CLASS – 12

WORKSHEET- CURRENT ELECTRICITY

A. MICROSCOPIC VIEW OF ELECTRIC CURRENT

(1 Mark Questions)

1. How does the random motion of fee electron in a conductor get affected when a electrons in a conductor get affected when a potential difference is applied across its ends?

Sol. Conductors contain free electrons. In the absence fo any external electric field, the free electrons are in random motion just like the molecules of gas in a container and thte net current through wire is zero.
If the ends of the wire are connected to a battery, an electric field (E) will set up at every point within the wire. Due to electric effect on the battery, the electrons will experience a force in the direction opposite to E.

2. The ratio of current density and electric field is called
(a) resistivity (b) conductivity (c) drift velocity (d)Mobility

Ans. (b) $\vec{J} = \sigma\vec{E} \Rightarrow \vec{J}/\vec{E} = \sigma$, conductivity of the material.

3. A copper wire of non-uniform area of cross-section is connected to a d.c battery. The physical quantity which remains constant along the wire is___________.

Sol. The physical quantity which remains constant along the wire is electric current.

4. How is the drift velocity in a conductor affected with the rise in temperature?

Sol. Drift velocity, $v_d = eE\tau/m$ i.e. $v_d \propto \tau$
By increasing temperature relaxation time decreases, therefore we can say that the drift velocity decreases with the rise in temperature.

5. Define the term 'electrical conductivity' of a metallic wire. Write its S.I. unit.

Sol. The electrical conductivity of a metallic wire is defined as the ratio of the current density to the electric field it creates. It is reciprocal of resistivity (ρ).
Electrical conductivity, $(\sigma) = \frac{1}{\rho} = \frac{j}{E}$
Si unit = mho m^{-1} or $(ohm\ m)^{-1}$ or Sm^{-1}

6. Define the term drift velocity of change carries in a conductor and write its S.I. unit.

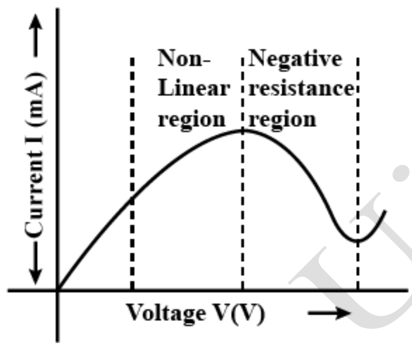
Sol. When an electric field is applied across a conductor then the charge carriers insie the conductor move with an average velocity which is independent of time. This velocity is known as drift velocity (v_d).
Relationship between current (I) and drift velocity (v_d), $I = neAv_d$ where ne = amount of charge inside the conductor, A = area of cross section of conductor.

7. When electrons drift in a metal from lower to higher potential, does it mean that all the free electrons of the metal are moving in the same direction?

Sol. Yes, all the electrons will move in same direction during drift due to external electric field.

8. Plot a graph showing variation of current versus voltage for the material GaAs.

Sol.

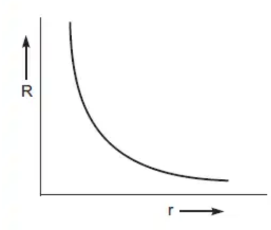


9. How does one explain increase in resistivity of a metal with increase of temperature?

Sol. Increasing temperature causes greater electron scattering due to increased thermal vibrations of atoms and hence resistivity ρ (reciprocal of conductivity) of metals increases linearly with temperature.

10. Plot a graph showing the variation of resistance of a conducting wire as a function of its radius. Keeping the length of the wire and its temperature as constant.

Sol.



Resistance of a conductor of length l, and radius r is given by $R = \rho \frac{l}{\pi r^2}$

11. Ni, chrome and cooper 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.

12. Answer the following questions: (1 mark each)

(a) A steady current flows in a metallic conductor of non-uniform cross- section. Which of these quantities is constant along the conductor: current, current density, electric field, drift speed?

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(b) Is Ohm's law universally applicable for all conducting elements?
If not, give examples of elements which do not obey Ohm's law.

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(c) A low voltage supply from which one needs high currents must have very low internal resistance. Why?

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(d) A high tension (HT) supply of, say, 6 kV must have a very large internal resistance. Why?

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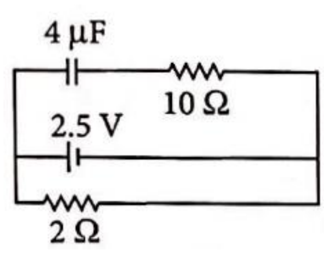
13. A capacitor of 4 μ F is connected as shown in the circuit. The internal resistance of the battery is 0.5Ω . The amount of charge on the capacitor plates will be



(a) 0 (b) 4 μ C (c) 16 μ C (d) 8 μ C

Ans. (d)

14. Is the motion of a charge across junction momentum conserving? Why or why not?

Sol. When an electron approaches a junction. In addition in the uniform **E** that it normally faces (which keep the drift velocity $\mathbf{v}_a$ fixed), there are accumulation of charges on the surface of wires at the junction. These produce electric field. These fields alter direction of momentum.

15. Consider a current carrying wire (current I) in the shape of a circle. Note that as the current progresses along the wire, the direction of j (current density) changes in an exact manner, while the current I remain unaffected. The agent that is essentially responsible for is
(a) source of emf.
(b) electric field produced by charges accumulated on the surface of wire.
(c) the charges just behind a given segment of wire which push them just the right way by repulsion. (d) the charges ahead.

Sol. (b)
As we know electric current per unit area I/A is called current density j, i.e., j = I/A
The SI units of the current density are A/m^2
The current density is also directed along E and is also a vector and the relationship is $j = \sigma E$ Current density changes due to electric field produced by charges accumulated on the surface of the wire

16. Which of the following characteristics of electrons determines the current in a conductor?
(a) Drift velocity alone. (b) Thermal velocity alone.
(c) Both drift velocity and thermal velocity. (d) Neither drift nor thermal velocity

Sol. (a)
We know that the relationship between current and drift speed is $I = neAv_d$ where I is the current and v_d is the drift velocity.
So, $I \propto v_d$
Hence only drift velocity determines the current in a conductor

(2 Marks Questions)

17. Define the term 'mobility' of charge carriers in a current carrying conductor. Obtain the relation for mobility in terms of relaxation time.

Sol. Mobility of charge carrier is defined as the drift velocity of the charge carrier per unit electric field. It is generally denote by μ.
$\mu = v_d/E$
The SI unit of mobility is $m^2 V^{-1}s^{-1}$.
Mobility intern of relaxation time: $\vec{v}_d = \frac{=e\vec{E}}{m}\tau$
In magnitude, $v_d = \frac{eE}{m}\tau$ or $\frac{v_d}{E} = \frac{e\tau}{m}$ or $\mu = \frac{e\tau}{m}$

18. Using the concept of drift velocity of charge carriers in a conductor, deduce the relationship between current density and resistivity of the conductor.

Sol. As we know that $I = neAv_d$
Also current density j is given by j = I/A
$\therefore |\vec{j}| = \frac{ne^2}{m}\tau|\vec{E}|$ ($\because v_d = \frac{E\tau E}{m}$)
Since $\vec{j}$ is parallel to $\vec{E}$
$\therefore \vec{j} = \frac{ne^2}{m}\tau\vec{E}$

$\because \sigma = \frac{1}{\rho} = \frac{ne^2}{m}\tau$

$\therefore \vec{J} = \frac{\vec{E}}{\rho}$

19. Estimate the average drift speed of conduction electrons in a copper wire of cross sectional area 1.0×10^{-7} m^2 carrying a current of 1.5A. Assume the density of conductor electrons to be 9×10^{28} m^{-3}.

Sol. $I = neAv_d$

$V_d = \frac{I}{neA} = \frac{1.5}{9\times10^{28}\times1.6\times10^{-19}\times1.0\times10^{-7}} ms^{-1}$

$= 1.042 \times 10^{-3}$ ms^{-1} = 1 mms^{-1}

20. A conductor of length 'l' is connected to a dc source of potential 'V'. if the length of the conductor is tripled by gradually stretching it keeping 'V' constant, how will (i) drift speed of electrons and (ii) resistance of the conductor be affected. Justify your answer.

Sol. (i) We know that $v_d = \frac{eV\tau}{ml} \Rightarrow v_d \propto \frac{1}{l}$

When length is tripled, the drift velocity becomes one third.

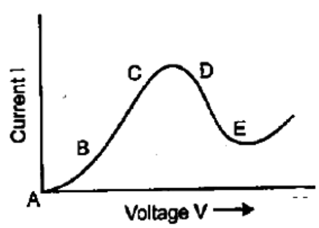
(ii) $R = \rho\frac{l'}{v'} = \rho \times \frac{l^2}{V}$, $l' = 3l$

New resistance $R' = \rho\frac{l'}{v'} = \rho \times \frac{(3l)^2}{V} = 9R$

R' = 9R

Hence the new resistance will be 9 times the original.

21. Graph showing the variation of current versus voltage for a material GaAs is shown in the figure. Identify the region of



(i) Negative resistance (ii) Where ohm's law is obeyed.

Sol. (i) Region DE has negative resistance property because current decreases with increase in voltage or slope of DE is negative.

(ii) Region BC obeys Ohm's law because current varies linearly with the voltage.

(3 Marks Questions)

22. (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 relaxtion time. Hence obtain the relation between current density and the applied electric field E.

Sol. (a) The electrical conductivity of a metallic wire is defined as the ratio of the current density to the electric field it creates. It is reciprocal of resistivity (ρ).

Electrical conductivity, $(\sigma) = \frac{1}{\rho} = \frac{j}{E}$

Si unit = mho m^{-1} or $(\text{ohm m})^{-1}$ or Sm^{-1}

(b) The elector field E exerts an electrostatics force – Ee.

Acceleration of each electron ,d = -eE/m …(i)

Where m = mass of an electron, e = charge on an electron

$\vec{v}_d = \frac{\vec{v}_1+\vec{v}_2+\cdots+\vec{v}_n}{n}$

$\vec{v}_d = \frac{(\vec{u}_1+\vec{a}\tau_1)+(\vec{u}_2+\vec{a}\tau_2)+\cdots+(\vec{u}_n+\vec{a}\tau_n)}{n}$

Where $\vec{u}_1, \vec{u}_2$ - thermal velocities of the electrons, $\vec{a}\tau_1, \vec{a}\tau_2$ - velocities acquired by the electrons, τ_1, τ_2 - time elapsed after the collision.

$\vec{v}_d = \frac{(\vec{u}_1+\vec{u}_2+\cdots+\vec{u}_n)}{n} + \frac{\vec{a}(\tau_1+\tau_2+\cdots+\tau_n)}{n}$

Since $\frac{\vec{u}_1+\vec{u}_2+\cdots+\vec{u}_n}{n} = 0$ we get

$\vec{v}_d = a\tau$, …(ii)

where $\tau = \frac{\tau_1+\tau_2+\cdots+\tau_n}{n}$ is the average time elapsed.

Substituting the value of a in equation (ii) from equation (i) we have

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

Hence average drift velocity, $v_d = \frac{eE}{m}\tau$

$I = \frac{q}{t} = \frac{-Ne}{t} = \frac{-nAle}{I/v_d}$

$I = -\,neAv_d = \frac{ne^2A\tau}{m}E$

$\Rightarrow j = \frac{I}{A} - \left(\frac{ne^2\tau}{m}\right)E = \sigma E$

(5 Marks Questions)

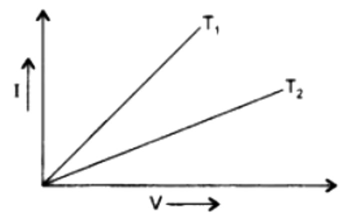
23. Define the term ‘drift velocity’ of charge carriers in a conductor . Obtain the expression for the current density in term of relaxation time.

Sol. Drift velocity is defined as the average velocity with which the free electrons get drifted towards the positive end of the conductor under the influence of external field applied. It is given by $\vec{v}_d = \frac{e\vec{E}}{m}\tau;\ v_d = \frac{eV}{ml}\tau$ where m = mass of electron, e = charge of electron, E = electric field applied.

B. OHM'S LAW

(1 Mark Questions)

1. I-V graph for a metallic wire at two different temperatures, T_1 and T_2 is as shown in the figure. Which of the two Temperature is lower and why?



Sol. As $R = \frac{\Delta V}{\Delta I}$

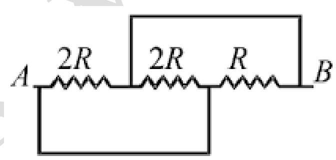
So in I-V graph, $R \propto \frac{1}{(\text{Slope of I}-\text{V graph})}$

$\therefore R_1 < R_2$

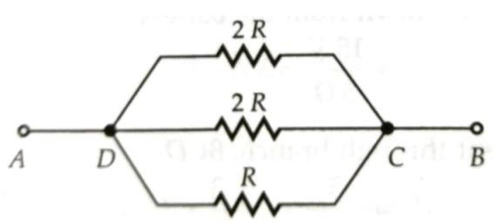
Resistance of metallic wire increases with temperature.

Hence, $T_1 < T_2$.

2. What is the equivalent resistance between points A and B of the circuit in Figure?



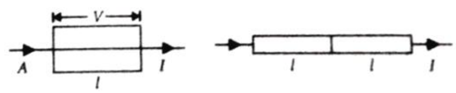
Sol. Obviously the points A and D are equipotential points. Also, the points B and C are equal potential points. SO, the given network of resistances reduces to the equivalent circuit shown in figure.



The three resistances form a parallel combination. Their equivalent resistance R_{eq} is given by $\frac{1}{R_{eq}} = \frac{1}{2R} + \frac{1}{2R} + \frac{1}{R} = \frac{1+1+2}{R} = \frac{2}{R}$ or $R_{eq} = R/2$.

(2 Marks Questions)

3. A metal rod of square cross-sectional area A having length l has current I flowing through if when a potential difference of V volt is applied across its ends (figure 1). Now the rod is cut parallel to its length into two identical pieces and joined as shown in figure II. What potential difference must be maintained across the length of 2l so that the current in the rod is still?



(I) (II)

Sol. From Ohm's law, we have $V = IR \Rightarrow V = I\rho\frac{l}{A}$ …(i)

When the rod is cut parallel, and rejoined by length, the length of the conductor becomes 2l, whereas the area decreases to $\frac{A}{2}$. If the current remains the same the potential changes as $V = I\rho\frac{2l}{A/2} = 4 \times \rho\frac{l}{A} = 4V$ [Using (i)]

The new potential applied across the metal rod will be four times the original potential (V).

4. At room temperature (27.0 °C) the resistance of a heating element is 100 Ω. What is the temperature of the element if the resistance is found to be 117 Ω, given that the temperature coefficient of the material of the resistor is $1.70\times10^{-4\circ C}$.

Sol. Here $R_1 = 100\Omega$, $R_2 = 117\Omega$, $I_1 = 27°C$, $\alpha = 1.70 \times 10^{-4}°C^{-1}$

As $\alpha = \frac{R_2 - R_1}{R_1(I_2 - I_1)}$

$\therefore t_2 - t_1 = \frac{R_2 - R_1}{R_1\alpha} = \frac{117-100}{100\times1.70\times10^{-4}} = 1000$

$\therefore t_2 = 1000 + t_1 = 1000 + 27 = 1027°C.$

5. A negligibly small current is passed through a wire of length 15 m and uniform cross-section 6.0×10^{-7} m², and its resistance is measured to be 5.0 Ω. What is the resistivity of the material at the temperature of the experiment?

Sol. Here $l = 15m$, $A = 6.0 \times 10^{-7}\ m^2$, $R = 5.0\Omega$

Resistivity, $\rho = \frac{RA}{l} = \frac{5.0\times6.0\times10^{-7}}{15} = 2.0\times10^{-7}\Omega m.$

6. A silver wire has a resistance of 2.1 Ω at 27.5 °C, and a resistance of 2.7 Ω at 100 °C. Determine the temperature coefficient of resistivity of silver.

Sol. Here $R_1 = 2.1\Omega$, $t_1 = 27.5°C$, $R_2 = 2.7\Omega$, $t_2 = 100°C$.

Temperature coefficient of resistivity of silver, $\alpha = \frac{R_2 - R_1}{R_1(I_2 - I_1)}$

$= \frac{2.7-2.1}{2.1(100-27.5)} = \frac{0.6}{2.1\times72.5} = 0.00394°C^{-1}$.

7. The earth's surface has a negative surface charge density of 10^{-9} C m^{-2}. The potential difference of 400 kV between the top of the atmosphere and the surface results (due to the low conductivity of the lower atmosphere) in a current of only 1800 A over the entire globe. If there were no mechanism of sustaining atmospheric electric field, how much time (roughly) would be required to neutralise the earth's surface? (This never happens in practice because there is a mechanism to replenish electric charges, namely the continual thunderstorms and lightning in different parts of the globe). (Radius of earth = 6.37×10^6 m.)

Sol. Surface charge density, $\sigma = 10^{-9} Cm^{-2}$

Radius of earth, $R = 6.37 \times 10^6 m$

Current, I = 1800A

Total charge of the globe, q = surface area × σ = $4\pi R^2\sigma$

$= 4\times 3.14 \times (6.37 \times 10^6)^2 \times 10^{-9} = 509.65 \times 10^3 C$

Required time, $t = \frac{q}{I} = \frac{509.65\times10^3}{1800} = 283.13s = 283s$

8. Two wires of equal length, one of aluminium and the other of copper have the same resistance. Which of the two wires is lighter? Hence explain why aluminium wires are preferred for overhead power cables. ($\rho_{Al} = 2.63 \times 10^{-8}\ \Omega$ m, $\rho_{Cu} = 1.72 \times 10^{-8}\ \Omega$ m, Relative density of Al = 2.7, of Cu = 8.9.)

Sol. Mass = volume × density = Ald

$= \frac{\rho l}{R}.ld = \frac{\rho d\, l^2}{R}$ [$\because R = \rho\frac{l}{A}$]

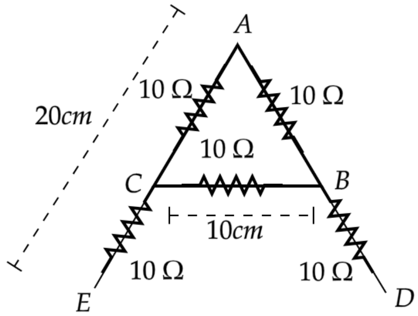
As the two wires are of equal length and have the same resistance, their mass ratio will be

$\frac{m_{Cu}}{m_{Al}} = \frac{\rho_{Cu}d_{Cu}}{\rho_{Al}d_{Al}} = \frac{0.72\times10^{-8}\times8.9}{2.63\times10^{-8}\times2.7} = 2.1558 = 2.2.$

i.e., copper wire is 2.2 times heavier than aluminium wire. Since aluminium is lighter, it is preferred for long suspension of cables otherwise heavy cable may sag down due to its own weight.

9. A letter A consists of a uniform wire of resistance 1 ohm per cm. The sides of the letter are 20cm long and the cross piece in the middle is 10cm long while apex angle is 60° Find the resistance of the letter between the two ends of the legs.

Sol.



Clearly, AB = BC = CD = DE = BD = 10cm

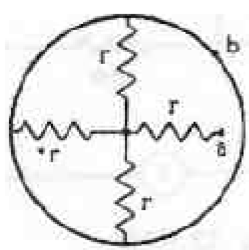
$\therefore R_1 = R_2 = R_3 = R_4 = R_5 = 10\Omega$

As R_1 and R_2 are in series, their combination resistance = 10 +10 = 20Ω. This combination is in parallel with RR_5 (= 10Ω)

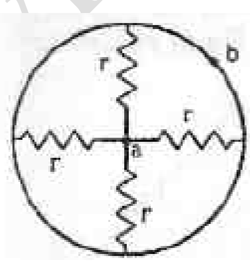
Hence resistance between points B and D is given by: $\frac{1}{R} = \frac{1}{20} + \frac{1}{10} = \frac{3}{20}$ or R = $\frac{20}{3}\Omega$

Now resistances R_1, R and R_4 form a series combination. So, resistance between the ends A and E is 10 + $\frac{20}{3}$ + 10 = 26.67Ω.

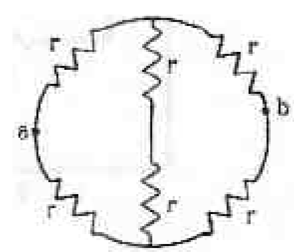
10. Find the equivalent resistance of the networks shown in the figure between the points A and B.



(a)

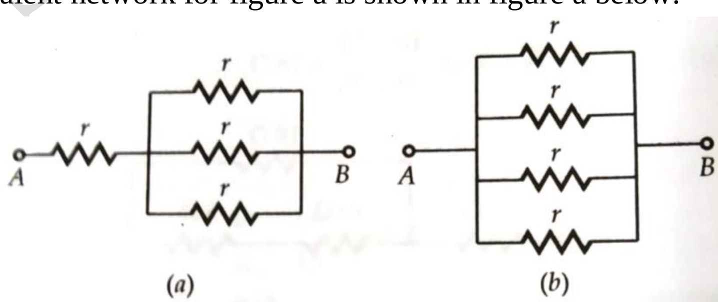


(b)



(c)

Sol. (a) The equivalent network for figure a is shown in figure a below.

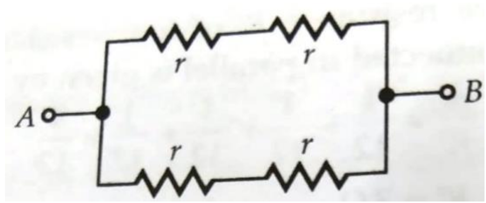


$\therefore$ R = r + r/3 = 4/3 r

(b) The equivalent network for b is shown in figure b above.

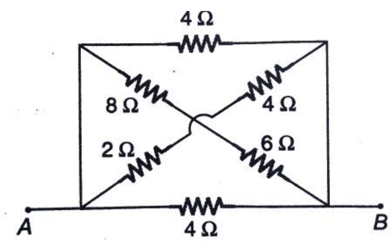
$\frac{1}{R} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r} + \frac{1}{r} = \frac{4}{r}$ or R = $\frac{r}{4}$.

(c) The current divides symmetrically in the two upper and the two lower resistances. So the resistances in the vertical arm are ineffective. The given network reduces to the equivalent network shown in figure below.

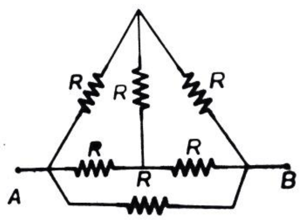


$R = \frac{2r \times 2r}{2r+2r} = r.$

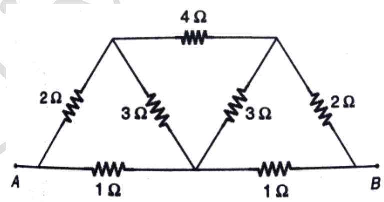
11. Calculate the equivalent resistance between points A and B in each case of the following networks of resistors:



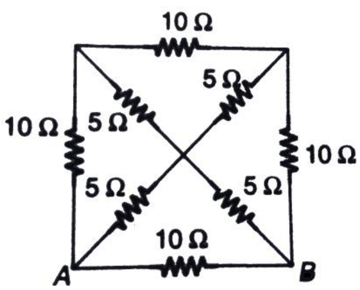
(a)



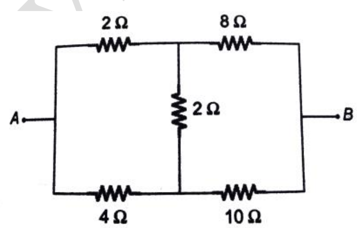
(b)



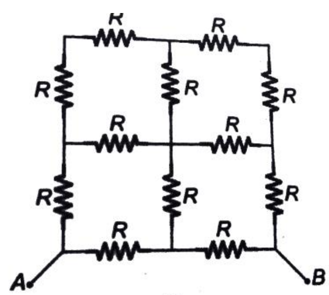
(c)



(d)



(e)



(f)

12. Name two factors on which the resistivity of a given material depends? A carbon resistor has a value of 62kΩ with a tolerance of 5%. Give the colour code for the resistor.

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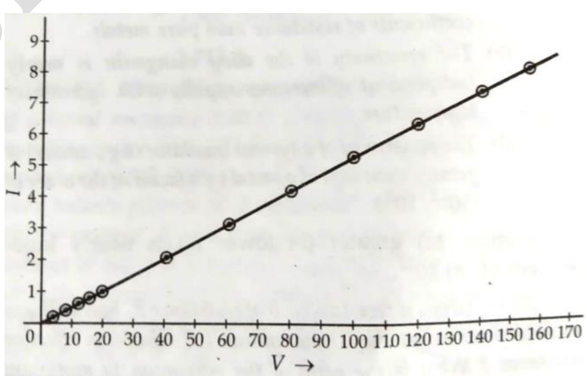
(3 Marks Questions)

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

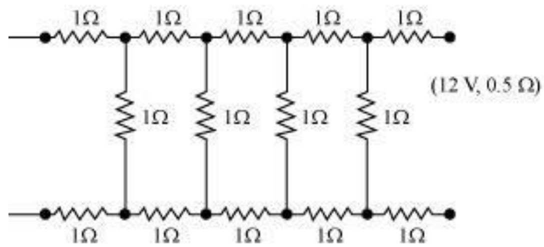
Current **A**	**Voltage** **V**	**Current** **A**	**Voltage** **V**
0.2	3.94	3.0	59.2
0.4	7.87	4.0	78.8
0.6	11.8	5.0	98.6
0.8	15.7	6.0	118.5
1.0	19.7	7.0	138.2
2.0	39.4	8.0	158.0

Sol. We plot the graph between current I (along y axis) and voltage V (along x axis) as shown in figure.



Since the VI graph is almost a straight line, therefore manganin resistor is an ohmic resistor for ranges of voltage and current. As the current increases from 0 to 8A, the temperature increases by the resistance of manganin does not change. This indicates that the temperature coefficient of resistivity of manganin alloy is negligibly small.

14. Determine the current drawn from a 12 V supply with internal resistance 0.5 Ω by the infinite network shown in Fig. Each resistor has 1 Ω resistance.



[Ans. 3.713 A]

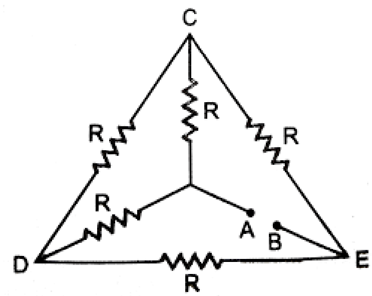
15. Two metallic rods, each of length L, area of cross section A_1 and A_2 having resistivity ρ_1 and ρ_2 are connected in parallel across a d.c. battery. Obtain the expression for the effective resistivity of this combination.

Sol. For the first rod, $R_1 = \frac{\rho_1 L}{A_1}$ and for second rod, $R_2 = \frac{\rho_2 L}{A_2}$

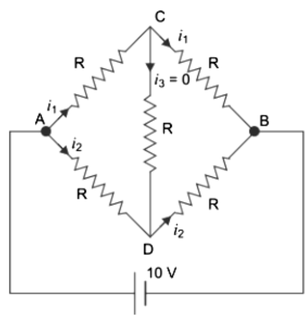
Now, $R_{eq} = \frac{\rho_{eq} L}{A_1 + A_2} = \frac{R_1 R_2}{R_1 + R_2} = \frac{\left(\frac{\rho_1 L}{A_1}\right)\left(\frac{\rho_2 L}{A_2}\right)}{\frac{\rho_1 L}{A_1} + \frac{\rho_2 L}{A_2}}$

$\Rightarrow \frac{\rho_{eq} L}{A_1 + A_2} = \frac{\rho_1 \rho_2}{(\rho_1 A_2 + \rho_2 A_1)} \Rightarrow \rho_{eq} = \frac{\rho_1 \rho_2 (A_1 + A_2)}{\rho_1 A_2 + \rho_2 A_1}$

16. (i) Calculate the equivalent resistance of the given electrical network between points A and B.
(ii) Also calculate the current through CD and ACB, if a 10V dc source is connected between A and B and the value of R is assumed as 2Ω.

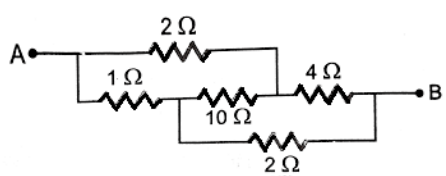


Sol. (i) The equivalent network is shown in figure. It is balanced Wheatstone bridge because $\frac{R\Omega}{R\Omega}$

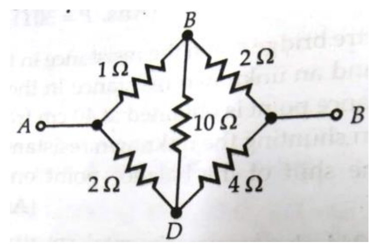


Hence the points C and D are at same potential. The resistance in arm CD is ineffective.
Total resistance along FCE = R + R = 2RΩ
Total resistance along FDE = R + R = 2RΩ
These two resistances form a parallel combination.
∴ Equivalent resistances between points A and B = $\frac{R\times R}{R+R}$ = RΩ i.e R_{AB} = RΩ
(ii) Total current in the circuit = $\frac{V}{R} = \frac{RV}{R\Omega}$ = 1A
Current through the arm I_{CD} = 0 and I_{ACB} = 2.5A.

17. Calculate the equivalent resistance between points A and B of the network shown in figure.



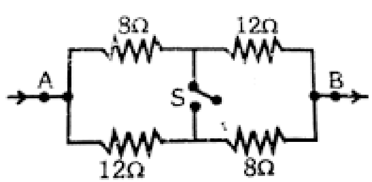
Sol. As $\frac{1}{2} = \frac{2}{4}$
∴ The given circuit is a balanced Wheatstone bridge as shown in figure below. The resistance of 10Ω is ineffective.



We have (1Ω + 2Ω) and (2Ω + 4Ω) combinations in parallel.

∴ R = $\frac{3\times6}{3+6}$ = 2Ω.

18. Find the effective resistance of the network shown in Figure between points A and B when (i) the switch S is open (ii) switch S is closed.



Sol. (i) When the switch S is open, the resistances of 6Ω and 12Ω in upper portion are in series, the equivalent resistance is 18Ω. Similarly, resistances in the lower portion have equivalent resistance of 18Ω. No the two resistances of 18Ω are in parallel between points A and B.

∴ Effective resistance between points A and B = $\frac{18\times18}{18+18}$ = 9Ω

(ii) When the switch S is closed, the resistances of 6Ω and 12Ω on the left are in parallel. Their equivalent resistance is $\frac{6\times12}{6+12}$ = 4Ω

Similarly, the resistances on the right have equivalent resistance of 4Ω.The equivalent of 4Ω are in series. Now the two resistances of 4Ω are in series.

∴ Effective resistance between points A and B = 4 +4 = 8Ω

(5 Marks Questions)

19. (i) Derive a expression for drift velocity of electron in a conductor. Hence deduce Ohm's law

(ii) A wire whose cross-sectional area is increasing linearly from its one end to the other, is connected across a battery of V volts. Which of the following quantities remain constant in the wire?

(a) drift speed (b) current density (c) electric current (d) electric field

Justify your answer.

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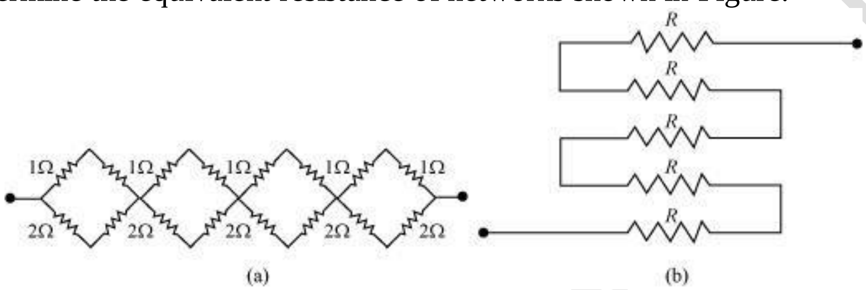
20. **(a)** Given *n* resistors each of resistance *R*, how will you combine them to get the (i) maximum (ii) minimum effective resistance? What is the ratio of the maximum to minimum resistance?
(b) Given the resistances of 1 Ω, 2 Ω, 3 Ω, how will be combine them to get an equivalent resistance of (i) (11/3) Ω (ii) (11/5) Ω, (iii) 6 Ω, (iv) (6/11) Ω?
(c) Determine the equivalent resistance of networks shown in Figure.



Sol. (a) For maximum effective resistance, all the n resistors must be connected in series.

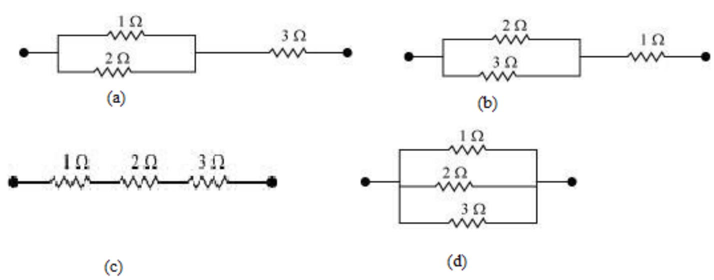
∴ Maximum effective ressitance, $R_s = nR$

For minimum effective resistance, al the n resistors must be connected in parallel,. It is given by $\frac{1}{R_p} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} + \cdots \text{n terms} = \frac{n}{R}$

∴ Minimum effective resistance, $R_p = \frac{R}{n}$

Resistance of the maximum to minimum resistance is $\frac{R_s}{R_p} = \frac{nR}{R/n} = \frac{n^2}{1} = n^2:1$.

(b) Here $R_1 = 1\Omega$, $R_2 = 2\Omega$, $R_3 = 3\Omega$



(i) When a parallel combination 1Ω and 2Ω resistors is connected in series with 3Ω resistor (fig (a)), the equivalent resistance is

$R = R_p + R_s = \frac{R_1 R_2}{R_1+R_2} + R_3 = \frac{1\times 2}{1+2} + 3 = \frac{2}{3} + 3 = \frac{11}{3}\Omega$

(ii) When the three resistances are connected in series (figure b), the equivalent resistnce is

$R = \frac{R_2 R_3}{R_2+R_3} + R_1 = \frac{2\times 3}{2+3} + 1 = \frac{6}{5} + 1 = \frac{11}{5}\Omega$

(iii) When the three resistances are connected in series (fig (c)), the equivalent resistance is

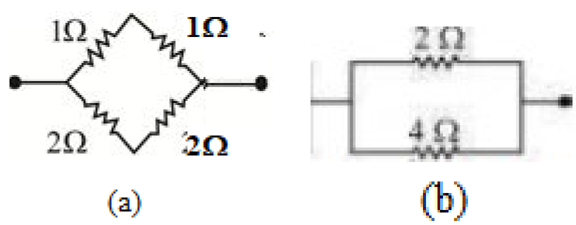
$R = R_1 + R_2 + R_3 = (1 + 2 + 3)W = 6W$

(iv) When all the resistances are connected in parallel (fig(d))

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{1} + \frac{1}{2} + \frac{1}{3} = \frac{11}{6}$$

∴ Equivalent resistance, $R = \frac{6}{11}\Omega$.

(c) The network shown in figure (a) below is a series combination of four identical units. One such unit is shown in figure (a) and is equivalent to the parallel combination of two resistances of 2Ω and 4Ω as shown in figure (b).



Resistance of the total network (4 such units) = $4 \times \frac{4}{3} = \frac{16}{3}W$

(ii) The network shown in figure (b) is a series combination of 5 resistors each of resistance R. Therefore, equivalent resistance = 5R.

C. KIRCHHOFF'S LAW AND ELECTRIC CURRENT

(1 Mark Questions)

1. On what conservation principle is the Kirchhoff's first law based?

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2. On what conservation principle is the Kirchhoff's second law based?

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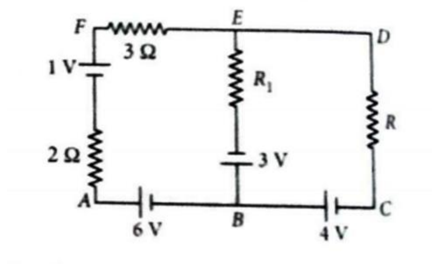
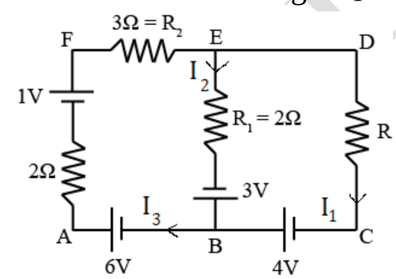
(2 Marks Questions)

3. Use Kirchhoff's rules to determine the potential between the points A and D when no current flows in the BE of the electric network shown in the figure.



Sol. First we need to calculate R for no current through R_1



By Kirchhoff's law, 3I + RI + 2L = 1 + 4 + 6

5I + RI = 11 …(i)

Also in loop (1), 3I + 2I = 3 + 6 + 1

5I = 10 or I = 2 amp …(ii)

Using in eqn (i), 10 + R × 2 = 11

2R = I or R = 0.5Ω …(iii)

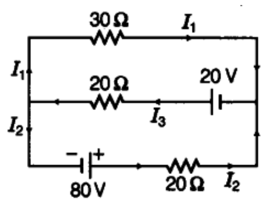
Now to determine the potential difference between A and D, we can assume a cell of required potential V_{AD} between two points. On applying Kirchhoff's law

$V_{AD} = 6 - 4 = -2 \times 0.5$

$V_{AD} - 10 = -1$

$V_{AD} = 9$ volt

4. Use Kirchhoff's rules to determine the value of the current I_1 flowing in the circuit shown in the figure.



Sol. Applying Kirchhoff's 1st law,

$I_3 = I_1 + I_2$ (at C) … (i)

Applying Kirchoff's loop rule to CDFEC

$- 30I_1 + 20 – 20I_3 = 0$

$3I_1 + 2I_3 = 2$ …(ii)

For loop ABFEA

$- 30I_1 + 20I_2 – 80 = 0$

$- 3I_1 + 2I_2 = 8$ …(iii)

From eq. (i) put the value of I_3 in eq. (ii)

$3I_1 + 2I_1 + 2I_2 = 2$

$5I_1 + 2I_2 = 2$ …(iv)

$\underline{-3I_1 + 2I_2} = 8$

$8I_1 = - 6$

$I_1 = - ¾$ A

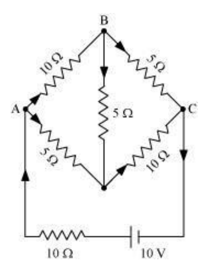
Putting I_1 in eq. (iv)

$- 5 \times ¾ + 2I_2 = 2 \Rightarrow I_2 = \frac{23}{8}$A

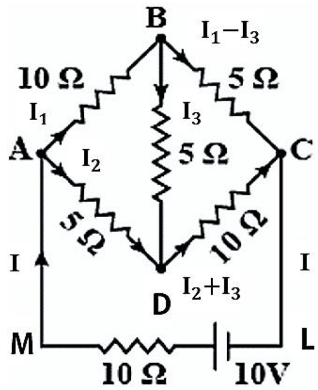
From eq. (i)

$I_3 = \frac{-3}{4} + \frac{23}{8} = \frac{-6+23}{8} = \frac{17}{8}$A

5. Determine the current in each branch of the network shown in figure.



Sol. Let I, I_1, I_2, I_3 be the currents as shown in figure below. We apply Kirchhoff's second rule to different loops.



For loop ABCDA, $10I_1 + 5I_3 – 5I_2 = 0$
For loop BCDB, $5(I_1 – I_3) – 10(I_2 + I_3) – 5I_3= 0$
For loop ADCFGA,
$5I_2 + 10(I_2 + I_3) + 10(I_1+ I_2) = 10$ ($\because I_1 + I_2 = I$)
Or $10I_1 – 5I_2 + 5I_3 = 0$ …(1)
$5I_1 – 10I_2 – 20I_3 = 0$ …(2)
$10I_1 + 25I_2 + 10I_3 = 10$ …(3)
Solving (1), (2) and (3) we get, $I_{AB} = I_1 = \frac{4}{17}$A, $I_{BC} = I_3 = \frac{6}{17}$A, $I_{DC} = I_2 + I_3 = \frac{4}{17}$A, $I_{AD} = I_2 = \frac{6}{17}$A, $I_{BD} = I_3 = -\frac{2}{17}$A
Total current, $I = I_1 + I_2 = \frac{10}{17}$A

6. A point charge Q is kept at the intersection of (i) face diagonals (ii) diagonals of a cube of side a. What is the electric flux linked with the cube in (i) & (ii)?

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(3 Marks Questions)

7. **(a)** Three resistors 1 Ω, 2 Ω, and 3 Ω are combined in series. What is the total resistance of the combination?
(b) If the combination is connected to a battery of emf 12 V and negligible internal resistance, obtain the potential drop across each resistor.

Sol. (a) $R_s = R_1 + R_2 + R_3 = 6\Omega$
(d) Current in the circuit, $I = \frac{\varepsilon}{R} = \frac{12}{6} = 2A$
∴ Potential drops across different resistors are
$V_1 = IR_1 = 2 \times 1 = 2V.$
$V_2 = IR_2 = 2 \times 2 = 4V.$
$V_3 = IR_3 = 2 \times 3 = 6V.$

8. **(a)** Three resistors 2 Ω, 4 Ω and 5 Ω are combined in parallel. What is the total resistance of the combination?
(b) If the combination is connected to a battery of emf 20 V and negligible internal resistance, determine the current through each resistor, and the total current drawn from the battery.

Sol. (a) $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{2} + \frac{1}{4} + \frac{1}{6} = \frac{19}{20}$

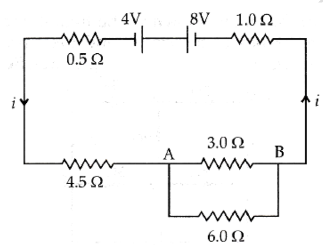
$\therefore R_p = \frac{20}{19}\Omega.$

(b) Currents drawn through different resistors are

$I_1 = \frac{\varepsilon}{R_1} = \frac{20}{2} = 10A,\ I_2 = \frac{\varepsilon}{R_2} = \frac{20}{4} = 5A,\ I_3 = \frac{\varepsilon}{R_3} = \frac{20}{5} = 4A$

Total current drawn from the battery, $I = I_1 + I_2 + I_3 = 10 + 5 + 4 = 19A$

9. In the circuit shown in the figure, find the current through each resistor.



Sol. $E_2 - E_1 = 8 - 4 = 4$ volt

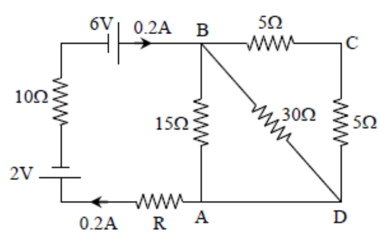
Total resistance = $0.5 + 1 + 4.5 + \frac{6\times3}{6+3} = 8\Omega$

$I = \frac{4}{8} = 0.5A$

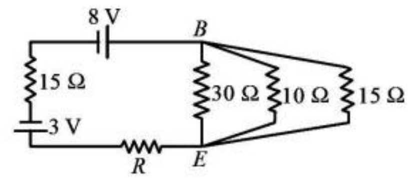
Current through 3Ω resistor = $\frac{6\times0.5}{6+3} = 0.33A$

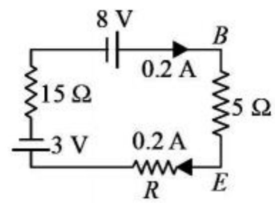
Current through 6Ω resistor = $\frac{3\times0.5}{6+3} = \frac{1.5}{9} = 0.16A$

10. Calculate the value of the resistance R in the circuit shown in the figure so that the current in the circuit is 0.2 A. what would be the potential difference between points B and E.



Sol. The given circuit can be simplified





For BCD, equivalent resistance $R_1 = 5\Omega + 5\Omega = 10\Omega$.

Across BE equivalent resistance $R_2 = \frac{1}{R_2} = \frac{1}{10} + \frac{1}{30} + \frac{1}{15} = \frac{3+1+2}{30} = \frac{6}{30} = \frac{1}{5}$

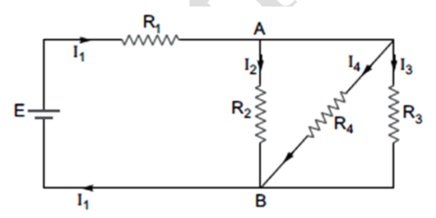
$\Rightarrow R_2 = 5\Omega$

Applying Kirchhoff's second law, $6 - 2 = 5 \times 0.2 + R \times 0.2 + 10 \times 0.2$

$4 = 3 + 0.2R$ or $R = 5\Omega$

Potential difference $V_{BE} = I \times R_2 = 0.2 \times 5 \Rightarrow V_{BE} = 1V$

11. In the circuit shown $R_1=4\,\Omega$, $R_2=R_3=15\ \Omega$, $R_4=30\ \Omega$ and E=10 V. Calculate the equivalent resistance of the circuit and the current is the current in each resistor.



Sol. From figure, R_2, R_3 and R_4 are connected in parallel.

$\therefore$ Effective resistance R_p

$\frac{1}{R_p} = \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} = \frac{1}{15} + \frac{1}{15} + \frac{1}{30} = \frac{5}{30}$

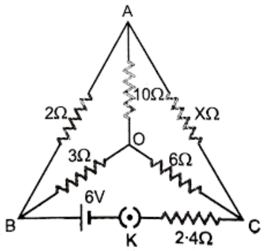
$\Rightarrow R_p = 6\Omega$

Now equivalent resistance of circuit, $R = R_1 + R_p = 4 + 6 = 10\Omega$

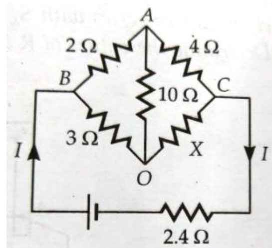
Current through R_2 or R_3; $I_2 = \frac{6}{15}A$, $I_3 = \frac{6}{15}A \Rightarrow I_2 = \frac{2}{5}A$, $I_3 = \frac{1}{5}A$

Current through R_4, $I_4 = \frac{6}{30}A \Rightarrow I_4 = \frac{1}{5}A$

12. Find the value of the unknown resistance X, in the following circuit, if no current flows through the section AO. Also calculate the current drawn by the circuit from the battery of emf 6V and negligible internal resistance.



Sol. The equivalent circuit for the given network is shown in figure.



As no current flows through the section AO, so the given circuit is a balanced Wheatstone bridge. Hence

$\frac{2}{4} = \frac{3}{X}$ or X = $\frac{3 \times 4}{2}$ = 6Ω

The resistance of 10 10Ω is section AO is not effective.

Total resistance along BAC = 2 +4 = 6Ω

Total resistance along BOC = 3 +6 = 9Ω

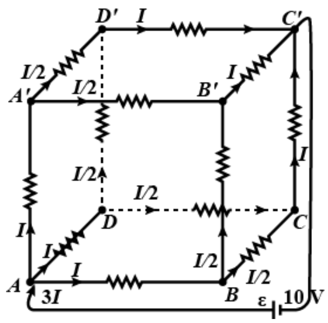
These two resistances form a parallel combination. The effective resistance between B and C is R = $\frac{6 \times 9}{6+9} = \frac{18}{5}$ = 3.6W

Total resistance in the circuit = 3.6 +2.4 = 6Ω.

Current, I = $\frac{6V}{6\Omega}$ = 1A

13. A battery of 10V and negligible internal resistance is connected across the diagonally opposite corners of a cubical network consisting of 12 resistors each of resistors 1Ω. Determine the equivalent resistance of the network and the current along each edge of the cube.

Sol. Let 6I be the current through the cell. Since the paths AA', AD and AB are symmetrically placed, current through each of them is same, i.e., 2I. At the junctions A', B and D the incoming current 2I splits equally into the two outgoing branches, the current through each branch is I, as shown in figure. At the junctions B', C' and D' these currents reunite and the currents along B'C', D'C' and CC' are 2I each. The total current at junction C' is 6I again.



Applying Kirchhoff's second law to the loop ABCC'EA, we get

$-2\,IR - IR - 2IR + \varepsilon = 0$ or $\varepsilon = 5IR$

Where R is the resistance of each bridge and ε is the emf of the battery.

∴ The equivalent resistance of the network is $R' = \frac{\text{Total emf}}{\text{Total current}} = \frac{\varepsilon}{6I} = \frac{5IR}{6I} = \frac{5}{6}R$

But R = 1Ω

∴ $R' = \frac{5}{6}\Omega$

Total current in the network is $6I = \frac{\varepsilon}{R'} = \frac{10}{5/6} = 12A$ or $I = 2A$

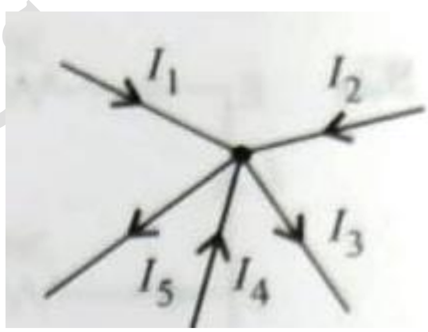
The current flowing in each branch can be read off easily.

(5 Marks Questions)

14. (a)State Kirchhoff's rules for an elective network.

(b) Using Kirchhoff's rules, obtain the balance condition in terms of the resistance of four arms of Wheatstone bridge.

Sol. Kirchhoff's first rule: The algebraic sum of all the current passing through a junction of an electric circuit is zero.

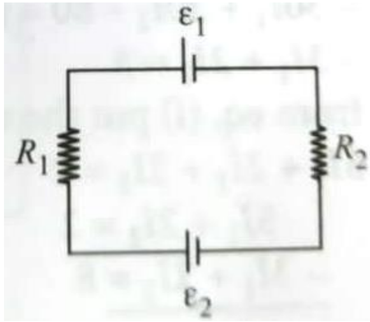


Here I_1, I_2, I_3, I_4 are current in different branches of a circuit which meet at a junction.

$I_1 + I_2 - I_3 + I_4 - I_5 = 0$

This rule is based on the principle of conservation of charge.

Kirchhoff's second rule" The algebraic sum of the applied emfs of an electrical circuit is equal to the algebraic sum of potential drop across the resistors of the loops.

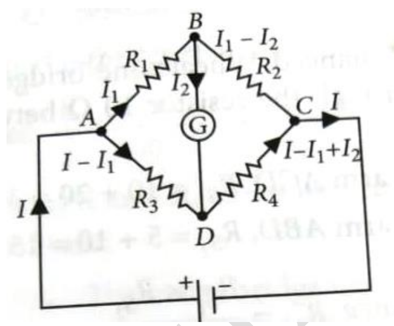


Mathematically, $\Sigma\varepsilon = \Sigma IR$

This is based on energy conservation principle.

Using this rule, $\varepsilon_1 - \varepsilon_2 = IR_1 + IR_2$

(b)



Consider loop ABDA, $I_1R_1 + I_2G - (I - I_1)R_3 = 0$

$I_1(R_1+R_3) + I_2G - IR_3 = 0$ …(i)

Consider loop BCDB, $(I_1 - I_2)R_2 - (I - I_1 + I_2)R_4 - I_2G = 0$

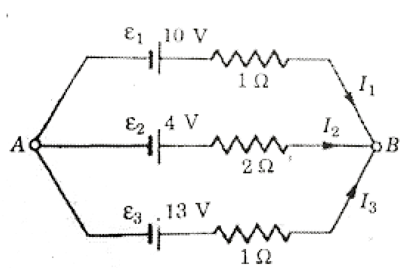
$I_1(R_2 + R_4) - I_2(R_2 + R_4 + G) - IR_4 = 0$ …(ii)

When bridge is balanced, B and D are at same potential i.e., $I_2 = 0$/. From equations (i) and (ii) we get $\frac{R_1+R_3}{R_2+R_4} = \frac{R_3}{R_4}$

$R_1R_4 + R_3R_4 = R_3R_4 + R_2R_3$; $R_1R_4 = R_2R_3$

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

15. Find the current flowing through each cell in the circuit shown. Also calculate the potential difference across the terminals of each cell. [Ans. 0, -3A, 3A, 3V]



Sol. Applying Kirchhoff's first law at the junction B, we get

$I_1 + I_2 + I_3 = 0$ …(1)

Applying Kirchhoff's second law to the loop $AE_1 BE_2$ A, we have

$I_1 \times 1_2 \times 2 = (10 - 4)$

$I_1 - 2I_2 = 6$ …(2)

Similarly, from the closed loop AE_2BE_3 A, we have

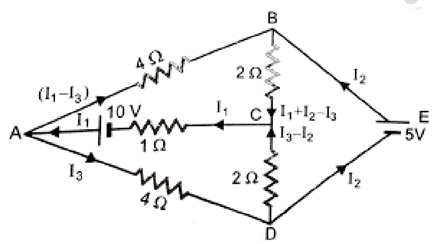
$I_2 \times 2 - I_3 \times 1 = 4 - 13$ or $2I_2 - I_3 = -9$ …(3)

Solving equations (1), (2) and (3) we get $I_1 = 0$, $I_2 = -3A$, $I_3 = 3A$

Thus the current in the 10V cell is zero. The current given by the 13V cell to the circuit is 3A, and the current taken by the 4V cell from the circuit is 3A.

As there is no current in the 10V cell, so the potential difference across its ends is equal to its emf i.e., 10V. Since all the three cells are in parallel, the potential difference across the terminals of each is 10V.

16. Determine the current in each branch of the network shown in figure.



Sol. Let I_1, I_2 and I_3 be the currents as shown in figure. Kirchhoff's second rule for the closed loop ADCA gives

$10 - 4(I_1 - I_2) + 2(I_2 + I_3 - I_1) - I_1 = 0$

Or $7I_1 - 6I_2 - 2I_3 = 10$ …(1)

For the closed loop ABCA, we get

$10 - 4I_2 - 2(I_2 + I_3) - I_1 = 0$

Or $I_1 + 6I_2 + 2I_3 = 10$ ….(2)

For the closed loop BCDEB, we get

$5 - 2(I_2 + I_3) - 2(I_2 + I_3 - I_1) = 0$

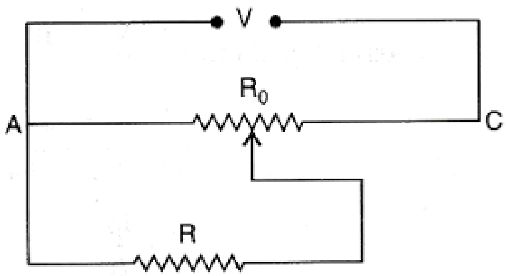
Or $2I_1 - 4I_2 - 4I_3 = -5$ …(3)

On solving equations (1), (2) and (3) we get

$I_1 = 2.5A$, $I_2 = \frac{5}{8}A$, $I_3 = 1\frac{7}{8}A$

The currents in the various branches of the network are: $I_{AB} = = \frac{5}{8}A$, $I_{CA} = 2\frac{1}{2}A$, $I_{DEB} = 1\frac{7}{8}A$, $I_{AD} = 1\frac{7}{8}A$, $I_{CD} = 0$, $I_{BC} = 2\frac{1}{2}A$

17. A resistance of RΩ draws current from a potentiometer. A potentiometer has a total resistance of R_0Ω (figure). A voltage V is supplied to the potentiometer. Derive an expression for the voltage fed into the circuit when the slide is in the middle of the potentiometer.



Sol. When the slide is in the middle of the potentiometer, only half the resistance of the potentiometer wire ($R_0/2$) is introduced between the points A and B. Hence the effective resistance R_1 between the points A and B is given by

$\frac{1}{R_1} = \frac{1}{R} + \frac{1}{R_0/2}$ or $R_1 = \frac{R_0 R}{R_0 + 2R}$

Two resistance between A and C = $R_1 + R_0/2$. Current through the potentiometer will be

$I = \frac{V}{R_1 + R0/2} = \frac{2V}{2R_1 + R_0}$

The voltage V_1 fed into the circuit will be the product of current I and resistance R_1.

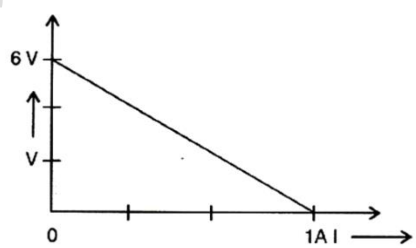
$\therefore V_1 = IR_1 = \left(\frac{2V}{2R_1 + R_0}\right) \times R_1$

$= \frac{2V}{2\left(\frac{R_0+R}{R+2R_0}\right)+R_0} \times \frac{R_0 R}{R_0 + 2R}$

$= \frac{2VR}{2R + R_0 + 2R} = \frac{2VR}{R_0 + 4R}$

D. BATTERY
(1 Mark Questions)

1. The plot of the variation of potential difference across of tree identical cells in series versus current is shown in the figure. What is the emf internal resistance of each cell?



Sol. Potential difference across a cell with internal resistance, r is $V = \varepsilon - Ir$.

As three cells are in series, so emf = 3ε and internal resistance = 3r

$\therefore V = 3\varepsilon - 3rI$

When I = 0 the V = 6V so $6 = 3\varepsilon - 0$ or $\varepsilon = 2V$. When V = 0 then I = 1A so $0 = 6 - 1 \times 3r$ or $3r = 6$ or $r = 2\Omega$

2. The emf of a cell is always greater that its terminal voltage. Why? Give reason?

Sol. We know the relation V = ε – Ir. The emf of a cell is greater than it terminal voltage because there may be some potential drop within the cell due to its small internal resistance offered by the electrolyte.

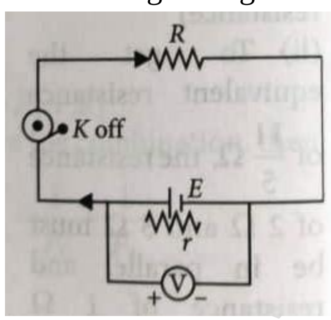
3. Why is the terminal voltage of a cell less than its emf?

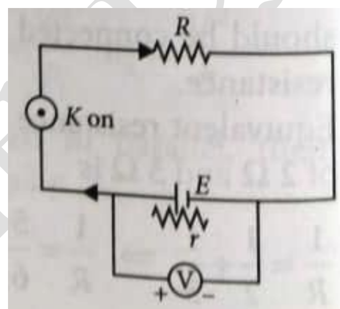
Sol. Same as 2.

(2 Marks Questions)

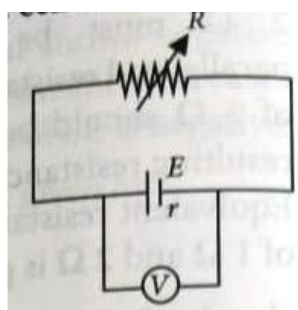
4. (a) Distinguish between emf (ε) and terminal voltage (V) of a cell having internal resistor ‘r’ (b) Draw a plot showing the variation of terminal voltage (V) vs the current (I) drawn from the cell. Using this plot, how does one determine the internal resistance of the cell?

Sol. (a) Electronegative force of emf ‘ε’of a cell is the potential difference across its terminals when no electric current is flowing through its pr it is in an open circuit.
Terminal voltage V of a cell is the potential difference across its terminals when some electric-current is flowing through it or it is in a closed circuit.

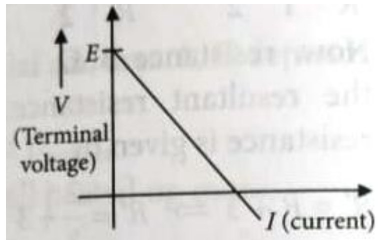




(b) Terminal voltage ‘V” of the cell is V = E - Ir
E = Ir. E is the emf fo the cell, r is the internal resistance of the cell and I is the current through the circuit.



So. V = - Ir + E
Comparing with the equation of a straight line y = mx +c. we gt y = V_1x + I; m = - r, c = . E
Graph showing variation of terminal voltage ‘V’ of the cell versus the current ‘I’.

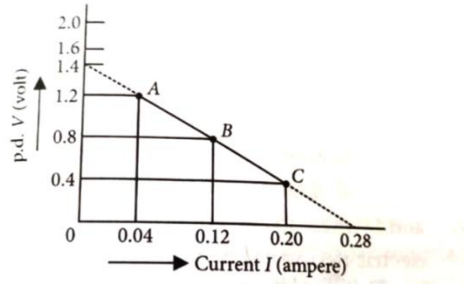


Emf of the cell = Intercept of V axis
Internal resistance = slope of line.

5. A cell of emf E and internal resistance r is connected to two external resistances R_1 and R_2 and a perfect ammeter. The current in the circuit is measured in four different situations:
(i) without any external resistance in the circuit.
(ii) with resistance R_1 only
(iii) with R_1 and R_2 in series combination
(iv) with R_1 and R_2 in parallel combination
The currents measured in the four cases are 0.42 A, 1.05A, 1.4 A and 4.2 A, but not necessarily in that order. Identify the current corresponding to the four cases mentioned above.

Sol. The current relating to corresponding situations are as follows:
(i) Without any external resistance, $I_1 = \frac{E}{r}$
In this case, effective resistance of circuit is minimum so current is maximum.
Hence, I_1 = 4.2A.
(ii) With resistance R_1 only $I_2 = \frac{E}{r+R_1}$
In this case, effective resistance of circuit is more than situations (i) and (iv) but less than (iii). So, I_2 = 1.05A.
(iii) With R_1 and R_2 in series combination, $I_3 = \frac{E}{r+R_1+R_2}$
In this case, effective resistance of circuit is maximum so, current is minimum. Hence, I_3 = 0.42A.
(iv) $I_4 = \frac{E}{r+\frac{R_1R_2}{R_1+R_2}}$
In this case, the effective resistance is more than (i) but less than (ii) and (iii). So. I_4 = 1.4A.

6. A straight line plot showing the terminal potential difference (V) of a cell as a function of current (I) drawn from it is shown in the figure. Using this plot, determine (i) the emf and (ii) internal resistance of the cell.



Sol. (i) The value of potential difference corresponding to zero current gives the emf of cell. The value is 1.4 Volt.

(ii) Maximum current is drawn from the cell when the terminal potential difference is zero. The current corresponding to zero value of terminal potential difference is 0.28A. This is maximum value of current.

$r = \frac{E}{I} = \frac{1.4}{0.25}\Omega$; r= 5Ω.

7. The storage battery of a car has an emf of 12 V. If the internal resistance of the battery is 0.4Ω, what is the maximum current that can be drawn from the battery?

Sol. Here ε = 12V, r = 0.4Ω.

The current drawn from the battery will be maximum when the external resistance in the circuit is zero, i.e., R = 0

$\therefore I_{max} = \frac{\varepsilon}{r} = \frac{12}{0.4} = 30A$

(3 Marks Questions)

8. A battery of emf 10 V and internal resistance 3 Ω is connected to a resistor. If the current in the circuit is 0.5 A, what is the resistance of the resistor? What is the terminal voltage of the battery when the circuit is closed?

Ans. As $I = \frac{\varepsilon}{R+r}$ or $R + r = \frac{\varepsilon}{I}$

$\therefore R = \frac{\varepsilon}{I} - r = \frac{10}{0.5} - 3 = 17\Omega$

Terminal voltage, V = IR = 0.5 × 17 = 8.5V

9 A storage battery of emf 8.0 V and internal resistance 0.5 Ω is being charged by a 120 V dc supply using a series resistor of 15.5 Ω. What is the terminal voltage of the battery during charging? What is the purpose of having a series resistor in the charging circuit?

Sol. When the storage battery of 8.0 volt is charged with a dc supply of 120V, the net emf in the circuit will be ε' = 120 – 8.0 = 112V

Current in the circuit during charging, $I = \frac{\varepsilon}{R+r} = \frac{112}{15.5+0.5} = 7A$

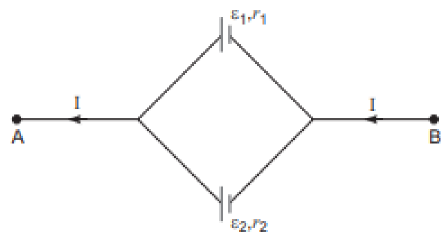
The terminal voltage of the battery during the charging, V = ε + Ir = 8.0 + 7×0.5 = 11.5V.

The series resistor limits the current drawn from the external source. In its absence the current will be dangerously high.

10. (a) Two cells of emf E_1 and E_2 have their internal resistance r_1 and r_2 respectively. Deduce an expression for the equivalent emf and internal resistance of their parallel combination when connected across and external resistance of their R, assume that the two cells are supporting each other.

(b) In case the two cells are identical , each of emf E= 5V and internal resistance r=2 Ω, calculate voltage across the external resistance R=10 Ω.

Sol. (a) Here $I = I_1 + I_2$ …(i)



Let V = Potential difference between A and B.

For cell E_1, $V = E_1 - I_1r_1 \Rightarrow I_1 = \frac{E_1 - V}{r_1}$

Similarly for cell E_2, $I_2 = \frac{E_2 - V}{r_2}$

Putting these values in equation (i)

$I = \frac{E_1 - V}{r_1} + \frac{E_2 - V}{r_2}$

Or $I = \left(\frac{E_1}{r_1} + \frac{E_2}{r_2}\right) - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$

Or $V = \left(\frac{E_1r_2 + E_2r_1}{r_1 + r_1}\right) - V\left(\frac{r_1r_2}{r_1 + r_1}\right)$ …(ii)

Comparing the above equation with the equivalent circuit and emf 'E_{eq}' and internal resistance 'r_{eq}' then

$V = E_{eq} - Ir_{eq}$ ….(iii)

Then, $E_{eq} = \frac{E_1r_2 + E_2r_1}{r_1 + r_1}$ and $r_{eq} = \frac{r_1r_2}{r_1 + r_1}$

(e) Given $E_1 = E_2 = E = 5V$ and $r_1 - r_2 = r = 2\Omega$ and $R = 10\Omega$

Then current, $I = \frac{E_{eq}}{R + r_{eq}} = \frac{5}{10 + 2/2} = \frac{5}{11}A$

$\therefore V = IR = \frac{5}{11} \times 10 = \frac{50}{11} = 4.55V$

(5 Marks Questions)

11. **(a)** Six lead-acid type of secondary cells each of emf 2.0 V and internal resistance 0.015 Ω are joined in series to provide a supply to a resistance of 8.5 Ω. What are the current drawn from the supply and its terminal voltage?

(b) A secondary cell after long use has an emf of 1.9 V and a large internal resistance of 380 Ω. What maximum current can be drawn from the cell? Could the cell drive the starting motor of a car?

Sol. (a) Here ε = 2V, r = 0.015Ω, R = 8.5Ω, n = 6

When the cells are joined in series, the current is

$I = \frac{n\varepsilon}{R+\pi r} = \frac{6\times2}{8.5+6\times0.015} = \frac{12}{8.59}A = 1.4A$

Terminal voltage, V = IR = 1.4 × 8.5 = 11.9V

(b) Here ε = 1.9V, r = 380Ω

$I_{max} = \frac{\varepsilon}{r} = \frac{1.9}{380}A = 0.005A$

E. METRE BRIDGE AND POTENTIOMETER

(1 Mark Question)

1. Define potential gradient. Give its SI unit.

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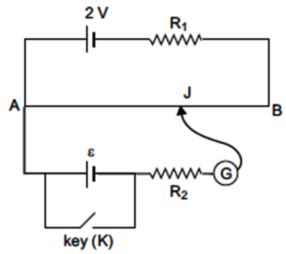
(2 Marks Questions)

2. (i) State the principle of working of a potentiometer.

(ii) In the following potentiometer circuit A.B is a uniform wire of length 1 m and resistance 10 Ω. Calculate the potential gradient along the wire and balance length AO (= *l*)



Sol. (i) When a constant current flows through a wire of uniform thickness, the potential difference between its two point is directly proportional to the length of the wire between these two points.

V ∝ l ⇒ V = Kl, where K is the potential gradient.

(ii) Here AB = 1m, R_{AB} = 10Ω, Potential gradient, k = ?, A) = l = ?

Current passing through AB, $I = \frac{2}{15+R_{AB}} = \frac{2}{15+10} = \frac{2}{25}A$

$V_{AB} = I \times R_{AB} = \frac{2}{25} \times 10 = \frac{4}{5}V$

Therefore $k = \frac{V_{AB}}{AB} = \frac{4}{5} Vm^{-1}$

Current in the external circuit, $I' = \frac{1.5}{1.2+0.3} = \frac{1.5}{1.5} = 1A$

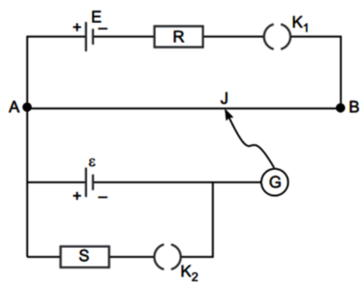
For no deflection in galvanometer, Potential difference across AO = 1.5 – 1.2I'

$\Rightarrow k(l) = 1.5 - 1.2 \times I'$

$\Rightarrow$ 4/5 I 0r 0.3 or $l = \frac{0.3\times5}{4} = 0.375m$

Therefore, l = 37.5 cm

3. Two students 'X' and 'Y' preform an experiment on potentiometer separately using the circuit given; keeping other parameters unchanged, how will the position of the null point be affected if.



(i)'X' increase the value of resistance R in the set-up by keeping the key K_1 closed and the key K_2 open ?

(ii)'Y' decrease the value of resistance S in the set-ip, white the key K_2 remains open and the key K_1closed?

Sol. (i) By increasing resistance R, the current through AB decreases, so potential gradient decreases. Hence a greater length of wire would be needed for balancing the same potential difference. So, the null point would shift towards B.

(ii) By decreasing resistance S, the current through AB remains same, potential gradient does not change. As K_2 is open so there is no effect of S on null point.

4. Why should we get the null point in the middle of the metre bridge wire?

Sol. The meter bridge is most sensitive when the four resistances forming Wheatstone bridge are equal. This is possible only if the balance point is somewhere near the middle of the wire.

5. An electric dipole of dipole moment p, is held perpendicular to an electric field. If the dipole is released does it have (a) only rotational motion 24 Physics Class - XII) (b) only translatory motion (c) both translatory and rotatory motion explain?

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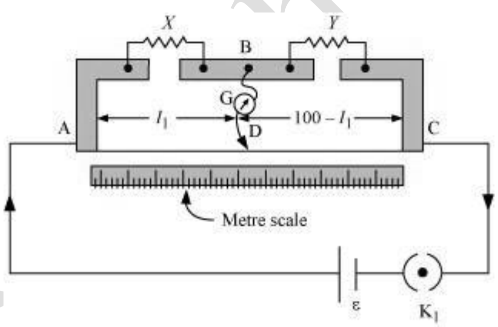
6. The net charge of a system is zero. Will the electric field intensity due to this system also be zero.

(3 Marks Questions)

7. **(a)** In a metre bridge [Fig. below], the balance point is found to be at 39.5 cm from the end *A*, when the resistor *Y* is of 12.5 Ω. Determine the resistance of *X*. Why are the connections between resistors in a Wheatstone or meter bridge made of thick copper strips?
(b) Determine the balance point of the bridge above if *X* and *Y* are interchanged.
(c) What happens if the galvanometer and cell are interchanged at the balance point of the bridge? Would the galvanometer show any current?



Sol. (a) Here l = 25.9cm, R = X = 7, S = Y = 12.5Ω.
As $S = \frac{100-l}{l} \times R \therefore 12.5 = \frac{100-39.5}{39.5} \times R$
Or $R = \frac{12.5\times39.5}{60.5} = 8.16\Omega$
Connections are made by thick copper strips to minimize the resistance of connections which are not accounted for in the above formula.
(b) When X and Y are interchanged, R = Y = 12.5Ω, S = X = 8.16Ω, I = ?
As $S = \frac{100-l}{l} \times R \therefore 8.16 = \frac{100-l}{l} \times 12.5$
Or 8.16I = 1250 – 12.5l
Or $l = \frac{1250}{20.66} = 60.5\Omega$
(c) When the galvanometer and cell are interchanged at the balanced point the conditions of the balanced bridge are still satisfied and so again the galvanometer will not show any current.

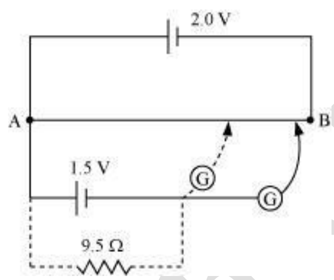
8. In a potentiometer arrangement, a cell of emf 1.25 V gives a balance point at 35.0 cm length of the wire. If the cell is replaced by another cell and the balance point shifts to 63.0 cm, what is the emf of the second cell?

Sol. Here $\varepsilon_1 = 1.25V$, $l_1 = 35.0cm$, $l_2 = 63.0cm$, $\varepsilon_2 = ?$

As, $\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}$

$\therefore \varepsilon_2 = \frac{l_1}{l_2} \times \varepsilon_1 = \frac{63 \times 1.25}{35} = 2.25V$

9. Figure shows a 2.0 V potentiometer used for the determination of internal resistance of a 1.5 V cell. The balance point of the cell in open circuit is 76.3 cm. When a resistor of 9.5 Ω is used in the external circuit of the cell, the balance point shifts to 64.8 cm length of the potentiometer wire. Determine the internal resistance of the cell. [Ans. 1.7 Ω]



Sol. Here $l_1 = 76.3cm$, $l_2 = 64.8cm$, $R = 9.5\Omega$.

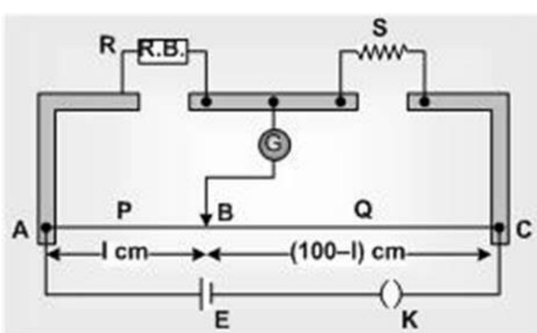
The formula for the internal resistance of a cell by potentiometer method is

$r = R\left(\frac{l_1 - l_2}{l_2}\right) = 9.5\left(\frac{76.3 - 64.8}{64.8}\right) = \frac{9.5 \times 11.5}{64.8} = 1.7\Omega$

10. Draw the circuit diagram of a meter bridge to explain how it is based on Wheatstone bridge.

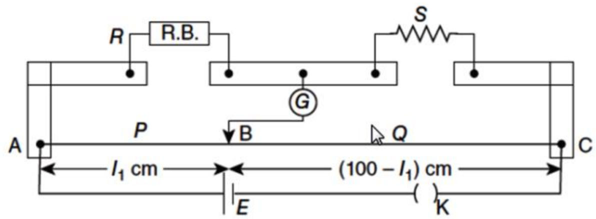
Sol. Metre bridge: It is the simplest practical application of the Wheatstone bridge that is used to measure an unknown resistance.

Principle: Its working is based on the principle of Wheatstone bridge.



When the bridge is balanced, $\frac{P}{Q} = \frac{R}{S}$ where unknown resistance, $S = \frac{R(100 - l)}{l}$

11. What is end error in a meter bridge? How is it overcome? The resistance in the two arms of the meter bridge are R=5 Ω and S respectively.



Sol. The shifting of zero at the scale of different points as well as the stray resistance give rise to the end error in metre bridge. The end error in the metre bridge occur due to the following reasons:

(i) The zero mark provided along the wire may not start from the position where the bridge wire leave the copper strip and 100cm mark of the scale may not end at position where the wire touches the copper strip.

(ii) The resistance of copper wires and copper strips of the meter bridge has not been taken into account.

In first case, $\frac{R}{S} = \frac{l_1}{(100-l_1)} \Rightarrow R = \frac{Sl_1}{(100-l_1)}$...(i)

In second case, $\frac{R}{\left(\frac{RS}{R+S}\right)} = \frac{1.5l_1}{(100-1.5l_1)}$ or $R = \frac{1.5l_1}{(100-1.5l_1)} \times \frac{RS}{R+S}$ ...(ii)

From (i) and (ii)

$$\frac{Sl_1}{(100-l_1)} = \frac{1.5l_1 \times RS}{(100-1.5l_1)\times(R+S)}$$

$(100 – 1.5\,l_1)(R + S) = 1.5\,(100 – l_1)R$

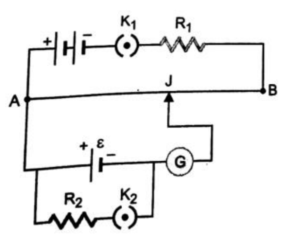
$100R + 100S – 1.5l_1R – 1.5l_1S = 150R – 1.50l_1R$

Or $S = \frac{50R}{(100-1.5l_1)}$

Given R = 5Ω

Therefore $S = \frac{250}{(100-1.5l_1)}$

12. (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 increase

The order factors remaining the same in the circuit? Justify your answer in each case.

(b) why is a potentiometer preferred over a voltmeter? Give reason?

Sol. (a) (i) If R_1 is decreased then current in the given circuit is increased. Hence potential gradient across wire AB will be increased. So, jockey J will shift towards point A i.e., balancing length will be decreased.

(ii) If R_2 is increased, emf of the cell will not be affected. Hence balancing length will not be affected.

(b) When a potentiometer is used to measure the potential difference in a branch, it does not draw any current from the circuit. Hence it gives accurate reading.

13. (a) State the underlying principle of a photometer why is it necessary to (i)use a long wire.(ii)have uniform area of cross-section of the wire and (iii)use a driving cell of emf is taken be greater than the emf of the length of the wire increases uniformly from one end to the other, draw a graph showing how potential gradient would vary as the length of the wire increase from one end.

Sol. (a) Principle of potentiometer: The potentiometer drop across he length of a steady current carrying wire of uniform cross-section is proportional to the length of the wire.

(i) We use a long wire to have a lower value of potential gradient i.e., a lower "least count" or greater sensitivity of the potentiometer.

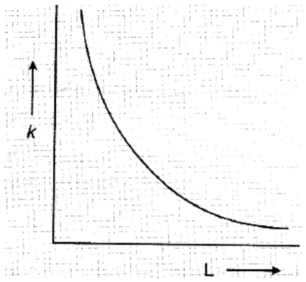
(ii) The area of cross section has to be uniform to get a uniform wire as per the principle of potentiometer.

(iii) The emf of the driving cell has to be greater than the emf of the primary cells as otherwise, no balance point would be obtained.

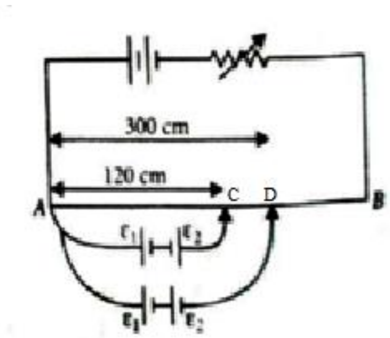
(b) Potential gradient, K = $\frac{V}{L} = \frac{IR}{L} = \frac{IP}{A}$

KA = constant

∴ The required graph is shown in the figure



14. In the figure a long uniform potentiometer wire AB is having a constant potential for the two primary cells of elf ε_1 and ε_2 connected in the manner shown are obtained at a distance of 120 cm and 300cm from the end A. find (i) $\varepsilon_1/\varepsilon_0$ and (ii)position of null point for the cell ε_1. .How is the sensitively of a potentiometer increased?



Sol. Let ϕ V cm^{-1} be potential gradient of the wire.

Applying Kirchhoff's loop rule to the closed loop ACA, we get

$\phi(120) = \varepsilon_1$ □ ε_2 …(i)

Again applying Kirchhoff's loop rule to the closed loop ADA, we get

$\phi(300) = \varepsilon_1 + \varepsilon_2$ …(ii)

$\frac{\varepsilon_1 - \varepsilon_2}{\varepsilon_1 + \varepsilon_2} = \frac{120}{300} = \frac{2}{5}$

$5\varepsilon_1 + 5\varepsilon_2 = 2\varepsilon_1 + 2\varepsilon_2$ or $3\varepsilon_1 = 7\varepsilon_2$

$\frac{\varepsilon_1}{\varepsilon_2} = \frac{7}{3}$ …(iii)

(ii) Le the position of null point for the cell ε_1 is I_3.

$\therefore \varepsilon_1 = \phi I_3$ …(iv)

Divide (i) by (iv) we get

$\frac{\varepsilon_1 - \varepsilon_2}{\varepsilon_1} = \frac{120}{l_3}$ or $1 - \frac{\varepsilon_2}{\varepsilon_1} = \frac{120}{l_3}$

$1 - \frac{3}{7} = \frac{120}{l_3}$ …(Using (iii))

$\frac{4}{7} = \frac{120}{l_3}$ or $l_3 = 210$cm

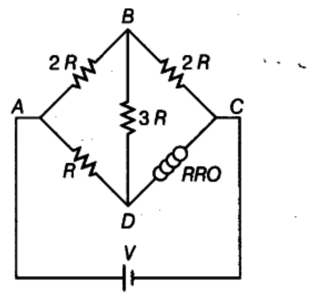
Sensitivity of a p[potentiometer is increased by increasing the length of the potentiometer wire.

15. What are the advantages of the null-point method in a Wheatstone bridge? What additional measurements would be required to calculate $R_{unknown}$ by any other method?

Sol. The advantage of null point method in a Wheatstone bridge is that the resistance of galvanometer does not affect the balance point and there is no need to determine current in resistances and galvanometer and the internal resistance of a galvanometer $R_{unknown}$ can be calculated applying Kirchhoff's rules to the circuit. We would need additional accurate measurement of all the currents in resistances and galvanometer and internal resistance of the galvanometer.

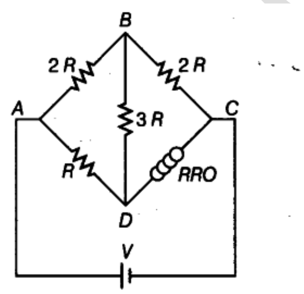
(5 Marks Questions)

16. Use Kirchhoff's rules to obtain the balance condition in a Wheatstone bridge. Calculate the value of R in the balance condition of the Wheatstone bridge. If the carbon resistor connected across the arm CD has the color sequence red, red and orange, as is shown in the figure.



If now the resistance of the arms BC and CD are interchanged, to obtain the balance condition, another carbon resistor is connected in place of R. What would now be the sequence of color bands of the carbon resistor.

Sol. Let the carbon resistor be S in the given Wheatstone bridge, we have



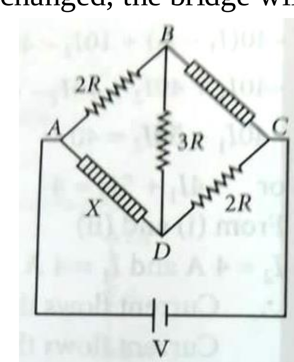
$\frac{2R}{R} = \frac{2R}{S}$

$\Rightarrow I = \frac{R}{S}$

$\Rightarrow$ R = S = resistance of carbon resistor.

$\therefore R = S = 22 \times 10^3\ \Omega = 22\ k\Omega$

When the resistance are interchanged, the bridge will be a balanced if

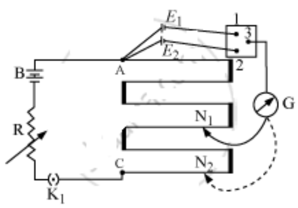


$\frac{2R}{X} = \frac{22\times10^3}{2\times22\times10^3} = \frac{1}{2}$

$\therefore X = 4R = 4 \times 22k\Omega = 88\ k\Omega$. Thus the sequence of colour will be grey, grey, orange.

17. (a) State the working principle of a potentiometer. Draw a circuit diagram to compare emf of two primary cells. Drive the formula used.
(b) Which material is used for potentiomer wire and why?
(c) How can the sensitivity of a potentiometer be increased ?

Sol. (a) Working principle of potentiometer: When a constant current is passed through a wire of uniform area of cross section, the potential drop across any portion of the wire is directly proportional to the length of that portion.



Application of potentiometer for comparing emfs of two cells: The given figure shows an application of the potentiometer to compare the emf of two cells of emf E_1 and E_2. E_1, E_2 are the emfs of the two cells and 1, 2, 3, from the two way key.

When 1 and 2 are connected, E is connected to the galvanometer (G).

Jokey is removed to N_1 which is at distance $I_1$from A, to find the balancing length.

Applying loop rule to AN_1G31A, $\phi I_1 + 0 - E_1 = 0$ …(i)

Where ϕ is teg potential drop per unit length. Similarly for E_2 balanced against $I_1(AN_2)$,

$\phi I_2 + 0 - E_2 = 0$ …(ii)

From equation (i) and (ii)

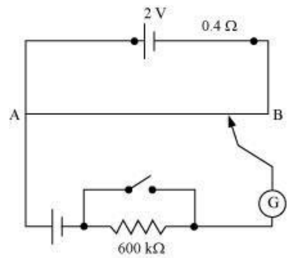
$E_1/E_2 = I_1/I_2$…(iii)

Thus we can compare the emfs of any two sources. Generally one of the cells is chosen as a standard cell whose emf is known to a high degree of accuracy. The emf of the other cell is then calculated from equation (iii).

(b) The potentiometer wire is made of an alloy, such as constantan or manganin. It is because an alloy has high resistivity and a low value of temperature coefficient of resistance.

(c) The sensitivity of a potentiometer can be increased by increasing the length of potentiometer wire which is responsible for decreasing the value of potential gradient.

18. Figure shows a potentiometer with a cell of 2.0 V and internal resistance 0.40 Ω maintaining a potential drop across the resistor wire AB. A standard cell which maintains a constant emf of 1.02 V (for very moderate currents up to a few mA) gives a balance point at 67.3 cm length of the wire. To ensure very low currents drawn from the standard cell, a very high resistance of 600 kΩ is put in series with it, which is shorted close to the balance point. The standard cell is then replaced by a cell of unknown emf ε and the balance point found similarly, turns out to be at 82.3 cm length of the wire.



(a) What is the value ε ?
(b) What purpose does the high resistance of 600 kΩ have?
(c) Is the balance point affected by this high resistance?
(d) Is the balance point affected by the internal resistance of the driver cell?
(e) Would the method work in the above situation if the driver cell of the potentiometer had an emf of 1.0 V instead of 2.0 V?
(f) Would the circuit work well for determining an extremely small emf, say of the order of a few mV (such as the typical emf of a thermo-couple)? If not, how will you modify the circuit?

F. HEATING EFFECT OF CURRENT

(1 Mark Questions)

1. An electric current of 4.0A flows through a 12Ω resistor. What is the rate at which the heat energy is produced in the resistor?

Sol. Here I = 4A, R = 12Ω
Rate of production of heat energy $P = I^2R = 4^2 \times 12 = 192W$.

2. A heating element is marked 210V, 630W. What is the current drawn by the element when connected to a 210V dc mains? What is eh resistance of the element? [Ans. 70Ω]

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(2 Marks Questions)

3. 100W, 220V bulb is connected to 110V source. Calculate the power consumed by the bulb.

Sol. Here P = 100W, V = 2220V

$\therefore$ Resistance of bulb, $R = \frac{V^2}{P} = \frac{220 \times 220}{100} = 484\Omega$

When the bulb is connected to 110V source, the power consumed by the bulb is

$P' = \frac{V'^2}{P} = \frac{100 \times 110}{484} = 25W$

4. A 100W and a 200 W domestic bulbs joined in series are connected to the mains. Which bulb will glow more brightly? Justify.

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(3 Marks Questions)

5. Two bulbs are marked 220V, 100W and 200V, 50W respectively. They are connected in series to 220V mains. Find the ratio of heats generated in them. [Ans. 1:2]

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6. Two bulbs rated 25W, 220V and 100W, 220V respectively connected in series to a 440V supply. (i) Show with necessary calculations which bulb will fuse (ii) What will happen if the two bulbs are connected in parallel to the same supply?

Sol. Currents required by the two bulbs for the normal glowness are $I_1 = \frac{P_1}{V} = \frac{25}{220} = 0.11A$

and $I_2 = \frac{P_2}{V} = \frac{100}{220} = 0.45A$

The resistances of the two bulbs are $R_1 = \frac{V}{I_1} = \frac{220}{0.11} = 2000\Omega$ and $R_2 = \frac{V}{I_2} = \frac{220}{0.45} = 490\Omega$

When the bulbs are connected ins series across the 440V supply, the current through each bulb will be $I = \frac{V}{R_1 + R_2} = \frac{440}{2000+490} = 0.17A$

As $I_1 < I$ and $I_2 > I$, so that 25W bulb will fuse while the 100W bulb will light up dim.
When the bulb are joined in parallel, their equivalent resistance is

$$R' = \frac{R_1R_2}{R_1+R_2} = \frac{2000\times490}{2000+490} = 394\Omega$$

Current drawn from the 440V supply will be $I' = \frac{V}{R'} = \frac{440}{394} = 1.11A$

In the two bulbs of resistance R_1 (= 2000Ω) and R_2 (= 490Ω) the current of 1.11A will split up into roughly 0.37A and 0.74A respectively. Hence both the bulbs will fuse.

(5 Marks Questions)

7. Two heating elements of resistances R_1 and R_2 when operated at a constant supply of voltage V, consume powers P_1 and P_2 respectively. Deduce the expressions for the power of their combination when they are in turn, connected in (i) series and (ii) parallel across the same voltage supply.

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G. CASE STUDY

1. Current density $\vec{j}$ gives the amount of charge flowing per second per unit area normal to the flow: $\vec{j} = nq\,\vec{v}_d$
where n is the number density (number per unit volume) of charge carriers each of charge q, and $\vec{v}_d$ is the drift velocity of the charge carriers. For electrons q = - e, if $\vec{j}$ is normal to a cross sectional area A and is constant over the area, the magnitude of the current I through area is (ne $\vec{v}_d$ A).

If a current I is flowing through a wire of non-uniform cross section, then current will remain constant at all cross sections. But drift velocity and current density are inversely proportional to cross section. This is because

$$I = neA|\vec{v}_d| \quad \text{or} \quad |\vec{v}_d| = \frac{I}{neA} \quad \text{or} \quad |\vec{v}_d| \propto \frac{1}{A}$$

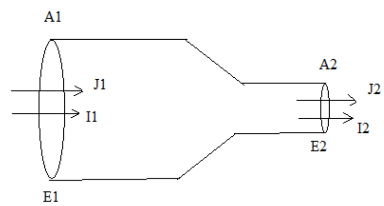
Further, $j = \frac{I}{A}$ or $j \propto \frac{1}{A}$

(i) Drift speed of the electrons when 1A current exists in a copper wire of cross section $2mm^2$. (No. of free electrons in $1cm^3$ of copper is 8.5×10^{22}).

(a) 4.6×10^{-6}m/s (b) 3.6×10^{-5}m/s (c) 8.2×10^{-5}m/s (d) 9.5×10^{-3}m/s

Ans. (b)

(ii) Diagram shows a conductor having variable cross section



I_1, J_1 and I_2, J_2 are the values of electric current and current densities at cross section A_1 and A_2 respectively, then

(a) $I_1>I_2$ (b) $J_1>J_2$ (c) $J_1<J_2$ (d) $J_1 = J_2$

Ans. (c)

(iii) V_{d_1} and V_{d_2} are the drift velocities at cross section A_1 and A_2 respectively then

(a) $V_{d_1}=V_{d_2}$ (b) $V_{d_1}>V_{d_2}$ (c) $V_{d_1}<V_{d_2}$ (d) none

Ans. (c)

2. Kirchhoff's Rule:

(a) First rule (Junction rule): At any junction of circuit elements, the sum of currents entering the junction must equal the sum of currents leaving it.

(b) Second rule (Loop rule): The algebraic sum of changes in potential around any closed loop must be zero.

(i) Junction rule follows conservation of

(a) Energy (b) Charge (c) Linear momentum (d) none

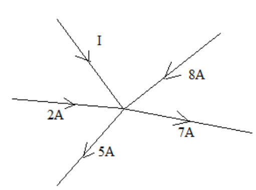
Ans. (b)

(ii) Loop rule follows , conservation of

(a) Energy (b) Charge (c) Linear momentum (d) none

Ans. (a)

(iii) Value of I in the given diagram will be



(a) 2A (b) 3A (c) 4A (d) 5A

Ans. (a)

H. ASSERTION REASON TYPE QUESTIONS:

(a) If both assertion and reason are true and reason is the correct explanation of assertion.
(b) If both assertion and reason are true but reason is not the correct explanation of assertion.
(c) If assertion is true but reason is false **(d) If both assertion and reason are false**
(e) If assertion is false but reason is true.

1. Assertion: Insulator do not allow flow of current through them.
Reason: Insulator have no free charge carrier.

Ans. (a) Both assertion and reason are true and reason is the correct explanation of assertion
Since current arises due to continuous flow of charged particles. There is no free charge in insulator hence no flow of charges are possible. Therefore current do not low through insulators.

2. Assertion: The average thermal velocity of the electrons in a conductor is zero.
Reason: Direction of motion of electrons are randomly oriented.
(a) Both assertion and reason are true and reason is the correct explanation of assertion
In normal conductor, the direction of electrons are randomly oriented such that the total sum of their velocities is equal to zero.

3. Assertion: material used in the construction of a standard resistance is constantan or manganin.
Reason: Temperature coefficient of constantan is very small.
(a) Both assertion and reason are true and reason is the correct explanation of assertion
These alloys (constantan or manganin) are used for making standard resistance because they possess high resistivity and low temperature coefficient of resistance.

4. Assertion: Current is passed through a metallic wire, heating it red. Half of its portion is cooled (by cold water jacket) then rest of the half portion becomes more hot.
Reason: Resistance decreases due to decrease in temperature and so current through wire increases.
(a) Both assertion and reason are true and reason is the correct explanation of assertion
When half the portion of the wire is cooled, its resistance decreases due to decrease in temperature. As a result of this total resistance of circuit decrease i.e. current through each portion of wire increases i.e. rise of the half portion becomes still more hot.

5. Assertion: Though the same current flows through the line wires and the filament of the bulb but heat produced in the filament is much higher than that in line wires.
Reason: The filament of bulbs is made of a material of high resistance and high melting point.
(b) Both assertion and reason are true but reason is not the correct explanation of assertion.
As filament of bulb and line wire are in series, hence current through both is same. Now, because $H = i^2Rt/4.2$ and resistance of the filament of the bulb is much higher than that of line wires, hence heat produced in the filament is much higher than that in line wires.

6. Assertion: Voltage is not proportional to current in the case of non-ohmic devices.
Reason: Voltage is equal to product of resistance and current as per Ohm's law
(b) Both assertion and reason are true but reason is not the correct explanation of assertion.

For non-ohmic devices resistance is not a constant or voltage does not vary linearly with the current. Thus Ohm's law is not obeyed by such devices.

I. CHALLENGING PROBLEMS

1. Answer the following questions:

(a) A steady current flows in a metallic conductor of non-uniform cross- section. Which of these quantities is constant along the conductor: current, current density, electric field, drift speed?

(b) Is Ohm's law universally applicable for all conducting elements?
If not, give examples of elements which do not obey Ohm's law.

(c) A low voltage supply from which one needs high currents must have very low internal resistance. Why?

(d) A high tension (HT) supply of, say, 6 kV must have a very large internal resistance. Why?

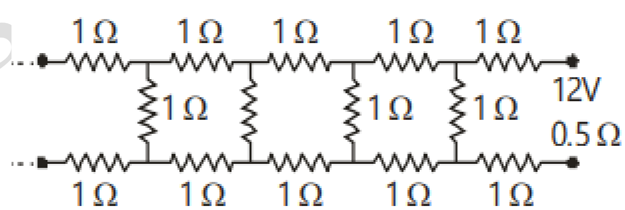
Sol. (a) Only current is constant because it is given to be steady. Other quantities : current density, electric field and drift speed vary inversely with area of cross section.

(b) No, Ohm's law is not universally applicable for al conducting elements. Examples of non-ohmic elements are vacuum diode, semiconductor diode, thyristor, gas discharge tube, electrolytic solution, etc.

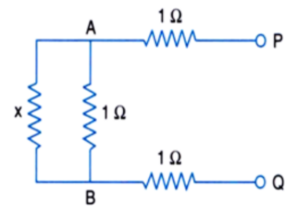
(c) The maximum current that can be drawn from a voltage supply is given by
$I_{max} = \frac{\varepsilon}{r}$. Clearly I_{max} will be large if r is small.

(f) If the internal resistance is not very large, then the current will exceed the safety limits in case the circuit is short circuited accidently.

2. Determine the current drawn from a 12V supply with internal resistance 0.5Ω by the following infinite network. Each resistor has 1Ω resistance.



Sol. Let the equivalent resistance of the infinite network be X. The network consists of infinite units of three resistors 1Ω, 1Ω, 1Ω. The addition of one more such unit across AB will not affect the total resistance. The network obtained by adding one more unit would appear as shown in figure.



Resistance between A and B = resistance equivalent to parallel combination of X and 1Ω

$= \frac{X \times 1}{X+1} = \frac{X}{X+1}$

Resistance between P and Q = $1 + \frac{X}{X+1} + 1 = 2 + \frac{X}{X+1}$

This must be equal to the original resistance X.

$X = 2 + \frac{X}{1+X}$

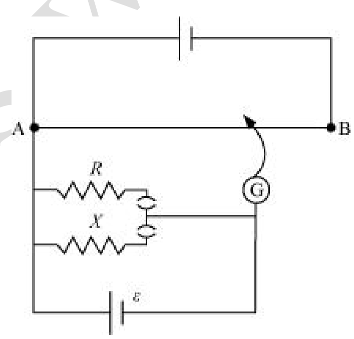
Or $X^2 - 2X - 2 = 0$

Or $X = 1 \pm \sqrt{3}$

As the value of resistance cannot be negative, so $X = 1 + \sqrt{3} = 2.732\Omega$

Current, $I = \frac{\text{emf}}{\text{Total resistance}} = \frac{\varepsilon}{X+r} = \frac{12}{2.732+0.5} = 3.713A$

3. Figure shows a potentiometer circuit for a comparison of two resistances. The balance point with a standard resistor R = 100Ω is found to be 58.3cm, while that with the unknown resistance X is 68.5cm. Determine the value of X. What might you do if you failed a balance point with the given cell ε?



Sol. Here R = 10.0Ω, l_1 = 58.3cm, l_2 = 68.5cm. Let ε_1 and ε_2 be the potential drops across R and X respectively and I be the current in potentiometer wire.

Then, $\frac{\varepsilon_1}{\varepsilon_2} = \frac{IX}{IR} = \frac{X}{R}$

But $\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_2}{l_1}$ $\quad\therefore \frac{X}{R} = \frac{l_2}{l_1}$

Or $X = \frac{l_2}{l_1}.R = \frac{6805}{58.3} \times 10 = 11.75\Omega$

If there is no balance point, it means potential drops across R or X are greater than the potential drop across the potentiometer wire AB. We should deduce current in the outside circuit (and hence potential drops across R and X) suitably by putting a series resistor.

SPACE FOR ROUGH WORK

SPACE FOR NOTES