Chapter 23
Problems

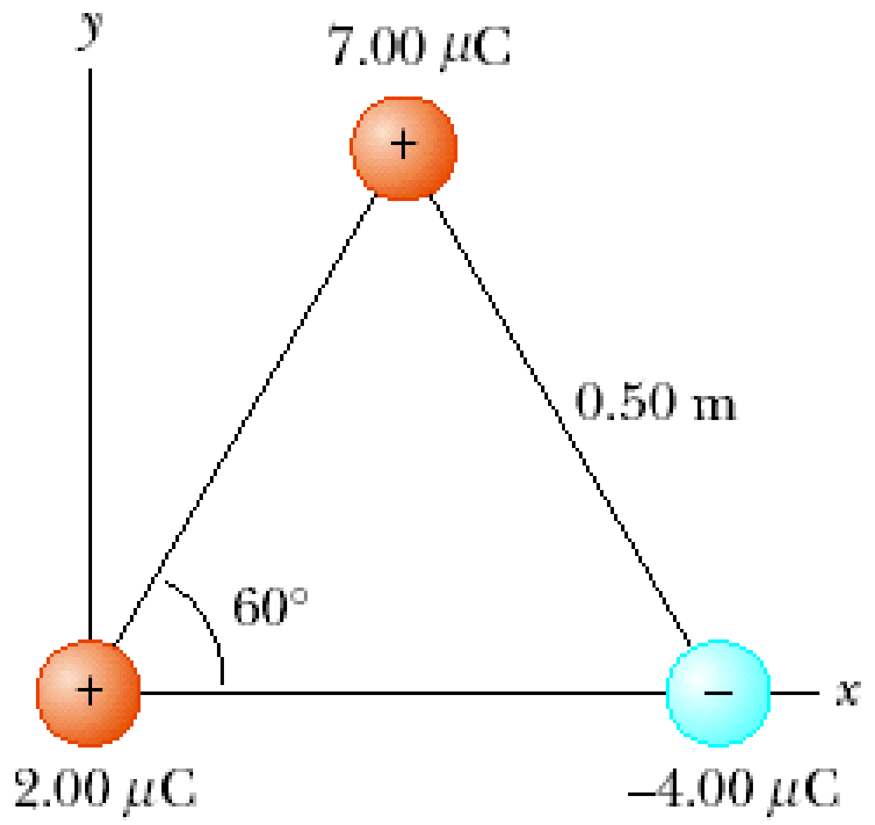
4,7,10,14,20,21,42,45,46

4. Two protons in an atomic nucleus are typically separated by a distance of 2×10^{-15} m. The electric repulsion force between the protons is huge, but the attractive nuclear force is even stronger and keeps the nucleus from bursting apart. What is the magnitude of the electric force between two protons separated by 2.00×10^{-15} m?

The force on one proton is $\mathbf{F} = \frac{k_e q_1 q_2}{r^2}$ away from the other proton. Its magnitude is

$$\left(8.99 \times 10^9\ \mathrm{N \cdot m/C^2}\right)\left(\frac{1.6 \times 10^{-19}\ \mathrm{C}}{2 \times 10^{-15}\ \mathrm{m}}\right)^2 = \boxed{57.5\ \mathrm{N}}.$$

7.Three point charges are located at the corners of an equilateral triangle as shown in Figure. Calculate the resultant electric force on the 7.00-μC charge.



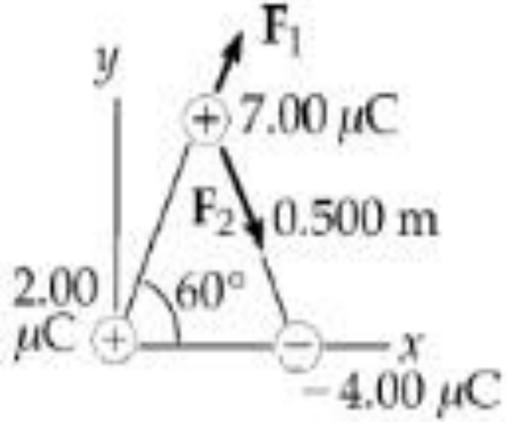
$$F_1 = k_e \frac{q_1 q_2}{r^2} = \frac{\left(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(7.00\times10^{-6}\ \text{C}\right)\left(2.00\times10^{-6}\ \text{C}\right)}{(0.500\ \text{m})^2} = 0.503\ \text{N}$$

$$F_2 = k_e \frac{q_1 q_2}{r^2} = \frac{\left(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(7.00\times10^{-6}\ \text{C}\right)\left(4.00\times10^{-6}\ \text{C}\right)}{(0.500\ \text{m})^2} = 1.01\ \text{N}$$

$$F_x = 0.503\cos 60.0^\circ + 1.01\cos 60.0^\circ = 0.755\ \text{N}$$

$$F_y = 0.503\sin 60.0^\circ - 1.01\sin 60.0^\circ = -0.436\ \text{N}$$

$$\mathbf{F} = (0.755\ \text{N})\hat{\mathbf{i}} - (0.436\ \text{N})\hat{\mathbf{j}} = \boxed{0.872\ \text{N at an angle of } 330^\circ}$$



14. An object having a net charge of 24.0 μC is placed in a uniform electric field of 610 N/C directed vertically. What is the mass of this object if it “floats” in the field?

$$\sum F_y = 0 : QE\hat{\mathbf{j}} + mg\left(-\hat{\mathbf{j}}\right) = 0$$

$$\therefore m = \frac{QE}{g} = \frac{\left(24.0 \times 10^{-6}\ \mathrm{C}\right)\left(610\ \mathrm{N/C}\right)}{9.80\ \mathrm{m/s^2}} = \boxed{1.49\ \text{grams}}$$

20. Two 2.00-μC point charges are located on the *x* axis. One is at $x = 1.00$ m, and the other is at $x = -1.00$ m. (a) Determine the electric field on the *y* axis at $y = 0.500$ m. (b) Calculate the electric force on a -3.00-μC charge placed on the *y* axis at $y = 0.500$ m.

(a) $$E=\frac{k_e q}{r^2}=\frac{\left(8.99\times10^{9}\right)\left(2.00\times10^{-6}\right)}{(1.12)^2}=14\,400\text{ N/C}$$

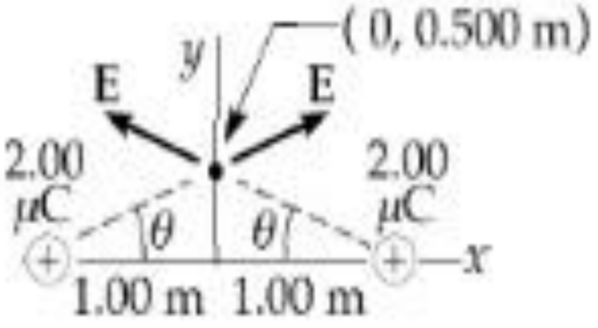


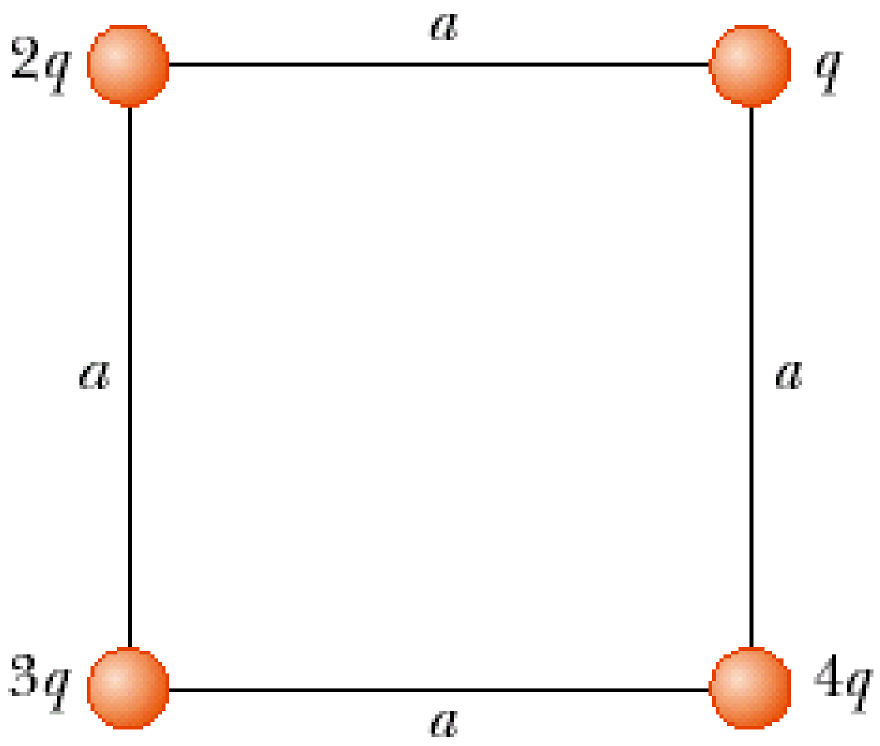
FIG. P23.20

$E_x=0$ and $E_y=2(14\,400)\sin 26.6°=1.29\times10^{4}\text{ N/C}$

so $\boxed{\mathbf{E}=1.29\times10^{4}\,\hat{\mathbf{j}}\text{ N/C}}$.

(b) $$\mathbf{F}=q\mathbf{E}=\left(-3.00\times10^{-6}\right)\left(1.29\times10^{4}\,\hat{\mathbf{j}}\right)=\boxed{-3.86\times10^{-2}\,\hat{\mathbf{j}}\text{ N}}$$

21. Four point charges are at the corners of a square of side a as shown in Figure P23.21. (a) Determine the magnitude and direction of the electric field at the location of charge q. (b) What is the resultant force on q?



(a) $$\mathbf{E} = \frac{k_e q_1}{r_1^2}\hat{\mathbf{r}}_1 + \frac{k_e q_2}{r_2^2}\hat{\mathbf{r}}_2 + \frac{k_e q_3}{r_3^2}\hat{\mathbf{r}}_3 = \frac{k_e(2q)}{a^2}\hat{\mathbf{i}} + \frac{k_e(3q)}{2a^2}\left(\hat{\mathbf{i}}\cos 45.0° + \hat{\mathbf{j}}\sin 45.0°\right) + \frac{k_e(4q)}{a^2}\hat{\mathbf{j}}$$

$$\mathbf{E} = 3.06\frac{k_e q}{a^2}\hat{\mathbf{i}} + 5.06\frac{k_e q}{a^2}\hat{\mathbf{j}} = \boxed{5.91\frac{k_e q}{a^2} \text{ at } 58.8°}$$

(b) $$\mathbf{F} = q\mathbf{E} = \boxed{5.91\frac{k_e q^2}{a^2} \text{ at } 58.8°}$$

42. An electron and a proton are each placed at rest in an electric field of 520 N/C. Calculate the speed of each particle 48.0 ns after being released.

$$F = qE = ma \qquad a = \frac{qE}{m}$$

$$v_f = v_i + at \qquad v_f = \frac{qEt}{m}$$

electron: $$v_e = \frac{(1.602 \times 10^{-19})(520)(48.0 \times 10^{-9})}{9.11 \times 10^{-31}} = \boxed{4.39 \times 10^{6} \text{ m/s}}$$

in a direction opposite to the field

proton: $$v_p = \frac{(1.602 \times 10^{-19})(520)(48.0 \times 10^{-9})}{1.67 \times 10^{-27}} = \boxed{2.39 \times 10^{3} \text{ m/s}}$$

in the same direction as the field

45. The electrons in a particle beam each have a kinetic energy *K*. What are the magnitude and direction of the electric field that will stop these electrons in a distance *d*?

The required electric field will be $\boxed{\text{in the direction of motion}}$.

Work done $= \Delta K$

so, $$-Fd = -\frac{1}{2}mv_i^2 \text{ (since the final velocity } = 0\text{)}$$

which becomes $$eEd = K$$

and $$E = \boxed{\frac{K}{ed}}.$$

46. A positively charged bead having a mass of 1.00 g falls from rest in a vacuum from a height of 5.00 m in a uniform vertical electric field with a magnitude of 1.00×10^4 N/C. The bead hits the ground at a speed of 21.0 m/s. Determine (a) the direction of the electric field (up or down), and (b) the charge on the bead.

The acceleration is given by

$$v_f^2 = v_i^2 + 2a\left(x_f - x_i\right) \quad \text{or} \quad v_f^2 = 0 + 2a(-h).$$

Solving $$a = -\frac{v_f^2}{2h}.$$

Now $$\sum \mathbf{F} = m\mathbf{a}: \quad -mg\hat{\mathbf{j}} + q\mathbf{E} = -\frac{mv_f^2\hat{\mathbf{j}}}{2h}.$$

Therefore $$q\mathbf{E} = \left(-\frac{mv_f^2}{2h} + mg\right)\hat{\mathbf{j}}.$$

(a) Gravity alone would give the bead downward impact velocity

$$\sqrt{2\left(9.80 \text{ m/s}^2\right)(5.00 \text{ m})} = 9.90 \text{ m/s}.$$

To change this to 21.0 m/s down, a $\boxed{\text{downward}}$ electric field must exert a downward electric force.

(b) $$q = \frac{m}{E}\left(\frac{v_f^2}{2h} - g\right) = \frac{1.00 \times 10^{-3} \text{ kg}}{1.00 \times 10^4 \text{ N/C}}\left(\frac{\text{N} \cdot \text{s}^2}{\text{kg} \cdot \text{m}}\right)\left[\frac{(21.0 \text{ m/s})^2}{2(5.00 \text{ m})} - 9.80 \text{ m/s}^2\right] = \boxed{3.43\ \mu\text{C}}$$