## ELECTROMAGNETIC INDUCTION-ALTERNATING CURRENT

**1.** A series LCR circuit is connected to a 45 sin ($\omega t$) Volt source. The resonant angular frequency of the circuit is $10^5$ rad $s^{-1}$ and current amplitude at resonance is $I_0$. When the angular frequency of the source is $\omega = 8 \times 10^4$ rad $s^{-1}$, the current amplitude in the circuit is 0.05 $I_0$. If L = 50 mH, match each entry in List-I with an appropriate value from List-II and choose the correct option. **[JEE(Advanced) 2023]**

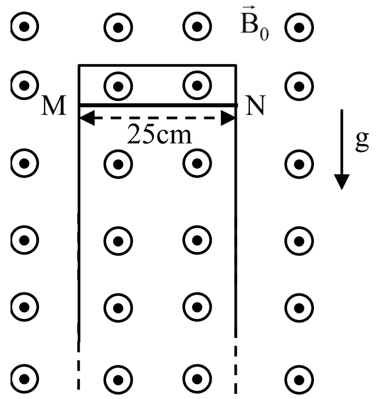
| | List-I | | List-II |
|---|---|---|---|
| (P) | $I_0$ in mA | (1) | 44.4 |
| (Q) | The quality factor of the circuit | (2) | 18 |
| (R) | The bandwidth of the circuit in rad $s^{-1}$ | (3) | 400 |
| (S) | The peak power dissipated at resonance in Watt | (4) | 2250 |
| | | (5) | 500 |

(A) P → 2, Q → 3, R → 5, S → 1 (B) P → 3, Q → 1, R → 4, S → 2

(C) P → 4, Q → 5, R → 3, S → 1 (D) P → 4, Q → 2, R → 1, S → 5

**2.** A thin conducting rod MN of mass 20 gm, length 25 cm and resistance 10 Ω is held on frictionless, long, perfectly conducting vertical rails as shown in the figure. There is a uniform magnetic field $B_0$ = 4 T directed perpendicular to the plane of the rod-rail arrangement. The rod is released from rest at time t = 0 and it moves down along the rails. Assume air drag is negligible. Match each quantity in List-I with an appropriate value from List-II, and choose the correct option.

[Given: The acceleration due to gravity $g = 10$ ms$^{-2}$ and $e^{-1} = 0.4$] **[JEE(Advanced) 2023]**



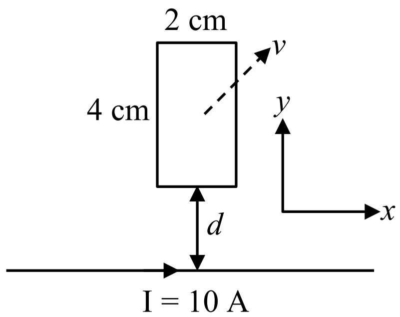

| | List-I | | List-II |
|---|---|---|---|
| (P) | At t = 0.2 s, the magnitude of the induced emf in Volt | (1) | 0.07 |
| (Q) | At $t$ = 0.2 s, the magnitude of the magnetic force in Newton | (2) | 0.14 |
| (R) | At $t$ = 0.2 s, the power dissipated as heat in Watt | (3) | 1.20 |
| (S) | The magnitude of terminal velocity of the rod in m $s^{-1}$ | (4) | 0.12 |
| | | (5) | 2.00 |

(A) P → 5, Q → 2, R → 3, S → 1 (B) P → 3, Q → 1, R → 4, S → 5

(C) P → 4, Q → 3, R → 1, S → 2 (D) P → 3, Q → 4, R → 2, S → 5

**3.** A rectangular conducting loop of length 4 cm and width 2 cm is in the xy-plane, as shown in the figure. It is being moved away from a thin and long conducting wire along the direction $\frac{\sqrt{3}}{2}\hat{x}+\frac{1}{2}\hat{y}$ with a constant speed v. The wire is carrying a steady current I = 10 A in the positive x-direction. A current of 10 μA flows through the loop when it is at a distance d = 4 cm from the wire. If the resistance of the loop is 0.1 Ω, then the value of v is _________ $ms^{-1}$.

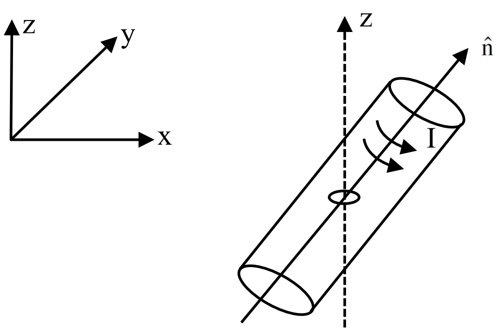
[Given: The permeability of free space $\mu_0 = 4\pi \times 10^{-7}\,NA^{-2}$] **[JEE(Advanced) 2023]**




**4.** Consider an LC circuit, with inductance L = 0.1 H and capacitance $C = 10^{-3}$ F, kept on a plane. The area of the circuit is 1 $m^2$. It is placed in a constant magnetic field of strength $B_0$ which is perpendicular to the plane of the circuit. At time t = 0, the magnetic field strength starts increasing linearly as $B = B_0 + \beta t$ with $\beta = 0.04\ Ts^{-1}$ . The maximum magnitude of the current in the circuit is____mA.

**[JEE(Advanced) 2022]**

**5.** A small circular loop of area *A* and resistance R is fixed on a horizontal xy-plane with the center of the loop always on the axis $\hat{n}$ of a long solenoid. The solenoid has m turns per unit length and carries current I counterclockwise as shown in the figure. The magnetic field due to the solenoid is in $\hat{n}$ direction. List-I gives time dependences of $\hat{n}$ in terms of a constant angular frequency ω. List-II gives the torques experienced by the circular loop at time $t = \frac{\pi}{6\omega}$, Let $\alpha = \frac{A^2\mu_0^2 m^2 I^2 \omega}{2R}$. **[JEE(Advanced) 2022]**



| List-I | | List-II | |
|---|---|---|---|
| (I) | $\frac{1}{\sqrt{2}}\left(\sin\omega t\,\hat{j}+\cos\omega t\,\hat{k}\right)$ | (P) | 0 |
| (II) | $\frac{1}{\sqrt{2}}\left(\sin\omega t\,\hat{i}+\cos\omega t\,\hat{j}\right)$ | (Q) | $-\frac{\alpha}{4}\hat{i}$ |
| (III) | $\frac{1}{\sqrt{2}}\left(\sin\omega t\,\hat{i}+\cos\omega t\,\hat{k}\right)$ | (R) | $\frac{3\alpha}{4}\hat{i}$ |
| (IV) | $\frac{1}{\sqrt{2}}\left(\cos\omega t\,\hat{i}+\sin\omega t\,\hat{k}\right)$ | (S) | $\frac{\alpha}{4}\hat{j}$ |
| | | (T) | $-\frac{3\alpha}{4}\hat{i}$ |

Which one of the following options is correct?

(A) I→Q, II→P, III→S, IV→T

(B) I→S, II→T, III→Q, IV→P

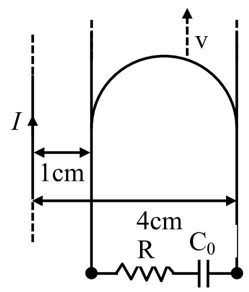
(C) I→Q, II→P, III→S, IV→R

(D) I→T, II→Q, III→P, IV→R

**6.** A long straight wire carries a current, I = 2 ampere. A semi-circular conducting rod is placed beside it on two conducting parallel rails of negligible resistance. Both the rails are parallel to the wire. The wire, the rod and the rails lie in the same horizontal plane, as shown in the figure. Two ends of the semi-circular rod are at distances 1cm and 4 cm from the wire. At time t = 0, the rod starts moving on the rails with a speed v = 3.0 m/s (see the figure).

A resistor R = 1.4 Ω and a capacitor $C_0$ = 5.0 μF are connected in series between the rails. At time t = 0, $C_0$ is uncharged. Which of the following statement(s) is(are) correct ? **[JEE(Advanced) 2021]**

[$\mu_0 = 4\pi \times 10^{-7}$ SI units. Take ln 2 = 0.7]




(A) Maximum current through R is $1.2 \times 10^{-6}$ ampere

(B) Maximum current through R is $3.8 \times 10^{-6}$ ampere

(C) Maximum charge on capacitor $C_0$ is $8.4 \times 10^{-12}$ coulomb

(D) Maximum charge on capacitor $C_0$ is $2.4 \times 10^{-12}$ coulomb

**Question Stem for Question Nos. 7 and 8**

**Question Stem**

In a circuit, a metal filament lamp is connected in series with a capacitor of capacitance C $\mu F$ across a 200 V, 50 Hz supply. The power consumed by the lamp is 500 W while the voltage drop across it is 100 V. Assume that there is no inductive load in the circuit. Take rms values of the voltages. The magnitude of the phase-angle (in degrees) between the current and the supply voltage is φ.

Assume, $\pi\sqrt{3} \approx 5$.

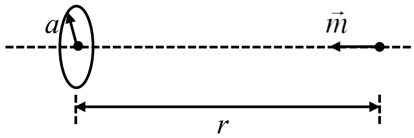
**7.** The value of C is _______. **[JEE(Advanced) 2021]**

**8.** The value of φ is _______. **[JEE(Advanced) 2021]**

**Paragraph for Question Nos. 9 and 10**

A special metal S conducts electricity without any resistance. A closed wire loop, made of S, does not allow any change in flux through itself by inducing a suitable current to generate a compensating flux. The induced current in the loop cannot decay due to its zero resistance. This current gives rise to a magnetic moment which in turn repels the source of magnetic field or flux. Consider such a loop, of radius *a*, with its center at the origin. A magnetic dipole of moment *m* is brought along the axis of this loop from infinity to a point at distance *r* (>> *a*) from the center of the loop with its north pole always facing the loop, as shown in the figure below.

The magnitude of magnetic field of a dipole m, at a point on its axis at distance r, is $\frac{\mu_0}{2\pi}\frac{m}{r^3}$, where $\mu_0$ is the permeability of free space. The magnitude of the force between two magnetic dipoles with moments, $m_1$ and $m_2$, separated by a distance r on the common axis, with their north poles facing each other, is $\frac{km_1m_2}{r^4}$, where k is a constant of appropriate dimensions. The direction of this force is along the line joining the two dipoles. **[JEE(Advanced) 2021]**



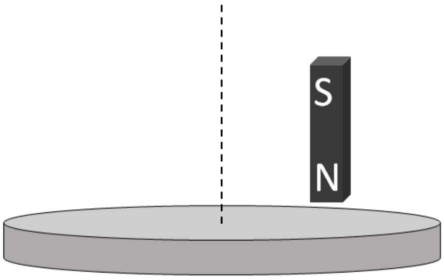

**9.** When the dipole m is placed at a distance r from the center of the loop (as shown in the figure), the current induced in the loop will be proportional to **[JEE(Advanced) 2021]**

(A) $\frac{m}{r^3}$ (B) $\frac{m^2}{r^2}$ (C) $\frac{m}{r^2}$ (D) $\frac{m^2}{r}$

**10.** The work done in bringing the dipole from infinity to a distance r from the center of the loop by the given process is proportional to **[JEE(Advanced) 2021]**

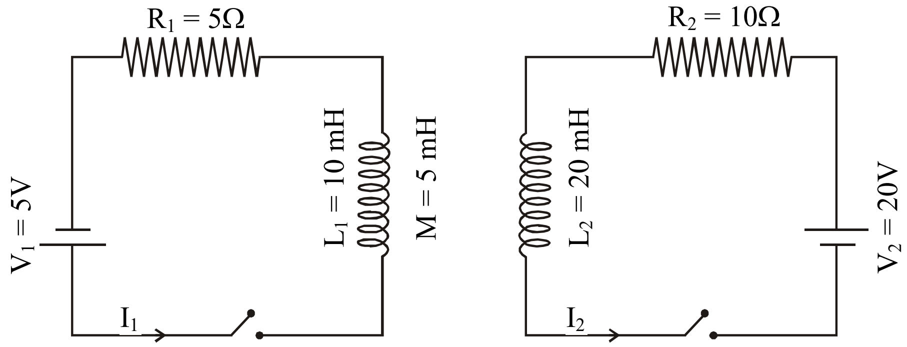
(A) $\frac{m}{r^5}$ (B) $\frac{m^2}{r^5}$ (C) $\frac{m^2}{r^6}$ (D) $\frac{m^2}{r^7}$

**11.** A light disc made of aluminium (a nonmagnetic material) is kept horizontally and is free to rotate about its axis as shown in the figure. A strong magnet is held vertically at a point above the disc away from its axis. On revolving the magnet about the axis of the disc, the disc will (figure is schematic and not drawn to scale)-
**[JEE(Advanced) 2020]**

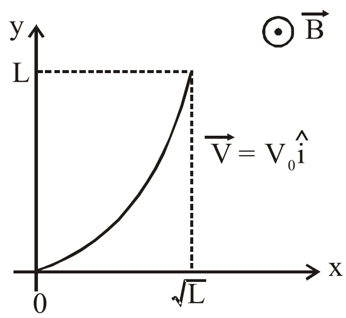



(A) rotate in the direction opposite to the direction of magnet's motion
(B) rotate in the same direction as the direction of magnet's motion
(C) not rotate and its temperature will remain unchanged
(D) not rotate but its temperature will slowly rise

**12.** The inductors of two LR circuits are placed next to each other, as shown in the figure. The values of the self-inductance of the inductors, resistances, mutual-inductance and applied voltages are specified in the given circuit. After both the switches are closed simultaneously, the total work done by the batteries against the induced EMF in the inductors by the time the currents reach their steady state values is________ mJ. **[JEE(Advanced) 2020]**




**13.** A conducting wire of parabolic shape, initially $y = x^2$, is moving with velocity $\vec{V} = V_0\hat{i}$ in a non-uniform magnetic field $\vec{B} = B_0\left(1+\left(\frac{y}{L}\right)^{\beta}\right)\hat{k}$, as shown in figure. If $V_0$, $B_0$, L and $\beta$ are positive constants and $\Delta\phi$ is the potential difference developed between the ends of the wire, then the correct statement(s) is/are: **[JEE(Advanced) 2019]**



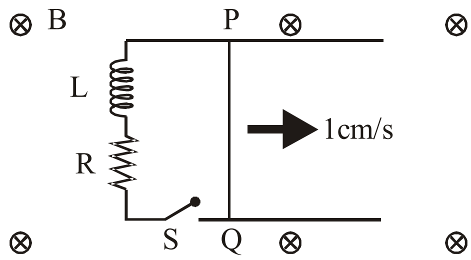

(A) $|\Delta\phi|$ remains the same if the parabolic wire is replaced by a straight wire, $y = x$ initially, of length $\sqrt{2}L$

(B) $|\Delta\phi|$ is proportional to the length of the wire projected on the y-axis.

(C) $|\Delta\phi| = \frac{1}{2}B_0V_0L$ for $\beta = 0$

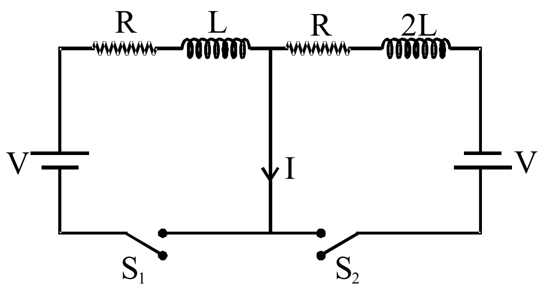
(D) $|\Delta\phi| = \frac{4}{3}B_0V_0L$ for $\beta = 2$

**14.** A 10 cm long perfectly conducting wire PQ is moving, with a velocity 1cm/s on a pair of horizontal rails of zero resistance. One side of the rails is connected to an inductor L = 1 mH and a resistance R = 1Ω as shown in figure. The horizontal rails, L and R lie in the same plane with a uniform magnetic field B = 1 T perpendicular to the plane. If the key S is closed at certain instant, the current in the circuit after 1 millisecond is $x \times 10^{-3}$A, where the value of x is_______.




[Assume the velocity of wire PQ remains constant (1 cm/s) after key S is closed.
Given : $e^{-1} = 0.37$ , where e is base of the natural logarithm] **[JEE(Advanced) 2019]**

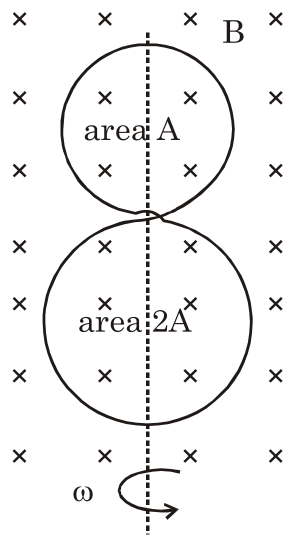
**15.** In the figure below, the switches $S_1$ and $S_2$ are closed simultaneously at t = 0 and a current starts to flow in the circuit. Both the batteries have the same magnitude of the electromotive force (emf) and the polarities are as indicated in the figure. Ignore mutual inductance between the inductors. The current I in the middle wire reaches its maximum magnitude $I_{max}$ at time t = τ. Which of the following statement(s) is (are) true? **[JEE(Advanced) 2018]**




(A) $I_{max} = \frac{V}{2R}$ (B) $I_{max} = \frac{V}{4R}$

(C) $\tau = \frac{L}{R}\ell n2$ (D) $\tau = \frac{2L}{R}\ell n2$

**16.** A circular insulated copper wire loop is twisted to form two loops of area A and 2A as shown in the figure. At the point of crossing the wires remain electrically insulated from each other. The entire loop lies in the plane (of the paper). A uniform magnetic field $\vec{B}$ points into the plane of the paper. At t = 0, the loop starts rotating about the common diameter as axis with a constant angular velocity ω in the magnetic field. Which of the following options is/are correct? **[JEE(Advanced) 2017]**



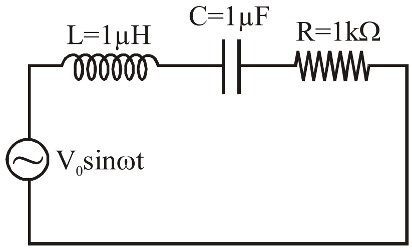

(A) The rate of change of the flux is maximum when the plane of the loops is perpendicular to plane of the paper

(B) The net emf induced due to both the loops is proportional to cos ωt

(C) The emf induced in the loop is proportional to the sum of the areas of the two loops

(D) The amplitude of the maximum net emf induced due to both the loops is equal to the amplitude of maximum emf induced in the smaller loop alone

**17.** In the circuit shown, L = 1 μH, C = 1 μF and R = 1 kΩ. They are connected in series with an a.c. source $V = V_0 \sin \omega t$ as shown. Which of the following options is/are correct ? **[JEE(Advanced) 2017]**



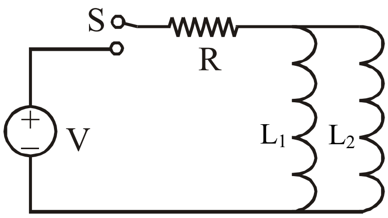

(A) The frequency at which the current will be in phase with the voltage is independent of R.

(B) At $\omega \sim 0$ the current flowing through the circuit becomes nearly zero

(C) At $\omega >> 10^6$ rad.s$^{-1}$, the circuit behaves like a capacitor.

(D) The current will be in phase with the voltage if $\omega = 10^4$ rad.s$^{-1}$.

**18.** A source of constant voltage V is connected to a resistance R and two ideal inductors $L_1$ and $L_2$ through a switch S as shown. There is no mutual inductance between the two inductors. The switch S is initially open. At t = 0, the switch is closed and current begins to flow. Which of the following options is/are correct?




(A) The ratio of the currents through $L_1$ and $L_2$ is fixed at all times (t > 0) **[JEE(Advanced) 2017]**

(B) After a long time, the current through $L_1$ will be $\frac{V}{R}\frac{L_2}{L_1+L_2}$

(C) After a long time, the current through $L_2$ will be $\frac{V}{R}\frac{L_1}{L_1+L_2}$

(D) At t = 0, the current through the resistance R is $\frac{V}{R}$

**19.** The instantaneous voltages at three terminals marked X, Y and Z are given by **[JEE(Advanced) 2017]**

$$V_X = V_0 \sin \omega t$$

$$V_Y = V_0 \sin\left(\omega t + \frac{2\pi}{3}\right) \text{ and}$$

$$V_Z = V_0 \sin\left(\omega t + \frac{4\pi}{3}\right)$$

An ideal voltmeter is configured to read rms value of the potential difference between its terminals. It is connected between points X and Y and then between Y and Z. The reading(s) of the voltmeter will be:-

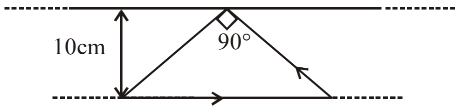
(A) $V_{XY}^{rms} = V_0$

(B) $V_{YZ}^{rms} = V_0\sqrt{\frac{1}{2}}$

(C) Independent of the choice of the two terminals

(D) $V_{XY}^{rms} = V_0\sqrt{\frac{3}{2}}$

**20.** A conducting loop in the shape of right angled isosceles triangle of height 10 cm is kept such that the 90° vertex is very close to an infinitely long conducting wire (see the figure). The wire is electrically insulated from the loop. The hypotenuse of the triangle is parallel to the wire. The current in the triangular loop is in counterclockwise direction and increased at constant rate of 10 A $s^{-1}$. Which of the following statement(s) is(are) true? **[JEE(Advanced) 2016]**




(A) The induced current in the wire is in opposite direction to the current along the hypotenuse.

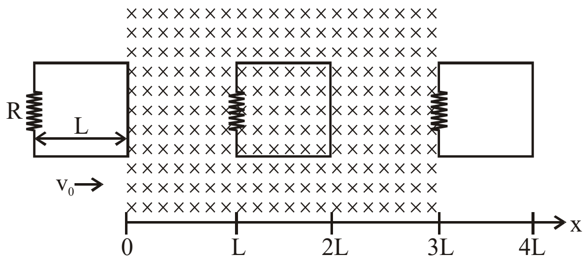
(B) There is a repulsive force between the wire and the loop

(C) If the loop is rotated at a constant angular speed about the wire, an additional emf of $\left(\frac{\mu_0}{\pi}\right)$ volt is induced in the wire

(D) The magnitude of induced emf in the wire is $\left(\frac{\mu_0}{\pi}\right)$ volt.

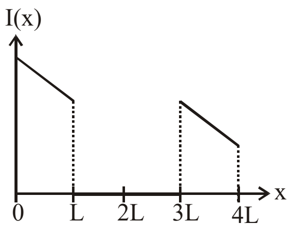
**21.** Two inductors $L_1$ (inductance 1 mH, internal resistance 3 Ω) and $L_2$ (inductance 2 mH, internal resistance 4Ω), and a resistor R (resistance 12 Ω) are all connected in parallel across a 5V battery. The circuit is switched on at time t = 0. The ratio of the maximum to the minimum current ($I_{max}/I_{min}$) drawn from the battery is. **[JEE(Advanced) 2016]**

**22.** A rigid wire loop of square shape having side of length L and resistance R is moving along the x-axis with a constant velocity $v_0$ in the plane of the paper. At t = 0, the right edge of the loop enters a region of length 3L where there is a uniform magnetic field $B_0$ into the plane of the paper, as shown in the figure. For sufficiently large $v_0$, the loop eventually crosses the region. Let x be the location of the right edge of the loop. Let v(x), I(x) and F(x) represent the velocity of the loop, current in the loop, and force on the loop, respectively, as a function of x. Counter-clockwise current is taken as positive.

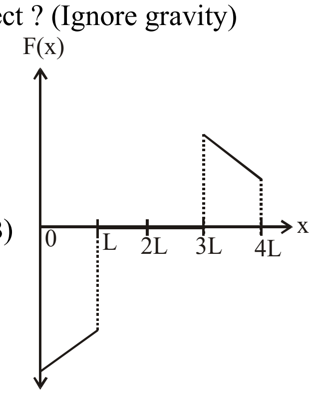



Which of the following schematic plot(s) is(are) correct ? (Ignore gravity) **[JEE(Advanced) 2016]**

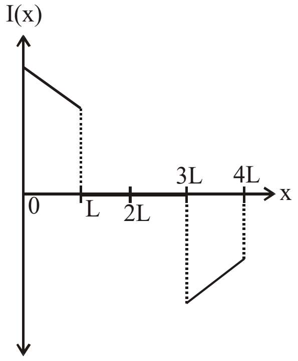
(A)



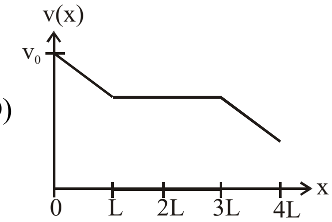

(B)



(C)



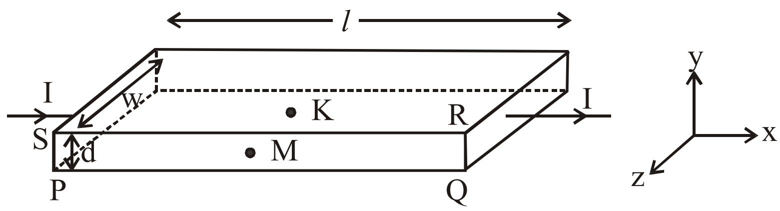

(D)




**Paragraph for Question No. 23 and 24**

In a thin rectangular metallic strip a constant current I flows along the positive x-direction, as shown in the figure. The length, width the thickness of the strip are $l$, w and d, respectively.

A uniform magnetic field $\vec{B}$ is applied on the strip along the positive y-direction. Due to this, the charge carriers experience a net deflection along the z-direction. This results in accumulation of charge carriers on the surface PQRS and appearance of equal and opposite charges on the face opposite to PQRS. A potential difference along the z-direction is thus developed. Charge accumulation continues until the magnetic force is balanced by the electric force. The current is assumed to be uniformly distributed on the cross section of the strip and carried by electrons.



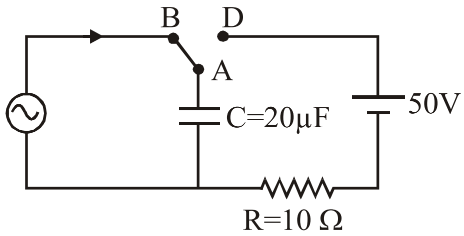

**23.** Consider two different metallic strips (1 and 2) of the same material. Their lengths are the same, widths are $w_1$ and $w_2$ and thicknesses are $d_1$ and $d_2$, respectively. Two points K and M are symmetrically located on the opposite faces parallel to the x-y plane (see figure). $V_1$ and $V_2$ are the potential differences between K and M in strips 1 and 2, respectively. Then, for a given current I flowing through them in a given magnetic field strength B, the correct statement(s) is(are) **[JEE(Advanced) 2015]**

(A) If $w_1 = w_2$ and $d_1 = 2d_2$, then $V_2 = 2V_1$
(B) If $w_1 = w_2$ and $d_1 = 2d_2$, then $V_2 = V_1$
(C) If $w_1 = 2w_2$ and $d_1 = d_2$, then $V_2 = 2V_1$
(D) If $w_1 = 2w_2$ and $d_1 = d_2$, then $V_2 = V_1$

**24.** Consider two different metallic strips (1 and 2) of same dimensions (length $l$, width w and thickness d) with carrier densities $n_1$ and $n_2$, respectively. Strip 1 is placed in magnetic field $B_1$ and strip 2 is placed in magnetic field $B_2$, both along positive y-direction. Then $V_1$ and $V_2$ are the potential differences developed between K and M in strips 1 and 2, respectively. Assuming that the current I is the same for both the strips, the correct option(s) is(are) **[JEE(Advanced) 2015]**

(A) If $B_1 = B_2$ and $n_1 = 2n_2$, then $V_2 = 2V_1$
(B) If $B_1 = B_2$ and $n_1 = 2n_2$, then $V_2 = V_1$
(C) If $B_1 = 2B_2$ and $n_1 = n_2$, then $V_2 = 0.5V_1$
(D) If $B_1 = 2B_2$ and $n_1 = n_2$, then $V_2 = V_1$

**25.** At time t = 0, terminal A in the circuit shown in the figure is connected to B by a key and an alternating current $I(t) = I_0\cos(\omega t)$, with $I_0$ = 1A and $\omega$ = 500 rad $s^{-1}$ starts flowing in it with the initial direction shown in the figure. At $t = \frac{7\pi}{6\omega}$, the key is switched from B to D. Now onwards only A and D are connected. A total charge Q flows from the battery to charge the capacitor fully. If C = 20 μF, R = 10 Ω and the battery is ideal with emf of 50 V, identify the correct statement (s). **[JEE(Advanced) 2014]**




(A) Magnitude of the maximum charge on the capacitor before $t = \frac{7\pi}{6\omega}$ is $1 \times 10^{-3}$C.

(B) The current in the left part of the circuit just before $t = \frac{7\pi}{6\omega}$ is clockwise.

(C) Immediately after A is connected to D, the current in R is 10A

(D) $Q = 2 \times 10^{-3}$ C

## SOLUTIONS

**1. Ans. (B)**

**Sol.** V = 45 sin ωt, L = 50 mH

$$\omega_0 = 10^5 \text{ rad/s} = \frac{1}{\sqrt{LC}} \Rightarrow C$$

$$= \frac{1}{L\omega_0^2} = \frac{1}{5\times10^{-2}\times10^{10}}$$

$= 2 \times 10^{-9}$ F

$$I_0 = \frac{45}{R}$$

$\omega = 8 \times 10^4$ rad/s = 0.8 $\omega_0$

$$I = 0.05I_0 = \frac{I_0}{20} \Rightarrow Z = 20R$$

$$X_L = 8\times10^4\times5\times10^{-2}\,\Omega = 4\text{k}\Omega$$

$$X_C = \frac{1}{8\times10^4\times2\times10^{-9}} = \frac{1}{16}\times10^5\,\Omega = \frac{25}{4}\text{k}\Omega$$

$$Z^2 = R^2 + (X_C - X_L)^2$$

$$400R^2 = R^2 + \left(\frac{9}{4}\text{k}\Omega\right)^2$$

$$R = \frac{\frac{9}{4}\text{k}\Omega}{\sqrt{399}} \approx \frac{9}{80}\text{k}\Omega = \frac{900}{8}\Omega$$

$$I_0 = \frac{V_0}{R} = \frac{45\times8}{900} = \frac{8}{20}A \approx 0.4A = 400\text{mA}$$

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}} = \frac{8}{900}\sqrt{\frac{5\times10^{-2}}{2\times10^{-9}}} = \frac{8}{900}\sqrt{25\times10^6}$$

$$Q = \frac{8}{900}\times5000 = 44.4$$

$$Q = \frac{\omega_0}{\Delta\omega} \Rightarrow \Delta\omega = \frac{\omega_0}{Q} = \frac{10^5}{44.4} = 2250.0$$

$$P_{max} = I_0^2R = \frac{45^2}{R^2}\times R$$

$$= \frac{45^2}{R} = \frac{45^2}{900}\times8 = 18.4\text{W}$$

**2. Ans. (D)**

**Sol.** From force equation

$$mg - Bi\ell = \frac{mdv}{dt}$$

$$mg - \frac{BBi\ell}{R}\times\ell = \frac{mdv}{dt}$$

$$\frac{mgR}{B^2\ell^2} - v = \frac{mR}{B^2\ell^2}\frac{dv}{dt}$$

$$\frac{B^2\ell^2}{mR}\int_{t=0}^{t} dt = \int_0^v \frac{dv}{\left(\frac{mgR}{B^2\ell^2} - v\right)}$$

Now $\frac{mgR}{B^2\ell^2} = \frac{20\times10^{-3}\times10\times10}{16\times\frac{1}{16}} = 2$

And $\frac{B^2\ell^2}{mR} = \frac{16\times\frac{1}{16}}{20\times10^{-3}\times10} = \frac{1}{0.2} = 5$

$$\therefore 5t = \left[-\ell n(2-v)\right]_0^v$$

$$-5t = \ell n\left[\frac{2-v}{v}\right]$$

$\therefore$ v = 2 (1 – $e^{-5t}$)

At t = 0.2 sec    v = 2 (1 – $e^{-5\times0.2}$)

v = 2 (1 – 0.4)

v = 1.2 m/s

(P) Now at t = 0.2 sec

The magnitude of the induced emf = E = Bvℓ

$$= 4\times1.2\times\frac{1}{4} = 1.2\text{Volt}$$

(Q) At t = 0.2 sec,

the magnitude of magnetic force = BIℓsinθ

$$= B\times\frac{B\ell v}{R}\times\ell\times\sin90°$$

$$= \frac{4\times4\times\frac{1}{4}\times1.3\times\frac{1}{4}}{10} = 0.12 \text{ Newton}$$

(R) At t = 0.2 sec, the power dissipated as heat

$$P = i^2R = \frac{v^2}{R} = \frac{1.2\times1.2}{10}$$

P = 0.144 watt

(S) Magnitude of terminal velocity

At terminal velocity, the net force become zero

$\therefore \quad mg = Bi\ell$

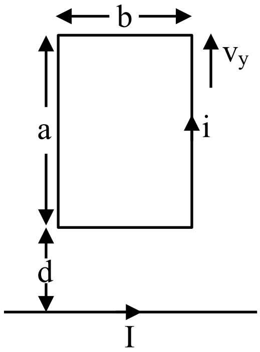
$$mg = B \times \frac{B\ell v_t}{R} \times \ell$$

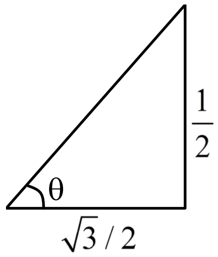
$$\therefore \quad v_T = \frac{mgR}{B^2\ell^2} = \frac{20 \times 10^{-3} \times 10 \times 10}{16 \times \frac{1}{16}}$$

$v_T = 2$ m/s

**3. Ans. (4)**

**Sol.**




$R = 0.1\Omega$

$\varepsilon = (B_1 - B_2)bv_y$

$$i = \frac{\varepsilon}{R} = \frac{\mu_0 I}{2\pi R}\left(\frac{1}{d} - \frac{1}{d+a}\right)bv_y$$

$$\Rightarrow 10^{-5} = \frac{2 \times 10^{-7} \times 10}{0.1}\left[\frac{1}{4} - \frac{1}{8}\right] \times 2.v_y$$

$\therefore v_y = 2$

$$\tan\theta = \frac{v_y}{v_x} = \frac{1}{\sqrt{3}}$$

$\therefore v_x = 2\sqrt{3}$

$\therefore \; v = \sqrt{v_x^2 + v_y^2} = 4$

**4. Ans. (3.98 - 4.02)**

**Sol.** Maximum energy will be

$$\frac{q_0^2}{2C} = \frac{1}{2}LI_0^2$$

$$\frac{q_0^2}{CL} = I_0^2$$

$$I_0 = \frac{q_0}{\sqrt{LC}}$$

$$I_0 = \frac{CV}{\sqrt{LC}}$$

$$I_0 = \sqrt{\frac{C}{L}} \times V \qquad V = \text{emf} = \left|\frac{AdB}{dt}\right|$$

$$I_0 = \sqrt{\frac{10^{-3}}{0.1}} \times 0.04 \qquad V = (1 \times 0.04)$$

Maximum current $I_0 = 0.004 = 4$mA

**Ans. (4)**

**5. Ans. (Dropped)**

**Sol.** (I) $\vec{B} = \frac{\mu_0 mI}{\sqrt{2}}\left(\sin\omega t\,\hat{j} + \cos\omega t\,\hat{k}\right)$

$$\phi = \vec{B}\cdot\vec{A} = \frac{\mu_0 mI}{\sqrt{2}}\cos(\omega t)\cdot A$$

$$\varepsilon = \frac{d\phi}{dt} = \frac{\mu_0 mI\omega A}{\sqrt{2}}\sin(\omega t)$$

$$i = \frac{\varepsilon}{R} = \frac{\mu_0 mI\omega A}{\sqrt{2}R}\sin(\omega t)$$

$$\vec{M} = i\vec{A} = iA(\hat{k}) = \frac{\mu_0 mI\omega A^2}{\sqrt{2}R}\sin(\omega t)(\hat{k})$$

$$\vec{\tau} = \vec{M} \times \vec{B} = \frac{\mu_0 m^2 I^2 \omega A^2}{\sqrt{2}R}\sin^2(\omega t)(-\hat{i})$$

$$= -\left(\frac{\alpha}{4}\right)\hat{i}$$

(II) $\vec{B} = \frac{\mu_0 mI}{\sqrt{2}}\left(\sin\omega t\,\hat{i} + \cos\omega t\,\hat{j}\right)$

$\phi = 0,\ \varepsilon = 0,\ i = 0,\ t = 0$

(III) $\vec{B} = \frac{\mu_0 mI}{\sqrt{2}}\left(\sin\omega t\,\hat{i} + \cos\omega t\,\hat{k}\right)$

$$\phi = \vec{B}\cdot\vec{A} = \frac{\mu_0 mI}{\sqrt{2}}\cdot\cos(\omega t)\cdot A$$

$$\varepsilon = -\frac{d\phi}{dt} = \frac{\mu_0 mI\omega A}{\sqrt{2}}\sin(\omega t)$$

$$i = \frac{\varepsilon}{R} = \frac{\mu_0 mI\omega A}{\sqrt{2}R}\sin(\omega t)$$

$$\vec{M} = i\vec{A} = iA(\hat{k}) = \frac{\mu_0 mI\omega A^2}{\sqrt{2}R}\sin(\omega t)(\hat{k})$$

$$\vec{\tau} = \vec{M} \times \vec{B} = \frac{\mu_0 m^2 I^2 \omega A^2}{2R}\sin^2(\omega t)(+\hat{j})$$

$$= \frac{\alpha}{4}\hat{j}$$

(IV) $\vec{B} = \frac{\mu_0 mI}{\sqrt{2}}\left(\cos\omega t\,\hat{j} + \sin\omega t\,\hat{k}\right)$

$\phi = \vec{B}\cdot\vec{A} = \frac{\mu_0 mI}{\sqrt{2}}\cdot\sin(\omega t)\cdot A$

$\varepsilon = -\frac{d\phi}{dt} = \frac{\mu_0 mI\omega A}{\sqrt{2}}\cos(\omega t)$

$i = \frac{\varepsilon}{R} = -\frac{\mu_0 mI\omega A}{\sqrt{2}R}\cos(\omega t)$

$\vec{M} = i\vec{A} = iA(\hat{k}) = -\frac{\mu_0 mI\omega A^2}{\sqrt{2}R}\cos(\omega t)(\hat{k})$

$\vec{\tau} = \vec{M}\times\vec{B} = -\frac{\mu_0 m^2 I^2\omega A^2}{2R}\cos^2(\omega t)(-\hat{i})$

$= \alpha\cdot\cos^2\left(\frac{\pi}{6}\right)\hat{i}$

$= \frac{3\alpha}{4}\hat{i}$

**Ans. (C) I –Q, II-P, III-S, IV-R**

**6. Ans. (A, C)**

**Sol.** EMF developed across the emf of semi-circular rod = $\int_1^4 \frac{\mu_0 i}{2\pi r}drv = \frac{\mu_0 iv}{2\pi}\ell n4 = \frac{\mu_0 iv}{\pi}\ell n2$

Form given value,

$E = \frac{4\pi\times10^{-7}\times2\times3\times0.7}{\pi} = 24\times7\times10^{-8}$

$i_{max} = \frac{E}{R} = \frac{24\times7\times10^{-8}}{1.4} = 1.2\times10^{-6}A$

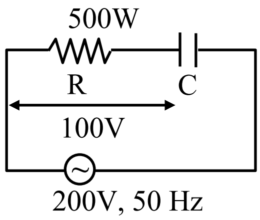
$Q_{max} = C_0E = 24\times7\times10^{-8}\times5\times10^{-6}$

$= 8.4\times10^{-12}C$

**7. Ans. (100.00)**

**8. Ans. (60.00)**

**Sol.**




$\sqrt{V_C^2 + V_R^2} = \varepsilon_{rms} \quad \Rightarrow V_C^2 + 100^2 = 200^2$

$V_C = 100\sqrt{3}V$ ...(i)

$\tan\phi = \frac{V_C}{V_R} = \frac{100\sqrt{3}}{100}$

$\therefore \phi = 60°$ ....(ii)

$P = I_{rms}\varepsilon_{rms}\cos\phi = \frac{\varepsilon_{rms}^2}{z}\frac{1}{2}$

$500 = \frac{200}{z}\frac{1}{2}$

$\therefore z = 40\,\Omega$ ....(iii)

$\cos\phi = \frac{R}{Z} \Rightarrow \frac{1}{2} = \frac{R}{40}$

$\therefore R = 20$

& $x_C = \sqrt{z^2 - R^2} = \sqrt{40^2 - 20^2} = 20\sqrt{3}\Omega$

$\Rightarrow \frac{1}{\omega C} = 20\sqrt{3} \quad \therefore C = 100$

**9. Ans. (A)**

**10. Ans. (C)**

**Sol.** $\phi = Li = \frac{\mu_0 m}{2\pi r^3}\times\pi a^2$

$\Rightarrow i = \frac{\mu_0 m\pi a^2}{2\pi r^3 L} \quad \Rightarrow i \propto \frac{m}{r^3}$

$m' = \pi a^2 i = \frac{\mu_0 m\pi^2 a^4}{2\pi r^3 L}$

$F = \frac{km^2\pi^2 a^4}{2\pi r^7 L}$

$W = \int Fdr \propto \int\frac{m^2 dr}{r^7}$

$W \propto \frac{m^2}{r^6}$

**11. Ans. (B)**

**Sol.** When the magnet is moved, it creates a state where the plate moves through the magnetic flux, due to which an electromotive force is generated in the plate and eddy currents are induced. These currents are such that it opposes the relative motion $\Rightarrow$ disc will rotate in the direction of rotation of magnet.

Note : This apparatus is called Arago's disk.

**12. Ans. (55.00)**

**Sol.** Mutal inductance is producing flux in same direction as self inductance.

$\therefore \quad U = \frac{1}{2}L_1I_1^2 + \frac{1}{2}L_2I_2^2 + MI_1I_2$

$\Rightarrow U = \frac{1}{2}\times(10\times10^{-3})1^2 + \frac{1}{2}\times(20\times10^{-3})\times2^2$

$+ (5\times10^{-3})\times1\times2$

$= 55$ mJ

**13. Ans. (A, B, D)**

**Sol.** $y = x^2$

$$B = B_0\left[1+\left(\frac{y}{L}\right)^{\beta}\right]\hat{k}$$

$$\int d\phi = \int_0^L V_0B_0\left(1+\frac{y^{\beta}}{L^{\beta}}\right)\cdot dy$$

$$\Delta\phi = V_0B_0\left[L+\frac{L^{\beta+1}}{(\beta+1)L^{\beta}}\right]$$

$$\Delta\phi = V_0B_0\left[L+\frac{L}{\beta+1}\right]$$

$$\because |\Delta\phi| = B_0V_0\left(1+\frac{1}{\beta+1}\right)\cdot L$$

$|\Delta\phi| \propto L$ $\therefore$ option '2' is also correct

If $\beta = 0$

$\Delta\phi = V_0B_0 [L + L]$

$\Delta\phi = 2V_0B_0L \Rightarrow$ option (3) is incorrect

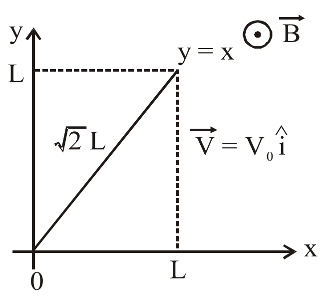
If $\beta = 2$

$$\Delta\phi = V_0B_0\left[L+\frac{L}{3}\right]$$

$\Delta\phi = \frac{4}{3}V_0B_0L$ option (4) is correct

$\Delta\phi$ will be same if the wire is repalced by the straight wire of length $\sqrt{2}L$ and $y = x$

$\because$ range of y remains same



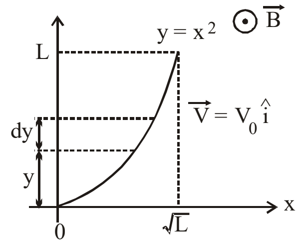

$\therefore$ option (A) is correct.

**14. Ans. (0.62 to 0.64)**

**Sol.** Since velocity of PQ is constant. So emf developed across it remains constant.

$\varepsilon = B\ell v$ where $\ell$ = length of wire PQ

Current at any time t is given by




$$i = \frac{\varepsilon}{R}\left(1-e^{-\frac{Rt}{L}}\right)$$

$$i = \frac{B\ell v}{R}\left(1-e^{-\frac{Rt}{L}}\right)$$

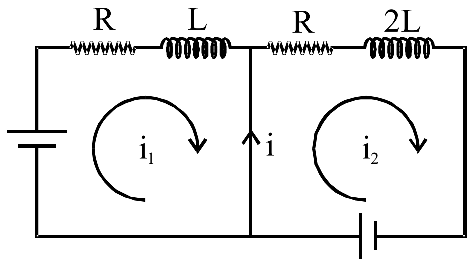
$$= 1\times\left(\frac{10}{100}\right)\times\left(\frac{1}{100}\right)\times\frac{1}{1}\left(1-e^{\frac{-1\times10^{-3}}{1\times10^{-3}}}\right)$$

$$= \frac{1}{1000}\times(1-e^{-1}) = \frac{1}{1000}\times(1-0.37)$$

$i = 0.63 \times 10^{-3}$ A $\Rightarrow x = 0.63$

**15. Ans. (B, D)**

**Sol.**




$i_{max} = (i_2 - i_1)_{max}$

$$\Delta i = (i_2 - i_1) = \frac{V}{R}\left[1-e^{-\left(\frac{R}{2L}\right)t}\right] - \frac{V}{R}\left[1-e^{\left(-\frac{R}{L}\right)t}\right]$$

$$\frac{V}{R}\left[e^{-\left(\frac{R}{L}\right)t} - e^{-\left(\frac{R}{2L}\right)t}\right]$$

For $(\Delta i)_{max}$ $\frac{d(\Delta i)}{dt} = 0$

$$\frac{V}{R}\left[-\frac{R}{L}e^{-\left(\frac{R}{L}\right)t} - \left(-\frac{R}{2L}\right)e^{-\left(\frac{R}{2L}\right)t}\right] = 0$$

$$e^{-\left(\frac{R}{L}\right)t} = \frac{1}{2}e^{-\left(\frac{R}{2L}\right)t}$$

$$e^{-\left(\frac{R}{2L}\right)t} = \frac{1}{2}$$

$$\left(\frac{R}{2L}\right)t = \ell n2$$

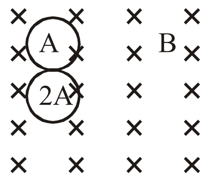
$t = \frac{2L}{R}\ell n2 \rightarrow$ time when i is maximum.

$$i_{max} = \frac{V}{R}\left[e^{-\frac{R}{L}\left(\frac{2L}{R}\ell n2\right)} - e^{-\left(\frac{R}{2L}\right)\left(\frac{2L}{R}\ell n2\right)}\right]$$

$$|i_{max}| = \frac{V}{R}\left|\left[\frac{1}{4}-\frac{1}{2}\right]\right| = \frac{1}{4}\frac{V}{R}$$

**16. Ans. (A, D)**

**Sol.**




$\phi = |B||A|\cos\theta$

$= BA\cos(\omega t)$

$$\varepsilon = -\frac{d\phi}{dt} = BA\omega\sin(\omega t)$$

so, $\varepsilon$ & $\frac{d\phi}{dt} \propto \sin(\omega t)$

so, maximum when, $\omega t = \theta = \frac{\pi}{2}$.

Net emf will be difference of emfs in both loops because their polarities are opposite.

$\varepsilon_{Net} = \varepsilon_{2A} - \varepsilon_A = B(2A)\omega\sin\omega t - B(A)\omega\sin(\omega t)$

$= B(2A - A)\omega\sin\omega t = BA\omega\sin\omega t$

**17. Ans. (A, B)**

**Sol.** $\tan\phi = \frac{\omega L - \frac{1}{\omega C}}{R} = 0$

$$\omega = \omega_0 = \frac{1}{\sqrt{LC}}$$

$\omega_0 = 10^6$ rad/s

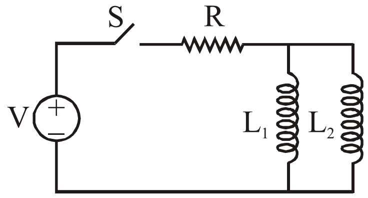
$$i_0 = \frac{V_0}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$$

$\omega \simeq 0,\ i_0 \simeq 0$

For $\omega >> \omega_0$, circuit behaves as inductor.

**18. Ans. (A, B, C)**

**Sol.**




Since inductors are connected in parallel

$V_{L_1} = V_{L_2}$

$$L_1\frac{dI_1}{dt} = L_2\frac{dI_2}{dt}$$

$L_1I_1 = L_2I_2$

$$\frac{I_1}{I_2} = \frac{L_2}{L_1}$$

Current through resistor at any time t is given by

$$I = V/R\ (1 - e^{-\frac{RT}{L}}) \text{ where } L = \frac{L_1L_2}{L_1+L_2}$$

After long time $I = \frac{V}{R}$

$I_1 + I_2 = I$ ...(i)

$L_1I_1 = L_2I_2$ ...(ii)

From (i) & (ii) we get

$$I_1 = \frac{V}{R}\frac{L_2}{L_1+L_2},\quad I_2 = \frac{V}{R}\frac{L_1}{L_1+L_2}$$

(D) value of current is zero at t = 0

value of current is V/R at $t = \infty$

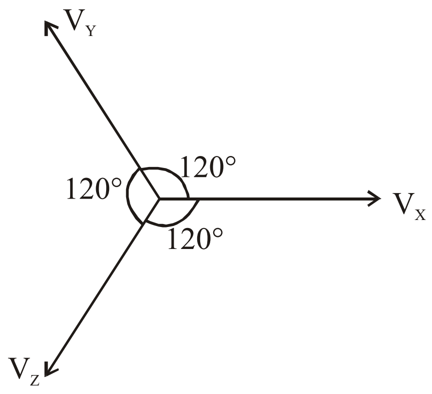
Hence option (D) is incorrect.

**19. Ans. (C, D)**

**Sol.** Potential difference between X & Y = $V_X - V_Y$

Potential difference between Y & Z = $V_Y - V_Z$

Phasor of the voltages :



$\therefore V_X - V_Y = \sqrt{3}V_0$

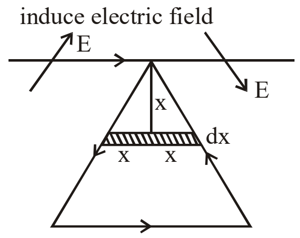
$$V_{XY}^{rms} = \frac{\sqrt{3}V_0}{\sqrt{2}}$$

similarly $V_{YZ}^{rms} = \frac{\sqrt{3}V_0}{\sqrt{2}}$

Also difference is independent of choice of two terminals.

**20. Ans. (B, D)**

**Sol.**




by direction of induced electric field, current in wire is in same direction of current along the hypotenuse.

Flux through triangle if wire have current i

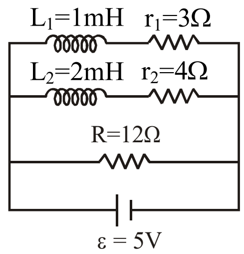
$$= \int_0^{0.1} \left(\frac{\mu_0 i}{2\pi x}\right)(2x dx) = \frac{\mu_0 i}{10\pi}$$

$\Rightarrow$ Mutual inductance $= \frac{\mu_0}{10\pi}$

Induced emf in wire $= \frac{\mu_0}{10\pi}\frac{di}{dt} = \frac{\mu_0}{10\pi} \times 10 = \frac{\mu_0}{\pi}$

**21. Ans. (8)**

**Sol.**




$$I_{max} = \frac{\varepsilon}{R} = \frac{5}{12}\text{A} \text{ (Initially at t = 0)}$$

$$I_{min} = \frac{\varepsilon}{R_{eq}} = \varepsilon\left(\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{R}\right)$$

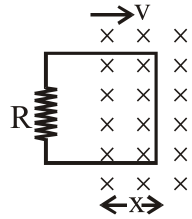
(finally in steady state)

$$= 5\left(\frac{1}{3} + \frac{1}{4} + \frac{1}{12}\right) = \frac{10}{3}\text{A}$$

$$\frac{I_{max}}{I_{min}} = 8$$

**22. Ans. (C, D)**

**Sol.**




When loop was entering (x < L)

$\phi = BLx$

$$e = -\frac{d\phi}{dt} = -BL\frac{dx}{dt}$$

$$|e| = BLVzd$$

$$i = \frac{e}{R} = \frac{BLV}{R}(\text{ACW})$$

F = i$\ell$B (Left direction) $= \frac{B^2L^2V}{R}$

(in left direction)

$$\Rightarrow a = \frac{F}{m} = -\frac{B^2L^2V}{mR} \qquad a = V\frac{dV}{dx}$$

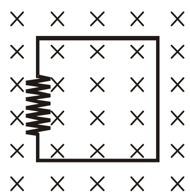
$$V\frac{dV}{dx} = -\frac{B^2L^2V}{mR} \Rightarrow \int_{V_0}^{V} dV = -\frac{B^2L^2}{mR}\int_0^x dx$$

$$\Rightarrow V = V_0 - \frac{B^2L^2}{mR}x$$

(straight line of negative slope for x < L)

$I = \frac{BL}{R}V \Rightarrow$ (I vs x will also be straight line of negative slope for x < L)

$L \le x \le 3L$

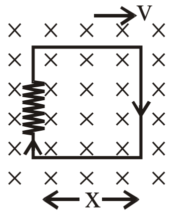


$$\frac{d\phi}{dt} = 0$$

e = 0i = 0

F = 0

x > 4L




$e = B\ell v$

Force also will be in left direction.

$i = \frac{BLV}{R}$ (clockwise) $a = -\frac{B^2L^2V}{mR} = V\frac{dV}{dx}$

$F = \frac{B^2L^2V}{R}$ $\int_L^x -\frac{B^2L^2}{mR}dx = \int_{V_i}^{V_f} dV$

$\Rightarrow -\frac{B^2L^2}{mR}(x-L) = V_f - V_i$

$V_f = V_i - \frac{B^2L^2}{mR}(x-L)$

(straight line of negative slope)

$I = \frac{BLV}{R} \rightarrow$ (Clockwise)

(straight line of negative slope)

**23. Ans. (A, D)**

**Sol.** $qv_dB = qE = \frac{qV}{w}$

$\Rightarrow V = wB \times v_d = \frac{wBI}{newd} = \frac{BI}{ned}$

$\therefore \frac{V_1}{V_2} = \frac{d_2}{d_1}$

$\therefore$ if $d_1 = 2d_2 \Rightarrow V_2 = 2V_1$

& if $d_1 = d_2 \Rightarrow V_1 = V_2$

**24. Ans. (A, C)**

**Sol.** As done in the above question

$V = \frac{BI}{ned}$

$\therefore V \propto \frac{B}{n}$

or $\frac{V_1}{V_2} = \frac{B_1n_2}{B_2n_1}$

$\therefore$ if $B_1 = B_2$ & $n_1 = 2n_2 \Rightarrow V_2 = 2V_1$

& if $B_1 = 2B_2$ & $n_1 = n_2 \Rightarrow V_2 = 0.5V_1$

**25. Ans. (C, D)**

**Sol.** Current $I = I_0 \cos(\omega t)$

$\frac{dq}{dt} = I_0 \cos(\omega t)$

$\Rightarrow q = \frac{I_0}{\omega}\sin(\omega t)$

$\Rightarrow q = \frac{1}{500}\sin(\omega t)$

$\Rightarrow q = (2 \times 10^{-3})\sin(\omega t)$

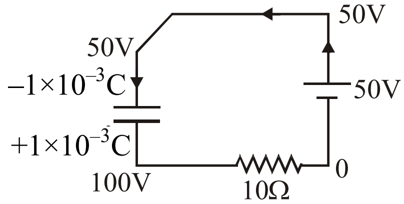
So, maximum charge = $2 \times 10^{-3}$ C

immediately before $t = \frac{7\pi}{6\omega}$

Current in left part just before $t = \frac{7\pi}{6\omega}$

$I = I_0 \cos\left(\omega \times \frac{7\pi}{6\omega}\right) = -\frac{I_0\sqrt{3}}{2}$

Since current is negative hence current will be anticlockwise.




immediately after $t = \frac{7\pi}{6\omega}$

$q = (2 \times 10^{-3})\sin\left(\omega \times \frac{7\pi}{6\omega}\right)$

$= -1 \times 10^{-3}$ C

Current in 10 Ω resistance,

$I = \frac{100}{10} = 10A$

At steady state, potential difference of capaictor is same as of battery,

So, final charge is

$Q_f = C\varepsilon = (20\ \mu F)(50\ V) = +1 \times 10^{-3}$ C

change in charge $= +10^{-3} - (-10^{-3}) = 2 \times 10^{-3}$ C