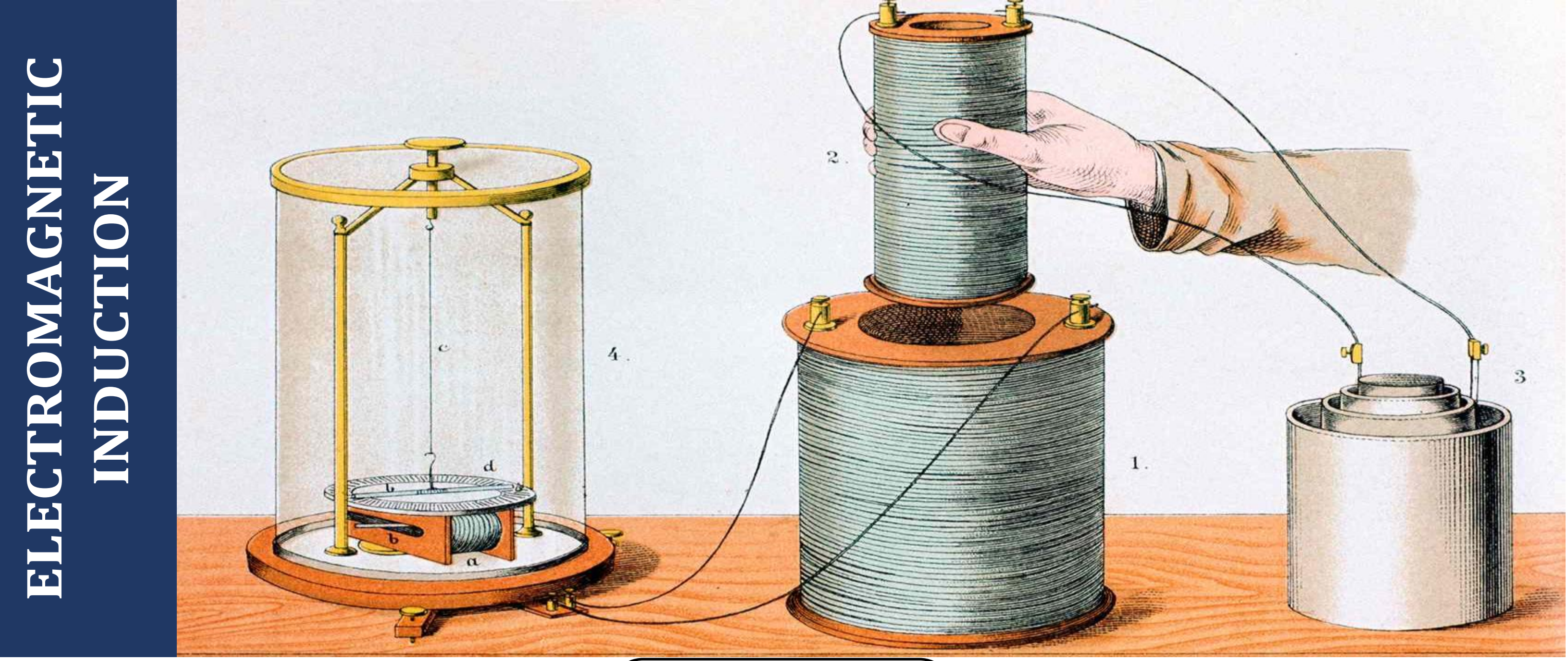


CHAPTER – 6

ELECTROMAGNETIC INDUCTION

Electromagnetic Induction

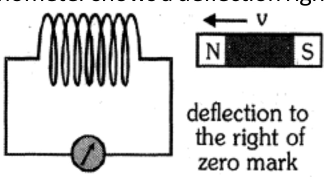
Michael Faraday demonstrated the reverse effect of Oersted experiment. He explained the possibility of producing emf across the ends of a conductor when the magnetic flux linked with the conductor changes. This was termed as electromagnetic induction. The discovery of this phenomenon brought about a revolution in the field of electric power generation.

Faraday's Experiment

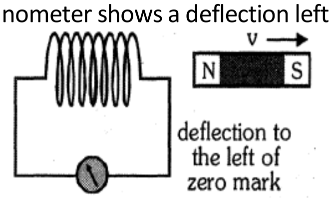
Faraday performed various experiments to discover and understand the phenomenon of electromagnetic induction. Some of them are:

When the magnetic is held stationary anywhere near or inside the coil, the galvanometer does not show any deflection.

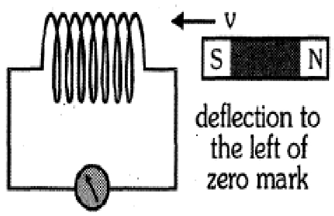
When the N–pole of a strong bar magnet is moved towards the coil, the galvanometer shows a deflection right to the zero mark.



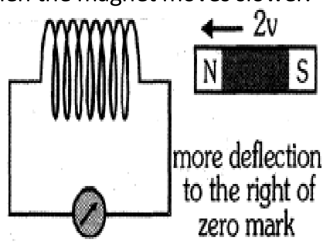
When the N–pole of a strong bar magnet is moved away from the coil, the galvanometer shows a deflection left to the zero mark.



If the above experiments are repeated by bringing the S–pole of the, magnet towards or away from the coil, the direction of current in the coil is opposite to that obtained in the case of N–pole.



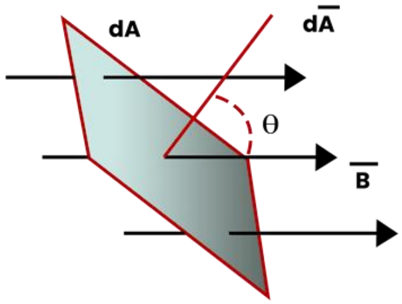
The deflection in galvanometer is more when the magnet moves faster and less when the magnet moves slower.



Conclusion-

Whenever there is a relative motion between the source of magnetic field (magnet) and the coil, an emf is induced in the coil. When the magnetic and coil move towards each other than the flux linked with the coil increases and emf is induced. When the magnet and coil move away from each other the magnetic flux linked with the coil decreases, again an emf is induced. This emf lasts so long as the flux is changing. Due to this emf an electric current start to flow and the galvanometer shows deflection. the deflection in galvanometer last as long the relative motion between the magnet and coil continues. Whenever relative motion between coil and magnet takes place an induced emf produced in coil. If coil is in closed circuit, then current and charge is also induced in the circuit. This phenomenon is called electromagnetic induction.

Magnetic Flux



Magnetic flux through a plane of area D $\vec{A}$ placed in a uniform magnetic field $\vec{B}$ is given by

$d\varphi_B = \vec{B}.\,d\vec{A} = BdA\cos\theta$

where θ is the angle between the vectors $\vec{B}$ and $d\vec{A}$ See figure 4. Magnetic flux through the entire surface can be calculated by integrating the dot product $\vec{B}.\,d\vec{A}$ as given below

$\varphi_B = \oint \vec{B}.\,d\vec{A}$

Magnetic flux is a scalar quantity. Its unit is Weber (or Volt-sec) or T-m^2. Its CGS unit is Maxwell (Mx).

Faraday's Laws of Electromagnetic Induction

Based on his experimental studies on the phenomenon of electromagnetic induction, Faraday proposed the following two laws.

First law - Whenever magnetic flux linked with a closed circular change, an emf is induced in the circuit. The induced emf lasts so long as the change in magnetic flux continues.

Second law - The magnitude of emf induced in a closed circuit is directly proportional to rate of change of magnetic flux linked with the circuit. If the change in magnetic flux in a time dt is dϕ then $e \propto \frac{d\phi}{dt}$

Q. A 800 turn coil of effective area 0.05 m^2 is kept perpendicular to a magnetic field 5×10^{-5} T. When the plane of the coil is rotated by 90° around any of its coplanar axis in 0.1 s, then find the emf induced in the coil.

Sol. Here $N = 800, A = 0.05\ \text{m}^2, \Delta t = 0.1\ \text{s}$

$B = 5 \times 10^{-5}$ T

Induced emf, $\varepsilon = -\frac{\Delta\phi}{\Delta t} = -\frac{(\phi_f - \phi_i)}{\Delta t}$

$\phi_i = N(\vec{B} \cdot \vec{A}) = 800 \times 5 \times 10^{-5} \times 0.05 \times \cos 0°$

$= 2 \times 10^{-3}\ \text{T m}^2$

$\phi_f = 0$

$\therefore \quad \varepsilon = \frac{-(0 - 2\times10^{-3})}{0.1} = 2 \times 10^{-2}\ \text{V} = 0.02\ \text{V}$

Q. A conducting circular loop is placed in a uniform magnetic field 0.04 T with its plane perpendicular to the magnetic field. The radius of the loop starts shrinking at 2 mm/s. Then find the induced emf in the loop when the radius is 2 cm.

Sol. Rate of decrease in the radius of the loop is 2 mm/s.

Final radius = 2 cm = 0.02 m

Initial radius = 2.2 cm = 0.022 m, B = 0.04 T

$\varepsilon = -\frac{d\phi}{dt} = -B\frac{dA}{dt}$

$\varepsilon + -\pi\ (0.22^2 - 0.02^2) \times 0.04 = -\pi \times 3.36 \times 10^{-6}$ V

$|\varepsilon| = \pi \times 3.36 \times 10^{-6}\ \text{V} = 3.4\pi\ \mu\text{V}$

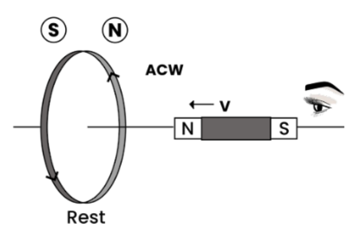
Lenz's Law

The Russian scientist H.F. Lenz in 1835 discovered a simple law giving the direction of the induced current produced in a circuit. The statement of the law is:

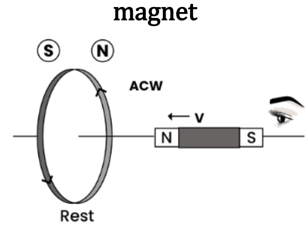
The polarity of induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produced it

If the coil has N number of turns and ϕ is the magnetic flux linked with each turn of the coil then, the total magnetic flux linked with the coil at any time = Nϕ

$\therefore \quad e = -\frac{d}{dt}(N\,\phi) = -N\frac{d\phi}{dt} = -\frac{N(\phi_2 - \phi_1)}{t}$



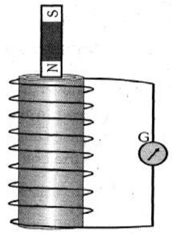
Coil face behaves as North Pole to oppose the motion of magnet



Coil face behave as south pole to oppose the motion of magnet

$e = (-)\frac{d\phi}{dt}$, here negative sign indicates the concept of Lenz law.

Lenz's Law – A Consequence Of Conservation Of Energy

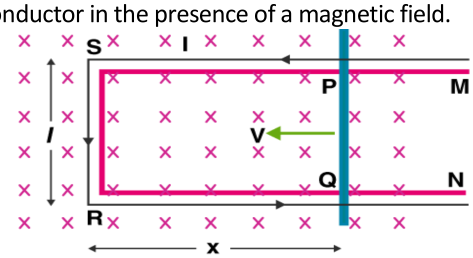


Copper coils are wound on a cylindrical cardboard and the two ends of the coil are connected to a sensitive galvanometer. When a bar magnet is move towards the coil (fig.) The upper face of the coil near the magnet acquired north polarity. Consequently, work has to be done to move the magnetic further against the force of repulsion. When we withdraw the magnet away from the coil, its nearer face acquires south polarity. Now the work done is against the face of attraction. When the magnet is moved, the number of magnetic lines of force linking the coil changes, which causes an induced current of flow through the coil. The direction of the induced current, according to Lenz's law is always to oppose the motion of the magnet.

The work done in moving the magnet is converted into electrical energy. This energy is dissipated as heat energy in the coil. Therefore, the induced current always flows in such a direction to oppose the cause. Thus it is proved that Lenz's law is the consequence of conservation of energy.

Motional Electromotive Force

When an electrical conductor is introduced into a magnetic field, due to its dynamic interaction with the magnetic field, emf is induced in it. This emf is known as induced emf. In this article, we will learn about motional emf where emf is induced in a moving electric conductor in the presence of a magnetic field.



Consider a straight conductor pq as shown in the figure, moving in the rectangular loop pqrs in a uniform and time-independent magnetic field b, perpendicular to the plane of the system. Let us suppose the motion of rod to be uniform at a constant velocity of v m/sec and the surface to be frictionless. Thus, the rectangle pqrs forms a closed circuit enclosing a varying area due to the motion of the rod pq. The magnetic flux ϕb enclosed by the loop pqrs can be given as

$\phi_B = Blx$

Where, RQ = x and RS = l, Since the conductor is moving, x is changing with time. Thus, the rate of change of flux ΦB will induce an emf, which is given by

$$\varepsilon = -\frac{d\varphi_B}{dt} = -\frac{d}{dt}(Blx)$$

$$\varepsilon = -Bl\frac{dx}{dt} = Blv$$

Where, the speed of conductor (PQ), v = -dx/dt and is the formula of induced emf. This induced emf due to the motion of an electric conductor in the presence of the magnetic field is called motional emf. Thus, emf can be induced in two major ways: Due to the motion of a conductor in the presence of a magnetic field. Due to the change in the magnetic flux enclosed by the circuit.

this concept of motional emf can be explained with the help of the concept of Lorentz force acting on free charge carriers of the conductor. Let us consider any arbitrary charge q in the conductor PQ. As the rod moves with a constant speed v, the charge is also moving with a speed v in the presence of magnetic field B. The Lorentz force on this charge is given by:

F = qvB

The work done in moving the charge from P to Q can be given by,

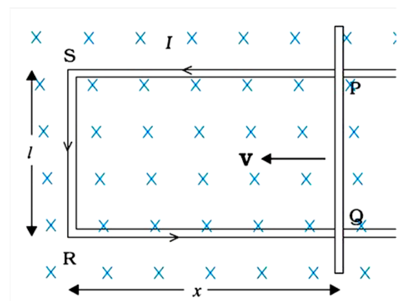
W = QBvl

Since, emf is defined as the work done per unit charge,

∈ = w/q=Bvl

Energy Consideration: A Quantitative Study

Lenz's law is consistent with the law of conservation of energy. Lenz's Law states that, when you induce a current in a wire via a changing magnetic field, the current flows through the wire in such a direction so that its magnetic field opposes the change that produced the current.



Suppose there is a rectangular conductor. now from the above figure, we can say that the sides of the sides of the rectangular conductor are PQ, RS, QR, and SP. Now in this rectangular conductor, the three sides are fixed, while one of it's side that is the side PQ is set free.

Let r be that movable resistance of the conductor. So the resistance of the other remaining sides of the rectangular conductor that is the resistance of side RS, SP and QR is very small as compared to this movable resistance. In a constant magnetic field, if we change the flux, an emf is induced. i.e $\boldsymbol{E} = \frac{\boldsymbol{d\varphi}}{\boldsymbol{dt}}$

If there is induced emf E and a movable resistance r in the conductor then, we can say that $I = \frac{Blv}{R}$.

As the magnetic field is present, there will also be a force F acting, as F = ILB. This force is directed outwards in the direction opposite to the velocity of the rod, given by $F = \frac{B^2l^2v}{R}$

Power= force × velocity = $\frac{B^2l^2v}{R}$

Now here the work done is mechanical and this mechanical energy is dissipated as Joule heat. This is given as

$P_J = I^2R = \frac{B^2l^2v}{R}$

Further, the mechanical energy converts into electrical energy and finally into thermal energy. From the Faraday's law, we have learned that,

$|E| = IR = \frac{\Delta Q}{\Delta t}R$

Hence, we get, $\Delta Q = \frac{\Delta \varphi_B}{R}$

Q. circular coil of radius 8.0 cm and 20 turns is rotated about its vertical diameter with an angular speed of 50 rads $^{-1}$ in a uniform horizontal magnetic field of magnitude 3.0×10^{-2} T. Obtain the maximum and average emf induced in the coil. If the coil forms a closed loop of resistance 10, calculate the maximum value of current in the coil. Calculate the average power loss due to Joule heating. Where does this power come from?

Sol. Maximum induced emf e = NwAB,

N = number of turns w = angular speed

A = Area of the coil B = Magnetic field

e = 0.603 V

Over a full cycle, the average emf induced in the coil is zero. Maximum current, I = e/R = 0.0603

Average power loss due to Joule heating is P = eI/2

= 0.018W

Q. A rectangular wire loop of sides 8 cm and 2 cm with a small cut is moving out of a region of a uniform magnetic field of magnitude 0.3 T directed normal to the loop. What is the emf developed across the cut if the velocity of the loop is in a direction normal to the (a) longer side, (b) shorter side of the loop? For how long does the induced voltage last in each case?

Sol. A = 8 × 2 = 16cm²

emf, e = d(A × B)/dt = 0.32×10^{-4} V

Induced current, i = e/R = 2×10^{-5} A

Power, P = i²R = 6.4×10^{-10} W

Q. A cycle wheel of radius 0.5 m is rotated with constant angular velocity of 10 rad/s in a region of magnetic field of 0.1 T which is perpendicular to the plane of the wheel. Then find the EMF generated between its center and the rim.

Sol. Here, $B = 0.1$ T, $r = 0.5$ m, $\omega = 10$ rad/s

So, the emf generated between its center and rim is,

$\varepsilon = \frac{1}{2}B\omega r^2 = \frac{1}{2} \times 0.1 \times 10 \times (0.5)^2 = 0.125$ V

Eddy Currents

When the magnetic flux coupled to the coil changes, induced electromotive force is produced in the coil. Eddy currents get their name from the fact that they resemble eddies or whirlpools. Eddy currents are the induced currents that occur when a conductor is placed in a changing magnetic field. According to the eddy current definition we understood that it is the current generated or induced as a result of the change in magnetic flux.

Now, what is eddy current meaning, or what do you mean by eddy current? Whenever the conductor encounters a change in the magnetic flux, then the free electrons present in the conductor will experience a magnetic force. As a result of the effect of the magnetic force on the free electrons, these free electrons will move in the form of small loops or eddies, the electric current generated due to the motion of free electrons in the form of eddies is known as the eddy current. The generation of eddy current follows Faraday's law of magnetic induction.

The magnitude of induced eddy current can be calculated using Faraday's law of magnetic induction. According to the second law of Faraday's laws of magnetic induction, we know that induced emf is written as, rate of change of magnetic flux with respect to time will give rise to induced emf in the conductor, mathematically we get:

Emf = E = -dΦ/dt

Φ -The magnetic flux passed through the conductor

The negative sign is corresponding to the direction of the magnetic flux and is determined by the Lenz law.

Now, the current induced in a conductor whose resistance is R can be calculated by using ohm's law, thus we get:

I= e/R

Were,

e-The emf induced in the good conductor as a result of the change in magnetic flux

R-The resistance of the conductor

Substituting the value of induced emf in the above equation we get,

I = - dΦ/dt/R = -1/RdΦ/dt

Equation is known as the expression for induced current. And the direction of induced current can be estimated by the Lenz law.

Eddy currents are used to advantage in certain applications like-

(i) Magnetic braking in trains

(ii) Electromagnetic damping

(iii) Induction furnace

(iv) Electric power meters

Inductance

Inductance is the tendency of an electrical conductor to oppose a change in the electric current flowing through it. L is used to represent the inductance, and Henry is the SI unit of inductance.

1 Henry is defined as the amount of inductance required to produce an emf of 1 volt in a conductor when the current change in the conductor is at the rate of 1 Ampere per second. An electric current flowing through a conductor creates a magnetic field around it. The strength of the field depends upon the magnitude of the current. The generated magnetic field follows any changes in the current, and from Faraday's law of induction, we know that changing the magnetic field induces an electromotive force in the conductor. Considering this principle, inductance is defined as the ratio of the induced voltage to the rate of change of current causing it. The electronic component designed to add inductance to a circuit is an inductor.

Inductance is classified into two types as: Self Inductance and Mutual Inductance

Self-Inductance

When there is a change in the current or magnetic flux of the coil, an electromotive force is induced. This phenomenon is termed Self Inductance. When the current starts flowing through the coil at any instant, it is found that, that the magnetic flux becomes directly proportional to the current passing through the circuit. The relation is given as:

$\varphi = L \times I$

Where L is termed as the self-inductance of the coil or the coefficient of self-inductance, the self-inductance depends on the cross-sectional area, the permeability of the material, and the number of turns in the coil. The rate of change of magnetic flux in the coil is given as,

$e = -\frac{d\varphi}{dt} = -\frac{d(LI)}{dt}$

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

$L = N\frac{\varphi}{I}$

Where, L is the self-inductance in Henries, N is the number of turns, φ is the magnetic flux, I is the current in amperes.

Mutual Inductance

Consider two coils: P – coil (Primary coil) and S – coil (Secondary coil). A battery and a key are connected to the P-coil, whereas a galvanometer is connected across the S-coil. When there is a change in the current or magnetic flux linked with the two coils, an opposing electromotive force is produced across each coil, and this phenomenon is termed Mutual Inductance. This phenomenon is given by the relation:

$\varphi = MI$

Where M is termed as the mutual inductance of the two coils or the coefficient of the mutual inductance of the two coils.

The rate of change of magnetic flux in the coil is given a

$e = -\frac{d\varphi}{dt} = -\frac{d(MI)}{dt}$ $\qquad$ $e = -M\frac{dI}{dt}$

$M = \frac{\mu_0\mu_r N_1 N_2 A}{l}$

Where, μ_0 is the permeability of free space, μ_r is the relative permeability of the soft iron core, N is the number of turns in coil, A is the cross-sectional area in m^2, l is the length of the coil in m.

Derivation of Inductance

Consider a DC source. When the switch is turned on, the current flows from zero to a certain value such that there is a change in the rate of current flowing. Let ϕ be the change in flux due to current flow. The change in flux is with respect to time which is given as $\frac{d\varphi}{dt}$

Apply Faraday's law of electromagnetic induction, $E = N\frac{d\varphi}{dt}$

Where, N is the number of turns in the coil and E is the induced EMF across the coil.

From Lenz's law, we can write the above equation as

$E = -N\frac{d\varphi}{dt}$

The above equation is modified for calculating the value of inductance

$E = -N\frac{di}{dt}$

N= $d\varphi$=Ldi

Nφ = Li

Therefore,

Li = Nφ = NBA

Where B is the flux density, A is the area of the coil.

Hl = Ni

Where H is the magnetizing force due to magnetic flux

B = μH $\qquad$ Li = NBA

L = NBA/i = N^2BA/Ni $\qquad$ N^2BA/Hl = N^2μHA/Hl

L = μN^2A/l = μ$N^2\pi r^2$/l $\qquad$ Where, r is the radius of the coil.

Q. There are two coils such that the current flowing through the first coil experiences a change in current flow from 2 A to 10 A in 0.4 sec. Calculate mutual inductance between the two coils when 60 mV emf is induced in the second coil. Determine the induced emf in the second coil if the current changes from 4 A to 16 A in 0.03 sec in the first coil.

Sol. Case 1:

Change in current, di = 10 -2 = 8 A $\qquad$ Change in time, dt = 0.4 sec $\qquad$ Magnitude of induced emf, $\varepsilon_2 = 60\times10^{-3}$ V

Case 2:

Change in current, di = 16 – 4 = 12 A $\qquad$ Change in time, dt = 0.03 sec

Mutual inductance of the second coil with respect to the first coil is given as:

$M_{21} = \varepsilon_2/(di/dt) = 60\times10^{-3}\times0.4/8 = 3\times10^{-3}$H

Induced emf in the second coil due to change in the rate of current in the first coil is given as:

$\varepsilon_2 = M_{21}\ di/dt = 3\times10^{-3}\times12/0.03 = 1.2$V

Q. Consider a solenoid with 500 turns which are wound on an iron core whose relative permeability is 800. 40 cm is the length of the solenoid, while 3 cm is the radius. The change in current is from 0 to 3 A. Calculate the average emf induced for this change in the current for a time of 0.4 seconds.

Sol. Number of turns, N = 500 turns

Relative permeability, $\mu_r = 800$

Length, l = 40 cm = 0.4 m

Radius, r = 3 cm = 0.03 m

Change in current, di = 3 – 0 = 3 A

Change in time, dt = 0.4 sec

Self-inductance is given as

$L = \mu N^2 A l = \mu_0 \mu_r N^2 \pi r^2 / l$

Substituting the values we get

$L = (4)(3.14)(10^{-7})(800)(500^2)(3.14)(3\times10^{-2})^2/0.4$

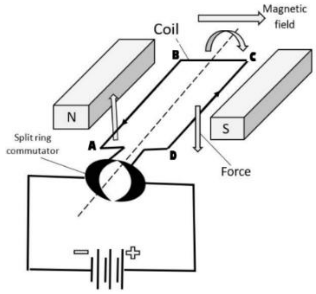
L = 1.77 H

Magnitude of induced emf, $\varepsilon = L\, di/dt = 1.77\times3/0.4$

$\varepsilon = 13.275$ V

AC generator

AC generators work on the principle of Faraday's law of electromagnetic induction. This law states that electro motive force is generated in a current carrying loop that is placed in a uniform magnetic field. Whenever a coil is rotated about its axis perpendicular to the uniform magnetic field, the magnetic flux in the coil changes and an induced emf is set up across its ends.



When the coil in the generator starts moving, the arm AB starts moving upwards and the arm CD moves downwards. These arms start cutting the magnetic lines of force therefore, by Fleming's right hand rule, the induced current set up in these arms is along the direction of AB and CD. Let us consider a coil of N turns and area A that is rotated at constant angular velocity in a magnetic field of B as shown in the figure. When the normal to the coil is at an angle θ, magnetic flux is generated in the coil. This flux is given by,

$\phi = BAN\cos\theta$

we know that,

$E = -\frac{d\varphi}{dt}$

Substituting the value of ϕ in above equation, we get

$\Rightarrow E = -\frac{dBAN\cos\theta}{dt}$

Now, we know that

$\theta = \omega t$

Therefore,

$\Rightarrow E = -\frac{dBAN\cos\omega t}{dt}$

On solving,

$\Rightarrow E = BAN\omega\sin\omega t$

We know that, the maximum value for induced emf will be obtained when

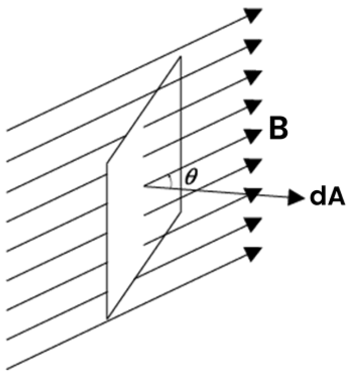
$\Rightarrow \theta = \omega t = 90°$

Therefore, the maximum value of induced emf will be,

$E = BAN\omega$

SUMMARY

- **Magnetic Flux:**
  Magnetic flux through a plane of area d*A* placed in a uniform



  Magnetic field B
  $\phi = \int \vec{B}.d\vec{A}$
  If the surface is closed, then
  $\phi = \int \vec{B}.d\vec{A}$
  This is because magnetic lines of force are closed lines and free magnetic poles do not exist.
- **Faraday's Law:**
  a) First Laws: whenever there is a change in the magnetic flux linked with a circuit with time, an induced emf is produced in the circuit which lasts as long as the change in magnetic flux continues.
  b) Second Law: According to this law,
  Induced emf, $E \propto \left(\frac{d\phi}{dt}\right)$
- **Lenz's Law:**
  The direction of the induced emf or current in the circuit is such that it opposes the cause due to which it is produced, so that,
  $$E = -N\left(\frac{d\phi}{dt}\right)$$
  Where N is the number of turns in coil
  Lenz's law is based on energy conservation.
- **Induced EMF and Induced Current:**
  (a) Induced EMF,
  $$E = -N\frac{d\phi}{dt}$$
  $$= -\frac{N(\phi_2 - \phi_1)}{t}$$
  (b) Induced current,
  $$I = \frac{E}{R} = -\frac{N}{R}\left(\frac{d\phi}{dt}\right)$$
  $$= -\frac{N}{R}\frac{(\phi_2 - \phi_1)}{t}$$
  Charge depends only on net change in flux does not depends on time.
- **Induced Emf due to Linear Motion of a Conducting Rod in Uniform Magnetic Field**
  The induced emf,
  $$E = -\vec{l}.\left(\vec{v}x\vec{B}\right)$$
  If $\vec{e}, \vec{v}$ *and* $\vec{B}$ are perpendicular to each other, then
  E = Bvl
- **Induced EMF due to Rotation of a Conducting Rod in a Uniform Magnetic Field:**
  The induced emf,
  $$E = \frac{1}{2}B\omega l^2 = B\pi n l^2 = BAn$$
  Where n is the frequency of rotation of the conducting rod.
- **Induced Emf due to Rotation of a Metallic Disc in a Uniform Magnetic Field:**
  $$E_{OA} = \frac{1}{2}B\omega R^2 = B\pi R^2 n = BAn$$
- **Induced Emf, Current and Energy Conservation in a Rectangular Loop Moving in a Non – Uniform Magnetic Field with a Constant Velocity:**
  a) The net increase in flux crossing through the coil in the Δt is,
  $$\Delta\phi = \left(B_2 - B_1\right)lv\Delta t$$
  b) Induced emf in the coil is,
  $E = (B_1 - B_2)lv$
  c) If the resistance of the coil is R, then the induced current in the coil is,
  $$I = \frac{E}{R} = \frac{\left(B_1 - B_2\right)}{R}lv$$
  d) Resultant force acting on the coil is
  $F = Il(B_1 - B_2)$ (towards left)
  e) The work done against the resultant force
  $$W = \left(B_1 - B_2\right)^2 \frac{l^2v^2}{R}\Delta t \text{ joule}$$
  Energy supplied in this process appears in the form of heat energy in the circuit.
  f) Energy supplied due to flow of current I in time Δt is,
  $$H = I^2R\Delta t$$
  $$Or\ H = \left(B_1 - B_2\right)^2 \frac{l^2v^2}{R}\Delta t \text{ joule}$$
  Or H = W
- **Rotation of Rectangular Coil in a Uniform Magnetic Field:**
  a) Magnetic flux linked with coil
  $\Phi = BAN\cos\theta$
  $= BAN\cos\omega t$
  b) Induced emf in the coil

$$E = \frac{d\phi}{dt} = BAN\omega \sin \omega t = E_0\, E \sin \omega t$$

c) Induced current in the coil.

$$I = \frac{E}{R} = \frac{BAN\omega}{R} \sin \omega t$$

$$= \frac{E_0}{R} \sin\ \omega \mathrm{t}$$

d) Both Emf and current induced in the coil are alternating

- **Self-Induction and Self Inductance:**

a) The phenomenon in which an induced emf is produced by changing the current in a coil is called self in induction.

$\phi \propto I \text{or} \phi = LI$

$or \mathrm{L} = \frac{\phi}{I}$

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

$L = \frac{E}{-(dI/dt)}$

Where L is a constant, called self-inductance or coefficient of self – induction.

b) Self-inductance of a circular coil

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

c) Self-inductance of a solenoid

$$L = \frac{\mu_0 N^2 A}{l}$$

d) Two coils of self – inductances L_1 and L_2 placed far away (i.e., without coupling) from each other.

(i) For series combination:

$L = L_1 + L_2 \ldots L_n$

ii) For series combination:

$$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + \ldots. + \frac{1}{L_n}$$

- **Mutual Induction and Mutual Inductance:**

(a) On changing the current in one coil, if the magnetic flux linked with a second coil changes and induced emf is produced in that coil, then this phenomenon is called mutual induction.

$$\phi_2 \propto I_1 \text{ or} \phi_2 = MI_1$$

$$\text{Or} M = \frac{\phi_2}{I_1}$$

$$E_2 = -\frac{d\phi_2}{dt} = -M\frac{dI_1}{dt}$$

$$M = \frac{E_2}{-(dI_1/dt)}$$

Therefore, $M_{12} = M_{21} = M$

b) Mutual inductance two coaxial solenoids

$$M = \frac{\mu_0 N_1 N_2 A}{l}$$

If two coils of self-inductance L_1 and L_2 are wound over each other, the mutual inductance is,

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

Where K is called coupling constant.

Mutual inductance for two coils wound in same direction and connected in series

$L = L_1 + L_2 + 2M$

Mutual inductance for two coils wound in opposite direction and connected in series

$L = L_1 + L_2 - 2M$

Mutual inductance for two coils in parallel

$$L = \frac{L_1 L_2 - M^2}{L_1 + L_2 \pm 2M}$$

- **Energy Stored in an Inductor:**

$$U_B = \frac{1}{2} L I^2{}_{max}$$

- **Magnetic Energy Density:**

$$U_B = \frac{B^2}{2\mu_0}$$

- **Eddy Current:**

When a conductor is moved in a magnetic field, induced currents are generated in the whole volume of the conductor. These currents are called eddy currents.

- **Transformer:**

It is a device which changes the magnitude of alternating voltage or current.

$$\frac{E_s}{E_p} = \frac{n_s}{n_p} = K$$

For ideal transformer:

$$\frac{I_p}{I_s} = \frac{n_s}{n_p}$$

In an ideal transformer:

$E_p I_p = E_s I_s$

In step – up transformer:

$n_s > n_p$ or $K > 1$

$E_s > E_p$ and $I_s < I_p$

In step – down transformer:

$n_s < n_p$ or $K > 1$

$E_s < E_p$ and $I_s > I_p$

Efficiency

$\eta = \frac{E_s I_s}{E_p I_p} x 100\%$

- **Generator or Dynamo:**

It is a device by which mechanical energy is converted into electrical energy. It is based on the principle of electromagnetic induction.

- **Different Types of Generators:**

a) AC Generator

It consists of field magnet, armature, slip rings and brushes.

b) DC Generator

It consists of field magnet, armature, commutator and brushes.

- **Motor:**

It is a device which converts electrical energy into mechanical energy.

Back emf $e \propto \omega$

Current flowing in the coil,

$$i_a = \frac{E - e_b}{R}$$

$$E = e_b + i_a R$$

Where R is the resistance of the coil.

Output Power = $i_a e_b$

Efficiency,

$$\eta = \frac{e_b}{E} \times 100\%$$

MIND MAP

Electromagnetic Induction

Contribution
In 1831, Michael Faraday discovered electromagnetic induction and James Clerk Maxwell mathematically described it.

Faraday's Law of Electromagnetic Induction
Whenever flux of magnetic field through the area bounded by a closed conducting loop changes, an emf is produced in the loop

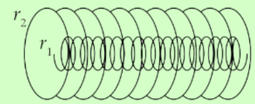
The emf is given by $E = -d\phi/dt$

where $\phi = \int \vec{B}.\vec{ds}$

is the flux of the magnetic field through the area.

Mutual Inductance
$\phi = Mi$

$\frac{d\phi}{dt} = -M\frac{di}{dt}$



$M_{12} = \mu_0 n_1 n_2 \pi r_1^2 l$

$M_{21} = \mu_0 n_1 n_2 \pi r_2^2 l$

Emf induced in an AC generator, $E = NBA\omega \sin \omega t$

Lenz's Law
The direction of the induced current is such that it opposes the changes that has induced it.

Self Induction
If a solenoid of N turns, the flux through each each turn $= \phi = \int \vec{B}.\vec{ds}$

emf induced between the ends of coil $= E = -N\frac{d}{dt}\int \vec{B}.\vec{ds}$

Self Inductance of long Solenoid
$L = \mu_0 n^2 \pi r^2 l$

n = no. of turns per unit length

ϕ = flux = $(\mu_0 ni)\, \pi r^2$

r = radius of each loop of solenoid

- Growth of current in LR Circuit

  $i = \frac{E}{R}(1 - e^{tR/L}) = i_0(1 - e^{-t/\tau})$

- Decay of current

  $i = i_0 e^{-t/\tau}$

- Energy stored in an Inductor

  $U = \frac{1}{2}Li^2$

Eddy Current
It is induced when magnetic flux linked with the conductor changes

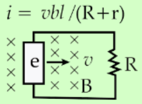
Induced current
$I = \frac{E}{R} = -\frac{1}{R}\frac{d\phi}{dt}$

Induced EMF
$E = \frac{d\phi}{dt}$

Motional EMF
$E = \left|\frac{d\phi}{dt}\right| = \left|Bl\frac{dx}{dt}\right|$

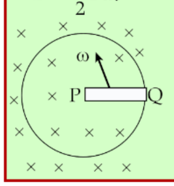
$= Blv$

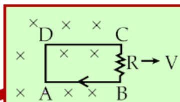
$i = vbl/(R+r)$



r = resistance of rod moving with velocity v in uniform magnetic field $\vec{B}$

EMF induced in a rotating conductor
$E = \frac{1}{2}B\omega l^2$



Rectangular loop


emf induced
$E = vBl$
$i = \frac{vBl}{R}$

Magnetic force on the loop
$F = B^2 l^2 v/R$
= force required to move the loop with constant velocity (v)

Thermal power developed in the loop is
$P = \frac{v^2 B^2 l^2}{R}$

PRACTICE EXERCISE

MULTIPLE CHOICE QUESTTION

Q1. A metal disc of radius 100 cm is rotated at a constant angular speed of 60 rad/s in a plane at right angle to an external field of magnetic induction 0.05 Wb/m^2. The emf induced between the center and a point on the rim will be
(a) 3V (b) 1.5 V
(c) 6V (d) 9V

Q2. A 10-meter wire is kept in east-west direction. It is falling down with a speed of 5.0 meter/second, perpendicular to the horizontal component of earth's magnetic field of 0.30×10^{-4} weber/$meter^2$. The momentary potential difference induced between the ends of the wire will be
(a) 0.0015 V (b) 0.015 V
(c) 0.15 V (d) 1.5 V

Q3. Two solenoids of equal number of turns have their lengths and the radii in the same ratio 1: 2 The ratio of their self-inductances will be
(a) 1: 2 (b) 2: 1
(c) 1: 1 (d) 1: 4

Q4. A metal conductor of length 1 m rotates vertically about one of its ends at angular velocity 5 radians per second. If the horizontal component of earth's magnetic field is 0.2 $\times 10^{-4}$T, then the e.m.f. developed between the two ends of the conductor is
(a) 5 Mv (b) 50μV
(c) 5μV (d) 50 mV

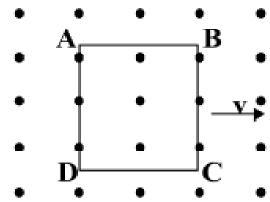
Q5. Eddy currents do not produce
(a) heat
(b) a loss of energy
(c) spark
(d)damping of motion

Q6. The magnetic flux (in weber) linked with a coil of resistance 10 Ω is varying with respect to time t as $\phi = 4t^2 + 2t + 1$. Then the current in the coil at time t = 1 second is
(a) 0.5 A (b) 2 A
(c) 1.5 A (d) 1 A

Q7. When the current changes from +2 A to -2A in 0.05 second, an e.m.f. of 8 V is induced in a coil. The coefficient of self- induction of the coil is
(a) 0.2 H (b) 0.4 H
(c) 0.8 H (d) 0.1 H

Q8. A long solenoid has 500 turns. When a current of 2 ampere is passed through it, the resulting magnetic flux linked with each turn of the solenoid is 4×10^{-3} Wb. The self-inductance of the solenoid is
(a) 2.5 henry
(b) 2.0 henry
(c) 1.0 henry
(d) 40 henry

Q9. A metallic square loop ABCD is moving in its own plane with velocity v in a uniform magnetic field perpendicular to its plane as shown in the figure. An electric field is induced



(a) in AD, but not in BC
(b) in BC, but not in AD
(c) neither in AD nor in BC
(d) in both AD and BC

Q10. In an AC generator, a coil with N turns, all of the same area A and total resistance R, rotates with frequency ω in a magnetic field B. The maximum value of emf generated in the coil is
(a) N.A.B.Rω (b) N.A.B
(c) N.A.B.R. (d) N.A.B.ω

Q11. In an inductor of self-inductance L = 2 mH, current changes with time according to relation $i = t^2 e^{-t}$. At what time emf is zero?
(a) 4s (b) 3s
(c) 2s (d) 1s

Q12. Choke coil works on the principle of
(a) transient current (b) self-induction
(c) mutual induction (d) wattles current

Q13. A boat is moving due east in a region where the earth's magnetic field is 5.0 $\times 10^{-5}$ NA^{-1} m^{-1} due north and horizontal. The boat carries a vertical aerial 2 m long. If the speed of the boat is 1.50 ms^{-1}, the magnitude of the induced emf in the wire of aerial is:
(a) 0.75 mV (b) 0.50mV
(c) 0.15mV (d) 1mV

Q14. In a coil of area 10 cm^2 and 10 turns with magnetic field directed perpendicular to the plane and is changing at the rate of 10^8 Gauss/second. The resistance of the coil is 20Ω. The current in the coil will be
(a) 0.5 A (b) 5 A
(c) 50 A (d) 5×10^8A

Q15. A horizontal straight wire 20 m long extending form east to west falling with a speed of 5.0 m/s, at right angles to the horizontal component of the earth's magnetic field 0.30×10^{-4} Wb/m^2. The instantaneous value of the e.m.f. induced in the wire will be
(a) 3mV (b) 4.5 mV
(c) 1.5 mV (d) 6.0 mV

Q16. The self-inductance of a long solenoid cannot be increased by
(a) increasing its area of cross section
(b) increasing its length
(c) changing the medium with greater permeability
(d) increasing the current through it

Q17. a metallic rod of length $'\ell'$ is tied to a string of length 2ℓ and made to rotate with angular speed ω on a horizontal table with one end of the string fixed. If there is a vertical magnetic field 'B' in the region, the e.m.f. induced across the ends of the rod is

(a) $\frac{2B\omega\ell^2}{2}$ (b) $\frac{3B\omega\ell^2}{2}$

(c) $\frac{4B\omega\ell^2}{2}$ (d) $\frac{5B\omega\ell^2}{2}$

Q18. Lenz's law gives

(a) the magnitude of the induced e.m.f.

(b) the direction of the induced current

(c) both the magnitude and direction of the induced current

(d) the magnitude of the induced Current

Q19. A metal rod of length 1 cuts across a uniform magnetic field B with a velocity v. If the resistance of the circuit of which the rod forms a part is r, then the force required to move the rod is

(a) $\frac{B^2l^2v}{r}$ (b) $\frac{Blv}{r}$

(c) $\frac{B^2lv}{r}$ (d) $\frac{B^2l^2v^2}{r}$

Q20. In an A.C. generator, when the plane of the armature is perpendicular to the magnetic field

(a) both magnetic flux and emf are maximum

(b) both magnetic flux and emf are zero

(c) both magnetic flux and emf are half of their respective maximum values

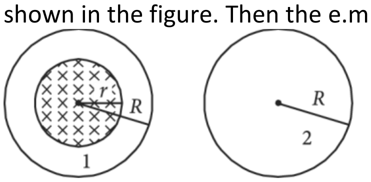
(d) magnetic flux is maximum and emf is zero

Q21. A circular disc of radius 0.2 meter is placed in a uniform magnetic field of induction $\frac{1}{\pi}\left(\frac{Wb}{m_2}\right)$ in such a way that its axis makes an angle of 60° with $\vec{B}$. The magnetic flux linked with the disc is

(a) 0.08 Wb (b) 0.01 Wb

(c) 0.02 Wb (d) 0.06 Wb

Q22. A uniform magnetic field is restricted within a region of radius r. The magnetic field changes with time at a rate $\frac{d\vec{B}}{dt}$. Loop 1 of radius $R > r$ encloses the region r and loop 2 of radius R is outside the region of magnetic field as shown in the figure. Then the e.m.f. generated is



(a) zero in loop 1 and zero in loop 2

(b) $-\frac{d\vec{B}}{dt}\pi r^2$ in loop 1 and $-\frac{d\vec{B}}{dt}\pi r^2$ in loop 2

(c) $-\frac{d\vec{B}}{dt}\pi R^2$ in loop 1 and zero in loop 2

(d) $-\frac{d\vec{B}}{dt}\pi r^2$ in loop 1 and zero in loop 2

Q23. A coil of resistance 400 Ω is placed in a magnetic field. If the magnetic flux ϕ (Wb) linked with the coil varies with time t (sec) as ϕ = $50t^2 + 4$. The current in the coil at t = 2 sec is

(a) 0.5 A (b) 0.1 A

(c) 2 A (d) 1 A

Q24. A conducting circular loop is placed in a uniform magnetic field, B = 0.025 T with its plane perpendicular to the loop. The radius of the loop is made to shrink at a constant rate of 1 mm s^{-1}. The induced emf when the radius is 2 cm, is

(a) $2\pi\ \mu V$ (b) $\pi\ \mu V$

(c) $\frac{\pi}{2}\mu V$ (d) $2\ \mu V$

Q25. A rectangular, a square, a circular and an elliptical loop, all in the $(x - y)$ plane, are moving out of a uniform magnetic field with a constant velocity, $\vec{V} = v\hat{\imath}$. The magnetic field is directed along the negative z axis direction. The induced emf, during the passage of these loops, out of the field region, will not remain constant for

(a) the circular and the elliptical loops(b) only the elliptical loop

(c) any of the four loops (d) the rectangular, circular and elliptical loops

ASSERTION AND REASONING

Directions: These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following four responses.

(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) If the Assertion is correct but Reason is incorrect.

(d) If both the Assertion and Reason are incorrect.

(e) if assertion is false but reason is true

Q1. Assertion: The image formed by a concave mirror is certainly real if the object is virtual.
Reason: The image formed by a concave mirror is certainly virtual if the object is real.

Q2. Assertion: The focal length of the convex mirror will increase, if the mirror is placed in water.
Reason: The focal length of a convex mirror of radius R is equal to , f = R/2.

Q3. Assertion: The image of a point object situated at the center of hemispherical lens is also at the center.
Reason: For hemisphere Snell's law is not valid.

Q4. Assertion: If the rays are diverging after emerging from a lens; the lens must be concave.
Reason: The convex lens can give diverging rays.

Q5. Assertion: The resolving power of a telescope is more if the diameter of the objective lens is more.
Reason: Objective lens of large diameter collects more light.

VERY SHORT ANSWER QUESTIONS

Q1. Two spherical bobs, one metallic and the other of glass, of the same size are allowed to fall freely from the same height above the ground. Which of the two would reach earlier and why?

Q2. When current in a coil change with time, how is the back emf induced in the coil related to it?

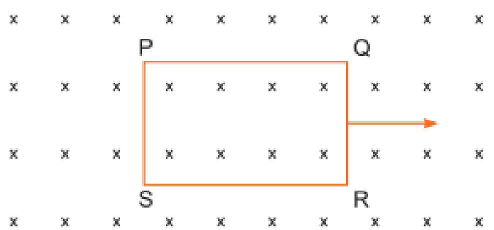
Q3. State the law that gives the polarity of the induced emf.

Q4. A long straight current carrying wire passes normally through the center of circular loop. If the current through the wire increases, will there be an induced emf in the loop? Justify.

Q5. A light metal disc on the top of an electromagnet is thrown up as the current is switched on. Why? Give reason.

SHORT ANSWER QUESTIONS

Q1. The closed loop (PQRS) of wire is moved out of a uniform magnetic field at right angles to the plane of the paper as shown in the figure. Predict the direction of the induced current in the loop.



Q2. Show that Lenz's law is in accordance with the law of conservation of energy.

Q3. (a) Define self-inductance of a coil and hence write the definition of 'Henry'.

(b) Write any two factors each on which the following depends :

(I) Self-inductance of a coil.

(ii) mutual inductance of a pair of coils.

Q4. How does the mutual inductance of a pair of coils change when:

(I) the distance between the coils is increased?

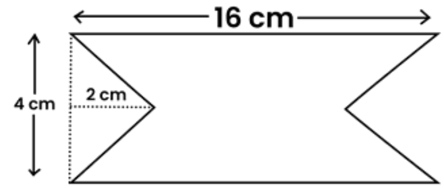
(ii) the number of turns in each coil is decreased?

(iii) a thin iron rod is placed between the two coils, other factors remaining the same? Justify your answer in each case.

NUMERICAL TYPE QUESTIONS

Q1. A circular disc of radius 0.2 m is placed in a uniform magnetic field of induction $(1/\pi)\ \mathrm{Wbm^{-2}}$ in such a way that its axis makes an angle of 60° with B. Then find the magnetic flux linked with the disc.

Q2. At time t = 0 magnetic field of 1000 G is passing perpendicularly through the area defined by the closed loop shown in the figure. If the magnetic field reduces linearly to 500 gausses, in the next 5 s, then determine the induced emf in the loop.



Q3. The magnetic flux linked with the coil varies with time as $\phi_B = 3t^2 + 4t + 9$. Then find the magnitude of the induced emf at 2s.

Q4. A-horizontal straight wire 20 m long extending from east to west is falling with a speed of 5.0 $\mathrm{ms^{-1}}$ at right angles to the horizontal component of the earth's magnetic field 0.30 x $10^{-4}\ \mathrm{Wbm^{-2}}$. Then determine the instantaneous value of the emf induced in the wire.

Q5. A toroidal solenoid with air core has an average radius of 15 cm, area of cross-section 12 cm^2 and has 1200 turns. Calculate the self-inductance of the toroid. Assume the field to be uniform across the cross-section of the toroid.

Q6. A rectangular loop of area 0.06 m^2 is placed in a magnetic field 12. T with its plane inclined 30° to the field direction. Find the flux linked with plane of loop.

Q7. A solenoid has 2000 turns wound over a length of 0.3 m. The area of cross–section is 1.2×10^{-3} m^2. Around its central section a coil of 300 turns is closely wound. If an initial current of 2A is reversed in 0.25 s, find the emf induced in the coil.

Q8. A circular coil of radius 8.0 cm and 20 turns rotates about its vertical diameter with an angular speed of 50 s^{-1} in a uniform horizontal magnetic field of magnitude 3×10^{-2} T. Obtain the maximum and average induced emf in the coil. If the coil forms and closed loop of resistance 10Ω, how much power is dissipated as heat? What is the source of this power?

Q9. As a.c. generator consists of a coil of 50 turns and area 2.5 m^2 rotating at an angular speed of 60 rad sec^{-1} in a uniform magnetic field B = 0.30 T between two fixed pole pieces. The resistance of the circuit including that of the coil is 500Ω.

(a) Calculate the maximum current drawn from the generator.

(b) What will be the orientation of the coil w.r.t. the magnetic field to have

(i) maximum magnetic flux (ii) zero magnetic flux.

(c) Would the generator work if the coil were stationary and instead the poles were rotated with same speed as above.

Q10. Two coils of self-inductances 2 mH and 8 mH are placed so close together that the effective flux in one coil is completely linked with the other. The find the mutual inductance between these coils.

HOMEWORK EXERCISE

MCQ

Q1. In a region of magnetic induction $B = 10^{-2}$ tesla, a circular coil of radius 30 cm and resistance π^2 ohm is rotated about an axis which is perpendicular to the direction of B and which forms a diameter of the coil. If the coil rotates at 200 rpm the amplitude of the alternating current induced in the coil is
(a) $4\pi^2$ mA (b) 30 mA
(c) 6 mA (d) 200 mA

Q2. A wire loop is rotated in a magnetic field. The frequency of change of direction of the induced e.m.f. is
(a) four times per revolution (b) six times per revolution
(c) once per revolution (d) twice per revolution

Q3. An inductor may store energy in
(a) its electric field (b) its coils
(c) its magnetic field (d)both in electric and magnetic fields

Q4. The current in self inductance L = 40 mH is to be increased uniformly from 1 amp to 11 amp in 4 milliseconds. The e.m.f. induced in inductor during process is
(a) 100 volt (b) 0.4 volt
(c) 4.0 volt (d) 440 volt

Q5. A rectangular coil of 20 turns and area of cross-section 25 sq. cm has a resistance of 100 Ω. If a magnetic field which is perpendicular to the plane of coil changes at a rate of 1000 tesla per second, the current in the coil is
(a) 1 A (b) 50 A
(c) 0.5 A (d) 5 A

Q6. A 100 millihenry coil carries a current of 1A. Energy stored in its magnetic field is
(a) 0.5 J (b) 1 J
(c) 0.05 J (d) 0.1 J

Q7. If the number of turns per unit length of a coil of solenoid is doubled, the self-inductance of the solenoid will
(a) remain unchanged (b) be halved
(c) be doubled (d) become four times

Q8. Eddy currents are produced when
(a) a metal is kept in varying magnetic field
(b) a metal is kept in steady magnetic field
(c) a circular coil is placed in a magnetic field
(d) current is passed through a circular coil

Q9. Faraday's laws are consequence of conservation of
(a) energy
(b) energy and magnetic field
(c) charge
(d) magnetic field

Q10. A straight-line conductor of length 0.4 m is moved with a speed of 7 m/s perpendicular to a magnetic field of intensity 0.9 $\mathrm{Wb/m^2}$. The induced e.m.f. across the conductor is
(a) 5.04 V (b) 25.2 V
(c) 1.26 V (d) 2.52 V

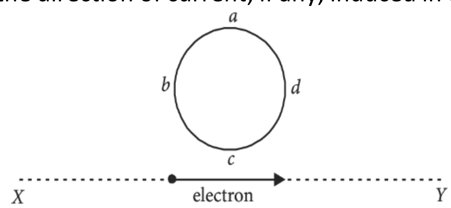
Q11. The magnetic flux through a circuit of resistance R changes by an amount $\Delta\phi$ in a time Δt. Then the total quantity of electric charge Q that passes any point in the circuit during the time Δt is represented by
(a) $Q = \frac{1}{R}\cdot\frac{\Delta\phi}{\Delta t}$ (b) $Q = \frac{\Delta\phi}{R}$
(c) $Q = \frac{\Delta\phi}{\Delta t}$ (d) $Q = R\cdot\frac{\Delta\phi}{\Delta t}$

Q12. In which of the following devices, the eddy current effect is not used?
(a) electric heater (b) induction furnace
(c) magnetic braking in train (d) electromagnet

Q13. A long solenoid of diameter 0.1 m has 2×10^4 turns per meter. At the center of the solenoid, a coil of 100 turns and radius 0.01 m is placed with its axis coinciding with the solenoid axis. The current in the solenoid reduces at a constant rate to 0 A from 4 A in 0.05 s. If the resistance of the coil is 10 $\pi^2\Omega$, the total charge flowing through the coil during this time is
(a) 16 μC (b) 32 μC
(c) 16π μC (d) 32π μC

Q14. A magnetic field of 2×10^{-2} T acts at right angles to a coil of area 100 cm^2, with 50 turns. The average e.m.f. induced in the coil is 0.1 V, when it is removed from the field in t sec. The value of t is
(a) 10 s (b) 0.1 s
(c) 0.01 s (d) 1 s

Q15. An electron moves on a straight-line path XY as shown. The $abcd$ is a coil adjacent to the path of electron. What will be the direction of current, if any, induced in the coil?



(a) The current will reverse its direction as the electron goes past the coil
(b) No current induced
(c) $abcd$
(d) $adcb$

Q16. The magnetic potential energy stored in a certain inductor is 25 mJ, when the current in the inductor is 60 mA. This inductor is of inductance
(a) 0.138 H (b) 138.88 H
(c) 1.389 H (d) 13.89 H

Q17. The phenomenon in which electric current is generated by varying magnetic field is appropriately known as electromagnetic
(a) conduction (b) induction
(c) pressure (d) radiation

ASSERTION AND REASONING

Directions: These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following four responses.

(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.

(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.

(c) If the Assertion is correct but Reason is incorrect.

(d) If both the Assertion and Reason are incorrect.

(e) if assertion is false but reason is true

Q1. Assertion: An emf is induced in a closed loop where magnetic flux is varied. The induced field $\vec{E}$ is not a conservative field.

Reason: The line integral $\oint \vec{E}.\vec{dl}$ around a closed path is non-zero.

Q2. Assertion: Faraday established induced emf experimentally.

Reason: Magnetic flux can produce an induced emf.

Q3. Assertion: An induced current has a direction such that the magnetic field due to the current opposes the change in the magnetic flux that induces the current.

Reason: Above statement is in accordance with conservation of energy.

Q4. Assertion: The bar magnet falling vertically along the axis of the horizontal coil will be having acceleration less than g.

Reason: Clockwise current induced in the coil.

Q5. Assertion: Induced current in a coil is maintained only by a change in magnetic field.

Reason: The presence of large magnetic flux through a coil maintains a current in the coil if the circuit is continuous.

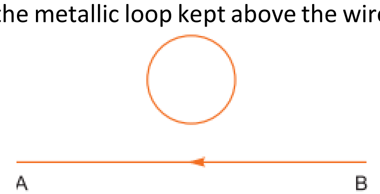
VERY SHORT ANSWER QUESTIONS

Q1. Give one example of use of eddy currents.

Q2. A planar loop of rectangular shape is moved within the region of a uniform magnetic field acting perpendicular to its plane. What is the direction and magnitude of the current induced in it?

Q3. The motion of copper plate is damped when it is allowed to oscillate between the two poles of a magnet. What is the cause of this damping?

Q4. The electric current flowing in a wire in the direction from B to A is decreasing. Find out the direction of the induced current in the metallic loop kept above the wire as shown.

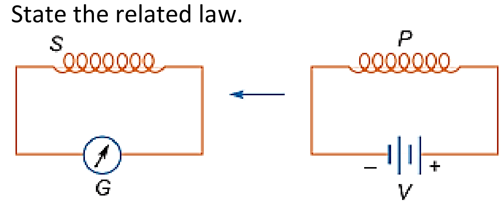


Q5. A wire in the form of a tightly wound solenoid is connected to a DC source, and carries a current. If the coil is stretched so that there are gaps between successive elements of the spiral coil, will the current increase or decrease? Explain.

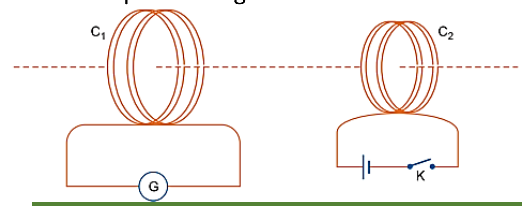
SHORT ANSWER QUESTIONS

Q1. State Lenz's Law. A metallic rod held horizontally along east-west direction, is allowed to fall under gravity. Will there be an emf induced at its ends? Justify your answer.

Q2. (i) When primary coil P is moved towards secondary coil S (as shown in the figure below) the galvanometer shows momentary deflection. What can be done to have larger deflection in the galvanometer with the same battery? (ii) State the related law.



Q3. A current is induced in coil C_1 due to the motion of current carrying coil C_2. (a) Write any two ways by which a large deflection can be obtained in the galvanometer G. (b) Suggest an alternative device to demonstrate the induced current in place of a galvanometer.



NUMERICAL TYPE QUESTIONS

Q1. A long solenoid has 500 turns. When a current of 2 ampere is passed through it, the resulting magnetic flux linked with each turn of the solenoid is 4×10^{-3} Wb. Then find the self-inductance of the solenoid.

Q2. Two coils have a mutual inductance 0.005 H. The current changes in the first coil according to equation $I = I_0 \sin \omega t$, where I_0 = 10 A and ω = 100π rad/sec. find the maximum value of e.m.f. in the second coil.

Q3. What is the self-inductance of a coil which produces 5 V when the current changes from 3 ampere to 2 ampere in one millisecond?

Q4. In a region of magnetic induction $B = 10^{-2}$ tesla, a circular coil of radius 30 cm and resistance π^2 ohm is rotated about an axis which is perpendicular to the direction of B and which forms a diameter of the coil. If the coil rotates at 200 rpm then what will be the amplitude of the alternating current induced in the coil.

PRACTICE EXERCISE SOLUTIONS

MCQ

S1. **(b)** Induced emf produced between the centre and a point on the disc is given by

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

Putting the values,

$\omega = \frac{60 rad}{s}, B = 0.05\frac{Wb}{m^2}$

and R = 100 cm = 1m

We get $e = \frac{1}{2} \times 60 \times 0.05 \times (1)^2 = \quad 1.5\ V$

S2. **(a)** If a wire, ℓ meter in length, moves perpendicular to a magnetic field of B weber/$meter^2$ with a velocity of v meter/second, then the e.m.f induced in the wire is given by

$V = B\ v\ell$ volt.

Here, B = 0.30 × 10^{-4} weber/$meter^2$,

v = 5.0 meter/second and ℓ = 10 meter.

∴ B = 0.30 × 10^{-4} × 5.0 × 10 = 0.0015 volt.

S3. **(a)** Self-inductance of a solenoid,

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

$\therefore \frac{L_1}{L_2} = \left(\frac{r_1}{r_2}\right)^2 \left(\frac{l_2}{l_1}\right)$

$[\therefore N_1 = N_2]$

Here, $\frac{l_1}{l_2} = \frac{1}{2}, \frac{r_1}{r_2} = \frac{1}{2}$

$\therefore \frac{L_1}{L_2} = \left(\frac{1}{2}\right)^2 \left(\frac{2}{1}\right) = \frac{1}{2}$

S4. **(b)** $\ell = 1m, \omega = 5\frac{rad}{s}$,

$B = 0.2 \times 10^{-4} T \varepsilon = \frac{B\omega\ell}{2} = \frac{0.2 \times 10^{-4} \times 5 \times 1}{2} = 50\mu V$

S5. (c) In eddy current, the electrons are only at the surface of the conductor and the electrons do not jump off to enter the air and heat it. Hence, there is no sparking. Therefore, eddy currents do not cause sparking.

S6. **(d)** Given: $\phi = 4t^2 + 2t + 1\ wb$

$\therefore \frac{d\phi}{dt} = \frac{d}{dt}(4t^2 + 2t + 1) = 8t + \quad 2 = |\varepsilon|$

Induced current, I = $\frac{|\varepsilon|}{R} = \frac{8t+2}{10\Omega} A$

At t = 1 s,

I = $\frac{8 \times 1 + 2}{10} A = 1A$

S7. **(d)** e = $-\frac{\Delta\phi}{\Delta t} = \frac{-\Delta(\mathrm{LI})}{\Delta t} = -L\frac{\Delta I}{\Delta t}$

$\therefore |e| = L\frac{\Delta I}{\Delta t} \Rightarrow = L \times \frac{4}{0.05}$

$\Rightarrow L = \frac{8 \times 0.05}{4} = 0.1H$

S8. **(c)** Total number of turns in the solenoid, N = 500

Current, I = 2A.

Magnetic flux linked with each turn

= 4 × 10^{-3} Wb

As, $\phi = LI$ or $N\phi = LI \Rightarrow$

$L = \frac{N\phi}{1}$

= $\frac{500 \times 4 \times 10^{-3}}{2}$henry = 1 H.

S9. (d) Electric field will be induced, as ABCD moves, in both AD and BC. The metallic square loop moves in its own plane with velocity v. A uniform magnetic field is imposed perpendicular to the plane of the square loop. AD and BC are perpendicular to the velocity as well as perpendicular to applied field so an emf is induced in both, this will cause electric fields in both.

S10. **(d)** E.M.F. generated, e = $-\frac{d\phi}{dt} = \quad -\frac{d(N\vec{B}.\vec{A})}{dt}$

$= -N\frac{d}{dt}(BA\cos\omega t) = \quad NBA\omega\sin\omega t$

$\Rightarrow e_{max} = NBA\omega$

S11. L = 2mH, i = $t^2 e^{-t}$

E = $-L\frac{di}{dt} = -L\,[-t^2\,e^{-t} + 2te^{-t}]$

S12. (b) The choke coil works because it acts as an inductor. When the current passing through changes, as AC currents do, it typically creates a magnetic field in the coil that works against that current. This property, known as inductance.

S13. **(c)** Induced emf = $vB_H\ l = 1.5 \times\ 5 \times 10^{-5} \times 2$

= 15 × 10^{-5}

= 0.15 mV

S14. **(b)** $\varepsilon = \frac{d\phi}{dt} = nA\frac{dB}{dt}$

$\therefore \varepsilon = 10 \times (10 \times 10^{-4})(10^4)$

$\left[10^8 \frac{Gauss}{sec} = 10^4 \frac{T}{s}\right]$ = 100 V.

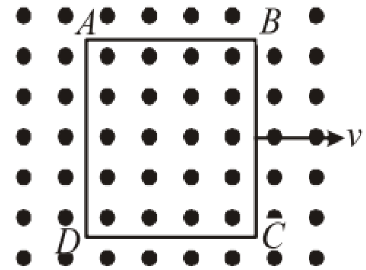
$I = \left(\frac{\varepsilon}{R}\right) = \left(\frac{100}{20}\right) = 5\ amp.$

S15. (a) $\varepsilon_{ind} = Bv\ell$

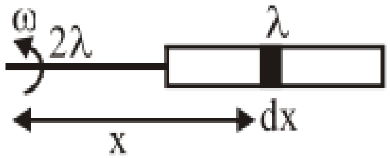
= 0.3 × 10^{-4} × 5 × 20

= 3 × 10^{-3} $V = 3\ mV.$

S16. **(d)** Self-inductance of a long solenoid is given by L = $\mu_r \mu_0 n^2 Al$



S17. **(d)** Here, induced e.m.f.



$e = \int_{2\ell}^{3\ell} (\omega x)\, B dx$

$= B\omega \frac{[(3\ell)^2 - (2\ell)^2]}{2} = \frac{5B\ell^2\omega}{2}$

S18. **(b)** The Lenz's law gives the direction of induced current. According to this law, the induced current opposes the cause that produces it.

S19. **(a)** induced emf=Bvl

$i = \frac{Bvl}{r}$

$F_m = ilB$

$F_m = \frac{Bvl}{r} lB$

$F_m = \frac{B^2 vl^2}{r} lB$

S20. Magnetic flux, $\phi_B = BA \cos\theta$

Induced emf, $\mathcal{E} = BA \sin\theta$

Here, $\theta = 0^0$

∴ Magnetic flux is maximum and induced emf is zero.

S21. (c) $B = \frac{1}{\pi}\left(\frac{\text{wb}}{\text{m}^2}\right)$

Area of the disc normal to B is $\pi R^2 \cos 60°$.

Flux = B × Area normal

∴ Flux $= \frac{1}{2} \times 0.04 = 0.02$ Wb

S22.(d) Emf generated in loop 1,

$\varepsilon_1 = -\frac{d\phi}{dt} = -\frac{d}{dt}(\vec{B}\cdot\vec{A}) = -\frac{d}{dt}(BA) = -A \times \frac{dB}{dt}$

$\varepsilon_1 = -\left(\pi r^2 \frac{dB}{dt}\right)$

($\because A = \pi r^2$ because $\frac{dB}{dt}$ is restricted upto radius r.)

Emf generated in loop 2,

$\varepsilon_2 = -\frac{d}{dt}(BA) = -\frac{d}{dt}(0 \times A) = 0$

S23.(a) Here, $\phi = 50t^2 + 4$ Wb, $R = 400\ \Omega$

Induced emf,

$\varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(50t^2 + 4) = -100t$ V

At $t = 2$ s, $\varepsilon = -200$ V; $|\varepsilon| = 200$ V

Induced current in the coil at t = 2 s is

$I = \frac{|\varepsilon|}{R} = \frac{200\ \text{V}}{400\ \Omega} = \frac{1}{2}\text{A} = 0.5$ A

S24.(b) Here, Magnetic field, B = 0.025 T

Radius of the loop, r = 2 cm = 2×10^{-2} m

Constant rate at which radius of the loop shrinks,

$\frac{dr}{dt} = 1 \times 10^{-3}$ m s^{-1}

Magnetic flux linked with the loop is

$\phi = BA\cos\theta = B(\pi r^2)\cos 0° = B\pi r^2$

The magnitude of the induced emf is

$$|\varepsilon| = \frac{d\phi}{dt} = \frac{d}{dt}(B\pi r^2) = B\pi 2r\frac{dr}{dt}$$

$= 0.025 \times \pi \times 2 \times 2 \times 10^{-2} \times 1 \times 10^{-3}$

$= \pi \times 10^{-6}$ V $= \pi$ μV

S25.(a) Once a rectangular loop or a square loop is being drawn out of the field, the rate of cutting the lines of field will be a constant for a square and rectangle, but not for circular or elliptical areas.

ASSERTION AND REASONING

S1. **(c)** The image of real object may be real in case of concave mirror.

S2. **(d)** Focal length of the spherical mirror does not depend on the medium in which it placed

S3. **(c)** The rays from centre of hemisphere cut at the centre after refraction – Snell's law is valid in each case of refraction.

S4. **(d)** If the rays cross focal point of convex lens, they become diverging.

S5. (a) RP α diameter of objective.

VERY SHORT ANSWER QUESTIONS

S1. Glass would reach earlier. This is because there is no effect of electromagnetic induction in glass, due to presence of earth's magnetic field, unlike in the case of metallic ball.

S2. The back emf induced in the coil opposes the change in current.

S3. Lenz's Law: The polarity of induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produces it.

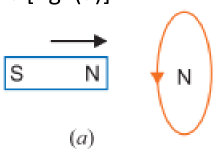
S4. No. Justification: As the magnetic field due to current carrying wire will be in the plane of the circular loop, so magnetic flux will remain zero. Also, magnetic flux does not change with the change in current.

S5. A metal disc is placed on the top of a magnet, as the electric current flows through the coil, an induced current in the form of Eddies flows through the metal plate, the lower face attains the same polarity, and hence the metal disc is thrown up.

SHORT ANSWER QUESTIONS

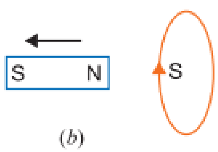
S1. So far the loop remains in the magnetic field, there is no change in magnetic flux linked with the loop and so no current will be induced in it, but when the loop comes out of the magnetic field, the flux linked with it will decrease and so the current will be induced so as to oppose the decrease in magnetic flux, i.e., it will cause magnetic field downwards; so the direction of current will be clockwise.

S2. Lenz's law: According to this law "the direction of induced current in a closed circuit is always such as to oppose the cause that produces it." Example: When the north pole of a coil is brought near a closed coil, the direction of current induced in the coil is such as to oppose the approach of north pole. For this the nearer face of coil behaves as north pole. This necessitates an anticlockwise current in the coil, when seen from the magnet side [fig. (a)]



(a)

Similarly when north pole of the magnet is moved away from the coil, the direction of current in the coil will be such as to attract the magnet. For this the nearer face of coil behaves as south pole. This necessitates a clockwise current in the coil, when seen from the magnet side [fig. (b)].



(b)

Conservation of Energy in Lenz's Law: Thus, in each case whenever there is a relative motion between a coil and the magnet, a force begins to act which opposes the relative motion. Therefore, to maintain the relative motion, a mechanical work must be done. This work appears in the form of electric energy of coil. Thus, Lenz's law is based on principle of conservation of energy.

S3. **(a)** The self-inductance (L) of a coil equals the magnetic flux linked with it, when a unit current flows through it.

One henry is the self-inductance of a coil for which the magnetic flux, linked with it, due to a current of 1A, flowing in it, equals one weber.

(b) (i) Self-inductance of a coil depends on

- Its geometry (area and length of a coil.
- Number of turns
- Medium within the coil

(ii) Mutual inductance of a given pair of coils depends on

- Their geometries
- Their distance of separation
- Number of turns in each coil.
- Nature of medium in the intervening space.

S4. (i) The mutual inductance of two coil, decreases when the distance between them is increased. This is because the flux passing from one coil to another decreases.

(ii) Mutual inductance $M = \frac{\mu_0 N_1 N_2 A}{l}$ i.e., M $\propto$ N_1 N_2

Clearly, when the number of turns N_1 and N_2 in the two coils is decreased, the mutual inductance decrease.

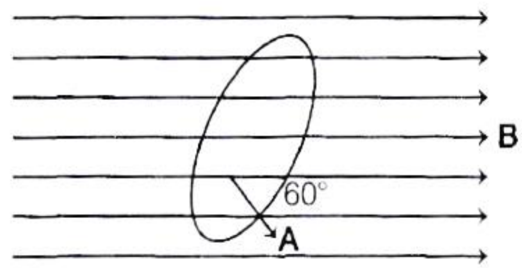
(iii) When an iron rod is placed between the two coils the mutual inductance increases, because M $\propto$ permeability (μ)

ASSERTION AND REASONING

S1. The magnetic flux ϕ_B passing through a plane surface of area *A* placed in a uniform magnetic field *B* is given by

$\phi_B = BA\cos\theta$

where, θ is the angle between the direction of *B* and the normal (axis) to the plane.



Given, $\theta = 60°, B = \left(\frac{1}{\pi}\right)$ Wbm^{-2}, $A = \pi(0.2)^2$

$\therefore \quad \phi_B = \frac{1}{\pi} \times \pi\,(0.2)^2 \times \cos 60° = (0.2)^2 \times \frac{1}{2} =$ 0.02 Wb

S2. Induced emf in the loop,

$E = -\frac{\Delta\phi}{\Delta t} = -\left(\frac{\Delta B}{\Delta t}\right)(A) \qquad [\because \phi = BA]$

$= -\left(\frac{B_2 - B_1}{\Delta t}\right)A \qquad \ldots(i)$

Here, $B_2 = 500\text{ G} = 500 \times 10^{-4}\text{ T}$,

$B_1 = 1000\text{ G} = 1000 \times 10^{-4}\text{ T}$,

$\Delta t = 5s$

$\therefore \qquad A = \text{area of loop}$

= Area of rectangle – Area of two triangles

$= \left(16 \times 4 - 2 \times \frac{1}{2} \times 4 \times 2\right)\text{cm}^2$

$= 56 \times 10^{-4}\text{ m}^2$

Using Eq. (i), we get

$E = \frac{(1000-500)\times 10^{-4} \times 56 \times 10^{-4}}{5}$

$= 56 \times 10^{-6}\,V$

$= 56\,\mu V$

S3. Magnitude of induced emf,

$|\varepsilon| = \frac{d\phi_B}{dt} = \frac{d}{dt}(3t^2 + 4t + 9) = 6t + 4 + 0$

At $t = 2s, |\varepsilon| = 6 \times 2 + 4 = 16V$

S4. Given, $B_H = 0.30 \times 10^{-4}$ Wbm^{-2},

$l = 20\,m$

and $v = 5.0\text{ ms}^{-1}$

Induced emf across the ends of wire,

$\varepsilon = B_H l v$

$= 0.30 \times 10^{-4} \times 20 \times 5.0 = 3\text{ mV}$

S5. Given-

R=15cm=0.15m

A= 12 cm^2=12$\times 10^{-4} m^2$

N=1200

Self-inductance, L= $\frac{\mu_0 N^2 A}{l} = \frac{\mu_0 N^2 A}{2\pi r}$

$= \frac{4\pi\times10^{-7}\times(1200)^2\times12\times10^{-4}}{2\pi\times0.15}$

L=$2.3 \times 10^{-3} H$

S6. Area of loop A = 0.06 m^2, B = 1.2 T and θ = 90° – 30° = 60°

So, the flux linked with the loop is ϕ = BA cos θ

= 1.2 × 0.06 × cos 60°

= 1.2 × 0.06 × 1/2

= 0.036 Wb

S7. $M = \frac{\mu_0 N_1 N_2 A}{l}$

$= \frac{4\pi\times10^{-7}\times2000\times300\times1.2\times10^{-3}}{0.3}$ = 3 × 10^{-3} H

$\varepsilon = -M\frac{\Delta I}{\Delta t} = -3\times10^{-3}\left[\frac{-2-2}{0.25}\right]$

= 48 × 10^{-3} V = 48 mV

S8. Induced emf in coil: –

e = NBAωsinωt

e_{max} = NBAω = NB(πr^2)ω = 20 × 3.0 × 10^{-2} × π × 64 × 10^{-4} × 50 = 0.603 V

e_{avg} is zero over a one cycle

$I_{max} = \frac{e_{max}}{R \frac{0.603}{10}}$ = 0.0603 A

$P_{avg} = \frac{I_{max R}^2}{2}$ = 0.018W

The induced current causes a torque opposing the rotation of the coil. An external agent (rotor) must supply torque (and do work) to counter this torque in order to keep the coil rotating uniformly. Thus, the source of the power dissipated as heat in the coil is the external rotor.

S9. **(a)** Maximum current, $I_{max} = \frac{e_{max}}{R\frac{NBA\omega}{R}\frac{50\times0.3\times2.5\times60}{500}}$ = 4.5 A

(b) Flux is maximum, when plane of coil is perpendicular to the magnetic field.

Flux is zero when plane of coil is parallel to the magnetic field.

(a) Yes, it will work.

S10. $\mathrm{L_1} = 2\mathrm{mH}$

$L_2 = 8mH$

The mutual inductance between coil is,

$M = \sqrt{L_1 L_2}$

$M = \sqrt{2\times8}$

$M = \sqrt{16}$mH

M=4mH.

HOMEWORK EXERCISE SOLUTIONS

MULTIPLE CHOICE QUESTIONS

S1. (c) $I_0 = \frac{E_0}{R} = N\frac{BA\omega}{R}$
Given, $N = 1, B = 10^{-2}\ \mathrm{T}, A = \pi(0.3)^2\ \mathrm{m}^2, R = \pi^2\Omega$
$f = (200/60)$ and $\omega = 2\pi(200/60)$
Substituting these values and solving, we get
$I_0 = 6 \times 10^{-3}\mathrm{A} = 6\ \mathrm{mA}$

S2. (d) Consider the ring starting to rotate from its initial position where it is perpendicular to the magnetic field. Thus initially maximum flux is passing through the loop. When it rotates, the flux passing through the loop starts to decrease. When it becomes parallel to the magnetic field, the flux becomes zero and then starts to increase. Here the direction of the induced emf remains the same. Then as it rotates further, it keeps on increasing, reaches maximum. Here the direction of induced emf changes. According to lenz law, the induced emf tends to oppose the flux when it was increasing and now since it is decreasing, it tends to increase it.

S3. (c) An inductor stores energy in its magnetic field.
Energy stored is given by: U=1/2 Li^2 where Li is magnetic flux.

S4. (a) $|\varepsilon| = L\frac{di}{dt}$
Given that, $L = 40 \times 10^{-3}\ \mathrm{H}, di = 11\ \mathrm{A} - 1\ \mathrm{A} = 10\ \mathrm{A}$ and $dt = 4 \times 10^{-3}\ \mathrm{s}$
$\therefore |\varepsilon| = 40 \times 10^{-3} \times \left(\frac{10}{4\times10^{-3}}\right) = 100\ \mathrm{V}$

S5. (c) $i = \frac{\varepsilon}{R} = \frac{\frac{NAdB}{dt}}{R}$
$= \frac{20\times(25\times10^{-4})\times1000}{100} = 0.5\ \mathrm{A}$

S6. (c) $E = \frac{1}{2}Li^2 = \frac{1}{2}(100 \times 10^{-3}) \times 1^2 = 0.05\ \mathrm{J}$

S7. (d) Self-inductance of a solenoid = μ_0 n^2 Al
where n is the number of turns per length.
So self- induction ∝ n^2
So inductance becomes 4 times when n is doubled

S8. (a) Eddy currents are produced when a metal is kept in a varying magnetic field.

S9. (a) According to Faraday's law, it is the conservation of energy

S10. (d) Length of conductor $(l) = 0.4\ \mathrm{m}$,
Speed $(v) = 7\ \mathrm{m/s}$ and magnetic field $(B) = 0.9\ \mathrm{Wb/m^2}$
Induced e.m.f. $(\varepsilon) = Blv = 0.9 \times 0.4 \times 7 = 2.52$ V.

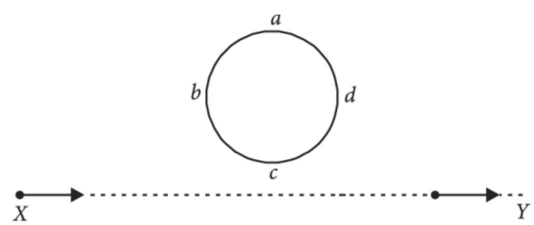
S11. (b) Induced emf is given by $V = \frac{\Delta\phi}{\Delta t}$
current$(i) = \frac{Q}{\Delta t} \Rightarrow \frac{\Delta\phi}{\Delta t} \times \frac{1}{R} = \frac{Q}{\Delta t}$[where Q is total charge in time Δt]
$\Rightarrow \quad Q = \frac{\Delta\phi}{R}$

S12. (a) Electric heater works on the principle of Joule's heating effect.

S13. (b) Given $n = 2 \times 10^4, I = 4\ \mathrm{A}$
Initially $I = 0$ A
$\therefore B_i = 0$ or $\phi_i = 0$
Finally, the magnetic field at the centre of the solenoid is given as
$B_f = \mu_0\, nI = 4\pi \times 10^{-7} \times 2 \times 10^4 \times 4 = 32\pi \times 10^{-3}\ \mathrm{T}$
Final magnetic flux through the coil is given as
$\phi_f = NBA = 100 \times 32\pi \times 10^{-3} \times \pi \times (0.01)^2$
$\phi_f = 32\pi^2 \times 10^{-5}\ \mathrm{T\ m^2}$
Induced charge, $q = \frac{|\Delta\phi|}{R} = \frac{|\phi_f - \phi_i|}{R} = \frac{32\pi^2\times10^{-5}}{10\pi^2}$
$= 32 \times 10^{-6}\ \mathrm{C} = 32\ \mu\mathrm{C}$

S14. (b) $\varepsilon = \frac{-(\phi_2-\phi_1)}{t} = \frac{-(0-NBA)}{t} = \frac{NBA}{t}$
$t = \frac{NBA}{\varepsilon} = \frac{50\times2\times10^{-2}\times10^{-2}}{0.1} = 0.1\ \mathrm{s}$

S15. (a)



When the electron moves from X to Y, the flux linked with the coil $abcd$ (which is into the page) will first increase and then decrease as the electron passes by. So the induced current in the coil will be first anticlockwise and will reverse its direction (i.e., will become clockwise) as the electron goes past the coil.

S16. (d) Magnetic potential energy stored in an inductor is given by
$U = \frac{1}{2}LI^2 \Rightarrow 25 \times 10^{-3} = \frac{1}{2} \times L \times (60 \times 10^{-3})^2$
$L = \frac{25\times2\times10^6\times10^{-3}}{3600} = \frac{500}{36} = 13.89$ H

Q17. (b) Electromagnetic induction is the production of an electromotive force. Across an electrical conductor in a changing magnetic field.

ASSERTION AND REASONING

S1. (a) According to Faraday's law of electromagnetic induction.
$\vec{\mathrm{E}}.\vec{\mathrm{dl}} = \frac{d\varphi}{dt}$
So, E is non-conservative field as in conservative field line integral over a closed loop is zero.

S2. **(e)** E.M.F. induces, when there is change in magnetic flux. Faraday did experiment in which, there is relative motion between the coil and magnet, the flux linked with the coil changes and e.m.f. induces

S3. **(a)** The assertion is the statement of Lenz's law. The reasons → illustration of Lenz's law as shown in figure (1). As magnetic move right current induced anti clockwise i.e, mechanical energy is converted into electrical energy. In this process energy is conserved

S4. **(c)** According to the Lenz's law, a reverse magnetic flux is induced in circuit when the external flux through a coil is varied with time. Hence when bar magnet falls through coil, the magnetic flux inside it increases with time in the downward direction. Hence an anticlockwise current is induced in coil to produce magnetic field in upward direction. Due to this opposing flux, a retarding force acts on the magnet upwards and thus the acceleration is less than g.

S5. **(c)** Induced emf $\propto \frac{d\varphi}{dt}$

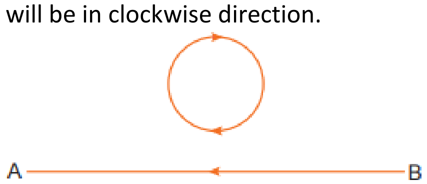
VERY SHORT ANSWER QUESTIONS

S1. **(i)** Electromagnetic damping in certain galvanometers.
(ii) Magnetic braking in trains.
(iii) Induction furnace to produce high temperature

S2. If planar loop moves within the region of uniform magnetic field, there is no magnetic flux changes by loop so, no current will be induced in the loop. Hence no direction.

S3. As the plate oscillate, the changing magnetic flux through the plate produces a strong eddy current in the direction, which opposes the cause. Also, copper being diamagnetic substance, it gets magnetized in the opposite direction, so the plate motion gets damped.

S4. The current in the wire produces a magnetic field vertically downward in the vicinity of the coil. When the current in wire BA decreases, according to Lenz's law, the current induced in the coil opposes this decrease; so, the current in the coil will be in clockwise direction.



S5. The current will increase. As the wires are pulled apart the flux will leak through the gaps. Lenz's law demands that induced emf resist this decrease, which can be done by an increase in current.

SHORT ANSWER QUESTIONS

S1. **Lenz's law:** According to this law "the direction of induced current in a closed circuit is always such as to oppose the cause that produces it." The direction of induced current in a circuit is such that it opposes the very cause which generates it. Yes, an emf will be induced at its ends. **Justification:** When a metallic rod held horizontally along east-west direction is allowed to fall freely under gravity i.e., fall from north to south, the intensity of earth magnetic field changes through it i.e., the magnetic flux changes and hence the emf is induced at it ends.

S2. (i) For larger deflection, coil P should be moved at a faster rate.
(ii) Faraday law: The induced emf is directly proportional to rate of change of magnetic flux linked with the circuit.

S3. **(a)** The deflection in galvanometer may be made large by
(i) moving coil C_2 towards C_1 with high speed.
(ii) by placing a soft iron laminated core at the centre of coil C_1.
(b) The induced current can be demonstrated by connecting a torch bulb (in place of galvanometer) in coil C_1. Due to induced current the bulb begins to glow.

NUMERICAL TYPE QUESTIONS

S1. Net flux $N\phi = Li$

Flux per turn $= 4 \times 10^{-3}$ Wb, $i = 2$ A

$L = \frac{N\phi}{i} = \frac{4\times10^{-3}\times500}{2} = 1$ henry

S2. As, $|\varepsilon| = M\frac{dI}{dt}$

$= M\frac{d}{dt}(I_0 \sin\omega t) = MI_0\omega\cos\omega t$

$\therefore \varepsilon_{\max} = 0.005 \times 10 \times 100\pi \times 1 = 5\pi$

S3. $\varepsilon = -L\frac{di}{dt}$

$L = \frac{-\varepsilon}{\frac{di}{dt}} = \frac{-5\times10^{-3}}{(2-3)}\text{H} = 5$ mH

S4. $I_0 = \frac{E_0}{R} = N\frac{BA\omega}{R}$

Given, $N = 1, B = 10^{-2}\ \text{T}, A = \pi(0.3)^2\ \text{m}^2, R = \pi^2\Omega$

$f = (200/60)$ and $\omega = 2\pi(200/60)$

Substituting these values and solving, we get

$I_0 = 6 \times 10^{-3}\text{A} = 6$ mA