3. **REASONING AND SOLUTION** When the charged insulating rod is brought near to (but not touching) the sphere, the free electrons in the sphere will move. If the rod is negatively charged, the free electrons will move to the side of the sphere that is opposite to the side where the rod is; if the rod is positively charged, the free electrons will migrate to the side of the sphere where the rod is. In either case, the region of the sphere near the vicinity of the rod will acquire a charge that has the opposite sign as the charge on the rod.

a. Since oppositely charged objects always attract each other, the rod and sphere will always experience a mutual attraction.

b. Since the side of the sphere in the vicinity of the rod will always have charge that is opposite in sign to the charge on the rod, the rod and the sphere will always attract each other. They never repel each other.
5. **REASONING AND SOLUTION** A balloon is blown up and rubbed against a person's shirt a number of times. The balloon is then touched to a ceiling. Upon being released, the balloon remains stuck to the ceiling. The balloon is charged by contact. The ceiling is neutral. The charged balloon will induce a slight surface charge on the ceiling that is opposite in sign to the charge on the balloon. Since the charge on the balloon and the ceiling are opposite in sign, they will attract each other. Since both the balloon and the ceiling are insulators, charge cannot flow from one to the other. The charge on the balloon remains fixed on the balloon, while the charge on the ceiling remains fixed on the ceiling. The electrostatic force that the ceiling exerts on the balloon is sufficient to hold the balloon in place.
6. **REASONING AND SOLUTION** A proton and electron are held in place on the $x$ axis. The proton is at $x = -d$, while the electron is at $x = +d$. They are released simultaneously, and the only force that affects their motions is the electrostatic force of attraction that each applies to the other. According to Newton's third law, the force $F_{pe}$ exerted on the proton by the electron is equal in magnitude and opposite in direction to the force $F_{ep}$ exerted on the electron by the proton. In other words, $F_{pe} = -F_{ep}$. According to Newton's second law, this equation can be written

$$m_p a_p = -m_e a_e$$

(1)

where $m_p$ and $m_e$ are the respective masses and $a_p$ and $a_e$ are the respective accelerations of the proton and the electron. Since the mass of the electron is considerably smaller than the mass of the proton, the acceleration of the electron at any instant must be considerably greater than the acceleration of the proton at that instant in order for Equation (1) to hold. Since the electron has a much greater acceleration than the proton, it will attain greater velocities than the proton and, therefore, reach the origin first.
3. **REASONING** The law of conservation of electric charges states that the net electric charge of an isolated system remains constant. Initially the plate-rod system has a net charge of $-3.0 \, \mu\text{C} + 2.0 \, \mu\text{C} = -1.0 \, \mu\text{C}$. After the transfer this charge is shared equally by both objects, so that each carries a charge of $-0.50 \, \mu\text{C}$. Therefore, 2.5 \, \mu\text{C} of negative charge must be transferred from the plate to the rod. To determine how many electrons this is, we will divide this charge magnitude by the magnitude of the charge on a single electron.

**SOLUTION** The magnitude of the charge on an electron is $e$, so that the number $N$ of electrons transferred is

$$N = \frac{\text{Magnitude of transferred charge}}{e} = \frac{2.5 \times 10^{-6} \, \text{C}}{1.60 \times 10^{-19} \, \text{C}} = \frac{1.6 \times 10^{13}}{}$$
5. **SSM REASONING** Identical conducting spheres equalize their charge upon touching. When spheres A and B touch, an amount of charge $+q$, flows from A and instantaneously neutralizes the $-q$ charge on B leaving B momentarily neutral. Then, the remaining amount of charge, equal to $+4q$, is equally split between A and B, leaving A and B each with equal amounts of charge $+2q$. Sphere C is initially neutral, so when A and C touch, the $+2q$ on A splits equally to give $+q$ on A and $+q$ on C. When B and C touch, the $+2q$ on B and the $+q$ on C combine to give a total charge of $+3q$, which is then equally divided between the spheres B and C; thus, B and C are each left with an amount of charge $+1.5q$.

**SOLUTION** Taking note of the initial values given in the problem statement, and summarizing the final results determined in the *Reasoning* above, we conclude the following:

a. Sphere C ends up with an amount of charge equal to $+1.5q$.

b. The charges on the three spheres before they were touched, are, according to the problem statement, $+5q$ on sphere A, $-q$ on sphere B, and zero charge on sphere C. Thus, the total charge on the spheres is $+5q - q + 0 = +4q$.

c. The charges on the spheres after they are touched are $+q$ on sphere A, $+1.5q$ on sphere B, and $+1.5q$ on sphere C. Thus, the total charge on the spheres is $+q + 1.5q + 1.5q = +4q$. 

7. **REASONING AND SOLUTION** The magnitude of the force of attraction between the charges is given by Coulomb’s law (Equation 18.1): 

\[ F = k \frac{|q_1||q_2|}{r^2}, \]

where \( |q_1| \) and \( |q_2| \) are the magnitudes of the charges and \( r \) is the separation of the charges. Let \( F_A \) and \( F_B \) represent the magnitudes of the forces between the charges when the separations are \( r_A \) and \( r_B = r_A/9 \), respectively. Then

\[
\frac{F_B}{F_A} = \frac{k \frac{|q_1||q_2|}{r_B^2}}{k \frac{|q_1||q_2|}{r_A^2}} = \left( \frac{r_A}{r_B} \right)^2 = \left( \frac{r_A}{r_A/9} \right)^2 = (9)^2 = 81
\]

Therefore, we can conclude that \( F_B = 81F_A = (81)(1.5 \text{ N}) = 120 \text{ N} \).
10. **REASONING** The magnitude of the electrostatic force that acts on particle 1 is given by Coulomb’s law as $F = k \left| q_1 \right| \left| q_2 \right| / r^2$. 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

$$|q_2| = \frac{Fr^2}{k|q_1|} = \frac{(3.4 \text{ N})(0.26 \text{ m})^2}{(9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(3.5 \times 10^{-6} \text{ C})} = 7.3 \times 10^{-6} \text{ C} \quad (18.1)$$

Since $q_1$ is positive and experiences an attractive force, the charge $q_2$ must be negative.
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 \( F = k \frac{|q_1||q_2|}{r^2} \), 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

\[
|q| = \sqrt{\frac{m_1 a_1 r^2}{k}} = \sqrt{\frac{(6.00 \times 10^{-6} \text{ kg})(4.60 \times 10^3 \text{ m/s}^2)(2.60 \times 10^{-2} \text{ m})^2}{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2}} = 4.56 \times 10^{-8} \text{ C}
\]

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

\[
m_2 = \frac{m_1 a_1}{a_2} = \frac{(6.00 \times 10^{-6} \text{ kg})(4.60 \times 10^3 \text{ m/s}^2)}{8.50 \times 10^3 \text{ m/s}^2} = 3.25 \times 10^{-6} \text{ kg}
\]
19. **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 $F_{AU}$ must cancel out the horizontal force $F_{A2}$. Therefore, $F_{AU}$ 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 $F_{AU}$ must cancel out the horizontal force $F_{A2}$. The magnitudes of these forces can be expressed using Coulomb’s law $F = k \frac{|q||q'|}{r^2}$, 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 $F_{AU}$ is $F_{AU} \cos \theta$, which must be equal to $F_{A2}$, so that we have

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

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

$$\frac{|q_U|}{17} = \frac{4}{\sqrt{17}} \quad \text{or} \quad |q_U| = \frac{17\sqrt{17}}{64} |q_2| = \frac{17\sqrt{17}}{64} \left(3.0 \times 10^{-6} \text{ C}\right) = 3.3 \times 10^{-6} \text{ C}$$

$$d$$
As discussed in the **REASONING**, the algebraic sign of the charge $q_U$ is [**negative**].
23. **REASONING** The charged insulator experiences an electric force due to the presence of the charged sphere shown in the drawing in the text. The forces acting on the insulator are the downward force of gravity (i.e., its weight, \(W = mg\)), the electrostatic force \(F = k \frac{|q_1||q_2|}{r^2}\) (see Coulomb's law, Equation 18.1) pulling to the right, and the tension \(T\) in the wire pulling up and to the left at an angle \(\theta\) with respect to the vertical as shown in the drawing in the problem statement. We can analyze the forces to determine the desired quantities \(\theta\) and \(T\).

**SOLUTION.**

a. We can see from the diagram given with the problem statement that

\[ T_x = F \quad \text{which gives} \quad T \sin \theta = k \frac{|q_1||q_2|}{r^2} \]

and

\[ T_y = W \quad \text{which gives} \quad T \cos \theta = mg \]

Dividing the first equation by the second yields

\[ \frac{T \sin \theta}{T \cos \theta} = \tan \theta = \frac{k \frac{|q_1||q_2|}{r^2}}{mg} \]

Solving for \(\theta\), we find that

\[ \theta = \tan^{-1} \left( \frac{k \frac{|q_1||q_2|}{mgr^2}}{mg} \right) = \tan^{-1} \left[ \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(0.600 \times 10^{-6} \text{ C})(0.900 \times 10^{-6} \text{ C})}{(8.00 \times 10^{-2} \text{ kg})(9.80 \text{ m/s}^2)(0.150 \text{ m})^2} \right] = 15.4^\circ \]

b. Since \(T \cos \theta = mg\), the tension can be obtained as follows:

\[ T = \frac{mg}{\cos \theta} = \frac{(8.00 \times 10^{-2} \text{ kg})(9.80 \text{ m/s}^2)}{\cos 15.4^\circ} = 0.813 \text{ N} \]