3. Current Electricity

Class: **12 CBSE/GSEB** Subject: **PHYSICS**

Course: **NCERT - JEE Main, NEET, GUJCET**

NCERT Simplified

Rationalised 2023-24 **Additional topics*

3.1 Introduction

- Charges in motion constitute an electric current.
- Lightning is one such phenomenon in which charges flow from the clouds to the earth through the atmosphere.
- The flow of charges in lightning is not steady.
- A torch and a cell-driven clock are examples of devices in which charges flow in a steady manner.

3.2 Electric Current

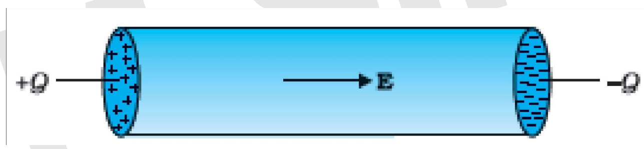
- Let ΔQ be the net charge flowing across a cross section of a conductor during the time interval Δt [i.e. between times t and $(t+\Delta t)$]. Then, the current at time t across the cross-section of the conductor is defined as the value of the ratio of ΔQ to Δt in the limit of Δt tending to zero.

$$I(t) = \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t}$$

- In SI units, the unit of current is **ampere**.
- An average lightning carries currents of the order of tens of thousands of amperes and at the other extreme, currents in our nerves are in microamperes.

3.3 Electric Currents in Conductors

- Consider solid conductors where the current is carried by the negatively charged electrons in the background of fixed positive ions.
- Let **electric field is not present in conductor**.
- The electrons will be moving due to thermal motion during which they collide with the fixed ions.
- An electron colliding with an ion emerges with the same speed as before the collision.However, the direction of its velocity after the collision is completely random.
- At a given time, there is no preferential direction for the velocities of the electrons.
- Thus on an average, the number of electrons travelling in any direction will be equal to the number of elctrons travelling in the opposite direction. So there will be no net electric current.
- Consider **a piece of conductor if an electric field is applied**.Imagine the conductor in the shape of a cylinder of radius R as shown in the figure below:



- Consider two thin circular discs of a dielectric of the same radius and with positive charge $+Q$ distributed over one disc and $-Q$ at the other disc.
- These two discs are attached on the two flat surfaces of the cylinder. Thus an electric field be created and will be directed from the positive towards the negative charge.
- The electrons will be accelerated due to this field towards $+Q$ .They will thus move to neutralise the charges.
- The electrons as long as they are moving, will constitue an electric current.
- Thus in this situation, there will be a current for a very short while and no current thereafter.
- Thus in the figure shown above, the current will stop after a while unless the charges $+Q$ and $-Q$ are continuously replenished.
- There is a mechanism when the ends of the cylinder are supplied with fresh charges to make up for any charges neutralised by electrons moving inside the conductor.In this case there will be a steady electric field in the body of the conductor. This results in a continuous current rather than a current for short period of time.Mechanisms which maitain a steady electric field are cells or batteries.

3.4 Ohm's Law

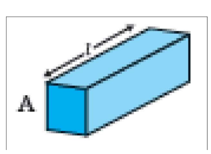
- Imagine a conductor through which a current I is flowing and let V be the potential difference between the ends of the conductor.Ohm's law states that

$$V \alpha I \quad \text{or} \quad V = RI \qquad ....(1)$$

where the constant of proportionality R is called the resistance of the conductor.

- The SI units of resistance is **ohm** and is denoted by the **symbol** Ω .The resistance R not only **depends on the material** of the conductor but also on the **dimensions of the conductor**.

$\Rightarrow$ The **dependence of R on the dimensions of the conductor:**



Consider a slab of length l and cross sectional area A .Resistance R is proportional to length l and inversely proportional to the cross-sectional area A .

$$R \propto \frac{l}{A} \text{ or } R = \rho \frac{l}{A} \quad ....(2)$$

where the constant of proportionality ρ **depends on the material of the conductor** but **not on its dimensions**. ρ is called resistivity.

From equation (1), Ohm's law can be written as $V = I \times R = I\rho \frac{l}{A}$. ....(3)

Current per unit area (taken normal to the current), $\frac{I}{A}$, is called **current density** and is denoted by $\vec{j}$.

The **SI units of the current density are** A/m^2.

If E is the magnitude of uniform electric field in the conductor whose length is l, then the potentil difference V across its ends is El.

From equation (3), $El = j\rho l$ or $E = j\rho$ ....(4)

The current density (the current through unit area normal to the current) is directed along $\vec{E}$, and is a vector $\vec{j}$.

Thus equation (4) can be written as $\vec{E} = \vec{j}\rho$ or $\vec{j} = \sigma\vec{E}$

where $\sigma = \frac{1}{\rho}$ is called the **conductivity**.

....**QUESTIONS**... from..... **COMPETITIVE EXAMS**..

1. A copper wire is stretched to make it 0.5% longer. The percentage change in its electrical resistance if its volume remains unchanged is:

(A) 0.5% (B) 2.5% (C) 1.0% (D) 2.0% **[JEE Main 2019]**

....**QUESTIONS from GSEB Board Exams.**..

Q. 1. According to Ohm's law $\left(R = \frac{V}{I}\right)$, as current flowing through a conductor increases, resistance of conductor ___

(A) Increases (B) Remains constant (C) Decreases (D) Nothing can be said

[1 mark, GSEB 2020]

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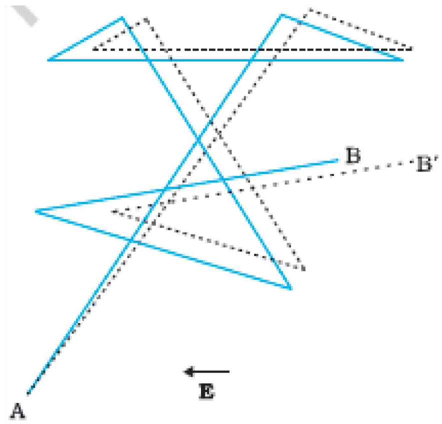
3.5 Drift of Electrons and the Origin of Resistivity

An electron will suffer collisions with the heavy fixed ions, but after collision, it will emerge with the same speed but in random directions.If all electrons are considered, their average velocity will be zero since their directions are random.

If there are N electrons and the velocity of the i^{th} electron $(i = 1,2,3,4,.....N)$ at a given time is $\vec{v}_i$,

then $$\frac{1}{N}\sum_{i=1}^{N}\vec{v}_i = 0 \quad ....(1)$$



- Consider now the situation when an electric field is present. Electrons will be accelerated due to this field by $\vec{a} = \frac{-e\vec{E}}{m}$, where $-e$ is the charge and m is the mass of an electron.

- Consider i^{th} electron at a given time t. This electron would have had its last collision some time before t, and let t_i be the time elapsed after its last collision. If $\vec{v}_i$ was its velocity immediately after the last collision, then its velocity $\vec{V}_i$ at time t is $$\vec{V}_i = \vec{v}_i - \frac{e\vec{E}}{m}t_i \qquad \text{.........................(2)}$$

since starting with its last collision it was accelerated with an acceleration $\vec{a} = \frac{-e\vec{E}}{m}$ for time interval t_i. The average velocity of the electrons at time t is the average of all the $\vec{V}_i$'s.

From equation (1) the average of $\vec{v}_i$'s is zero since immediately after any collision, the direction of the velocity of an electron is completely random.
The collisions of the electrons do not occur at regular intervals but at random times- denoted by τ **(relaxation time) -the average time between successive collisions**.

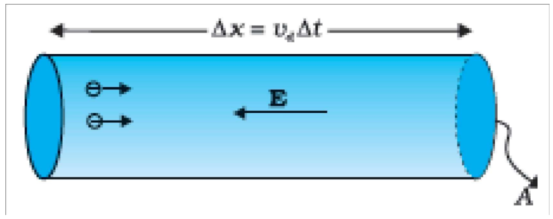
Averaging equation (2) over the N electrons at any given time t gives the average velocity $\vec{v}_d$

$$\vec{v}_d = \left(\vec{V}_i\right)_{average} = \left(\vec{v}_i\right)_{average} - \frac{e\vec{E}}{m}\left(t_i\right)_{average}$$

$$= 0 - \frac{e\vec{E}}{m}\tau$$

Thus **electrons move with an average velocity which is independent of time**, although **electrons are accelerated**. This is the **phenomenon of drift and the velocity $\vec{v}_d$ is called the drift velocity**.

$\Rightarrow$ As shown in figure below, consider a planar area A, located inside the conductor such that the normal to the area is parallel to $\vec{E}$.



Because of drift, therw will be net transport of charges across any area perpendicular to $\vec{E}$. In an infinitesimal amount of time Δt, all electrons to the left of the area at distances upto $|\vec{v}_d|\Delta t$ would have crossed the area.If n **is the number of free electrons per unit volume** in the metal, then **number of electrons crossing the area is** $n\,\Delta t|\vec{v}_d|\,A$.

As each electron carries a charge $-e$, the **total charge** transported across area A to the right in time Δt **is** $-neA|\vec{v}_d|\,\Delta t$.

$\vec{E}$ is directed towards the left and hence the total charge transported along $\vec{E}$ across the area is negative of this, i.e. $+neA|\vec{v}_d|\,\Delta t$ **.** Also the amount of charge crossing the area A in time Δt is $I\,\Delta t$, where I is the magnitude of the current.

Hence $I\,\Delta t = +neA|\vec{v}_d|\,\Delta t$ or $I = +neA|\vec{v}_d|$

As $|\vec{v}_d| = \frac{eE}{m}\tau$, $I\,\Delta t = \frac{e^2 A}{m}\tau\, n\,\Delta t\,|\vec{E}|$ or $I = \frac{e^2 A}{m}\tau\, n\,|\vec{E}|$

Current I is related to the magnitude of current density $|\vec{j}|$ as $I = |\vec{j}|A$

Thus, $$|\vec{j}| = \frac{ne^2}{m}\tau\,|\vec{E}|$$

The vector $\vec{j}$ is parallel to $\vec{E}$ and in vector form, $\vec{j} = \frac{ne^2}{m}\tau\,\vec{E}$

As $\vec{j} = \sigma\vec{E}$, conductivity $\sigma = \frac{ne^2}{m}\tau$.

Here τ and n are constants, independent of E.

....**QUESTIONS**... from..... **COMPETITIVE EXAMS**...

1. Drift speed of electrons, when $1.5\ A$ of current flows in a copper wire of cross section $5\ mm^2$, is v. If the electron density in copper is $9\times10^{28}\ /m^3$ the value of v in mm/s is close to (Take charge of electron to be $=1.6\times10^{-19}C$)

(A) 3 (B) 2 (C) 0.2 (D) 0.02 **[JEE Main 2019]**

2. A coppper road of cross-sectional area A carries a uniform current I through it. At temperature T, if the volume charge density of the rod is ρ, how long will the charges take to travel a distance d?

(A) $\frac{2\rho d A}{I}$ (B) $\frac{2\rho d A}{IT}$ (C) $\frac{\rho d A}{I}$ (D) $\frac{\rho d A}{IT}$ **[JEE Main 2018 Online]**

QUESTIONS from GSEB Board Exams..

Q. 1. A steady current flows in a metallic conductor of non-uniform cross-section. Which of the following quantities is constant along the conductor ?

(a) drift speed (B) current density (C) electric field (D) current **[1 mark, GSEB 2022]**

QUESTIONS from CBSE Board Exams..

Q. 1. If n, e, τ and m have their usual meanings, then the resistance of a wire of length l and cross-sectional area A is given by -

(A) $\frac{ne^2 A}{2m\tau l}$ (B) $\frac{ml}{ne^2\tau A}$ (C) $\frac{m\tau A}{ne^2 l}$ (D) $\frac{ne^2\tau A}{2ml}$ **[1 mark, CBSE 2022 (I)]**

Q. 2.

(a) Define the terms 'drift velocity' and 'relaxation time' giving their physical significance.

(b) A conductor of length L is connected across a dc source of emf E. If the conductor is replaced by another of the same material and area of cross-section but of length $5L$, by what factor will the drift velocity change ? **[3 marks, CBSE 2019]**

Q. 3.

(a) Define the term 'conductivity' of a metallic wire. Write its SI unit.

(b) Using the concept of free electrons in a conductor, derive the expression for the conductivity of a wire in terms of number density and relaxation time. Hence obtain the relation between current density and the applied electric field E. **[3 marks, CBSE 2018]**

Q. 4. Derive the expression for drift velocity of free electrons in a conductor in terms of relaxation time. **[2 marks, CBSE 2018]**

Q. 5.

(i) Define 'drift velocity' of electrons in a conductor.

(ii) Two conducting wires X and Y of same diameter but different materials are joined in series across a battery. If the number density of electrons in X is twice that in Y, find the ratio of drift velocity of electrons in the two wires. **[3 marks, CBSE 2018]**

Q. 6. Define the term 'drift velocity' in a conductor. Why does resistivity of a metal increase with temperature ? Explain. **[2 marks, CBSE 2017]**

3.5.1 Mobility

Mobility μ is defined as the magnitude of the drift velocity per unit electric field.

$$\mu = \frac{|v_d|}{E}$$

The SI unit of mobility is $m^2/V\,s$ and is 10^4 of the mobility in practical units $\left(cm^2/Vs\right)$. Mobility is positive.

As $v_d = \frac{eE}{m}\tau$, $\mu = \frac{v_d}{E} = \frac{e\tau}{m}$, where τ is the average collision time for electrons.

QUESTIONS... from..... **COMPETITIVE EXAMS**

1. A current of $5\ A$ passes through a copper conductor $\left(\text{resistivity } = 1.7\times10^{-8}\ \Omega m\right)$ of radius of cross -section $5\ mm$. Find the mobility of the charges if their drift velocity is $1.1\times10^{-3}\ m/s$.

(A) $1.8\ m^2/Vs$ (B) $1.5\ m^2/Vs$ (C) $1.3\ m^2/Vs$ (D) $1.0\ m^2/Vs$ **[JEE Main 2019]**

2. The dimensional formula of mobility is ______

(A) $M^{-1}L^1T^2A^1$ (B) $M^1L^0T^{-2}A^{-1}$ (C) $M^1L^{-1}T^{-2}A^{-1}$ (D) $M^{-1}L^0T^2A^1$ **[GUJCET 2018]**

QUESTIONS from GSEB Board Exams..

Q. 1. Which of the following physical quantitiy has unit $m^2V^{-1}s^{-1}$?

(A) resistivity (B) electrical field (C) mobility (D) drift velocity

[1 mark, GSEB 2022]

Q. 2. Write a note on Mobility. **[2 marks, GSEB 2020]**

QUESTIONS from CBSE Board Exams..

Q. 1. How does the mobility of electrons in a conductor change, if the potential difference applied across the conductor is doubled, keeping the length and temperature of the conductor constant ?

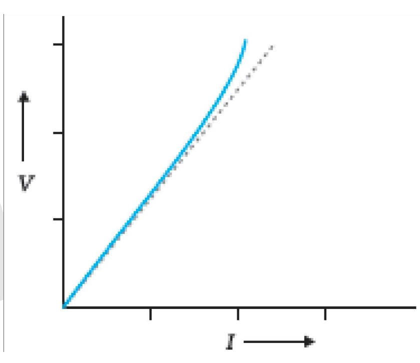
[1 mark, CBSE 2019]

Q. 2. Derive the expression for the current density of a conductor in terms of the conductivity and applied electric field. Explain, with reason how the mobility of electrons in a conductor changes when the potential difference applied is doubled, keeping the temperature of the conductor constant. **[3 marks, CBSE 2017]**

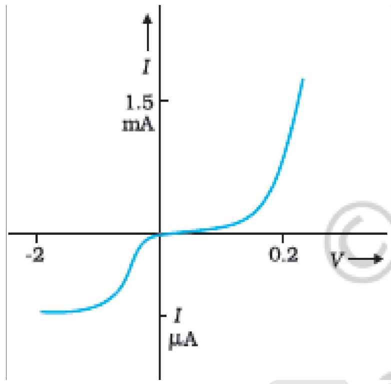
3.6 LIMITATIONS OF OHM'S LAW

Ohm's law (i.e. proportionality of V and I) has been found valid over large class of materials, there are materials and devices used in electrical circuits where it does not hold.

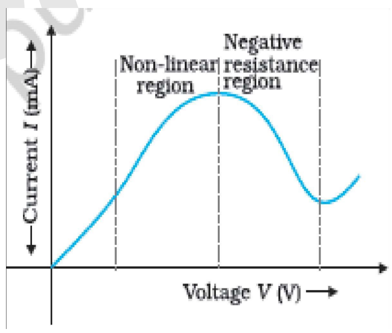
(a) V ceases to be proportional to I as shown in figure below.



(b) The relation between V and I depends on the sign of V. If I is the current for a certain V, then reversing the direction of V keeping its magnitude fixed, does not produce a current of the same magnitude as I in the opposite direction (as in case of a diode) shown in figure below:



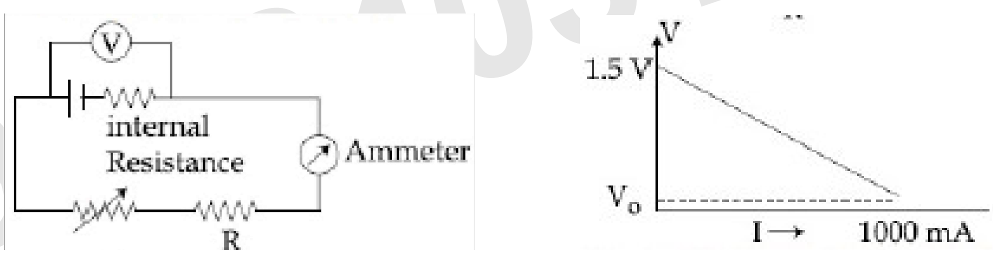
(c) The relation between V and I is not unique, i.e. there is more than one value of V for the same current I shown in figure below.A material exhibiting such behaviour is GaAs.



Materials and devices not obeying Ohm's law are actually widely used in electronic circuits. In this and subsequent chapters, electrical currents will be learnt for materials that obey Ohm's law.

....**QUESTIONS**... from..... **COMPETITIVE EXAMS**..

1.To verify Ohm's law, a student connects the voltmeter across the battery as, shown in the figure. The measured voltage is plotted as a function of the current, and the following graph is obtained:



If V_0 is almost zero, identify the correct statement:

(A)The emf of the battery is $1.5\,V$ and its internal resistance is $1.5\,\Omega$.

(B)The value of the resistance R is $1.5\,\Omega$.

(C)The potential difference across the battery is $1.5\,V$ when it sends a current of $1000\,mA$.

(D)The emf of the battery is $1.5\,V$ and the value of R is $1.5\,\Omega$. **[JEE Main 2019]**

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3.7 Resistivity of Various Materials

The materials are classified as conductors, semiconductors and insulators depending on their resistivities, in an increasing order of their values.

Metals have low resistivities in the range of $10^{-8}\ \Omega m$ to $10^{-6}\ \Omega m$. Insulators like ceramic, rubber and plastics have resistivities 10^{18} times greater than metals or more.In between the two are semiconductors. These have resistivities characteristically decreasing with a rise in temperature.The resistivities of semiconductors are also affected by the presence of small amount of impurities.

$\Rightarrow$ Commercially produced resistors for domestic use or in laboratories are of two major types: **wire bound** resistors and **carbon** resistors.

Wire bound resistors are made by winding the wires of an **alloy**, viz., **manganin, constantan, nichrome** or similar ones.The resistivities of these materials are relatively insensitive to temperature. These resistances are typically in the range of a fraction of an ohm to a few hundred ohms.

Resistors in the higher range are made mostly from carbon. **Carbon resistors** are compact, enexpensive and thus are extensively used in electronic circuits. **Carbon resistors are small in size and hence their values are given using a colour code**.

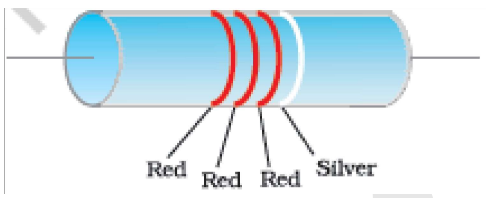
The resistors have a set of co-axial coloured rings on them whose significance are listed in table below:

RESISTOR COLOUR CODES

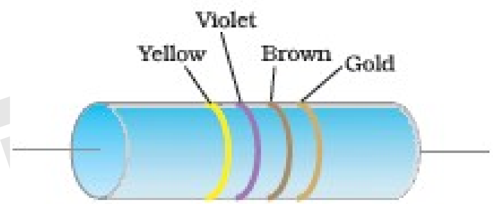
Colour	Number	Multiplier	Tolerance (%)
Black	**0**	**1**	
Brown	1	10^1	
Red	**2**	10^2	
Orange	3	10^3	
Yellow	**4**	10^4	
Green	5	10^5	
Blue	**6**	10^6	
Violet	7	10^7	
Gray	**8**	10^8	
White	9	10^9	
Gold		10^{-1}	**5**
Silver		10^{-2}	10
No colour			**20**

The **first two bands** from the end indicate the first two significant figures of the resistance in ohms. The **third band** indicates the decimal multiplier as listed in table. The **last band** stands for tolerance or possible variation in percentage about the indicated values. Sometimes, this last band is absent and that indicates a tolerance of 20%.

For example, if the four colours are orange, blue, yellow and gold, the resistance value is $36 \times 10^4\ \Omega$, with a tolerance value of 5%.



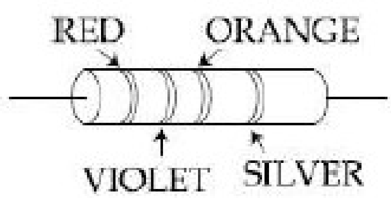
$(22 \times 10^2\ \Omega) \pm 10\%$



$(47 \times 10\ \Omega) \pm 5\%$

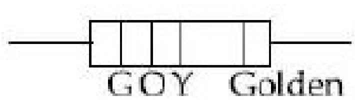
....**QUESTIONS**... from..... **COMPETITIVE EXAMS**...

1. A resistance is shown in the figure. Its value and tolerance are given respectively by :



(A) $270\ \Omega,\ 5\%$ (B) $27\,k\Omega, 10\%$ (C) $27\,k\Omega, 20\%$ (D) $270\,\Omega, 10\%$ **[JEE Main 2019]**

2. A carbon resistance has a following colour code. What is the value of the resistance ?



(A) $6.4\ M\Omega \pm 5\%$ (B) $530\ k\Omega \pm 5\%$ (C) $64\ k\Omega \pm 10\%$ (D) $5.3\ M\Omega \pm 5\%$ **[JEE Main 2019]**

3. A $2\,W$ carbon resistor is color coded with green, black, red and brown respectively. The maximum current which can be passed through this resistor is:

(A) $0.4\ mA$ (B) $20\ mA$ (C) $63\ mA$ (D) $100\ mA$ **[JEE Main 2019]**

4. A $200\,\Omega$ resistor has a certain color code. If one replaces the red color by green in the code, the new resistance will be:

(A) $100\,\Omega$ (B) $400\,\Omega$ (C) $300\,\Omega$ (D) $500\,\Omega$ **[JEE Main 2019]**

5. Space between two concentric conducting spheres of radii a and b $(b > a)$ is filled with a medium of resistivity ρ. The resistance between the two spheres will be:

(A) $\frac{\rho}{4\pi}\left(\frac{1}{a}-\frac{1}{b}\right)$ (B) $\frac{\rho}{2\pi}\left(\frac{1}{a}-\frac{1}{b}\right)$ (C) $\frac{\rho}{2\pi}\left(\frac{1}{a}+\frac{1}{b}\right)$ (D) $\frac{\rho}{4\pi}\left(\frac{1}{a}+\frac{1}{b}\right)$ **[JEE Main 2019]**

6. A carbon resistor has three bands as brown, black and green in order. What will be the range of resistance it offers ?

(A) $7 \times 10^5\,\Omega - 13 \times 10^5\,\Omega$ (B) $9 \times 10^5\,\Omega - 11 \times 10^5\,\Omega$

(C) $8 \times 10^5\,\Omega - 12 \times 10^5\,\Omega$ (D) None of these **[GUJCET 2019]**

7. A carbon resistor $(47 \pm 4.7)\,k\Omega$ is to be marked with rings of different colours for its identification. The colour code sequence will be :

(A) Violet – Yellow – Orange – Silver (B) Yellow – Violet – Orange – Silver

(C) Yellow – Green – Violet – Gold (D) Green – Orange – Violet – Gold **[NEET 2018]**

8. Brown, Red and Orange coloured bands on a Carbon resistor are followed by silver band. The value of resistor is ________

(A) $320\,\Omega \pm 5\%$ (B) $12\,k\Omega \pm 5\%$ (C) $320\Omega \pm 10\%$ (D) $12\,k\Omega \pm 10\%$ **[GUJCET 2017]**

....**QUESTIONS from GSEB Board Exams..**...

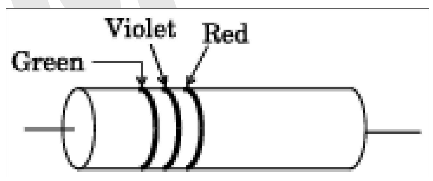
Q. 1. From the following which one is a colour code for a carbon resistance having resistance $(2200\,\Omega) \pm 5\,\%$

(A) Brown, Red, Red, Gold (B) Red, Red, Red, No Colour

(C) Red, Red, Red, Silver (D) Red, Red, Red, Gold **[1 mark, GSEB 2020]**

....**QUESTIONS from CBSE Board Exams..**...

Q. 1. A carbon resistor is shown in the figure. Using colour code, write the value of the resistance.



[1 mark, CBSE 2019]

Q. 2.

(a) You are required to select a carbon resistor of resistance of $56\,k\Omega \pm 10\,\%$ from a shopkeeper. What would be the sequence of colour bands required to code the desired resistor ?

(b) Write two characteristic properties of the material of a meter bridge wire.

(c) What precautions do you take to minimize the error in finding the unknown resistance of the given wire ?

[3 marks, CBSE 2019]

Q. 3. Define electrical resistivity of a given material. **[1 mark, CBSE 2018]**

Q. 4. Nichrome and copper wires of same length and same radius are connected in series. Current I is passed through them. Which wire gets heated up more ? Justify your answer. **[1 mark, CBSE 2017]**

Q. 5. Define the conductivity of a conductor. Write its SI unit. **[1 mark, CBSE 2017]**

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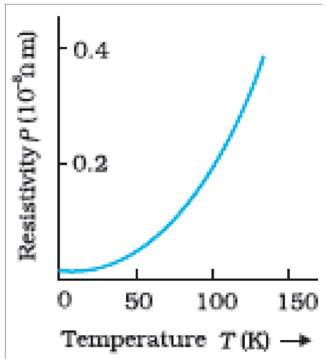
3.8 TEMPERATURE DEPENDENCE OF RESISTIVITY

Over a limited **(small) range of temperatures**, the resistivity of a metallic conductor is approximately given by $\rho_T = \rho_0\left[1 + \alpha(T - T_0)\right]$

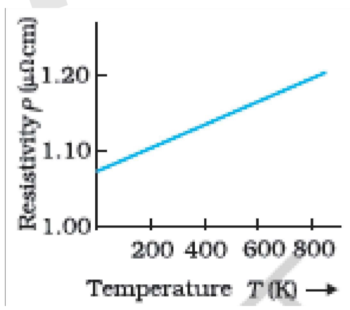
where ρ_T is the resistivity at a temperature T and ρ_0 is the same at a reference temperature T_0 . α is called the temperature coefficient of resistivity, and it dimension of is $(\text{Temperature})^{-1}$.

$\Rightarrow$ For **metals**, α is positive. A graph of ρ_T plotted against T would be a straigt line. At temperatures **much lower than** $0^0 C$, the graph however, **deviates considerably from a straight line** as shown in figure below:



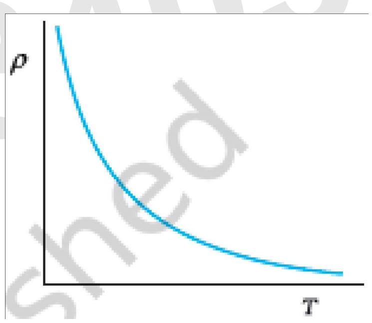
⇒ Therefore equation $\rho_T = \rho_0[1+\alpha(T-T_0)]$ can be used approximately over a **limited range of** T around any reference temperature T_0 , where the graph can be approximated as a straight line.

⇒ Some materials like **Nichrome** (which is an **alloy** of nickel,iron and chromium) exhibit a very weak dependence of resistivity with temperature as shown in figure below:



Manganin and **constantan** have similar properties. These materials are thus widely used in wire bound standard resistors since their resistance values would change very little with temperatures.

⇒ The resistivities of **semiconductors** decrease with increasing temperatures. A typical dependence is shown in figure below:



⇒ **Temperature dependence of resistivity**:

Resistivity of a material is given by $\rho = \dfrac{1}{\sigma} = \dfrac{m}{ne^2\tau}$

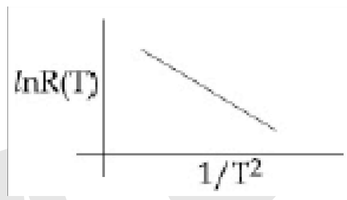
ρ **depends inversely both on the number** n **of free electrons per unit volume and on the average time** τ between collisions.As **temperature is increased**, **average speed of the electrons**, which act as the carriers of current, **increases resulting in more frequent collisions**.Thus **the average time of collisions** τ **decreases with temperature**.

In **metal**, n **is not dependent on temperature** to any appreciable extent and thus the decrease in the value of τ with rise in temperature causes ρ **to increase**.

For **insulators and semiconductors,** n **increases with temperature**. This increase more than compensates any decrease in τ so that for such materials, ρ **decreases** with temperature.

....**QUESTIONS**... from..... **COMPETITIVE EXAMS**...

1. In an experiment, the resistance of a material is plotted as a function of temperature (in some range). As shown in the figure, it is a straight line.



One may conclude that:

(A) $R(T) = \dfrac{R_0}{T^2}$ (B) $R(T) = R_0 e^{-T_0^2/T^2}$ (C) $R(T) = R_0 e^{-T^2/T_0^2}$ (D) $R(T) = R_0 e^{T^2/T_0^2}$

[JEE Main 2019]

2. A heating element has a resistance of $100\,\Omega$ at room temperature. When it is connected to a supply of $220\,V$, a steady current of $2\,A$ passes in it and temperature is $500^0 C$ more than room temperature. What is the temperature coefficient of resistance of the heating element ?

(A) $0.5\times10^{-4}\ {}^0C^{-1}$ (B) $5\times10^{-4}\ {}^0C^{-1}$ (C) $1\times10^{-4}\ {}^0C^{-1}$ (D) $2\times10^{-4}\ {}^0C^{-1}$

[JEE Main 2018 Online]

3. When the temperature of a conductor increases the ratio of conductivity and resistivity_____

(A) remain constant (B) increase (C) decrease (D) increase or decrease

[GUJCET 2018]

....**QUESTIONS from GSEB Board Exams..**...

Q. 1. A heating element using nichrome connected to a $230\,V$ supply draws an initial current of $4.6\,A$ which settles after a few seconds to a steady value of $2.3\,A$. What is the steady temperature of the heating element if the room temperature is $27^0 C \cdot \left[\alpha = 1.7\times10^{-4}\ {}^0C\right]$ **[3 marks, GSEB 2022]**

Q. 2. The value of the temperature co-efficient of resistivity (α) is_____ for metals.

(A) infinite (B) positive (C) zero (D) negative **[1 mark, GSEB 2022]**

Q. 3. The resistance of the platinum wire of a platinum resistance thermometer at the ice point is $5\,\Omega$ and at steam point is $5.23\,\Omega$. When it is inserted in a hot bath, the resistance of the wire is $5.46\,\Omega$. Calculate the temperature of the bath.

(A) $345.65\ {}^0C$ (B) $200\ {}^0C$ (C) $200\,K$ (D) $345.65\,K$

[1 mark, GSEB 2020(Oct)]

Q. 4. The resistance of the platinum wire of a platinum resistance thermometer at the ice point is $5\,\Omega$ and at steam point is $5.23\,\Omega$. When it is inserted in a hot bath, the resistance of the wire is $5.795\,\Omega$. Calculate the temperature of the bath. **[2 marks, GSEB 2020(M)]**

QUESTIONS from CBSE Board Exams..

Q. 1. Which of the following has negative temperature coefficient of resistivity ?

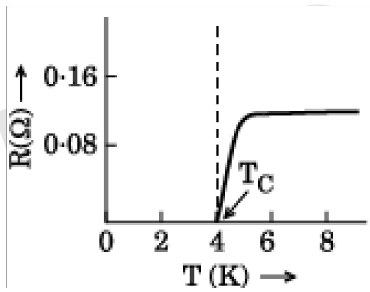
(A) metal (B) metal and semiconductor (C) semiconductor (D) metal and alloy

[1 mark, CBSE 2022 (I)]

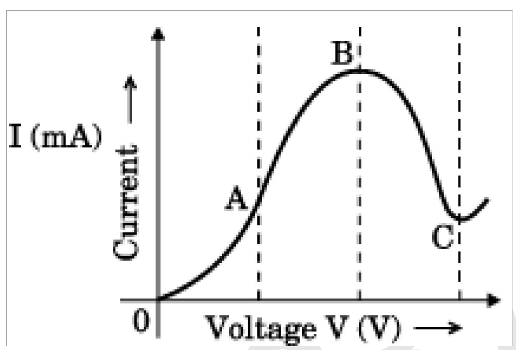
Q. 2.

(a) Draw a graph showing the variation of current versus voltage in an electrolyte when an external resistance is also connected.

(b) (i) The graph between resistance (R) and temperature (T) for Hg is shown in the figure (a). Explain the behaviour of Hg near $4\ K$.



(ii) In which region of the graph shown in the figure (b) is the resistance negative and why ?



[3 marks, CBSE 2019]

Q. 3. Define electrical resistivity of a given material. Why does resistivity of a metal increase with increase in temperature whereas in the case of a semiconductor, it decreases ? **[2 marks, CBSE 2019]**

Q. 4. The resistance of a heating element at $27^0 C$ is $100\,\Omega$. Find the

(a) temperature of the element at which its resistance is found to be $117\,\Omega$.

(b) resistance of the element at $427^0 C$.

The temperature coefficient of resistance of the material of the element is $1.70 \times 10^{-4}\ {}^0C^{-1}$.

[3 marks, CBSE 2019]

3.9 Electrical Energy, Power

Consider a conductor with end points A and B, in which a current I is flowing from A to B. The electric potential at A and B are denoted by $V(A)$ and $V(B)$ respectively. Since current is flowing from A to B, $V(A) > V(B)$ and the potential difference across AB is $V = V(A) - V(B) > 0$.

In a time interval Δt, an amount of charge $\Delta Q = I\,\Delta t$ travels from A to B. The potential energy of the charge at A, by the definition, was $Q\ V(A)$ and similarly at B, it is $Q\ V(B)$.

Thus change in potential energy ΔU_{pot} is

$$\Delta U_{pt} = \text{Final potential energy} - \text{Initial potential energy}$$
$$= \Delta Q\left[V(B) - V(A)\right] = -\Delta Q\,V$$
$$= -I\,V\Delta t < 0$$

If charges moved without collisions through the conductor, their kinetic energy would also change so that the total energy is unchanged.

Conservation of total energy would then imply that, $\Delta K = -\Delta U_{pot}$ i.e. $\Delta K = I\,V\,\Delta t > 0$

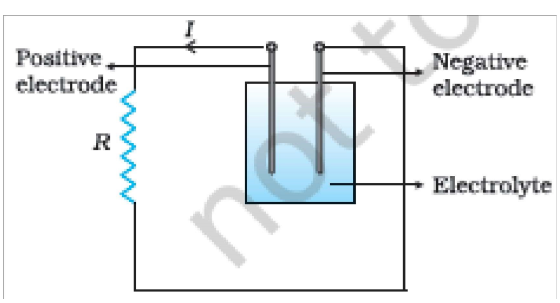
Thus in case charges were moving freely through the conductor under the action of electric field, their kinetic energy would increase as they move. On the average, charge carriers do not move with acceleration but with a steady drift velocity. This is because of the collisions with ions and atoms during transit. During collisions, the energy gained by the charges thus is shared with the atoms. The atoms vibrate more vigorously, i.e. the conductor heats up. Thus, in actual conductor, an amount of energy dissipated as heat in the conductor during the time interval Δt is, $\Delta W = I\,V\,\Delta t$

The energy dissipated per unit time is the power dissipated $P = \dfrac{\Delta W}{\Delta t}$ and $P = I\,V$.

Using Ohm's law, $V = IR$,

$$P = I^2 R = \frac{V^2}{R}$$ as the **power loss** ("ohmic loss") in a conductor of resistance R carrying a current I. It is this power which heats up, for example, the coil of an electric bulb to incandescence, radiating out heat and light.

$\Rightarrow$ An external source is required to keep a steady current through the conductor and power is supplied by this source.



As shown in figure above, it is the chemical energy of the cell which supplies this power for as long as it can.

$\Rightarrow$ **Power transmission**: Electric power is transmitted from power stations to homes and factories, which may be hundreds of miles away, via tranmission cables. Power loss in the transmission cables connecting the power stations to homes and factories is minimised as follows:

Consider a device R (*it is not resistance*),to which a power P is to be delivered via transmission cables having a resistance R_c to be dissipated by it finally. If V is the voltage across R and I the current through it, then $P = VI$.

The connecting wires from the power station to the device has a finite resistance R_c. The power dissipated in the connecting wires, which is wasted is P_c with

$$P_c = I^2 R_c$$
$$= \frac{P^2 R_c}{V^2}$$

Thus **to drive a device of power** P**, the power wasted in the connecting wires is inversely proportional to** V^2. The transmission cables from power stations are hundreds of miles long and their resistance R_c is considerable (large).

To reduce P_c**, these wires carry current at enormous values of** V and this is the reason for the **high voltage danger signs on transmission lines** as one moves away from populated areas.Using electricity at such voltage is not safe and hence at the other end, a device called a transformed lowers the voltage to a value suitable for use.

....**QUESTIONS**... from..... **COMPETITIVE EXAMS**..

1. A current of $2\ mA$ was passed through an unknown resistor which dissipated a power of $4.4\ W$. Dissipated power when an ideal power supply of $11\ V$ is connected across it is :

(A) $11 \times 10^{-3}\ W$ (B) $11 \times 10^{-4}\ W$ (C) $11 \times 10^{-5}\ W$ (D) $11 \times 10^{5}\ W$ **[JEE Main 2019]**

2. A cell of internal resistance r drives current through an external resistance R. The power delivered by the cell to the external resistance will be maximum when:

(A) $R = 0.001r$ (B) $R = 1000\ r$ (C) $R = 2r$ (D) $R = r$ **[JEE Main 2019]**

3. The heat produced per unit time, on passing electric current through a conductor at a given temperature, is directly proportional to the ....

(A) Reciprocal of electric current (B) Square of electric current
(C) Reciprocal of square of electric current (D) Electric current **[GUJCET 2019]**

4. A constant voltage is applied between two ends of a metallic wire. If the length is halved and the radius of the wire is doubled, the rate of heat developed in the wire will be :

(A) Doubled (B) Halved (C) Unchanged (D) Increased 8 times **[JEE Main 2018]**

....**QUESTIONS from CBSE Board Exams..**..

Q. 1. The electric power consumed by a $220\ V - 100\ W$ bulb when operated at $110\ V$ is

(A) $25\ W$ (B) $30\ W$ (C) $35\ W$ (D) $15\ W$ **[1 mark, CBSE 2022 (I)]**

Q. 2. An electric bulb is rated at $100\ W$ for a $220\ V$ supply. Calculate (a) the resistance of the bulb, and (b) the current flowing through the bulb. **[2 marks, CBSE 2018]**

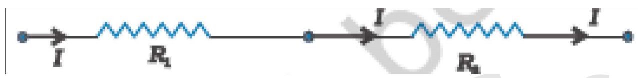
Q. 3. Two bulbs are rated (P_1, V) and (P_2, V). If they are connected (i) in series and (ii) in parallel across a supply V, find the power dissipated in the two combinations in terms of P_1 and P_2.

[2 marks, CBSE 2019]

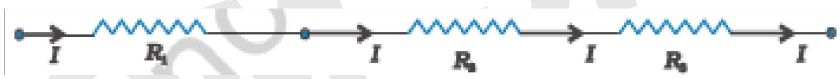
* Combination of Resistors - Series and Parallel

The current through a single resistor R across which there is a potential difference V is given by Ohm's law $I = \frac{V}{R}$. Simple rules are used for calculation of equivalent resistance in case resistors are joined together.

⇒ Two resistors are said to be in **series if only one of their end points is joined** as shown in figure below:



If a third resistor is joined with the series combination of the two, then all three are said to be in series.



Consider **two** resistors R_1 and R_2 in series. The charge which leaves R_1 must be entering R_2. Since current measures the rate of flow of charge, the same current I flows through R_1 and R_2.

Potential difference across R_1 is $V_1 = IR_1$

Potential difference across R_2 is $V_2 = IR_2$

Potential difference V across the combination is $V_1 + V_2$.

$$V = V_1 + V_2$$
$$= I\left(R_1 + R_2\right)$$

This is as if the combination had an equivalent resistance R_{eq}, which by Ohm's law is

$$R_{eq} \equiv \frac{V}{I} = \left(R_1 + R_2\right).$$

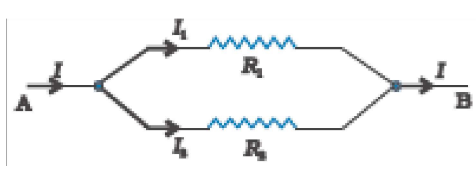
For **three** resistors connected in series,

$$V = IR_1 + IR_2 + IR_3$$
$$= I\left(R_1 + R_2 + R_3\right)$$

For a **series combination of** n **resistors** $R_1, R_2, R_3, R_4 ......, R_n$, the **equivalent resistance** R_{eq} **is**

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

⇒ Consider the **parallel combination** of two resistors. Two or more resistors are said to be in **parallel if one end of all the resistors is joined together and similarly the other ends joined together** as shown in figure below:



The charge that flows in at A from the left flows out partly through R_1 and partly through R_2. The currents I, I_1, I_2 shown in the figure are the rates of flow of charge at the points indicated.

Hence $I = I_1 + I_2$

Applying Ohm's law to R_1, the potential difference between A and B is given by

$$V = I_1 R_1$$

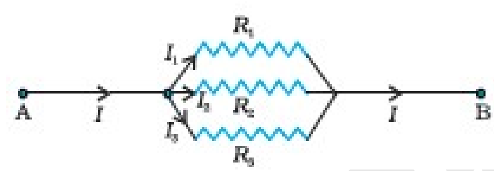
Also, Ohm's law applied to R_2 gives $V = I_2 R_2$

$$I = I_1 + I_2$$
$$= \frac{V}{R_1} + \frac{V}{R_2}$$
$$= V\left(\frac{1}{R_1} + \frac{1}{R_1}\right)$$

If the combination is replaced by an equivalent resistance R_{eq}, by Ohm's law $I = \frac{V}{R_{eq}}$

Hence, $$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

For **three resistors in parallel**, $I = I_1 + I_2 + I_3$



Applying Ohm's law to R_1, R_2 and R_3, $V = I_1 R_1$, $V = I_2 R_2$, $V = I_3 R_3$

So that

$$I = I_1 + I_2 + I_3$$
$$= V\left(\frac{1}{R_1} + \frac{1}{R_1} + \frac{1}{R_1}\right)$$

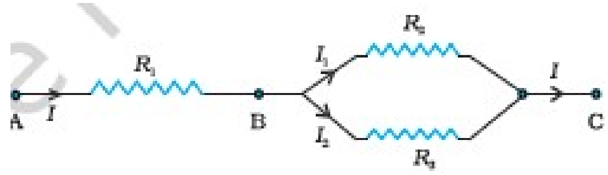
An equivalent resistance R_{eq} that replaces the combination, would be such that $I = \frac{V}{R_{eq}}$

Hence, $$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

For a **parallel combination of n resistors** $R_1, R_2, R_3, R_4 ......, R_n$, the **equivalent resistance** R_{eq} **is**

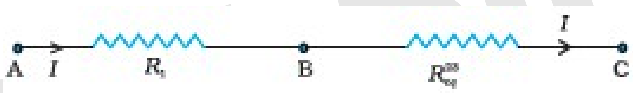
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ... + \frac{1}{R_n}$$

⇒ Consider three resistors R_1, R_2 and R_3 as shown in figure below.



Here R_2 and R_3 are in parallel, hence replacing them by an equivalent R_{eq}^{23} between point B and C

with $$\frac{1}{R_{eq}^{23}} = \frac{1}{R_2} + \frac{1}{R_3} \quad \text{or} \quad R_{eq}^{23} = \frac{R_2 R_3}{R_2 + R_3}$$



The circuit now has R_1 and R_{eq}^{23} in series and hence their combination can be replaced by an equivalent resistance R_{eq}^{123} with $R_{eq}^{123} = R_{eq}^{23} + R_1$

If the voltage between A and C is V, the current I is given by

$$I = \frac{V}{R_{eq}^{123}}$$

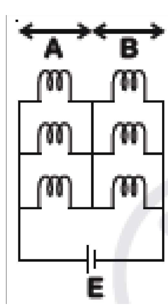
$$= \frac{V(R_1 + R_2)}{R_1 + \dfrac{R_2 R_3}{R_2 + R_3}}$$

$$I = \frac{V(R_2 + R_3)}{R_1 R_2 + R_1 R_3 + R_2 R_3}$$

....**QUESTIONS**... from..... **COMPETITIVE EXAMS**...

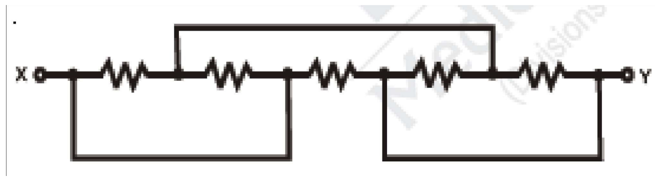
1.Six similar bulbs are connected as shown in the figure with a DC source of emf E and zero internal resistance.

The ratio of power consumption by the bulbs when (i) all are glowing and (ii) in the situation when two from section A and one from section B are glowing, will be:



(A)4:9 (B)9:4 (C)1:2 (D)2:1 **[NEET 2019]**

2.In the network shown in the figure the equivalent resistance between points X and Y will ..... Ω. Value of each resistance is $2\,\Omega$.



(A) $\frac{2}{3}$ (B) 1 (C) 4 (D) 2 **[GUJCET 2019]**

3. A uniform metallic wire has a resistance of $18\,\Omega$ and is bent into an equilateral triangle. Then, the resistance between any two vertices of the triangle is:

(A) $2\,\Omega$ (B) $12\,\Omega$ (C) $4\,\Omega$ (D) $8\,\Omega$ **[JEE Main 2019]**

4.Two equal resistances when connected in series to a battery, consume electric power of $60\,W$. If these resistances are now connected in parallel combination to the same battery, the electric power consumed will be:

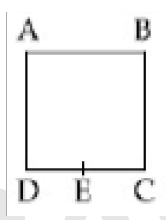
(A) $60\,W$ (B) $240\,W$ (C) $120\,W$ (D) $30\,W$ **[JEE Main 2019]**

5.Two electric bulbs, rated at $(25\,W, 220\,V)$ and $(100\,W, 220\,V)$, are connected in series across a $220\,V$ voltage source. If the $25\,W$ and $100\,W$ bulbs draw powers P_1 and P_2 respectively, then:

(A) $P_1 = 9\,W, P_2 = 16\,W$ (B) $P_1 = 16\,W, P_2 = 9\,W$

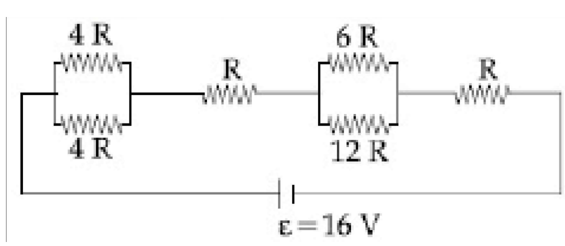
(C) $P_1 = 16\,W, P_2 = 4\,W$ (D) $P_1 = 4\,W, P_2 = 16\,W$ **[JEE Main 2019]**

6.A wire of resistance R is bent to form a square ABCD as shown in the figure. The effective resistance between E and C is: (E is mid-point of arm CD)



(A) R (B) $\frac{7}{64}R$ (C) $\frac{3}{4}R$ (D) $\frac{1}{16}R$ **[JEE Main 2019]**

7. The resistive network shown below is connected to a D.C. source of $16\,V$. The power consumed by the network is $4\,Watt$. The value of R is:

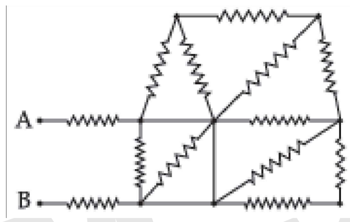


(A) $6\,\Omega$ (B) $8\,\Omega$ (C) $1\,\Omega$ (D) $16\,\Omega$ **[JEE Main 2019]**

8. A metal wire of resistance $3\ \Omega$ is elongated to make a uniform wire of double its previous length. This new wire is now bent and the ends joined to make a circle. If two points on this circle make an angle 60^0 at the centre, the equivalent resistance between these two points will be:

(A) $\frac{12}{5}\Omega$ (B) $\frac{5}{2}\Omega$ (C) $\frac{5}{3}\Omega$ (D) $\frac{7}{2}\Omega$ **[JEE Main 2019]**

9. In the given circuit all resistances are of value R ohm each.The equivalent resistance betweeen A and B is:



(A) $2R$ (B) $3R$ (C) $\frac{5R}{3}$ (D) $\frac{5R}{2}$ **[JEE Main 2018 Online]**

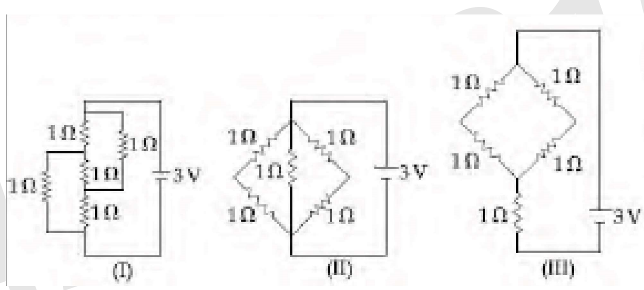
10. A set of n equal resistors, of value R each, are connected in series to a battery of emf E and internal resistance R. The current drawn is I. Now, the n resistors are connected in parallel to the same battery. Then the current drawn from battery becomes $10\,I$. The value of n is:

(A) 10 (B) 11 (C) 20 (D) 9 **[NEET 2018]**

11. You are given 10 resistors each of resistance $2\ \Omega$. First they are connected to obtain possible minimum resistance. Then they are connected to obtain possible maximum resistance. The ratio of maximum and minimum resistance is _______.

(A) 100 (B) 10 (C) 2.5 (D) 25 **[GUJCET 2018]**

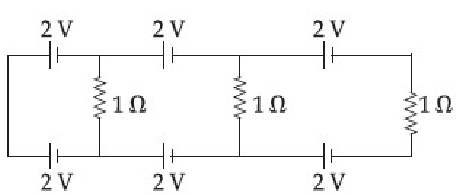
12. The figure shows three circuits I,II and III which are connected to a 3V battery. If the powers dissipated by the configurations I, II and III are P_1, P_2 and P_3 respectively, then :



(A) $P_3 > P_2 > P_1$ (B) $P_2 > P_1 > P_3$ (C) $P_1 > P_3 > P_2$ (D) $P_1 > P_2 > P_3$

[JEE Main 2017 Online]

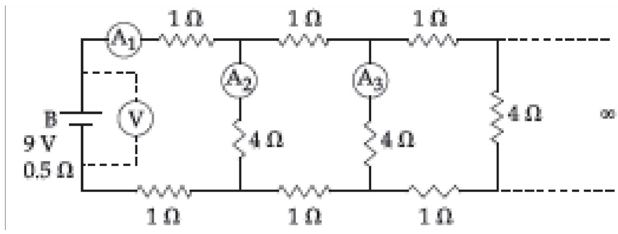
13.



In the above circuit the current in each resistance is :

(A) $1\ A$ (B) $0.25\ A$ (C) $0.5\ A$ (D) $0\ A$ **[JEE Main 2017]**

14.



A $9\,V$ battery with internal resistance of $0.5\,\Omega$ is connected across an infinite network as shown in the figure. All ammeters A_1, A_2, A_3 and voltmeter V are ideal.

Choose correct statement

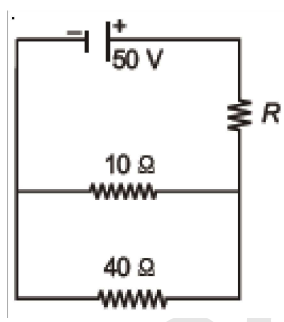
(A)Reading of A_1 is $2\,A$ (B)Reading of V is $7\,V$ (C)Reading of V is $9\,V$ (D)Reading of A_1 is $18\,A$

[JEE Main 2017 Online]

15. A uniform wire of length l and radius r has a resistance of 100Ω. It is recast into a wire of radius $\frac{r}{2}$. The resistance of new wire will be :

(A) 400Ω (B) 100Ω (C) 200Ω (D) 1600Ω **[JEE Main 2017Online]**

16.



In above circuit if current through $10\,\Omega$ resistor is $2.5\,A$, value of R is _____.

(A) $50\,\Omega$ (B) $40\,\Omega$ (C) $8\,\Omega$ (D) $10\,\Omega$ **[GUJCET 2017]**

17. The resistance of a wire is R ohm. If it is melted and stretched to n times its original length, its new resistance will be

(A) nR (B) $\frac{R}{n}$ (C) n^2R (D) $\frac{R}{n^2}$ **[NEET 2017]**

....**QUESTIONS from GSEB Board Exams..**..

Q.1. Three resistors $4\,\Omega$, $8\,\Omega$ and $10\,\Omega$ are combined in parallel, what is the total resistance of the combination?

(A) $2.10\,\Omega$ (B) $\frac{19}{20}\,\Omega$ (C) $1.05\,\Omega$ (D) $22\,\Omega$ **[1 mark, GSEB 2020]**

Q. 2. Two resistors when connected in series the net resistance is $5\,\Omega$ and when they are connected in parallel net resistance is $1.2\,\Omega$. What are these resistors ?

(A) $1\,\Omega, 4\,\Omega$ (B) $0.6\,\Omega, 0.6\,\Omega$ (C) $2\,\Omega, 3\,\Omega$ (D) $1\,\Omega, 2\,\Omega$ **[1 mark, GSEB 2020]**

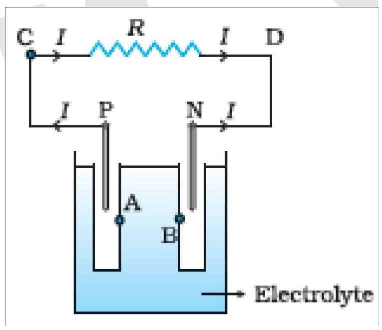
QUESTIONS from CBSE Board Exams..

Q. 1. A set of 'n' identical resistors, each of resistance 'R' when connected in series have an effective resistance 'X'. When they are connected in parallel, their effective resistance becomes 'Y'. Find out the product of X and Y. **[2 marks, CBSE 2019]**

Q. 2. Two electric bulbs P and Q have their resistances in the ratio of $1:2$. They are connected in series across a battery. Find the ratio of the power dissipation in these bulbs. **[2 marks, CBSE 2018]**

3.10 Cells, EMF, Internal Resistance

A simple device to maintain a steady current in an electric circuit is the **electrolytic cell**. Basically a cell has two electrodes, called the positive (P) and the negative (N) as shown in figure below.They are immersed in an electrolytic solution.

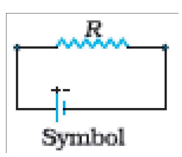


Dipped in the solution, the electrodes exchange charges with the electrolyte. The positive electrode has a potential difference V_+ $(V_+ > 0)$ between itself and the electrolyte solution immediately adjacent to it marked A in the figure.Similarly, the negative electrode develops a negative potential $-(V_-)(V_- \geq 0)$ relative to the electrolyte adjacent to it, marked as B in the figure.

When there is no current, the electrolyte has the same potential throughout, so that the potential difference between P and N is $V_+ - (-V_-) = V_+ + V_-$. This difference is called **electromotive force (emf)** of the cell and is denoted by ε. Thus $\varepsilon = V_+ + V_- > 0$.

Note that ε is, actually, a potential difference and not a force.

⇒ To understand the significance of ε, consider a resistor R connected across the cell as shown in figure below.



A current I flows across R from C to D. A steady current is maintained because current flows from N to P through the electrolyte.Across the electrolyte the same current flows through the electrolyte but from N to P, wherease **through R, it flows from P to N**.

The electrolyte through which a current flows has a finite resistance r, called internal resistance.

⇒ Consider first the situation when R is **infinite** so that $I = \frac{V}{R} = 0$, where V is the potential difference between P and N.

Now,

$V =$ Potential difference between P and A

$+$ Potential difference between A and B

$+$ Potential difference between B and N

$= \varepsilon$

Thus, emf ε is the potential difference between the positive and negative electrodes in an **open circuit, i.e. when no current is flowing through the cell**.

$\Rightarrow$ Consider the situation when R is **finite**, I is not zero.In that case potential difference between P and N is

$$V = V_+ + V_- - Ir$$
$$= \varepsilon - Ir$$

Note the **negative sign in the expression** (Ir) for the potential difference between A and B. This is because the current flows from B to A in the electrolyte.

$\Rightarrow$ In practical calculations, internal resistances of cells in the circuit may be neglected when the current I is such that $\varepsilon >> I\,r$. The actual values of the internal resistances of cells vary from cell to cell. The internal resistance of dry cells, however, is much higher than the common electrolytic cells.

$\Rightarrow$ Since V is the potential difference across R, from Ohm's law $V = IR$. Combining with $V = \varepsilon - Ir$,

$$IR = \varepsilon - Ir$$

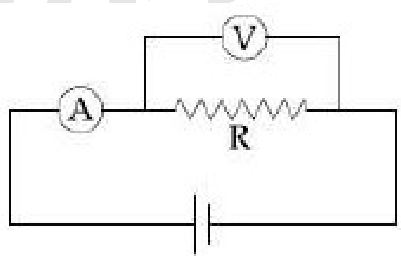
Or

The maximum current that can be drawn from a cell is for $R = 0$ and it is $I_{max} = \dfrac{\varepsilon}{r}$

However, in most cells the maximum allowed current is much lower than this to prevent permanent damage to the cell.

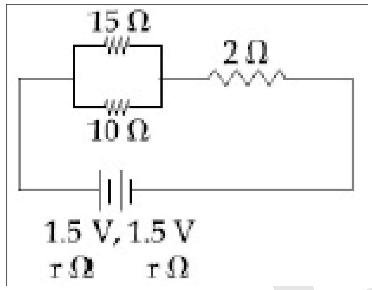
....**QUESTIONS**... from..... **COMPETITIVE EXAMS**...

1.The actual value of resistance R, shown in the figure is $80\,\Omega$. This is measured in an experiment as shown using the standard formula $R = \dfrac{V}{I}$, where V and I are the readings of the voltmeter and ammeter, respectively. If the measured value of R is $5\,\%$ less, then the internal resistance of the voltmeter is:



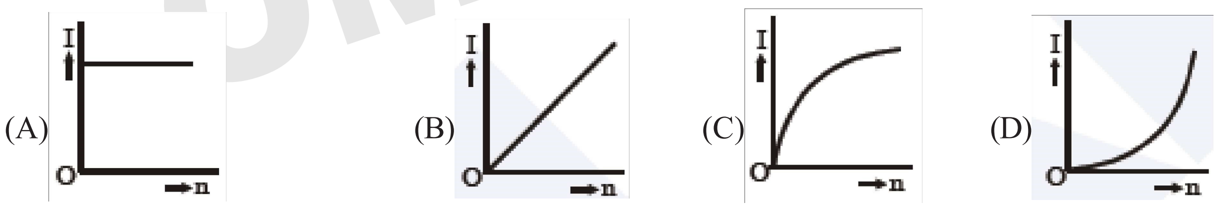
(A) $35\,\Omega$ (B) $350\,\Omega$ (C) $570\,\Omega$ (D) $600\,\Omega$ **[JEE Main 2019]**

2.In the given circuit, an ideal voltmeter connected across the $10\,\Omega$ resistance reads $2\,V$. The internal resistance r, of each cell is:



(A) $1\,\Omega$ (B) $0.5\,\Omega$ (C) $1.5\,\Omega$ (D) $0\,\Omega$ **[JEE Main 2019]**

3. A battery consists of a variable number n of identical cells (having internal resistance r each) which are connected in series. The terminals of the battery are short-circuited and the current I is measured. Which of the graphs shows the correct relationship between I and n?



[NEET 2018]

....**QUESTIONS from GSEB Board Exams..**..

Q. 1. The storage battery of a car emf $12\,V$. If the internal resistance of the battery is $0.4\,\Omega$. What is the maximum current that can be drawn from the battery ?

(A)0.3 A (B)30 A (C)3 A (D) 0.03A **[1 mark, GSEB 2020]**

....**QUESTIONS from CBSE Board Exams..**..

Q. 1.

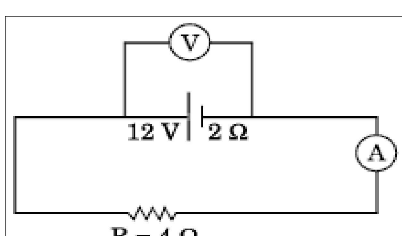
(a) Derive a relation between the internal resistance, emf and terminal potential difference of a cell from which current I is drawn. Draw V vs I graph for a cell and explain its significance.

(b) A voltmeter of resistance $998\,\Omega$ is connected across a cell of emf $2\,V$ and internal resistance $2\,\Omega$. Find the potential difference across the voltmeter and also across the terminals of the cell.
Estimate the percentage error in the reading of the voltmeter. **[5 marks, CBSE 2019]**

Q. 2.

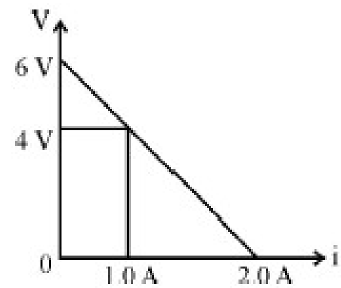
(a)The potential difference applied across a given resistor is altered so that the heat produced per second increases by a factor of 9. By what factor does the applied potential difference change ?

(b) In the figure shown, an ammeter A and a resistor of $4\,\Omega$ are connected to the terminals of the source.The emf of the source is $12\,V$ having an internal resistance of $2\,\Omega$. Calculate the voltmeter and ammeter readings.



[3 marks, CBSE 2017]

Q. 3. The figure shows a plot of terminal voltage 'V' versus the current 'i' of a given cell. Calculate from the graph (a) emf of the cell and (b) internal resistance of the cell.



[2 marks, CBSE 2017]

Q. 4. What is the difference between terminal voltage and emf of a cell ? **[1 mark, CBSE 2017]**

....

3.11 Cells in Series and Parallel

$\Rightarrow$ Consider first **two cells in series** as shown in figure (1) below:

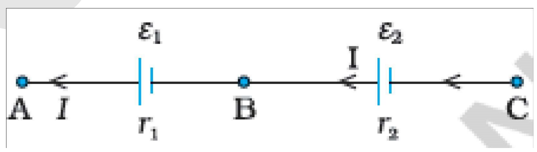


Figure 1

Here one terminal of the two cells is joined together leaving the other terminal in either cell free. $\varepsilon_1, \varepsilon_2$ are emfs of the two cells and r_1, r_2 their internal resistances respectively.

Let $V(A), V(B), V(C)$ be the potentials at points A, B and C shown in figure. $V(A)-V(B)$ is the potential difference between the positive and negative terminals of the first cell.

$$V(A)+Ir_1-\varepsilon_1=V(B) \qquad \text{or}$$

$$V_{AB}=V(A)-V(B)=\varepsilon_1-Ir_1$$

Similarly, $V_{BC}=V(B)-V(C)=\varepsilon_2-Ir_2$

Hence, the potential difference between the terminals A and C of the combination is

$$V_{AC}=V(A)-V(C)=V(A)-V(B)+V(B)-V(C)$$

$$=(\varepsilon_1+\varepsilon_2)-I(r_1+r_2) \qquad \text{..............................(1)}$$

As shown in figure 2, combination of two cells can be replaced by a single cell between A and C of emf ε_{eq} and internal resistance r_{eq},

$$V_{AC}=\varepsilon_{eq}-I\,r_{eq} \qquad \text{..............................(2)}$$

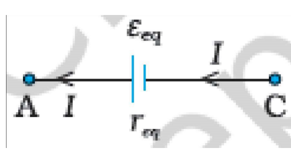


Figure 2

Comparing equation (1) and (2), $\varepsilon_{eq}=\varepsilon_1+\varepsilon_2$ and $r_{eq}=r_1+r_2$

In figure (1), the negative electrode of the first was connected to the positive electrode of the second. Instead if the two negatives were connected, $V_{BC} = -\varepsilon_2 - I\,r_2$, Then $\varepsilon_{eq} = \varepsilon_1 - \varepsilon_2$, $(\varepsilon_1 > \varepsilon_2)$.

The **rule for series combination** of n number of cells is:
(i) The equivalent emf of a series combination of n cells is just the **sum of their individual emf's**, and
(ii) The equivalent internal resistance of a series combination of n cells is just the **sum of their internal resistances**.

$\Rightarrow$ Consider a **parallel combination of the cells** as shown in figure 1 below:

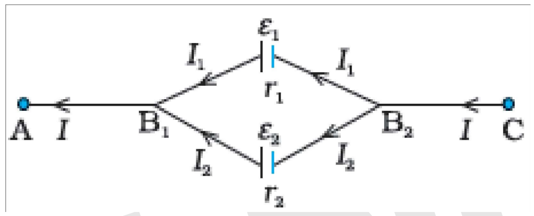


Figure 1

I_1 and I_2 are the currents leaving the positive electrodes of the cells. At the point B_1, I_1 and I_2 flow in whereas the current I flows out.

Since as much charge flows in as out, $I = I_1 + I_2$ ....(1)

Let $V(B_1)$ and $V(B_2)$ be the potentials at B_1 and B_2, respectively. Then, considering the first cell, the potential difference across its terminals is $V(B_1) - V(B_2)$.

$V \equiv V(B_1) - V(B_2) = \varepsilon_1 - I_1 r_1$. Thus, $I_1 = \dfrac{\varepsilon_1 - V}{r_1}$ ....(2)

Points are connected exactly similarly to the second cell. Considering second cell,

$V \equiv V(B_1) - V(B_2) = \varepsilon_2 - I_2 r_2$ Thus, $I_2 = \dfrac{\varepsilon_2 - V}{r_2}$ ....(3)

From equation (1), (2) and (3),

$$I = I_1 + I_2$$
$$= \frac{\varepsilon_1 - V}{r_1} + \frac{\varepsilon_2 - V}{r_2}$$
$$= \frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2} - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

Hence, V is given by, $V = \dfrac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2} - I\left(\dfrac{r_1 r_2}{r_1 + r_2}\right)$ ....(4)

As shown in figure 2 below, combination of two cells can be replaced by a single cell between B_1 and B_2 of emf ε_{eq} and internal resistance r_{eq}, $V = \varepsilon_{eq} - I\,r_{eq}$ ....(5)

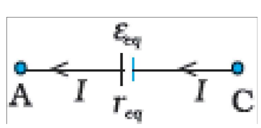


Figure 2

From eq. (4) and (5), $\varepsilon_{eq} = \dfrac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}$ and $r_{eq} = \dfrac{r_1 r_2}{r_1 + r_2}$

OR $\dfrac{1}{r_{eq}} = \dfrac{1}{r_1} + \dfrac{1}{r_2}$ and $\dfrac{\varepsilon_{eq}}{r_{eq}} = \dfrac{\varepsilon_1}{r_1} + \dfrac{\varepsilon_2}{r_2}$

If there are n cells of emf $\varepsilon_1, \varepsilon_2, ...\varepsilon_n$ and of internal resistances $r_1, r_2, ...r_n$ respectively, connected in parallel, the combination is equivalent to a single cell of emf ε_{eq} and internal resistance r_{eq} such that

$$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_1} + ... + \frac{1}{r_n} \quad \text{and} \quad \frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_1} + ... + \frac{\varepsilon_n}{r_n}$$

....**QUESTIONS**... from..... **COMPETITIVE EXAMS**..

1. Two batteries with e.m.f. $12\,V$ and $13\,V$ are connected in parallel across a load resistor of $10\,\Omega$. The internal resistances of the two batteries are $1\,\Omega$ and $2\,\Omega$ respectively. The voltage across the load lies between:

(A) $11.6\,V$ and $11.7\,V$ (B) $11.5\,V$ and $11.6\,V$ (C) $11.4\,V$ and $11.5\,V$ (D) $11.7\,V$ and $11.8\,V$

[JEE Main 2018]

....**QUESTIONS from CBSE Board Exams..**...

Q. 1. Derive the formula for equivalent emf and equivalent internal resistance for two cells having emf ε_1 and ε_1 ε_2, internal resistance r_1 and r_2 are connected in parallel.

Q. 2. Under what condition will the current in a wire be the same when connected in series and in parallel of n identical cells each having internal resistance r and external resistance R? **[1 mark, CBSE 2019]**

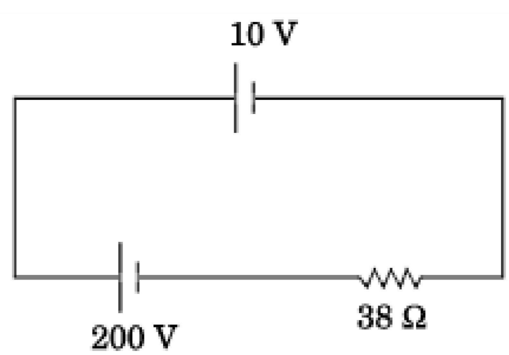
Q. 3.

(a) Two cells of different emfs and internal resistances are connected in parallel with one another. Derive the expression for the equivalent emf and equivalent internal resistance of the combination.

(b) Two identical cells of emf $1.5\,V$ and internal resistance r are each connected in parallel providing a supply to an external circuit consisting of two resistances of $17\,\Omega$ each joined in parallel. A very high resistance voltmeter reads the terminal voltage of the cell to be $1.4\,V$. Calculate the internal resistance of each cell. **[5 marks, CBSE 2019]**

Q. 4. Two cells of emf and internal resistance ε_1, r_1 and ε_2, r_2 are connected in parallel. Derive the expressions for the emf and internal resistance of a cell which can replace this combination. **[3 marks,CBSE 2019]**

Q. 5. A $10\,V$ cell of negligible internal resistance is connected in parallel across a battery of emf $200\,V$ and internal resistance $38\,\Omega$ as shown in the figure. Find the value of current in the circuit.



[2 marks, CBSE 2018]

Q. 6. Two cells of emfs ε_1 & ε_2 and internal resistances r_1 & r_2 respectively are connected in parallel. Obtain expressions for the equivalent
(i) resistance and
(ii) emf of the combination **[3 marks, CBSE 2018]**

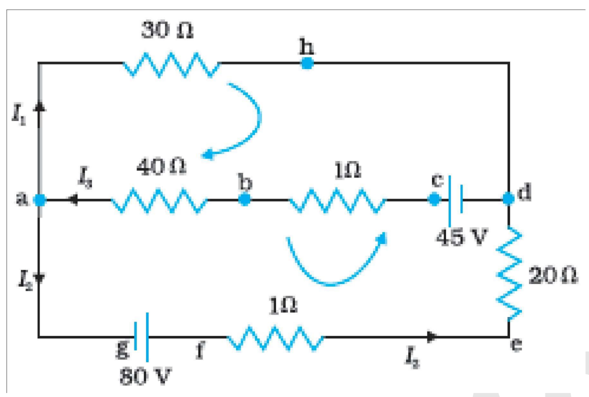
Q. 7. The reading on a high resistance voltmeter when a cell is connected across it is $2.2\,V$. When a $5\,\Omega$ resistance is connected across the terminals of the cell in parallel with the voltmeter the reading drops to $1.8\,V$. Determine the internal resistance of the cell. **[3 marks, CBSE 2018]**

3.12 KIRCHHOFF'S RULES

Two rules called Kirchhoff's rules are very useful for analysis (to determine the currents and potential differences) of electric ciruits in addition to series and parallel combinations of resistors.

(a) **Junction rule**: At any junction, the sum of the currents entering the junction is equal to the sum of currents leaving the junction.

(b) **Loop rule**: The algebraic sum of changes in potential around any closed loop involving resistors and cells in the loop is zero.

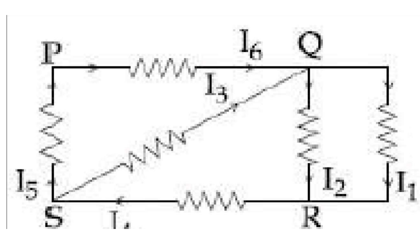


In the circuit shown, applying Kirchhoff's Junction rule at 'a', the current leaving is $I_1 + I_2$ and current entering is I_3. Thus $I_3 = I_1 + I_2$.

Applying Kirchhoff's loop rules to loops 'ahdcba': $-30I_1 - 41I_3 + 45 = 0$ and 'ahdefga': $-30I_1 + 21I_2 - 80 = 0$.

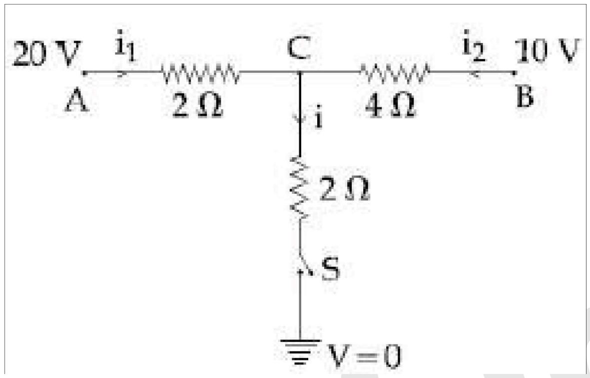
QUESTIONS... from..... COMPETITIVE EXAMS

1. In the given circuit diagram, the currents, $I_1 = -0.3\,A, I_4 = 0.8\,A$ and $I_5 = 0.4\,A$, are flowing as shown. The currents I_2, I_3 and I_6, respectively, are:



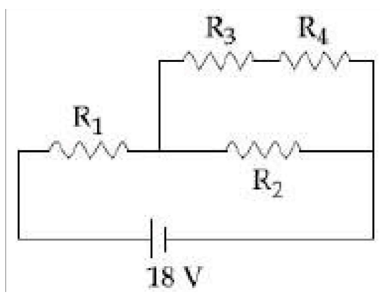
(A) $1.1\,A, -0.4\,A, 0.4\,A$
(B) $-0.4\,A, 0.4\,A, 1.1\,A$
(C) $1.1\,A, 0.4\,A, 0.4\,A$
(D) $0.4\,A, 1.1\,A, 0.4\,A$
[JEE Main 2019]

2.When the switch S, in the circuit shown, is closed, then the value of current will be:



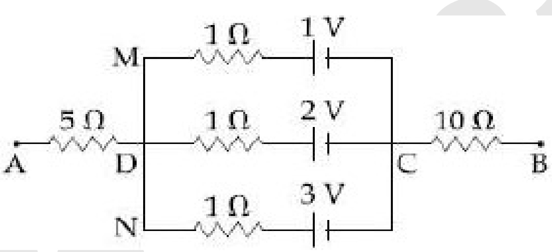
(A) 2 A (B) 2 A (C) 4 A (D) 4 A **[JEE Main 2019]**

3.In the given circuit the internal resistance of the $18\,V$ cell is negligible. If $R_1 = 400\,\Omega$, $R_3 = 100\,\Omega$ and $R_4 = 500\,\Omega$ and the reading of an ideal voltmeter across R_4 is $5\,V$, then the value of R_2 will be :



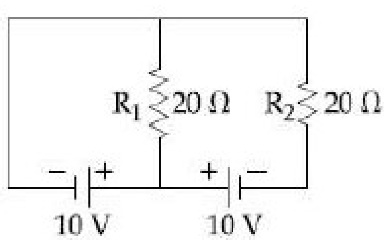
(A) $550\,\Omega$ (B) $230\,\Omega$ (C) $450\,\Omega$ (D) $300\,\Omega$ **[JEE Main 2019]**

4.In the circuit shown, the potential difference between A and B is:



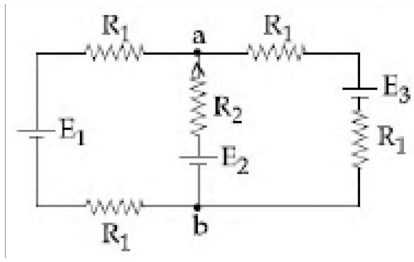
(A) $2\,V$ (B) $3\,V$ (C) $6\,V$ (D) $1\,V$ **[JEE Main 2019]**

5.In the given circuit the cells have zero internal resistance.The currents (in Amperes) passing through resistance R_1 and R_2 respectively, are :



(A) 0.5, 0 (B) 1 , 2 (C) 2 , 2 (D) 0 , 1 **[JEE Main 2019]**

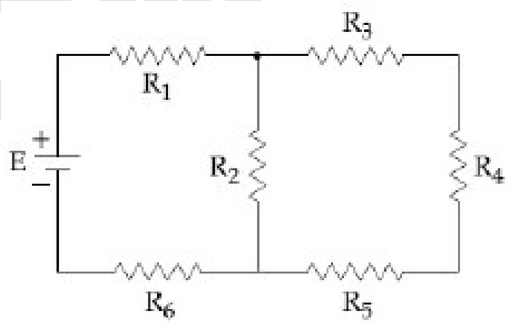
6.For the circuit shown, with $R_1 = 1.0\,\Omega, R_2 = 2.0\,\Omega$, $E_1 = 2\,V$ and $E_2 = E_3 = 4\,V$, the potential difference between the points 'a' and 'b' is approximately (in V):



(A) $2.7\,V$ (B) $3.7\,V$ (C) $2.3\,V$ (D) $3.3\,V$ **[JEE Main 2019]**

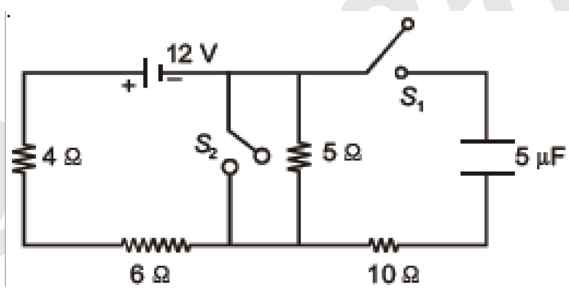
7.In the figure shown, what is the current (in Ampere) drawn from the battery ? You are given:

$R_1 = 15\,\Omega, R_2 = 10\,\Omega, R_3 = 20\,\Omega, R_4 = 5\,\Omega, R_5 = 25\,\Omega, R_6 = 30\,\Omega, E = 15\,V$



(A) $\frac{13}{24}$ (B) $\frac{7}{18}$ (C) $\frac{9}{32}$ (D) $\frac{20}{3}$ **[JEE Main 2019]**

8.What is the current in the $4\,\Omega$ resistor when switch S_1 is open and switch S_2 is closed in the given circuit ?



(A) $3.0\,A$ (B) $0.8\,A$ (C) $1.5\,A$ (D) $1.2\,A$ **[GUJCET 2017]**

....**QUESTIONS from GSEB Board Exams..**...

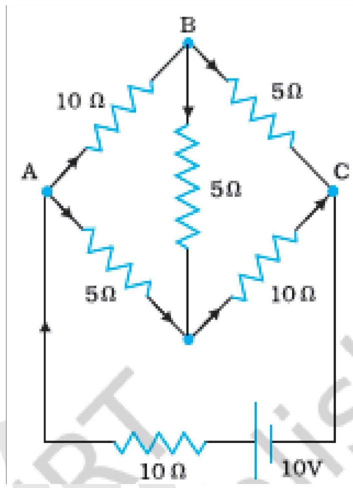
Q. 1. Kirchhoff's junction rule represents

(A) Conservation of energy (B) Conservation of angular momentum

(C) Conservation of linear momentum (D) Conservation of charge

[1 mark, GSEB 2020]

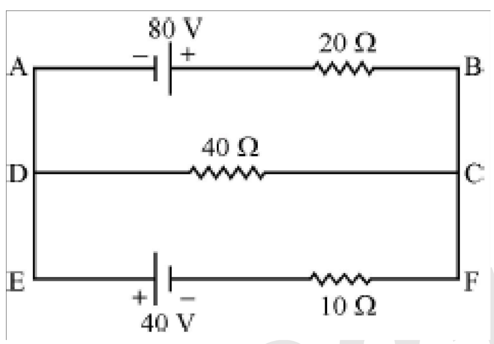
Q. 2. Detemine the current in each branch of the given network.



[4 marks, GSEB 2020]

....**QUESTIONS from CBSE Board Exams..**...

Q. 1. Using Kirchhoff's rules, calculate the current through the $40\,\Omega$ and $20\,\Omega$ resistors in the following circuit:

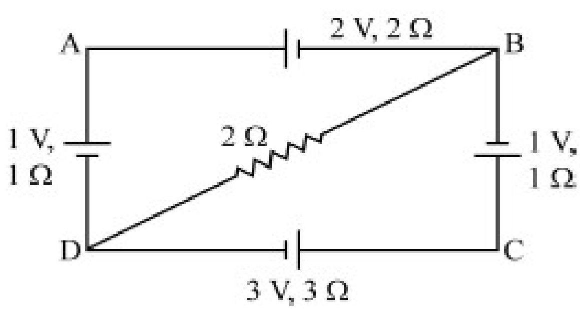


[3 marks, CBSE 2019]

Q. 2. Twelve wires each having a resistance of $3\,\Omega$ are connected to form a cubical network. A battery of $10\,V$ and negligible internal resistance is connected across the diagonally oposite corners of this network. Determine its equivalent resistance and the current along each edge of the cube. **[3 marks, CBSE 2019]**

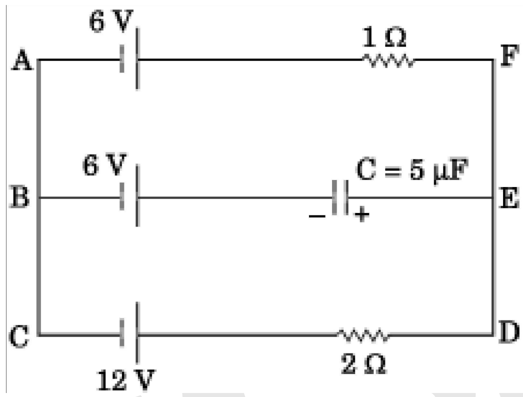
Q. 3. State Kirchhoff's rules. How are these rules justified ? **[2 marks, CBSE 2018]**

Q. 4. Using Kirchhoff's rules, calculate the potential difference between B and D in the circuit diagram as shown in the figure.



[3 marks, CBSE 2018]

Q. 5. In the given circuit, with steady current, calculate the potential difference across the capacitor and the charge stored in it.

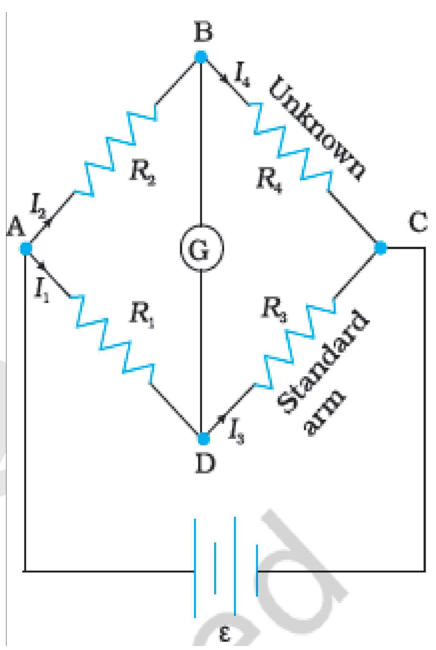


[3 marks, CBSE 2018]

Q.6. Three resistors, $2\,\Omega$, $5\,\Omega$ and $10\,\Omega$ are connected in parallel across a cell of emf of $6\,V$ and internal resistance $0.25\,\Omega$. Calculate the value of the
(i) current drawn from the cell and (ii) terminal potential difference of the cell. **[3 marks, CBSE 2018]**

3.13 WHEATSTONE BRIDGE

*Kirchhoff's rules are applied to Wheatstone bridge which is shown in the figure below.



*The bridge has four resistors R_1, R_2, R_3 and R_4.
* Across one pair of diagonally opposite points (AC) a source is connected. This (i.e. AC) is called battery arm.
*Between the other two vertices, B and D, a galvanometer G (which is a device to detect currents) is connected. This line, shown as BD in the figure, is called the galvanometer arm.
*Assume that cell has no internal resistance. There will be currents flowing across all the resistors as well as a current I_g through G.

Consider a balanced bridge where the values of resistors are such that $I_g = 0$. Condition of balanced bridge can easily be obtained such that there is no current through G.

Applying Kirchhoff's junciton rule to junctions D and B as shown in figure. Here $I_1 = I_3$ and $I_2 = I_4$. Applying Kirchhoff's loop rule to closed loops ADBA and CBDC.

Loop ADBA gives $-I_1R_1 + 0 + I_2R_2 = 0 \quad (I_g = 0)$

Therefore, $\frac{I_1}{I_2} = \frac{R_2}{R_1}$ ....(1)

Similarly loop CBDC gives $I_4R_4 + 0 - I_3R_3 = 0$

As $I_1 = I_3$ and $I_2 = I_4$, $\quad I_2R_4 + 0 - I_1R_3 = 0$

Thus, $\frac{I_1}{I_2} = \frac{R_4}{R_3}$ ....(2)

From equations (1) and (2), $\frac{R_2}{R_1} = \frac{R_4}{R_3}$

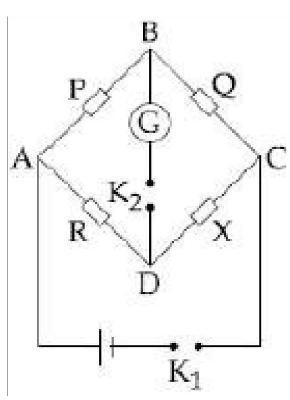
This **equation relating the four resistors is called the balance condition for the galvanometer to give zero or null deflection**.

The Wheatstone bridge and its balance condition provide a practical method for determination of an unknown resistance. Consider an unknown resistance inserted in the fourth arm i.e. R_4 is not known. Keeping known resistances R_1 and R_2 in the first and second arm of the bridge, R_3 is varied till the galvanometer shows a null deflection. The bridge then is balanced, and from the balance condition the value of the unknown resistance R_4 is given by, $\quad R_4 = R_3\frac{R_2}{R_1}$.

$\Rightarrow$ **A practical device using this principle of balanced condition is called the meter bridge**.

....**QUESTIONS**... from..... **COMPETITIVE EXAMS**..

1.In a Wheatstone bridge (see fig.), Resistances P and Q are approximately equal. When $R = 400\,\Omega$, the bridge is balanced. On interchanging P and Q, the value of R, for balance, is $405\,\Omega$. The value of X is close to:



(A) $401.5\,\Omega$ (B) $404.5\,\Omega$ (C) $402.5\,\Omega$ (D) $403.5\,\Omega$ **[JEE Main 2019]**

2. Which of the following statements is **false** ?

(A) Wheatstone bridge is the most sensitive when all the four resistances are of the same order of magnitude.

(B) In a balanced wheatstone bridge if the cell and the galvanometer are exchanged , the null point is disturbed.

(C) A rheostat can be used as a potential divider.

(D) Kirchhoff's second law represents energy conservation. **[JEE Main 2017]**

....**QUESTIONS from GSEB Board Exams..**...

Q. 1. The four arms of a wheatstone bridge have the resistances $R_1 = 100\,\Omega$, $R_2 = 10\,\Omega$, $R_3 = 500\,\Omega$ and R_4. What will be the value of R_4 if the wheatstone bridge is balanced ?

(A) $5\ k\Omega$ (B) $2\ \Omega$ (C) $2\ K\Omega$ (D) $50\ \Omega$ **[1 mark, GSEB 2020]**

....**QUESTIONS from CBSE Board Exams..**...

Q. 1.

(a)Use Kirchhoff's rules to obtain the balance condition in terms of the values of the four resistors in a Wheatstone bridge so as to give null deflection in a galvanometer.

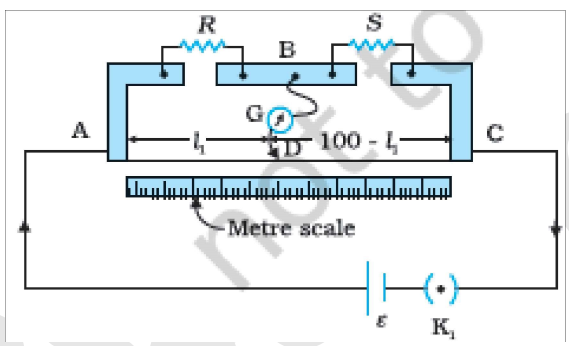
(b)Explain how the balance condition in a Wheatstone bridge is used in a meter bridge to determine the unknown resistance.Under what condition is the error in determining the unknown resistance minimized ?

[5 marks, CBSE 2017]

....

* *METER BRIDGE*

The meter bridge is shown in figure below:



It consists of a wire of length $1\ m$ and of uniform cross sectional area stretched taut and clampled between two thick metallic strips bent at right angles.The metallic strips has two gaps across which resistors can be connnected. The end points where the wire is clamped are connnected to a cell through a key. One end of a galvanometer is connected to the metallic strip midway between the two gaps.The other end of the galvanometer is connected to a 'jockey'. The jockey is essentially a metallic rod whose one end has a knofe-edge which can slide over the wire to make electrical connection.

R is an unknown resistance whose value is to be determined. It is connected across one of the gaps. Across the other gap, a standard resistance S is connected.The jockey is connected to some point D on the wire, a distance $l\ \ cm$ from the end A. The jockey can be moved along the wire. The portion AD of the wire has a resistance $R_{cm}\, l$, where R_{cm} is the resistance of the wire per unit centimetre.The portion DC of the wire similarly has a resistance $R_{cm}(100 - l)$.

The four arms AB, BC, DA and CD [with resistances R, S, $R_{cm}\,l$ and $R_{cm}(100-l)$] form a Wheatstone bridge with AC as the battery arm and BD the galvanometer arm. If the jockey is moved along the wire, then there will be one position where the galvanometer will show no current. Let the distance of the jockey from the end A at the balance point be $l = l_1$. The four resistances of the bridge at the balance point then are R, S, $R_{cm}\,l_1$ and $R_{cm}(100-l_1)$. The balance condition gives

$$\frac{R}{S} = \frac{R_{cm}\,l_1}{R_{cm}\,(100 - l_1)} = \frac{l_1}{(100 - l_1)}$$

Thus after finding l_1, the unknown resistance R is known in terms of the standard known resistance S by

$$R = S\left(\frac{l_1}{100 - l_1}\right)$$

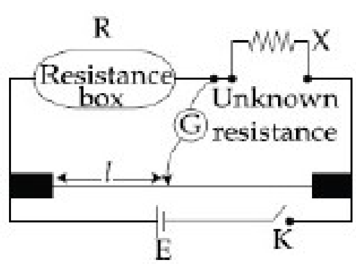
By choosing various values of S, values of l_1 will be obtained and R will be calculated each time.

An error in measurement of l_1 would result in an error in R. **The percentage error in R can be minimised by adjusting the balance point near the middle of the bridge, i.e. when l_1 is close to $50\,cm$.** (This requires a suitable choice of S).

$\Rightarrow$ **Meter bridge is based on the principle of balanced Wheatstone bridge.**

....**QUESTIONS**... from..... **COMPETITIVE EXAMS**..

1.In a meter bridge experiment,the circuit diagram and the corresponding observation table are shown in figure.

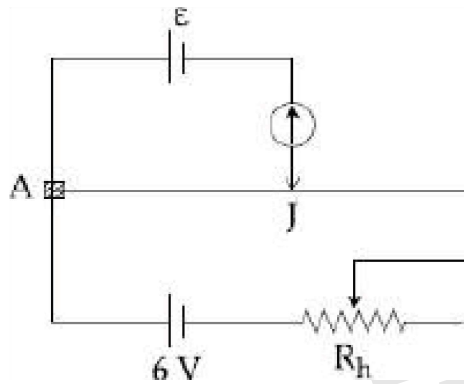


Which of the readings is inconsistent ?

Sl. No.	R (Ω)	l (cm)
1.	1000	60
2.	100	13
3.	10	1.5
4.	1	1.0

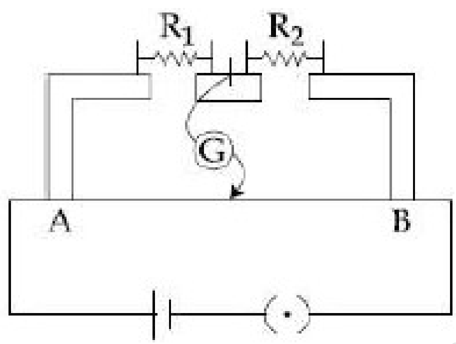
(A) 3 (B) 2 (C) 4 (D) 1 **[JEE Main 2019]**

2.The resistance of the meter bridge AB in given figure is $4\,\Omega$. With a cell of emf $\varepsilon = 0.5\,V$ and rheostat resistance $R_h = 2\,\Omega$ the null point is obtained at some point J. When the cell is replaced by another one of emf $\varepsilon = \varepsilon_2$ the same null point J is found for $R_h = 6\,\Omega$. The emf ε_2 is :



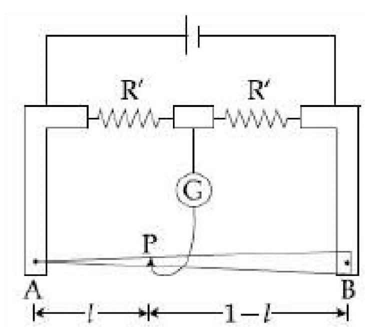
(A) $0.3\,V$ (B) $0.5\,V$ (C) $0.4\,V$ (D) $0.6\,V$ **[JEE Main 2019]**

3.In the experimental set up of metre bridge shown in the figure, the null point is obtained at a distance of $40\,cm$ from A.If a $10\ \Omega$ resistor is connected in series with R_1 , the null point shifts by $10\,cm$. The resistance that should be connected in parallel with $(R_1+10)\Omega$ such that the null point shifts back to its initial position is:



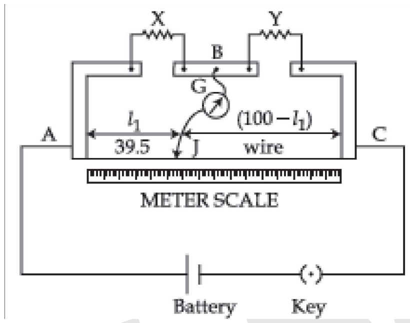
(A) $60\ \Omega$ (B) $40\ \Omega$ (C) $30\ \Omega$ (D) $20\ \Omega$ **[JEE Main 2019]**

4. In a meter bridge, the wire of length $1\,m$ has a non-uniform cross-section such that, the variation $\frac{dR}{dl}$ of its resistance R with length l is $\frac{dR}{dl}\alpha\frac{1}{\sqrt{l}}$. Two equal resistances are connected as shown in the figure. The galvanometer has zero deflection when the jockey is at point P . What is the length AP ?



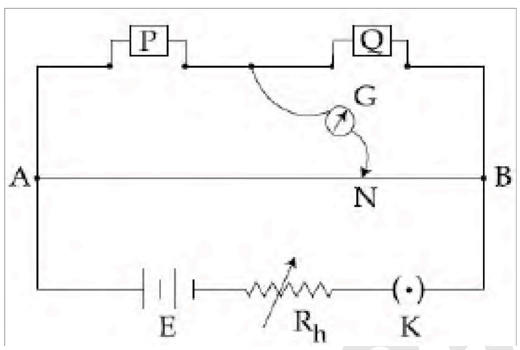
(A) $0.2\,m$ (B) $0.25\,m$ (C) $0.3\,m$ (D) $0.35\,m$ **[JEE Main 2019]**

5. In a meter bridge, as shown in the figure, it is given that resistance $Y = 12.5\,\Omega$ and that the balance is obtained at a distance 39.5 cm from end A (by Jockey J). After interchanging the resistances X and Y, a new balance point is found at a distance l_2 from end A. What are the values of X and l_2?



(A) $8.16\,\Omega$ and 60.5 cm (B) $19.15\,\Omega$ and 39.5 cm
(C) $8.16\,\Omega$ and 39.5 cm (D) $19.15\,\Omega$ and 60.5 cm **[JEE Main 2018 Online]**

6. In a meter bridge experiment resistances are connected as shown in the figure. Initially resistance $P = 4\,\Omega$ and the neutral point N is at $60\,cm$ from A. Now an unknown resistance R is connected in series to P and the new position of the neutral point is at $80\,cm$ from A. The value of unknown resistance R is:

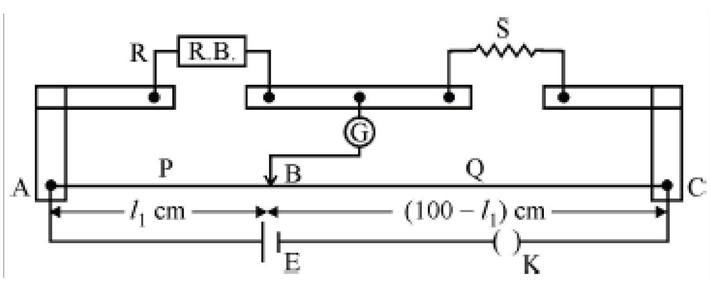


(A) $\frac{20}{3}\,\Omega$ (B) $\frac{33}{5}\,\Omega$ (C) $6\,\Omega$ (D) $7\,\Omega$ **[JEE Main 2017 Online]**

QUESTIONS from CBSE Board Exams..

Q. 1. What is end error in a meter bridge ? How is it overcome ? The resistances in the two arms of the metre bridge are $R = 5\,\Omega$ and S respectively.

When the resistance S is shunted with an equal resistance, the new balance length found to be $1.5\,l_1$, where l_1 is the initial balancing length. Calculate the value of S.



[3 marks, CBSE 2019]

Q. 2. State the underlying principle of meter bridge. Draw the circuit diagram and explain how the unknown resistance of a conductor can be determined by this method. **[3 marks, CBSE 2019]**

Q. 3.

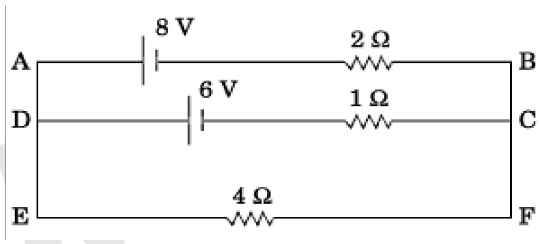
(a) State the working principle of a meter bridge used to measure an unknown resistance.

(b) Give reason

(i) why the connections between the resistors in a meter bridge are made of thick copper strips.

(ii) why is it generally preferred to obtain the balance length near the mid-point of the bridge wire.

(c) Calculate the potential difference across the $4\ \Omega$ resistor in the given electrical circuit, using Kirchhoff's rules.



[5 marks, CBSE 2019]

Q. 4.

(a) Use Kirchhoff's rules to obtain the balance condition in terms of the four resistors in a Wheatstone bridge.

(b) Explain how the balance condition in Wheatstone bridge is used in meter bridge to determine the value of unknown resistance. Under what condition is the error in determining the unknown resistance minimized ? **[5 marks, CBSE 2019]**

Q. 5.

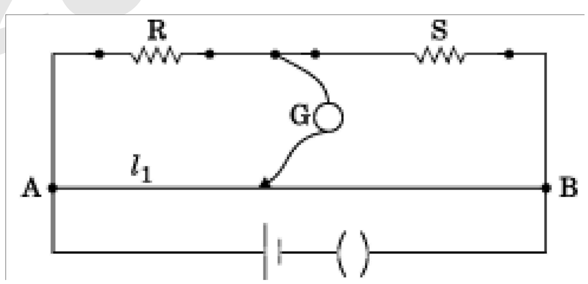
(a) Define electrical resistivity of a given material. Why does resistivity of a metal increase with temperature whereas in the case of a semiconductor it decreases ?

(b) In the set-up of a meter bridge, when two unknown resistances X and Y are inserted, the null point is obtained $35\ cm$ from the positive end of the meter bridge wire. When a resistance of $15\ \Omega$ is connected in series with X, the null point shifts by $15\ cm$. Determine the values of resistances X and Y. **[5 marks, CBSE 2018]**

Q. 6.

(a) Write the principle of working of a meter bridge.

(b) In a meter bridge, the balance point is found at a distance l_1 with resistances R and S as shown in the figure.



An unknown resistance X is now connected in parallel to the resistance S and the balance point is found at a distance l_2. Obtain a formula for X in terms of l_1, l_2 and S. **[3 marks, CBSE 2017]**

Q. 7.

(a) Draw a circuit diagram of a meter bridge used to determine the unknown resistance R of a given wire. Hence derive the expression for R in terms of the known resistance S.

(b)What does the term 'end error' in a meter bridge circuit mean and how is it corrected ? How will the balancing point be affected, if the positions of the battery and galvanometer are interchanged in a meter bridge experiment ? Give reason for your answer. **[5 marks, CBSE 2017]**

⇒ **Ans: (b)**The error which arises on account of resistance of copper strips and the connecting wire at both ends of the meter bridge is called end error.It is minimized by adjusting the balance point near the middle point of the bridge.

No effect, as the bridge remains balanced.

Q. 8.(a)Write the working principle of a meter bridge.

(b) Answer the following:

(i) Why are the connections between resistors in a meter bridge made of thick copper strips ?

(ii) Why is it generally preferred to obtain the balance point near the middle of a bridge wire in meter bridge experiment ? **[5 marks, CBSE 2017]**

⇒ **Ans: (b)** (i) Thick copper strips have (almost) zero resistance OR Thick Copper strips do not add additional resistance to the resistors being used.

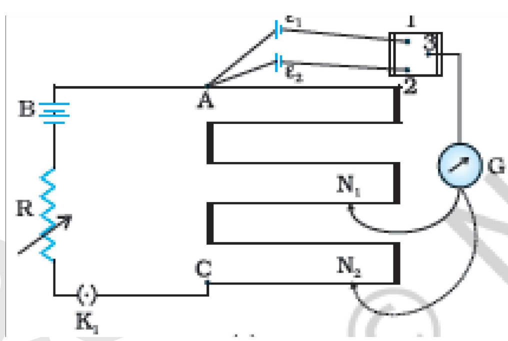
(ii) This results in a better accuracy in the measurements.

---

* *POTENTIOMETER*

It is a basically long piece of uniform wire, sometimes a few meters in length across which a standard cell (B) is connected. In actual design, the wire is sometimes cut in several pieces placed side by side and connected at the ends by thick metal strip.

⇒ **Potentiometer to compare the emf of two cells**



In the figure, the wires run from A to C. The small vertical portions are the thick metal strips connecting the various sections of the wire.

A current I flows through the wire which can be varied by a variable resistance (rheostat, R) in the circuit. Since the wire is uniform, the potential difference between A and any point at a distance l from A is

$$\varepsilon(l) = \varphi l$$ where φ is the potential drop per unit length.

Figure above shows an **application of the potentiometer to compare the emf of two cells of emf ε_1 and ε_2.**

The points marked 1, 2, 3 form a two way key. Consider first a position of the key where 1 and 3 are connected so that the galvanometer is connected to ε_1.The jockey is moved along the wire till at a point N_1, at a distance l_1 from A, there is no deflection in the galvanometer.

Applying Kirchhoff's loop rule to the closed loop $A\,N_1\,G\,31\,A$,

$$\varphi l_1 + 0 - \varepsilon_1 = 0 \qquad \text{i.e. } \varepsilon_1 = \varphi\, l_1 \qquad \text{......................(1)}$$

Similarly, if another emf ε_2 is balanced against $l_2\,(AN_2)$,

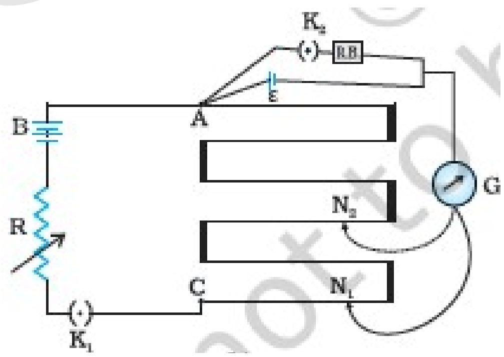
$$\varphi l_2 + 0 - \varepsilon_2 = 0 \qquad \text{i.e. } \varepsilon_2 = \varphi\, l_2 \qquad \text{......................(2)}$$

From equations (1) and (2), $$\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2} \qquad \text{......................(3)}$$

With this simple mechanism the emfs of any two sources $(\varepsilon_1, \varepsilon_2)$ can be compared. In practice one of the cells is chosen as a standard cell whose emf is known to a high degree of accuracy. The emf of other cell is then easily calculated from equation (3).

$\Rightarrow$ **Potentiometer to measure internal resistance of a cell**:

As shown in figure below, to measure internal resistance (r) of a cell (emf ε), it is connected across a resistance box through a key K_2.



With key K_2 open, balance is obtained at length $l_1\,(AN_1)$.

Then, $$\varepsilon = \varphi\, l_1 \qquad \text{......................(1)}$$

When key K_2 is closed, the cell sends a current (I) through the resistance box (R). If V is the terminal potential difference of the cell and balance is obtained at length $l_2\,(AN_2)$,

$$V = \varphi\, l_2 \qquad \text{......................(2)}$$

From (1) and (2), $$\frac{\varepsilon}{V} = \frac{l_1}{l_2} \qquad \text{......................(3)}$$

As $\varepsilon = I\,(r+R)$ and $V = IR$, $$\frac{\varepsilon}{V} = \frac{(r+R)}{R} \qquad \text{......................(4)}$$

From (3) and (4), $$\frac{R+r}{R} = \frac{l_1}{l_2}$$

$$\frac{R}{R} + \frac{r}{R} = \frac{l_1}{l_2} \qquad \text{or} \qquad 1 + \frac{r}{R} = \frac{l_1}{l_2}$$

Therefore, $r = R\left(\frac{l_1}{l_2} - 1\right)$ ....(5)

Using equation (5), the internal resistance of a given cell can be found.

The **potentiometer has the advantage that it draws no current from the voltage source being measured. As such it is unaffected by the internal resistance of the source**.

....**QUESTIONS**... from..... **COMPETITIVE EXAMS**..

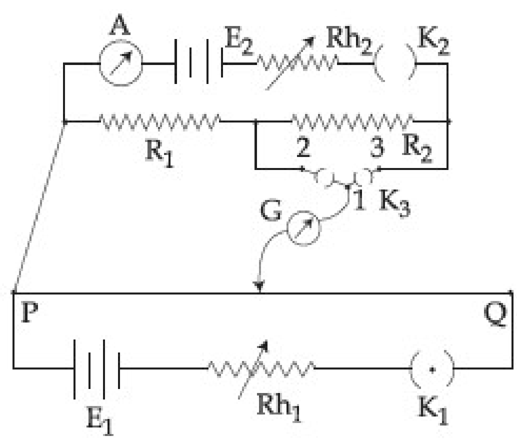
1.An ideal battery of $4\,V$ and resistance R are connected in series in the primary circuit of a potentiometer of length $1\,m$ and resistance $5\,\Omega$. The value of R to give a potential difference of $5\,mV$ across $10\,cm$ of potentiometer wire, is:

(A) $480\,\Omega$ (B) $490\,\Omega$ (C) $495\,\Omega$ (D) $395\,\Omega$ **[JEE Main 2019]**

2. In a potentiometer experiment, it is found that no current passes through the galvanometer when the terminals of the cell are connected across 52 cm of the potentiometer wire. If the cell is shunted by a resistance of $5\,\Omega$, a balance is found when the cell is connectedacross 40 cm of the wire. Find the internal resistance of the cell.

(A) $1\,\Omega$ (B) $15\,\Omega$ (C) $2\,\Omega$ (D) $25\,\Omega$ **[JEE Main 2018]**

3. A potentiometer PQ is set up to compare two resistances as shown in the figure. The ammeter A in the circuit reads $1.0\,A$ when two way key K_3 is open. The balance point is at a length $l_1\ cm$ from P when two way key K_3 is plugged in between 2 and 1, while the balance point is at a length $l_2\ cm$ from P when key K_3 is plugged in between 3 and 1. The ratio of two resistances $\frac{R_1}{R_2}$, is found to be :



(A) $\frac{l_1}{l_1 + l_2}$ (B) $\frac{l_1}{l_1 - l_2}$ (C) $\frac{l_1}{l_2 - l_1}$ (D) $\frac{l_2}{l_2 - l_1}$ **[JEE Main 2017 Online]**

4. A potentiometer is an accurate and versatile device to make electrical measurements of E.M.F., because the method involves:

(A) Cells

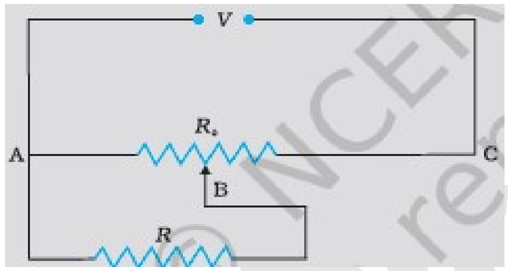
(B) Potential gradients

(C) A condition of no current flow through the galvanometer

(D) A combination of cells, galvanometer and resistances **[NEET 2017]**

...QUESTIONS from GSEB Board Exams...

Q. 1. A resistance of $R\ \Omega$ draws current from a potentiometer. The potentiometer has a total resistance $R_0\ \Omega$. A voltage V is supplied to the potentiometer. Derive an expression for the voltage across R when the sliding contact is in the middle of the potentiometer.



[3 marks, GSEB 2020]

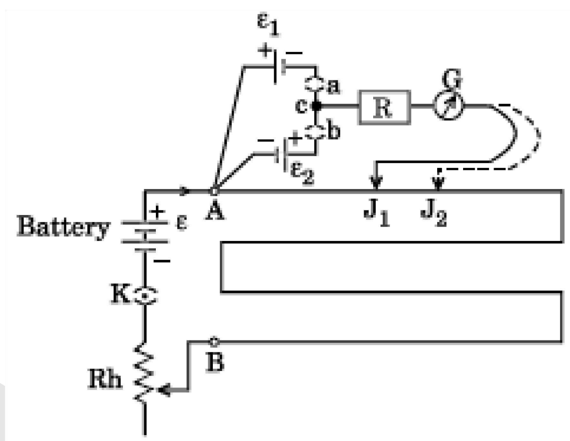
...QUESTIONS from CBSE Board Exams...

Q. 1. A student uses the circuit diagram of a potentiometer as shown in the figure:

(a) For a steady current I passing through the potentiometer wire, he gets a null point for the cell ε_1 and not for ε_2. Give reason for this observation and suggest how this difficulty can be resolved.

(b) What is the function of resistance R used in the circuit ? How will the change in its value affect the null point ?

(c) How can the sensitivity of the potentiometer be increased ?



[3 marks, CBSE 2019]

$\Rightarrow$ **Ans:**

(a) Reason:

Both ε_1 and ε have positive terminal connected at A whereas negative terminal of ε_2 is connected to A.

By interchanging the terminal of ε_2, the difficulty can be resolved.

(b) Resistance R protects the galvanometer by reducing the current flowing through it. Null point position remains unaffected.

(c) Sensitivity can be increased by any of the following:

$\rightarrow$ Increasing the length of potentiometer

$\rightarrow$ reducing the value of ε

$\rightarrow$ increasing resistance of rheostate

$\rightarrow$ reducing value of current

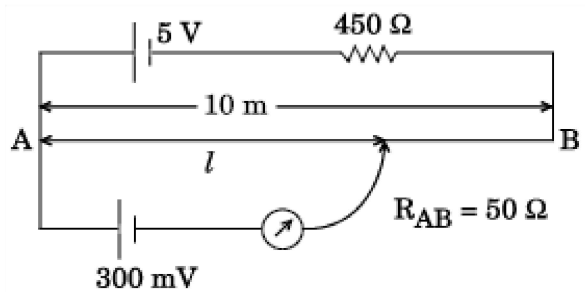
$\rightarrow$ decreasing value of potential gradient

Q. 2.

(a) Describe briefly, with the help of a circuit diagram, the method of measuring the internal resistance of a cell.

(b) Give reason why a potentiometer is preferred over a voltmeter for the measurement of emf of a cell.

(c) In the potentiometer circuit given below, calculate the balancing length l. Give reason, whether the circuit will work, if the driver cell of emf $5\,V$ is replaced with a cell of $2\,V$, keeping all other factors constant.



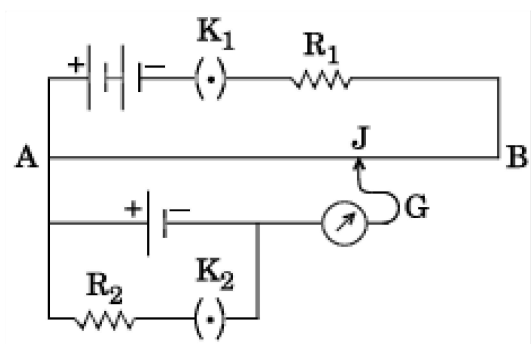
[5 marks, CBSE 2019]

Q. 3.

(a) For the circuit shown in the figure, how would the balancing length be affected, if

(i) R_1 is decreased, (ii) R_2 is increased,

the other factors remaining the same in the circuit ? Jusify your answer in each case.



(b)Why is a potentiometer preferred over a voltmeter ? Give reason. **[3 marks, CBSE 2019]**

$\Rightarrow$ **Ans:**

(a)

(i)When R_1 is decreased, the balancing length decreases.

Justification: When R_1 is decreased, current I through the potentiometer increases. Hence potential gradient increases. Therefore balancing length decreases.

(ii) When R_2 is increased, balancing length decreases.

Justification: When R_2 is increased, current $I = \dfrac{E}{r + R_2}$ decreases. This increases $V\left(= E - Ir\right)$ hence balancing length increases.

(b) At balance, Potentiometer draws no current from the voltage source, measurement of emf / potential difference will be more accurate.

Q. 4. Explain brifly the principle and working of a device used for comparing the emf's of two cells. Define the potential gradient and write its S.I. unit. How can the current sensitivity of such a device be increased ? In what way is this method of comparing the emf's of two cells different from the one using voltmeter ?

[5 marks, CBSE 2019]

⇒ **Ans:** Current sensitivity of potentiometer is increased by increasing the length of the potentiometer wire.

Voltmeter requires current for its working hence measures terminal voltage V and not ε, while potentiometer at null deflection has no current and hence measures ε.

Q. 5. In a potentiometer arrangement for determining the emf of a cell, the balance point of the cell in open circuit is $350\ cm$. When a resistance of $9\ \Omega$ is used in the external circuit of the cell, the balance point shifts to $300\ cm$ Detemine the internal resistance of the cell. **[2 marks, CBSE 2018]**

Q. 6.

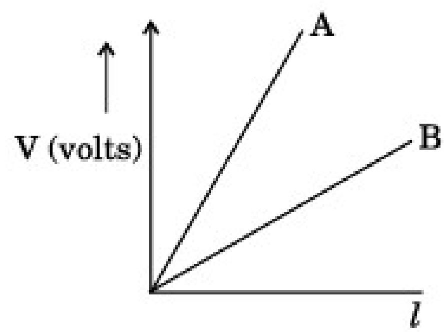
(a) Destinguish between emf and terminal voltage of a cell. Write the relation between the emf, terminal voltage and internal resistance of the cell.

(b) State the principle of working of a potentiometer. Define potential gradient and write its SI unit. Describe briefly how the emfs of two cells is compared using a potentiometer. **[5 marks, CBSE 2018]**

Q. 7.

(a)(i) State the principle on which a potentiometer works. How can a given potentiometer be made more sensitive ?

(ii) In the graph shown below for two potentiometers, state with reason which of the two potentiometers, A or B, is more sensitive.



(b) Two metallic wires, P_1 and P_2 of the same material and same length but different cross-sectional areas, A_1 and A_2 are joined together and connected to a source of emf. Find the ratio of the drift velocities of free electrons in the two wires when they are connected (i) in series, and (ii) in parallel.

[5 marks, CBSE 2017]

Q. 8. State the principle of the device used for comparing the emfs of two cells. Define the potential gradient and write its S.I. unit. How can the sensitivity of such a device be increased ? In what way is this method of comparing the emfs of two cells different from the one using a voltmeter ? Explain. **[5 marks, CBSE 2017]**

Q. 9.

(a) State the working principle of a potentiometer with help of the circuit diagram, explain how the internal resistance of a cell is determined.

(b) How are the following affected in the potentiometer circuit when (i) the internal resistance of the driver cell increases and (ii) the series resistor connected to the driver cell is reduced ? Justify your answer.

[5 marks, CBSE 2017]

⇒ Ans: (b) **Bonus of 1 mark was given to all students who attempted this as this question is incomplete.**