1. **SSM** ***REASONING AND SOLUTION*** The charge on a single electron is -1.60×10^{-19} C. In order to give a neutral silver dollar a charge of +2.4 μC, we must remove an amount of negative charge equal to –2.4 μC. This corresponds to

$$\left(-2.4\times10^{-6}\ \text{C}\right)\left(\frac{1\ \text{electron}}{-1.60\times10^{-19}\ \text{C}}\right)=\boxed{1.5\times10^{13}\ \text{electrons}}$$

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2. ***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

$$N = \frac{\text{Magnitude of transferred charge}}{e} = \frac{2.5\times10^{-6}\ \text{C}}{1.60\times10^{-19}\ \text{C}} = \boxed{1.6\times10^{13}}$$

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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 $\boxed{+1.5q}$.

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 $+5q - q + 0 = \boxed{+4q}$.

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 $+q + 1.5q + 1.5q = \boxed{+4q}$.

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6. ***REASONING***

a. The number N of electrons is 10 times the number of water molecules in 1 liter of water. The number of water molecules is equal to the number n of moles of water molecules times Avogadro's number N_A: $N = 10\,n\,N_A$.

b. The net charge of all the electrons is equal to the number of electrons times the change on one electron.

SOLUTION

a. The number N of water molecules is equal to $10\ n\ N_A$, where n is the number of moles of water molecules and N_A is Avogadro's number. The number of moles is equal to the mass m of 1 liter of water divided by the mass per mole of water. The mass of water is equal to its density ρ times the volume, as expressed by Equation 11.1. Thus, the number of electrons is

$$N = 10\ n\ N_A = 10\left(\frac{m}{18.0\ \text{g/mol}}\right)N_A = 10\left(\frac{\rho\ V}{18.0\ \text{g/mol}}\right)N_A$$

$$= 10\left[\frac{\left(1000\ \text{kg/m}^3\right)\left(1.00\times10^{-3}\ \text{m}^3\right)\left(\dfrac{1000\ \text{g}}{1\ \text{kg}}\right)}{18.0\ \text{g/mol}}\right]\left(6.022\times10^{23}\ \text{mol}^{-1}\right)$$

$$= \boxed{3.35\times10^{26}\ \text{electrons}}$$

b. The net charge Q of all the electrons is equal to the number of electrons times the change on one electron: $Q = \left(3.35\times10^{26}\right)\left(-1.60\times10^{-19}\ \text{C}\right) = \boxed{-5.36\times10^{7}\ \text{C}}$.

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7. **SSM** ***REASONING AND SOLUTION*** The magnitude of the force of attraction between the charges is given by Coulomb's law (Equation 18.1): $F = k|q_1||q_2|/r^2$, 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

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

Therefore, we can conclude that $F_B = 81F_A = (81)(1.5\text{ N}) = \boxed{120\text{ N}}$.

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9. **SSM** **WWW** ***REASONING*** Initially, the two spheres are neutral. Since negative charge is removed from the sphere which loses electrons, it then carries a net positive charge. Furthermore, the neutral sphere to which the electrons are added is then negatively charged. Once the charge is transferred, there exists an electrostatic force on each of the two spheres, the magnitude of which is given by Coulomb's law (Equation 18.1), $F = k|q_1||q_2|/r^2$.

SOLUTION

a. Since each electron carries a charge of $-1.60\times10^{-19}\ \text{C}$, the amount of negative charge removed from the first sphere is

$$\left(3.0\times10^{13}\ \text{electrons}\right)\left(\frac{1.60\times10^{-19}\ \text{C}}{1\ \text{electron}}\right) = 4.8\times10^{-6}\ \text{C}$$

Thus, the first sphere carries a charge $+4.8 \times 10^{-6}$ C, while the second sphere carries a charge -4.8×10^{-6} C. The magnitude of the electrostatic force that acts on each sphere is, therefore,

$$F = \frac{k|q_1||q_2|}{r^2} = \frac{\left(8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(4.8\times10^{-6}\ \text{C}\right)^2}{\left(0.50\ \text{m}\right)^2} = \boxed{0.83\ \text{N}}$$

b. Since the spheres carry charges of opposite sign, the force is $\boxed{\text{attractive}}$.

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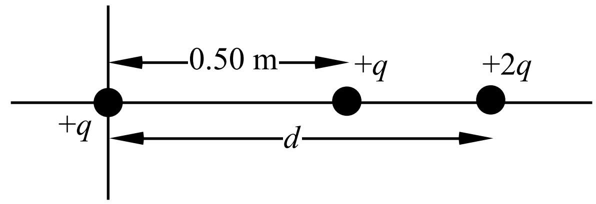
10. ***REASONING*** The drawing at the right shows the set-up. The force on the $+q$ charge at the origin due to the other $+q$ charge is given by Coulomb's law (Equation 18.1), as is the force due to the $+2q$ charge. These two forces point to the left, since each is repulsive. The sum of the two is twice the force on the $+q$ charge at the origin due to the other $+q$ charge alone.



SOLUTION Applying Coulomb's law, we have

$$\underbrace{\frac{k|q||q|}{(0.50\text{ m})^2}}_{\substack{\text{Force due to } +q \\ \text{charge at } x=+0.50\text{ m}}} + \underbrace{\frac{k|2q||q|}{(d)^2}}_{\substack{\text{Force due to } +2q \\ \text{charge at } x=+d}} = \underbrace{2\frac{k|q||q|}{(0.50\text{ m})^2}}_{\substack{\text{Twice the force due to} \\ +q\text{ charge at } x=+0.50\text{ m}}}$$

Rearranging this result and solving for d give

$$\frac{k|2q||q|}{(d)^2} = \frac{k|q||q|}{(0.50\text{ m})^2} \qquad \text{or} \qquad d^2 = 2(0.50\text{ m})^2 \qquad \text{or} \qquad d = \pm 0.71\text{ m}$$

We reject the negative root, because a negative value for d would locate the $+2q$ charge to the left of the origin. Then, the two forces acting on the charge at the origin would have different directions, contrary to the statement of the problem. Therefore, the $+2q$ charge is located at a position of $\boxed{x = +0.71\text{ m}}$.

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11. **SSM** ***REASONING AND SOLUTION*** The net electrostatic force on charge 3 at $x = +3.0\text{ m}$ is the vector sum of the forces on charge 3 due to the other two charges, 1 and 2. According to Coulomb's law (Equation 18.1), the magnitude of the force on charge 3 due to charge 1 is

$$F_{13} = \frac{k|q_1||q_3|}{r_{13}^2}$$

where the distance between charges 1 and 3 is r_{13}.

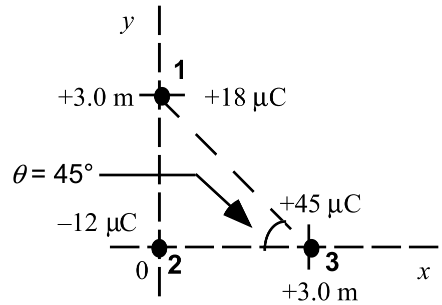

Figure 1

According to the Pythagorean theorem, $r_{13}^2 = x^2 + y^2$. Therefore,

$$F_{13} = \frac{\left(8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(18\times10^{-6}\ \text{C}\right)\left(45\times10^{-6}\ \text{C}\right)}{(3.0\ \text{m})^2 + (3.0\ \text{m})^2} = 0.405\ \text{N}$$

Charges 1 and 3 are equidistant from the origin, so that $\theta = 45°$ (see Figure 1). Since charges 1 and 3 are both positive, the force on charge 3 due to charge 1 is repulsive and along the line that connects them, as shown in Figure 2. The components of F_{13} are:

$$F_{13x} = F_{13}\cos 45° = 0.286\ \text{N} \qquad \text{and} \qquad F_{13y} = -F_{13}\sin 45° = -0.286\ \text{N}$$

The second force on charge 3 is the attractive force (opposite signs) due to its interaction with charge 2 located at the origin. The magnitude of the force on charge 3 due to charge 2 is, according to Coulomb's law ,

$$F_{23} = \frac{k|q_2||q_3|}{r_{23}^2} = \frac{k|q_2||q_3|}{x^2}$$

$$= \frac{\left(8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(12\times10^{-6}\ \text{C}\right)\left(45\times10^{-6}\ \text{C}\right)}{(3.0\ \text{m})^2}$$

$$= 0.539\ \text{N}$$

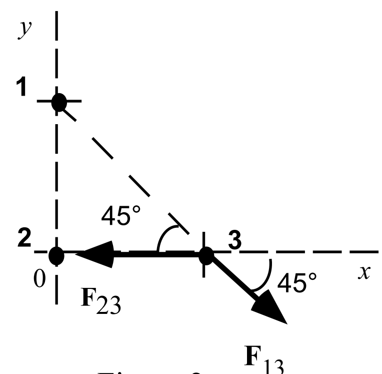

Figure 2

Since charges 2 and 3 have opposite signs, they attract each other, and charge 3 experiences a force to the left as shown in Figure 2. Taking up and to the right as the positive directions, we have

$$F_{3x} = F_{13x} + F_{23x} = +0.286\ \text{N} - 0.539\ \text{N} = -0.253\ \text{N}$$

$$F_{3y} = F_{13y} = -0.286\ \text{N}$$

Using the Pythagorean theorem, we find the magnitude of F_3 to be

$$F_3 = \sqrt{F_{3x}^2 + F_{3y}^2} = \sqrt{(-0.253\ \text{N})^2 + (-0.286\ \text{N})^2} = \boxed{0.38\ \text{N}}$$

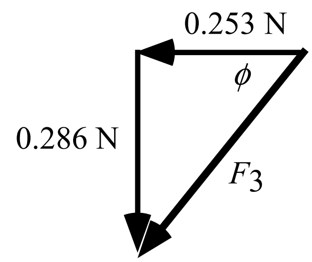

Figure 3

The direction of F_3 relative to the $-x$ axis is specified by the angle ϕ, where

$$\phi = \tan^{-1}\left(\frac{0.286\ \text{N}}{0.253\ \text{N}}\right) = \boxed{49^\circ \text{ below the } -x \text{ axis}}$$

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14. ***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 $\boxed{\text{repulsive}}$.

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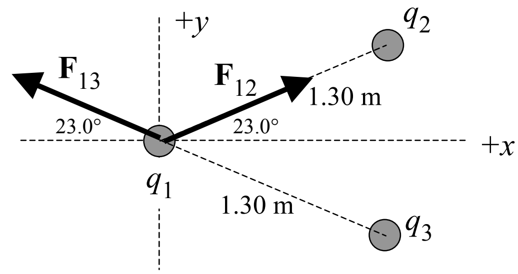
17. ***REASONING***

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 the acceleration is along the +y axis.