Welcome to

Fall 2023-24

COE 2101: INTRODUCTION TO ELECTRICAL CIRCUITS

Introduction of Course Teacher

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Course Descriptions

- Basic concepts of DC circuit. Familiarizing with different components: Resistor, capacitor, Inductor, Voltage source, etc.
- Familiarizing with Series, Parallel and Series-parallel circuits Basic idea about alternating quantity: Period and cycle, frequency, angular velocity, angular frequency, Sinusoidal waveform. Vector Diagram.
- Ohm's Law; Total resistance of series & parallel circuits; KVL; KCL. Equation of instantaneous voltage, current and power of an R branch, L branch, C branch, RL, RC and RLC circuits. Impedance of R, L and C; Total impedances of their series or parallel combinations. Calculation of power and power factor Brief study of transients in capacitive networks.
- AC Power. Y-Delta and Delta-Y conversions; Dependent Current Source, Dependent Voltage Source; Network Theorems for DC and AC circuits: Superposition theorem Network Theorems for DC and AC circuits. Electromagnetism, Flemings hand rules,
- DC generator and DC motor, Transformer, Induction motor, Synchronous generator, Alternator, Stepper Motor, Induction Motor, Universal Motor, Servo Motor, Permanent-magnet Synchronous motor, hysteresis motor, Reluctance motor, Linear motor

Text Books

[1] R. L. Boylestad, "Introductory Circuit Analysis," 12th Edition, Pearson Education, Inc.

[2] B. L. Theraja, A. K. Theraja, "A Textbook of ELECTRICAL TECHNOLOGY in SI Units Volume II, AC & DC Machines," S. Chand & Company Ltd.

[3] V.K. Mehta, Rohit Mehta, "Principles of Electrical Machines," 2nd Edition, S. Chand & Company Ltd.

[4] Jack Rosenblatt, M. Harold Friedman, "Direct and Alternating Current Machinery," C.E. Merrill Publishing Company, 1984

Reference Books

[**1**] Robert P. Ward, “Introduction to Electrical Engineering”, 3rd Edition, Prentice Hall Inc.

[**2**] Charles K. Alexander & Mathew N.O. Sadiku, “Fundamentals of Electric Circuits”, 3rd edition, The McGraw-Hill companies.

[**3**] Stephen J. Chapman, “Electric Machinery Fundamentals” - 3rd Edition, McGraw- Hill International Editions

[**4**] Irving L. Kosow, “Electrical Machinery and Transformers”- Second Edition, Prentice – Hall India Pvt. Limited.

[**5**] S. K. Bhattacharya, “Electrical Machines”, McGraw Hill Education, 2014

[**6**] J. David Irwin and R. mark Nelms, “Basic Engineering Circuit Analysis”, Eleventh Edition, John Wiley & Sons, Inc. , 2015.

Topics will Be Covered:

Electrical System

- Electrical Energy Sources;
- Conductors or Wires
- Control Elements or Switches
- Electrical Load
- Load Represent by Passive Elements

Basic Elements of a Circuit

- Basic of Circuit Elements
- Passive Elements
- Independent and Dependent or Controlled Sources

Defining Direction of Current and Polarity of Voltage Drop

Passive Sign Convention of Power

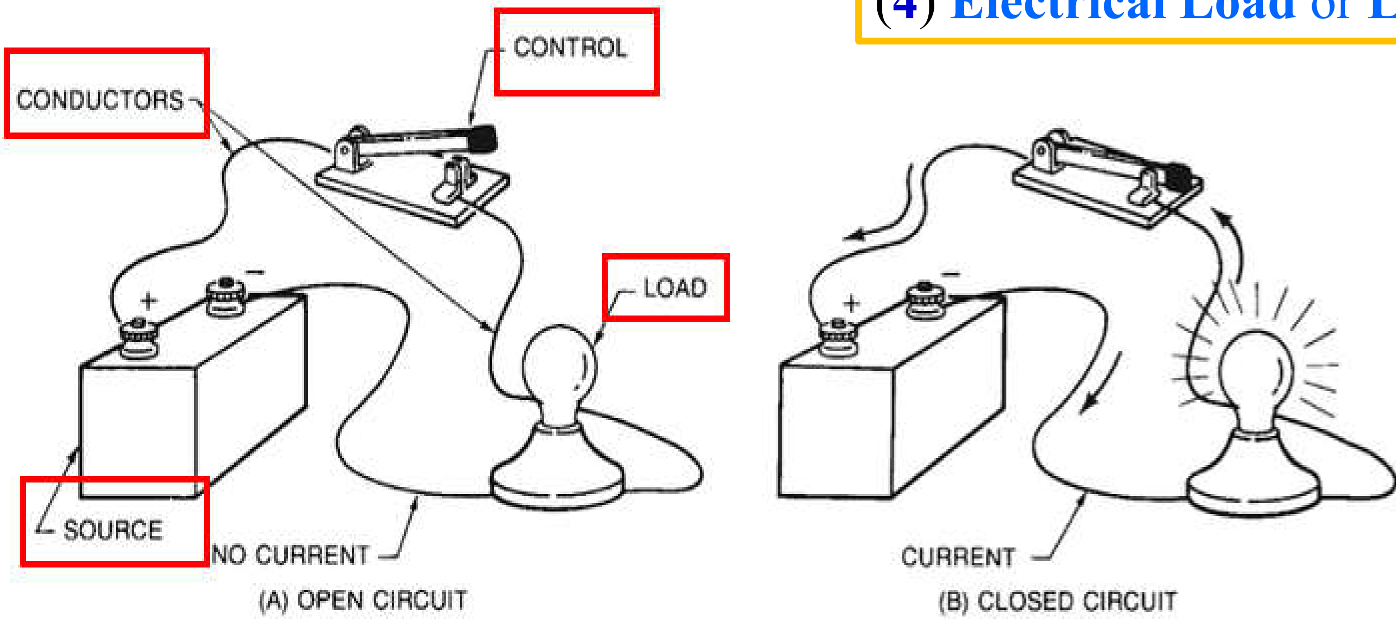
Branch, Junction Point, Node and Mesh (or Loop) in a Circuit

Power of Ten

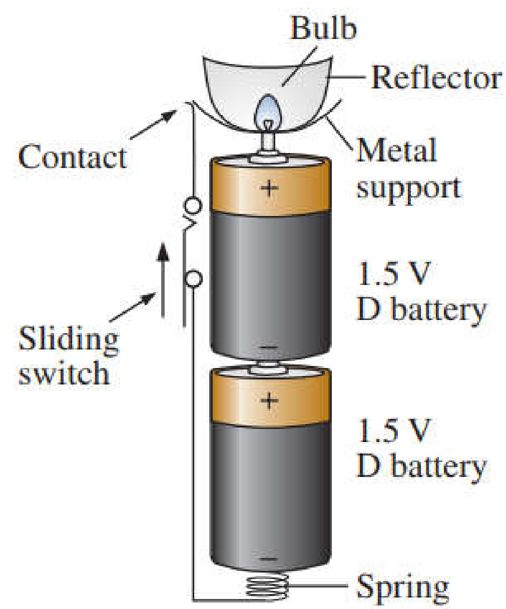
Electrical System

An **electric circuit** or **network** is an interconnection of electrical elements.

The components or elements of an electrical system are: (**1**) **Source**, (**2**) **Conductors** or **Wires**, (**3**) **Control Elements** or **Switches**, and (**4**) **Electrical Load** or **Load**



A closed path is required to flow of current.



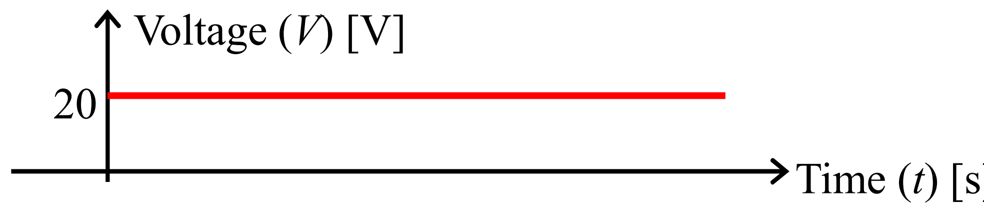
Electrical Energy Sources (I)

In electrical system has mainly two types of source:

DC (Direct Current) Source

AC (Alternating Current) Source

Graphical representation of DC Source



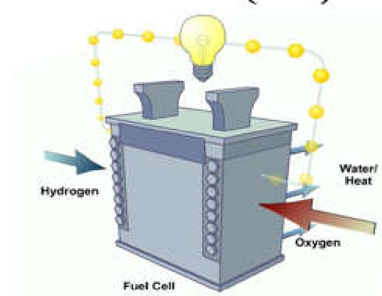
DC Source

- ❑ Battery (DC)
- ❑ DC Generator
- ❑ Lab DC Power Supply
- ❑ Solar (PV) Cell
- ❑ Fuel Cell

Battery (DC)

Solar Cell (DC)

Lab Power Supply (DC)

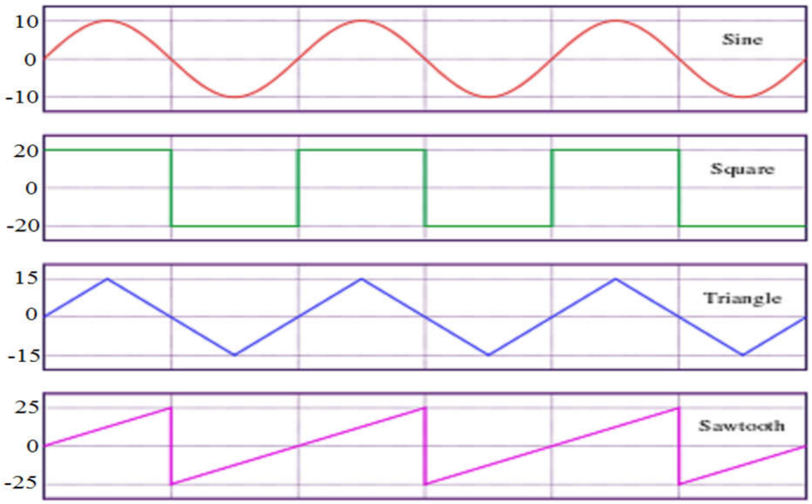


Fuel Cell (DC)

Electrical Energy Sources (II)

AC Source

- ❖ AC Generator in power Plant
- ❖ Lab AC Power Supply
- ❖ Portable AC Generator
- ❖ Standby AC Generator
- ❖ Wind Generation
- ❖ Biogas Power Plant

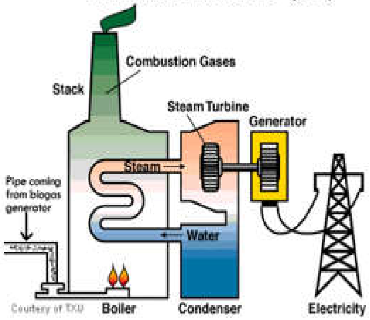


Generator in Power Plant (AC)

Portable Generator (AC)

Lab Power Supply (AC)

Wind Generation (AC)



Biogas Power Plant (AC)

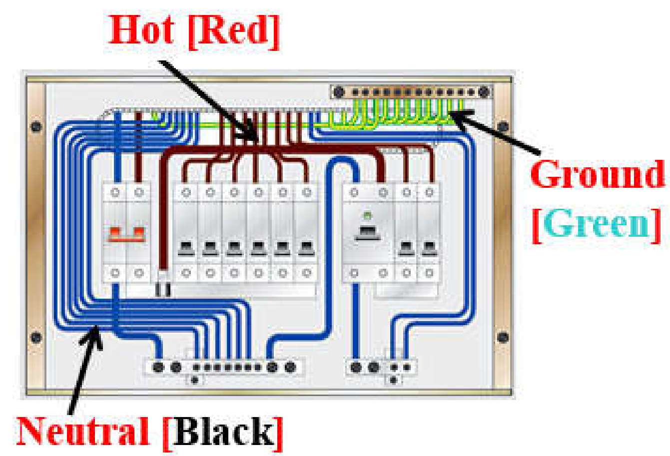
Standby Generator (AC)

Conductors or Wires

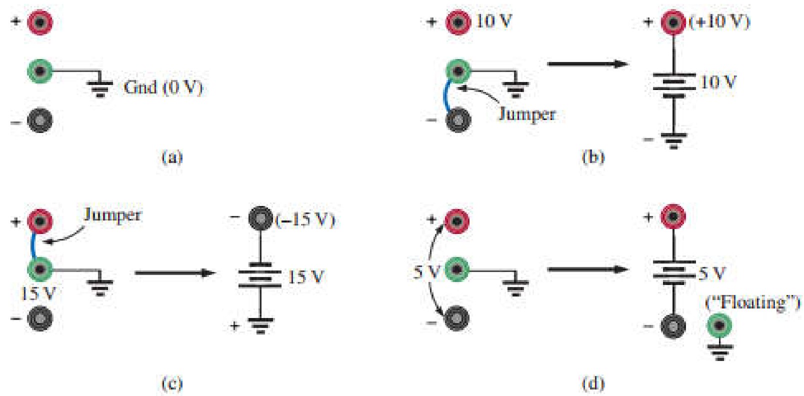
In any electrical circuit mainly three types of wires are used:

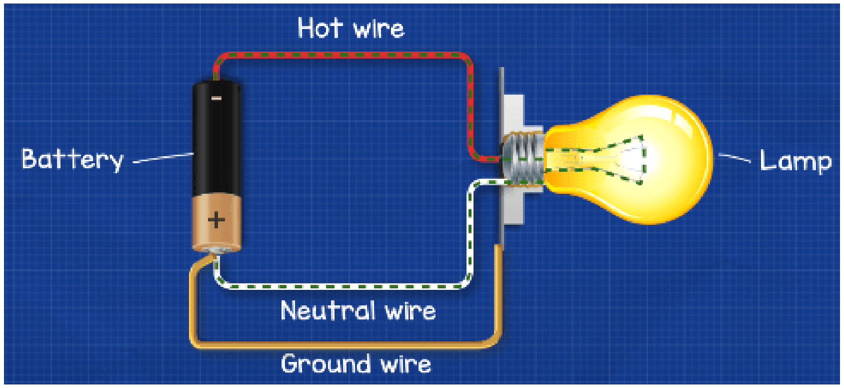
Hot or Positive or Phase wire: Hot wire carries the electricity from the power supply to the load

Neutral or Negative wire: Neutral wire carries the used electricity back to the power supply



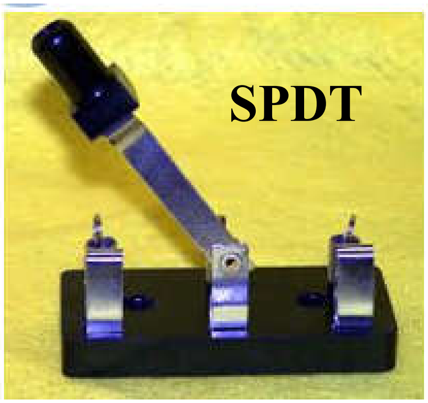
Grounding or Earthing: Connected to any metal parts in an appliance such as a microwave oven or coffee pot. This is a safety feature, in case the hot or neutral wires somehow come in contact with metal parts. Connecting the metal parts to earth ground eliminates the shock hazard in the event of a short circuit





Control Elements or Switches

Control Elements or Switches are used to turn-on or turn-off a circuit.



SPST SPDT DPDT

Fuses

Relay

Switches

Circuit Breaker

Electrical Load

Electrical Load: The devices which consume or absorb or receive the electrical energy is called electrical load.

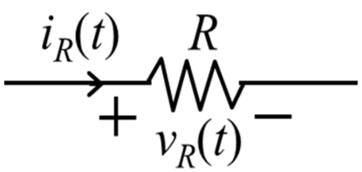
Water Heater

Load Represent by Passive Elements

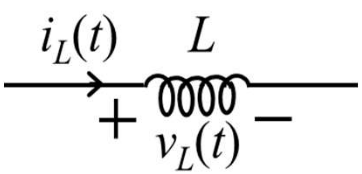
Loads can be represented by the combination of passive elements such as Resistor, Inductor, and Capacitor.

Passive Elements As a Load: Resistance (R), Inductance (L) and Capacitance (C)

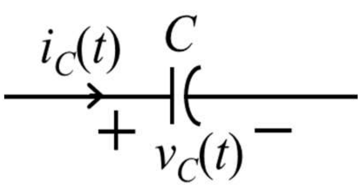
Combination of these elements: Series, Parallel and Series-Parallel



Resistance measured in **ohm** (Ω)

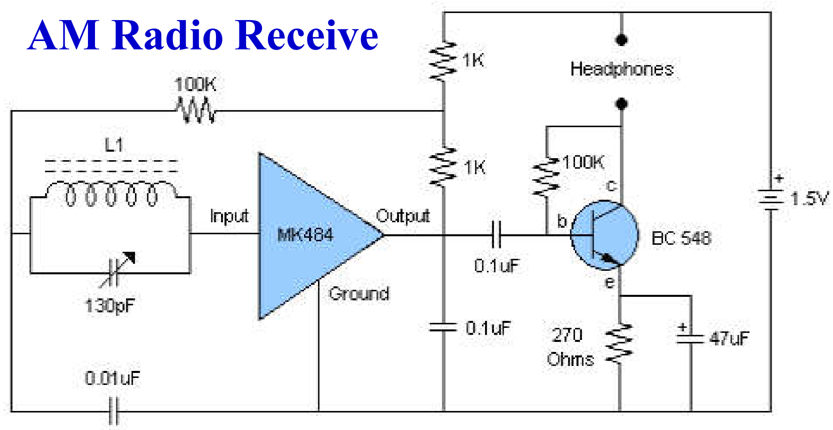


Inductance measured in **Henry** (H)



Capacitance measured in **Farad** (F)

AM Radio Receive



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 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**)

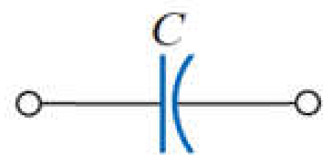
(***b***) **Current Controlled Source**

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

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

Passive Elements

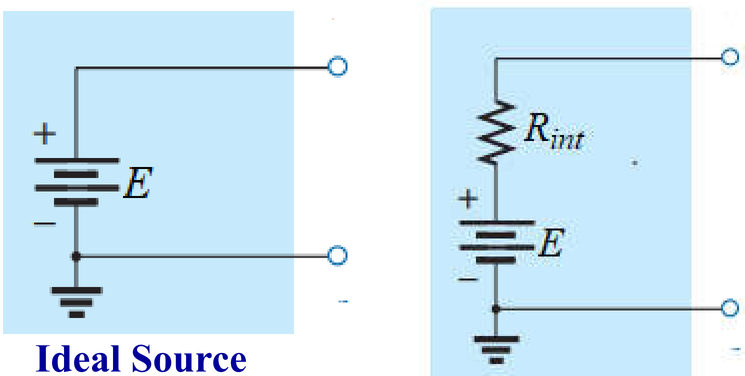
There are basic three passive elements: **Resistor**, **Inductor** and **Capacitor**

			
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 (I)

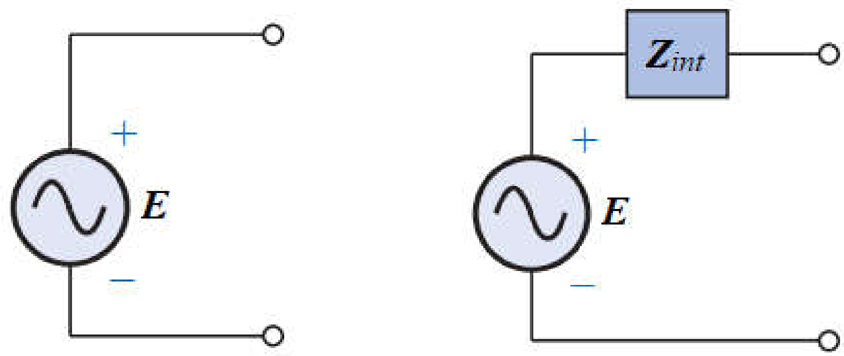
Independent Source: An **independent source** is an active element that provides a specified **voltage** or **current** that is completely independent of other circuit variables.

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.



Ideal Source   Practical Source

DC Voltage Source

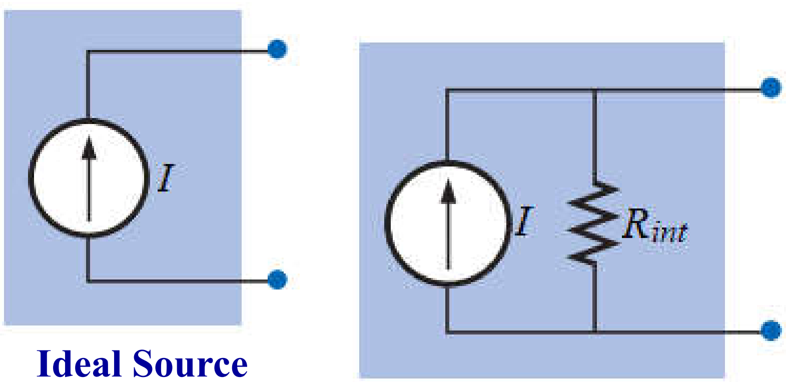


Ideal Source   Practical Source

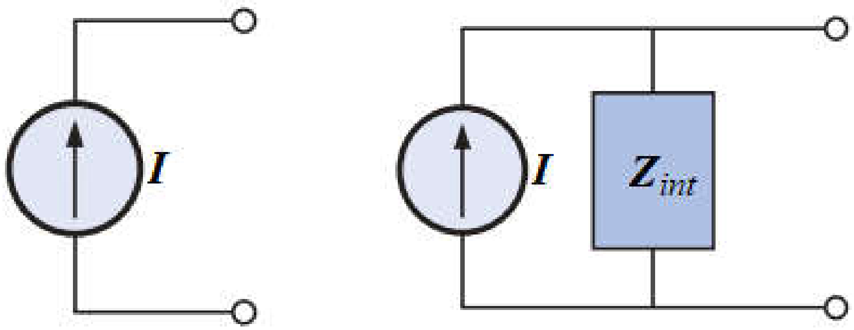
AC Voltage Source

Independent Sources (II)

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.



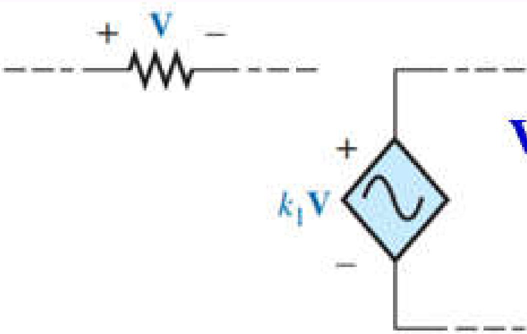
DC Current Source



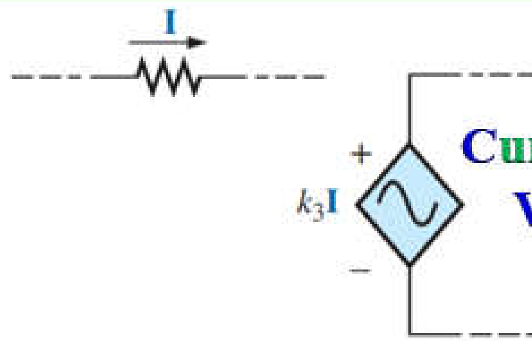
AC Current Source

Dependent or Controlled Sources

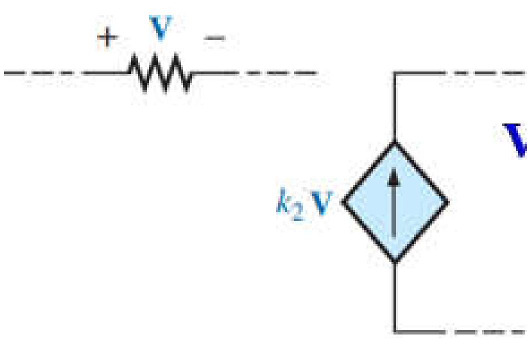
Dependent or Controlled Source: A **dependent** (or **controlled**) source is an active element in which the source quantity (voltage or current) is controlled by another voltage or current.



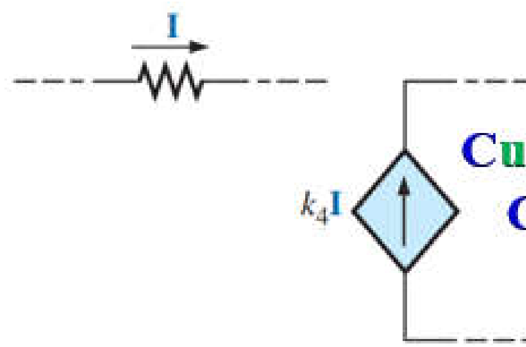
Voltage-Controlled Voltage Source (VCVS)



Current-Controlled Voltage Source (CCVS)



Voltage-Controlled Current Source (VCCS)

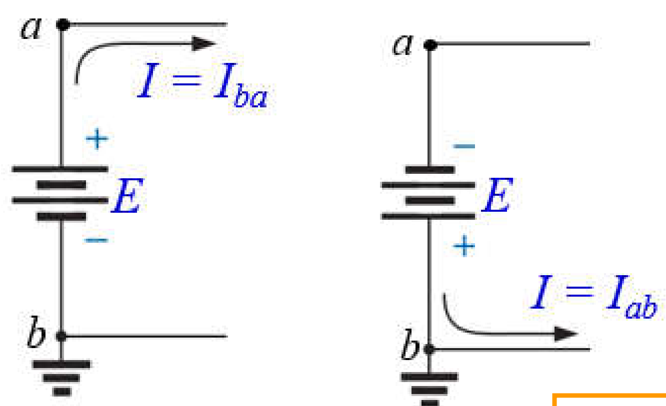


Current-Controlled Current Source (CCCS)

Defining Direction of Current

Current Direction for a Source:

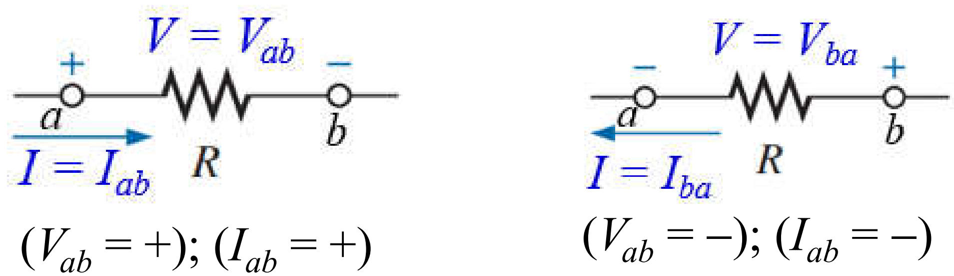
- **Current leaves** from the **positive (+) terminal** of a source.
- **Current enters** to the **negative (–) terminal** of a source.



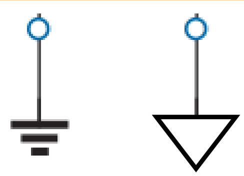
Defining Polarities of Voltage Drop

Voltage Drop Polarities for a Load:

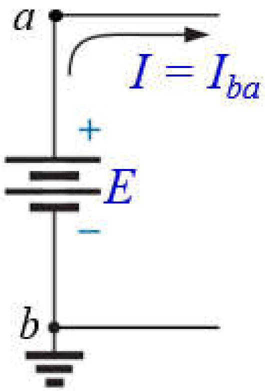
- **Current entering terminal** is considered as **positive (+) terminal** of voltage drop in a load.
- **Current leaving terminal** is considered as **negative (–) terminal** of voltage drop in a load.



Symbol of Ground



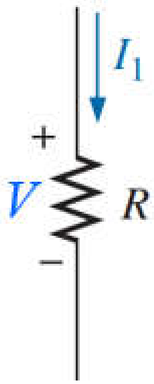
Passive Sign Convention of Power



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)

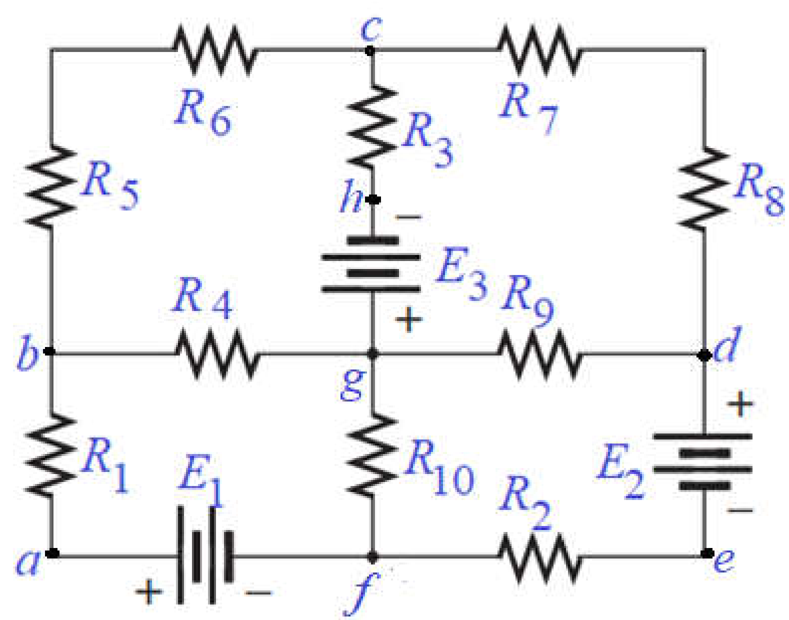
Branch: A part of network which connects the various points of the network with one another is called a **branch**. A **branch** of a circuit is any portion of the circuit that has one or more elements in series.
In the figure *ab*, *bc*, *cd*, *de*, *ef*, *fa*, *bg*, *fg*, *dg*, *gh*, *hc* are the various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

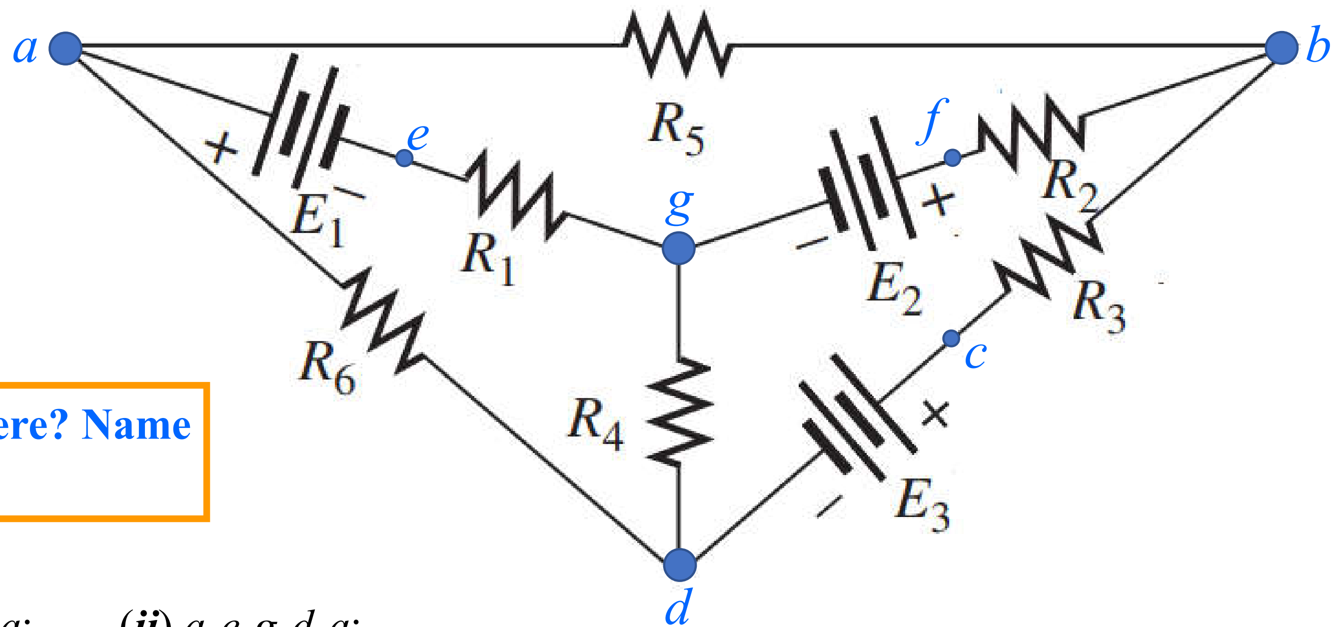
Answer: Six branches are here. They are: *ab*, *bd*, *da*, *ag*, *bg*, *dg*.

(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*, *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*;

1.6 Power of Ten

The International System of Units [SI] prefixes

1.6 POWERS OF TEN

$$1 = 10^0 \qquad 1/10 = 0.1 = 10^{-1}$$
$$10 = 10^1 \qquad 1/100 = 0.01 = 10^{-2}$$
$$100 = 10^2 \qquad 1/1000 = 0.001 = 10^{-3}$$
$$1000 = 10^3 \qquad 1/10{,}000 = 0.0001 = 10^{-4}$$

EXAMPLE 1.10

a. 1,000,000 ohms = 1×10^6 ohms = 1 megohm (MΩ)

b. 100,000 meters = 100×10^3 meters = 100 kilometers (km)

c. 0.0001 second = 0.1×10^{-3} second = 0.1 millisecond (ms)

d. 0.000001 farad = 1×10^{-6} farad = 1 microfarad (μF)

Observation:

When convert smaller to larger decimal point shift to left.

When convert larger to smaller decimal point shift to right.

TABLE 1.2

Multiplication Factors	Prefix	SI Symbol
1 000 000 000 000 000 000 = 10^{18}	exa	E
1 000 000 000 000 000 = 10^{15}	peta	P
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
1 00 = 10^{2}	hector	h
1 0 = 10^{1}	deka	da
1 = 10^{0}	unit	unit
0.1= 10^{-1}	deci	d
0.0 1= 10^{-2}	centi	c
0.001= 10^{-3}	mili	m
0.000 001= 10^{-6}	micro	μ
0.000 000 001= 10^{-9}	nono	n
0.000 000 000 001= 10^{-12}	pico	p
0.000 000 000 000 001= 10^{-15}	femto	f
0.000 000 000 000 000 001= 10^{-18}	atto	a

1.8 CONVERSION BETWEEN LEVELS OF POWERS OF TEN

EXAMPLE 1.12 a. Convert 20 kHz to megahertz. b. Convert 0.002 km to millimeters.

Solutions:

a. In the power-of-ten format:

$$20 \text{ kHz} = 20 \times 10^3 \text{ Hz}$$

The conversion requires that we find the multiplying factor to appear in the space below:

Increase by 3

$$20 \times 10^3 \text{ Hz} \Rightarrow \_\_\_ \times 10^6 \text{ Hz}$$

Decrease by 3

Since the power of ten will be *increased* by a factor of *three*, the multiplying factor must be *decreased* by moving the decimal point *three* places to the left, as shown below:

$$\underbrace{020.}_{3} = 0.02$$

and $\qquad 20 \times 10^3 \text{ Hz} = 0.02 \times 10^6 \text{ Hz} = \mathbf{0.02\ MHz}$

b. In the power-of-ten format:

$$0.002 \text{ km} = 0.002 \times 10^3 \text{ m}$$

Reduce by 6

$$0.002 \times 10^3 \text{ m} \Rightarrow \_\_\_ \times 10^{-3} \text{ m}$$

Increase by 6

In this example we have to be very careful because the difference between +3 and −3 is a factor of 6, requiring that the multiplying factor be modified as follows:

$$0.\underbrace{002000}_{6} = 2000$$

and $\qquad 0.002 \times 10^3 \text{ m} = 2000 \times 10^{-3} \text{ m} = \mathbf{2000\ mm}$

When convert smaller to larger decimal point shift to left.

When convert larger to smaller decimal point shift to right.

EXAMPLE 1.1.1 [Similar of Problem 25]: Perform the following conversions:

a. 2000 μs to milliseconds **b. 0.04 ms to microseconds** **c.** 0.06 μF to nanofarads

Solution: **a**. In the power of ten format: $2000\ \mu s = 2000 \times 10^{-6}$ s $2000 \times 10^{-6}\ s = \_\_\_\_\_\_ \times 10^{-3}$ s

Since the power of ten will be ***increased*** by a factor of *three*, the multiplying factor must be ***decreased*** by moving the decimal point *three* places to the left, as follows:

$$2000 \times 10^{-6}\ s = \underline{\mathbf{2.0}}\ ms$$

b. In the power of ten format: $0.04\ ms = 0.04 \times 10^{-3}$ s $0.04 \times 10^{-3}\ s = \_\_\_\_\_\_ \times 10^{-6}$ s

Since the power of ten will be ***reduced*** by a factor of *three*, the multiplying factor must be ***increased*** by moving the decimal point *three* places to the right, as follows:

$$0.04 \times 10^{-3}\ s = \underline{\mathbf{40}}\ \mu s$$

c. In the power of ten format: $0.06\ \mu F = 0.06 \times 10^{-6}$ F $0.06 \times 10^{-6}\ F = \_\_\_\_\_\_ \times 10^{-9}$ F

Since the power of ten will be ***reduced*** by a factor of *three*, the multiplying factor must be ***increased*** by moving the decimal point *three* places to the right, as follows:

$$0.06 \times 10^{-6}\ F = \underline{\mathbf{60}}\ nF$$

EXAMPLE 1.1.2 [Similar of Problem 25]: Perform the following conversions:

a. 8400 ps to microseconds **b**. 0.006 km to milimeters **c. 260 × 10^3 mm to kilometers**

Solution: **a**. In the power of ten format: 8400 ps = 8400×10^{-12} s $\quad 8400 \times 10^{-12}$ s = ________ $\times 10^{-6}$ s

Since the power of ten will be ***increased*** by a factor of ***six***, the multiplying factor must be ***decreased*** by moving the decimal point ***six*** places to the left, as follows:

8400×10^{-12} s = $\underline{\mathbf{0.0084}}$ μs

b. In the power of ten format: 0.006 km = 0.006×10^3 m $\quad 0.006 \times 10^3$ m = ________ $\times 10^{-3}$ m

Since the power of ten will be ***reduced*** by a factor of ***six***, the multiplying factor must be ***increased*** by moving the decimal point ***six*** places to the right, as follows:

0.006×10^3 m = $\underline{\mathbf{6000}}$ m

c. In the power of ten format: 260×10^3 mm = $260 \times 10^3 \times 10^{-3}$ m = 260 m

260×10^0 m = ________ $\times 10^3$ m

Since the power of ten will be ***increased*** by a factor of ***three***, the multiplying factor must be ***decreased*** by moving the decimal point ***three*** places to the left, as follows:

260×10^0 m = $\underline{\mathbf{0.26}}$ km

Practice Book Problem [SECTION 1.8 and SECTION 1.9] Problems: 24, 26 and 27

Chapter 2

Charge, Voltage and Current

Electric Charge

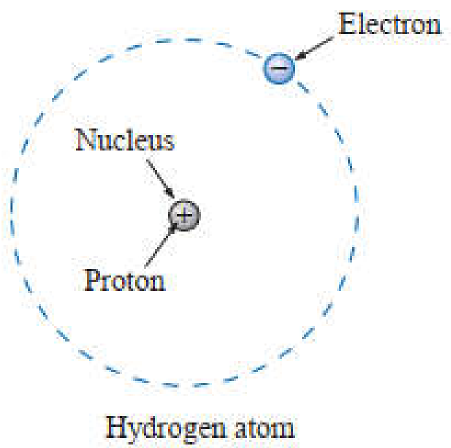
Atomic Charge:

- Two components of an electric charge [measured in **Coulombs** (**C**)] in an atom are:

  Proton [+] Charge [Charge of an electron: $+ 1.602 \times 10^{-19}$ C]

  Electron [–] Charge [Charge of a proton: -1.602×10^{-19} C]

- Normally atoms charge is ***neutral*** (there are an equal number of number of protons and electrons in an atom).
- When electrons are ***removed***, **positive** charges are developed.
- When electrons are ***attached***, **negative** charges are developed.



Total deficiency or addition of excess electrons in an atom is called its charge and the element is said to be charged.

Important Characteristic of electric charge are:

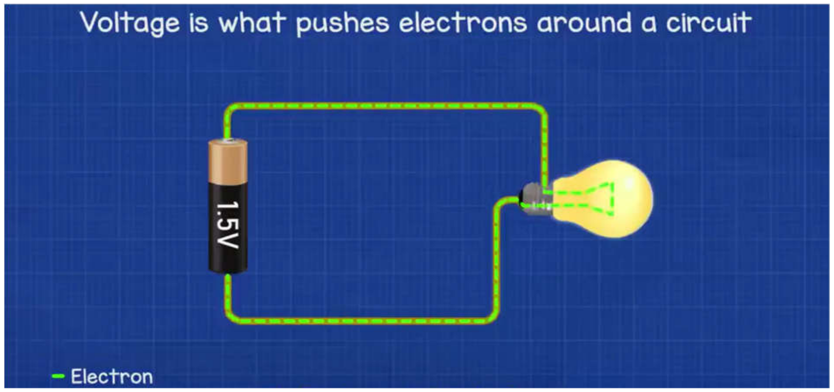
- The charge is bipolar, meaning that electrical effects are described in terms of positive and negative charges.
- The electric charge exits in discrete quantities, which are ***integral multiple of the electronic charge***, 1.602×10^{-19} C [Charge is measured in **Coulombs** (**C**) and represent by Q or q]
- Electric effects are attributes to:

(*i*) the **separation of charge** which is creates an **electric force** (electromotive force, voltage)

(*ii*) the **charges in motion** which is creates an **electric** fluid (**current**).

$$\boxed{1\text{ C} = \frac{1}{1.602 \times 10^{-19}} = 6.24 \times 10^{18}\text{ electrons}}$$

2.3 Voltage



Electromotive Force (emf): An ***electrical effort*** (some work or energy transfer) is required to move the free electron in one particular direction, in a conductor is called electromotive force (emf). This emf is also known as ***voltage*** or ***potential difference***. EMF is ***created*** by chemical reaction (where positive charge and negative charge are separated) in battery or by changing magnetic field in a generator. It represents by "E". Some time also use "V".

Electric Potential: **The ability of a charged particle to do work** (when two similarly charged particles are brought near, they try to repel each other while dissimilar charges attracts each other) is called its ***electrical potential***. Electric potential is also known as ***voltage***. It also represents by "V".

Potential Difference: The difference between the electric potentials at any two points in a circuit is known as ***potential difference***. Potential difference is also called ***voltage*** or ***voltage drop*** between two points. It also represents by "V".

Unit: The unit of emf or electric potential or voltage or potential difference is **volt** [V].
A potential difference of 1 volt (V) exists between two points if 1 joule (J) of energy is exchanged in moving 1 coulomb (C) of charge between the two points.

The potential difference between two points is determined by:

$$\boxed{V = \frac{W}{Q}} \qquad \begin{aligned} V &= \text{volts (V)} \\ W &= \text{joules (J)} \\ Q &= \text{coulombs (C)} \end{aligned} \qquad \textbf{(2.2)}$$

$$\boxed{W = QV} \qquad \text{(joules, J)} \qquad \textbf{(2.3)}$$

$$\boxed{Q = \frac{W}{V}} \qquad \text{(coulombs, C)} \qquad \textbf{(2.4)}$$

$$\boxed{1\text{ V} = \frac{1\text{ J}}{1\text{ C}}}$$

According to Eq. (2.2), **voltage** is the energy (work done) needed to move a unit charge from one point to another point.

EXAMPLE 2.1 Find the voltage between two points if 60 J of energy are required to move a charge of 20 C between the two points.

Solution: Eq. (2.2): $V = \frac{W}{Q} = \frac{60\text{ J}}{20\text{ C}} = \mathbf{3\ V}$

EXAMPLE 2.2 Determine the energy expended moving a charge of 50 μC between two points if the voltage between the points is 6 V.

Solution: Eq. (2.3):

$$W = QV = (50 \times 10^{-6}\text{ C})(6\text{ V}) = 300 \times 10^{-6}\text{ J} = \mathbf{300\ \mu J}$$

Example 2.3.1: Find the charge that requires 120 J of energy to be moved through a potential difference of 20 V.

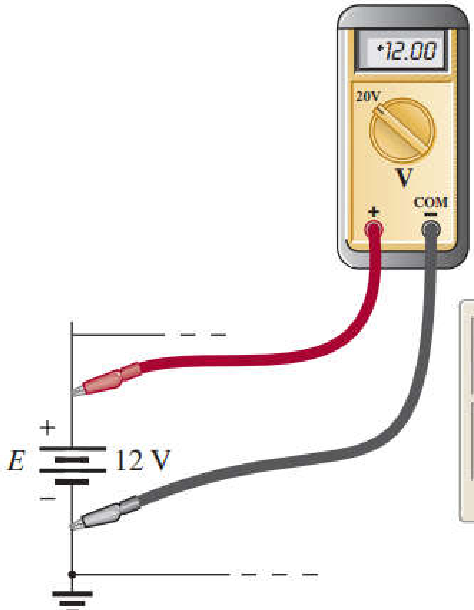
Solution: Given, $W = 120$ J, $V = 20$ V and $Q = ?$

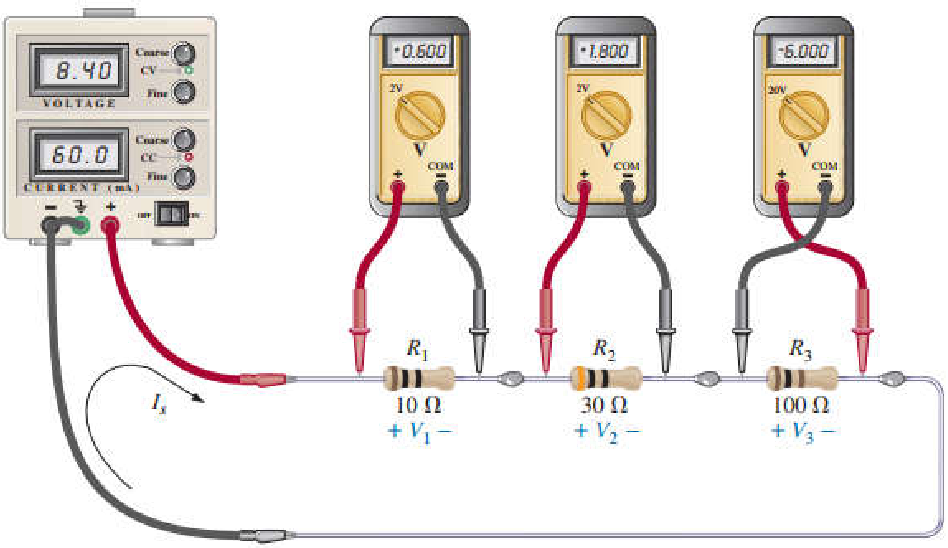
$$Q = \frac{W}{V} = \frac{120\ \text{J}}{20\ \text{V}} = 6\ \text{V}$$

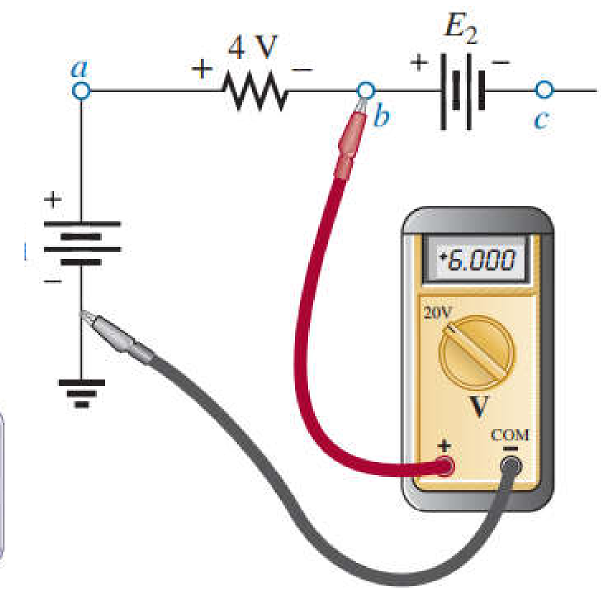
Practice Book Problem [SECTION 2.3 Voltage] Problems: 7 to 10

Voltmeter

Voltmeter measures the voltage.
Voltage always measure between two points.
Voltmeter is connected always in **parallel**.







2.4 Current

The applied voltage (emf) is the starting mechanism —the current is a reaction to the applied voltage.

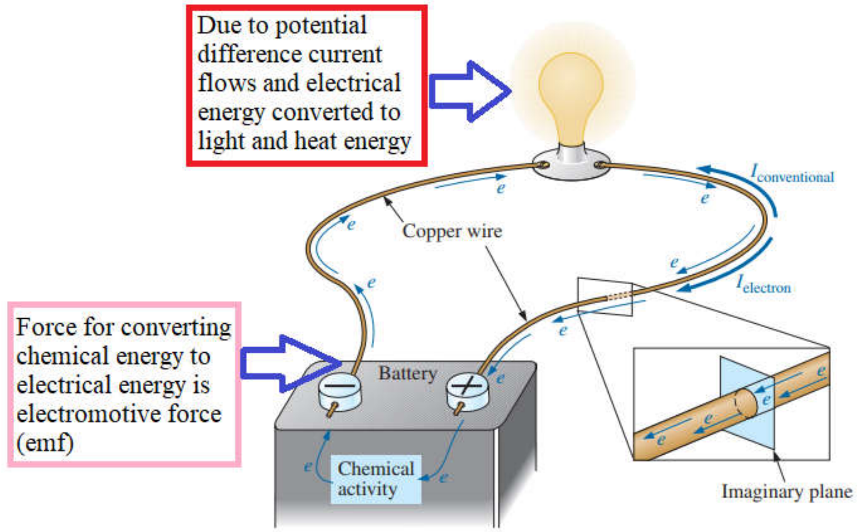
Definition: The rate of charge (Q) with respect to time (t) is known as the electric **current**.

Letter Symbol: It is represented by " I ". **Unit** is Ampere (A).

Relation Among Current, Charge and Time

$$\boxed{I = \frac{Q}{t}} \qquad \begin{aligned} I &= \text{amperes (A)} \\ Q &= \text{coulombs (C)} \\ t &= \text{time (s)} \end{aligned} \qquad \textbf{(2.5)}$$

1 Ampere: If 1 C [or 6.24×10^{18} electrons] **charge pass through a conductor in 1 second, the flow of charge, or current, is said to be 1 ampere (A).**



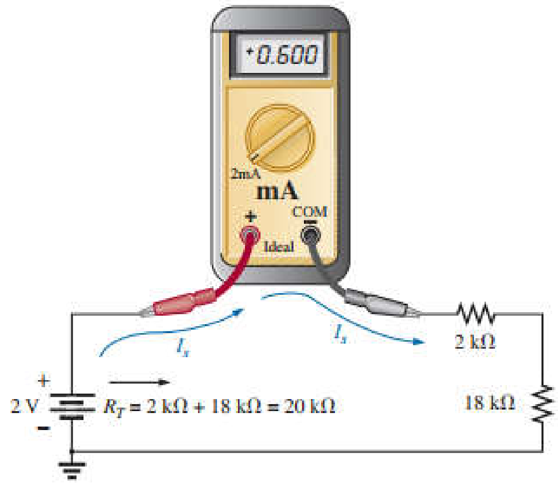
$$\boxed{1\ \text{A} = \frac{1\ \text{C}}{1\ \text{s}}}$$

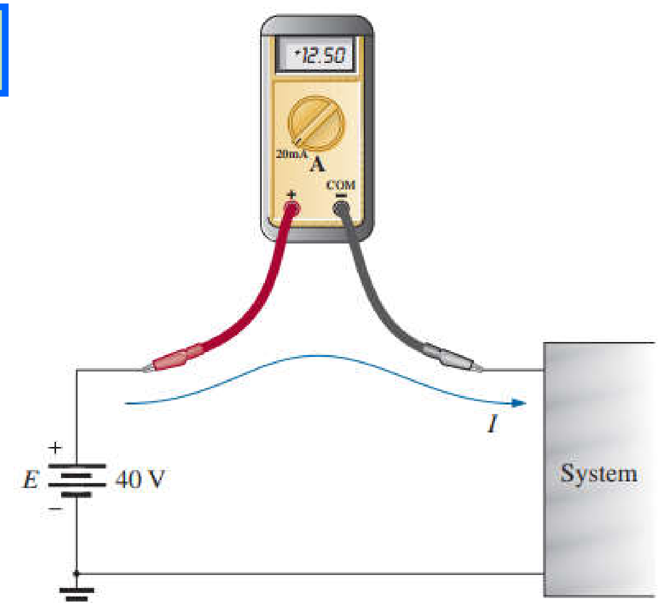
$$\boxed{t = \frac{Q}{I}} \quad \text{(s)} \quad \textbf{(2.7)}$$

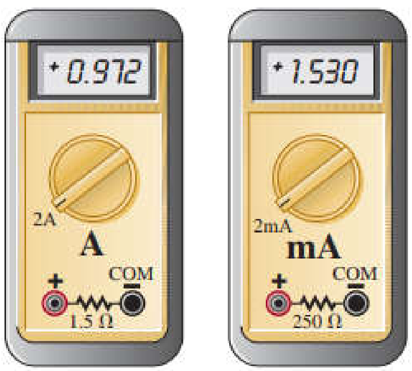
$$\boxed{Q = It} \quad \text{(C)} \quad \textbf{(2.6)}$$

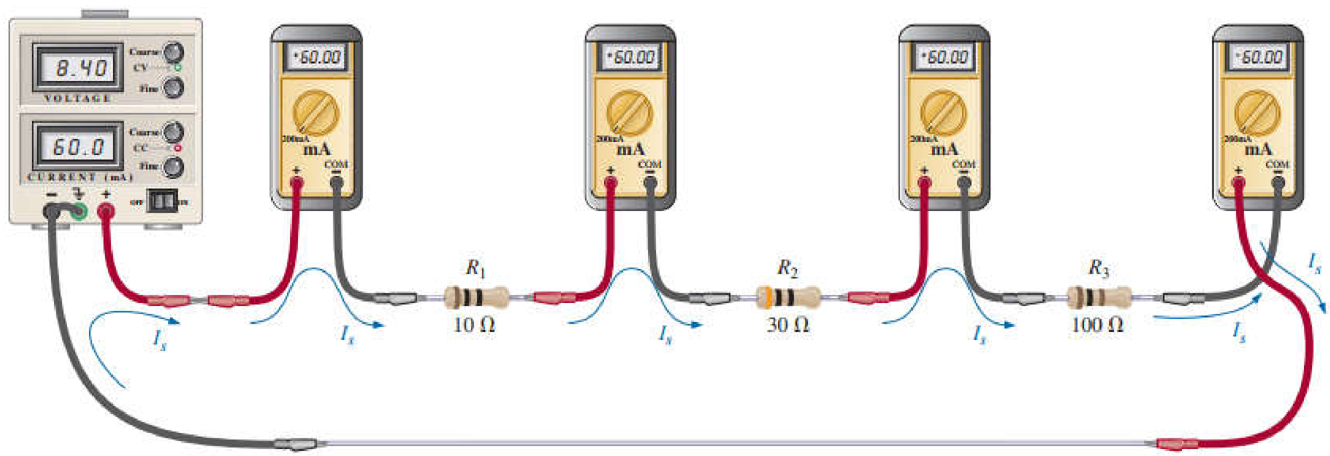
Ammeter

Ammeter measures the current in a circuit.
Ammeter is always connected in **series**.









EXAMPLE 2.3 The charge flowing through the imaginary surface in Fig. 2.9 is 0.16 C every 64 ms. Determine the current in amperes.

Solution: Eq. (2.5): $I = \dfrac{Q}{t} = \dfrac{0.16\ \text{C}}{64 \times 10^{-3}\text{s}} = \dfrac{160 \times 10^{-3}\ \text{C}}{64 \times 10^{-3}\ \text{s}} = \mathbf{2.50\,A}$

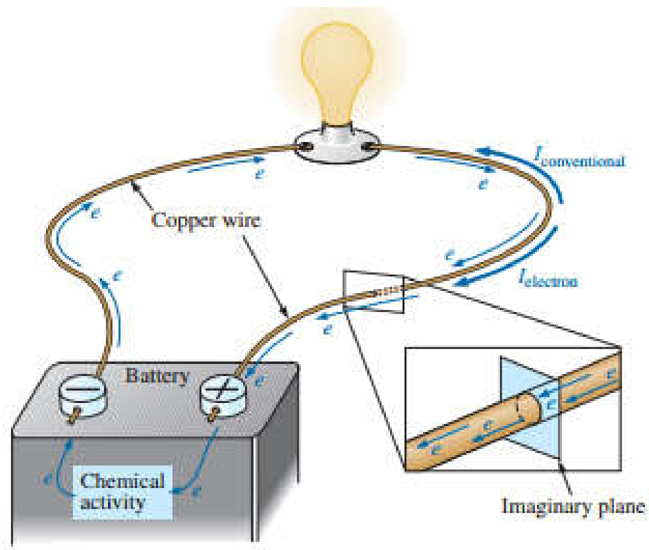


FIG. 2.9 *Basic electric circuit.*

EXAMPLE 2.4 Determine how long it will take 4×10^{16} electrons to pass through the imaginary surface in Fig. 2.9 if the current is 5 mA.

Solution: Determine the charge in coulombs:

$$4 \times 10^{16}\ \cancel{\text{electrons}} \left(\frac{1\ \text{C}}{6.242 \times 10^{18}\ \cancel{\text{electrons}}} \right) = 0.641 \times 10^{-2}\ \text{C}$$

$$= 6.41\ \text{mC}$$

Eq. (2.7): $t = \dfrac{Q}{I} = \dfrac{6.41 \times 10^{-3}\ \text{C}}{5 \times 10^{-3}\ \text{A}} = \mathbf{1.28\ s}$

$$V = \frac{W}{Q} \qquad Q = It$$

Example 2.4.1: If a current 100 mA exists for 1.5 min, (*i*) how many coulomb of charge, and (*ii*) how many electrons have passed through the wire?

Solution: Given, $I = 100$ mA $= 100 \times 10^{-3}$ A, $t = 1.5$ min $= 1.5 \times 60 = 90$ s

(*i*) $Q = I \times t = (100 \times 10^{-3}) \times 90$

$= 9000 \times 10^{-3}$ C $= 9$ C

(*ii*) We know that, $1\text{ C} = 6.24 \times 10^{18}$ electrons

$9\text{ C} = 9 \times (6.24 \times 10^{18})$

$= 56.16 \times 10^{18}$ electrons

Example 2.4.2: If a conductor with a current of 120 mA passing through it converts 20 J of electrical energy into heat in 20 s, what is the potential drop across the conductor?

Solution: Given, $I = 120$ mA $= 120 \times 10^{-3}$ A,

$W = 20$ J, $t = 20$ s

We know that, $Q = It = (120 \times 10^{-3}\text{ A}) \times 20\text{ s}$

$= 2.4$ C

We know that, $V = \frac{W}{Q} = \frac{20\text{ J}}{2.4\text{ C}} = 8.33\text{ V}$

$$V = \frac{W}{Q} \qquad Q = It$$

Example 2.4.3: Charge is flowing through a conductor at the rate of 200 C/min. If 750 J of electrical energy are converted to heat in 45 s, what is the potential drop across the conductor?

Solution: Given, $I = Q/t = 200$ C/min $= (200/60)$ C/s, $W = 360$ J, $t = 45$ s

We know that, $Q = It = (200/60 \text{ C/s}) \times 45 \text{ s}$

$= 150$ C

We know that, $V = \frac{W}{Q} = \frac{750 \text{ J}}{150 \text{ C}} = 5 \text{ V}$

Example 2.4.4: The potential difference between two points in an electric circuit is 48 V. If 1.2 J of energy were dissipated in a period of 15 ms, what would the current be between the two points?

Solution: Given, $V = 24$ V, $W = 0.4$ J, $t = 15$ ms $= 15 \times 10^{-3}$ s,

We know that, $V = \frac{W}{Q}$

$$\therefore Q = \frac{W}{V} = \frac{1.2 \text{ J}}{48 \text{ V}} = 0.025 \text{ C}$$

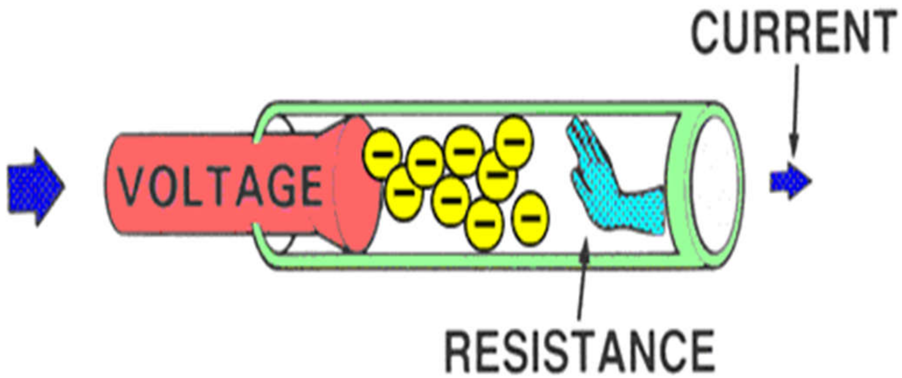
We know that, $I = \frac{Q}{t} = \frac{0.025 \text{ C}}{15 \times 10^{-3} \text{ s}} = 1.67 \text{ A}$

Practice Book Problem [SECTION 2.4 Current] Problems: 11 – 17 and 21 – 23

3.2 Resistance

- The current in the electrical circuit not only depends on emf but also the circuit materials. Material in general have a property or ability to oppose/resist the flow of electric charge as well as current.
- This opposition, due to the collisions between electrons and between electrons and other atoms in the material, *which converts electrical energy into another form of energy such as heat*.

Definition: The property of materials in an electrical circuit tending to prevent/resist the flow of current and at the same time causes electrical energy to be converted to heat is called resistance.



Letter Symbol: It is represented by " *R* ".

Unit is ohm (Ω).

1 ohm: The resistance of a material in an electrical circuit, in which a current 1 Ampere generates the heat at the rate of one Joules per Second is said to be 1 ohm.

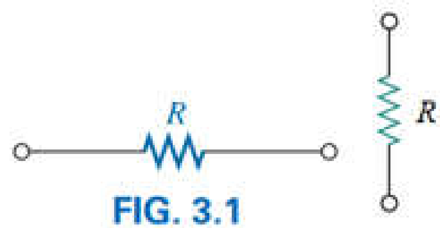


FIG. 3.1
Resistance symbol and notation.

3.2 Resistance: Circular Wires

Equation of Resistance:

$$\boxed{R = \rho \frac{l}{A}} \qquad \begin{aligned} \rho &= \Omega\text{-cm at } T = 20°\text{C} \\ l &= \text{centimeters (cm)} \\ A &= \text{area in centimeters (cm}^2) \end{aligned} \qquad \textbf{(3.1)}$$

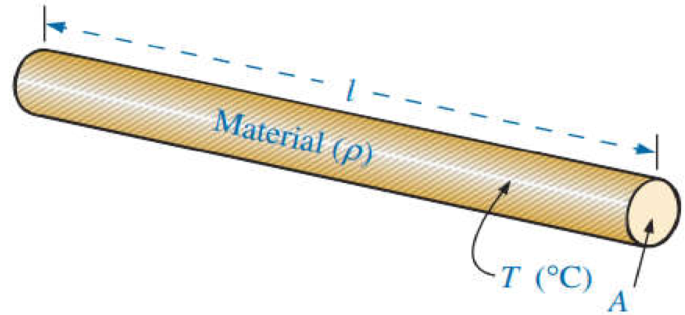


FIG. 3.2

Factors affecting the resistance of a conductor.

Factors Affecting the Resistance:

1. **Length (l)**: Resistance is directly proportional to length.
2. **Cross-sectional area (A)**: ***Resistance is inversely proportional to area***.
3. **Material (ρ called *rho*)**: The material is identified by a factor called the ***resistivity***, which is measured in Ω–cm or Ω–m. ***The higher the resistivity, the greater the resistance of a conductor***.
4. **Temperature of the material (T)**: Generally, ***the resistance increases as materials temperature increases***. The effect of small changes in temperature on the resistance is not considered.

Resistivity: The resistance of a material having unit length (1 cm) and unit cross-sectional area (1 cm^2) is known as its ***resistivity*** or ***specific resistance***.

TABLE 3.3 *Resistivity (ρ) of various materials.*

Material	Ω-cm
Silver	1.645×10^{-6}
Copper	1.723×10^{-6}
Gold	2.443×10^{-6}
Aluminum	2.825×10^{-6}
Tungsten	5.485×10^{-6}
Nickel	7.811×10^{-6}
Iron	12.299×10^{-6}
Tantalum	15.54×10^{-6}
Nichrome	99.72×10^{-6}
Tin oxide	250×10^{-6}
Carbon	3500×10^{-6}

EXAMPLE 3.7 Determine the resistance of 100 ft of #28 copper (From Table 3.3, $\rho = 1.723 \times 10^{-6}\ \Omega$–cm) telephone wire if the diameter is 0.0126 in.

Solution: $l = 100$ ft, $\rho = 1.723 \times 10^{-6}\ \Omega$–cm, $d = 0.0126$ in.

Since l is given in feet (ft) and d is given in inch (in), first convert these quantities in cm.

We know that 1 ft = 12 in and 1 in = 2.54 cm

$$l = 100\ \cancel{\text{ft}}\left(\frac{12\ \cancel{\text{in.}}}{1\ \cancel{\text{ft}}}\right)\left(\frac{2.54\ \text{cm}}{1\ \cancel{\text{in.}}}\right) = 3048\ \text{cm} \qquad d = 0.0126\ \text{in.}\left(\frac{2.54\ \text{cm}}{1\ \text{in.}}\right) = 0.032\ \text{cm}$$

We know that the area of a circle is: $A = \pi r^2 \qquad r = \dfrac{d}{2} \qquad A = \dfrac{\pi d^2}{4}$

$$\text{Therefore,}\quad A = \frac{\pi d^2}{4} = \frac{(3.1416)(0.032\ \text{cm})^2}{4} = 8.04 \times 10^{-4}\ \text{cm}^2$$

$$R = \rho\frac{l}{A} = \frac{(1.723 \times 10^{-6}\Omega\text{-cm})(3048\ \text{cm})}{8.04 \times 10^{-4}\ \text{cm}^2} \cong \mathbf{6.5\ \Omega}$$

Example 3.2.1: Determine the value of resistance of an aluminum conductor if the area is increased by a factor of 3. The original resistance was 12 Ω.

Solution: Let in original case: length = l_1 cm, Area = A_1 cm^2, and resistivity = ρ_1 Ω-cm and R_1 = 4 Ω

When the area is increased by a factor of 3: length $l_2 = l_1$ cm, Area $A_2 = 3A_1$ cm^2, and resistivity $\rho_2 = \rho_1$ Ω-cm and R_2 = ?

$$\frac{R_2}{R_1}=\left[\frac{\rho_2 l_2}{A_2}\div\frac{\rho_1 l_1}{A_1}\right]=\left[\frac{\rho_2 l_2}{A_2}\times\frac{A_1}{\rho_1 l_1}\right]=\left[\frac{\rho_1 l_1}{3A_1}\times\frac{A_1}{\rho_1 l_1}\right]=\frac{1}{3} \qquad R_2=\frac{1}{3}R_1=\frac{1}{3}\times 12=4\ \Omega$$

Example 3.2.2: Determine the value of resistance of a silver conductor if the length is doubled. The original resistance was 5 Ω.

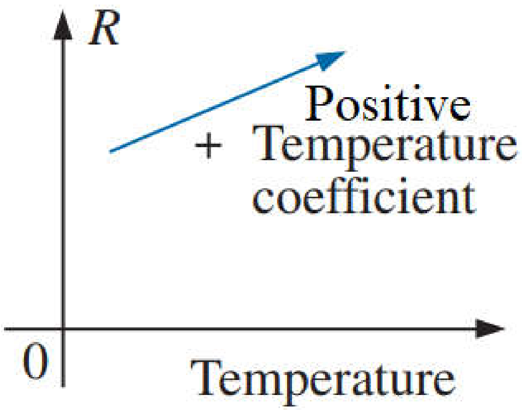
Solution: Let in original case: length = l_1 cm, Area = A_1 cm^2, and resistivity = ρ_1 Ω-cm and R_1 = 6 Ω

When the length is doubled : length $l_2 = 2l_1$ cm, Area $A_2 = A_1$ cm^2, and resistivity $\rho_2 = \rho_1$ Ω-cm and R_2 = ?

$$\frac{R_2}{R_1}=\left[\frac{\rho_2 l_2}{A_2}\div\frac{\rho_1 l_1}{A_1}\right]=\left[\frac{\rho_2 l_2}{A_2}\times\frac{A_1}{\rho_1 l_1}\right]=\left[\frac{\rho_1 2l_1}{A_1}\times\frac{A_1}{\rho_1 l_1}\right]=2 \qquad R_2=2R_1=2\times 5=10\ \Omega$$

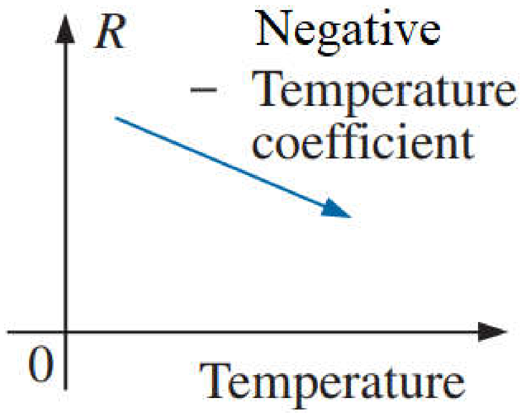
Practice Book Problem [SECTION 3.2 Resistance] Problems: 4, 7, 12 and 13

3.5 Temperature Effects on Resistance



Conductors

For good conductors, an increase in temperature results in an increase in the resistance level. Consequently, conductors have a **positive temperature coefficient**.



Semiconductors

For semiconductor materials, an increase in temperature results in a decrease in the resistance level. Consequently, semiconductors have **negative temperature coefficients**.

Insulators

Same as semiconductor materials, an increase in temperature results in a decrease in the resistance level of an insulator. Consequently, semiconductors have **negative temperature coefficients**.

Relation of Resistances in Different Two Temperature

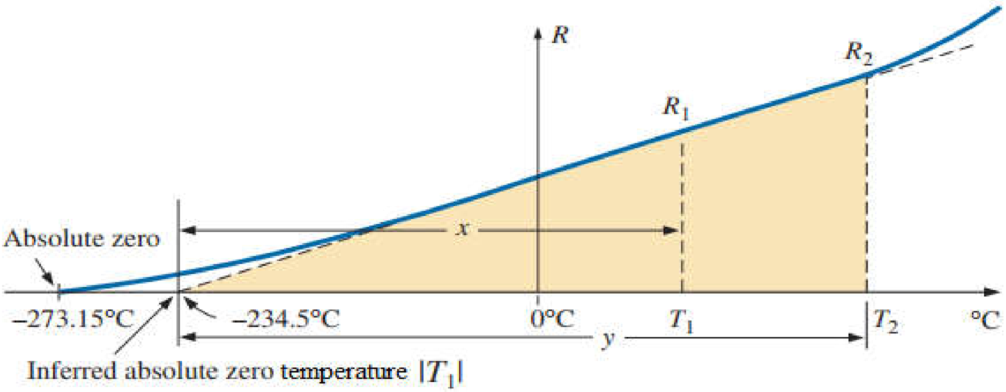


FIG. 3.13 *Effect of temperature on the resistance of copper.*

$$\alpha_{20} = \frac{1}{|T_1| + 20°C} \qquad \textbf{(3.9)}$$

$$R_1 = R_{20}[1 + \alpha_{20}(T_1 - 20°C)] \qquad \textbf{(3.10)}$$

$$\frac{|T_1| + T_1}{R_1} = \frac{|T_1| + T_2}{R_2} \qquad \textbf{(3.8)}$$

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

$$R_2 = R_1[1 + \alpha_1(T_2 - T_1)] \quad \text{where, } \alpha_1 = \frac{1}{|T_1| + T_1}$$

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

TABLE 3.5

Inferred absolute temperatures (T_i).

Material	°C
Silver	−243
Copper	−234.5
Gold	−274
Aluminum	−236
Tungsten	−204
Nickel	−147
Iron	−162
Nichrome	−2,250
Constantan	−125,000

TABLE 3.6

Temperature coefficient of resistance for various conductors at 20°C.

Material	Temperature Coefficient (α_{20})
Silver	0.0038
Copper	0.00393
Gold	0.0034
Aluminum	0.00391
Tungsten	0.005
Nickel	0.006
Iron	0.0055
Constantan	0.000008
Nichrome	0.00044

EXAMPLE 3.9 If the resistance of a copper wire is 50 Ω at 20°C, what is its resistance at 100°C (boiling point of water)?

Solution: Given, $R_1 = 50\ \Omega$, $T_1 = 20°C$, $T_2 = 100°C$, From Table 3.5, $|T_1| = 234.5°C$, $R_2 = ?$

$$\boxed{\frac{|T_1| + T_1}{R_1} = \frac{|T_1| + T_2}{R_2} \qquad \textbf{(3.8)}}$$

$$\frac{234.5°C + 20°C}{50\ \Omega} = \frac{234.5°C + 100°C}{R_2}$$

$$R_2 = \frac{234.5°C + 100°C}{-234.5°C + 20°C} \times 50\ \Omega = 65.72\ \Omega$$

EXAMPLE 3.10 If the resistance of a copper wire at freezing (0°C) is 30Ω , what is its resistance at –40°C?

Solution: Given, $R_1 = 30\ \Omega$, $T_1 = 0°C$, $T_2 = -40°C$, From Table 3.5, $|T_1| = 234.5°C$, $R_2 = ?$

$$\frac{234.5°C + 0°C}{30\ \Omega} = \frac{234.5°C + 40°C}{R_2}$$

$$R_2 = \frac{234.5°C - 40°C}{234.5°C + 0°C} \times 30\ \Omega = 24.88\ \Omega$$

Practice also EXAMPLE 3.11

Practice Book Problem [SECTION 3.5 Temperature Effects] Problems: 23 to 27 and 29

3.7 Types of Resistors

Fixed Resistors

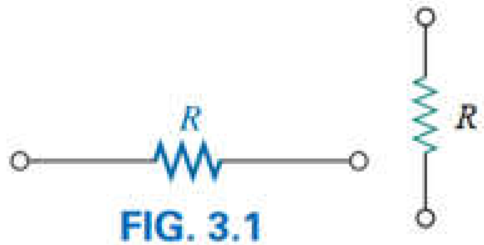


FIG. 3.1
Resistance symbol and notation.

Variable Resistors

Circuit Symbol

Variable resistor is usually referred to as a **rheostat** or **potentiometer.**

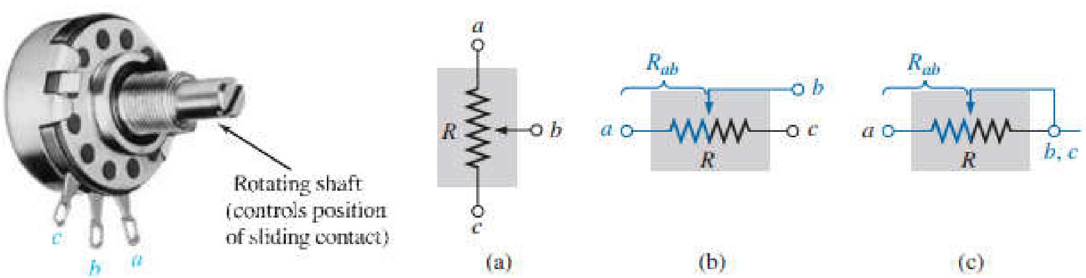


TABLE 3.7
Standard values of commercially available resistors.

Ohms (Ω)					Kilohms (kΩ)		Megohms (MΩ)	
0.10	1.0	10	100	1000	10	100	1.0	10.0
0.11	1.1	11	110	1100	11	110	1.1	11.0
0.12	**1.2**	**12**	**120**	**1200**	**12**	**120**	**1.2**	**12.0**
0.13	1.3	13	130	1300	13	130	1.3	13.0
0.15	1.5	15	150	1500	15	150	1.5	15.0
0.16	1.6	16	160	1600	16	160	1.6	16.0
0.18	**1.8**	**18**	**180**	**1800**	**18**	**180**	**1.8**	**18.0**
0.20	2.0	20	200	2000	20	200	2.0	20.0
0.22	2.2	22	220	2200	22	220	2.2	22.0
0.24	2.4	24	240	2400	24	240	2.4	
0.27	**2.7**	**27**	**270**	**2700**	**27**	**270**	**2.7**	
0.30	3.0	30	300	3000	30	300	3.0	
0.33	3.3	33	330	3300	33	330	3.3	
0.36	3.6	36	360	3600	36	360	3.6	
0.39	**3.9**	**39**	**390**	**3900**	**39**	**390**	**3.9**	
0.43	4.3	43	430	4300	43	430	4.3	
0.47	4.7	47	470	4700	47	470	4.7	
0.51	5.1	51	510	5100	51	510	5.1	
0.56	**5.6**	**56**	**560**	**5600**	**56**	**560**	**5.6**	
0.62	6.2	62	620	6200	62	620	6.2	
0.68	6.8	68	680	6800	68	680	6.8	
0.75	7.5	75	750	7500	75	750	7.5	
0.82	**8.2**	**82**	**820**	**8200**	**82**	**820**	**8.2**	
0.91	9.1	91	910	9100	91	910	9.1	

Ohmmeter

Ohmmeter measures the resistance in a circuit.

Ohm meter is connected in the two terminals of the resistance which ohm is needed to measure.

Ohmmeter is always connected in **parallel**.

In Figure (a) ohm meter is connected in between terminals *a* and *b*. So, it measured the total resistance (1 MΩ) in between terminals *a* and *b*.

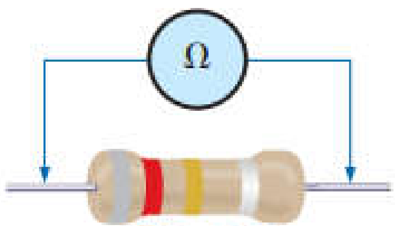
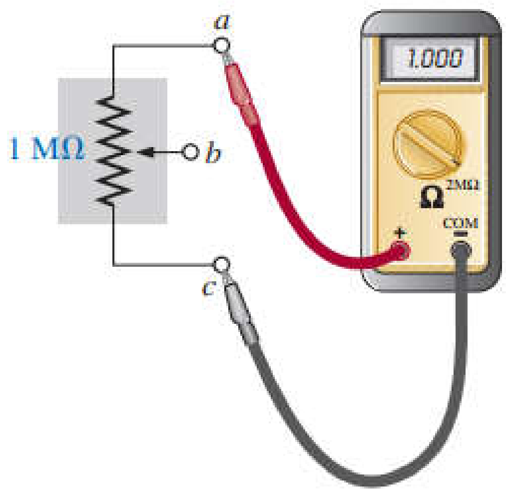
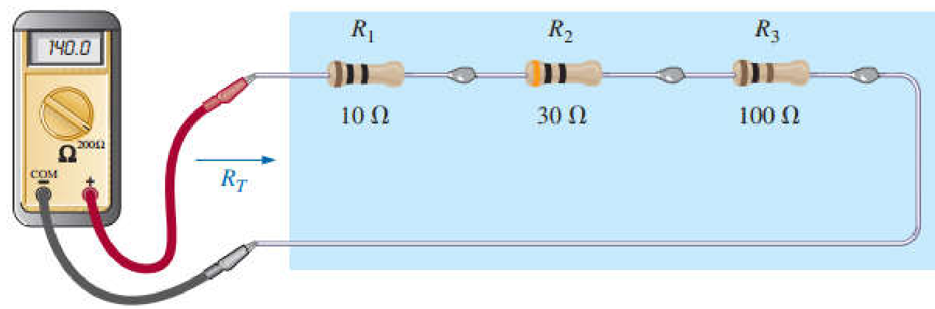


FIG. 3.32



(a)



3.9 Conductance

3.9 Conductance

Definition: The reciprocal of resistance is called conductance.

Conductance of a circuit indicates how well the material conducts electricity.

Letter Symbol: It is represented by " G ".

Unit is siemens (S).

$$G = \frac{1}{R} = \frac{A}{\rho l} = \sigma \frac{A}{l} \quad \text{(siemens, S)}$$

Conductivity: ($\sigma = 1/\rho$): The reciprocal of resistivity is called conductivity.

EXAMPLE 3.9.1 Determine the conductance of 3048 cm length of copper telephone wire which resistivity is $\rho = 1.723 \times 10^{-6}\ \Omega$–cm and the area is 8.04×10^{-4} cm^2.

Solution: $l = 3048$ cm, $\rho = 1.723 \times 10^{-6}\ \Omega$–cm, $A = 8.04 \times 10^{-4}$ cm^2.

$$R = \rho \frac{l}{A} = \frac{(1.723 \times 10^{-6}\ \Omega - \text{cm})(3048\,\text{cm})}{8.04 \times 10^{-4}\ \text{cm}^2} = 6.5\ \Omega$$

$$G = \frac{1}{R} = \frac{1}{6.5\ \Omega} = \mathbf{0.1538\ S\ \ or\ \ 153.8\ mS}$$

EXAMPLE 3.15

a. Determine the conductance of a 1 Ω, 50 kΩ, and 10 MΩ resistor.
b. How does the conductance level change with increase in resistance?

Solution: Eq. (3.14):

a. 1Ω: $G = \frac{1}{R} = \frac{1}{1\,\Omega} = \mathbf{1\,S}$

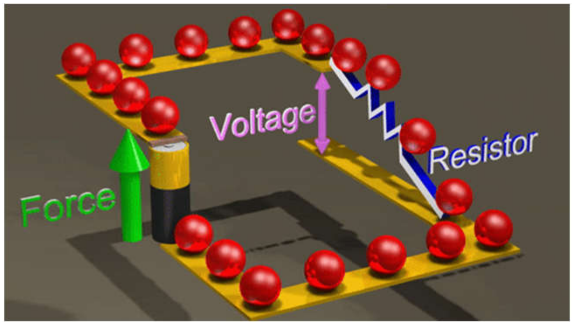
$$50\,\text{k}\Omega:\ G = \frac{1}{R} = \frac{1}{50\,\text{k}\Omega} = \frac{1}{50 \times 10^{3}\,\Omega} = 0.02 \times 10^{-3}\,\text{S} = \mathbf{0.02\,mS}$$

$$10\,\text{M}\Omega:\ G = \frac{1}{R} = \frac{1}{10\,\text{M}\Omega} = \frac{1}{10 \times 10^{6}\,\Omega} = 0.1 \times 10^{-6}\,\text{S} = \mathbf{0.1\,\mu S}$$

Practice Book Problem [SECTION 3.9 Conductance] Problem: 29

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:

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

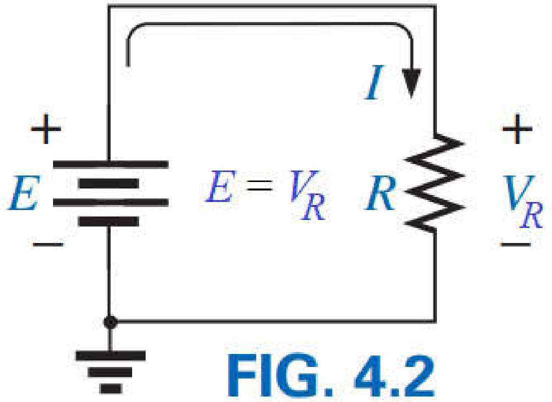


FIG. 4.2
Basic circuit.

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.

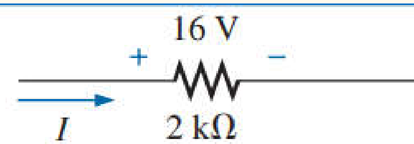


FIG. 4.4 *Example 4.3.*

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:

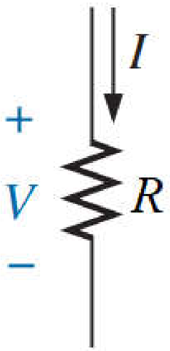
$$P = \frac{W}{t} = \frac{VQ}{t} \quad \left[\because V = \frac{W}{Q}\right]$$

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

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

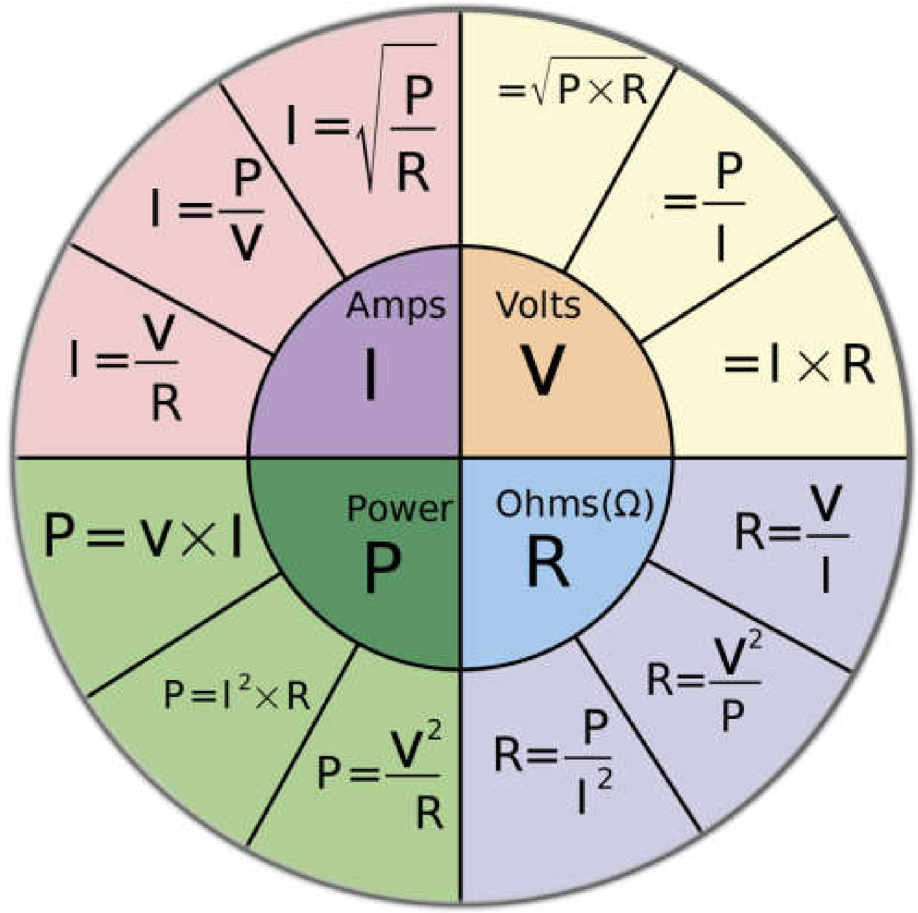
According to Eq. (4.10) we have:

For Load *R*:

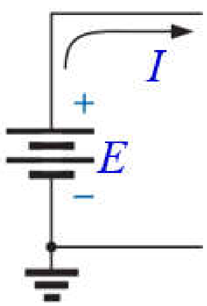


$$P = VI = V\frac{V}{R} = \frac{V^2}{R} \quad \text{(watts, W)} \qquad \textbf{(4.11)}$$

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



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

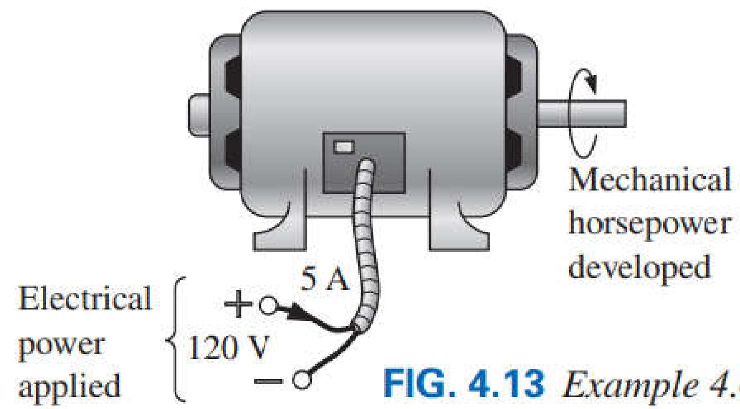


FIG. 4.13 *Example 4.6.*

EXAMPLE 4.7 What is the power dissipated by a 5 Ω resistor if the cur rent 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 $= (4 \times 60)$ 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

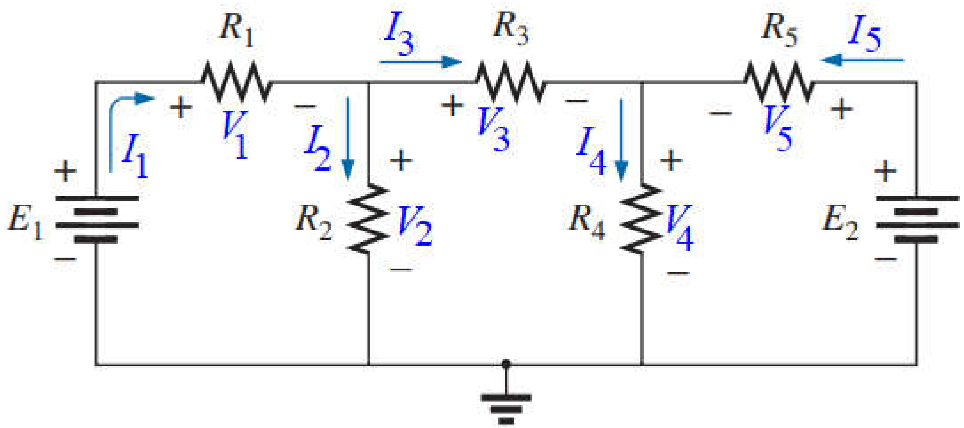
Tellegen's Theorem [1952 by B. D. H. Tellegen] for Power

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.



According to Statement (1):

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

According to Statement (2):

$$E_1 I_1 + E_2 I_5 = I_1^2 R_1 + I_2^2 R_2 + I_3^2 R_3 + I_4^2 R_4 + I_5^2 R_5$$

$$= \frac{V_1^2}{R_1} + \frac{V_2^2}{R_2} + \frac{V_3^2}{R_3} + \frac{V_4^2}{R_4} + \frac{V_5^2}{R_5}$$

$$P_{E1} = -E_1 I_1$$

$$P_{E2} = -E_2 I_5$$

$$P_{R1} = I_1^2 R_1 = \frac{V_1^2}{R_1}$$

$$P_{R2} = I_2^2 R_2 = \frac{V_2^2}{R_2}$$

$$P_{R3} = I_2^2 R_3 = \frac{V_3^2}{R_1}$$

$$P_{R4} = I_4^2 R_4 = \frac{V_4^2}{R_4}$$

$$P_{R5} = I_5^2 R_5 = \frac{V_5^2}{R_5}$$

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

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

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

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

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

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

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.

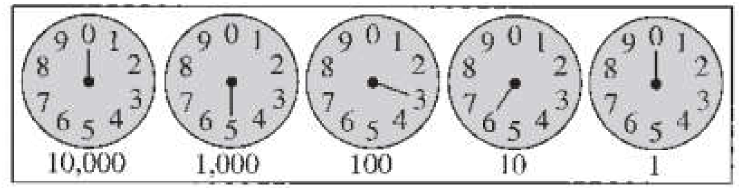


FIG. 4.16 *Kilowatthour meters: (a) analog; (b) digital.* (Courtesy of ABB Electric Metering Systems.)

SOLUTION:

Reading from Meter: $5\times1{,}000 + 3\times100 + 6\times10 + 0\times1 = 5360\ \text{kWh}$

Used Energy: $5360\ \text{kWh} - 4650\ \text{kWh} = 710\ \text{kWh}$

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

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

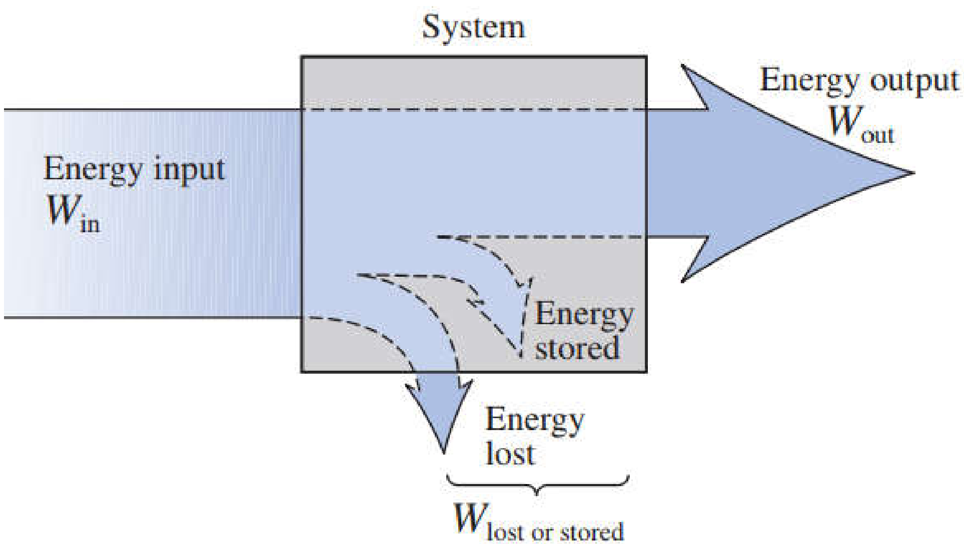


FIG. 4.18 *Energy flow through a system.*

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:

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

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

Efficiency of cascaded system:

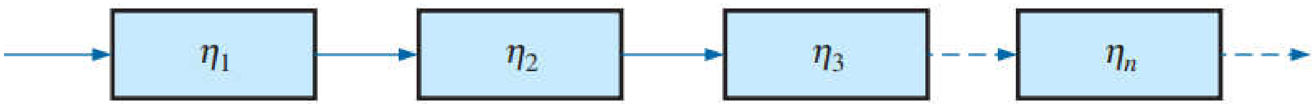


FIG. 4.20 *Cascaded system.*

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

Example of a cascaded system

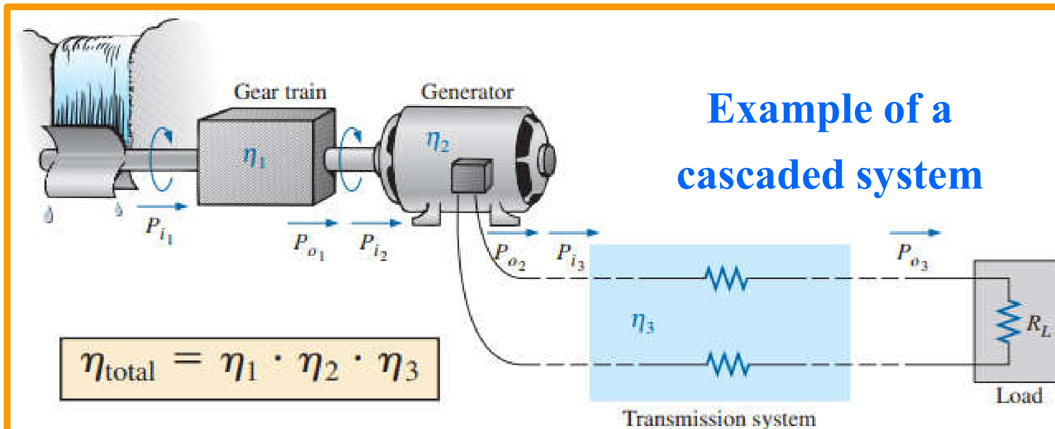


FIG. 4.19 *Basic components of a generating system.*

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

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

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

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

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

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:

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

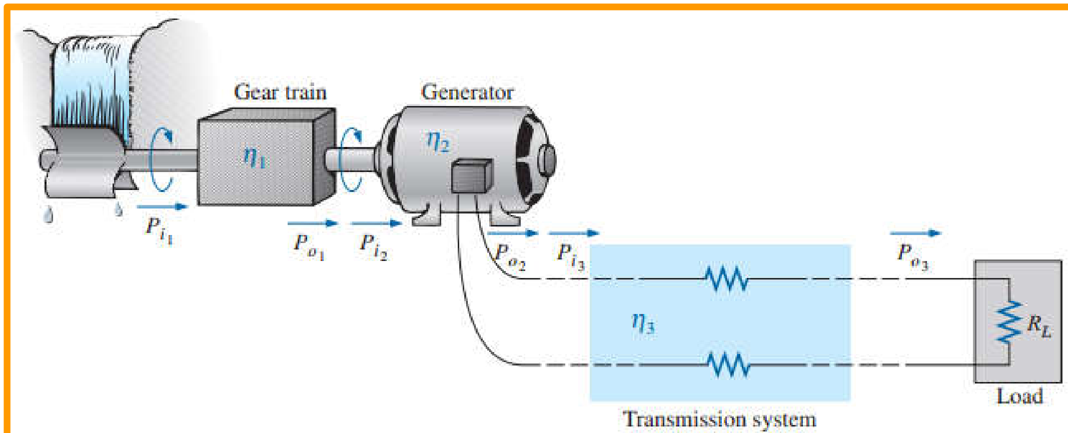


FIG. 4.19 *Basic components of a generating system.*

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

Test Your Knowledge

46. **a.** If a house is supplied with 120 V, 100 A service, find the maximum power capability.

b. Can the homeowner safely operate the following loads at the same time?

5 hp motor
3000 W clothes dryer
2400 W electric range
1000 W steam iron

c. If all the appliances are used for 2 hours, how much energy is converted in kWh?