $x$ axis is given by

$$\theta = \tan^{-1}\left(\frac{E_y}{E_x}\right) = \tan^{-1}\left(\frac{8.00\times10^{3}\text{ N/C}}{6.00\times10^{3}\text{ N/C}}\right) = \boxed{53.1^\circ}$$

---

71. ***REASONING*** The two charges lying on the $x$ axis produce no net electric field at the coordinate origin. This is because they have identical charges, are located the same distance from the origin, and produce electric fields that point in opposite directions. The electric field produced by $q_3$ at the origin points away from the charge, or along the $-y$ direction. The electric field produced by $q_4$ at the origin points toward the charge, or along the $+y$ direction. The net electric field is, then, $E = -E_3 + E_4$, where $E_3$ and $E_4$ can be determined by using Equation 18.3.

***SOLUTION*** The net electric field at the origin is

$$E = -E_3 + E_4 = \frac{-k|q_3|}{r_3^2} + \frac{k|q_4|}{r_4^2}$$

$$= \frac{-\left(8.99\times10^{9}\text{ N}\cdot\text{m}^2/\text{C}^2\right)\left(3.0\times10^{-6}\text{ C}\right)}{\left(5.0\times10^{-2}\text{ m}\right)^2} + \frac{\left(8.99\times10^{9}\text{ N}\cdot\text{m}^2/\text{C}^2\right)\left(8.0\times10^{-6}\text{ C}\right)}{\left(7.0\times10^{-2}\text{ m}\right)^2}$$

$$= \boxed{+3.9\times10^{6}\text{ N/C}}$$

The plus sign indicates that $\boxed{\text{the net electric field points along the +y direction}}$.

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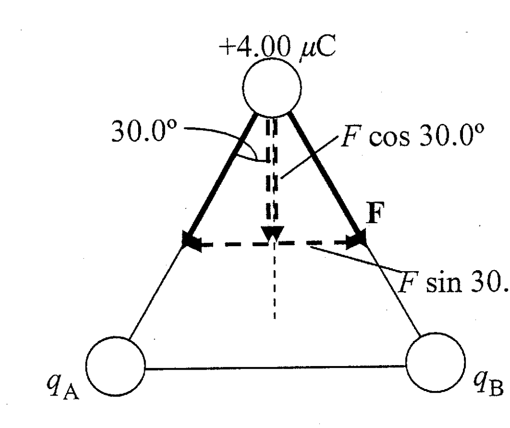
72. ***REASONING*** The unknown charges can be determined using Coulomb's law to express the electrostatic force that each unknown charge exerts on the 4.00 $\mu$C charge. In applying this law, we will use the fact that the net force points downward in the drawing. This tells us that the unknown charges are both negative and have the same magnitude, as can be understood with the help of the free-body diagram for the 4.00 $\mu$C charge that is shown at the right. The diagram shows



the attractive force **F** from each negative charge directed along the lines between the charges. Only when each force has the same magnitude (which is the case when both unknown charges have the same magnitude) will the resultant force point vertically downward. This occurs because the horizontal components of the forces cancel, one pointing to the right and the other to the left (see the diagram). The vertical components reinforce to give the observed downward net force.

***SOLUTION*** Since we know from the ***REASONING*** that the unknown charges have the same magnitude, we can write Coulomb's law as follows:

$$F = k\frac{\left(4.00\times10^{-6}\ \text{C}\right)|q_\text{A}|}{r^2} = k\frac{\left(4.00\times10^{-6}\ \text{C}\right)|q_\text{B}|}{r^2}$$

The magnitude of the net force acting on the 4.00 $\mu$C charge, then, is the sum of the magnitudes of the two vertical components $F\cos 30.0°$ shown in the free-body diagram:

$$\Sigma F = k\frac{\left(4.00\times10^{-6}\ \text{C}\right)|q_\text{A}|}{r^2}\cos 30.0° + k\frac{\left(4.00\times10^{-6}\ \text{C}\right)|q_\text{B}|}{r^2}\cos 30.0°$$

$$= 2k\frac{\left(4.00\times10^{-6}\ \text{C}\right)|q_\text{A}|}{r^2}\cos 30.0°$$

Solving for the magnitude of the charge gives

$$|q_\text{A}| = \frac{(\Sigma F)r^2}{2k\left(4.00\times10^{-6}\ \text{C}\right)\cos 30.0°}$$

$$= \frac{(405\ \text{N})(0.0200\ \text{m})^2}{2\left(8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(4.00\times10^{-6}\ \text{C}\right)\cos 30.0°} = 2.60\times10^{-6}\ \text{C}$$

Thus, we have $q_\text{A} = q_\text{B} = \boxed{-2.60\times10^{-6}\ \text{C}}$.

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73. ***REASONING*** The electric field is given by Equation 18.2 as the force **F** that acts on a test charge $q_0$, divided by $q_0$. Although the force is not known, the acceleration and mass of the charged object are given. Therefore, we can use Newton's second law to determine the force as the mass times the acceleration and then determine the magnitude of the field directly from Equation 18.2. The force has the same direction as the acceleration. The direction of the field, however, is in the direction opposite to that of the acceleration and force. This is



because the object carries a negative charge, while the field has the same direction as the force acting on a positive test charge.

***SOLUTION*** According to Equation 18.2, the magnitude of the electric field is

$$E = \frac{F}{|q_0|}$$

According to Newton's second law, the net force acting on an object of mass $m$ and acceleration $a$ is $\Sigma F = ma$. Here, the net force is the electrostatic force $F$, since that force alone acts on the object. Thus, the magnitude of the electric field is

$$E = \frac{F}{|q_0|} = \frac{ma}{|q_0|} = \frac{\left(3.0\times10^{-3}\ \text{kg}\right)\left(2.5\times10^{3}\ \text{m/s}^2\right)}{34\times10^{-6}\ \text{C}} = \boxed{2.2\times10^{5}\ \text{N/C}}$$

The direction of this field is opposite to the direction of the acceleration. Thus, the field points $\boxed{\text{along the } -x \text{ axis}}$.

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74. ***REASONING*** The magnitude of the electric field between the plates of a parallel plate capacitor is given by Equation 18.4 as $E = \frac{\sigma}{\varepsilon_0}$, where $s$ is the charge density for each plate and $e_0$ is the permittivity of free space. It is the charge density that contains information about the radii of the circular plates, for charge density is the charge per unit area. The area of a circle is $pr^2$. The second capacitor has a greater electric field, so its plates must have the greater charge density. Since the charge on the plates is the same in each case, the plate area and, hence, the plate radius, must be smaller for the second capacitor. As a result, we expect that the ratio $r_2/r_1$ is less than one.

***SOLUTION*** Using $|q|$ to denote the magnitude of the charge on the capacitor plates and $A = pr^2$ for the area of a circle, we can use Equation 18.4 to express the magnitude of the field between the plates of a parallel plate capacitor as follows:

$$E = \frac{\sigma}{\varepsilon_0} = \frac{|q|}{\varepsilon_0 \pi r^2}$$

Applying this result to each capacitor gives

$$\underbrace{E_1 = \frac{|q|}{\varepsilon_0 \pi r_1^2}}_{\text{First capacitor}} \quad \text{and} \quad \underbrace{E_2 = \frac{|q|}{\varepsilon_0 \pi r_2^2}}_{\text{Second capacitor}}$$