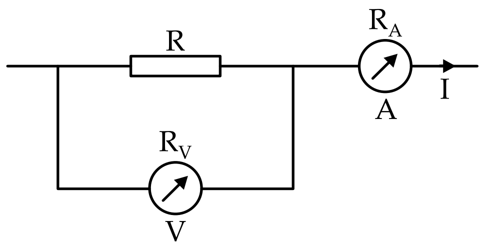
CURRENT ELECTRICITY

Note: (*) → Multiple Correct Type Question

1. Let V and I be the readings of the voltmeter and the ammeter respectively as shown in the figure. Let R_V and R_A be their corresponding resistance Therefore, **[NSEP-2017]**



(A) $R = \frac{V}{I}$ (B) $R = \frac{V}{I - \left(\frac{V}{R_v}\right)}$ (C) $R = R_V - R_A$ (D) $R = \frac{V(R + R_A)}{IR_A}$

Ans. (B)

Sol. $\frac{RR_v}{R + R_v} \cdot I = V$

$$\frac{RR_v}{R + R_v} = \frac{V}{I} \Rightarrow \frac{I}{V} = \frac{1}{R} + \frac{1}{R_v} \Rightarrow \frac{I}{v} - \frac{1}{R_v} = \frac{1}{R} \Rightarrow R = \frac{1}{\frac{I}{V} - \frac{1}{R_v}} = \frac{V}{I - \frac{v}{R_v}}$$

2. Two cells each of emf E and internal resistance r_1 and r_2 respectively are connected in series with an external resistance R. The potential difference between the terminals of the first cell will be zero when R is equal to **[NSEP-2017]**

(A) $\frac{r_1 + r_2}{2}$ (B) $\sqrt{r_1^2 - r_2^2}$ (C) $r_1 - r_2$ (D) $\frac{r_1 r_2}{r_1 + r_2}$

Ans. (C)

Sol. $\varepsilon_1 - \left\{\frac{\varepsilon_1 + \varepsilon_2}{r_1 + r_2 + R}\right\} r_1 = 0$

$r_1 + r_2 + R = 2r_1 \Rightarrow R = r_1 - r_2$

Group of question Nos 3 to 7 are based on the following paragraph and its subsequent continuation of after some question. The following question are concerned with experiments of the characterization and use of a moving coil galvanometer. The series combination of variable resistance R, one 100Ω resistor and moving coil galvanometer is connected to a mobile phone charger having negligible internal resistance. The zero of the galvanometer lies at the centre and the pointer can move 30 division full scale on either side depending on the direction of current. The reading of the galvanometer is 10 divisions and the voltages across the galvanometer and 100Ω resistor are respectively 12 mV and 16 mV. **[NSEP-2017]**

3. The figure of merit of the galvanometer is microampere per division is :

(A) 16 (B) 20 (C) 32 (D) 10

Ans. (A)

4. The resistance of the galvanometer in ohm is :

(A) 50Ω (B) 75Ω (C) 100Ω (D) 80Ω

The series combination of the galvanometer with a resistance of R is connected across an ideal voltage supply of 12 V and this time the galvanometer shows full scale deflection of 30 divisions.

Ans. (B)

5. The value of R is nearly

(A) $12.5k\Omega$ (B) $25\ K\Omega$ (C) $75k\Omega$ (D) $100k\Omega$

Ans. (B)

6. A 24Ω resistance is connected to a 5 V battery with internal resistance of 1Ω. A $25k\Omega$ resistance is connected in series with the galvanometer and this combination is used to measure the voltage across the 24Ω resistance. The number of divisions shown in the galvanometer is

(A) 6 (B) 8 (C) 10 (D) 12

Ans. (D)

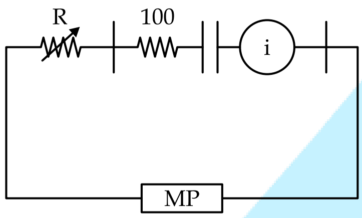
7. Now a $1000\mu\ F$ capacitor is charged using the 12 V supply and is discharged through the galvanometer-resistance combination used in the previous question. The current i (in ampere) at different time t (in second) are recorded. A graph of (In i) against (t) is plotted. The slope of the graph is

(A) $-0.02\ s^{-1}$ (B) $-0.01\ s^{-1}$ (C) $-0.04\ s^{-1}$ (D) $+0.04\ s^{-1}$

Ans. (C)

Sol. 3 to 7

Case-1



$10i_0G = 12\times10^{-3}$ $10i_0(100) = 16\times10^{-3} \Rightarrow 10^3 i_0 = 16\times10^{-3} \Rightarrow i_0 = 16\times10^{-6}$ A $\frac{G}{100} = \frac{3}{4} \Rightarrow G = 75\Omega$

Case-2

$30i_0(R+G) = 12$ $R+G = \frac{12}{30i_0} = \frac{2}{5\times16\times10^{-6}} = \frac{2\times10^6}{80} = 2.5\times10^4\Omega = 25k\Omega$ $R = 25k\Omega - 75\Omega$

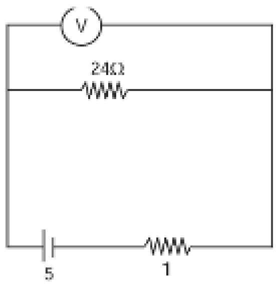
Case-3

$30i_0(R+G) = 12$

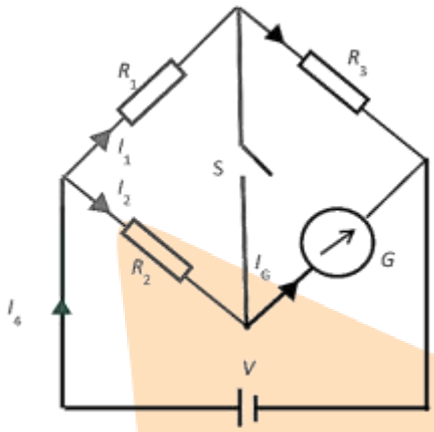
$ni._0(R+G) = \left(\frac{5}{25}\right)24$

$n = 12$ $i = i_0 e^{-t/r\tau}$ $\ell ni = \ell ni_0 - t/\tau$

$$\text{slope} = -\frac{1}{e} = -\frac{1}{(25\times10^3)(10^{-3})} = -\frac{1}{25} = -0.04\text{sec}^{-1}$$

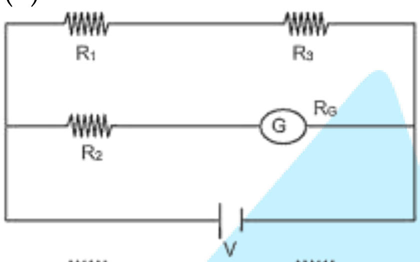


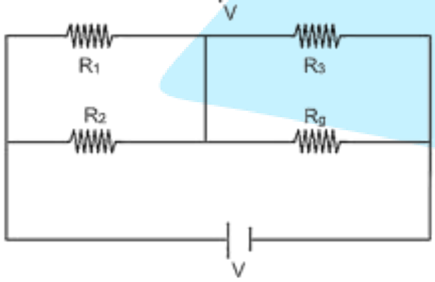
8. In the circuit shown $R_1 \neq R_2$. The reading in the galvanometer is the same with switch S open or closed. Then, **[NSEP-2018]**



(A) $I_1 = I_G$ (B) $I_2 = I_G$ (C) $I_3 = I_G$ (D) $I_4 = I_G$

Ans. (B)





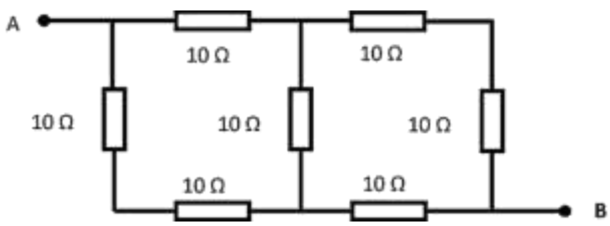
Sol.

$I_2 = I_G$

Circuit behaving a_0

Balanced Wheatstone network

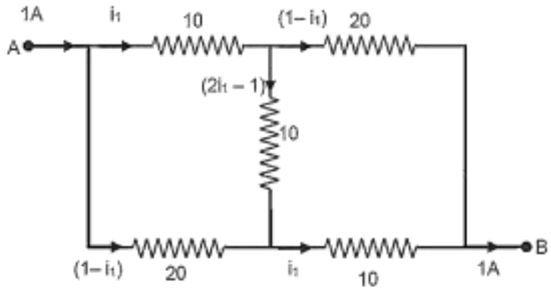
9. The effective resistance between points A and B in the circuit arrangement shown below is **[NSEP-2018]**



(A) 14Ω. (B) 15Ω. (C) 30Ω. (D) none of the above.

Ans. (A)

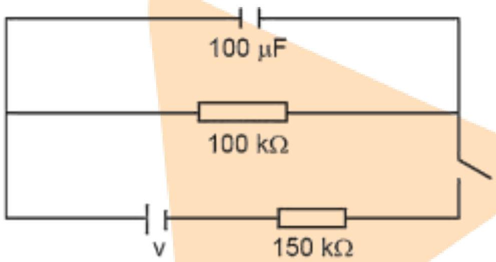
Sol.



KVL: $10i_1+(2i_1-1)\times10-20(1-i_1)=0$

$\Rightarrow 50i_1=30 \Rightarrow i_1=3/5 \therefore R_{eq}=\frac{V_{AB}}{I_{AB}}=\frac{10i_1+20(1-i_1)}{1A} -10\times\frac{3}{5}+20\times\frac{2}{5}=14\Omega$

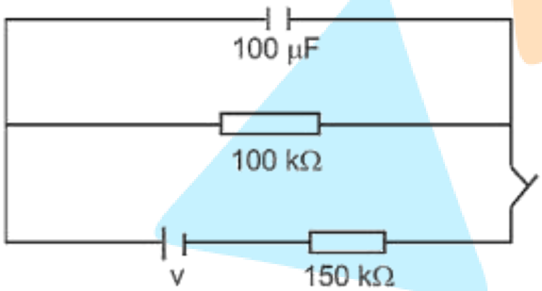
10. The switch S in the circuit shown is closed for a long time and then opened at time $t=0$. The current in the $100k\Omega$ resistance at $t=3\,s$ is **[NSEP-2018]**



(A) Zero (B) 48μ A (C) 35.5μ A (D) 16μ A

Ans. (Bonus)

Sol.

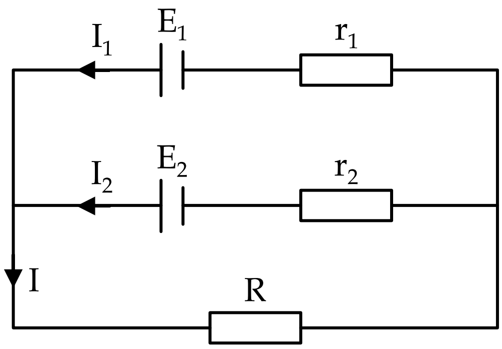


After very long time

$V_c=\frac{2v}{5} \Rightarrow Q_c=\left(\frac{2v}{5}\times100\right)\mu c=(40v)\mu c$ $\frac{V_{100k\Omega}}{V_{150k\Omega}}=\frac{100}{150}=\frac{2}{3}$ Now from $t=0$ discharging of capacitor will start time constant of discharging

$=RC=100\times10^3\times100\times10^{-6}=100sec$ $V=v_0e^{-t/RC} \Rightarrow v'=\frac{2v}{5}e^{-t/10} \Rightarrow q=cv'$ $i=\frac{-dq}{dt}$

***11.** In the circuit arrangement shown two cells supply a current I to a load resistance R = 9Ω. One cell has an emf $E_1=9\text{ V}$ and internal resistance $r_1=1\Omega$ and the other cell has an emf $E_2=6\text{ V}$ and internal resistance $r_2=3\Omega$. The currents are as shown. Then, **[NSEP-2018]**



(A) $I_1 = 0.9$ A and $I_2 = 0.5$ A.

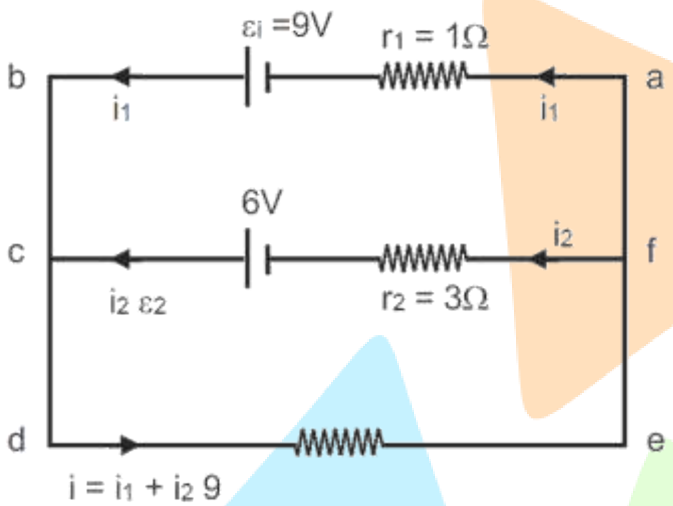
(B) I $\cong 0.85$ A

(C) if the cell of emf E_1 is removed, current I will be smaller.

(D) if the cell of emf E_2 is removed, current I will be smaller.

Ans. (B, D)

Sol.



$$\varepsilon = \frac{\frac{9}{1}+\frac{6}{3}}{\frac{1}{1}+\frac{1}{3}} = \frac{11\times3}{4} = \frac{33}{4} \vee \ r = \frac{3}{4}\Omega \ i = i_1 + i_2 = \frac{33/4}{9+\frac{3}{4}} = \frac{33}{39} \text{ A}$$

KVL in abcdefa

$$9-(i_1+i_2)9-i_1=0$$

$$\Rightarrow 10i_1+9i_2=9\#(ii)$$

KVL uin Fcdefc

$$6-(i_1+i_2)9-i_23=0$$

$$\Rightarrow 9i_1+12i_2=6$$

$$\Rightarrow 3i_1+4i_2=3 \quad \ldots (i)$$

$$\begin{aligned} 10i_1+9i_2&=9 \quad \ldots.(i) \quad \times3 \\ 3i_1+4i_2&=2 \quad \ldots (ii) \quad \times10 \end{aligned} \#(ii)$$

$$0-13i_2=7$$

$$I_2 = -\frac{7}{13}$$

From (ii)

$$i_1 = \frac{2+4\times\frac{7}{13}}{3} = \frac{54}{39}\ \text{A}$$

$$i = i_1 + i_2 = \frac{56}{35} - \frac{7}{13} = \frac{56-21}{39} = \frac{33}{39}\text{A} = 0.846\text{A} = 0.85\text{A}$$

if $E_1 =$ removed

$$i = \frac{6}{13} = \frac{1}{2}\text{A i decreases}$$

if E_2 removed

$$\frac{i=9}{10} = 0.9\ \text{A i Increases}$$

12. If a cell of constant emf produces the same amount of heat during the same time in two independent resistors R_1 and R_2 when they are separately connected across the terminals of the cell, one after the other. The internal resistance of the cell is: **[NSEP-2019]**

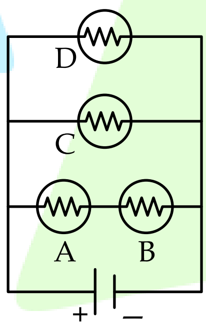
(A) $\frac{R_1+R_2}{2}$ (B) $\frac{R_1 \sim R_2}{2}$ (C) $\frac{\sqrt{R_1^2+R_2^2}}{2}$ (D) $\sqrt{R_1R_2}$

Ans. (D)

Sol. $$\frac{\varepsilon^2}{(r+R_1)}R_1 = \frac{\varepsilon^2}{(r+R_2)^2}R_2$$

On solving $r = \sqrt{R_1R_2}$

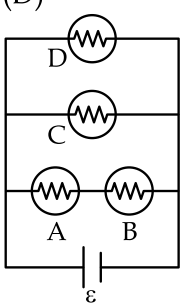
13. Identify the rank in order from the dimmest to the brightest when all the identical bulbs are connected in the circuit as shown below. **[NSEP-2019]**



(A) A = B > C = D (B) A = B = C = D
(C) A > C > B > D (D) A = B < C = D

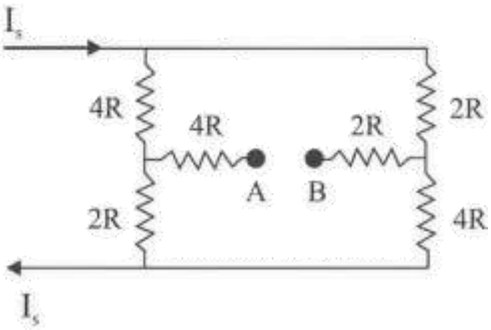
Ans. (D)

Sol.



$V_D = V_C = \varepsilon \quad V_A = V_B = \frac{\varepsilon}{2} \quad P_C = P_D > P_A = P_B$

14. In the circuit shown if an ideal ammeter is connected between A and B then the direction of current and the current reading would be (assume I remains unchanged) **[NSEP-2019]**

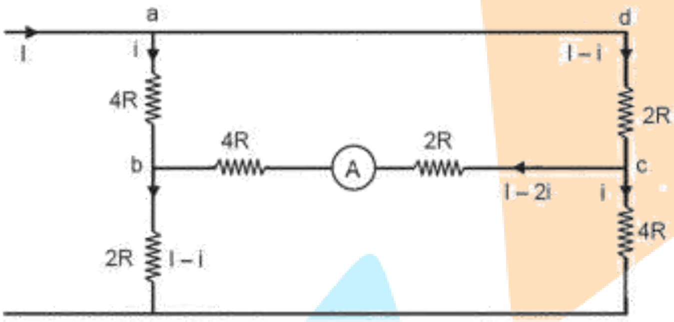


(A) B to A and $I_s / 2$ (B) A to B and Is/4

(C) B to A and I $I/9$ (D) B to A and I $s/3$

Ans. (C)

Sol.



KVL in lets abcda

$-i4R + (I - 2i)6R + (I - i)2R = 0 \; -2i + 3i - 6i + (i - i) = 0 \Rightarrow 4I = 9i \Rightarrow i = \frac{4}{9}I$

$\therefore$ current through ammeter $= 1 - 2i = 1 - \frac{8}{9}I = \frac{1}{9}$

15. In an experiment with potentiometer, the balancing length is 250 cm for a cell. When the cell is shunted by a resistance of 7.5Ω, balancing point is shifted by 25 cm. If the cell is shunted by a resistance of 20Ω, the balancing length will be nearly **[NSEP-2020]**

(A) 240 cm (B) 236 cm (C) 232 cm (D) 230 cm

Ans. (A)

Sol. The internal resistance 'r' of a cell is measured by a potentiometer as

$r = \left(\frac{L}{L_1} - 1\right)R_1 = \left(\frac{L}{L_2} - 1\right)R_2$, where L is the balancing length when cell is in open circuit and L_1 when the cell is shunted by resistance R_1 and L_2 when cell is shunted by resistance R_2. Given that $L = 250\text{ cm}, R_1 = 7.5\Omega,\ L_1 = 250 - 25 = 225\text{ cm}, R_2 = 20\Omega$, This gives $L_2 = 240\text{ cm}$

16. A simple circuit consists of a known resistance $R_A = 2M\Omega$ and an unknown resistance R_B both in series with a battery of 9 volt and negligible internal resistance. When the voltmeter is connected across the resistance R_A, it measures 3 volt but when the same voltmeter is connected across R_B it reads 4.5 volt. The voltmeter measures 9 V across the battery. Considering that the voltmeter has a finite resistance r, the correct option is **[NSEP-2021]**

(A) $R_B = 3M\Omega$ and $r = 6.0M\Omega$ (B) $R_B = 2.5M\Omega$ and $r = 6.0M\Omega$

(C) $R_B = 4M\Omega$ and $r = 12M\Omega$ (D) $R_B = 4.5M\Omega$ and $r = 6.0M\Omega$

Ans. (A)

Sol. The $2.0M\Omega$ resistance is connected in series with R_B and the cell. When we connect the voltmeter of resistance rM Ω in parallel to $2.0M\Omega$ we get

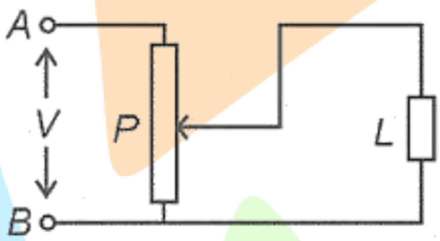
$3 = \dfrac{9}{\dfrac{2r}{r+2} + R_B} \times \dfrac{2r}{r+2} \Rightarrow 2r + R_B(r+2) = 6r \Rightarrow R_B = \dfrac{4r}{r+2}$ When we connect the same voltmeter in parallel with R_B we get

$4.5 = \dfrac{9}{2 + \dfrac{rR_B}{r+R_B}} \times \dfrac{rR_B}{r+R_B} \Rightarrow 2(r+R_B) + rR_B = 2rR_B \Rightarrow R_B = \dfrac{2r}{r-2}$ Comparing the result

$\dfrac{4r}{r+2} = \dfrac{2r}{r-2} \Rightarrow r = 6$ Thus

$r = 6M\Omega$ and $R_B = 3M\Omega$

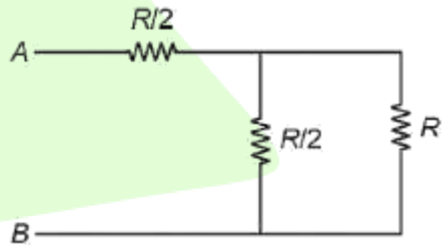
17. Voltage across the load L is controlled by using circuit as shown in figure. P is a potentiometer. Resistance R_L of the load and R_P of the potentiometer are equal to R. Load L is connected to the middle of potentiometer. Input voltage V is constant. If now R_L is doubled, the voltage across load will change by a factor **[NSEP-2022]**



(A) $\frac{5}{4}$ (B) $\frac{8}{9}$ (C) $\frac{7}{4}$ (D) $\frac{10}{9}$

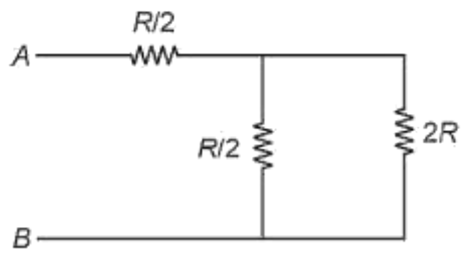
Ans. (D)

Sol. Initial :



Parallel combination $= \dfrac{R \cdot \dfrac{R}{2}}{\dfrac{3R}{2}} = \dfrac{R}{3}$

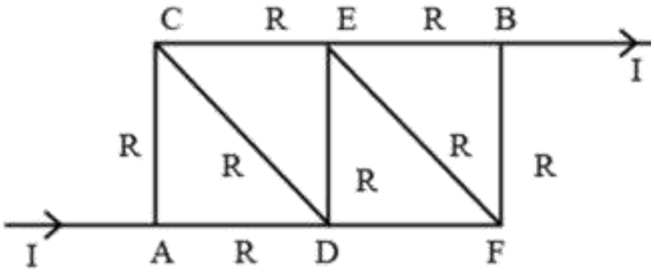
$\Rightarrow V_L = \dfrac{\dfrac{R}{3}}{\dfrac{R}{2} + \dfrac{R}{3}} V = \dfrac{2}{5} V$ Final



Parallel $= \dfrac{\dfrac{R}{2} \cdot 2R}{\dfrac{5R}{2}} = \dfrac{2R}{5}$

$\Rightarrow V_L = \dfrac{\dfrac{2R}{5}}{\dfrac{2R}{5} + \dfrac{R}{2}} V = \dfrac{4V}{9} \Rightarrow \dfrac{4/9}{2/5} = 10/9$

*18. Each of 9 sides of frame ACDEFB has resistance R (Nine in all) A current enters at A and leaves at B. Choose the correct alternatives. **[NSEP-2022]**



(A) Currents in branches CD and EF are zero.

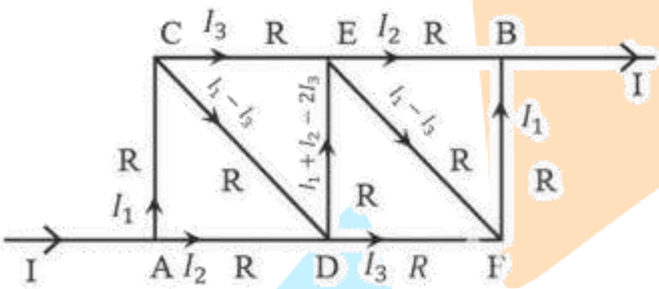
(B) Currents in branches CE and DF are each equal to $\frac{4}{11}$ I

(C) Effective resistance between A and B is $\frac{15}{11}$R

(D) Effective resistance between A and B is $\frac{3}{4}$R

Ans. (B, C)

Sol.



Based on the Input Output symmetry, the current distribution is shown in the figure.

$V_A - V_B = V_A - V_C + V_C - V_E + V_E - V_B$

$V = I_1R + I_3R + I_2R$

$\Rightarrow I_1 + I_2 + I_3 = \frac{V}{R}$ … (i)

$V_A - V_B = V_A - V_D + V_D - V_E + V_E - V_B$ $V = I_2R + (I_1 + I_2 - 2I_3)R + I_2R$

$I_1 + 3I_2 - 2I_3 = \frac{V}{R}$ … (ii)

$V_A - V_B = V_A - V_C + V_C - V_D + V_D - V_F + V_F + V_F - V_B$ $V = I_1R + (I_1 - I_3)R + I_3R + I_1R$

$V = 3I_1R$

$I_1 = \frac{V}{3R}$ … (iii)

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

$I_1 = \frac{V}{3R}$ $I_2 = \frac{2V}{5R}$ $I_3 = \frac{4V}{15R}$ $R_{eq} = \frac{V}{I} = \frac{V}{I_1 + I_2} = \frac{15R}{11}$ Current through CD and

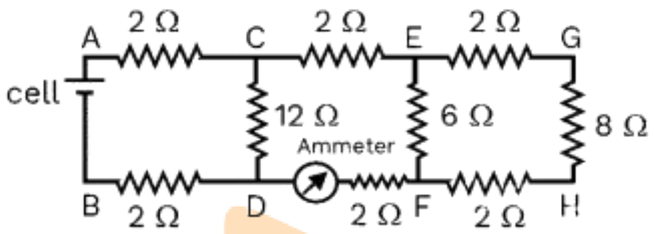
$EF = I_1 - I_3 = \frac{V}{3R} - \frac{4V}{15R} = \frac{V}{15R}$

Current through CE and DF = $I_3 = \frac{4\ V}{15R}$

$I = I_1 + I_2 = \frac{11V}{15R}\ I_3 = \frac{41}{11}$ Correct option (B), (C)

***19.** In the circuit shown, the current in the 8Ω resistance across G and H is $i = 0.5$ ampere. The ammeter is ideal. The internal resistance of the cell is 0.8Ω. Choose correct option(s).

[NSEP-2023]



(A) Reading of the ammeter is 1.5 ampere

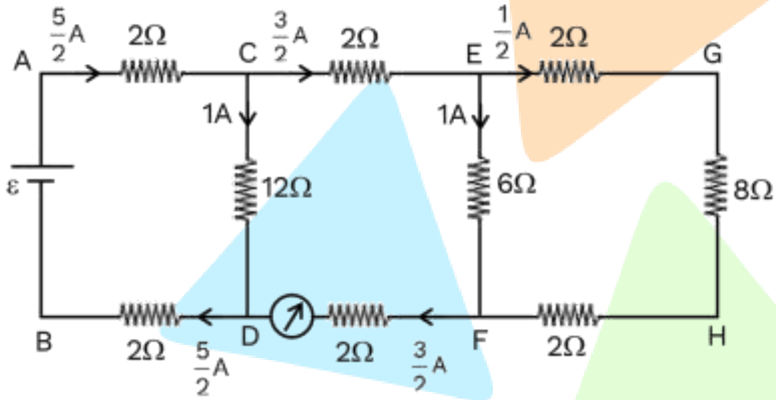
(B) Potential difference across A and H is 13 V

(C) Potential difference across C and F is 9 V

(D) The emf of the cell is 24 V

Ans. (A, B, C, D)

Sol.



(A) $i_A = 1.5\ A$

(B) $\Delta V_{AH} = \frac{5}{2}(2) + \frac{3}{2}(2) + \frac{1}{2}(2+8)$

$= 5 + 3 + 5 = 13V$

(C) $\Delta V_{CF} = \frac{3}{2}(2) + 1(6) = 9\ V$

(D) Applying KVL in left loop

$\varepsilon - \frac{5}{2}(2) - 1(12) - \frac{5}{2}(2) - \frac{5}{2}(0.8) = 0\ \ \varepsilon = 24\ V$

CAPACITOR

1. Consider a parallel plate capacitor. When half of the space between the plates is filled with some dielectric material of dielectric constant K as shown in Fig. (1) below, the capacitance is C_1. However, if the same dielectric material fills half the space as shown in Fig. (2), the capacitance is C_2. Therefore, the ratio $C_1 : C_2$ is **[NSEP-2017]**

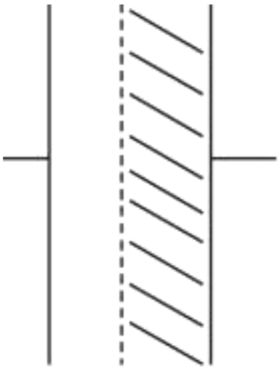


Fig. (1)

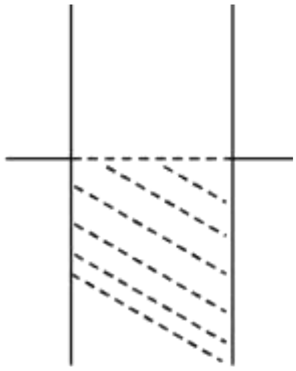


Fig. (2)

(A) 1 (B) $\frac{2K}{K+1}$ (C) $\frac{4K}{(K+1)^2}$ (D) $\frac{K+1}{2}$

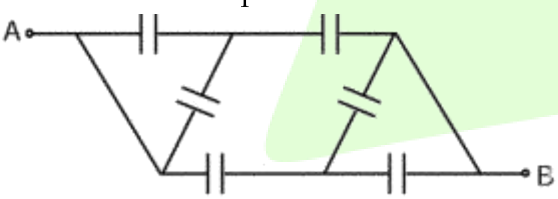
Ans. (C)

Sol. $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$

$$\frac{1}{\frac{A\varepsilon_0}{\frac{d}{2}}} + \frac{1}{\frac{KA\varepsilon_0}{\frac{d}{2}}} = \frac{d}{2A\varepsilon_0} + \frac{d}{2KA\varepsilon_0} \quad \frac{1}{C_{eq}} = \frac{d}{2A\varepsilon_0}\left(\frac{K+1}{K}\right) \quad C_{eq} = \frac{2KA\varepsilon_0}{d(K+1)}$$

$$\frac{C_{eq}}{C'_{eq}} = \frac{2KA\varepsilon_0}{d(K+1)} \cdot \frac{2d}{A\varepsilon_0 (K+1)} = \frac{4K}{(K+1)^2}$$

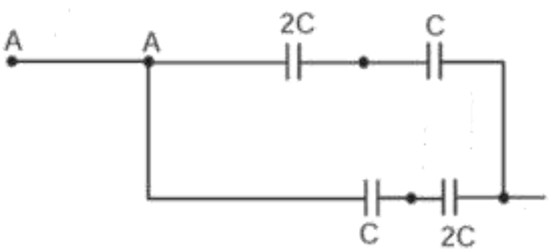
2. A network of six identical capacitors, each of capacitance C is formed as shown below. The equivalent capacitance between the point A and B is **[NSEP-2017]**



(A) 3 C (B) 6 C (C) $3C/2$ (D) $4C/3$

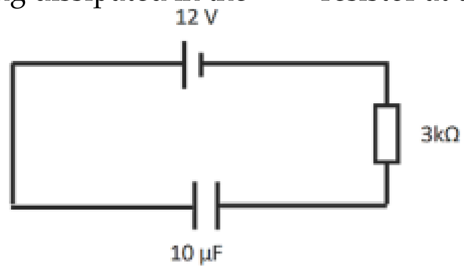
Ans. (D)

Sol. Rearrange the circuit



$$C_{eq} = \frac{2C}{3} \times 2$$

3. The capacitor in the circuit shown below carries a charge of $30\mu C$ at a certain time instant. The rate at which energy is being dissipated in the $3k\Omega$ resistor at that instant is **[NSEP-2018]**



(A) 4 mW (B) 9 mW (C) 27 mW (D) 48 mW

Ans. (C)

Sol. $q = c\varepsilon\left(1-e^{-t/\tau}\right)$

$i = \frac{\varepsilon}{R}e^{-t/\tau}$ $P = i^2R$

$P = \frac{\varepsilon^2}{R}e^{-2t/\tau}...(1)$

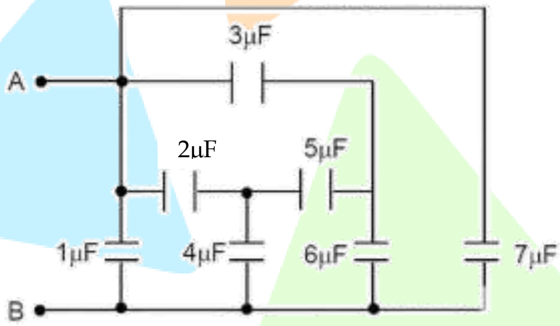
$30 = 120\left(1-e^{-t/\tau}\right)$

$e^{-t/t} = \frac{3}{4}...(2)$

From (1) & (2)

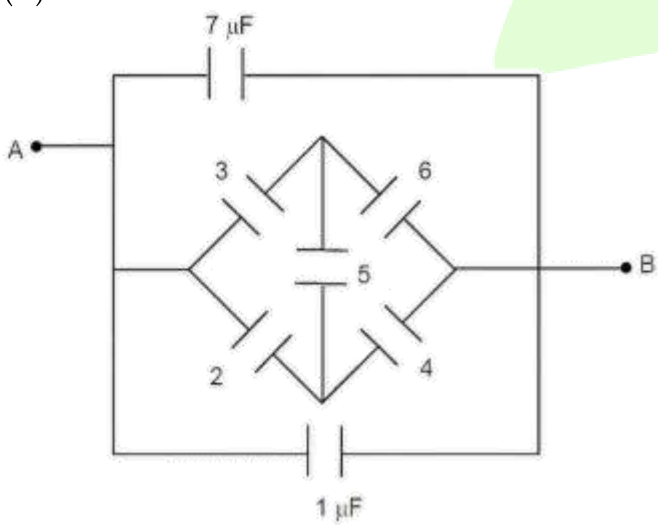
$P = \frac{144}{3000}\times\frac{9}{4} = 27mw$

4. The total capacitance between points A and B in the arrangement shown below is **[NSEP-2018]**



(A) 28μ F (B) $\frac{34}{7}\mu$ F (C) 23μ F (D) $\frac{34}{3}\mu$ F

Ans. (D)



Sol.

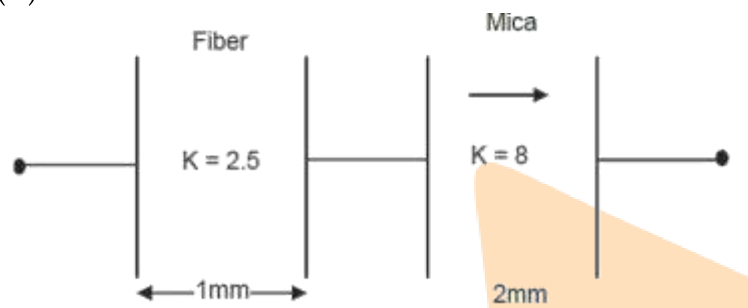
Note : - Middle Network is Balanced Wheatstone network

$$C_{eq} = 7+1+\left(2+\frac{4}{3}\right) = 10+\frac{4}{3} = \frac{34}{3}\mu\ F$$

5. A fiber sheet of thickness 1 mm and a mica sheet of thickness 2 mm are introduced between two metallic parallel plates to form a capacitor. Given that the dielectric strength of fiber is $6400\text{kV}/\text{m}$ and the dielectric constants of fiber and mica are 2.5 and 8 respectively, the electric field inside the mica sheet just at the breakdown of fiber will be **[NSEP-2018]**

(A) $2000\text{kV}/\text{m}$ (B) $2048\text{kV}/\text{m}$ (C) $3200\text{kV}/\text{m}$ (D) $6400\text{kV}/\text{m}$

Ans. (A)

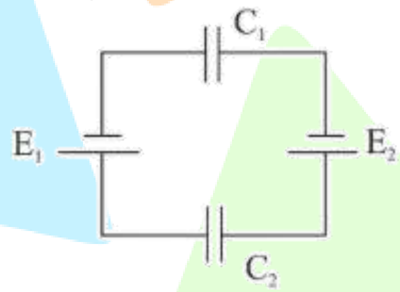


Sol.

$$E_1\ d_1 = V_1 = \frac{Q}{C_1} = \frac{Qd_1}{\varepsilon_0 AK_1}\ E_2\ d_2 = \frac{Q}{C_2} = \frac{Qd_2}{\varepsilon_0 AK_2} \Rightarrow \frac{E_1}{E_2} = \frac{K_2}{K} \Rightarrow E_2 = \frac{K_2}{K_1} \Rightarrow E_2 = \frac{K_1}{K_2}E_{1_{max}}$$

$$= \frac{5/2}{8}\times 6400\text{kv}/\text{m} = 2000\text{kV}/\text{m}$$

6. In the circuit shown beside the charge on each capacitor is **[NSEP-2019]**

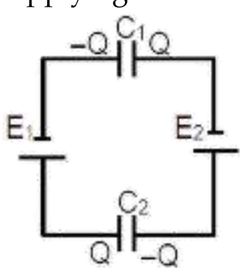


(A) $(C_1+C_2)(E_1-E_2)$ (B) $\frac{C_1C_2}{C_1+C_2}(E_1+E_2)$

(C) $\frac{C_1C_2}{C_1+C_2}(E_1-E_2)$ (D) $(C_1-C_2)(E_1+E_2)$

Ans. (C)

Sol. Applying KVL in the circuit



$$+E_1 - Q/C_2 - E_2 - Q/C_1 = 0\ \frac{Q}{C_1}+\frac{Q}{C_2} = E_1 - E_2\ Q = \frac{C_1C_2}{C_1+C_2}(E_1-E_2)$$

*7. A parallel plate capacitor of plate area A and plate separation d is charged to potential V. Then the battery is disconnected. A slab of dielectric constant k is then inserted between the plates of the capacitor so as to fill the space between the plates completely. If Q, E and W denote respectively, the magnitude of charge on each plate, the electric field between the plates (after the slab is inserted) and work done on the system, in question, in the process of inserting the slab, then **[NSEP-2020]**

(A) $Q = k\varepsilon_0 AE$ (B) $Q = \frac{\varepsilon_0 kAV}{d}$ (C) $E = \frac{V}{kd}$ (D) $W = \frac{\varepsilon_0 AV^2}{2d}\left(1 - \frac{1}{k}\right)$

Ans. (A, C)

Sol. When battery has been disconnected, the charge Qremains unchanged

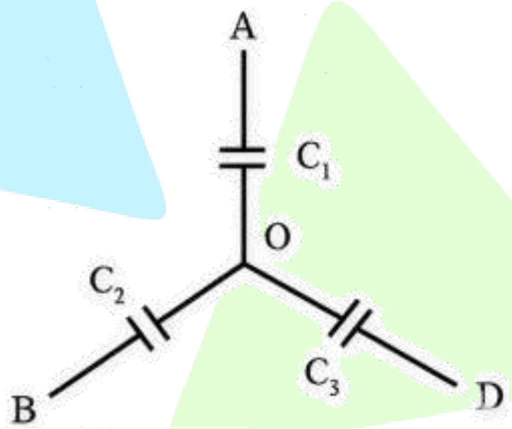
$Q = C_{air}V = \left(\frac{\varepsilon_0 A}{d}\right)V = k\varepsilon_0 AE$ Electric field in dielectric between plates of capacitor

$$E = \frac{\sigma}{K\varepsilon_0} = \frac{E_{air}}{K} = \frac{V}{Kd}$$

Work done on the system $= \frac{Q^2}{2C_{air}} - \frac{Q^2}{2C_{dielectric}} = \frac{Q^2}{2}\left[\frac{1}{C_{air}} - \frac{1}{C_{dielectric}}\right]$

$$W = \frac{1}{2}\left(\frac{\varepsilon_0 AV}{d}\right)^2\left(\frac{d}{\varepsilon_0 A} - \frac{d}{k\varepsilon_0 A}\right) = \frac{\varepsilon_0 AV^2}{2d}\left[1 - \frac{1}{k}\right]$$

8. Three uncharged capacitors $C_1 = 2\mu F, C_2 = 3\mu F$ and $C_3 = 5\mu F$ are connected as shown in figure to one another at O and to points A, B and D potentials $V_A = 300$ V, $V_B = 200$ V and $V_D = 400$ V respectively the potential V_0 at O is **[NSEP-2022]**



(A) 300 V (B) 320 V (C) 240 V (D) 280 V

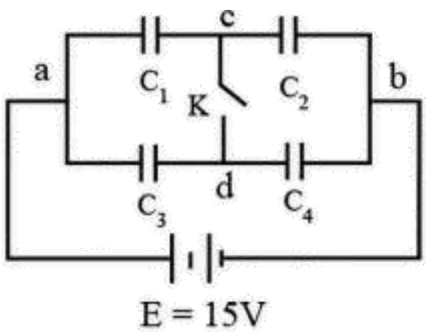
Ans. (B)

Sol. $\Rightarrow$ Using KCL

$$\Rightarrow Q_1 + Q_2 + Q_3 = 0 \Rightarrow C_1(V_0 - 300) + C_2(V_0 - 200) + C_3(V_0 - 400) = 0$$

$$\Rightarrow 2(V_0 - 300) + 3(V_0 - 200) + 5(V_0 - 400) = 0 \Rightarrow 10\,V_0 = 3200 \Rightarrow V_0 = 320\text{Volt}$$

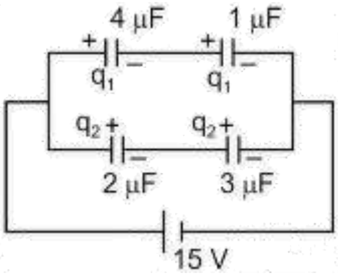
9. A system of capacitors $C_1 = 4\mu F, C_2 = 1\mu F, C_3 = 2\mu F$ and $C_4 = 3\mu F$ connected across a battery of emf $E = 15$ V is shown in figure. The charge that will flow, through the switch K, when it is closed, is **[NSEP-2022]**



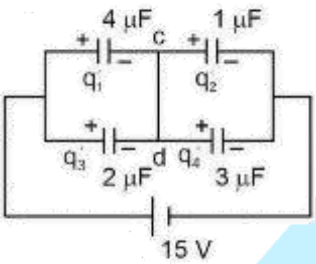
(A) $15\mu C$ c to d (B) $12\mu C$c to d (C) $6\mu C$d to c (D) $9\mu C$ d to c

Ans. (A)

Sol. Before closing the switch



After switch is closed



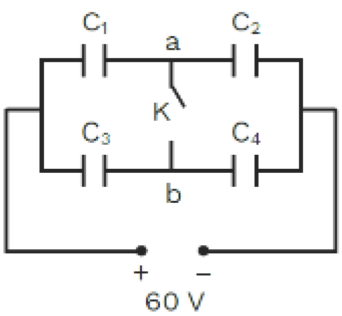
Calculating from the diagram of the value of q_1, q_2, q_1, q_2 we get the values as

$q_1 = 15\frac{4}{5}\mu C$ $q_2 = 15\frac{6}{5}\mu C$,

$q_1 = 24\mu C$,

$q_2 = 9\mu C$ Initially plates of capacitors which are connected to c has total charge 0 before switch is closed and net charge of $-24 + 9 = 15\mu C$ after the switch is closed thus total charge flown is $15\mu C$ from c to d .

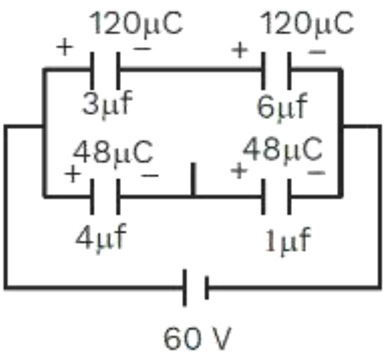
10. Capacitors $C_1 = 3\mu\ F, C_2 = 6\mu\ F, C_3 = 4\mu\ F$ and $C_4 = 1\mu\ F$ are connected in a circuit as shown to a battery of 60 V . Now if key K is closed, the charge that will flow through K is **[NSEP-2023]**



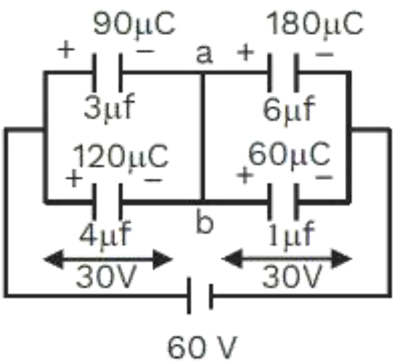
(A) $90\mu C$ from b to a (B) $60\mu C$ from b to a

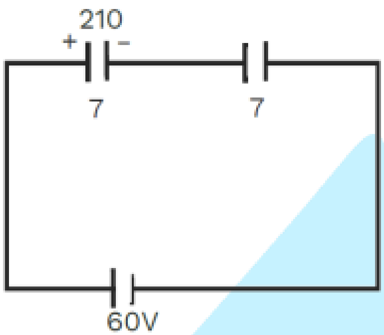
(C) $30\mu C$ from a to b (D) $150\mu C$ from b to a

Ans. (A)



Sol.





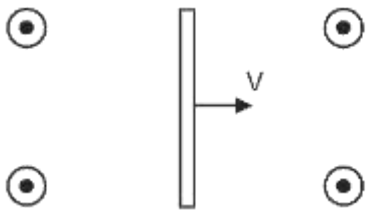
90μC from b to a

Ans. 9

MAGNETIC EFFECTS OF CURRENT

1. A neutral metal bar moves at a constant velocity v to the right through a region of uniform magnetic field directed out the page, as shown. **[NSEP-2017]**

Therefore,



(A) positive charges accumulate to the left side and negative charges to the right side of the rod

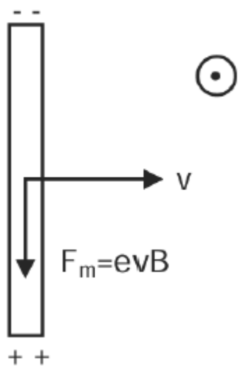
(B) negative charges accumulate to the left side and positive charges to the right side of the rod.

(C) positive charges accumulate to the top end and negative charges to the bottom end of the rod

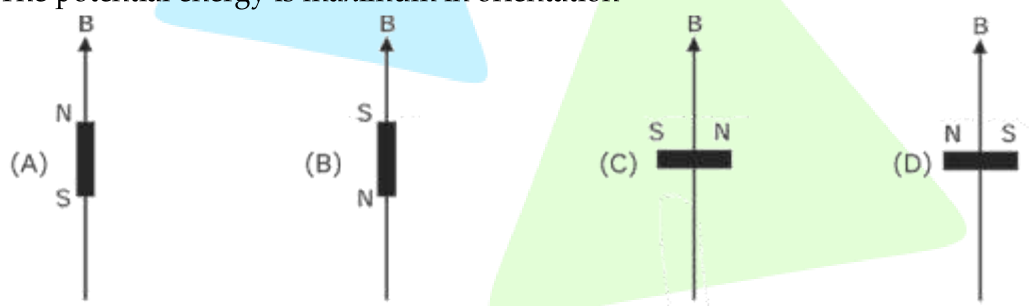
(D) negative charges accumulate to the top end and positive charges to the bottom end of the rod

Ans. (D)

Sol.



2. Consider different orientations of a bar magnet lying in a uniform magnetic field as shown below. The potential energy is maximum in orientation **[NSEP-2017]**



Ans. (B)

Sol. $U = -\vec{M} \cdot \vec{B}$

U is max when $\theta = 180^\circ$

3. An infinitely long straight non-magnetic conducting wire of radius a carries a dc current I. The magnetic field B, at a distance $r(r < a)$ from axis of the wire is : **[NSEP-2017]**

(A) $\frac{\mu_0 I}{2\pi a}$ (B) $\frac{\mu_0 I\, r}{2\pi a^2}$ (C) $\frac{2\mu_0 Ir}{\pi a^2}$ (D) $\frac{\mu_0 I\, r^2}{2\pi a^3}$

Ans. (B)

Sol. $B = \frac{\mu_0 Ir}{2} = \frac{\mu_0 Ir}{2\pi a^2}$

4. The earth's magnetic field at a certain point is 7.0×10^{-5} T. This field is to be balanced by a magnetic field at the centre of a circular current carrying coil of radius 5.0 cm by suitably orienting it. If the coil has 100 turns then the required current is about **[NSEP-2017]**

(A) 28 mA (B) 56 mA (C) 100 mA (D) 560 mA

Ans. (B)

Sol. $\frac{N\mu_0 I}{2r} = B_E \Rightarrow I = \frac{B_E 2r}{N\mu_0}$

$$I = \frac{7\times10^{-5}\times2\times5\times10^{-2}}{10^2\left(4\times\frac{22}{7}\times10^{-7}\right)} = 5.57\times10^{-2} = 55.7\times10^{-3}\text{ A} = 55.7\text{ mA}$$

5. A coil 2.0 cm in diameter has 300 turns. If the coil carries a current of 10 mA and lies in a magnetic field 5×10^{-2} T, the maximum torque experienced by the coil is: **[NSEP-2017]**

(A) 4.7×10^{-2} N – m (B) 4.7×10^{-4} N – m
(C) 4.7×10^{-5} N – m (D) 4.7×10^{-8} N – m

Ans. (C)

Sol. $\tau_{max} = NiAB$

$$\tau_{max} = 300\times10\times10^{-3}\times\frac{\pi4\times10^{-4}}{4}\times5\times10^{-2} = 4.7\times10^{-5}$$

6. A rectangular loop carrying a current is placed in a uniform magnetic field. The net force acting on the loop **[NSEP-2018]**

(A) depends on the direction and magnitude of the current.
(B) depends on the direction and magnitude of the magnetic field.
(C) depends on the area of the loop.
(D) is zero.

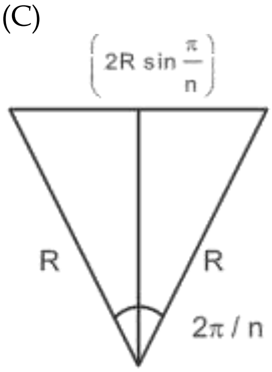
Ans. (D)

Sol. Force on a closed loop in uniform magnetic field is zero.

7. A conducting wire is bent in the form of a n sided regular polygon enclosed by a circle of radius R. The magnetic field produced at its centre by a current i flowing through the wire is **[NSEP-2018]**

(A) $\frac{\mu_0 i}{2R}\frac{\sin\frac{\pi}{n}}{\frac{\pi}{n}}$ (B) $\frac{\mu_0 i}{2R}\frac{\cos\frac{\pi}{n}}{\frac{\pi}{n}}$ (C) $\frac{\mu_0 i}{2R}\frac{\tan\frac{\pi}{n}}{\frac{\pi}{n}}$ (D) $\frac{\mu_0 i}{2R}\frac{\cot\frac{\pi}{n}}{\frac{\pi}{n}}$

Ans. (C)



Sol.

$$\vec{B}_{Net} = n\cdot\frac{\mu_0 I}{4\pi(R\cos\pi/n)}\cdot\left(2\sin\cdot\frac{\pi}{n}\right) = \frac{\mu_0 nI}{2\pi R}\tan\frac{\pi}{n}$$

8. The magnetic dipole moment of an electron in the S state of hydrogen atom revolving in a circular orbit of radius 0.0527 nm with a speed $2.2\times10^{6}\ m/s$ is **[NSEP-2018]**

(A) $4.64\times10^{-24}\,Am^2$ (B) $9.28\times10^{-24}\,Am^2$ (C) $18.56\times10^{-24}\,Am^2$ (D) $2.32\times10^{-24}\,Am^2$

Ans. (B)

Sol. $\vec{M} = I\vec{A}$

$$=\frac{e\cdot V}{2\pi r}\pi r^2=\frac{evr}{2}=\frac{1.6\times10^{-19}\times2.2\times10^{6}\times0.0527\times10^{-9}}{2}=9.2752\times10^{-24}\,Am^2=9.28\times10^{-2}\,Am^2$$

9. A tightly wound long solenoid carries a current 5 A . An electron shot perpendicular to the solenoid axis inside it revolves at a frequency $10^8\,rev/s$. The number of turns per meter length of the solenoid is: **[NSEP-2018]**

(A) 57 (B) 176 (C) 569 (D) 352

Ans. (C)

Sol. $\omega=\frac{qB}{m}$

$$\Rightarrow \omega=\frac{q}{m}\mu_0 nI \Rightarrow n=\frac{m\omega}{\mu_0 qI}=\frac{9.1\times10^{31}\times2\pi\times10^{8}}{4\pi\times10^{-7}\times1.6\times10^{-19}\times5}=\frac{9.1}{16}\times10^{3}=569$$

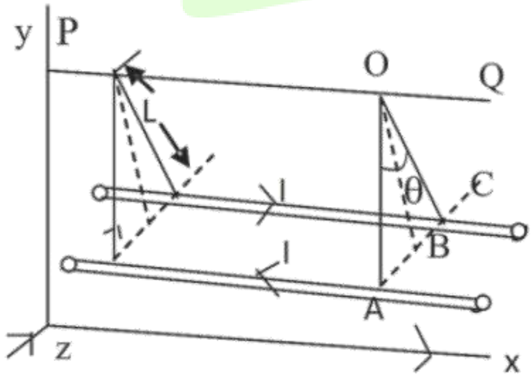
10. A spherical capacitor is formed by two concentric metallic spherical shells. The capacitor is then charged so that the outer shell carries a positive charge and the inner shell carries an equal but negative charge. Even if the capacitor is not connected to any circuit, the charge will eventually leak away due to a small electrical conductivity of the material between the shells. What is the character of the magnetic field produced by this leakage current? **[NSEP-2019]**

(A) Radially outwards from the inner shell to the outer shell.
(B) Radially inwards from the outer shell to the inner shell.
(C) Circular field lines between the shells and perpendicular to the radial direction.
(D) No magnetic field will be produced.

Ans. (D)

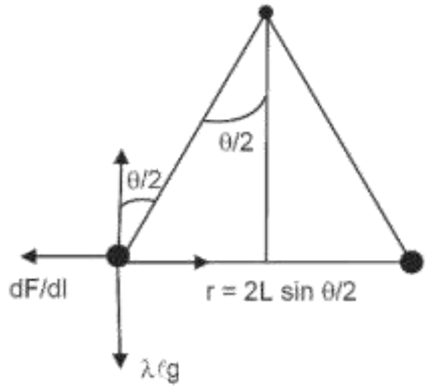
Sol. Due to spherical symmetry no magnetic field is produced

11. Two long parallel wires carry currents of equal magnitude (I) but in opposite directions. These wires are suspended from fixed rod PQ by four chords of equal length L as shown. The mass per unit length of each wire is λ, the value of angle θ subtended by two chords OA and OB, assuming it to be small, is: **[NSEP-2019]**



(A) $\theta=I\sqrt{\frac{\mu_0}{4\pi}\frac{\lambda}{gL}}$ (B) $\theta=I\sqrt{\frac{\mu_0}{\pi}\frac{1}{\lambda gL}}$ (C) $\theta=I\sqrt{\frac{\mu_0}{4\pi}\frac{g}{\lambda L}}$ (D) $\theta=I\sqrt{\frac{\mu_0}{\pi}\frac{\lambda g}{L}}$

Ans. (B)



Sol.

$2\ T\cos\frac{\theta}{2}=(\lambda l)g\ \ 2\ T\sin\frac{\theta}{2}=\frac{\mu_0}{2\pi}\frac{i^2\ell}{r}$ Divide

$\theta \approx i\sqrt{\frac{\mu_0}{\pi\lambda\ g\ell}}$

12. Knowing that the parallel currents attract, the inward pressure on the curved surface of a thin walled, long hollow metallic cylinder of radius $R = 50$ cm carrying a current of $i = 2\text{amp}$ parallel to its axis distributed uniformly over the entire circumference, is **[NSEP-2021]**

(A) $2.05\times10^{-1}\,\text{Nm}^{-2}$ (B) $2.55\times10^{-3}\,\text{Nm}^{-2}$ (C) $2.05\times10^{-5}\,\text{Nm}^{-2}$ (D) $2.55\times10^{-7}\,\text{Nm}^{-2}$

Ans. (D)

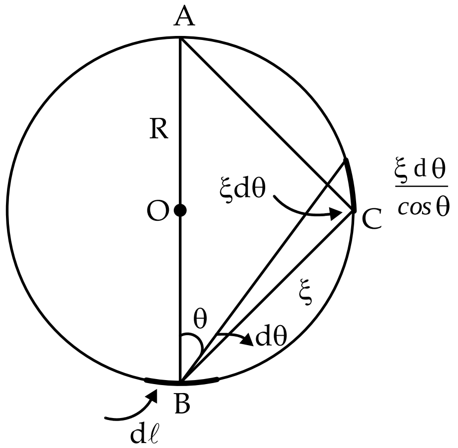
Sol. In a hollow metallic cylinder current is sent parallel to its axis along the entire curved surface. Let us consider a thin strip of width dl on the surface and along the length of the cylinder at a point B and another parallel strip of width $\frac{\xi d\theta}{\cos\theta}$ at the end of the chord of length ξ at angle θ. If I be the current through the metallic cylinder then the current per unit width shall be $j=\frac{1}{2\pi R}$.

Thereby the current through the two parallel strips separated by ξ shall be jdl and $j\frac{\xi d\theta}{\cos\theta}$ respectively.

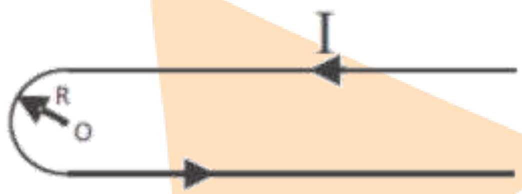
The force of attraction between these two parallel wires shall thus be $F=\frac{\mu_0}{2\pi}\frac{jdl\times j\xi d\theta}{\xi\cos\theta}\text{Nm}^{-1}$.

Component of this force towards the centre will add togive resultant inward force then dividing by dl and integrating over θ within the limits $-\frac{\pi}{2}\le\theta\le\frac{\pi}{2}$ we obtain force per unit surface of the hollow cylinder. Thus the inward force per unit surface area is

$$=\sum F\cos\theta=\frac{\mu_0 j^2}{2\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}d\theta=\frac{\mu_0 j^2}{2}=\frac{\mu_0}{2}\left(\frac{I}{2\pi R}\right)^2=2.55\times10^{-7}\,\text{Nm}^{-2}$$



13. What is the magnetic induction B at the centre O of the semicircular arc if a current carrying wire has shape of an hair pin as shown in figure? The radius of the curved part of the wire is R, the linear parts are assumed to be very long. **[NSEP-2020]**



(A) $B=\frac{\mu_0 I}{4\pi R}(2+\pi)$

(B) $B=\frac{\mu_0 I}{4R}(2+\pi)$

(C) $B=\frac{3\mu_0 I}{4R}(2+\pi)$

(D) $B=\frac{\mu_0}{4\pi}\frac{21}{R}$

Ans. (A)

Sol. Magnetic field at the centre of arc O is due to semi-circular part and to two semi infinite straight lines.

So $B=\frac{\mu_0 I}{4R}+2\left[\frac{\mu_0}{4\pi}\frac{I}{R}(\sin 0+\sin 90)\right]=\frac{\mu_0 I}{4R}\left(1+\frac{2}{\pi}\right)$

$B=\frac{\mu_0}{4\pi}\frac{1}{R}(\pi+2)$

14. A long solenoid having 1000 turns per meter carries a current of 1 A. It has a soft iron core of $\mu_r=1000$. The core is heated beyond the Curie temperature (T_c). Then **[NSEP-2022]**

(A) The H field in the solenoid is nearly unchanged but the B field decreases drastically.

(B) The H and B fields in the solenoid are nearly unchanged.

(C) The magnetization in the core reverses direction.

(D) The magnetization in the core diminished by a factor of about 10^8

Ans. (A)

Sol. $n=1000$

$\mu_r=1000$ $H=nI\rightarrow$ remain unchanged

$B=\mu_0(H+I)$

Above curi temperature ferromagnetic substance becomes paramagnetic, I decreases by large amount so, B decrease drastically but magnetization does not reverse the direction.

*15. A thin infinitely long metal sheet of appreciable finite width b carrying current I (distributed uniformly through out of its cross section) parallel to its length is placed in an external magnetic field B_e. Parallel to its plane and perpendicular to the direction of current **[NSEP-2022]**

(A) The thin metal sheet experiences a mechanical pressure $P=\frac{IB_e}{b}$ perpendicular to its face.

(B) The direction of the pressure does not change if the direction of current is reversed.

(C) In case the external magnetic field B_e is switched off, a magnetic field $B=\frac{\mu_0 I}{2b}$ is observed parallel to the plane of the sheet but perpendicular to the direction correct.

(D) The magnetic field produced in part (c) $B=\frac{2\mu_0 I}{b}$

Ans. (A, C)

Sol. $dI=\frac{1}{b}dx$

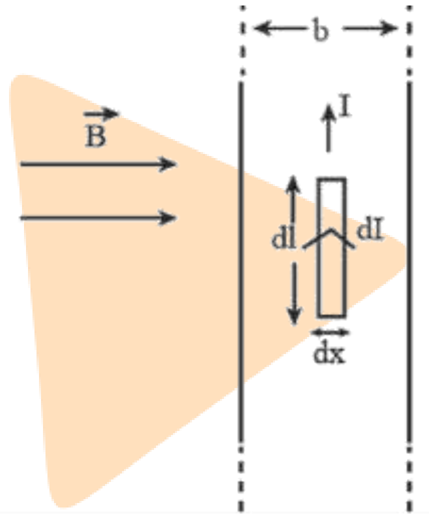
$$d\vec{F}=(dl)\,d\vec{l}\times\vec{B}_e$$

$$d\vec{F}=\frac{1}{b}dx\,dl\left(\hat{i}\right)\times B_e\left(\hat{l}\right)$$

$$d\vec{F}=\frac{1}{b}B_e(dl)(dx)\left(-\hat{k}\right)$$

$$P=\frac{dF}{dA}=\frac{\frac{1}{b}B_e(dl)(dx)}{(dl)(dx)}$$

$$P=\frac{1}{b}B_e$$



If the direction of current is reversed, direction of force is reversed and so, the direction of pressure.

Magnetic field due to infinity plane sheet (near the sheet) is $B=\frac{\mu_0 K}{2}=\frac{\mu_0 I}{2b}$

16. Current I flows through a long thin-walled metallic cylinder of radius R with a thin longitudinal slit of width $\xi(\xi \ll R)$ running parallel to the axis of the cylinder. The magnetic induction B produced at any point on the axis of the cylinder is approximately **[NSEP-2022]**

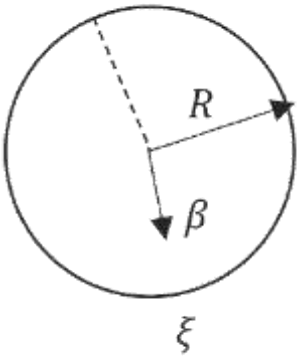
(A) $B=$ zero (B) $B=\frac{\mu_0 I}{2\pi R^2}$ (C) $\frac{\mu_0 I\xi}{4\pi^2 R^2}$ (D) $\frac{\mu_0 I\xi}{2\pi R^2}$

Ans. (C)

Sol. Current for unit width $=\frac{i}{2\pi R}$

Field due to one element is multiplied by geometrically opposite element except the element opposite to slit, Current through the opposite element is $di=\frac{i\xi}{2\pi R}$

$$\therefore B=\frac{\mu_0 di}{2\pi R}=\frac{\mu_0 I\,\xi}{4\pi^2 R^2}$$



17. An insulating rod of length ℓ carries charge q distributed uniformly over its length. The rod is pivoted at its midpoint and is rotated at a frequency f (in Hz) about an axis perpendicular to the rod passing through the point at the pivot. The magnetic moment of the system is **[NSEP-2022]**

(A) $\frac{1}{12}\pi qf\ell^2$ (B) $\frac{1}{3}\pi qf^2$ (C) $\frac{1}{6}\pi qf^2$ (D) πqf^2

Ans. (A)

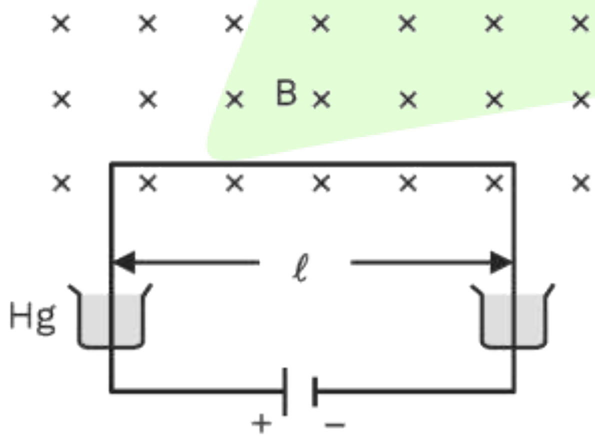
Sol. We know, $\frac{M}{L}=\frac{q}{2m}$

$M=$ magnetic moment, $L=$ Angular Momentum

$q=$ charge, $m=$ mass

$$\Rightarrow \frac{M}{\frac{m^2}{12}\cdot 2\pi f.}=\frac{q}{2m} \Rightarrow M=\frac{ql^2 2\pi f}{2\times 12}=\frac{\pi fql^2}{12}$$

18. A $\cup$-shaped conducting wire of mass $m=10$ g, having length of its horizontal section as $\ell=20$ cm, is free to move vertically up and down. The two ends of the wire are immersed in mercury for proper electrical contact. The wire is in a homogeneous field of magnetic induction $B=0.1T$ as shown. The wire jumps up to a height $h=3m$ when a charge q, in the form of a current pulse, is sent through the wire. Considering that the duration of the current pulse is very small compared to the time of flight, the charge q passed through the wire is estimated to be nearly **[NSEP-2023]**



(A) 6.85μC (B) 9.80μC (C) 2.84 C (D) 3.84 C

Ans. (D)

Sol. $(Bil.dt) = mv$

$B.\frac{dq}{dt}.l.\ dt = mv$

$B.dq.l = mv$

$B.dq.l = m\sqrt{2gh}$

$dq = \frac{m}{Bl}\sqrt{2gh} = \frac{10\times10^{-3}}{0.1\times0.2}\sqrt{2\times9.8\times3} = \frac{1}{2}\sqrt{6\times9.8} = 3.834C$

ELECTROMAGNETIC INDUCTION & ALTERNATING CURRENT

***1.** In a series $R-C$ circuit the supply voltage (Vs) is kept constant at 2 V and the frequency f of the sinusoidal voltage is varied from 500 Hz to 2000 Hz . The voltage across the resistance $R=1000$ ohm is measured each time as V_R . For the determination of the C a student wants to draw a linear graph and try to get C from the slope. Then she may draw a graph of **[NSEP-2017]**

(A) f^2 against V_R^2 (B) $\frac{1}{f^2}$ against $\frac{V_S^2}{V_R^2}$ (C) $\frac{1}{f^2}$ against $\frac{1}{V_R^2}$ (D) f against $\frac{V_R}{\sqrt{V_s^2-V_R^2}}$

Ans. (B, C, D)

Sol. $V_R = \frac{VR}{\sqrt{R^2+\left(\frac{1}{2\pi fc}\right)^2}}$

$R^2+\left(\frac{1}{2\pi fc}\right)^2 = \frac{v^2}{v_R^2}R^2 \left(\frac{1}{2\pi fc}\right) = \sqrt{\frac{v^2-v_R^2}{v_R^2}}R \;\; 2\pi fc(R) = \frac{v_R}{\sqrt{v^2-v_R^2}}$ Graph between f & $\frac{v_R}{\sqrt{v^2-v_R^2}}$ is a straight line.

$\frac{1}{f^2}$ vs $\frac{1}{v_R^2}$ is also straight line

2. Two identical coils each of self-inductance L , are connected in series and are placed so close to each other that all the flux from one coil links with the other. The total self-inductance of the system is: **[NSEP-2017]**

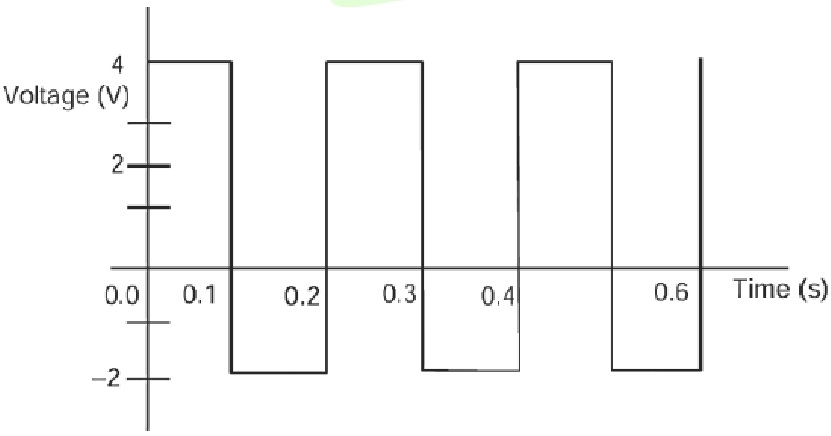
(A) L (B) 2 L (C) 3 L (D) 4 L

Ans. (D)

Sol.

$M = k\sqrt{L_1L_2} = L \;\; \phi = LI + LI + 2ml = 4LI = L_{eq}l \;\; L_{eq} = 4\,L$

3. A 10 ohm resistor is connected to a supply voltage alternating between +4 V and -2 V as shown in the following graph. The average power dissipated in the resistor per cycle is **[NSEP-2017]**



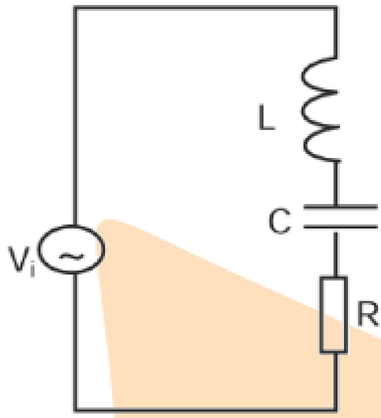
(A) 1.0 W (B) 1.2 W (C) 1.4 W (D) 1.6 W

Ans. (A)

Sol. $R = 10\Omega$

$$P_{av} = \frac{\frac{(4)^2}{10}\times 0.1 + \frac{(2)^2}{10}\times 10.1}{0.2} = \frac{1.6+0.4}{2} = 1\text{watt}$$

4. In the following circuit the current is in phase with the applied voltage. Therefore, the current in the circuit and the frequency of the source voltage respectively, are **[NSEP-2017]**



(A) $\frac{V_i}{R}$ and $\frac{1}{2\pi\sqrt{LC}}$ (B) zero and $\frac{1}{\sqrt{LC}}$

(C) $\sqrt{\frac{C}{L}}v_i$ and $\frac{2}{\pi\sqrt{LC}}$ (D) $4\sqrt{\frac{C}{LR^2}}$ and $\frac{2}{\sqrt{LC}}$

Ans. (A)

Sol. $f = \frac{1}{2\pi\sqrt{LC}}$ the circuit is in resonance with the applied voltage.

$i = \frac{V_i}{R}$

5. A thin wire of length 1 m is placed perpendicular to the XY plane. If it is moved with velocity $\vec{v} = u\hat{i} - \hat{j}$ in the region of magnetic induction $\vec{B} = \hat{i} + 4\hat{j}\,\text{Wb}/\text{m}^2$. The potential difference developed between the ends of the wire is: **[NSEP-2018]**

(A) Zero (B) 3 V (C) 15 V (D) 17 V

Ans. (D)

Sol. $E_{ind} = Bv\ell$

$= \sqrt{17}\cdot\sqrt{17}\times 1 = 17\text{ V}$ $\vec{B}$ is $\perp^r$ to $\vec{v} \perp^r$ to $\vec{\ell}$

6. In a series LCR circuit fed with an alternating emf $E = E_0\sin\omega t$, **[NSEP-2018]**

(A) the voltage across L is in phase with the applied emf E.

(B) the voltage across R is in phase with the applied emf E.

(C) the voltage across R is in phase with the applied emf E.

(D) the voltages across L, C and R are all in phase with the applied emf E.

Ans. (BONUS)

Sol. Voltage acros R may be in phase with source voltage provided circuit is Resistive ($\omega L = \frac{1}{\omega C}$)

7. The same alternating voltage $v = V_0 \sin(\omega t)$ is applied in both the LCR circuits shown below. The current through the resistance R at resonance is **[NSEP-2018]**

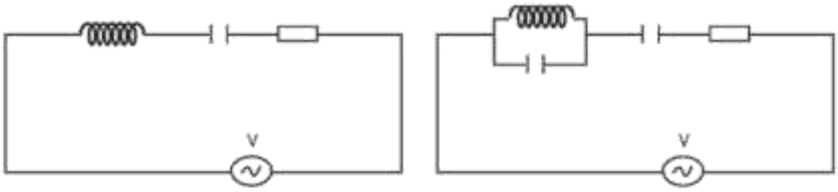


Figure -1 Figure -2

(A) maximum in Fig. (1) and maximum in Fig. (2).
(B) minimum in Fig. (1) and maximum in Fig. (2).
(C) maximum in Fig. (1) and minimum in Fig. (2).
(D) minimum in Fig. (1) and minimum in Fig. (2).

Ans. (C)

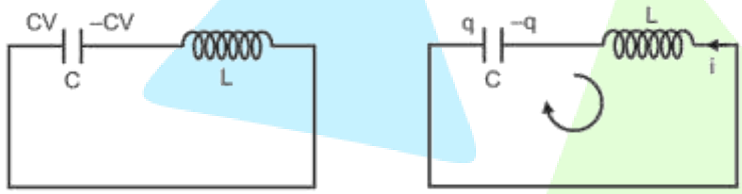
Sol. Circuit A behaves as an acceptor circuit (current maximizes at resonance) whereas circuit B behaves as a rejecter circuit (current minimizes at resonance).

***8.** After charging a capacitor C to a potential V, it is connected across an ideal inductor L. The capacitor starts discharging simple harmonically at time $t = 0$. The charge on the capacitor at a later time instant is q and the periodic time of simple harmonic oscillations is T. Therefore, **[NSEP-2018]**

(A) $q = CV\sin(\omega t)$ (B) $q = CV\cos(\omega t)$ (C) $T = 2\pi\sqrt{\frac{1}{LC}}$ (D) $T = 2\pi\sqrt{LC}$

Ans. (B, D)

Sol.



t = 0 time 't'

Applying KVL

$$-\frac{q}{c} + \frac{Ldi}{dt} = 0 \quad i = \frac{-dq}{dt} \quad \therefore \frac{d^2q}{dt^2} = -\frac{1}{LC}q \quad T = 2\pi\sqrt{LC} \quad \omega = \frac{1}{\sqrt{LC}} \quad \therefore q = q_0\sin(\omega t + \phi) \quad I = q_0\omega\cos(\omega t + \phi)$$

$$t = 0 \; i = 0 \Rightarrow \cos\phi = 0 \Rightarrow \phi = \frac{\pi}{2} \quad \therefore q = q_0\cos\omega t \quad t = 0 \; q = CV \Rightarrow CV = q_0 \quad \therefore q = CV\cos\omega t$$

***9.** Mysteriously a charged particle moving with velocity $\vec{v} = v_0\hat{i}$ entered the tube of Thomson's apparatus where the parallel metallic plates of length 5 cm along X axis are separated by 2 cm. Under the influence of a magnetic field $\vec{B}(4.57 \times 10^{-2}\hat{k})T$, the particle is found to deflect by an angle of 5.7°. When a potential of 2000 volt is applied between the two plates, the particle is found to move straight to the screen without any deflection. Then, **[NSEP-2018]**

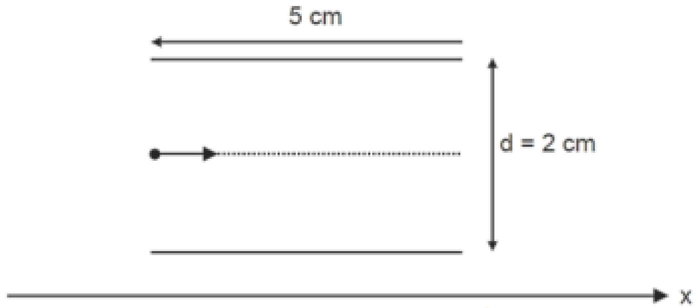
(A) the velocity $v_0 = 2.19\times10^6\ m/s$.

(B) the charge to mass ratio of the particle is $9.58\times10^7 C/kg$.

(C) radius of the circular path in the magnetic field is 50 cm .

(D) the particle is identified as a proton.

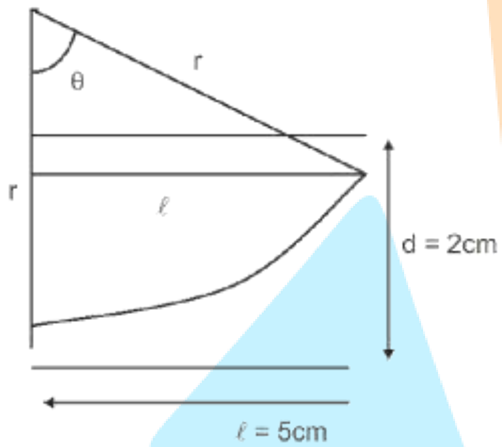
Ans. (A, B, C, D)



Sol.

When voltage is applied and particle goes undeflected $qE = qvv_oB$

$V_0 = \frac{E}{B} = \frac{2000}{0.02} 4.57\times10^{-2} = 2.19\times10^6\ m/s$ When only B is applied



$\frac{\ell}{r} = \sin\theta\ \frac{5}{r} = \sin 57^\circ = 0.095\ r = \frac{5}{0.099} = 50.5\text{ cm}\ r = \frac{mv_0}{qB} \Rightarrow \frac{q}{m} = \frac{v_0}{rB} = \frac{2.19\times10^6}{\frac{1}{2}\times4.57\times10^{-2}}$

$= 957{,}62967 \approx 9.58\times10^7$ kg Charge to mass ration of proton $= \frac{1.6\times10^{-19}}{1.6726219\times10^{-74}} = 9.58\times10^7$ kg

$\therefore$ Identified particle is proton

***10.** An inductance L, a resistance R and a battery B are connected in series with a switch S. The voltages across L and R are V_L and V_R respectively. Just after closing the switch S, **[NSEP-2018]**

(A) V_L will be greater than V_R.

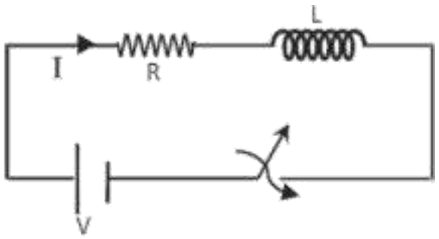
(B) V_L will be less than V_R.

(C) V_L will be the same as V_R.

(D) V_L will decrease while V_R will increase as time progresses.

Ans. (A, D)

Sol.



$I=\frac{V}{R}\left(1-e^{-\frac{RT}{L}}\right)$ At $t=0 I=0$

$\therefore V_R=1R=0$ $V_L=\frac{LdI}{dt}=L\frac{V}{R}\times\frac{R}{L}e^{-\frac{Rt}{L}}$ At $t=0$ V L = V

$\therefore$ (A) is correct at $t=\infty$, I become constant

$\therefore V_L=L\frac{dl}{dt}=0$ & $V_R=IR=V$

$\therefore$ (D) is correct

***11.** A circular loop of conducting wire of radius 1 cm is cut at a point A on its circumference. It is then folded along a diameter through A such that the two semicircular loops lie in two mutually perpendicular planes. In this region a uniform magnetic field $\vec{B}$ of magnitude 100 mT is directed perpendicular to the diameter through A and makes angles of 30° and 60° with the planes of the two semicircles. The magnetic field reduces at a uniform rate from 100 mT to zero in a time interval of 4.28 ms . Therefore, **[NSEP-2018]**

(A) instantaneous emf in the two loops are in the ratio $\sqrt{2}:1$.

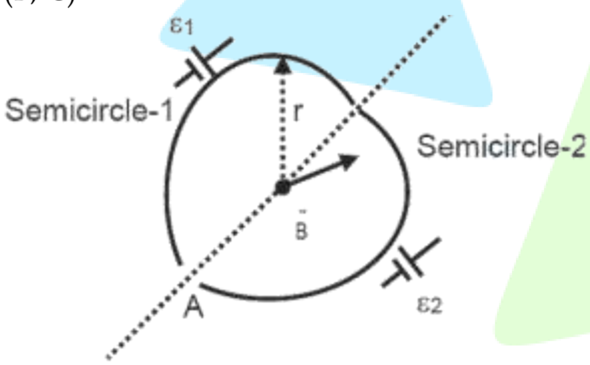
(B) instantaneous emf in the two loops are in the ratio $\sqrt{3}:1$.

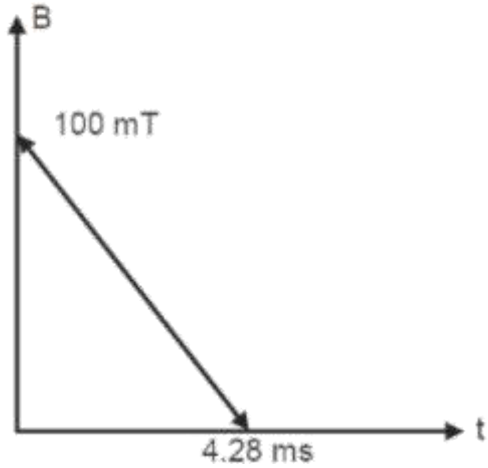
(C) the total emf between free ends at point A is 5 mV .

(D) the total emf between free ends at point A is 1.4 mV .

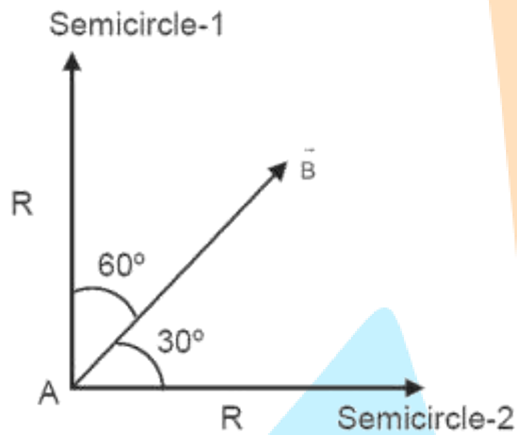
Ans. (B, C)

Sol.

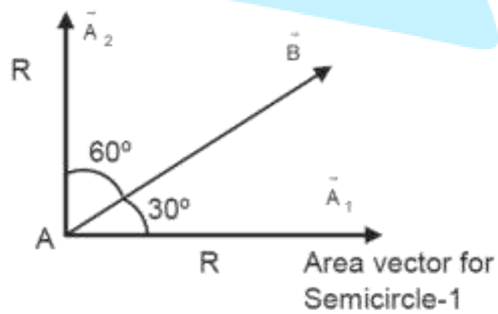




$$\left|\frac{dB}{dt}\right| = \frac{100\times10^{-3}}{4.28\times10^{-3}} = \frac{100}{4.28}\ T/s$$ Side view



$A_1 = A_2 = a = \frac{\pi R^2}{2}$ Area vector for Semicircle-2



$$\phi_1 = BA_1\cos30^\circ = \frac{\sqrt{3}}{2}Ba \quad \varepsilon_1 = \left|\frac{d\phi}{dt}\right| = \frac{\sqrt{3}}{2}a\left|\frac{dB}{dt}\right| \quad \phi_2 = BA_2\cos60^\circ = \frac{1}{2}Ba \quad \varepsilon 2 = \left|\frac{d\phi_2}{dt}\right| = \frac{1}{2}a\left|\frac{dB}{dt}\right| \quad \frac{\varepsilon_1}{\varepsilon_2} = \frac{\sqrt{3}}{1}\ \phi\ \therefore$$

(a) $$\varepsilon_{total} = \varepsilon_1 + \varepsilon_2 = \left(\frac{\sqrt{3}}{2} + \frac{1}{2}\right)a\left|\frac{dB}{dt}\right| = \left(\frac{2.732}{2}\right)\times\frac{\pi(.01)^2}{2}\times\frac{100}{4.28} = 5.01\times10^{-3}\ V = 5mV$$

12. The dc component of current in the output of a half-wave rectifier with peak value I_0 is:

[NSEP-2019]

(A) zero (B) $\frac{I_0}{\pi}$ (C) $\frac{I_0}{2\pi}$ (D) $\frac{2I_0}{\pi}$

Ans. (B)

Sol. Output is half-wave rectifier

$i = i_0 \sin\omega t$(for $0 < t < T/2$)

$i = 0$($T/2 < t < T$) Average current $= \frac{\int i dt}{\int dt} = \frac{\int i_0 \sin\omega t dt + \int 0 dt}{(t)}$

$$= \frac{i_0\left(-\frac{\cos\omega t}{\omega}\right)_0^{T/2} + 0}{T} = \frac{i_0(-\cos\pi + \cos 0)}{\omega T} = \frac{2i_0}{T\omega} = \frac{2i_0}{2\pi} = \frac{i_0}{\pi}$$

13. An Alternating Current is expressed as $i = i_1\cos\omega t + i_2\sin\omega t$. The RMS value of current is

[NSEP-2020]

(A) $\sqrt{\frac{(i_1+i_2)^2}{2}}$ (B) $\sqrt{\frac{i_1 i_2}{2}}$ (C) $\sqrt{\frac{(i_1^2+i_2^2)}{2}}$ (D) $\sqrt{\frac{(i_1-i_2)^2}{2}}$

Ans. (C)

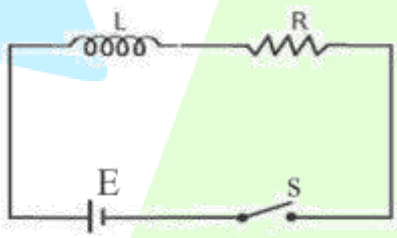
Sol. The current is $i = i_1\cos\omega t + i_2\sin\omega t = i_1\left(\cos\omega t + \frac{i_2}{i_1}\sin\omega t\right)$ let us put

$\frac{i_2}{i_1} = \cot\theta = \frac{\cos\theta}{\sin\theta}$ then $i = \frac{i_1}{\sin\theta}(\cos\omega t \sin\theta + \sin\omega t\cos\theta)$ or

$i = \frac{i_1}{\frac{i_1}{\sqrt{i_1^2+i_2^2}}}\sin(\omega t + \theta)$ or $i = \sqrt{(i_1^2+i_2^2)}\sin(\omega t+\theta)$ Thereby rms current is $i_{rms} = \sqrt{\frac{(i_1^2+i_2^2)}{2}}$

14. In the LR circuit shown in figure, switch S is closed at time $t=0$, the charge that passes through the battery of emf E in one time constant is (e being the base of natural logarithm).

[NSEP-2020]



(A) $\frac{EL}{eR^2}$ (B) $\frac{EL}{eR}$ (C) $\frac{eER^2}{L}$ (D) $\frac{EL}{R}$

Ans. (A)

Sol. When switch S is closed, current starts flowing and is given by

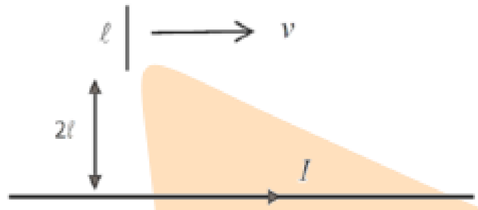
$I = I_0\left(1 - e^{\frac{-t}{\tau}}\right) = \frac{E}{R}\left(1 - e^{\frac{-t}{\tau}}\right) = \frac{dq}{dt}$ Therefore $q = \int_0^\tau I dt = q = \frac{E}{R}\int_0^\tau\left(1 - e^{\frac{-t}{\tau}}\right)dt$

Where charge q flows in time $\tau\left(\because \tau = \frac{L}{R} = \right.$ time constant)

$$q=\frac{E}{R}\tau-\frac{E}{R}\int_0^{\tau}e^{\frac{-t}{\tau}}dt=\frac{E}{R}\tau-\frac{E}{R}\left[\frac{e^{\frac{-t}{\tau}}}{\left(\frac{-1}{\tau}\right)}\right]_0^{\tau}=\frac{E}{R}\tau+\frac{E}{R}\tau\left[e^{\frac{-t}{\tau}}\right]_0^{\tau}$$

$$q=\frac{E}{R}\tau+\left(\frac{E}{R}\tau e^{-1}-\frac{E}{R}\tau e^{0}\right)=\frac{E\tau}{eR}=\frac{E\left(\frac{L}{R}\right)}{eR}=\frac{EL}{eR^2}$$

15. A metal bar of length ℓ moves with a velocity v parallel to an infinitely long straight wire carrying a current I as shown in the figure. If the nearest end of the perpendicular bar always remains at a distance 2ℓ from the current carrying wire, the potential difference (in volt) between two ends of the moving bar is **[NSEP-2021]**



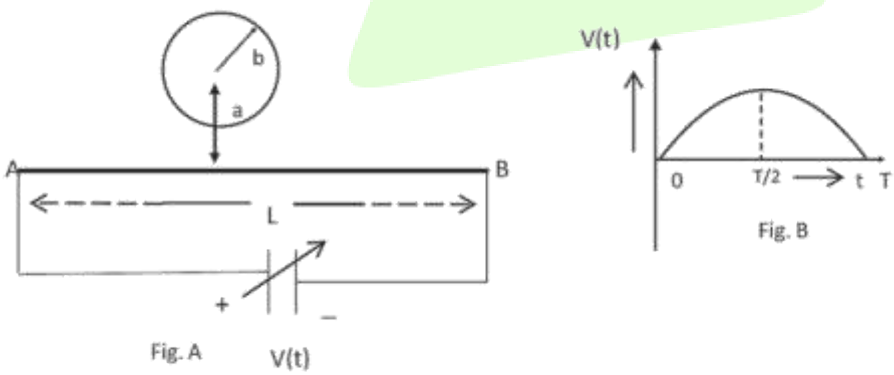
(A) $\frac{\mu_0 IV}{2\pi}$ (B) $\frac{\mu_0 IV}{6\pi}$ (C) $\frac{\mu_0 Iv}{2\pi}\ell$ (D) $\frac{\mu_0 IV}{2\pi}\ell$

Ans. (D)

Sol. The magnetic field produced by a current carrying conductor at a distance x is $B=\frac{\mu_0 I}{2\pi x}$ Therefore the induced emf in a conductor of length dx moving with velocity v is $d\varepsilon=-\ell Bv=-\frac{\mu_0 I}{2\pi x}vdx$.

Total emf produced in the present problem is $\varepsilon=-\int_{2\ell}^{3\ell}\frac{\mu_0 I}{2\pi x}vdx=-\frac{\mu_0 I}{2\pi}v\int_{2\ell}^{3\ell}\frac{dx}{x}=\frac{\mu_0 I}{2\pi}v\times\ln 1.5$

16. A long straight wire AB of length $L(L\gg a, L\gg b)$ and resistance R is connected to a time varying source of emf $V(t)$. The variation of applied emf $V(t)$ with time is shown in Fig. B. A circular metallic loop of radius $r=b$ is placed coplanar with the current carrying wire with its centre at a distance 'a' from the axis of the wire as shown. The induced current in the loop is **[NSEP-2021]**



(A) clockwise from 0 to $T/2$ and anticlockwise from $T/2$ to T

(B) anticlockwise from 0 to $T/2$ and clockwise from $T/2$ to T

(C) clock wise from 0 to T
(D) anticlockwise from 0 to T

Ans. (A)

Sol. When the current flows in the wire along AB, the magnetic field in the circular loop is directed outward perpendicular to the plane of the paper. During the increase of current i.e., from 0 to $T/2$, the induced current in the loop is clockwise while during the decrease of current i.e., $T/2$ to T the induced current shall be anticlockwise. Hence the answer is a.

***17.** A thick hollow cylinder of height h and inner and outer radii a and $b(b>a)$ made up of a poorly conducting material of resistivity ρ lies coaxially inside a long solenoid at its middle. The radius of the solenoid is larger than b. Throughout the interior of the solenoid, a uniform time varying magnetic field $B=\beta t$ is produced parallel to solenoid axis. Here β is a constant. In this time varying magnetic field **[NSEP-2021]**

(A) the emf induced at a certain radius $r(a<r<b)$ in the hollow cylinder is $\pi r^2\beta$

(B) the induced current circulating in the thick hollow cylinder between radii a and b is $i=\frac{\beta h}{4\rho}\left(b^2-a^2\right)$

(C) The resistance offered to the circulation of current by the thick hollow cylinder is $R=\frac{2\pi\rho}{h\times\ln\frac{b}{a}}$

(D) no electric field is detectable outside the solenoid.

Ans. (A, B, C)

Sol. A poorly conducting thick hollow cylinder is placed coaxially inside a long solenoid. If we consider a circle of radius $r(a<r<b)$, the magnetic flux through this area shall be $\phi=\pi r^2\beta t$ The induced emf therefore shall be $\varepsilon=-\frac{d\phi}{dt}=-\pi r^2\beta$ Thus $|\varepsilon|=\pi r^2\beta$ If R be the resistance offered to the circulating current then $\frac{1}{R}=\int_a^b\frac{hdr}{\rho\times 2\pi r}=\frac{h}{2\pi\rho}\ln\frac{b}{a}$ Thereby $R=\frac{2\pi\rho}{h\times\ln\frac{b}{a}}$ Further the circulating current induced in the thick hollow poorly conducting cylinder is

$$i=\frac{\varepsilon}{R}=\int_a^b\pi r^2\beta\frac{hdr}{\rho 2\pi r}=\frac{\beta h}{2\rho}\int_a^b rdr=\frac{\beta h}{4\rho}\left(b^2-a^2\right)$$

The time varying magnetic field parallel to the axis of the solenoid produces an electric field even outside the solenoid. The lines of force being circular with their centres lying on the axis of the solenoid so option d is wrong.

18. A total charge Q is uniformly distributed over a non - conducting ring of radius r. There is a time varying magnetic field perpendicular to its plane and changing at the uniform rate of $\frac{dB}{dt}$. The magnitude of induced tangential electric field E on ring is **[NSEP-2022]**

(A) $r\frac{dB}{dt}$ (B) $\frac{1}{2}r\frac{dB}{dt}$ (C) $r^2\frac{dB}{dt}$ (D) $\frac{1}{2}r^2\frac{dB}{dt}$

Ans. (B)

Sol. Faraday's law of EMI:

$$\oint\vec{E}\vec{dl}=\left|-\frac{d\phi}{dt}\right|\Rightarrow E.2\pi r=\pi r^2\frac{dB}{dt}\Rightarrow E=\frac{r}{2}\cdot\frac{dB}{dt}$$

19. DC emf of 15 V is applied to a circuit containing 5 H inductance and 10Ω resistance in series at $t=0$. The ratio of the currents in the circuit at $t=0.5\text{sec}$ and at $t=1.0\text{sec}$ is **[NSEP-2022]**

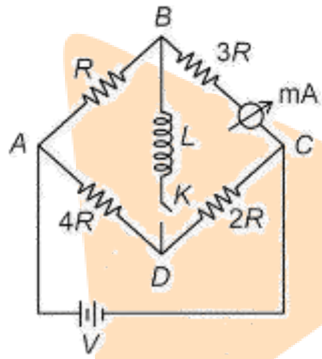
(A) $\frac{e^2}{e^2-1}$ (B) $\frac{e}{e+1}$ (C) $\frac{\sqrt{e}}{\sqrt{e}-1}$ (D) $\frac{1}{e}$

Ans. (B)

Sol. Time constant, $\frac{L}{R}=\frac{5}{10}=0.5\text{ s}$

$$i(t)=\frac{E}{R}\left[1-e^{-t/\tau}\right]\Rightarrow\frac{i_{t=0.5s}}{i_{t=1s}}=\frac{1-e^{-1}}{1-e^{-2}}=\frac{1-\frac{1}{e}}{1-\frac{1}{e^2}}=\frac{(e-1)e}{e^2-1}\Rightarrow\frac{e}{e+1}$$

20. The reading of the ammeter, used in the electrical network shown below, is 20 mA , a long time after the key K is closed **[NSEP-2022]**

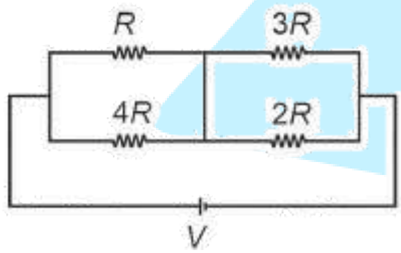


The reading of the same ammeter, immediately after the key was closed was

(A) zero (B) 16 mA (C) 25 mA (D) 32 mA

Ans. (C)

Sol. As $t\to\infty$ inductor is short $\Rightarrow$

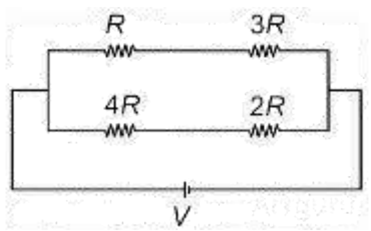


Since current in $3R$ is $20m\Rightarrow V=\left[\frac{4R}{5}+\frac{6R}{5}\right]\times 50mA$

$=(100)mA\cdot A$

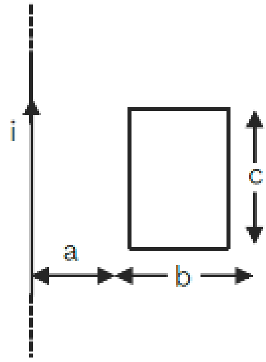
A $t\to 0$ inductor is open $\Rightarrow$

$\therefore i=i_3+i_A$



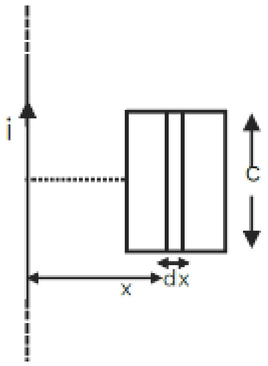
Reading of ammeter is given by $=\frac{V}{4R}=\frac{100R}{4R}=25\text{ mA}$

21. A long straight wire carrying a current $i = 10\text{ A}$ and a rectangular metallic loop of dimensions $b \times c$ lie in the same plane as shown in the figure. The parameters are $a = 10\text{ cm}, b = 30\text{ cm}$ and $c = 50\text{ cm}$. The mutual inductance of the system is nearly **[NSEP-2023]**



(A) 69 nH (B) 71 nH (C) 139 nH (D) 281 nH

Ans. (C)

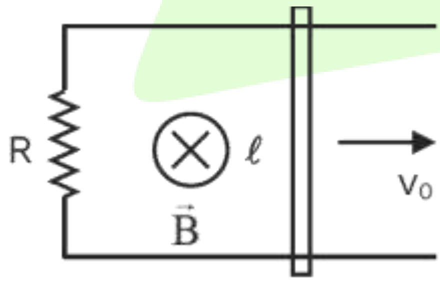


Sol.

$B = \frac{\mu_0 i}{2\pi x}$ $d\phi = \frac{\mu_0 i}{2\pi x} \times c dx$ $\phi = \frac{\mu_0 i c}{2\pi} \ln\left[\frac{a+b}{a}\right] = mi$ $m = \frac{\mu_0 c}{2\pi} \ln\left[\frac{a+b}{a}\right]$ $m = 2 \times 10^{-7} \times 50 \times 10^{-2} \ln[4]$

$= 100 \times 10^{-9} \times 2 \times 0.6932$ $= 69.32 \times 2 \times 10^{-9}$ $= 138.64 \times 10^{-9}$ $\simeq 139\text{nH}$

***22.** A metal rod of mass m and length ℓ slides on frictionless parallel metal rails of negligible resistance, A resistance R is connected between the rails at their ends as shown in the figure. A uniform magnetic field B is directed into the plane of paper perpendicular to the plane of rails throughout the space. The rod is given an initial velocity v_0 (towards right). No other force acts on the rod. Then **[NSEP-2023]**



(A) $v(t) = v_0 e^{\frac{-B/t}{mR}}$

(B) the rod stops after traveling a distance $x = \frac{mv_0 R}{B^2 \ell^2}$

(C) the total energy dissipated in resistance is $\frac{1}{4}mv_0^2$ i.e. half of the initial kinetic energy

(D) the total charge that flows in the circuit is $q = \frac{mv_0}{B\ell}$

Ans. (B, D)

Sol. (A) $BVl - iR = 0$

$i = \frac{BVl}{R}$

(B) $\Rightarrow F = ilB = -\frac{mdv}{dt}$

$\Rightarrow \frac{B^2L^2V}{R} = -m\frac{dV}{dt}$

$\Rightarrow -\frac{B^2L^2}{MR}\int dt = \int \frac{dV}{V}$

$\Rightarrow V = V_0 e^{-\frac{B^2L^2t}{MR}}$

(B) $V = \frac{dx}{dt} = V_0 e^{-\frac{B^2L^2t}{MR}}$

$\int_0^x dx = V_0 \int_0^\infty e^{-\frac{B^2L^2t}{MR}} dt$

$x = \frac{V_0 mR}{-B^2l^2}\left[e^{\frac{-B^2l^2t}{mR}}\right]_0^\infty$

$x = \frac{-mV_0R}{B^2l^2}(0-1)$

$x = \frac{mV_0R}{B^2l^2}$

(C) total energy dissipated $= \frac{1}{2}mV_0^2$

(D) $i = \frac{BL}{R}V$

$\int \frac{dq}{dt} = \frac{Bl}{R}\int \frac{dx}{dt}$

$Q = \frac{Bl}{R}\cdot x$

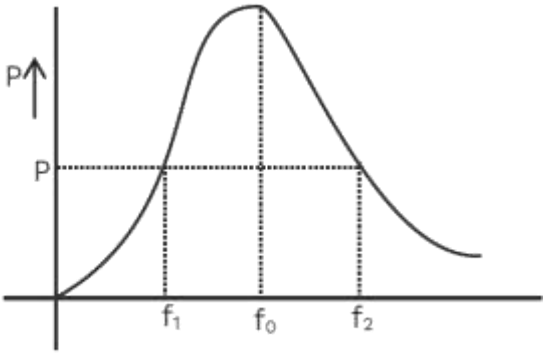
$Q = \frac{Bl}{R}\cdot\frac{mV_0R}{B^2L^2}$

$Q = \frac{mV_0}{Bl}$

23. Impedance of a given series LCR circuit, fed with alternating current, is the same for two frequencies f_1 and f_2. The resonance frequency f_R of the circuit is **[NSEP-2023]**

(A) $\frac{f_1+f_2}{2}$ (B) $\frac{2f_1f_2}{f_1+f_2}$ (C) $\sqrt{f_1f_2}$ (D) $\sqrt{f_1^2+f_2^2}$

Ans. (C)



Sol.

$$P = \frac{v^2R}{R^2\left(X_L - X_C\right)} \quad \frac{1}{C\omega_1} - L\omega_1 = L\omega_2 - \frac{1}{C\omega_2} \quad \frac{1}{C}\frac{\omega_1 + \omega_2}{\omega_1\omega_2} = L\left(\omega_1 + \omega_2\right) \quad \frac{1}{LC} = \omega_1\omega_2 \quad \omega_0^2 = \omega_1\omega_2 \quad \omega_0 = \omega_1\omega_2$$

$$f_0 = \sqrt{f_1 f_2}$$