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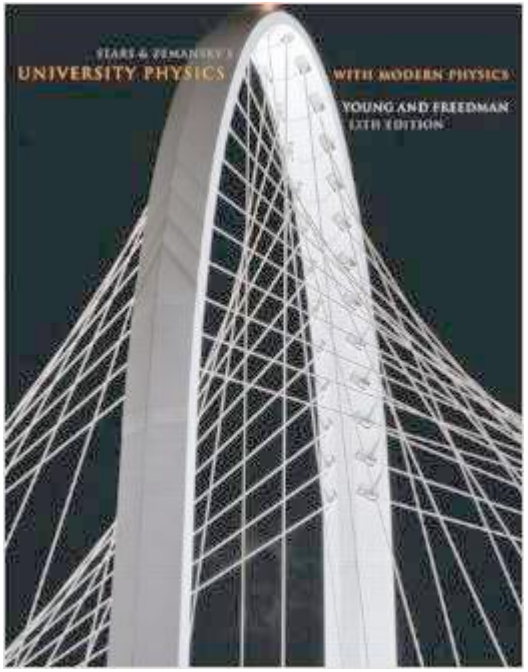

University Physics with Modern Physics

(13th Edition, 2012)

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21.6 • Two small spheres spaced 20.0 cm apart have equal charge. How many excess electrons must be present on each sphere if the magnitude of the force of repulsion between them is 4.57×10^{-21} N?

The magnitude of the charge of an electron is $e = 1.60 \times 10^{-19}$ C.

And

$$F = \frac{1}{4\pi\epsilon_0}\frac{q^2}{r^2}$$

$$|q| = \sqrt{4\pi\epsilon_0 F r^2} \quad = \sqrt{4\pi\epsilon_0 (4.57\times10^{-21}\ \text{N})(0.200\ \text{m})^2}$$

$$= 1.43\times10^{-16}\ \text{C}.$$

the total number of electrons required

$$n = |q|/e \quad = (1.43\times10^{-16}\ \text{C})/(1.60\times10^{-19}\ \text{C/electron}) = 890\ \text{electrons}.$$

21.9 •• Two small plastic spheres are given positive electrical charges. When they are 15.0 cm apart, the repulsive force between them has magnitude 0.220 N. What is the charge on each sphere (a) if the two charges are equal and (b) if one sphere has four times the charge of the other?

(a) $q_1 = q_2 = q$

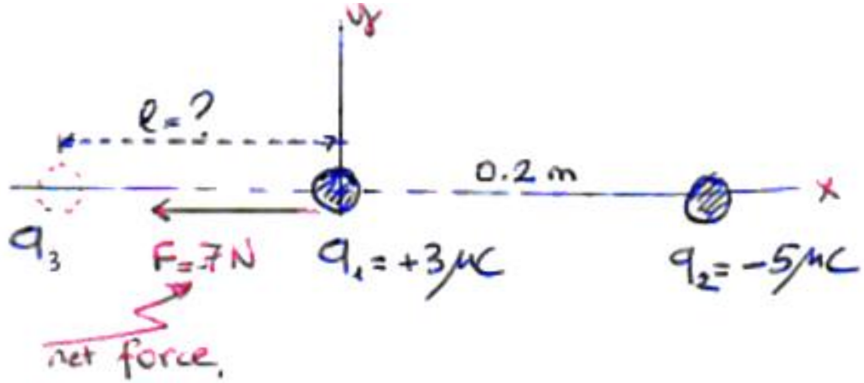
$$F = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_2|}{r^2} = \frac{q^2}{4\pi\epsilon_0 r^2} \quad \text{so } q = r\sqrt{\frac{F}{(1/4\pi\epsilon_0)}} = 0.150\ \text{m}\sqrt{\frac{0.220\ \text{N}}{8.988\times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2}} = 7.42\times 10^{-7}\ \text{C (on each)}$$

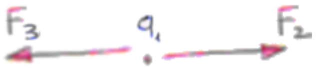
(b) $q_2 = 4q_1$

$$F = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_2|}{r^2} = \frac{4q_1^2}{4\pi\epsilon_0 r^2} \quad \text{so } q_1 = r\sqrt{\frac{F}{4(1/4\pi\epsilon_0)}} = \tfrac{1}{2} r\sqrt{\frac{F}{(1/4\pi\epsilon_0)}} = \tfrac{1}{2}(7.42\times 10^{-7}\ \text{C}) = 3.71\times 10^{-7}\ \text{C}.$$

And then $q_2 = 4q_1 = 1.48\times 10^{-6}$ C.

21.19 •• Three point charges are arranged along the x-axis. Charge $q_1 = +3.00\ \mu C$ is at the origin, and charge $q_2 = -5.00\ \mu C$ is at $x = 0.200$ m. Charge $q_3 = -8.00\ \mu C$. Where is q_3 located if the net force on q_1 is 7.00 N in the $-x$-direction?





$$F_2 = k\frac{|q_1 q_2|}{r_{12}^2} = 3.37\text{ N}, \text{ so } F_{2x} = +3.37\text{ N}$$

$$F_x = F_{2x} + F_{3x} \text{ and } F_x = -7.00\text{ N}$$

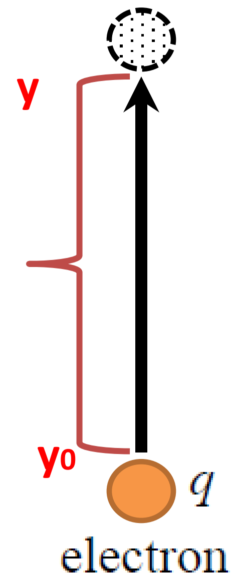
$$F_{3x} = F_x - F_{2x} = -7.00\text{ N} - 3.37\text{ N} = -10.37\text{ N}$$

For F_{3x} to be negative, q_3 must be on the $-x$-axis.

$$F_3 = k\frac{|q_1 q_3|}{x^2} \qquad \text{so } |x| = \sqrt{\frac{k|q_1 q_3|}{F_3}} = 0.144\text{ m}, \qquad \text{so } x = -0.144\text{ m}$$

21.28 • CP An electron is released from rest in a uniform electric field. The electron accelerates vertically upward, traveling 4.50 m in the first 3.00 μs after it is released. (a) What are the magnitude and direction of the electric field? (b) Are we justified in ignoring the effects of gravity? Justify your answer quantitatively.

Let $+y$ be upward.

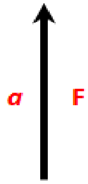


(a) $v_{0y} = 0$ and $a_y = a$,

so $y - y_0 = v_{0y}t + \frac{1}{2}a_y t^2$ ⇒ $y - y_0 = \frac{1}{2}at^2$

$$a = \frac{2(y-y_0)}{t^2} = \frac{2(4.50\text{ m})}{(3.00\times10^{-6}\text{ s})^2} = 1.00\times10^{12}\text{ m/s}^2$$

$$E = \frac{F}{q} = \frac{ma}{q} = \frac{(9.11\times10^{-31}\text{ kg})(1.00\times10^{12}\text{ m/s}^2)}{1.60\times10^{-19}\text{ C}} = 5.69\text{ N/C}$$



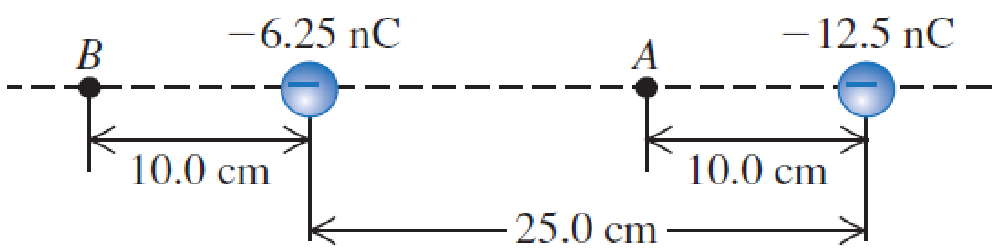
(b) The electron's acceleration is $\sim 10^{11} g$

so gravity must be negligibly small

$$\frac{F_a}{F_g} = \frac{1x10^{12}}{\sim 10} \cong 10^{11}$$

21.31 • Two point charges are separated by 25.0 cm (Fig. E21.31). Find the net electric field these charges produce at (a) point *A* and (b) point *B*. (c) What would be the magnitude and direction of the electric force this combination of charges would produce on a proton at *A*?

Figure **E21.31**

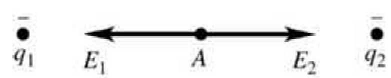


$$\vec{F} = q\vec{E}$$

$$E = k\frac{|q|}{r^2}$$

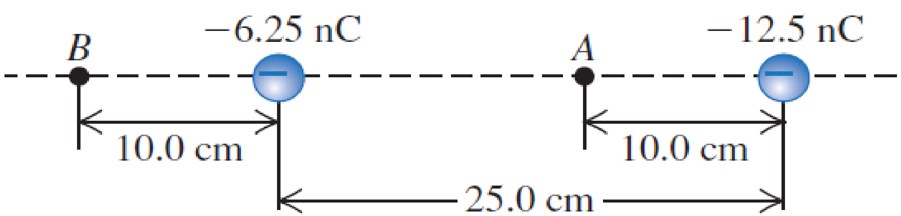
(a) $$E_1 = k\frac{|q_1|}{r_{A1}^2} = (8.99\times10^9\ \mathrm{N\cdot m^2/C^2})\frac{6.25\times10^{-9}\ \mathrm{C}}{(0.150\ \mathrm{m})^2} = 2.50\times10^3\ \mathrm{N/C}$$

$$E_2 = k\frac{|q_2|}{r_{A2}^2} = (8.99\times10^9\ \mathrm{N\cdot m^2/C^2})\frac{12.5\times10^{-9}\ \mathrm{C}}{(0.100\ \mathrm{m})^2} = 1.124\times10^4\ \mathrm{N/C}$$



the net field $E = E_2 - E_1 = 8.74\times10^3\ \mathrm{N/C}$, to the right.

Figure E21.31



(b)

$$E_1 = k\frac{|q_1|}{r_{B1}^2} = (8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\frac{6.25\times10^{-9}\ \text{C}}{(0.100\ \text{m})^2}$$

$$= 5.619\times10^3\ \text{N/C}$$

$$E_2 = k\frac{|q_2|}{r_{B2}^2} = (8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\frac{12.5\times10^{-9}\ \text{C}}{(0.350\ \text{m})^2} = 9.17\times10^2\ \text{N/C}$$

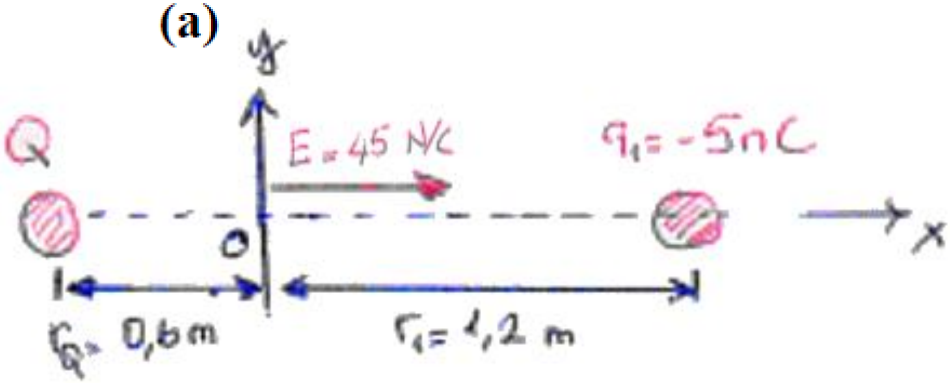
the fields are in the same direction $E = E_1 + E_2 = 6.54\times10^3\ \text{N/C}$, to the right.

(c) At A, $E = 8.74\times10^3\ \text{N/C}$, to the right

$$F = qE = (1.60\times10^{-19}\ \text{C})(8.74\times10^3\ \text{N/C}) = 1.40\times10^{-15}\ \text{N, to the right.}$$

21.72 •• A -5.00-nC point charge is on the x-axis at $x = 1.20$ m. A second point charge Q is on the x-axis at -0.600 m. What must be the sign and magnitude of Q for the resultant electric field at the origin to be (a) 45.0 N/C in the $+x$-direction, (b) 45.0 N/C in the $-x$-direction?

(a)



$$E_1 = (8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\frac{(5.00\times10^{-9}\ \text{C})}{(1.20\ \text{m})^2}$$

$$E_1 = 31.2\ \text{N/C}$$

$$E_{1x} = +31.2\ \text{N/C}$$

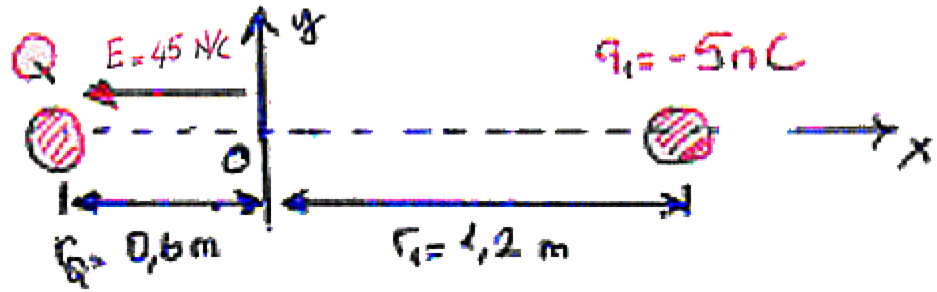
$$\left.\begin{aligned} E_x &= E_{1x} + E_{2x} \\ E_x &= +45.0\ \text{N/C} \end{aligned}\right\} \quad E_{2x} = E_x - E_{1x} = +45.0\ \text{N/C} - 31.2\ \text{N/C} = 13.8\ \text{N/C}$$

$\vec{E}$ is away from Q

Q is positive $\qquad E_2 = k\dfrac{|Q|}{r^2}$

$$|Q| = \frac{E_2 r^2}{k} = \frac{(13.8\ \text{N/C})(0.600\ \text{m})^2}{8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2} = 5.53\times10^{-10}\ \text{C}$$

(b)



$E_x = -45.0 \text{ N/C}$,

so $E_{2x} = E_x - E_{1x}$

$$= -45.0 \text{ N/C} - 31.2 \text{ N/C} = -76.2 \text{ N/C}.$$

$\vec{E}$ is toward Q so

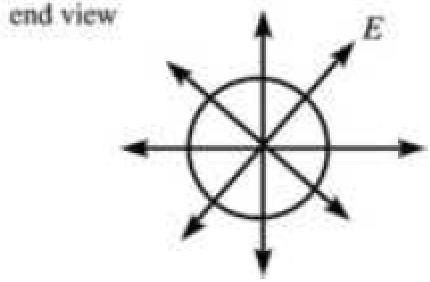
Q is negative

$$E_2 = k\frac{|Q|}{r^2} \Rightarrow |Q| = \frac{E_2 r^2}{k}$$

$$= \frac{(76.2 \text{ N/C})(0.600 \text{ m})^2}{8.99\times10^9 \text{ N}\cdot\text{m}^2/\text{C}^2} = 3.05\times10^{-9} \text{ C}.$$

22.4 • It was shown in Example 21.11 (Section 21.5) that the electric field due to an infinite line of charge is perpendicular to the line and has magnitude $E = \lambda/2\pi\epsilon_0 r$. Consider an imaginary cylinder with radius $r = 0.250$ m and length $l = 0.400$ m that has an infinite line of positive charge running along its axis. The charge per unit length on the line is $\lambda = 3.00\ \mu$C/m. (a) What is the electric flux through the cylinder due to this infinite line of charge? (b) What is the flux through the cylinder if its radius is increased to $r = 0.500$ m? (c) What is the flux through the cylinder if its length is increased to $l = 0.800$ m?

$A = 2\pi r l$



$E = \lambda/2\pi\epsilon_0 r$ at all points on this surface. Thus $\phi = 0°$

$\vec{E} \cdot \vec{A} = 0$

(a) $E = \lambda/2\pi\epsilon_0 r$ at all points on this surface. Thus $\phi = 0°$

$$\Phi_E = EA\cos\phi = EA = (\lambda/2\pi\epsilon_0 r)(2\pi r l) = \frac{\lambda l}{\epsilon_0} = \frac{(3.00\times10^{-6}\ \text{C/m})(0.400\ \text{m})}{8.854\times10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2} = 1.36\times10^5\ \text{N}\cdot\text{m}^2/\text{C}$$

(b) the radius r of the cylinder divided out, so the flux remains the same,

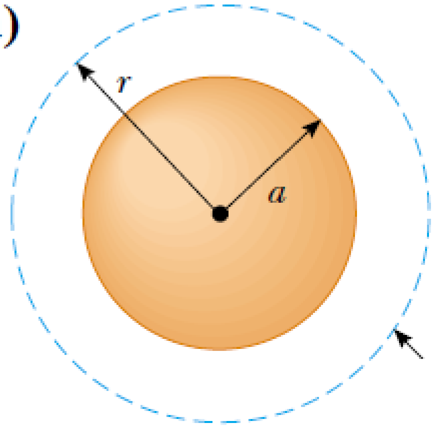
$$\Phi_E = 1.36\times10^5\ \text{N}\cdot\text{m}^2/\text{C}$$

(c) $$\Phi_E = \frac{\lambda l}{\epsilon_0} = \frac{(3.00\times10^{-6}\ \text{C/m})(0.800\ \text{m})}{8.854\times10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2} = 2.71\times10^5\ \text{N}\cdot\text{m}^2/\text{C}$$

(twice the flux calculated in parts (a) and (b))

22.14 •• A solid metal sphere with radius 0.450 m carries a net charge of 0.250 nC. Find the magnitude of the electric field (a) at a point 0.100 m outside the surface of the sphere and (b) at a point inside the sphere, 0.100 m below the surface.

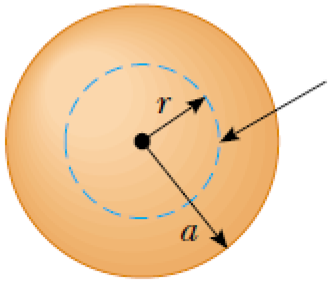
(a)



$$r = a + 0.100\ \text{m}$$
$$= 0.450\ \text{m} + 0.100\ \text{m}$$
$$r = 0.550\ \text{m}$$

$$E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2} = \frac{1}{4\pi\epsilon_0}\frac{(2.50\times10^{-10}\ \text{C})}{(0.550\ \text{m})^2} = 7.44\ \text{N/C}$$

(b)



$E = 0$ inside of a conductor (charges aren't moving)

22.27 ••• **CP CALC** An insulating sphere of radius $R = 0.160$ m has uniform charge density $\rho = +7.20 \times 10^{-9}$ C/m^3. A small object that can be treated as a point charge is released from rest just outside the surface of the sphere. The small object has positive charge $q = 3.40 \times 10^{-6}$ C. How much work does the electric field of the sphere do on the object as the object moves to a point very far from the sphere?

$$Q = \rho V = \rho\left(\frac{4}{3}\pi R^3\right)$$

$$E = \frac{kQ}{r^2}$$

for points outside its surface

$$W = \int_R^\infty F(r)dr.$$

The work done on the object

$$Q = \rho V = \rho\left(\frac{4}{3}\pi R^3\right)$$

$$= (7.20\times10^{-9}\ \text{C/m}^3)\left(\frac{4}{3}\pi\right)(0.160\ \text{m})^3 = 1.235\times10^{-10}\ \text{C}$$

The work done on the object

$$W = \int_R^\infty F(r)dr \quad = kQq\int_R^\infty \frac{dr}{r^2} \quad = \frac{kQq}{R}$$

$$= \frac{(8.988\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(1.235\times10^{-10}\ \text{C})(3.40\times10^{-6}\ \text{C})}{0.160\ \text{m}}$$

$$W = 2.36\times10^{-5}\ \text{J}$$