2. A particle of charge $+3.00 \times 10^{-6} \text{ C}$ is 12.0 cm distant from a second particle of charge $-1.50 \times 10^{-6} \text{ C}$. Calculate the magnitude of the electrostatic force between the particles.

The magnitude of the mutual force of attraction at $r = 0.120 \text{ m}$ is

$$F = k \frac{|q_1||q_2|}{r^2} = \left(8.99 \times 10^9 \right) \frac{\left(3.00 \times 10^{-6}\right)\left(1.50 \times 10^{-6}\right)}{0.120^2} = 2.81 \text{ N}.$$ 

11. In Figure 21-24a, particles 1 and 2 have charge 20.0 $\mu\text{C}$ each and are held at separation distance $d = 1.50 \text{ m}$. (a) What is the magnitude of the electrostatic force on particle 1 due to particle 2? (b) Particle 3 of charge 20.0 $\mu\text{C}$ is now added and positioned so as to complete an equilateral triangle. What is the magnitude of the net electrostatic force on particle 1 due to particles 2 and 3?

(a) Eq. 21-1 gives

$$F_{12} = k \frac{q_1q_2}{d^2} = \left(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2\right) \left(20.0 \times 10^{-6} \text{ C}\right)^2 = 1.60 \text{ N}.$$ 

(b) A force diagram is shown as well as our choice of $y$ axis (the dashed line).

The $y$ axis is meant to bisect the line between $q_2$ and $q_3$ in order to make use of the symmetry in the problem (equilateral triangle of side length $d$, equal-magnitude charges $q_1 = q_2 = q_3 = q$). We see that the resultant force is along this symmetry axis, and we obtain

$$|F_3| = 2 \left( k \frac{q^2}{d^2}\right) \cos 30^\circ = 2.77 \text{ N}.$$
24. Two tiny, spherical water drops, with identical charges of \(-1.00 \times 10^{-16} \text{ C}\), have a center-to-center separation of 1.00 cm. (a) What is the magnitude of the electrostatic force acting between them? (b) How many excess electrons are on each drop, giving it its charge imbalance?

(a) Eq. 21-1 gives

\[
F = \left(\frac{8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2}{(100 \times 10^{-2} \text{ m})^2}\right)(1.00 \times 10^{-16} \text{ C})^2 = 8.99 \times 10^{-19} \text{ N}.
\]

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

\[
n = -\frac{q}{e} = - \frac{1.00 \times 10^{-16} \text{ C}}{1.60 \times 10^{-19} \text{ C}} = 625.
\]

54. In the return stroke of a typical lightning bolt, a current of \(2.5 \times 10^4 \text{ A}\) exists for 20 \(\mu\text{s}\). How much charge is transferred in this event?

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

\[
q = it = \left(2.5 \times 10^4 \text{ A}\right)\left(20 \times 10^{-6} \text{ s}\right) = 0.50 \text{ C}.
\]

Chapter 22

2. In Figure 22-29 the electric field lines on the left have twice the separation of those on the right. (the field lines point left.) (a) If the magnitude of the field at \(A\) (on the right) is 40 N/C, what is the magnitude of the force on a proton at \(A\)? (b) What is the magnitude of the electric field at \(B\) (on the left)?

(a) We note that the electric field points leftward at both points. Using \(\vec{F} = q_0 \vec{E}\), and orienting our \(x\) axis rightward (so \(\hat{i}\) points right in the figure), we find

\[
\vec{F} = \left(+1.6 \times 10^{-19} \text{ C}\right)\left(-40 \text{ N/C} \hat{i}\right) = -6.4 \times 10^{-18} \text{ N} \hat{i}
\]

which means the magnitude of the force on the proton is \(6.4 \times 10^{-18} \text{ N}\) and its direction (-\(\hat{i}\)) is leftward.

(b) As the discussion in §22-2 makes clear, the field strength is proportional to the “crowdedness” of the field lines. It is seen that the lines are twice as crowded at \(A\) than at \(B\), so we conclude that \(E_A = 2E_B\). Thus, \(E_B = 20 \text{ N/C}\).
6. Two particles are fixed to an $x$ axis; particle 1 of charge $-2.00 \times 10^{-7}$ C at $x = 6.00$ cm and particle 2 of charge $+2.00 \times 10^{-7}$ C at $x = 21.0$ cm. Midway between the particles, what is their net electric field in unit-vector notation?

With $x_1 = 6.00$ cm and $x_2 = 21.00$ cm, the point midway between the two charges is located at $x = 13.5$ cm. The values of the charge are $q_1 = -q_2 = -2.00 \times 10^{-7}$ C, and the magnitudes and directions of the individual fields are given by:

$$
\vec{E}_1 = -\frac{|q_1|}{4\pi \varepsilon_0 (x - x_1)^2} \hat{i} = -(3.196 \times 10^5 \text{ N/C}) \hat{i}
$$

$$
\vec{E}_2 = -\frac{|q_2|}{4\pi \varepsilon_0 (x - x_2)^2} \hat{i} = -(3.196 \times 10^5 \text{ N/C}) \hat{i}
$$

Thus, the net electric field is

$$
\vec{E}_{\text{net}} = \vec{E}_1 + \vec{E}_2 = -(6.39 \times 10^5 \text{ N/C}) \hat{i}
$$

11. In Figure 22-32, the four particles form a square of edge length $a = 5.00$ cm and have charges $q_1 = +10.0$ nC (upper left), $q_2 = -20.0$ nC (upper right), $q_3 = +20.0$ nC (lower right), and $q_4 = -10.0$ nC (lower left). In unit-vector notation, what net electric field do the particles produce at the square’s center?

The $x$ component of the electric field at the center of the square is given by

$$
E_x = \frac{1}{4\pi \varepsilon_0} \left[ \frac{|q_1|}{(a/\sqrt{2})^2} + \frac{|q_2|}{(a/\sqrt{2})^2} - \frac{|q_3|}{(a/\sqrt{2})^2} - \frac{|q_4|}{(a/\sqrt{2})^2} \right] \cos 45^\circ
$$

$$
= \frac{1}{4\pi \varepsilon_0} \frac{1}{a^2/2} (|q_1| + |q_2| - |q_3| - |q_4|) \frac{1}{\sqrt{2}}
$$

$$
= 0.
$$

Similarly, the $y$ component of the electric field is

$$
E_y = \frac{1}{4\pi \varepsilon_0} \left[ -\frac{|q_1|}{(a/\sqrt{2})^2} + \frac{|q_2|}{(a/\sqrt{2})^2} + \frac{|q_3|}{(a/\sqrt{2})^2} - \frac{|q_4|}{(a/\sqrt{2})^2} \right] \cos 45^\circ
$$

$$
= \frac{1}{4\pi \varepsilon_0} \frac{1}{a^2/2} (-|q_1| + |q_2| + |q_3| - |q_4|) \frac{1}{\sqrt{2}}
$$

$$
= \left(8.99 \times 10^9 \text{ N} \cdot \text{m}^2 / \text{C}^2\right) \left(2.0 \times 10^{-8} \text{ C}\right) \frac{1}{(0.050 \text{ m})^2/2} \frac{1}{\sqrt{2}} = 1.02 \times 10^5 \text{ N/C}.
$$

Thus, the electric field at the center of the square is $\vec{E} = E_y \hat{j} = (1.02 \times 10^5 \text{ N/C}) \hat{j}$. 