Chapter 23

3. We use $\Phi = \vec{E}\cdot\vec{A}$, where $\vec{A} = A\hat{\mathrm{j}} = (1.40\mathrm{m})^2\,\hat{\mathrm{j}}$.

(a) $\Phi = (6.00\ \mathrm{N/C})\,\hat{\mathrm{i}}\cdot(1.40\ \mathrm{m})^2\,\hat{\mathrm{j}} = 0.$

(b) $\Phi = (-2.00\ \mathrm{N/C})\,\hat{\mathrm{j}}\cdot(1.40\ \mathrm{m})^2\,\hat{\mathrm{j}} = -3.92\ \mathrm{N\cdot m^2/C}.$

(c) $\Phi = \left[(-3.00\ \mathrm{N/C})\,\hat{\mathrm{i}} + (400\,\mathrm{N/C})\,\hat{\mathrm{k}}\right]\cdot(1.40\ \mathrm{m})^2\,\hat{\mathrm{j}} = 0$.

(d) The total flux of a uniform field through a closed surface is always zero.

4. The flux through the flat surface encircled by the rim is given by $\Phi = \pi a^2 E.$ Thus, the flux through the netting is

$$\Phi' = -\Phi = -\pi a^2 E = -\pi(0.11\ \mathrm{m})^2(3.0\times10^{-3}\ \mathrm{N/C}) = -1.1\times10^{-4}\ \mathrm{N\cdot m^2/C}\,.$$

7. We use Gauss' law: $\varepsilon_0\Phi = q$, where Φ is the total flux through the cube surface and q is the net charge inside the cube. Thus,

$$\Phi = \frac{q}{\varepsilon_0} = \frac{1.8\times10^{-6}\ \mathrm{C}}{8.85\times10^{-12}\ \mathrm{C^2/N\cdot m^2}} = 2.0\times10^{5}\ \ \mathrm{N\cdot m^2/C}.$$

17. **THINK** The system has spherical symmetry, so our Gaussian surface is a sphere of radius R with a surface area $A = 4\pi R^2$.

EXPRESS The charge on the surface of the sphere is the product of the surface charge density σ and the surface area of the sphere: $q = \sigma A = \sigma(4\pi R^2)$. We calculate the total electric flux leaving the surface of the sphere using Gauss' law: $q = \varepsilon_0\Phi$.

ANALYZE (a) With $R = (1.20\ \mathrm{m})/2 = 0.60\ \mathrm{m}$ and $\sigma = 8.1\times10^{-6}\ \mathrm{C/m^2}$, the charge on the surface is

$$q = 4\pi R^2\sigma = 4\pi(0.60\ \mathrm{m})^2\,(8.1\times10^{-6}\ \mathrm{C/m^2}) = 3.7\times10^{-5}\ \mathrm{C}.$$

(b) We choose a Gaussian surface in the form of a sphere, concentric with the conducting sphere and with a slightly larger radius. By Gauss's law, the flux is

$$\Phi = \frac{q}{\varepsilon_0} = \frac{3.66\times10^{-5}\ \text{C}}{8.85\times10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2} = 4.1\times10^{6}\ \text{N}\cdot\text{m}^2/\text{C}\,.$$

LEARN Since there is no charge inside the conducting sphere, the total electric flux through the surface of the sphere only depends on the charge residing on the surface of the sphere.

18. Using Eq. 23-11, the surface charge density is

$$\sigma = E\varepsilon_0 = \left(2.3\times10^{5}\ \text{N/C}\right)\left(8.85\times10^{-12}\text{C}^2/\text{N}\cdot\text{m}^2\right) = 2.0\times10^{-6}\ \text{C/m}^2.$$

22. We combine Newton's second law ($F = ma$) with the definition of electric field ($F = qE$) and with Eq. 23-12 (for the field due to a line of charge). In terms of magnitudes, we have (if r = 0.080 m and $\lambda = 6.0\times10^{-6}\text{C/m}$)

$$ma = eE = \frac{e\lambda}{2\pi\varepsilon_0 r} \quad\Rightarrow\quad a = \frac{e\lambda}{2\pi\varepsilon_0 r\, m} = 2.1\times10^{17}\ \text{m/s}^2\ .$$

25. **THINK** Our system is an infinitely long line of charge. Since the system possesses cylindrical symmetry, we may apply Gauss' law and take the Gaussian surface to be in the form of a closed cylinder.

EXPRESS We imagine a cylindrical Gaussian surface A of radius r and length h concentric with the metal tube. Then by symmetry,

$$\oint_A \vec{E}\cdot d\vec{A} = 2\pi rhE = \frac{q}{\varepsilon_0},$$

where q is the amount of charge enclosed by the Gaussian cylinder. Thus, the magnitude of the electric field produced by a uniformly charged infinite line is

$$E = \frac{q/h}{2\pi\varepsilon_0 r} = \frac{\lambda}{2\pi\varepsilon_0 r}$$

where λ is the linear charge density and r is the distance from the line to the point where the field is measured.

ANALYZE Substituting the values given, we have

$$\lambda = 2\pi\varepsilon_0 Er = 2\pi\left(8.85\times10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2\right)\left(4.5\times10^4\ \text{N/C}\right)\left(2.0\ \text{m}\right)$$
$$= 5.0\times10^{-6}\ \text{C/m}.$$

LEARN Since $\lambda > 0$, the direction of $\vec{E}$ is radially outward from the line of charge. Note that the field varies with r as $E \sim 1/r$, in contrast to the $1/r^2$ dependence due to a point charge.

45. (a) Since r_1 = 10.0 cm < r = 12.0 cm < r_2 = 15.0 cm,

$$E(r) = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r^2} = \frac{\left(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(4.00\times10^{-8}\ \text{C}\right)}{\left(0.120\ \text{m}\right)^2} = 2.50\times10^4\ \text{N/C}.$$

(b) Since $r_1 < r_2 < r$ = 20.0 cm,

$$E(r) = \frac{1}{4\pi\varepsilon_0}\frac{q_1+q_2}{r^2} = \frac{\left(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(4.00+2.00\right)\left(1\times10^{-8}\ \text{C}\right)}{\left(0.200\ \text{m}^2\right)} = 1.35\times10^4\ \text{N/C}.$$

47. **THINK** The unknown charge is distributed uniformly over the surface of the conducting solid sphere.

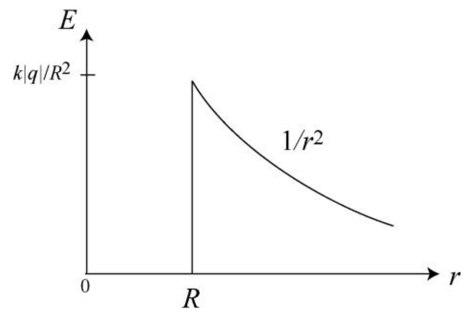
EXPRESS The electric field produced by the unknown charge at points outside the sphere is like the field of a point particle with charge equal to the net charge on the sphere. That is, the magnitude of the field is given by $E = |q|/4\pi\varepsilon_0 r^2$, where $|q|$ is the magnitude of the charge on the sphere and r is the distance from the center of the sphere to the point where the field is measured.

ANALYZE Thus, we have

$$|q| = 4\pi\varepsilon_0 r^2 E = \frac{\left(0.15\ \text{m}\right)^2\left(3.0\times10^3\ \text{N/C}\right)}{8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2} = 7.5\times10^{-9}\ \text{C}.$$

The field points inward, toward the sphere center, so the charge is negative, i.e., $q = -7.5\times10^{-9}\,\text{C}$.

LEARN The electric field strength as a function of r is shown to the right. Inside the metal sphere, $E = 0$; outside the sphere, $E = k|q|/r^2$, where $k = 1/4\pi\varepsilon_0$.



52. The field is zero for $0 \le r \le a$ as a result of Eq. 23-16. Thus,

(a) $E = 0$ at $r = 0$,

(b) $E = 0$ at $r = a/2.00$, and

(c) $E = 0$ at $r = a$.

For $a \le r \le b$ the enclosed charge q_{enc} (for $a \le r \le b$) is related to the volume by

$$q_{\text{enc}} = \rho\left(\frac{4\pi r^3}{3} - \frac{4\pi a^3}{3}\right).$$

Therefore, the electric field is

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q_{\text{enc}}}{r^2} = \frac{\rho}{4\pi\varepsilon_0 r^2}\left(\frac{4\pi r^3}{3} - \frac{4\pi a^3}{3}\right) = \frac{\rho}{3\varepsilon_0}\frac{r^3 - a^3}{r^2}$$

for $a \le r \le b$.

(d) For $r = 1.50a$, we have

$$E = \frac{\rho}{3\varepsilon_0}\frac{(1.50a)^3 - a^3}{(1.50a)^2} = \frac{\rho a}{3\varepsilon_0}\left(\frac{2.375}{2.25}\right) = \frac{(1.84\times10^{-9}\text{ C/m}^3)(0.100\text{ m})}{3(8.85\times10^{-12}\text{ C}^2/\text{N}\cdot\text{m}^2)}\left(\frac{2.375}{2.25}\right) = 7.32\text{ N/C}.$$

(e) For $r = b = 2.00a$, the electric field is

$$E = \frac{\rho}{3\varepsilon_0}\frac{(2.00a)^3 - a^3}{(2.00a)^2} = \frac{\rho a}{3\varepsilon_0}\left(\frac{7}{4}\right) = \frac{(1.84\times10^{-9}\text{ C/m}^3)(0.100\text{ m})}{3(8.85\times10^{-12}\text{ C}^2/\text{N}\cdot\text{m}^2)}\left(\frac{7}{4}\right) = 12.1\text{ N/C}.$$

(f) For $r \ge b$ we have $E = q_{\text{total}}/4\pi\varepsilon_0 r^2$ or

$$E = \frac{\rho}{3\varepsilon_0}\frac{b^3 - a^3}{r^2}.$$

Thus, for r = 3.00b = 6.00a, the electric field is

$$E = \frac{\rho}{3\varepsilon_0}\frac{(2.00a)^3 - a^3}{(6.00a)^2} = \frac{\rho a}{3\varepsilon_0}\left(\frac{7}{36}\right) = \frac{(1.84\times10^{-9}\text{ C/m}^3)(0.100\text{ m})}{3(8.85\times10^{-12}\text{ C}^2/\text{N}\cdot\text{m}^2)}\left(\frac{7}{36}\right) = 1.35\text{ N/C.}$$