Lecture One

Basic concepts

1.1 Introduction

An **electrical circuit** is a **closed-loop** system that allows the continuous flow of electric current through interconnected components to perform a specific function. It consists of elements such as **voltage sources, resistors, capacitors, inductors, and switches** that control the movement of electrons.

1.2 INTERNATIONAL SYSTEM OF UNITS

The *International System of Units* ***(SI)*** is the international measurement language. **SI** has nine base units, which are shown in Table 1-1 along with the unit symbols. Units of all other physical quantities are derived from these.

Table 1

Physical Quantity	Unit	Symbol
length	meter	m
mass	kilogram	kg
time	second	S
current	ampere	A
temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd
plane angle	radian	rad
solid angle	steradian	sr

The *International System of Units* **has** symbols as shown in Table 2, which also shows the corresponding powers of 10.

Table 2

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

1.2 Electric charge

Understanding the fundamental concepts of current and voltage requires a degree of familiarity with the atom and its structure. Scientists have discovered two kinds of electric charge: *positive* and *negative*. Positive charge is carried by subatomic particles called ***protons***, and negative charge by subatomic particles called electrons. The unit of measurement charge is Coulomb (C).

The charge of an electron is **-1.602×10^{-19}** C and that of a proton is **1.602×10^{-19}** C.

The mass of the electron is **9.11×10^{-28}** g, and that of the proton and neutron is **1.672×10^{-24} g.**

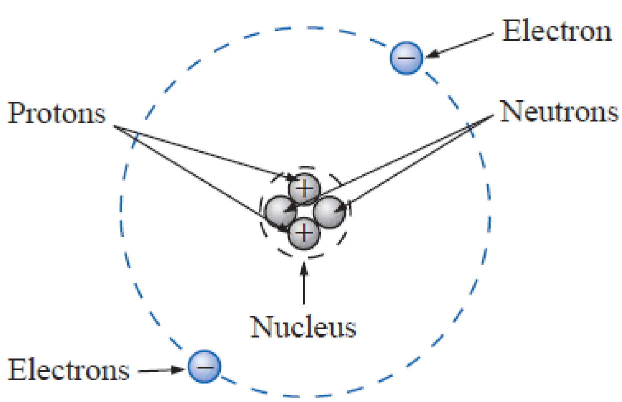


Fig. 1 Helium atom

Example (1): Find the charge in coulombs of ***(a)*** 5.31 x 10^{20} electrons, and *(b)* 2.9 x 10^{22} protons.

Solution ***(a)*** Since the charge of an electron is - **1.602** x **10^{-19}** C, the total charge is

5.31 x 10^{20} ×- 1.602 x 10^{-19} = -85.1 *C*

(b) Similarly, the total charge is

2.9 x 10^{22} × 1.602 x 10^{-19} = 4.65 kC

1.3 Electric current

Electric current results from the movement of electric charge. The unit of current is ampere with unit symbol A**.** The quantity symbol is **I** for a constant current and ***i*** for a time-varying current. If a steady flow of 1 C of charge passes a given point in a conductor in 1 s, the resulting current is **1 A.**

$$I\ (ampere) = \frac{Q(Coulombs)}{S\ (Seconds)} \qquad (1.1)$$

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

$$i\ = \frac{dq}{dt} \qquad (1.2)$$

The charge transferred between time t_0 and t is obtained by integrating both sides of Eq. (1.2). We obtain

$$q = \int_{t0}^{t} i\ dt \qquad (1.3)$$

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

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

Example (3): The charge flowing through the imaginary surface of Fig. 2 is 0.16 C every 64 *ms*. Determine the current in amperes

Solution

$$I = \frac{Q}{t} = \frac{0.16\ C}{64\times10^{-3}s} = \frac{160\times10^{-3}}{64\times10^{-3}s} = 2.5 \text{ A}$$

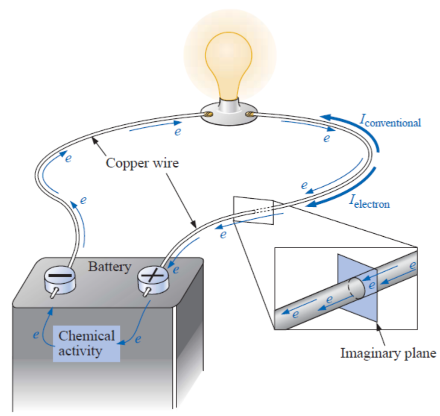


Figure 2

Example (4): Determine the time required for 4 × 10^{16} electrons to pass through the imaginary surface of Fig. 2 if the current is 5 mA.

Solution

$$t = \frac{Q}{I}$$

The total charge = the total number of electrons × the charge of one electron

$$Q = (4\times10^{16})\times(1.602\times10^{-19}) = 6.408\times10^{-3} = 6.41\ mC$$

$$t = \frac{Q}{I} = \frac{6.41\times10^{-3}}{5\times10^{-3}} = 1.28\ s$$

Example (5): *Assuming a steady current flow through a switch, find the time required for* ***(a)*** *20* ***C*** *to flow if the current is 15 mA, and* ***(b) 12 μC*** *to flow if the current is 30 pA.*

Solution

$$t = \frac{Q}{I} = \frac{20}{15\times10^{-3}} = 1.33\times10^{3}\text{ s} = 22.2 \text{ min}$$

$$t = \frac{Q}{I} = \frac{12\times10^{-6}}{30\times10^{-12}} = 4\times10^{5}\text{ s} = 111\text{h}$$

1.4 VOLTAGE

To move the electron in a conductor in a particular direction, some work or energy is required. In general, the work required in joules is the product of the force in newtons and the distance moved in meters:

$$W(\text{joules}) = F(\text{newtons}) \times s\ (\text{meters})$$

The *voltage difference* (also called the *potential difference)* between two points is the work in **joules** required to move 1 ***C*** of charge from one point to the other.

$$v\ (volls) = \frac{W(joules)}{Q(coulombs)} = \frac{dw}{dq} \qquad (1.4)$$

Pictorially, if one joule of energy (1 J) is required to move the one coulomb (1 C) of charge of Fig. 3 from position *x* to position *y*, the potential difference or voltage between the two points is one volt (1 V).

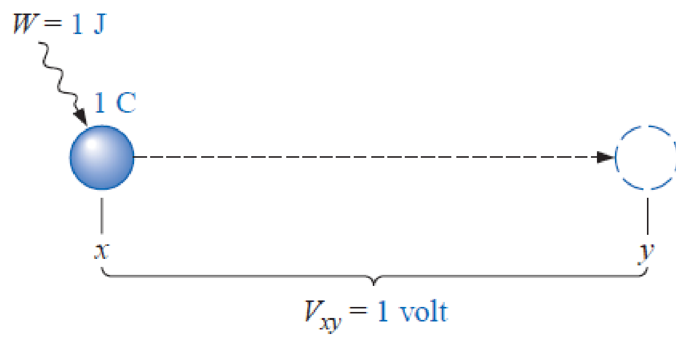


Figure 3

A constant voltage is called a ***DC*** *voltage*, and a voltage that varies sinusoidally with time **is** called an ***AC*** *voltage.*

A **voltage source** (battery) provides a constant **DC voltage** regardless of current flow. The **battery symbol** consists of a long line (positive terminal) and a short line (negative terminal) as shown in Figure 4.

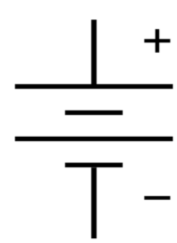


Figure 4

Example (6): Find the potential difference between two points in an electrical system if 60 J of energy is expended by a charge of 20 C between these two points.

Solution:

$$V = \frac{W}{Q} = \frac{60}{20} = 3V$$

Example (7): Determine the energy expended moving a charge of 50 µC through a potential difference of 6 V.

Solution:

$$W = VQ = 50 \times 10^{-6} \times 6\ \text{V} = 300 \times 10^{-6}\ \text{J} = 300\ \mu\text{J}$$

1.5 POWER

The power is the rate at which electrical energy is transferred or converted in a circuit. It is measured in **watts (W)** and represents how much energy is supplied or consumed per unit of time.

$$P = \frac{dw}{dt} \qquad (1.5)$$

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

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

From equ. 1.2 and 1.4 $\quad P = vi \qquad (1.6)$

For practical purposes, we need to know how much *power* an electric device can handle. We all know from experience that a 100-watt bulb gives more light than a 60-watt bulb. We also know that when we pay our bills to the electric utility companies, we are paying for the electric *energy* consumed over a certain time.

The power output rating of motors is usually expressed in a power unit called the ***horsepower*** (hp). The relation between horsepower and watts is I hp = 745.7 **W.**

Example (8): Find the average input power to a radio that consumes 3600 J in 2 min.

Solution

$$P = \frac{w}{t} = \frac{3600}{2\times 60s} = \frac{3600}{120\ s} = 30\text{W}$$

Example (9): How much power does a stove element absorb if it draws 10 A when connected to a 1 15-V line?

Solution

P = VI = 115 x 10 = 1.l5kW

1.6 ENERGY

Electric energy used or produced is the product of the electric power input or output and the time over which this input or output occurs:

$$W(\text{joules}) = P(\text{watts}) \times t(\text{seconds}) \tag{1.7}$$

Example (10): How many joules does a 60-W light bulb consume in 1 h?

Solution: $W = P\,t = 60 \times 1(60min \times 60sec) = 216000 = 216\ kJ$

Example (11): How long does a 100-W light bulb take to consume 13**kJ?**

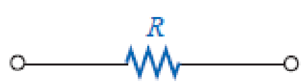
Solution: $t = \frac{w}{p} = \frac{13\times10^3}{100} = 130\ s$

RESISTANCE

OHM'S LAW

The flow of charge through any material encounters an opposing force similar in many respects to mechanical friction. This opposition is 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*, which is called the **resistance** of the material. The unit of measurement of resistance is the **ohm,** for which the symbol is Ω.

$$R\ (ohms) = \frac{V\ (volts)}{I\ (Amperes)}$$



The resistance of any material with a uniform cross-sectional area is determined by four factors: 1- *Material* 2- *Length* 3- *Cross-sectional area* 4- *Temperature*

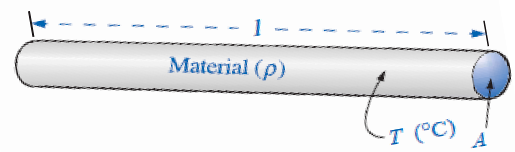
The inverse of resistance is called ***conductance*** and its quantity symbol is G.

$$I = V \times G$$

RESISTIVITY

The resistance of a conductor of uniform cross-section is directly proportional to the length of the conductor and inversely proportional to the cross-sectional area.

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



Where ***l*** is the conductor length in meters, and **A** is the cross-sectional area (in square meters). The constant of proportionality **ρ** (the Greek lowercase letter **rho**) is the quantity symbol for resistivity, a factor that depends on the type of material.

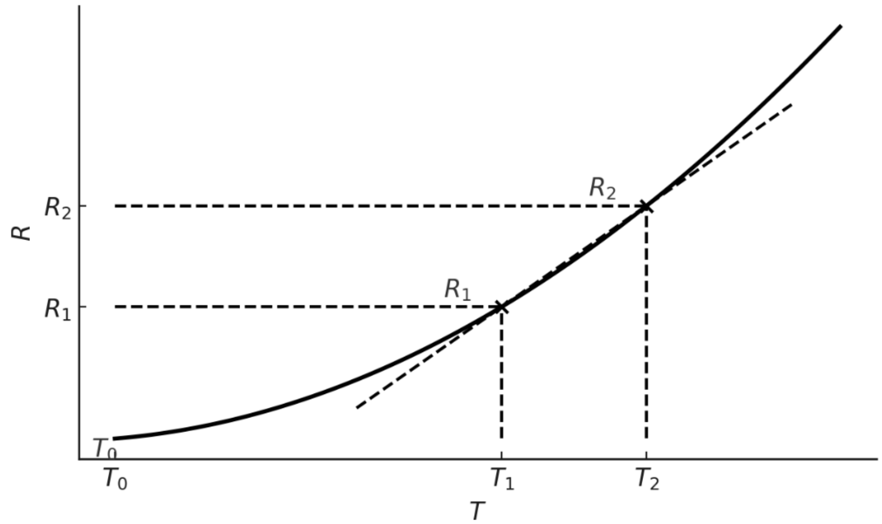
Table 1

No.	Material	Resistivity (Ω.m at 20 C)	Usage
1	Silver	1.64×10^{-8}	Conductor
2	Copper, annealed	1.72×10^{-8}	Conductor
3	Aluminum	2.83×10^{-8}	Conductor
4	Iron	12.3×10^{-8}	Conductor
5	Carbon	4×10^{-5}	Semiconductor
6	Germanium	47×10^{-2}	Semiconductor
7	Silicon	6.4×10^{2}	Semiconductor
8	Paper	10^{10}	Insulator
9	Glass	10^{12}	Insulator
10	Teflon	3×10^{12}	Insulator

TEMPERATURE EFFECTS

The resistances of most good conducting materials increase almost linearly with temperature over the range of normal operating temperatures, as shown by the solid line in Fig. 2-1. However, some materials, and common semiconductors, in particular, have resistances that decrease with temperature increases.

$$R_2 = \frac{T_2 - T_0}{T_1 - T_0} R1$$



RESISTOR POWER ABSORPTION

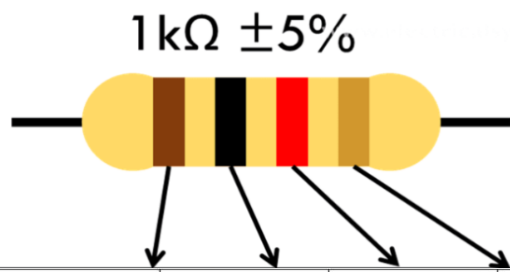
$$P = V \times I$$

gives the power absorbed by a linear resistor in terms

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

COLOR CODE

The most popular resistance color code has nominal resistance values and tolerances indicated by the colors of either three or four bands around the resistor casing, as shown in the figure below



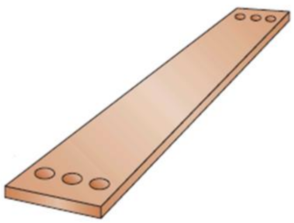
Color	Color	1st Band	2nd Band	3rd Band Multiplier	4th Band Tolerance
Black		0	0	x1Ω	
Brown		1	1	x10Ω	±1%
Red		2	2	x100Ω	±2%
Orange		3	3	x1kΩ	
Yellow		4	4	x10kΩ	
Green		5	5	x100kΩ	±0.5%
Blue		6	6	x1MΩ	±0.25%
Violet		7	7	x10MΩ	±0.10%
Grey		8	8	x100MΩ	±0.05%
White		9	9	x1GΩ	
Gold				x0.1Ω	±5%
Silver				x0.01Ω	±10%

The colors of the first and second bands represent the first two digits of the nominal resistance value. Since the first digit is never zero, the first band can never be black. The third band, unless it is silver or gold, indicates the number of zeros following the first two digits. If the third band is silver, it represents a multiplier of **0.01**, while a gold third band represents a multiplier of **0.1**. The fourth band specifies the tolerance: **gold** means a **5% tolerance**, **silver** means **10%**, and if the band is missing, the tolerance is **20%**

Examples

1- Find the resistance at 20°C of an annealed copper bus bar 3 m in length and 0.5 cm by 3 cm in rectangular cross-section.

Solution:



The cross-sectional area of the bar is $(0.5 \times 10^{-2})\ (3 \times 10^{-2}) = 1.5 \times 10^{-4} m^2$

Table **2-1** has the resistivity of annealed copper: 1.72×10^{-8} ***Ω*.m** at **20** C.

So, $R = \rho \frac{l}{A} = 1.72 \times 10^{-8} \times \frac{3}{1.5\times10^{-4}} = 344\mu\Omega$

2- **A** wire 50 m in length and 2 mm^2 in cross-section has a resistance of 0.56***Ω.*** A 100m length of wire of the same material has a resistance of 2 Ω at the same temperature. Find the **diameter** of this wire.

From the data given for the first wire, the resistivity of the conducting material is $\rho = R\frac{A}{l} = 0.56 \times \frac{2\times10^{-6}}{50} = 2.24\times10^{-8}\Omega.m$

$$A = \rho\frac{l}{R} = 2.24\times10^{-8}\times\frac{100}{2} = 112\times10^{-8}\ m^2$$

$A = \pi r^2 = r = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{112\times10^{-8}}{\pi}} = 5.97\times10^{-4}$

$d = r \times 2 = 5.97\times10^{-4} \times 2 = 1.19\times10^{-3} = 1.19mm$