LECTURE 1: Electric Circuit Theory

1.1 Introduction

Technology is rapidly changing the way we do things; we now have computers in our homes, electronic control systems in our cars, cellular phones that can be used just about anywhere, robots that assemble products on production lines, 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 systems.

As an example, consider Figure 1.1 below, which shows a basic Radio receiver system.

Its design is based on electrical, electronic, and magnetic circuit principles. For example, resistors, capacitors, transistors, and integrated circuits are used to control the voltages and currents that operate its motors and amplify the audio and video signals that are the heart of the system. A magnetic circuit, the power transformer, transforms the ac voltage from the 240-volt wall outlet voltage to the lower voltages required by the system.

Figure 1.1: A Radio receiver is a familiar example of an electrical/electronic system.

Its applications are all rooted in the principles of circuit theory.

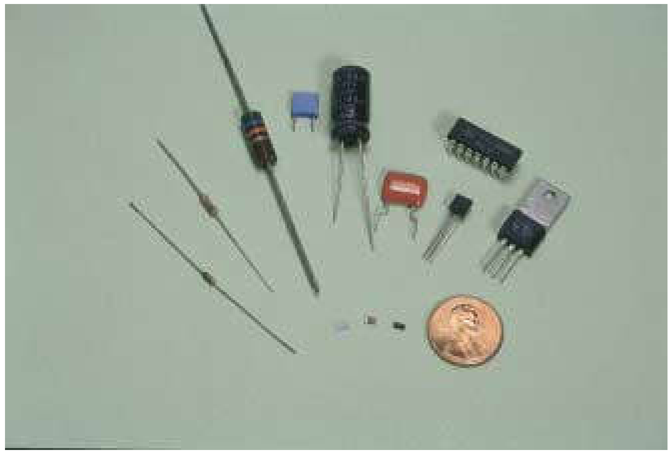


Figure 1.2: Some typical electronic components.

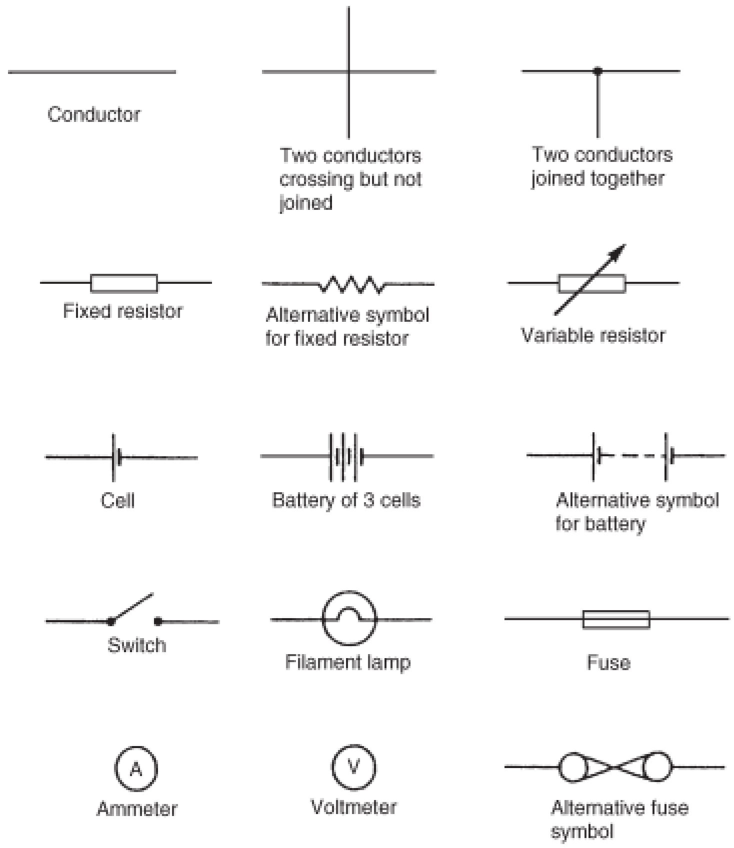
1.2 Units associated with basic electrical quantities

SI units

The system of units used in engineering and science is the Systeme Internationale d'Unites (International system of units), usually abbreviated to ´SI units, It is based on the metric system.

Quantity	Quantity Symbol	Unit	Unit symbol
Length	l	metre	m
Mass	m	kilogram	kg
Time	t	second	s
Velocity	v	metres per second	m/s or $m\ s^{-1}$
Acceleration	a	metres per second squared	m/s^2 or $m\ s^{-2}$
Force	F	newton	N
Electrical charge or quantity	Q	coulomb	C
Electric current	I	ampere	A
Resistance	R	ohm	Ω
Conductance	G	siemen	S
Electromotive force	E	volt	V
Potential difference	V	volt	V
Work	W	joule	J
Energy	E (or W)	joule	J
Power	P	watt	W

1.3 Standard symbols for electrical components



1.4 Potential difference and resistance

For a continuous current to flow between two points in a circuit a potential difference (p.d.) or voltage, V, is required between them; a complete conducting path is necessary to and from the source of electrical energy. The unit of p.d. is the volt, V.

Current flow, by convention, is considered as flowing from the positive terminal of the cell, around the circuit to the negative terminal.

1.5 Basic electrical measuring instruments

An ammeter is an instrument used to measure current and must be connected in series with the circuit.

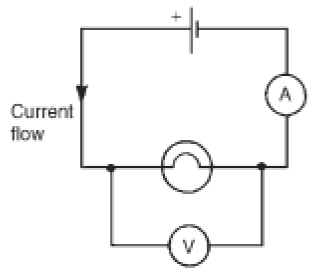


Figure 1.3

Figure 1.3 shows an ammeter connected in series with the lamp to measure the current flowing through it.

A **voltmeter** is an instrument used to measure potential difference and must be connected in parallel with the part of the circuit whose potential difference is required. To avoid a significant current flowing through it a voltmeter must have a very high resistance.

An **ohmmeter** is an instrument for measuring resistance.
A multimeter, or universal instrument, may be used to measure voltage, current and resistance.

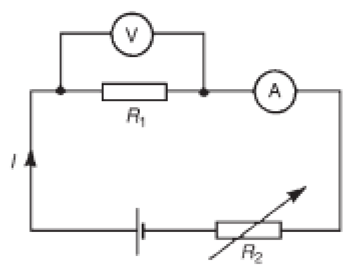


Figure 1.4

1.6 Ohm's law

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 L.

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

Where ρ is known as the resistivity of the material in ohmmeters. Good conductors, such as copper and aluminum, have low resistivities, while insulators, such as mica and paper, have high resistivities

Ohm's law states that the current I flowing in a circuit is directly proportional to the applied voltage V and inversely proportional to the resistance R, provided the temperature remains constant. Thus,

$$I = \frac{V}{R} \; or \; V = IR \; or \; R = \frac{V}{I}$$

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

Example 1.1

The current flowing through a resistor is 0.8 A when a potential difference of 20 V is applied. Determine the value of the resistance.

From Ohm's law, resistance R

$$\frac{V}{I} = \frac{20}{0.8} = \frac{200}{8} = 25\Omega$$

Currents, voltages and resistances can often be very large or very small. Thus, multiples and sub-multiples of units are often used;

Prefix	*Name*	*Meaning*	*Example*
M	mega	multiply by 1 000 000 (i.e., $\times 10^6$)	2 MΩ = 2 000 000 ohms
k	kilo	multiply by 1000 (i.e., $\times 10^3$)	10 kV = 10 000 volts
m	milli	divide by 1000 (i.e., $\times 10^{-3}$)	$25 \text{ mA} = \frac{25}{1000} \text{ A} = 0.025$ amperes
μ	micro	divide by 1 000 000 (i.e., $\times 10^{-6}$)	$50 \text{ μV} = \frac{50}{1\,000\,000} \text{ V} = 0.000\,05$ volts

Example 1.2.

Determine the p.d., which must be applied to a 2 k resistor in order that a current of 10 mA may flow.

$$Resistance\ R = 2k\Omega = 2 \times 10^3 = 2000\Omega$$

$$Current\ I = 10mA = 10 \times 10^{-3}A\ or\ \frac{10}{10^3}\ or\ \frac{10}{1000}A = 0.01A$$

$$From\ Ohm's law, potential\ difference, V = IR = (0.01)(2000) = 20V$$

1.7 Conductors and insulators

A conductor is a material having a low resistance, which allows electric current to flow in it. All metals are conductors and some examples include copper, aluminium, brass, platinum, silver, gold and carbon.
An insulator is a material having a high resistance, which does not allow electric current to flow in it. Some examples of insulators include plastic, rubber, glass, porcelain, air, paper, cork, mica, ceramics and certain oils.

1.8 Electrical power and energy

The product of potential difference V and current I gives power, P in an electrical circuit. The unit of power is the watt, W. Hence;

$$P = V \times I\ watts$$

$$From\ Ohm's\ law, V\ =\ IR$$

Substituting for V in equation above gives,

$$P = (IR) \times I$$

$$P = I^2R\ watts$$

Also, from Ohm's law,

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

Substituting for I in equation above gives,

$$P = V \times \frac{V}{R}$$

$$P = \frac{V^2}{R}\ watts$$

There are thus three possible formulae, which may be used for calculating power.

Exercise:

A 100 W electric light bulb is connected to a 250 V supply. Determine (a) the current flowing in the bulb, and (b) the resistance of the bulb.

1. 9 Electrical energy

Electrical energy = power × time

If the power is measured in watts and the time in seconds then the unit of energy is watt-seconds or joules.

If the power is measured in kilowatts and the time in hours then the unit of energy is kilowatt-hours, often called the 'unit of electricity'. The 'electricity meter' in the home records the number of kilowatt-hours used and is thus an energy meter.

Example 1.3

A 12 V battery is connected across a load having a resistance of 40Ω. Determine the current flowing in the load, the power consumed and the energy dissipated in 2 minutes.

Current;

$$I = \frac{V}{R} = \frac{12}{40} = 0.3A$$

Power consumed;

$$P = VI = (12)(0.3) = 3.6W$$

$$Energy\ dissipated = Power\ \times Time = (3.6\ W)(2 \times 60s) = 432J(\ Since\ 1J = 1\ Ws)$$

1.10. Kirchhoff's laws

(a) Current Law. At any junction in an electric circuit, the total current flowing towards that junction is equal to the total current flowing away from the junction, i.e.

$$\Sigma I = 0$$

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

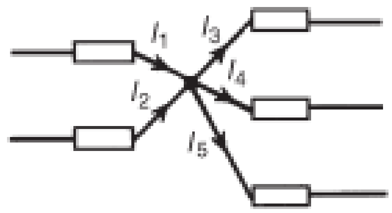


Figure 1.5

(b)Voltage Law. In any closed loop in a network, the algebraic sum of the voltage drops (i.e. products of current and resistance) taken around the loop is equal to the resultant e.m.f. acting in that loop.

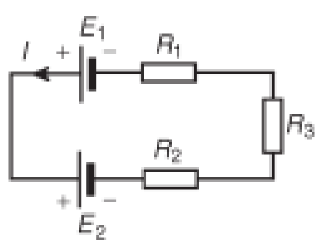


Figure 1.6