REVIEW ON THE LAST CLASS

Charge
Electromotive Force (emf)
Electric Potential
Potential Difference
Current
Resistance
Conductance
Temperature Effect on Resistance

Remember

1 electron = 1.602×10^{-19} C

1 C = 6.242×10^{18} electrons

$$V = \frac{W}{Q} \quad [\text{V}]$$

$$Q = \frac{W}{V} \quad [\text{C}]$$

$$W = VQ \quad [\text{J}]$$

$$I = \frac{Q}{t} \quad [\text{A}]$$

$$Q = It \quad [\text{C}]$$

$$t = \frac{I}{Q} \quad [\text{s}]$$

$$R = \frac{1}{G} = \rho\frac{l}{A} \quad [\Omega]$$

$$G = \frac{1}{R} = \frac{A}{\rho l} \quad [\text{S}]$$

$$\frac{|T_1| + T_1}{R_1} = \frac{|T_1| + T_2}{R_2}$$

$$R_2 = R_1[1 + \alpha_1(T_2 - T_1)] \qquad \alpha_1 = \frac{1}{|T_1| + T_1}$$

$$R_1 = R_{20}[1 + \alpha_{20}(T_1 - 20°C)] \qquad \alpha_{20} = \frac{1}{|T_1| + 20°C}$$

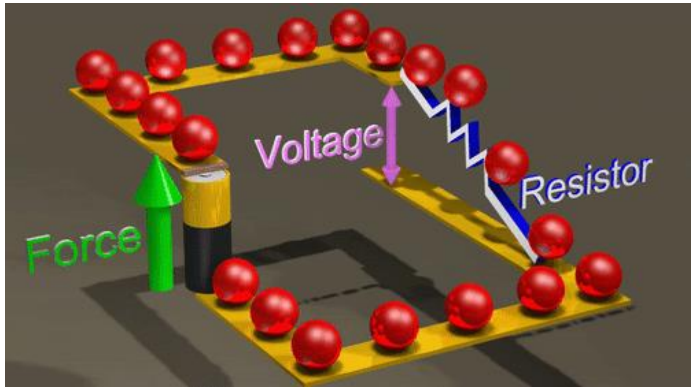
Voltmeter: Measure the voltage; Connect in parallel
Ammeter: Measure the current ; Connect in series
Ohmmeter: Measure the resistance ; Connect in parallel

$|T_1|$ is called the ***inferred absolute temperature*** of the material.

α_1 is called the ***temperature coefficient of resistance*** at a temperature of T_1.

4.2 Ohm's Law

4.2 OHM'S LAW



Statement of Ohm's Law: **At fixed temperature**, the current (I) flowing through a particular conductor is **proportional** to the potential or voltage difference (V) between the two points or ends of the conductor.

According to Ohm's Law:

$$\text{Current} = \frac{\text{Potential Difference}}{\text{Resistance}}$$

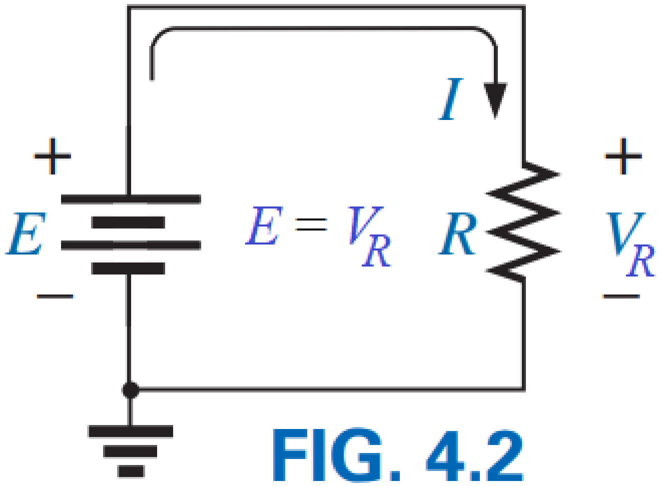


FIG. 4.2
Basic circuit.

The symbol E is applied to all sources of voltage.
The symbol V is applied to all voltage drops across components of the network.
The symbol V_R is applied to represent voltage drops across a resistor.

According to Fig. 4.2 and Ohm's Law:

$$I = \frac{E}{R} = \frac{V_R}{R} \quad \text{(amperes, A)} \qquad \textbf{(4.2)}$$

$$E = V_R = IR \quad \text{(volts, V)} \qquad \textbf{(4.3)}$$

$$R = \frac{E}{I} = \frac{V_R}{I} \quad \text{(ohms, }\Omega\text{)} \qquad \textbf{(4.4)}$$

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

EXAMPLE 4.3 Calculate the current through the 2 kΩ resistor in Fig. 4.4 if the voltage drop across it is 16 V.

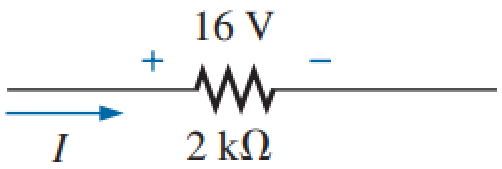


FIG. 4.4 *Example 4.3.*

Solution: $$I = \frac{V}{R} = \frac{16\text{ V}}{2 \times 10^3\ \Omega} = \mathbf{8\ mA}$$

Practice Book Problem [SECTION 4.2 Ohm's Law] Problems: 1 to 11 and 14

4.4 Power

4.4 POWER

Definition: The rate at which work (expending or absorbing or conversion of energy) is done is called power.

Power indicates "***how much work (energy conversion) can be accomplished in a specified amount of time***".

Letter Symbol: It is represented by " P ".

Unit is Watt (W).

1 Watt (W) = 1 joule/second (J/s)

1 horsepower ≈ 746 watts

According to Definition:

$$\boxed{P = \frac{W}{t}} \quad \text{(watts, W, or joules/second, J/s)} \quad \textbf{(4.9)}$$

Relation among power, voltage and Current:

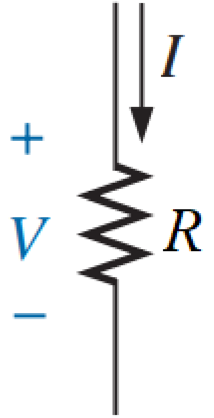
$$P = \frac{W}{t} = \frac{VQ}{t} \quad \left[\because V = \frac{W}{Q}\right]$$

$$P = \frac{VQ}{t} = \frac{VIt}{t} \quad [\because Q = IT]$$

$$\boxed{P = VI} \quad \text{(watts, W)} \quad \textbf{(4.10)}$$

According to Eq. (4.10) we have:

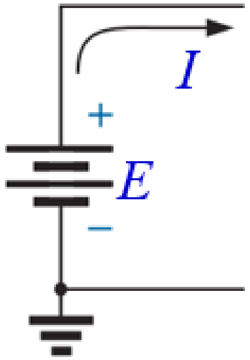
For Load *R*:



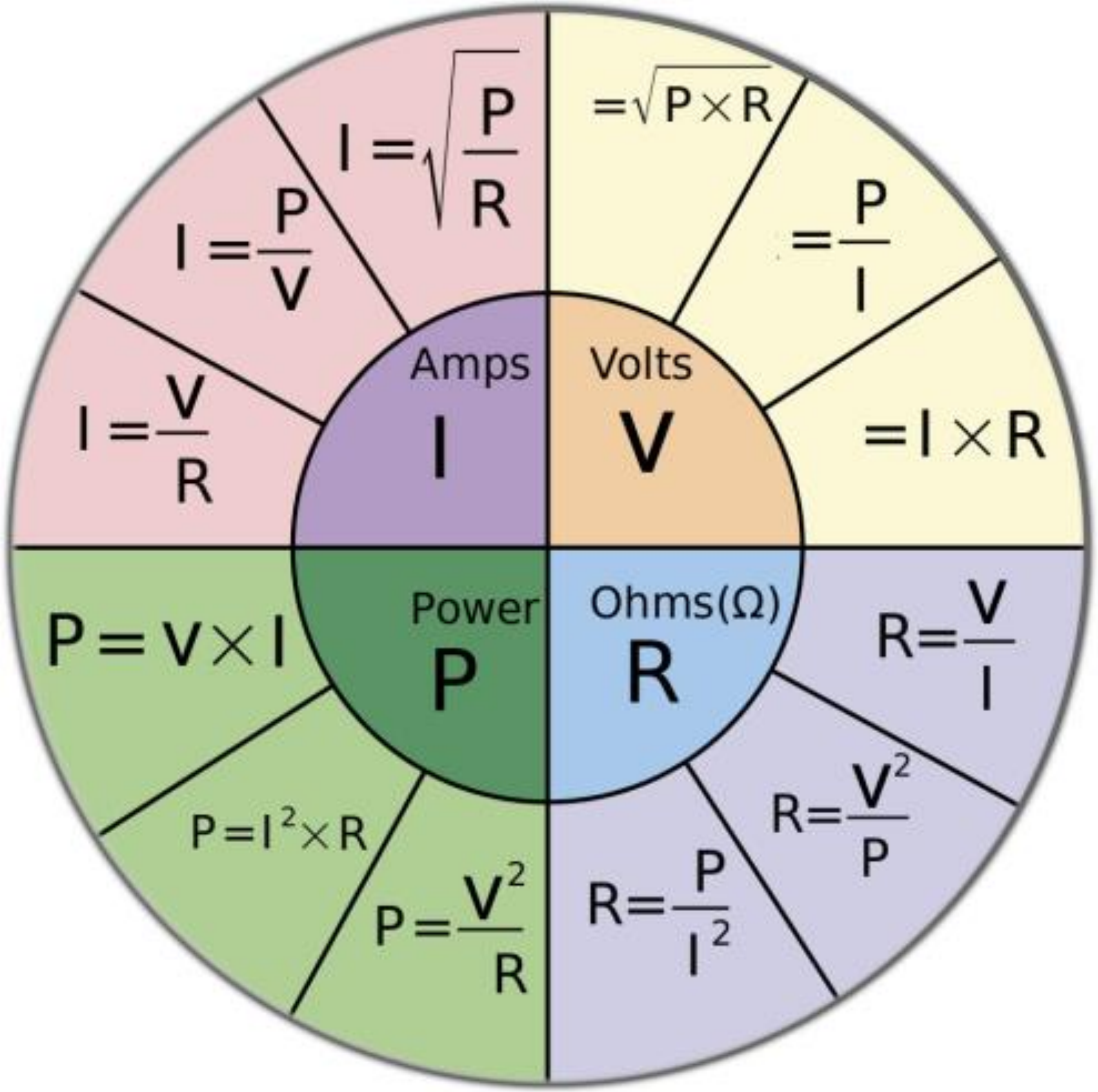
$$P = VI = V\frac{V}{R} = \frac{V^2}{R} \quad \text{(watts, W)} \qquad \textbf{(4.11)}$$

$$P = VI = (IR)I = I^2R \quad \text{(watts, W)} \qquad \textbf{(4.12)}$$

For Source *E*:



$$P = EI \quad \text{(watts, W)} \qquad \textbf{(4.13)}$$



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

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

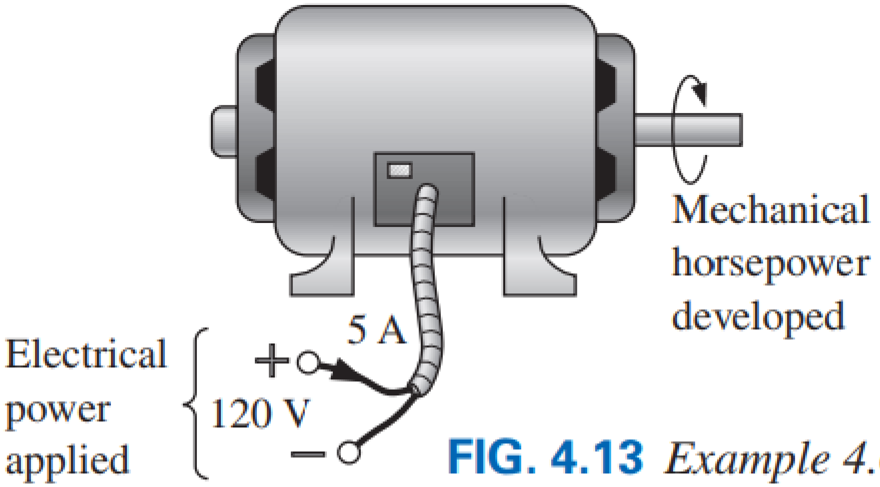


FIG. 4.13 *Example 4.6.*

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

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

EXAMPLE 4.9 Determine the current through a 5 kΩ resistor when the power dissipated by the element is 20 mW.

Solution:
$$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{20 \times 10^{-3}\ \text{W}}{5 \times 10^{3}\ \Omega}} = \sqrt{4 \times 10^{-6}} = 2 \times 10^{-3}\ \text{A}$$
$$= \mathbf{2\ mA}$$

Exercise Problems

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

Solution: Given, $W = 420$ J, $t = 4$ min $= (4\times60)$ s $=240$ s and $P = ?$

$$P = \frac{W}{t} = \frac{420\ \text{J}}{240\ \text{s}} = 1.75\ \text{W}$$

Practice Book Problem [SECTION 4.4 Power] Problems: 21 to 37

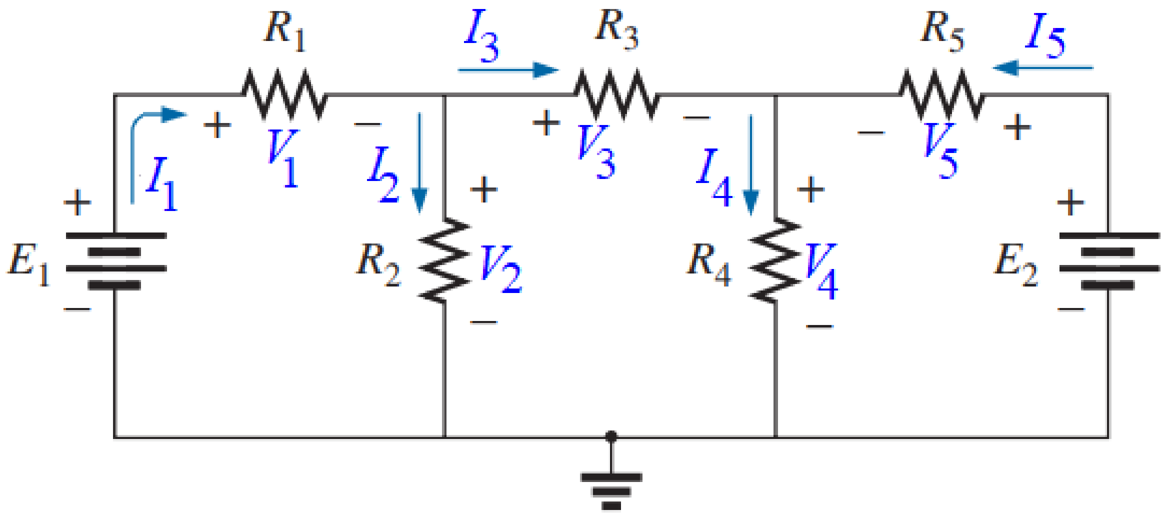
Tellegen's Theorem [1952 by B. D. H. Tellegen] for Power

Statement:

(1) The sum of the powers absorbed by all elements in an electrical network is zero.

OR

(2) The power supplied in a network is exactly equal to the power absorbed.



$$P_{E1} = -E_1 I_1$$
$$P_{E2} = -E_2 I_5$$
$$P_{R1} = I_1^2 R_1 = \frac{V_1^2}{R_1}$$
$$P_{R2} = I_2^2 R_2 = \frac{V_2^2}{R_2}$$
$$P_{R3} = I_3^2 R_3 = \frac{V_3^2}{R_1}$$
$$P_{R4} = I_4^2 R_4 = \frac{V_4^2}{R_4}$$
$$P_{R5} = I_5^2 R_5 = \frac{V_5^2}{R_5}$$

According to Statement (1):

$$P_{E1} + P_{E2} + P_{R1} + P_{R2} + P_{R3} + P_{R4} + P_{R5} = 0$$

According to Statement (2):

$$E_1 I_1 + E_2 I_5 = I_1^2 R_1 + I_2^2 R_2 + I_3^2 R_3 + I_4^2 R_4 + I_5^2 R_5$$
$$= \frac{V_1^2}{R_1} + \frac{V_2^2}{R_2} + \frac{V_3^2}{R_3} + \frac{V_4^2}{R_4} + \frac{V_5^2}{R_5}$$

4.5 Energy

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.**

The capacity or ability to do work is called energy.

Letter Symbol: It is represented by " W ".

Unit is Watt-s (W-s) or kilowatt-hour (kWh).

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

$$W = Pt \qquad \text{(wattseconds, Ws, or joules)} \qquad \textbf{(4.16)}$$

$$W = Pt = EIt = VIt \ \ (\text{W-s})$$

$$\text{Energy (Wh)} = \text{power (W)} \times \text{time (h)} \qquad \textbf{(4.17)}$$

$$\text{Energy (kWh)} = \frac{\text{power (W)} \times \text{time (h)}}{1000} \qquad \textbf{(4.18)}$$

$$\begin{aligned} 1\ \text{Wh} &= 1\ \text{Watt} \times 1\ \text{hour} \\ &= 1\ \text{Watt} \times 3600\ \text{s} = 3600\ \text{w-s}\ i.e\ \text{J} \\ 1\ \text{kWh} &= 1000\ \text{Wh} = 3.6 \times 10^6\ \text{J} \end{aligned}$$

When a power of 1 kW is utilized for 1 hour the energy consumed or absorbed or conversion is said to be 1 kWh.

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 Taka per kilowatthour.

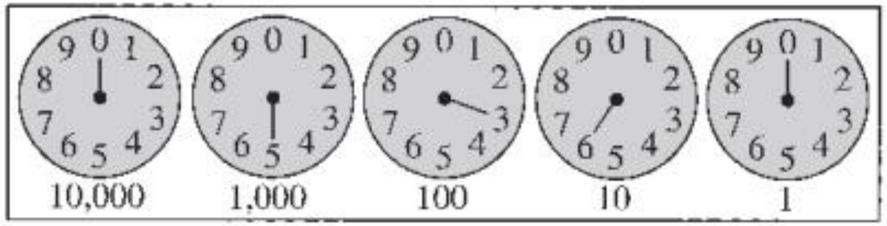


FIG. 4.16 *Kilowatthour meters: (a) analog; (b) digital.* (Courtesy of ABB Electric Metering Systems.)

SOLUTION:

Reading from Meter: 5×1,000 + 3×100 + 6×10 + 0×1 = 5360 kWh

Used Energy: 5360 kWh – 4650 kWh = 710 kWh

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

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

Solution: $$W = \frac{Pt}{1000} = \frac{(60\text{ W})(24\text{ h/day})(365\text{ days})}{1000} = \frac{525{,}600\text{ Wh}}{1000} = \mathbf{525.60\ kWh}$$

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

$$= \frac{600\text{ Wh} + 1200\text{ Wh} + 300\text{ Wh} + 1600\text{ Wh}}{1000} = \frac{3700\text{ Wh}}{1000} = 3.7\text{ kWh}$$

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

Practice Book Problem [SECTION 4.5 Energy] Problems: 42 to 48

4.6 Efficiency

4.6 Efficiency

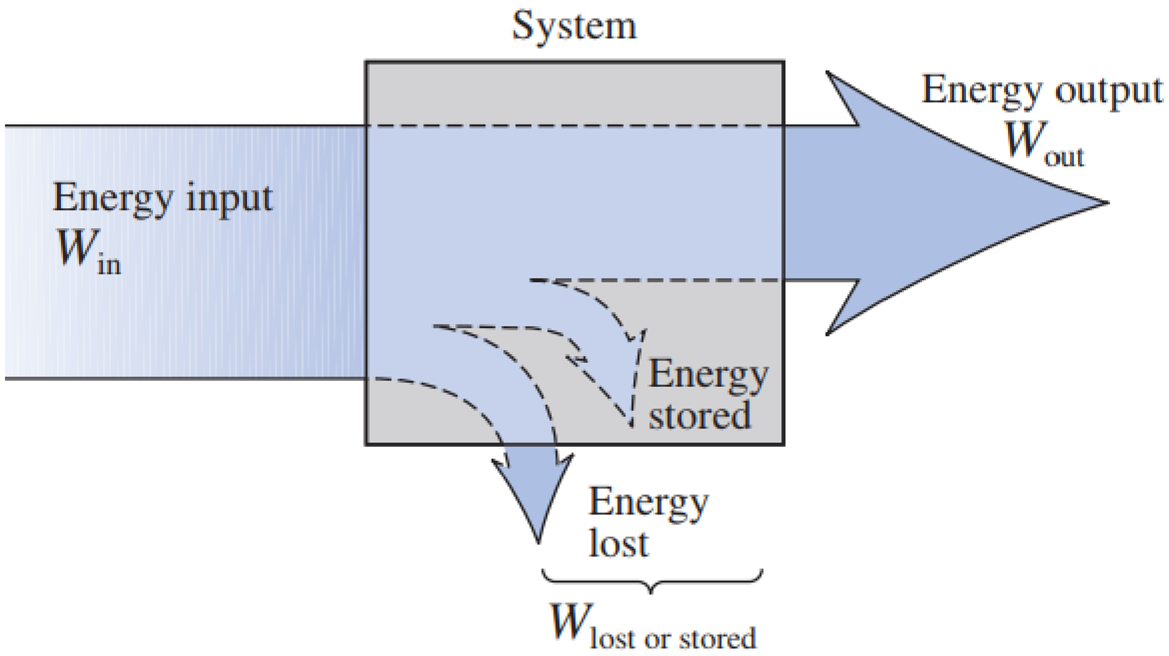


FIG. 4.18 *Energy flow through a system.*

Definition: **Efficiency is the ratio of output power (or energy) to input power (or energy).**

Letter Symbol: It is represented by (the lowercase Greek letter *eta*) " η ".

Efficiency is **unitless**.

Energy Input = **Energy Output** + **Energy Lost or Stored**

Energy Output = **Energy Input** – **Energy Lost or Stored**

Energy Lost or Stored = **Energy Input** – **Energy Output**

In decimal number:

$$\text{Efficieny } (\eta) = \frac{\text{Power Output } (P_o)}{\text{Power Input } (P_i)}$$

$$\text{Efficieny } (\eta) = \frac{\text{Energy Output } (W_o)}{\text{Energy Input } (W_i)}$$

In percentage:

$$\eta\% = \frac{P_o}{P_i} \times 100\% \quad \text{(percent)} \quad \textbf{(4.21)}$$

$$\eta\% = \frac{W_o}{W_i} \times 100\% \quad \text{(percent)} \quad \textbf{(4.22)}$$

Efficiency of cascaded system:

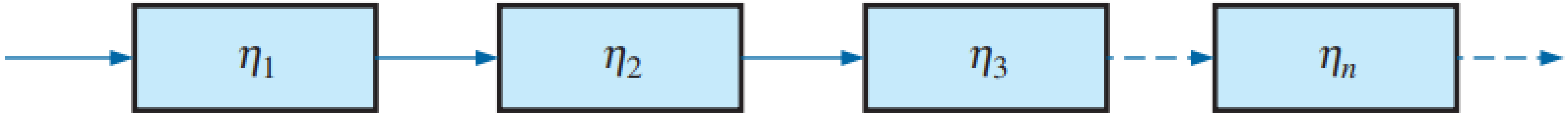
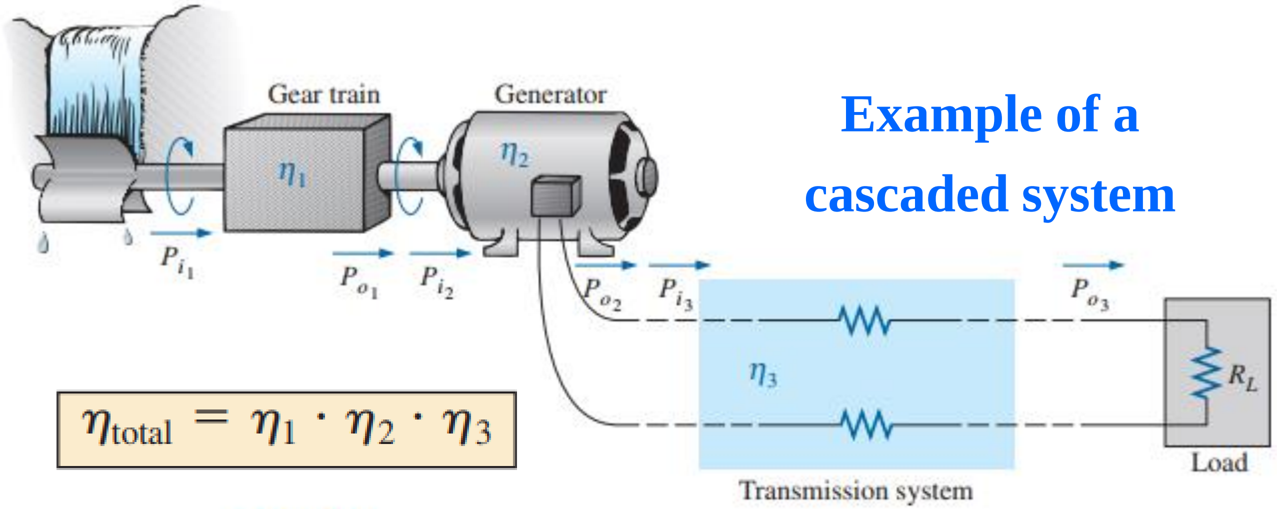


FIG. 4.20 *Cascaded system.*

$$\eta_{\text{total}} = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdots \eta_n \quad \textbf{(4.23)}$$



$$\eta_{\text{total}} = \eta_1 \cdot \eta_2 \cdot \eta_3$$

Example of a cascaded system

FIG. 4.19 *Basic components of a generating system.*

EXAMPLE 4.15 A 2 hp motor operates at an efficiency of 75%. What is the power input in watts? If the applied voltage is 220 V, what is the input current?

Solution: $\eta\% = \dfrac{P_o}{P_i} \times 100\%$ 1 hp = 746 W

$$0.75 = \frac{(2\text{ hp})(746\text{ W/hp})}{P_i} \quad \text{and} \quad P_i = \frac{1492\text{ W}}{0.75} = \mathbf{1989.33\ W}$$

$$P_i = EI \quad \text{or} \quad I = \frac{P_i}{E} = \frac{1989.33\text{ W}}{220\text{ V}} = \mathbf{9.04\ A}$$

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: $\eta\% = \dfrac{P_o}{P_i} \times 100\%$ $0.80 = \dfrac{P_o}{(120\text{ V})(8\text{ A})}$ and $P_o = (0.80)(120\text{ V})(8\text{ A}) = 768\text{ W}$

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

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

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

EXAMPLE 4.18 Find the overall efficiency of the system in Fig. 4.19 if $\eta_1 = 90\%$, $\eta_2 = 85\%$, and $\eta_3 = 95\%$.

Solution:

$$\eta_T = \eta_1 \cdot \eta_2 \cdot \eta_3$$
$$= (0.90)(0.85)(0.95)$$
$$= 0.727, \text{ or } \mathbf{72.7\%}$$

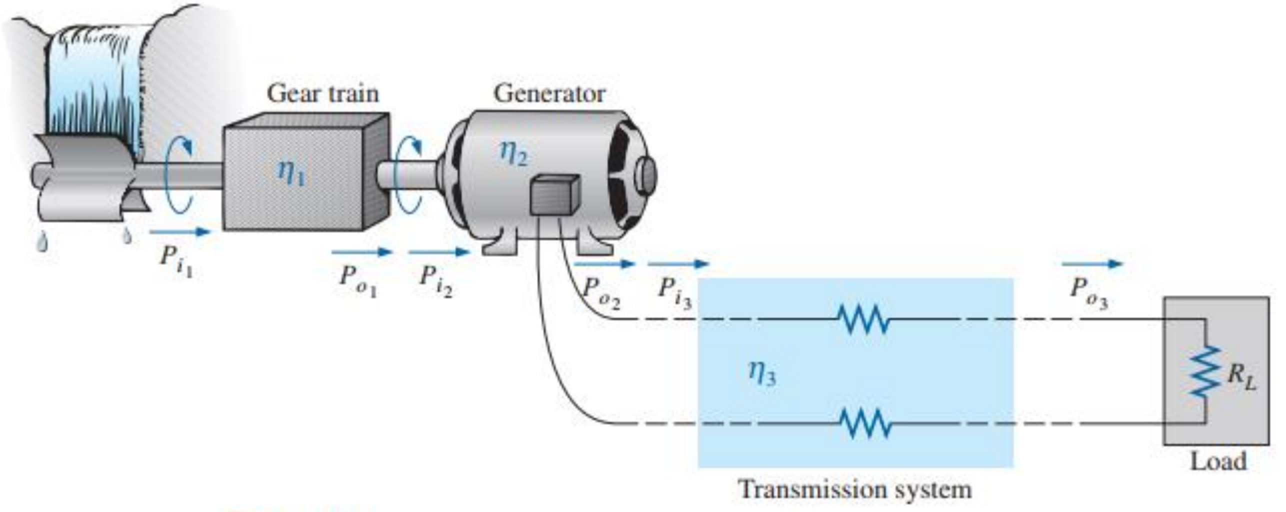


FIG. 4.19 *Basic components of a generating system.*

Practice Book Problem [SECTION 4.6 Efficiency] Problems: 49 to 59

Basic Elements of a Circuit

Basic of Circuit Elements

There are two types of elements found in electric circuits:

(1) **Passive Elements**: (*i*) **Resistor** (*ii*) **Inductor** (*iii*) **Capacitor**

(2) **Active Elements**:

(*i*) **Independent or Ideal Source**: (*a*) **Voltage source** (*b*) **Current source**

(*ii*) **Dependent** or **Controlled Source**:

(*a*) **Voltage controlled source**

(*i*) A voltage-controlled voltage source (VCVS)

(*ii*) A voltage-controlled current source (VCCS)

(*b*) **Current controlled source**

(*i*) A current-controlled voltage source (CCVS)

(*ii*) A current-controlled current source (CCVS)

Passive Elements

There are basic three passive elements: **Resistor**, **Inductor** and **Capacitor**

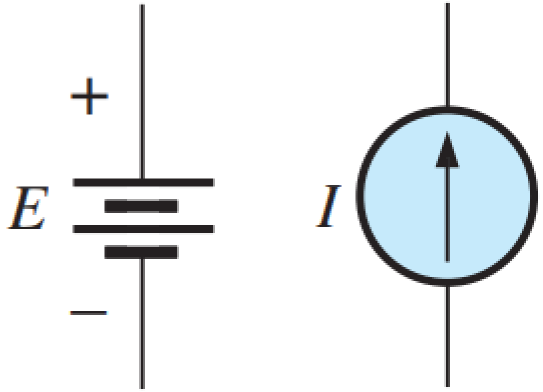
			
Physical Element Name:	**Resistor**	**Inductor** or **Choke**	**Capacitor** or **Condenser**
Properties Name in Circuit:	**Resistance measured in** Ohm **ohm** (Ω)	**Inductance measured in Henry** (H)	**Capacitance measured in Farad** (F)
Characteristics or Function in circuit:	Opposes or limits or controls the flow of **current** (*i*)	Opposes or limits or controls the **rate of current** (*di/dt*) Also, stored **magnetic** energy	Opposes or limits or controls the **rate of voltage** (*dv/dt*) Also, stored **electrical** energy

Independent Sources

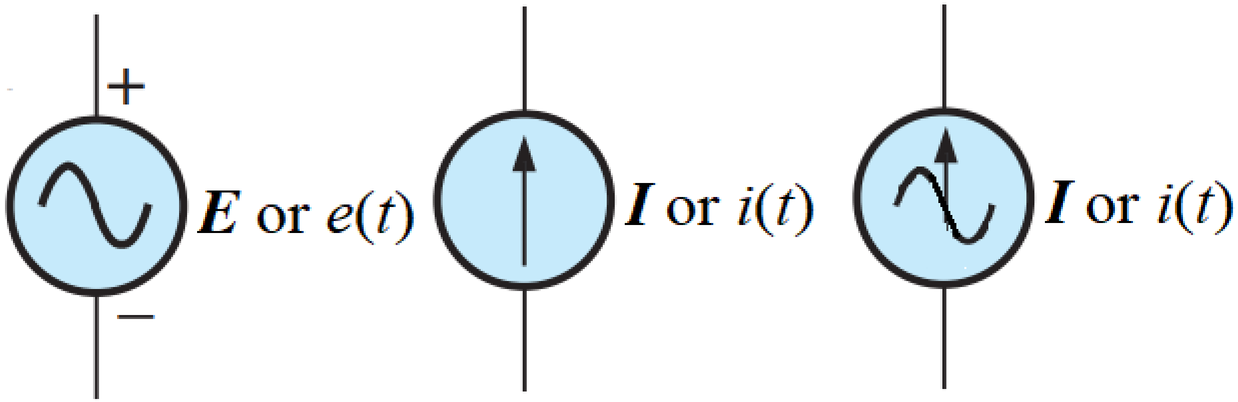
Independent Source: An **independent source** is an active element that provides a specified **voltage** or **current** that is completely independent of other circuit variables.

Voltage Sources: A voltage source is an active element of a circuit that maintains a prescribed voltage across its terminals regardless current flowing in those terminals.

Current sources: A current source is an active element of a circuit that maintains a prescribed current through its terminals regardless voltage across those terminals.



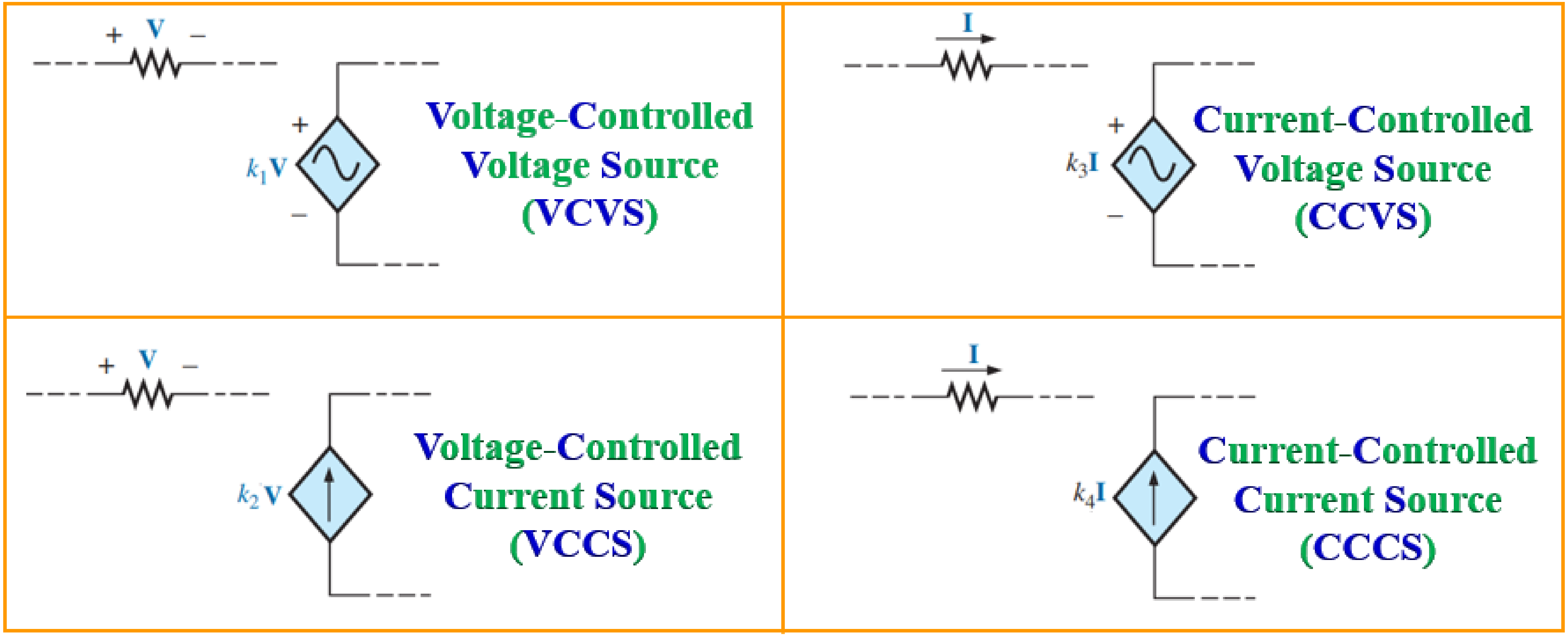
Direct Current(AC)



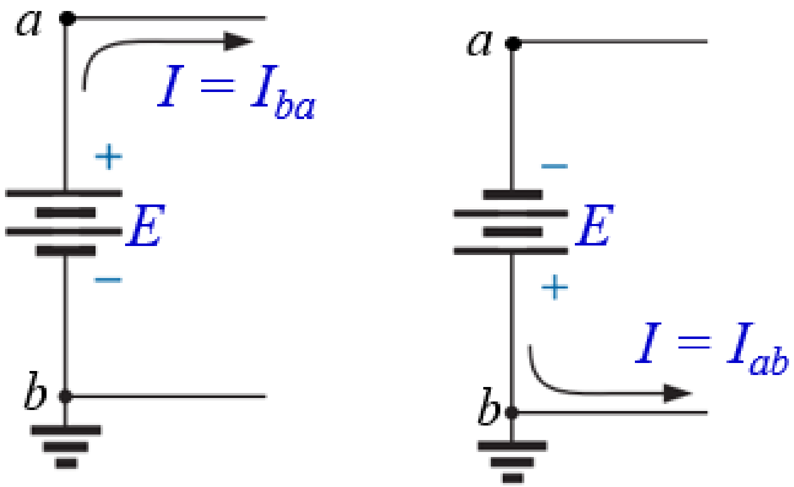
Alternating Current(AC)

Dependent or Controlled Sources

Dependent or Controlled Source: A **dependent** (or **controlled**) source is an active element in which the source quantity (voltage or current) is controlled by another voltage or current.



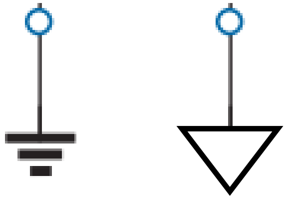
DEFINING DIRECTION OF CURRENT



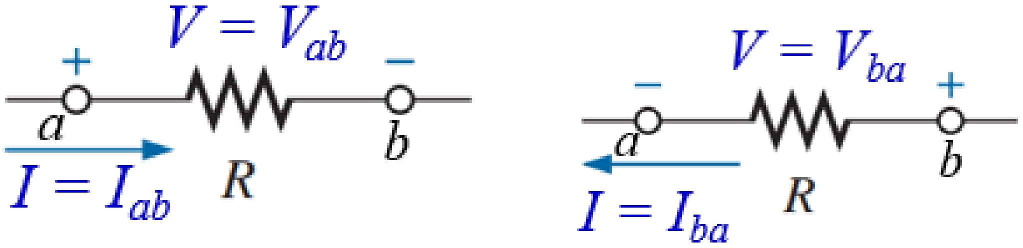
Current Direction for a Source:

- **Current leaves** from the **positive (+) terminal** of a source.
- **Current enters** to the **negative (–) terminal** of a source.
- Alternatively, from positive (+) terminal current leaves and in negative (–) terminal current enters for the source E.

Symbol of Ground



DEFINING POLARIES OF VOLTAGE DROP

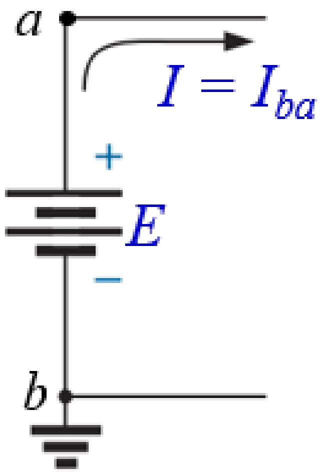


$(V_{ab} = +)$; $(I_{ab} = +)$ $(V_{ab} = –)$; $(I_{ab} = –)$

Voltage drop polarity for a load such as R:

- The terminal of a load, at which **current enters**, is referred as **positive (+) polarity**.
- The terminal of a load, at which **current leaves**, is referred as **negative (–) polarity**.
- Alternatively, the current enters the positive terminal and leaves the negative terminal for the load resistor R.

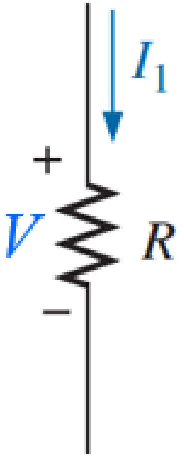
Passive Sign Convention of Power



If current leaves from the positive polarity (or current enters through negative terminal) of the voltage power is considered negative (*i.e. P*<0).

P<0 implies that the element is releasing or supplying or delivering power.

$$\boxed{P = -EI}$$



If current enters through the positive polarity (or current leaves from negative terminal) of the voltage power is considered positive (*i.e. P*>0).

P>0 implies that the element is consuming or absorbing power.

$$\boxed{P = VI = \frac{V^2}{R} = I^2 R}$$

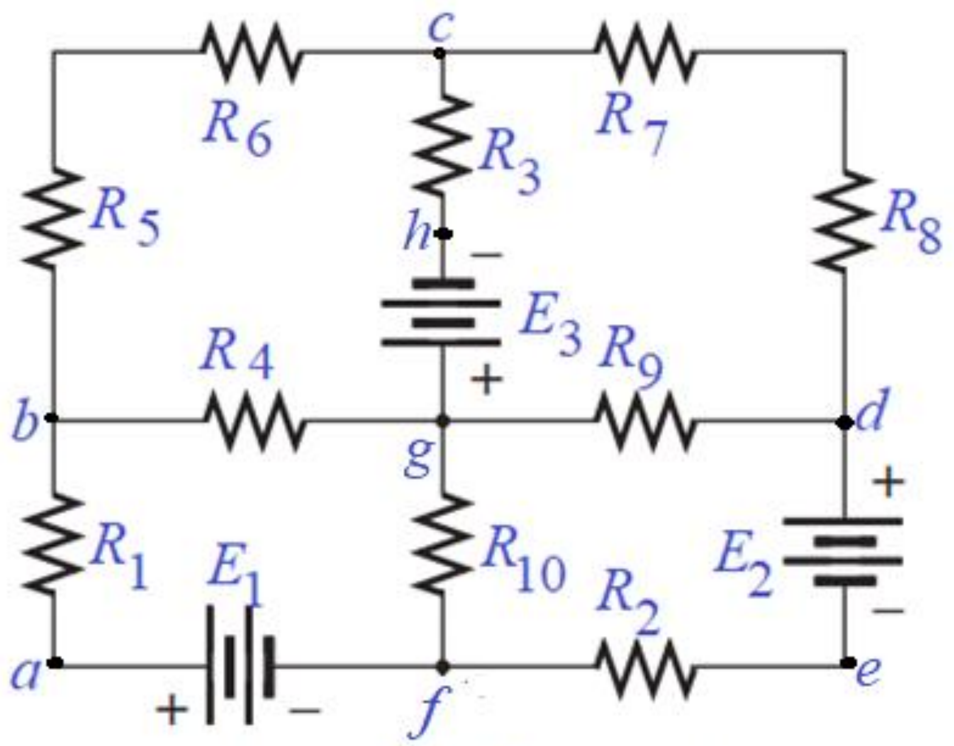
Branch, Junction Point, Node and Mesh (or Loop)

Branch: A part of network which connects the various points of the network with one another is called a **branch**. A **branch** of a circuit is any portion of the circuit that has one or more elements in series.
In the figure *ab*, *bc*, *cd*, *de*, *ef*, *fa*, *bg*, *fg*, *dg*, *gh*, *hc* are the various branches.

Junction Point: A point where three or more branches meet is called a junction point. Points *b*, *c*, *d*, *f*, and *g* are **junction points**.

Node: A point at which two or more elements are joined is called a **node**. The junction points are also called node. Points *a*, *b*, *c*, *d*, *e*, *f*, *g* and *f* are node.

Mesh or Loop: A mesh or loop is a set of branches forming a closed path in a network in such a way that if one branch is removed then remaining branches do not form a closed path.
In figure loops are: *a-b-c-d-e-f-a*; *a-b-g-f-a*; *b-c-h-g-b*; *g-h-c-d-g*; *d-e-f-g-d*



An Electrical Network

Test Your Knowledge

(a) How many branches are here? Name Them.

Answer: Six branches are here. They are: *ab*, *bd*, *da*, *ag*, *bg*, *dg*.

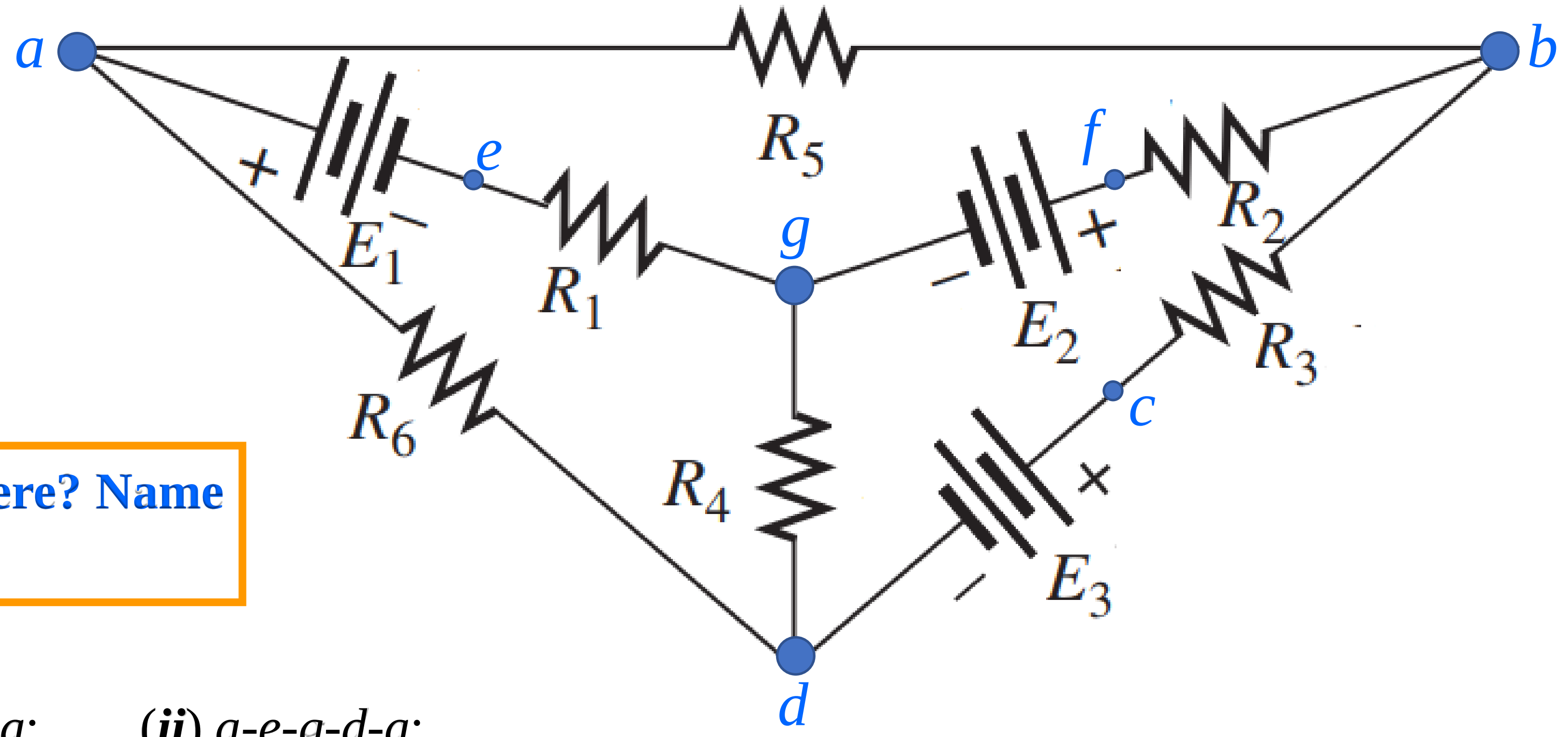
(b) How many nodes are here? Name Them.

Answer: Seven nodes are here. They are: *a*, *b*, *c*, *d*, *e*, *f*, *g*.

(c) How many junction points are here? Name Them.

Answer: Four junction points here.

They are: *a*, *b*, *c*, *d*, and *g*.



(d) How many mesh or loops are here? Name Them.

Answer: Four mesh or loops here.

They are: (***i***) *a-b-c-d-a*; (***ii***) *a-e-g-d-a*; (***iii***) *b-f-g-e-a-b*; (***iv***) *b-f-g-d-c-b*;

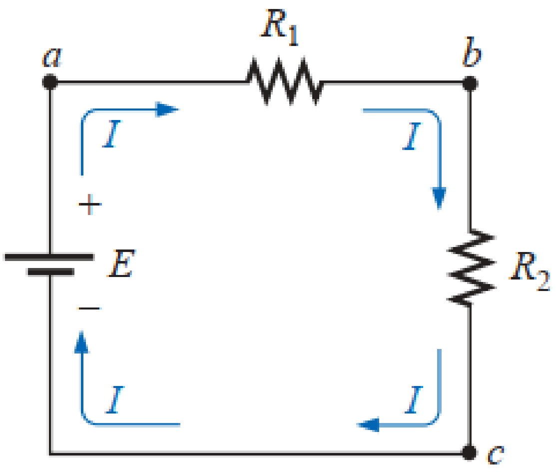
Chapter 5

Series DC Circuit

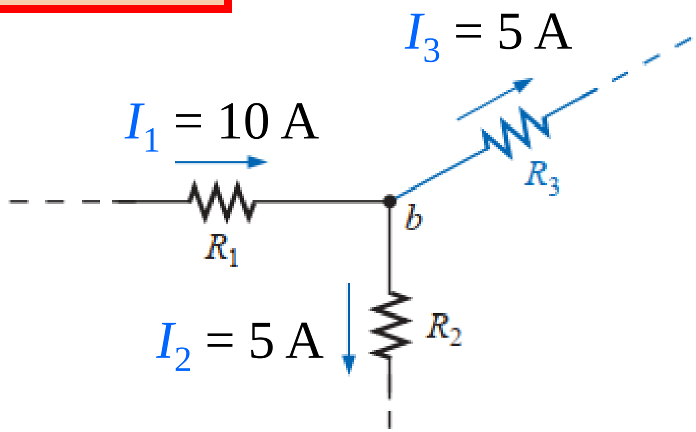
Two Elements are in Series

Two elements are in series if

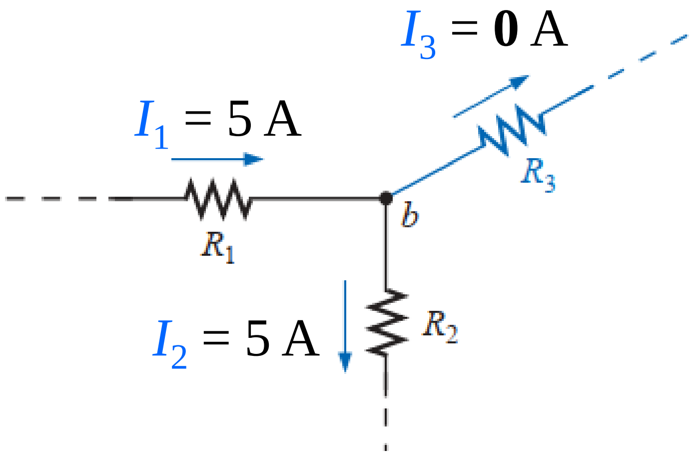
1. They have **only one terminal in common** (i.e., one lead of one is connected to only one lead of the other).
2. The common point between the two elements is **not connected to another current-carrying element**.
3. The current is the same through the two series elements.



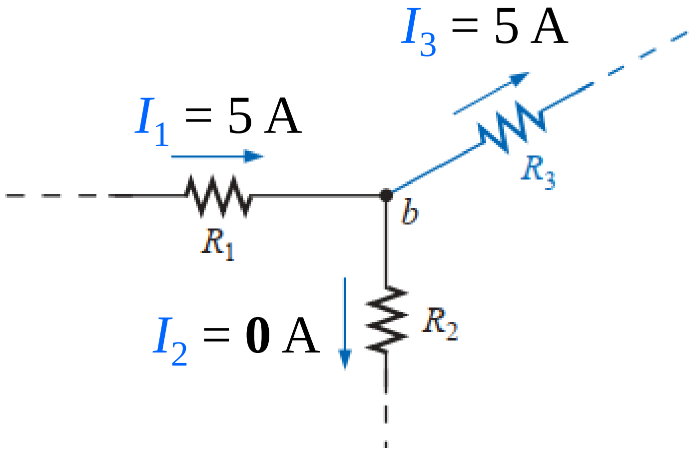
R_1 and R_2 are in series



R_1 and R_2 are not in series
R_2 and R_3 are not in series



R_1 and R_2 may be in series



R_1 and R_3 may be in series

5.2 Series Resistance

Total or Net or Effective Resistance of a Series Circuit or a Branch:

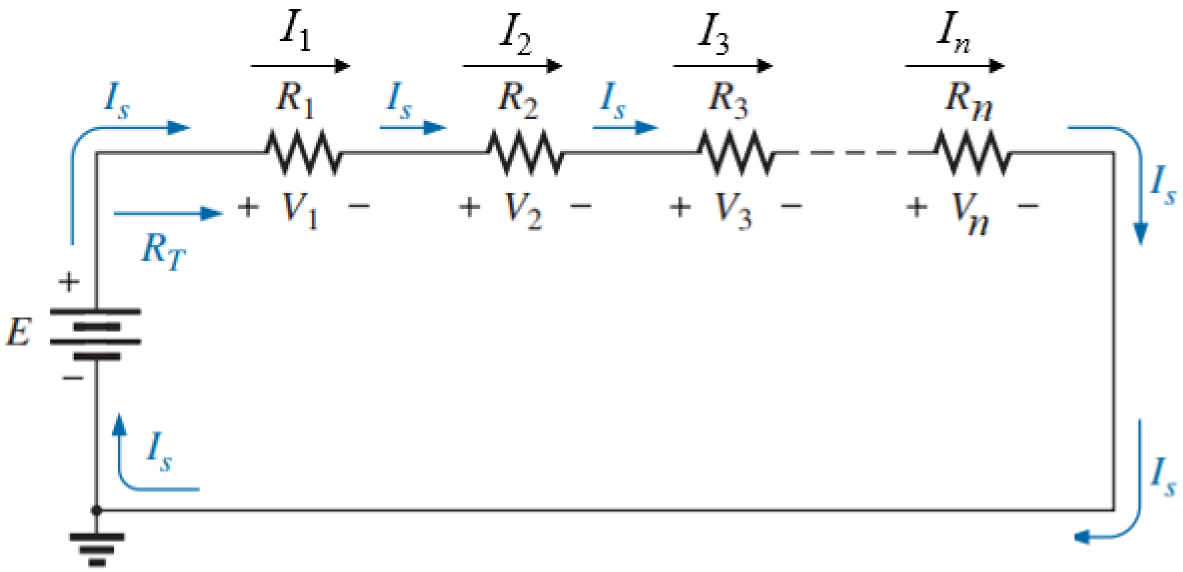
- The total resistance of a series configuration is the sum of the value of individual resistance, that is Eq. (**5.1**).
- The more resistors we add in series, the greater the resistance, no matter what their value.
- The total resistance greater than the value of all the individual resistance , that is Eq. (**5.1.1**).
- The total resistance of n resistors of the same value in series is simply ***multiply the value of one of the resistors by the number in series***; that is as Eq. (**5.2**)

$$\boxed{R_T = R_{eff} = R_1 + R_2 + R_3 + \ldots\ldots + R_n} \qquad \textbf{(5.1)}$$

If $R_1 = R_2 = R_3 = \ldots\ldots = R_n = R$

$$\boxed{R_T = R_{eff} = nR} \qquad \textbf{(5.2)}$$

$$\boxed{R_T > R_1;\ \ R_T > R_2;\ldots\ldots, R_T > R_N} \qquad \textbf{(5.1.1)}$$



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.

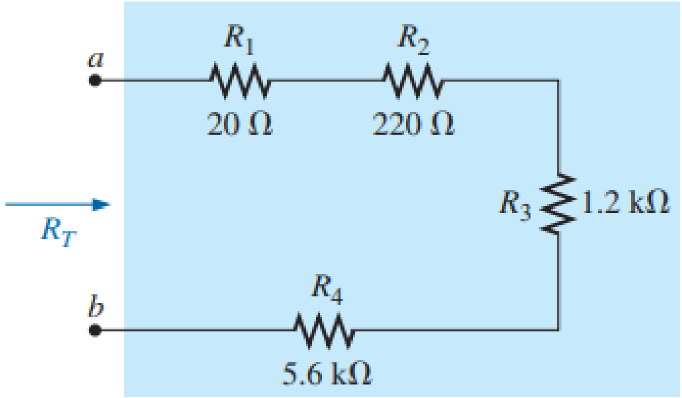


FIG. 5.6
Series connection of resistors for Example 5.1.

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

EXAMPLE 5.2 Find the total resistance of the series resistors in Fig. 5.7. Again, recognize 3.3 kΩ as a standard value.

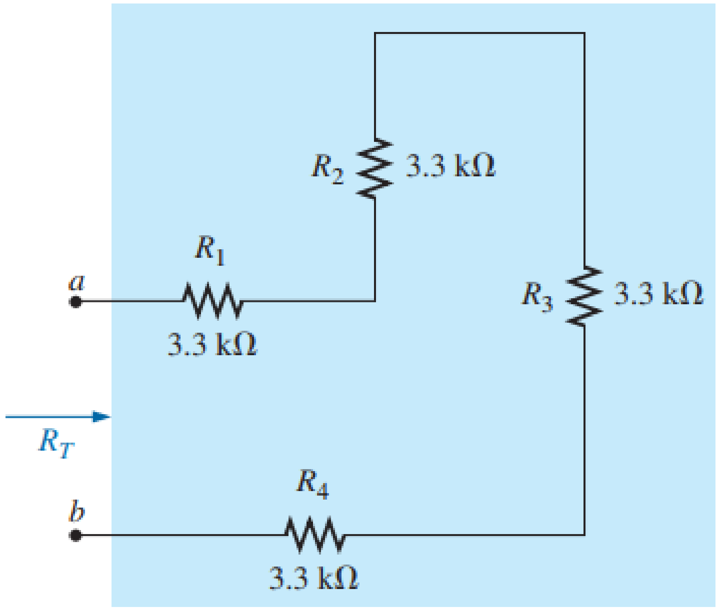


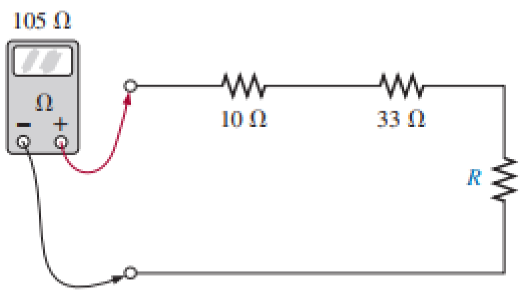
FIG. 5.7
Series connection of four resistors of the same value (Example 5.2).

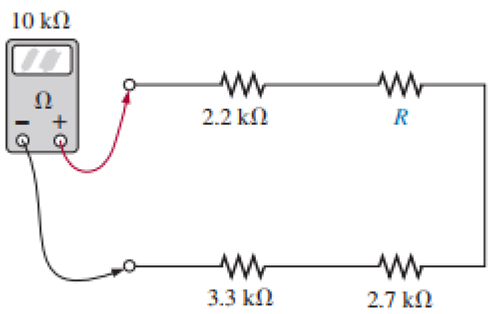
Solution: Again, don't be concerned about the change in configuration. Neighboring resistors are connected only at one point, satisfying the definition of series elements.

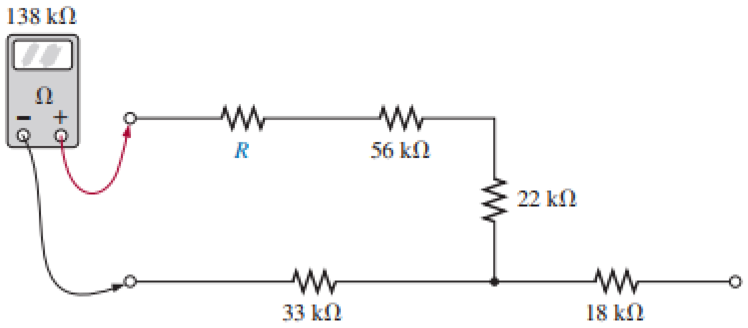
Eq. (5.2): $$R_T = NR$$
$$= (4)(3.3\ \text{k}\Omega) = \mathbf{13.2\ k\Omega}$$

Practice Book Problem [5.2 Series Resistance] Problems: 1, 2, 5,6

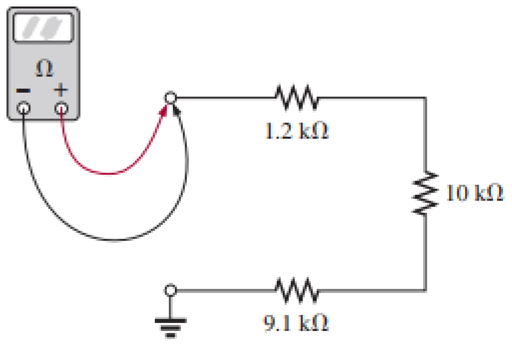
What is the value of ***R*** for the following cases of the reading of **OHM METER**?



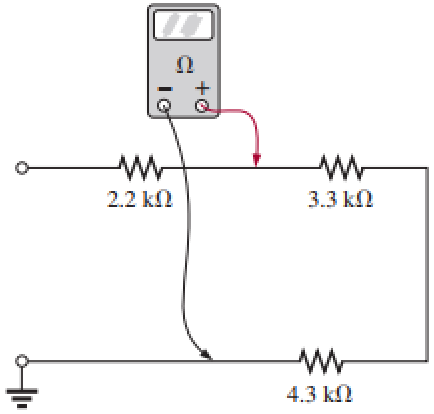




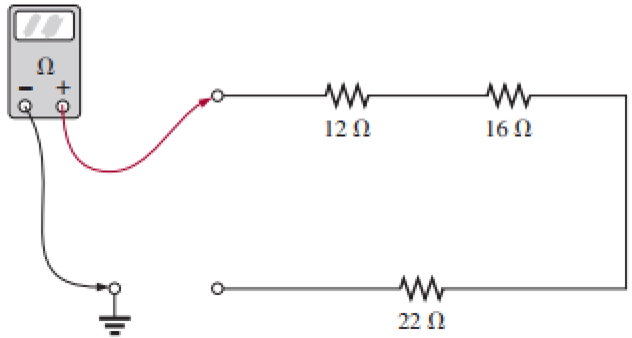
What is the reading of **OHM METER** for the following cases?



(c)



(b)



(d)