Halliday/Resnick/Walker 7e
Chapter 21

1. (a) With *a* understood to mean the magnitude of acceleration, Newton's second and third laws lead to

$$m_2 a_2 = m_1 a_1 \Rightarrow m_2 = \frac{\left(6.3\times 10^{-7}\,\text{kg}\right)\left(7.0\,\text{m/s}^2\right)}{9.0\,\text{m/s}^2} = 4.9\times 10^{-7}\,\text{kg}.$$

(b) The magnitude of the (only) force on particle 1 is

$$F = m_1 a_1 = k\frac{|q_1||q_2|}{r^2} = \left(8.99\times 10^9\right)\frac{|q|^2}{0.0032^2}.$$

Inserting the values for m_1 and a_1 (see part (a)) we obtain $|q| = 7.1\times 10^{-11}$ C.

3. Eq. 21-1 gives Coulomb's Law, $F = k\frac{|q_1||q_2|}{r^2}$, which we solve for the distance:

$$r = \sqrt{\frac{k|q_1||q_2|}{F}} = \sqrt{\frac{\left(8.99\times 10^9\,\text{N}\cdot\text{m}^2/\text{C}^2\right)\left(26.0\times 10^{-6}\,\text{C}\right)\left(47.0\times 10^{-6}\,\text{C}\right)}{5.70\,\text{N}}} = 1.39\,\text{m}.$$

4. The fact that the spheres are identical allows us to conclude that when two spheres are in contact, they share equal charge. Therefore, when a charged sphere (q) touches an uncharged one, they will (fairly quickly) each attain half that charge ($q/2$). We start with spheres 1 and 2 each having charge q and experiencing a mutual repulsive force $F = kq^2/r^2$. When the neutral sphere 3 touches sphere 1, sphere 1's charge decreases to $q/2$. Then sphere 3 (now carrying charge $q/2$) is brought into contact with sphere 2, a total amount of $q/2 + q$ becomes shared equally between them. Therefore, the charge of sphere 3 is $3q/4$ in the final situation. The repulsive force between spheres 1 and 2 is finally

$$F' = k\frac{(q/2)(3q/4)}{r^2} = \frac{3}{8}k\frac{q^2}{r^2} = \frac{3}{8}F \quad\Rightarrow\quad \frac{F'}{F} = \frac{3}{8} = 0.375.$$

7. The force experienced by q_3 is

$$\vec{F}_3 = \vec{F}_{31} + \vec{F}_{32} + \vec{F}_{34} = \frac{1}{4\pi\varepsilon_0}\left(-\frac{|q_3||q_1|}{a^2}\hat{\text{j}} + \frac{|q_3||q_2|}{(\sqrt{2}a)^2}(\cos 45^\circ\hat{\text{i}} + \sin 45^\circ\hat{\text{j}}) + \frac{|q_3||q_4|}{a^2}\hat{\text{i}}\right)$$

(a) Therefore, the x-component of the resultant force on q_3 is

$$F_{3x} = \frac{|q_3|}{4\pi\varepsilon_0 a^2}\left(\frac{|q_2|}{2\sqrt{2}} + |q_4|\right) = \left(8.99\times10^9\right)\frac{2\left(1.0\times10^{-7}\right)^2}{(0.050)^2}\left(\frac{1}{2\sqrt{2}}+2\right) = 0.17\,\text{N}.$$

(b) Similarly, the y-component of the net force on q_3 is

$$F_{3y} = \frac{|q_3|}{4\pi\varepsilon_0 a^2}\left(-|q_1| + \frac{|q_2|}{2\sqrt{2}}\right) = \left(8.99\times10^9\right)\frac{2\left(1.0\times10^{-7}\right)^2}{(0.050)^2}\left(-1+\frac{1}{2\sqrt{2}}\right) = -0.046\,\text{N}.$$

8. (a) The individual force magnitudes (acting on Q) are, by Eq. 21-1,

$$k\frac{|q_1|Q}{\left(-a-\frac{a}{2}\right)^2} = k\frac{|q_2|Q}{\left(a-\frac{a}{2}\right)^2}$$

which leads to $|q_1| = 9.0\ |q_2|$. Since Q is located between q_1 and q_2, we conclude q_1 and q_2 are like-sign. Consequently, $q_1/q_2 = 9.0$.

(b) Now we have

$$k\frac{|q_1|Q}{\left(-a-\frac{3a}{2}\right)^2} = k\frac{|q_2|Q}{\left(a-\frac{3a}{2}\right)^2}$$

which yields $|q_1| = 25\ |q_2|$. Now, Q is not located between q_1 and q_2, one of them must push and the other must pull. Thus, they are unlike-sign, so $q_1/q_2 = -25$.

10. With rightwards 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 $L_{23}= L_{12}$ and canceling k, q_3 and L_{12} leads to

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

21. (a) The magnitude of the force between the (positive) ions is given by

$$F = \frac{(q)(q)}{4\pi\varepsilon_0 r^2} = k\frac{q^2}{r^2}$$

where q is the charge on either of them and r is the distance between them. We solve for the charge:

$$q = r\sqrt{\frac{F}{k}} = \left(5.0\times10^{-10}\text{ m}\right)\sqrt{\frac{3.7\times10^{-9}\text{ N}}{8.99\times10^{9}\text{ N}\cdot\text{m}^2/\text{C}^2}} = 3.2\times10^{-19}\text{ C}.$$

(b) Let N be the number of electrons missing from each ion. Then, $Ne = q$, or

$$N = \frac{q}{e} = \frac{3.2\times10^{-9}\text{ C}}{1.6\times10^{-19}\text{ C}} = 2\,.$$

23. Eq. 21-11 (in absolute value) gives

$$n = \frac{|q|}{e} = \frac{1.0\times10^{-7}\text{C}}{1.6\times10^{-19}\text{C}} = 6.3\times10^{11}.$$

25. The unit Ampere is discussed in §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

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

45. For the net force on $q_1 = +Q$ to vanish, the x force component due to $q_2 = q$ must exactly cancel the force of attraction caused by $q_4 = -2Q$. Consequently,

$$\frac{Qq}{4\pi\varepsilon_0 a^2} = \frac{Q|2Q|}{4\pi\varepsilon_0(\sqrt{2}a)^2}\cos 45° = \frac{Q^2}{4\pi\varepsilon_0\sqrt{2}a^2}$$

or $q = Q/\sqrt{2}$. This implies that $q/Q = 1/\sqrt{2} = 0.707$.

51. Coulomb's law gives

$$F = \frac{|q|\cdot|q|}{4\pi\varepsilon_0 r^2} = \frac{k(e/3)^2}{r^2} = \frac{\left(8.99\times10^9\text{ N}\cdot\text{m}^2/\text{C}^2\right)(1.60\times10^{-19}\text{ C})^2}{9(2.6\times10^{-15}\text{m})^2} = 3.8\,\text{N}.$$

53. Let the two charges be q_1 and q_2. Then $q_1 + q_2 = Q = 5.0\times10^{-5}$ C. We use Eq. 21-1:

$$1.0\text{N} = \frac{\left(8.99\times10^9\text{ N}\cdot\text{m}^2/\text{C}^2\right)q_1 q_2}{\left(2.0\text{m}\right)^2}.$$

We substitute $q_2 = Q - q_1$ and solve for q_1 using the quadratic formula. The two roots obtained are the values of q_1 and q_2, since it does not matter which is which. We get 1.2×10^{-5} C and 3.8×10^{-5} C. Thus, the charge on the sphere with the smaller charge is 1.2×10^{-5} C.

54. The unit Ampere is discussed in §21-4. Using i for current, the charge transferred is

$$q = it = \left(2.5\times10^4\,\text{A}\right)\left(20\times10^{-6}\,\text{s}\right) = 0.50\ \text{C}.$$

56. Keeping in mind that an Ampere is a Coulomb per second, and that a minute is 60 seconds, the charge (in absolute value) that passes through the chest is

$$|\,q\,| = (\,0.300\,\frac{\text{Coulomb}}{\text{second}}\,)\,(\,120\ \text{seconds}\,) = 36.0\ \text{Coulombs}\,.$$

This charge consists of a number N of electrons (each of which has an absolute value of charge equal to e). Thus,

$$N = \frac{|\,q\,|}{e} = \frac{36.0\ \text{C}}{1.60\ \text{x}\ 10^{-19}\,\text{C}} = 2.25\times10^{20}\,.$$

59. If the relative difference between the proton and electron charges (in absolute value) were

$$\frac{q_p - |q_e|}{e} = 0.0000010$$

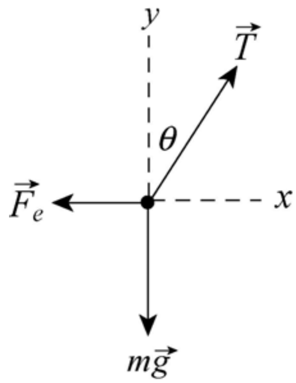
then the actual difference would be $q_p - |q_e| = 1.6\times10^{-25}\,\text{C}$. Amplified by a factor of $29\times3\times10^{22}$ as indicated in the problem, this amounts to a deviation from perfect neutrality of

$$\Delta q = \left(29\times3\times10^{22}\right)\left(1.6\times10^{-25}\,\text{C}\right) = 0.14\,\text{C}$$

in a copper penny. Two such pennies, at $r = 1.0$ m, would therefore experience a very large force. Eq. 21-1 gives

$$F = k\frac{(\Delta q)^2}{r^2} = 1.7\times10^8\,\text{N}.$$

66. (a) A force diagram for one of the balls is shown below. The force of gravity $m\vec{g}$ acts downward, the electrical force $\vec{F}_e$ of the other ball acts to the left, and the tension in the thread acts along the thread, at the angle θ to the vertical. The ball is in equilibrium, so its acceleration is zero. The y component of Newton's second law yields $T\cos\theta - mg = 0$ and the x component yields $T\sin\theta - F_e = 0$. We solve the first equation for T and obtain $T = mg/\cos\theta$. We substitute the result into the second to obtain $mg\tan\theta - F_e = 0$.



Examination of the geometry of Figure 21-43 leads to

$$\tan\theta = \frac{x/2}{\sqrt{L^2 - (x/2)^2}}.$$

If L is much larger than x (which is the case if θ is very small), we may neglect $x/2$ in the denominator and write $\tan\theta \approx x/2L$. This is equivalent to approximating $\tan\theta$ by $\sin\theta$. The magnitude of the electrical force of one ball on the other is

$$F_e = \frac{q^2}{4\pi\varepsilon_0 x^2}$$

by Eq. 21-4. When these two expressions are used in the equation $mg\tan\theta = F_e$, we obtain

$$\frac{mgx}{2L} \approx \frac{1}{4\pi\varepsilon_0}\frac{q^2}{x^2} \Rightarrow x \approx \left(\frac{q^2 L}{2\pi\varepsilon_0 mg}\right)^{1/3}.$$

(b) We solve $x^3 = 2kq^2L/mg$) for the charge (using Eq. 21-5):

$$q = \sqrt{\frac{mgx^3}{2kL}} = \sqrt{\frac{(0.010\,\text{kg})(9.8\,\text{m/s}^2)(0.050\,\text{m})^3}{2(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(1.20\,\text{m})}} = \pm 2.4\times10^{-8}\ \text{C}.$$

Thus, the magnitude is $|q| = 2.4\times10^{-8}$ C.