PHYSICS

Class XII

Chapter 3 - Current Electricity

1 Mark Questions

1. If the temperature of a good conductor decreases, how does the relaxation time of electrons in the conductor change?

Ans. We know $\rho = \frac{m}{ne^2 \tau}$

When temperature decreases, collision decreases and thus relaxation time increases which in turn decreases the resistivity.

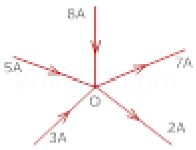
2. If potential difference V applied across a conductor is increased to 2V, how will the drift velocity of the electron change?

Ans. $Vd = \frac{eE\tau}{m}$

$Vd = \frac{eV\tau}{\ell m}$

$\therefore$ Double the P.D means drift velocity gets doubled.

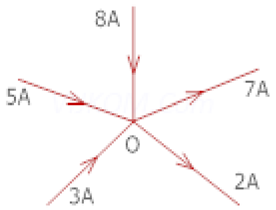
3. What is the value of current I at O in the adjoining circuit?



Ans. i = 5 + 3 – 2 – 7 + 8

i = 16 – 9

i = 7A



4. State one condition for maximum current to be drawn from the cell ?

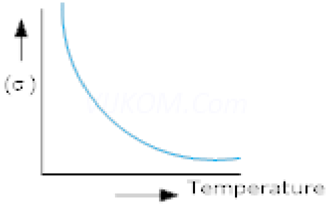
Ans. Since $I = \frac{E}{R + r}$ for maximum current, internal resistance should be Zero.

5. Resistivites of copper, silver and manganin are $1.7\times10^{-8}m$, $1.0\times10^{-8}m$ and $44\times10^{-8}m$. respectively which of these is the best conductor ?

Ans. For a particular length and area of cross-section, The resistance is directly proportionate to, specific resistance .

$\therefore$ silver is the best conductor because its specific resistance is less.

6. Draw the graph showing the variation of conductivity with temperature for a metallic conductor?



Ans. The conductivity decreases with the increase in temperature.

7. If a wire is stretched to double of its length. What will be its new resistivity?
Ans. No change in its resistivity because resistivity depends only on the nature of the material.

8. Name any one material having a small value of temperature coefficient of resistance. Write one use of this material?
Ans. Nichrome, an alloy has small value of temperature coefficient of resistance. It is used for making standard resistance coil.

9. Two wires A and B are of the same metal and of same length have their areas of cross section in the ratio 2:1 if the same potential difference is applied across each wire in turn, what will be the ratio of current flowing in A & B?

Ans. Since R $= \frac{1}{A}$

If area are in the ratio 2:1 resistance will be in the ratio 1:2.

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

$\therefore$ current will be in the ratio 2:1

2 Mark Questions

1. Two electric bulbs A and B are marked 220V, 40 w and 220V, 60 W respectively. Which one has a higher resistance?

Ans. We know $R \ \frac{V^2}{p}$

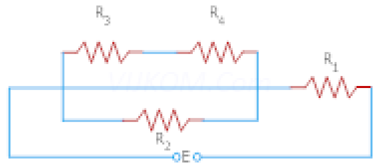
For Bulb A, $R_1 = \frac{(220)^2}{40} = 1210\Omega$

For Bulb B $R_2 = \frac{(220)^2}{60} = 806.67\Omega$

Bulb A has higher resistance because its power is less.

2. A Carbon resistor has three strips of red colour and a gold strip. What is the value of resistor? What is its tolerance?
Ans. R R R Gold
$(22\times10^2)^{+}5\%$ Value of the Resistor = 2200 Ω
Tolerance = $^{+}$ 5 %

3. Determine the voltage drop across the resistor R_1 in the circuit given below with E= 60V, $R_1 = 18\Omega$, $R_2 = 10\Omega$ $R_3 = 5\Omega$ and $R_4 = 10\Omega$?



Ans. R_3 & R_4 are in series

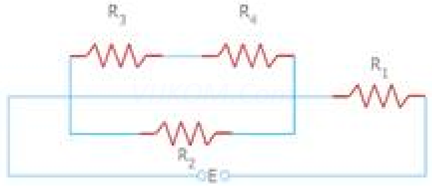
$= R^1 = 5 + 10 = 15\ \Omega$

Now $R_1 and\ R_2$ are parallel

$\therefore \frac{1}{R''} = \frac{1}{R^1} + \frac{1}{R_2}$

$\frac{1}{R''} = \frac{1}{15} + \frac{1}{10} = \frac{4+6}{60} = \frac{10}{60}$

$R'' = \frac{60}{10} = 6\Omega$



Now $R_1 and\ R^{11}$ are series

Rnet = $R'' + R_1$

$\Rightarrow$ Rnet = 6+18 = 24Ω

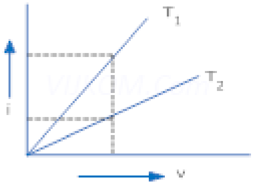
I= $\frac{V}{R} = \frac{60}{24} Ampere$

Now voltage drop across

$R_1 = IR_1 = \frac{60}{24} \times 18$

$V = 45$ Volts

4. Two heated wires of same dimensions are first connected in series and then it's parallel to a source of supply. What will be the ratio of heat produced in the two cases?



Ans. $H = I^2 Rt$ $\left(\because I = \frac{V}{R}\right)$ Let Resistance of each wire =R

$$H = \frac{V^2}{R^{\cancel{2}}} \times \cancel{R} \times t$$

$$\text{H} = \frac{V^2}{R} t$$

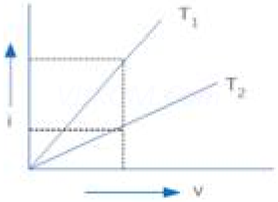
$$\Rightarrow \text{H} \, \alpha \, \frac{1}{R}$$

$$\frac{Hseries}{Hparallel} = \frac{Rparallel}{Rseries}$$

$$= \frac{\left(\frac{1}{R}+\frac{1}{R}\right)^{-\frac{1}{R}}}{R+R} \; \frac{R/2}{2R} = \frac{R}{2R \times 2} = \frac{1}{4}$$

5. V.I graph for a metallic wire at two different temperatures T_1 and T_2 is shown in figure. Which of these two temperatures is higher and why?

Ans. Slope $\frac{i}{V} = \frac{1}{R}$



= Smaller the slope larger is the resistance and since resistance increases with the increases in temperature for metals. Slope is small for T_2

T_2 temperature is higher

6.A set of n-identical resistors, each of resistance R ohm when connected in series have an effective resistance of X ohm and when the resistors are connected in parallel the effective resistance is Y ohm. Find the relation between R, X and Y ?

Ans. n – resistors connected in series

X = nR ——1)

n – Resistors connected in parallel

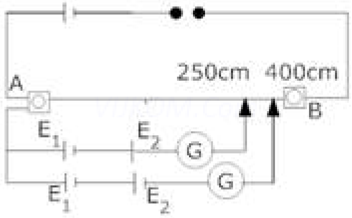
Y = ——2)

Multiply eg. (1) & (2)

XY = $\cancel{n}R \times \frac{R}{\cancel{n}}$

XY = R^2 $\boxed{R = \sqrt{XY}}$

7. Show the resistance of a conductor is given by $R = \dfrac{ml}{ne^2\tau A}$



Ans. For a conductor of length and area A if electric field is applied, Then the digit velocity of electrons is given by

Since I = neAv

I = neA

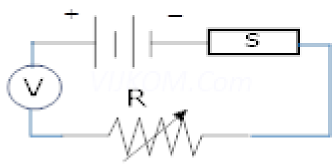
I = neA $\left(\dfrac{eV}{ml}\tau\right)$ $(\because E = v/\ell)$

$$\frac{V}{I} = \frac{ml}{ne^2 A\zeta}$$

$$R = \frac{m}{ne^2\tau}\left(\frac{l}{A}\right) \quad (\because V/I = R)$$

$$or\ R = \frac{ml}{ne^2\tau A}$$

8. Figure shows a piece of pure semiconductor S in series with a variable resistor Rand a source of constant voltage V. Would you increase and decrease the value of R to keep the reading of ammeter (A) constant, when semiconductor S is heated ? Give reasons.



Ans. Resistance of a semi conductor decreases on increasing the temperature, so in order to increase the temperature, s is heated and in order to maintain the ammeter current constant total resistance is the above circuit should remain unchanged, hence value of r has to be increased.

9. Why is constantan or manganin used for making standard resistors?
Ans. The alloys such as constantan or manganin are used for making standard resistors because their resistivities are high and has low temperature coefficient of resistance.

10. What are ohmic and non-ohmic resistors? Give one example of each?
Ans. A resistor which obey ohm's law are called ohmic resistors for eg -> metals
A resistor which do not obey ohm's law are called non-ohmic resistors .eg -> semiconductor diode , transistor etc.

11. **The storage battery of a car has an emf of 12 V. If the internal resistance of the battery is 0.4 Ω , what is the maximum current that can be drawn from the battery?**
Ans. Emf of the battery, E = 12 V
Internal resistance of the battery, r = 0.4 Ω
Maximum current drawn from the battery can be calculated as:
The maximum current drawn from the given battery is 30 A.

12. In a potentiometer arrangement, a cell of emf 1.25 V gives a balance point at 35.0 cm length of the wire. If the cell is replaced by another cell and the balance point shifts to 63.0 cm, what is the emf of the second cell?

Ans. Emf of the cell, $E_1 = 1.25V$

Balance point of the potentiometer, $l_1 = 35cm$

The cell is replaced by another cell of emf E_2.

New balance point of the potentiometer, $l_2 = 63cm$
The balance condition id given by the relation,

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

$$E_2 = E_1 \times \frac{l_2}{l_1}$$

$$= 1.25 \times \frac{63}{35} = 2.25V$$

Therefore, emf of the second cell is 2.25 V.

13. What conclusion can you draw from the following observations on a resistor made of alloy manganin?

CURRENT	VOLTAGE	CURRENT	VOLTAGE
0.2	3.94	3	59.2
0.4	7.87	4	78.8
0.6	11.8	5	98.6
0.8	15.7	6	118.5
1.0	19.7	7	138.2
2.0	39.7	8	158.0

Ans. It can be inferred from the given table that the ratio of voltage with current is a constant, which is equal to 19.7. Hence, manganin is an ohmic conductor i.e., the alloy obeys Ohm's law. According to Ohm's law, the ratio of voltage with current is the resistance of the conductor. Hence, the resistance of manganin is 19.7 Ω.

4 Mark Questions

1. Two cells of voltage 10V and 2V and internal resistances 10O and 5O, respectively, are connected in parallel with the positive end of the 10V battery connected to the negative pole of the 2V battery (Fig 3.8). Find the effective voltage and effective resistance of the combination.

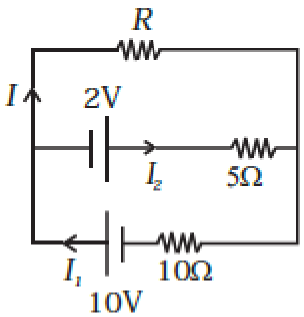


Fig 3.8

Solution:

According to the junction rule, at A

$I_1 = I + I_2$

When Kirchhoffs rule on loop ADEF and loop BCEF

$10 = IR + 10I_1$
$2 = 5I_2 - IR$
$\therefore 2 = 5(I_1 - I) - IR$
From the above equations, we get $4 = 10I_1 - 10I - 2IR$
Subtract the above equation from the first equation,

$6 = 3IR + 10I$
$3IR + 10I = 6$
$I(3R + 10) = 2 \times 3$
$\frac{I(3R + 10)}{3} = 2$
$2 = I(R + \frac{10}{3})$
The resultant potential difference due to the two batteries is V_{eq}. It is will be along resistance R.

$\therefore V_{eq} = I(R + R_{eq})$

R_{eq} is the circuit's resistance except for R.

$V_{eq} = 2$ Volts and $R_{eq} = \frac{10}{3}\Omega$

2. A room has AC run for 5 hours a day at a voltage of 220V. The wiring of the room consists of Cu of 1 mm radius and a length of 10m, and power consumption per day is ten commercial units. What fraction of it goes in the joule heating in wires? What would happen if the wiring is made of the same dimensions?

$[\boldsymbol{\rho_{cu} = 1.7 \times 10^{-8}\Omega m, \rho_{Al} = 2.7 \times 10^{-8}\Omega m}]$

Solution:

The entire energy used in five hours a day by AC and wiring is 10kWh

Therefore, the energy used in one hour by AC and wiring is 2kWh.

The total power of the AC and wire is 2000W.

$P = VI$

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

$= \frac{2000}{220} \cong 9.0A$

Take P_0 as the power of wiring then,

$P_0 = I^2 R_W [R_W = \text{resistance of wiring}]$

$= 9 \times 9 \cdot \frac{P!}{A}$

$= \frac{9 \times 9 \times 1.7 \times 10^{-8} \times 10}{3.14 \times 1 \times 10^{-3} \times 1 \times 10^{-3}}$

$= \frac{81 \times 17 \times 10^{-8+6}}{3.14}$

$= \frac{1377}{3.14} \times 10^{-2}$

$= 4.38 = 4.4 Watt$

Thus, the energy loss in the wiring

$\cong 4.4 J/sec$

The fractional loss due to wire heating

$= \frac{4.4}{2000} \times 100\%$

$= 0.22\%$

$\frac{P_A(wiring)}{P_{Cu}(wiring)} = \frac{I^2 R_A}{I^2 R_{Cu}}$

$$= \frac{\rho Ai \frac{I_A}{A_{Ai}}}{\rho Cu \frac{I_{Cu}}{A_{Cu}}} \text{ as } 1_{AI} = L_{Cu} \text{ and } A_{AI} = A_{Cu}$$

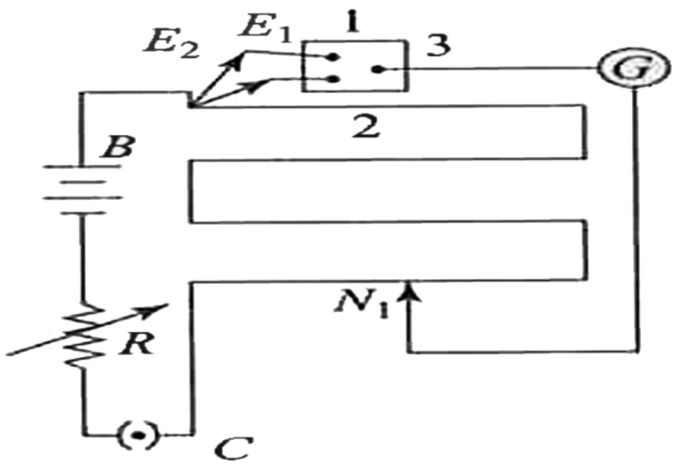
$$\frac{P_A}{P_{Cu}} = \frac{\rho_A}{\rho_{Cu}}$$

$$P_A = \frac{2.7 \times 10^{-8}}{1.7 \times 10^{-8}} \times 4.4Watt$$

Therefore, the loss of power in Al wiring is 7 Watts.

7 Marks Questions

1. In an experiment with a potentiometer, VB = 10V. R is adjusted to be 50O (Fig. 3.9). A student wanting to measure voltage E_1 of a battery (approx 8V) finds no null point possible. He then diminishes R to 10O and is able to locate the null point on the last (4th) segment of the potentiometer. Find the resistance of the potentiometer wire and potential drop per unit length across the wire in the second case.



Solution:

Consider R as the potentiometer wire's resistance.

Variable resistance, R=50Ω

I is the electrical current in the primary, which is located at E_B = 10V.

$$I \frac{V_B}{R + R'} \Rightarrow \frac{10}{50 + R} = I(\text{ in primary circuit})$$

Potential difference along the potentiometer wire is

$$V' = IR'$$

From $IV' = \frac{10R'}{50+R}$

Since R = 50O, the null point cannot be acquired by 8 Volt. Therefore, V < 8 Volt.

$\frac{10R'}{50+R'}$ (no balance point)

As 50 + R' is positive, therefore, we can multiply the above relation by a positive number, and we get

10R' < 400 + 8R'

2R' < 400

R' < 200

The null point acquired by R = 10O.

V' > 8 at balance point. Thus, it is possible when

$\frac{10R'}{10+R} > 8$(as from I, R = 10)

Multiply the above equation by the positive value 10 + R' to both sides

10R' > 80 + 8R

2R' > 80

R' > 40

Since the null point is acquired on the fourth segment or at 3\4 of the total length. Thus, at (3\4)R' (no balance point)

Or $\frac{10 \times \frac{3}{4} R'}{10+R} < 8$

$\therefore 7.5R' < 80 + 8R$

$-0.5R' < 80$

$-R' < 160$

$R' > -160$

R' can never be a negative value. Therefore -160O is considered as 160O

So, $[160 < R' < 200] \dots . V$

Any of the R's between 200O and 160O will attaina null point. As the null point is on the last fourth segment of the potentiometer wire, the potential drop along 400cm wire > 7 Volt.

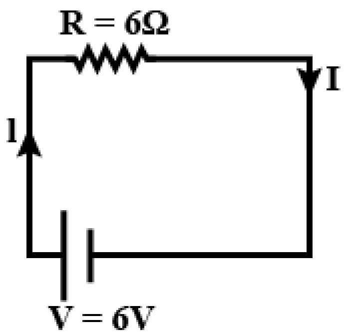
Therefore, K(400cm) > 8V (at balance point)

$$K > \frac{8}{400} Volt/cm$$
$$K > \frac{8}{4} Volt/,$$
$$K > 2 Volt/m$$

Since the balance point is at the fourth wire, therefore no balance point at 3m.

$$K(3) < 8 (\text{no balance point})$$
$$K < \frac{8}{3} Volt/m$$
$$K < 2\frac{2}{3} Volt/m$$
$$\therefore [2\frac{2}{3} V/m \rangle K > 2 Volt/m]$$
$$\therefore [2\frac{2}{3} V/m > K > 2 Volt/m]$$

2. (a) Consider the circuit in the Figure. How much energy is absorbed by electrons from the initial state of no current (ignore thermal motion) to the state of drift velocity?



(b) Electrons give up energy at the rate of RI^2 per second to the internal energy. What time scale would one associate with energy in problem (a)? N = no of electrons/volume = $10^{29}/m^3$, length of circuit = 10cm, cross-section = A = $(1mm)^2$.

Solution:

(a) By using ohm's law, current I is represented by

$$I = \frac{6V}{6\Omega} = 1A$$
$$i = neAv_d$$

$$v_d = \frac{i}{neA}$$

On substituting the quantities,

n = the number of electrons/volume $= 10^{29}/m^3$

Circuit length = 10cm

Cross section area A = $1(mm)^2$

$$v_d = \frac{1}{10^{29} \times 1.6 \times 10^{-19} \times 10^{-6}}$$

$$= \frac{1}{1.6} \times 10^{-4} m/s$$

Thus, the energy absorbed in the form of kinetic energy is represented by

$$KE = \frac{1}{2} m_e v_d^2 \times nAI$$

$$= \frac{1}{2} \times 9.1 \times 10^{31} \times \frac{1}{2.56} \times 10^{20} \times 10^{8} \times 10^{6} \times 10^{1}$$

$$= 2 \times 10^{-17} J$$

(b) Loss of power is represented by

$$P = I^2 R = 6 \times 1^2 = 6W = 6J/s$$

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

or $t = \frac{E}{P}$

$$= \frac{2 \times 10^{-17}}{6} = 10^{-17} s$$

Fill in the blanks

1. What is the order of magnitude of the resistance of a dry human body -----------------.

(10^4 Ω)

2. A silver wire has a resistance of 2.1 Ω at 27.5 °C, and a resistance of 2.7 Ω at 100 °C. What is the temperature coefficient of resistivity of silver---------------------- **(0.0039)**

3. The rate of flow of electric charge through any cross-section of a conductor is known as **___________.**
(Electric current)

4. Mobility is denoted by **___________.(μ)**

5. Which of the following is non-ohmic resistance------------------ **(Diode is non-ohmic resistance.)**

6. Unit of conductance is __________. **(Siemen)**

7. Current density is a __________. **(vector quantity.)**

8. The resistivity of certain metals or alloys drops to zero when they are cooled below a certain temperature, this phenomenon is known as __________. **(Superconductivity).**

9. State true or false: The total resistance in the series combination is more than the greatest resistance in the circui---------------- **(True)**

10. The opposition offered by the electrolyte of the cell to the flow of current through itself is known as __________.**(Internal resistance)**

Multiple Choices

1. What is the order of magnitude of the resistance of a dry human body?

a. 10 Ω
b. 10^4 Ω
c. 10 MΩ
d. 10 μΩ

Answer: (b) 10^4 Ω

Explanation: It is known that the resistance of a dry human body is 10 kΩ = 10^4 Ω.

2. A silver wire has a resistance of 2.1 Ω at 27.5 °C, and a resistance of 2.7 Ω at 100 °C. What is the temperature coefficient of resistivity of silver?

a. 0.0059
b. 0.0039
c. 0.0129
d. 0.0159

Answer: (b) 0.0039

$T_1 = 27.5^oC, R_1 = 2.1\Omega, T_2 = 100^oC, R_1 = 2.7\Omega$
The temperature coefficient of resistivity is:
$$\alpha = \frac{R_2 - R_1}{R_1(T_2 - T2)} = 0.0039^oC^{-1}$$
Explanation: Hence, the temperature coefficient of resistivity of silver is 0.0039.

3. The rate of flow of electric charge through any cross-section of a conductor is known as __________.

a. Electric flux
b. Electric potential
c. Electric current
d. Electric field

Answer: (c) Electric current

Explanation: The rate of flow of electric charge through any cross-section of a conductor is known as electric current.

4. Mobility is denoted by __________.

a. η
b. α
c. μ
d. ρ

Answer: (c) μ

Explanation: Mobility is denoted by μ.

5. Which of the following is non-ohmic resistance?

a. Lamp filament
b. Copper wire
c. Carbon resistor
d. Diode

Answer: (d) Diode is non-ohmic resistance.

Explanation: A non-ohmic resistance is a resistance that does not obey ohm's law. Among the given options, a diode is a non-ohmic resistance.

6. Unit of conductance is __________.

a. Dyne
b. Siemen
c. Ohm
d. Volts

Answer: (b) Siemen

Explanation: Unit of conductance is siemen.

7. Current density is a __________.

a. scalar quantity.
b. vector quantity.
c. dimensionless quantity.
d. none of these options

Answer: (b) vector quantity.

Explanation: Current density is a vector quantity.

8. The resistivity of certain metals or alloys drops to zero when they are cooled below a certain temperature, this phenomenon is known as __________.

a. Conductivity
b. Partial conductivity
c. Superconductivity
d. Non-conductivity

Answer: (c) Superconductivity

Explanation: The resistivity of certain metals or alloys drops to zero when they are cooled below a certain temperature, this phenomenon is known as superconductivity.

9. State true or false: The total resistance in the series combination is more than the greatest resistance in the circuit.

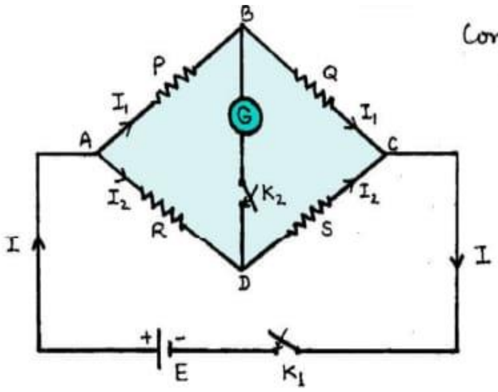
a. True (b) False

Answer: (a) True

Explanation: The total resistance in the series combination is more than the greatest resistance in the circuit.

Diagrams

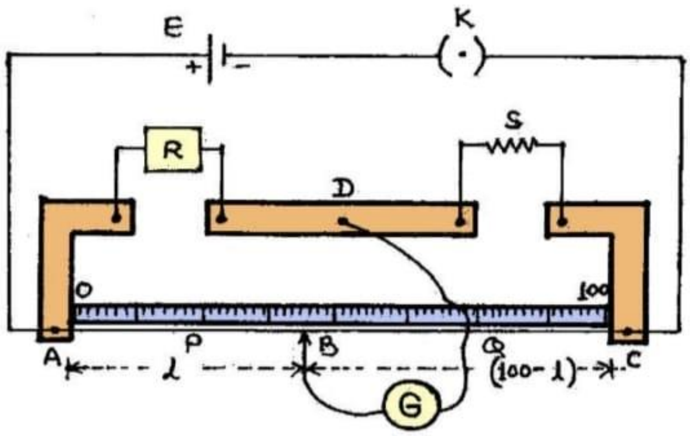
Wheatstone Bridge Principle



Condition for the balanced wheatstone bridge.

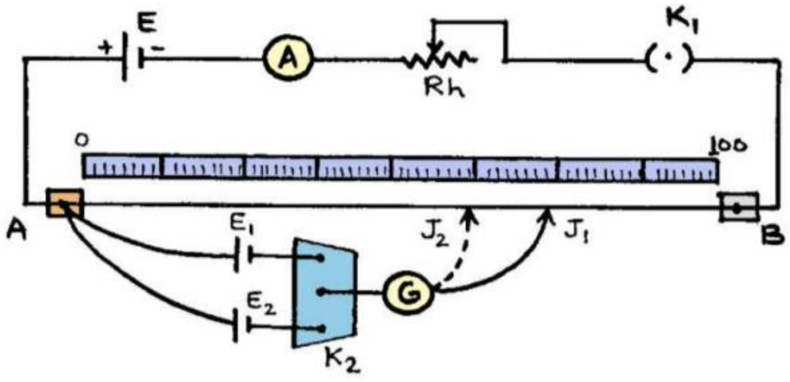
$$\frac{P}{Q} = \frac{R}{S}$$

Meter Bridge



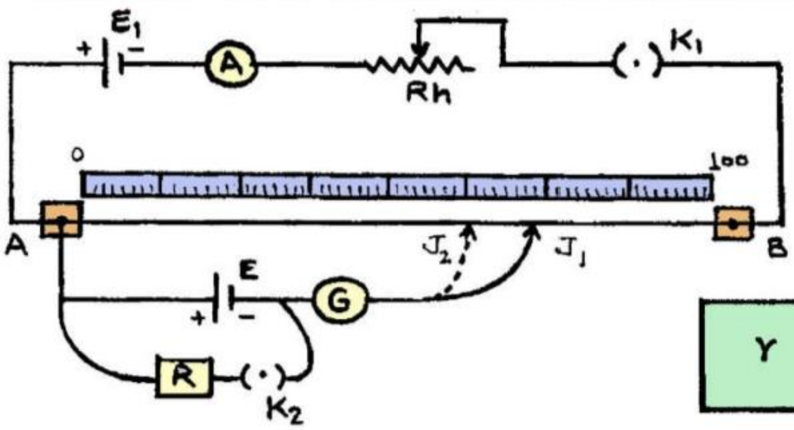
$$S = \left(\frac{100-l}{l}\right) \times R$$

(i) Comparison of EMF's of two cells using potentiometer



$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

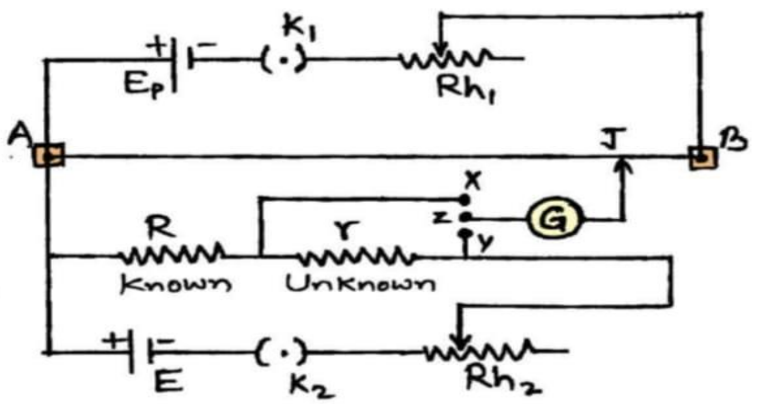
(ii) Determination of internal resistance of the cell



$$\frac{E}{V} = \frac{l_1}{l_2}$$

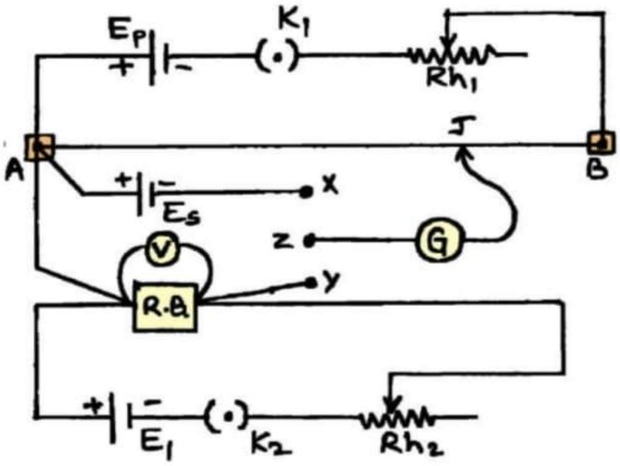
$$r = \left(\frac{l_1}{l_2} - 1\right) R$$

(iii) Determination of a small resistance by potentiometer



$$r = \left(\frac{l_2 - l_1}{l_1}\right) R$$

(iv) calibration of a vottmeter by potentiometer

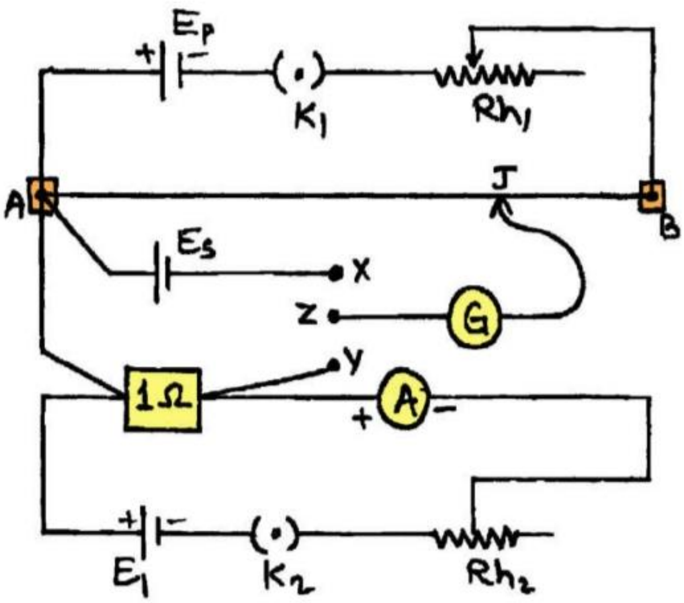


$$V' = \frac{E_s}{l_1} \times l_2$$

V = voltmeter reading

Error in Voltmeter reading $\Delta V = V - V'$

(v) calibration of a ammeter by potentiometer



I = ammeter reading

$$I' = \frac{E_s}{l_1} \times l_2$$

Error in ammeter reading $\Delta I = I - I'$

SUMMARY

- **Electrical Conductivity:**
  It is the inverse of specific resistance for a conductor whereas the specific resistance is the resistance of unit cube of the material of the conductor.
  $$\sigma = \frac{1}{\rho} = \frac{ne^2\tau}{m}$$
  Where σ is the conductivity and ρ is resistivity.
- **SI Unit of Conductivity:**
  The SI unit of conductivity is $mhom^{-1}$.
- **Current through a given area of a conductor:**
  It is the net charge passing per unit time through the area.
- **Current Density Vector:**
  The current density vector $\vec{J}$ gives current per unit area flowing through area ΔA when it is held normal to the direction of charge flow. Note that the direction of $\vec{J}$ is in the direction of current flow.
- **Current Density:**
  Current density j gives the amount of charge flowing per second per unit area normal to the flow.
  $$J = nqV_d$$
  where n is the number density (number per unit volume) of charge carriers each of charge q and vd is the drift velocity of the charge carriers. For electrons q = −e. If j is normal to a cross – sectional area A and is constant over the area, the magnitude of the current I through the area is neV_dA.
- **Mobility:**
  Mobility μ is defined to be the magnitude of drift velocity per unit electric field.
  $$\mu = \left(\frac{V_d}{E}\right)$$
  Now, $V_d = \dfrac{q\tau E}{m_q}$

  where q is the electric charge of the current carrier and mq is its mass.
  $$\therefore \mu = \left(\frac{q_\tau}{m_q}\right)$$
  Thus, mobility is a measure of response of a charge carrier to a given external electric field.

- **Resistivity:**

  Resistivity ρ is defined to be reciprocal of conductivity.

  $$\rho = \frac{1}{\sigma}$$

  It is measured in ohm-metre (Ωm).

- **Resistivity as a function of temperature:**

  It is given as,

  $$\rho_T = \rho_0[1+\alpha(T-T_0)]$$

  Where α is the temperature coefficient of resistivity and ρ_T is the resistivity of the material at temperature T.

- **Ranges of Resistivity:**

  a) Metals have low resistivity: Range of ρ varies from $10^{-8}\ \Omega$ m to $10^{-6}\ \Omega$ m.

  b) Insulators like glass and rubber have high resistivity: Range of ρ varies from 10^{22} to 10^{24} times greater than that of metals.

  c) Semiconductors like Si and Ge lie roughly in the middle range of resistivity on a logarithmic scale.

- **Total resistance in Series and in Parallel**

  (a) Total resistance R of n resistors connected in series is given by R = R1 + R2 + ... + Rn

  (b) Total resistance R of n resistors connected in parallel is given by

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

- If the mass of a charge carrier is large, then for a given field $\vec{E}$, its acceleration will be small and will contribute very little to the electric current.

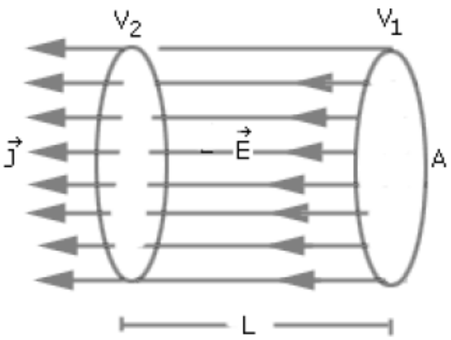
- **Electrical Conductivity:**

  When a conducting substance is brought under the influence of an electric field $\vec{E}$, free charges (e.g. free electrons in metals) move under the influence of this field in such a manner, that the current density $\vec{J}$ due to their motion is proportional to the applied electric field.

  $$\vec{J} = \sigma \vec{E}$$

  where σ is a constant of proportionality called electrical conductivity. This statement is one possible form of Ohm's law.

- Consider a cylindrical material with cross sectional area A and length L through which a current is passing along the length and normal to the area A, then, since $\vec{J}$ and $\vec{E}$ are in the same direction,



  $$J = \sigma E$$

  $$JAL = \sigma ELA$$

  Where A is cross sectional area and L is length of the material through which a current is passing along the length, normal to the area A. But, JA = I, the current through the area A and EL = $V_1 - V_2$, the potential difference across the ends of the cylinder denoting V_1-V_2 as V,

$$V = \frac{IL}{\sigma A} = RI$$

Where $R = \frac{L}{\sigma A}$ is called resistance of the material. In this form, Ohm's law can be stated as a linear relationship between the potential drop across a substance and the current passing through it.

- **Measuring resistance:**

  R is measured in ohm ((Ω)), where $1\Omega = \frac{1V}{A}$

- **EMF:**

  Emf (Electromotive force) is the name given to a non-electrostatic agency. Typically, it is a battery, in which a chemical process achieves this task of doing work in driving the positive charge from a low potential to a high potential. The effect of such a source is measured in terms of work done per unit charge in moving a charge once around the circuit. This is denoted by $\in$.

- **Significance of Ohm's Law:**

  Ohm's law is obeyed by many substances, but it is not a fundamental law of nature. It fails if

  a) V depends on I non- linearly. Example is when ρ increases with I (even if temperature is kept fixed).
  b) The relation between V and I depends on the sign of V for the same absolute value of V.
  c) The relation between V and I is non- unique. For e.g., GaAs

  An example of (a) & (b) is of a rectifier

- When a source of emf ((ε)) is connected to an external resistance R, the voltage V_{ext} across R is given by

  $$V_{ext} = IR = \frac{\varepsilon}{R+r}R$$

  Where r is the internal resistance of the source.

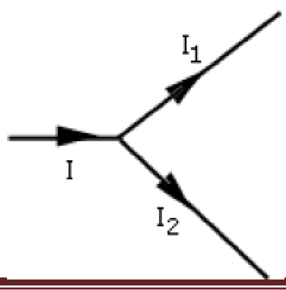
- **Kirchhoff's First Rule**:

  At any junction of several circuit elements, the sum of currents entering the junction must equal the sum of currents leaving it.

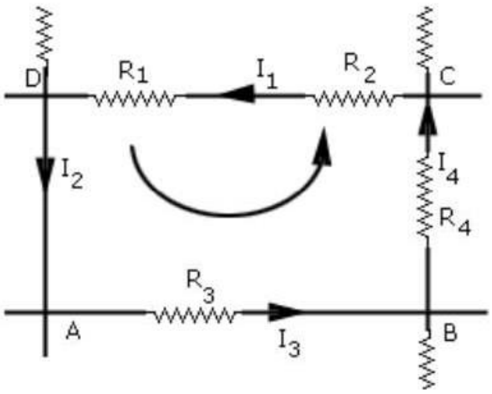
  In the above junction, current I enters it and currents I_1 and I_2 leave it. Then,

  $$I = I_1 + I_2$$

  This is a consequence of charge conservation and assumption that currents are steady, that is no charge piles up at the junction.

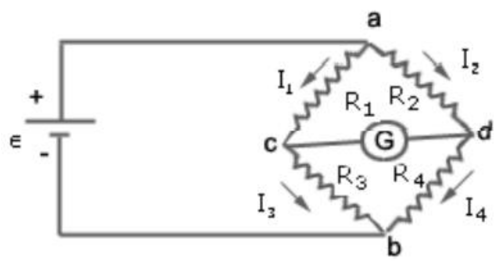


- **Kirchhoff's Second Rule**:
  The algebraic sum of changes in potential around any closed resistor loop must be zero. This is based on the principle that electrostatic forces alone cannot do any work in a closed loop, since this work is equal to potential difference, which is zero, if we start at one point of the loop and come back to it.



  This gives: $(R_1 + R_2) I_1 + R_3 I_3 + R_4 I_4 = 0$
- **In case of current loops:**
  i) Choose any closed loop in the network and designate a direction (in this example counter clockwise) to traverse the loop.
  ii) Go around the loop in the designated direction, adding emf's and potential differences. An emf is counted as positive when it is traversed (-) to (+) and negative in the opposite case i.e., from (+) to (-). An IR term is counted negative if the resistor is traversed in the same direction of the assumed current, and positive if in the opposite direction.
  iii) Equate the total sum to zero.
- **Wheatstone Bridge:**
  Wheatstone bridge is an arrangement of four resistances R_1, R_2, R_3, R_4. The null point condition is given by,

$$\therefore \frac{R_1}{R_2} = \frac{R_3}{R_4}$$



  This is also known as the balanced condition. If R_1, R_2, R_3 are known, R_4 can be determined.

$$R_4 = \left(\frac{R_2}{R_1}\right) R_3$$

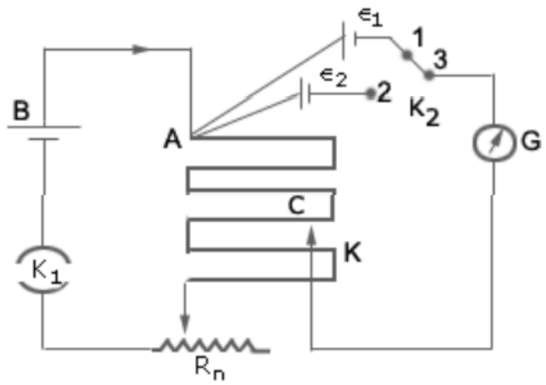
- In a balanced condition of the meter bridge,

$$\frac{R}{S} = \frac{P}{Q} = \frac{\sigma l_1}{100 - l_1}$$

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

Where σ is the resistance per unit length of wire and l_1 is the length of wire from one end where null point is obtained.

- **Potentiometer:**
  The potentiometer is a device to compare potential differences. Since the method involves a condition of no current flow, the device can be used to measure potential differences; internal resistance of a cell and compare emf's of two sources.



- **Potential Gradient:**
  The potential gradient of the wire in a potentiometer depends on the current in the wire.
- If an emf $\in_1$ is balanced against length l_1, then
  $\in_1 = \rho l_1$
  Similarly, if $\in_2$ is balanced against l_2, then
  $\in_2 = \rho l_2$
  The comparison of emf's of the two cells is given by,

$$\therefore \frac{\in_1}{\in_2} = \frac{l_1}{l_2}$$