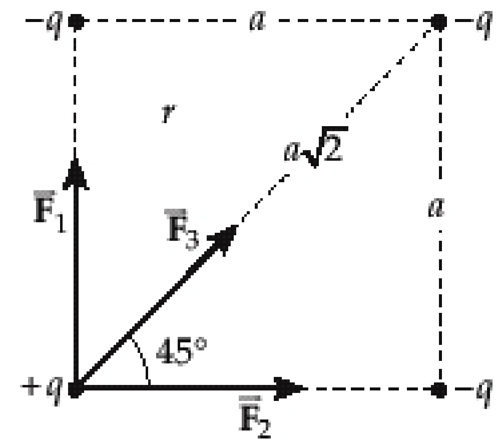
15.4 The attractive forces exerted on the positive charge by the negative charges are shown in the sketch and have magnitudes



$$F_1 = F_2 = \frac{k_e q^2}{a^2} \quad \text{and} \quad F_3 = \frac{k_e q^2}{\left(a\sqrt{2}\right)^2} = \frac{k_e q^2}{2a^2}$$

$$\Sigma F_x = F_2 + F_3 \cos 45° = \frac{k_e q^2}{a^2} + \frac{k_e q^2}{2a^2}(0.707) = 1.35\left(\frac{k_e q^2}{a^2}\right)$$

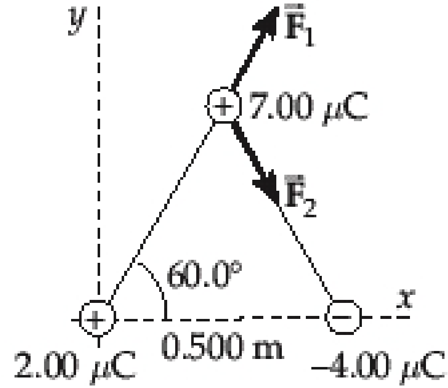
and $$\Sigma F_y = F_1 + F_3 \sin 45° = \frac{k_e q^2}{a^2} + \frac{k_e q^2}{2a^2}(0.707) = 1.35\left(\frac{k_e q^2}{a^2}\right)$$

$$F_R = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2} = 1.91\frac{k_e q^2}{a^2} \text{ and } \theta = \tan^{-1}\left(\frac{\Sigma F_y}{\Sigma F_x}\right) = \tan^{-1}(1) = 45°$$

so $$\boxed{\vec{\mathbf{F}}_R = 1.91\left(\frac{k_e q^2}{a^2}\right) \text{ along the diagonal toward the negative charge}}$$

15.5 (a) $$F = \frac{k_e (2e)^2}{r^2} = \left(8.99 \times 10^9 \frac{\text{N}\cdot\text{m}^2}{C^2}\right)\frac{\left[4\left(1.60 \times 10^{-19}\right)^2\right]}{\left(5.00 \times 10^{-15}\text{ m}\right)^2} = \boxed{36.8\text{ N}}$$

15.13 The forces on the 7.00 μC charge are shown at the right.



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

$$= 0.503\ \text{N}$$

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

$$= 1.01\ \text{N}$$

Thus, $\Sigma F_x = \left(F_1 + F_2\right)\cos 60.0° = 0.755\ \text{N}$

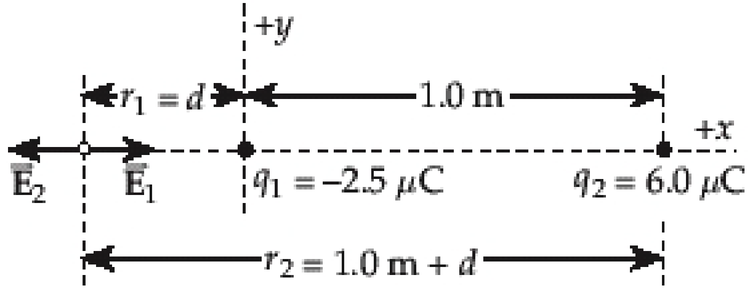
and $\Sigma F_y = \left(F_1 - F_2\right)\sin 60.0° = -0.436\ \text{N}$

The resultant force on the 7.00 μC charge is

$$F_R = \sqrt{\left(\Sigma F_x\right)^2 + \left(\Sigma F_y\right)^2} = 0.872\ \text{N} \ \text{ at } \ \theta = \tan^{-1}\left(\frac{\Sigma F_y}{\Sigma F_x}\right) = -30.0°$$

or $\vec{F}_R =$ $\boxed{0.872\ \text{N} \quad \text{at } 30.0° \text{ below the } +x \text{ axis}}$

15.27 If the resultant field is zero, the contributions from the two charges must be in opposite directions and also have equal magnitudes. Choose the line connecting the charges as the x-axis, with the origin at the $-2.5\ \mu C$ charge. Then, the two contributions will have opposite directions only in the regions $x < 0$ and $x > 1.0\ \text{m}$. For the magnitudes to be equal, the point must be nearer the smaller charge. Thus, the point of zero resultant field is on the x-axis at $x < 0$.



Requiring equal magnitudes gives $\dfrac{k_e|q_1|}{r_1^2} = \dfrac{k_e|q_2|}{r_2^2}$ or $\dfrac{2.5\ \mu C}{d^2} = \dfrac{6.0\ \mu C}{(1.0\ \text{m} + d)^2}$

Thus, $(1.0\ \text{m} + d)\sqrt{\dfrac{2.5}{6.0}} = d$

Solving for d yields

$d = 1.8\ \text{m}$, or **1.8 m to the left of the $-2.5\ \mu C$ charge**

16.13 (a) Calling the 2.00 μC charge q_3,

$$V = \sum_i \frac{k_e q_i}{r_i} = k_e\left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{\sqrt{r_1^2 + r_2^2}}\right)$$

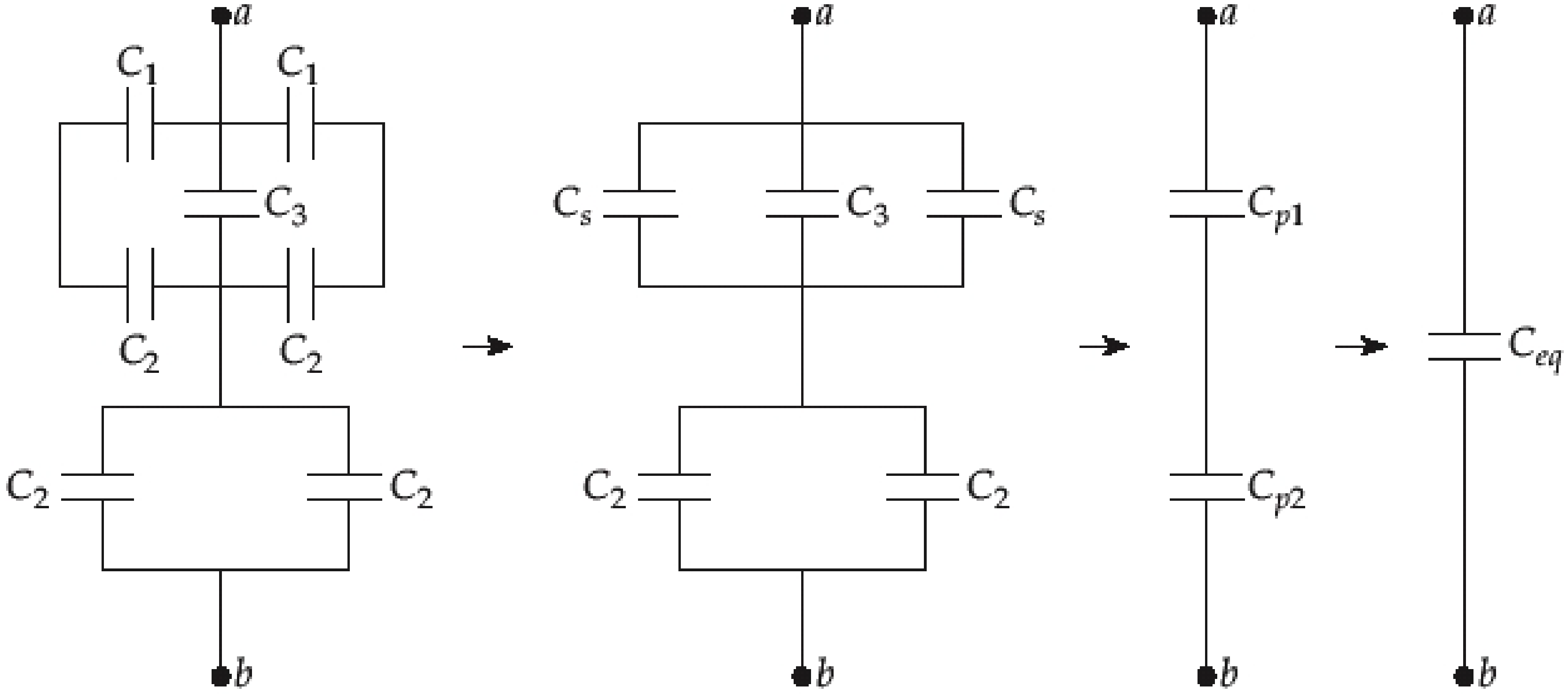
$$= \left(8.99\times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\left(\frac{8.00\times 10^{-6}\ \text{C}}{0.060\,0\ \text{m}} + \frac{4.00\times 10^{-6}\ \text{C}}{0.030\,0\ \text{m}} + \frac{2.00\times 10^{-6}\ \text{C}}{\sqrt{(0.060\,0)^2 + (0.030\,0)^2}\ \text{m}}\right)$$

$$V = \boxed{2.67\times 10^6\ \text{V}}$$

(b) Replacing 2.00×10^{-6} C by -2.00×10^{-6} C in part (a) yields

$$V = \boxed{2.13\times 10^6\ \text{V}}$$

16.40 The original circuit reduces to a single equivalent capacitor in the steps shown below.



$$C_s = \left(\frac{1}{C_1} + \frac{1}{C_2}\right)^{-1} = \left(\frac{1}{5.00\ \mu\text{F}} + \frac{1}{10.0\ \mu\text{F}}\right)^{-1} = 3.33\ \mu\text{F}$$

$$C_{p1} = C_s + C_3 + C_s = 2(3.33\ \mu\text{F}) + 2.00\ \mu\text{F} = 8.66\ \mu\text{F}$$

$$C_{p2} = C_2 + C_2 = 2(10.0\ \mu\text{F}) = 20.0\ \mu\text{F}$$

$$C_{eq} = \left(\frac{1}{C_{p1}} + \frac{1}{C_{p2}}\right)^{-1} = \left(\frac{1}{8.66\ \mu\text{F}} + \frac{1}{20.0\ \mu\text{F}}\right)^{-1} = \boxed{6.04\ \mu\text{F}}$$

16.43 The capacitance is

$$C = \frac{\epsilon_0 A}{d} = \frac{\left(8.85\times 10^{-12}\ \mathrm{C^2/N\cdot m^2}\right)\left(2.00\times 10^{-4}\ \mathrm{m^2}\right)}{5.00\times 10^{-3}\ \mathrm{m}} = 3.54\times 10^{-13}\ \mathrm{F}$$

and the stored energy is

$$W = \frac{1}{2}C(\Delta V)^2 = \frac{1}{2}\left(3.54\times 10^{-13}\ \mathrm{F}\right)(12.0\ \mathrm{V})^2 = \boxed{2.55\times 10^{-11}\ \mathrm{J}}$$

16.47 The initial capacitance (with air between the plates) is $C_i = Q/(\Delta V)_i$, and the final capacitance (with the dielectric inserted) is $C_f = Q/(\Delta V)_f$ where Q is the constant quantity of charge stored on the plates.

Thus, the dielectric constant is $\kappa = \dfrac{C_f}{C_i} = \dfrac{(\Delta V)_i}{(\Delta V)_f} = \dfrac{100 \text{ V}}{25 \text{ V}} = \boxed{4.0}$

17.4 $\Delta Q = I(\Delta t)$ and the number of electrons is

$$n = \frac{\Delta Q}{|e|} = \frac{I(\Delta t)}{|e|} = \frac{(60.0\times10^{-6}\ \text{C/s})(1.00\ \text{s})}{1.60\times10^{-19}\ \text{C}} = \boxed{3.75\times10^{14}\ \text{electrons}}$$

17.13 From $R = \dfrac{\rho L}{A}$, we obtain $A = \dfrac{\pi d^2}{4} = \dfrac{\rho L}{R}$, or

$$d = \sqrt{\frac{4\rho L}{\pi R}} = \sqrt{\frac{4\left(5.6\times10^{-8}\ \Omega\cdot\text{m}\right)\left(2.0\times10^{-2}\ \text{m}\right)}{\pi\left(0.050\ \Omega\right)}} = 1.7\times10^{-4}\ \text{m} = \boxed{0.17\ \text{mm}}$$

17.52 The resistance of the 4.0 cm length of wire between the feet is

$$R = \frac{\rho L}{A} = \frac{\left(1.7\times 10^{-8}\ \Omega\cdot\text{m}\right)\left(0.040\ \text{m}\right)}{\pi\left(0.011\ \text{m}\right)^2} = 1.79\times 10^{-6}\ \Omega,$$

so the potential difference is

$$\Delta V = IR = \left(50\ \text{A}\right)\left(1.79\times 10^{-6}\ \Omega\right) = 8.9\times 10^{-5}\ \text{V} = \boxed{89\ \mu\text{V}}$$

17.57 The current in the wire is $I = \dfrac{\Delta V}{R} = \dfrac{15.0\ \text{V}}{0.100\ \Omega} = 150\ \text{A}$

Then, from $v_d = I/nqA$, the density of free electrons is

$$n = \frac{I}{v_d e\left(\pi r^2\right)} = \frac{150\ \text{A}}{\left(3.17\times10^{-4}\ \text{m/s}\right)\left(1.60\times10^{-19}\ \text{C}\right)\pi\left(5.00\times10^{-3}\ \text{m}\right)^2}$$

or $$n = \boxed{3.77\times10^{28}/\text{m}^3}$$

18.8 (a) The rules for combining resistors in series and parallel are used to reduce the circuit to an equivalent resistor in the stages shown below. The result is $R_{eq} = \boxed{5.13\ \Omega}$.

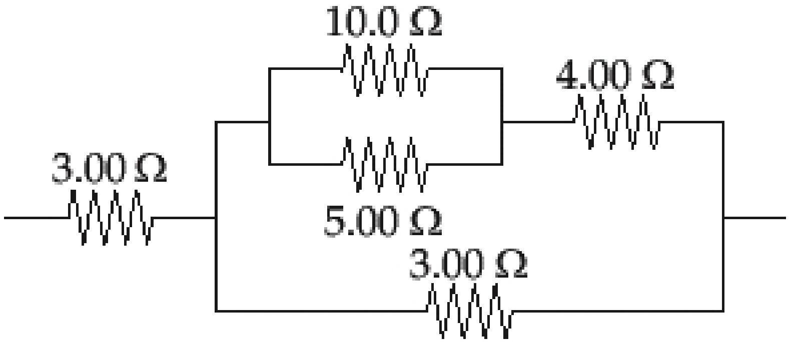


Figure 1

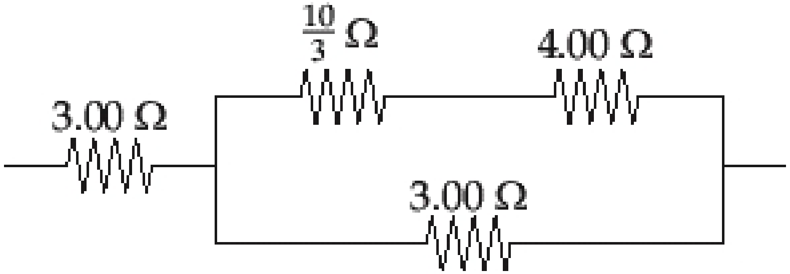


Figure 2

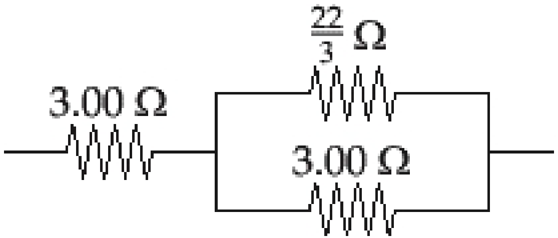


Figure 3

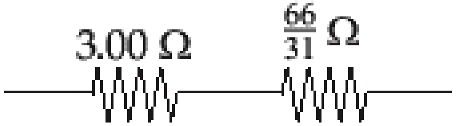


Figure 4

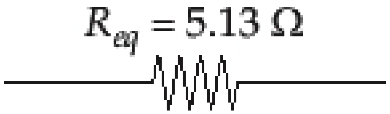
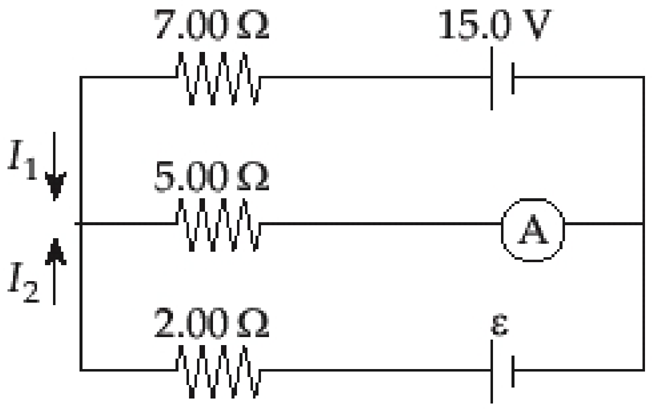


Figure 5

18.16 Going counterclockwise around the upper loop, applying Kirchhoff's loop rule, gives



$$+15.0\text{ V}-(7.00)I_1-(5.00)(2.00\text{ A})=0$$

or $$I_1=\frac{15.0\text{ V}-10.0\text{ V}}{7.00\ \Omega}=\boxed{0.714\text{ A}}$$

From Kirchhoff's junction rule, $I_1+I_2-2.00\text{ A}=0$

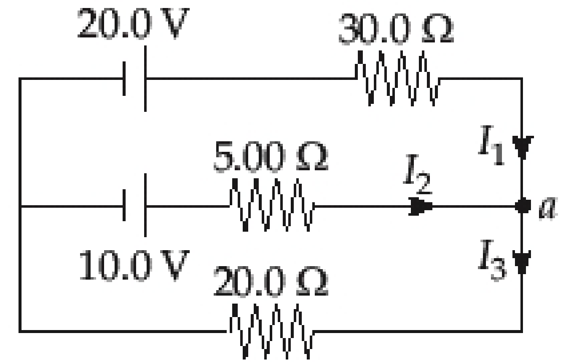
so $$I_2=2.00\text{ A}-I_1=2.00\text{ A}-0.714\text{ A}=\boxed{1.29\text{ A}}$$

Going around the lower loop in a clockwise direction gives

$$+\mathcal{E}-(2.00)I_2-(5.00)(2.00\text{ A})=0$$

or $$\mathcal{E}=(2.00\ \Omega)(1.29\text{ A})+(5.00\ \Omega)(2.00\text{ A})=\boxed{12.6\text{ V}}$$

18.27 Assume currents I_1, I_2, and I_3 in the directions shown. Then, using Kirchhoff's junction rule at junction *a* gives



$$I_3 = I_1 + I_2 \qquad (1)$$

Applying Kirchhoff's loop rule on the upper loop,

$$+20.0\text{ V} - (30.0)I_1 + (5.00)I_2 - 10.0\text{ V} = 0$$

or $\qquad 6I_1 - I_2 = 2.00\text{ A} \qquad (2)$

and for the lower loop, $+10.0\text{ V} - (5.00)I_2 - (20.0)I_3 = 0$

or $\qquad I_2 + 4I_3 = 2.00\text{ A} \qquad (3)$

Solving equations (1), (2), and (3) simultaneously yields

$$\boxed{I_1 = 0.353\text{ A},\ I_2 = 0.118\text{ A, and } I_3 = 0.471\text{ A}}$$