



D.C CIRCUITS PROF: IMRAN HASHMI



DEFINITION:

The rate of flow of net charge through a cross-section of a conductor is called the **current** through that conductor. It is a scalar quantity.

FORMULA:

Suppose the net amount of charge \mathbf{q} flows past a given point in a wire in time \mathbf{t} . In such a case, we say that the current, \mathbf{I} , in the wire is

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

UNIT:

The SI unit of current is ampere, A

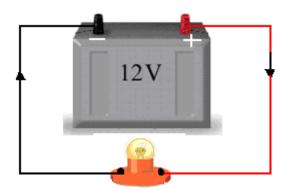
The unit of current, the ampere (A) or *amp* for short, is named for the French mathematician $Andre' - Marie\ Ampe're$ and is defined simply as 1 coulomb per second

1 ampere = 1 coulomb / second

Smaller units of current are often used such as the milli-ampere (1 mA = 10^{-3} A) and micro ampere (1µA = 10^{-6} A).

DIRECTION OF ELECTRIC CURRENT

The conventional of electric current is from positive terminal of the cell (or battery) to the negative terminal, trough the outer circuit. So in our circuit diagram, we put the arrows on the connecting wire pointing from the positive terminal of the cell towards the negative terminal of the cell

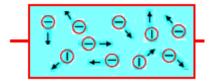


HOW TO CURRENT FLOWS IN A WIRE

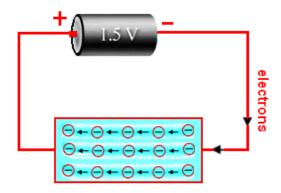
We know that electric current is the flow of electrons in a metal wire

(or conductor) when a cell or battery is applied across its ends. A metal has plenty of free electrons in it.

(i) When the metal wire has not connected to a source of electricity like a cell or battery, then the electron present in it moving at random in all directions between the atoms of metal wire.



(ii) When a source of electricity like a cell is connected between the ends of the metal wire, then an electric force acts on the electrons present in the wire. Since the electron negatively charged, they start moving from negative end of to the positive end of the wire. This flows of electrons continues the electric current in the wire.



OHMS'S LAW

German scientist "George Simon Ohm" found experimentally a relation between current and potential difference for metallic conductor, known as Ohm's Law.

Statement:

The electric current through a conductor is directly proportional to the potential difference across its ends, provided its physical state remains constant.

Mathematical Expression:

If $\, I \,$ is the current flowing through a conductor and $\, V \,$ is the potential difference across its ends then according to ohm's $\, I \,$ law

Where K is a constant of proportionality called conductance of the material of conductor. Reciprocal of conductance is called resistance,

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

From equation (1)

$$I = \frac{1}{R}V$$

$$V = IR$$

This is the equation representing Ohm's Law.

Ohms law is an empirical relationship that is valid only for certain materials. Materials that obey Ohm's law, and hence have a constant range of voltage, are said to *Ohmic conductor*. Materials whose resistance changes with voltage or current are *non-Ohmic*. Ohmic materials have a linear current–voltage relationship over a large range of applied voltage. Non-Ohmic material have a nonlinear current –voltage relationships.



Definition:

The property of a conductor due to which it opposes the flow of current through it is called resistance.

OR

The resistance of a conductor is numerically equal to the ratio of the potential difference across its ends to the current through it.

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

Circuit Symbol:

A conductor whose function in a circuit is to provide a specified resistance is called a resistor. The symbol for a resistor in a circuit diagram is,



Unit:

The SI unit of resistance is ohm, which is denoted by the symbol Ω (Greek omega)

$$1 \frac{\text{Volt}}{\text{ampere}} = 1 \text{ ohm } (\Omega)$$



ONE "OHM" RESISTANCE:

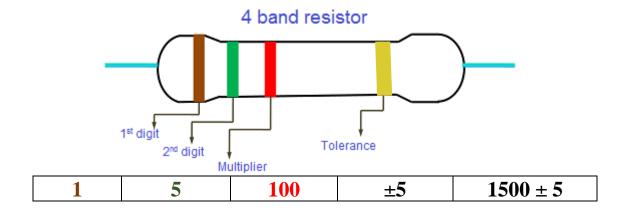
One ohm is the resistance of a conductor such that when a potential difference of one volt is applied to its ends a current of one ampere flows through it.



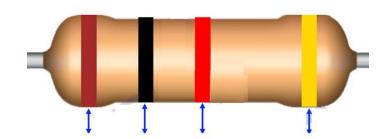
We know that a resistor is a two-terminal device and is an important component in building many electronic devices. The resistor is a component that is used to limit or regulate the flow of electric current. We commonly see resistors printed with different colours. It usually contains four bands of colours.

Color Name	Value As Figure	As Decimal Multiplier	Tolerance ±
Black	0	x 1	
Brown	1	x 10 ¹	
Red	2	x 10 ²	
Orange	3	x 10 ³	-
Yellow	4	x 10 ⁴	
Green	5	x 10 ⁵	
Blue	6	x 10 ⁶	
Violet	7	x 10 ⁷	
Grey	8	x 10 ⁸	
White	9	x 10 9	±10%
Golden	-	x 10 ⁻¹	±5%
Silver	-	x 10 ⁻²	±10%



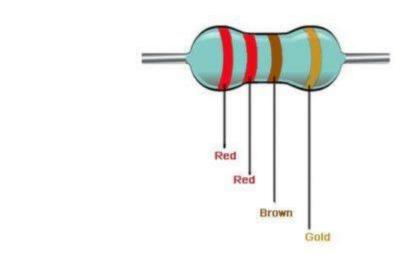


Q-2



1 0 100 ±5 1000 ± 5

Q3



2 2 10 ±5 220 ± 10

Q-4

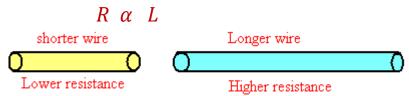


1 0	10	±5	100 ± 5
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FACTORS AFFECTING THE RESISTANCE OF A CONDUCTOR:

1. EFFECT OF LENGTH OF THE CONDUCTOR

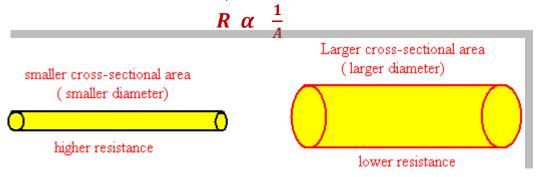
It is found experimentally that resistance **R** of a metal wire is directly proportional to its length "L"



Since the resistance of a wire is proportional to its length, therefore, when length of a wire is doubled, its resistance also gets doubled; and if the length of a wire is halved, then its resistance also gets halved

2. EFFECT OF AREA OF CROSS-SECTION OF THE CONDUCTOR

It is found experimentally that resistance **R** of a metal wire is inversely proportional to its area of cross-section "**A**", that is



Since the resistance of a wire is inversely proportional to its area cross-section, therefore, when the area of cross-section of a wire is doubled, its resistance gets halved; and if the area of cross-section of a wire is halved, then its resistance will get doubled.

Resistivity

Definition:

Resistance per unit length of a material per unit cross section area is called its resistivity.

Formula:

It is found experimentally that resistance **R** of a metal wire is is directly proportional to its length "L" and inversely proportional to its cross sectional area "A". That is

$$R \alpha \frac{L}{A}$$
$$R = \rho \frac{L}{A}$$

Where ρ (Greek Letter Rho) is a constant of proportionality, is called resistivity and depends on the material used. If L = 1m and A = 1x1 = m² then,

$$R=\rho \frac{1}{1}=\rho.$$

Thus, resistance of unit cube of any material between its opposite faces is called its resistivity.

Unit:

The SI unit of resistivity is ohm-meter. Which is written in symbol as Ω m.

Factors Affecting Resistivity:

Resistivity of a material depends upon its

- 1- Nature (electronic structure)
- 2- Temperature

Dependence of Resistivity Upon Temperature:

The resistivity, and hence the resistance of a conductor depends upon number of factors. One of the most important is the temperature of the metal. For most metals, resistivity increases with increasing temperature. This correlation can be understood as follows. As the temperature of the material increases, its constituent atom vibrates with increasingly greater amplitude. The electrons find it more difficult to pass atoms vibration with large amplitude. The increased electron scattering with increasing with increasing temperature result in increasing resistivity.



For most metal, resistivity increases approximately linearly with temperature over a limited temperature range. That is

$$\rho_t = \rho_o (1 + \alpha \Delta t)$$

Where ρ_t is the resistivity at some temperature T (in Celsius degree). ρ_o is the resistivity at some reference temperature T_o (usually taken to be $20^{\circ}C$) and α is a parameter called the temperature coefficient of resistivity.

Temperature Coefficient:

Fractional change in resistance per Kelvin rise in temperature of a conductor is called its temperature co-efficient of resistance.

Formula:

Consider a conductor with:

 R_o = resistance at 0° C

 R_t = resistance at $t^{\circ}C$

 $\Delta R = R_t \square R_o = \text{change in resistance}$

 Δt = change in temperature.

It is found experimentally that the change in the resistance of a metallic conductor is directly proportional to the change in temperature and the initial resistance of the conductor, i.e.,

$$\Delta R \propto R_o \Delta t$$

$$\Delta R = \alpha R_o \Delta t$$

$$R_t - R_o = \alpha R_o \Delta t$$

$$R_t = R_o + \alpha R_o \Delta t$$

$$\alpha = \frac{R_t - R_0}{R_0 \Delta t}$$

Where α is called the temperature coefficient of resistance.

Unit of "a":

From equation (1)

$$\alpha = \frac{\Delta R}{\text{Ro}\Delta t}$$
$$= \frac{\Delta \Omega}{\Delta \Omega . K}$$
$$= K^{-1}$$

Its unit is per kelvin.

CONDUCTANCE AND CONDUCTIVITY:

It is defined as 'The measure of how easily flow of charges (electrical current) can pass through a material" or Conductivity is the ability of a material to conduct electricity and quantifies the effect of matter on current flow in response to an electric field.

Conductance is the reciprocal, or inverse, of resistance. The greater the resistance, the less the conductance and vice versa. It is denoted by symbol " ρ " and its unit is the mho " δ ", The unit of the mho has been replaced by the unit of Siemens (abbreviated by the capital letter "S").

Conductivity is denoted by Greek letter sigma (σ) and is the reciprocal of the resistivity i.e.

 $\frac{1}{\rho}$. It is measured in siemens per meter (S/m). Since electrical conductivity $\sigma = \frac{1}{\rho}$, the previous expression for electrical resistance, R can be rewritten as a function of conductivity

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

$$R = \frac{1}{\sigma} \left(\frac{L}{A}\right)$$

ELECTRO-MOTIVE FORCE

A cell's electromotive force (e.m.f.) is the energy converted from non-electrical forms to electrical forms when one coulomb of positive charge passes through the cell.

OR

The electromotive force of a source is the total work done per unit of positive charge to move it from the negative to the positive terminal of a battery in a reversible process is called its electromotive force.

Notation:

The symbol of electromotive force is "ε" and its abbreviation is **e.m.f.**

FORMULA

$$\mathbf{E} = \frac{\mathbf{w}}{\mathbf{o}}$$

Where,

E = e.m.f.

W = energy converted from non-electrical forms to electrical form

Q = positive charge

Unit:

The unit of e.m.f is the joule/ coulomb, which is the volt (V).

POTENTIAL DIFFERENCE

The potential difference (p.d) between two points is defined as the energy converted from electrical to other forms when one coulomb of positive charge passes between the two points.

FORMULA

$$V = \frac{W}{Q}$$

Where,

V = potential difference

W = energy converted from electrical to other forms and

Q = charge.

UNIT

The SI unit of potential difference is the volt.

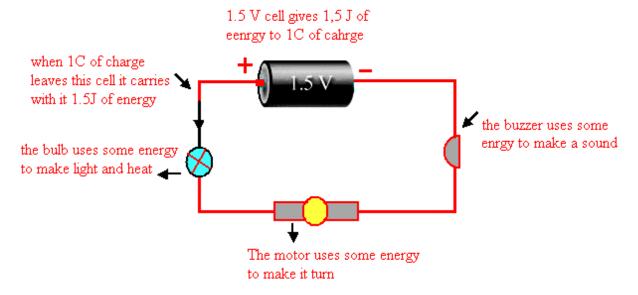
VOLT

The potential difference (p.d.) between two points in a conductor is 1 volt, if 1 joule of energy is converted from electrical to other forms when 1 coulomb of positive charge flows through it.

THE VOLTAGE OF A CELL

Charges need energy in order to move around a circuit. They may receive this energy from a cell or a battery.

The amount of energy given to the charges depends upon the **voltage** of the cell. Voltage is also called **potential difference** or **p.d**. A cell which has a voltage of 1.5 V gives 1.5 J(joule) of energy to each coulomb (C) of charge which travel through it. The charges release this energy as they travel through the component of the circuit. When the energy is released the bulb glows and becomes warm, the motor spin and the buzzer makes a sound.



If 1.5 V cell is replaced with a battery which has a voltage of 4.5 V, the battery gives 4.5 J(joule) of energy to each coulomb of charge which travel through it. As they travel around the circuit the charges are able to release three times as much energy as before. This means that the bulb glows more brightly and feels a lot warmer,

the motor spin more quickly and buzzer sound louder. The table below summarizes the effect of replacing 1.5 V cell with the 4.5 V battery.

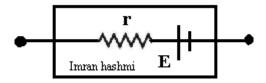
	Circuit using 1.5 V cell	
Voltage	1.5 volts	4.5 volts
Energy given to each Coulomb of charge	1.5 J	4.5 J
What happens to; a) Bulb	a) glows and feels warm	a) glows more brightly and feels warmer
b) motor c) buzzer	b) spins around c) makes around	b) spins around fasterc) makes a loudersound

TERMINAL POTENTIAL DIFFERENCE

It is the potential difference between the terminals of the source of e.m.f when it is supplying a current to external circuit.

EXPLANATION:

When a battery sends a current in external circuit, same amount of current also flows through the battery from its negative to positive terminal. Internally the current comes across some resistance



by the electrolyte. This is called internal resistance. A source of e.m.f E having internal resistance r is equivalent to a source of pure e.m.f E with a resistance r in series.

When no current is drawn from a battery, there is no potential drop across its intrnal resistance. Hence potential difference between the internals of a battery is equal to the e.m.f of the source.

$$E = IR$$

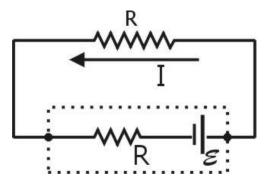
When the circuit is closed, the current I is supplied by the battery to an external resistance 'R' then

where

$$\begin{split} IR &= terminal\ potential\ difference\ (\ Vt\) \\ Ir &= lost\ voltage\ across\ internal\ resistance \\ E &= V_t + Ir \end{split}$$

$$\mathbf{V_t} = \mathbf{E} - \mathbf{Ir}$$

This shows that the potential difference between the terminals of a battery drops when it delivers a current.



PROF: IMRAN HASHMI

SOURCES OF EMF:

There must be a source of electromotive force (emf) or voltage for electrons to flow. This EMF source can be produced from different primary energy sources. These primary sources supply energy in one form, which is then converted to electric energy. Some Primary sources of electromotive force include

S.No.	Primary Source of emf	Example	
1.	Light	A solar or photovoltaic cells and solar module or panel converts solar light to electric energy. These are made up of semiconducting, light-sensitive material which makes electrons available when struck by the light energy.	
2.	Chemical Reaction	A battery or voltaic cell directly converts chemical energy into electric energy. It consists of two electrodes and an electrolyte solution. One electrode connects to the (+) or positive terminal (anode), and the other to the (-) or negative terminal (cathode).	
3.	Heat	Thermocouple converts heat energy directly into electric energy. When we supplied heat to the hot junction, electrons start moving from one metal to the other. This creates a negative charge on one and a positive charge on the other.	
4.	Mechanical- Magnetic	An electric generator converts mechanical-magnetic energy into electric energy. To produce mechanical energy, a generator should be driven by an engine, a turbine or any other machine.	
5.	Piezoelectric Effect	In this type a substance is used which produces an electric charge when a mechanical pressure is applied. Certain crystals like quartz are piezoelectric in nature. They generate an electric charge when they are compressed or struck. A common example of piezoelectricity is the piezo gas igniter.	

POWER DISSIPATION IN RESISTORS

If a battery is used to establish an electric current in a conductor, chemical energy stored in the battery is continuously transformed into kinetic energy is quickly lost as a result of collision between the charge carrier and fixed atom in the conductor, causing an increase in the temperature of the conductor. Thus, The chemical energy stored in the battery is continuously transformed into internal energy of atoms. This is known as power dissipation.



Formula:

Consider a charge 'q' loses energy $\mathbf{q}\mathbf{V}$ as it passes through the resistor \mathbf{R} . if \mathbf{t} is the time it takes the charge to pass through the resistor, then the rate at which it loses electrical potential energy is

But
$$Power = \frac{energy}{time}$$

$$P = \frac{qV}{t}$$

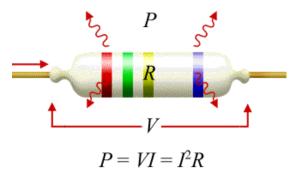
$$P = \left(\frac{q}{t}\right)V$$

$$P = IV.....(i)$$

We have developed this result by considering a battery delivering energy to a resistor.

However, equation (i) can be used to determine the power transformed from a voltage source to any device carrying a current **I** and having a potential difference **V** between the terminals.

Using equation (i) and the fact that V = IR for a resistor, we can express the power delivered to the resistor in the alternate forms.



$$P = I (I R)$$

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

$$P = \left(\frac{V}{R}\right) V$$

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

Unit:

The SI unit of power is watt (W)

Some larger units are kilowatt and megawatt.

$$1 \text{ kW} = 10^3 \text{W}$$

 $1 \text{MV} = 10^6 \text{W}$

It is a common misconception that Power and Energy/Electricity are same. Interestingly, they have a very different meaning. Power is the rate at which electricity is used and energy is the actual consumption. To give an analogy, power is similar to speed but energy is the actual distance travelled.

Power x Time = Energy

$$\mathbf{E} = (\mathbf{I} \mathbf{V}) \mathbf{t}$$

Similarly

$$\mathbf{E} = \mathbf{I}^2 \, \mathbf{R} \, \times \mathbf{t}$$

$$\mathbf{P} = \frac{V^2}{R} \times t$$

Unit:

- 1- SI unit of energy is joule (J)
- 2- Kilowatt hour (kWh)

Commercial unit of electrical energy is kilowatt hour. <u>It is the amount of energy supplied at a rate of 1000 J/sec in an hour.</u>

1kWh = 3600000 J

$$1kWh = 3.6 \times 10^6 J$$

Problem 1: If the current and voltage of an electric circuit are given as 2.5A and 10V respectively. Calculate the electrical power?

DATA

I = 2.5A and V = 10V

The formula for electric power is,

$$P = VI$$

 $P = 10 \times 2.5 = 25$ watts

Problem 2: Calculate the power of an electrical circuit consisting of resistance 3Ω and a current 4A flowing through this circuit?

DATA

I = 4A and $R = 3\Omega$

Electric power formula is,

$$\mathbf{P} = \mathbf{I}^2 \mathbf{R}$$

$$P = 42 \times 3$$

$$P = 16 \times 3 = 48$$
 watts

CONDITION FOR MAXIMUM POWER TRANSFER:

The maximum power transfer theorem states that, maximum external power can be obtained from a source with a finite internal resistance, if the resistance of the load is equal to the

resistance of the source. This Theorem is another useful circuit analysis method; it ensures that the maximum amount of power will be dissipated in the load resistance when the value of the load resistance is exactly equal to the resistance of the power source. Consider a circuit in which we have load resistance R_L (Variable 0-100 Ω), internal resistance R_S = 25 Ω and a voltage supply Vs. = 100V. We can find the value of the load resistance, R_L that will give the maximum power transfer in this circuit as shown in figure 10.6. By using the Ohm's Law equations:

Fig:10.6 Maximum power

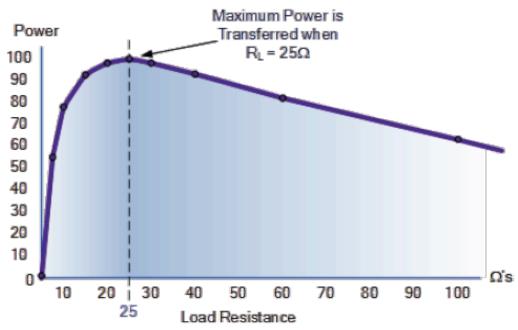
$$I = \frac{V_S}{R_S + R_L}$$
 and $P = I^2 R_L$ (10.8)

In the table below we have determined the current and power in the circuit for different values of load resistance. Using the above data, we can plot a graph of load resistance, R_L against power, P for different values of load resistance.

We can see that the **Maximum Power Transfer** occurs when $R_S = R_L = 25\Omega$. It is called a "matched condition" and in this case maximum power is transferred. Also notice that power is zero for an open-circuit (zero current condition) and also for a short-circuit (zero voltage condition). The graph for the power against load resistance is shown below.

Table 10.4

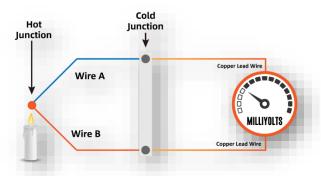
$R_L(\Omega)$	I	P
KL (32)	(amps)	(watts)
0	4.0	0
5	3.3	55
10	2.8	78
15	2.5	93
20	2.2	97
25	2.0	100
30	1.8	97
40	1.5	94
60	1.2	83
100	0.8	64



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THERMOCOUPLE

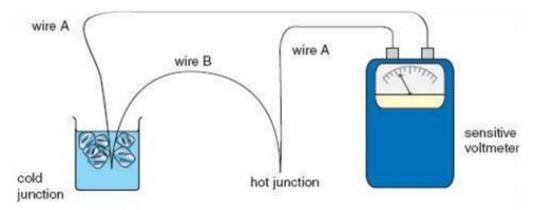
The thermocouple working principle is based on the Seeback Effect. This effect states that when a closed circuit is formed by jointing two dissimilar metals at two junctions, and junctions are maintained at different temperatures then an electromotive force (e.m.f.) is induced in this closed circuit.



VARIATION OF THERMOELECTRIC E.M.F WITH TEMPERATURE

Variation of thermoelectric emf with temperature can be studied using an iron-copper thermocouple as shown in Fig. One junction is dipped in an oil bath and other junction is kept at melting ice (temperature kept constant). Now we observe that:

- The galvanometer shows no deflection when the temperature of both junctions are same (0°C), so thermal emf is also zero
- As the temperature of the hot junction is increased gradually, and the cold junction is remain at 0° C, thermo emf also increase till it becomes maximum. Temperature of the hot junction at which the thermo emf becomes maximum is called neutral temperature (T_n) .



If we increase the temperature of the hot junction beyond neutral temperature (T_n) , thermo emf starts to decrease and becomes zero and changes its polarity at a temperature called inversion temperature (T_i)

As the temperature is increased beyond T_i, the direction of thermal emf is reversed. The inversion temperature depends upon the temperature of cold junction and nature of metals used in the thermocouple.

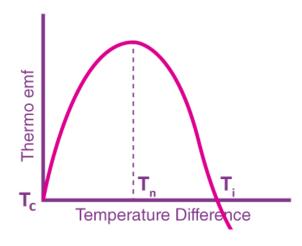
The variation of thermal emf with temperature (T) is given by

$$E = \alpha T + \frac{1}{2} \beta T^2$$

Where, α and β are constant whose value depends upon material of conductor and the temperature difference of two junctions.

If T_c is the temperature of cold junction, then we can write

$$T_i-T_n=T_n-T_c$$
 $T_c+T_i=T_n+T_n$ $T_c+T_i=2T_n$ $rac{T_c+T_i}{2}=T_n$ We know that $T_c=0$ $rac{0+T_i}{2}=T_n$



$$\frac{0+T_i}{2} = T_n$$

$$\frac{T_i}{2} = T_n$$

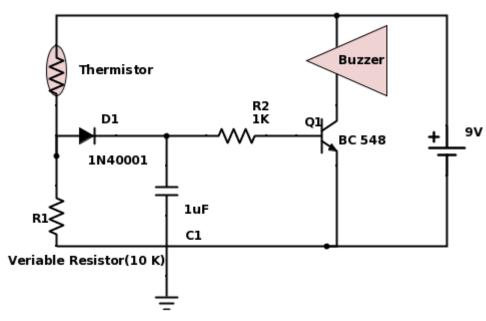
$$T_i = 2T_n$$

the above expression shows that the inverion temperature (T_i) equals to twice the neutral temperatre (T_n)

FIRE ALARM:

A thermistor is a variable resistor whose resistance changes with temperature. Its temperature detection can be used in fire alarms for the detection of fires. Fire Alarm Circuit is a simple circuit that detects the fire and activates the Siren Sound or Buzzer.

In this fire alarm circuit, the resistance of thermistor the in kiloapproximately at normal temperature. During fire, the resistance reduces to a few ohms as the temperature increases which switches ON the *transistor. Once the transistor is turned ON, the current from Vee starts to flow via buzzer which produces a beep



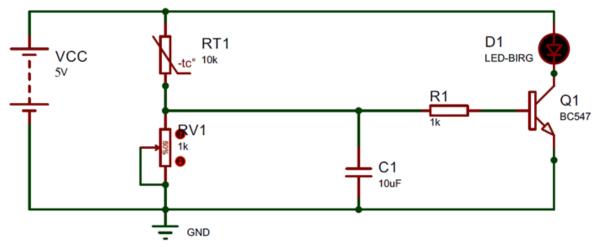
sound. For unidirectional conduction a Diode is used and the use of capacitor removes sudden transients from the thermistor.

THERMOSTATS

Thermostat is formed by two Greek words thermo and statos, thermos means heat and statos means stationary or fixed. Thermostat is used to control the devices or home appliances according to the temperature, like turn on/off air conditioner, room heaters etc.

The thermostat circuit compromise of a voltage divider circuit and input ON and OFF circuit. Voltage divider circuit compromise of the thermistor is a variable resistor. Voltage divider circuit output is connected to the base of NPN transistor through a 1 k Ω resistor. Voltage divider circuit makes it possible to sense the variation in voltage caused by variation

in resistance of Thermistor. LED will be switched On, only if temperature crosses a particular value



KIRCHHOFF'S FIRST LAW OR KIRCHHOFF'S CURRENT LAW(KCL)

Kirchhoff's Current Law,

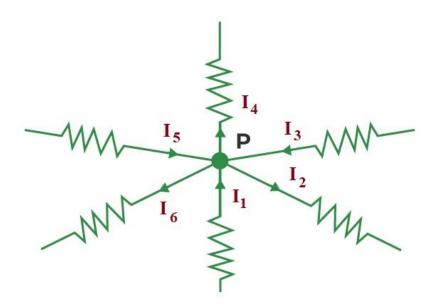
STATEMENT

The sum of the currents entering a junction always equal the sum of the currents out of the junction

KEY PONITS

- This is a consequence of conservation of charge current shouldn't decrease or increase in circuit when it splits In a circuit:
- A junction is a point where at least three circuit paths meet

According to Kirchhoff's Current Law



sum of the currents entering a junction = sum of the currents out of the junction

$$I_1 + I_3 + I_5 = I_2 + I_4 + I_6$$

KIRCHHOFF'S SECOND LAW OR KIRCHHOFF'S VOLTAGE LAW(KVL)

Kirchhoff's Voltage Law,

STATEMENT

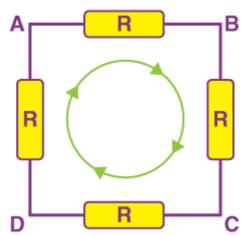
The net electromotive force around a closed-circuit loop is equal to the sum of potential drops around the loop

KEY PONITS

- the sum of all voltages around a closed loop in any circuit must be equal to zero $\sum \Delta V = 0$
- ► Kirchhoff's voltage law is a consequence of charge conservation and also conservation of energy.

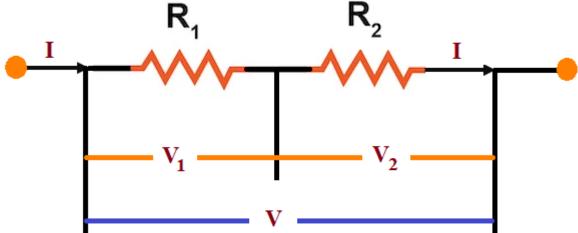
The sum of all the voltage drops around the loop is equal to zero

$$V_{AB} + V_{BC} + V_{CD} + V_{DA} = 0$$



KIRCHHOFF'S LAWS FOR SERIES RESISTORS COMBINATIONS:

Consider two resistors of resistances R₁ and R₂ connected in series as shown in figure



According to Kirchhoff's first law, the current in each resistor is the same

$$I_1 = I$$
, $I_2 = I$

According to Kirchhoff's second law, the potential difference V across the combination is equal to the sum of the potential differences across the two resistors:

$$\mathbf{V} = \mathbf{V_1} + \mathbf{V_2} \dots \dots (i)$$

Since
$$V = IR$$
, $V_1 = IR_1$, $V_2 = IR_2$, we can write equation (i):

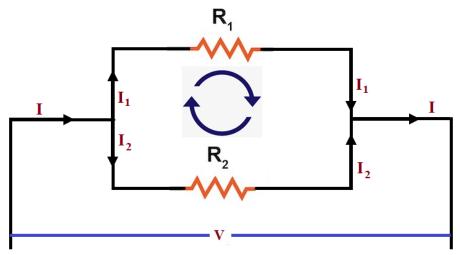
$$IR = IR_1 + IR_2$$

$$IR = I(R_1 + R_2)$$

$$R = R_1 + R_2$$

KIRCHHOFF'S LAWS FOR PARALLEL RESISTORS COMBINATIONS:

Consider two resistors of resistances R₁ and R₂ connected in series as shown in figure



We have the situation where the current divides between them. Hence, using Kirchhoff's first law, we can write

$$I = I_1 + I_2 \dots \dots (i)$$

If we apply Kirchhoff's second law to the loop that contains the two resistors, we have:

$$-V_1 + V_2 = 0V$$
 (Because there is no source of e.m. f. in the loop)

$$-I_1 R_1 + I_2 R_2 = 0$$

This equation states that the two resistors have the same p.d. V across them. Hence we can write

$$I = \frac{V}{R}$$
, $I_1 = \frac{V}{R_1}$, $I_2 = \frac{V}{R_2}$

Substituting these expressions in equation (i), we get

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2}$$

$$\frac{V}{R} = V \left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

WHEATSTONE BRIDGE

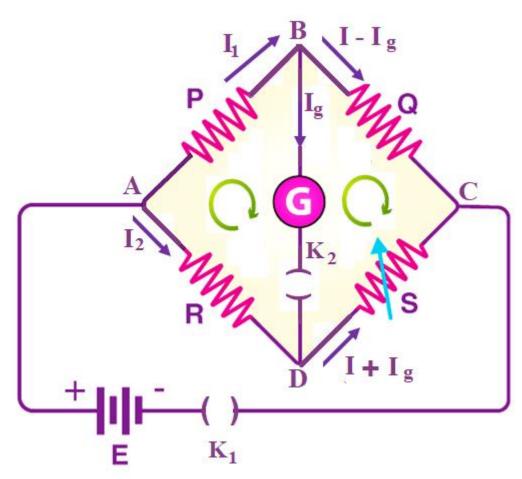
Wheatstone bridge, also known as the resistance bridge, calculates the unknown resistance by balancing two legs of the bridge circuit. One leg includes the component of unknown resistance.

PRINCIPLE OF WHEATSTONE BRIDGE:

The Wheatstone bridge works on the principle of null deflection. In normal conditions, current flows through the galvanometer and the bridge is said to be in an unba lanced condition. Adjusting the known resistance and variable resistance a condition is achieved when no current flows through the galvanometer i.e. a balanced condition.

WORKING OF WHEATSTONE BRIDGE:

Wheatstone Bridge Principle states that if four resistance P, Q, R and S are arranged to form a bridge as shown in figure with a cell E and one key K_1 between the point A and C and galvanometer G and tapping key K_2 between the points B and D, closing K_1 first and K_2 later on, if the galvanometer shows no deflection, then bridge is balanced. Current distribution in the circuit is shown in the figure.



If we apply Kirchhoff's 2nd law in ABDA, we get

$$I_1 P + I_g R_g - I_2 R = 0$$

If value of R is such that the galvanometer shows no deflection that is $\lg = 0$. Putting this value in above equation

$$I_1 P + (0) R_g - I_2 R = 0$$

 $I_1 P - I_2 R = 0$

$$I_1 P = I_2 R \dots (i)$$

If we apply Kirchhoff's 2nd law in BCDB, we get

$$(I_1 - I_g) Q + I_g R_g - (I_2 - I_g) S = 0$$

If value of R is such that the galvanometer shows no deflection that is lg = 0. Putting this value in above equation

$$(I_1 - 0) Q + (0) R_g - (I_2 - 0) S = 0$$

$$I_1 Q - I_2 S = 0$$

$$I_1 Q = I_2 S \dots \dots (ii)$$

Dividing equation (i) by (ii)

$$\frac{I_1 P}{I_1 Q} = \frac{I_2 R}{I_2 S}$$

$$\frac{P}{Q} = \frac{R}{S}$$

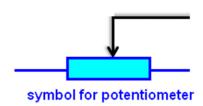
RHEOSTAT

Working of rheostat as a potential divider: A rheostat is a variable resistor, used for controlling the flow of electric current by increasing or decreasing the resistance. The term rheostat is derived from the Greek word "rheas" and "statis" which means current controlling device.



POTENTIAL DIVIDER

In previous chapter, we have learnt about how a variable resistor can be used as a rheostat to vary the current in the circuit. When a variable resistor is used to vary voltage it is known as a **potential divider** or **potentiometer.**



POTENTIOMETER

Consider a potentiometer of length AB. There are two cells of e.m.fs E_I and E₂. Now the positive ends of the cells are connected to point 'A' and the negative ends of the cells are connected to the jockey through galvanometer (G). When the key is closed and the jockey is moved along wire AB to find the null point (P) where there is no deflection in the galvanometer (G). Let P₁ be the null point when cell E₁ is connected and corresponding length between the end A of the wire to the null point P_I be 'L₁'. The potential difference across this length balances emf E₁,

$$E_1 = K L_1....(i)$$

Where K is the potential gradient of the wire.

Then disconnect the cell of e.m.f E_1 , and connect the cell of e.m.f E_2 in the circuit. Let P_2 be the null point and let ' L_2 ' be the length between the end A of the wire to the null point P_2 . Then we have

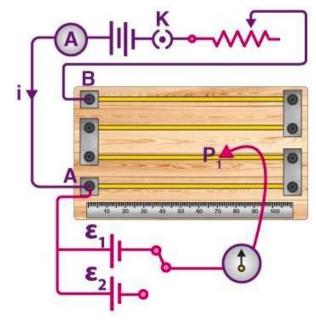
$$E_2 = K L_2 \dots (ii)$$

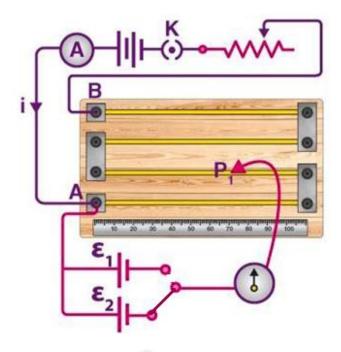
By dividing equation (i) by equation (ii), we get

$$\frac{E_1}{E_2} = \frac{K L_1}{K L_2}$$

$$\frac{E_1}{E_2} = \frac{L_1}{L_2}$$

As we measure the value of L_1 , h we can compare the emf of two cells.







SHORT REASONING QUESTIONS

1. Why is the terminal voltage of a cell less than its emf?

Ans:

EMF is the potential difference across the two terminals of a voltage source when it is not connected to any circuit. Once it is connected to a circuit, the voltage reduces slightly because of the internal resistance of the voltage source. The terminal voltage of the voltage source is the potential difference across the terminals when it is connected to a circuit. This is why the terminal voltage is always less than the EMF of the same voltage source.

When the current starts to flow in the circuit, then there is a voltage drop due to internal resistance... Thus V is always less than E. This can also be observed from the following equation:

2. Why is a potentiometer preferred over a voltmeter for determining the emf of a cell?

Ans: Voltmeter:

A voltmeter is an instrument that is used to measure the potential difference between two points in an electrical circuit.

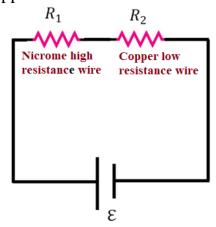
Potentiometer:

The potentiometer is an instrument that is used to measure the EMF of a cell and also works as a voltage divider.

A voltmeter has a finite resistance and draws current from a cell, therefore voltmeter measures terminal potential difference rather than emf, while a potentiometer at balance condition, does not draw any current from the cell; so the cell remains in open circuit. Hence potentiometer reads the actual value of emf.

Nichrome and copper wires of same length and same radius are connected in series. Current I is passed through them. Which wire gets heated up more? Justify your answer.

Ans: Consider Nicrome and copper wire are connected in series



In series circuit same current I flows through both the wires. Hence, heat produced $E=I^2R$ or $E(energy) \propto R$. For same length and same radius the resistance of nichrome wire is more due to its higher resistivity, hence nichrome wire is heated up more than the copper wire.

4. Explain why the terminal potential of a battery decreases when the current drawn from it in increased?

Ans: The *terminal potential difference* of a batter is

$$IR = E - Ir$$
 $V_t = E - Ir$

Where, E is the emf of the battery, r is the internal resistance of battery, and I.r is the potential difference across internal resistance.

When I increased then Ir becomes larger and terminal potential becomes small. Thus, we can say that when we draw more current from battery then its terminal potential difference will *decrease*.

5. What are thermistors? Write their importance

Ans: Thermistor is a type of resistor whose resistance changes rapidly with the small change in temperature. In other words, it is a type of resistor in which the flow of electric current changes rapidly with small change in temperature. They are very sensitive and react to very small changes in temperature. They are best used when a specific temperature needs to be maintained, and when monitoring temperatures within 50°C of ambient.

6 State Kirchhoffs Laws.

Ans Kirchhoff's Current Law,

The sum of the currents entering a junction always equal the sum of the currents out of the junction

Kirchhoff's voltage Law

The net electromotive force around a closed-circuit loop is equal to the sum of potential drops around the loop

7 If Copper and Aluminum wires of the same length have same resistance, which has the larger diameter? And why?

Ans The aluminum wire has a larger diameter than the copper wire if both have the same length and the same resistance. This is because aluminum has a higher resistivity $(\rho_A=2.82\times10^{-8}~\Omega~m)$ than copper $(\rho_C=1.68\times10^{-8}~\Omega~m)$, resulting in a larger diameter needed to achieve the same resistance.

8 What is the difference between potential difference and emf

Ans ELECTRO-MOTIVE FORCE

The electromotive force (e.m.f.) of a cell is defined as the energy converted from non-electrical forms to electrical form, when one coulomb of positive charge passes through the cell.

POTENTIAL DIFFERENCE

The potential difference (p.d) between two points is defined as the energy converted from electrical to other forms when one coulomb of positive charge passes between the two points.



SELF-ASSESSMENT QUESTIONS

1 What causes the terminal voltage to be greater than the emf in Cars and in batteries for small electrical appliances and electronic devices while recharging them?

Ans The terminal voltage of a battery charger must be greater than the emf of the battery during the charging process for the following reasons.

When a battery is being charged, a charging voltage is applied across the battery terminals, which is higher than the battery's own EMF. This higher charging voltage drives a charging current through the battery, which causes the battery to store energy in chemical potential.

The difference between the terminal voltage and the EMF of the battery is known as the overvoltage or the polarization voltage. This overvoltage is required to overcome the internal resistance of the battery and drive the charging current through it.

2 Do thermocouples tell you the temperature?

Ans yes, but they do so in a different way than other thermometers. A thermocouple is a device for measuring temperature. It comprises two dissimilar metallic wires joined together to form a junction. If the two junctions are at different temperatures, that is, one junction is hot and the other is cold, a small electromotive force(emf) is produced. The greater the temperature difference, the greater the emf(potential difference) produced across the ends of the two junctions.

Thermocouple Equation

The magnitude of the emf is directly proportional to the difference in temperature of two junctions

$emf \alpha \Delta T$

Why are two different metals required in a thermocouple?

Ans It is the inherent properties of the metal that affect how electrons behave within the wires of thermocouple. For example, electrons will flow differently through iron than they do through copper. The two wires of a Thermocouple are exposed to the same temperature at the same measurement Junction, exciting electrons initiate a current. However, the electrical flow through e ach wire is slightly different so if you take a voltage measurement at the reference junction of one wire will have more potential compared to the other it's this difference in potential that we use to calculate the temperature.

4 What are the common causes of thermistor failure?

Ans Thermistors, as semiconductor resistors sensitive to temperature changes.

common causes of thermistor failure

- 1 Excessive or insufficient ambient temperature
- 2 Excessive or insufficient current
- 3 Aging of thermistor materials
- 4 Mechanical damage caused by collisions
- 5 Excessive humidity in the environment, among other factors.

5 Can we apply Kirchhoff's laws in the presence of a magnetic field?

Ans In the presence of a magnetic field, Kirchhoff's law does not apply. Because Kirchhoff's law assumes that magnetic fields are not present in closed loops, this is the case. As a result, when there are time-varying magnetic fields, this law cannot be used.

6. Is it true that Kirchhoff's first law supports law of conservation of charge?

Ans Yes, Kirchhoff's first supports the law of conservation of charge.

- > The total charge entering a junction must be equal to the charge leaving the junction.
- ➤ The conservation of charge ideologically states that the total electric charge in a closed system never changes

7 Can Kirchhoff's rules be applied to simple series and parallel circuits or are they restricted for use in more complicated circuits that are not combinations of series and parallel?

Ans Kirchhoff's circuit laws are two equalities that deal with the current and potential difference (commonly known as voltage) in electrical circuits.

They do not care whether your circuit is simple series, parallel, or some complicated circuit. You can use them wherever you want to.

The problem here is that two resistors in a series are not a circuit. For a circuit to exist a closed path must exist, so current can "circulate". Two resistors in parallel is

a closed path must exist, so current can "circulate". Two resistors in parallel is different, there is a circuit here, but as far as there are no sources, both current and voltage will be zero.

8 In a potentiometer of 5 wires, the balance point is obtained on the 2nd wire. To shift the balance point to the 4th wire, what should be done?

Ans 1 The balance point in a potentiometer is obtained by adjusting the ratio of potential differences across the wires.

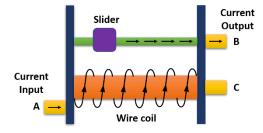
- 2. Since the balance point is initially on the 2nd wire and needs to be shifted to the 4th wire, we need to increase the potential difference across the 4th wire.
- 3. If we have to shift the balance point of a potentiometer to a higher length, the potential gradient of the wire is to be decreased. This can also be achieved by increasing the resistance in series with the potentiometer wire, and this is possible by decreasing the current of the main circuit

9 When is Wheatstone bridge most sensitive?

Ans The Wheatstone bridge is most sensitive when the resistances in the arms of the bridge are balanced, meaning that the ratio of the resistances in the two legs of the bridge is equal. This condition results in the bridge being most sensitive to small changes in resistance

10 When rheostat works as a potential divider, which resistance is taken?

Ans A rheostat is a type of variable resistor that can be used as a potential divider. A potential divider is a circuit that divides a voltage into two or more parts. When the rheostat is turned to its minimum resistance, the voltage across the first resistor will be the maximum. As the rheostat is turned to increase its resistance, the voltage across the first resistor decreases



and the voltage across the second resistor increases. The voltage across the rheostat remains constant as it is being supplied directly from the battery. Thus, the voltage across the two resistors can be varied by adjusting the resistance of the rheostat.