Chapter 28 Solutions

28.1 (a) $\mathcal{P} = \frac{(\Delta V)^2}{R}$ becomes $20.0\text{ W} = \frac{(11.6\text{ V})^2}{R}$ so $R = \boxed{6.73\ \Omega}$

(b) $\Delta V = IR$ so $11.6\text{ V} = I(6.73\ \Omega)$ and $I = 1.72\text{ A}$

$\mathcal{E} = IR + Ir$ so $15.0\text{ V} = 11.6\text{ V} + (1.72\text{ A})r$

$r = \boxed{1.97\ \Omega}$

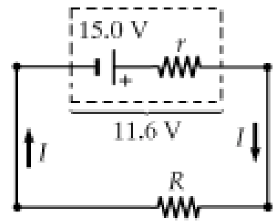


Figure for Goal Solution

<u>Goal Solution</u>

A battery has an emf of 15.0 V. The terminal voltage of the battery is 11.6 V when it is delivering 20.0 W of power to an external load resistor R. (a) What is the value of R? (b) What is the internal resistance of the battery?

G: The internal resistance of a battery usually is less than $1\ \Omega$, with physically larger batteries having less resistance due to the larger anode and cathode areas. The voltage of this battery drops significantly (23%), when the load resistance is added, so a sizable amount of current must be drawn from the battery. If we assume that the internal resistance is about $1\ \Omega$, then the current must be about 3 A to give the 3.4 V drop across the battery's internal resistance. If this is true, then the load resistance must be about $R \approx 12\text{ V} / 3\text{ A} = 4\ \Omega$.

O: We can find R exactly by using Joule's law for the power delivered to the load resistor when the voltage is 11.6 V. Then we can find the internal resistance of the battery by summing the electric potential differences around the circuit.

A: (a) Combining Joule's law, $\mathcal{P} = \Delta VI$, and the definition of resistance, $\Delta V = IR$, gives

$$R = \frac{\Delta V^2}{\mathcal{P}} = \frac{(11.6\text{ V})^2}{20.0\ W} = 6.73\ \Omega$$

(b) The electromotive force of the battery must equal the voltage drops across the resistances: $\mathcal{E} = IR + Ir$, where $I = \Delta V/R$.

$$r = \frac{\mathcal{E} - IR}{I} = \frac{(\mathcal{E} - \Delta V)R}{\Delta V} = \frac{(15.0\text{ V} - 11.6\text{ V})(6.73\ \Omega)}{11.6\text{ V}} = 1.97\ \Omega$$

L: The resistance of the battery is larger than $1\ \Omega$, but it is reasonable for an old battery or for a battery consisting of several small electric cells in series. The load resistance agrees reasonably well with our prediction, despite the fact that the battery's internal resistance was about twice as large as we assumed. Note that in our initial guess we did not consider the power of the load resistance; however, there is not sufficient information to accurately solve this problem without this data.

28.2 (a) $\Delta V_{term} = IR$

becomes $10.0\ \text{V} = I(5.60\ \Omega)$

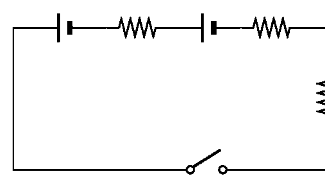
so $I = \boxed{1.79\ \text{A}}$

(b) $\Delta V_{term} = \mathcal{E} - Ir$

becomes $10.0\ \text{V} = \mathcal{E} - (1.79\ \text{A})(0.200\ \Omega)$

so $\mathcal{E} = \boxed{10.4\ \text{V}}$

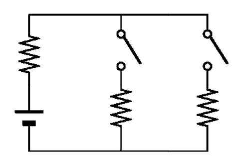
28.3 The total resistance is $R = \dfrac{3.00\ \text{V}}{0.600\ \text{A}} = 5.00\ \Omega$



(a) $R_{lamp} = R - r_{batteries} = 5.00\ \Omega - 0.408\ \Omega = \boxed{4.59\ \Omega}$

(b) $\dfrac{\mathcal{P}_{batteries}}{\mathcal{P}_{total}} = \dfrac{(0.408\ \Omega)I^2}{(5.00\ \Omega)I^2} = 0.0816 = \boxed{8.16\%}$

28.4 (a) Here $\mathcal{E} = I(R + r)$, so $I = \dfrac{\mathcal{E}}{R + r} = \dfrac{12.6\ \text{V}}{(5.00\ \Omega + 0.0800\ \Omega)} = 2.48\ \text{A}$



Then, $\Delta V = IR = (2.48\ \text{A})(5.00\ \Omega) = \boxed{12.4\ \text{V}}$

(b) Let I_1 and I_2 be the currents flowing through the battery and the headlights, respectively.

Then, $I_1 = I_2 + 35.0\ \text{A}$, and $\mathcal{E} - I_1 r - I_2 R = 0$

so $\mathcal{E} = (I_2 + 35.0\ \text{A})(0.0800\ \Omega) + I_2(5.00\ \Omega) = 12.6\ \text{V}$

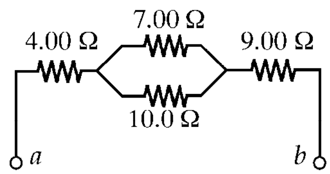
giving $I_2 = 1.93\ \text{A}$

Thus, $\Delta V_2 = (1.93\ \text{A})(5.00\ \Omega) = \boxed{9.65\ \text{V}}$

28.5 $\Delta V = I_1 R_1 = (2.00\ \text{A})R_1$ and $\Delta V = I_2(R_1 + R_2) = (1.60\ \text{A})(R_1 + 3.00\ \Omega)$

Therefore, $(2.00\ \text{A})R_1 = (1.60\ \text{A})(R_1 + 3.00\ \Omega)$ or $R_1 = \boxed{12.0\ \Omega}$

28.6 (a) $R_p = \dfrac{1}{(1/7.00\ \Omega)+(1/10.0\ \Omega)} = 4.12\ \Omega$



$R_s = R_1 + R_2 + R_3 = 4.00 + 4.12 + 9.00 = \boxed{17.1\ \Omega}$

(b) $\Delta V = IR$

$34.0\text{ V} = I(17.1\ \Omega)$

$I = \boxed{1.99\text{ A}}$ for 4.00 Ω, 9.00 Ω resistors

Applying $\Delta V = IR$, $(1.99\text{ A})(4.12\ \Omega) = 8.18\text{ V}$

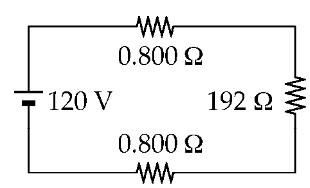
$8.18\text{ V} = I(7.00\ \Omega)$ so $I = \boxed{1.17\text{ A}}$ for 7.00 Ω resistor

$8.18\text{ V} = I(10.0\ \Omega)$ so $I = \boxed{0.818\text{ A}}$ for 10.0 Ω resistor

***28.7** If $\boxed{\text{all 3 resistors are placed in parallel}}$,

$\dfrac{1}{R} = \dfrac{1}{500} + \dfrac{2}{250} = \dfrac{5}{500}$ and $R = 100\ \Omega$

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



$I = \dfrac{\mathcal{P}}{\Delta V} = \dfrac{75.0\text{ W}}{120\text{ V}} = 0.625\text{ A}$ and $R = \dfrac{\Delta V}{I} = \dfrac{120\text{ V}}{0.625\text{ A}} = 192\ \Omega$

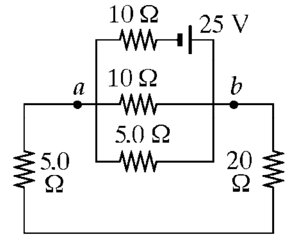
Now, presuming the bulb resistance is unchanged,

$I = \dfrac{120\text{ V}}{193.6\ \Omega} = 0.620\text{ A}$

Across the bulb is $\Delta V = IR = 192\ \Omega(0.620\text{ A}) = 119\text{ V}$

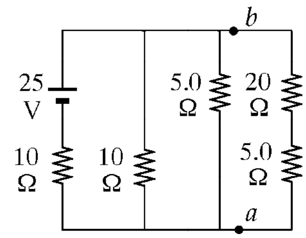
so its power is $\mathcal{P} = (\Delta V)I = 119\text{ V}(0.620\text{ A}) = \boxed{73.8\text{ W}}$

28.9 If we turn the given diagram on its side, we find that it is the same as Figure (a). The 20.0-Ω and 5.00-Ω resistors are in series, so the first reduction is as shown in (b). In addition, since the 10.0-Ω, 5.00-Ω, and 25.0-Ω resistors are then in parallel, we can solve for their equivalent resistance as:



$$R_{eq} = \frac{1}{\left(\frac{1}{10.0\ \Omega} + \frac{1}{5.00\ \Omega} + \frac{1}{25.0\ \Omega}\right)} = 2.94\ \Omega$$

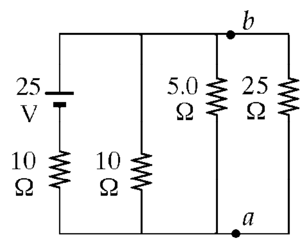
This is shown in Figure (c), which in turn reduces to the circuit shown in (d).



(a)

Next, we work backwards through the diagrams applying $I = \Delta V / R$ and $\Delta V = IR$. The 12.94-Ω resistor is connected across 25.0-V, so the current through the battery in every diagram is

$$I = \frac{\Delta V}{R} = \frac{25.0\ \text{V}}{12.94\ \Omega} = 1.93\ \text{A}$$

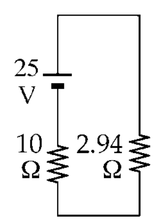


(b)

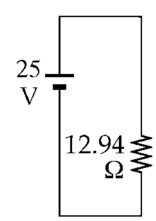
In Figure (c), this 1.93 A goes through the 2.94-Ω equivalent resistor to give a potential difference of:

$$\Delta V = IR = (1.93\ \text{A})(2.94\ \Omega) = 5.68\ \text{V}$$

From Figure (b), we see that this potential difference is the same across V_{ab}, the 10-Ω resistor, and the 5.00-Ω resistor.



(c)



(d)

(b) Therefore, $V_{ab} = \boxed{5.68\ \text{V}}$

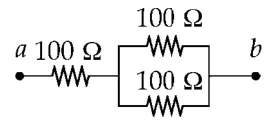
(a) Since the current through the 20.0-Ω resistor is also the current through the 25.0-Ω line *ab*,

$$I = \frac{V_{ab}}{R_{ab}} = \frac{5.68\ \text{V}}{25.0\ \Omega} = 0.227\ \text{A} = \boxed{227\ \text{mA}}$$

28.10 $$120\ \text{V} = IR_{eq} = I\left(\frac{\rho l}{A_1} + \frac{\rho l}{A_2} + \frac{\rho l}{A_3} + \frac{\rho l}{A_4}\right), \text{ or } \quad I\rho l = \frac{(120\ \text{V})}{\left(\frac{1}{A_1} + \frac{1}{A_2} + \frac{1}{A_3} + \frac{1}{A_4}\right)}$$

$$\Delta V_2 = \frac{I\rho l}{A_2} = \frac{(120\ \text{V})}{A_2\left(\frac{1}{A_1} + \frac{1}{A_2} + \frac{1}{A_3} + \frac{1}{A_4}\right)} = \boxed{29.5\ \text{V}}$$

28.11 (a) Since all the current flowing in the circuit must pass through the series 100-Ω resistor, $\mathcal{P} = RI^2$



$$\mathcal{P}_{max} = RI_{max}^2 \quad \text{so} \quad I_{max} = \sqrt{\frac{\mathcal{P}}{R}} = \sqrt{\frac{25.0\text{ W}}{100\ \Omega}} = 0.500\text{ A}$$

$$R_{eq} = 100\ \Omega + \left(\frac{1}{100} + \frac{1}{100}\right)^{-1}\Omega = 150\ \Omega$$

$$\Delta V_{max} = R_{eq} I_{max} = \boxed{75.0\text{ V}}$$

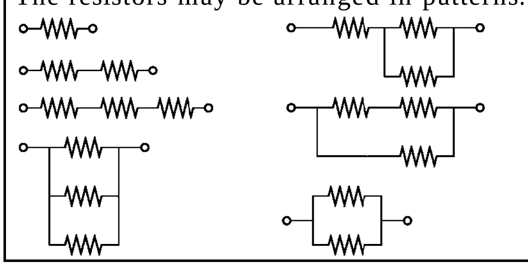
(b) $\mathcal{P} = (\Delta V)I = (75.0\text{ V})(0.500\text{ A}) = \boxed{37.5\text{ W}}$ total power

$\mathcal{P}_1 = \boxed{25.0\text{ W}}$ $\quad \mathcal{P}_2 = \mathcal{P}_3 = RI^2 = (100\ \Omega)(0.250\text{ A})^2 = \boxed{6.25\text{ W}}$

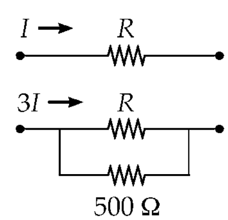
28.12 Using 2.00-Ω, 3.00-Ω, 4.00-Ω resistors, there are 7 series, 4 parallel, and 6 mixed combinations:

Series		Parallel	Mixed
2.00 Ω	6.00 Ω	0.923 Ω	1.56 Ω
3.00 Ω	7.00 Ω	1.20 Ω	2.00 Ω
4.00 Ω	9.00 Ω	1.33 Ω	2.22 Ω
5.00 Ω		1.71 Ω	3.71 Ω
			4.33 Ω
			5.20 Ω

The resistors may be arranged in patterns:



28.13 The potential difference is the same across either combination.



$$\Delta V = IR = 3I\frac{1}{\left(\frac{1}{R} + \frac{1}{500}\right)} \quad \text{so} \quad R\left(\frac{1}{R} + \frac{1}{500}\right) = 3$$

$$1 + \frac{R}{500} = 3 \quad \text{and} \quad R = 1000\ \Omega = \boxed{1.00\text{ k}\Omega}$$

28.14 If the switch is open, $I = \mathcal{E}/(R' + R)$ and $\mathcal{P} = \mathcal{E}^2 R'/(R' + R)^2$

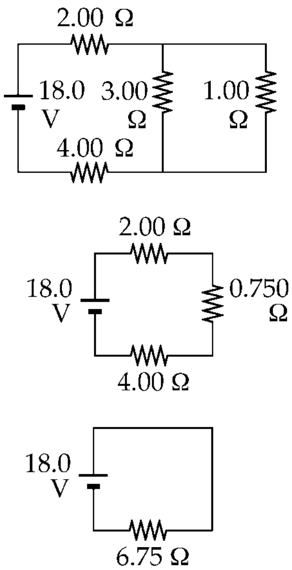
If the switch is closed, $I = \mathcal{E}/(R + R'/2)$ and $\mathcal{P} = \mathcal{E}^2 (R'/2)/(R + R'/2)^2$

Then,

$$\frac{\mathcal{E}^2 R'}{(R' + R)^2} = \frac{\mathcal{E}^2 R'}{2(R + R'/2)^2}$$

$$2R^2 + 2RR' + R'^2/2 = R'^2 + 2RR' + R^2$$

The condition becomes $R^2 = R'^2/2$ so $R' = \sqrt{2}\,R = \sqrt{2}(1.00\ \Omega) = \boxed{1.41\Omega}$



28.15 $R_p = \left(\frac{1}{3.00} + \frac{1}{1.00}\right)^{-1} = 0.750\ \Omega$

$R_s = (2.00 + 0.750 + 4.00)\ \Omega = 6.75\ \Omega$

$I_{\text{battery}} = \frac{\Delta V}{R_s} = \frac{18.0\ \text{V}}{6.75\ \Omega} = 2.67\ \text{A}$

$\mathcal{P} = I^2 R$: $\mathcal{P}_2 = (2.67\ \text{A})^2 (2.00\ \Omega)$

$\mathcal{P}_2 = \boxed{14.2\ \text{W}}$ in 2.00 Ω

$\mathcal{P}_4 = (2.67\ \text{A})^2 (4.00\ \Omega) = \boxed{28.4\ \text{W}}$ in 4.00 Ω

$\Delta V_2 = (2.67\ \text{A})(2.00\ \Omega) = 5.33\ \text{V}$, $\Delta V_4 = (2.67\ \text{A})(4.00\ \Omega) = 10.67\ \text{V}$

$\Delta V_p = 18.0\ \text{V} - \Delta V_2 - \Delta V_4 = 2.00\ \text{V} \quad (= \Delta V_3 = \Delta V_1)$

$\mathcal{P}_3 = \frac{(\Delta V_3)^2}{R_3} = \frac{(2.00\ \text{V})^2}{3.00\ \Omega} = \boxed{1.33\ \text{W}}$ in 3.00 Ω

$\mathcal{P}_1 = \frac{(\Delta V_1)^2}{R_1} = \frac{(2.00\ \text{V})^2}{1.00\ \Omega} = \boxed{4.00\ \text{W}}$ in 1.00 Ω

28.16 Denoting the two resistors as x and y,

$x + y = 690$, and $\frac{1}{150} = \frac{1}{x} + \frac{1}{y}$

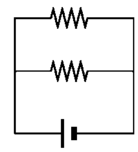
$\frac{1}{150} = \frac{1}{x} + \frac{1}{690 - x} = \frac{(690 - x) + x}{x(690 - x)}$

$x^2 - 690x + 103{,}500 = 0$

$x = \frac{690 \pm \sqrt{(690)^2 - 414{,}000}}{2}$

$x = \boxed{470\ \Omega}$ $y = \boxed{220\ \Omega}$

28.17 (a) $\Delta V = IR$: $33.0\text{ V} = I_1(11.0\ \Omega)$ $33.0\text{ V} = I_2(22.0\ \Omega)$



$I_1 = 3.00\text{ A}$ $I_2 = 1.50\text{ A}$

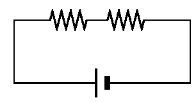
$P = I^2R$: $P_1 = (3.00\text{ A})^2(11.0\ \Omega)$ $P_2 = (1.50\text{ A})^2(22.0\ \Omega)$

$P_1 = 99.0\text{ W}$ $P_2 = 49.5\text{ W}$

The 11.0-Ω resistor uses more power.

(b) $P_1 + P_2 = \boxed{148\text{ W}}$ $P = I(\Delta V) = (4.50)(33.0) = \boxed{148\text{ W}}$

(c) $R_s = R_1 + R_2 = 11.0\ \Omega + 22.0\ \Omega = 33.0\ \Omega$



$\Delta V = IR$: $33.0\text{ V} = I(33.0\ \Omega)$, so $I = 1.00\text{ A}$

$P = I^2R$: $P_1 = (1.00\text{ A})^2(11.0\ \Omega)$ $P_2 = (1.00\text{ A})^2(22.0\ \Omega)$

$P_1 = 11.0\text{ W}$ $P_2 = 22.0\text{ W}$

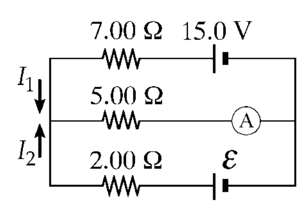
The 22.0-Ω resistor uses more power.

(d) $P_1 + P_2 = I^2(R_1 + R_2) = (1.00\text{ A})^2(33.0\ \Omega) = \boxed{33.0\text{ W}}$

$P = I(\Delta V) = (1.00\text{ A})(33.0\text{ V}) = \boxed{33.0\text{ W}}$

(e) The parallel configuration uses more power.

28.18 $+15.0 - (7.00)I_1 - (2.00)(5.00) = 0$



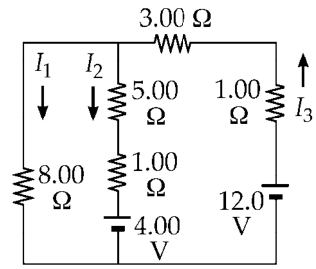
$5.00 = 7.00I_1$ so $\boxed{I_1 = 0.714\text{ A}}$

$I_3 = I_1 + I_2 = 2.00\text{ A}$

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

$+\mathcal{E} - 2.00(1.29) - (5.00)(2.00) = 0$ $\boxed{\mathcal{E} = 12.6\text{ V}}$

28.19 We name the currents I_1, I_2, and I_3 as shown.



From Kirchhoff's current rule, $I_3 = I_1 + I_2$

Applying Kirchhoff's voltage rule to the loop containing I_2 and I_3,

$12.0\text{ V} - (4.00)I_3 - (6.00)I_2 - 4.00\text{ V} = 0$

$8.00 = (4.00)I_3 + (6.00)I_2$

Applying Kirchhoff's voltage rule to the loop containing I_1 and I_2,

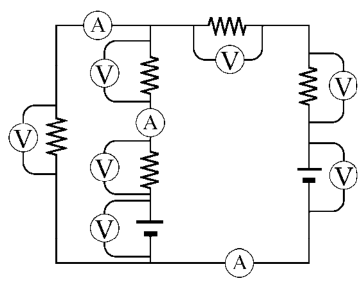
$-(6.00)I_2 - 4.00\text{ V} + (8.00)I_1 = 0$

$(8.00)I_1 = 4.00 + (6.00)I_2$

Solving the above linear systems, $\boxed{I_1 = 846\text{ mA}, \quad I_2 = 462\text{ mA}, \quad I_3 = 1.31\text{ A}}$

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

***28.20** The solution figure is shown to the right.



***28.21** We use the results of Problem 19.

(a) By the 4.00-V battery: $\Delta U = (\Delta V)It = 4.00\text{ V}(-0.462\text{ A})120\text{ s} = \boxed{-222\text{ J}}$

By the 12.0-V battery: $12.0\text{ V}(1.31\text{ A})\,120\text{ s} = \boxed{1.88\text{ kJ}}$

(b) By the 8.00 Ω resistor: $I^2Rt = (0.846\text{ A})^2(8.00\ \Omega)\,120\text{ s} = \boxed{687\text{ J}}$

By the 5.00 Ω resistor: $(0.462\text{ A})^2(5.00\ \Omega)\,120\text{ s} = \boxed{128\text{ J}}$

By the 1.00 Ω resistor: $(0.462\text{ A})^2(1.00\ \Omega)\,120\text{ s} = \boxed{25.6\text{ J}}$

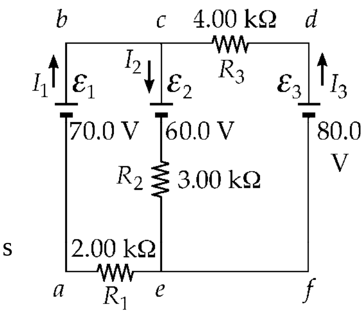
By the 3.00 Ω resistor: $(1.31\text{ A})^2(3.00\ \Omega)\,120\text{ s} = \boxed{616\text{ J}}$

By the 1.00 Ω resistor: $(1.31\text{ A})^2(1.00\ \Omega)\,120\text{ s} = \boxed{205\text{ J}}$

(c) $-222\text{ J} + 1.88\text{ kJ} = \boxed{1.66\text{ kJ}}$ from chemical to electrical.

687 J + 128 J + 25.6 J + 616 J + 205 J = 1.66 kJ from electrical to heat.

28.22 We name the currents I_1, I_2, and I_3 as shown.



[1] $70.0 - 60.0 - I_2 (3.00\ \text{k}\Omega) - I_1 (2.00\ \text{k}\Omega) = 0$

[2] $80.0 - I_3 (4.00\ \text{k}\Omega) - 60.0 - I_2 (3.00\ \text{k}\Omega) = 0$

[3] $I_2 = I_1 + I_3$

(a) Substituting for I_2 and solving the resulting simultaneous equations yields

$I_1 = \boxed{0.385\ \text{mA}}$ (through R_1)

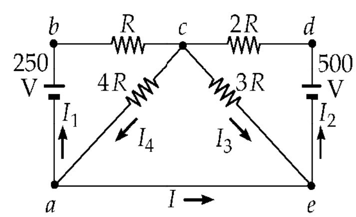
$I_3 = \boxed{2.69\ \text{mA}}$ (through R_3)

$I_2 = \boxed{3.08\ \text{mA}}$ (through R_2)

(b) $\Delta V_{cf} = -60.0\ \text{V} - (3.08\ \text{mA})(3.00\ \text{k}\Omega) = \boxed{-69.2\ \text{V}}$

$\boxed{\text{Point } c \text{ is at higher potential.}}$

28.23 Label the currents in the branches as shown in the first figure. Reduce the circuit by combining the two parallel resistors as shown in the second figure.

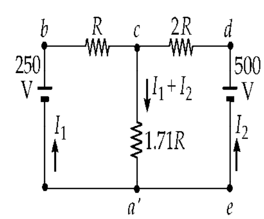


(a)

Apply Kirchhoff's loop rule to both loops in Figure (b) to obtain:

$$(2.71R)I_1 + (1.71R)I_2 = 250 \quad \text{and} \quad (1.71R)I_1 + (3.71R)I_2 = 500$$

With $R = 1000\ \Omega$, simultaneous solution of these equations yields:



(b)

$I_1 = 10.0\ \text{mA}$ and $I_2 = 130.0\ \text{mA}$

From Figure (b), $V_c - V_a = (I_1 + I_2)(1.71R) = 240\ \text{V}$

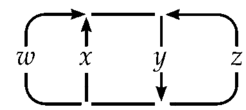
Thus, from Figure (a), $I_4 = \dfrac{V_c - V_a}{4R} = \dfrac{240\ \text{V}}{4000\ \Omega} = 60.0\ \text{mA}$

Finally, applying Kirchhoff's point rule at point a in Figure (a) gives:

$I = I_4 - I_1 = 60.0\ \text{mA} - 10.0\ \text{mA} = +50.0\ \text{mA}$,

or $I = \boxed{50.0\ \text{mA flowing from point } a \text{ to point } e}$.

28.24 Name the currents as shown in the figure to the right. Then $w + x + z = y$. Loop equations are



$-200w - 40.0 + 80.0x = 0$

$-80.0x + 40.0 + 360 - 20.0y = 0$

$+360 - 20.0y - 70.0z + 80.0 = 0$

Eliminate y by substitution. $\begin{cases} x = 2.50w + 0.500 \\ 400 - 100x - 20.0w - 20.0z = 0 \\ 440 - 20.0w - 20.0x - 90.0z = 0 \end{cases}$

Eliminate x: $\begin{cases} 350 - 270w - 20.0z = 0 \\ 430 - 70.0w - 90.0z = 0 \end{cases}$

Eliminate $z = 17.5 - 13.5w$ to obtain $430 - 70.0w - 1575 + 1215w = 0$

$w = 70.0/70.0 = \boxed{1.00 \text{ A upward in } 200\ \Omega}$

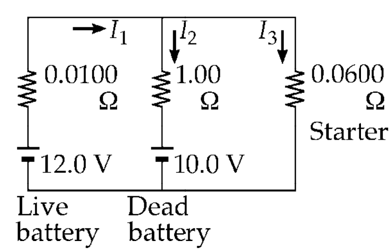
Now $z = \boxed{4.00 \text{ A upward in } 70.0\ \Omega}$

$x = \boxed{3.00 \text{ A upward in } 80.0\ \Omega}$

$y = \boxed{8.00 \text{ A downward in } 20.0\ \Omega}$

and for the 200 Ω, $\Delta V = IR = (1.00 \text{ A})(200\ \Omega) = \boxed{200 \text{ V}}$

28.25 Using Kirchhoff's rules,



$12.0 - (0.0100)I_1 - (0.0600)I_3 = 0$

$10.0 + (1.00)I_2 - (0.0600)I_3 = 0$

and $I_1 = I_2 + I_3$

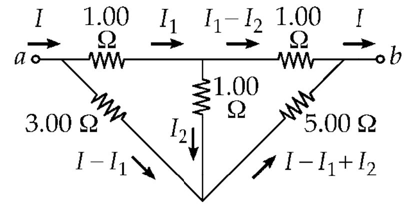
$12.0 - (0.0100)I_2 - (0.0700)I_3 = 0$

$10.0 + (1.00)I_2 - (0.0600)I_3 = 0$

Solving simultaneously, $I_2 = \boxed{0.283 \text{ A downward}}$ in the dead battery,

and $I_3 = \boxed{171 \text{ A downward}}$ in the starter.

28.26 $V_{ab} = (1.00)I_1 + (1.00)(I_1 - I_2)$



$V_{ab} = (1.00)I_1 + (1.00)I_2 + (5.00)(I - I_1 + I_2)$

$V_{ab} = (3.00)(I - I_1) + (5.00)(I - I_1 + I_2)$

Let $I = 1.00$ A, $I_1 = x$, and $I_2 = y$

Then, the three equations become:

$V_{ab} = 2.00x - y$, or $y = 2.00x - V_{ab}$

$V_{ab} = -4.00x + 6.00y + 5.00$

and $V_{ab} = 8.00 - 8.00x + 5.00y$

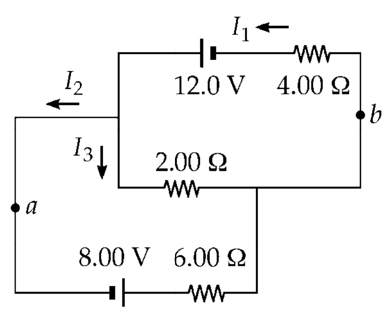
Substituting the first into the last two gives:

$7.00V_{ab} = 8.00x + 5.00$ and $6.00V_{ab} = 2.00x + 8.00$

Solving these simultaneously yields $V_{ab} = \frac{27}{17}$ V

Then, $R_{ab} = \frac{V_{ab}}{I} = \frac{27/17 \text{ V}}{1.00 \text{ A}}$ or $\boxed{R_{ab} = \frac{27}{17}\ \Omega}$

28.27 We name the currents I_1, I_2, and I_3 as shown.



(a) $I_1 = I_2 + I_3$

Counterclockwise around the top loop,

$12.0 \text{ V} - (2.00\ \Omega)I_3 - (4.00\ \Omega)I_1 = 0$

Traversing the bottom loop,

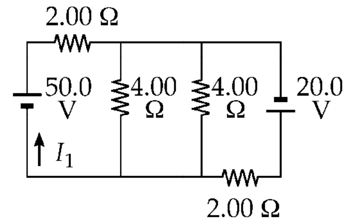
$8.00 \text{ V} - (6.00\ \Omega)I_2 + (2.00\ \Omega)I_3 = 0$

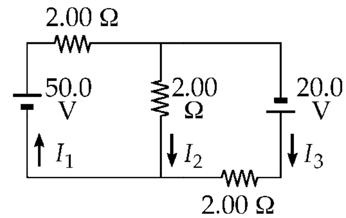
$I_1 = 3.00 - \frac{1}{2}I_3 \quad I_2 = \frac{4}{3} + \frac{1}{3}I_3$ and $\boxed{I_3 = 909 \text{ mA}}$

(b) $V_a - (0.909 \text{ A})(2.00\ \Omega) = V_b$

$V_b - V_a = \boxed{-1.82 \text{ V}}$

28.28 We apply Kirchhoff's rules to the second diagram.





$50.0 - 2.00I_1 - 2.00I_2 = 0$ (1)

$20.0 - 2.00I_3 + 2.00I_2 = 0$ (2)

$I_1 = I_2 + I_3$ (3)

Substitute (3) into (1), and solve for I_1, I_2, and I_3

$I_1 = 20.0$ A; $I_2 = 5.00$ A; $I_3 = 15.0$ A

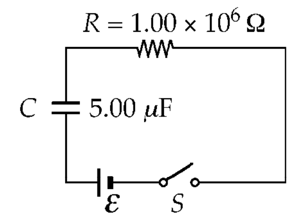
Then apply $P = I^2R$ to each resistor:

$(2.00\ \Omega)_1$: $P = I_1^2(2.00\ \Omega) = (20.0\text{ A})^2(2.00\ \Omega) = \boxed{800\text{ W}}$

$(4.00\ \Omega)$: $P = \left(\dfrac{5.00}{2}\text{ A}\right)^2(4.00\ \Omega) = \boxed{25.0\text{ W}}$
(Half of I_2 goes through each)

$(2.00\ \Omega)_3$: $P = I_3^2(2.00\ \Omega) = (15.0\text{ A})^2(2.00\ \Omega) = \boxed{450\text{ W}}$

28.29 (a) $RC = (1.00\times10^6\ \Omega)(5.00\times10^{-6}\text{ F}) = \boxed{5.00\text{ s}}$



(b) $Q = C\mathcal{E} = (5.00\times10^{-6}\text{ C})(30.0\text{ V}) = \boxed{150\ \mu\text{C}}$

(c) $I(t) = \dfrac{\mathcal{E}}{R}e^{-t/RC} = \dfrac{30.0}{1.00\times10^6}\exp\left[\dfrac{-10.0}{(1.00\times10^6)(5.00\times10^{-6})}\right] = \boxed{4.06\ \mu\text{A}}$

28.30 (a) $I(t) = -I_0e^{-t/RC}$

$$I_0 = \frac{Q}{RC} = \frac{5.10\times10^{-6}\text{ C}}{(1300\ \Omega)(2.00\times10^{-9}\text{ F})} = 1.96\text{ A}$$

$$I(t) = -(1.96\text{ A})\exp\left[\frac{-9.00\times10^{-6}\text{ s}}{(1300\ \Omega)(2.00\times10^{-9}\text{ F})}\right] = \boxed{-61.6\text{ mA}}$$

(b) $q(t) = Qe^{-t/RC} = (5.10\ \mu\text{C})\exp\left[\dfrac{-8.00\times10^{-6}\text{ s}}{(1300\ \Omega)(2.00\times10^{-9}\text{ F})}\right] = \boxed{0.235\ \mu\text{C}}$

(c) The magnitude of the current is $\boxed{I_0 = 1.96\text{ A}}$

28.31 $U = \frac{1}{2}C(\Delta V)^2$ and $\Delta V = Q/C$

Therefore, $U = Q^2/2C$ and when the charge decreases to half its original value, the stored energy is one-quarter its original value: $\boxed{U_f = \frac{1}{4}U_0}$

28.32 (a) $\tau = RC = (1.50 \times 10^5\ \Omega)(10.0 \times 10^{-6}\ \text{F}) = \boxed{1.50\ \text{s}}$

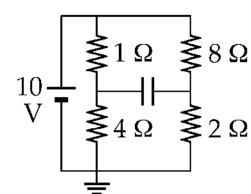
(b) $\tau = (1.00 \times 10^5\ \Omega)(10.0 \times 10^{-6}\ \text{F}) = \boxed{1.00\ \text{s}}$

(c) The battery carries current $\dfrac{10.0\ \text{V}}{50.0 \times 10^3\ \Omega} = 200\ \mu\text{A}$

The 100 kΩ carries current of magnitude $I = I_0 e^{-t/RC} = \left(\dfrac{10.0\ \text{V}}{100 \times 10^3\ \Omega}\right) e^{-t/\,1.00\ \text{s}}$

So the switch carries downward current $\boxed{200\ \mu\text{A} + (100\ \mu\text{A})e^{-t/1.00\ \text{s}}}$

28.33 (a) Call the potential at the left junction V_L and at the right V_R. After a "long" time, the capacitor is fully charged.



V_L = 8.00 V because of voltage divider: $I_L = \dfrac{10.0\ \text{V}}{5.00\ \Omega} = 2.00\ \text{A}$

$V_L = 10.0\ \text{V} - (2.00\ \text{A})(1.00\ \Omega) = 8.00\ \text{V}$

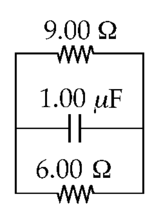
Likewise, $V_R = \left(\dfrac{2.00\ \Omega}{2.00\ \Omega + 8.00\ \Omega}\right) 10.0\ \text{V} = 2.00\ \text{V}$

or $I_R = \dfrac{10.0\ \text{V}}{10.0\ \Omega} = 1.00\ \text{A}$

$V_R = (10.0\ \text{V}) - (8.00\ \Omega)(1.00\ \text{A}) = 2.00\ \text{V}$

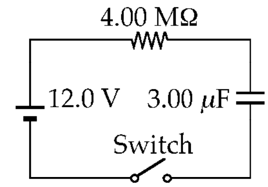
Therefore, $\Delta V = V_L - V_R = 8.00 - 2.00 = \boxed{6.00\ \text{V}}$

(b) Redraw the circuit $R = \dfrac{1}{(1/9.00\ \Omega) + (1/6.00\ \Omega)} = 3.60\ \Omega$



$RC = 3.60 \times 10^{-6}\ \text{s}$

and $e^{-t/RC} = \dfrac{1}{10}$ so $t = RC \ln 10 = \boxed{8.29\ \mu\text{s}}$



28.34 (a) $\tau = RC = \left(4.00\times10^{6}\ \Omega\right)\left(3.00\times10^{-6}\ \text{F}\right) = \boxed{12.0\ \text{s}}$

(b) $I = \frac{\mathcal{E}}{R}e^{-t/RC} = \frac{12.0}{4.00\times10^{6}}\,e^{-t/12.0\ \text{s}}$

$q = C\mathcal{E}\left[1-e^{-t/RC}\right] = 3.00\times10^{-6}(12.0)\left[1-e^{-t/12.0}\right)$

$\boxed{q = 36.0\ \mu\text{C}\left[1-e^{-t/12.0}\right]}$ $\boxed{I = 3.00\ \mu\text{A}e^{-t/12.0}}$

28.35 $\Delta V_0 = \frac{Q}{C}$

Then, if $q(t) = Qe^{-t/RC}$ $\Delta V(t) = \Delta V_0 e^{-t/RC}$

$$\frac{\Delta V(t)}{\Delta V_0} = e^{-t/RC}$$

Therefore $\frac{1}{2} = \exp\left(-\frac{4.00}{R\left(3.60\times10^{-6}\right)}\right)$

$$\ln\left(\frac{1}{2}\right) = -\frac{4.00}{R\left(3.60\times10^{-6}\right)}$$

$$R = \boxed{1.60\ \text{M}\Omega}$$

28.36 $\Delta V_0 = \frac{Q}{C}$

Then, if $q(t) = Q\,e^{-t/RC}$ $\Delta V(t) = \left(\Delta V_0\right)e^{-t/RC}$

and $\frac{\Delta V(t)}{\left(\Delta V_0\right)} = e^{-t/RC}$

When $\Delta V(t) = \frac{1}{2}\left(\Delta V_0\right)$, then $e^{-t/RC} = \frac{1}{2}$

$$-\frac{t}{RC} = \ln\left(\frac{1}{2}\right) = -\ln 2$$

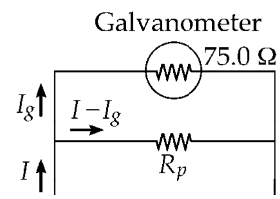
Thus, $\boxed{R = \frac{t}{C(\ln 2)}}$

28.37 $q(t) = Q\left[1 - e^{-t/RC}\right]$ so $\frac{q(t)}{Q} = 1 - e^{-t/RC}$

$0.600 = 1 - e^{-0.900/RC}$ or $e^{-0.900/RC} = 1 - 0.600 = 0.400$

$\frac{-0.900}{RC} = \ln(0.400)$ thus $RC = \frac{-0.900}{\ln(0.400)} = \boxed{0.982 \text{ s}}$

28.38 Applying Kirchhoff's loop rule, $-I_g(75.0\ \Omega) + \left(I - I_g\right)R_p = 0$



Therefore, if $I = 1.00$ A when $I_g = 1.50$ mA,

$$R_p = \frac{I_g(75.0\ \Omega)}{\left(I - I_g\right)} = \frac{\left(1.50 \times 10^{-3}\text{ A}\right)(75.0\ \Omega)}{1.00\text{ A} - 1.50 \times 10^{-3}\text{ A}} = \boxed{0.113\ \Omega}$$

28.39 Series Resistor → Voltmeter

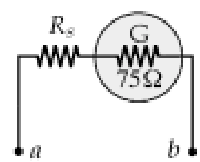


Figure for Goal Solution

$\Delta V = IR$: $25.0 = 1.50 \times 10^{-3}(R_s + 75.0)$

Solving, $\boxed{R_s = 16.6\text{ k}\Omega}$

Goal Solution

The galvanometer described in the preceding problem can be used to measure voltages. In this case a large resistor is wired in series with the galvanometer in a way similar to that shown in Figure P28.24b This arrangement, in effect, limits the current that flows through the galvanometer when large voltages are applied. Most of the potential drop occurs across the resistor placed in series. Calculate the value of the resistor that enables the galvanometer to measure an applied voltage of 25.0 V at full-scale deflection.

G: The problem states that the value of the resistor must be "large" in order to limit the current through the galvanometer, so we should expect a resistance of kΩ to MΩ.

O: The unknown resistance can be found by applying the definition of resistance to the portion of the circuit shown in Figure 28.24b.

A: $\Delta V_{ab} = 25.0$ V; From Problem 38, $I = 1.50$ mA and $R_g = 75.0\ \Omega$. For the two resistors in series, $R_{eq} = R_s + R_g$ so the definition of resistance gives us: $\Delta V_{ab} = I(R_s + R_g)$

Therefore, $R_s = \frac{\Delta V_{ab}}{I} - R_g = \frac{25.0\text{ V}}{1.50 \times 10^{-3}\text{ A}} - 75.0\ \Omega = 16.6\text{ k}\Omega$

L: The resistance is relatively large, as expected. It is important to note that some caution would be necessary if this arrangement were used to measure the voltage across a circuit with a comparable resistance. For example, if the circuit resistance was 17 kΩ, the voltmeter in this problem would cause a measurement inaccuracy of about 50%, because the meter would divert about half the current that normally would go through the resistor being measured. Problems 46 and 59 address a similar concern about measurement error when using electrical meters.

28.40 We will use the values required for the 1.00-V voltmeter to obtain the internal resistance of the galvanometer. $\Delta V = I_g(R + r_g)$

Solve for r_g: $$r_g = \frac{\Delta V}{I_g} - R = \frac{1.00\text{ V}}{1.00\times 10^{-3}\text{ A}} - 900\ \Omega = 100\ \Omega$$

We then obtain the series resistance required for the 50.0-V voltmeter:

$$R = \frac{V}{I_g} - r_g = \frac{50.0\text{ V}}{1.00\times 10^{-3}\text{ A}} - 100\ \Omega = \boxed{49.9\text{ k}\Omega}$$

28.41 $\Delta V = I_g r_g = \left(I - I_g\right)R_p$, or $R_p = \dfrac{I_g r_g}{\left(I - I_g\right)} = \dfrac{I_g(60.0\ \Omega)}{\left(I - I_g\right)}$

Therefore, to have $I = 0.100\text{ A} = 100\text{ mA}$ when $I_g = 0.500\text{ mA}$:

$$R_p = \frac{(0.500\text{ mA})(60.0\ \Omega)}{99.5\text{ mA}} = \boxed{0.302\ \Omega}$$

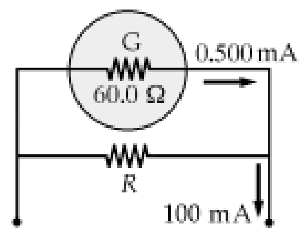


Figure for Goal Solution

<u>Goal Solution</u>
Assume that a galvanometer has an internal resistance of $60.0\ \Omega$ and requires a current of 0.500 mA to produce full-scale deflection. What resistance must be connected in parallel with the galvanometer if the combination is to serve as an ammeter that has a full-scale deflection for a current of 0.100 A?

G: An ammeter reads the flow of current in a portion of a circuit; therefore it must have a low resistance so that it does not significantly alter the current that would exist without the meter. Therefore, the resistance required is probably less than $1\ \Omega$.

O: From the values given for a full-scale reading, we can find the voltage across and the current through the shunt (parallel) resistor, and the resistance value can then be found from the definition of resistance.

A: The voltage across the galvanometer must be the same as the voltage across the shunt resistor in parallel, so when the ammeter reads full scale,

$$\Delta V = (0.500\text{ mA})(60.0\ \Omega) = 30.0\text{ mV}$$

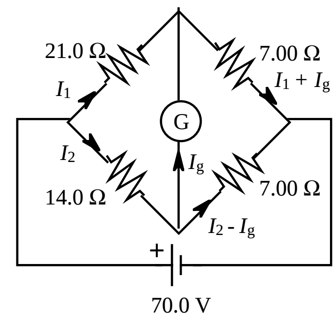
Through the shunt resistor, $I = 100\text{ mA} - 0.500\text{ mA} = 99.5\text{ mA}$

Therefore, $$R = \frac{\Delta V}{I} = \frac{30.0\text{ mV}}{99.5\text{ mA}} = 0.302\ \Omega$$

L: The shunt resistance is less than $1\ \Omega$ as expected. It is important to note that some caution would be necessary if this meter were used in a circuit that had a low resistance. For example, if the circuit resistance was $3\ \Omega$, adding the ammeter to the circuit would reduce the current by about 10%, so the current displayed by the meter would be lower than without the meter. Problems 46 and 59 address a similar concern about measurement error when using electrical meters.

28.42 $R_x = \frac{R_2 R_3}{R_1} = \frac{R_2 R_3}{2.50 R_2} = \frac{1000\ \Omega}{2.50} = \boxed{400\ \Omega}$

28.43 Using Kirchhoff's rules with $R_g << 1$,



$-(21.0\ \Omega)I_1 + (14.0\ \Omega)I_2 = 0$, so $I_1 = \frac{2}{3}I_2$

$70.0 - 21.0I_1 - 7.00\left(I_1 + I_g\right) = 0$, and

$70.0 - 14.0I_2 - 7.00\left(I_2 - I_g\right) = 0$

The last two equations simplify to

$10.0 - 4.00\left(\frac{2}{3}I_2\right) = I_g$, and $10.0 - 3.00I_2 = -I_g$

Solving simultaneously yields: $I_g = \boxed{0.588\ \text{A}}$

28.44 $R = \frac{\rho L}{A}$ and $R_i = \frac{\rho L_i}{A_i}$

But, $V = AL = A_i L_i$, so $R = \frac{\rho L^2}{V}$ and $R_i = \frac{\rho L_i^2}{V}$

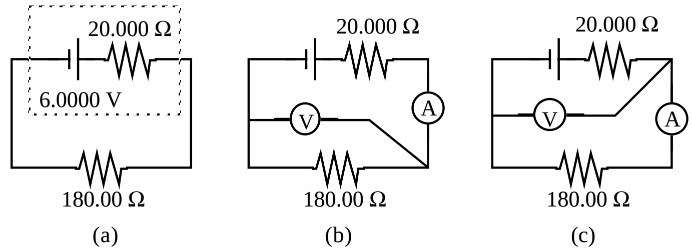
Therefore, $R = \frac{\rho\left(L_i + \Delta L\right)^2}{V} = \frac{\rho L_i\left[1 + \left(\Delta L/L_i\right)\right]^2}{V} = R_i\left[1 + \alpha\right]^2$ where $\alpha \equiv \frac{\Delta L}{L}$

This may be written as: $\boxed{R = R_i(1 + 2\alpha + \alpha^2)}$

28.45 $\frac{\mathcal{E}_x}{R_s} = \frac{\mathcal{E}_s}{R_s}$; $\mathcal{E}_x = \frac{\mathcal{E}_s R_x}{R_s} = \left(\frac{48.0\ \Omega}{36.0\ \Omega}\right)(1.0186\ \text{V}) = \boxed{1.36\ \text{V}}$

***28.46** (a) In Figure (a), the emf sees an equivalent resistance of 200.00 Ω.

$$I = \frac{6.000\ 0\ \text{V}}{200.00\ \Omega} = \boxed{0.030\ 000\ \text{A}}$$



The terminal potential difference is $\Delta V = IR = (0.030\ 000\ \text{A})(180.00\ \Omega) = \boxed{5.400\ 0\ \text{V}}$

(b) In Figure (b), $R_{eq} = \left(\frac{1}{180.00\ \Omega} + \frac{1}{20\ 000\ \Omega}\right)^{-1} = 178.39\ \Omega$

The equivalent resistance across the emf is $178.39\ \Omega + 0.500\ 00\ \Omega + 20.000\ \Omega = 198.89\ \Omega$

The ammeter reads $I = \frac{\mathcal{E}}{R} = \frac{6.000\ 0\ \text{V}}{198.89\ \Omega} = \boxed{0.030\ 167\ \text{A}}$

and the voltmeter reads $\Delta V = IR = (0.030\ 167\ \text{A})(178.39\ \Omega) = \boxed{5.381\ 6\ \text{V}}$

(c) In Figure (c), $\left(\frac{1}{180.50\ \Omega} + \frac{1}{20\ 000\ \Omega}\right)^{-1} = 178.89\ \Omega$

Therefore, the emf sends current through $R_{tot} = 178.89\ \Omega + 20.000\ \Omega = 198.89\ \Omega$

The current through the battery is $I = \frac{6.000\ 0\ \text{V}}{198.89\ \Omega} = 0.030\ 168\ \text{A}$

but not all of this goes through the ammeter.

The voltmeter reads $\Delta V = IR = (0.030\ 168\ \text{A})(178.89\ \Omega) = \boxed{5.396\ 6\ \text{V}}$

The ammeter measures current $I = \frac{\Delta V}{R} = \frac{5.396\ 6\ \text{V}}{180.50\ \Omega} = \boxed{0.029\ 898\ \text{A}}$

The connection shown in Figure (c) is better than that shown in Figure (b) for accurate readings.

28.47 (a) $\mathcal{P} = I(\Delta V)$ So for the Heater, $I = \frac{\mathcal{P}}{\Delta V} = \frac{1500\ \text{W}}{120\ \text{V}} = \boxed{12.5\ \text{A}}$

For the Toaster, $I = \frac{750\ \text{W}}{120\ \text{W}} = \boxed{6.25\ \text{A}}$

And for the Grill, $I = \frac{1000\ \text{W}}{120\ \text{V}} = \boxed{8.33\ \text{A}}$ (Grill)

(b) $12.5 + 6.25 + 8.33 = \boxed{27.1\ \text{A}}$ The current draw is greater than 25.0 amps, so this would not be sufficient.

28.48 (a) $\mathcal{P} = I^2 R = I^2\left(\frac{\rho \ell}{A}\right) = \frac{(1.00\text{ A})^2(1.70\times10^{-8}\ \Omega\cdot\text{m})(16.0\text{ ft})(0.3048\text{ m / ft})}{\pi(0.512\times10^{-3}\text{ m})^2} = \boxed{0.101\text{ W}}$

(b) $\mathcal{P} = I^2 R = 100(0.101\ \Omega) = \boxed{10.1\text{ W}}$

28.49 $I_{\text{Al}}^2 R_{\text{Al}} = I_{\text{Cu}}^2 R_{\text{Cu}}$ so $I_{\text{Al}} = \sqrt{\frac{R_{\text{Cu}}}{R_{\text{Al}}}}\, I_{\text{Cu}} = \sqrt{\frac{\rho_{\text{Cu}}}{\rho_{\text{Al}}}}\, I_{\text{Cu}} = \sqrt{\frac{1.70}{2.82}}(20.0) = 0.776(20.0) = \boxed{15.5\text{ A}}$

***28.50** (a) Suppose that the insulation between either of your fingers and the conductor adjacent is a chunk of rubber with contact area 4 mm^2 and thickness 1 mm. Its resistance is

$$R = \frac{\rho \ell}{A} \cong \frac{\left(10^{13}\ \Omega\cdot\text{m}\right)\left(10^{-3}\text{ m}\right)}{4\times10^{-6}\text{ m}^2} \cong 2\times10^{15}\ \Omega$$

The current will be driven by 120 V through total resistance (series)

$$2\times10^{15}\ \Omega + 10^4\ \Omega + 2\times10^{15}\ \Omega \cong 5\times10^{15}\ \Omega$$

It is: $I = \frac{\Delta V}{R} \sim \frac{120\text{ V}}{5\times10^{15}\ \Omega}$ $\boxed{\sim 10^{-14}\text{ A}}$

(b) The resistors form a voltage divider, with the center of your hand at potential $V_h/2$, where V_h is the potential of the "hot" wire. The potential difference between your finger and thumb is $\Delta V = IR \sim \left(10^{-14}\text{ A}\right)\left(10^4\ \Omega\right) \sim 10^{-10}\text{ V}$. So the points where the rubber meets your fingers are at potentials of

$\boxed{\sim \frac{V_h}{2} + 10^{-10}\text{ V}}$ and $\boxed{\sim \frac{V_h}{2} - 10^{-10}\text{ V}}$

***28.51** The set of four batteries boosts the electric potential of each bit of charge that goes through them by $4\times1.50\text{ V} = 6.00\text{ V}$. The chemical energy they store is

$$\Delta U = q\Delta V = (240\text{ C})(6.00\text{ J / C}) = 1440\text{ J}$$

The radio draws current $I = \frac{\Delta V}{R} = \frac{6.00\text{ V}}{200\ \Omega} = 0.0300\text{ A}$

So, its power is $\mathcal{P} = (\Delta V)I = (6.00\text{ V})(0.0300\text{ A}) = 0.180\text{ W} = 0.180\text{ J / s}$

Then for the time the energy lasts, we have $\mathcal{P} = E/t$: $t = \frac{E}{\mathcal{P}} = \frac{1440\text{ J}}{0.180\text{ J / s}} = 8.00\times10^3\text{ s}$

We could also compute this from $I = Q/t$: $t = \frac{Q}{I} = \frac{240\text{ C}}{0.0300\text{ A}} = 8.00\times10^3\text{ s} = \boxed{2.22\text{ h}}$

***28.52** $I = \dfrac{\mathcal{E}}{R+r}$, so $\mathsf{P} = I^2 R = \dfrac{\mathcal{E}^2 R}{(R+r)^2}$ or $(R+r)^2 = \left(\dfrac{\mathcal{E}^2}{\mathsf{P}}\right)R$

Let $x \equiv \dfrac{\mathcal{E}^2}{\mathsf{P}}$, then $(R+r)^2 = xR$ or $R^2 + (2r - x)R - r^2 = 0$

With $r = 1.20\ \Omega$, this becomes $R^2 + (2.40 - x)R - 1.44 = 0$,

which has solutions of $R = \dfrac{-(2.40 - x) \pm \sqrt{(2.40 - x)^2 - 5.76}}{2}$

(a) With $\mathcal{E} = 9.20$ V and $\mathsf{P} = 12.8$ W, $x = 6.61$: $R = \dfrac{+4.21 \pm \sqrt{(4.21)^2 - 5.76}}{2} = \boxed{3.84\ \Omega}$ or $\boxed{0.375\ \Omega}$

(b) For $\mathcal{E} = 9.20$ V and $\mathsf{P} = 21.2$ W, $x \equiv \dfrac{\mathcal{E}^2}{\mathsf{P}} = 3.99$ $R = \dfrac{+1.59 \pm \sqrt{(1.59)^2 - 5.76}}{2} = \dfrac{1.59 \pm \sqrt{-3.22}}{2}$

The equation for the load resistance yields a complex number, so $\boxed{\text{there is no resistance}}$ that will extract 21.2 W from this battery. The maximum power output occurs when $R = r = 1.20\ \Omega$, and that maximum is: $\mathsf{P}_{max} = \mathcal{E}^2 / 4r = 17.6$ W

28.53 Using Kirchhoff's loop rule for the closed loop, $+12.0 - 2.00I - 4.00I = 0$, so $I = 2.00$ A

$V_b - V_a = +4.00\text{ V} - (2.00\text{ A})(4.00\ \Omega) - (0)(10.0\ \Omega) = -4.00\text{ V}$

Thus, $|\Delta V_{ab}| = \boxed{4.00\text{ V}}$ and $\boxed{\text{point } a \text{ is at the higher potential}}$.

28.54 The potential difference across the capacitor $\Delta V(t) = \Delta V_{max}\left[1 - e^{-t/RC}\right]$

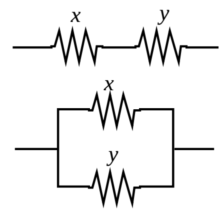
Using 1 Farad = 1 s/Ω, $4.00\text{ V} = (10.0\text{ V})\left[1 - e^{-(3.00\text{ s})/R(10.0 \times 10^{-6}\text{ s}/\Omega)}\right]$

Therefore, $0.400 = 1.00 - e^{-(3.00 \times 10^5\ \Omega)/R}$ or $e^{-(3.00 \times 10^5\ \Omega)/R} = 0.600$

Taking the natural logarithm of both sides, $-\dfrac{3.00 \times 10^5\ \Omega}{R} = \ln(0.600)$

and $R = -\dfrac{3.00 \times 10^5\ \Omega}{\ln(0.600)} = +5.87 \times 10^5\ \Omega = \boxed{587\text{ k}\Omega}$

28.55 Let the two resistances be x and y.



Then, $R_s = x + y = \frac{P_s}{I^2} = \frac{225\text{ W}}{(5.00\text{ A})^2} = 9.00\ \Omega$ $\qquad y = 9.00\ \Omega - x$

and $R_p = \frac{xy}{x+y} = \frac{P_p}{I^2} = \frac{50.0\text{ W}}{(5.00\text{ A})^2} = 2.00\ \Omega$

so $\frac{x(9.00\ \Omega - x)}{x + (9.00\ \Omega - x)} = 2.00\ \Omega$ $\qquad x^2 - 9.00x + 18.0 = 0$

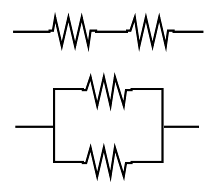
Factoring the second equation, $\qquad (x - 6.00)(x - 3.00) = 0$

so $\qquad x = 6.00\ \Omega$ or $x = 3.00\ \Omega$

Then, $y = 9.00\ \Omega - x$ gives $\qquad y = 3.00\ \Omega$ or $y = 6.00\ \Omega$

The two resistances are found to be $\boxed{6.00\ \Omega}$ and $\boxed{3.00\ \Omega}$.

28.56 Let the two resistances be x and y.



Then, $R_s = x + y = \frac{P_s}{I^2}$ and $R_p = \frac{xy}{x+y} = \frac{P_p}{I^2}$.

From the first equation, $y = \frac{P_s}{I^2} - x$, and the second

becomes $\frac{x\left(P_s/I^2 - x\right)}{x + \left(P_s/I^2 - x\right)} = \frac{P_p}{I^2}$ or $x^2 - \left(\frac{P_s}{I^2}\right)x + \frac{P_s P_p}{I^4} = 0$.

Using the quadratic formula, $x = \frac{P_s \pm \sqrt{P_s^2 - 4P_s P_p}}{2I^2}$.

Then, $y = \frac{P_s}{I^2} - x$ gives $y = \frac{P_s > \sqrt{P_s^2 - 4P_s P_p}}{2I^2}$.

The two resistances are $\boxed{\frac{P_s + \sqrt{P_s^2 - 4P_s P_p}}{2I^2}}$ and $\boxed{\frac{P_s - \sqrt{P_s^2 - 4P_s P_p}}{2I^2}}$

28.57 The current in the simple loop circuit will be $I = \dfrac{\mathcal{E}}{R+r}$

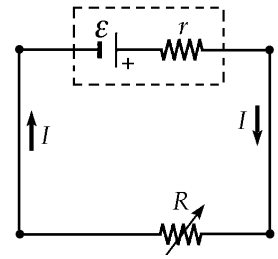


Figure for Goal Solution

(a) $\Delta V_{\text{ter}} = \mathcal{E} - Ir = \dfrac{\mathcal{E}R}{R+r}$ and $\Delta V_{\text{ter}} \to \mathcal{E}$ as $\boxed{R \to \infty}$

(b) $I = \dfrac{\mathcal{E}}{R+r}$ and $I \to \dfrac{\mathcal{E}}{r}$ as $\boxed{R \to 0}$

(c) $\mathcal{P} = I^2 R = \mathcal{E}^2 \dfrac{R}{(R+r)^2}$

$$\frac{d\mathcal{P}}{dR} = \mathcal{E}^2 R(-2)(R+r)^{-3} + \mathcal{E}^2 (R+r)^{-2} = \frac{-2\mathcal{E}^2 R}{(R+r)^3} + \frac{\mathcal{E}^2}{(R+r)^2} = 0$$

Then $2R = R + r$ and $\boxed{R = r}$

Goal Solution

A battery has an emf $\mathcal{E}$ and internal resistance r. A variable resistor R is connected across the terminals of the battery. Determine the value of R such that (a) the potential difference across the terminals is a maximum, (b) the current in the circuit is a maximum, (c) the power delivered to the resistor is a maximum.

G: If we consider the limiting cases, we can imagine that the **potential** across the battery will be a maximum when $R = \infty$ (open circuit), the **current** will be a maximum when $R = 0$ (short circuit), and the **power** will be a maximum when R is somewhere between these two extremes, perhaps when $R = r$.

O: We can use the definition of resistance to find the voltage and current as functions of R, and the power equation can be differentiated with respect to R.

A: (a) The battery has a voltage $\Delta V_{\text{terminal}} = \mathcal{E} - Ir = \dfrac{\mathcal{E}R}{R+r}$ or as $R \to \infty$, $\Delta V_{\text{terminal}} \to \mathcal{E}$

(b) The circuit's current is $I = \dfrac{\mathcal{E}}{R+r}$ or as $R \to 0$, $I \to \dfrac{\mathcal{E}}{r}$

(c) The power delivered is $\mathcal{P} = I^2 R = \dfrac{\mathcal{E}^2 R}{(R+r)^2}$

To maximize the power $\mathcal{P}$ as a function of R, we differentiate with respect to R, and require that $d\mathcal{P}/dR = 0$

$$\frac{d\mathcal{P}}{dR} = \mathcal{E}^2 R(-2)(R+r)^{-3} + \mathcal{E}^2 (R+r)^{-2} = \frac{-2\mathcal{E}^2 R}{(R+r)^3} + \frac{\mathcal{E}^2}{(R+r)^2} = 0$$

Then $2R = R + r$ and $R = r$

L: The results agree with our predictions. Making load resistance equal to the source resistance to maximize power transfer is called impedance matching.

28.58 (a) $\mathcal{E} - I(\Sigma R) - (\mathcal{E}_1 + \mathcal{E}_2) = 0$

$40.0\text{ V} - (4.00\text{ A})[(2.00 + 0.300 + 0.300 + R)\Omega] - (6.00 + 6.00)\text{ V} = 0;$ so $R = \boxed{4.40\ \Omega}$

(b) Inside the supply, $P = I^2R = (4.00\text{ A})^2(2.00\ \Omega) = \boxed{32.0\text{ W}}$

Inside both batteries together, $P = I^2R = (4.00\text{ A})^2(0.600\ \Omega) = \boxed{9.60\text{ W}}$

For the limiting resistor, $P = (4.00\text{ A})^2(4.40\ \Omega) = \boxed{70.4\text{ W}}$

(c) $P = I(\mathcal{E}_1 + \mathcal{E}_2) = (4.00\text{ A})[(6.00 + 6.00)\text{V}] = \boxed{48.0\text{ W}}$

28.59 Let R_m = measured value, R = actual value,

I_R = current through the resistor R

I = current measured by the ammeter.

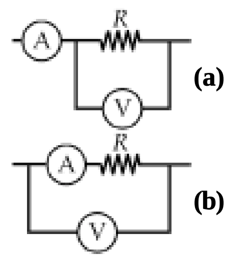


Figure for Goal solution

(a) When using circuit (a), $I_RR = \Delta V = 20\,000(I - I_R)$ or $R = 20\,000\left[\dfrac{I}{I_R} - 1\right]$

But since $I = \dfrac{\Delta V}{R_m}$ and $I_R = \dfrac{\Delta V}{R}$, we have $\dfrac{I}{I_R} = \dfrac{R}{R_m}$

and $R = 20\,000\dfrac{(R - R_m)}{R_m}$ (1)

When $R > R_m$, we require $\dfrac{(R - R_m)}{R} \le 0.0500$

Therefore, $R_m \ge R(1 - 0.0500)$ and from (1) we find $\boxed{R \le 1050\ \Omega}$

(b) When using circuit (b), $I_RR = \Delta V - I_R(0.5\ \Omega)$.

But since $I_R = \dfrac{\Delta V}{R_m}$, $R_m = (0.500 + R)$ (2)

When $R_m > R$, we require $\dfrac{(R_m - R)}{R} \le 0.0500$

From (2) we find $\boxed{R \ge 10.0\ \Omega}$

Goal Solution

The value of a resistor R is to be determined using the ammeter-voltmeter setup shown in Figure P28.59. The ammeter has a resistance of $0.500\ \Omega$, and the voltmeter has a resistance of $20\,000\ \Omega$. Within what range of actual values of R will the measured values be correct to within 5.00% if the measurement is made using (a) the circuit shown in Figure P28.59a (b) the circuit shown in Figure P28.59b?

G: An ideal ammeter has zero resistance, and an ideal voltmeter has infinite resistance, so that adding the meter does not alter the current or voltage of the existing circuit. For the non-ideal meters in this problem, a low values of R will give a large voltage measurement error in circuit (b), while a large value of R will give significant current measurement error in circuit (a). We could hope that these meters yield accurate measurements in either circuit for typical resistance values of $1\ \Omega$ to $1\ \text{M}\Omega$.

O: The definition of resistance can be applied to each circuit to find the minimum and maximum current and voltage allowed within the 5.00% tolerance range.

A: (a) In Figure P28.59a, at least a little current goes through the voltmeter, so less current flows through the resistor than the ammeter reports, and the resistance computed by dividing the voltage by the inflated ammeter reading will be too small. Thus, we require that $\Delta V / I = 0.950R$ where I is the current through the ammeter. Call I_R the current through the resistor; then $I - I_R$ is the current in the voltmeter. Since the resistor and the voltmeter are in parallel, the voltage across the meter equals the voltage across the resistor. Applying the definition of resistance:

$$\Delta V = I_R R = (I - I_R)(20\,000\ \Omega) \quad \text{so} \quad I = \frac{I_R(R + 20\,000\ \Omega)}{20\,000\ \Omega}$$

Our requirement is $$\frac{I_R R}{\left(\dfrac{I_R(R + 20\,000\ \Omega)}{20\,000\ \Omega}\right)} \geq 0.95R$$

Solving, $$20\,000\ \Omega \geq 0.95(R + 20\,000\ \Omega) = 0.95R + 19\,000\ \Omega$$

and $$R \leq \frac{1000\ \Omega}{0.95} \quad \text{or} \quad R \leq 1.05\ \text{k}\Omega$$

(b) If R is too small, the resistance of an ammeter in series will significantly reduce the current that would otherwise flow through R. In Figure 28.59b, the voltmeter reading is $I(0.500\ \Omega) + IR$, at least a little larger than the voltage across the resistor. So the resistance computed by dividing the inflated voltmeter reading by the ammeter reading will be too large.

We require $$\frac{V}{I} \leq 1.05R \quad \text{so that} \quad \frac{I\,(0.500\ \Omega) + IR}{I} \leq 1.05R$$

Thus, $$0.500\ \Omega \leq 0.0500R \quad \text{and} \quad R \geq 10.0\ \Omega$$

L: The range of R values seems correct since the ammeter's resistance should be less than 5% of the smallest R value ($0.500\ \Omega \leq 0.05R$ means that R should be greater than $10\ \Omega$), and R should be less than 5% of the voltmeter's internal resistance ($R \leq 0.05 \times 20\ \text{k}\Omega = 1\ \text{k}\Omega$). Only for the restricted range between 10 ohms and 1000 ohms can we indifferently use either of the connections (a) and (b) for a reasonably accurate resistance measurement. For low values of the resistance R, circuit (a) must be used. Only circuit (b) can accurately measure a large value of R.

28.60 The battery supplies energy at a changing rate $\frac{dE}{dt} = \mathcal{P} = \mathcal{E}I = \mathcal{E}\left(\frac{\mathcal{E}}{R}e^{-1/RC}\right)$

Then the total energy put out by the battery is $\int dE = \int_{t=0}^{\infty} \frac{\mathcal{E}^2}{R} \exp\left(-\frac{t}{RC}\right)dt$

$$\int dE = \frac{\mathcal{E}^2}{R}(-RC)\int_0^{\infty} \exp\left(-\frac{t}{RC}\right)\left(-\frac{dt}{RC}\right) = -\mathcal{E}^2C \exp\left(-\frac{t}{RC}\right)\Big|_0^{\infty} = -\mathcal{E}^2C[0-1] = \mathcal{E}^2C$$

The heating power of the resistor is $\frac{dE}{dt} = \mathcal{P} = \Delta V_R I = I^2R = R\frac{\mathcal{E}^2}{R^2}\exp\left(-\frac{2t}{RC}\right)$

So the total heat is $\int dE = \int_0^{\infty} \frac{\mathcal{E}^2}{R}\exp\left(-\frac{2t}{RC}\right)dt$

$$\int dE = \frac{\mathcal{E}^2}{R}\left(-\frac{RC}{2}\right)\int_0^{\infty} \exp\left(-\frac{2t}{RC}\right)\left(-\frac{2dt}{RC}\right) = -\frac{\mathcal{E}^2C}{2}\exp\left(-\frac{2t}{RC}\right)\Big|_0^{\infty} = -\frac{\mathcal{E}^2C}{2}[0-1] = \frac{\mathcal{E}^2C}{2}$$

The energy finally stored in the capacitor is $U = \frac{1}{2}C(\Delta V)^2 = \frac{1}{2}C\mathcal{E}^2$. Thus, energy is conserved: $\mathcal{E}^2C = \frac{1}{2}\mathcal{E}^2C + \frac{1}{2}\mathcal{E}^2C$ and resistor and capacitor share equally in the energy from the battery.

28.61 (a) $q = C(\Delta V)\left[1 - e^{-t/RC}\right]$

$$q = \left(1.00\times10^{-6}\text{ F}\right)(10.0\text{ V})\left[1 - e^{-\frac{10.0}{\left(2.00\times10^{6}\right)\left(1.00\times10^{-6}\right)}}\right] = \boxed{9.93\ \mu\text{C}}$$

(b) $I = \frac{dq}{dt} = \left(\frac{\Delta V}{R}\right)e^{-t/RC}$

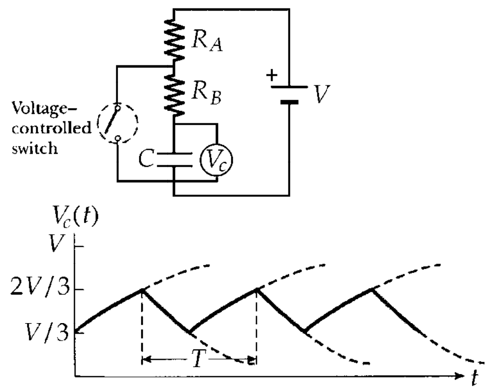
$$I = \left(\frac{10.0\text{ V}}{2.00\times10^{6}\ \Omega}\right)e^{-5.00} = 3.37\times10^{-8}\text{ A} = \boxed{33.7\text{ nA}}$$

(c) $\frac{dU}{dt} = \frac{d}{dt}\left(\frac{1}{2}\frac{q^2}{C}\right) = \frac{q}{C}\frac{dq}{dt} = \left(\frac{q}{C}\right)I$

$$\frac{dU}{dt} = \left(\frac{9.93\times10^{-6}\text{ C}}{1.00\times10^{-6}\text{ C/V}}\right)\left(3.37\times10^{-8}\text{ A}\right) = 3.34\times10^{-7}\text{ W} = \boxed{334\text{ nW}}$$

(d) $\mathcal{P}_{\text{battery}} = I\mathcal{E} = \left(3.37\times10^{-8}\text{ A}\right)(10.0\text{ V}) = 3.37\times10^{-7}\text{ W} = \boxed{337\text{ nW}}$

28.62 Start at the point when the voltage has just reached $\frac{2}{3}V$ and the switch has just closed. The voltage is $\frac{2}{3}V$ and is decaying towards 0 V with a time constant R_BC.



$$V_C(t) = \left[\frac{2}{3}V\right]e^{-t/R_BC}$$

We want to know when $V_C(t)$ will reach $\frac{1}{3}V$.

Therefore, $\left(\frac{1}{3}\right)V = \left[\frac{2}{3}V\right]e^{-t/R_BC}$ or $e^{-t/R_BC} = \frac{1}{2}$

or $t_1 = R_BC \ln 2$

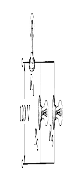
After the switch opens, the voltage is $\frac{1}{3}V$, increasing toward V with time constant $(R_A + R_B)C$:

$$V_C(t) = V - \left[\frac{2}{3}V\right]e^{-t/(R_A+R_B)C}$$

When $V_C(t) = \frac{2}{3}V$, $\frac{2}{3}V = V - \frac{2}{3}Ve^{-t/(R_A+R_B)C}$ or $e^{-t/(R_A+R_B)C} = \frac{1}{2}$

so $t_2 = (R_A + R_B)C \ln 2$ and $T = t_1 + t_2 = \boxed{(R_A + 2R_B)C \ln 2}$

28.63 (a) First determine the resistance of each light bulb: $\mathcal{P} = (\Delta V)^2/R$



$$R = \frac{(\Delta V)^2}{\mathcal{P}} = \frac{(120\text{ V})^2}{60.0\text{ W}} = 240\ \Omega$$

We obtain the equivalent resistance R_{eq} of the network of light bulbs by applying Equations 28.6 and 28.7:

$$R_{eq} = R_1 + \frac{1}{(1/R_2) + (1/R_3)} = 240\ \Omega + 120\ \Omega = 360\ \Omega$$

The total power dissipated in the 360 Ω is $\mathcal{P} = \frac{(\Delta V)^2}{R_{eq}} = \frac{(120\text{ V})^2}{360\ \Omega} = \boxed{40.0\text{ W}}$

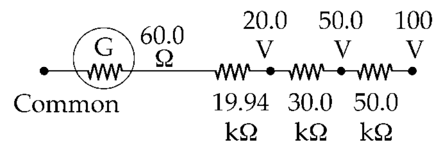
(b) The current through the network is given by $\mathcal{P} = I^2R_{eq}$: $I = \sqrt{\frac{\mathcal{P}}{R_{eq}}} = \sqrt{\frac{40.0\text{ W}}{360\ \Omega}} = \frac{1}{3}\text{ A}$

The potential difference across R_1 is $\Delta V_1 = IR_1 = \left(\frac{1}{3}\text{ A}\right)(240\ \Omega) = \boxed{80.0\text{ V}}$

The potential difference ΔV_{23} across the parallel combination of R_2 and R_3 is

$$\Delta V_{23} = IR_{23} = \left(\frac{1}{3}\text{ A}\right)\left(\frac{1}{(1/240\ \Omega) + (1/240\ \Omega)}\right) = \boxed{40.0\text{ V}}$$

28.64 $\Delta V = IR$



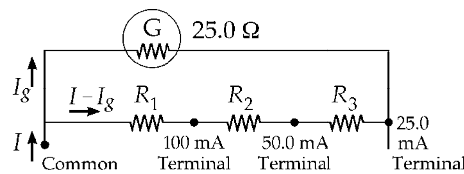
(a) $20.0\text{ V} = (1.00 \times 10^{-3}\text{ A})(R_1 + 60.0\ \Omega)$

$R_1 = 1.994 \times 10^4\ \Omega = \boxed{19.94\text{ k}\Omega}$

(b) $50.0\text{ V} = (1.00 \times 10^{-3}\text{ A})(R_2 + R_1 + 60.0\ \Omega)$ $R_2 = \boxed{30.0\text{ k}\Omega}$

(c) $100\text{ V} = (1.00 \times 10^{-3}\text{ A})(R_3 + R_1 + 60.0\ \Omega)$ $R_3 = \boxed{50.0\text{ k}\Omega}$

28.65 Consider the circuit diagram shown, realizing that $I_g = 1.00$ mA. For the 25.0 mA scale:



$$(24.0\text{ mA})(R_1 + R_2 + R_3) = (1.00\text{ mA})(25.0\ \Omega)$$

or $$R_1 + R_2 + R_3 = \left(\frac{25.0}{24.0}\right)\Omega \qquad (1)$$

For the 50.0 mA scale: $$(49.0\text{ mA})(R_1 + R_2) = (1.00\text{ mA})(25.0\ \Omega + R_3)$$

or $$49.0(R_1 + R_2) = 25.0\ \Omega + R_3 \qquad (2)$$

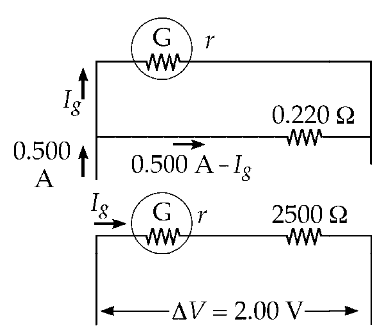
For the 100 mA scale: $$(99.0\text{ mA})R_1 = (1.00\text{ mA})(25.0\ \Omega + R_2 + R_3)$$

or $$99.0R_1 = 25.0\ \Omega + R_2 + R_3 \qquad (3)$$

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

$$\boxed{R_1 = 0.260\ \Omega,\quad R_2 = 0.261\ \Omega,\quad R_3 = 0.521\ \Omega}$$

28.66 <u>Ammeter:</u> $I_g r = (0.500\text{ A} - I_g)(0.220\ \Omega)$



or $I_g(r + 0.220\ \Omega) = 0.110\text{ V}$ (1)

<u>Voltmeter:</u> $2.00\text{ V} = I_g(r + 2500\ \Omega)$ (2)

Solve (1) and (2) simultaneously to find:

$I_g = \boxed{0.756\text{ mA}}$ and $r = \boxed{145\ \Omega}$

28.67 (a) After steady-state conditions have been reached, there is no DC current through the capacitor.

Thus, for R_3: $\boxed{I_{R_3} = 0 \quad \text{(steady-state)}}$

For the other two resistors, the steady-state current is simply determined by the 9.00-V emf across the 12-kΩ and 15-kΩ resistors in series:

For R_1 and R_2: $$I_{(R_1+R_2)} = \frac{\mathcal{E}}{R_1 + R_2} = \frac{9.00\text{ V}}{(12.0\text{ k}\Omega + 15.0\text{ k}\Omega)} = \boxed{333\ \mu\text{A (steady-state)}}$$

(b) After the transient currents have ceased, the potential difference across C is the same as the potential difference across $R_2(= IR_2)$ because there is no voltage drop across R_3. Therefore, the charge Q on C is

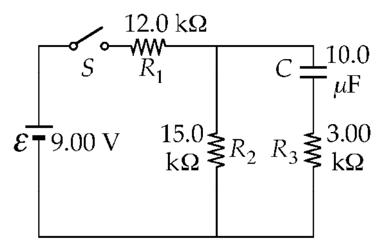
$$Q = C(\Delta V)_{R_2} = C(IR_2) = (10.0\ \mu\text{F})(333\ \mu\text{A})(15.0\text{ k}\Omega) = \boxed{50.0\ \mu\text{C}}$$

(c) When the switch is opened, the branch containing R_1 is no longer part of the circuit. The capacitor discharges through $(R_2 + R_3)$ with a time constant of $(R_2 + R_3)C = (15.0\text{ k}\Omega + 3.00\text{ k}\Omega)(10.0\ \mu\text{F}) = 0.180$ s. The initial current I_i in this discharge circuit is determined by the initial potential difference across the capacitor applied to $(R_2 + R_3)$ in series:

$$I_i = \frac{(\Delta V)_C}{(R_2 + R_3)} = \frac{IR_2}{(R_2 + R_3)} = \frac{(333\ \mu\text{A})(15.0\text{ k}\Omega)}{(15.0\text{ k}\Omega + 3.00\text{ k}\Omega)} = 278\ \mu\text{A}$$

Thus, when the switch is opened, the current through R_2 changes instantaneously from 333 μA (downward) to 278 μA (downward) as shown in the graph. Thereafter, it decays according to

$$I_{R_2} = I_i e^{-t/(R_2+R_3)C} = \boxed{(278\ \mu\text{A})e^{-t/(0.180\text{ s})} \quad (\text{for } t > 0)}$$



(a)

(d) The charge q on the capacitor decays from Q_i to $Q_i/5$ according to

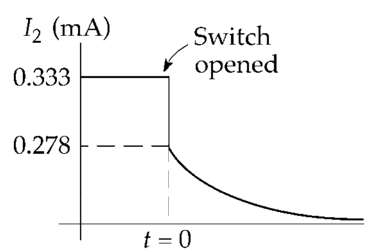
$$q = Q_i e^{-t/(R_2+R_3)C}$$

$$\frac{Q_i}{5} = Q_i e^{(-t/0.180\text{ s})}$$

$$5 = e^{t/0.180\text{ s}}$$

$$\ln 5 = \frac{t}{180\text{ ms}}$$

$$t = (0.180\text{ s})(\ln 5) = \boxed{290\text{ ms}}$$



(b)

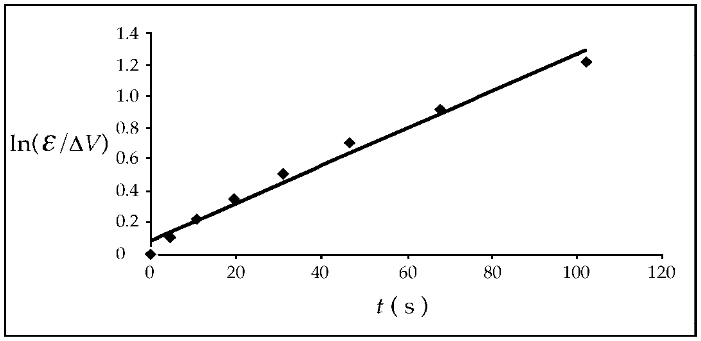
28.68 $\Delta V = \mathcal{E} e^{-t/RC}$ so $\ln\left(\frac{\mathcal{E}}{\Delta V}\right) = \left(\frac{1}{RC}\right)t$

A plot of $\ln\left(\frac{\mathcal{E}}{\Delta V}\right)$ versus t should be a straight line with slope $= \frac{1}{RC}$.

Using the given data values:

t (s)	ΔV (V)	$\ln(\mathcal{E}/\Delta V)$
0	6.19	0
4.87	5.55	0.109
11.1	4.93	0.228
19.4	4.34	0.355
30.8	3.72	0.509
46.6	3.09	0.695
67.3	2.47	0.919
102.2	1.83	1.219

(a) A least-square fit to this data yields the graph to the right.



$\Sigma x_i = 282$, $\Sigma x_i^2 = 1.86 \times 10^4$, $\Sigma x_i y_i = 244$, $\Sigma y_i = 4.03$, $N = 8$

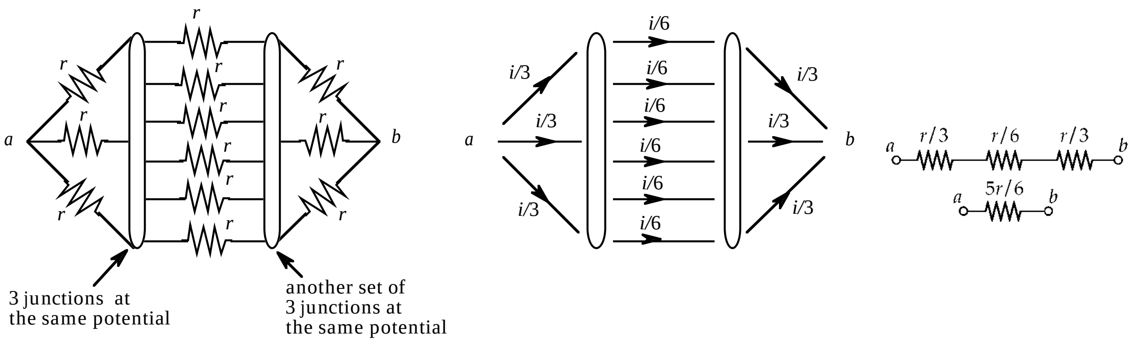
$$\text{Slope} = \frac{N(\Sigma x_i y_i) - (\Sigma x_i)(\Sigma y_i)}{N(\Sigma x_i^2) - (\Sigma x_i)^2} = 0.0118 \qquad \text{Intercept} = \frac{(\Sigma x_i^2)(\Sigma y_i) - (\Sigma x_i)(\Sigma x_i y_i)}{N(\Sigma x_i^2) - (\Sigma x_i)^2} = 0.0882$$

The equation of the best fit line is: $\boxed{\ln\left(\frac{\mathcal{E}}{\Delta V}\right) = (0.0118)t + 0.0882}$

(b) Thus, the time constant is $\tau = RC = \frac{1}{\text{slope}} = \frac{1}{0.0118} = \boxed{84.7 \text{ s}}$

and the capacitance is $C = \frac{\tau}{R} = \frac{84.7 \text{ s}}{10.0 \times 10^6 \ \Omega} = \boxed{8.47 \ \mu\text{F}}$

28.69



28.70 (a) For the first measurement, the equivalent circuit is as shown in Figure 1.

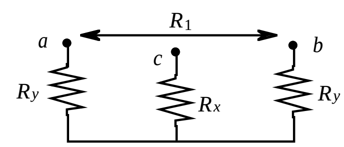


Figure 1

$$R_{ab} = R_1 = R_y + R_y = 2R_y$$

so $$R_y = \frac{1}{2}R_1 \qquad (1)$$

For the second measurement, the equivalent circuit is shown in Figure 2.

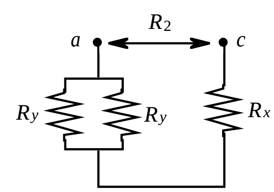


Figure 2

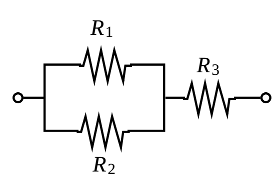
Thus, $$R_{ac} = R_2 = \frac{1}{2}R_y + R_x \qquad (2)$$

Substitute (1) into (2) to obtain: $R_2 = \frac{1}{2}\left(\frac{1}{2}R_1\right) + R_x$, or $\boxed{R_x = R_2 - \frac{1}{4}R_1}$

(b) If $R_1 = 13.0\ \Omega$ and $R_2 = 6.00\ \Omega$, then $\boxed{R_x = 2.75\ \Omega}$

The antenna is inadequately grounded since this exceeds the limit of $2.00\ \Omega$.

28.71 Since the total current passes through R_3, that resistor will dissipate the most power. When that resistor is operating at its power limit of 32.0 W, the current through it is


$R_1 = R_2 = R_3 = 2.00\ \Omega$

$$I_{\text{total}}^2 = \frac{\mathsf{P}}{R} = \frac{32.0\ \text{W}}{2.00\ \Omega} = 16.0\ \text{A}^2,\ \text{or}\ I_{\text{total}} = 4.00\ \text{A}$$

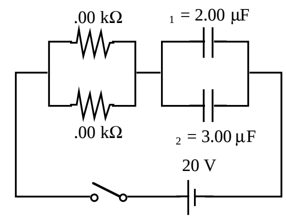
Half of this total current (2.00 A) flows through each of the other two resistors, so the power dissipated in each of them is:

$$\mathsf{P} = \left(\tfrac{1}{2}I_{\text{total}}\right)^2 R = (2.00\ \text{A})^2(2.00\ \Omega) = 8.00\ \text{W}$$

Thus, the total power dissipated in the entire circuit is:

$$P_{total} = 32.0\text{ W} + 8.00\text{ W} + 8.00\text{ W} = \boxed{48.0\text{ W}}$$

28.72 The total resistance between points b and c is:



$$R = \frac{(2.00\text{ k}\Omega)(3.00\text{ k}\Omega)}{2.00\text{ k}\Omega + 3.00\text{ k}\Omega} = 1.20\text{ k}\Omega$$

The total capacitance between points d and e is:

$$C = 2.00\ \mu\text{F} + 3.00\ \mu\text{F} = 5.00\ \mu\text{F}$$

The potential difference between point d and e in this series RC circuit at any time is:

$$\Delta V = \mathcal{E}\left[1 - e^{-t/RC}\right] = (120.0\text{ V})\left[1 - e^{-1000t/6}\right]$$

Therefore, the charge on each capacitor between points d and e is:

$$q_1 = C_1(\Delta V) = (2.00\ \mu\text{F})(120.0\text{ V})\left[1 - e^{-1000t/6}\right] = \boxed{(240\ \mu\text{C})\left[1 - e^{-1000t/6}\right]}$$

and $q_2 = C_2(\Delta V) = (3.00\ \mu\text{F})(120.0\text{ V})\left[1 - e^{-1000t/6}\right] = \boxed{(360\ \mu\text{C})\left[1 - e^{-1000t/6}\right]}$

***28.73** (a) $R_{eq} = 3R$ $\qquad I = \dfrac{\mathcal{E}}{3R}$ $\qquad P_{series} = \mathcal{E}I = \boxed{\mathcal{E}^2/3R}$

(b) $R_{eq} = \dfrac{1}{(1/R) + (1/R) + (1/R)} = \dfrac{R}{3}$ $\qquad I = \dfrac{3\mathcal{E}}{R}$ $\qquad P_{parallel} = \mathcal{E}I = \boxed{\dfrac{3\mathcal{E}^2}{R}}$

(c) Nine times more power is converted in the $\boxed{\text{parallel}}$ connection.