7. First, we observe that $V(x)$ cannot be equal to zero for $x > d$. In fact $V(x)$ is always negative for $x > d$. Now we consider the two remaining regions on the x axis: $x < 0$ and $0 < x < d$.

(a) For $0 < x < d$ we have $d_1 = x$ and $d_2 = d - x$. Let

$$V(x) = k\left(\frac{q_1}{d_1} + \frac{q_2}{d_2}\right) = \frac{e}{4\pi\varepsilon_0}\left(\frac{15}{x} + \frac{-5}{d-x}\right) = 0$$

and the solution is $x = 3d/4$. With $d = 24.0$ cm, we have $x = 18.0$ cm.

(b) Similarly, for $x < 0$ the separation between q_1 and a point on the x axis whose coordinate is x is given by $d_1 = -x$; while the corresponding separation for q_2 is $d_2 = d - x$. We set

$$V(x) = k\left(\frac{q_1}{d_1} + \frac{q_2}{d_2}\right) = \frac{e}{4\pi\varepsilon_0}\left(\frac{15}{-x} + \frac{-5}{d-x}\right) = 0$$

to obtain $x = -3d/2$. With $d = 24.0$ cm, we have $x = -36.0$ cm.

9. (a) All the charge is the same distance *R* from *C*, so the electric potential at *C* is

$$V=\frac{1}{4\pi\varepsilon_0}\left(\frac{Q_1}{R}-\frac{6Q_1}{R}\right)=-\frac{5Q_1}{4\pi\varepsilon_0 R}=-\frac{5(8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2})(7.07\times10^{-12}\,\mathrm{C})}{8.20\times10^{-2}\ \mathrm{m}}=-3.88\ \mathrm{V},$$

where the zero was taken to be at infinity.

(b) All the charge is the same distance from *P*. That distance is $\sqrt{R^2+D^2}$, so the electric potential at *P* is

$$\begin{aligned}V&=\frac{1}{4\pi\varepsilon_0}\left[\frac{Q_1}{\sqrt{R^2+D^2}}-\frac{6Q_1}{\sqrt{R^2+D^2}}\right]=-\frac{5Q_1}{4\pi\varepsilon_0\sqrt{R^2+D^2}}\\&=-\frac{5(8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2})(7.07\times10^{-12}\,\mathrm{C})}{\sqrt{(8.20\times10^{-2}\ \mathrm{m})^2+(2.05\times10^{-2}\ \mathrm{m})^2}}\\&=-3.76\ \mathrm{V}.\end{aligned}$$

13. We use the conservation of energy principle. The initial potential energy is $U_i = q^2/4\pi\varepsilon_0 r_1$, the initial kinetic energy is $K_i = 0$, the final potential energy is $U_f = q^2/4\pi\varepsilon_0 r_2$, and the final kinetic energy is $K_f = \frac{1}{2}mv^2$, where v is the final speed of the particle. Conservation of energy yields

$$\frac{q^2}{4\pi\varepsilon_0 r_1} = \frac{q^2}{4\pi\varepsilon_0 r_2} + \frac{1}{2}mv^2 .$$

The solution for v is

$$v = \sqrt{\frac{2q^2}{4\pi\varepsilon_0 m}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)} = \sqrt{\frac{(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(2)(3.1\times10^{-6}\,\text{C})^2}{20\times10^{-6}\text{kg}}\left(\frac{1}{0.90\times10^{-3}\,\text{m}} - \frac{1}{1.5\times10^{-3}\,\text{m}}\right)}$$
$$= 1960\,\text{m/s}$$

and the corresponding momentum is

$$p = mv = (20\times10^{-6}\text{kg})(1960\ \text{m/s}) = 3.9\times10^{-2}\text{kg}\cdot\text{m/s}$$

17. **THINK** The component of the electric field $\vec{E}$ in a given direction is the negative of the rate at which potential changes with distance in that direction.

EXPRESS With $V = 2.00xyz^2$, we apply Eq. 24–41 to calculate the x, y, and z components of the electric field:

$$E_x = -\frac{\partial V}{\partial x} = -2.00\,yz^2$$
$$E_y = -\frac{\partial V}{\partial y} = -2.00xz^2$$
$$E_z = -\frac{\partial V}{\partial z} = -4.00xyz$$

which, at (x, y, z) = (–1.00 m, –2.00 m, 4.00 m), gives

$$(E_x, E_y, E_z) = (+64.0\text{ V/m}, +32.0\text{ V/m}, -32.0\text{ V/m}).$$

ANALYZE The magnitude of the field is therefore

$$\left|\vec{E}\right| = \sqrt{E_x^2 + E_y^2 + E_z^2} = \sqrt{(64.0\text{ V/m})^2 + (+32.0\text{ V/m})^2 + (-32.0\text{ V/m})^2}$$
$$= 78.4\text{ V/m} = 78.4\text{ N/C}.$$

LEARN If the electric potential increases along some direction, say x, with $\partial V/\partial x > 0$, then there is a corresponding non-vanishing component of $\vec{E}$ in the opposite direction ($-E_x \neq 0$).

41. **THINK** Ampere is the SI unit for current. An ampere is one coulomb per second.

EXPRESS To calculate the total charge through the circuit, we note that $1\text{ A} = 1\text{ C/s}$ and $1\text{ h} = 3600\text{ s}$.

ANALYZE (a) Thus,

$$q = 70\text{A}\cdot\text{h} = \left(70\frac{\text{C}\cdot\text{h}}{\text{s}}\right)\left(3600\frac{\text{s}}{\text{h}}\right) = 2.52\times10^{5}\text{ C} \approx 2.5\times10^{5}\text{ C}.$$

(b) The change in potential energy is $\Delta U = q\,\Delta V = (2.52\times10^{5}\text{ C})(25\text{ V}) = 6.3\times10^{6}\text{ J}$.

LEARN Potential difference is the change of potential energy per unit charge. Unlike electric field, potential difference is a scalar quantity.

47. Let the distance in question be r. The initial kinetic energy of the electron is $K_i = \frac{1}{2} m_e v_i^2$, where v_i = 3.2 × 10^5 m/s. As the speed doubles, K becomes $4K_i$. Thus

$$\Delta U = \frac{-e^2}{4\pi\varepsilon_0 r} = -\Delta K = -(4K_i - K_i) = -3K_i = -\frac{3}{2} m_e v_i^2 ,$$

or

$$r = \frac{2e^2}{3(4\pi\varepsilon_0) m_e v_i^2} = \frac{2\left(1.6\times10^{-19}\,\text{C}\right)^2\left(8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)}{3\left(9.11\times10^{-31}\text{kg}\right)\left(1.6\times10^5\ \text{m/s}\right)^2} = 6.6\times10^{-9}\,\text{m}.$$