CHAPTER 19

1. When the bulbs are connected in series, the equivalent resistance is
   \[ R_{\text{series}} = R_1 = 4R_{\text{bulb}} = 4(140 \, \Omega) = 560 \, \Omega. \]

   When the bulbs are connected in parallel, we find the equivalent resistance from
   \[ \frac{1}{R_{\text{parallel}}} = (\frac{1}{R_1}) = 4\frac{1}{R_{\text{bulb}}} = 4\frac{1}{140 \, \Omega} \]
   which gives \( R_{\text{parallel}} = \frac{35}{\Omega} \).

2. (a) When the bulbs are connected in series, the equivalent resistance is
   \[ R_{\text{series}} = R_1 = 3R_1 + 3R_2 = 3(40 \, \Omega) + 3(80 \, \Omega) = 360 \, \Omega. \]

   (b) When the bulbs are connected in parallel, we find the equivalent resistance from
   \[ \frac{1}{R_{\text{parallel}}} = (\frac{1}{R_1}) = (\frac{3}{R_1}) + (\frac{3}{R_2}) = \frac{3}{40 \, \Omega} + \frac{3}{80 \, \Omega} \]
   which gives \( R_{\text{parallel}} = \frac{8.9}{\Omega} \).

3. If we use them as single resistors, we have
   \( R_1 = 30 \, \Omega; \quad R_2 = 50 \, \Omega \).

   When the bulbs are connected in series, the equivalent resistance is
   \[ R_{\text{series}} = R_1 + R_2 = 30 \, \Omega + 50 \, \Omega = 80 \, \Omega. \]

   When the bulbs are connected in parallel, we find the equivalent resistance from
   \[ \frac{1}{R_{\text{parallel}}} = (\frac{1}{R_1}) = (\frac{1}{R_1}) + (\frac{1}{R_2}) = \frac{1}{30 \, \Omega} + \frac{1}{50 \, \Omega} \]
   which gives \( R_{\text{parallel}} = 19 \, \Omega \).

4. Because resistance increases when resistors are connected in series, the maximum resistance is
   \[ R_{\text{series}} = R_1 + R_2 + R_3 = 500 \, \Omega + 900 \, \Omega + 1400 \, \Omega = 2800 \, \Omega = 2.80 \, k\Omega. \]

   Because resistance decreases when resistors are connected in parallel, we find the minimum resistance from
   \[ \frac{1}{R_{\text{parallel}}} = (\frac{1}{R_1}) + (\frac{1}{R_2}) + (\frac{1}{R_3}) = \frac{1}{500 \, \Omega} + \frac{1}{900 \, \Omega} + \frac{1}{1400 \, \Omega} \]
   which gives \( R_{\text{parallel}} = 261 \, \Omega \).

5. The voltage is the same across resistors in parallel, but is less across a resistor in a series connection. We connect three 1.0-\Omega resistors in series as shown in the diagram. Each resistor has the same current and the same voltage:
   \( V_i = \mathbb{V} = \mathbb{V}(6.0 \, \mathbb{V}) = 2.0 \, \mathbb{V}. \)

   Thus we can get a 4.0-\mathbb{V} output between a and c.
6. When the resistors are connected in series, as shown in A, we have
\[ R_A = R_1 = 3R = 3(240 \, \Omega) = 720 \, \Omega. \]
When the resistors are connected in parallel, as shown in B, we have
\[ \frac{1}{R_B} = \frac{1}{R_1} = \frac{3}{240 \, \Omega} = 80 \, \Omega. \]
In circuit C, we find the equivalent resistance of the two resistors in parallel:
\[ \frac{1}{R_1} = \frac{1}{240 \, \Omega} \]
This resistance is in series with the third resistor, so we have
\[ R_C = R_1 + R = 120 \, \Omega + 240 \, \Omega = 360 \, \Omega. \]
In circuit D, we find the equivalent resistance of the two resistors in series:
\[ R_2 = 2.8 \, k\Omega + 2.8 \, k\Omega = 5.6 \, k\Omega. \]
This resistance is in parallel with the third resistor, so we have
\[ \frac{1}{R_D} = \frac{1}{240 \, \Omega} + \frac{1}{240 \, \Omega} = \frac{1}{480 \, \Omega} + \frac{1}{240 \, \Omega} = 160 \, \Omega. \]

7. We can reduce the circuit to a single loop by successively combining parallel and series combinations.
We combine \( R_1 \) and \( R_2 \), which are in series:
\[ R_3 = R_1 + R_2 = 2.8 \, k\Omega + 2.8 \, k\Omega = 5.6 \, k\Omega. \]
We combine \( R_3 \) and \( R_7 \), which are in parallel:
\[ \frac{1}{R_8} = \frac{1}{R_3} + \frac{1}{R_7} = \frac{1}{2.8 \, k\Omega} + \frac{1}{5.6 \, k\Omega} \]
which gives \( R_8 = 1.87 \, k\Omega \).
We combine \( R_4 \) and \( R_8 \), which are in series:
\[ R_9 = R_4 + R_8 = 2.8 \, k\Omega + 1.87 \, k\Omega = 4.67 \, k\Omega. \]
We combine \( R_5 \) and \( R_9 \), which are in parallel:
\[ \frac{1}{R_{10}} = \frac{1}{R_5} + \frac{1}{R_9} = \frac{1}{2.8 \, k\Omega} + \frac{1}{4.67 \, k\Omega} \]
which gives \( R_{10} = 1.75 \, k\Omega \).
We combine \( R_{10} \) and \( R_6 \), which are in series:
\[ R_{eq} = R_{10} + R_6 = 1.75 \, k\Omega + 2.8 \, k\Omega = 4.6 \, k\Omega. \]
8. (a) In series the current must be the same for all bulbs. If all bulbs have the same resistance, they will have the same voltage:

$$V_{\text{bulb}} = \frac{V}{N} = \frac{110\, \text{V}}{8} = 13.8\, \text{V}.$$ 

(b) We find the resistance of each bulb from

$$R_{\text{bulb}} = \frac{V_{\text{bulb}}}{I} = \frac{13.8\, \text{V}}{0.40\, \text{A}} = 34\, \Omega.$$ 

The power dissipated in each bulb is

$$P_{\text{bulb}} = IV_{\text{bulb}} = (0.40\, \text{A})(13.8\, \text{V}) = 5.5\, \text{W}.$$ 

9. For the parallel combination, the total current from the source is

$$I = N I_{\text{bulb}} = 8(0.240\, \text{A}) = 1.92\, \text{A}.$$ 

The voltage across the leads is

$$V_{\text{leads}} = IR_{\text{leads}} = (1.92\, \text{A})(1.5\, \Omega) = 2.9\, \text{V}.$$ 

The voltage across each of the bulbs is

$$V_{\text{bulb}} = V - V_{\text{leads}} = 110\, \text{V} - 2.88\, \text{V} = 107\, \text{V}.$$ 

We find the resistance of a bulb from

$$R_{\text{bulb}} = \frac{V_{\text{bulb}}}{I_{\text{bulb}}} = \frac{107\, \text{V}}{0.240\, \text{A}} = 450\, \Omega.$$ 

The power dissipated in the leads is

$$IV_{\text{leads}}$$ and the total power used is $$IV$$, so the fraction wasted is

$$\frac{IV_{\text{leads}}}{IV} = \frac{V_{\text{leads}}}{V} = \frac{2.9\, \text{V}}{110\, \text{V}} = 0.026 = 2.6\%.$$ 

10. In series the current must be the same for all bulbs. If all bulbs have the same resistance, they will have the same voltage:

$$V_{\text{bulb}} = \frac{V}{N} = \frac{110\, \text{V}}{8} = 13.8\, \text{V}.$$ 

We find the resistance of each bulb from

$$P_{\text{bulb}} = \frac{V_{\text{bulb}}^2}{R_{\text{bulb}}};$$

$$7.0\, \text{W} = \frac{(13.8\, \text{V})^2}{R_{\text{bulb}}},$$ which gives $$R_{\text{bulb}} = 27\, \Omega.$$ 

11. Fortunately the required resistance is less. We can reduce the resistance by adding a parallel resistor, which does not require breaking the circuit. We find the necessary resistance from

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2};$$

$$\frac{1}{320\, \Omega} = \left[\frac{1}{480\, \Omega}\right] + \frac{1}{R_2},$$ which gives $$R_2 = 960\, \Omega$$ in parallel.

12. The equivalent resistance of the two resistors connected in series is

$$R_s = R_1 + R_2.$$ 

We find the equivalent resistance of the two resistors connected in parallel from

$$\frac{1}{R_p} = \left(\frac{1}{R_1}\right) + \left(\frac{1}{R_2}\right),$$ or $$R_p = \frac{R_1 R_2}{R_1 + R_2}.$$ 

The power dissipated in a resistor is $$P = \frac{V^2}{R},$$ so the ratio of the two powers is

$$\frac{P_p}{P_s} = \frac{R_s}{R_p} = \frac{R_1 + R_2}{\frac{R_1 R_2}{R_1 + R_2}} = 4.$$ 

When we expand the square, we get

$$R_1^2 + 2R_1R_2 + R_2^2 = 4R_1R_2,$$ or $$R_1^2 - 2R_1R_2 + R_2^2 = (R_1 - R_2)^2 = 0,$$ which gives $$R_2 = R_1 = 220\, \Omega.$$
13. With the two bulbs connected in parallel, there will be 110 V across each bulb, so the total power will be 75 W + 40 W = 115 W. We find the net resistance of the bulbs from
\[ P = \frac{V^2}{R}; \]
115 W = (110 V)^2 / R, which gives R = 105 Ω.

14. We can reduce the circuit to a single loop by successively combining parallel and series combinations.
We combine \( R_1 \) and \( R_2 \), which are in series:
\[ R_7 = R_1 + R_2 = 2.20 \, \text{kΩ} + 2.20 \, \text{kΩ} = 4.40 \, \text{kΩ}. \]
We combine \( R_3 \) and \( R_7 \), which are in parallel:
\[ \frac{1}{R_8} = \left( \frac{1}{R_3} \right) + \left( \frac{1}{R_7} \right) = \left[ \frac{1}{2.20 \, \text{kΩ}} \right] + \left[ \frac{1}{4.40 \, \text{kΩ}} \right], \]
which gives \( R_8 = 1.47 \, \text{kΩ} \).
We combine \( R_4 \) and \( R_8 \), which are in series:
\[ R_9 = R_4 + R_8 = 2.20 \, \text{kΩ} + 1.47 \, \text{kΩ} = 3.67 \, \text{kΩ}. \]
We combine \( R_{10} \) and \( R_6 \), which are in parallel:
\[ \frac{1}{R_{10}} = \left( \frac{1}{R_5} \right) + \left( \frac{1}{R_6} \right) = \left[ \frac{1}{2.20 \, \text{kΩ}} \right] + \left[ \frac{1}{3.67 \, \text{kΩ}} \right], \]
which gives \( R_{10} = 1.38 \, \text{kΩ} \).
We combine \( R_{10} \) and \( R_6 \), which are in series:
\[ R_{eq} = R_{10} + R_6 = 1.38 \, \text{kΩ} + 2.20 \, \text{kΩ} = 3.58 \, \text{kΩ}. \]
The current in the single loop is the current through \( R_6 \):
\[ I_6 = I = \frac{\Delta V}{R_{eq}} = \frac{12 \, \text{V}}{3.58 \, \text{kΩ}} = 3.36 \, \text{mA}. \]
For \( V_{AC} \) we have
\[ V_{AC} = IR_{10} = (3.36 \, \text{mA})(1.38 \, \text{kΩ}) = 4.63 \, \text{V}. \]
This allows us to find \( I_5 \) and \( I_4 \):
\[ I_5 = \frac{V_{AC}}{R_5} = \frac{(4.63 \, \text{V})}{(2.20 \, \text{kΩ})} = 2.11 \, \text{mA}; \]
\[ I_4 = \frac{V_{AC}}{R_9} = \frac{(4.63 \, \text{V})}{(3.67 \, \text{kΩ})} = 1.26 \, \text{mA}. \]
For \( V_{AB} \) we have
\[ V_{AB} = IR_6 = (1.26 \, \text{mA})(1.47 \, \text{kΩ}) = 1.85 \, \text{V}. \]
This allows us to find \( I_3 \), \( I_2 \), and \( I_1 \):
\[ I_3 = \frac{V_{AB}}{R_3} = \frac{(1.85 \, \text{V})}{(2.20 \, \text{kΩ})} = 0.84 \, \text{mA}; \]
\[ I_1 = I_2 = \frac{V_{AB}}{R_7} = \frac{(1.85 \, \text{V})}{(4.40 \, \text{kΩ})} = 0.42 \, \text{mA}. \]
From above, we have \( V_{AB} = 1.85 \, \text{V} \).
15. (a) When the switch is closed the addition of $R_2$ to the parallel set will decrease the equivalent resistance, so the current from the battery will increase. This causes an increase in the voltage across $R_1$, and a corresponding decrease across $R_3$ and $R_4$. The voltage across $R_2$ increases from zero.

Thus we have
$V_1$ and $V_2$ increase; $V_3$ and $V_4$ decrease.

(b) The current through $R_1$ has increased. This current is now split into three, so currents through $R_3$ and $R_4$ decrease. Thus we have
$I_1 = I$ and $I_2$ increase; $I_3$ and $I_4$ decrease.

(c) The current through the battery has increased, so the power output of the battery increases.

(d) Before the switch is closed, $I_2 = 0$. We find the resistance for $R_3$ and $R_4$ in parallel from
$$1/R_A = (1/ R_1) + 2/ R_3 = 2/ (100 \, \Omega)$$
which gives $R_A = 50 \, \Omega$. For the single loop, we have
$$I = I_1 = V / (R_1 + R_A) = (45.0 \, V) / (100 \, \Omega + 50 \, \Omega) = \frac{3}{2} \, 0.300 \, A.$$ 
This current will split evenly through $R_3$ and $R_4$:
$$I_3 = I_4 = \frac{1}{2} I (0.300 \, A) = 0.150 \, A.$$ 

After the switch is closed, we find the resistance for $R_2$, $R_3$, and $R_4$ in parallel from
$$1/R_B = (1/ R_1) + 3/ R_3 = 3/ (100 \, \Omega),$$
which gives $R_B = 33.3 \, \Omega$. For the single loop, we have
$$I = I_1 = V / (R_1 + R_B) = (45.0 \, V) / (100 \, \Omega + 33.3 \, \Omega) = \frac{3}{2} \, 0.338 \, A.$$ 
This current will split evenly through $R_2$, $R_3$, and $R_4$:
$$I_2 = I_3 = I_4 = \frac{1}{3} I (0.338 \, A) = 0.113 \, A.$$
16. (a) When the switch is opened, the removal of a resistor from the parallel set will increase the equivalent resistance, so the current from the battery will decrease. This causes a decrease in the voltage across $R_1$, and a corresponding increase across $R_2$. The voltage across $R_3$ decreases to zero. Thus we have

\[ V_1 \text{ and } V_3 \text{ decrease; } V_2 \text{ increases.} \]

(b) The current through $R_1$ has decreased. The current through $R_2$ has increased. The current through $R_3$ has decreased to zero. Thus we have

\[ I_1 = \text{I and } I_3 \text{ decrease; } I_2 \text{ increases.} \]

(c) Because the current through the battery decreases, the $Ir$ term decreases, so the terminal voltage of the battery will increase.

(d) When the switch is closed, we find the resistance for $R_2$ and $R_3$ in parallel from

\[ \frac{1}{R_A} = \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{2.8 \, \text{k} \Omega} + \frac{1}{2.1 \, \text{k} \Omega}, \]

which gives $R_A = 2.75 \, \Omega$.

For the single loop, we have

\[ I = \frac{V}{R_1 + R_A + r} = \frac{18.0 \, \text{V}}{(5.50 \, \Omega + 2.75 \, \Omega + 0.50 \, \Omega)} = 2.06 \, \text{A}. \]

For the terminal voltage of the battery, we have

\[ V_{ab} = \dot{a} - l \cdot r = 18.0 \, \text{V} - (2.06 \, \text{A})(0.50 \, \Omega) = 17.0 \, \text{V}. \]

When the switch is opened, for the single loop, we have

\[ I' = \frac{V}{R_1 + R_2 + r} = \frac{18.0 \, \text{V}}{(5.50 \, \Omega + 5.50 \, \Omega + 0.50 \, \Omega)} = 1.57 \, \text{A}. \]

For the terminal voltage of the battery, we have

\[ V_{ab}' = \dot{a} - l' \cdot r = 18.0 \, \text{V} - (1.57 \, \text{A})(0.50 \, \Omega) = 17.2 \, \text{V}. \]

17. We find the resistance for $R_1$ and $R_2$ in parallel from

\[ \frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{(2.8 \, \text{k} \Omega)} + \frac{1}{(2.1 \, \text{k} \Omega)}, \]

which gives $R_p = 1.2 \, \text{k} \Omega$.

Because the same current passes through $R_p$ and $R_3$, the higher resistor will have the higher power dissipation, so the limiting resistor is $R_3$, which will have a power dissipation of $0.50 \, \text{W}$. We find the current from $P_{3\text{max}} = I_{3\text{max}}^2 R_3$:

\[ 0.50 \, \text{W} = I_{3\text{max}}^2 (1.8 \times 10^3 \, \Omega), \]

which gives $I_{3\text{max}} = 0.0167 \, \text{A}$.

The maximum voltage for the network is

\[ V_{\text{max}} = I_{3\text{max}} (R_p + R_3) = (0.0167 \, \text{A})(1.2 \times 10^3 \, \Omega + 1.8 \times 10^3 \, \Omega) = 50 \, \text{V}. \]

18. (a) For the current in the single loop, we have

\[ I_1 = \frac{V}{R_1 + r} = \frac{8.50 \, \text{V}}{(8.1 \, \text{O} \Omega + 0.900 \, \Omega)} = 0.104 \, \text{A}. \]

For the terminal voltage of the battery, we have

\[ V_a = \dot{a} - l_1r = 8.50 \, \text{V} - (0.104 \, \text{A})(0.900 \, \Omega) = 8.41 \, \text{V}. \]

(b) For the current in the single loop, we have

\[ I_2 = \frac{V}{R_2 + r} = \frac{8.50 \, \text{V}}{(8.10 \, \Omega + 0.900 \, \Omega)} = 0.0105 \, \text{A}. \]

For the terminal voltage of the battery, we have

\[ V_b = \dot{a} - l_2r = 8.50 \, \text{V} - (0.0105 \, \text{A})(0.900 \, \Omega) = 8.49 \, \text{V}. \]
19. The voltage across the bulb is the terminal voltage of the four cells:
\[ V = IR_{\text{bulb}} = 4(\text{â} - \text{I}r); \]
\[ (0.62 \text{ A})(12 \Omega) = 4[2.0 \text{ V} - (0.62 \text{ A})r], \]
which gives \( r = 0.23 \Omega \).

20. We find the resistance of a bulb from the nominal rating:
\[ R_{\text{bulb}} = \frac{V_{\text{nominal}}^2}{P_{\text{nominal}}}; \]
We find the current through each bulb when connected to the battery from:
\[ I_{\text{bulb}} = \frac{V}{R_{\text{bulb}}} = \frac{11.8 \text{ V}}{48 \Omega} = 0.246 \text{ A}. \]
Because the bulbs are in parallel, the current through the battery is
\[ I = 2I_{\text{bulb}} = 2(0.246 \text{ A}) = 0.492 \text{ A}. \]
We find the internal resistance from
\[ V = \text{â} - Ir; \]
\[ 11.8 \text{ V} = [12.0 \text{ V} - (0.492 \text{ A})r], \]
which gives \( r = 0.4 \Omega \).

21. If we can ignore the resistance of the ammeter, for the single loop we have
\[ I = \frac{\Delta}{r}; \]
\[ 25 \text{ A} = (1.5 \text{ V})/ r, \]
which gives \( r = 0.060 \Omega \).

22. We find the internal resistance from
\[ V = \text{â} - Ir; \]
\[ 8.8 \text{ V} = [12.0 \text{ V} - (60 \text{ A})r], \]
which gives \( r = 0.053 \Omega \).
Because the terminal voltage is the voltage across the starter, we have
\[ V = Ir; \]
\[ 8.8 \text{ V} = (60 \text{ A})R, \]
which gives \( R = 0.15 \Omega \).

23. From the results of Example 19–7, we know that the current through the 6.0-\,\Omega resistor, \( I_6 \), is 0.48 A.
We find \( V_{bc} \) from
\[ V_{bc} = I_6 R_{2.7} = (0.48 \text{ mA})(2.7 \Omega) = 1.30 \text{ V}. \]
This allows us to find \( I_8 \):
\[ I_8 = \frac{V_{bc}}{R_8} = \frac{1.30 \text{ V}}{(8.0 \text{ k}\Omega)} = 0.16 \text{ A}. \]
24. For the current in the single loop, we have
\[ I = \frac{V}{R_1 + R_2 + r} \]
\[ = \frac{9.0 \text{ V}}{8.0 \Omega + 12.0 \Omega + 2.0 \Omega} = 0.41 \text{ A}. \]
For the terminal voltage of the battery, we have
\[ V_{ab} = V - (0.41 \text{ A})(2.0 \Omega) = 8.18 \text{ V}. \]
The current in a resistor goes from high to low potential.
For the voltage changes across the resistors, we have
\[ V_{bc} = -IR_2 = -0.41 \text{ A})(12.0 \Omega) = -4.91 \text{ V}; \]
\[ V_{ca} = -IR_1 = -0.41 \text{ A})(8.0 \Omega) = -3.27 \text{ V}. \]
For the sum of the voltage changes, we have
\[ V_{ab} + V_{bc} + V_{ca} = 8.18 \text{ V} - 4.91 \text{ V} - 3.27 \text{ V} = 0. \]

25. For the loop, we start at point a:
\[-IR_a - IR_b + \alpha_1 - IR_1 = 0; \]
\[-I(6.6 \Omega) - 12 \text{ V} - I(2 \Omega) + 18 \text{ V} - I(1 \Omega) = 0, \]
which gives \( I = 0.625 \text{ A}. \)
The top battery is discharging, so we have
\[ V_1 = \alpha_1 - IR_1 = 18 \text{ V} - 0.625 \text{ A})(1 \Omega) = 17.4 \text{ V}. \]
The bottom battery is charging, so we have
\[ V_2 = \alpha_2 + IR_2 = 12 \text{ V} + 0.625 \text{ A})(2 \Omega) = 13.3 \text{ V}. \]

26. To find the potential difference between points a and d, we can use any path. The simplest one is through the top resistor \( R_1 \). From the results of Example 19-8, we know that the current \( I_1 \) is \(-0.87 \text{ A}. \)
We find \( V_{ad} \) from
\[ V_{ad} = V_a - V_d = I_1 R_1 = (-0.87 \text{ A})(30 \Omega) = -26 \text{ V}. \]

27. From the results of Example 19-8, we know that the currents are
\( I_1 = -0.87 \text{ A}, I_2 = 2.6 \text{ A}, I_3 = 1.7 \text{ A}. \)
On the circuit diagram, both batteries are discharging, so we have
\[ V_{ab} = \alpha_2 - I_2 f_2 = 45 \text{ V} - (1.7 \text{ A})(1 \Omega) = 43 \text{ V}. \]
\[ V_{eg} = \alpha_1 - I_1 f_1 = 80 \text{ V} - (2.6 \text{ A})(1 \Omega) = 77 \text{ V}. \]
28. For the conservation of current at point c, we have
\[ I_{\text{in}} = I_{\text{out}}; \]
\[ I_1 = I_2 + I_3. \]
For the two loops indicated on the diagram, we have
loop 1: \[ V_1 - I_2 R_2 - I_1 R_1 = 0; \]
\[ +9.0 \text{ V} - I_2 (15 \Omega) - I_1 (22 \Omega) = 0; \]
loop 2: \[ V_3 + I_2 R_2 = 0; \]
\[ +6.0 \text{ V} + I_2 (15 \Omega) = 0. \]
When we solve these equations, we get
\[ I_1 = 0.68 \text{ A}, \ I_2 = -0.40 \text{ A}, \ I_3 = 1.08 \text{ A}. \]
Note that \( I_2 \) is opposite to the direction shown.

29. For the conservation of current at point c, we have
\[ I_{\text{in}} = I_{\text{out}}; \]
\[ I_1 = I_2 + I_3. \]
When we add the internal resistance terms for the two
loops indicated on the diagram, we have
loop 1: \[ V_1 - I_2 R_2 - I_1 R_1 - I_3 r_1 = 0; \]
\[ +9.0 \text{ V} - I_2 (15 \Omega) - I_1 (22 \Omega) - I_3 (1.2 \Omega) = 0; \]
loop 2: \[ V_3 + I_2 R_2 + I_3 r_3 = 0; \]
\[ +6.0 \text{ V} + I_2 (15 \Omega) + I_3 (1.2 \Omega) = 0. \]
When we solve these equations, we get
\[ I_1 = 0.60 \text{ A}, \ I_2 = -0.33 \text{ A}, \ I_3 = 0.93 \text{ A}. \]

30. For the conservation of current at point b, we have
\[ I_{\text{in}} = I_{\text{out}}; \]
\[ I_1 + I_3 = I_2. \]
For the two loops indicated on the diagram, we have
loop 1: \[ \hat{A}_2 - I_1 R_1 - I_2 R_2 = 0; \]
\[ +9.0 \text{ V} - I_1 (15 \Omega) - I_2 (20 \Omega) = 0; \]
loop 2: \[ \hat{A}_2 + I_2 R_2 + I_3 R_3 = 0; \]
\[ -12.0 \text{ V} + I_2 (20 \Omega) + I_3 (30 \Omega) = 0. \]
When we solve these equations, we get
\[ I_1 = 0.156 \text{ A \ right}, \ I_2 = 0.333 \text{ A \ left}, \ I_3 = 0.177 \text{ A \ up}. \]
We have carried an extra decimal place to show the agreement with the junction equation.
31. For the conservation of current at point b, we have
   \[ I_{in} = I_{out}; \]
   \[ I_1 + I_3 = I_2. \]
   When we add the internal resistance terms for the two loops indicated on the diagram, we have
   \[ \begin{align*}
   \text{loop 1:} & \quad \hat{I}_1 - I_1R_1 - I_2R_2 = 0; \\
   & \quad + 9.0 \text{ V} - I_2(1.0 \Omega) - I_2(15 \Omega) - I_2(20 \Omega) = 0; \\
   \text{loop 2:} & \quad - \hat{I}_2 + I_2R_2 + I_2R_3 = 0; \\
   & \quad - 12.0 \text{ V} + I_3(1.0 \Omega) + I_2(20 \Omega) + I_2(30 \Omega) = 0.
   \end{align*} \]
   When we solve these equations, we get
   \[ I_1 = 0.15 \text{ A} \text{ right}, \quad I_2 = 0.33 \text{ A} \text{ left}, \quad I_3 = 0.18 \text{ A} \text{ up}. \]

32. When we include the current through the battery, we have six unknowns. For the conservation of current, we have
   \[ \begin{align*}
   \text{junction a:} & \quad I_4 = I_1 + I_2; \\
   \text{junction b:} & \quad I_3 = I_1 + I_5; \\
   \text{junction d:} & \quad I_2 + I_5 = I_4.
   \end{align*} \]
   For the three loops indicated on the diagram, we have
   \[ \begin{align*}
   \text{loop 1:} & \quad - I_1R_1 - I_3R_3 + I_1R_2 = 0; \\
   & \quad - I_2R_2 - I_3R_3 + I_2R_3 = 0; \\
   \text{loop 2:} & \quad - 1.0 \text{ V} + I_3(15 \Omega) + I_3(10 \Omega) = 0; \\
   & \quad + 6.0 \text{ V} - I_2(15 \Omega) - I_2(10 \Omega) = 0; \\
   \text{loop 3:} & \quad + \hat{I}_3 - I_2R_2 - I_3R_3 = 0; \\
   & \quad + 6.0 \text{ V} - I_3(15 \Omega) - I_3(10 \Omega) = 0.
   \end{align*} \]
   When we solve these six equations, we get
   \[ I_1 = 0.274 \text{ A}, \quad I_2 = 0.222 \text{ A}, \quad I_3 = 0.266 \text{ A}, \quad I_4 = 0.229 \text{ A}, \quad I_5 = 0.007 \text{ A}, \quad I = 0.496 \text{ A}. \]
   We have carried an extra decimal place to show the agreement with the junction equations.

33. When the 25-Ω resistor is shorted, points a and d become the same point and we lose \[ I_2. \]
    For the conservation of current, we have
    \[ \begin{align*}
    \text{junction a:} & \quad I_4 = I_1 + I_3; \\
    \text{junction b:} & \quad I_3 = I_1 + I_5; \\
    \end{align*} \]
    For the three loops indicated on the diagram, we have
    \[ \begin{align*}
    \text{loop 1:} & \quad - I_1R_1 - I_3R_3 = 0; \\
    & \quad - I_2R_2 - I_3R_3 = 0; \\
    \text{loop 2:} & \quad - 1.0 \text{ V} + I_3(15 \Omega) + I_3(10 \Omega) = 0; \\
    & \quad + 6.0 \text{ V} - I_2(15 \Omega) - I_2(10 \Omega) = 0; \\
    \text{loop 3:} & \quad + \hat{I}_3 - I_3R_3 = 0; \\
    & \quad + 6.0 \text{ V} - I_3(15 \Omega) - I_3(10 \Omega) = 0.
    \end{align*} \]
    When we solve these six equations, we get
    \[ I_1 = 0.23 \text{ A}, \quad I_3 = 0.69 \text{ A}, \quad I_4 = 3.00 \text{ A}, \quad I_5 = -0.46 \text{ A}, \quad I = 3.69 \text{ A}. \]
    Thus the current through the 10-Ω resistor is \[ 0.46 \text{ A} \text{ up}. \]
34. For the conservation of current at point a, we have
   \[ I_2 + I_3 = I_1. \]
   For the two loops indicated on the diagram, we have
   loop 1: \[ \dot{a}_2 - I_1 R_3 + \dot{a}_2 - I_2 R_2 + I_3 R_1 = 0; \]
   \[ +12.0 \text{ V} - I_1(1.0 \Omega) - I_2(8.0 \Omega) + 12.0 \text{ V} - \]
   \[ I_2(10 \Omega) - I_3(12 \Omega) = 0; \]
   loop 2: \[ \dot{a}_3 - I_3 R_5 + I_2 R_2 - \dot{a}_2 + I_2 R_2 - I_3 R_4 = 0; \]
   \[ +6.0 \text{ V} - I_3(10 \Omega) - I_3(18 \Omega) - 12.0 \text{ V} + \]
   \[ I_3(10 \Omega) - I_3(15 \Omega) = 0. \]
   When we solve these equations, we get
   \[ I_1 = 0.77 \text{ A}, I_2 = 0.71 \text{ A}, I_3 = 0.055 \text{ A}. \]
   For the terminal voltage of the 6.0-V battery, we have
   \[ V_{ab} = \dot{a}_3 - I_3 R_5 = 6.0 \text{ V} - (0.055 \text{ A})(10 \Omega) = 5.95 \text{ V}. \]

35. The upper loop equation becomes
   loop 1: \[ \dot{a}_3 - I_3 R_5 + \dot{a}_3 - I_2 R_2 - I_3 R_1 = 0; \]
   \[ +12.0 \text{ V} - I_3(10 \Omega) - I_3(8.0 \Omega) + 12.0 \text{ V} - I_3(10 \Omega) - I_3(12 \Omega) = 0. \]
   The other equations are the same:
   \[ I_2 + I_3 = I_1. \]
   loop 2: \[ \dot{a}_3 - I_3 R_5 + I_2 R_2 - \dot{a}_2 + I_2 R_2 - I_3 R_4 = 0; \]
   \[ +6.0 \text{ V} - I_3(10 \Omega) - I_3(18 \Omega) - 12.0 \text{ V} + I_3(10 \Omega) - I_3(15 \Omega) = 0. \]
   When we solve these equations, we get
   \[ I_1 = 1.30 \text{ A}, I_2 = 1.12 \text{ A}, I_3 = 0.18 \text{ A}. \]

36. For the conservation of current at point b, we have
   \[ I_1 + I_2 = 1. \]
   For the two loops indicated on the diagram, we have
   loop 1: \[ \dot{a}_3 - I_1 R_3 - \dot{a}_1 = 0; \]
   \[ +2.0 \text{ V} - I_1(0.10 \Omega) - I_1(4.0 \Omega) = 0; \]
   loop 2: \[ \dot{a}_3 - I_2 R_2 - \dot{a}_2 = 0; \]
   \[ +3.0 \text{ V} - I_2(10 \Omega) - I_2(4.0 \Omega) = 0. \]
   When we solve these equations, we get
   \[ I_1 = 5.31 \text{ A}, I_2 = -4.69 \text{ A}, I_1 = 0.62 \text{ A}. \]
   For the voltage across R we have
   \[ V_{ab} = I R = (0.62 \text{ A})(4.0 \Omega) = 2.5 \text{ V}. \]
   Note that one battery is charging the other with a significant current.

37. We find the equivalent capacitance for a parallel connection from
   \[ C_{\text{parallel}} = \frac{1}{C_1} = 6(3.7 \mu\text{F}) = 22 \mu\text{F}. \]
   When the capacitors are connected in series, we find the equivalent capacitance from
   \[ 1/C_{\text{series}} = (1/C_1 + 1/C_2) = 6/3.7 \mu\text{F}, \]
   which gives \( C_{\text{series}} = 0.62 \mu\text{F}. \)

38. Fortunately the required capacitance is greater. We can increase the capacitance by adding a parallel
    capacitor, which does not require breaking the circuit. We find the necessary capacitor from
    \[ C = C_1 + C_2; \]
    \[ 16 \mu\text{F} = 5.0 \mu\text{F} + C_2, \]
    which gives \( C_2 = 11 \mu\text{F in parallel}. \)
39. We can decrease the capacitance by adding a series capacitor. We find the necessary capacitor from
\[
\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2};
\]
\[
\frac{1}{(3300 \text{ pF})} = \frac{1}{(4800 \text{ pF})} + \frac{1}{C_2},
\]
which gives \( C_2 = 10,560 \text{ pF} \).
Yes, it is necessary to break a connection to add a series component.

40. The capacitance increases with a parallel connection, so the maximum capacitance is
\[
C_{\text{max}} = C_1 + C_2 + C_3 = 2000 \text{ pF} + 7500 \text{ pF} + 0.0100 \mu \text{F} = 0.0020 \mu \text{F} + 0.0075 \mu \text{F} + 0.0100 \mu \text{F} = 0.0195 \mu \text{F}.
\]
The capacitance decreases with a series connection, so we find the minimum capacitance from
\[
\frac{1}{C_{\text{min}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{(2000 \text{ pF})} + \frac{1}{(7500 \text{ pF})} + \frac{1}{(0.0100 \mu \text{F})}
\]
\[
= \frac{1}{(2.0 \text{ nF})} + \frac{1}{(7.5 \text{ nF})} + \frac{1}{(10.0 \text{ nF})},
\]
which gives \( C_{\text{min}} = 1.4 \text{ nF} \).

41. The energy stored in a capacitor is
\[
U = \frac{1}{2} CV^2.
\]
To increase the energy we must increase the capacitance, which means adding a parallel capacitor. Because the potential is constant, to have three times the energy requires three times the capacitance:
\[
C = 3C_1 = C_1 + C_2,
\]
or
\[
C_2 = 2C_1 = 2(150 \text{ pF}) = 300 \text{ pF} \text{ in parallel}.
\]

42. (a) From the circuit, we see that \( C_2 \) and \( C_3 \) are in series and find their equivalent capacitance from
\[
\frac{1}{C_4} = \frac{1}{C_2} + \frac{1}{C_3},
\]
which gives \( C_4 = \frac{C_2 C_3}{C_2 + C_3} \).
From the new circuit, we see that \( C_1 \) and \( C_4 \) are in parallel, with an equivalent capacitance
\[
C_{\text{eq}} = C_1 + C_4 = C_1 + \frac{C_2 C_3}{C_2 + C_3}
\]
\[
= \frac{(C_1 C_2 + C_1 C_3 + C_2 C_3)}{(C_2 + C_3)}.
\]
(b) Because \( V \) is across \( C_1 \), we have
\[
Q_1 = C_1 V = (12.5 \mu \text{F})(45.0 \text{ V}) = 563 \mu \text{C}.
\]
Because \( C_2 \) and \( C_3 \) are in series, the charge on each is the charge on their equivalent capacitance:
\[
Q_2 = Q_3 = C_2 V = C_3 V = \frac{C_2 C_3}{C_2 + C_3} V
\]
\[
= \frac{(12.5 \mu \text{F})(6.25 \mu \text{F})}{(12.5 \mu \text{F} + 6.25 \mu \text{F})}(45.0 \text{ V}) = 188 \mu \text{C}.
\]

43. From Problem 42 we know that the equivalent capacitance is
\[
C_{\text{eq}} = \frac{C_1 C_2 + C_1 C_3 + C_2 C_3}{C_2 + C_3} = \frac{3C_1}{2} = 3(8.8 \mu \text{F})/2 = 13.2 \mu \text{F}.
\]
Because this capacitance is equivalent to the three, the energy stored in it is the energy stored in the network:
\[
U = \frac{1}{2} C_{\text{eq}} V^2 = \frac{1}{2} (13.2 \times 10^{-6} \text{ F})(90 \text{ V})^2 = 0.053 \text{ J}.
\]
44. (a) We find the equivalent capacitance from
\[ \frac{1}{C_{\text{series}}} = \left( \frac{1}{C_1} \right) + \left( \frac{1}{C_2} \right) = \left[ \frac{1}{(0.40 \text{ mF})} \right] + \left[ \frac{1}{(0.50 \text{ mF})} \right], \]
which gives \( C_{\text{series}} = 0.222 \text{ mF} \).

The charge on the equivalent capacitor is the charge on each capacitor:
\[ Q_1 = Q_2 = Q_{\text{series}} = C_{\text{series}}V = (0.222 \text{ mF})(9.0 \text{ V}) = 2.00 \mu \text{C}. \]

We find the potential differences from
\[ Q_1 = C_1V_1; \]
\[ 2.00 \mu \text{C} = (0.40 \text{ mF})V_1, \]
which gives \( V_1 = 5.0 \text{ V}. \)

\[ Q_2 = C_2V_2; \]
\[ 2.00 \mu \text{C} = (0.50 \text{ mF})V_2, \]
which gives \( V_2 = 4.0 \text{ V}. \)

(b) As we found above
\[ Q_1 = Q_2 = 2.0 \mu \text{C}. \]

(c) For the parallel network, we have
\[ V_1 = V_2 = 9.0 \text{ V}. \]

We find the two charges from
\[ Q_1 = C_1V_1 = (0.40 \text{ mF})(9.0 \text{ V}) = 3.6 \mu \text{C}; \]
\[ Q_2 = C_2V_2 = (0.50 \text{ mF})(9.0 \text{ V}) = 4.5 \mu \text{C}. \]

45. For the parallel network the potential difference is the same for all capacitors, and the total charge is the sum of the individual charges. We find the charge on each from
\[ Q_1 = C_1V_1 = (0.40 \text{ mF})(9.0 \text{ V}) = 3.6 \mu \text{C}; \]
\[ Q_2 = C_2V_2 = (0.50 \text{ mF})(9.0 \text{ V}) = 4.5 \mu \text{C}. \]

46. The potential difference must be the same on each half of the capacitor, so we can treat the system as two capacitors in parallel:
\[ C = C_1 + C_2 = \left[ K_1 \frac{A_1}{d_1} \right] + \left[ K_2 \frac{A_2}{d_2} \right] \]
\[ = \left( \frac{A_1}{d_1} \right) (K_1 + K_2) = \left( \frac{A_2}{d_2} \right) (K_1 + K_2). \]

47. If we think of a layer of equal and opposite charges on the interface between the two dielectrics, we see that they are in series. For the equivalent capacitance, we have
\[ \frac{1}{C} = \left( \frac{1}{C_1} \right) + \left( \frac{1}{C_2} \right) = \left( \frac{1}{d} \frac{A_1}{K_1} \right) + \left( \frac{1}{d} \frac{A_2}{K_2} \right) \]
\[ = \left( \frac{2A}{2d} \right) \left[ \left( \frac{1}{K_1} \right) + \left( \frac{1}{K_2} \right) \right] = \left( \frac{2C_0}{K_1 + K_2} \right) \left( K_1 + K_2 \right). \]

which gives
\[ C = \frac{2C_0 K_1 K_2}{K_1 + K_2}. \]
48. For a series network, we have
\[ Q_1 = Q_2 = Q_{\text{series}} = 125 \text{ pC}. \]
We find the equivalent capacitance from
\[ Q_{\text{series}} = C_{\text{series}}V; \]
\[ 125 \text{ pC} = C_{\text{series}}(25.0 \text{ V}), \] which gives \( C_{\text{series}} = 5.00 \text{ pF}. \)
We find the unknown capacitance from
\[ 1/ C_{\text{series}} = (1/ C_1) + (1/ C_2); \]
\[ 1/(5.00 \text{ pF}) = (1/ (200 \text{ pF})) + (1/ C_2), \] which gives \( C_2 = 5.13 \text{ pF}. \)

49. (a) We find the equivalent capacitance of the two in series from
\[ 1/ C_4 = (1/ C_1) + (1/ C_2) = [1/ (7.0 \text{ mF})] + [1/ (3.0 \text{ mF})], \]
which gives \( C_4 = 2.1 \text{ \(\mu\)F}. \)
This is in parallel with \( C_3 \), so we have
\[ C_{\text{eq}} = C_3 + C_4 = 4.0 \text{ \(\mu\)F} + 2.1 \text{ \(\mu\)F} = 6.1 \text{ \(\mu\)F}. \)
(b) We find the charge on each of the two in series:
\[ Q_1 = Q_2 = Q_4 = C_4V = (2.1 \text{ \(\mu\)F})(24 \text{ V}) = 50.4 \text{ \(\mu\)C}. \]
We find the voltages from
\[ Q_1 = C_1V_1; \]
\[ 50.4 \text{ \(\mu\)C} = (7.0 \text{ \(\mu\)F})V_1, \] which gives \( V_1 = 7.2 \text{ V}. \)
\[ Q_2 = C_2V_2; \]
\[ 50.4 \text{ \(\mu\)C} = (3.0 \text{ \(\mu\)F})V_2, \] which gives \( V_2 = 16.8 \text{ V}. \)
The applied voltage is across \( C_3 \):
\[ V_3 = 24 \text{ V}. \]

50. Because the two sides of the circuit are identical, we find the resistance from the time constant:
\[ \tau = RC; \]
\[ 3.0 \text{ s} = R(3.0 \text{ \(\mu\)F}), \] which gives \( R = 1.0 \text{ M}\Omega. \)
51. (a) We know from Example 19–7 that the equivalent resistance of the two resistors in parallel is 2.7 Ω. There can be no steady current through the capacitor, so we can find the current in the series resistor circuit:

\[ I = \frac{9.0 \text{ V}}{6.0 \Omega + 2.7 \Omega + 5.0 \Omega + 0.50 \Omega} = 0.634 \text{ A.} \]

We use this current to find the potential difference across the capacitor:

\[ V_{ac} = I(R_6 + R_{2.7}) = (0.634 \text{ A})(6.0 \Omega + 2.7 \Omega) = 5.52 \text{ V.} \]

The charge on the capacitor is

\[ Q = CV_{ac} = (7.5 \text{ mF})(5.52 \text{ V}) = 41 \text{ mC.} \]

(b) As we found above, the steady state current through the 6.0-Ω and 5.0-Ω resistors is 0.63 A. The potential difference across the 2.7-Ω resistor is

\[ V_{bc} = IR_{2.7} = (0.634 \text{ A})(2.7 \Omega) = 1.7 \text{ V.} \]

We find the currents through the 8.0-Ω and 4.0-Ω resistors from

\[ V_{bc} = I_8 R_8; \]

\[ 1.7 \text{ V} = I_8(8.0 \Omega), \text{ which gives } I_8 = 0.21 \text{ A;} \]

\[ V_{bc} = I_4 R_4; \]

\[ 1.7 \text{ V} = I_4(4.0 \Omega), \text{ which gives } I_4 = 0.42 \text{ A.} \]

52. (a) We find the capacitance from

\[ \tau = RC; \]

\[ 3.5 \times 10^{-6} \text{ s} = (15 \times 10^3 \Omega)C, \]

which gives \( C = 2.3 \times 10^{-9} \text{ F = 2.3 nF.} \)

(b) The voltage across the capacitance will increase to the final steady state value. The voltage across the resistor will start at the battery voltage and decrease exponentially:

\[ V_R = \Delta V e^{-t/\tau}; \]

\[ 16 \text{ V} = (24 \text{ V})e^{-t/(35 \mu s)}, \text{ or } t/(35 \mu s) = \ln(24 \text{ V}/16 \text{ V}) = 0.405, \text{ which gives } t = 14 \mu s. \]

53. The time constant of the circuit is

\[ \tau = RC = (6.7 \times 10^3 \Omega)(3.0 \times 10^{-6} \text{ F}) = 0.0201 \text{ s = 20.1 ms.} \]

The capacitor voltage will decrease exponentially:

\[ V_C = V_0 e^{-t/\tau}; \]

\[ 0.01V_0 = V_0 e^{-t/(20.1 \text{ ms})}, \text{ or } t/(20.1 \text{ ms}) = \ln(100) = 4.61, \]

which gives \( t = 93 \text{ ms.} \)
54. (a) In the steady state there is no current through the capacitors. Thus the current through the resistors is

\[ I = \frac{V_{cd}}{R_1 + R_2} = \frac{(24 \text{ V})}{(8.8 \Omega + 4.4 \Omega)} = 1.82 \text{ A}. \]

The potential at point a is

\[ V_a = V_{ad} = IR_2 = (1.82 \text{ A})(4.4 \Omega) = 8.0 \text{ V}. \]

(b) We find the equivalent capacitance of the two series capacitors:

\[ \frac{1}{C} = \left( \frac{1}{C_1} \right) + \left( \frac{1}{C_2} \right) = \left[ \frac{1}{(0.48 \text{ mF})} \right] + \left[ \frac{1}{(0.24 \text{ mF})} \right], \]

which gives \( C = 0.16 \text{ mF} \).

We find the charge on each of the two in series:

\[ Q_1 = Q_2 = Q = CV_{cd} = (0.16 \text{ mF})(24 \text{ V}) = 3.84 \text{ mC}. \]

The potential at point b is

\[ V_b = V_{bd} = Q/C_2 = \frac{3.84 \text{ mC}}{0.24 \text{ mF}} = 16 \text{ V}. \]

(c) With the switch closed, the current is the same. Point b must have the same potential as point a:

\[ V_b = V_a = 8.0 \text{ V}. \]

(d) We find the charge on each of the two capacitors, which are no longer in series:

\[ Q_1 = C_1 V_{db} = (0.48 \text{ mF})(24 \text{ V} - 8.0 \text{ V}) = 7.68 \mu\text{C}; \]

\[ Q_2 = C_2 V_{bd} = (0.24 \text{ mF})(8.0 \text{ V}) = 1.92 \mu\text{C}. \]

When the switch was open, the net charge at point b was zero, because the charge on the negative plate of \( C_1 \) had the same magnitude as the charge on the positive plate of \( C_2 \). With the switch closed, these charges are not equal. The net charge at point b is

\[ Q_b = -Q_1 + Q_2 = -7.68 \mu\text{C} + 1.92 \mu\text{C} = -5.8 \mu\text{C}, \]

which flowed through the switch.

55. We find the resistance on the voltmeter from

\[ R = \text{(sensitivity)} \times \text{(scale)} = (30,000 \Omega/\text{V})(250 \text{ V}) = 7.50 \times 10^6 \Omega = 7.50 \text{ M}\Omega. \]

56. We find the current for full-scale deflection of the ammeter from

\[ I = \frac{V_{\text{max}}}{R} = \frac{V_{\text{max}}}{(\text{sensitivity})V_{\text{max}}} = \frac{1}{(10,000 \Omega/\text{V})} = 1.00 \times 10^{-4} \text{ A} = 100 \mu\text{A}. \]

57. (a) We make an ammeter by putting a resistor in parallel with the galvanometer. For full-scale deflection, we have

\[ V_{\text{meter}} = I_G R_y; \]

\[ (50 \times 10^6 \text{ A})(30 \Omega) = 30 \text{ A} - 50 \times 10^{-6} \text{ A})R_y, \]

which gives \( R_y = 50 \times 10^6 \Omega \) in parallel.

(b) We make a voltmeter by putting a resistor in series with the galvanometer. For full-scale deflection, we have

\[ V_{\text{meter}} = I(R_x + r) = I_G (R_x + r); \]

\[ 1000 \text{ V} = (50 \times 10^{-6} \text{ A})(R_x + 30 \Omega), \]

which gives \( R_x = 20 \times 10^6 \Omega = 20 \text{ M}\Omega \) in series.
58. (a) The current for full-scale deflection of the galvanometer is
\[ I = \frac{1}{\text{sensitivity}} = \frac{1}{35 \text{ k}\Omega/\text{V}} = 2.85 \times 10^{-2} \text{ mA} = 28.5 \mu\text{A}. \]

We make an ammeter by putting a resistor in parallel with the galvanometer. For full-scale deflection, we have
\[ V_{\text{meter}} = I_{G} = I_{s}R_{s}, \]
\[ (28.5 \times 10^{-6} \text{ A})(20.0 \text{ } \Omega) = (2.0 \text{ A} - 28.5 \times 10^{-6} \text{ A})R_{s}, \]
which gives \[ R_{s} = 2.9 \times 10^{-5} \text{ } \Omega \] in parallel.

(b) We make a voltmeter by putting a resistor in series with the galvanometer. For full-scale deflection, we have
\[ V_{\text{meter}} = I(R_{x} + r) = I_{G}(R_{x} + r); \]
\[ 1.00 \text{ V} = (28.5 \times 10^{-6} \text{ A})(R_{x} + 20 \text{ } \Omega), \]
which gives \[ R_{x} = 3.5 \times 10^{4} \text{ } \Omega = 35 \text{ k}\Omega \] in series.

59. We can treat the milliammeter as a galvanometer coil, and find its resistance from
\[ 1/R_{A} = (1/R_{x}) + (1/r) = (1/0.20 \text{ } \Omega) + (1/30 \text{ } \Omega), \]
which gives \[ R_{A} = 0.199 \text{ } \Omega. \]

We make a voltmeter by putting a resistor in series with the galvanometer. For full-scale deflection, we have
\[ V_{\text{meter}} = I(R_{x} + R_{A}) = I_{G}(R_{x} + R_{A}); \]
\[ 10 \text{ V} = (10 \times 10^{-3} \text{ A})(R_{x} + 0.199 \text{ } \Omega), \]
which gives \[ R_{x} = 1.0 \times 10^{3} \text{ } \Omega = 1.0 \text{ k}\Omega \] in series.

The sensitivity of the voltmeter is
\[ \text{Sensitivity} = \frac{1000 \text{ } \Omega}{10 \text{ V}} = 100 \text{ } \Omega/\text{V}. \]
60. Before connecting the voltmeter, the current in the series circuit is 
\[ I_0 = \frac{V}{R_1 + R_2} = \frac{45\, \text{V}}{37\, \text{k}\Omega + 28\, \text{k}\Omega} = 0.692\, \text{mA}. \]

The voltages across the resistors are 
\[ V_{01} = I_0 R_1 = (0.692\, \text{mA})(37\, \text{k}\Omega) = 25.6\, \text{V}; \]
\[ V_{02} = I_0 R_2 = (0.692\, \text{mA})(28\, \text{k}\Omega) = 19.4\, \text{V}. \]

When the voltmeter is across \( R_1 \), we find the equivalent resistance of the pair in parallel:
\[ \frac{1}{R_A} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{37\, \text{k}\Omega} + \frac{1}{100\, \text{k}\Omega}, \]
which gives \( R_A = 27.0\, \text{k}\Omega \).

The current in the circuit is 
\[ I_1 = \frac{V}{R_A + R_2} = \frac{45\, \text{V}}{27\, \text{k}\Omega + 28\, \text{k}\Omega} = 0.818\, \text{mA}. \]

The reading on the voltmeter is 
\[ V_{V1} = I_1 R_A = (0.818\, \text{mA})(27.0\, \text{k}\Omega) = 22.1\, \text{V} = 22\, \text{V}. \]

When the voltmeter is across \( R_2 \), we find the equivalent resistance of the pair in parallel:
\[ \frac{1}{R_B} = \frac{1}{R_2} + \frac{1}{R_V} = \frac{1}{28\, \text{k}\Omega} + \frac{1}{100\, \text{k}\Omega}, \]
which gives \( R_B = 21.9\, \text{k}\Omega \).

The current in the circuit is 
\[ I_2 = \frac{V}{R_1 + R_B} = \frac{45\, \text{V}}{37\, \text{k}\Omega + 22\, \text{k}\Omega} = 0.764\, \text{mA}. \]

The reading on the voltmeter is 
\[ V_{V1} = I_2 R_B = (0.764\, \text{mA})(21.9\, \text{k}\Omega) = 16.7\, \text{V} = 17\, \text{V}. \]

We find the percent inaccuracies introduced by the meter:
\[(25.6\, \text{V} - 22.1\, \text{V})(100)/(25.6\, \text{V}) = 14\%\, \text{low}; \]
\[(19.4\, \text{V} - 16.7\, \text{V})(100)/(19.4\, \text{V}) = 14\%\, \text{low}. \]

61. We find the voltage of the battery from the series circuit with the ammeter in it:
\[ \tilde{I} = I_e (R_A + R_1 + R_2) = (5.25 \times 10^{-3}\, \text{A})(60\, \Omega + 700\, \Omega + 400\, \Omega) = 6.09\, \text{V}. \]

Without the meter in the circuit, we have 
\[ \tilde{I} = I_0 (R_1 + R_2), \]
\[ 6.09\, \text{V} = I_0 (700\, \Omega + 400\, \Omega), \]
which gives \( I_0 = 5.54 \times 10^{-3}\, \text{A} = 5.54\, \text{mA}. \)
62. We find the equivalent resistance of the voltmeter in parallel with one of the resistors:
\[ \frac{1}{R} = \left( \frac{1}{R_1} \right) + \left( \frac{1}{R_V} \right) = \frac{1}{9.0 \, \text{k} \Omega} + \frac{1}{15 \, \text{k} \Omega}, \]
which gives \( R = 5.63 \, \text{k} \Omega \).

The current in the circuit, which is read by the ammeter, is
\[ I = \frac{V}{R + R_1 + R_2} = \frac{12.0 \, \text{V}}{1.0 \, \text{Ω} + 0.50 \, \text{Ω} + 5.63 \, \text{k} \Omega + 9.0 \, \text{k} \Omega} = 0.82 \, \text{mA}. \]

The reading on the voltmeter is
\[ V_{ab} = IR = (0.82 \, \text{mA})(5.63 \, \text{k} \Omega) = 4.6 \, \text{V}. \]

63. In circuit 1 the voltmeter is placed in parallel with the resistor, so we find their equivalent resistance from
\[ \frac{1}{R_{eq1}} = \left( \frac{1}{R} \right) + \left( \frac{1}{R_V} \right), \quad \text{or} \quad R_{eq1} = \frac{RR_V}{R + R_V}. \]
The ammeter measures the current through this equivalent resistance and the voltmeter measures the voltage across this equivalent resistance, so we have
\[ R_1 = \frac{V}{I} = R_{eq1} = \frac{RR_V}{R + R_V}. \]

In circuit 2 the ammeter is placed in series with the resistor, so we find their equivalent resistance from
\[ R_{eq2} = R + R_A. \]
The ammeter measures the current through this equivalent resistance and the voltmeter measures the voltage across this equivalent resistance, so we have
\[ R_2 = \frac{V}{I} = R_{eq2} = R + R_A. \]

(a) For circuit 1 we get
\[ R_{1a} = \frac{(2.00 \, \text{Ω})(10.0 \times 10^3 \, \text{Ω})}{(2.00 \, \text{Ω} + 10.0 \times 10^3 \, \text{Ω})} = 2.00 \, \text{Ω}. \]
For circuit 2 we get
\[ R_{2a} = (2.00 \, \text{Ω} + 1.00 \, \text{Ω}) = 3.00 \, \text{Ω}. \]
Thus circuit 1 is better.

(b) For circuit 1 we get
\[ R_{1b} = \frac{(100 \, \text{Ω})(10.0 \times 10^3 \, \text{Ω})}{(100 \, \text{Ω} + 10.0 \times 10^3 \, \text{Ω})} = 99 \, \text{Ω}. \]
For circuit 2 we get
\[ R_{2b} = (100 \, \text{Ω} + 1.00 \, \text{Ω}) = 101 \, \text{Ω}. \]
Thus both circuits give about the same inaccuracy.

(c) For circuit 1 we get
\[ R_{1c} = \frac{(5.0 \, \text{k} \Omega)(10.0 \, \text{k} \Omega)}{(5.0 \, \text{k} \Omega + 10.0 \, \text{k} \Omega)} = 3.3 \, \text{k} \Omega. \]
For circuit 2 we get
\[ R_{2c} = (5.0 \, \text{k} \Omega + 1.00 \, \text{Ω}) = 5.0 \, \text{k} \Omega. \]
Thus circuit 2 is better.

Circuit 1 is better when the resistance is small compared to the voltmeter resistance. Circuit 2 is better when the resistance is large compared to the ammeter resistance.
64. The resistance of the voltmeter is
\[ R_V = \text{sensitivity}(\text{scale}) = (1000 \Omega/V) (3.0 V) = 3.0 \times 10^3 \Omega = 3.0 \, k\Omega. \]
We find the equivalent resistance of the resistor and the voltmeter from
\[ \frac{1}{R_{eq}} = \left( \frac{1}{R} \right) + \left( \frac{1}{R_V} \right), \]
or
\[ R_{eq} = R V / (R + R_V) = (7.4 \, k\Omega)(3.0 \, k\Omega) / (7.4 \, k\Omega + 3.0 \, k\Omega) = 2.13 \, k\Omega. \]
The voltmeter measures the voltage across this equivalent resistance, so the current in the circuit is
\[ I = V_{ab} / R = (2.0 V) / (2.13 \, k\Omega) = 0.937 \, mA. \]
For the series circuit, we have
\[ \Delta V = I (R + R_{eq}) = (0.937 mA)(7.4 \, k\Omega + 2.13 \, k\Omega) = 8.9 \, V. \]

65. We know from Example 19–14 that the voltage across the resistor without the voltmeter connected is 4.0 V.
Thus the minimum voltmeter reading is
\[ V_{ab} = (0.97)(4.0 V) = 3.88 V. \]
We find the maximum current in the circuit from
\[ I = V_{bc} / R_2 = (8.0 V - 3.88 V) / (15 k\Omega) = 0.275 mA. \]
Now we can find the minimum equivalent resistance for the voltmeter and \( R_1 \):
\[ R_{eq} = V_{ab} / I = (3.88 V) / (0.275 mA) = 14.1 \, k\Omega. \]
For the equivalent resistance, we have
\[ 1 / R_{eq} = \left( \frac{1}{R_1} \right) + \left( \frac{1}{R_V} \right); \]
\[ 1 / (14.1 k\Omega) = \left( \frac{1}{(15 k\Omega)} \right) + \left( \frac{1}{R_V} \right), \]
which gives \( R_V = 240 \, k\Omega. \)
We see that the minimum \( R_{eq} \) gives the minimum \( R_V \), so we have \( R_V \geq 240 \, k\Omega. \)

66. We find the resistances of the voltmeter scales:
\[ R_{V100} = \text{(sensitivity)(scale)} = (20,000 \Omega/V)(100 V) = 2.0 \times 10^5 \Omega = 2000 \, k\Omega; \]
\[ R_{V30} = \text{(sensitivity)(scale)} = (20,000 \Omega/V)(30 V) = 6.0 \times 10^5 \Omega = 600 \, k\Omega. \]
The current in the circuit is
\[ I = (V_{ab} / R_V) + (V_{bc} / R_2). \]
For the series circuit, we have
\[ \Delta V = V_{ab} + IR_2. \]
When the 100-volt scale is used, we have
\[ I = [(25 V) / (2000 k\Omega)] + [(25 V) / (120 k\Omega)] = 0.221 mA. \]
\[ \Delta V = 25 V + (0.221 mA) R_2. \]
When the 30-volt scale is used, we have
\[ I = [(23 V) / (600 k\Omega)] + [(23 V) / (120 k\Omega)] = 0.230 mA. \]
\[ \Delta V = 23 V + (0.230 mA) R_2. \]
We have two equations for two unknowns, with the results: \( \Delta V = 74.1 \, V \), and \( R_2 = 222 \, k\Omega. \)
Without the voltmeter in the circuit, we find the current:
\[ \Delta V = I (R_1 + R_2); \]
\[ 74.1 \, V = I (120 k\Omega + 222 k\Omega), \]
which gives \( I = 0.217 \, mA. \)
Thus the voltage across \( R_1 \) is
\[ V_{ab'} = I R_1 = (0.217 mA)(120 k\Omega) = 26 \, V. \]
67. When the voltmeter is across \( R_1 \), for the junction \( b \), we have
\[
I_{1A} + I_{1V} = I_1;
\]
\[
([5.5 \, V] / R_1) + ([5.5 \, V] / (15.0 \, k\Omega)) = (12.0 \, V - 5.5 \, V) / R_2;
\]
\[
([5.5 \, V] / R_1) + 0.367 \, mA = (6.5 \, V) / R_2.
\]
When the voltmeter is across \( R_2 \), for the junction \( e \), we have
\[
I_{2A} = I_{2}.
\]
\[
(12.0 \, V - 4.0 \, V) / R_1 = ([4.0 \, V] / R_2) + ([4.0 \, V] / (15.0 \, k\Omega));
\]
\[
[(8.0 \, V) / R_1] = [(4.0 \, V) / R_2] + 0.267 \, mA.
\]
We have two equations for two unknowns, with the results:
\( R_1 = 9.4 \, k\Omega \), and \( R_2 = 6.8 \, k\Omega \).

68. The voltage is the same across resistors in parallel, but is less across a resistor in a series connection. We connect two resistors in series as shown in the diagram. Each resistor has the same current:
\[
I = V / (R_1 + R_2) = (9.0 \, V) / (R_1 + R_2).
\]
If the desired voltage is across \( R_1 \), we have
\[
V_{ab} = I \cdot R_1 = (9.0 \, V) \cdot R_1 / (R_1 + R_2);
\]
\[
0.25 \, V = (9.0 \, V) / (R_1 + R_2) = (9.0 \, V) / [1 + (R_2 / R_1)],
\]
which gives \( R_2 / R_1 = 35 \).
When the body is connected across \( ab \), we want very negligible current through the body, so the potential difference does not change. This requires \( R_{body} = 2000 \, \Omega \). If we also do not want a large current from the battery, a possible combination is \( R_1 = 2 \, \Omega \), \( R_2 = 70 \, \Omega \).

69. Because the voltage is constant and the power is additive, we can use two resistors in parallel. For the lower ratings, we use the resistors separately; for the highest rating, we use them in parallel. The rotary switch shown allows the \( B \) contact to successively connect to \( C \) and \( D \). The \( A \) contact connects to \( C \) and \( D \) for the parallel connection.
We find the resistances for the three settings from
\[
P = V^2 / R;
\]
50 \, W = \((120 \, V)^2 / R_1 \), which gives \( R_1 = 288 \, \Omega \);
100 \, W = \((120 \, V)^2 / R_2 \), which gives \( R_2 = 144 \, \Omega \);
150 \, W = \((120 \, V)^2 / R_3 \), which gives \( R_3 = 96 \, \Omega \).
As expected, for the parallel arrangement we have
\[
1 / R_{eq} = (1 / R_1) + (1 / R_2);
\]
\[
1 / R_{eq} = [1 / (288 \, \Omega)] + [1 / (144 \, \Omega)],
\]
which gives \( R_{eq} = 96 \, \Omega = R_3 \).
Thus the two required resistors are \( 288 \, \Omega, 144 \, \Omega \).
70. The voltage drop across the two wires is
\[ V_{\text{drop}} = IR = (3.0 \, \text{A})(0.0065 \, \Omega/\text{m})(2)(95 \, \text{m}) = 3.7 \, \text{V}. \]
The applied voltage at the apparatus is
\[ V = V_0 - V_{\text{drop}} = 120 \, \text{V} - 3.7 \, \text{V} = 116 \, \text{V}. \]

71. We find the current through the patient (and nurse) from the series circuit:
\[ I = \frac{V}{(R_{\text{motor}} + R_{\text{bed}} + R_{\text{nurse}} + R_{\text{patient}})} = \frac{(220 \, \text{V})}{(10^4 \, \Omega + 0 + 10^4 \, \Omega + 10^4 \, \Omega)} = 7.3 \times 10^{-3} \, \text{A} = 7.3 \, \text{mA}. \]

72. (a) When the capacitors are connected in parallel, we find the equivalent capacitance from
\[ C_{\text{parallel}} = C_1 + C_2 = 0.40 \, \mu\text{F} + 0.60 \, \mu\text{F} = 1.00 \, \mu\text{F}. \]
The stored energy is
\[ U_{\text{parallel}} = \frac{1}{2} C_{\text{parallel}} V^2 = \frac{1}{2}(1.00 \times 10^{-6} \, \text{F})(45 \, \text{V})^2 = 1.0 \times 10^{-3} \, \text{J}. \]
(b) When the capacitors are connected in series, we find the equivalent capacitance from
\[ \frac{1}{C_{\text{series}}} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{(0.40 \, \mu\text{F})} + \frac{1}{(0.60 \, \mu\text{F})}, \]
which gives \[ C_{\text{series}} = 0.24 \, \mu\text{F}. \]
The stored energy is
\[ U_{\text{series}} = \frac{1}{2} C_{\text{series}} V^2 = \frac{1}{2}(0.24 \times 10^{-6} \, \text{F})(45 \, \text{V})^2 = 2.4 \times 10^{-4} \, \text{J}. \]
(c) We find the charges from
\[ Q_{\text{parallel}} = C_{\text{parallel}} V = (1.00 \, \mu\text{F})(45 \, \text{V}) = 45 \, \mu\text{C}. \]
\[ Q_{\text{series}} = C_{\text{series}} V = (0.24 \, \mu\text{F})(45 \, \text{V}) = 11 \, \mu\text{C}. \]

73. The time between firings is
\[ t = \frac{(60 \, \text{s})}{(72 \, \text{beats})} = 0.833 \, \text{s}. \]
We find the time for the capacitor to reach 63% of maximum from
\[ V = V_0(1 - e^{-t/T}) = 0.63V_0, \]
which gives \( e^{-t/T} = 0.37 \), or
\[ t = T = RC; \]
\[ 0.833 \, \text{s} = R(7.5 \, \mu\text{C}), \]
which gives \[ R = 0.11 \, \text{M} \Omega. \]

74. We find the required current for the hearing aid from
\[ P = IV; \]
\[ 2 \, \text{W} = I(4.0 \, \text{V}), \]
which gives \( I = 0.50 \, \text{A}. \)
With this current the terminal voltage of the three mercury cells would be
\[ V_{\text{mercury}} = 3(\hat{a}_{\text{mercury}} - Ir_{\text{mercury}}) = 3[1.35 \, \text{V} - (0.50 \, \text{A})(0.030 \, \Omega)] = 4.01 \, \text{V}. \]
With this current the terminal voltage of the three dry cells would be
\[ V_{\text{dry}} = 3(\hat{a}_{\text{dry}} - Ir_{\text{dry}}) = 3[1.5 \, \text{V} - (0.50 \, \text{A})(0.35 \, \Omega)] = 3.98 \, \text{V}. \]
Thus the mercury cells would have a higher terminal voltage.

75. (a) We find the current from
\[ I_1 = \frac{V}{R_{\text{body}}} = \frac{(110 \, \text{V})}{(900 \, \Omega)} = 0.12 \, \text{A}. \]
(b) Because the alternative path is in parallel, the current is the same: \( 0.12 \, \text{A}. \)
(c) The current restriction means that the voltage will change. Because the voltage will be the same across both resistances, we have
\[ I_2 R_{\text{2}} = I_{\text{body}} R_{\text{body}}; \]
\[ I_2(40) = I_{\text{body}}(900), \]
or \[ I_2 = 22.5 I_{\text{body}}. \]
For the sum of the currents, we have
\[ I_2 + I_{\text{body}} = 23.5 I_{\text{body}} = 1.5 \, \text{A}, \]
which gives \( I_{\text{body}} = 6.4 \times 10^{-2} \, \text{A} = 64 \, \text{mA}. \)
76. (a) When there is no current through the galvanometer, we have \( V_{BD} = 0 \), a current \( I_1 \) through \( R_1 \) and \( R_2 \), and a current \( I_3 \) through \( R_3 \) and \( R_x \). Thus we have
\[
V_{AD} = V_{AB}, \quad I_1 R_1 = I_3 R_3, \quad \text{and} \quad V_{BC} = V_{DC}, \quad I_1 R_2 = I_3 R_x.
\]
When we divide these two equations, we get
\[
\frac{V_{AD}}{V_{BC}} = \frac{V_{AB}}{V_{DC}}, \quad \text{and} \quad \frac{I_1}{I_3} = \frac{R_1}{R_2} = \frac{R_3}{R_x}.
\]
(b) The unknown resistance is
\[
R_x = \left( \frac{R_2}{R_1} \right) R_3 = \left( \frac{972 \, \Omega}{630 \, \Omega} \right) (42.6 \, \Omega) = 65.7 \, \Omega.
\]

77. The resistance of the platinum wire is
\[
R_x = \left( \frac{R_2}{R_1} \right) R_3 = \left( \frac{46.0 \, \Omega}{38.0 \, \Omega} \right) (3.48 \, \Omega) = 4.21 \, \Omega.
\]
We find the length from
\[
R = \rho \frac{L}{A};
\]
\[
= \left( 10.6 \times 10^{-8} \, \Omega \cdot m \right) \cdot \left( 0.460 \times 10^{-3} \, m \right)^2, \text{which gives} \quad L = 26.4 \, m.
\]

78. (a) When there is no current through the galvanometer, the current \( I \) must pass through the long resistor \( R' \), so the potential difference between \( A \) and \( C \) is \( V_{AC} = IR \).

Because there is no current through the measured emf, for the bottom loop we have
\[
\Delta V = IR;
\]
When different emfs are balanced, the current \( I \) is the same, so we have
\[
\Delta V_s = R_s \Delta I, \quad \text{and} \quad \Delta V_x = R_x \Delta I.
\]
When we divide the two equations, we get
\[
\frac{\Delta V_s}{\Delta V_x} = \frac{R_s}{R_x}, \quad \text{or} \quad \Delta V_x = \left( \frac{R_x}{R_s} \right) \Delta V_s.
\]
(b) Because the resistance is proportional to the length, we have
\[
\Delta V_x = \left( \frac{R_x}{R_s} \right) \Delta V_s = \left( \frac{45.8 \, cm}{25.4 \, cm} \right) (1.0182 \, V) = 1.836 \, V.
\]
(c) If we assume that the current in the slide wire is much greater than the galvanometer current, the uncertainty in the voltage is
\[
\Delta V = \pm \left( \frac{R_x}{R_s} \right) \Delta V_s = \pm 0.45 \, mV.
\]
Because this can occur for each setting and there will be uncertainties in measuring the distances, the minimum uncertainty is \( \pm 0.90 \, mV \).
(d) The advantage of this method is that there is no effect of the internal resistance, because there is no current through the cell.

79. (a) We see from the diagram that all positive plates are connected to the positive side of the battery, and that all negative plates are connected to the negative side of the battery, so the capacitors are connected in parallel.

(b) For parallel capacitors, the total capacitance is the sum, so we have
\[
C_{\text{min}} = \sum C_i \text{ for } \min, \quad \text{and} \quad C_{\text{max}} = \sum C_i \text{ for } \max.
\]
\[
C_{\text{min}} = \sum (8.85 \times 10^{-12} \, C / N \cdot m^2)(2.0 \times 10^{-4} \, m^2) / (2.0 \times 10^{-3} \, m) = 6.2 \times 10^{-12} \, F = 6.2 \, pF.
\]
\[
C_{\text{max}} = \sum (8.85 \times 10^{-12} \, C / N \cdot m^2)(12.0 \times 10^{-4} \, m^2) / (2.0 \times 10^{-3} \, m) = 3.7 \times 10^{-11} \, F = 37 \, pF.
\]
Thus the range is \( 6.2 \, pF \leq C \leq 37 \, pF \).
80. The terminal voltage of a discharging battery is
\[ V = \hat{V} - Ir. \]
For the two conditions, we have
\[ 40.8\ V = \hat{V} - (7.40\ A)r; \]
\[ 47.3\ V = \hat{V} - (2.20\ A)r. \]
We have two equations for two unknowns, with the solutions: \( \hat{V} = 50.1\ V \), and \( r = 1.25\ \Omega \).

81. One arrangement is to connect \( N \) resistors in series. Each resistor will have the same power, so we need
\[ N = \frac{P_{\text{total}}}{P} = \frac{5\ W}{1\ W} = 10 \text{ resistors.} \]
We find the required value of resistance from
\[ R_{\text{total}} = N R_{\text{series}}; \]
\[ 2.2\ \Omega = 10R_{\text{series}}, \text{ which gives } R_{\text{series}} = 0.22\ \Omega. \]
Thus we have \( 10\ 0.22\text{-k}\Omega \) resistors in series.
Another arrangement is to connect \( N \) resistors in series. Each resistor will again have the same power, so we need the same number of resistors: 10.
We find the required value of resistance from
\[ \frac{1}{R_{\text{total}}} = \frac{1}{R_{\text{series}}} = \frac{N}{R_{\text{parallel}}}; \]
\[ \frac{1}{2.2\ \Omega} = 10/ R_{\text{parallel}}, \text{ which gives } R_{\text{parallel}} = 22\ \Omega. \]
Thus we have \( 10\ 22\text{-k}\Omega \) resistors in parallel.

82. If we assume the current in \( R_4 \) is to the right, we have
\[ V_{cd} = I_4 R_4 = (3.50\ mA)(4.0\ \text{k}\Omega) = 14.0\ V. \]
We can now find the current in \( R_5 \):
\[ I_8 = V_{cd}/ R_5 = (14.0\ V)/(8.0\ \text{k}\Omega) = 1.75\ mA. \]
From conservation of current at the junction \( c \), we have
\[ I = I_4 + I_8 = 3.50\ mA + 1.75\ mA = 5.25\ mA. \]
If we go clockwise around the outer loop, starting at \( a \), we have
\[ V_{ba} = I R_5 - I_4 R_4 - \hat{V} - Ir = 0, \] or
\[ V_{ba} = (5.25\ mA)(5.0\ \text{k}\Omega) - (3.50\ mA)(4.0\ \text{k}\Omega) - 12.0\ V - (5.25\ mA)(1.0\ \Omega) = 52\ V. \]
If we assume the current in \( R_4 \) is to the left, all currents are reversed, so we have
\[ V_{ba} = 14.0\ V; \ I = 1.75\ mA, \text{ and } I = 5.25\ mA. \]
If we go counterclockwise around the outer loop, starting at \( a \), we have
\[ -I + \hat{V} - I_4 R_4 - I_8 R_5 - Ir + V_{ab} = 0, \] or
\[ V_{ba} = - V_{ab} = -I + \hat{V} - I_4 R_4 - I_8 R_5 - Ir; \]
\[ V_{ba} = -(5.25\ mA)(1.0\ \Omega) + 12.0\ V - (3.50\ mA)(4.0\ \text{k}\Omega) - (5.25\ mA)(5.0\ \text{k}\Omega) = -28\ V. \]
The negative value means the battery is facing the other direction.
83. When the leads are shorted ($R_x = 0$), there will be maximum current in the circuit, including the galvanometer. We have

$$V_{ab,\text{max}} = I_{G,\text{max}}(25 \, \Omega) = 8.75 \times 10^{-4} \, \text{V}.$$  

We can now find the current in the shunt, $R_{sh}$:

$$I_{sh,\text{max}} = V_{ab,\text{max}} / R_{sh} = (8.75 \times 10^{-4} \, \text{V}) / R_{sh}.$$  

From conservation of current at the junction $a$, we have

$$I_{\text{max}} = I_{G,\text{max}} + I_{sh,\text{max}} = 35 \times 10^{-6} \, \text{A} + (8.75 \times 10^{-4} \, \text{V}) / R_{sh}.$$  

If we go clockwise around the outer loop, starting at $a$, we have

$$V_{ba,\text{max}} + V - I_{\text{max}} R_{ser} = 0;$$  

$$- 8.75 \times 10^{-4} \, \text{V} + 3.0 \, \text{V} - [35 \times 10^{-6} \, \text{A} + (8.75 \times 10^{-4} \, \text{V}) / R_{sh}] R_{ser} = 0;$$  

$$35 \times 10^{-6} \, \text{A} + (8.75 \times 10^{-4} \, \text{V}) / R_{sh} = (3.0 \, \text{V} - 8.75 \times 10^{-4} \, \text{V}) / R_{ser};$$  

$$35 \times 10^{-6} \, \text{A} + (8.75 \times 10^{-4} \, \text{V}) / R_{sh} = (3.0 \, \text{V}) / R_{ser}.$$  

When the leads are across $R_x = 30 \, \text{k}\Omega$, all currents will be one-half their maximum values. We have

$$V_{ab} = I_{G} R = (35 \times 10^{-6} \, \text{A})(25 \, \Omega) = 4.375 \times 10^{-4} \, \text{V}.$$  

The current in the shunt is

$$I_{sh} = V_{ab} / R_{sh} = (4.375 \times 10^{-4} \, \text{V}) / R_{sh}.$$  

From conservation of current at the junction $a$, we have

$$I = I_{G} + I_{sh} = 17.5 \times 10^{-6} \, \text{A} + (4.375 \times 10^{-4} \, \text{V}) / R_{sh}.$$  

If we go clockwise around the outer loop, starting at $a$, we have

$$V_{ba} + V - I (R_x + R_{ser}) = 0;$$  

$$- 4.375 \times 10^{-4} \, \text{V} + 3.0 \, \text{V} - [17.5 \times 10^{-6} \, \text{A} + (4.375 \times 10^{-4} \, \text{V}) / R_{sh}] (30 \times 10^3 \, \Omega + R_{ser}) = 0;$$  

$$17.5 \times 10^{-6} \, \text{A} + (4.375 \times 10^{-4} \, \text{V}) / R_{sh} = (3.0 \, \text{V} - 4.375 \times 10^{-4} \, \text{V}) / (30 \times 10^3 \, \Omega + R_{ser});$$  

$$17.5 \times 10^{-6} \, \text{A} + (4.375 \times 10^{-4} \, \text{V}) / R_{sh} = (3.0 \, \text{V}) / (30 \times 10^3 \, \Omega + R_{ser}).$$  

We have two equations for two unknowns, with the solutions:

$$R_{sh} = 13 \, \Omega,$$

$$R_{ser} = 30 \times 10^3 \, \Omega = 30 \, \text{k}\Omega.$$
84. The resistance along the potentiometer is proportional to the length, so we find the equivalent resistance between points b and c:

\[
\frac{1}{R_{eq}} = \frac{1}{xR_{pot}} + \frac{1}{R_{bulb}}, \quad \text{or} \quad R_{eq} = xR_{pot}R_{bulb} / (xR_{pot} + R_{bulb}).
\]

We find the current in the loop from

\[
I = \frac{V}{[(1 - x)R_{pot} + R_{eq}]}.\]

The potential difference across the bulb is

\[
V_{bc} = IR_{eq}, \quad \text{so the power expended in the bulb is} \quad P = V_{bc}^2 / R_{bulb}.
\]

(a) For \(x = 1\) we have

\[
R_{eq} = (1)(100 \text{ } \Omega)(200 \text{ } \Omega) / [(1)(100 \text{ } \Omega) + 200 \text{ } \Omega] = 66.7 \text{ } \Omega.
\]

\[
I = (120 \text{ } V) / [(1 - 1)(100 \text{ } \Omega) + 66.7 \text{ } \Omega] = 1.80 \text{ } A.
\]

\[
V_{bc} = (1.80 \text{ } A)(66.7 \text{ } \Omega) = 120 \text{ } V.
\]

\[
P = (120 \text{ } V)^2 / (200 \text{ } \Omega) = 72.0 \text{ } W.
\]

(b) For \(x = 0\) we have

\[
R_{eq} = (0)(100 \text{ } \Omega)(200 \text{ } \Omega) / [(0)(100 \text{ } \Omega) + 200 \text{ } \Omega] = 40.0 \text{ } \Omega.
\]

\[
I = (120 \text{ } V) / [(1 - 0)(100 \text{ } \Omega) + 40.0 \text{ } \Omega] = 1.33 \text{ } A.
\]

\[
V_{bc} = (1.33 \text{ } A)(40.0 \text{ } \Omega) = 53.3 \text{ } V.
\]

\[
P = (53.3 \text{ } V)^2 / (200 \text{ } \Omega) = 14.2 \text{ } W.
\]

(c) For \(x = #\) we have

\[
R_{eq} = (#)(100 \text{ } \Omega)(200 \text{ } \Omega) / [(#)(100 \text{ } \Omega) + 200 \text{ } \Omega] = 22.2 \text{ } \Omega.
\]

\[
I = (120 \text{ } V) / [(1 - #)(100 \text{ } \Omega) + 66.7 \text{ } \Omega] = 1.23 \text{ } A.
\]

\[
V_{bc} = (1.23 \text{ } A)(22.2 \text{ } \Omega) = 27.4 \text{ } V.
\]

\[
P = (27.4 \text{ } V)^2 / (200 \text{ } \Omega) = 3.75 \text{ } W.
\]

85. (a) Normally there is no DC current in the circuit, so the voltage of the battery is across the capacitor. When there is an interruption, the capacitor voltage will decrease exponentially:

\[
V_C = V_0 e^{-\frac{t}{\tau}}.
\]

We find the time constant from the need to maintain 70% of the voltage for 0.20 s:

\[
0.70V_0 = V_0 e^{-\frac{0.20 \text{ } s}{\tau}}, \quad \text{or} \quad (0.20 \text{ } s)/\tau = \ln(1.43) = 3.57,
\]

which gives \(\tau = 0.56 \text{ } s\).

We find the required resistance from

\[
\tau = RC;
\]

\[
0.56 \text{ } s = R(22 \times 10^{-6} \text{ } F), \quad \text{which gives} \quad R = 2.5 \times 10^4 \text{ } \Omega = 25 \text{ } k\Omega.
\]

(b) In normal operation, there will be no voltage across the resistor, so the device should be connected between b and c.

86. (a) Because the capacitor is disconnected from the power supply, the charge is constant. We find the new voltage from

\[
Q = C_1V_1 = C_2V_2;
\]

\[
(10 \text{ } \text{pF})(10,000 \text{ } V) = (1 \text{ } \text{pF})V_2, \quad \text{which gives} \quad V_2 = 1.0 \times 10^6 \text{ } V = 0.10 \text{ } \text{MV}.
\]

(b) A major disadvantage is that, when the stored energy is used, the voltage will decrease exponentially, so it can be used for only short bursts.