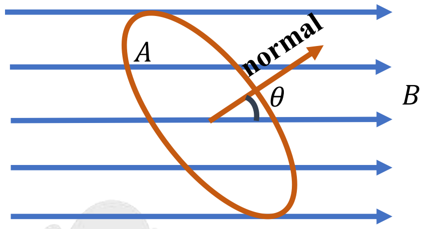
SYNOPSIS

- The phenomenon in which electric current is induced by varying magnetic fields is called electromagnetic induction.
- Magnetic Flux (ϕ): The number of magnetic lines of force passing normally through a given area is called magnetic flux.



When a surface of area A is placed in a uniform magnetic field of induction B, such that the unit vector along the normal $(\hat{n})$ makes an angle 'θ' with the direction of the magnetic field then the flux passing through it is given by $\phi = \bar{B}.\bar{A} = BA\cos\theta$

- If magnetic field is non uniform then $\phi = \int \bar{B}.\overline{ds}$
- The SI unit of flux is weber (W(B).

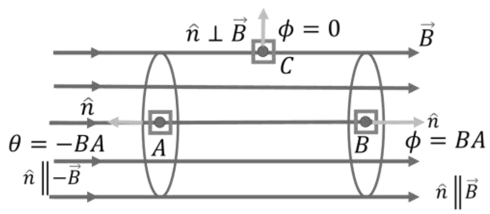
  CGS unit of flux is maxwell (Mx)

  1 weber = 1 tesla - meter^2

  1 weber = 10^8 maxwell

  The dimensional formula of the magnetic flux is $ML^2T^2A^{-1}$

  Magnetic flux is a scalar
- Magnetic flux can be positive, negative, or zero depending upon the angle between the area vector and field direction.
- When a cylinder is placed in a uniform magnetic field as shown in the below figure.



(i) When the plane of the surface is parallel to the direction of the magnetic field (or) normal drawn to the surface is perpendicular to the magnetic field

$(\hat{n} \perp \vec{B})$ then magnetic flux linked with the surface is zero i.e., $\phi = 0$ $[\because \theta = 90^\circ]$

(ii) When the plane of the surface is perpendicular to the magnetic field (or) normal drawn to the surface is parallel to the magnetic field $(\hat{n} \| \vec{B})$, then the magnetic flux linked with the surface is maximum i.e., $\phi_{max} = BA \ (\because \theta = 0^0)$

(iii) When the flux entering the surface is opposite to the area vector $(\hat{n})$ then

$\phi = -BA \ (\because \theta = 180^0)$

➢ The magnetic flux linked with a coil $(\phi = NBA\cos\theta)$ can be changed by

(A) Changing the no. of turns (N)

(B) Varying the magnetic field (B)

(C) Changing the area of the magnetic field bounded by the coil by moving the coil into or out of the magnetic field

(D) Changing the angle made by the coil with the direction of the field

➢ The change of flux due to rotation of the coil:

When the coil is rotated from an angle of θ_1 to an angle of θ_2 (both are measured with respect to normal) in a uniform magnetic field then the initial flux through the coil is

$\phi_i = NBA\cos\theta_1$

The final flux through the coil after rotation is

$\phi_f = NBA\cos\theta_2$

The change in the flux associated with the coil is

$\Delta\phi = \phi_f - \phi_i$

$\Delta\phi = NBA(\cos\theta_2 - \cos\theta_1)$

If $\theta_1 = 0^0$ and $\theta_2 = 90^0$ then $\Delta\phi = -NBA$

If $\theta_1 = 90^0$ and $\theta_2 = 180^0$ then $\Delta\phi = -NBA$

if $\theta_1 = 0^0$ and $\theta_2 = 180^0$ then $\Delta\phi = -2NBA$

FARADAY'S LAWS OF ELECTROMAGNETIC INDUCTION

First Law: Whenever the magnetic flux linked with an electric circuit (coil) changes, an emf is induced in the circuit (coil). The induced emf exists as long as the change in magnetic flux continues.

Second Law: The induced emf produced in the coil is equal to the negative rate of change of magnetic flux linked with it.

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

where ϕ = flux through each turn

If the coil contains N turns, an emf appears in every turn and all these emfs are to be added.

Then, the induced emf is given by

$$e = -N.\frac{d\phi}{dt} = -\frac{d}{dt}(N\phi)$$

Where $'N\phi'$ is total flux linked with the coil of N turns.

(or) $e = -\frac{d}{dt}(N\phi) = -\frac{d}{dt}(NBA\cos\theta)$

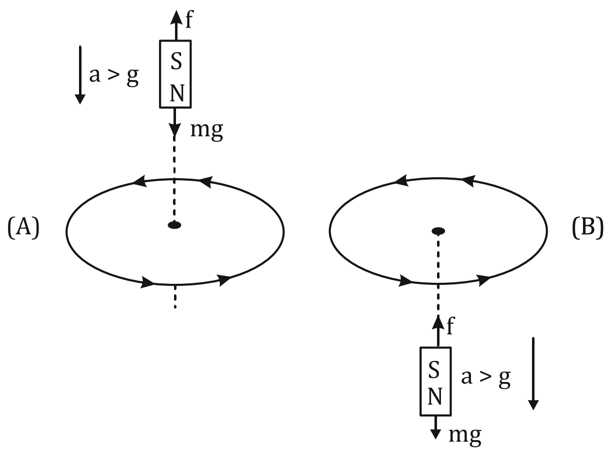
Negative sign is in accordance with Lenz's law.

The above law is also called **Neumann's law.**

LENZ'S LAW AND CONSERVATION OF ENERGY

"The direction of the induced emf is always such that it tends to produce a current which opposes the change in magnetic flux"

- Induced emf can exist whether the circuit is opened or closed. But induced current can exist only in the closed circuits.
- A metallic ring is held horizontally and a bar magnet is dropped through the ring with its length along the axis of the ring, as shown in figure.



In both the cases net force on the magnet is

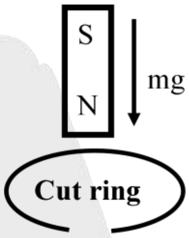
$$F_{net} = mg - f$$

Hence net acceleration of the fall is

$$a_{net} = g - \frac{f}{m} \Rightarrow a_{net} < g$$

Where f = force exerted by the induced magnetic field of ring on the magnet.

- When the magnet is allowed to fall through an open ring (or) cut ring, then



(A) an emf is induced

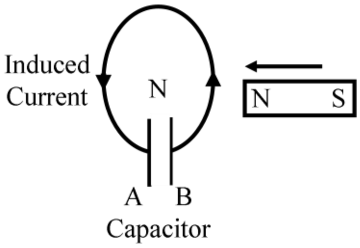
(B) No current is induced (since the ring is not close(D) and hence no induced magnetic field.

(C) No opposition to the motion of the magnet.

(D) $F_{net} = mg$

e) $a_{net} = g$ Magnet falls with an acceleration = g

- When a magnet is allowed to fall through two identical metal coils at different temperatures then magnet falls slowly through the coil at low temperature. As its resistance is less more induced current flows so more is the opposition.
- A magnet allowed to fall through a long cylindrical pipe then the acceleration of magnet is always less than 'g' and the acceleration continuously decreases due to induced currents. But the velocity increases until the magnet moves with acceleration. At a particular instant the acceleration becomes zero and the magnet moves downwards with uniform velocity, called terminal velocity.
- When north pole of a magnet is moved perpendicular to the plane of the coil as shown in figure, then



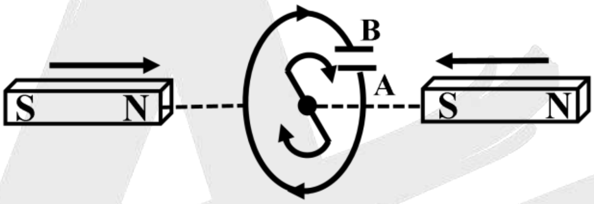
(A) emf is induced

(B) Induced current flows from B to A along the coil when A and B are connected through resistor.

(C) Electrons flow from A to B along the coil

(D) Hence plate A will become positively charged and plate B becomes negatively charged.

- When the two magnets are moved perpendicular to plane of coil as shown, then



(A) emf is induced

(B) Induced current flows from A to B along the coil when A and B are connected through resistor.

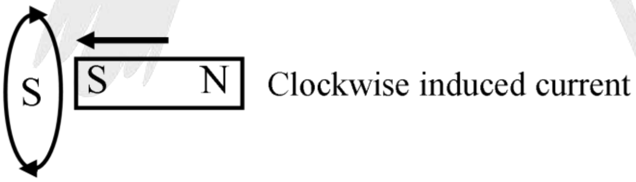
(C) Electrons flow from B to A along the coil

(D) Hence plate A will become negatively charged and plate B becomes positively charged.

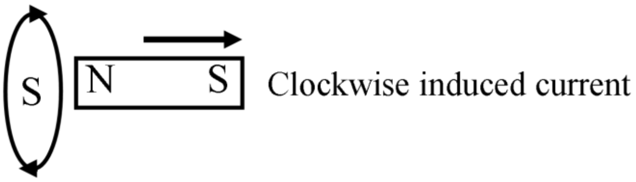
- The directions of induced current in coil for different kinds of motion of magnets

(because there is no change of flux linked with the coil)

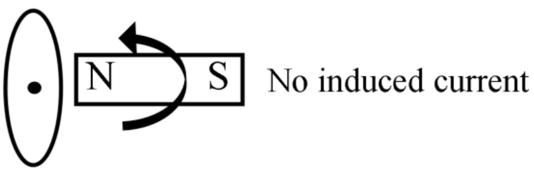
(a)



(b)

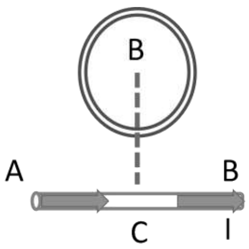


(c)



- When a current carrying conductor is placed beside a closed loop in its plane then the induced current direction for the following are

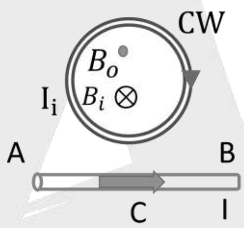
(A) Current in conductor is constant.



I = Constant
ϕ = Constant
I_i = Zero
(A)

$\therefore$ No induced current

(B) Current through the conductor increases as shown.

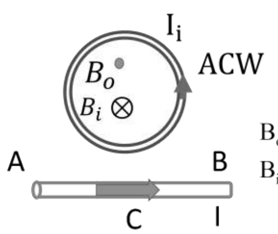


B_o – Original field
B_i – Induced field

I = Increasing
ϕ = Increasing
I_i = clock wise
(B)

- In this case, the flux through the loop due to current carrying wire is out of the plane of the coil.
- As current is increasing, the outward flux through the coil also increases.
- Hence to oppose this, an inward flux is created by the clockwise induced current.

(A) Current through the conductor decreases as shown.



B_o – Original field
B_i – Induced field

I = Decreasing
ϕ = Decreasing
I_i = Anticlock wise
(C)

In this case, the flux through the loop due to current carrying wire is out of the plane of the coil.

As current is decreasing, the outward flux through the coil also decreases.

Hence to oppose this, an outward flux is created by the anti-clock wise induced current.

EXPRESSIONS FOR INDUCED EMF, INDUCED CURRENT AND INDUCED CHARGE

- According to Faraday's second law and Lenz's law the induced emf is given by $e = -\frac{d\phi}{dt}$

  If the coil has N turns than $e = -N\frac{d\phi}{dt} \Rightarrow e = -N\frac{(\phi_2 - \phi_1)}{dt}$

- As $\phi = BAN\cos\theta$ and $e = -\frac{d\phi}{dt}$

  The emf is induced or change in flux is caused by changing B or A or N or θ

- If 'B' is changed then

  (A) Average induced emf $e = -AN\cos\theta\frac{(B_2 - B_1)}{(t_2 - t_1)}$

  Here B_1 is magnetic field induction at an instant t_1 and B_2 is magnetic field induction at an instant t_2

  (B) If the plane of the coil is perpendicular to magnetic field, then $\theta = 0^0 \Rightarrow \cos\theta = 1$ then

  $$e = -AN\frac{(B_2 - B_1)}{(t_2 - t_1)}$$

  (C) Instantaneous emf $e = -AN\cos\theta\frac{dB}{dt}$

- If 'A' is changed then

  (A) Average induced emf

  $$e = -BN\cos\theta\frac{(A_2 - A_1)}{(t_2 - t_1)}$$

  (B) If the plane of the coil is perpendicular to magnetic field, then $\theta = 0^0 \Rightarrow \cos\theta = 1$

  then $e = -BN\frac{(A_2 - A_1)}{(t_2 - t_1)}$

  (C) Instantaneous emf $e = -BN\cos\theta\frac{dA}{dt}$

- If 'θ' is changed (i.e., if coil is rotate(D)

(A) Average induced emf

$$e = -BAN\frac{(\cos\theta_2 - \cos\theta_1)}{(t_2 - t_1)}$$

(B) Instantaneous emf $e = -BAN\frac{d}{dt}(\cos\theta)$

If the coil is rotated with constant angular velocity $'\omega'$ then $\theta = \omega t$ and

$$e = -BAN\frac{d}{dt}(\cos\omega t) = BAN\omega\sin\omega t$$

$\therefore e = BAN\omega\sin\omega t$

(C) $\omega t = 90^0$, if the plane is parallel to the magnetic field then induced emf is maximum.

Then Peak emf.

$e_0 = BAN\omega \qquad \therefore e = e_0 \sin\omega t$

This is the principle of AC generator.

INDUCED CURRENT

If the magnetic flux in a coil of resistance R changes from ϕ_1 to ϕ_2 in a time 'dt', then a current 'i' is induced in the coil as $i = \frac{e}{R}$

$$i = \frac{N(\phi_2 - \phi_1)}{Rdt} \qquad \left[\because e = -N.\frac{d\phi}{dt}\right]$$

$\therefore$ Induced current is given by

Magnitude of current

$$i = \frac{\text{Induced emf}}{\text{Resistance in the circuit}} = \frac{N}{R}\left(\frac{d\phi}{dt}\right)$$

INDUCED CHARGE

➢ The amount of charge induced in a conductor is given as follows

We know, $I = \frac{e}{R}$ or $I = \frac{1}{R}\left(-\frac{d\phi}{dt}\right) = \frac{dq}{dt} = \frac{-1}{R}\frac{d\phi}{dt}$ or $dq = \frac{-1}{R}d\phi$

$\therefore$ Induced charge, $q = -\frac{1}{R}\int_{\phi_i}^{\phi_f} d\phi$

$q = -\frac{1}{R}[\phi_f - \phi_i]$ (or) $q = \frac{\phi_i - \phi_f}{R}$ (magnitude of charge)

$\therefore$ In general, induced charge is given by

$$q = \frac{\text{change of magnetic flux}}{\text{resistance}}$$

For N turns, the induced charge is $q = \frac{N}{R}(d\phi)$

- Induced emf is independent of total resistance of the circuit but depends on rate of change of flux.
- Induced current depends on both rate of change of flux and resistance of circuit
- Induced charge is independent of time but depends on the resistance of circuit.
- When a magnet is moved towards a stationary coil (i) slowly and (ii) quickly, then

  (A) induced charge is same in both cases

  (B) induced emf is more in second case

  (C) induced current is more in second case

MOTIONAL EMF

The motional emf is the emf which results from relative motion between a conductor and the source of magnetic field.

When a conductor of length ℓ is moved with a velocity v perpendicular to its length in uniform magnetic field (B), which is perpendicular to both its length and as well as its velocity, the emf induced across its ends $e = B\ell v$

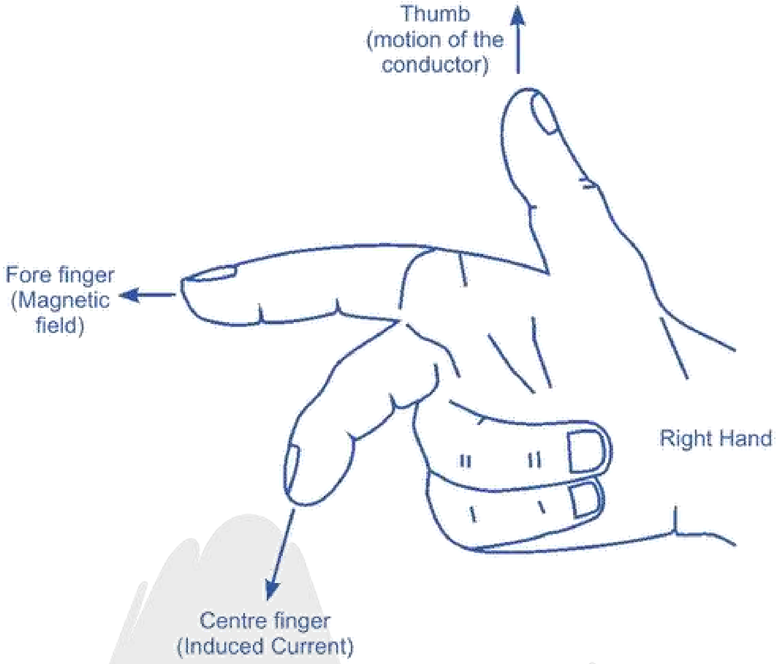
If the rod moved making an angle with its length, then $e = B\ell v \sin\theta$

In vector form $e = \vec{B}.(\vec{\ell} \times \vec{v})$ or $\vec{\ell}.(\vec{v} \times \vec{B})$ among $\vec{B}, \vec{\ell}$ and v if any two are parallel the emf induced

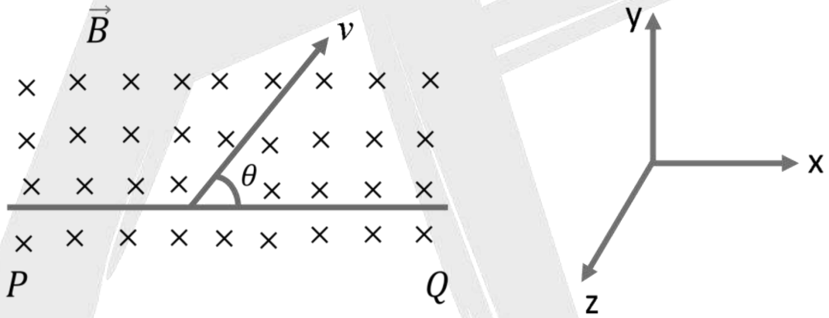
across the conductor is zero

FLEMINGS'S RIGHT HAND RULE

Stretch the first three fingers of right hand such that they are mutually perpendicular to each other. If the fore finger represents the direction of magnetic field and the thumb represents the direction of the motion of the conductor, then the central finger indicates the direction of induced current



A conductor of length 'l' measured from P to Q is moved with a speed of 'v' in a uniform magnetic field 'B' as shown in figure.



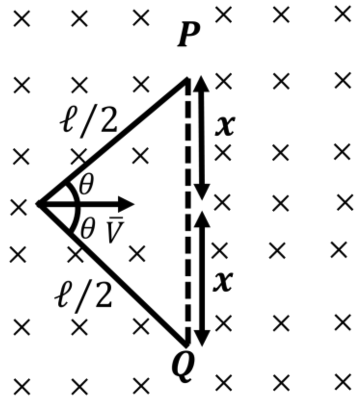
Here $\vec{B} = B\left(-\hat{k}\right), \vec{\ell} = \ell(\hat{i})$ and $\vec{v} = v\cos\theta\hat{i} + v\sin\theta\hat{j}$

Induced emf is $e = \vec{\ell}.\left(\vec{v}\times\vec{B}\right) = \ell(\hat{i}).\left(v\cos\theta\hat{i} + v\sin\theta\hat{j}\right)\times B\left(-\hat{k}\right) = -B\ell v\sin\theta$

The change in the flux in the time of 'Δt' is

$\therefore \Delta\phi = e\Delta t = -B\ell v\sin\theta\Delta t$

➢ A conductor of length 'ℓ' is bent at its midpoint and is moved along its perpendicular bisector with a constant speed of 'v' in a uniform magnetic field of strength 'B' as shown in figure.



From the figure $\sin\theta = \frac{x}{\ell/2} \Rightarrow x = \frac{\ell}{2}\sin\theta$

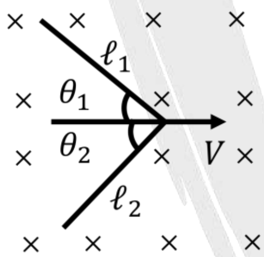
Here $\vec{B} - = B(-\hat{k}), \vec{v} = v\hat{i}$ and effective length of the conductor $\vec{\ell} = 2x(-\hat{j}) = \ell\sin\theta(-\hat{j})$

Induced emf is $e = \vec{\ell}.(\vec{v}\times\vec{B}) = \ell\sin\theta(-\hat{j}).v\hat{i}\times B(-\hat{k}) = -B\ell v\sin\theta$

The change in the flux associated in time interval of 'Δt' is $\Delta\phi = e\Delta t = -B\ell v\sin\theta\Delta t$

Here the effective length between free ends of conductor is $\ell\sin\theta$

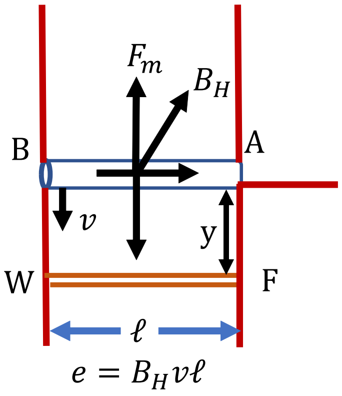
➢ The emf induced across the ends of the conductor shown in the figure is



$e = BV\ell = BV(\ell_1\sin\theta_1 + \ell_2\sin\theta_2)$

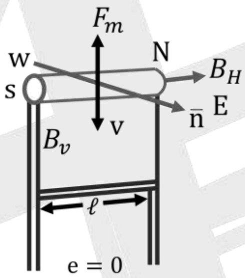
i) If a conductor is moving vertically downwards with constant velocity v with its ends pointing east-west, it will cut the horizontal component of earth's field B_H as shown in figure ((A) and hence the flux linked with the area generated by the motion of the conductor, and induced emf will be $\phi_H = B_H(\ell y)$ and $e = \frac{d\phi_H}{dt} = B_H v_y \ell$

$\left(\text{with } v_y = \frac{dy}{dt}\right)$



(A)

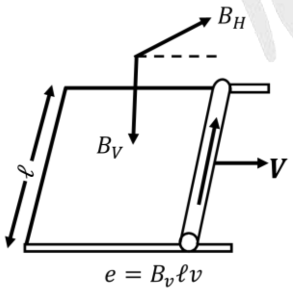
ii) However in case of vertical motion, if the ends of the conductor point north-south, both B_H and B_V will be parallel to the plane of area generated by the motion of the conductor as shown figure (B) and hence it doesn't cut the magnetic lines. So



(B)

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

iii) If the wire is moving in a horizontal plane in any direction as shown in figure(C), it will cut flux of B_V (as B_H will always be parallel to are(A) and so

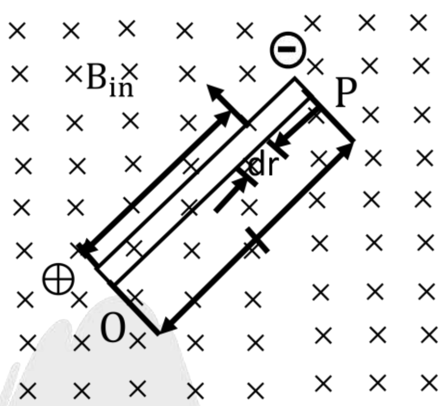


(C)

$\phi_V = B_v \ell s$ and $e = \frac{d\phi_V}{dt} = B_V v\ell$

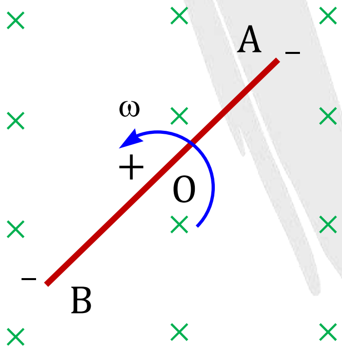
$$\left[\text{with } v = \frac{ds}{dt}\right]$$

MOTIONAL EMF INDUCED IN A ROTATING BAR



If a rod of length ℓ is rotated with a constant angular velocity 'ω' about an axis passing through its end (O) and perpendicular to its length and if a uniform magnetic field $\vec{B}$ is present perpendicular to it, then emf across its ends is given by $e = \frac{1}{2}B\ell^2\omega$

In the above case if the rod is rotated about an axis passing through its centre (O) and perpendicular to its length them emf across its ends is zero



emf across OA is $e = +\frac{1}{8}B\ell^2\omega$

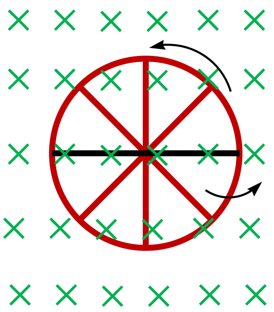
emf across OB is $e = -\frac{1}{8}B\ell^2\omega$

Net emf across AB is zero

end 'A' is -ve with respect to 'O'

end 'B' is -ve with respect to 'O'

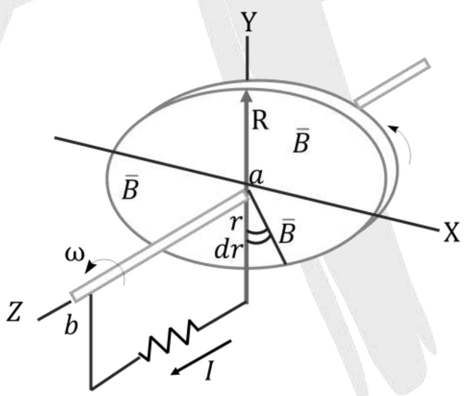
➢ A spoked wheel of spoke length 'ℓ' is rotated about its axis with an angular velocity 'ω' in a plane normal to uniform magnetic field B as shown.



The emf induced across the ends of each spoke is $e=\frac{1}{2}B\ell^2\omega$, with axle (centre) at higher potential. Since all the spokes are parallel between axle and rim, the emf indued between axle and rim is $e=\frac{1}{2}B\ell^2\omega$.

It is independent of number of spokes.

MOTIONAL EMF INDUCED IN A ROTATING DISC

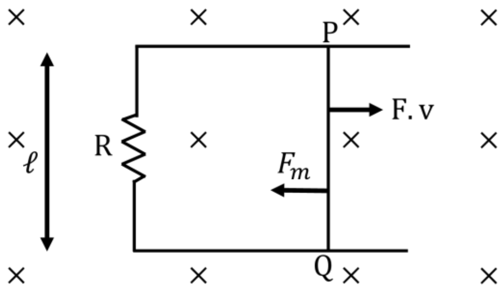


A circular disc of radius 'R' is rotating with an angular velocity 'ω' about an axis passing through centre and plane of rotation is normal to an uniform magnetic field of induction B. It is equivalent to a spoked wheel with a large number of spokes each of length 'R' between centre and rim without any air gap. The emf induced between centre and rim is independent of number of spokes.

So, the emf induced between centre and rim is

$$e=\frac{1}{2}B\ell^2\omega=\frac{1}{2}BR^2\omega$$

ENERGY CONSIDERATION



A conductor PQ is moved with a constant velocity v on parallel sides of a U-shaped conductor in a magnetic field as shown in figure. Let R be the resistance of the closed loop. The emf induced in the rod is $e = B\ell v$

The current in the circuit is $i = \frac{e}{R} = \frac{B\ell v}{R}$

As current flows in the conductor PQ from Q to P of the conductor. So, an equal and opposite force F has to be applied on the conductor to move the conductor with a constant velocity v.

Thus, $F = F_m = \frac{B^2\ell^2 v}{R}$

The rate at which work is done by the applied force to move the rod is,

$$P_{applied} = Fv = \frac{B^2\ell^2 v^2}{R}$$

The rate at which energy is dissipated in the circuit is,

$$P_{dissipated} = i^2 R = \left(\frac{Bv\ell}{R}\right)^2 R = \frac{B^2\ell^2 v^2}{R}$$

This is just equal to the rate at which work is done by the applied force.

EDDY CURRENTS

- When bulk pieces of conductors are subjected to changing magnetic flux, induced currents are produced in them.
- The flow patterns of induced currents resemble the whirling eddies in water. This effect was discovered by Foucault and these currents are called eddy currents or Foucault currents.

- A copper plate is allowed to swing like a simple pendulum between the pole pieces of a strong magnet, its motion is damped and the plate comes to rest in the magnetic field due to eddy currents in the plate.
- If rectangular slots are made in the copper plate area available to the flow of eddy currents is less. So, electromagnetic damping is reduced and the plate swings more freely.
- The eddy currents heat up the metallic cores and dissipate electrical energy in the form of heat in the devices like transformers, electric motors and other such devices.
- The eddy currents are minimized by using laminations of metal to make a metal core. The laminations are separated by an insulating material like lacquer.
- The plane of the laminations must be arranged parallel to the magnetic field, so that they cut across the eddy current paths reduces the strength of the eddy current.
- **Advantages:**

  Eddy currents are used in

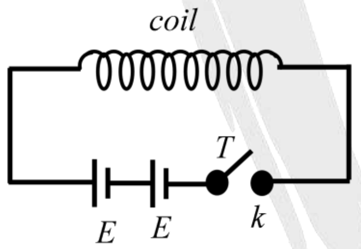
  (A) Magnetic braking in trains.

  (B) Electromagnetic damping.

  (C) Induction furnace.

  (D) Electric power meters.

SELF INDUCTION:



- If current flowing in a coil changes, the magnetic flux linked with the coil changes. Then emf induced in the coil is called self-induced emf and the phenomenon is called self-induction.
- If 'i' is the current flowing through the coil and 'ϕ' is magnetic flux linked with the coil, then

  $\phi \propto i \Rightarrow \phi = Li, \quad \therefore L = \frac{\phi}{i}$

  Here 'L' is called coefficient of self-induction of the coil or self-inductance of the coil.

  $\phi \propto i \Rightarrow \phi = Li, \quad \therefore L = \frac{\phi}{i}$
- Self-induced e.m.f is given by

$$e = \frac{-d\phi}{dt} = -L\frac{di}{dt}$$

- Self inductance of a coil is magnetic flux linked with the coil when unit current flows through it (or) emf induced in the coil when current changes in it at the rate of 1 A/sec.
- S.I. Unit of self-inductance: Henry.

  Other Units weber / ampere, volt-second/ampere, $J/amp^2, Wb^2/J, volt\,sec^2\,coul^{-1}$

  Dimensional formula of L is $\left[ML^2T^{-2}I^{-2}\right]$

  A coil having high self-inductance is called inductor.

  Self-induction is also known as inertia of electricity as it opposes the growth or decay of the current in the circuit.

  Inductance may be viewed as electrical inertia. It is analogous to inertia in mechanics. It does not oppose the current, but is opposes the change in current.

SELF INDUCTANCE OF A FLAT CIRCULAR COIL:

Let us consider a circular coil of radius r and containing N-turns. Suppose it carries a current 'i'.

The magnetic field at the centre due to this current $B = \frac{\mu_0 Ni}{2r}$

And total flux = $NBA = N\left(\frac{\mu_0 Ni}{2r}\right)\pi r^2 = \frac{\mu_0 \pi N^2 ri}{2}$

Now comparing with $N\phi_B = Li$ we get

$$L = \frac{\mu_0 \pi N^2 r}{2}$$

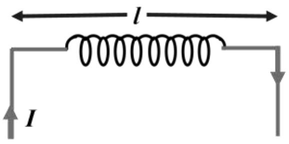
SELF INDUCTANCE OF A SOLENOID:

Consider a long solenoid of length ℓ, area of cross section A and number of turns per unit length n and length is very large when compared with radius of cross section.

Let I be the current flowing through the solenoid. The magnetic field inside the long solenoid is uniform and is given by $B = \mu_0 nI$

Total number of turns in the solenoid of length ℓ is $N = n\ell$.

Now, the magnetic flux linked with each turn of the solenoid $B \times A = \mu_0 nIA$



$\therefore$ Total magnetic flux linked with the whole solenoid, ϕ =magnetic flux with each turn $\times$ number of turns in the solenoid.

$\phi = \mu_0 nIA \times n\ell = \mu_0 n^2 IA\ell$ .... (1)

But $\phi = LI \Rightarrow LI = \mu_0 n^2 IA\ell$ from (1) & (2)

$\therefore L = \mu_0 n^2 A\ell$ since $n = \dfrac{N}{\ell}, L = \mu_0 \dfrac{N^2}{\ell} A$

- Self-inductance of coil depends on

  i) Geometry of the coil i.e.,

  (A) Number of turns of the coil

  (B) The length (l) of the solenoid,

  (C) The area of cross-section ((A) of the solenoid,

  ii) Medium inside the coil (permeability)

  iii) Nature of the material of the core of the solenoid.

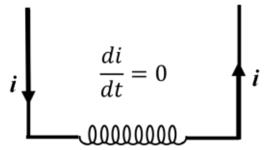
- More is the permeability of the medium, more is the self-inductance
- An inductor will have large inductance and low resistance.
- Resistor opposes the current, inductor opposes the change of current
- One can have resistance without inductance
- One cannot have inductance without resistance. An ideal inductor has inductance and no resistance.
- When the current in the coil either increases or decreases at a rate, then the coil can be imagined

  to be a cell of emf $e = L.\dfrac{di}{dt}$

- One can have self-inductance without mutual inductance.
- One cannot have mutual inductance without self-inductance.

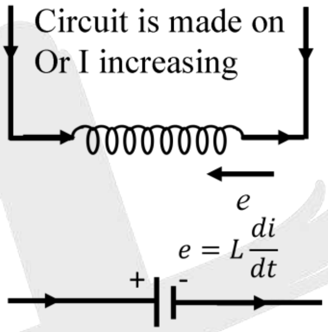
The direction of induced emf for different states of current in a coil:

(A) steady current



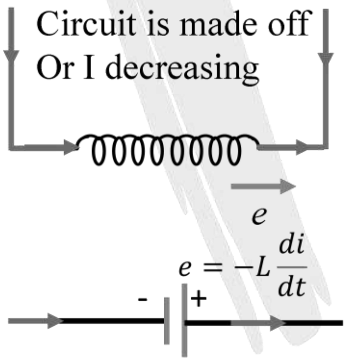
e = 0 no opposition

(B) Making of circuit or increasing current



(A)

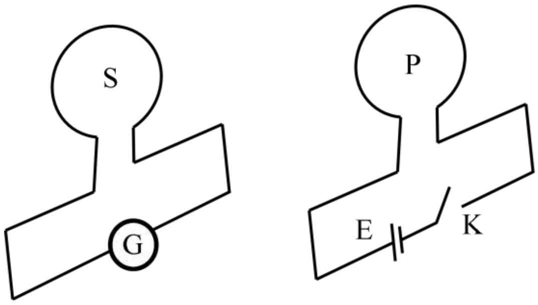
(C) Breaking of circuit of decreasing of current



(B)

MUTUAL INDUCTION

- When current in one coil changes, magnetic flux linked with the second coil placed near by it also changes. The emf induced in secondary is called mutually induced emf and the phenomenon is called mutual induction.



- If $'i_p'$ is current flowing in the primary coil, $'\phi_S'$ is magnetic flux linked with secondary coil, then $\phi_S \propto i_p$

  $\Rightarrow \phi_S \propto Mi_p$, $\quad \therefore M = \dfrac{\phi_S}{i_p}$

  Here 'M' is called coefficient of mutual induction or mutual inductance.

- Induced emf in secondary coil is

  $$e = \frac{-d\phi}{dt} = -M\left(\frac{di_p}{dt}\right) \text{ (or) } M = \frac{e}{-di_p / dt}$$

  Mutual inductance between two coils is equal to the magnetic flux linked in the secondary coil when unit current passes through the primary coil or emf induced in one coil when current in the other coil changes at the rate of 1 Amp/second.

- S.I. unit: Herry
- Dimensional formula of self-inductance or mutual inductance is $ML^2T^{-2}A^{-2}$
- The value of mutual inductance depends on

  1) Distance between the two coils

  2) Number of turns of coils

  3) Geometrical shape of the coil

  4) Material of the core medium between the coils

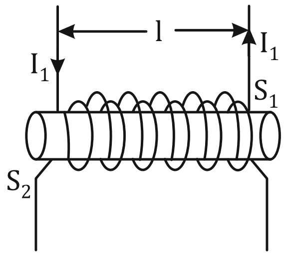
  5) Orientation of the coils i.e., angle between the axes of the coils.

  If the axes are parallel, then M is maximum

  If the axes are perpendicular then M is minimum

MUTUAL INDUCTANCE OF TWO LONG COAXIAL SOLENOIDS:

Consider two solenoids S_1 and S_2 such that the solenoid S_2 completely surrounds the solenoid S_1



Let ℓ be length of each solenoid (or length of primary coil) and of nearly same area of cross-section A. N_1 and N_2 are the total number of turns of solenoid S_1 and S_2 respectively.

$\therefore$ Number of turns per unit length of solenoid S_1 is $n_1 = \frac{N_1}{\ell}$

Number of turns per unit length of solenoid S_2 is $n_2 = \frac{N_2}{\ell}$

Magnetic field inside the solenoid S_1 is given by

$$B_1 = \mu_0 n_1 I_1 = \mu_0 \frac{N_1}{\ell} I_1$$

$\therefore$ Magnetic flux linked with each turn of solenoid

$$S_2 = B_1 A = \mu_0 \frac{N_1}{\ell} I_1 A$$

$\therefore$ Total magnetic flux linked with N_2 turns of the solenoid S_2 is

$$\phi_2 = N_2 (B_1 A) = \mu_0 \frac{N_1}{\ell} I_1 A \times N_2$$

$$\phi_2 = \frac{\mu_0 N_1 N_2 I_1 A}{\ell} \text{ .... (i)}$$

But $\phi_2 = M_{12} I_1$ .... (ii)

Where M_{12} is the mutual inductance when current varies is solenoid S_1 and makes magnetic flux linked with solenoid S_2,

from (i) and (ii) we get

$$M_{12} I_1 = \frac{\mu_0 N_1 N_2 I_1 A}{\ell} \therefore M_{12} = \frac{\mu_0 N_1 N_2 A}{\ell}$$

Similarly,

$$M_{12}I_1 = \frac{\mu_0 N_1 N_2 I_1 A}{\ell} \qquad \therefore \qquad M_{12} = \frac{\mu_0 N_1 N_2 A}{\ell}$$

Similarly, $M_{21} = \frac{\mu_0 N_1 N_2 A}{\ell}$, where M_{21} is the mutual inductance when current varies solenoid S_2 and makes magnetic flux linked with solenoid S_1.

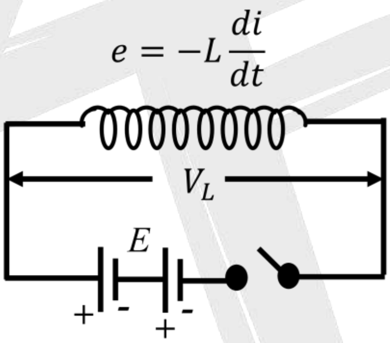
It can be proved that $M_{12} = M_{21} = M$

The above equation is treated as a general result, if the two solenoids are wound on a magnetic substance of relative permeability μ_r, then the mutual inductance is given by

$$M = \frac{\mu_0 \mu_r N_1 N_2 A}{\ell} = \mu_0 \mu_r n_1 n_2 A\ell$$

ENERGY STORED IN AN INDUCTOR

Consider an ideal inductor of inductance 'L' connected with a battery. Let I be the current in the circuit at any instant 't'



This induced emf is given by $e = -L\frac{dI}{dt}$

negative sign shows that 'e' opposes the change of current I in the inductor.

To drive the current through the inductor against the induced emf 'e', the external voltage is applied. Here external voltage is emf of the battery = E

According to Kirchoff's voltage law, E + e = 0

$$E = -e; \; E = L\frac{dI}{dt}$$

Let an infinitesimal charge dq be driven through the inductor in time dt. So, the rate of work done by the external voltage is given by

$$\frac{dW}{dt} = EI = L\frac{dI}{dt} \times I = LI\frac{dI}{dt}$$

The total work done in establishing a current through the inductor from 0 to I is given by

$$W=\int dW=\int_0^I LIdI;\ W=L\left(\frac{I^2}{2}\right)=\frac{1}{2}LI^2$$

$$\boxed{W=\frac{1}{2}LI^2}$$

The work done in maintaining the current through the inductor is stored as the potential energy (U) in its magnetic field. Hence energy stored in the inductor is given by

$$\boxed{U=\frac{1}{2}LI^2}$$

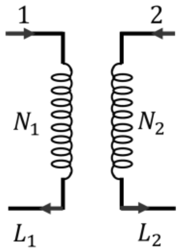
- The equation $U=\frac{1}{2}LI^2$ is similar to the expression for kinetic energy $E=\frac{1}{2}mv^2$. It shows that L is analogues to mass 'm' and self-inductance is called electrical inertia.
- The self-inductance of a coil is numerically equal to twice the energy stored in it when unit current flows through it.
  i.e., When $i=1A, L=2U$
- Induced power $P=e\times i=Li\left(\frac{di}{dt}\right)$
- In case of solenoid $L=\mu_0 n^2 A\ell$
- Magnetic energy stored per unit volume

$$u_B=\frac{\frac{1}{2}Li^2}{A\ell}\Rightarrow u_B=\frac{1}{2}u_0 n^2 i^2\ ; \qquad \text{Hence } u_B=\frac{B^2}{2\mu_0}$$

- The magnetic energy stored per unit volume similar to electrostatic energy stored per unit volume in a parallel plate capacitor $u_B=\frac{1}{2}\varepsilon_0 E^2$

In both cases the energy is proportional to the square of field strength.

RELATION BETWEEN L_1, L_2 and M:



The flux linked with coil 1 is

$$N_1\phi_1 = L_i i_1 \Rightarrow L_1 = \frac{N_1\phi_1}{i_1}$$

The flux linked with coil 2 is

$$N_2\phi_2 = L_2 i_2 \Rightarrow L_2 = \frac{N_2\phi_2}{i_2}$$

M on 1 because of 2;

$$M_{12} = \frac{N_1\phi_1}{i_2}$$

M on 2 because of 1;

$$M_{21} = \frac{N_2\phi_2}{i_1}$$

- If the flux in linkage is maximum, then

$$M_{12} = M_{21} = M;\ M_{12} \times M_{21} = \frac{N_2\phi_2}{i_1} \times \frac{N_1\phi_1}{i_2}$$

$$M^2 = L_1 L_2;$$

$$\therefore\ M = \sqrt{L_1 L_2}$$

This is the maximum mutual inductance when all the flux linked with one coil is also completely linked with the other.

In general, only a fraction of the total flux will be linked with the coil due to the flux leakage.

$$\therefore M = K\sqrt{L_1 L_2}$$

Where K-coefficient of coupling

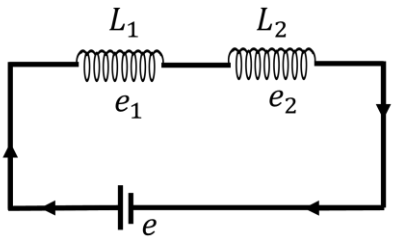
$$(K \le 1)$$

For tight coupling (or) if the coils are closely wound, then K=1.

$$\therefore\ M_{max} = \sqrt{L_1 L_2}$$

INDUCTORS IN SERIES:

If two coils of inductances L_1 and L_2 are connected in series then the potential divides.



i.e., $e = e_1 + e_2$ or $L_s \frac{di}{dt} = L_1 \frac{di}{dt} + L_2 \frac{di}{dt}$

Since in series, $\frac{di}{dt}$ is same for all coils

$\therefore L_S = L_1 + L_2$

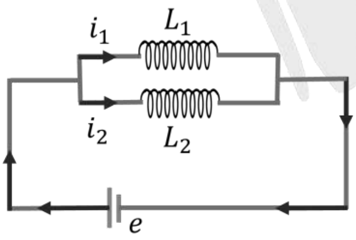
If n coils of inductances $L_1, L_2, L_3 .... \ L_n$ are connected in series then effective inductance of the arrangement,

$L = L_1 + L_2 + L_3 + ... + L_n$

(When coils are far away)

INDUCTORS IN PARALLEL:

If two coils of inductances L_1 and L_2 are connected in parallel then the current divides.



i.e., $i = i_1 + i_2$ or $\frac{di}{dt} = \frac{di_1}{dt} + \frac{di_2}{dt} \Rightarrow \frac{e}{L_P} = \frac{e_1}{L_1} + \frac{e_2}{L_2}$

However, in parallel as potential difference remains same i.e., $e = e_1 = e_2$, so

$\frac{1}{L_P} = \frac{1}{L_1} + \frac{1}{L_2}$ or $L_p = \frac{L_1 L_2}{(L_1 + L_2)}$

If n coil of inductances $L_1, L_2, L_3 ......\ L_n$ are connected in parallel then effective inductance of the arrangement,

$$\frac{1}{L_P} = \frac{1}{L_1} + \frac{1}{L_2} + ... + \frac{1}{L_n} \text{ (when coils are far away)}$$

- Let two coils of inductances L_1 and L_2 are connected in series and M is their mutual inductance. The flux linked with one coil will be the sum of two fluxes which exist independently. When the flux in the two coils support each other

$$N_1\phi_1 = L_1 i_1 + M_{12} i_2$$

From Faraday's law, $e_1 = -L_1 \frac{di_1}{dt} - M_{12}\frac{di_2}{dt}$

Similarly, $N_2\phi_2 = L_2 i_2 + M_{21} i_1$

$$e_2 = -L_2 \frac{di_2}{dt} - M_{21}\frac{di_1}{dt}$$

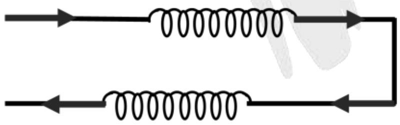
$$e = e_1 + e_2 = L_1 \frac{di_1}{dt} - M_{12}\frac{di_2}{dt} - L_2\frac{di_2}{dt} - M_{21}\frac{di_1}{dt}$$

In series the current *i* and the change in current di is same

$$e = -(L_1 + M_{21} + L_2 + M_{12})\frac{di}{dt}$$

$$L = (L_1 + M_{21} + L_2 + M_{12}) = L_1 + L_2 + 2M$$

If the two coils oppose each other, then



$$L = (L_1 - M) + (L_2 - M) = L_1 + L_2 - 2M$$

AC GENERATOR:

- An ac generator converts mechanical energy into electrical energy. The device used for the purpose is called ac generator.
- When the coil having N turns is rotated with a constant angular speed ω, the angle between the area vector A and the magnetic field vector B is at any instant t is $\theta = \omega t$ (assuming $\theta = 0^0$ at t=0). The flux linked with the coil at any instant t is

$$\phi_B = NBA\cos\theta = NBA\cos\omega t$$

From Faraday's law, the induced emf for the rotating coil of N turns is,

$$\varepsilon = -\frac{d\phi_B}{dt} = -\frac{d}{dt}(NBA\cos\omega t) = NBA\omega\sin\omega t$$

- The magnitude of induced emf is

  $\varepsilon = NBA\ \omega\sin\omega t = \varepsilon_0 \sin\omega t$

  Where $\varepsilon_0 = NBA\omega$ is the maximum value of the emf.

  ε_0 is called the amplitude or peak value of emf.

- The induced emf depends upon

  (i) strength of the magnetic field ,

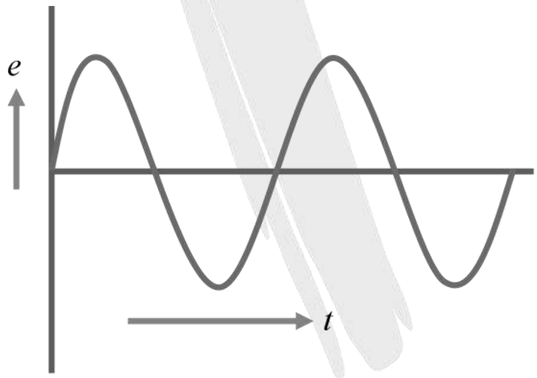
  (ii) are of the coil,

  (iii) speed of rotation, and

  (iv) the number of turns of the coil.

  If *f* be the frequency of rotation of coil, then $\varepsilon = \varepsilon_0 \sin 2\pi ft$

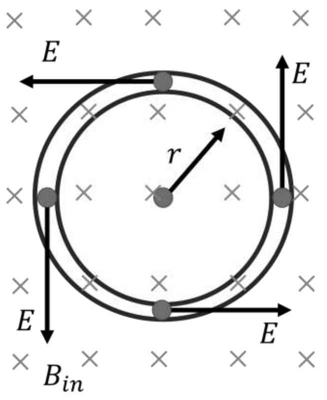
- A graph plotted between ε and ωt, is a sine curve as shown in fig.



INDUCED ELECTRIC FIELDS:

When a conducting loop is placed in a varying magnetic field, a varying electric field produced in the loop, is called induced electric field. An electric field is always generated by a changing magnetic field, even in free space where no charges are present.

Consider a conducting loop of radius R, situated in a uniform magnetic field $\overline{B}$ that is perpendicular to the plane of the loop as shown in the figure



If the magnetic field changes with time, then an emf $e = \frac{-d\phi}{dt}$ is induced in the loop. The induced current thus produced implies the presence of an induced electric field E that must be tangential to the loop in order to provide an electric force on the charge around the loop. The work done by the electric field on the loop in moving a test charge q once around the loop = qe. Because the magnitude of electric force on the charge is qE, the work done by the electric field can also be expressed as $qE(2\pi r)$, where $2\pi r$ is the circumference of the loop. These two expressions for the work must be equal;

therefore, we see that

$$qe = qE(2\pi r);\ E = \frac{e}{2\pi r}$$

Using this result along with the Faraday's law and the fact that $\phi_B = BA = B\pi r^2$ for a circular loop, the induced electric field can be expressed as

$$E = \frac{1}{2\pi r}\left(-\frac{d\phi_B}{dt}\right) = -\frac{1}{2\pi r}\frac{d}{dt}\left(B\pi r^2\right) = -\frac{r}{2}\frac{dB}{dt}$$

The emf for any closed path can be expressed as the line integral of $\vec{E}.\vec{d\ell}$ over that path.

Hence, the general form of Faraday's law of induction is $e = \oint \vec{E}.\vec{d\ell} = \frac{d\phi_B}{dt}$

It is important to recognize that the induced electric field E that appears in the equation is a non-conservative field that is generated by a changing magnetic field.

- Points to remember about induced electric field.

  1) The induced electric field is produced only by changing magnetic field and not by charged particles.

2) One cannot define potentials w.r.t this induced field

3) The lines of induced electric field are closed curves and have no starting and terminating points.

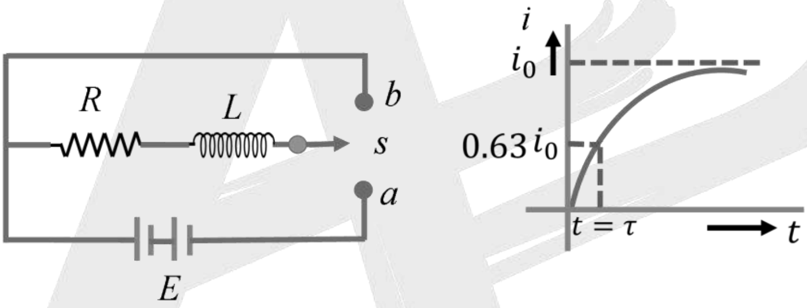
4) As long as the magnetic field keeps on changing, the induced electric field will be present because this electric field is produced only by variable magnetic field.

D.C. CIRCUITS

Growth and decay of current in an Inductor - Resistor (L-R) circuit.

I. **Growth of current**

Consider a circuit shown in the diagram



(A)When a switch S is connected to 'a', the current in the circuit begins to increase from zero to a maximum value 'i_0'.

The Inductor opposes the growth of the current.

$$\therefore E - L\frac{di}{dt} = Ri$$

Where 'i' is the current in the circuit at any instant 't' and $i = i_0\left\{1 - e^{\frac{-t}{\tau}}\right\}$

Where i_0 is the maximum current.

Here $\tau = \frac{L}{R}$ called Inductive time constant

(B) At $t = \tau, i = i_0\left(1 - \frac{1}{e}\right) = 0.63\ i_0$

(C) Thus, the inductive time constant of a circuit is defined as the time in which the current rises from zero to 63% of its final value.

(D) Greater the value of 'τ' smaller will be the rate of growth of current.

(E) Current reaches i_0 after infinite time.

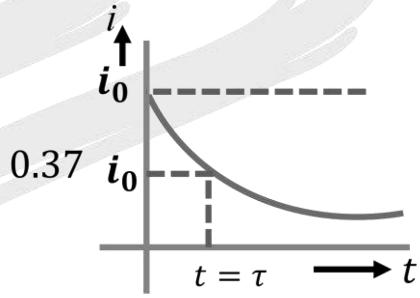
(F) When current attains maximum value, Inductor doesn't work.

$$\therefore i_0 = \frac{E}{R}$$

II. Decay of Current

(A) When circuit is disconnected from the battery and switch 's' is connected to point 'b', the current now beings to fall. But inductor opposes decay of current

$$\therefore -L\frac{di}{dt} = Ri$$



Where *i* is the current at any instant and $i = i_0 e^{\frac{-t}{\tau}}$

where $t = \tau = \frac{L}{R}$

(B) At $t = \tau, i = \frac{i_0}{e} = 0.37 i_0$

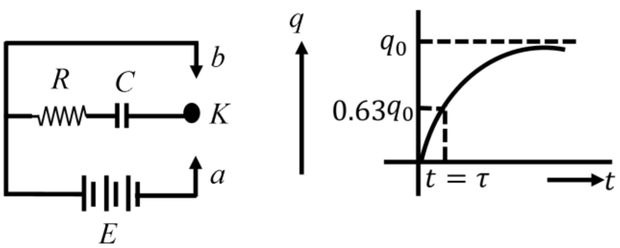
(C) The inductive time constant (τ) can also be defined as the time interval during which the current decays to 37% of the maximum current.

(D) For small value of 'L', rate of decay of current will be large.

(E) Current becomes zero after infinite time.

GROWTH AND DECAY OF CHARGE IN A CAPACITOR – RESISTOR (C-R) CIRCUIT

I. Growth of Charge: Consider a circuit shown in the diagram



(A) When the key's is connected to point 'a', the charging of capacitor takes place until the potential difference across the plates of the condenser becomes E.

(B) But charge attained already on the plates opposes further introduction of charge

$$E-\frac{q}{C}=Ri \quad \text{or} \quad E-\frac{q}{C}=R\frac{dq}{dt}$$

Where 'q' is the instantaneous charge, i is the instantaneous current in the circuit.

and $q=q_0\left(1-e^{\frac{-t}{\tau}}\right)$

where q_0 is the maximum charge.

Where $\lambda = CR$, called capacitive time constant.

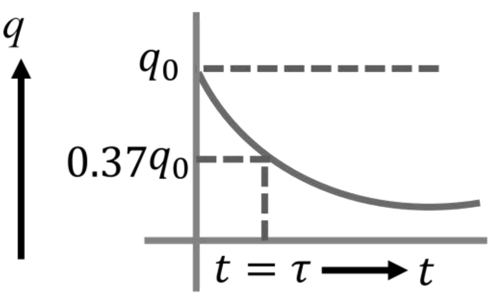
(C) When $t=\tau$. $q=q_0\left(1-\frac{1}{e}\right)=0.63q_0$

(D) Thus, the capacitive time constant is the time in which the charge on the plates of the capacitor becomes 0.63 q_0

e) Smaller the value of CR, more rapid is the growth of charge on the condenser.

f) Charge on the capacitor becomes maximum after infinite time and it is $q_0 = EC$. Then current in the circuit becomes zero.

II. Decay of charge:



(A) When the capacitor is fully charged, the key is connected to point 'b'

(B) Charge slowly reduces to zero after infinite time

$$\therefore \ -\frac{q}{C} = Ri \ \text{(or)} \ -\frac{q}{C} = R\frac{dq}{dt} \ \text{and} \ q = q_0 e^{\frac{-t}{\tau}}$$

(C) At $t = \tau,\ q = \frac{q_0}{e} = 0.37q_0$

(D) Thus, capacitive time constant can also be defined as the time interval in which the charge decreases to 37% of the maximum charge

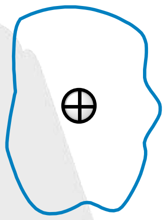
(E) Smaller the time constant, quicker is the discharge of the condenser.

EXERCISE – 1

1. A rectangular loop of sides of length ℓ and b is placed in x-y plane. A uniform but time varying magnetic field of strength $\vec{B} = 20t\hat{i} + 10t^2\hat{j} + 50\hat{k}$ where t is time elapsed. The magnitude of induced e.m.f. at time t is:

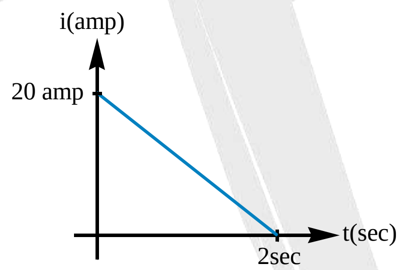
(A) 20+20t (B) 20 (C) 20t (D) Zero

2. A loop having negligible self inductance but a constant resistance is placed in a uniform magnetic field but varying with time at a rate of 1 T/s. The area of loop is $1 m^2$ and it is single turn. If at some time t, the current in the loop is 1A, the rate of change of current would be:

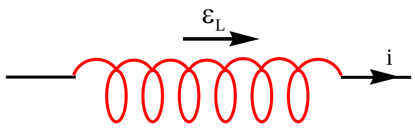


(A) 1 A/s (B) 0 (C) 2 A/s (D) 3 A/s

3. Due to change in magnetic flux linked with a coil of resistance 10 ohm, a current is induced in it. The variation of induced current i (in amperes) with time t (in seconds) is shown in figure. The magnitude of change in flux through the coil (from t = 0 to t = 2seconds) in Webers is:



4. At a given instant the current and self-induced emf in an inductor are directed as shown in figure. If the induced emf is 17 volt and rate of change of current is 25 k A/s the correct statement is:



(A) Current is increasing and inductance of coil is $3.4\ \mu H$

(B) Current is decreasing and inductance of coil is $680\ \mu H$

(C) Current is decreasing and inductance of coil is $3.4\ \mu H$

(D) Current is increasing and inductance of coil is $6.8\ \mu H$

5. The number of turns, cross-sectional area and length for four solenoids are given in the following table.

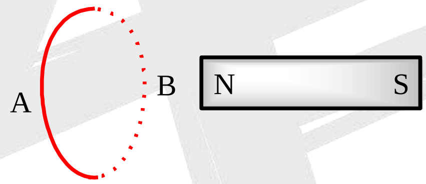
Solenoid	Total Turns	Area	Length
1	2N	2A	ℓ
2	2N	A	ℓ
3	3N	3A	2ℓ
4	2N	2A	$\ell/2$

The solenoid with maximum self-inductance is:

6. When the current in a certain inductor coil is 5.0 A and is increasing at the rate of 10.0 A/s, the potential difference across the coil is 140 V. When the current is 5.0 A and decreasing at the rate of 10.0 A/s, the potential difference is 60 V. The self-inductance of the coil is:

(A) 2H (B) 4H (C) 8H (D) 12H

7. In the figure shown, the magnet is pushed towards the fixed ring along the axis of the ring and it passes through the ring.



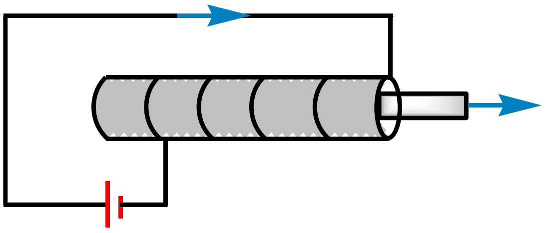
(A) When magnet goes towards the ring the face B becomes south pole and the face A becomes north pole

(B) When magnet goes away from the ring the face B becomes north pole and the face A becomes south pole

(C) When magnet goes away from the ring the face A becomes north pole and the face B becomes south pole

(D) The face A will always be a north pole

8. A solenoid having an iron core has its terminals connected across an ideal DC source. If the iron core is removed, the current flowing through the solenoid:



(A) increases (B) decreases

(C) remains unchanged (D) nothing can be said

9. A metallic ring with a small cut is held horizontally and a magnet is allowed to fall vertically through the ring then the acceleration of the magnet is

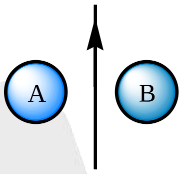
(A) always equal to g

(B) initially less than g but greater than g once it passes through the ring

(C) initially greater than g but less than g once it passes through the ring

(D) always less than g

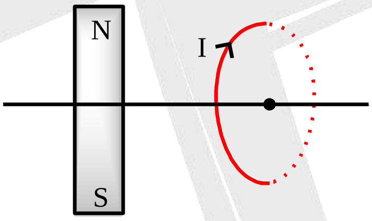
10. A and B are two metallic rings placed at opposite sides of an infinitely long straight conducting wire as shown. If current in the wire is slowly decreased, the direction of induced current will be



(A) clockwise in A and anticlockwise in B
(B) anticlockwise in A and clockwise in B

(C) clockwise in both A and B
(D) anticlockwise in both A and B

11. As shown in figure, a permanent magnet and current carrying coil are placed. If the coil is moved towards magnet, then current in coil (Magnet is symmetrical):



(A) increases
(B) decreases

(C) remains same
(D) first increases then decreases

12. A conducting ring lies on a horizontal plane. If a charged metallic particle is released from a point (on the axis) at some height from the plane, then:

(A) an induced current will flow in clockwise or anticlockwise direction in the loop depending upon the nature of the charge

(B) The acceleration of the particle will decrease as it comes down

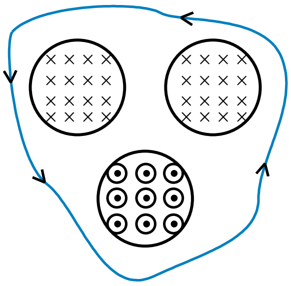
(C) The rate of production of heat in the ring will increase as the particle comes down

(D) no heat will be produced in the ring

13. A long straight current carrying wire is placed along the axis of a current carrying circular ring of radius R. The mutual inductance of this system is:

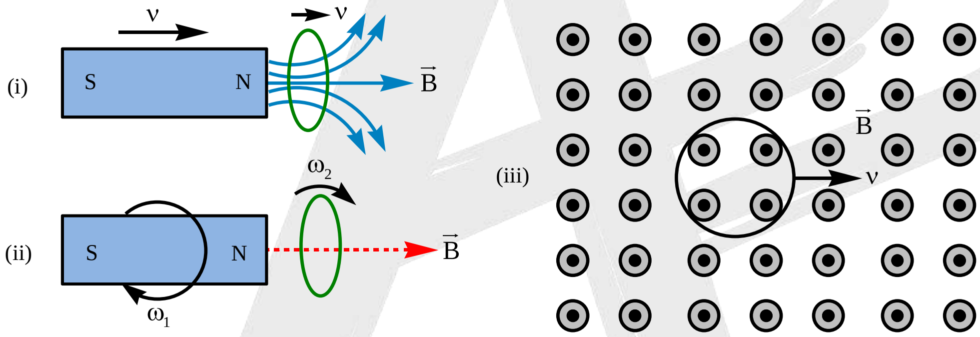
(A) $\frac{\mu_0 R}{2}$
(B) $\frac{\mu_0 \pi R}{2}$
(C) $\frac{\mu_0}{2}$
(D) 0

14. Figure shows three regions of magnetic field, each of area A, and in each region magnitude of magnetic field decreases at a constant rate α. If $\vec{E}$ is induced electric field then value of line integral $\oint \vec{E}.d\vec{r}$ along the given loop is equal to:



(A) αA (B) $-\alpha A$ (C) $3\alpha A$ (D) $-3\alpha A$

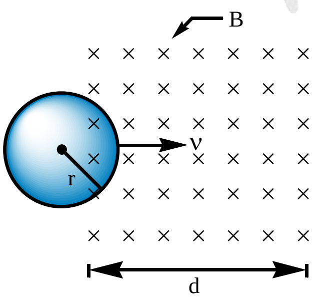
15. In the following figures, the rate of change of magnetic flux linked with area is measured as $\left(\frac{d\phi}{dt}\right)_A, \left(\frac{d\phi}{dt}\right)_B, \left(\frac{d\phi}{dt}\right)_C$ respectively at the instant shown in diagram then:



(A) $\left(\frac{d\phi}{dt}\right)_A = \left(\frac{d\phi}{dt}\right)_B = 0$ (B) $\left(\frac{d\phi}{dt}\right)_A = \left(\frac{d\phi}{dt}\right)_C = 0, \left(\frac{d\phi}{dt}\right)_B \neq 0$

(C) $\left(\frac{d\phi}{dt}\right)_C = 0$ (D) $\left(\frac{d\phi}{dt}\right)_C = \left(\frac{d\phi}{dt}\right)_B = 0$ and $\left(\frac{d\phi}{dt}\right)_A \neq 0$

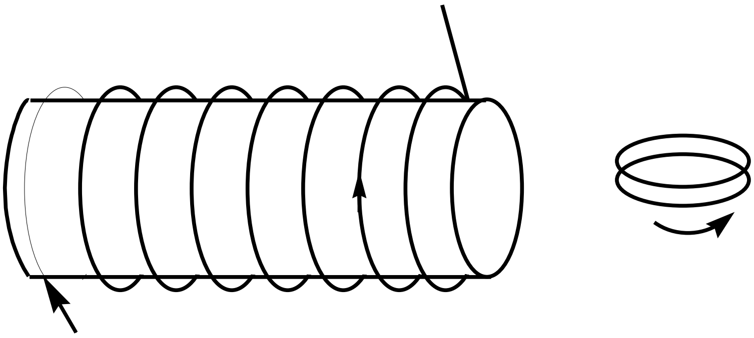
16. A conducting loop is pulled with a constant velocity towards a region of uniform magnetic field of induction B as shown in the figure. Then the current involved in the loop is $(d > r)$:



(A) clockwise while entering (B) anti-clockwise while entering

(C) zero when completely inside (D) clockwise while leaving

17. At a small distance from a solenoid carrying a current there is placed a circular coil with a current in such a manner that the solenoid's axis lies in the plane of the circular coil. The directions of the currents in solenoid and circular coil are shown by arrows. Mark the correct statement(s)



(A) Circular coil rotates counter clockwise and begins to moves towards the solenoid.

(B) Circular coil rotates clockwise and begins to moves away from the solenoid

(C) If the direction of current in the circular coil is opposite to that in figure then circular coil rotates counter clockwise and begins to moves away the solenoid

(D) If the direction of current in the circular coil is opposite to that in figure then circular coil rotates clockwise and begins to moves towards the solenoid

18. An infinite solenoid has radius R and n turns per unit length. The current grows linearly with time, according to $I_t = Ct$, in the solenoid. Here C is some constant. Let the induced electric field at distance r from axis of solenoid is E. Choose **correct** alternative(s)

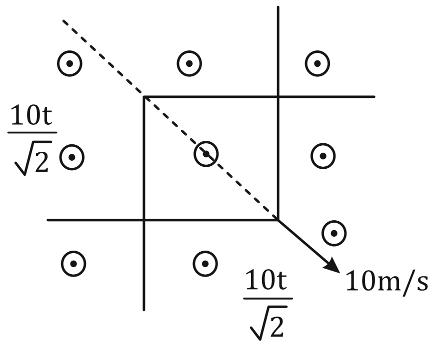
(A) $E \propto r$ for $r < R$

(B) $E \propto \frac{1}{r}$ for $r > R$

(C) If an infinite line charge having uniform linear charge density λ is placed along the axis, then electrostatic field produced by line charge and induced electric field are perpendicular to each other.

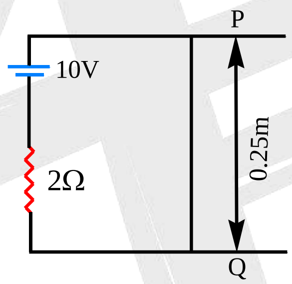
(D) The induced field and electrostatic field produced by line charge placed along axis of solenoid can be added vectorically to get net electric field at a point.

19. The L-shaped conductor as shown in figure moves a 10m/s across a stationary L-shaped conductor in a 0.10T magnetic field. The two vertices overlap so that the enclosed area is zero at t = 0. The conductor has resistance of 0.010 ohms per meter. What is current at t = 0.10 sec. (Round off to nearest integer)?



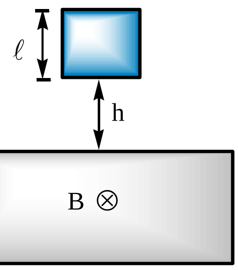
(A) 25 A (B) 30 A (C) 35 A (D) 40 A

20. A metal wire PQ slides on parallel metallic rails having separation 0.25m, each having negligible resistance. There is a $2\,\Omega$ resistor and 10V battery as shown in figure. There is a uniform magnetic field directed into the plane of the paper of magnitude 0.5 T. A force of 0.5 N to the left is required to keep the wire PQ moving with constant speed to the right. With what speed is the wire PQ moving? (Neglect self inductance of the loop)



(A) 4 m/s (B) 8 m/s (C) 12 m/s (D) 16 m/s

21. A square loop of side length $\ell\,(=25\text{cm})$ falls into a finite and uniform magnetic field $(B = 0.5T)$ confined to a region as shown. find the height 'h' through which the loop should be dropped, so that its velocity does not change during the period it enters the magnetic field. Assume mass of loop $m = 25gm$, the resistance $R = 2.5\,\Omega$ and $g = 10\,m/s^2$.

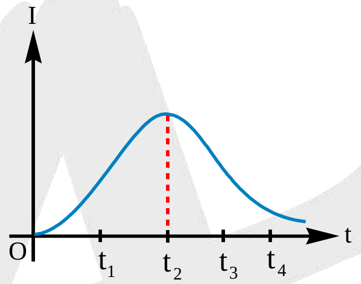


(A) 40 m (B) 80 m (C) 60 m (D) 20 m

EXERCISE – 2

1. A uniform but time varying magnetic field $B = C - Kt$, where K and C are positive constants and t is time, is applied perpendicular to the plane of a circular loop of radius 'a' and resistance R. The total charge that will pass through any point of the loop by the time B becomes zero is $\frac{C\pi a^{\alpha}}{\beta R}$. Find $\alpha + \beta$

2. An induction coil is connected to a source that delivers current varying with time. Variation of the current with time that passes through the coil is shown in the graph. Four moments are marked as t_1, t_2, t_3 and t_4 in the graph. The moment at which self-induced emf is maximum, is:



(A) t_1 (B) t_2 (C) t_3 (D) t_4

3. Induced emf produced in a coil rotating about a diameter with constant angular velocity and axis (diameter) perpendicular to a uniform magnetic field will be maximum when the angle between the plane of coil and direction of magnetic field is:

(A) $0°$ (B) $90°$ (C) $45°$ (D) None of these

4. A flat coil with a cross – sectional area s and with N turns is placed in a magnetic field of constant density B. When the coil is moved out of the field an emf is induced in the coil. The graph of induced emf is drawn with respect to time. The total area under the emf time curve:

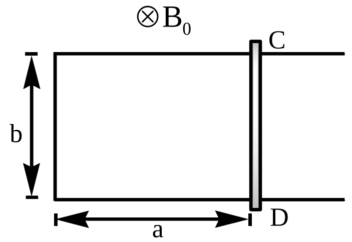
(A) will be independent of the velocity of the removal of the coil from field

(B) will be inversely proportional to the velocity of removal of coil from the field

(C) will be directly proportional to the velocity of removal of coil from the field

(D) None of the above

5. A U – shaped conducting frame is fixed in space. A conducting rod CD lies at rest on the smooth frame as shown. The frame is in uniform magnetic field B_0, which is perpendicular to the plane of frame. At time t = 0, the magnitude of magnetic field begins to change with time t as, $B = \frac{B_0}{1+kt}$, where k is a positive constant. For no current to be ever induced in frame, the speed with which rod should be pulled starting from time t = 0 is (the rod CD should be moved such that its velocity must lie in the plane of frame and perpendicular to rod C(D)

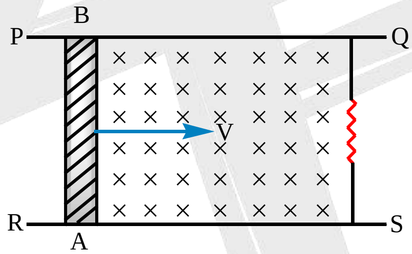


Frame in magnetic field
before time t = 0

(A) ak (B) bk (C) a (1+kt) (D) b(1+kt)

6. A superconducting loop of radius R has half inductance L. A uniform and constant magnetic field B is applied perpendicular to the plane of the loop. Initially current in this loop is zero. The loop is rotated by $180°$. The current in the loop after rotation is equal to $\frac{\alpha B\pi R^{\beta}}{L}$. Find $\alpha+\beta$.

7. A plastic rod AB is moving on a fixed conducting frame PQRS. No other external force is acting. (Consider $V_{AB} \neq 0$)



(A) A will be at high potential (B) Its velocity becomes reduced

(C) Current will flow in clockwise direction (D) None of the above

8. Two identical cycle wheels (geometrically) have different number of spokes connected from centre to rim. One is having 20 spokes and other having only 10 (the rim and the spokes are resistanceless). One resistance of value R is connected between centre and rim. The current in R will be

(A) double in first wheel than in the second wheel

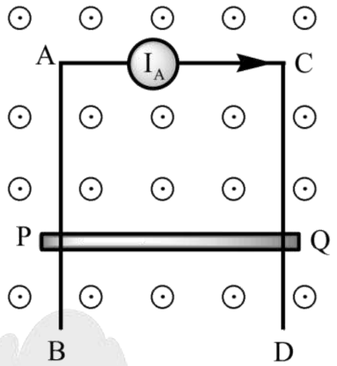
(B) four times in first wheel than in the second wheel

(C) will be double in second wheel than that of the first wheel

(D) will be equal in both these wheels

9. A uniform magnetic field exists in region given by $\vec{B}=3\hat{i}+4\hat{j}+5\hat{k}$. A rod of length 5m is placed along y – axis is moved along x – axis with constant speed 1 m/sec. Then induced e.m.f. (in volt) in the rod will be:

10. AB and CD are fixed conducting smooth rails placed in a vertical plane and joined by a constant current source at its upper end. PQ is a conducting rod which is free to slide on the rails. A horizontal uniform magnetic field exists in space as shown. If the rod PQ in released from rest then:



(A) The rod PQ will move downward with constant acceleration

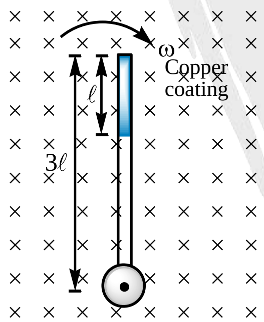
(B) The rod PQ will move upward with constant acceleration

(C) The rod will move downward with decreasing acceleration and finally acquire a constant velocity

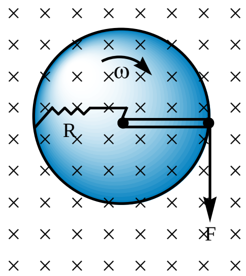
(D) Either ((A) or (B)

11. A wooden stick of length 3ℓ is rotated about an end with constant angular velocity ω in a uniform magnetic field B perpendicular to the plane of motion. If the upper one third of its length in coated with copper, the potential difference across the whole length of the stick is $\frac{nB\omega\ell^2}{2}$.

Find n?



12. A metallic ring of mass m and radius r with a uniform metallic spoke of same mass m and length r is rotated about its axis with angular velocity ω in a perpendicular uniform magnetic field B as shown. If the central end of the spoke is connected to the rim of the wheel through a resistor R as shown. The resistor does not rotate, its one end is always at the centre of the ring and other end is always in contact with the ring. A force F as shown is needed to maintain constant angular velocity of the wheel. F is equal to $\frac{B^{\alpha}\omega r^{\beta}}{4R}$. Find $\alpha+\beta$? (The ring and the spoke has zero resistance)



13. A wire of fixed length is wound in such a way that it forms a solenoid of length 'ℓ' and radius 'r'. Its self-inductance is found to be L. Now if same wire is wound in such a way that it forms a solenoid of length $\frac{\ell}{2}$ and radius $\frac{r}{2}$, then the self-inductance will be:

(A) 2L (B) L (C) 4L (D) 8L

14. A current carrying ring is placed in a horizontal plane. A charged particle is dropped along the axis of the ring to fall under the influence of gravity.

(A) The current in the ring may increase

(B) The current in the ring may decrease

(C) The velocity of the particle will continuously increase till it reaches the centre of the ring

(D) The acceleration of particle will decrease continuously till it reaches the centre

15. A very small circular loop of area $5\times10^{-4}\,m^2$ and resistance 2 ohm is initially concentric and coplanar with a stationary loop of radius 0.1 m. If one ampere constant current is passed through the bigger loop and the smaller loop is rotated about its diameter with constant angular velocity ω. The current induced (in ampere) in the smaller loop will be:

(A) $\frac{\pi\omega}{2}\times10^{-9}\cos\omega t$ (B) $\pi\omega\times10^{-9}\sin\omega t$

(C) $\frac{\pi\omega}{2}\times10^{-9}\sin\omega t$ (D) $\pi\omega\times10^{-9}\cos\omega t$

16. A metallic charged ring is placed in a uniform magnetic field with its plane perpendicular to the field. If the magnitude of field starts increasing with time, then:

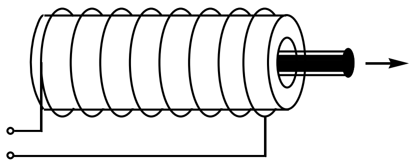
(A) The ring starts translating

(B) The ring starts rotating about its axis

(C) The ring starts rotating about a diameter

(D) The ring remains at rest

17. A solenoid carrying a current supplied by a DC source with a constant emf contains an iron core inside it. Mark the correct statement(s).



(A) The current will increase when the core is pulled out of the solenoid

(B) The current will decrease when the core is pulled out of the solenoid

(C) The self inductance will decrease when the core is pulled out of the solenoid

(D) The self inductance will increase when the core is pulled out of the solenoid

18. A ring of radius 20 cm has a total resistance of 0.04Ω. A uniform magnetic field varying with time $B = 0.4t\,T$ is perpendicular to the plane of the ring:

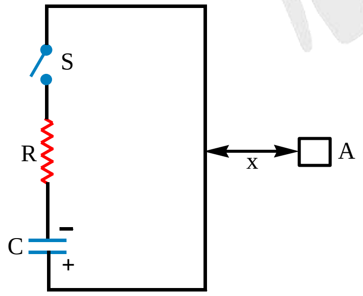
(A) The induced current in the ring is $\frac{2\pi}{5}A$

(B) The ring will be in tension

(C) The ring will be in compression

(D) The magnetic field due to ring at centre of ring will be in a direction opposite to the applied magnetic field

19. In figure the switch is closed at t = 0, with the capacitor of capacity $1\,\mu F$ and having initial charge of $20\,\mu C$ (the polarity shown). The left square loop has very large dimensions as compared to the distance between loops and a resistance of $10\,\Omega$ is connected in series with capacitor as shown. A wire of length 8mm and resistance per unit length of $0.5\,\Omega/mm$ is bent in the form of square loop A and placed at a distance x = 1m from left loop.



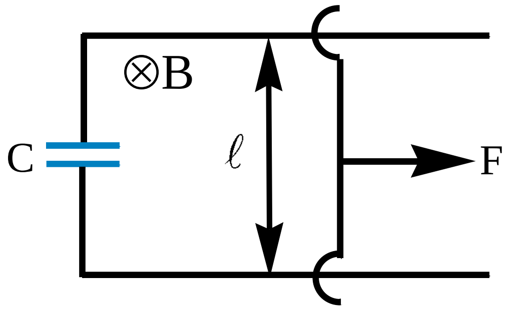
(A) The mutual inductance of the system will be $8\times10^{-13}\,H$

(B) The induced current in the loop A will be clockwise

(C) The induced current in the loop A will be anticlockwise

(D) The induced current in the loop A at time $t = 2RC\ln 2$ will be $10^{-8}A$

20. A conducting wire of length ℓ and mass m can slide without friction on two parallel rails and is connected to capacitance C initial charge zero. Whole system lies in a magnetic field B and a constant force F is applied to the rod at t = 0. If initial speed of rod is zero. Then:



(A) Speed of the rod at time $t = \dfrac{Ft}{B^2\ell^2C + m}$

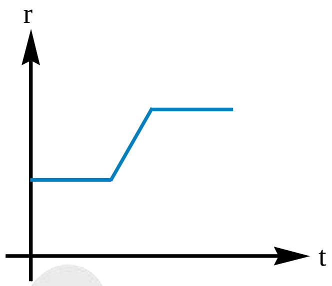
(B) The rod moves with constant acceleration

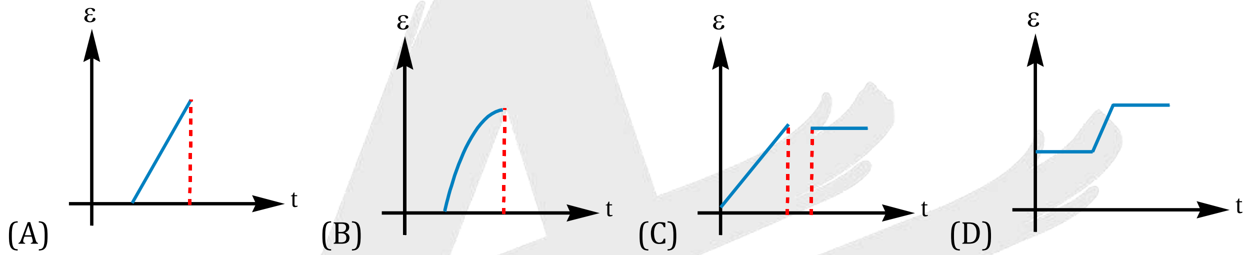
(C) The charge of capacitor varies linearly with velocity

(D) Charge on the capacitor will never attain steady state value

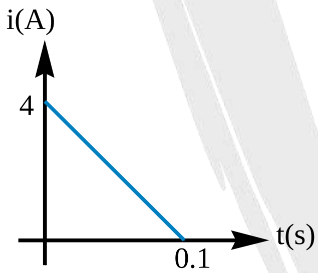
EXERCISE – 3

1. Radius of a circular ring is changing with time and the coil is placed in uniform constant magnetic field perpendicular to its plane. The variation of 'r' with time 't' is shown in the figure. Then induced e.m.f. ε with time will be best represented by:

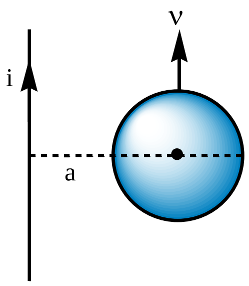




2. When magnetic flux through a coil is changed, the variation of induced current in the coil with time is as shown in graph. If resistance of coil is $10\,\Omega$, then the total change in flux of coil (in webers) will be:

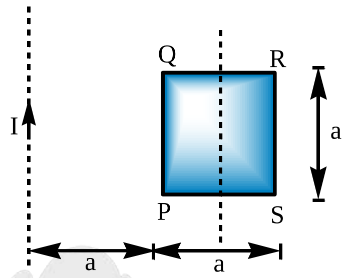


3. A circular loop of radius r is moved with a velocity ν as shown in the diagram. The force needed to maintain its velocity constant is:



(A) $\dfrac{\mu_0 i\nu r}{2\pi a}$ (B) $\dfrac{\mu_0 i\nu r}{2\pi(a+r)}$ (C) $\dfrac{\mu_0 i\nu r}{2\pi}\ln\left(\dfrac{2r+a}{a}\right)$ (D) Zero

4. In the figure shown a square loop PQRS of side 'a' and resistance 'r' is placed in near an infinitely long wire carrying a constant current – I. The sides PQ and RS are parallel to the wire. The wire and the loop are in the same plane. The loop is rotated by 180° about an axis parallel to the long wire and passing through the mid points of the side QR and PS. The total amount of charge which passes through any point of the loop during rotation is:



(A) $\frac{\mu_0 Ia}{2\pi r}\ln 2$ (B) $\frac{\mu_0 Ia}{\pi r}\ln 2$ (C) $\frac{\mu_0 Ia^2}{2\pi r}$

(D) Cannot be found because time of rotation is not given

5. A closed circuit consists of a resistor R, inductor of inductance L and a source of emf E are connected in series. If the inductance of the coil is abruptly decreased to $\frac{L}{4}$ (by removing its magnetic core), the new current immediately after this moment is $\frac{\alpha E}{\beta R}$. Find $\alpha+\beta$? (before decreasing the inductance the circuit is in steady state)

6. A plane loop of wire is placed in a region where the magnetic field is perpendicular to the plane of the loop and has the same magnitude and direction at all points within the area of the loop at any time. The magnitude of the magnetic field B varies with time according to the expression $B = B_0 e^{-at}$. Where B_0 is maximum value of magnetic field and a is a positive constant. The time at which induced emf in the loop is maximum when:

(A) $t = 0$ (B) $t = \frac{1}{a}$ (C) $t = \frac{2}{a}$ (D) $t = \frac{1}{a}\ln 2$

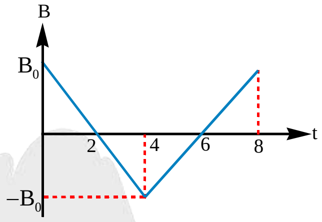
7. A rod of length ℓ having uniformly distributed charge Q is rotated about one end with constant frequency 'f'. Its magnetic moment is:

(A) $\pi f Q\ell^2$ (B) $\frac{\pi f Q\ell^2}{3}$ (C) $\frac{2\pi f Q\ell^2}{3}$ (D) $2\pi f Q\ell^2$

8. A metallic rod of length ℓ rotates at angular velocity ω about an axis passing through one end and perpendicular to the rod. If mass of electron is m and its charge is –e then the magnitude of potential difference between its two ends is:

(A) $m\omega^2 \frac{\ell^2}{2e}$ (B) $m\omega^2 \frac{\ell^2}{e}$ (C) $m\omega^2 \frac{\ell}{e}$ (D) none of these

9. In the graph variation of magnetic field with time 't' applied perpendicular to the plane of the ring is shown:



(A) At t = 2 sec and current flowing in ring is equal to zero

(B) Current will change its direction two times in time intervals t = 0 to t = 8 sec

(C) Current will change its direction only once in the above interval

(D) Flux in ring is same at t = 0 and t = 4 sec

10. A vertical conducting ring of radius R falls vertically with a speed V in a horizontal uniform magnetic field B which is perpendicular to the plane of the ring:

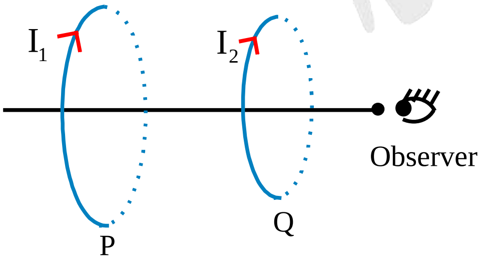
(A) A and B are at same potential

(B) C and D are at same potential

(C) current flows in clockwise direction

(D) current flows in anticlockwise direction

11. Two circular coils P and Q are coaxially and carry currents I_1 and I_2 respectively: (all direction are w.r.t. the observer)



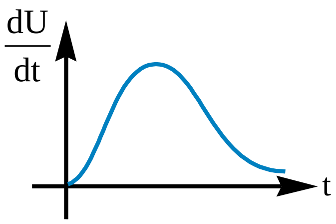
(A) if $I_2 = 0$ and P moves towards Q, a current in the same direction as I_1 is induced in Q

(B) if $I_1 = 0$ and Q move towards P, a current in the opposite direction to that of I_2 is induced in P

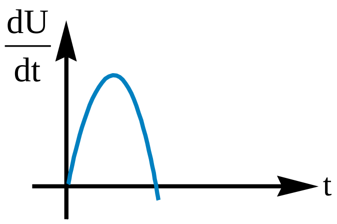
(C) When $I_1 \neq 0$ and $I_2 \neq 0$ are in the same direction then the two coils tend to move apart

(D) When $I_1 \neq 0$ and $I_2 \neq 0$ are in opposite directions then the coils attract each other.

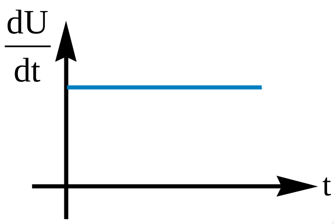
12. Rate of increment of energy in an inductor with time in series LR circuit getting charge with battery of e.m.f. E is best represented by: [inductor has initially zero current]



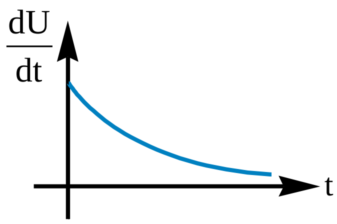
(A)



(B)

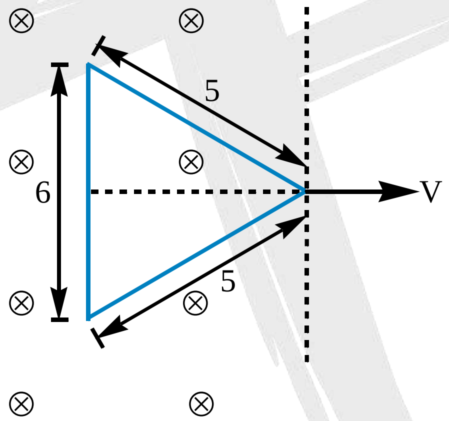


(C)



(D)

13. A triangular loop as shown in the figure is started to being pulled out at t = 0 from a uniform magnetic field with a constant velocity V. Total resistance of the loop is constant and equals to R. Then the variation of power produced in the loop with time will be:



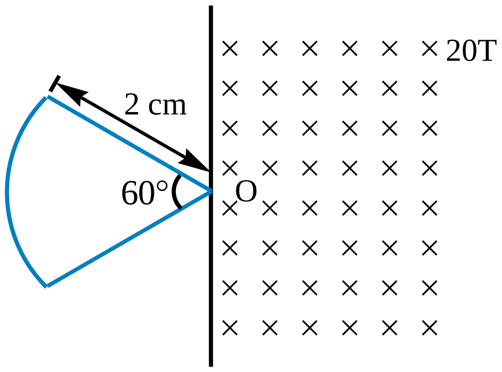
(A) linearly increasing with time till whole loop comes out

(B) increases parabolically till whole loop comes out

(C) $P \propto t^3$ till whole loop come out

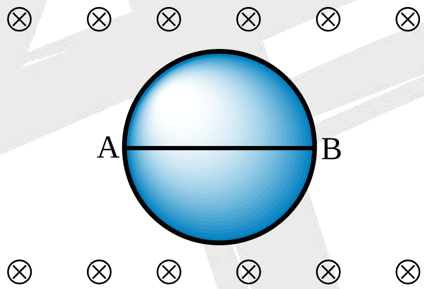
(D) will be constant with time

14. A uniform magnetic field 20 T exists in a gravity free space all over the space on right side of the shown boundary. The given circular arc of radius 2cm made of conducting wire of total resistance $4\,\Omega$ is rotated around point O at a constant angular speed 2 rad per second. Power required to maintain the constant angular velocity is $n\mu W$. Find n?



15. In a L-R growth circuit, inductance and resistance used are 1 Henry and $20\ \Omega$ respectively. If at $t = 50$ millisecond, current in the circuit is 3.165 A then applied direct current emf is (in volt)

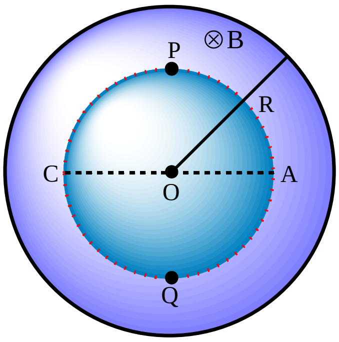
16. A circular conducting loop is placed in a region of uniform magnetic field such that the field is in direction normal to plane of the loop. The radius of the loop is R and the resistance per unit length of the loop is λ. A straight wire AB of resistance per unit length λ is connected along one diameter of the loop. The uniform magnetic field is decreasing with time at a constant rate α (tesla/se(C). Then current in the straight wire AB is:



Uniform Magnetic Field
(Normal to Plane of Paper)

(A) $\frac{R\alpha}{2\lambda}$ from A to B (B) $\frac{R\alpha}{2\lambda}$ from B to A (C) $\frac{2R\alpha}{\lambda}$ from A to B (D) zero

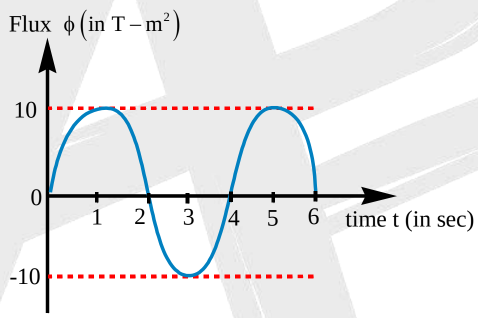
17. A uniform magnetic field B increasing with time exists in a cylindrical region of centre O and radius R. The direction of magnetic field is inwards the paper as shown. The work done by external agent in taking a unit positive charge slowly from A to C via paths APC, AOC and AQC be W_{APC}, W_{AOC} and W_{AQC} respectively. Then:



(A) $W_{APC} = W_{AOC} = W_{AQC}$ (B) $W_{APC} > W_{AOC} > W_{AQC}$

(C) $W_{APC} < W_{AOC} < W_{AQC}$ (D) $W_{APC} = W_{AQC} < W_{AOC}$

18. A closed conducting loop, having resistance R, is being rotated about an axis perpendicular to the magnetic field. Magnetic flux through the closed conducting loop is continuously changing according to the graph shown in the adjacent figure. Then, which of the following statement(s) is/are correct?



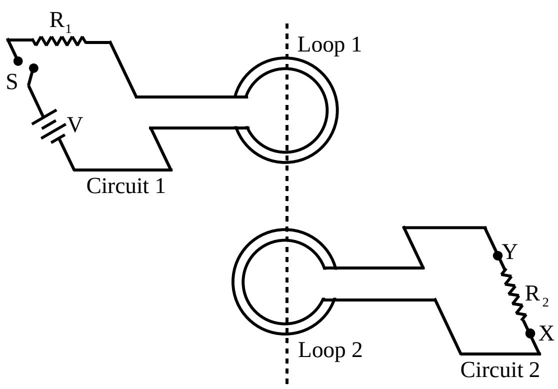
(A) The electric current through the loop is minimum (zero) at t = 1s, 3s and 5s

(B) The electric current through the loop is minimum (zero) at t = 0s, 2s and 6s

(C) Total charge flown through any cross-section of a closed conducting loop between 0 and 6s is zero

(D) Total work done in rotating the loop in the magnetic field is zero

19. The diagram below shows two conducting loops having a common axis. Which of the following is/are correct?



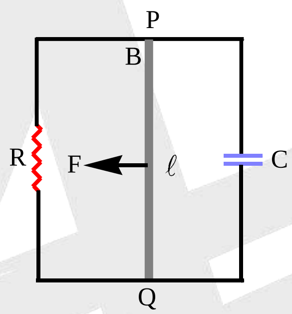
(A) After the switch S is closed, the initial current through resistor R_2 is from point X to point Y

(B) After the switch S is closed, the initial current through resistor R_2 is from point Y to point X

(C) After the switch S has been closed for a very long time, the current is $\frac{V}{R_1}$ in circuit 1 and zero in circuit 2

(D) After the switch S has been closed for a very long time, the current is zero in circuit 1 and $\frac{V}{R_2}$ in circuit 2

20. A conducting rod PQ of length ℓ is dogged with a constant force F along two smooth parallel rails separated by a distance ℓ as shown in the figure. Then choose the correct statement(s)



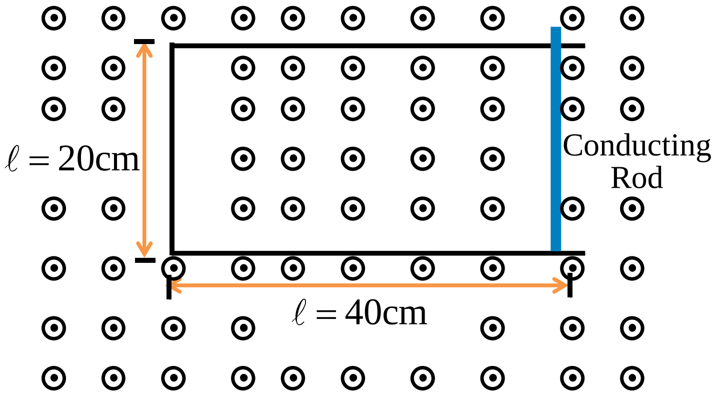
(A) Terminal velocity of the rod, $v_t = \frac{2FR}{B^2\ell^2}$

(B) Terminal velocity of the rod, $v_t = \frac{FR}{B^2\ell^2}$

(C) Maximum charge on the capacitor, $q_{max} = \frac{FCR}{B\ell}$

(D) Maximum charge on the capacitor, $q_{max} = \frac{2FCR}{B\ell}$

21. Figures shows a conducting rod of negligible resistance that can slide on smooth U – shaped rail made of wire of resistance $1\Omega/m$. Position of the conducting rod at t = 0 is shown. A time dependent magnetic field B = 2t tesla is switched on at t = 0. After the magnetic field is switched on, the conducting rod is moved to the left perpendicular to the rails at constant speed 5cm/s by some external agent.



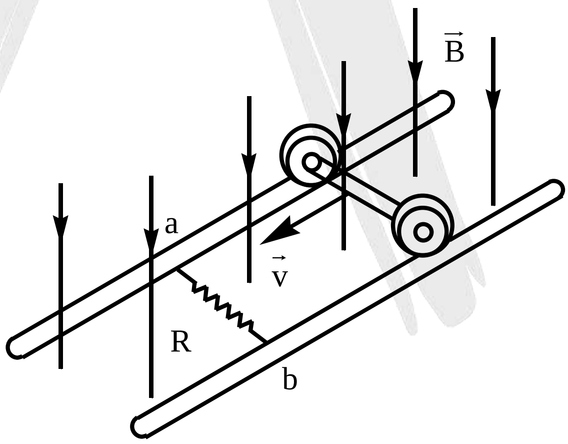
(A) The current in the loop at t = 0 due to induced emf is 0.16 A, clockwise

(B) At t = 2s, induced emf has magnitude 0.08 V

(C) The magnitude of the force required to move the conducting rod at constant speed 5 cm/s at t =2s, is equal to 0.08 N

(D) The magnitude of the force required to move the conducting rod at constant speed 5 cm/s at t =2s, is equal to 0.16 N

22. In figure the rolling axle, of length ℓ is pushed along horizontal rails at a constant speed v. A resistor R is connected to the rails at points a and b, directly opposite each other. The wheels make good electrical contact with the rails, so the axle, rails, and R form a closed-loop circuit. The only significant resistance in the circuit is R. A uniform magnetic field B is vertically downward. Mark the correct statement(s).



(A) The induced current I in the resistor is $\frac{B\ell v}{R}$

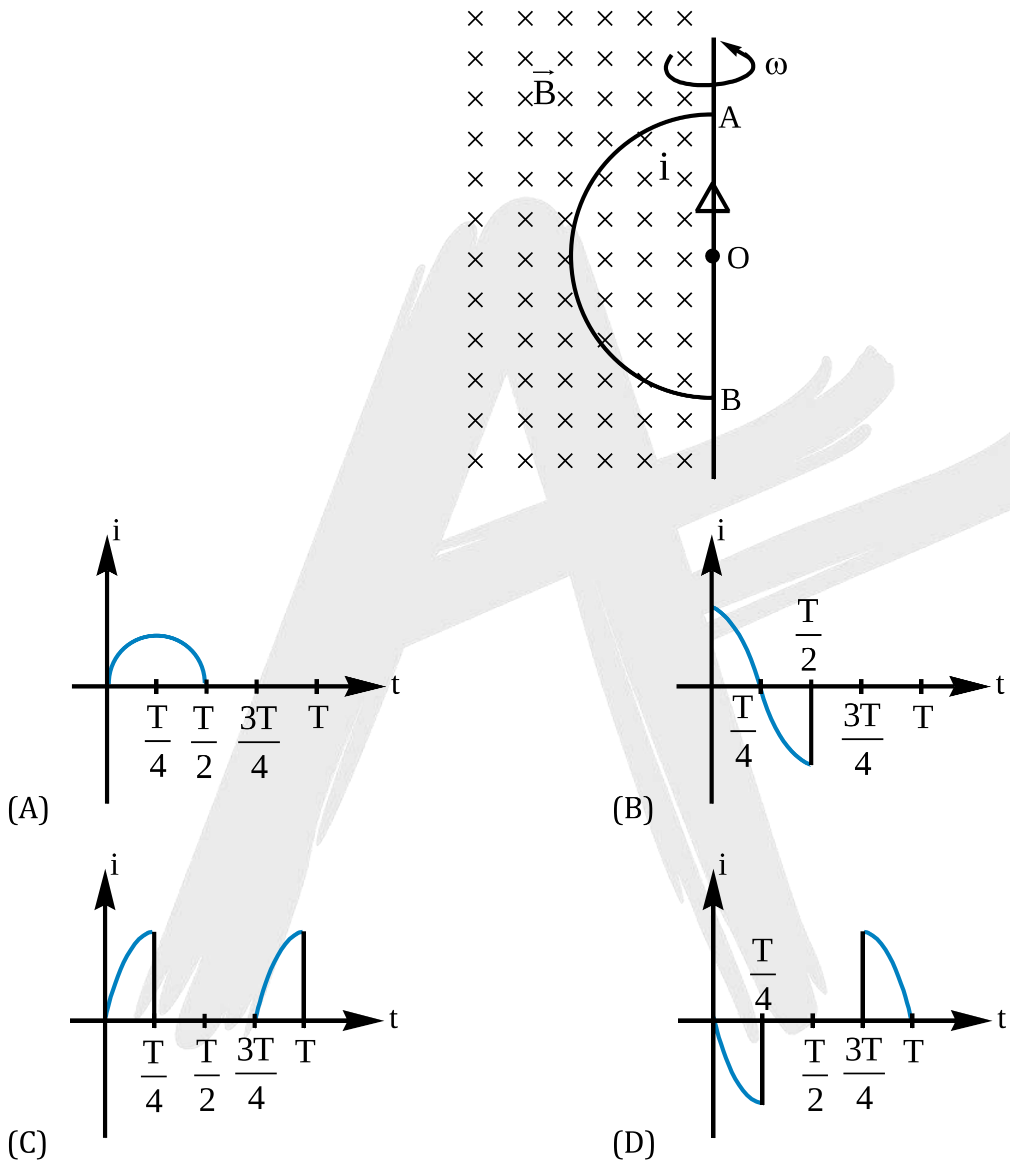
(B) Horizontal force F is required to keep the axle rolling at constant speed is $\frac{B^2\ell^2v^2}{R}$

(C) End of the resistor, a is at the higher electric potential than b

(D) After the axle rolls past the resistor, the current in R reverse direction.

EXERCISE – 4

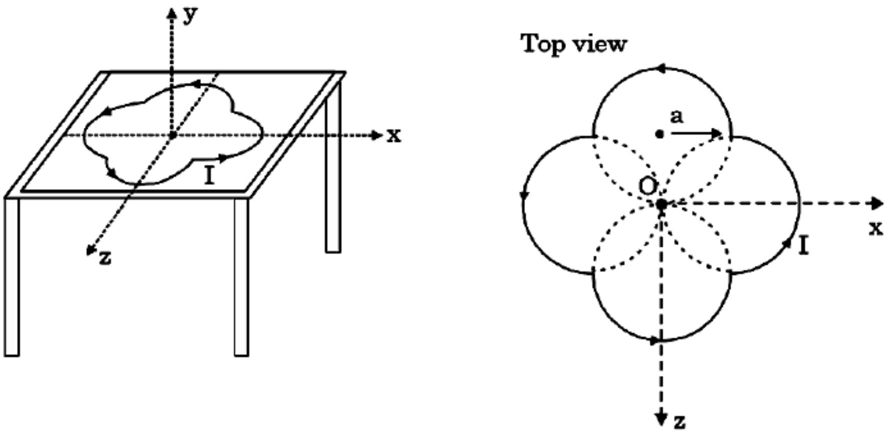
1. A semi-circular loop of radius R is rotated about its straight edge which divides the space into two regions one having a uniform magnetic field B and the other having no field. If initially the plane of loop is perpendicular to $\vec{B}$ (as shown), and if current flowing from O to A be taken as positive, the correct plot of induced current v/s time for one time period is



2. A rectangular loop of sides 'a' and 'b' is placed in xy plane. A very long wire is also placed in xy plane such that side of length 'a' of the loop is parallel to the wire. The distance between the wire and the nearest edge of the loop is 'd'. Then find the mutual inductance of this system is

(A) $\frac{\mu_0 a}{2\pi}\ln\frac{b+d}{d}$ (B) $\frac{\mu_0 a}{2\pi}\ln\frac{b-d}{d}$ (C) $\frac{\mu_0 a}{4\pi}\ln\frac{b+d}{d}$ (D) $\frac{\mu_0 a}{4\pi}\ln\frac{b-d}{d}$

3. A current carrying uniform frame made by four semi-circular wire each of radius 'a' kept on smooth horizontal table shown. Uniform external magnetic field $\vec{B} = B_0\hat{i}$ present in the region (mass of loop is m, current in loop is I, center of loop is origin, number of turn in the loop is 1)



Choose **CORRECT** option(s).

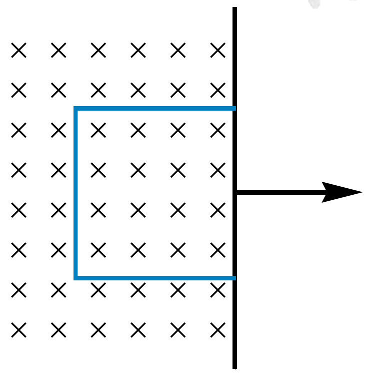
(A) Torque due to external magnetic field on the loop is $2Ia^2B_0(2+\pi)\hat{k}$

(B) Torque due to external magnetic field on the loop is $2Ia^2B_0(1+\pi)(-\hat{k})$

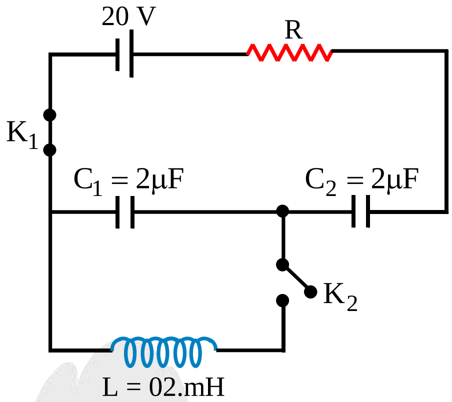
(C) Magnetic dipole moment of loop is $2Ia^2B_0(2+\pi)\hat{j}$

(D) Magnetic dipole moment of loop is $2Ia^2B_0(1+\pi)\hat{j}$

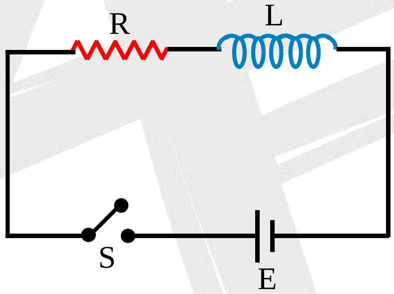
4. A square loop of area $2.5\times10^{-3}\,m^2$ and having 100 turns with a total resistance of 100Ω is moved out of a uniform magnetic field of 0.40 T in 1 sec with a constant speed. Then work done, in pulling the loop is $n\times10^{-4}\,mJ$. Find n?

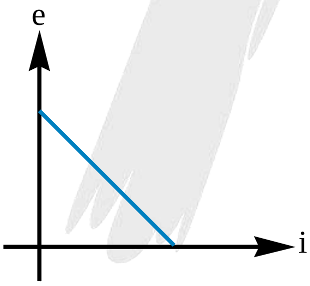


5. A circuit containing capacitors C_1 and C_2 as shown in the figure are in steady state with key K_1 closed. At the instant t = 0, if K_1 is opened and K_2 is closed then the maximum current in the circuit will be (in (A)

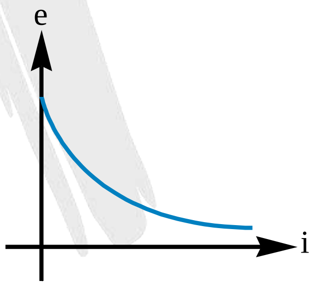


6. In an L-R circuit connected to a battery of constant e.m.f. E switch S is closed at time t = 0. If e denotes the induced e.m.f. across inductor and i the current in the circuit at any time t. Then which of the following graphs shown the variation of e with i?

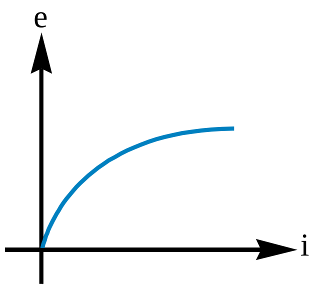




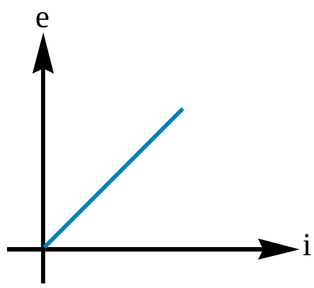
(A)



(B)

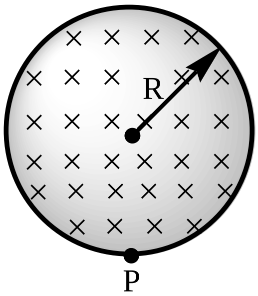


(C)



(D)

7. A uniform magnetic field of induction B is confined to a cylindrical region of radius R. The magnetic field is increasing at a constant rate of $\frac{dB}{dt}$ (tesla/secon(D). A negative charge of magnitude e, placed at the point P on the periphery of the field, experiences an acceleration:



(A) $\frac{1}{2}\frac{eR}{m}\frac{dB}{dt}$ towards left

(B) $\frac{1}{2}\frac{eR}{m}\frac{dB}{dt}$ towards right

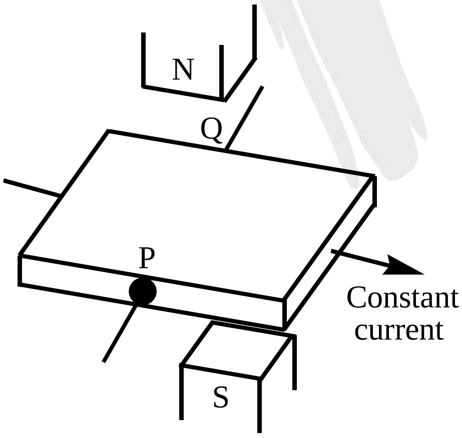
(C) $\frac{eR}{m}\frac{dB}{dt}$ towards left

(D) zero

8. A ring of mass m, radius r having charge q uniformly distributed over it and free to rotate about its own axis is placed in a region having a magnetic field B parallel to its axis. If the magnetic field is suddenly switched off, the angular velocity acquired by the ring is:

(A) $\frac{qB}{m}$ (B) $\frac{2qB}{m}$ (C) $\frac{qB}{2m}$ (D) none of these

9. Figure shows the essential parts of an apparatus to demonstrate the Hall Effect. Which of the following statements is/are correct?



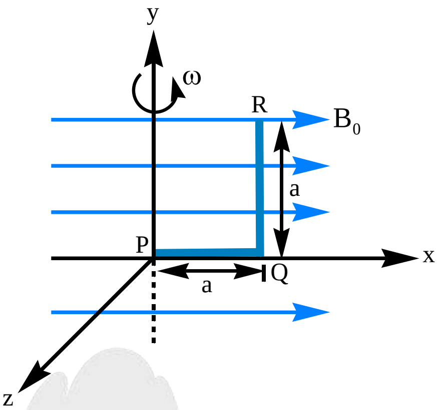
(A) In the arrangement above, the Hall potential difference is developed across PQ

(B) The magnitude of the Hall potential is greater if the applied magnetics flux density is increased

(C) The magnitude of the Hall potential is less if the width PQ of the specimen is decreased

(D) Hall potential is independent of material used for conductor

10. In a region there exist a magnetic field B_0 along positive x – axis. A metallic wire of length 2a and one side along x – axis and one side parallel of y – axis is rotating about y – axis with a angular velocity ω. Then at the instant shown.



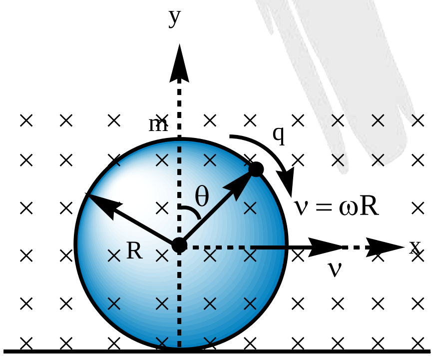
(A) Potential difference across PQ is 0

(B) Potential difference across PQ is $\frac{1}{2}B_0\omega a^2$

(C) Potential difference across QR is $\frac{1}{2}B_0\omega a^2$

(D) Potential difference across QR is $B_0\omega a^2$

11. A ring of mass m and radius R is set into pure rolling on horizontal rough surface in a uniform magnetic field of strength B as shown in the figure. A point charge q of negligible mass is attached to rolling ring. Friction is sufficient so that it does not slip at any point of its motion. (θ is measured in clockwise from positive y – axis)



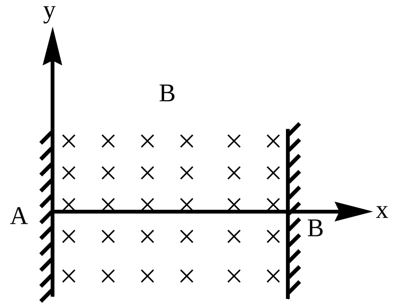
(A) Ring will continue to move with constant velocity for the case when it does not loose contact

(B) The value of friction acting on ring is $Bqv\cos\theta$

(C) The value of friction acting on ring is $Bqv\sin\theta$

(D) Ring will lose contact with ground if v is greater than $\left(\frac{mg}{2qB}\right)$

12. A standing wave $y = 2A\sin kx\cos\omega t$ is setup in the conducting wire PQ fixed at both ends by two vertical walls (see the figure). The region between the walls contains a constant magnetic field B. The wire is found to vibrate in the 3rd harmonic (where PQ = L)



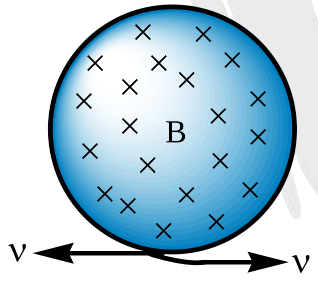
(A) The maximum emf induced is $\frac{4AB\omega}{k}$

(B) The time when the emf becomes zero for the first time is $\frac{\pi}{2\omega}$

(C) The total emf induced is always zero between x = 0 and $x = \frac{2L}{3}$

(D) At t = 0, the emf in the entire wire is zero.

13. A circular conducting loop of radius r_0 and having resistance per unit length λ as shown in the figure is placed in a magnetic field B which is constant in space and time. The ends of the loop are crossed and pulled in opposite directions with a velocity ν such that the loop always remains circular and the radius of the loop goes on decreasing, then:



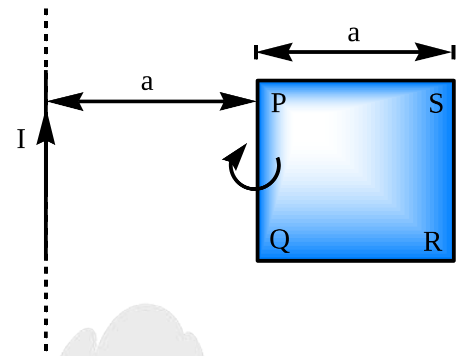
(A) Radius of the loop changes with r as $r = r_0 - \frac{\nu t}{\pi}$

(B) EMF induced in the loop as a function of time is $e = 2B\nu\left[r_0 - \frac{\nu t}{\pi}\right]$

(C) Current induced in the loop is $I = \frac{B\nu}{2\pi\lambda}$

(D) Current induced in the loop is $I = \frac{B\nu}{\pi\lambda}$

14. A square frame of resistance $\ln(2)\Omega$ and side $a = 20\text{cm}$ and a long straight wire carrying a current $I = 10\,\text{amp}$ are located in the same plane. The frame is rotated through an angle of 120° about the side PQ. Find the amount of charge flown through the loop during this time is

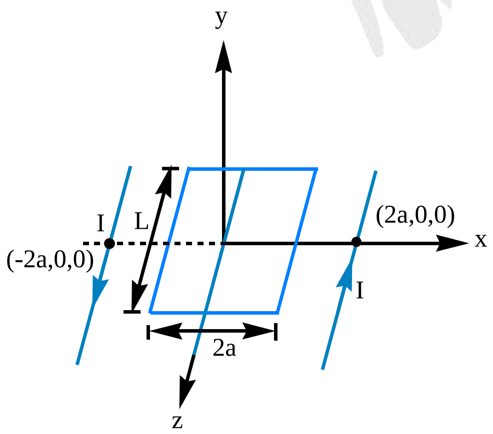


(A) 2×10^{-7} C (B) 2×10^{-6} C (C) 4×10^{-7} C (D) 4×10^{-6} C

15. A coil of circular shape having radius R and N turns begins to rotate about its diameter in uniform magnetic field B with a constant angular speed ω. The resistance of coil is η ohms. Find the amplitude of current in the coil is found to be $P\left(\frac{NB\omega\pi R^2}{2\eta}\right)$. Find P.

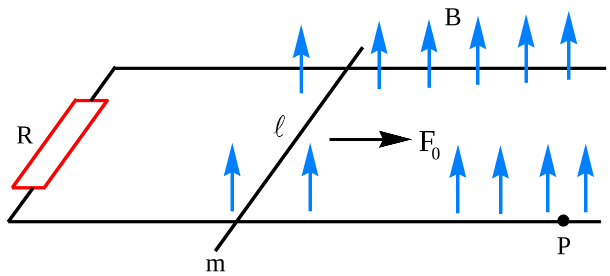
(A) 1 (B) 2 (C) 3 (D) 4

16. Two very long wires parallel to the z-axis (in xz plane) and a distance '4a' (along x-axis) apart carry equal currents I in opposite directions as shown in the figure. A rectangular strip of width 2a and length L has its centre on the origin midway between the wires, calculate the net upward magnetic flux through strip.



(A) $\frac{\mu_0 IL}{\pi}\ln 3$ (B) $\frac{\mu_0 IL}{2\pi}\ln 3$ (C) $\frac{2\mu_0 IL}{\pi}\ln 3$ (D) $\frac{3\mu_0 IL}{2\pi}\ln 3$

17. The long horizontal pair of rails shown in the figure is connected using resistance R. The distance between the rails is ℓ, the electrical resistance of the rails is negligible. A conducting wire of mass m and length ℓ can slide without friction on the pair of rails, in a vertical, homogeneous magnetic field of induction B.

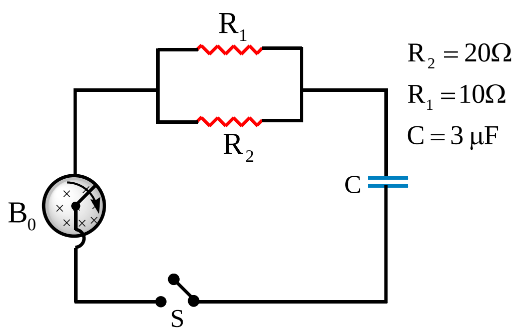


A force of magnitude F_0 is exerted for sufficiently long time onto the conducting wire, so that the speed of the wire becomes nearly constant. The force F_0 is now removed at a certain point P. What distance does the conducting wire cover on rails from point P before stopping?

(Given: $F_0 = 20\,\text{N},\ m = 1.6\,\text{gm},\ R = 0.01\Omega,\ \ell = 10\,\text{cm}, B = 0.1\,\text{T}$)

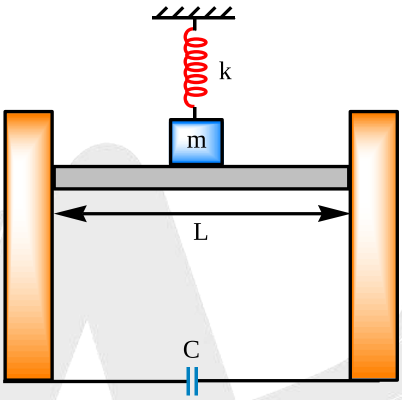
((A) 80 m (B) 160 m (C) 240 m (D) 320 m

18. There is a metallic ring of radius 1m and having negligible resistance placed perpendicular to a constant magnetic field of magnitude 1T as shown in figure. One end of a resistance less rod is hinged at the centre of ring O and other end is placed on the ring. Now rod is rotated with constant angular velocity 4rad/s by some external agent and circuit is connected as shown in the figure, initially switch is open and capacitor is uncharged. If switch S is closed at t = 0, then calculate heat loss from the resistor R_1 from t = 0 to the instant when voltage across the capacitor becomes half of steady state voltage. (Assume plane of ring to be horizontal and friction to be absent at all the contacts).



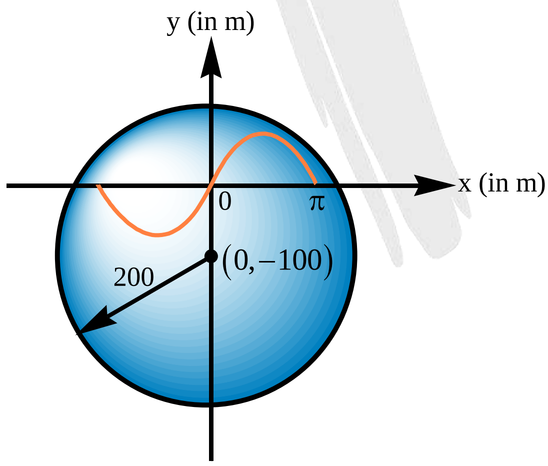
(A) $1\,\mu J$ (B) $2\,\mu J$ (C) $3\,\mu J$ (D) $4\,\mu J$

19. A block of mass 300g is attached to the ceiling by a spring that has a force constant $k = 200\ N/m$. A conducting massless rod is rigidly attached to the block and can slide without friction along two vertical parallel rails which are at a distance $L = 1m$ apart. A capacitor of known capacitance $C = 500\ \mu F$ is attached to the rails by the wire and the entire system is kept in magnetic field $B = 20T$ as shown in figure. Neglect the self-inductance and electrical resistance of all wire and rod. Find angular frequency (in rad/se(C) of vertical oscillation of block



(A) 10 (B) 15 (C) 20 (D) 25

20. A time varying uniform magnetic field, varying at constant rate 1T/sec exists in a circular region of radius 200 m centred at (0, -100). A conducting wire is placed along $y = \sin kx$, where $k = 1 rad/m$, from, $x = -\pi$ to $+\pi$. Find the magnitude of e.m.f. generated in the wire?

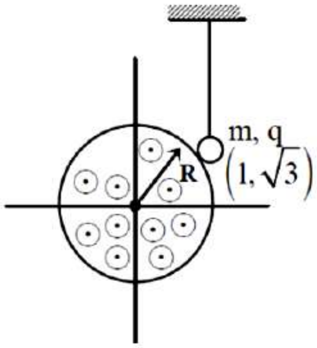


(A) 214V (B) 254V (C) 314V (D) 354V

21. A long straight conductor, having a circular cross section of radius 2m carries a current along its length such its magnetic field varies as $B = Kr^2, 0 \le r \le 2m$, where K is a positive constant. The slope of the current density (j)vs radial distance 'r' at $r = \frac{1}{2} m$ is $\frac{\alpha K}{\mu_0}$. The value of α is.

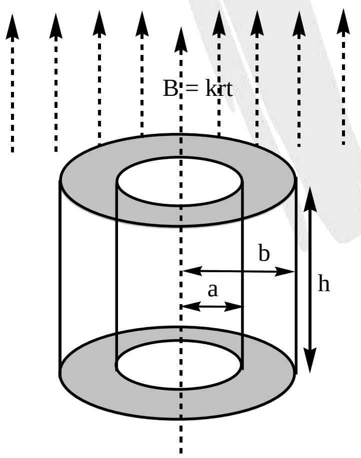
(A) 4 (B)8 (C)2 (D)3

22. A charged particle of mass m and charge q is suspended with the help of a string having breaking strength of 2mg and mass having co-ordinates $\left(1,\sqrt{3}\right)$ while the space carries a uniform magnetic field in cylindrical region with centre at origin and radius R=2m. Maximum charge q if string does not break at the instant magnetic field start increasing with rate 0.5 Tesla per second is found out to be 'Kmg' coulombs. The value of K is



(A) 4 (B) 8 (C) 2 (D) 6

23. A ring of circular cross section and thickness 'h' is made of a material of resistivity 'ρ'. The inner and outer radii of ring are 'a' and $b\left(=2a\right)$ respectively. A magnetic field $B=krt$ (where k is a constant, r is the radial distance from the axis of the ring and t is time) is existing in the region parallel to the axis of the ring as shown. Then choose the correct option (s).



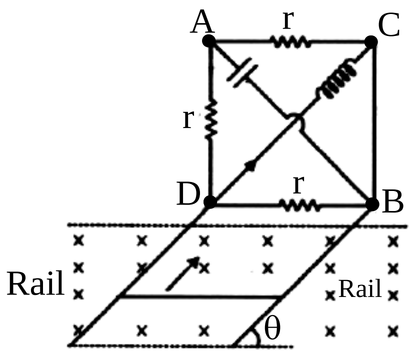
(A) The emf induced in the ring at $r=\frac{3a}{2}$ is $\frac{9}{4}k\pi a^3$

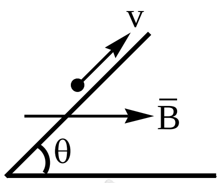
(B) The emf induced in the ring at $r=\frac{3a}{2}$ is $\frac{27}{8}k\pi a^3$

(C) The net induced current in the ring is $\frac{7kha^3}{9\rho}$

(D) The net induced current in the ring is $\dfrac{7kha^3}{6\rho}$

24. The electric circuit arrangement shown is confined in a vertical plane which is attached to two rails inclined at an angle θ with horizontal. A horizontal rod of length 'l' moves on the rails with constant speed v, in the region with transverse field B as shown in adjacent figure. Choose the correct alternative(s). The rod starts moving at time t = 0.





(A) At t=0, current in the rod is $\dfrac{2Blv\sin\theta}{r}$

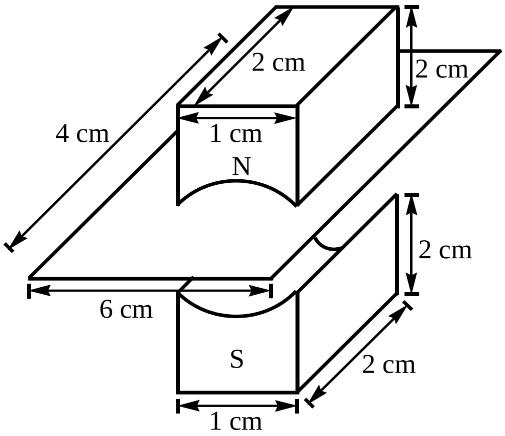
(B) After long time current in the rod is $\dfrac{Blv\sin\theta}{r}$

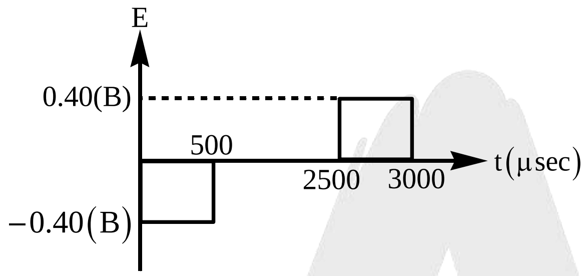
(C) at any time t (except at t = 0) $|V_A - V_B|$ is non zero

(D)at any time t (except at t=0) $|V_D - V_C| = 0$.

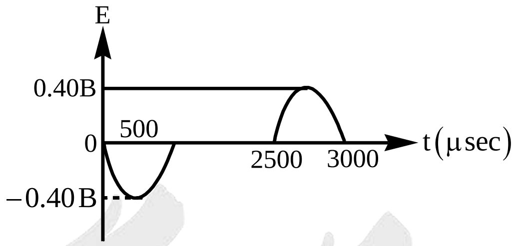
EXERCISE – 5

1. A magnetic field (B), uniform between two magnets can be determined measuring the induced voltage in the loop as it is pulled through the gap at uniform speed 20 m/sec. Size of magnet and coil is 2cm $\times$1cm$\times$2cm and 4cm $\times$ 6cm as shown in figure. The correct variation of induced emf with time is: (Assume at t = 0, the coil enters in the magnetic fiel(D)

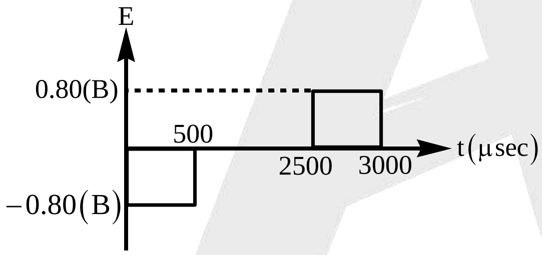




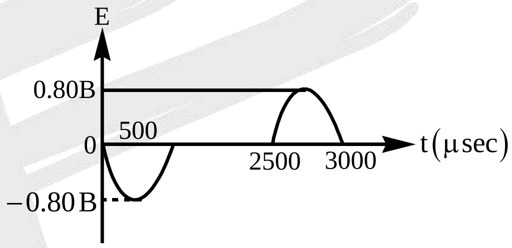
(A)



(B)

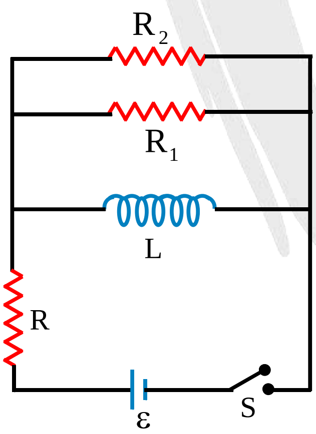


(C)



(D)

2. Switch S is closed for a long time at t = 0. It is opened, then:



(A) Total heat produced in resistor R after opening the switch is $\frac{1}{2}\frac{LV^2}{R^2}$

(B) Total heat produced in resistor R_1 after opening the switch is $\frac{1}{2}\frac{LV^2}{R^2}\left(\frac{R_1}{R_1+R_2}\right)$

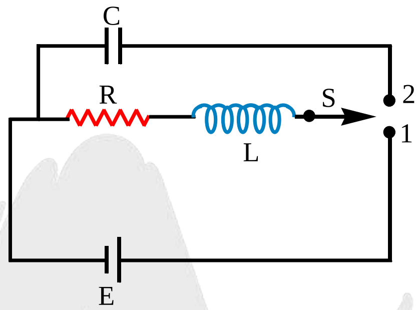
(C) Heat produced in resistor R_1 after opening the switch is $\frac{1}{2}\frac{R_2LV^2}{(R_1+R_2)R^2}$

(D) No heat will be produced in R_1

3. An inductor L and a resistor R are connected in series with a direct current source of emf E. The maximum rate at which energy is stored in the magnetic field is:

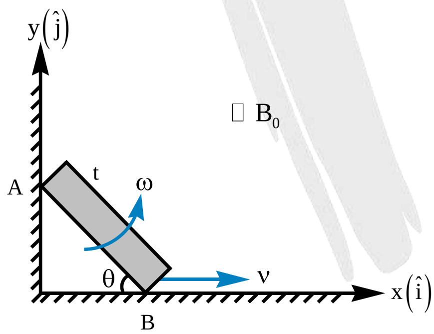
(A) $\frac{E^2}{4R}$ (B) $\frac{E^2}{R}$ (C) $\frac{4E^2}{R}$ (D) $\frac{2E^2}{R}$

4. In the circuit shown in figure, the switch S was initially at position 1. After sufficiently long time, the switch S was thrown from position 1 to position 2. The voltage drop across the resistor at that instant is:



(A) zero (B) E (C) $\frac{E}{R}LC$ (D) None of these

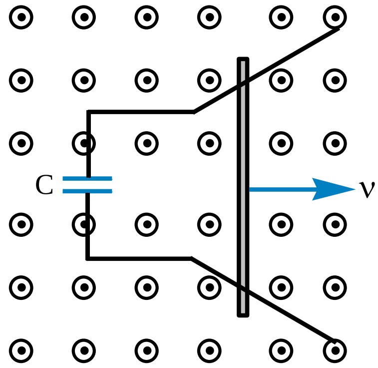
5. A thin conducting rod of length ℓ is moved such that its end B moves along the x – axis while end A moves along the y – axis. A uniform magnetic field $B = B_0\hat{k}$ exists in the region. At some instant, velocity of end B is v and the rod makes an angle of $\theta = 60°$ with the x – axis as shown in the figure. Then, at this instant:



(A) Angular speed of rod AB is $\omega = \frac{2v}{\sqrt{3}\ell}$ (B) Angular speed of rod AB is $\omega = \frac{\sqrt{3}v}{2\ell}$

(C) e.m.f. induced in rod AB is $B\ell v\sqrt{3}$ (D) e.m.f. induced in rod AB is $\frac{B\ell v}{2}\sqrt{3}$

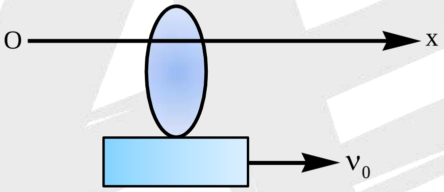
6. In the configuration shown below, the circuit has no resistance. There is uniform magnetic field B perpendicular to the plane of paper. A force F is applied on the rod to move it with constant velocity towards the right side. Which of the following increase(s) linearly with time?



(A) Charge on capacitor
(B) Current in the circuit
(C) Force applied
(D) Potential drop across the capacitor

7. Magnetic field along x – axis varies according to the relation $\vec{B} = B_0 x\hat{i}$. Given a coil of area A with its axis along x – axis is connected over the top of a plastic trolley which moves along x – axis with velocity v. If the resistance of coil is R, then:

(at t = 0, coil is at x = 0 and $v = v_0$)



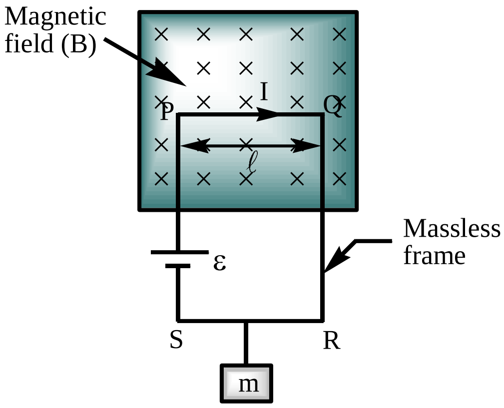
(A) The flux linked with the coil at any position x is $B_0 xA$

(B) An observer at origin 'O' finds the induced current as $\frac{B_0 A v_0}{R}$ anticlockwise if trolley moves with constant velocity $v = v_0$

(C) If the trolley has acceleration α then the induced current as a function of time t is given as $\frac{B_0 A(v_0 + \alpha t)}{R}$ anticlockwise

(D) If the trolley has acceleration α then the induced current as a function of position x is given as $\frac{B_0 A\left(\sqrt{v_0^2 + 2\alpha x}\right)}{R}$ anticlockwise

8. A massless frame is present in uniform magnetic field and a block of mass m hangs on the frame as shown in figure. When a constant current $I > \frac{mg}{\ell B}$ is maintained in the frame, it gets displaced by 'h' in some time interval. If ε is the emf of battery, then which of the following is/are **correct**?



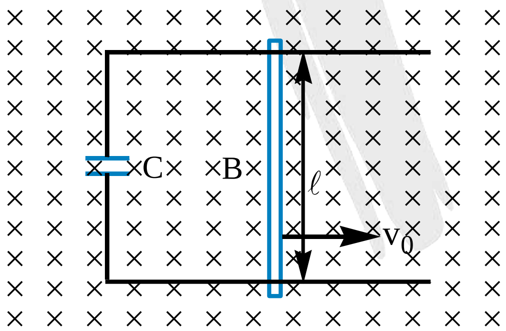
(A) Work done by magnetic force is $I\ell Bh$

(B) Work done by battery is $I\ell Bh$

(C) Velocity of block when it gets displacement by h is $\sqrt{\frac{2(I\ell B-mg)h}{m}}$

(D) Force on charges in the segment PQ while the frame moves up is in the vertical direction

9. Two fixed parallel conducting rails of negligible resistance are connected at one end by a capacitor C. Distance between the rails is ℓ. Arrangement is kept on a horizontal plane with vertical uniform magnetic field as shown in the figure. Initially capacitor is uncharged and a rod of resistance R and mass m is laid perpendicularly on to the rails and given a velocity v_0. Choose the correct option(s), provided that the rail is long enough and homogeneous field extends far enough (Friction and effect of self induction is negligible).



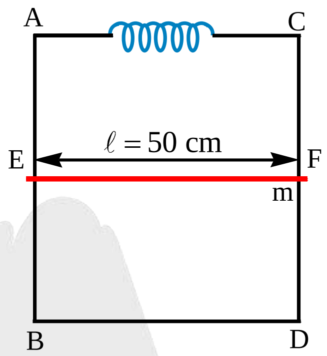
(A) Final velocity of the wire is $\frac{B^2\ell^2C}{m+B^2\ell^2C}v_0$

(B) Final charge on the capacitor is $\left[\frac{mB\ell C}{m+B^2\ell^2C}\right]v_0$

(C) Final current in the circuit is $\frac{Bv_0\ell}{2R}$

(D) Ratio of final kinetic energy and initial kinetic energy is $\left(\frac{m}{m+B^2\ell^2C}\right)$

10. A conducting frame ABCD is kept in a vertical plane. A conducting rod EF of mass 1kg and length 50cm can slide smoothly on it remaining horizontal always. The resistance of the frame is negligible and inductance is constant having value 1H. The rod is left from rest and allowed to fall under gravity with no current in the inductor. A magnetic field of constant magnitude 2T is present throughout the loop pointing inwards. Then (Assume length AB and CD of frame is sufficiently large):



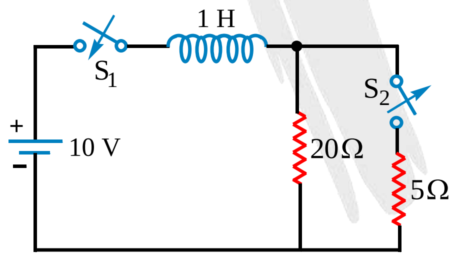
(A) Position of the rod as a function of time assuming initial position of the rod to be x = 0 and vertically downward as the positive x – axis is $x = 10[1 - \cos t]$

(B) Maximum current in the circuit is 20A

(C) Maximum velocity of the rod is 20 m/s

(D) After some time velocity of rod becomes constant.

11. In the circuit shown, switch S_1 is initially open and switch S_2 is initially closed. At time t = 0, S_1 is closed and at time t = 0.25s, S_2 is opened. The voltage across the inductor, V_L :



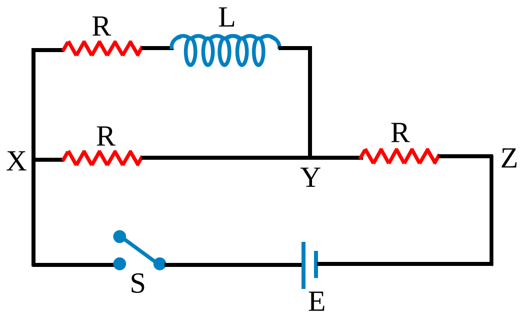
(A) Just after switch S_1 is closed, $V_L = 10\,V$

(B) Just before switch S_2 is opened, $V_L = 10/e\ V$

(C) Just after switch S_2 is opened, $V_L = (40 - 50/e)V$

(D) Just after switch S_2 is opened, $V_L = (60 - 50/e)V$

12. The switch is closed at t = 0 in the adjoining circuit. Which of the following is/are **correct**?



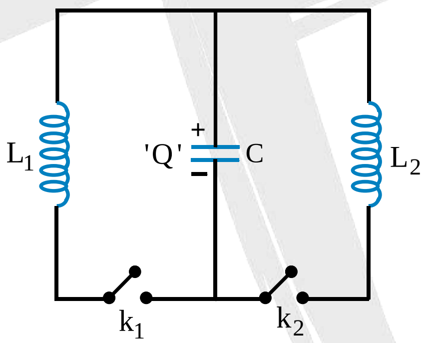
(A) The potential difference across YZ at t = 0 is $\frac{2E}{3}$

(B) The potential difference across XY at t = ∞ is $\frac{E}{2}$

(C) The potential difference across YZ at t = 0 is $\frac{E}{2}$

(D) The potential difference across XY at t = ∞ is $\frac{2E}{3}$

13. The given arrangement carries a capacitor with capacitance 40 mF and two inductors $L_1 = 25H$ and $L_2 = 100H$. If the capacitor initially carries a charge of 10 mC, then:



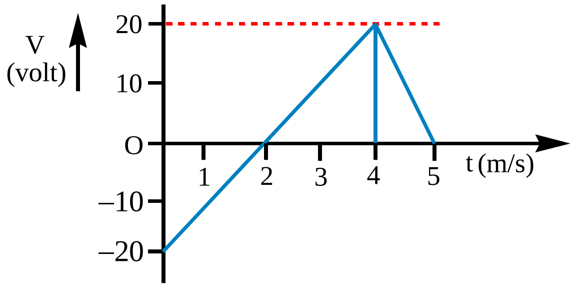
(A) The maximum current through the inductor L_1 when key k_1 is closed is 20 mA

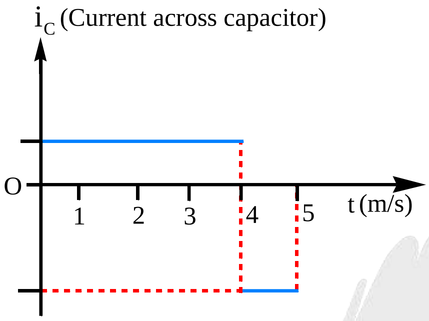
(B) The maximum current through the inductor L_2 when key k_2 is closed is 5 mA

(C) The maximum current through inductor L_2 when both the keys are closed is $\sqrt{5}$ mA

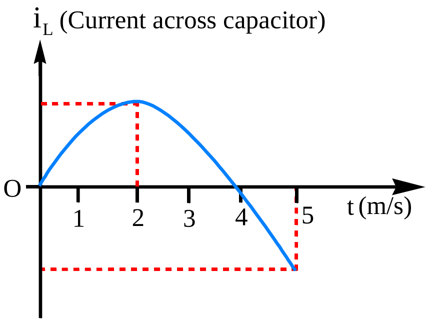
(D) Time period of oscillation of charge is minimum when both the keys are closed

14. The voltage shown in the figure is applied to a $2.5\ \mu F$ capacitor and a 0.5 H inductor separately. Choose **correct** graph:

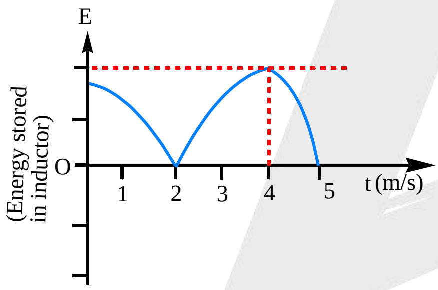




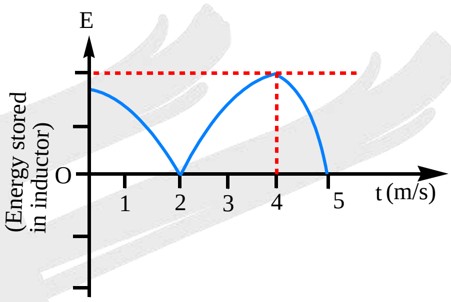
(A)



(B)

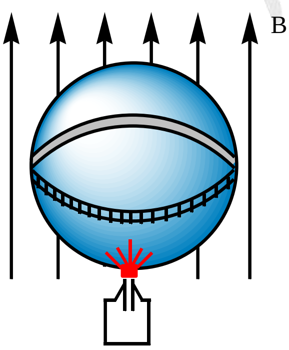


(C)



(D)

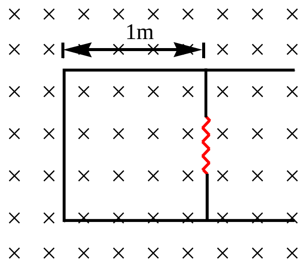
15. In the arrangement shown, a gas is filled inside a balloon, which is placed in a vertical magnetic field of intensity B. The initial volume of balloon is V_0 and the gas is filled inside it at the rate of $a\,m^3/s$. If there is no leakage, find the emf induced at $t = 8\pi \sec$, in a conducting ring, which is elastic and placed horizontally along the largest circumference of balloon. [Take: $B = 1.5T$, $V_0 = (20\pi)m^3$, $a = 2$]



(A) 0.5 V (B) 1 V (C) 1.5 V (D) 2 V

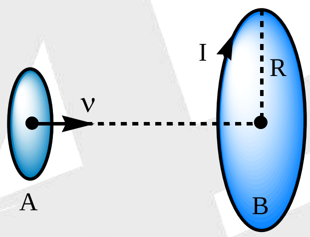
16. A rod of length $\ell = 1m$ and resistance $R = 10\Omega$ is being pulled with a constant velocity of 4m/s towards right. At t = 0 the rod is 1m away from the left end. The magnetic field is

$B = (1-3t)$ tesla. Find the work done by the external agent to move the rod with constant velocity for first 5sec. The rest of circuit is resistance less. Neglect friction.



(A) 967 J (B) 1021 J (C) 1067 J (D) 1121 J

17. Loop A of radius $r(r << R)$ moves towards a stationary constant current carrying loop B with a constant velocity v in such a way that their planes are parallel and coaxial. The distance between the loops when the induced emf in loop A is maximum is

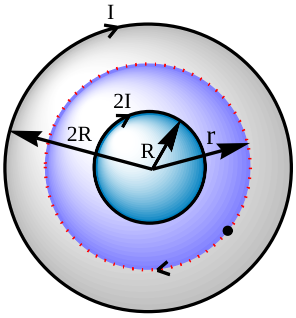


(A) R (B) R/2 (C) R/3 (D) R/4

18. A small bead of mass m and positive charge +q is mounted on a fixed, thin, smooth horizontal plastic ring of radius R. At t = 0, bead is stationary. Ring lies in x-y plane with centre at (0, 0). Magnetic field $\vec{B} = \frac{E_0 t}{r}\hat{k}$ (where $r \neq 0$) is switched on, where t denotes time, r distance from z – axis and E_0 is a positive constant. Find the magnitude of normal reaction exerted by ring on bead is λ (Gravity is absent)

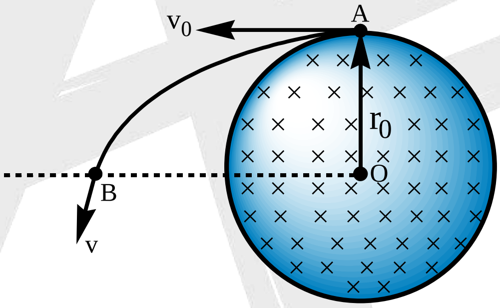
(A) 2 N (B) 4 N (C) 6 N (D) 0 N

19. A long solenoid contains another coaxial solenoid (whose radius R is half of its own). Their coils have the same number of turns per unit length and initially both carry no current. At the same instant current starts increasing linearly with time in both solenoids. At any moment the current flowing in the inner coil is twice as large as that in the outer one and their directions are the same. As a result of the increasing currents a charged particle, initially at rest between the solenoids, starts moving along a circular trajectory of radius r (see figure). Find r?



(A) R (B) $\sqrt{2}R$ (C) $\sqrt{3}R$ (D) $2R$

20. Consider a cylindrical region of uniform but time varying magnetic field. Now consider a plane perpendicular to this field. Top view of this cylindrical magnetic field on the plane is shown in the diagram which is a circular region of radius $r_0 = 1m$. A particle of mass π kg and charge 2C is projected with velocity of $v_0 = \sqrt{5}\,m/s$, tangential to this circle from point A. This particle intersects another radial line OB at point B with velocity v. If the magnetic field is increasing at the rate of 4T/s then find the value of v.



(A) 2 m/s (B) 4 m/s (C) 3 m/s (D) 5 m/s

21. Two coils, 1 and 2, have a mutual inductance = M and resistance R each. A current flows in coil 1, which varies with time as: $i_1 = kt^2$, where k is a constant and 't' is time. Find the total charge that has flown through coil 2, between t = 0 and t = T is

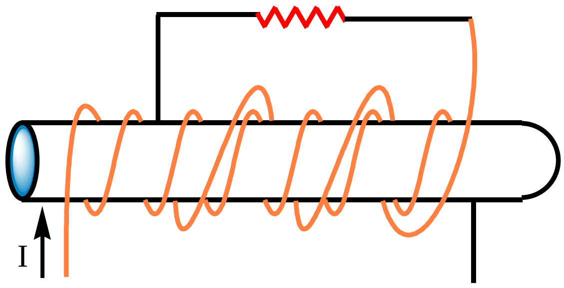
(A) $\frac{kMT^2}{2R}$ (B) $\frac{2kMT^2}{R}$ (C) $\frac{3kMT^2}{R}$ (D) $\frac{kMT^2}{R}$

22. Two small current carrying loops each of radius r are kept in same plane such that separation between their centres is a $(a >> r)$, then their mutual inductance will be

(A) $\frac{\mu_0 \pi r^4}{a^4}$ (B) $\frac{\mu_0 \pi r^4}{2a^4}$ (C) $\frac{\mu_0 \pi r^4}{3a^4}$ (D) $\frac{\mu_0 \pi r^4}{4a^4}$

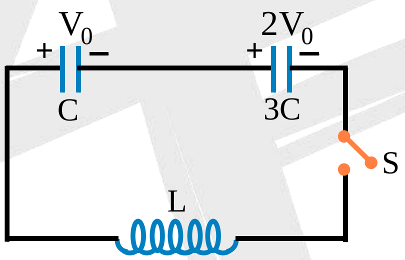
23. A coil with 1500 turns, a radius of 5.0 cm and a resistance of 12Ω surrounds a solenoid with 240 turns/cm and a radius of 4cm; see figure. The current in the solenoid changes at a constant rate from 0 to 20 A in 0.10 s. Calculate the magnitude of the induced current (in m(A) in the 1500 turn coil.

($\pi^2 = 10$ Neglect self inductance of the coil).



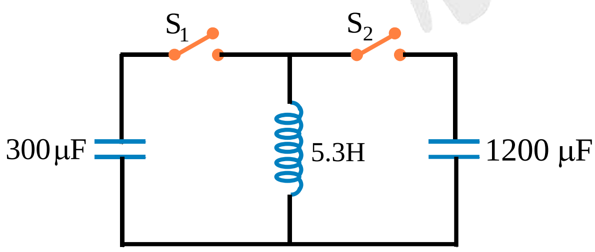
(A) 2 mA (B) 4 mA (C) 6 mA (D) 8 mA

24. Two capacitors of capacitance C and 3C are charged to potential difference V_0 and $2V_0$ respectively and connected to an inductor of inductance L as shown in the figure. Initially the current in the inductor is zero. Now the switch S is closed. Find the maximum current in the inductor. (Take $C = 12\mu F$, $L = 1H$ and $V_0 = 1V$)



(A) 3 mA (B) 6 mA (C) 9 mA (D) 12 mA

25. The $300\mu F$ capacitor in figure is initially charged to 16V, the $1200\mu F$ capacitor is uncharged and the switches are both open. What is the maximum voltage to which you can charge the $1200\mu F$ capacitor by the proper closing and opening of the two switches.

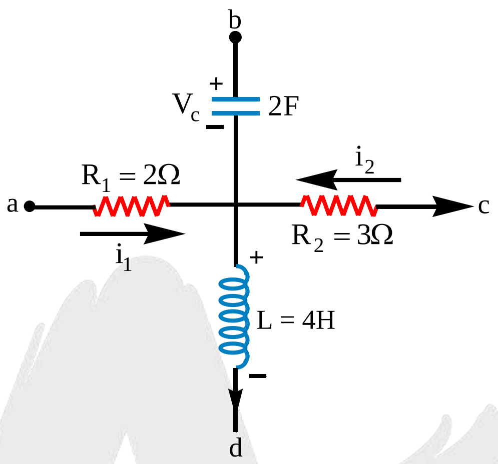


(A) 2V (B) 4V (C) 6V (D) 8V

26. There are two concentric coplanar rings where outer ring has radius 4m. The inner ring has radius 1mm, resistance $1\,\Omega$ and self-inductance $2\,\mu H$. Initially the outer and inner rings have current of $5\times10^6 A$ and 2A respectively in clockwise sense. Later on, current in inner ring is found to be 3A clockwise whereas for outer ring it is 5×10^{6} A anticlockwise. Find total charge flown through the inner ring till this moment is (Take $\pi^2 = 10$)

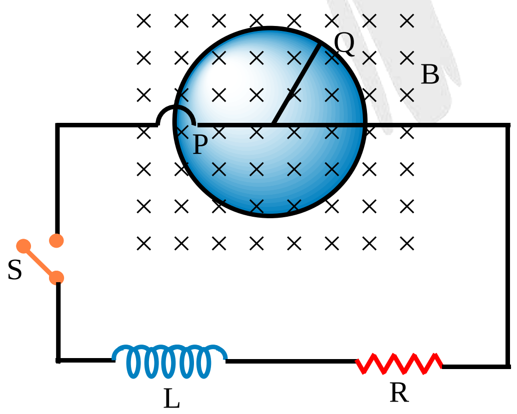
(A) 1 μC (B) 2 μC (C) 3 μC (D) 4 μC

27. In the figure shown $i_1 = 10e^{-2t}$A, $i_2 = 4$A and $V_C = 3e^{-2t}$V. Then find V_C?



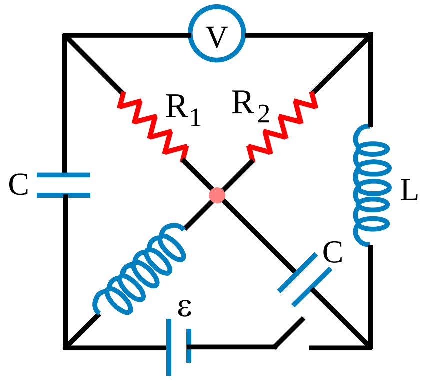
(A) $-16e^{-2t}$ (B) $-12e^{-2t}$ (C) $-8e^{-2t}$ (D) $-4e^{-2t}$

28. The diagram shows a circuit having a coil of resistance R and inductance L connected to a conducting rod PQ which can slide on a perfectly conducting circular ring of radius 10cm with its centre at 'P'. Assume that friction and gravity are absent and a constant uniform magnetic field of 5T exists as shown in figure. At t = 0, the circuit is switched on and simultaneously a time varying external torque is applied on the rod so that it rotates about P with a constant angular velocity 40 rad/s. Find magnitude of this torque when current reaches half of its maximum value. Neglect the self inductance of the loop formed by the circuit. Resistance $R = 1\,\Omega$.



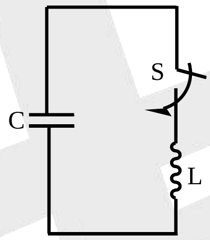
(A) 125×10^{-4} Nm (B) 125×10^{-5} Nm (C) 75×10^{-4} Nm (D) 75×10^{-5} Nm

29. In the circuit shown below we first put the switch on and wait for the currents to come to a steady state. Then we put the switch back off. What is the magnitude of the potential difference measured by the voltmeter immediately after the switch was turned off? Take the capacitors and coils to be ideal and assume that the voltmeter provides an infinite resistance. Put $\varepsilon = 1V$ and $R_1 = 3R_2$

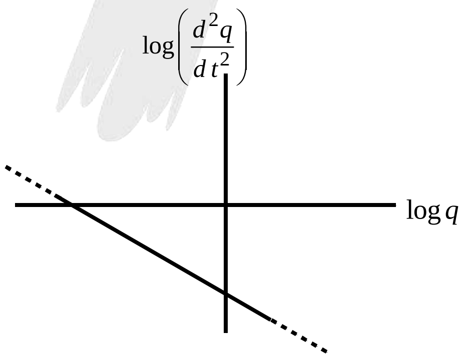


(A) 1V (B) 2V (C) 3V (D) 4V

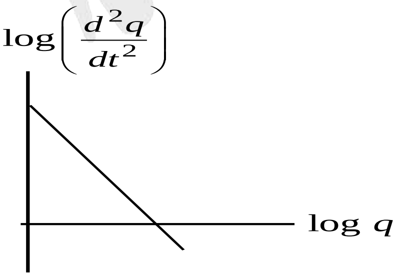
30. An ideal capacitor of capacitance 'C' is completely charged to a charge q_0. At the instant t = 0,



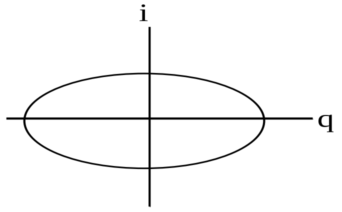
switch S is closed so that a pure inductor of self-inductance L is included in the circuit as shown. Then which of the following graph(s) is/are correct. Here q, *i*, represent charge, current respectively at any given instant and $\omega = \frac{1}{\sqrt{LC}}$; $\frac{dq}{dt}$ *and* $\frac{d^2q}{dt^2}$ represent the time derivatives

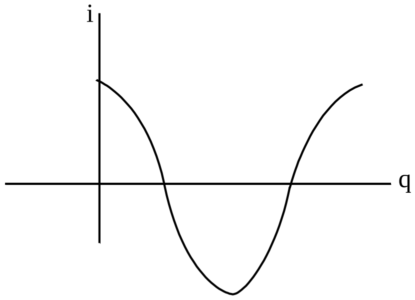


(A)



(B)

(C) 

(D) 

31. Two co-planar, concentric circular coils of radii a and b are placed in the y-z plane such that the common center of the coils is origin (a >> (B). A current i flows in the outer coil. Now the inner coil is moved along the x-axis with a constant speed v keeping its plane unchanged. The emf induced in the inner coil is maximum at:

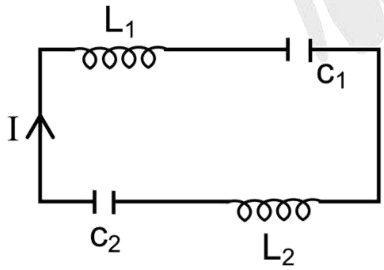
(A) $t=\frac{a}{v}$ (B) $t=\frac{3a}{v}$ (C) $t=\frac{a}{2v}$ (D) $t=\frac{4a}{v}$

32. A conducting disc of conductivity σ has radius a and thickness δ. A uniform magnetic field $\vec{B}$ is applied in a direction perpendicular to the plane of the disc. If the magnetic field changes with time at the rate of dB/dt, then the power dissipated in the disc due to the induced current.

(A) $\frac{\pi\delta\sigma a^4}{8}\left(\frac{dB}{dt}\right)^2$ (B) $\frac{\pi\delta\sigma a^4}{12}\left(\frac{dB}{dt}\right)^2$ (C) $\frac{\pi\delta\sigma a^4}{4}\left(\frac{dB}{dt}\right)^2$ (D) $\frac{\pi\delta\sigma a^4}{6}\left(\frac{dB}{dt}\right)^2$

33. Figure shows LC circuit with two inductors and two capacitors. When the circuit was set-up (not at t = 0), the capacitors were not charged. The current in circuit is given by $I=12\sin(2t+\pi/3)$, where 't' is time in seconds. Given $L_1=3H$, $L_2=2H$, $C_1=0.2F$.

Select the correct statements:



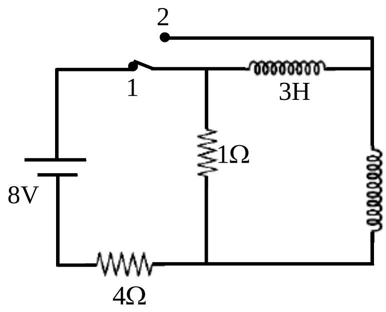
(A) C_2 = 1/15 F

(B) C_2= 0.15 F

(C) At $t=7\pi/12$ s energy in inductor (L_1) is maximum

(D) At $t=\pi/3$ s energy in capacitor (C_2) is increasing

34. The switch is in position 1 for a long time. Then it is suddenly shifted to 2 at t = 0. Inductors are ideal and battery has no internal resistance.



(A) Before switch being shifted to 2, current in 3H inductor is 2/3A.

(B) Before switch being shifted to 2, current in 1Ω resistor is zero.

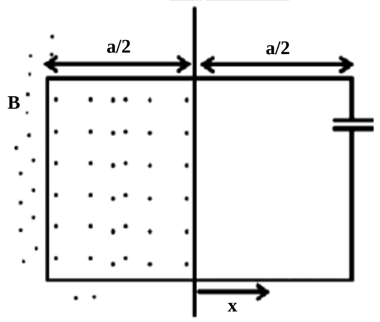
(C) After switch is shifted to 2, current in 1Ω resistor is $2e^{-t/9}$ A.

(D) The total heat dissipated in 1Ω resistor after t = 0 is 12 J.

35. A square rigid loop of dimension 'a' meter is placed in a region of uniform magnetic field B, as shown. Half of the loop is inside & the other half is outside the field. Self-inductance of the loop is L = 100 Henry & the resistance of loop is R = 50Ω. A capacitor is also connected in loop in one of the sides of loop having capacitance

C = 1μF. At t = 0 external force (agent) starts moving loop according to equation $x = \frac{a}{2}\sin(\omega_0 t)$,

where ω_0 = 100 rad/s.



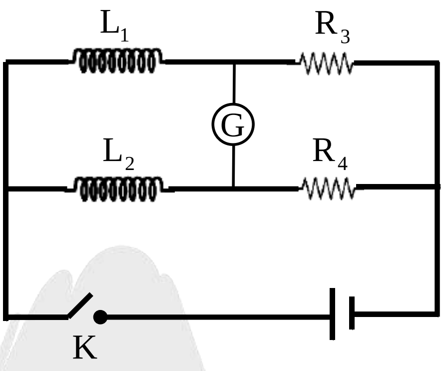
(A) Current starts with anticlock wise direction, after some time its direction may change.

(B) Peak value of current in loop is $\left(\frac{B\omega_0 a^2}{2R}\right)$

(C) Average power delivered by external agent in one cycle is $\left(\frac{B^2\omega_0^2 a^4}{8R}\right)$

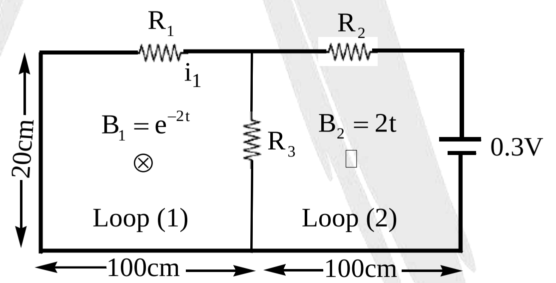
(D) If angular frequency of oscillation is more than ω_0 then average power delivered by external agent will decrease.

36. Two inductors of self-inductances L_1 and L_2 and of resistances R_1 and R_2 (not shown here) respectively, are connected in the circuit as shown in figure. At the instant t = 0, key K is closed. Choose the correct options for which the galvanometer will show zero deflection at all times after the key is closed.



(A) $\frac{L_1}{L_2} = \frac{R_3}{R_4}$ (B) $\frac{L_1}{L_2} = \frac{R_1}{R_2}$ (C) $\frac{R_1}{R_2} = \frac{R_3}{R_4}$ (D) $R_1 \times R_4 = R_2 \times R_3$

37. Shown in figure there is a simple network of these resistors $R_1 = 1\Omega, R_2 = 2\Omega$ and $R_3 = 3\Omega$. A battery of emf 0.3 volt is connected. The dimension of the loop are given. In loop (1) inward magnetic field $B_1 = e^{-2t}$ is applied and in loop (2) outward magnetic field $B_2 = 2t$ is applied. (t is time)

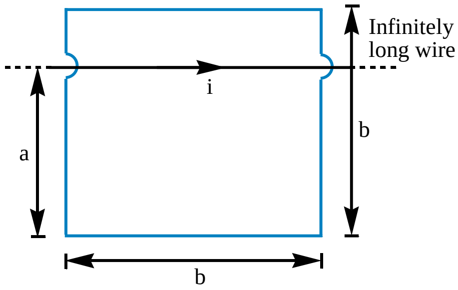


(A) initial current in $R_3 = \frac{9}{110}A$ (B) initial current in $R_2 = \frac{16}{110}A$

(C) initial current in $R_2 = \frac{8}{110}A$ (D) initial current in $R_3 = \frac{7}{110}A$

Proficiency Test-1

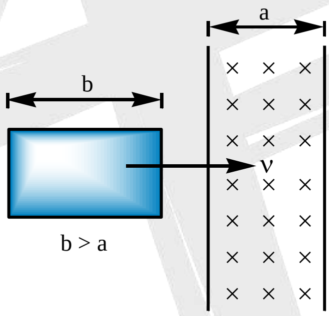
1. For the situation shown in the figure, flux through the square loop is:



(A) $\left(\frac{\mu_0 ia}{2\pi}\right)\ln\left(\frac{a}{2a-b}\right)$ (B) $\left(\frac{\mu_0 ib}{2\pi}\right)\ln\left(\frac{a}{a-2b}\right)$

(C) $\left(\frac{\mu_0 ib}{2\pi}\right)\ln\left(\frac{a}{b-a}\right)$ (D) $\left(\frac{\mu_0 ia}{2\pi}\right)\ln\left(\frac{2a}{a-b}\right)$

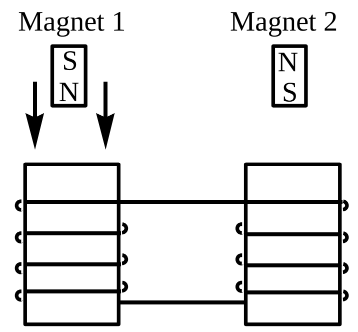
2. In the given arrangement, the loop is moved with constant velocity v in a uniform magnetic field B in a restricted region of width a. The time for which the emf is induced in the circuit is:



(A) $\frac{2b}{v}$ (B) $\frac{2a}{v}$

(C) $\frac{(a+b)}{v}$ (D) $\frac{2(a-b)}{v}$

3. Two hollow – core solenoids, A and B, are connected by a wire and separated by a large distance, as shown in the diagram. Two bar magnets, 1 and 2, are suspended just above the solenoids. If the magnet 1 is dropped through solenoid A as shown, then the magnet 2 will simultaneously be:



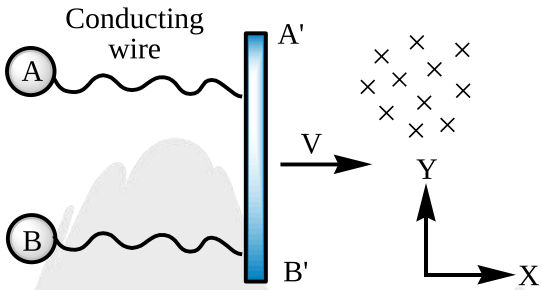
(A) attracted by a magnetic force towards solenoid B

(B) repelled by a magnetic force away from solenoid B

(C) repelled by a electric force away from solenoid B

(D) unaffected by solenoid B

4. Initially A' and B'(ends of the conducting ro(D) are moving with velocity 'v' and are connected to two stationary balls A and B with conducting wires as shown, after some time (when the rod has reached into the magnetic fiel(D) wires are cut:



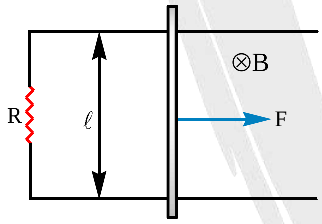
(A) A will become positively charged and B will become negatively charged

(B) A will become negatively charged and B will become positively charged

(C) If rod is moving in y – direction then A become negatively charged and B positively charged

(D) If rod is moving in y – direction then A is positively charged and B is negatively charged

5. A constant force F is being applied on a rod of length 'ℓ' kept at rest on two parallel conducting rails connected at ends by resistance R in uniform magnetic field B as shown.



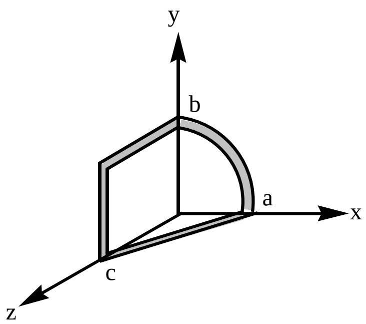
(A) The power delivered by force will be constant with time

(B) The power delivered by force will be increasing first and then will decrease

(C) The rate of power delivered by the external force will be increasing continuously

(D) The rate of power delivered by external force will be decreasing continuously

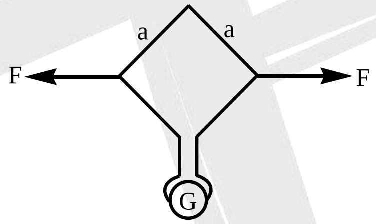
6. A wire loop has been bent so that it has three segments: segment ab (a quarter circle), bc (a square corner), and ca (straight) as shown in the figure. There are four choices for a magnetic field through the loop namely B_1, B_2, B_3 and B_4 as expressed in the options. By choosing which one, the induced current will be maximum:



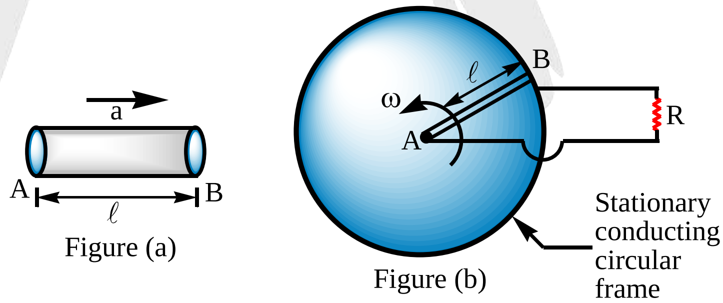
(A) $\vec{B}_1 = 3\hat{i} + 7\hat{j} - 5t\hat{k}$ (B) $\vec{B}_2 = 5t\hat{i} + 4\hat{j} - 15\hat{k}$

(C) $\vec{B}_3 = 2\hat{i} + 5t\hat{j} - 12\hat{k}$ (D) $\vec{B}_4 = 4\hat{i} + 7\hat{j} + 8\hat{k}$

7. The plane of a square loop of wire with edge length $a = 0.2\,m$ is perpendicular to the earth's magnetic field B_E at a point where $B_E = 15\ \mu T$. The total resistance of the loop and the wires connecting it to the galvanometer is $0.5\ \Omega$. If the loop is suddenly collapsed (such that area of the loop becomes zero) by horizontal forces as shown, the total charge passing through the galvanometer is $\frac{12}{n} \times 10^{-6}\,C$. Find n?



8. Consider a metal rod of length L that is given a uniform acceleration as shown in figure ((A) and an identical rod rotating with constant angular velocity in figure (B).



(A) If V_A and V_B are potentials of end A and B respectively, then $V_A < V_B$ in figure ((A)

(B) If V_A and V_B are potentials of end A and B respectively, then $V_A > V_B$ in figure (B)

(C) Electric field inside rod has magnitude $\frac{ma}{e}$ in figure ((A)

(D) Electric field inside rod has magnitude $\frac{m\omega^2 r}{e}$ in figure (B)

9. A cylindrical space is having uniform magnetic field. The field varies with time as $B = B_0 + \alpha t$.

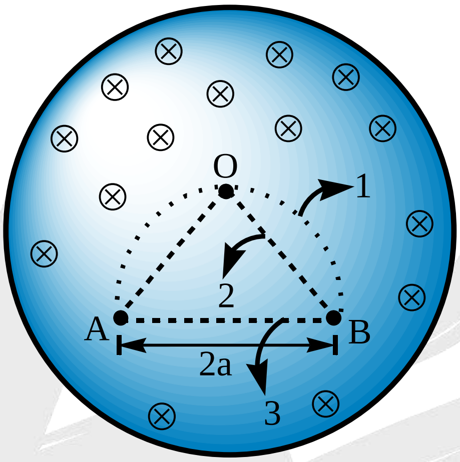
From point A to B there are three different paths as shown in figure.

Path 1 is a semi-circle of radius a, with AB as diameter

Path 2 contains two straight line AO and OB

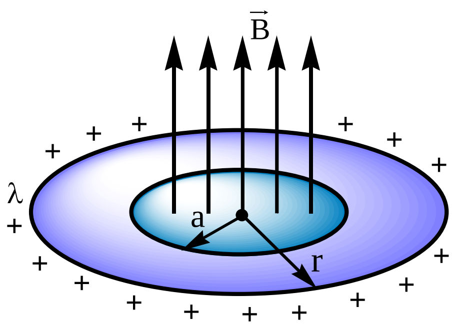
Path 3 is a single straight-line AB

If $\int \vec{E}.\vec{d\ell}$ from A to B along paths 1, 2 and 3 are E_1, E_2 and E_3 respectively, then mark the **incorrect** options.



(A) $E_1 = E_2 = E_3$ (B) $E_1 = E_3 > E_2$ (C) $E_1 > E_3 > E_2$ (D) $E_3 > E_2 > E_1$

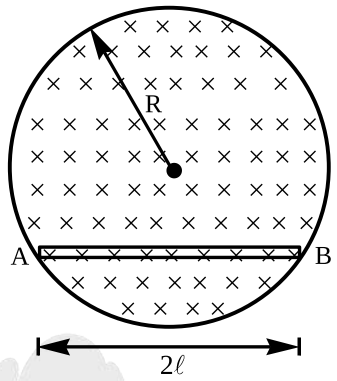
10. A non-conducting ring of mass 4kg is uniformly charged with $\lambda = 4\ C/cm^{-1}$ and kept on rough horizontal surface with friction coefficient $\mu = \frac{\pi}{4}$. A time varying magnetic field $B = B_0 t^2$ is applied in a circular region of radius a $(a < r)$ perpendicular to the plane of ring as shown in figure. Find out the time when ring just starts to rotate on surface. (Take $a = 5cm$ and $g = 10m/s^2$, $B_0 = 125$ SI unit)



(A) 0.4 sec (B) 0.04 sec (C) 4 sec (D) 40 sec

Proficiency Test-2

1. A uniform magnetic field, $B = B_0 t$, fills a cylindrical volume of radius R, then the emf induced in the rod AB is:



(A) $B_0\ell\sqrt{R^2+\ell^2}$ (B) $B_0\ell\sqrt{R^2-\frac{\ell^2}{4}}$ (C) $B_0\ell\sqrt{R^2-\ell^2}$ (D) $B_0R\sqrt{R^2-\ell^2}$

2. The magnetic flux ϕ linked with a coil depends on time t as $\phi = at^n$, where a and n are constants. The emf induced in the coil is e:

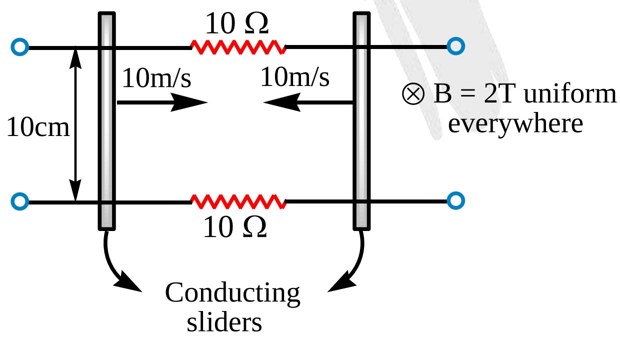
(A) if $0<n<1$, $e=0$

(B) if $0<n<1$, $e\neq 0$

(C) if $n=1$, e is constant

(D) if $n>1$, $|e|$ increases with time

3. The circuit below shows two parallel rails separated by distance of 10cm. The rails has $10\,\Omega$ resistor each at its middle. The region of space contains magnetic field which is uniform throughout the space. There are two conducting wires on the parallel rails moving towards each other with speed of 10m/s.



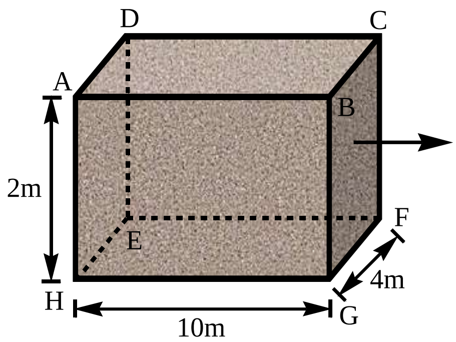
(A) Current in the circuit is 0.2 A

(B) Power lost in the circuit is 0.8 W

(C) The electric field inside the wires is non-conservative in nature

(D) The electric field inside the wires is conservative in nature.

4. A train is going from Kanpur to Patna in east direction at 90 km/hr. The compartment can be assumed to be a metal box whose dimensions are as shown in the figure. The horizontal component of earth's magnetic field is 0.04T with an angle of dip as $37°$. The angle of declination is zero.



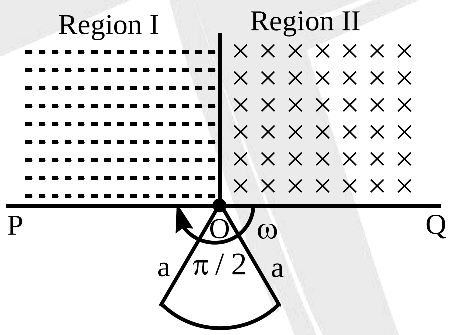
(A) The potential difference between A and B is 0

(B) The potential difference between B and C is 3V

(C) The potential difference between B and D is 0.6V

(D) The potential difference between B and G is 2V

5. A wire frame is in the shape of a quadrant of a circle of radius a, having resistance R and is free to rotate about O axis perpendicular to plane of paper. Above line PQ a uniform magnetic field exist having magnitude B and direction out of plane for region I and inside plane for region II. If frame rotates with constant ω. Mark the **correct** options.



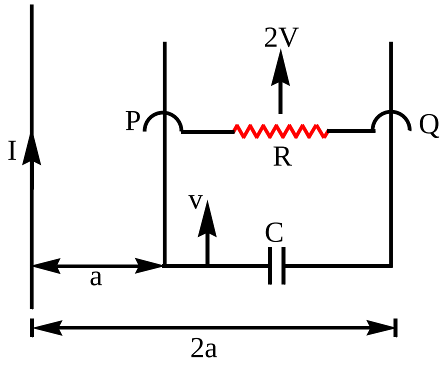
(A) As frame goes from region I to region II, the thermal energy dissipated is $\dfrac{B^2\omega\pi a^2}{2R}$

(B) As frame goes from region I to region II, the thermal energy dissipated is $\dfrac{B^2\omega\pi a^4}{4R}$

(C) Total thermal energy dissipated in one cycle is $\dfrac{3B^2\omega\pi a^4}{8R}$

(D) Average power is $\dfrac{3B^2\omega^2 a^4}{8R}$

6. A U-shaped conducting wire frame having capacitor C is coplanar with an infinite wire having current I. On frame, a wire PQ having resistance R makes sliding contact as shown. frame and wire are moving with speed v and $2v$ respectively as shown. (There is no friction anywhere) mark the **correct** options.



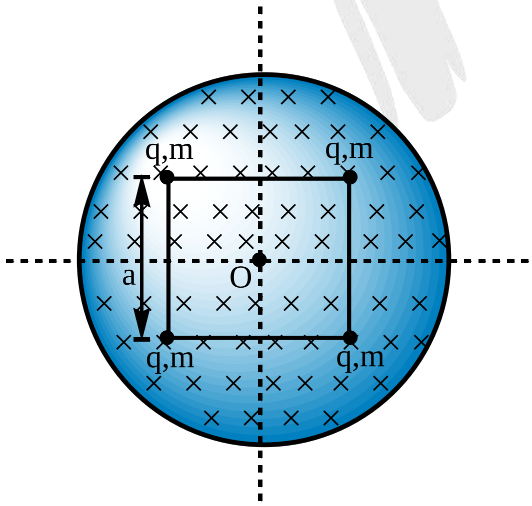
(A) Charge on capacitor at time t is $q = \frac{C\mu_0 I v(\ln 2)}{2\pi}(1 - e^{-t/RC})$

(B) Charge on capacitor at time t is $q = \frac{C\mu_0 I v(\ln 2)}{\pi}(1 - e^{-t/RC})$

(C) Current through resistor at time t is $i = \frac{\mu_0 I v(\ln 2)}{2\pi R}(e^{-t/RC})$

(D Current through capacitor at time t is $i = \frac{\mu_0 I v(\ln 2)}{\pi R}(e^{-t/RC})$

7. Four identical charge particles each of mass 0.1 kg and charge 2C connected to each other via massless non-conducting rods of equal length. The whole arrangement is placed in a cylindrical region carrying a uniform magnetic field as shown in the figure $(B_0 = 4T, a = 1m)$. Suddenly the magnetic field is switched off. Then choose the correct statement(s)



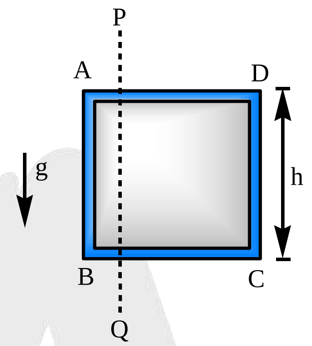
(A) The angular momentum of the system is 8 Nm/s

(B) The angular momentum of the system is $8\sqrt{2}$ Nm / s

(C) Angular velocity of the system is 40 rad/s

(D) The magnetic field at point O after the magnetic field is switched off is non zero

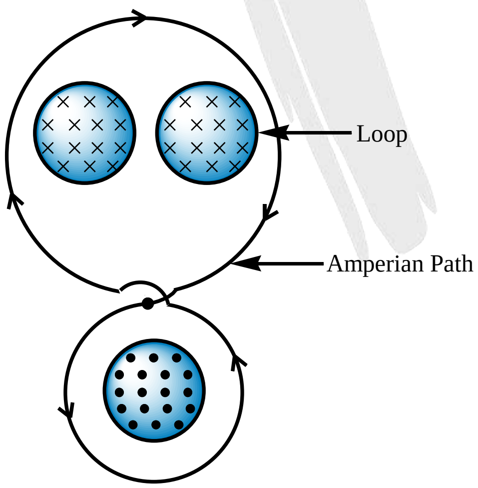
8. ABCD is a square frame of conductor of electrical resistivity ρ. The frame lies in a vertical plane. PQ is an imaginary boundary separating space into two parts. Left of PQ, a uniform gravitational field $\vec{g}$ exists (see figure) whereas no gravitational field is present right of PQ. The electrical potential difference between A and B will be



(A) $\frac{mgh}{4e}$ (B) $\frac{2mgh}{4e}$ (C) $\frac{3mgh}{4e}$ (D) $\frac{5mgh}{4e}$

9. Area of shown three loops is A each and the rate of change of magnetic field with time $\frac{dB}{dt} = \alpha$

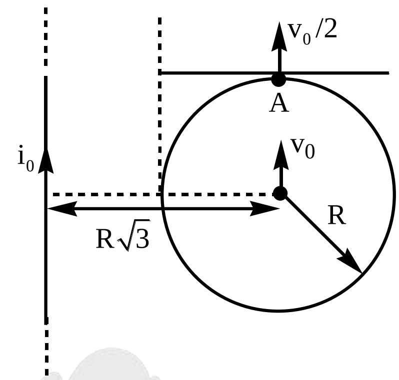
Find the line integral of electric field over the shown amperian path $\left(\int \vec{E}.\vec{d\ell}\right)$ is



(A) $A\alpha$ (B) $2A\alpha$ (C) $3A\alpha$ (D) $4A\alpha$

Paragraph For Questions 10 and 11:

A circular loop of radius R and resistance per unit length λ is moving with constant velocity v_0 parallel to a very long current carrying wire carrying current i_0. A resistance less rod of length 2R is also moving parallel to the wire as shown in the figure. The rod and the loop are in contact at point A and road is symmetrical with respect to the center of the loop and at t = 0, rod starts sliding over the loop without friction. Neglect self-inductance.



10. The current through the rod when it is at a distance $\left(\frac{R}{2}\right)$ from the point A of the loop will be:

(A) $\frac{v_0\mu_0 i_0}{16R\lambda\pi^2}\ln 3$

(B) $\frac{16v_0\mu_0 i_0}{R\lambda\pi^2}\ln 3$

(C) $\frac{9v_0\mu_0 i_0}{16R\lambda\pi^2}\ln 3$

(D) Zero

11. Force required to maintain the uniform velocity of the rod at this instant is:

(A) $\frac{9\mu_0^2}{16}\frac{i_0^2 v_0(\ln 3)^2}{R\lambda\pi^3}$

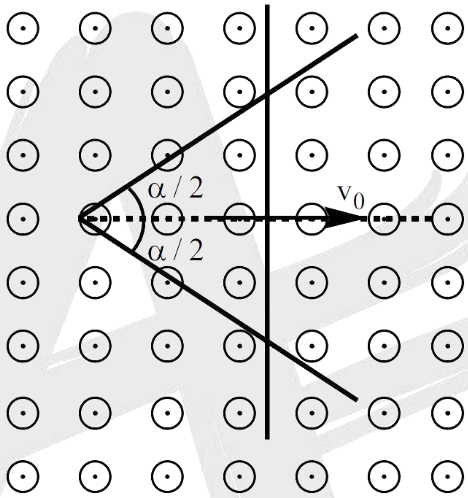
(B) $\frac{9\mu_0^2 i_0^2 v_0(\ln 3)^2}{R\lambda\pi^3}$

(C) $\frac{\mu_0^2 i_0^2 v_0(\ln 3)^2}{32R\lambda\pi^3}$

(D) $\frac{9\mu_0^2 i_0^2 v_0(\ln 3)^2}{32R\lambda\pi^3}$

Proficiency Test-3

1. A long straight wire of negligible resistance is bent into V shape, its two arms making an angle α with each other and placed horizontally in a vertical, homogeneous field B. A rod of total mass m, and resistance r per unit length, is placed on V shaped conductor, at a distance x_0 from its vertex A, and perpendicular to the bisector of angle α (see figure). The rod is started off with an initial velocity v_0 in the direction of bisector and away from vertex A. The rod is long enough not to fall off the wire during the subsequent motion, and the electrical contact between the two is good although friction between them is negligible. Choose **correct** statement(s).



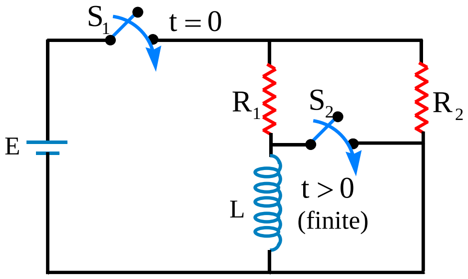
(A) At any position x, let velocity of wire is v then $\frac{B^2}{r}x_0^2 \tan\frac{\alpha}{2} + mV_0 = \frac{B^2}{r}x^2\tan\frac{\alpha}{2} + mv$

(B) Maximum value of x coordinate of wire is $x_{max} = \sqrt{x_0^2 + \frac{mv_0 r}{B^2 \tan\frac{\alpha}{2}}}$

(C) As x increases, v decreases

(D) Whatever is the direction of vertical magnetic field, the rod will ultimately stop

2. In the circuit shown below, the current through inductor is zero when battery is not connected $(t<0)$. At t = 0, switch S_1 is closed. If at a later time $t = t_1$ (finite), switch S_2 is also closed, then which of the following is **true** just after time t_1 ?



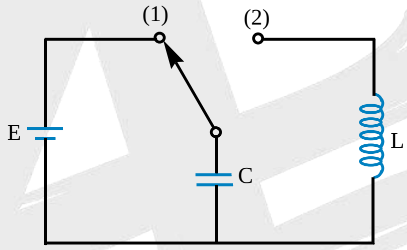
(A) Current through resistor R_1 increases

(B) Current through resistor R_2 increases

(C) Current through inductor L increases

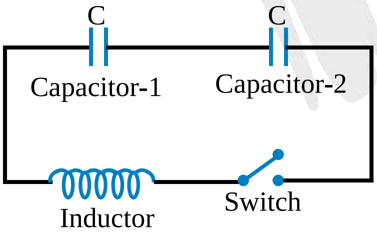
(D) Current through the battery increases

3. Initially key was placed on (1) till the capacitor got fully charged. Key is placed on (2) at t = 0. The time when the energy in both capacitor and inductor will be same:



(A) $\frac{\pi}{4\sqrt{LC}}$ (B) $\frac{\pi}{2\sqrt{LC}}$ (C) $\frac{5\pi}{4\sqrt{LC}}$ (D) $\frac{5\pi}{2\sqrt{LC}}$

4. Consider the circuit shown with respective specifications of elements marked in the figure. Capacitor-1 is charged such that charge on it is Q_0 and it's left plate is positively charged. While capacitor-2 is uncharged. The switch is closed at t = 0.



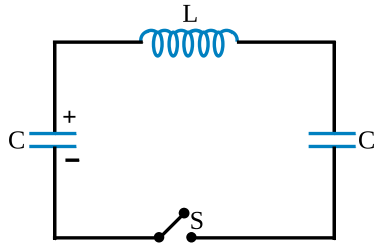
(A) Frequency of oscillation of charge on left plate of capacitor - 1 is $\frac{1}{\pi\sqrt{2LC}}$

(B) Frequency of oscillation of charge on left plate of capacitor – 1 is $\frac{1}{\pi}\sqrt{\frac{2}{LC}}$

(C) Maximum current through the inductor is $\frac{Q_0}{\sqrt{2LC}}$

(D) Maximum current through the inductor is $\frac{Q_0}{\sqrt{LC}}$

5. Figure shows on electric circuit with negligibly small active resistance. Initially left capacitor is charged to a potential V_0 and then the switch was closed.



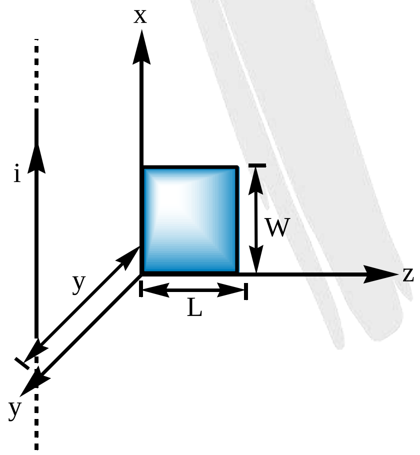
(A) Charge on right capacitor is given by $\frac{CV_0}{2}(1-\cos\omega t)$; $\omega=\sqrt{\frac{2}{LC}}$

(B) At the instant when charge on capacitor plates have same magnitude, total energy in capacitor and inductor is equal

(C) Maximum current in the circuit has magnitude $V_0\sqrt{\frac{C}{2L}}$

(D) Maximum magnitude of induced emf in circuit is V_0

6. In the figure, a long thin wire carrying a varying current $i = 2\sin 5t$ lies at a distance y above one edge of a rectangular wire loop of length L and width W lying in the x-z plane. Find the magnitude of emf induced in the loop at $t=\frac{\pi}{15}$ sec is $(y = 2m, L = 3m, W = 1m)$



(A) $5\times10^{-6}\ln\left(\frac{13}{4}\right)V$

(B) $5\times10^{-7}\ln\left(\frac{13}{4}\right)V$

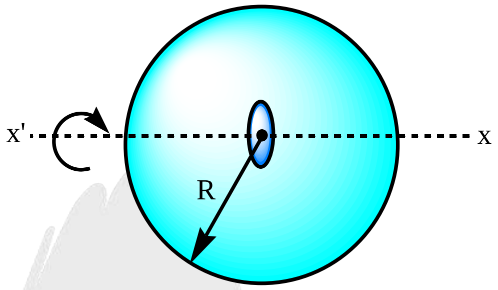
(C) $10\times10^{-6}\ln\left(\frac{13}{4}\right)V$

(D) $10\times10^{-7}\ln\left(\frac{13}{4}\right)V$

7. A non-conducting ring of radius R having uniformly distributed charge q starts rotating about $x-x'$ axis passing through diameter with an angular acceleration α as shown in the figure.

Another small conducting ring having radius $a\left(a << R\right)$ is kept fixed at the centre of bigger ring in such a way that axis xx' is passing through its centre and perpendicular to its plane. If the resistance of small ring is $r = 1\Omega$, find the induced current

(Given: $q = \dfrac{16\times10^2}{\mu_0}C, R = 1m, a = 0.1m, \alpha = 8rad/s^2$)



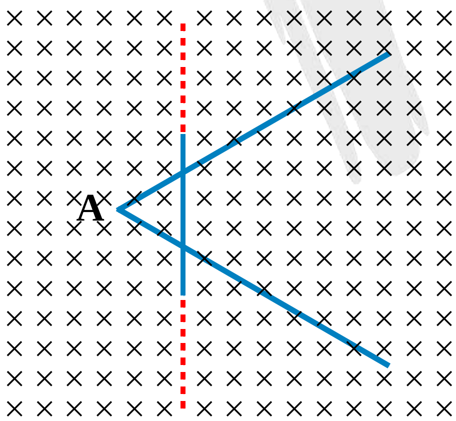
(A) 2 A

(B) 4 A

(C) 6 A

(D) 8 A

8. A long wire bend into the shape of a right angle is held stationary on a horizontal frictionless plane. A very long rod of mass 1kg initially starts with velocity $v_0 = 4m/s$ from the apex A of the bend wire. The resistance per unit length of the wire and the rod is $\left(\sqrt{2}-1\right)\times10^{-2}\ \Omega/m$. The whole arrangement is put in a region of uniform magnetic field of 0.05 T directed normally into the horizontal plane. Find the distance travelled by the rod before it comes to rest.



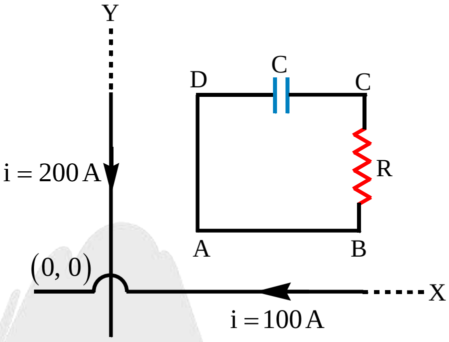
(A) 2m

(B) 3m

(C) 4m

(D) 5m

9. Two straight infinitely long current wires lying along the x-axis and the y-axis carry currents 100 A and 200 A as indicated in the figure. A rigid square metallic wire frame ABCD of side 10 cm and resistance $(R = 10\ \Omega)$ is connected to a capacitor $C_1 = 1\text{mF}$ as shown in the figure. The wire frame, which lies in the x-y plane, moves with a constant velocity $30(\hat{i} + \hat{j})\ m/s$. At the instant, when the point A is located at (20cm, 20cm) the charge q_0 on the capacitor (as shown in the figure) is $0.2\ \mu C$. If, at the above-mentioned instant, find the current flowing in the circuit is



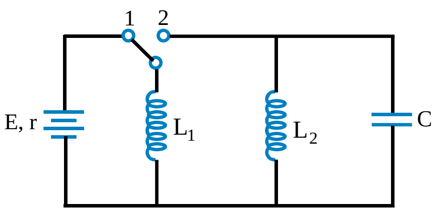
(A) 10^{-2} A (B) 10^{-3} A (C) 10^{-4} A (D) 10^{-5} A

10. A small bead of mass m and positive charge +q is mounted on a fixed, thin, smooth horizontal plastic ring of radius R. At t = 0, bead is stationary. Ring lies in x-y plane with centre at (0, 0). Magnetic field $\vec{B} = \frac{E_0 t}{r}\hat{k}$ (where $r \neq 0$) is switched on, where t denotes time, r distance from z – axis and E_0 is a positive constant. Find the magnitude of normal reaction exerted by ring on bead is λ. (Gravity is absent)

(A) 2 N (B) 4 N (C) 6 N (D) 0 N

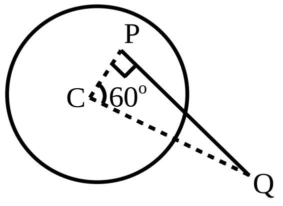
11. A circuit shown consists of two inductors of inductances L_1 and L_2, a capacitor of capacitance C, a battery of electromotive force E and internal resistance r and a switch. Initially the switch was in position 1 for a long time. Find the maximum current in the inductor L_2 after the switch is thrown to position 2.

(Given: $E = 5V$, $L_1 = 4\text{mH}$, $L_2 = 1\text{mH}$, $r = 2\ \Omega$)



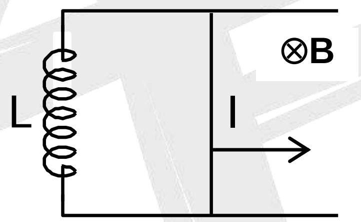
(A) 2A (B) 4A (C) 6A (D) 8A

12. A magnetic field, confined in a cylindrical region of radius R, is changing at the rate of 4 T/s. A conducting rod PQ of length $\sqrt{\frac{3}{2}}R$ is placed in the region as shown. The induced emf across the rod will be



(A) $\frac{R^2}{24}(\pi+6)V$ (B) $\frac{R^2\pi}{24}V$ (C) $\frac{R^2\pi}{6}V$ (D) $\frac{R^2}{6}(\pi+6)V$

13. Two parallel resistance less rails are connected by an inductor of inductance L at one end as shown in figure. A magnetic field B exists in the space which is inward perpendicular to the plane of the rails. Now a conductor of length *l*, mass *m* and negligible resistance is placed transverse on the rail and given an impulse J towards the rightward direction. Then select the correct option(s):



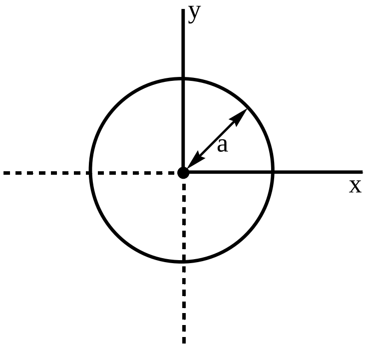
(A) Displacement of the conductor when velocity of the conductor is half of the initial velocity is $\sqrt{\frac{3J^2L}{4B^2l^2m}}$

(B) Displacement of the conductor when velocity of the conductor is half of the initial velocity is $\sqrt{\frac{3J^2L}{B^2l^2m}}$

(C) Current flowing through the inductor at the instant when velocity of the conductor is half of the initial velocity is $\sqrt{\frac{3J^2}{4Lm}}$

(D) Current flowing through the inductor at the instant when velocity of the conductor is half of the initial velocity is $\sqrt{\frac{3J^2}{Lm}}$

14. A circular ring of radius a and resistance R is placed (fixe(D) in x-y plane with its center origin as shown in the figure. A magnetic field $\vec{B}=(\alpha x)\hat{i}+(\beta y)\hat{j}+(\gamma t)\hat{k}$ is switched on at $t=0$.



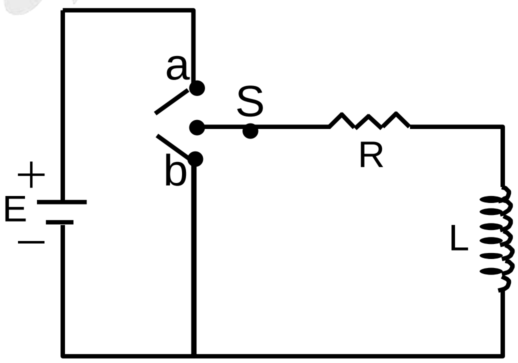
(A) current induced in ring is $\frac{\pi a^2\gamma}{R}$

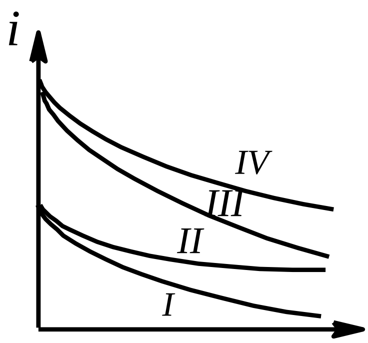
(B) current induced in ring is $\frac{\pi a^2\gamma}{2R}$

(C) the magnetic force acting on the ring is $\frac{\pi^2a^4(\alpha+\beta)\gamma}{2R}$

(D) the magnetic force acting on the ring is $\frac{\pi^2a^4(\alpha+\beta)\gamma}{R}$

15. The switch S in the circuit is connected with point 'a' for a very long time, and then it is shifted to position 'b'. The current through the inductor as a function of time after shifting the switch to position 'b', is shown by curves in the graph for four sets of values for the resistance R and inductance L (given in column 1). Which set corresponds with which curve? [the switching is done such that the current through conductor does not change during switching]





Column-I		Column-II	
(A)	R_0 and L_0	(P)	I
(B)	$2R_0$ and L_0	(Q)	II
(C)	R_0 and $2L_0$	(R)	III
(D)	$2R_0$ and $2L_0$	(S)	IV

EXERCISE – 1

1	2	3	4	5	6	7	8	9	10
D	B	200	B	4	B	C	A	A	B
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
C	D	D	B	AC	BCD	BC	ABCD	C	D
21									
B									

EXERCISE – 2

1	2	3	4	5	6	7	8	9	10
3	B	A	A	A	4	D	D	25	D
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
5	5	A	C	C	B	AC	ACD	ABD	ABCD

EXERCISE – 3

1	2	3	4	5	6	7	8	9	10
A	2	D	B	5	A	B	A	C	B
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
B	A	B	16	100	D	C	AC	AC	BC
21	**22**								
ABC	AD								

EXERCISE – 4

1	2	3	4	5	6	7	8	9	10
D	A	BC	1	1	A	A	C	AB	AD
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
ACD	ACD	ABD	C	B	A	D	C	C	C
21	**22**	**23**	**24**						
D	A	AD	AC						

EXERCISE – 5

1	2	3	4	5	6	7	8	9	10
A	C	A	B	AD	ACD	ABCD	BCD	BD	AB
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
BC	C	BCD	AB	A	C	B	D	B	C
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
D	D	C	C	D	C	A	A	B	C
31	**32**	**33**	**34**	**35**	**36**	**37**			
C	A	AC	BD	ABCD	ABCD	BD			

Proficiency Test-1

1	2	3	4	5	6	7	8	9	10
C	B	A	A	A	B	10	ABCD	AD	B

Proficiency Test-2

1	2	3	4	5	6	7	8	9	10
C	BCD	ABD	ABD	AD	AC	ACD	C	C	C
11									
D									

Proficiency Test-3

1	2	3	4	5	6	7	8	9	10
ABCD	AD	AC	AC	ABCD	B	D	D	D	D
11	**12**	**13**	**14**	**15**					
B	D	AC	AD	A-R; B-P; C-S; D-Q					