11. 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: $F = k \frac{|q_1||q_2|}{r^2}$. Thus, we see that the electrostatic force between two charges falls as $1/r^2$ and $F_1r_1^2 = F_2r_2^2$.

(a) The ratio of the two distances is

$$\frac{r_2}{r_1} = \sqrt{\frac{F_1}{F_2}} = \sqrt{\frac{5.70 \text{ N}}{0.570 \text{ N}}} = 3.16$$
.

(b) The new separation is

$$r_{2} = \sqrt{\frac{k |q_{1}||q_{2}|}{F_{2}}} = \sqrt{\frac{\left(8.99 \times 10^{9} \,\mathrm{N \cdot m^{2}/C^{2}}\right) \left(26.0 \times 10^{-6} \,\mathrm{C}\right) \left(47.0 \times 10^{-6} \,\mathrm{C}\right)}{0.570 \,\mathrm{N}}} = 4.39 \,\mathrm{m}.$$

16. In experiment 1, sphere *C* first touches sphere *A*, and they divide up their total charge (4Q and 0) equally between them. Thus, sphere *A* and sphere *C* each would acquire charge 2*Q*. Then, sphere *C* touches *B* and those spheres split up their total charge (2Q plus -12Q) so that *B* and *C* end up with charge equal to -5Q. Finally, when *C* touches *A* again, they divide up their total charge equally (2Q and -5Q), so *A* and *C* each has -3Q/2. The force of repulsion between *A* and *B* at the end of experiment 1 is

$$|F_1| = k \frac{(3Q/2)(5Q)}{d^2} = \frac{15kQ^2}{2d^2}$$

Now, in experiment 2, sphere C first touches B, which leaves each of them with charge – 6Q. When C next touches A, they divide up their total charge (4Q, -6Q), and spheres A and C are left with charge –Q. Consequently, the force of repulsion between A and B is

$$|F_2| = k \frac{(Q)(6Q)}{d^2} = \frac{6kQ^2}{d^2}$$

at the end of experiment 2. The ratio of the two forces is

$$\frac{|F_2|}{|F_1|} = \frac{6}{15/2} = \frac{12}{15} = 0.800.$$

17. (a) 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 $4\pi R^2 = 4\pi (6.37 \times 10^6 \text{ m})^2 = 5.1 \times 10^{14} \text{ m}^2$ would be

$$i = (5.1 \times 10^{14} \text{ m}^2) \left(1500 \frac{\text{protons}}{\text{s} \cdot \text{m}^2}\right) (1.6 \times 10^{-19} \text{ C/proton}) = 0.122 \text{ A}.$$

(b) The charge collected in one day (86400 s) is

$$q = it = (0.122 \text{ A})(86400 \text{ s}) = 1.05 \times 10^4 \text{ C}.$$

31. If θ is the angle between the force and the *x*-axis, then

$$\cos\theta = \frac{x}{\sqrt{x^2 + d^2}}.$$

We note that, due to the symmetry in the problem, there is no y component to the net force on the third particle. Thus, F represents the magnitude of force exerted by q_1 or q_2 on q_3 . Let $e = +1.60 \times 10^{-19}$ C, then $q_1 = q_2 = +4e$ and $q_3 = 8e$ and we have

$$F_{\text{net}} = 2F\cos\theta = \frac{2(4e)(8e)}{4\pi\varepsilon_0(x^2+d^2)} \frac{x}{\sqrt{x^2+d^2}} = \frac{64e^2x}{4\pi\varepsilon_0(x^2+d^2)^{3/2}}$$

(a) To find where the force is at an extremum, we can set the derivative of this expression equal to zero and solve for x, but it is good in any case to graph the function for a fuller understanding of its behavior, and as a quick way to see whether an extremum point is a maximum or a minimum. In this way, we find that the value coming from the derivative procedure is a maximum (and will be presented in part (b)) and that the minimum is found at the lower limit of the interval. Thus, the net force is found to be zero at x = 0, which is the smallest value of the net force in the interval 5.0 m $\geq x \geq 0$.

- (b) The maximum is found to be at $x = d/\sqrt{2}$ or roughly 12 cm.
- (c) The value of the net force at x = 0 is $F_{net} = 0$.
- (d) The value of the net force at $x = d/\sqrt{2}$ is $F_{\text{net}} = 2.0 \times 10^{-25} \text{ N}.$

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

$$F_3 = F_{13} + F_{23} = k \frac{q_1 q_3}{\left(L_{12} + L_{23}\right)^2} + k \frac{q_2 q_3}{L_{23}^2}.$$

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 $2.0L_{23} = L_{12}$ and canceling k, q_3 , and L_{12} leads to

$$\frac{q_1}{9.00} + q_2 = 0 \implies \frac{q_1}{q_2} = -9.00.$$