Introduction to Electrical Circuits

Mid Term
Lecture – 2

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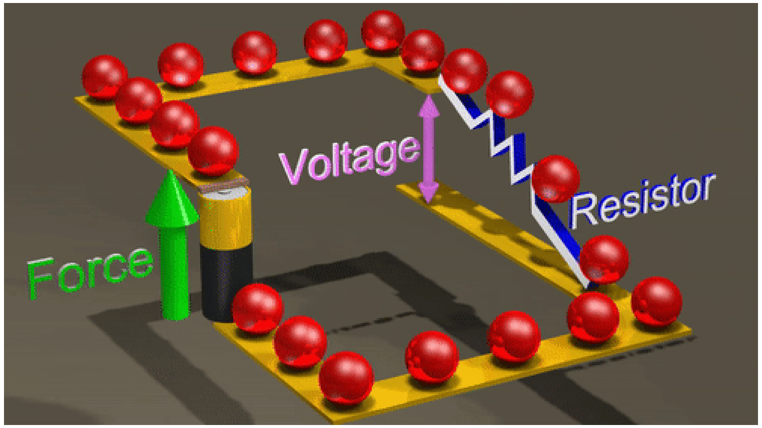
Reference Book:

Introductory Circuit Analysis

Robert L. Boylestad, 11th Edition

Week No.	Class No.	Chapter No.	Article No., Name and Contents	Example No.	Exercise No.
W1	MC2	Chapter 4	4.2 OHM'S LAW (Statement and Representation)	4.1, 4.2	19, 20, 57, 58
			4.4 POWER (Definition, Symbol, Unit and Equation)	4.6, 4.8	
			4.5 ENERGY (Definition, Symbol, Unit and Equation)	4.11, 4.12, 4.13, 4.14	
			4.6 EFFICIENCY (Definition, Symbol, Unit and Equation)	4.15, 4.16, 4.17	
		Chapter 5	5.2 SERIES RESISTORS	5.1, 5.2, 5.3	5, 8, 9, 11, 25
			5.3 SERIES CIRCUITS	5.4, 5.5, 5.6	
			5.4 POWER DISTRIBUTION IN A SERIES CIRCUIT	5.7	
			5.5 VOLTAGE SOURCES IN SERIES (Figure: 5.23 only)		
			5.6 KIRCHHOFF'S VOLTAGE LAW (KVL)	5.9-5.12	

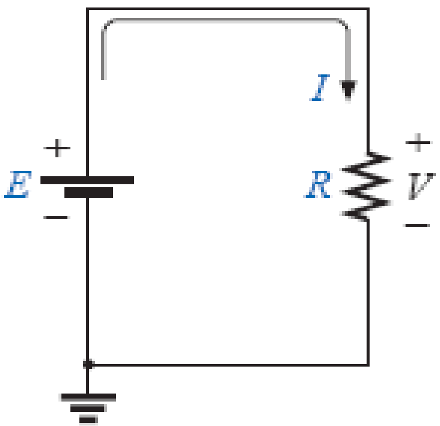
Ohm's Law



4.2 OHM'S LAW

$$\text{Current} = \frac{\text{potential difference}}{\text{resistance}}$$

$$\boxed{I = \frac{E}{R}} \qquad \text{(amperes, A)}$$



Note: *Temperature must be constant*

EXAMPLE 4.1 Determine the current resulting from the application of a 9 V battery across a network with a resistance of 2.2 Ω.

Solution: Eq. (4.2):

$$I = \frac{V_R}{R} = \frac{E}{R} = \frac{9\text{ V}}{2.2\ \Omega} = \mathbf{4.09\ A}$$

EXAMPLE 4.2 Calculate the resistance of a 60 W bulb if a current of 500 mA results from an applied voltage of 120 V.

Solution: Eq. (4.4):

$$R = \frac{V_R}{I} = \frac{E}{I} = \frac{120\text{ V}}{500 \times 10^{-3}\text{ A}} = \mathbf{240\ \Omega}$$

4.4 POWER

Definition: The term power is applied to provide an indication of how much work (energy conversion) can be accomplished in a specified amount of time; that is, power is a rate of doing work.

Symbol: It is represented by 'P' . P_E represents source power and P_R represents power consumption of a resistor.

Unit: Watt (W)

$$\boxed{P = EI} \quad \text{(watts)}$$

$$\boxed{P = I^2R} \quad \text{(watts)}$$

Equation of Power:

$$P = \frac{W}{t} = \frac{QV}{t} = V\frac{Q}{t}$$

$$I = \frac{Q}{t}$$

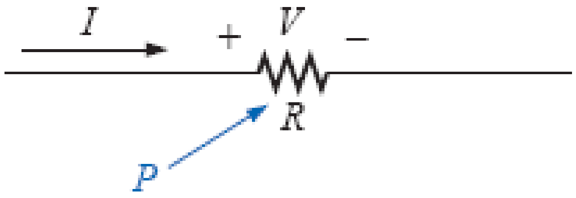
$$\boxed{P = VI} \quad \text{(watts)}$$

$$P = VI = V\left(\frac{V}{R}\right)$$

$$\boxed{P = \frac{V^2}{R}} \quad \text{(watts)}$$

$$P = VI = (IR)I$$

$$\boxed{P = I^2R} \quad \text{(watts)}$$



EXAMPLE 4.6 Find the power delivered to the dc motor of Fig. 4.13.

Solution: $P = EI = (120\ \text{V})(5\ \text{A}) = 600\ \text{W} = \mathbf{0.6\ kW}$

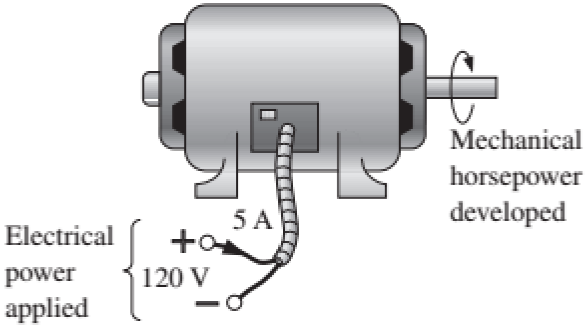


FIG. 4.13
Example 4.6.

EXAMPLE 4.7 What is the power dissipated by a 5 Ω resistor if the current is 4 A?

Solution:

$$P = I^2R = (4\ \text{A})^2(5\ \Omega) = \mathbf{80\ W}$$

4.5 ENERGY

Definition: For power, which is the rate of doing work, to produce an energy conversion of any form, it must be *used over a period of time.*

Symbol: It is represented by 'W'.

Unit: Kilo Watt Hour (kWh)

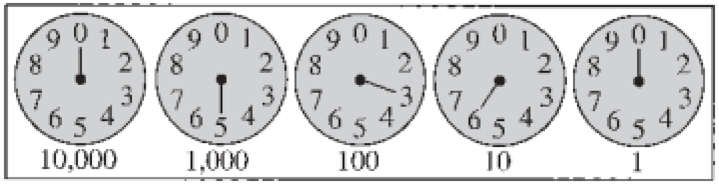
Equation of Power: The energy (W) lost or gained by any system is therefore determined by

$$\boxed{W = Pt} \qquad \text{(wattseconds, Ws, or joules)}$$

$$\boxed{\text{Energy (Wh)} = \text{power (W)} \times \text{time (h)}}$$

$$\boxed{\text{Energy (kWh)} = \frac{\text{power (W)} \times \text{time (h)}}{1000}}$$

EXAMPLE 4.10 For the dial positions in Fig. 4.16(a), calculate the electricity bill if the previous reading was 4650 kWh and the average cost in your area is 9¢ per kilowatthour.



(a)

Solution:

$$5360 \text{ kWh} - 4650 \text{ kWh} = 710 \text{ kWh used}$$

$$710 \cancel{\text{kWh}}\left(\frac{9¢}{\cancel{\text{kWh}}}\right) = \mathbf{\$63.90}$$

EXAMPLE 4.11 How much energy (in kilowatthours) is required to light a 60 W bulb continuously for 1 year (365 days)?

Solution:

$$W = \frac{Pt}{1000} = \frac{(60 \text{ W})(24 \text{ h/day})(365 \text{ days})}{1000} = \frac{525{,}600 \text{ Wh}}{1000}$$

$$= \mathbf{525.60 \text{ kWh}}$$

EXAMPLE 4.14 What is the total cost of using all of the following at 9¢ per kilowatthour?

A 1200 W toaster for 30 min
Six 50 W bulbs for 4 h
A 400 W washing machine for 45 min
A 4800 W electric clothes dryer for 20 min

Solution:

$$W = \frac{(1200 \text{ W})(\frac{1}{2} \text{ h}) + (6)(50 \text{ W})(4 \text{ h}) + (400 \text{ W})(\frac{3}{4} \text{ h}) + (4800 \text{ W})(\frac{1}{3} \text{ h})}{1000}$$

$$= \frac{600 \text{ Wh} + 1200 \text{ Wh} + 300 \text{ Wh} + 1600 \text{ Wh}}{1000} = \frac{3700 \text{ Wh}}{1000}$$

$$W = 3.7 \text{ kWh}$$

$$\text{Cost} = (3.7 \text{ kWh})(9¢/\text{kWh}) = \mathbf{33.3¢}$$

4.6 EFFICIENCY

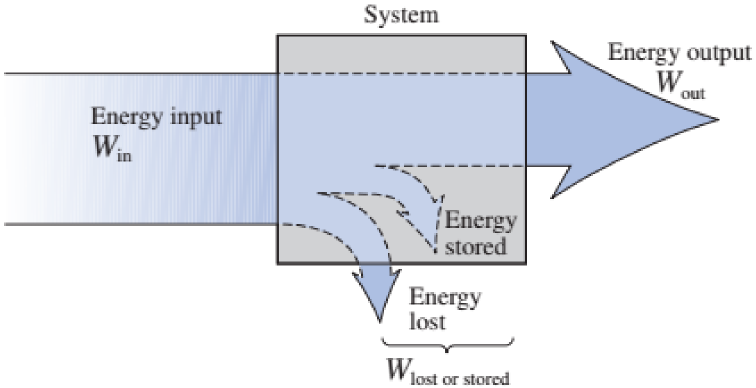
The **efficiency** (η) of the system is then determined by the following equation:

$$\text{Efficiency} = \frac{\text{power output}}{\text{power input}}$$

$$\boxed{\eta = \frac{P_o}{P_i}}$$

where η (lowercase Greek letter eta) is a decimal number. Expressed as a percentage,

$$\boxed{\eta\% = \frac{P_o}{P_i} \times 100\%} \qquad \text{(percent)}$$



$$\boxed{\eta\% = \frac{W_o}{W_i} \times 100\%} \qquad \text{(percent)}$$

EXAMPLE 4.16 What is the output in horsepower of a motor with an efficiency of 80% and an input current of 8 A at 120 V?

Solution:

$$\eta\% = \frac{P_o}{P_i} \times 100\%$$

$$0.80 = \frac{P_o}{(120\text{ V})(8\text{ A})}$$

and $\quad P_o = (0.80)(120\text{ V})(8\text{ A}) = 768\text{ W}$

with $\quad 768\text{ W}\left(\frac{1\text{ hp}}{746\text{ W}}\right) = \mathbf{1.03\ hp}$

EXAMPLE 4.17 If $\eta = 0.85$, determine the output energy level if the applied energy is 50 J.

Solution:

$$\eta = \frac{W_o}{W_i} \Rightarrow W_o = \eta W_i = (0.85)(50\text{ J}) = \mathbf{42.5\ J}$$

Exercise Problems

20. If 420 J of energy are absorbed by a resistor in 4 min, what is the power to the resistor?

Solution:

$$P = \frac{W}{t} = \frac{420\text{ J}}{4\ \cancel{\text{min}}\left[\frac{60\text{ s}}{1\ \cancel{\text{min}}}\right]} = \frac{420\text{ J}}{240\text{ s}} = \mathbf{1.75\ W}$$

57. A 2 hp motor drives a sanding belt. If the efficiency of the motor is 87% and that of the sanding belt is 75% due to slippage, what is the overall efficiency of the system?

Solution:

$$\eta_T = \eta_1 \cdot \eta_2 = (0.87)(0.75) = 0.6525 \Rightarrow \mathbf{65.25\%}$$

58. If two systems in cascade each have an efficiency of 80% and the input energy is 60 J, what is the output energy?

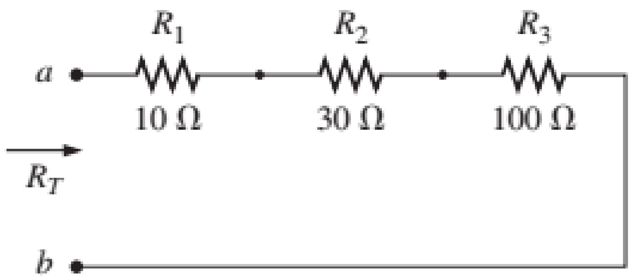
Solution:

$$\eta_1 = \eta_2 = .08$$
$$\eta_T = (\eta_1)(\eta_2) = (0.8)(0.8) = 0.64$$
$$\eta_T = \frac{W_o}{W_i} \Rightarrow W_o = \eta_T W_i = (0.64)(60\text{ J}) = \mathbf{38.4\ J}$$

Class Practice

*19. a. Plot the I-V characteristics of a 2 kΩ, 1 MΩ, and a 100 Ω resistor on the same graph. Use a horizontal axis of 0 to 20 V and a vertical axis of 0 to 10 mA.
b. Comment on the steepness of the curve with decreasing levels of resistance.
c. Are the curves linear or nonlinear? Why?

The total resistance of a series configuration is the sum of the resistance levels. The more resistors we add in series, the greater the resistance, no matter what their value. The largest resistor in a series combination will have the most impact on the total resistance.



$$\boxed{R_T = R_1 + R_2 + R_3 + R_4 + \cdots + R_N}$$

For equal value resistors the equation is,

$$\boxed{R_T = NR}$$

EXAMPLE 5.1 Determine the total resistance of the series connection in Fig. 5.6. Note that all the resistors appearing in this network are standard values.

Solution: Note in Fig. 5.6 that even though resistor R_3 is on the vertical and resistor R_4 returns at the bottom to terminal b, all the resistors are in series since there are only two resistor leads at each connection point.

Applying Eq. (5.1):

$$R_T = R_1 + R_2 + R_3 + R_4$$
$$R_T = 20\ \Omega + 220\ \Omega + 1.2\ \text{k}\Omega + 5.6\ \text{k}\Omega$$

and $R_T = 7040\ \Omega = \mathbf{7.04\ k\Omega}$

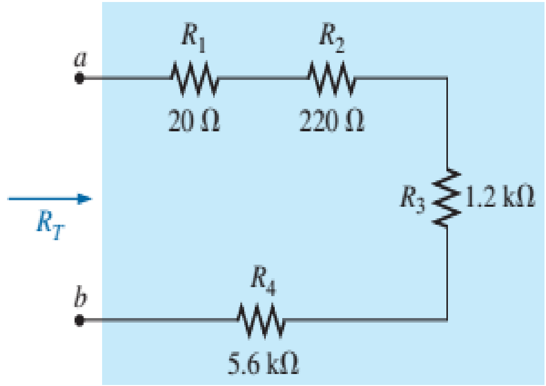
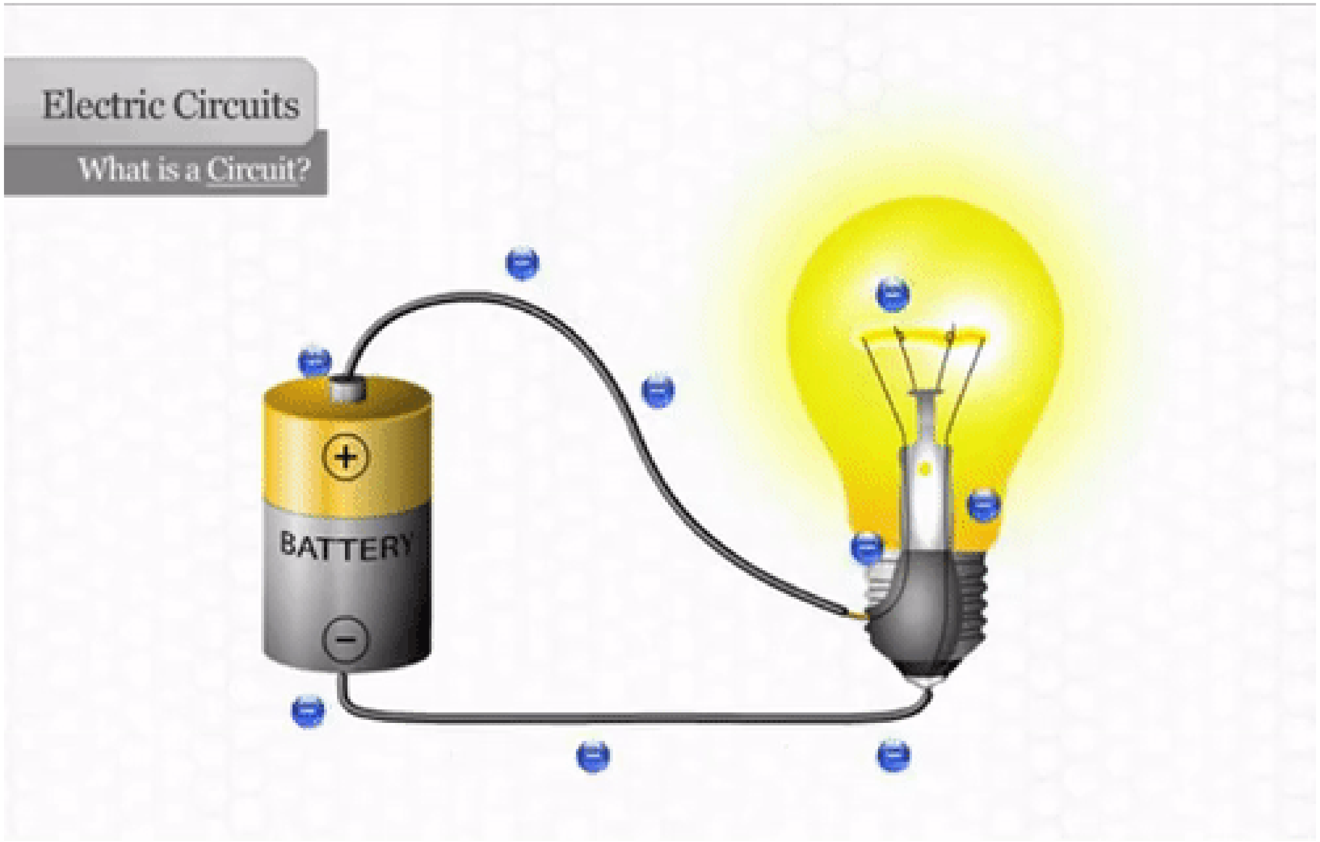


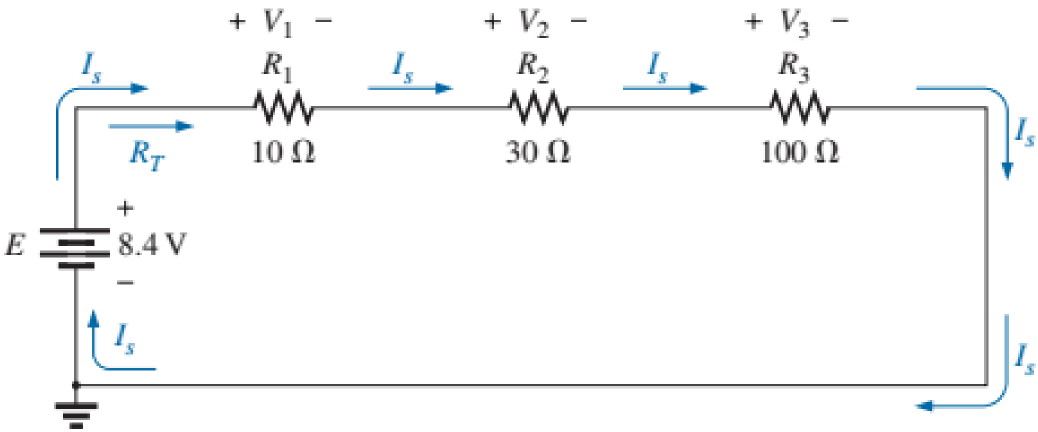
FIG. 5.6
Series connection of resistors for Example 5.1.

Series Circuits



5.3 SERIES CIRCUITS

(Equations associated to analyze series network)



1. Total resistance: $R_T = R_1 + R_2 + R_3$

2. Total current: $I_s = \dfrac{E}{R_T}$

3. Voltage drop of each resistor:

<u>Ohm's Law approach:</u>

$$V_1 = I_1 R_1 = I_s R_1$$
$$V_2 = I_2 R_2 = I_s R_2$$
$$V_3 = I_3 R_3 = I_s R_3$$

4. Power delivered by the source

$$\boxed{P_E = EI_s} \quad \text{(watts, W)}$$

5. Power consumed by the load

$$\boxed{P_1 = V_1 I_1 = I_1^2 R_1 = \frac{V_1^2}{R_1}} \quad \text{(watts, W)}$$

6. 5.6 KIRCHHOFF'S VOLTAGE LAW

$$\boxed{\Sigma_{C} V_{\text{rises}} = \Sigma_{C} V_{\text{drops}}}$$

<u>5.7 Voltage divider approach:</u>

$$V_1 = \frac{R_1}{R_1 + R_2 + R_3} \times E$$
$$V_2 = \frac{R_2}{R_1 + R_2 + R_3} \times E$$
$$V_3 = \frac{R_3}{R_1 + R_2 + R_3} \times E$$

General formula:

$$\boxed{V_x = R_x \frac{E}{R_T}} \quad \text{(voltage divider rule)}$$

EXAMPLE 5.1 Determine the total resistance of the series connection in Fig. 5.6. Note that all the resistors appearing in this network are standard values.

Solution: Note in Fig. 5.6 that even though resistor R_3 is on the vertical and resistor R_4 returns at the bottom to terminal *b*, all the resistors are in series since there are only two resistor leads at each connection point.

Applying Eq. (5.1):

$$R_T = R_1 + R_2 + R_3 + R_4$$
$$R_T = 20\ \Omega + 220\ \Omega + 1.2\ \text{k}\Omega + 5.6\ \text{k}\Omega$$

and $$R_T = 7040\ \Omega = \mathbf{7.04\ k\Omega}$$

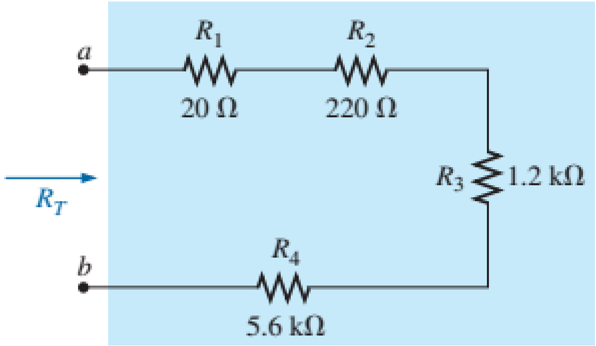


FIG. 5.6
Series connection of resistors for Example 5.1.

EXAMPLE 5.7 For the series circuit in Fig. 5.22 (all standard values):

a. Determine the total resistance R_T.
b. Calculate the current I_s.
c. Determine the voltage across each resistor.
d. Find the power supplied by the battery.
e. Determine the power dissipated by each resistor.
f. Comment on whether the total power supplied equals the total power dissipated.

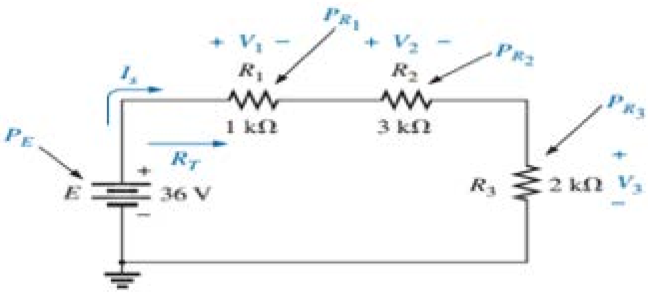


FIG. 5.22
Series circuit to be investigated in Example 5.7.

Solutions:

a. $R_T = R_1 + R_2 + R_3$
$= 1\ \text{k}\Omega + 3\ \text{k}\Omega + 2\ \text{k}\Omega$
$R_T = \mathbf{6\ k\Omega}$

b. $I_s = \dfrac{E}{R_T} = \dfrac{36\ \text{V}}{6\ \text{k}\Omega} = \mathbf{6\ mA}$

c. $V_1 = I_1R_1 = I_sR_1 = (6\ \text{mA})(1\ \text{k}\Omega) = \mathbf{6\ V}$
$V_2 = I_2R_2 = I_sR_2 = (6\ \text{mA})(3\ \text{k}\Omega) = \mathbf{18\ V}$
$V_3 = I_3R_3 = I_sR_3 = (6\ \text{mA})(2\ \text{k}\Omega) = \mathbf{12\ V}$

d. $P_E = EI_s = (36\ \text{V})(6\ \text{mA}) = \mathbf{216\ mW}$

e. $P_1 = V_1I_1 = (6\ \text{V})(6\ \text{mA}) = \mathbf{36\ mW}$
$P_2 = I_2^2R_2 = (6\ \text{mA})^2(3\ \text{k}\Omega) = \mathbf{108\ mW}$
$P_3 = \dfrac{V_3^2}{R_3} = \dfrac{(12\ \text{V})^2}{2\ \text{k}\Omega} = \mathbf{72\ mW}$

f. $P_E = P_{R_1} + P_{R_2} + P_{R_3}$
$216\ \text{mW} = 36\ \text{mW} + 108\ \text{mW} + 72\ \text{mW} = \mathbf{216\ mW}$ (checks)

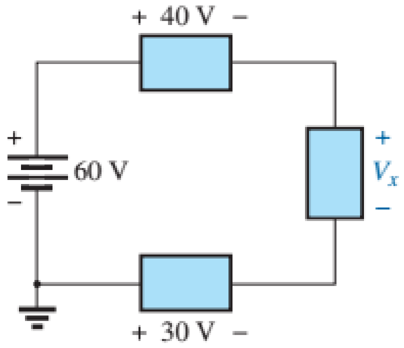


FIG. 5.30

EXAMPLE 5.11 Using Kirchhoff's voltage law, determine the unknown voltage for the circuit in Fig. 5.30.

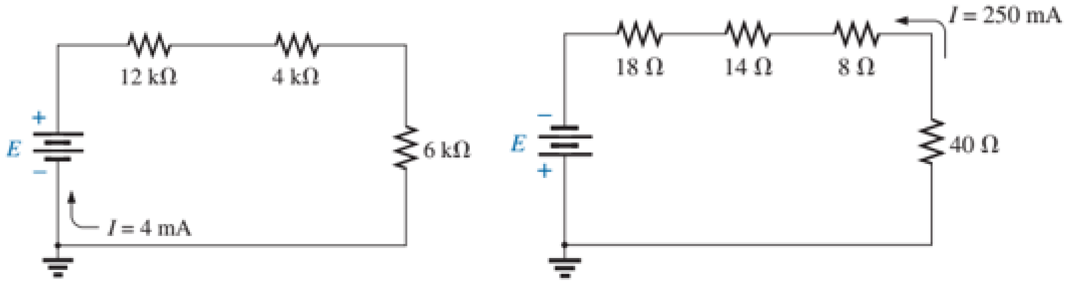
Solution: Note that in this circuit, there are various polarities across the unknown elements since they can contain any mixture of components. Applying Kirchhoff's voltage law in the clockwise direction results in

$$+60\text{ V} - 40\text{ V} - V_x + 30\text{ V} = 0$$

and $\quad V_x = 60\text{ V} + 30\text{ V} - 40\text{ V} = 90\text{ V} - 40\text{ V}$

with $\quad V_x = \mathbf{50\text{ V}}$

9. Find the applied voltage necessary to develop the current specified in each circuit in Fig. 5.93.



(a) (b)

Solution:

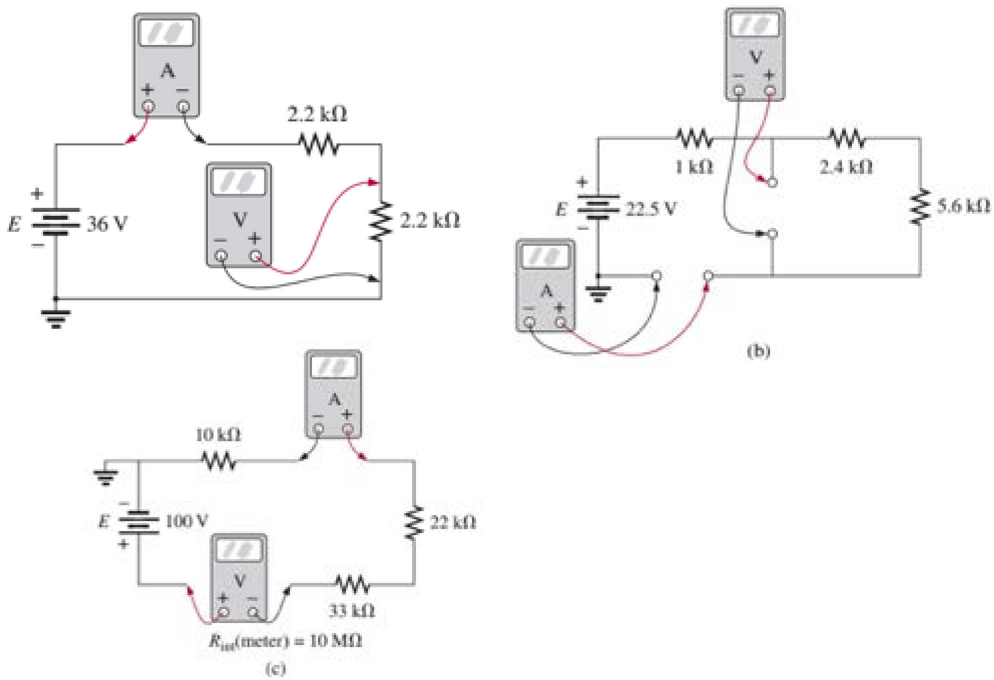
a. $R_T = 12\ \text{k}\Omega + 4\ \text{k}\Omega + 6\ \text{k}\Omega = 22\ \text{k}\Omega$

$E = IR_T = (4\ \text{mA})(22\ \text{k}\Omega) = \mathbf{88\ V}$

b. $R_T = 18\ \Omega + 14\ \Omega + 8\ \Omega + 40\ \Omega = 80\ \Omega$

$E = IR_T = (250\ \text{mA})(80\ \Omega) = \mathbf{20\ V}$

11. For each configuration in Fig. 5.95, what are the readings of the ammeter and the voltmeter?



Solution:

a. $I = \dfrac{E}{R_T} = \dfrac{36\ \text{V}}{4.4\ \text{k}\Omega} = \mathbf{8.18\ mA},\ V = \dfrac{1}{2}E = \dfrac{1}{2}(36\ \text{V}) = \mathbf{18\ V}$

b. $R_T = 1\ \text{k}\Omega + 2.4\ \text{k}\Omega + 5.6\ \text{k}\Omega = 9\ \text{k}\Omega$

$I = \dfrac{E}{R_T} = \dfrac{22.5\ \text{V}}{9\ \text{k}\Omega} = \mathbf{2.5\ mA},\ V = 2.5\ \text{mA}(2.4\ \text{k}\Omega + 5.6\ \text{k}\Omega) = \mathbf{20\ V}$

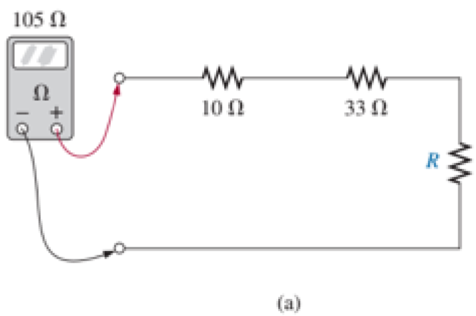
c. $R_T = 10\ \text{k}\Omega + 22\ \text{k}\Omega + 33\ \text{k}\Omega + 10\ \text{M}\Omega = 10.065\ \text{M}\Omega$

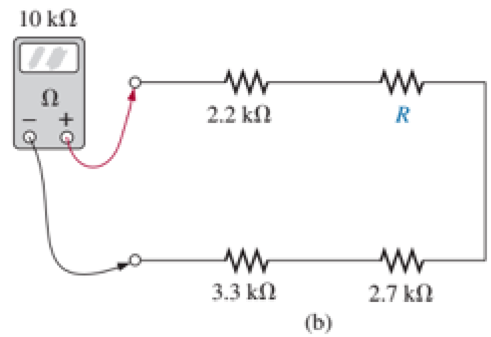
$I = \dfrac{E}{R_T} = \dfrac{100\ \text{V}}{10.065\ \text{M}\Omega} = \mathbf{9.94\ \mu A}$

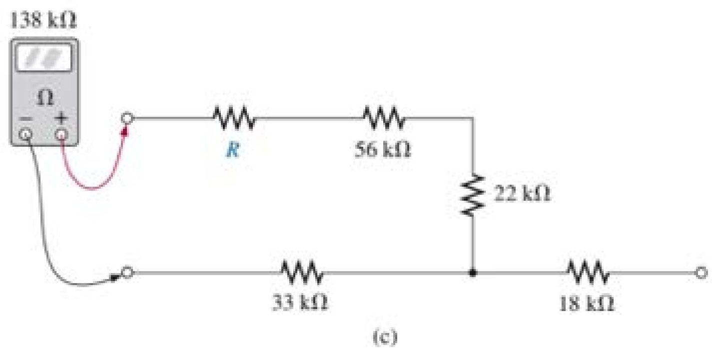
$V = (9.935\ \mu\text{A})(10\ \text{M}\Omega) = \mathbf{99.35\ V}$

Exercise Problems

5. For each configuration in Fig. 5.89, find the unknown resistors using the ohmmeter reading.







Solution:

a. $R_T = 105\ \Omega = 10\ \Omega + 33\ \Omega + R$, $\quad R = \mathbf{62\ \Omega}$

b. $R_T = 10\ \text{k}\Omega = 2.2\ \text{k}\Omega + R + 2.7\ \text{k}\Omega + 3.3\ \text{k}\Omega$, $\quad R = \mathbf{1.8\ k\Omega}$

c. $R_T = 138\ \text{k}\Omega = R + 56\ \text{k}\Omega + 22\ \text{k}\Omega + 33\ \text{k}\Omega$, $\quad R = \mathbf{27\ k\Omega}$

Exercise Problems

8. For the series configuration in Fig. 5.92, constructed using standard value resistors:

a. Without making a single calculation, which resistive element will have the most voltage across it? Which will have the least?

b. Which resistor will have the most impact on the total resistance and the resulting current? Find the total resistance and the current.

c. Find the voltage across each element and review your response to part (a).

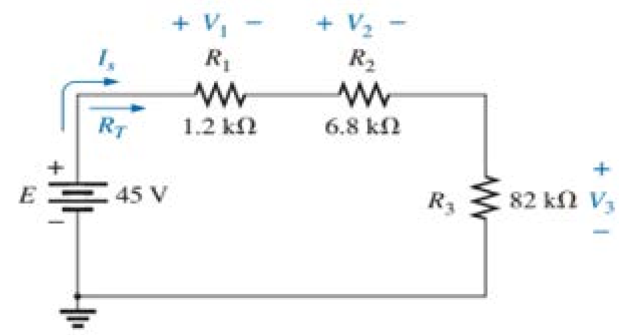


FIG. 5.92

Solution:

a. the most: R_3, the least: R_1

b. R_3, $R_T = 1.2\text{ k}\Omega + 6.8\text{ k}\Omega + 82\text{ k}\Omega = \mathbf{90\text{ k}\Omega}$

$$I_s = \frac{E}{R_T} = \frac{45\text{ V}}{90\text{ k}\Omega} = \mathbf{0.5\text{ mA}}$$

c. $V_1 = I_1R_1 = (0.5\text{ mA})(1.2\text{ k}\Omega) = \mathbf{0.6\text{ V}}$, $V_2 = I_2R_2 = (0.5\text{ mA})(6.8\text{ k}\Omega) = \mathbf{3.4\text{ V}}$,
$V_3 = I_3R_3 = (0.5\text{ mA})(82\text{ k}\Omega) = \mathbf{41\text{ V}}$, results agree with part (a)


THE END.