CHAPTER 1: BASIC CONCEPTS

1.1 Introduction

- An electrical circuit is an interconnection of several elements. It is a mathematical model that approximates the behavior of an actual electrical system.
- Circuit theory is the study of *analyzing* an electrical circuit.

1.2 International System of Units (SI)

- SI is an international measurement language.
- There are six principal units.

Quantity	Basic unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd

- The SI units also uses prefixes based on the power of 10 to relate larger and smaller units to the basic unit.

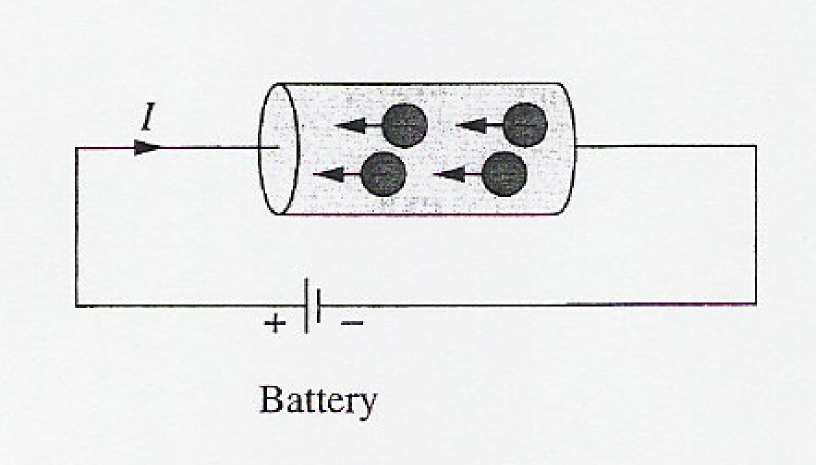
Multiplier	Prefix	Symbol
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	mili	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

1.3 Charge and Current

- Most basic quantity in an electric circuit – *electric charge*

> **Charge**, *e*, is an electrical property of the atomic particles of which matter consists, measured in coulomb (C)

- Elementary physics – all matter is made of atoms that consists of elcetrons, protons and neutrons.
- The charge, *e* of electron is negative and equal in magnitude to 1.602 x 10^{-19} C.
- A proton carries a positive charge of the same magnitude as the electron.
- Notes on electric charge:
  - (i) Coulomb is a large unit for charges. 1C = 1/(1.602 x 10^{-19}) = 6.24 x 10^{18} electrons.
  - (ii) Charges are intergral multiplies of the elctron charge.
  - (iii) The *law of conservation of charge* – charge can neither be created nor destroyed, only transferred.
- Electric charge is mobile.
- The motion of charges creates electric current, *I*.



Rajah 1.1

- The current flow in a conductor:

Electric current, *I*, is the time rate of change of charge, measured in amperes (A).

- The relationship between current i, charge q and time t is

$$i = \frac{dq}{dt} \qquad (1.1)$$

where current is measured in amperes (A) and

1 ampere = 1 coulomb/second

- From Equation 1.1, the charge transferred between time t_0 to t is obtained using

$$q = \int_{t_0}^{t} i dt \qquad (1.2)$$

- Two types of current:

  (i) direct current (dc)

A direct current is a current that remains constant with time

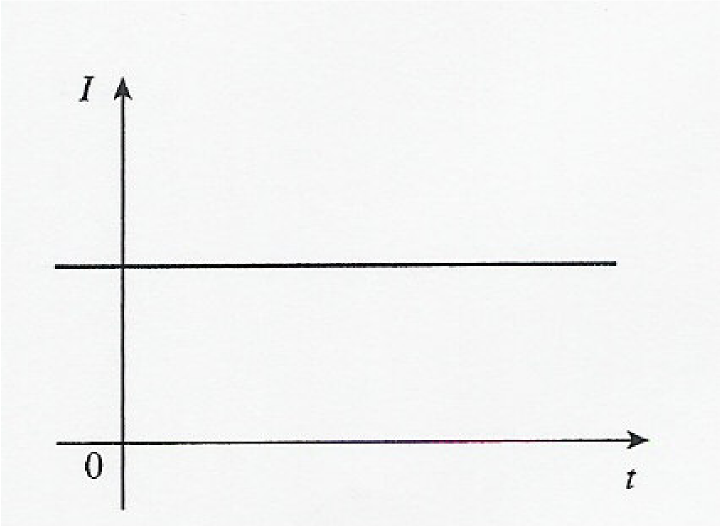


Figure 1.2

(ii) alternating current (ac)

A alternating current is a current that varies sinusoidally with time

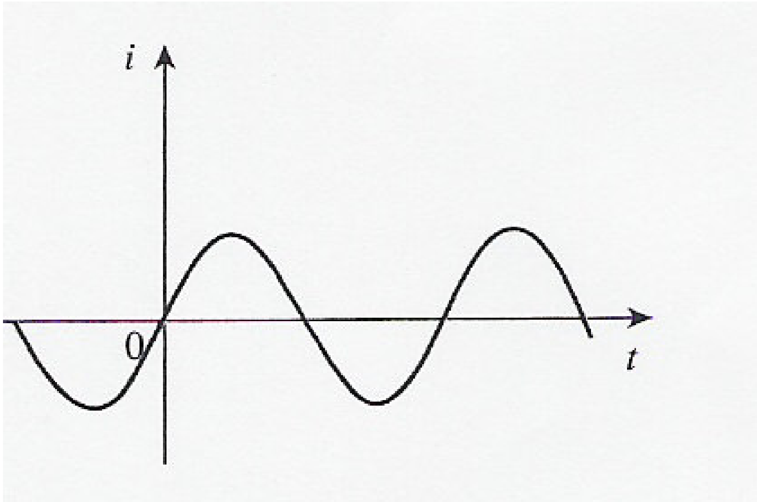


Figure 1.3

- Examples:

(i) The total charge entering a terminal is given by $q = (10 - 10e^{-2t})mC$. Calculate the current at t = 0.5 s.

$$i = \frac{dq}{dt} = \frac{d}{dt}(5t\sin 4\pi t)mC/s$$

$$= (5\sin 4\pi t + 20\pi t\cos 4\pi t)mA$$

At t=0.5,

$$i = 5\sin 2\pi + 10\pi\cos 2\pi = 0 + 10\pi$$

$$= 31.42mA$$

(ii) The current flowing through an element is

$$i = \begin{cases} 2A & 0 < t < 1 \\ 2t^2 A & t > 1 \end{cases}$$

Calculate the charge entering the element from t = 0 to t = 2 s.

$$q = \int_0^2 idt = \int_0^1 2dt + \int_1^2 2t^2 dt$$

$$= 2t\Big|_0^1 + \frac{2t^3}{3}\Big|_1^2 = (2-0) + \left(\frac{16}{3} - \frac{2}{3}\right) = \frac{20}{3}C$$

1.4 Voltage

- Voltage is an external electromotive force (emf) (typically represented by the battery) which performs work to move the electron in a conductor.
- Also known as potential difference between two points.

> **Voltage**, v_{ab} between two points a and b in a electric circuit is the energy (or work) needed to move a unit charge from a to b.

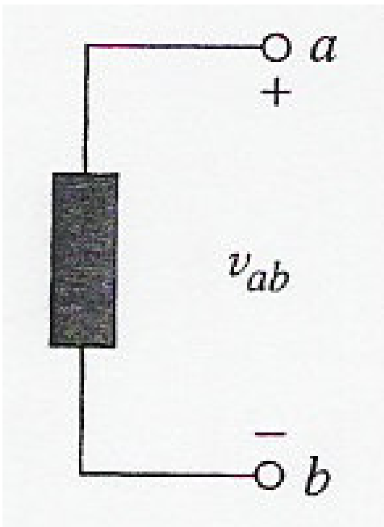


Figure 1.4

- Mathematically:

$$v_{ab} = \frac{dw}{dq} \qquad (1.3)$$

where w is energy in joules (J) and q is charge in coulombs (C).

- Voltage is measured in volts (V), where
  1 volt = 1 joule/coulomb = 1 newton meter/coulomb
- Examples:

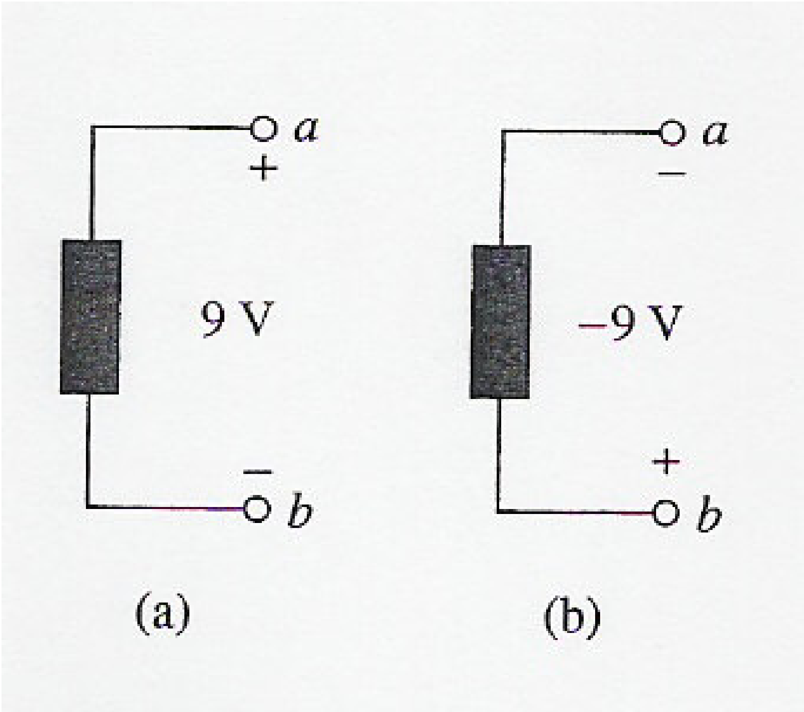


Figure 1.5

For case (a), $v_{ab} = 9V$ and for case (b) $v_{ba} = -9V$

1.5 Power and Energy

- Definition of power

Power is the time rate of expanding or absorbing energy, measured in watts (W)

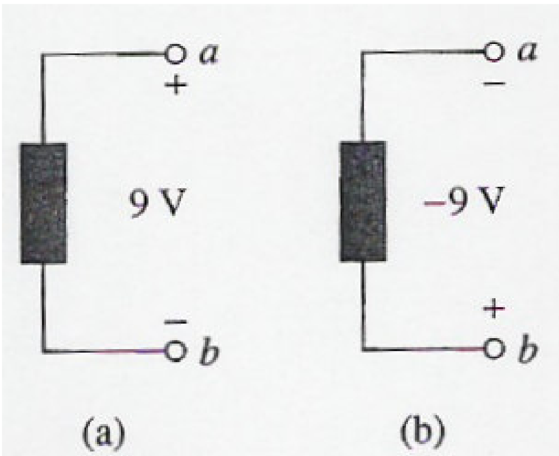
- Mathematically can be defined as:

$$p = \frac{dw}{dt} \tag{1.4}$$

$$p = \frac{dw}{dq} \cdot \frac{dq}{dt} = vi \tag{1.5}$$

where p is power in watts (W), w is energy in joules (J) and t is time in seconds (s).

- +power – power is delivered to/absorbed by element.
- -power – power is being supplied by element.



(a) absorbing power (b) supplying power
Figure 1.6

- +Power absorbed = -Power supplied
- The law of conversion of energy – the algebraic sum of power in a circuit at any instant of time must be zero:

$$\sum p = 0 \qquad (1.6)$$

- From Equation (1.5), the energy absorbed or supplied by an element from time t_0 to t is

$$w = \int_{t_0}^{t} p\,dt = \int_{t_0}^{t} vi\,dt \qquad (1.7)$$

Energy is the capacity to do work, measured in joules (J)

- Examples:

(i) Find the power delivered to an element at t = 5s if the current entering its positive terminal is:

$$i = 5\cos 60\pi t \text{ A}$$

and the voltage is:

$$v = 3\frac{di}{dt}$$

$$v = 3\frac{di}{dt} = 3(-60\pi)5\sin 60\pi t$$

$$v = -900\pi \sin 60\pi t \text{ V}$$
$$\therefore\ p = iv = -4500\pi \sin 60\pi t \cos 60\pi t \text{ W}$$

(ii) A stove element draws 15 A when connected to a 120 V line. How long does it take to consume 30 kJ?

$$w = pt$$
$$t = \frac{w}{p} = \frac{w}{iv} = \frac{30\times10^3}{(15)(120)} = 16.67 \text{ s}$$

1.6 Circuit Elements

- Two types of elements:
  (i) Active elements
    – Capable of generating energy.
    – i.e. generators, batteries, op-amp
  (ii) Passive elements
    – Not capable of generating energy.
    – i.e. resistors, capacitors, inductors
- Two types of sources (current or voltage):

  Type 1:

An ideal independent source is an active element that provides a specified voltage or current that is completely independent of other circuit elements.

The symbol for independent sources:

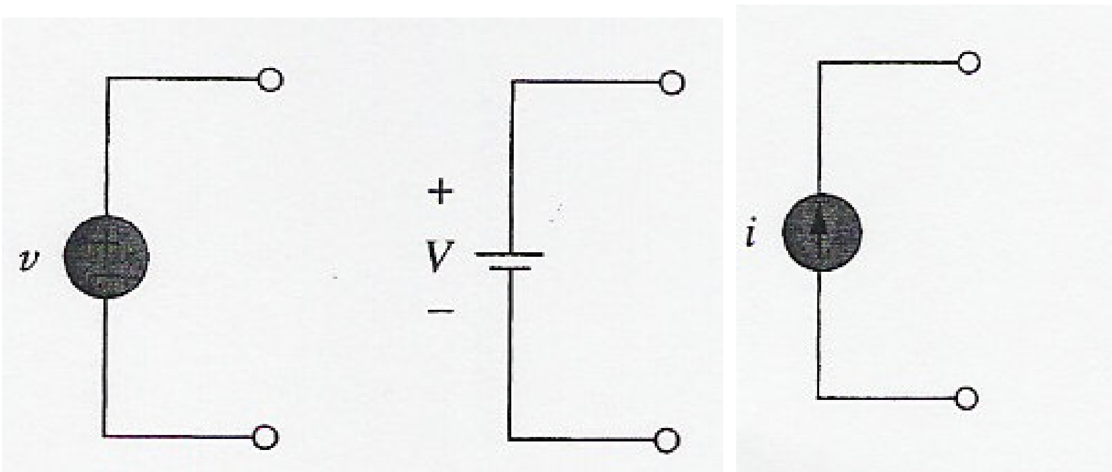


Figure 1.7

Type 2:

An ideal dependent (or controlled) source is an active element in which the source quantity is controlled by another voltage or current.

Example of dependent source: transistor, op-amp
The symbol for dependent source:

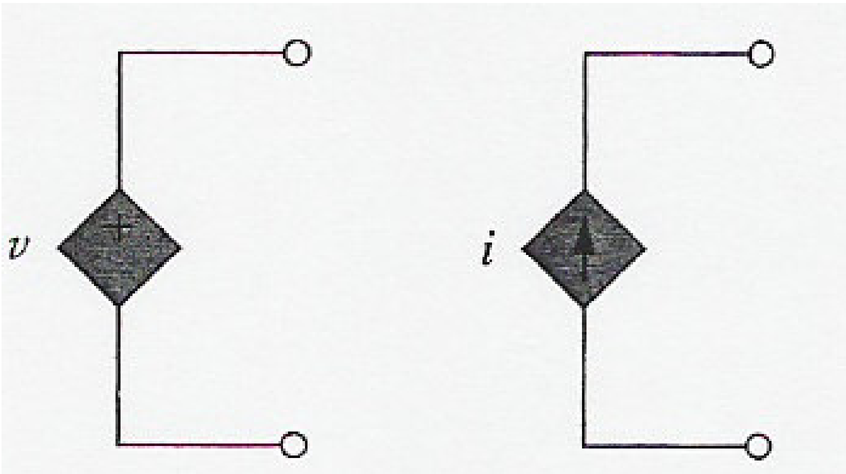


Figure 1.8