1.1 Introduction

Electric circuit theory is one of the basic subjects in electrical engineering. It is used in many fields such as power systems, electronics, control, and communications. Therefore, studying electric circuits is very important for first-year electrical engineering students.

An electric circuit is a connection of electrical components that allows electric energy to flow from one point to another. Each part in the circuit is called an element.

A simple electric circuit may consist of a battery, a lamp, and connecting wires. Such circuits are used in daily life, for example in flashlights. More complex circuits are used in devices like radios and computers, but they are based on the same basic principles.

In this course, we will learn how electric circuits work and how to analyze them. We will study basic concepts such as electric charge, current, voltage, power, and energy. These concepts will help us understand how electrical systems operate.

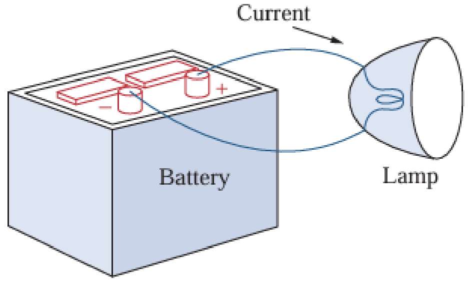


Figure 1.1 Asimple electric circuit.

1.2 Systems of Units

As electrical engineers, we deal with measurable quantities. Our measurement, however, must be communicated in a standard language that virtually all professionals can understand, irrespective of the country where the measurement is conducted. Such an international measurement

TABLE 1.1

Six basic SI units and one derived unit relevant to this text.

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
Charge	coulomb	C

TABLE 1.2

The SI prefixes.

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}	milli	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

1. ***Charge*** is the basic quantity in electrical circuits and the underlying principle of all electrical phenomena.

We experience electric charge effects in daily life, such as: Clothes sticking to the body after removing a wool sweater. Receiving a small shock when walking on a carpet.

Charge is an electrical property of atomic particles and is measured in coulombs (C).

- Atomic Structure and Charge
- Atoms consist of electrons, protons, and neutrons.
- Electron: negative charge $e=-1.602*10^{-19}C$
- Proton: positive charge +e, same magnitude as electron.
- Equal numbers of protons and electrons make the atom electrically neutral.
- . Important Points about Charge
- Coulomb is a large unit:
  $1\ C \approx 6.24\times10^{18}$ electrons.
- Laboratory charges are often in pC (pico Coulombs), nC (nano Coulombs).

- Charges in nature always occur as integer multiples of the electron charge.
- Law of Conservation of Charge:
- Charge cannot be created or destroyed, only transferred.
- The total charge in a closed system remains constant.

2. Electric Current

- Current is the flow of electric charges.

When a conducting wire is connected to a battery:

Positive charges move in one direction, negative charges move in the opposite.

Conventional current direction is defined as the flow of positive charges.

Although current in metallic conductors is due to electron movement, we follow the universally accepted convention introduced by Benjamin Franklin.

Definition of Electric Current

Current is the rate of change of charge with respect to time. Measured in amperes (A).

Mathematically, the relationship between current i, charge q, and time t is

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

…………………..(1.1)

where current is measured in amperes (A),
and 1 ampere 1 coulomb/second

The charge transferred between time t0 (1.1) and t is obtained by integrating both sides of Eq. (1.1). We obtain

$$Q \triangleq \int_{t_0}^{t} i\, dt$$

…………………….(1.2)

Types of Electric Current

- *Electric current (i)* represents the rate of flow of electric charge and does not have to be constant; it can change with time.

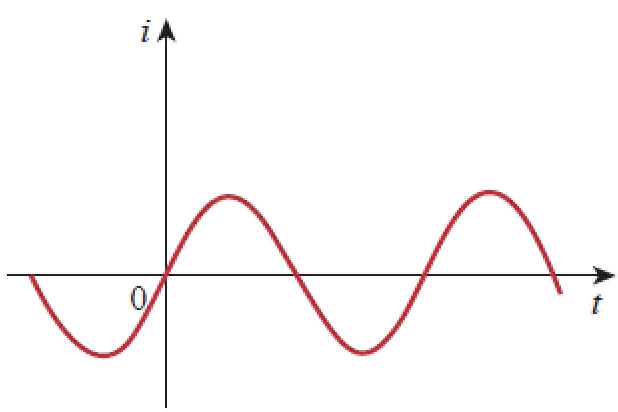
- If the current remains constant with time, it is **called Direct Current (DC).** Represented by the symbol I. Example: current from batteries.

- If the current varies with time, it is called time-varying current and is represented by i. A common type of time-varying current is **Alternating Current (AC).** AC varies sinusoidally with time.

Used in household electricity to operate appliances such as air conditioners, refrigerators, and washing machines.

(a)

Figure 1.2Two common types of current: (a) direct current (dc),



(b)

(b) alternating current (ac).

Example.1

The total charge entering a terminal is given by $q = 5t \sin 4\pi t$ mC. Calculate the current at $t = 0.5$ s.

Solution:

$$i = \frac{dq}{dt} = \frac{d}{dt}(5t \sin 4\pi t) \text{ mC/s} = (5 \sin 4\pi t + 20\pi t \cos 4\pi t) \text{ mA}$$

At $t = 0.5$,

$$i = 5 \sin 2\pi + 10\pi \cos 2\pi = 0 + 10\pi = 31.42 \text{ mA}$$

Example.2

Determine the total charge entering a terminal between $t = 1$ s and $t = 2$ s if the current passing the terminal is $i = (3t^2 - t)$ A.

Solution:

$$Q = \int_{t=1}^{2} i\, dt = \int_{1}^{2} (3t^2 - t)\, dt$$

$$= \left(t^3 - \frac{t^2}{2}\right)\Big|_1^2 = (8 - 2) - \left(1 - \frac{1}{2}\right) = 5.5 \text{ C}$$

3. Voltage

To move electrons in a conductor, energy (work) is required.

This energy is supplied by an external electromotive force (emf), such as a battery.

Voltage (v) or potential difference is the energy required to move a unit charge between two points in an electric circuit. measured in volts (V).

The voltage between two points a and b in an electric circuit is the energy (or work) needed to move a unit charge from a to b;

mathematically,

$$v_{ab} \triangleq \frac{dw}{dq} \qquad \text{..................(1.3)}$$

Where

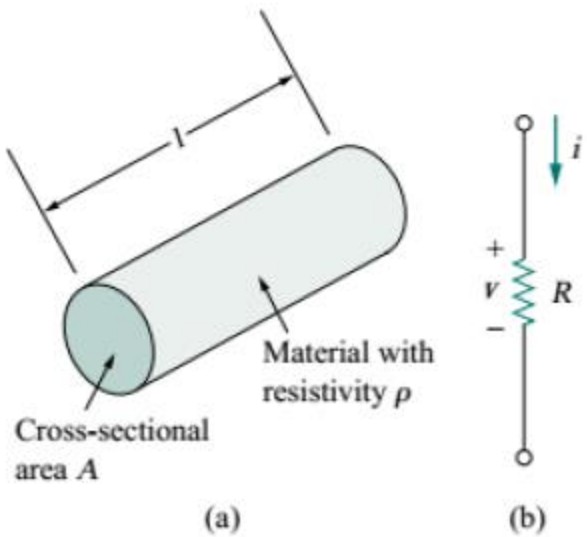
w is energy in joules (J)

q is charge in coulombs (C)

4. Resistance

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

Materials in general have a characteristic behavior of resisting the flow of electric charge. This physical property, or ability to resist current, is known as resistance and is represented by the symbol R. The resistance of any material with a uniform cross-sectional area A depends on A and its length, as shown in Fig. below



(a) Resistor, (b) Circuit symbol for resistance.

In mathematical form,

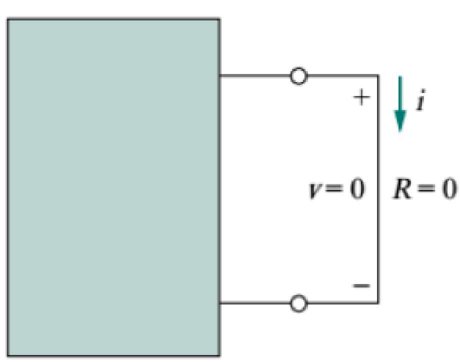
$$R = \rho \frac{\ell}{A}$$

where ρ is known as the resistivity of the material in ohm-meters. Good conductors, such as copper and aluminum, have low resistivities, while insulators, such as mica and paper, have high resistivities. Table below presents the values of ρ for some common materials and shows which materials are used for conductors, insulators, and semiconductors.

Table - Resistivities of common materials.

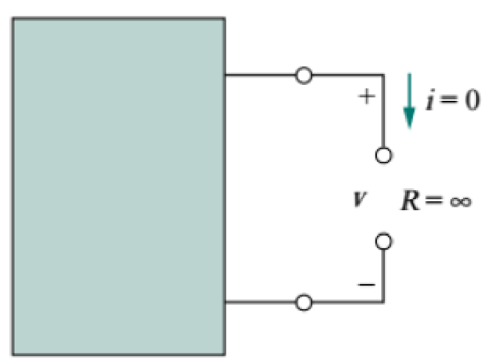
Material	Resistivity (Ω·m)	Usage
Silver	1.64×10^{-8}	Conductor
Copper	1.72×10^{-8}	Conductor
Aluminum	2.8×10^{-8}	Conductor
Gold	2.45×10^{-8}	Conductor
Carbon	4×10^{-5}	Semiconductor
Germanium	47×10^{-2}	Semiconductor
Silicon	6.4×10^{2}	Semiconductor
Paper	10^{10}	Insulator
Mica	5×10^{11}	Insulator
Glass	10^{12}	Insulator
Teflon	3×10^{12}	Insulator

A short circuit is a circuit element with resistance approaching zero.
An open circuit is a circuit element with resistance approaching infinity.



Short circuit $(R = 0)$

$v = iR = 0$



Open circuit $(R = \infty)$

$$i = \lim_{R \to \infty} \frac{v}{R} = 0$$

5. Conductance

Conductance is the ability of an elemt to conduct electric current; it is measured in mhos (℧)

$$G = \frac{1}{R} = \frac{i}{v}$$

The power dissipated by a resistor can be expressed in terms of R. as

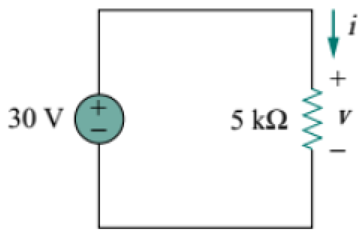
$$p = vi = i^2 R = \frac{v^2}{R}$$

The power dissipated by a resistor may also be expressed in terms of G. as:

$$p = vi = v^2 G = \frac{i^2}{G}$$

Example 3

In the circuit shown in Fig. shown, calculate the current i, the conductance G, and the power p.



Solution:

The current is

$$i = \frac{v}{R} = \frac{30}{5 \times 10^3} = 6 \text{ mA}$$

The conductance is

$$G = \frac{1}{R} = \frac{1}{5 \times 10^3} = 0.2 \text{ mS}$$

We can calculate the power in various ways

$$p = vi = 30(6 \times 10^{-3}) = 180 \text{ mW}$$

or

$$p = i^2 R = (6 \times 10^{-3})^2 5 \times 10^3 = 180 \text{ mW}$$