Mazaya University College
Department Of Computer Techniques Engineering

Lecture Notes

On

Fundamentals of Electrical Engineering

For 1st year undergraduate students

Lecturer

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Chapter one: Basic concepts and Basic laws

1.1Introduction

Technology is rapidly changing the way we do things; we now have computers in our homes, electronic control systems in our cars, and so on.
A first step to understanding these technologies is electric circuit theory. Circuit theory provides you with the knowledge of basic principles that you need to understand the behavior of electric and electronic devices, circuits, and system.
An electric circuit is an interconnection of electrical elements.

1.2 Basic concepts

1.2.1 The SI system of units

The system of units used in engineering and science is international system of units, usually abbreviated to SI units.

The units in Table 1–1 are defined units, while table 1-2 is Engineering Prefixes

Quantity	Symbol	Unit	Abbreviation
Length	ℓ	meter	m
Mass	m	kilogram	kg
Time	t	second	s
Electric current	I, i	ampere	A
Temperature	T	kelvin	K

Table 1-1

Power of 10	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Table 1-2

1.2.2 Electrical charge and current

Electrical charge (q) is an intrinsic property of matter that manifests itself in the form of forces—electrons repel other electrons but attract protons, while protons repel each other but attract electrons. The electrical charge is measured in coulombs (c). The charge of an electron is (-$1.602*10^{-19}c$).

$$q = It$$

Where I is the current in amperes and t is the time in seconds.

<u>Example 1.1:</u>
If a current of 5 A flows for 2 minutes, find the quantity of electricity transferred?
Solution
Quantity of electricity $q = It$
$I = 5A$, $t = 2*60 = 120s$
Hence, $q = 5*120 = 600C$

Electrical current

An electric current is a flow of electric charge. In electric circuits this charge is often carried by moving electrons in a wire. In other words, electrical current is the rate of change of charge, measured in amperes (A). It is defined mathematically as:

$$i = \frac{dq}{dt}$$

$$q = \int_{t_1}^{t_2} i dt$$

<u>Example 1.2:</u>
Determine the total charge entering a terminal between t=1s and t=2s, if the current passing the terminal is $i = (3t^2 - t)$ A.

Solution

$$q = \int_{t_1}^{t_2} i dt$$

$$q = \int_{1}^{2} (3t^2 - t) dt = \left(t^3 - \frac{t^2}{2} \right)_1^2 = 5.5C$$

- **Direct current (DC):**
  It is a current that remains constant with time, as shown in figure 1.1. It is represented by (I).

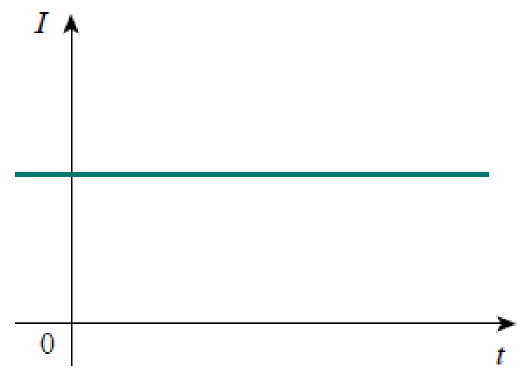


Figure 1.1: Direct current

- **Alternating current (AC):**
  Alternating current is that varies sinusoidally with time. AC is shown in figure 1.2, and it is represented by i.

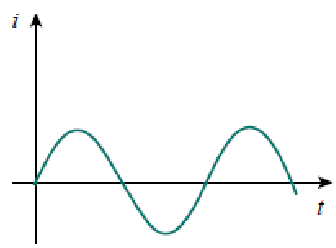
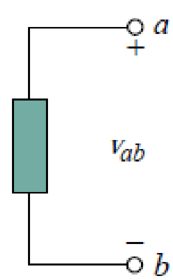


Figure 1.2: Alternating current

1.2.3 Voltage

Voltage is the electric potential difference between two points, or the difference in electric potential energy of a unit charge transported between two points. It is measured in volts (V).



For the voltage V_{ab} , this means that the potential of point a is higher than that of point b.

$$V_{ab} = V_a - V_b$$

1.2.4 Power and Energy

The unit of power is the watt (W) where one watt is one joule per second. Power is defined as the rate of doing work or transferring energy. Thus,

$$P = \frac{dw}{dt}$$

Where:

P: is the power in watts (w)

W: is the energy in joules (J)

t: is the time in seconds (s)

$$P = \frac{dw}{dt} = \frac{dw}{dq} . \frac{dq}{dt} = vi$$

$$\therefore P = vi$$

Energy: is the capacity to do work, measured by joule

The energy absorbed or supplied by an element from time t_0 to t is:

$$w = \int_{t_0}^{t} Pdt = \int_{t_0}^{t} vidt$$

OR

$$w = Pt$$

The electric power utility companies measure energy in watt-hour (wh), where

$$1wh = 3600 Joule$$

<u>Example 1.3:</u>

How much energy does a 100-W electric bulb consume in two hours?

Solution

$W = Pt = 100*2 = 200$ wh

OR

$W = 200*3600 = 720000J = 720kJ$

1.2.5 Circuit Elements

An electric circuit is simply an interconnection of the elements.

There are two types of elements found in electric circuits: *passive* elements and *active* elements.

- ✓ Active element: is capable of generating energy. Examples of active elements are generators, batteries, and operational amplifiers.

- ✓ Passive elements is cannot generate energy such as resistors, inductors and capacitors

1.3 Basic Laws

1.3.1 OHM'S LAW

Ohm's law states that the voltage *v* across a resistor is directly proportional to the current *i* flowing through the resistor.

$$V \propto I$$
$$V = RI$$

Where R is the resistance.

The *resistance* R of an element denotes its ability to resist the flow of electric current; it is measured in ohms (Ω).

The resistance of any material with uniform cross-sectional area A depends on A, its length ℓ and resistivity, as shown in figure 1.3.

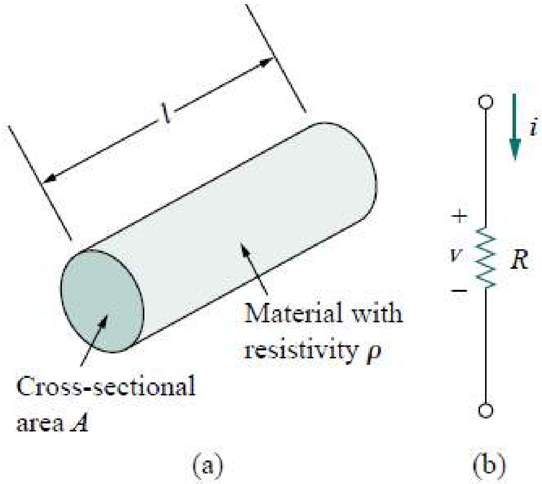


Figure 1.3: (a) Resistor, (b) Circuit symbol for resistance

In mathematical form,

$$R = \rho \frac{\ell}{A}$$

Where ρ is known as the resistivity of the material in ohm-meters. ℓ and A are length and the cross area of the material respectively.

Example 1.5

Calculate the resistance of a 2km length of aluminum overhead power cable if the cross-sectional area of the cable is 100 mm^2. Take the resistivity of aluminum to be 0.03×10^{-6} Ω.m.

Solution

$$R = \rho \frac{\ell}{A} = (0.03*10^{-6}\Omega.m)\frac{2000m}{1000*10^{-6}m^2} = 0.6\Omega$$

Example 1.6

Solid copper wire having a diameter of 1.63 mm is used to provide electrical distribution to outlets and light sockets. Determine the resistance of 75 meters of a solid copper wire having the above diameter. Resistivity of copper at $20^{\circ}C$ is $1.723*10^{-8}\Omega.m$

Solution

$$A = \frac{\pi d^2}{4} = \frac{\pi (1.63*10^{-3} m)^2}{4} = 2.09*10^{-6} m^2$$

$$R = \rho \frac{\ell}{A}$$

$$R = (1.723*10^{-8} \Omega.m)\frac{75m}{2.09*10^{-6} m^2} = 0.619\Omega$$

Short and open circuits

Since the value of *R* can range from zero to infinity, it is important that we consider the two extreme possible values of *R*. $R = 0$ and $R = \infty$.

- An element with *R* = 0 is called a *short circuit (i.e.* A short circuit is a circuit element with resistance approaching zero), as shown in Fig. 1.4 (a).
- An element with $R = \infty$ is known as an *open circuit* (i.e. an open circuit is a circuit element with resistance approaching infinity), as shown in figure 1.4 (b).

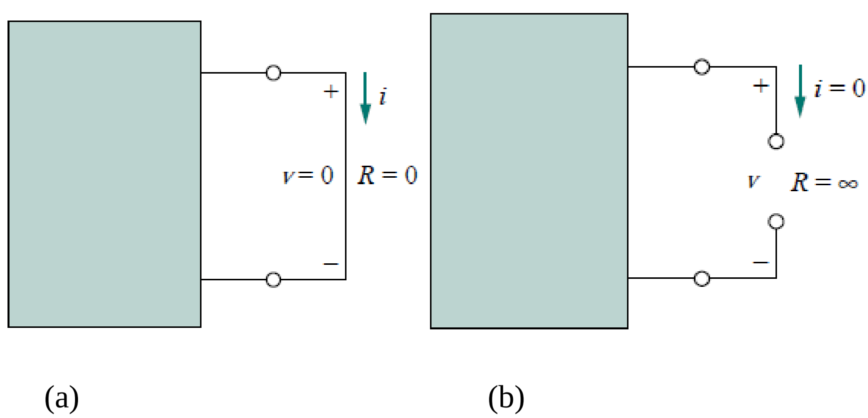


Figure 1.4: (a) short circuit ($R = 0$), (b) open circuit ($R = \infty$)

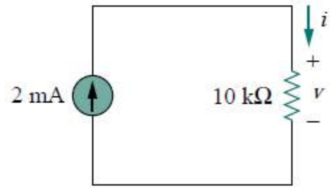
Conductance (G)

The quantity inverse of the electrical resistance is known as conductance (G). On the other words, the conductance is a measure of how well an element will conduct electric current.

$$G = \frac{1}{R} = \frac{I}{V}$$

It is measured in siemens (S).

Example 1.7:
For the circuit shown below, calculate the voltage V, the conductance G, and the power P?



Solution:

$V = IR = 2*10^{-3}*10*10^{3} = 20v$

$G = \frac{1}{R} = \frac{1}{10*10^{3}} = 0.0001s = 100\mu s$

$P = VI = 20*2*10^{-3} = 0.04w = 40mw$

OR

$P = \frac{V^{2}}{R} = \frac{(20)^{2}}{10*10^{3}} = 0.04w = 40mw$

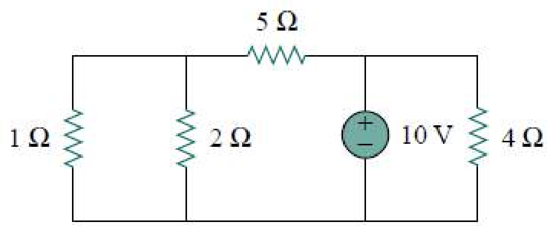
OR

$P = I^{2}R = (2*10^{-3})^{2}*10*10^{3} = 0.04w = 40mw$

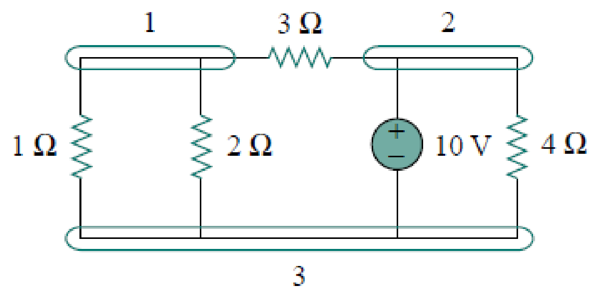
1.3.2 Nodes, Branches and Loops

- ***A branch*** represents a single element such as voltage source or current source or a resistor.
- ***A node*** is the point of connection between two or more branches.
- ***A loop*** is any closed path in a circuit.

Example 1.8
How many branches and nodes does the circuit in figure below have?

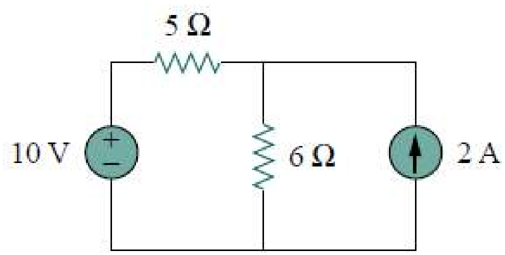


Solution
Five branches and three nodes are identified in the figure below



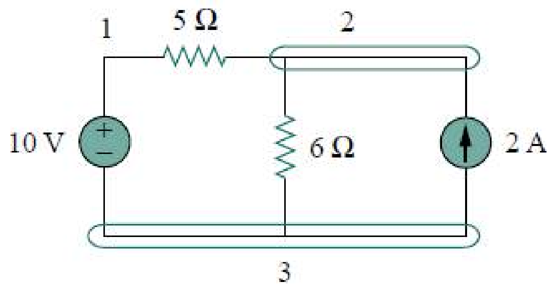
Example 1.9

Determine the number of branches and nodes in the circuit shown below?



Solution

Since there are four elements in the circuit, the circuit has four branches.
The circuit has three nodes as identified in the figure below.



1.3.3 Kirchhoff's Laws

1. ***Kirchhoff's current law (KCL)*** states that the algebraic sum of currents entering a node is zero.
   Mathematically, KCL implies that

$$\sum_{n=1}^{N} i_n = 0$$

OR

The sum of the currents entering a node is equal to the sum of the currents leaving the node

$$\sum_{n=1}^{N} i_{ni} = \sum_{m=1}^{M} i_{mo}$$

Where:

i_{ni} : are the currents entering the node

i_{mo} : are the currents leaving the node

For example, referring to figure 1.5

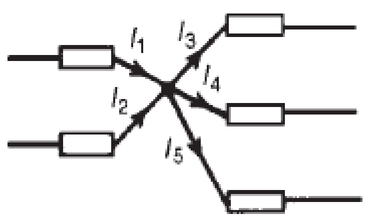


Figure 1.5

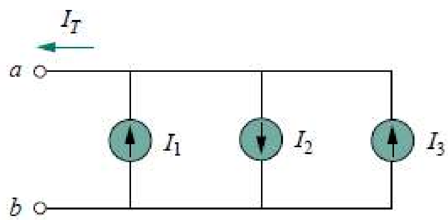
$I_1 + I_2 - I_3 - I_4 - I_5 = 0$

OR

$I_1 + I_2 = I_3 + I_4 + I_5$

Example 1.10

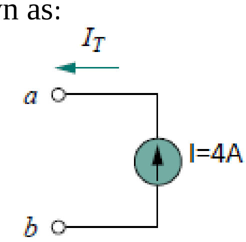
For the circuit shown below, calculate the total current (I_T) if $I_1 = 3A$, $I_2 = 1A$ and $I_3 = 2A$?



According to KCL

$I_T = I_1 - I_2 + I_3 = 3 - 1 + 2 = 4A$

The equivalent circuit can be shown as:



2. ***Kirchhoff's voltage law (KVL)*** states that the algebraic sum of all voltages around a closed path(or loop) is zero

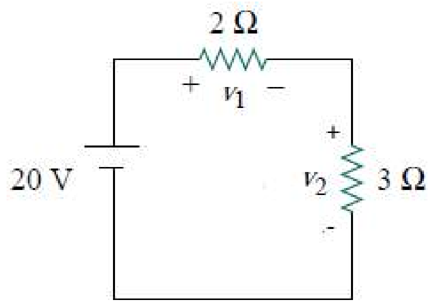
   Expressed mathematically, KVL states that

$$\sum_{m=1}^{M} V_m = 0$$

Where m is the number of voltages in the loop (or the number of branches in the loop) and V_m is the *m*th voltage.

Example 1.11

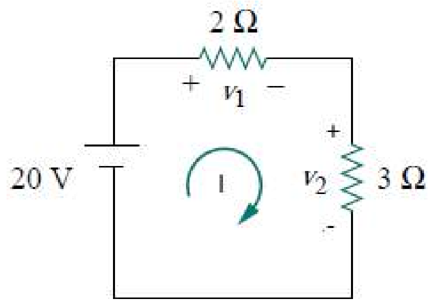
For the circuit shown below, find v_1 and v_2 ?



Solution:

To find v1 and v2, we apply Ohm's law and Kirchhoff's voltage law.

Assume that current i flows through the loop as shown in the figure below



From Ohm's law,

$v_1 = 2I$, $v_2 = 3I$

Applying KVL around the loop gives,

$$20 - v_1 - v_2 = 0$$

$$20 = v_1 + v_2 = 2I + 3I = 5I$$

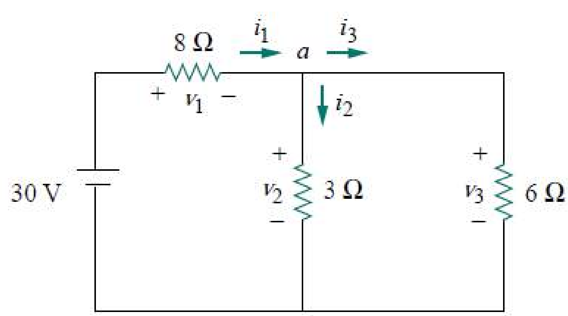
$$\therefore I = \frac{20}{5} = 4A$$

$$\therefore v_1 = 2*4 = 8v,$$

$$v_2 = 3*4 = 12v$$

Example 1.12:

Find the currents and voltages in the circuit shown below using Kirchhoff's law



Solution:

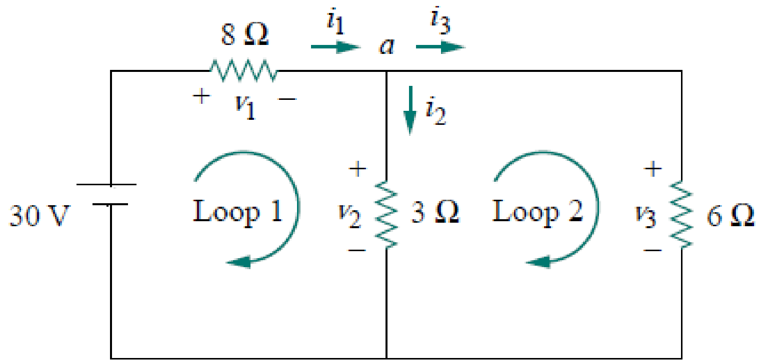
By Ohm's law

$v_1 = 8i_1$, $v_2 = 3i_2$, $v_3 = 6i_3$

At node a KCL gives:

$$i_1 - i_2 - i_3 = 0 \text{ .... (1)}$$

Applying KVL to loop 1, as shown in the figure below:



$$30 - v_1 - v_2 = 0$$

We express this in terms i_1 , i_2 to obtain:

$$30 - 8i_1 - 3i_2 = 0$$

$$i_1 = \frac{30 - 3i_2}{8} \quad \text{.............. (2)}$$

Applying KVL to loop 2:

$$v_2 - v_3 = 0$$

$$3i_2 - 6i_3 = 0 \rightarrow i_3 = \frac{i_2}{2} \quad \text{................. (3)}$$

Substituting eqs. (2 and 3) into eq. (1):

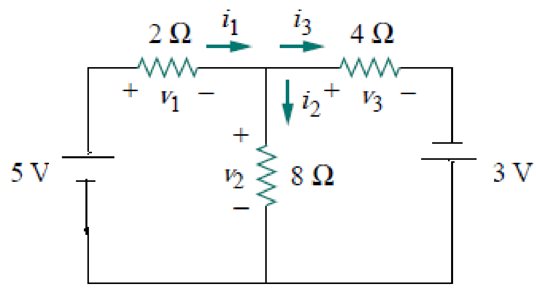
$$\frac{30 - 3i_2}{8} - i_2 - \frac{i_2}{2} = 0$$

$$\therefore i_2 = 2A$$

From the value of i_2 , we obtain

$i_1 = 3A, i_3 = 1A$, $v_1 = 24v$,$v_2 = 6v$,$v_3 = 6v$

H.W: Find the currents and voltages shown in the figure below:



Answer: $v_1 = 3v, v_2 = 2v, v_3 = 5v, i_1 = 1.5A, i_2 = 0.25, i_3 = 1.25A$