Al-Mustaqbal University

College of Engineering & Technology

Electrical Engineering Fundamentals

Asst. Lec.   ALI IMAD

Lectur (1)

Electrical Engineering Fundamentals

System of Units

1) The English system.

2) The metric system which is subdivided into two interrelated standards:

- The MKS system uses Meters, Kilograms, and Seconds.
- The CGS system uses Centimeters, Grams, and Seconds.

3) The international metric system of units (SI).

The international system of units, commonly called SI, is used in electricity. The base units of SI are listed in Table (1).

1.1 Basic Concepts and Basic Laws

1.1.1 System of Units

Table (1). The international system of units SI

Quantity	Symbol	Basic SI Unit	Abbreviation
length	L; l	meter	m
mass	M; m	kilogram	kg
time	T; t	second	s
electric current	I; i	ampere	A
electric charge	Q; q	coulomb	C
electric potential	V; v	volt	V
resistance	R	ohm	Ω
inductance	L	henry	H
capacitance	C	farad	F
Frequency	f	hertz	Hz
Force	F	newton	N
energy, work	W	joule	J
power	P; p	watt	W
magnetic		weber	Wb
magnetic flux density	B	tesla	T

- The SI Prefixes can be illustrated as table below :

Prefiks	Symbol	Multiplying factor
yotta	Y	1 000 000 000 000 000 000 000 000 = 10^{24}
zetta	Z	1 000 000 000 000 000 000 000 = 10^{21}
exa	E	1 000 000 000 000 000 000 = 10^{18}
peta	P	1 000 000 000 000 000 = 10^{15}
tera	T	1 000 000 000 000 = 10^{12}
giga	G	1 000 000 000 = 10^{9}
mega	M	1 000 000 = 10^{6}
kilo	k	1 000 = 10^{3}
hecto	h	100 = 10^{2}
deka	da	10 = 10^{1}
deci	d	0,1 = 10^{-1}
centi	c	0,01 = 10^{-2}
milli	m	0,001 = 10^{-3}
mikro	μ	0,000 001 = 10^{-6}
nano	n	0,000 000 001 = 10^{-9}
piko	p	0,000 000 000 001 = 10^{-12}
femto	f	0,000 000 000 000 001 = 10^{-15}
atto	a	0,000 000 000 000 000 001 = 10^{-18}
zepto	z	0,000 000 000 000 000 000 001 = 10^{-21}
yocto	y	0,000 000 000 000 000 000 000 001 = 10^{-24}

For example : -

10 MHZ ➔ 10×10^{6} HZ

2 mA = 2×10^{-3} = 0.002A

5 μS = 5×10^{-6} S

1,000,000 ohms 1 10^{6} ohms ➔ 1 meg-ohm 1 M

- **ATOMS AND THEIR STRUCTURE**

- The orbiting electron carries a negative charge equal in magnitude to the positive charge of the proton.
- The atomic structure of any stable atom has an equal number of electrons and protons.

As shown in figure (1) below:

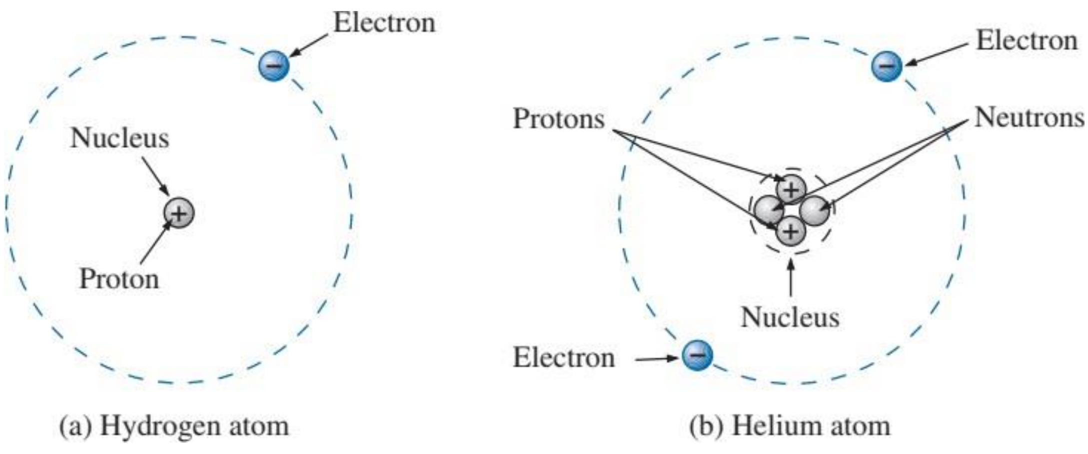


Fig.1. Hydrogen and helium atoms.

Copper is the most commonly used metal in the electrical/electronics industry. It has 29 electrons in orbits around the nucleus, with the 29th electron appearing all by itself in the 4th shell. Note that the number of electrons in each shell and subshell is as defined in Figure (2) below.

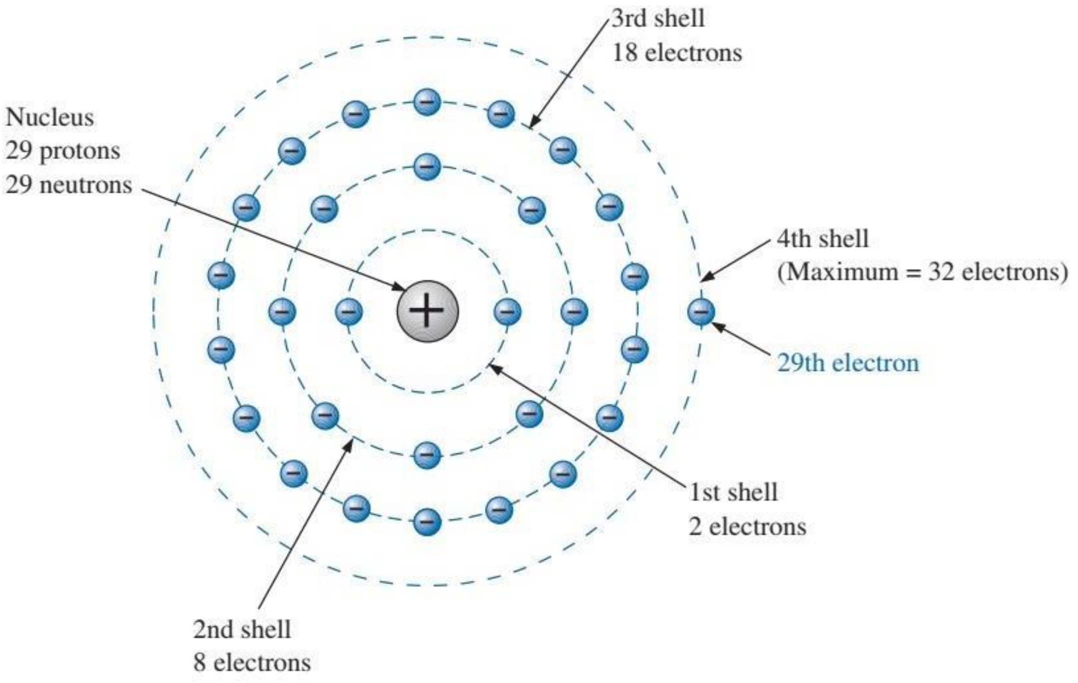


Fig. (2). The atomic structure of copper

Coulomb's law is the force of attraction between the nucleus and the electron of atomic.

As it visible in equation below:

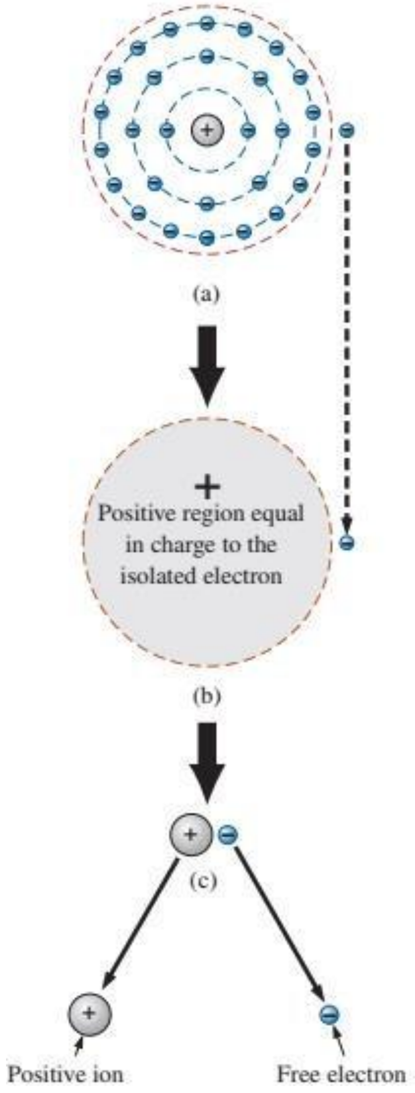
$$F = k\frac{Q_1 Q_2}{r^2} \quad \text{(newtons, N)}$$

, -------(1)

where ***F*** is in newton's (N), *k* a constant ($9.0 \times 10^9\ N \cdot m^2/C^2$), Q_1 and Q_2 are the charges in coulombs, and *r* is the distance between the two charges in meters.

Other metals, that appear the same properties as copper, but to a different degree, are silver, gold, and aluminum, and some rarer metals such as tungsten. Additional comments on the characteristics of conductors are can be seen in several references.

Fig. 3(b) Defining the positive ion.



- One coulomb of charge is the total charge associated with 6.242×10^{18} electrons.
- if a total of 1 joule (J) of energy is used to move the negative charge of 1 coulomb (C), there is a difference of 1 volt (V) between the two points

- every source of voltage is established by simply creating a separation of positive and negative charges.
- One coulomb of charge is the total charge associated with 6.242×10^{18} electrons.

  1 coulomb = 6.242×10^{18} electrons
- if a total of 1 joule (J) of energy is used to move the negative charge of 1 coulomb (C), there is a difference of 1 volt (V) between the two points.

The defining equation is:

$$V = \frac{W}{Q} \qquad \text{------(2)}$$

Where:

V	volts (V)
W	joules (J)
Q	coulombs (C)

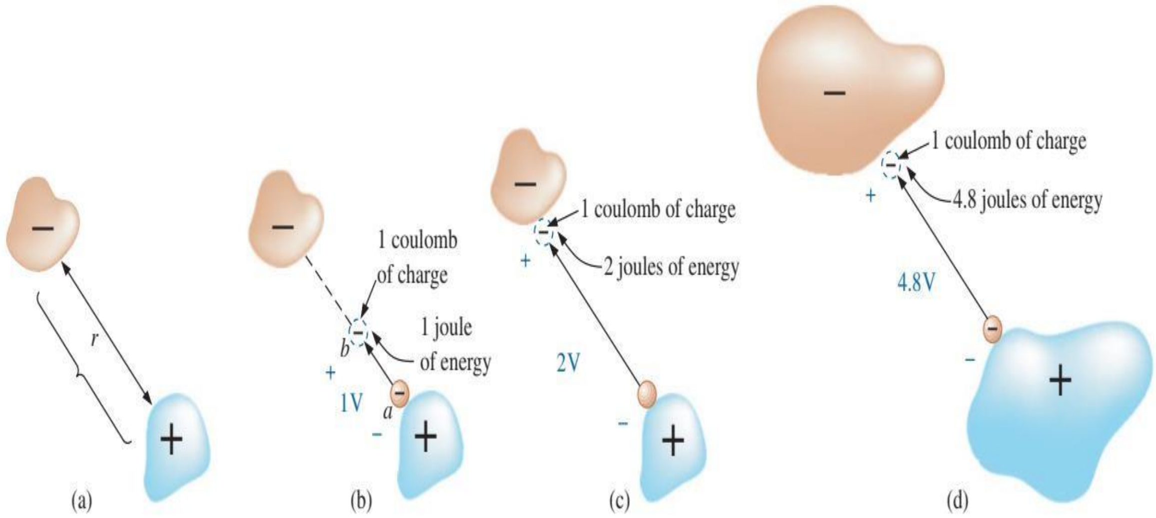


Fig. (4) Defining the voltage between two points.

1.1.2 Charge and Electric Current

Definitions & Terminologies

1- **Electric charge (Q)** : is a physical prosperity of electrons and protons in the atoms that gives rise to force between atoms. The charge is measured in coulomb [C].

The ***coulomb*** is defined as the quantity of electricity which flows in an electric circuit when a current of one ampere flow for one second. The charge of proton is arbitrarily chosen as positive and has the value of (1.602×10^{-19} C), while the charge of an electron is chosen as negative with a value (-1.602×10^{-19} C).

$Q = I \times t$-- (3)

Where, Q ➔ electric charge ➔ coulomb.
I ➔ electric current ➔ ampere.
T➔ time ➔ second.

The total charge (Q) transferred during the time from (t_1) to (t_2) can be calculated as,

$$q = \int_{t1}^{t2} i \, . dt \qquad \text{---------- (4)}$$

Example 1: If a current of (10A) flows for (4 minutes). Find the quantity of electricity transferred?	
Solution: Quantity of electricity is (Q) = $I \times t$ I=10A, t = 4 × 60 S = 240 second [S] Hence Q = (10A)×(240S) = 2400 Coulombs	

2- **Electric Current** : is the rate of change of charge , measured in amperes (A). An ampere is defined as the flow of charge at the rate of one coulomb per second (1A = 1C/S).

The current (I) is defined mathematically as:

$$I = \frac{Q}{t} \qquad \text{or} \qquad i(t) = \frac{dq}{dt} \qquad \text{---------- (5)}$$

Observed: the traditional direction of current flow in reverse to the direction of electrons flow as shown in Figure (5=6).

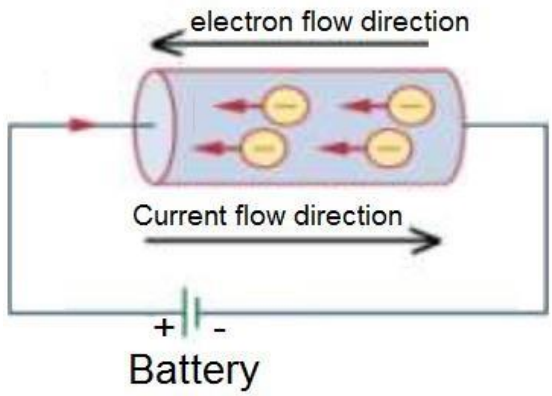


Fig. (6) direction

3- **Direct current (dc)**: is the current that remains constant in direction & magnitude (constant with time) as shown in Figure (7)(a).The symbol (I) is usually used to represent such a constant current. The reason for such unidirectional current is that the voltage source maintain the same polarity for the output voltage. The voltage supplied by these sources is called direct current voltage or dc voltage.

Fig.(7) Direct current (dc), constant with time.

4- **Alternating current (ac)**: is the current that reverse or alternates in polarity with time such sinusoidal current as shown in Figure (8) ac usually represent by a symbol ***i*** or ***i* (t)**.

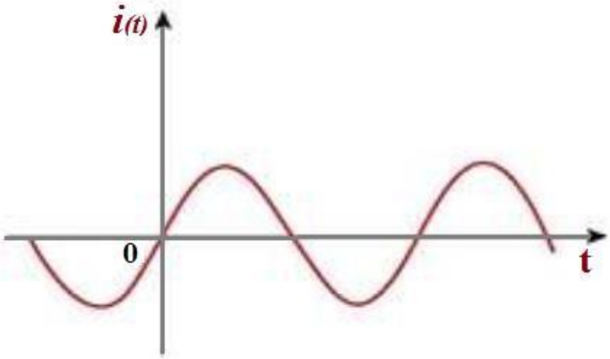


Fig. (8) Alternating current (ac)

5- **Voltage or Potential Difference (PD):-** potential difference (V_{AB}) between two points A & B, is the amount of energy required (or work done) to move a unit positive charge from point A to point B. If this energy is positive, then (V_{AB}) is positive & point A is higher potential with respect to point B.

$V_{AB} = V_A - V_B$ ➔ and ➔ $V_A > V_B$ ----------------------------(6)

- using the unit of volt [V].
- One joule (1J) used to move a charge of one coulomb (1 coulomb) between two points.

$V = \frac{w}{q}$ or $v = \frac{dw}{dq}$ - --------(7)

6- **Power (P):-** it is defined as the rate of work done, or it is the rate of energy with respect to time.

$$p = \frac{w}{t}$$ - --------(10)

$$\text{watt} = \frac{\text{joule}}{\text{second}}$$

from equation (7), ➔ $w = q \times V$

$$p = \frac{q \times V}{t}$$

from equation (5), ➔ $I = \frac{Q}{t}$,

⇨ Therefore,➔ $p = I \times V$

Note :

⇨ $1 \text{ Watt} = 1 \frac{joule}{Second}$

⇨ 1 horse power (h.p.) = 746 watt.

⇨ Negative power means the element gives energy to network (such as sources).

⇨ Positive power means the element absorbs energy from network (such as resistors)

7- **Energy (W) :** It is quantity represents the product of power (P) & the period (t).

$w = p \times t$---(11)

($\text{watt} \times second$) or (joule)

from equation (2), ➔ $V = \frac{W}{Q}$

$$W = Q \times V$$

From equation (2),

$$q = \int_{t1}^{t2} i \, . dt$$ ----------(2)

$$W = \{\int_{t1}^{t2} i \,.\, dt\} \times V$$

$$W = \{\int_{t1}^{t2} (i \,.\, V) dt\}$$

$$W = \int_{t1}^{t2} P.\,dt \qquad \text{--------- (12)}$$

$$Energy = \frac{p \times t}{1000} \qquad \text{--------- (13)}$$

$$Energy[kW.\,h] = \frac{p[w] \times t[s]}{1000}$$

Example 2 : How much energy does a 100w electric lamp consumes in 2 hours?

Solution:

$w = p \times t$

$w = 100W \times 2h = 200 \text{ w.h}$

Or

$2h = 2 \times (60 \times 60)s = 7200S$

$w = 100\ W \times 7200\ S = 720{,}000 = 720 \text{ kW.h} = 720 \text{ kJ}$

Example 3: Determine the energy expended in moving a charge of 50 μC through a potential difference of 6V?

Solution:

W =Q.V = $(50 \times 10^{-6}) \times 6 = 300 \times 10^{-6}$ J = 300 μ J

Example 4: A voltage source of (6V), supplies a current of 4A for 20 minutes. How much energy is supplied in this time?

Solution:

$w = p \times t = (V.\,I)t$

$w = (6 \times 4) \times (20 \times 60) = 28800[w.\,s] = 28.8\text{kJ}$

HW: A voltage source of (3.853V), supplies a current for a resistance having a length (l=75 meters), Area $A = 2.09 \times 10^{-6}\ m^2$, and resistivity ($\rho = 1.723 \times 10^{-8}\ \ \Omega\,.\,m$) for 20 minutes. How much energy is supplied in this time ?

Example 6: several of homes employ copper wire having a diameter of 1.63 mm to provide electrical distribution to outlets and light sockets. Determine the resistance of 75 meters of a solid copper wire having the above diameter?

Solution:

Calculate the cross-sectional area of the wire:

$$A = \left(\frac{\pi d^2}{4}\right) = \frac{\pi\,(1.63\times10^{-3})}{4} = 2.09 \times 10^{-6}\ \ m^2$$

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

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

8- **Circuit Elements** :- can be divided into two types:

(i) Active Elements: the elements which are able to supply energy to the network such as voltage and current sources which includes generators, batteries and operational amplifier.

(ii) Passive Elements: the elements which take energy from sources and either convert it to another form, or store it as electric or magnetic field, such as resistors, inductors & capacitors.

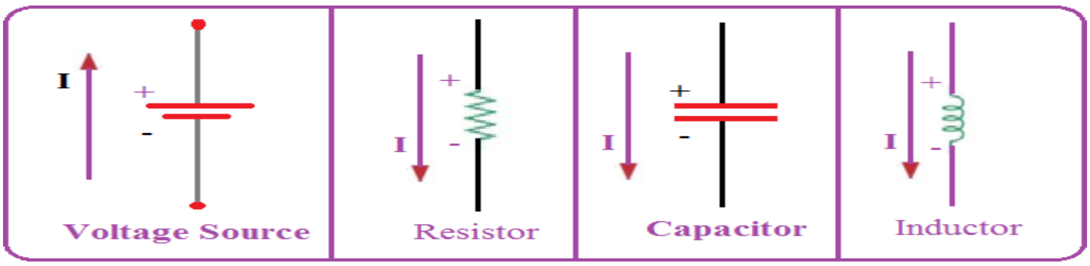


Fig. (9). Circuit Elements

Sources: sources (voltage or current sources) can be divided into two types,

(i) Independent Sources.
(ii) Dependent Sources.

i) **Independent Source**, is an active element that provides a specified voltage or current that is completely independent of other circuit elements.

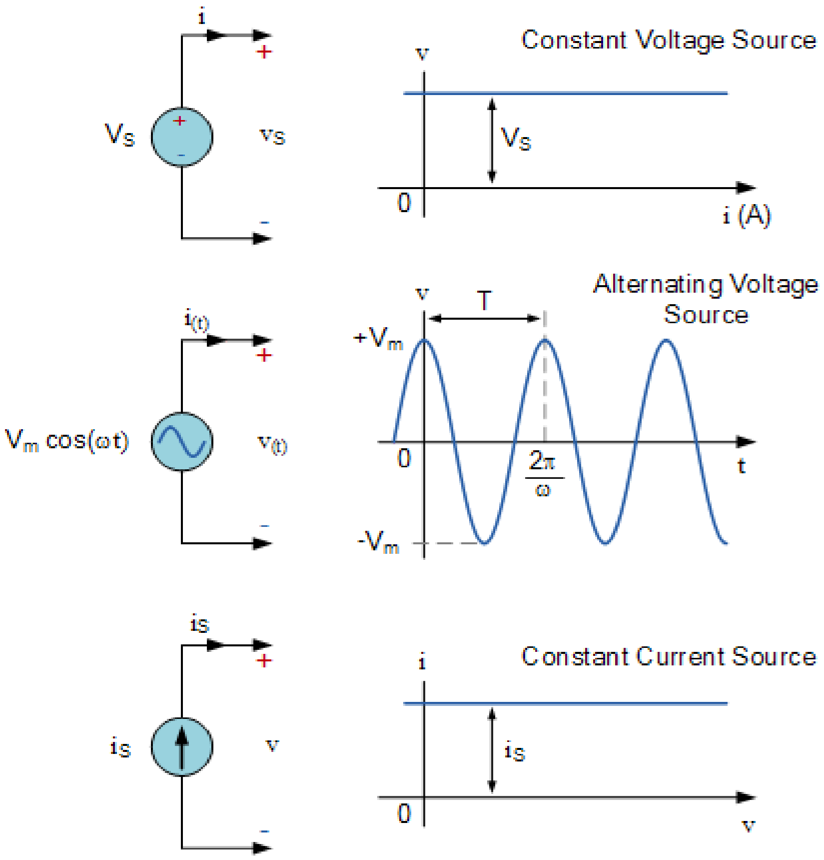


Fig.(10). Representation of sources.

ii) Dependent (or controlled) Source, an active element in which the source quantity is controlled by another voltage or current. It can be classified as:

1) A voltage-controlled voltage source (VCVS).
2) A current-controlled voltage source (CCVS).
3) A voltage-controlled current source (VCCS).
4) A current-controlled current source (CCCS).

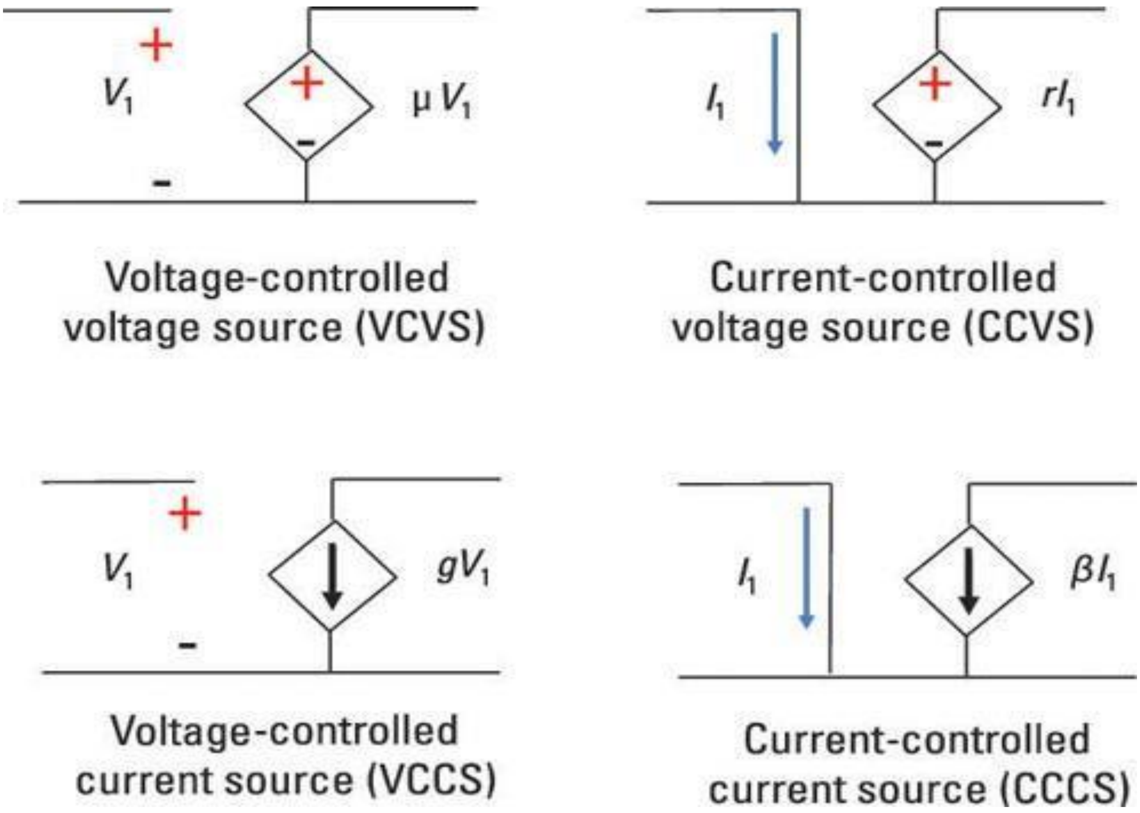


Fig.(9). Representation of controlled sources

Resistance

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

The resistance of any material with a uniform cross-sectional area is determined by the following four factors:

1. Material (it depends on the nature of the material).
2. Length (it varies directly as it's length).
3. Cross-sectional area (it varies inversely as the cross-section of the conductor).
4. Temperature (it depends on the temperature of the conductor

At a fixed temperature of 20°C (room temperature), the resistance is related to the other three factors by

$$R \ \alpha \ \frac{l}{A} \qquad (\Omega)$$

$$R = \rho \frac{l}{A} \qquad \text{---------(14)}$$

Where ρ is a characteristic of the material called the specific resistance or ***resistivity***, (***l***) is the length of the material, and (**A**) is the cross sectional area of the material.).

Table(3). Resistivity of Materials

Material	Resistivity ($\Omega \cdot m$)
Silver	1.59×10^{-8}
Copper	1.7×10^{-8}
Gold	2.44×10^{-8}
Aluminum	2.82×10^{-8}
Tungsten	5.6×10^{-8}
Iron	10.0×10^{-8}
Platinum	11×10^{-8}
Lead	22×10^{-8}
Nichrome[a]	150×10^{-8}
Carbon	3.5×10^{-5}
Germanium	0.46
Silicon	640
Glass	10^{10}–10^{14}
Hard rubber	$\approx 10^{13}$
Sulfur	10^{15}
Quartz (fused)	75×10^{16}

Conductance: is an expression of electric current flows through a materials. In equations, conductance is symbolized by the letter G. The standard unit of conductance is the siemens (abbreviated S), formerly known as the mho.

Conductance (G) is inverse of Resistance (R) as show in equation below:

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

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

$$G = \gamma \frac{A}{l} \qquad \text{---------- (15)}$$

Where: $\gamma = \frac{1}{\rho}$ called conductivity of material in [s/m]. A resistance of [1MΩ] is equivalent to a conductance of [10^{-6} S], and resistance of [10Ω], is equivalent to a conductance of [10^{-1} S]. The larger the conductance, therefore, the less the resistance and the greater the conductivity.

Example 5: What is the relative increase or decrease in conductivity of a conductor if the area is reduced by 30% and the length is increased by 40%? The resistivity is fixed.

Solution:

From equation (14);

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

if the area is reduced by 30% ; therefore, ➔ $A_2=A_1- 0.3A_1$ ➔ $A_2=0.7A_1$

and

the length is increased by 40% ; therefore , ➔ $l_2=l_1+0.4l_1$ ➔ $l_2=1.4l_1$

For case one :

$$G_1 = \frac{A_1}{\rho_1 l_1} \qquad \text{---------- (1)}$$

For case two:

$$G_2 = \frac{A_2}{\rho_2 l_2} \qquad \text{---------- (1)}$$

Since $\rho_1 = \rho_2$

Substitute equation (1) in (2);

$$G_2 = \frac{0.7A_1}{\rho_1 1.4 l_1}$$

$$G_2 = (\frac{0.7}{1.4}) \frac{A_1}{\rho_1 l_1}$$

$$G_2 = 0.5G_1$$

Example 6: several of homes employ copper wire having a diameter of 1.63 mm to provide electrical distribution to outlets and light sockets. Determine the resistance of 75 meters of a solid copper wire having the above diameter?

Solution:

Calculate the cross-sectional area of the wire:

$$A = \left(\frac{\pi d^2}{4}\right) = \frac{\pi\ (1.63\times10^{-3})}{4} = 2.09 \times 10^{-6}\ m^2$$

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

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

Example 7: Bus bars are bare solid conductors (usually rectangular) used to carry large currents within buildings such as power generating stations, telephone exchanges, and large factories. Given a piece of aluminum bus bar as shown in Figure (10) , determine the resistance between the ends of this bar at a temperature of 20°C.

Solution:

The cross-sectional area is

$A = (150\ mm)(6\ mm)$
$= (0.15\ m)(0.006\ m)$
$= 0.0009\ m^2$
$= 9.00 \times 10^{-4}\ m^2$

The resistance between the ends of the bus bar is determined as

$$R = \rho\frac{l}{A} = \frac{(2.825\ \times10^{-8}\ \Omega.m)\times(270\ m)}{9\times10^{-4}\quad m^2}$$

$= 8.48 \times 10^{-3}\ \Omega$
$= 8.48\ m\Omega$

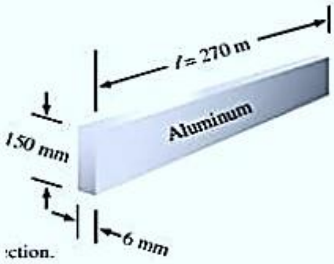


Figure (10) : Conductor with rectangular cross section

Type of Resistance (ch. 3, page 74)

Fixed resistor: A fixed resistor is one that has a single value of resistance which remains constant under normal conditions. The two main types of fixed resistors are carbon-composition and wire-wound resistors. As shown in figure (11).

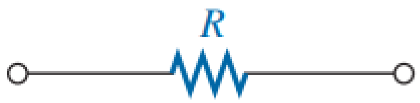


Fig. (11). fixed resistor.

Variable resistors: Variable resistors are used to change the resistance value in a circuit. This lead to variable the voltage in circuit therefore, variable resistors are called potentiometers. As shown in figure (12).

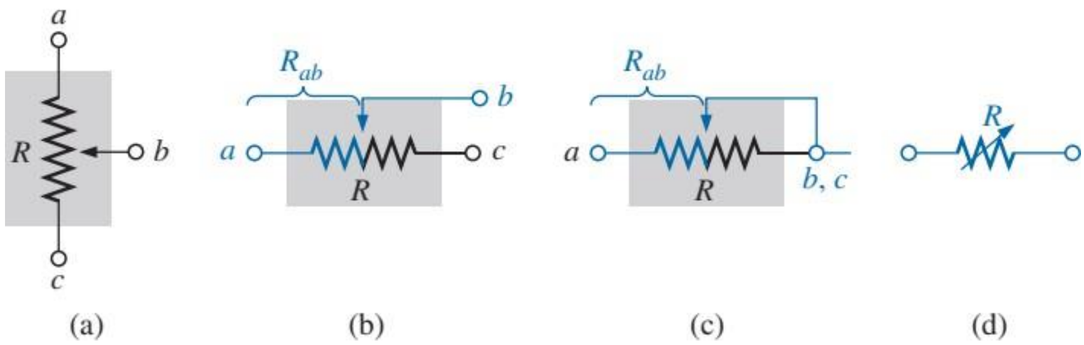


Fig.(12). Potentiometer: (a) symbol; (b) and (c) rheostat connections; (d) rheostat symbol.

Color Coding of Resistors: The colored bands provide code for determining the value of resistance, the tolerance (in percentage), and occasionally the expected reliability of the resistor. The colored bands are always read from left to right, left being defined as the side of the resistor with the band nearest to it. AS shown in fig.(13).

Color band resistor can be determined using the following relation.

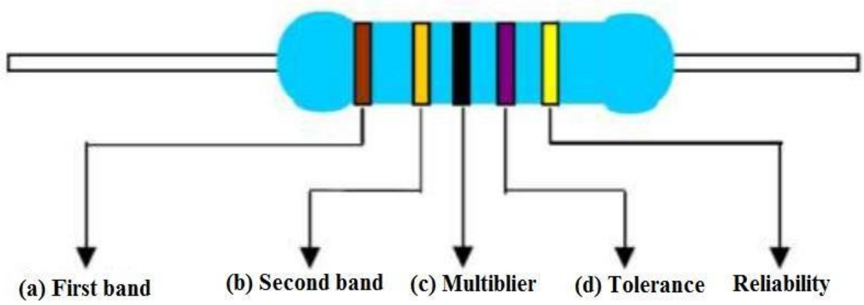


Fig.(14)

$R_{Color} = ab \times 10^{e} \pm d$ ---------------------------- (16)

For examples see figure (15) below:

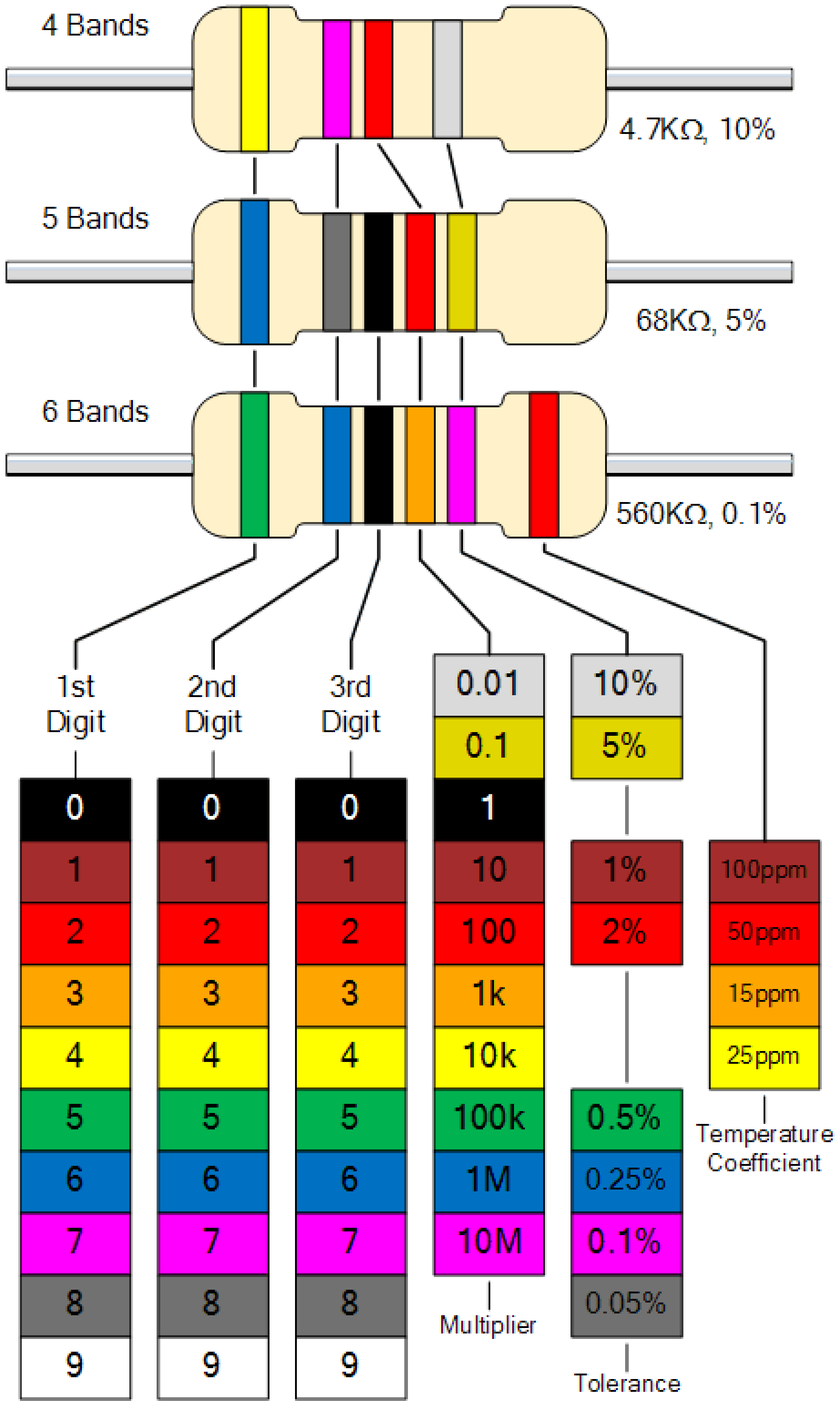


Fig.(15) Color code resistor

Temperature effects

Temperature Coefficient of Resistance : There is a second popular equation for calculating the resistance of a conductor at different temperatures. Defining :

$$R_1 = R_{20}[1 + \alpha_{20}(T_1 - 20°C)]$$ -------(17)

Where , α_{20} is the **temperature coefficient of resistance** at a temperature of 20°C, and R_{20} as the resistance of the sample at 20°C, the resistance R_1 at a temperature T_1 is determined by

$$\alpha_{20} = \frac{1}{|T_1| + 20°C} \quad (\Omega/°C/\Omega)$$ -------(18)

Table (4) Temperature coefficient of resistance for various conductors at 20°C.

Material	Temperature Coefficient (α_{20})
Silver	0.0038
Copper	0.00393
Gold	0.0034
Aluminum	0.00391
Tungsten	0.005
Nickel	0.006
Iron	0.0055
Constantan	0.000008
Nichrome	0.00044

Example 8: For a (1kΩ) copper composition resistor with a temperature coefficient at (20°C) 0.00393, determine the resistance at (60°C) ?

Solution:

From equation (17) ;

$$R_1 = R_{20}[1 + \alpha_{20}(T_1 - 20°\,C\,)]$$

$$R_1 = (1 \times 10^3)[\,1 + 0.00393(60 - 20°\,C\,)]$$

$$R_1 = 1.157\ \text{k}\Omega$$