CHAPTER 12

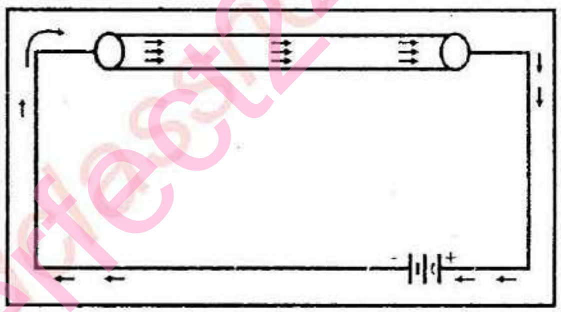
# CURRENT ELECTRICITY

**Q1: Describe the concept of steady state current as a flow of positive, negative or both. Define the unit of current.**

**Answer: Steady State Current:**

**Definition:** "The continuous flow of free electrons is known as steady state current."

**Explanation:**



Consider a conductor which contains large number of free electrons, as shown in the figure. Now if an electric field or voltage is applied to the conductor, then the free electrons [negatively charged] will start moving towards the positive terminal around the circuit. This directed flow of electrons is called electric current.

The current may be produced due to flow of positive charges or negative charges or both. For example,

1. In metallic conductors, the current is produced due to flow of electrons which are negatively charged.
2. In electrolytes, the current is produce due to flow of positive and negative ions.
3. In gases, the current is produced due to flow of electrons and ions.
4. In semi conductor material, current is produced due to motion of electrons and holes.

Now if "ΔQ" is the amount of charge flowing through any crosssectional area of a conductor in time "$\Delta t$", then the current flowing through the conductor is given by,

$$\boxed{I = \frac{\Delta Q}{\Delta t}} \qquad \text{———————} (1)$$

## Unit of Current:

If $\Delta Q = 1$ coulomb, $\Delta t = 1$ sec, then equation (1)

$$I = \frac{1 coulmb}{1 \ sec} = 1 \ \text{ampere}$$

So the unit of current is "ampere" which is defined as "the current is said to be one ampere if one coulomb charge is flowing through any cross-section of a conductor in one second".

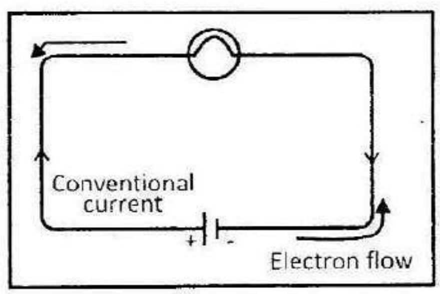
| |
|---|
| 1 milliampere (mA) = $10^{-3}$ amp |
| 1 microampere ($\mu$A) = $10^{-6}$ amp |

**Q2: (a) What is conventional current?**
**(b) Discuss the direction of electric current.**

Answer: a) **Conventional Current:**

**Definition:** "The current which flows due to flow of positive charges from a point at higher potential to a point at lower potential is known as conventional current.

## Direction of Electric Current:

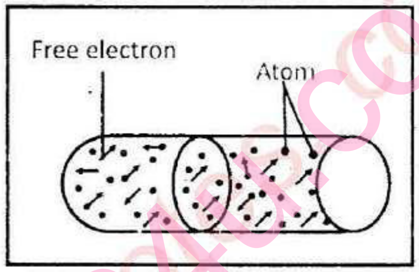



In a certain circuit, the electric current can be produced due to flow of positive as well as negative charges. But the positive and negative charges flow in opposite direction in the circuit. Thus for the specification of direction of electronic current, the current was consider due to flow of positive charges. Such current is known as conventional current. The direction of conventional current is the direction in which the positive charges could move under the influence of electric field.

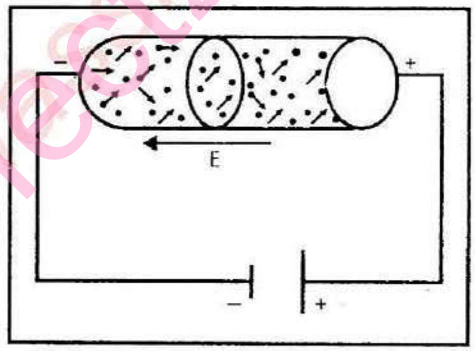
**Q3: Explain the electronic current in a metallic wire as due to drift of free electrons in the wire.**

Answer: We know that every metal has large number of free electrons which move randomly within the body of the conductor. The average speed of free electrons is sufficiently high [$\approx 10^5 m/sec$]. During random motion, the free electrons collide with atoms of the conductor again and again and their direction of motion changes after each collision. Due to random motion of all free electrons, there is no net flow of charges in any particular direction. As a result no current is established in the conductor.

The current is a scalar quantity because it does not follow the vector law of addition.




Now if the potential difference is applied across the ends of a conductor, an electric field "$\vec{E}$" is set up at every point within the wire. The electrons experience a force in a direction opposite to electric field "$\vec{E}$". Due to this force and the continuous collision with the atoms, the electron acquires a net drift velocity.




The average velocity with which free electrons get drifted in a metallic conductor under the influence of electric field is known as drift velocity "$\vec{V}_d$". The drift velocity of free electrons is of the order of $10^{-5} m/sec$.

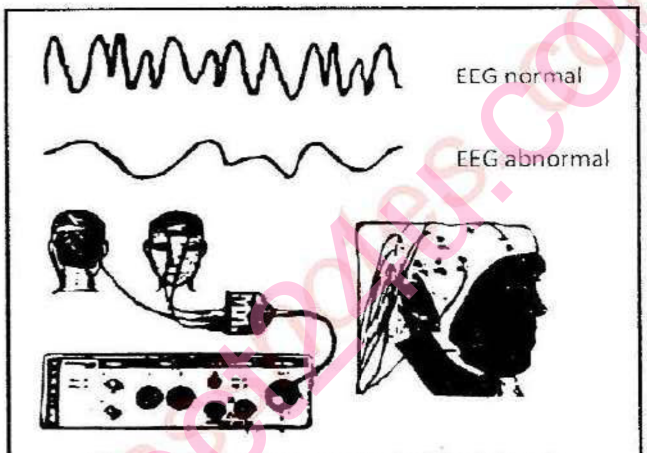
**Note:** If electrons drift so slowly, how room light turns on quickly when switch is closed? The answer is that propagation of electric field takes place with the speed of light.

Q4: Write a note on electroencephalogram (EEG).

Answer: **Electroencephalogram (EEG):**

EEG is a neurological test that uses an electronic monitoring device to measure and record electrical activity in the brain. Special sensors [electrodes] are attached and hooked by wires to a computer. EEG measures the voltage fluctuations resulting from ionic current flows within the neurons of the brain.

The brain's electrical charge is maintained by billions of neurons. Neurons are electrically charged [or polarized] by membrane transport proteins that pump ions across their membranes. Brain electrical current consists mostly of $Na^+$, $K^+$, $Ca^{++}$ and $Cl^-$ ions that are pumped through channels in neuron membranes. The computer records your brain's electrical activity on the screen or on paper as wavy lines. Thus the P.D created by the electrical activity of the brain is used for diagnosing abnormal behavior. The electrodes are not harmful to your body.

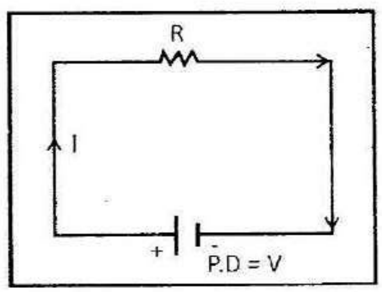


EEG detects and measures electrical signals

**Q5: State and explain Ohm's law. Discuss its scope and range of validity. (ETEA 2005)**

Answer: **Ohm's Law:**

This law states that "the magnitude of the current in metals is proportional to the applied voltage if the physical state of the conductor remains unchanged."




**Explanation:**

If "V" represents the applied voltage and "I" represents the amount of current flowing through the conductor, then we have,

$$I \propto V \Rightarrow I = constant \times V \Rightarrow I = \frac{1}{R} \times V$$

$$\boxed{V = IR} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_}(1)$$

Equation (1) represents the mathematical form of ohm's law. In equation (1) "R" is constant and is known as resistance of the conductor.

## Scope and Validity of Ohm's Law:

The ohm's law plays an important role in electrodynamics. Using this law, we can measure the current, voltage or resistance in a given electric circuit.

The ohm's law is valid for metallic circuits and many other circuits containing electrolytic resistance. The graph between current and voltage for ohmic conductors gives us a straight line, as shown in figure (a).

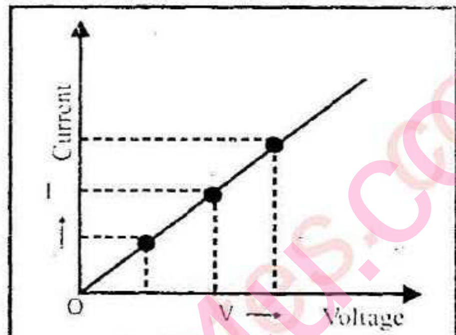
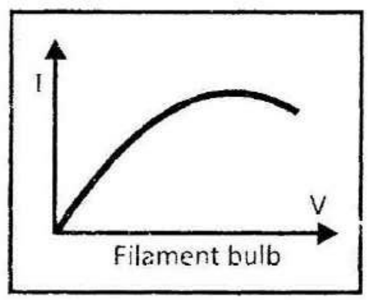


Fig (a)

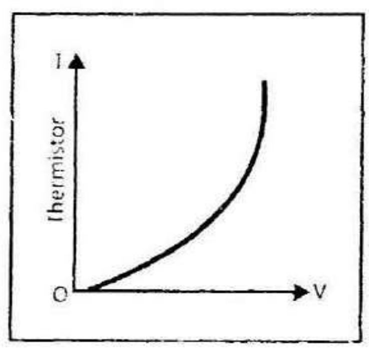
## Ohm's Law and Non-Ohmic Conductors: (ETEA 2007,2012-13)

The ohm's law is not valid for all conducting materials. Those materials for which the slope of "I" verses "V" graph is not constant are called non-ohmic materials. For example,

1. The filament of an electric bulb behaves like non-ohmic conductor. The I-V graph for a filament bulb shows that the graph bends over as "V" and "I" increases. It shows that a given change of "V" causes a correspondingly smaller change in "I" at larger values of "V". Thus the slope of graph decreases with the increase of voltage.

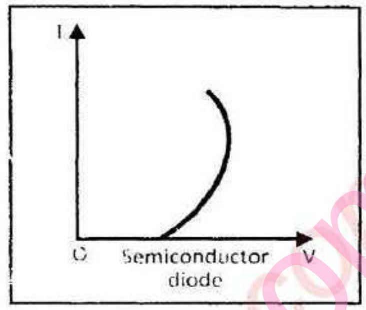



2. Thermistor is also an example of non-ohmic conductor. The I-V graph for thermistor bends upward which shows that their resistance decreases sharply as their temperature rises and hence current increases.




3. Semi conductor diode is another example of non-ohmic conductors. The I-V

graph of a semi conductor diode shows that it is also non-linear graph. The current passes when the voltage is applied in one direction but it is almost zero when it acts in the opposite direction.



Semiconductor diode

**Q6: (a) Define and explain electrical resistance.**
**(b) Discuss the factors upon which the resistance of a conductor depends. (ETEA 2006-2008)**

**Answer: a) <u>Electrical Resistance</u>:**

**<u>Definition</u>:** "The opposition offered by the molecules or atoms of a substance to the flow of free electrons is known as electrical resistance."

**<u>Explanation</u>:**

The resistance depends upon the nature of the material. Certain metals like silver, copper and aluminum offer very little opposition to the flow of electric current. The resistance is the electric friction offered by the substance which causes the production of heat with the flow of electric current. The moving electrons collide with atoms or molecules of the material and each collision results in the liberation of minute quantity of heat.

**<u>Unit of Resistance</u>:** The S.I unit of resistance is "ohm" which is represented by the symbol "$\Omega$". [$\Omega \rightarrow$ omega]

As $\quad V = IR \Rightarrow R = \dfrac{V}{I}$

$$\Rightarrow R = \frac{1\,\text{volt}}{1\,\text{ampere}} = 1\,\text{ohm}\,[\Omega]$$

So the unit of resistance is ohm which is defined as "**<u>the resistance of a conductor is said to be 1 ohm if one ampere current is flowing through it by applying a P.D of one volt across its ends.</u>**"

**b) <u>Factors upon which Resistance depends</u>:**

The resistance of a conductor depends upon the following factors:

The resistance is directly proportional to the length of the conductor i.e.

$R \propto L$ ______________ (1)

2. The resistance is inversely proportional to the area of cross-section of the conductor i.e.

$R \propto \frac{1}{A}$ ______________ (2)

Thus a thicker wire [conductor] will have smaller resistance per metre and hence less amount of energy will be lasted as heat.

3. The resistance of a conductor depends upon its nature. Some material offer high resistance while some offer smaller resistance.

4. The resistance of a conductor also depends upon temperature. Its resistance increases with increase in temperature and vice versa.

Now by keeping the temperature constant, relation (1), (2) can be combined as,

$$R \propto \frac{L}{A}$$

$$\Rightarrow R = \text{constant} \cdot \frac{L}{A} \Rightarrow \boxed{R = \frac{\delta L}{A}} \text{ ______________ (3)}$$

In equation (3), "δ" is constant and is known as specific resistance or resistivity of the material.

| Q7: Define and explain resistivity or specific resistance. (ETEA 2011) |
|---|

Answer: **Resistivity or Specific Resistance:**

**Definition:** "The resistance offered by 1m length of wire of a material having an area of cross-section of $1m^2$ is known as resistivity or specific resistance."

**Explanation:**

Different materials posses different values of resistivity. The resistivity of metals and alloys is very small. Therefore, these materials are good conductors of electric current.

On the other hand, resistivity of insulators is extremely large. So these materials hardly conduct any current.

There is also an intermediate class of material which are known as semiconductors. The resistivity of these material lies between conductors and insulators.

**Unit of Resistivity:**

We know that,

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

$$\Rightarrow \quad \delta = \frac{RA}{L} = \Omega \cdot m^2/m = \Omega \cdot m$$

So the unit of resistivity is $(\Omega \cdot m)$.

**Q8: Define: (a) conductance (b) conductivity (ETEA 2007)**

Answer: **a) Conductance:**

"The reciprocal of resistance of a conductor is known as conductance." It is represented by "G". If "R" represents the resistance of a conductor, then its conductance "G" can be written as,

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

**Unit of Conductance:** The unit of conductance is "mho". Another unit is "siemen". It is represented by "S".

**b) Conductivity: (ETEA 2015)**

"The reciprocal of resistivity of a conductor is called its conductivity." It is represented by "σ". If "δ" represents the resistivity of a conductor, then its conductivity can be written as,

$$\boxed{\sigma = \frac{1}{\delta} = \frac{L}{RA}}$$

**Unit of Conductivity:** The unit of conductivity is "$mho \cdot m^{-1}$" or "$siemen \cdot meter^{-1}$" $(S \cdot m^{-1})$.

**Q9: (a) Discuss the effect of temperature on resistance of a conductor. Also explain the temperature co-efficient of resistance. (b) Discuss the temperature's effect on resistivity of a conductor. Also discuss the temperature co-efficient of resistivity.**

Answer: **a) Effect of Temperature on Resistance:**

The resistance of a material changes with the change in temperature. The change in resistance due to temperature depends upon the type of material. For example,

1. The resistance of pure metals like copper, aluminum increases with the increase in temperature.
2. The resistance of electrolytes, insulators like glass, mica, rubber etc decreases with the increase in temperature.

The resistance of semi-conductors like germanium and silicon etc also decreases with increase in temperature.

## Temperature Coefficient of Resistance:

Consider a conductor having resistance "$R_o$" at temperature "0°C" and "$R_T$" at "T°C". Let "$R_T - R_o$" represents the change in resistance due to increase in temperature, then we have,

1. $(R_T - R_o)$ is directly proportional to initial resistance "$R_o$" i.e.

$$(R_T - R_o) \propto R_o \quad \text{\_\_\_\_\_\_\_\_\_\_(1)}$$

And

2. $(R_T - R_o)$ is directly proportional to the rise in temperature "T". i.e.

$$(R_T - R_o) \propto T \quad \text{\_\_\_\_\_\_\_\_\_\_(2)}$$

Combining relations (1), (2), we get,

$$(R_T - R_o) \propto R_o T$$

$$\Rightarrow R_T - R_o = \text{constant } R_o T$$

$$\Rightarrow R_T - R_o = \alpha R_o T \quad \text{\_\_\_\_\_\_\_\_\_\_(3)}$$

In equation (3), "$\alpha$" is constant and is known as temperature coefficient of resistance. From equation (3), we have,

$$R_T = R_o + \alpha R_o T$$

$$\Rightarrow \boxed{R_T = R_o(1 + \alpha T)} \quad \text{\_\_\_\_\_\_\_\_\_\_(4)}$$

Equation (4) represents the final resistance of the conductor.

## Definition of $\alpha$:

From equation (3), we have,

$$\boxed{\alpha = \frac{(R_T - R_o)}{R_o T}} \quad \text{\_\_\_\_\_\_\_\_\_\_(5)}$$

From equation (5) "$\alpha$" can be defined as "the temperature coefficient of resistance is equal to increase in resistance per ohm initial resistance per degree rise in temperature". Its unit is $K^{-1}$.

> **Note:** *The resistance of metals increases with the increase in temperature, so "$\alpha$" is taken as positive. While the resistance of semi-conductors decreases with increases in temperature, so "$\alpha$" is taken as negative.*

### b) Effect of Temperature on Resistivity:

The resistivity of pure metals increases with increase in temperature. While the resistivity of insulators and semi-conductors decreases with increase in temperature.

### Temperature Co-efficient of Resistivity:

In terms of resistivity, equation (5) can be written as,

$$\boxed{\alpha = \frac{(\rho_T - \rho_o)}{\rho_o T}} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_ (6)}$$

From equation (6), "$\alpha$" can be defined as, "<u>the temperature co-efficient of resistivity is equal to increases in resistivity per unit initial resistivity per degree rise in temperature</u>". Its unit is $K^{-1}$.

> **Note:** *The resistivity of metals increases with the increase in temperature, so "$\alpha$" is taken as positive. On the other hand, the resistivity of semi-conductors decreases with increase in temperature, so "$\alpha$" in such a case is taken as negative.*

> **Q10: What are wire wound resistors? Discuss the use of wire wound variable resistors as (a) rheostat (b) potential divider**

Answer: **Wire Wound Resistor:**

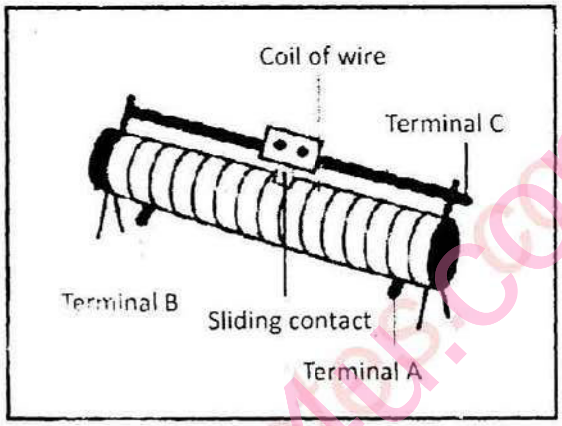
The wire wound resistors are those which posses high stability and give accurate values. These resistors are designed on the principle that if the length of wire increases, then resistance will also increases and vice versa.

### Variable Wire Wound Resistors:

It is a type of wire wound resistor whose resistance can be varied according to our needs and desires. It consists of a bare manganin wire which is wound on an isolated cylinder. The end of the wire is connected to two fixed ends "A" and "B". There is a 3rd terminal "C" which is attached to a sliding contact. This terminal can be moved over the wire.

## a) Use of Variable Wire Resistor as Rheostat:

The rheostat is a variable type of wire wound resistor which can be used for controlling current in a circuit. It consists of three terminals A, B and C as shown in the figure.




The terminal "A" and "B" are fixed while the terminal "C" can slide over the wire. If the sliding contact "C" is moved away from terminal "A", the length increases and hence the resistance included in the circuit increases.

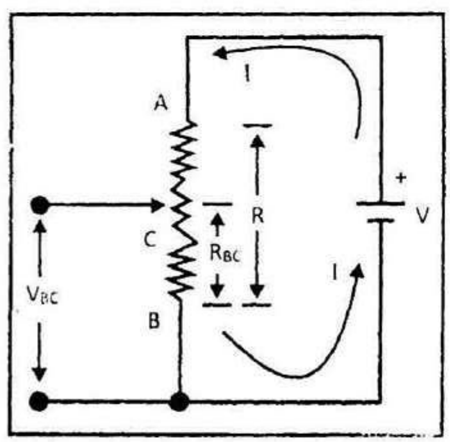
If the sliding contact "C" is moved towards "A", the resistance decreases. By adjusting the resistance in the circuit, the current in the circuit can be controlled.

## b) Use of Variable Wire Resistor as Potential Divider:

A potential divider is a type of variable wire resistor which provides a convenient way of getting a variable potential difference from a fixed potential difference. With the help of the battery, a potential difference "V" is applied across ends "A" and "B" of the resistor. Let "R" be the resistance of wire "AB" and "I" be the current passing through it, then

$$V = IR \Rightarrow I = \frac{V}{R} \quad \text{———} (1)$$

If "$R_{BC}$" is the resistance of the portion of the wire "BC" and "I" is the current passing through it, then the potential difference between the points "B" and "C" is given by,




$$V_{BC} = IR_{BC} \quad \text{———} (2)$$

Putting equation (1) in equation (2), we get,

$$\boxed{V_{BC} = \frac{V}{R} R_{BC}} \quad \text{———} (3)$$

Depending on the position of the sliding contact "C", the value of the fraction "$\frac{R_{BC}}{R}$" can be varied from "0" to "1". When the contact "C" is moved towards "B", the length decreases and hence the resistance "$R_{BC}$" of the portion of the wire decreases. Thus "$V_{BC}$" decreases. On the other hand if the sliding contact "C" is moved towards the end "A", the length from "B" increases and "$R_{BC}$" of the portion of the wire increases. Thus "$V_{BC}$" increases.

**Q11: What is a thermistor? Discuss its properties and uses.**

Answer: **Thermistor:**

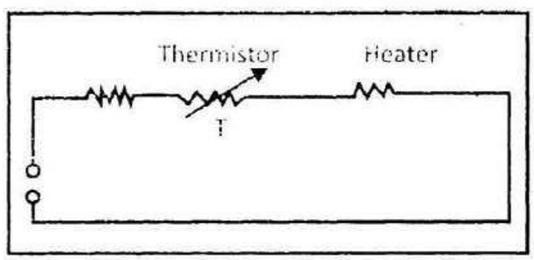
Thermistor is another type of resistor which made from semi conductors. Its resistance varies rapidly and predictably with temperature.

**Properties of Thermistor:**

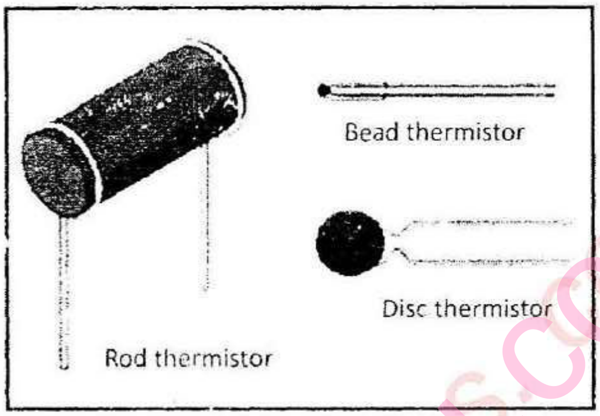
1. It is a heat sensitive device whose resistance changes very rapidly with change in temperature.
2. The temperature co-efficient of a thermistor is very high.
3. The temperature co-efficient of a thermistor can be both positive and negative.

**Uses or Applications of Thermistor:**

1. A thermistor with negative temperature co-efficient of resistance may be used to safeguard against current surges in a circuit where this could be harmful. For example, in a circuit where the heaters of the radio valves are in series, a thermistor "T" is included in the circuit. When the voltage supply is switched ON, the thermistor has a high resistance at first because it is cold. So it limits the current to a moderate value. As it warm up, the thermistor resistance drops appreciably and an increased current then flow through the heaters.




Modern applications, communication tools and accessories like mobile phones, computers, LCD displays, CPUs, rechargeable batteries, medical and patient monitoring equipment are all equipped with thermistors, so they can be used continuously without fear of overheating and appliance damage.




2. A thermistor with a negative temperature co-efficient (NTC) can be used to issue an alarm for excessive temperature of winding of motors, transformers and generators. When the temperature of windings is low, the thermistor is cool and its resistance is high. Therefore, only a small current flows through the thermistor. When the temperature of the windings is high, the thermistor is hot and its resistance is low. So a large current flows in the coil to close the contact.

3. Some appliances like washing machines, clothes dryers, refrigerators and freezers, hair dryers, curling irons, ovens, toasters, thermostat, air conditioners and fire alarms also have negative temperature co-efficient for temperature control.

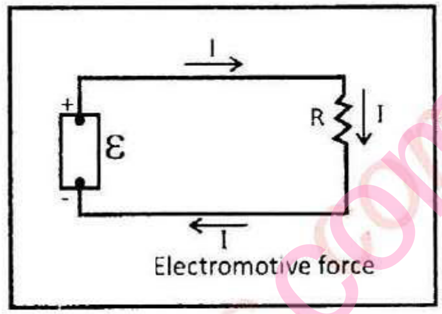
**Q12: Write a note on electromotive force (e.m.f).**

**Answer: Electromotive Force (e.m.f):**

**Definition:** "The strength of a source which can maintain a potential difference between two points for maintaining steady current in the circuit is known as electromotive force (e.m.f)."

**Explanation:**

We know that for maintaining a steady current in a circuit, there is need of steady potential difference across the circuit. This is possible only, if certain device changes some other form of energy into electrical energy. For example, an electric generator converts mechanical energy into electrical energy. Such devices are able to drive the positive charge from its negative terminal to positive terminal. For doing so, work must be done on the charge. This work on the charge is converted into electrical energy. Such devices which can maintain steady potential difference across its terminal for maintaining steady current is known as source of emf.




Now if the work done by the source on charge "q" is "W", then the emf of such source is given by,

$$emf = \frac{work}{charge}$$

$$\Rightarrow \boxed{\varepsilon = \frac{W}{q}}$$

Its unit is "$\frac{J}{C}$" or "volt".

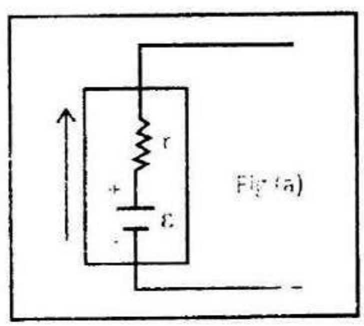
## Sources of e.m.f:

The work done by emf on charge carriers in its interior must be derived from a source of energy. There are many sources of emf. For example,

1. Batteries or cells convert chemical energy into electrical energy.
2. Electrical generators convert mechanical energy into electrical energy.
3. Thermocouples convert heat energy into electrical energy.
4. A solar cell [radiant] converts sunlight directly into electrical energy.

**Q13: Discuss the internal resistance of a supply.**

Answer:



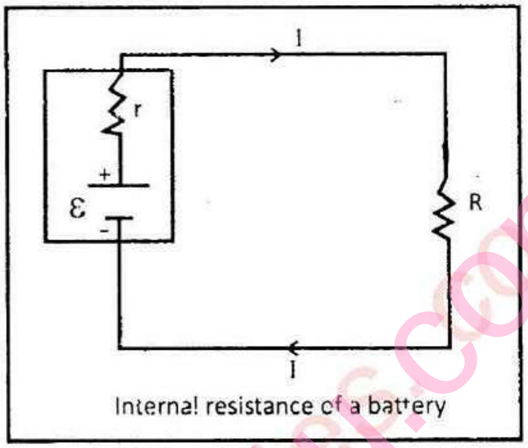

Consider a battery [cell] of emf "ε" having internal resistance "r" as shown in figure (a).

Now if the terminals of the battery are connected to external resistance "R", then current will flow in the circuit, as shown in figure (b).

Now the potential drop across the internal resistance is given by,

$V_{ir} = Ir$ ____________ (1)

While the terminal P.D is given by,




$V_T = IR$ ________ (2)

Now the emf "ε" of the circuit is given by,

$\varepsilon = V_{in} + V_T$ ______ (3)

Putting equation (1), (2) in equation (3), we get,

$\varepsilon = Ir + IR$

$\Rightarrow \varepsilon = I(r + R)$ ______ (4)

Equation (4) represents the relation between emf "ε" of the source, internal resistance "r" and terminal P·D ($V_T = IR$)· From equation (3), we have,

$V_T = \varepsilon - V_{in}$

$\Rightarrow V_T = \varepsilon - Ir$ __________ (5)

Equation (5) shows that the terminal voltage "$V_T$" is less than the emf "ε" because of the term "Ir" which represents the potential drop across the internal resistance "r".

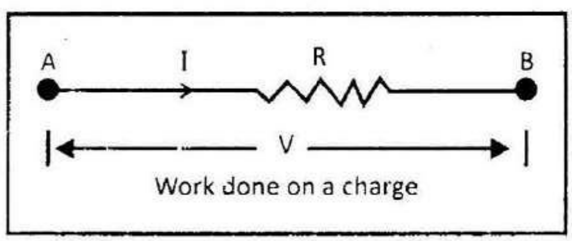
**Q14: Define and explain electric power·**

**Answer: Electric Power:**

**Definition:** "The rate at which work is done in an electric circuit is known as electric power·" i·e·

$$\text{Electric power} = \frac{\text{work done in electric circuit}}{\text{time}}$$

**Explanation:**




When voltage is applied to a circuit, it causes current to flow through it· Clearly work is being done in moving the charges in the circuit· This work done in moving the charges in a unit time is called the electric power·

Let "V" represents the P·D across AB, "Q" represents the total charge flowing in time "t", then

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

$\Rightarrow W = QV$ ______ (1)

We know that,

$I = \frac{Q}{t}$ [$I \rightarrow$ current]

$\Rightarrow Q = It$ ______ (2)

Putting equation (2) in equation (1), we get,

$W = ItV$ ______ (3)

We know that,

$P = \frac{w}{t}$ ______ (4)

Putting equation (3) in equation (4), we get,

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

$\Rightarrow \boxed{P = IV}$ ______ (5)

We know that,

$V = IR$ ______ (6)

Putting equation (6) in equation (5), we get,

$\boxed{P = I^2R}$ ______ (7)

As $V = IR \Rightarrow I = \frac{V}{R}$ ______ (8)

Putting equation (8) in equation (5), we get,

$\boxed{P = \frac{V^2}{R}}$ ______ (9)

Equations (5), (7) and equation (9) represents the amount of power consumed in electric circuit.

**Unit of Electric Power:**

As $P = IV$

$\Rightarrow P = 1amp \times 1volt = 1$ watt

So the S.I unit of power is "watt" which is defined as, "the power consumed in a circuit is said to be 1 watt if a P.D of 1 volt causes a current of 1 ampere to flow through it."

| 1kilo watt (Kw) = $10^3$ watts; 1mega watt (Mw) = $10^6$ watts |
|---|

| Q15: Define kilowatt-hour. |
|---|

Answer:

Joule is a very small unit of energy, while the electric energy is commonly consumed in very large quantity", so for the measurement of electric energy, we need a bigger unit which is known as kilowatt-hour. It is defined as, "the amount of energy obtained by a power of 1 kilowatt in one hour".

$$\boxed{\begin{aligned} 1\,Kw - h &= 10^3 w \times 3600 sec = 3.6 \times 10^6 w \cdot s \\ 1Kw - h &= 3.6 \times 10^6 J \end{aligned}}$$

[$1h = 3600s$

[$1J = 1w \cdot 1sec$

**Q16: Explain the concept of electric energy and obtain the energy equation for a current carrying circuit.**

Answer:

The electric generators, car batteries, dry cells, solar cells etc are the devices that convert various forms of energy into electric energy. These devices maintain P.D across its terminals and cause current through the circuit.

A current carrying circuit always consume electrical energy and converts it to some other form of energy. For example,

1. The electric motor converts electrical energy into mechanical energy.
2. The electric iron converts electrical energy into heat energy.
3. The electric lamp converts electrical energy into light energy.

Now to obtain an equation for the energy expended in a circuit, consider a closed electric circuit energized by a source of emf such as a battery or generator. The circuit may comprise only one or of several components such as a lamp, fan, heater, bell, motor, radio etc. If "V" is the P.D between two points in the circuit and "I" is the current in the circuit, then the electrical energy delivered to the circuit is given by,

$$W = p \times t \quad \text{\_\_\_\_\_\_\_\_\_\_} (1)$$

As $P = IV$ ____________ (2)

Putting equation (2) in equation (1), we get,

$$\boxed{W = Ivt} \quad \text{\_\_\_\_\_\_\_\_\_\_} (3)$$

We also know that,

$$V = IR \quad \text{\_\_\_\_\_\_\_\_\_\_} (4)$$

Putting equation (4) in equation (3), we get,

$$\boxed{W = I^2Rt} \quad \text{\_\_\_\_\_\_\_\_\_\_} (5)$$

Equation (3). (5) represents the energy equation for a current carrying circuit. The energy equation is applicable to the lightning of a lamp, the turning of a motor and the charging of a battery etc.

**Q17: Explain maximum power output or maximum power transfer theorem.**

Answer:

In many electronic circuits and systems it is important to have maximum transfer of power from the source to the load. For example, in radio or TV transmitting systems, we need maximum transfer of power from the transmitting medium to the antenna systems. We want maximum transfer of power from amplifier to the speaker system. This is accomplished by proper matching of load resistance "R" and source resistance "r".

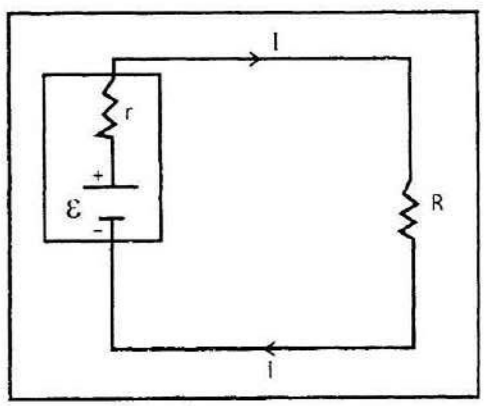
For better understanding, consider a circuit in which a source of emf "ε" having internal resistance "r" is connected to a load resistor "R" as shown in the figure. In such case, the charges flow from a point of higher potential to a point of lower potential. Here loss of P.E occurs and the loss of P.E per second is known as power delivered to "R" by the current "I". Now we know that the electric power is given by,

$$P_{out} = I^2R \quad \text{\_\_\_\_\_\_\_\_(1)}$$

We also know that, the relation between I, r, ε and "R" is given by,

$$I = \frac{\varepsilon}{(R+r)} \quad \text{\_\_\_\_\_\_\_\_(2)}$$

Putting equation (2) in equation (1), we get,




$$P_{out} = \frac{\varepsilon^2 R}{(R+r)^2}$$

$$\Rightarrow P_{out} = \frac{\varepsilon^2 R}{(R^2 + r^2 + 2Rr)}$$

$$\Rightarrow P_{out} = \frac{\varepsilon^2 R}{(R^2 + r^2 + 2Rr + 2Rr - 2Rr)}$$

$$\Rightarrow P_{out} = \frac{\varepsilon^2 R}{(R^2 + r^2 + 4Rr - 2Rr)}$$

$$\Rightarrow P_{out} = \frac{\varepsilon^2 R}{(R^2 + r^2 - 2Rr + 4Rr)} \qquad \left[(a-b)^2 = a^2 + b^2 - 2ab\right]$$

$$\Rightarrow P_{out} = \frac{\varepsilon^2 R}{\left[(R-r)^2 + 4Rr\right]} \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} (3)$$

*Equation (3) shows that power delivered will be maximum if the internal resistance "r" is equal to the load resistance "R". It is also known as maximum power transfer theorem. So by putting r = R, equation (3) can be written as,*

$$P_{out} = \frac{\varepsilon^2 R}{\left[(R-R)^2 + 4R \cdot R\right]}$$

$$\Rightarrow P_{out} = \frac{\varepsilon^2 R}{4R^2}$$

$$\Rightarrow \boxed{(P_{out})_{max} = \frac{\varepsilon^2}{4R}} \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} (4)$$

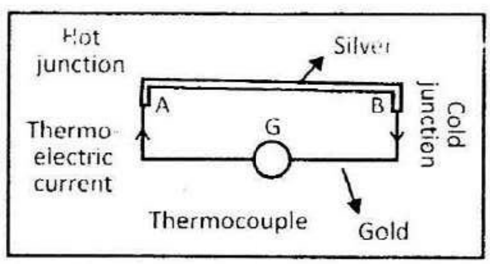
*Equation (4) represents the maximum value of output power. In terms of "r", equation (4) can be written as,*

$$\boxed{(P_{out})_{max} = \frac{\varepsilon^2}{4r}} \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} (5)$$

| *Q18: Write a note on thermocouple.* |
|---|

*Answer:* ***Thermocouple:***

*It is a two junction circuit device which gives an experimental relationship between heat and electricity. This relation between heat and electricity was studied by Thomas Seebeck in 1821.*




*He joined two wires of two dissimilar metals to form a circuit. A galvanometer was also connected to the ends of wires, as shown in the figure. He pointed out that if one junction is heated to a high temperature and the other end remained at low temperature, then an emf is generated in the circuit due to which current flows in the* circuit and the galvanometer shows deflection. Such emf is known as thermoelectric emf and the current is known as thermoelectric current. This phenomenon is known as "Seebeck Effect". In this process, heat energy is converted into electrical energy.

The thermo emf produced is very small i.e. of the order of milli volt per every degree of temperature difference. The "Seebeck Effect" is reversible. i.e. if the hot junction and cold junction are interchanged, then the direction of emf and current reverses. The value of thermo emf depends upon the separation of two metals and temperature difference. If the temperature of hot junction is $T°C$ and temperature of cold junction is $0°C$, then the thermo emf is given by,

$$\boxed{\varepsilon = \propto T + \frac{1}{2}\beta T^2} \quad \text{———————} (1)$$

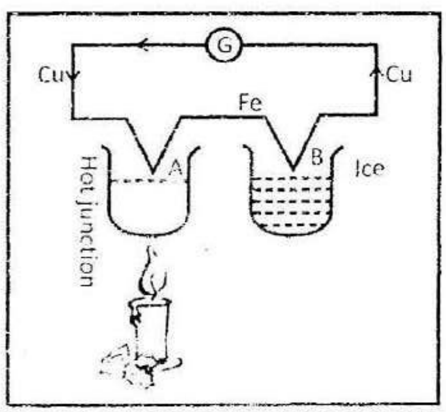
In equation (1), "$\propto$" and "$\beta$" are constants and are known as "thermoelectric coefficients". The values of "$\propto$" and "$\beta$" depends on the nature of the metals.

The thermocouples are mostly used as temperature sensors in industry due to their low cost, simplicity, size and useable temperature range.

**Q19: Discuss the variation in thermoelectric emf with temperature.**

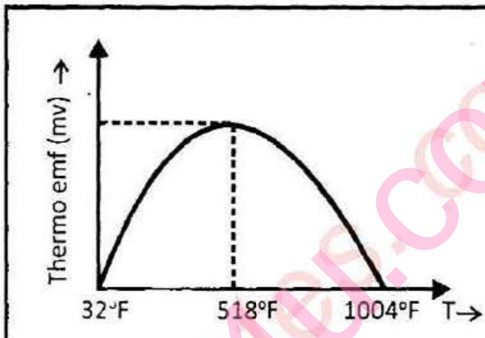
Answer:

Consider a Cu-Fe thermocouple, having two junctions "A" and "B" as shown in the figure.




In the beginning, the two junctions are at the same temperature, so there is no thermo emf and no current and hence the galvanometer "G" shows no deflection.

Now if the junction "B" is kept at 0°C, and the temperature of junction "A" is allowed to increase gradually, then the thermo emf increases and current flows in the circuit due to which the galvanometer shows deflection. The thermo emf increases with increase in temperature and finally reaches to its maximum value at a certain temperature. The temperature at such stage is known as neutral temperature "$T_n$".



Variation of thermo emf with temperature T for copper-iron thermocouple

Now on further increasing of temperature, the thermo emf begins to decrease. The temperature at which the thermo emf becomes zero is known as inversion temperature. The given graph shows the variation of thermo emf with the temperature.

**Q20: Write a note on resistance thermometers.**

Answer: **Resistance Thermometers:**

The resistance thermometers are also known as resistance temperature detectors "RTD". These thermometers can be used as sensors to measure the temperature by correlating the resistance of "RTD" element with temperature.

The "RTD" consists of certain unique elements like platinum, copper or nickel. These elements have a unique, repeatable and predictable resistance versus temperature [R vs T].

The [R vs T] relationship is defined as, "the amount of resistance change of the sensor per degree of temperature change".

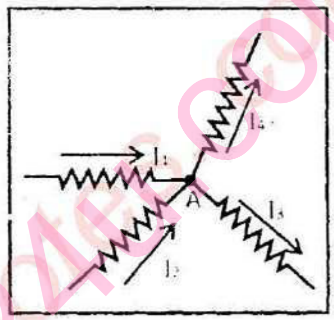
The platinum is the best metal for RTDs because it follows a very linear resistance-temperature relationship and it follows the [R vs T] relationship in a highly repeatable manner over a wide range of temperature. The unique properties of platinum make it the best material of choice for temperature standards over the range of -185°C to 630°C. The RTDs are now used instead of thermocouples in industry due to their high accuracy and repeatability.

**Q21: State and explain Kirchhoff's current law (KCL). (ETEA 2012)**

Answer: **Statement:**

It states that the algebraic sum of all the currents meeting at a junction of a circuit is equal to zero. i.e. $\sum I = 0$

**Explanation:**




Consider a circuit having a junction "A" as shown in the figure. Let "$I_1$" and "$I_2$" be the current flowing into the junction and $I_3$, $I_4$ be the current leaving the junction.

The current which is flowing into the junction is taken as positive. While the current leaving the junction is taken as negative. Now according to Kirchhoff's current law, we have,

$$\sum I = 0$$

$$\Rightarrow \quad I_1 + I_2 + (-I_3) + (-I_4) = 0$$

$$\Rightarrow \quad \boxed{I_1 + I_2 = I_3 + I_4} \quad \text{------} (1)$$

Equation (1) represents another form of Kirchhoff's current law. From equation (1), KCL can be defined as, **"the total current entering a junction is equal to the total current leaving the junction".**

> **Note:** In case of KCL, no charge can accumulate at a junction. So the total charge entering the junction per unit time must be equal to the total charge leaving the junction per unit time. Charge per unit time is called current. Thus KCL is a manifestation of the conservation of electric charge.

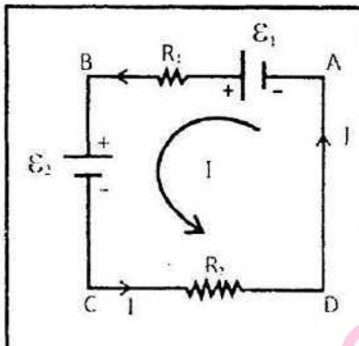
**Q22: State and explain Kirchhoff's voltage law (KVL).**

Answer: **Statement:**

KVL states that, in any closed electrical circuit, the algebraic sum of all the electromotive force (emf) and voltage drops in "IR" resistors is equal to zero. i.e.

$$\sum emf + \sum IR = 0$$

## Explanation:



Kirchoff's voltage law

Consider a circuit which consists of two emf sources "$\varepsilon_1$" and "$\varepsilon_2$" and two resistors "$R_1$" and "$R_2$" as shown in the figure.

Let we start from "A" and go around the circuit in anti-clock wise direction. Now the sign conventions for "emf" and "IR" drops are given below:

1. If we consider the circuit from minus to plus direction, then the emf will be taken as positive. So in given circuit, "$\varepsilon_1$" is taken as positive.
2. If we go through a resistor in the same direction of assumed current, then "IR" drops will be taken as negative. So in above circuit, "$IR_1$" and "$IR_2$" are taken as negative.
3. If we consider the circuit from positive to negative, then emf will be taken as negative. So in the given circuit, "$\varepsilon_2$" is taken as negative.

Now applying Kirchhoff's voltage law to the given circuit, we get,

Sum of emfs + sum of IR drops = 0

$$\Rightarrow \varepsilon_1 + (-\varepsilon_2) + (-IR_1) + (-IR_2) = 0$$

$$\Rightarrow \varepsilon_1 + (-\varepsilon_2) = IR_1 + IR_2$$

$$\Rightarrow \boxed{\sum \varepsilon = \sum IR} \qquad \text{(1)}$$

Equation (1) represents another form of KVL. From equation (1), KVL can be also defined as "the sum of all the emfs in a circuit is equal to the sum of all the IR voltage drops in that loop or circuit".

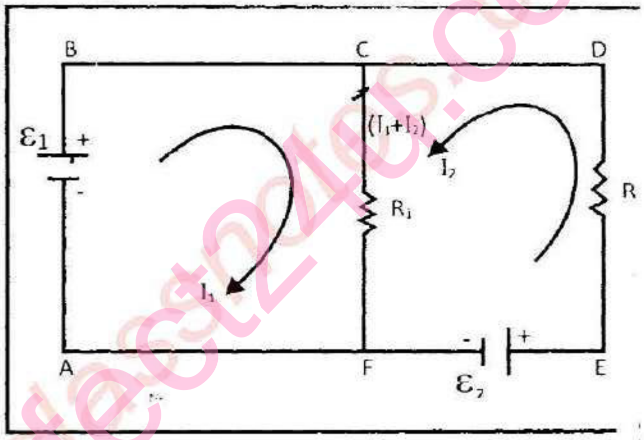
Note. The left hand side of equation (1) represents the total work done by the sources of emf to impart energy [illegible] charge. The right hand side of equation (1) represents the dissipation of acquired energy as the charge falls through a resistive medium. The gain in energy is equal to the loss in energy. So KVL is a manifestation of law of conservation of energy.

**Q23: Discuss the procedures of Kirchhoff's laws for problem solution.**

**Answer:**

Consider a circuit which consists of two sources of emfs "$\varepsilon_1$" an "$\varepsilon_2$" and two resistors "$R_1$" and "$R_2$" as shown in the figure. No for given values of $\varepsilon_1$, $\varepsilon_2$, $R_1$ and $R_2$ we can use Kirchhoff's law t determine the current $I_1$, $I_2$ in all branches of the circuit.

Here we divide the circuit into two loops i.e. "ABCFA" and "CDEFC". Let "$I_1$" be the current through loop "ABCFA" and "$I_2$" be current through loop "CDEFC". The current in branch "CF" will be $(I_1 + I_2)$.




**Loop "ABCFA":**

In case of loop "ABCFA", we go from negative to positive termin so the emf "$\varepsilon_1$" is taken as positive. As we go through resist "$R_1$" in the assumed direction of current, so $(I_1 + I_2)R_1$ drop is ta en as negative.

Now applying Kirchhoff's voltage law to loop "ABCFA", we get,

$$\varepsilon_1 + \left[-(I_1 + I_2)R_1\right] = 0$$

$$\Rightarrow \varepsilon_1 = (I_1 + I_2)R_1$$

$$\Rightarrow \varepsilon_1 = I_1R_1 + I_2R_1 \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_} (1)$$

**Loop "CDEFC":**

In case of loop "CDEFC", we go from positive to negative termin so emf "$\varepsilon_2$" is taken as negative. As we go through "$R_2$" and "$R_1$" opposite direction of assumed current, so $I_2R_2$ drop and $(I_1 + I_2)$ drop is taken as positive.

Now applying Kirchhoff's voltage law to loop "CDEFC", we get,

$$-\varepsilon_2 + I_2R_2 + (I_1 + I_2)R_1 = 0$$

$$\Rightarrow \varepsilon_2 = I_2R_2 + I_1R_1 + I_2R_1 \quad \text{\_\_\_\_\_\_\_\_\_\_} (2)$$

low for given values of $\varepsilon_1$, $\varepsilon_2$, $R_1$, $R_2$, we can simplify equations (1), 2) for finding the values of $I_1$ and $I_2$ in the given circuit.

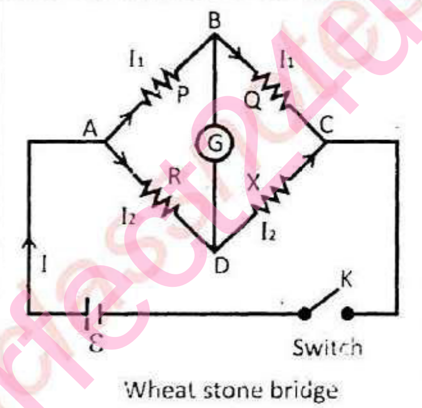
**Q24: What is a Wheatstone bridge? Explain with diagram, the principle, working and uses of Wheatstone bridge. (ETEA 2007)**

**nswer: Wheatstone Bridge:**

he Wheatstone bridge is an instrument which was proposed by Vheatstone for finding the value of unknown resistance accurately.

**onstruction:**

t consists of four resistors P, Q, R nd X as shown in the figure.



Wheat stone bridge

 and Q are known fixed resistors, R variable resistor while "X" is unnown resistor whose value is to be ound. A battery of emf "$\varepsilon$" is conected across the junctions "A" and C" while a galvanometer "G" is conected across the junctions "B" and D" as shown in the figure.

**rinciple:**

he principle of Wheatstone bridge is that, if $\frac{P}{Q} = \frac{R}{X}$, then the ridge will be in balance conditions and no current will pass through lvanometer.

**lorking:**

e value of "P" and "Q" are fixed properly. When the key "K" is vitched ON, the current "I" flows through the circuit. When the irrent "I" reaches the junction "A", it divide between the two anches unequally and as a result, the galvanometer shows deflection.

ow the value of resistance "R" is varied gradually until the galvanometer shows zero current. Under such conditions, the bridge is id to be in balance conditions. The point at which the bridge is lanced is known as null point.

der balance conditions, let "$I_1$" be the current through "P" and

"Q", and "$I_2$" be the current through "R" and "X" respectively.
Now under balance conditions, we have,

Potential drop across AB = potential drop across AD

$$\Rightarrow I_1P = I_2R \qquad (1)$$

Similarly,

Potential drop across BC = potential drop across DC

$$\Rightarrow I_1Q = I_2X \qquad (2)$$

Dividing equation (1) by equation (2), we get

$$\frac{I_1P}{I_1Q} = \frac{I_2R}{I_2X}$$

$$\Rightarrow \boxed{\frac{P}{Q} = \frac{R}{X}} \qquad (3)$$

Equation (3) represents the principle of Wheatstone bridge.
From equation (3), we have,

$$\boxed{X = \frac{RQ}{P}} \qquad (4)$$

As the values of R, Q and P are known, so using equation (4), the value of unknown resistance "X" can be calculated accurately.

**Uses of Wheatstone Bridge:**

The Wheatstone bridge can be used for determining the value of unknown resistance accurately under balance conditions.

Q25: What is potentiometer? Explain its principle, construction and working theory. What are the advantages of using potentiometer for measuring potential difference? (ETEA 2009)

Answer: **Potentiometer:**

A potentiometer is a null type resistance network device which is used for measuring potential differences.

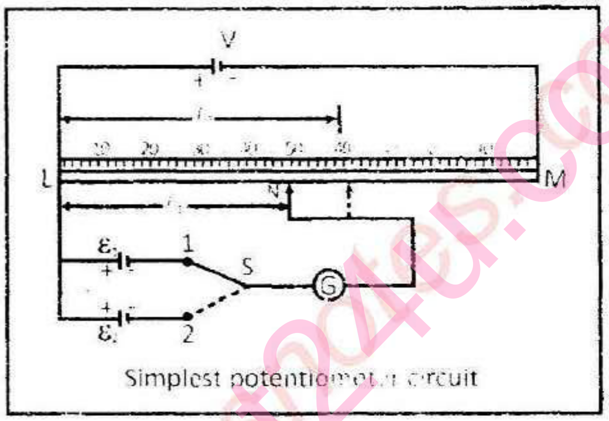
**Principle:**

The principle of potentiometer is that, the potential difference across any length of wire is directly proportional to its length when a constant current flows through it.

**Construction:**

A simplest type of potentiometer consists of wire "LM" of uniform area of cross-section. The wire is stretched along side of a scale and connected across a battery of potential "V" as shown in the figure. A standard cell of known emf "$\varepsilon_1$" is connected between "L" and terminal 1 of a two way switch "S" as shown in the figure.

## Working:



Simplest potentiometer circuit

The slider "N" is pressed momentarily against wire LM and its position is adjusted until the galvanometer deflection becomes zero. Let "$l_1$" be the length of wire between "L" and "N" under null condition. The fall of potential over length "$l_1$" of the wire is then the same as the emf "$\varepsilon_1$".

Now move the switch to terminal 2 where the cell of unknown emf "$\varepsilon_2$" is connected between "L" and "G". Now again adjust the slider "N" over the wire until the galvanometer shows zero deflection. Let "$l_2$" be the length of wire between "L" and "N" under null condition.

Here "$\varepsilon_1$" is equivalent to "$l_1$" and "$\varepsilon_2$" is equivalent to "$l_2$", so we get,

$\varepsilon_1 =$ [illegible] (1)

And $\varepsilon_2 =$ [illegible] (2)

Dividing equation (2) by equation (1), we get,

[illegible]

$\varepsilon_2 =$ [illegible] (3)

Using equation (3), we can determine the unknown emf "$\varepsilon_2$" of the cell

## Advantage of Using Potentiometer:

The potentiometer has greater advantage over other devices, because of null condition it draws no current from the source. Due to this, errors do not take place and as a result, we can measure the true value of emf.

## Applications of Potentiometer:

1. With the help of potentiometer, we can measure small emf up to 2V.
2. With the help of potentiometer, we can measure high emf i.e. 250V.
3. Using potentiometer, we can compare the emf of two cells.
4. Using potentiometer, we can measure the resistance.
5. Using potentiometer, we can measure the current.
6. With the help of potentiometer, we can make calibration of ammeter and voltmeter.

## SOLUTIONS OF EXAMPLES & ASSIGNMENTS

**EXAMPLE 12.1:**
Each second $10^{18}$ electrons flow from right to left across a cross-section of a wire attached to the two terminals of a battery. (a) Calculate the current in the wire, (b) in which direction the current is flowing?

**Solution:**

**Given Data:**

Number of electrons $= n = 10^{18}$

Time taken $= t = 1sec$

If "e" is the charge on a single electron, then charge on "n" electron is given by,

$$Q = ne = 10^{18} \times 1.6 \times 10^{-19}\,C$$

**Required:**

a) Current in the wire $= I = ?$

b) Direction of current $= ?$

Charge on electron $= e = 1.6 \times 10^{-19}C$

**Calculation:**

a) We know that,

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

$$\Rightarrow \quad I = \frac{10^{18} \times 1.6 \times 10^{-19}}{1}$$

$$\Rightarrow \quad I = 1.6 \times 10^{-1} \text{ amp}$$

$$\Rightarrow \quad I = 160.0 \times 10^{-3} \text{ amp}$$

$\boxed{10^{-3} = \text{milli}}$

$$\Rightarrow \quad \boxed{I = 160mA}$$

b) The current is flowing from left to right i.e. in opposite direction of electron flow.

**EXAMPLE 12.2:**
The high voltage is a TV receiver is 17KV. The maximum allowable current is 150μA. What is the least permissible value of load resistance?

<u>Solution:</u>

<u>Given Data:</u>

Voltage = $V$ = 17KV = $17 \times 10^3 V$

Current = $I$ = 150μA

$$\Rightarrow \quad I = 150 \times 10^{-6} A$$

Kilo = K = $10^3$ =
Micro = μ = $10^{-6}$

<u>Required:</u>

Load resistance = $R$ = ?

<u>Calculation:</u>

We know that,

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

$$\Rightarrow \quad R = \frac{17 \times 10^3}{(150 \times 10^{-6})}$$

$$\Rightarrow \quad R = 0.1133 \times 10^9 \Omega$$

$$\Rightarrow \quad \boxed{R = 113.3 \times 10^6 \Omega}$$

**EXAMPLE 12.3:**
A transmission line made of copper has a resistance of 100Ω at 0°C. Calculate the change in resistance between summer and winter, knowing that temperature varies from +35°C to -30°C. Assume the temperature coefficient of copper to be $0.00427 C^{-1}$ at 0°C.

<u>Solution:</u>

==================================================================

<u>Given Data:</u>

Resistance at $0°C = R_o = 100\Omega$

Temperature $= T = 35°C$

Temperature $= T' = -30°C$

Temperature coefficient of resistance of copper $= \alpha = 0{\cdot}00427C^{-1}$

<u>Required:</u>

Change in resistance $= \Delta R = ?$

<u>Calculation:</u>

We know that,

$$R_t = R_o(1 + \alpha T) \quad \_\_\_\_\_\_\_\_ (1)$$

For $T = 35°C$, equation (1) becomes,

$$R_{35} = 100(1 + 0{\cdot}00427 \times 35) = 100(1 + 0{\cdot}14945)$$

$$\Rightarrow R_{35} = (100 \times 1{\cdot}14945)\Omega = 114{\cdot}945$$

$$\Rightarrow \boxed{R_{35} = 115\Omega}$$

Now for $T' = -30°C$, equation (1) becomes,

$$R_{-30} = 100\left[1 + 0{\cdot}00427(-30)\right] = 100(1 - 0{\cdot}1281)$$

$$\Rightarrow R_{-30} = 100(0{\cdot}8719)\Omega = 87{\cdot}19\Omega$$

$$\Rightarrow \boxed{R_{-30} = 87{\cdot}2\Omega}$$

Now the change in resistance is given by,

$$\Delta R = R_{35} - R_{-30} = 115\Omega - 87{\cdot}2\Omega$$

$$\Rightarrow \boxed{\Delta R = 27{\cdot}8\Omega}$$

**EXAMPLE 12·4:**

Calculate the resistance of copper conductor having a length of 2km and a cross-section of $22mm^2$· Assume the resistivity is $18 \times 10^{-9}\Omega{\cdot}m$·

<u>Solution:</u>

<u>Given Data:</u>

Length of conductor $= L = 2km$

$$\Rightarrow L = 2 \times 10^{3} m$$

Area of cross-section $= A = 22mm^2 = 22 \times 10^{-6} m$

Resistivity of copper $= \delta = 18 \times 10^{-9}\Omega{\cdot}m$

<u>Required:</u>

==================================================================

Resistance of the conductor = R = ?

Calculation:

We know that,

$$R = \frac{\delta L}{A} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ (1)}$$

Putting the values in equation (1), we get,

$$R = \left(\frac{18 \times 10^{-9} \times 2 \times 10^{3}}{22 \times 10^{-6}}\right)\Omega = \frac{36 \times 10^{-9+3+6}}{22}$$

$$\Rightarrow R = 1.64 \times 10^{0}\,\Omega \Rightarrow \boxed{R = 1.64\Omega}$$

**ASSIGNMENT 12.1:**

**(a) Calculate the resistance per unit length of a 22 nichrome wire of radius 0.321mm. (b) If a potential difference of 10V is maintained across 1m length of nichrome wire, what is the current in the wire? $\rho_{nichromes} = 1.5 \times 10^{-6}\Omega \cdot m$.**

Solution:

Given Data:

Radius of nichrome wire = r = 0.321mm

$\Rightarrow r = 0.321 \times 10^{-3}\,m$,

Area of cross-section of wire = $A = \pi r^2 = 3.14 \times (0.321 \times 10^{-3})^2$

$= 0.32 \times 10^{-6}\,m^2$

Potential difference = V = 10V

Resistivity of nichrome wire = $\delta = 1.5 \times 10^{-6}\Omega \cdot m$

Required:

a) Resistance per unit length = $\frac{R}{L} = ?$

b) Current in the wire = I = ?

Calculation:

a) We know that,

$$R = \frac{\delta L}{A} \Rightarrow \frac{R}{L} = \frac{\delta}{A} = \left(\frac{1.5 \times 10^{-6}}{0.32 \times 10^{-6}}\right)\frac{\Omega}{m}$$

$$\Rightarrow R = \left(\frac{1.5}{0.32}\right)\frac{\Omega}{m} = 4.6\frac{\Omega}{m}$$

$$\Rightarrow \boxed{R = 4.6\,\frac{\Omega}{m}}$$

b) As $V = IR \Rightarrow I = \frac{V}{R} = \left(\frac{10}{4.6}\right)A$

$\Rightarrow \boxed{I = 2.2A}$

**EXAMPLE 12.5:**
A heating coil has a resistance of 20Ω. It is designed to operate on 220V. What electric energy in joules is supplied to the heater in 10 seconds?

<u>Solution:</u>

<u>Given Data:</u>

Resistance = R = 20Ω

Voltage = V = 220V, Time = t = 10sec

$V = IR$

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

<u>Required:</u>

Electric energy = W = ?

<u>Calculation:</u>

We know that,

$$W = I^2Rt$$

$$\Rightarrow W = \frac{V^2}{R^2} \times Rt$$

$$\Rightarrow W = \frac{V^2 t}{R}$$

$$\Rightarrow W = \frac{(220)^2 \times 10}{20} \Rightarrow \boxed{W = 24200J}$$

**EXAMPLE 12.6:**
The following are the details of load and a circuit connected through a supply meter. (i) Six lamps of 40 watts each working for 4 hours per day. (ii) Two fluorescent tubes 125 watts each working for 2 hours per day. (iii) 1000 watts heater working for 3 hours per day. Find the cost of electrical energy consumed in 30 days of a month when the rate of electricity is 7.0 Rs per unit.

<u>Solution:</u>

<u>Given Data:</u>

i) Power of 1 lamp = 40 watts

Power of six lamps = 40 x 6 = 240 watts

Time = t = 4 hours

Energy consumed = $w_1 = p \times t$

$\Rightarrow \quad w_1 = 240 \times 4 \quad \Rightarrow \quad \boxed{w_1 = 960 \text{ watt} \cdot \text{hour}}$

ii) Power of 1 tube = 125 watts

$\Rightarrow$ Power of 2 tubes = 125 x 2 = 250 watts

Time = t = 2 hours

Energy consumed = p x t = 250 x 2

$\Rightarrow \quad \boxed{w_2 = 500 \text{ watt} \cdot \text{hour}}$

iii) Power of heater = p = 1000 watts

Time = t = 3 hours

Energy consumed = p x t

$\Rightarrow \quad w_3 = 1000 \times 3 = 3000 \text{ watts} \cdot \text{hour}$

$\Rightarrow \quad \boxed{w_3 = 3000 \text{ watt} \cdot \text{hour}}$

Now the total energy consumed per day is given by,

$w = w_1 + w_2 + w_3$

$\Rightarrow \quad w = (960 + 500 + 3000) \text{ watt} \cdot \text{hour}$

$\Rightarrow \quad w = 4460 \text{ watt} \cdot \text{hour}$

$\Rightarrow \quad w = 4.460 \times 10^3 \text{ watt} \cdot \text{hour}$

$\Rightarrow \quad w = 4.460 \text{ kilcwatt} \cdot \text{hour}$

Now the total energy consumed in the month of June [for 30 days] is given by,

$w' = w \times 30 = 4.46 \times 30 \text{ kwatt} \cdot \text{hour}$

$\Rightarrow \quad w' = 133.8 \text{ kwatt} \cdot \text{hour}$

Now the bill for month of June = 7 x 133.8 Rs

$\Rightarrow \quad \boxed{\text{Bill for month of June} = 936.6 \text{ Rs}}$

**ASSIGNMENT 12.2:**
A heating coil is rated at 100W, 200V. The coil is cut in half and two pieces are joined in parallel to the same source. Now what is the energy liberated per second?

**Solution:**

**Given Data:**

Power = P = 100 watt

Potential difference = V = 200V

**Required:**

Energy liberated per second = ?

**Calculation:**

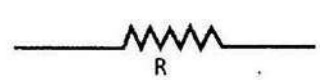


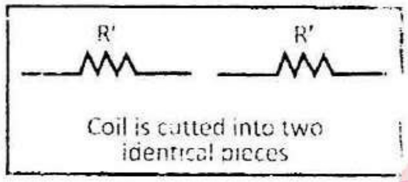
Fig (a)

First we calculate the resistance of coil. We know that,

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

$$\therefore R = \frac{(200)^2}{100} \Rightarrow \frac{40000}{100}\,\Omega$$

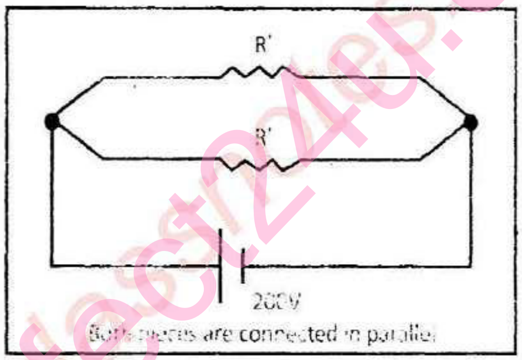
$$\Rightarrow R = 400\Omega$$




Now when the coil is cut into two identical pieces, then resistance of each piece is given by,

$$R' = \frac{R}{2} = \frac{400}{2} = 200\Omega$$

Now the equivalent resistance for parallel combination is given by,




$$\frac{1}{R_{eq}} = \frac{1}{R'} + \frac{1}{R'} = \frac{2}{R'}$$

$$\Rightarrow \frac{1}{R_{eq}} = \frac{2}{R'}$$

$$\Rightarrow R_{eq} = \frac{R'}{2} = \left(\frac{200}{2}\right)\Omega$$

$$\Rightarrow R_{eq} = 100\,\Omega$$

Again we have,

$$P = \frac{V^2}{R_{eq}} = \frac{(200)^2}{100}$$

$$\Rightarrow P = \frac{40000}{100} \Rightarrow P = 400 \text{ watt}$$

Since $P = \frac{Energy}{Time}$

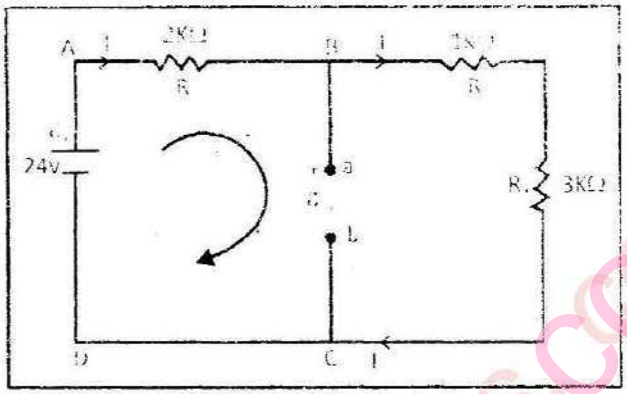
$$\frac{Energy}{Time} = P$$

$$\frac{Energy}{Time} = 400\,\frac{J}{sec}$$

Energy liberated per second = 400 J

| EXAMPLE 12.7: |
|---|
| Figure shows three resistors and two voltage sources. Use Kirchhoff's voltage law to find the emf $\varepsilon_2$. |

Solution.



**Given Data:**

$\varepsilon_1 = 24V$, $R_1 = 2K\Omega$,
$R_2 = 1K\Omega$, $R_3 = 3K\Omega$

**Required:**

$emf = \varepsilon_{ab} = ?$

**Calculation:**

The equivalent resistance of the circuit is given by,

$$R_{eq} = R_1 + R_2 + R_3$$

$$\Rightarrow R_{eq} = (2 + 1 + 3)K\Omega$$

$$\Rightarrow R_{eq} = 6K\Omega = 6 \times 10^3\Omega$$

Now the current in the circuit is given by,

$$I = \frac{V}{R} = \frac{\varepsilon_1}{R} = \frac{24}{6 \times 10^3}$$

$$\Rightarrow \boxed{I = 4 \times 10^{-3} amp} \text{ or } \boxed{I = 4mA}$$

Now applying Kirchhoff's law to loop ABCDA, we get,

$$\varepsilon_1 - IR_1 - \varepsilon_{ab} = 0$$

$$\Rightarrow 24 - 4 \times 10^{-3} \times 2 \times 10^3 - \varepsilon_{ab} = 0$$

$$\Rightarrow 24 - 8 - \varepsilon_{ab} = 0$$

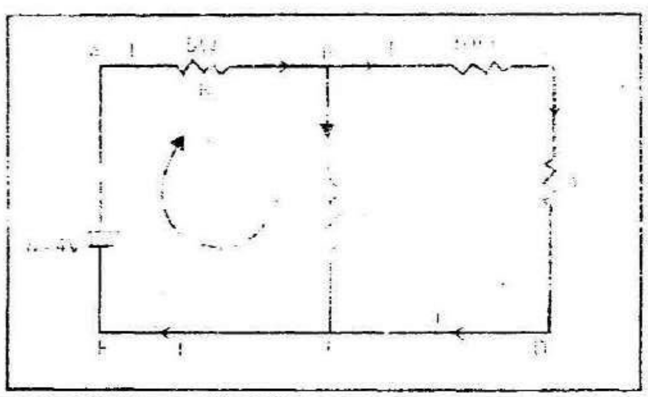
$$\Rightarrow 16 - \varepsilon_{ab} = 0 \Rightarrow \boxed{\varepsilon_{ab} = 16 \text{ volts}}$$

$I = 4 \times 10^{-3}A$
$R_1 = 2K\Omega$
$= 2 \times 10^3\Omega$

**ASSIGNMENT 12.3**
Circuit ABCDEF is shown in figure. Calculate the current in each branch of the circuit using Kirchhoff's voltage law.

**Solution:**

**Given Data:**



Let we divide the given circuit into two loops i.e. loop "ABEFA" and loop "BCDEB".

**Consider Loop "ABEFA":**

Applying Kirchhoff's voltage law to loop "ABEFA", we get,

$$\varepsilon - I_1R_1 - (I_1 - I_2)R_2 = 0$$
$$\Rightarrow 4 - 5I_1 - 20(I_1 - I_2) = 0$$
$$\Rightarrow 4 - 5I_1 - 20I_1 + 20I_2 = 0$$
$$\Rightarrow 4 - 25I_1 + 20I_2 = 0 \quad \text{\_\_\_\_\_\_\_\_}(1)$$

**Consider Loop "BCDEB":**

Applying Kirchhoff's voltage law to loop "BCDEB", we get,

$$(I_1 - I_2)R_2 - I_2R_3 - I_2R_4 = 0$$
$$\Rightarrow 20(I_1 - I_2) - 10I_2 - 30I_2 = 0$$
$$\Rightarrow 20I_1 - 20I_2 - 10I_2 - 30I_2 = 0$$
$$\Rightarrow 20I_1 - 60I_2 = 0$$
$$\Rightarrow 20I_1 = 60I_2$$
$$\Rightarrow I_1 = \frac{60}{20}I_2$$
$$\Rightarrow I_1 = 3I_2 \quad \text{\_\_\_\_\_\_\_\_}(2)$$

Putting equation (2) in equation (1), we get,

$$4 - 25 \times 3I_2 + 20I_2 = 0$$
$$\Rightarrow 4 - 75I_2 + 20I_2 = 0$$
$$\Rightarrow 4 - 55I_2 = 0$$
$$\Rightarrow 55I_2 = 4$$
$$\Rightarrow I_2 = \frac{4}{55} \Rightarrow \boxed{I_2 = 0{\cdot}0727A}$$

Putting the values of "$I_2$" in equation (2), we get,

$$I_1 = 3 \times 0{\cdot}0727A \Rightarrow \boxed{I_1 = 0{\cdot}2181A}$$

a) Now the current through "$R_1$" is given by,

$$\boxed{I_1 = 0{\cdot}2181A}$$

b) The current through "$R_3$" and "$R_4$" is given by,

$$\boxed{I_2 = 0{\cdot}0727A}$$

c) The current through "$R_2$" is given by,

$$= (I_1 - I_2) = 0{\cdot}2181 - 0{\cdot}0727 \Rightarrow \boxed{(I_1 - I_2) = 0{\cdot}1454A}$$

**EXAMPLE 12·8:**

Using a Weston cadium cell of 1·0183V and a standard resistance of 0·1Ω a potentiometer was adjusted so that 1·0183m was equivalent to the emf of the cell: when a certain direct current was flowing through the standard resistance, the voltage across it corresponds to 150cm· what was the value of current?

**Solution:** **Given Data:**

emf of the cell = $\varepsilon_1$ = 1·0183V , Standard resistance = R = 0·1Ω

Length = $l_1$ = 0·0183m , Length = $l_2$ = 150cm = 1·5m

**Required:** Current through standard resistance "R" = $I_2$ = ?

**Calculation:** The current through standard resistance "R" is given by,

$$I_2 = \frac{\varepsilon_2}{R} \quad \text{———} (1)$$

We also know that,

$$\frac{\varepsilon_2}{\varepsilon_1} = \frac{l_2}{l_1} \Rightarrow \varepsilon_2 = \frac{l_2\varepsilon_1}{l_1} \quad \text{———} (2)$$

Putting equation (2) in equation (1), we get,

$$I_2 = \frac{l_2\varepsilon_1}{R\,l_1}$$

$$\Rightarrow I_2 = \left(\frac{1{\cdot}5 \times 1{\cdot}0183}{0{\cdot}1 \times 1{\cdot}0183}\right)A = 15A \Rightarrow \boxed{I_2 = 15A}$$

**ASSIGNMENT 12·4:**

A potentiometer wire of length 1m is connected to a driver cell of emf 3V. When a cell of 1·5V emf is secondary circuit the balance point is found to be at 60cm. On replacing this cell and using a cell of unknown emf the balance point shifts to 80cm. Calculate unknown emf of the cell.

**Solution:** **Given Data:**

emf of the cell in secondary circuit = $\varepsilon_1$ = 1·5V

$l_1$ = 60cm , $l_2$ = 80cm

**Required:** emf the other cell = $\varepsilon_2$ = ?

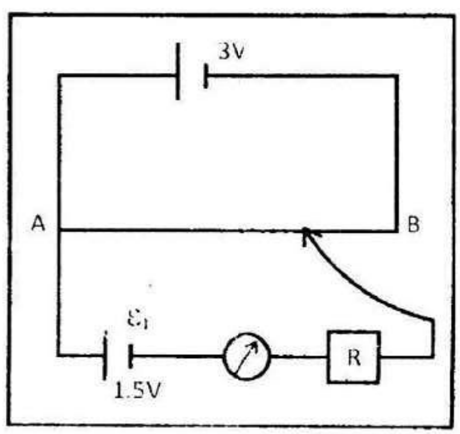
**Calculation:** We know that,

$$\frac{\varepsilon_2}{\varepsilon_1} = \frac{l_2}{l_1} \Rightarrow \varepsilon_2 = \frac{l_2\varepsilon_1}{l_1}$$

$$\Rightarrow \varepsilon_2 = \frac{80 \times 1{\cdot}5}{60}$$

$$\Rightarrow \varepsilon_2 = \frac{120}{60} = 2V$$

$$\Rightarrow \boxed{\varepsilon_2 = 2V}$$



## Exercise

<u>Choose the best possible answer:</u>

1. Three resistors of resistance "R" each are combined in various ways. Which of the following cannot be obtained?

a) $3R\Omega$  b) $\frac{2R}{4}\Omega$ ✓

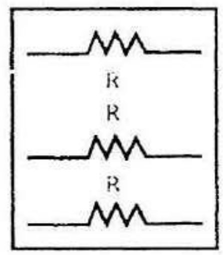
c) $\frac{R}{3}\Omega$  d) $\frac{2R}{3}\Omega$

<u>Solution:</u>

<u>CASE-1:</u> Let the resistors are connected in series, then

$$R_{eq} = R + R + R = 3R$$

$$\Rightarrow \boxed{R_{eq} = 3R\Omega}$$




<u>CASE-2:</u> Let the resistors are connected in parallel, then

$$\frac{1}{R_{eq}} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} \qquad \frac{1}{R_{eq}} = \frac{3}{R}\Omega$$

$$\Rightarrow \boxed{R_{eq} = \frac{R}{3}\Omega}$$

<u>CASE-3:</u> Let two resistors are connected in series and then their equivalent is connected in parallel with third resistor, then we have,

$$\Rightarrow R_{eq} = R + R = 2R\Omega$$

Now $$\frac{1}{R'_{eq}} = \frac{1}{R_{eq}} + \frac{1}{R} = \frac{1}{2R} + \frac{1}{R}$$

$$\frac{1}{R'_{eq}} = \frac{R + 2R}{2R} = \frac{3}{2R} \Rightarrow \boxed{R'_{eq} = \frac{2R}{3}}$$

<u>CASE-4:</u> Let the two resistors are connected in parallel and their equivalent is connected in series with their resistor, then we have,

$$\frac{1}{R_{eq}} = \frac{1}{R} + \frac{1}{R} = \frac{2}{R} \Rightarrow \frac{1}{R_{eq}} = \frac{2}{R}$$

$$\Rightarrow R_{eq} = \frac{R}{2}\Omega$$

Now $$R'_{eq} = R_{eq} + R = \frac{R}{2} + R = \frac{3R}{2}\Omega$$

$$\Rightarrow \boxed{R'_{eq} = \frac{3}{2}R\Omega}$$

Now we see that option (b) i.e. $\frac{2R}{4}\Omega$ do not match with any possible equivalent resistors, so this option is correct.

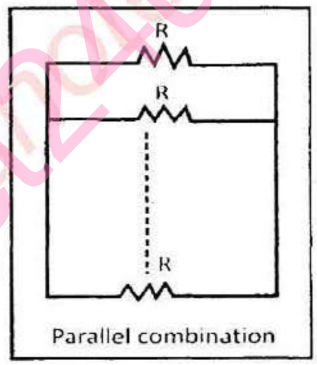
2. When "n" resistances each of value "R" are connected in parallel, then resultant resistance is x. When these "n" resistances are connected in series, total resistance is:

a) $nx$ b) $rnx$

c) $\frac{x}{n}$ d) $n^2x$ ✓

<u>Solution:</u>

Let "n" number of resistor are connected in parallel, then their equivalent resistance is given by,



Parallel combination

$$\frac{1}{Re} = \frac{1}{R} + \frac{1}{R} + \cdots\cdots + \frac{1}{R}$$

$$\Rightarrow \frac{1}{R_{eq}} = \frac{n}{R}$$

$$\Rightarrow R_{eq} = \frac{R}{n} \text{ \_\_\_\_\_\_\_\_\_\_ } (1)$$

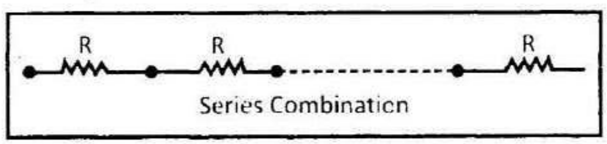
As we have given that the equivalent resistance is equal to "x", so we have,

$$Re = x \text{ \_\_\_\_\_\_\_\_\_\_ } (2)$$

Comparing equation (1) and equation (2), we get,

$$\frac{R}{n} = x \Rightarrow R = nx \text{ \_\_\_\_\_\_\_\_\_\_ } (3)$$

Now for series combination, the equivalent resistance is given by,



Series Combination

$$R_{eq} = R + R + \cdots\cdots + R$$

$$\Rightarrow R_{eq} = nR \text{ \_\_\_\_\_\_\_\_\_\_ } (4)$$

Putting equation (3) in equation (4), we get,

$$R_{eq} = n(nx) \Rightarrow \boxed{R_{eq} = n^2x}$$

So option "d" is correct.

3. Two bulbs marked 200 watt-250 volts and 100 watt-250 volts are joined in series at 250 volts supply. Power consumed in circuit is:

a) 33 watt      b) 67 watt✓

c) 100 watt      d) 300 watt

Solution:

Power of one bulb = $P_1$ = 200 watt

Potential difference = $V_1$ = 250 volts

Resistance of the bulb = $R_1 = \frac{V_1^2}{P_1}$

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

$$\therefore R_1 = \frac{(250)^2}{200} = \frac{250 \times 250}{200}$$

$$\Rightarrow R_1 = 312.5\ \Omega$$

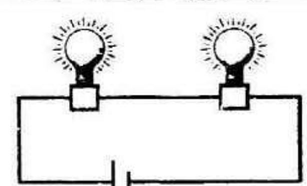
Power of $2^{nd}$ bulb = $P_2$ = 100 watt

Potential difference = $V_2$ = 250 volts

Resistance of the $2^{nd}$ bulb = $R_2 = \frac{V_2^2}{P_2} = \frac{(250)^2}{100}$

$$\Rightarrow R_2 = 625\ \Omega$$

Now when both bulbs are connected in series, then their equivalent resistance is given by,



Series Combination

$$R_{eq} = R_1 + R_2 = (312.5 + 625)\Omega$$

$$\Rightarrow R_{eq} = 937.5\ \Omega$$

Now total power consumed in the circuit is given by,

$$P_{total} = \frac{V^2}{R_{eq}} = \left(\frac{(250)^2}{937.5}\right) \text{ watts}$$

$$\boxed{P_{total} = 67 \text{ watt}}$$

So option "b" is correct.

4. Resistance of a wire is R ohms. The wire is stretched to double its length, then its resistance in ohms is:

a) $\frac{R}{2}$      b) 4R      c) 2R✓      d) $\frac{R}{4}$

Solution:

We know that the resistance of a conductor of length "L" is given by,

$$R = \frac{\rho L}{A} \quad \text{------------ (1)}$$

When the wire is stretched to double its length, then we have,

$$L' = 2L \qquad \text{\_\_\_\_\_\_\_\_\_\_}(2)$$

The resistance in this case will be:

$$R' = \frac{\delta L'}{A} \qquad \text{\_\_\_\_\_\_\_\_\_\_}(3)$$

Putting equation (2) in equation (3), we get,

$$R' = \frac{\delta(2L)}{A} \Rightarrow R' = 2\left(\frac{\delta L}{A}\right) \qquad \text{\_\_\_\_\_\_\_\_\_\_}(4)$$

Putting equation (1) in equation (4), we get,

$$\boxed{R' = 2R}$$

So option "c" is correct.

5. $10^6$ electrons are moving through a wire per second, the current developed is:

a) $1.6 \times 10^{-19} A$      b) $1A$

c) $1.6 \times 10^{-13} A$ ✓      d) $10^6 A$

**Solution:**

Number of electrons $= N = 10^6$

Charge on single electron is "e", so charge on "N" electrons is given by,

$$Q = Ne$$

$$Time = 1sec$$

We know that,

Charge on electron $= e = 1.6 \times 10^{-19} C$

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

$$\Rightarrow I = \frac{10^6 \times 1.6 \times 10^{-19} C}{1sec}$$

$$\Rightarrow \boxed{I = 1.6 \times 10^{-13} A}$$

So option "c" is correct.

6. When a wire is stretched and its radius becomes $\frac{R}{2}$, then its resistance will be:

a) $16R$ ✓      b) $4R$

c) $2R$      d) $0$

**Solution:**

The resistance of a wire is given by,

$$R = \frac{\delta L}{A} = \frac{\delta L}{\pi r^2}$$

Area $= \pi r^2$

$\Rightarrow R = \frac{\delta L}{\pi r^2}$ ______ (1)

When radius becomes half ($\frac{r}{2}$), then we have,

$r' = \frac{r}{2}$ ______ (2)

Now for "r'", equation (1) can be written as,

$R' = \frac{\delta L'}{\pi r'^2}$ ______ (3) $\left[\begin{array}{l} Volume = Area \times Length \\ \Rightarrow V = AL \end{array}\right]$

As volume remain constant, so we have,

$V = V' \Rightarrow Al = A'L'$

$\Rightarrow \pi r^2 L = \pi r'^2 L' \Rightarrow L' = \frac{r^2 L}{r'^2} = \frac{r^2 L}{\left(\frac{r}{2}\right)^2} \Rightarrow L' = 4L$ ______ (4)

Putting equation (2) and equation (4) in equation (3), we get,

$R' = \frac{\delta 4L}{\pi\left(\frac{r}{2}\right)^2} = \frac{4\delta L}{\left(\frac{\pi r^2}{4}\right)} = \frac{4 \times 4\delta L}{\pi r^2}$

$\Rightarrow R' = 16 \frac{\delta L}{\pi r^2}$ ______ (5)

Putting equation (1) in equation (5), we get,

$\boxed{R' = 16R}$

So option "a" is correct.

7. How much voltage is required to make 2A current flow through a resistance of $8\Omega$.

a) $16A\Omega^{-1}$ b) $16\Omega A^{-1}$

c) $16A\Omega$ ✓ d) $A^{-1}\Omega^{-1}$

<u>Solution:</u>

Current $= I = 2A$

Resistance $= R = 8\Omega$

We know that, $V = IR$

$\Rightarrow V = 2 \times 8A\Omega$

$\Rightarrow \boxed{V = 16A\,\Omega}$

So option "c" is correct.

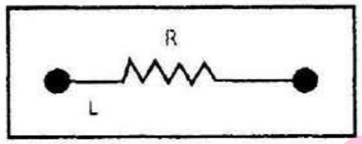
8. A wire of uniform cross-section, a length L and resistance R is cut into two equal parts. The resistivity of each part will be:

a) Doubled                 b) Halved

c) Remains the same✓      d) One fourth

<u>Solution:</u>

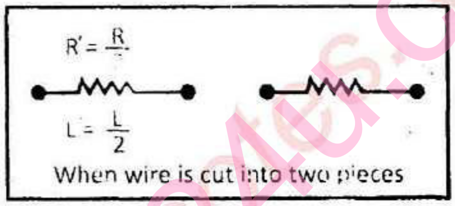
We know that,




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

$$\therefore \delta = \frac{RA}{L} \quad \_\_\_\_\_\_\_\_\_\_ (1)$$

When wire is cut into two pieces, then for each piece equation (1) becomes,



When wire is cut into two pieces

$$\delta' = \frac{R'A}{L'} \quad \_\_\_\_\_\_\_\_\_\_ (2)$$

For each piece, we have,

$$R' = \frac{R}{2} \text{ and } L' = \frac{L}{2}$$

So equation (2) becomes,

$$\delta' = \frac{\frac{R}{2} \times A}{\left(\frac{L}{2}\right)} = \frac{RA}{2} \times \frac{2}{L} = \frac{RA}{L}$$

$$\therefore \delta' = \frac{RA}{L} \quad \_\_\_\_\_\_\_\_\_\_ (3)$$

Putting equation (1) in equation (3), we get,

$$\boxed{\delta' = \delta}$$

Thus resistivity remains the same. So option "c" is correct.

9. The resistivity of two wires is $\rho_1$ and $\rho_2$ which are connected in series. If there dimensions are same then the equivalent resistivity of the combination will be:

a) $(\rho_1 + \rho_2)$            b) $\frac{1}{\rho_1} + \frac{1}{\rho_2}$

c) $\frac{\rho_1 + \rho_2}{2}$ ✓            d) $\frac{\rho_1}{\rho_2}$

<u>Solution:</u>

Let the total length of both wires be "L" then length of each wire is given by,

$$L_1 = \frac{L}{2} \text{ and } L_2 = \frac{L}{2}$$

Now the resistance of $1^{st}$ wire $= R_1 = \frac{\delta_1 L_1}{A}$

$$\Rightarrow R_1 = \frac{\delta_1 L}{2A} \text{ ——————— (1)}$$

Similarly, $R_2 = \frac{\delta_2 L}{2A}$ ——————— (2)

For series combination, we have,

$$R_{eq} = R_1 + R_2 = \frac{\delta_1 L}{2A} + \frac{\delta_2 L}{2A}$$

$$\Rightarrow \frac{\delta L}{A} = \frac{\delta_1 L}{2A} + \frac{\delta_2 L}{2A} \qquad \left[R = \frac{\delta L}{A}\right]$$

$$\Rightarrow \frac{\delta L}{A} = \frac{L}{A}\left(\frac{\delta_1}{2} + \frac{\delta_2}{2}\right) = \frac{L}{A}\left(\frac{\delta_1 + \delta_2}{2}\right)$$

$$\Rightarrow \frac{\delta L}{A} = \frac{L}{A}\left(\frac{\delta_1 + \delta_2}{2}\right)$$

$$\Rightarrow \boxed{\delta = \frac{\delta_1 + \delta_2}{2}}$$

So opt[illegible] is correct.

10. The powers of two electric bulbs are 100w and 200w which are connected to power supply of 220V. The ratio of resistance of their filament will be:

a) 1:2 b) 2:1✓

c) 1:3 d) 4:3

<u>Solution:</u>

$$P_1 = 100w,\ P_2 = 200w,\ V = 220V$$

We know that,

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

$$\Rightarrow R_1 = \frac{V^2}{P_1} \text{ ——————— (1)}$$

Similarly,

$$R_2 = \frac{V^2}{P_2} \text{ ——————— (2)}$$

Dividing equation (2) by equation (1), we get,

$$\frac{R_2}{R_1} = \frac{V^2}{P_2} \div \frac{V^2}{P_1} = \frac{V^2}{P_2} \times \frac{P_1}{V^2}$$

$$\Rightarrow \frac{R_2}{R_1} = \frac{P_1}{P_2} \Rightarrow \frac{R_2}{R_1} = \frac{100}{200} = \frac{1}{2}$$

$$\Rightarrow \frac{R_2}{R_1} = \frac{1}{2} \Rightarrow \frac{R_1}{R_2} = \frac{2}{1} = 2:1$$

$$\Rightarrow \boxed{\frac{R_1}{R_2} = 2:1}$$

So option "b" is correct.

11. Thermocouple is an arrangement of two different metals:
    a) To convert heat energy into electrical energy✓
    b) To produce more heat
    c) To convert heat energy into chemical energy
    d) To convert electric energy into heat energy

12. In order to achieve high accuracy, the slide wire of a potentiometer should be:
    a) As long as possible✓ b) As short as possible
    c) Very thin d) Very thick

13. When a potentiometer is used for measurement of voltage of an unknown source, the power consumed in the circuit of the unknown source under null condition is:
    a) High b) Small
    c) Ideally zero✓ d) Very high

14. In a Wheatstone bridge method, the bridge is said to be balanced, when the current through the galvanometer is:
    a) 1A b) 0 A✓
    c) Maximum d) Half of the maximum value

## CONCEPTUAL QUESTIONS

**Q1: A heavy duty battery of a truck maintains a current of 3A for 24 hour. How much charge flows from the battery during this time?**

Answer:

Given Data: Current maintain by the truck battery = $I = 3A$

Required: Time = 24 hour = 24 x 3600sec = 86400 sec

Charge flows from the battery during 24 hour = $Q = ?$

Calculation: We know that,

$$I = \frac{Q}{t} \quad \therefore \quad Q = It \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_}(1)$$

Putting the values in equation (1), we get,

$$Q = 3 \times 86400C = 259200C$$

$$\boxed{Q = 259200C}$$

or $$\boxed{Q = 2.592 \times 10^5 C}$$

Thus $2.592 \times 10^5 C$

Charge will flow from the during 24 hours.

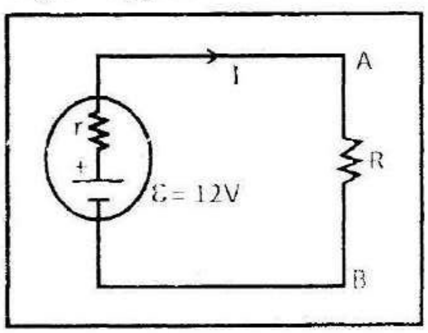
**Q2: While analyzing a circuit the internal resistance of emf sources are ignored why?**

Answer:

The internal resistance of emf sources is very small. So we generally ignore it while analyzing a circuit.

<u>Reason and Explanation</u>:

The opposition offered by the source of emf such as battery to the flow of electric current is called internal resistance. It is represented by "r". In case of a battery, the electrolyte opposes the flow of electric current flowing through it.




The value of internal resistance "r" is very small as compared to the load resistance "R" connected to the source. Thus the voltage drop "$V_r$" across the internal resistance is very small.

EXAMPLE: Consider a 12V battery having internal resistance of 0.01Ω.

Let a load resistor of 3Ω is connected to the battery as shown in the figure. The current flowing in the circuit is given by,

$$I = \frac{\text{total voltage}}{\text{total resistance}} = \left(\frac{12}{3 + 0.01}\right) A$$

$$\Rightarrow I = \left(\frac{12}{3.01}\right) A \Rightarrow I = 4A$$

Now the terminal voltage is given by,

$$V_T = \varepsilon - Ir \Rightarrow V_T = (12 - 4 \times 0.01) \text{ volts}$$

$$\Rightarrow V_T = (12 - 0.04) \text{ volts} \Rightarrow \boxed{V_T = 11.96 \text{ volts}}$$

Comparing "ε" and "$V_T$", we see that the terminal voltage is nearly equal to the emf "ε" of the source. Due to such small difference we generally ignore the internal resistance of a battery or cell.

**Q3: If aluminum and copper wires of the same length have the same resistance, which has the larger diameter. Why?**

Answer:

For same length and same resistance, the diameter of aluminum should be larger than that of copper.

<u>Reason and Explanation:</u>

We know that the resistance of a conductor is given by,

$$R = \frac{\delta L}{A} \quad \text{———————— (1)}$$

For copper, equation (1) can be written as,

$$R_{copper} = \frac{\delta_c L_c}{A_c} \quad \text{———————— (2)}$$

For aluminum equation (1) can be written as,

$$R_A = \frac{\delta_A L_A}{A_A} \quad \text{———————— (3)}$$

For same resistance, we have,

$$R_{copper} = R_A \Rightarrow \frac{\delta_c L_c}{A_c} = \frac{\delta_A L_A}{A_A}$$

For same length, $L_c = L_A = L$

$$\Rightarrow \frac{\delta_c L}{\pi r_c^2} = \frac{\delta_A L}{\pi r_A^2}$$

$\boxed{\text{Area} = \pi r^2}$

$$\Rightarrow \frac{\delta_c}{r_c^2} = \frac{\delta_A}{r_A^2} \Rightarrow \frac{\delta_c}{\frac{d_c^2}{4}} = \frac{\delta_A}{\frac{d_A}{4}}$$

$\boxed{r = \frac{d}{2}}$

$$\Rightarrow \frac{\delta_C}{d_C^2} = \frac{\delta_A}{d_A^2} \qquad (4)$$

Resistivity of aluminum $= \delta_A = 2.65 \times 10^{-8}\,\Omega\cdot m$
resistivity of copper $= \delta_{copper} = 1.68 \times 10^{-8}\,\Omega\cdot m$

Now we know that the resistivity of aluminum is higher than that of copper, so according to equation (4), aluminum would need larger diameter to match the resistance per unit length of copper wire.

**Q4: Under what circumstances can the terminal potential differences of a battery exceeds its emf?**

Answer:

The terminal potential difference of a battery exceeds its emf when the battery is charged through a battery charger.

Reason and Explanation:

We know that the relation between terminal potential difference "$V_T$" and emf "$\varepsilon$" of a battery is given by,

$$V_T = \varepsilon - IR \qquad (1)$$

Now when a battery is connected to battery charger for charging, the current reverses its direction. So we replace "I" by "-I" in equation (1), we get,

$$V_T = \varepsilon - (-Ir) = \varepsilon + Ir$$

$$\Rightarrow V_T = \varepsilon + Ir \qquad (2)$$

Equation (2) shows that, $V_T > \varepsilon$

Thus the terminal potential difference will exceed battery emf during charging of the battery.

**Q5: What is the difference between an emf and a P.D?**

Answer:

The difference between an emf and a P.D is given below:

| e.m.f | Potential Difference |
|---|---|
| 1. An emf represents the voltage across the terminals of a cell or battery when it is giving no current to the circuit. | 1. The P.D represents the work done per unit positive charge between two points against the electric field. |
| 2. The emf is regarded as "cause", because it causes the | 2. The P.D is regarded as an "effect" because it is developed |

| | |
|---|---|
| flow of current due to which P·D is developed across any two points in the circuit· | due to flow of current causes by the emf· |
| 3· The emf is restricted to the source of current in the circuit· | 3· The P·D is developed between two points across any part of a circuit· |
| 4· The emf of a battery is generated by the chemical action occurs in the battery· | 4· The P·D develops between low and high potential points· |
| 5· The emf of the source decreases with the passage of time by using the source frequently· | 5· The P·D remains constant between two points |
| 6· The emf of the source is generally greater than terminal P·D· i·e· $\boxed{\varepsilon = Ir + V_T}$ | The P·D is generally less than emf of the source i·e· $\boxed{V_T = \varepsilon - Ir}$ |

**Q6: The loop rule is based on conservation of energy principle and junction rule is based on the conservation of charge principle· Explain·**

**Answer:**

The loop rule is based on the conservation of energy principle and junction rule is based on the conservation of charge principle·

<u>Reason and Explanation:</u>

**1· <u>Kirchhoff's Loop Rule:</u>**

This law states that, in any closed electrical circuit, the algebraic sum of all the electromotive force and the voltage drops in resistors is equal to zero· Mathematically, we have,

$$\sum \varepsilon + \sum(-IR) = 0 \Rightarrow \sum \varepsilon = \sum IR \quad \text{\_\_\_\_\_\_\_\_(1)}$$

Multiplying both sides of equation (1) by "I" and "t", we get,

$$\sum I\varepsilon t = \sum I^2 Rt \quad \text{\_\_\_\_\_\_\_\_(2)}$$

In equation (2), $\sum I\varepsilon t$ represents the total energy consumed by the source to do work on the charge· While $\sum I^2 Rt$ represents the total energy produced due to power dissipation in resistors· So we have,

$\boxed{\text{Energy lost} = \text{Energy gian}}$

Thus Kirchhoff's loop rule is based on the conservation of energy principles.

## 2. Kirchhoff's Junction Rule:

This law states that the algebraic sum of all the currents flowing towards a junction is equal to the sum of all currents leaving the junction. Mathematically, we have,

$$\sum I = 0 \qquad \boxed{I = \frac{Q}{t}}$$

$$\sum \frac{Q}{t} = 0 \quad \therefore \sum Q = 0 \quad \text{\_\_\_\_\_\_\_\_\_\_}(1)$$

Equation (1) shows that net charge at the junction is zero. This shows that charges neither accumulates nor produced at the junction. In other words we can say that, total charges entering a junction are equal to total charge leaving the junction. So at junction we have,

$\boxed{\text{Charge gain} = \text{Charge lost}}$

Thus the Kirchhoff's junction rule is based on the conservation of charge principle.

**Q7: Why rise is temperature of a conductor is accompanied by a rise in the resistance?**

Answer:

When temperature of a conductor increases, its resistance also increases.

Reason and Explanation:

The atoms of the conductor vibrate with certain amplitude and frequency. These atoms opposes the motion of free electrons passes through the conductors. Such opposition offered by the atoms of the conductor is known as resistance. It is represented by "R".

The resistance of the conductor depends upon the temperature i.e. if the temperature of the conductor increases, then its resistance also increases. It is due to the fact, when temperature increases, the K.E of atoms of the conductor also increases. Due to increase in K.E of the atoms, its amplitude of vibration also increases. Due to increase in amplitude of vibration, these atoms offer greater resistance in the path of free electrons passing through the conductors. Thus the resistance of the conductor increases with increase in temperature.

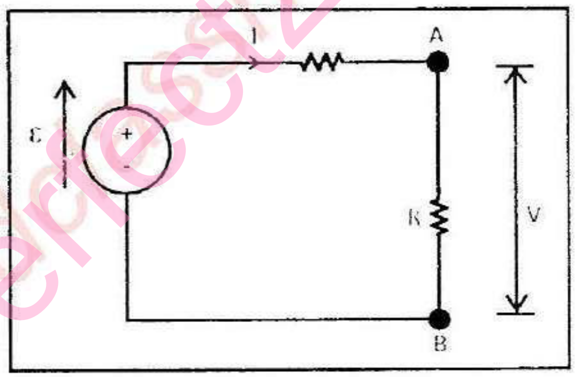
**Q8: Does the direction of emf provided by a battery depends on the direction of current flow through the battery?**

Answer:

The direction of emf provided by a battery does not depend on the direction of current flowing through the battery.

Reason and Explanation:

The emf is a scalar quantity. It represents the work done in moving a charge from low potential to high potential. This shows that the direction of current inside the battery is from lower potential to higher potential of the battery.




Now when the battery is connected to an external circuit, it drives the current in the external circuit. It moves the charge from higher potential towards the lower potential in external circuit. Thus the direction of emf does not depend on the direction of current flowing through the battery.

**Q9: Voltages are always measured between two points, why?**

Answer:

Voltages are always measured between two points.

Reason and Explanation:

Voltage is the potential difference which represents the work done in bring a unit positive charge from one point to another against electric field. One point is at higher potential (positive) and the other is a lower potential (negative). For a single point, it is not possible to have two different values of potential and thus no work is required for a single point. For voltage, we should have two different points having different values of potential. Mathematically, we have,

Let "V" represents the potential difference, then we have,

$$V = \frac{w}{q} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} (1)$$

We also know that,

$$w = F_e \cdot d \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_} (2)$$

Equation (2) shows that work done in electric field depends upon electric force and displacement. Displacement represents the shortest distance between two points. If we restrict the displacement to a single point, then according to equation (2), work done on the charge will be equal to zero. When work done becomes zero, then according to equation (1), the voltage or P.D will becomes zero. This shows that for measurement of voltage, we need two points not a single point.

**Q10: Is every emf a potential difference? Is every potential difference an emf?**

*Answer:*

The potential difference and emf are two different quantities.

Reason and Explanation:

1. The emf represents the voltage across the terminals of a cell or battery when it is giving no current to the circuit. While the P.D represents the work done per unit positive charge between two points against the electric field.
2. The emf is regarded as "cause" because it causes the flow of current due to which P.D is developed across any two points in the circuit. While the P.D is regarded as an effect because it is developed due to flow of current causes by the emf.
3. The emf is restricted to the source of current in the circuit while the P.D is developed between two points across any part of a circuit.
4. The case when we can say that the emf is equal to the P.D is when the internal resistance of the battery is zero or terminal of a battery is not connected externally. In such a case the P.D

between the terminal of the battery is equal to the emf of the battery.

5. Every P.D is not an emf and is less than emf. It is because some energy is spent against the internal resistance "r" of the battery.

**Q11: How much charge flow in pocket calculator each minute when the current is 0.0001A?**

Answer: 0.006 coulomb or $6.0 \times 10^{-3}$ coulomb charge will flow in pocket calculator each minute when the current is 0.0001A.

**Reason and Explanation:**

**Given Data:**

Amount of charge = Q = ?, Current = I = 0.0001A

**Required:**

Amount of charge = Q = ?

**Calculation:**

We know that,

$$I = \frac{Q}{t} \Rightarrow Q = It \quad \text{\_\_\_\_\_\_\_\_}(1)$$

Putting the values in equation (1), we get,

$$Q = (0.0001 \times 60) \text{ coulomb}$$

$$\Rightarrow \boxed{Q = 0.006C}$$

OR $\boxed{Q = 6.0 \times 10^{-3}C}$

Thus 0.006C or $6.0 \times 10^{-3}C$ charge will flow in pocket calculator each minute when the current is 0.0001A.

**Q12: When wheatstone bridge is balanced, then no current flows through the galvanometer, why?**

Answer: When wheatstone bridge is balanced, then no current flows through the galvanometer.

**Reason and Explanation:**

Consider a circuit of wheatstone bridge as shown in the figure

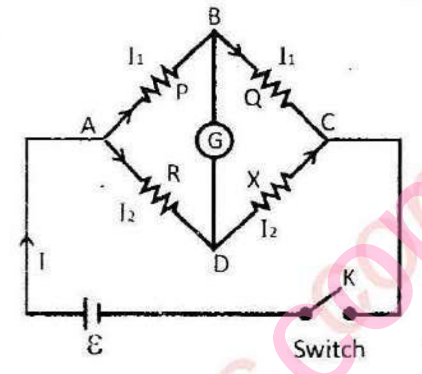
Let "$I_1$" be the current flowing through resistor "P" and "$I_2$" be the current flowing through resistor "R" respectively. Under balanced condition the voltage drops from "A" to "B" and from "A" to "D" must be equal i.e.

Potential drop across "AB" = Potential drop across "AD" ______(1)

Similarly the voltage drops from "B" to "C" and from "D" to "C" must be equal i.e.

Potential drop across "BC" = Potential drop across "DC"________(2)

When equation (1) and equation (2) are satisfied, then the terminal of galvanometer i.e. point "B" and "D" must be at the same potential, and thus no current will flow through galvanometer.



Wheat stone bridge

## COMPREHENSIVE QUESTIONS

**Q1: Describe the concept of steady state current as a flow of positive negative or both. Define the unit of current.**

Answer: See answer of question # 1 in the text.

**Q2: Explain the electronic current in a metallic wire as due to the drift of free electrons in the wire.**

Answer: See answer of question # 3 in the text.

**Q3: State Ohms law. Discuss its scope and validity. (a) Discuss resistivity and conductivity of a material (b) How does resistance change with temperature?**

Answer: See answer of question # 5, 7, 8, 9 in the text.

**Q4: Explain the term: emf, internal resistance and terminal potential difference of a battery.**

Answer: See answer of question # 12, 13 in the text.

**Q5: Explain the construction of rheostat. How is it used as, (a) control the current, (b) as a potential divider?**

Answer: See answer of question # 10 in the text.

**Q6: What is Wheatstone bridge? Explain with diagram the balancing, the principle and the working of this bridge?**

Answer: See answer of question # 24 in the text.

Q7: What is potentiometer? Explain its principle, construction and working. What is the advantage of using potentiometer for measuring potential difference?

Answer: See answer of question # 25 in the text.

Q8: What is thermocouple? Explain the working of thermocouple by drawing its diagram. By sketching curve explain the variation in thermoelectric emf with temperature.

Answer: See answer of question # 18, 19 in the text.

Q9: Why we use Kirchhoff's law for circuit problems solution? Explain its rules for circuit solution by giving proper example.

Answer: See answer of question # 21, 22 in the text.

## NUMERICAL QUESTIONS

Q1: A battery has an emf of 12.8V and supplies a current of 3.2A. What is the resistance of the circuit? How many coulombs leave the battery in 5 minute?

Solution:

Given Data:

emf = $\varepsilon$ = 12.8V, Current = $I$ = 3.2A

Time = $t$ = 5min = 5 x 60 = 300sec

Required:

Magnitude of charge = $Q$ = ?

Calculation:

We know that,

$$V = IR \Rightarrow R = \frac{V}{I} \qquad \boxed{V = \varepsilon = 12.8V}$$

$$\Rightarrow R = \frac{\varepsilon}{I} = \frac{12.8}{3.2} \Rightarrow \boxed{R = 4\,\Omega}$$

We also know that,

$$I = \frac{Q}{t} \Rightarrow Q = It = 3.2 \times 300 \Rightarrow \boxed{Q = 960C}$$

Q2: Two light bulbs designed for 120-V use are rated at 40W and 60W. Which light bulb has the greater filament resistance? Why?

Solution:

<u>Given Data:</u>

Voltage = $V$ = 120V

Power of one bulb = $P_1$ = 40 watt

Power of $2^{nd}$ bulb = $P_2$ = 60 watt

<u>Required:</u>

a) Resistance of one bulb = $R_1$ = ?

b) Resistance of $2^{nd}$ bulb = $R_2$ = ?

<u>Calculation:</u>

a) We know that,

$$P = \frac{V^2}{R} \Rightarrow P_1 = \frac{V^2}{R_1}$$

$$\Rightarrow R_1 = \frac{V^2}{P_1} = \frac{(120)^2}{40} = 360\,\Omega$$

$$\Rightarrow \boxed{R_1 = 360\,\Omega}$$

b) For $2^{nd}$ bulb, we have,

$$R_2 = \frac{V^2}{P_2}$$

$$\Rightarrow R_2 = \frac{(120)^2}{60} = \frac{14400}{60}\Omega \Rightarrow \boxed{R_2 = 240\,\Omega}$$

<u>Conclusion about Greater Resistance:</u>

We see that for given values of $P_1$ and $P_2$, we get greater resistance in case of bulb having smaller power. It is because the resistance of filament is inversely proportional to the power of the bulb. i.e. smaller the power of the bulb, greater will be its filament's resistance and vice versa. So for $P_1$ = 40 watt, we get greater value of resistance.

Q3: A carbon electrode has a resistance of 0.125Ω at 20°C. The temperature co-efficient of carbon is -0.0005 at 20°C. What will be the resistance of the electrode at 85°C?

<u>Solution:</u>

<u>Given Data:</u>

$T$ = 20°C, Resistance of 20°C = $R_{20}$ = 0.125Ω

$\alpha$ = $-0.0005C^{-1}$

<u>Required:</u> Resistance at 85°C = $R_{85}$ = ?

<u>Calculation:</u>

First we calculate the initial resistance "$R_o$" of carbon electrode, we have,

$$R_f = R_o(1+\alpha T) \qquad \boxed{R_f = R_{20}}$$

$$\Rightarrow R_{20} = R_o(1+\alpha T) \Rightarrow R_o = \frac{R_{20}}{(1+\alpha T)}$$

$$\Rightarrow R_o = \frac{0.125}{(1-0.0005\times 20)} = \frac{0.125}{(1-0.01)}$$

$$\Rightarrow R_o = \frac{0.125}{(0.99)} \Rightarrow R_o = 0.126\,\Omega$$

Now the resistance at 85°C is given by,

$$R_{85} = R_o(1+\alpha T)$$

$$\Rightarrow R_{85} = 0.126(1-0.0005\times 85) = 0.126(1-0.0425)$$

$$\Rightarrow R_{85} = 0.126\times 0.9575 \Rightarrow \boxed{R_{85} = 0.12\Omega}$$

**Q4: Calculate the resistance of wire 10m long that has a diameter of 2mm and resistivity of $2.63\times 10^{-2}\Omega\cdot m$**

<u>Solution:</u>

<u>Given Data:</u>

Length of wire = $L$ = 10m

Diameter of wire = $D$ = 2mm = $2\times 10^{-3}$m

Radius of wire = $r = \frac{D}{2} = \frac{2\times 10^{-3}}{2} = 10^{-3}m$

Resistivity of wire = $\delta = 2.63\times 10^{-2}\Omega\cdot m$

<u>Required:</u>

Resistance of wire = $R$ = ?

<u>Calculation:</u>

We know that,

$$R = \frac{\delta L}{A} = \frac{\delta L}{\pi r^2} = \left[\frac{2.63\times 10^{-2}\times 10}{3.14\times(10^{-3})^2}\right]\Omega \qquad \boxed{A = \pi r^2}$$

$$\Rightarrow R = 8.38\times 10^{-2+6}\Omega = 8.38\times 10^{4}\Omega$$

$$\Rightarrow R = 0.0838\times 10^{6}\Omega = 0.0838M\Omega \qquad \boxed{mega = 10^6}$$

$$\Rightarrow \boxed{R = 0.0838 M\Omega}$$

**Q5: A typical 12V automobile battery has a resistance of $0.012\Omega$. What is the terminal voltage of this battery when the starter draws a current of 100A? Calculate the R, P, $P_\varepsilon$ and $P_r$.**

**Solution:**

**Given Data:**

emf of battery = $\varepsilon$ = 12V

Internal resistance of the battery = r = $0.012\Omega$

Current = I = 100A

**Required:**

(a) $V_T$ = ?, (b) R = ?, (c) $P_\varepsilon$ = ?, (d) $P_R$ = ?, (e) $P_r$ = ?

**Calculation:**

a) We know that,

$$\varepsilon = I_r + V_T$$

$$\Rightarrow V_T = \varepsilon - I_r$$

$$\Rightarrow V_T = 12 - 100 \times 0.012$$

b) We know that,

$$\varepsilon = Ir + IR$$

$$\Rightarrow IR = \varepsilon - Ir$$

$$\Rightarrow R = \frac{(\varepsilon - I_r)}{I} = \frac{[12 - 100 \times 0.012)}{100} = \frac{(12 - 1.2)}{100}$$

$$\Rightarrow \boxed{R = 0.108\Omega}$$

c) We know that,

$$P = IV = I\varepsilon \qquad \boxed{V = \varepsilon}$$

$$\Rightarrow P = 100 \times 12 \Rightarrow \boxed{P = 1200 \text{ watt}}$$

d) For "R", we have $P_R = I^2R$

$$\Rightarrow P_r = (100)^2 \times 0.108 = 10000 \times 0.108 \text{ watt}$$

$$\Rightarrow \boxed{P_R = 1080 \text{ watt}}$$

e) For small "r", we have, $P_r = I^2r$

$$\Rightarrow P_r = (100)^2 \times 0.012 = 10000 \times 0.012\,\Omega$$

$$\Rightarrow \boxed{P_r = 120 \text{ watt}}$$

**Q6: A 10 watt resistor has a value of 120Ω. What is the rated current through the resistor?**

**Solution:**

**Given Data:**

Power = P = 10 watt

Resistance = R = 120Ω

**Required:**

Current = I = ?

**Calculation:**

We know that,

$$P = I^2R$$

$$\Rightarrow I^2 = \frac{P}{R} = \frac{10}{120} \Rightarrow I^2 = 0.0833A^2$$

$$\Rightarrow I = \sqrt{0.0833A^2} = 0.2886A \Rightarrow \boxed{I = 0.2886A}$$

**Q7: A resistor of 50Ω has a P.D of 100V, D.C across 1 hour. Calculate (a) Power and (b) Energy**

**Solution:**

**Given Data:**

Resistance = R = 50Ω, Potential difference = V = 100V

Time = t = 1 hour = 3600 sec

**Required:**

a) Power = P = ?

b) Energy = E = ?

**Calculation:**

a) We know that,

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

$$\Rightarrow P = \frac{(100)^2}{50} = \left(\frac{10000}{50}\right) \text{ watt}$$

$$\Rightarrow \boxed{P = 200 \text{ watt}}$$

b) We also know that, energy = power x time

$$\Rightarrow E = p \times t = 200 \times 3600J = 720000J$$

$$\Rightarrow E = 0.72 \times 10^6 J \Rightarrow \boxed{E = 0.72MJ}$$ $\boxed{\text{mega} = 10^6}$

**Q8: Calculate the current through the a single loop circuit if $\varepsilon$ = 120V, R = 1000Ω and internal resistance r = 0·01Ω·**

__Solution:__

__Given Data:__ emf = $\varepsilon$ = 120V, Resistance = R = 1000Ω

Resistance = r = 0·01Ω

__Required:__ Current = I = ?

__Calculation:__ We know that,

$$\varepsilon = Ir + IR$$

$$\Rightarrow \varepsilon = I(r + R) \Rightarrow I = \frac{\varepsilon}{r + R}$$

$$\Rightarrow I = \frac{120}{0{\cdot}01 + 1000} = \left(\frac{120}{1000{\cdot}01}\right)A$$

$$\Rightarrow I = 0{\cdot}11999A$$

$$\Rightarrow I = 119{\cdot}99 \times 10^{-3}A = 120 \times 10^{-3}A$$

$$\Rightarrow \boxed{I = 120mA}$$

$\boxed{10^{-3} = \text{milli}}$

**Q9: Find the terminal potential difference of each cell in circuit of the figure·**

__Solution:__ __Given Data:__

emf of 1st cell = $\varepsilon_1$ = 24V

emf of 2nd cell = $\varepsilon_2$ = 6V

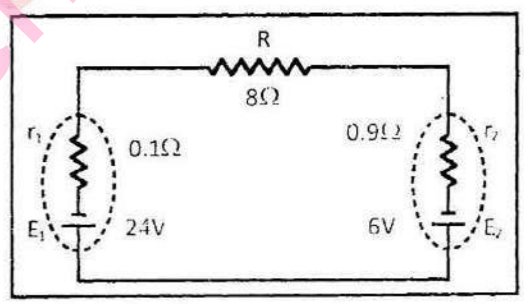
Internal resistance of 1st cell

= $r_1$ = 0·1Ω

Internal resistance of 2nd cell

= $r_2$ = 0·9Ω

Resistance = R = 8Ω




__Required:__

Terminal potential difference of 1st cell = $V_{T_1}$ = ?

Terminal potential difference of 2nd cell = $V_{T_2}$ = ?

__Calculation:__

In given circuit, all resistors are connected in series, so their equivalent resistance is given by,

$$R_{eq} = r_1 + R + r_2 = (0{\cdot}1 + 8 + 0{\cdot}9)\Omega$$

$$\Rightarrow R_{eq} = 9\,\Omega$$

$$\varepsilon = Ir + IR$$
$$\Rightarrow \varepsilon = Ir + I_T$$
$$\Rightarrow V_T = \varepsilon - Ir$$

The effective voltage in the circuit is given by,

$$\varepsilon = \varepsilon_1 - \varepsilon_2 = (24 - 6)V \Rightarrow \varepsilon = 18V$$

Now the current in the circuit is given by,

$$I = \frac{V}{R_{eq}} = \frac{\varepsilon}{R_{eq}} = \frac{18V}{9\Omega} \Rightarrow I = 2A$$

Now the terminal P·D of $1^{st}$ cell is given by,

$$V_{T_1} = \varepsilon_1 - Ir_1$$

$$\Rightarrow V_{T_1} = 24 - 2 \times 0{\cdot}1 = (24 - 0{\cdot}2)V$$

$$\Rightarrow \boxed{V_{T_1} = 23{\cdot}8V}$$

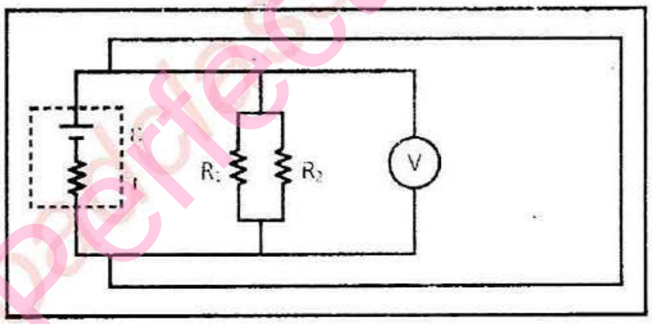
Similarly, the terminal P·D of $2^{nd}$ cell is given by,

$$V_{T_2} = \varepsilon_2 - Ir = (6 - (-2) \times 0{\cdot}9)V$$

$$\Rightarrow V_{T_2} = (6 + 1{\cdot}8)V \Rightarrow \boxed{V_{T_2} = 7{\cdot}8V}$$

For "$\varepsilon_2$" the Current is Flowing in Opposite direction So we put $I = -2A$ for $\varepsilon_2$

**Q10: The voltmeter in the circuit at the right may be considered to be ideal· Values are, ε = 15·0V; internal resistance, r = 5·00Ω, $R_1$ = 100Ω; $R_2$ = 300Ω· Calculate the current in $R_1$·**




__Solution:__

__Given Data:__ emf of the battery = ε = 15V

Internal resistance of the battery = r = 5Ω

Resistance = $R_1$ = 100Ω,

Resistance = $R_2$ = 300Ω

__Required:__ Current through "$R_1$" = $I_1$ = ?

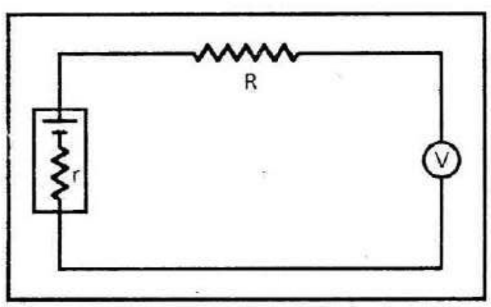
__Calculation:__ First we determine the equivalent resistance of the circuit· We see that $R_1$ and $R_2$ are in parallel, so their equivalent resistance is given by,

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

$$\Rightarrow R = \frac{R_1 R_2}{(R_2 + R_1)}$$

$$= \frac{100 \times 300}{(300 + 100)} = \frac{30000}{400}$$

$$\Rightarrow R = 75\,\Omega$$




Now we see that, "r" and "R" are in series, so their equivalent resistance is given by,

$$R' = r + R = 5 + 75$$
$$\Rightarrow R' = 80\,\Omega$$

Now the current passing through the battery is given by,

$$I = \frac{\varepsilon}{R'} = \frac{15}{80}$$
$$\Rightarrow I = 0.1875A$$

Now the voltage across "r" is given by,

$$V_r = Ir = 0.1875 \times 5$$
$$\Rightarrow V_r = 0.9375$$

The remaining voltage is given by,

$$V = \varepsilon - V_r = 15 - 0.9375$$
$$\Rightarrow V = 14.0625$$

As $R_1$ and $R_2$ are in parallel, so voltage for both will be the same. i.e.

$$V = V_1 = V_2 = 14.0625$$

Now the current through "$R_1$" is given by,

$$I_1 = \frac{V_1}{R_1} = \frac{14.0625}{100}$$
$$\Rightarrow \boxed{I_1 = 0.1406 \text{ amp}}$$

**Q11: Three arms of a wheatstone bridge are of 75Ω each. What is the resistance of the fourth arm?**

<u>Solution</u>: <u>Given Data</u>:

Resistance of one arm $= P = 75\Omega$

Resistance of $2^{nd}$ arm $= Q = 75\Omega$

Resistance of $3^{rd}$ arm $= R = 75\Omega$

<u>Required</u>: Resistance of fourth arm $= X = ?$

<u>Calculation</u>: The principle of wheatstone bridge is given by,

$$\frac{P}{Q} = \frac{R}{x} \Rightarrow \frac{R}{x} = \frac{P}{Q}$$

$$\Rightarrow \frac{x}{R} = \frac{Q}{P} \Rightarrow x = \frac{RQ}{P} \quad \text{\_\_\_\_\_\_\_\_\_\_(1)}$$

Putting the values in equation (1), we get,

$$x = \frac{75 \times 75}{75} = 75\Omega \Rightarrow \boxed{x = 75\Omega}$$