Chapter 21

3. **THINK** The magnitude of the electrostatic force between two charges q_1 and q_2 separated by a distance r is given by Coulomb's law.

EXPRESS Equation 21-1 gives Coulomb's law, $F = k\frac{|q_1||q_2|}{r^2}$, which can be used to solve for the distance:

$$r = \sqrt{\frac{k\,|q_1||q_2|}{F}}.$$

ANALYZE With $F = 5.70\text{ N}$, $q_1 = 2.60\times10^{-6}$ C and $q_2 = -47.0\times10^{-6}$ C, the distance between the two charges is

$$r = \sqrt{\frac{k\,|q_1||q_2|}{F}} = \sqrt{\frac{\left(8.99\times10^{9}\,\text{N}\cdot\text{m}^2/\text{C}^2\right)\left(26.0\times10^{-6}\,\text{C}\right)\left(47.0\times10^{-6}\,\text{C}\right)}{5.70\,\text{N}}} = 1.39\text{ m}.$$

LEARN The electrostatic force between two charges falls as $1/r^2$. The same inverse-square nature is also seen in the gravitational force between two masses.

7. With rightward positive, the net force on q_3 is

$$F_3 = F_{13} + F_{23} = k\frac{q_1q_3}{\left(L_{12}+L_{23}\right)^2} + k\frac{q_2q_3}{L_{23}^2}.$$

We note that each term exhibits the proper sign (positive for rightward, negative for leftward) for all possible signs of the charges. For example, the first term (the force exerted on q_3 by q_1) is negative if they are unlike charges, indicating that q_3 is being pulled toward q_1, and it is positive if they are like charges (so q_3 would be repelled from q_1). Setting the net force equal to zero $L_{23}= L_{12}$ and canceling k, q_3, and L_{12} leads to

$$\frac{q_1}{4.00} + q_2 = 0 \quad\Rightarrow\quad \frac{q_1}{q_2} = -\,4.00.$$

24. (a) Equation 21-1 gives

$$F = \frac{\left(8.99\times10^{9}\text{ N}\cdot\text{m}^2/\text{C}^2\right)\left(1.00\times10^{-16}\,\text{C}\right)^2}{\left(1.00\times10^{-2}\text{ m}\right)^2} = 8.99\times10^{-19}\,\text{N}.$$

(b) If n is the number of excess electrons (of charge $-e$ each) on each drop then

$$n = -\frac{q}{e} = -\frac{-1.00\times10^{-16}\text{ C}}{1.60\times10^{-19}\text{ C}} = 625.$$

31. The unit ampere is discussed in Section 21-4. The proton flux is given as 1500 protons per square meter per second, where each proton provides a charge of $q = +e$. The current through the spherical area $4\pi R^2 = 4\pi(6.37\times10^6\text{ m})^2 = 5.1\times10^{14}\text{ m}^2$ would be

$$i = \left(5.1\times10^{14}\,\text{m}^2\right)\left(1500\,\frac{\text{protons}}{\text{s}\cdot\text{m}^2}\right)\left(1.6\times10^{-19}\text{ C/proton}\right) = 0.122\,\text{A}.$$

67. **THINK** Our system consists of two charges along a straight line. We'd like to place a third charge so that the net force on it due to charges 1 and 2 vanishes.

EXPRESS The net force on particle 3 is the vector sum of the forces due to particles 1 and 2: $\vec{F}_{3,\text{net}} = \vec{F}_{31} + \vec{F}_{32}$. In order that $\vec{F}_{3,\text{net}} = 0$, particle 3 must be on the x axis and be attracted by one and repelled by another. As the result, it cannot be between particles 1 and 2, but instead either to the left of particle 1 or to the right of particle 2. Let q_3 be placed a distance x to the right of $q_1 = -5.00q$. Then its attraction to q_1 particle will be exactly balanced by its repulsion from $q_2 = +2.00q$:

$$F_{3x,\text{net}} = k\left[\frac{q_1q_3}{x^2} + \frac{q_2q_3}{(x-L)^2}\right] = kq_3q\left[\frac{-5}{x^2} + \frac{2}{(x-L)^2}\right] = 0.$$

ANALYZE (a) Cross-multiplying and taking the square root, we obtain

$$\frac{x}{x-L} = \sqrt{\frac{5}{2}}$$

which can be rearranged to produce

$$x = \frac{L}{1-\sqrt{2/5}} \approx 2.72\,L.$$

(b) The y coordinate of particle 3 is $y = 0$.

LEARN We can use the result obtained above for consistency check. We find the force on particle 3 due to particle 1 to be

$$F_{31} = k\frac{q_1q_3}{x^2} = k\frac{(-5.00q)(q_3)}{(2.72L)^2} = -0.675\frac{kqq_3}{L^2}.$$

Similarly, the force on particle 3 due to particle 2 is

$$F_{32} = k\frac{q_2 q_3}{x^2} = k\frac{(+2.00q)(q_3)}{(2.72L - L)^2} = +0.675\frac{kqq_3}{L^2}.$$

Indeed, the sum of the two forces is zero.

71. (a) The second shell theorem states that a charged particle inside a shell with charge uniformly distributed on its surface has no net force acting on it due to the shell. Thus, inside the spherical metal shell at $r = 0.500R < R,$ the net force on the electron is zero, and therefore, $a = 0.$

(b) The first shell theorem states that a charged particle outside a shell with charge uniformly distributed on its surface is attracted or repelled as if the shell's charge were concentrated as a particle at its center. Thus, the magnitude of the Coulomb force on the electron at $r = 2.00R$ is

$$\begin{aligned} F &= k\frac{Q|e|}{r^2} = k\frac{(4\pi R^2\sigma)|e|}{(2.0R)^2} = k\pi\sigma|e| \\ &= (8.99\times10^9\ \mathrm{N\cdot m^2/C^2})\pi(6.90\times10^{-13}\ \mathrm{C/m^2})(1.60\times10^{-19}\ \mathrm{C}) \\ &= 3.12\times10^{-21}\ \mathrm{N}, \end{aligned}$$

and the corresponding acceleration is

$$a = \frac{F}{m} = \frac{3.12\times10^{-21}\ \mathrm{N}}{9.11\times10^{-31}\ \mathrm{kg}} = 3.43\times10^9\ \mathrm{m/s^2}.$$