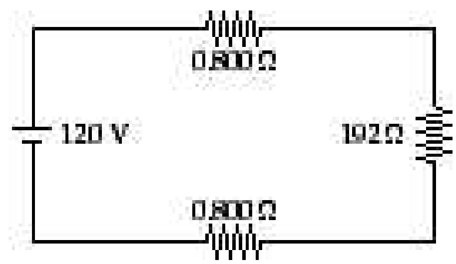
# Chapter 18
# Direct-Current Circuits

## Problem Solutions

**18.1** From $\Delta V = I(R + r)$, the internal resistance is

$$r = \frac{\Delta V}{I} - R = \frac{9.00\text{ V}}{0.117\text{ A}} - 72.0\ \Omega = \boxed{4.92\ \Omega}$$

**18.3** For the bulb in use as intended,




$$R_{bulb} = \frac{(\Delta V)^2}{\mathcal{P}} = \frac{(120\text{ V})^2}{75.0\text{ W}} = 192\ \Omega$$

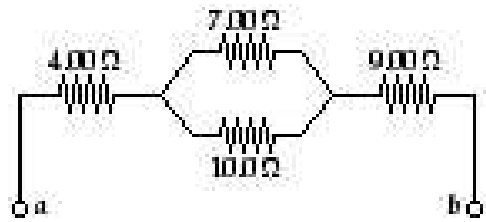
Now, presuming the bulb resistance is unchanged, the current in the circuit shown is

$$I = \frac{\Delta V}{R_{eq}} = \frac{120\text{ V}}{0.800\,\Omega + 192\,\Omega + 0.800\,\Omega} = 0.620\text{ A}$$

and the actual power dissipated in the bulb is

$$\mathcal{P} = I^2 R_{bulb} = (0.620\text{ A})^2 (192\ \Omega) = \boxed{73.8\text{ W}}$$

**18.5** (a) The equivalent resistance of the two parallel resistors is




$$R_p = \left( \frac{1}{7.00\ \Omega} + \frac{1}{10.0\ \Omega} \right)^{-1} = 4.12\ \Omega$$

Thus,

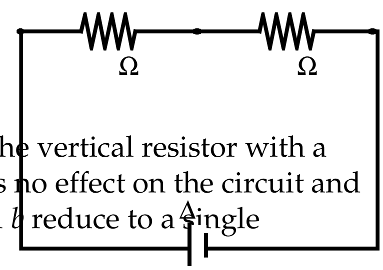
$$R_{ab} = R_4 + R_p + R_9 = (4.00 + 4.12 + 9.00)\ \Omega = \boxed{17.1\ \Omega}$$

(b) $I_{ab} = \dfrac{(\Delta V)_{ab}}{R_{ab}} = \dfrac{34.0\ \text{V}}{17.1\ \Omega} = 1.99\ \text{A}$, so $\boxed{I_4 = I_9 = 1.99\ \text{A}}$

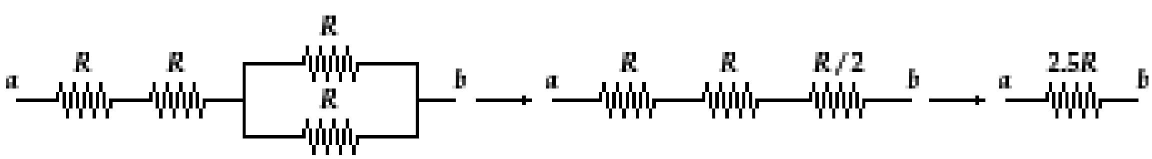
Also, $(\Delta V)_p = I_{ab} R_p = (1.99\ \text{A})(4.12\ \Omega) = 8.18\ \text{V}$

Then, $I_7 = \dfrac{(\Delta V)_p}{R_7} = \dfrac{8.18\ \text{V}}{7.00\ \Omega} = \boxed{1.17\ \text{A}}$

and $I_{10} = \dfrac{(\Delta V)_p}{R_{10}} = \dfrac{8.18\ \text{V}}{10.0\ \Omega} = \boxed{0.818\ \text{A}}$




**18.7** If a potential difference is applied between points *a* and *b*, the vertical resistor with a free end is not part of any closed current path. Hence, it has no effect on the circuit and can be ignored. The remaining four resistors between *a* and *b* reduce to a single equivalent resistor, $R_{eq} = \boxed{2.5R}$, as shown below:



**18.13** The resistors in the circuit can be combined in the stages shown below to yield an equivalent resistance of $R_{ad} = (63/11)\ \Omega$.

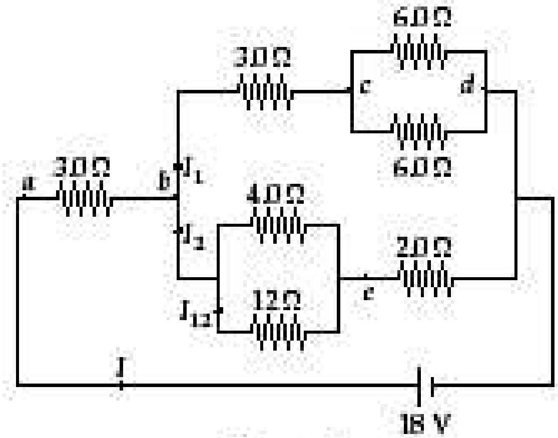


Figure 1

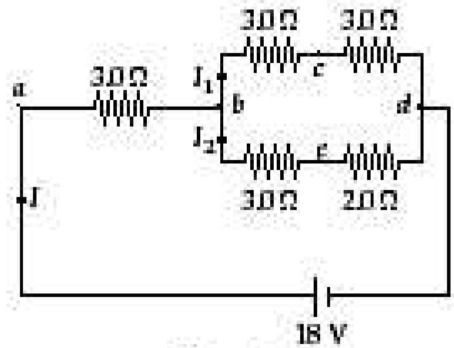


Figure 2

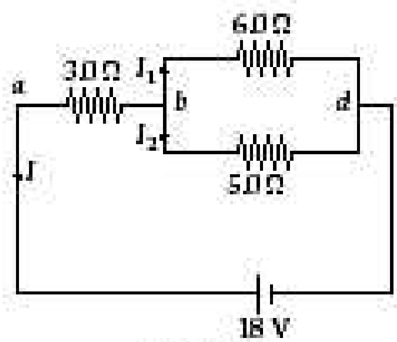


Figure 3

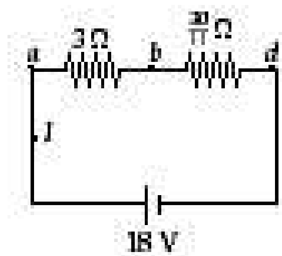


Figure 4

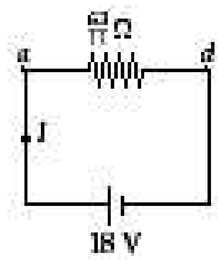


Figure 5

From Figure 5, $I = \dfrac{(\Delta V)_{ad}}{R_{ad}} = \dfrac{18\ \text{V}}{(63/11)\ \Omega} = 3.14\ \text{A}$

Then, from Figure 4, $(\Delta V)_{bd} = I R_{bd} = (3.14\ \text{A})(30/11\ \Omega) = 8.57\ \text{V}$

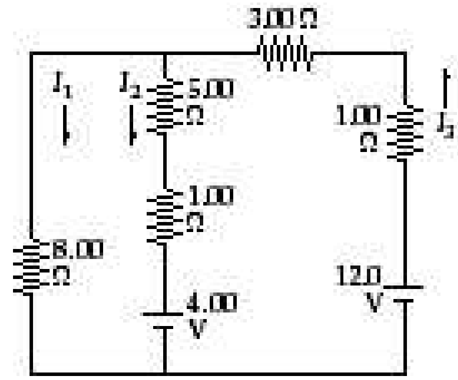
Now, look at Figure 2 and observe that

$$I_2 = \frac{(\Delta V)_{bd}}{3.0\ \Omega + 2.0\ \Omega} = \frac{8.57\ \text{V}}{5.0\ \Omega} = 1.71\ \text{A}$$

so $(\Delta V)_{be} = I_2 R_{be} = (1.71\ \text{A})(3.0\ \Omega) = 5.14\ \text{V}$

Finally, from Figure 1, $I_{12} = \dfrac{(\Delta V)_{be}}{R_{12}} = \dfrac{5.14\ \text{V}}{12\ \Omega} = \boxed{0.43\ \text{A}}$

**18.17** We name the currents $I_1$, $I_2$, and $I_3$ as shown. Using Kirchhoff's loop rule on the rightmost loop gives




$$+12.0\text{ V}-(1.00+3.00)I_3 -(5.00+1.00)I_2-4.00\text{ V}=0$$

or $\quad (2.00)I_3+(3.00)I_2=4.00\text{ V} \qquad (1)$

Applying the loop rule to the leftmost loop yields

$$+4.00\text{ V}+(1.00+5.00)I_2-(8.00)I_1=0$$

or $\quad (4.00)I_1-(3.00)I_2=2.00\text{ V} \qquad (2)$

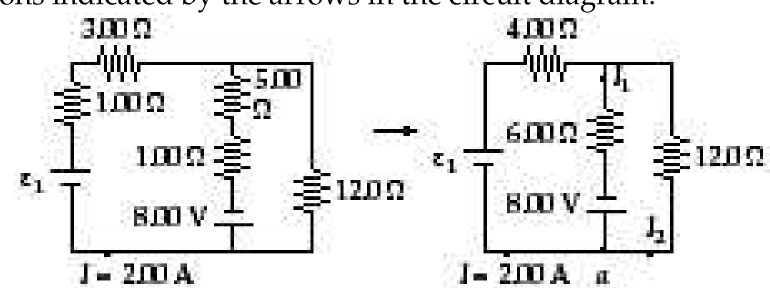
From Kirchhoff's junction rule, $I_1+I_2=I_3 \qquad (3)$

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

$$\boxed{I_1=0.846\text{ A},\ I_2=0.462\text{ A, and } I_3=1.31\text{ A}}$$

All currents are in the directions indicated by the arrows in the circuit diagram.

**18.21** First simplify the circuit by combining the series resistors. Then, apply Kirchhoff's junction rule at point *a* to find




$$I_1+I_2=2.00\text{ A}$$

Next, we apply Kirchhoff's loop rule to the rightmost loop to obtain

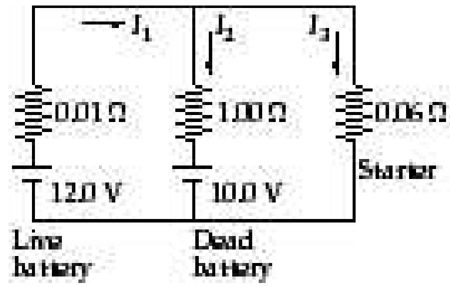
$$-8.00\text{ V}+(6.00)I_1-(12.0)I_2=0$$

or $\quad -8.00\text{ V}+(6.00)I_1-(12.0)(2.00\text{ A}-I_1)=0 \quad$ This yields $\quad I_1=1.78\text{ A}$

Finally, apply Kirchhoff's loop rule to the leftmost loop to obtain

$$+\varepsilon_1-(4.00)(2.00\text{ A})-(6.00)I_1+8.00\text{ V}=0$$

or $\quad \varepsilon_1=(4.00)(2.00\text{ A})+(6.00)(1.78\text{ A})-8.00\text{ V}=\boxed{10.7\text{ V}}$




**18.26** Using Kirchhoff's loop rule on the outer perimeter of the circuit gives

$$+12\text{ V}-(0.01)I_1-(0.06)I_3=0$$

or $\quad I_1+6I_3=1.2\times10^3\text{ A} \qquad (1)$

For the rightmost loop, the loop rule gives

$$+10\text{ V}+(1.00)I_2-(0.06)I_3=0$$

or $\quad I_2-0.06I_3=-10\text{ A} \qquad (2)$

Applying Kirchhoff's junction rule at either junction gives

$$I_1=I_2+I_3 \qquad (3)$$

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

$$\boxed{I_2=0.28\text{ A (in dead battery) and } I_3=1.7\times10^2\text{ A (in starter)}}$$

**18.31** (a) $\tau=RC=\left(2.0\times10^6\ \Omega\right)\left(6.0\times10^{-6}\text{ F}\right)=\boxed{12\text{ s}}$

(b) $Q_{max}=C\varepsilon=\left(6.0\times10^{-6}\text{ F}\right)(20\text{ V})=\boxed{1.2\times10^{-4}\text{ C}}$

**18.33** $Q_{max}=C\varepsilon=\left(5.0\times10^{-6}\text{ F}\right)(30\text{ V})=1.5\times10^{-4}\text{ C}$, and

$$\tau=RC=\left(1.0\times10^6\ \Omega\right)\left(5.0\times10^{-6}\text{ F}\right)=5.0\text{ s}$$

Thus, at $t=10\text{ s}=2\tau$

$$Q=Q_{max}\left(1-e^{-t/\tau}\right)=\left(1.5\times10^{-4}\text{ C}\right)\left(1-e^{-2}\right)=\boxed{1.3\times10^{-4}\text{ C}}$$

**18.35** From $Q = Q_{\max}\left(1 - e^{-t/\tau}\right)$, we have at $t = 0.900 \text{ s}$,

$$\frac{Q}{Q_{\max}} = 1 - e^{-0.900\text{ s}/\tau} = 0.600$$

Thus, $e^{-0.900\text{ s}/\tau} = 0.400$, or $-\dfrac{0.900\text{ s}}{\tau} = \ln(0.400)$

giving the time constant as $\tau = -\dfrac{0.900\text{ s}}{\ln(0.400)} = \boxed{0.982\text{ s}}$

| $R$ (Ω) | $\mathcal{P}_L$ (W) |
|---|---|
| 1.00 | 1.19 |
| 5.00 | 3.20 |
| 10.0 | 3.60 |
| 15.0 | 3.46 |
| 20.0 | 3.20 |
| 25.0 | 2.94 |
| 30.0 | 2.70 |

The curve peaks at $\mathcal{P}_L = 3.60\text{ W}$ at a load resistance of $R = 10.0\ \Omega$.