Unit – 14

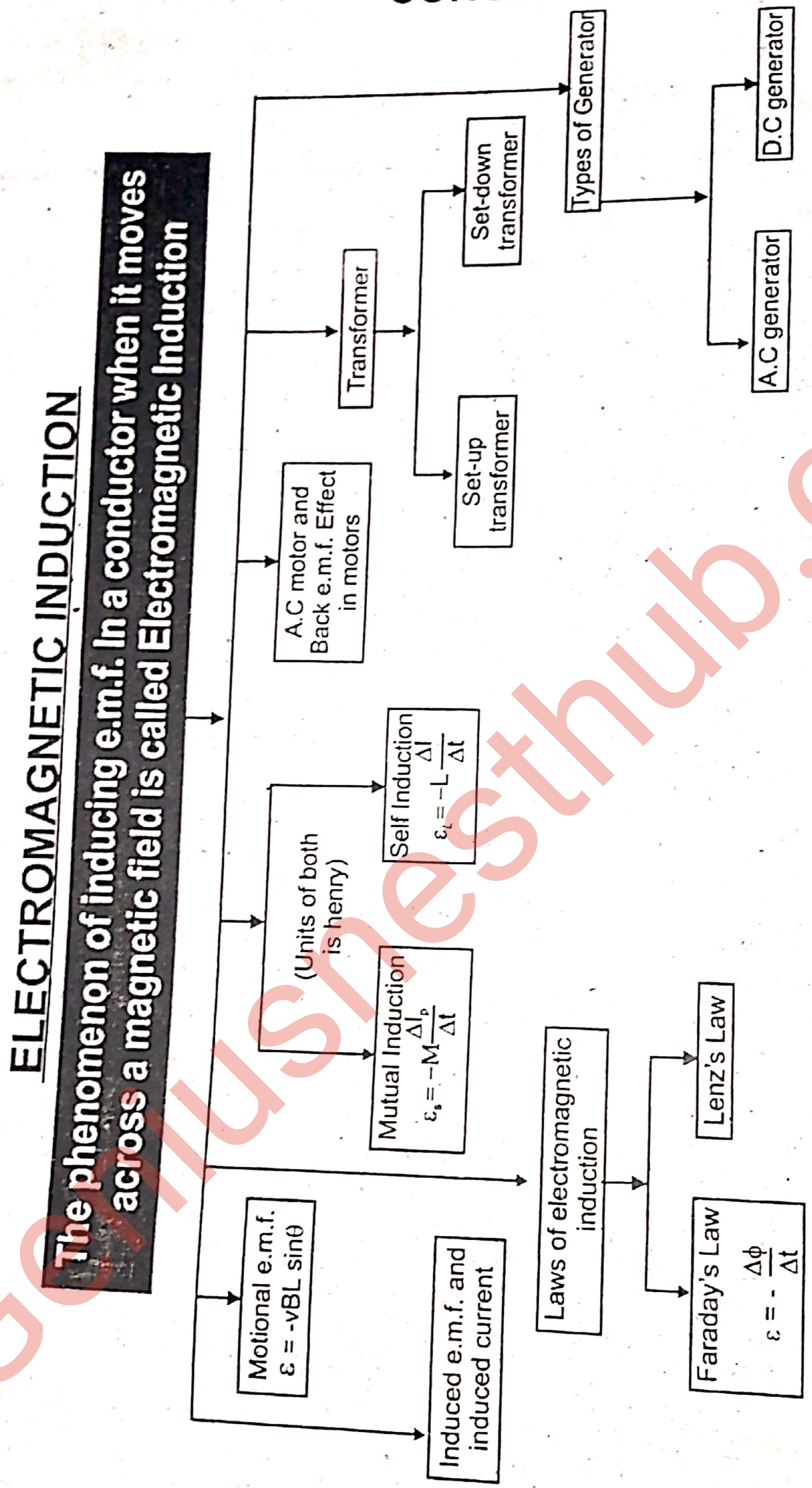
ELECTROMAGNETIC INDUCTION

Learning Objectives

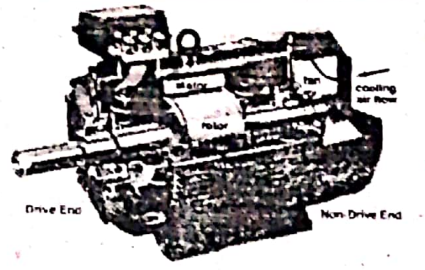
After studying this chapter the students will be able to

- Describe the production of electricity by magnetism.
- Explain that induced emf's can be generator in two ways.
  (i) by relative movement (the generator effect).
  (ii) by changing a magnetic field (the transformer effect).
- Infer the factors affecting the magnitude of the induced emf.
- State Faraday's law of electromagnetic induction.
- Account for Lenz's law to predict the direction of an induced current and relate to the principle of conservation of energy.
- Apply Faraday's law of electromagnetic induction and Lenz's law to solve problems.
- Explain the production of eddy currents and identify their magnetic and heating effects.
- Explain the need for laminated iron cores in electric motors, generators and transformers.
- Explain what is meant by motional emf. Given a rod or wire moving through a magnetic field in a simple way, compute the potential difference across its ends.
- Define mutual inductance (M) and self-inductance (L), and their unit henry.
- Describe the main components of A.C generator and explain how it works.
- Describe the main features of an A.C electric motor and the role of each feature.
- Explain the production of back emf in electric motors.
- Describe the construction of a transformer and explain how it works.
- Identify the relationship between the ratio of the number of turns in the primary and secondary coils and the ratio of primary to secondary voltages.

CONCEPT MAP


ELECTROMAGNETIC INDUCTION
The phenomenon of inducing e.m.f. In a conductor when it moves across a magnetic field is called Electromagnetic Induction
Motional e.m.f. $\varepsilon = -vBL \sin\theta$
Induced e.m.f. and induced current
Laws of electromagnetic induction
Faraday's Law $\varepsilon = -\frac{\Delta\phi}{\Delta t}$
Lenz's Law
Mutual Induction $\varepsilon_s = -M\frac{\Delta I_p}{\Delta t}$
(Units of both is henry)
Self Induction $\varepsilon_L = -L\frac{\Delta I}{\Delta t}$
A.C motor and Back e.m.f. Effect in motors
Transformer
Set-up transformer
Set-down transformer
Types of Generator
A.C generator
D.C generator

INTRODUCTION: Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produces magnetic force and moving magnets produce electric forces. The interplay of electric and magnetic force is the basis for electric motors, generators, and many other modem technologies. The essential feature of an electric motor is the supply of electric motor is the supply of electrical energy to a coil in a magnetic field causing it to electrical power requires relative motion between a magnetic field and a conductor. In a generator, mechanical energy is converted into electrical energy while the opposite occurs in an electric motor. The electric motor is a simple device in principle. It converts electric energy into mechanical energy. In this chapter we will discuss these basic motor principles.



Electric motor is the heart of domestic applications such as vacuum cleaners, washing machines, electric trains, lifts, and cars etc.,

Michael Faraday

In 1831, English scientist Michael Faraday discovered that when the magnetic flux linking a conductor changes, an emf is induced in the conductor. This phenomenon is known as electromagnetic induction. In this chapter, we will study the various aspects of electromagnetic induction.

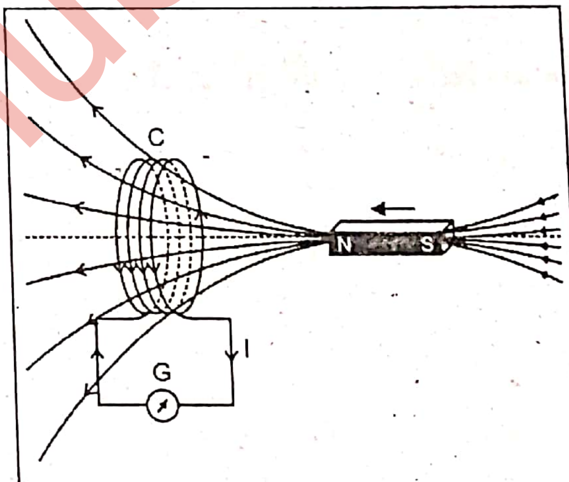
Q.1 What is electromagnetic induction? Give its applications. What is Induced emf and Induced Current?

Electromagnetic Induction:

The phenomenon in which the change in magnetic flux causes an induced e.m.f in a conductor is called electromagnetic induction.

The basic requirement for electromagnetic induction is the change in magnetic flux linking the conductor (or coil).

In this experiment we use a bar magnet and a coil connected with a sensitive galvanometer is connected as shown in figure.



When the bar magnet is pushed towards the coil, the pointer in the galvanometer G deflects.

Case- I

When there is no relative motion between magnet and coil then galvanometer shows no current.

Case- II

When the bar magnet is moved towards the coil, the magnetic flux changes and a current is induced in the coil

Case- III

When the bar magnet is moved away from the coil, the magnetic flux changes and a current is induced in the coil in opposite direction.

FLUX LANKAGE

The product of number of turns (N) of the coil and the magnetic flux (Φ) linking the coil is called flux linkage i.e.

$$\text{Flux linkages} = N\,\Phi$$

The phenomenon of electromagnetic induction may be demonstrate in another way as when the current carrying primary coil is moved away or towards the stationary coil. The current in the primary coil set up a magnetic field that links the stationary coil. Again it is the relative motion of the primary coil which causes induced emf in the coil, and the voltmeter shows deflection.

The e.m.f and current will persist in the coil as long as flux through the coil is changing.

Q.2 State and explain Faraday's law of electromagnetic induction. Give its application.

Faraday's Laws of Electromagnetic Induction:

It states that 'the magnitude of induced e.m.f. is directly proportional to the rate of change of magnetic flux linking the coil.

If N is the number of turns of the coil and the induced e.m.f., ε ∝ rate of change of flux linkages.

$$\text{Induced e.m.f} \propto \frac{\text{Total change in magnetic flux}}{\text{Total time}}$$

$$\text{Induced e.m.f, } \varepsilon \propto N\frac{\Delta\phi}{\Delta t}$$

$$\varepsilon = kN\frac{\Delta\phi}{\Delta t}$$

Where k is constant and its value is k = 1.

$$\varepsilon \propto N\frac{\Delta\phi}{\Delta t}$$

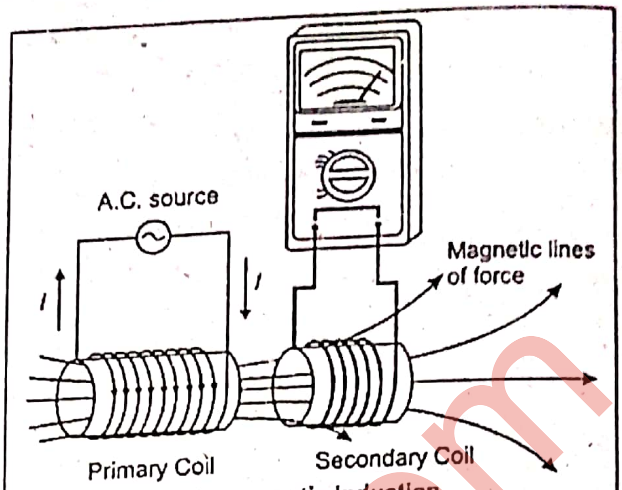
Above equation is called Faraday law of induction.

Faraday proposed two laws of electromagnetic induction.

(1) A changing magnetic field induced an electromagnetic force in a conductor.

(2) The electromagnetic force is proportional to the rate of change of the field.

The induced emf always opposes the change in flux. The direction of induced emf is given by Lenz's law.



Electromagnetic Induction

$$\varepsilon = -N\frac{\Delta\phi}{\Delta t}$$

This is the expression for Faraday's law of electro-magnetic induction.

The negative sign shows that the direction of induced emf is such that it opposes the change in flux.

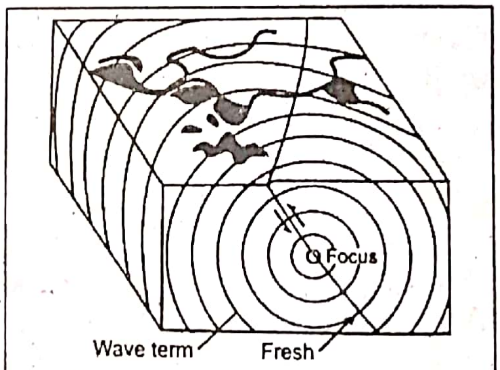
Q.3 Give application of Faradays; Law in Seismometer:

Faradays; Law Application in Seismometer:

A device used for the measurement and detection of earth quick is called seismometer.

- An earthquake is a shaking of the earth's surface, known as the crust.
- The earth's crust is made of huge rock plates, which can shift to cause an earthquake.
- Most earthquakes happen when two rock plates meet, creating friction. The force is so strong it will send shockwaves through the ground, creating an earthquake.

There are large number of earthquakes everyday! Most earthquakes are very small, so no one can feel it. Earthquakes can happen anywhere: land, mountains and oceans.



The focus of an earthquake is the location Where rupture begins and energy is released. The place on the surface vertically above the focus is the epicenter. Seismic wave fronts move out in all directions from their source, the focus of an earth.

Seismometer is used by seismologists in order to detect earthquakes.

- There are two types of seismometer
  1. Inertial type Seismometer
  2. Electromagnetic induction type seismometer

1. Inertial type Seismometer

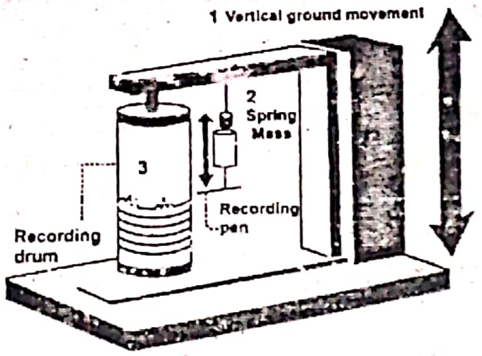
It is based on Newton's 1st Law. It consists of spring mass system which records the vibrations in the earth's surface and will pick up even the slightest vibration.

This is recorded on a sheet of paper under the seismograph needle that writes it. When there are vibrations, the needle sways, causing bigger lines to be drawn. As shown in figure.

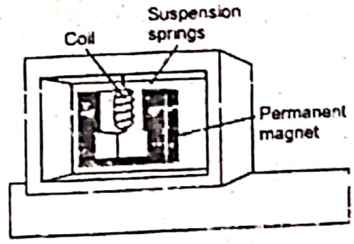
2. Electromagnetic induction type seismometer

This kind of seismometer works on the principle of electromagnetic induction. It transforms received vibration energy into an electrical voltage. During earth quick the relative motion between a magnet and a coil induces an emf in the coil that is proportional to the velocity of the relatives motion. The magnitude of emf is also proportional to the strength of the magnet used and the number of turns in the coil.

- In practice either the magnet or the coil can be attached to the inertial mass (in commercial systems the magnet is itself often used as the inertial mass).



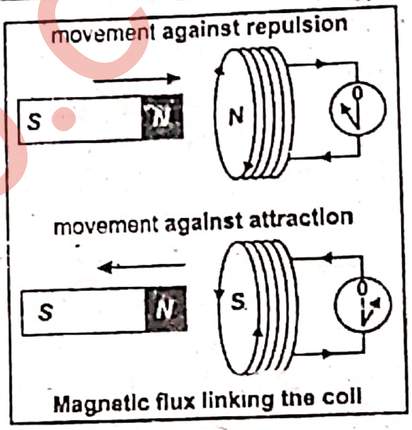
A Vertical-motion seismograph. This Seismograph operates on the same principle as a horizontal-motion instrument and records as a horizontal-motion instrument and records vertical ground movement.



Electromagnetic seismometer has a coil fixed to the case and moves with the earth. The magnet suspended by spring has inertia and does not move instantaneously with the coil (and case), so there is relative motion between magnet and coil.

Q.4 State and Explain the Lenz's Law. Show that Lenz's Law in accordance with law of conversation of energy

Lenz's Law



In 1834 Russian Physicist Heinrich Lenz found that the polarity of induced emf always leads to an induced current that opposes the change which induces the emf.

Statement

The induced current will always flow in such a direction so as to oppose the cause which produce the current.

Condition for its Application

We can apply Lenz's law directly to closed loop because it refers to induced currents and not to induced emf. However if the loop is not closed, we imagine as if it is closed and then from the direction of induced current, we can find the polarity of induced emf.

Explanation

As current carrying coil behaves as a bar magnet due to magnetic effect of current. One face of the coil acts as the north pole while the other one as the south pole. Then by Lenz's Law, if the coil is to oppose the motion of bar magnet then the face of the coil towards the magnet must become a north pole, as shown in figure.

The two north poles repel each other. By right hand rule, the induced current must be in anti-clock wise direction from the side of bar magnet.

According to Lenz's law the 'push' of magnet is the 'change' which produces the induced current which tends to oppose the 'push'. Similarly if we 'pull' the magnet away from the coil, the induced current opposes the 'pull' by creating the south pole towards the bar magnet.

Lenz's Law and Law of Conservation of Energy

When the N-Pole of magnet is approaching the coil , the induced current flows in such a direction that that left side of coil becomes N-Pole as a result the motion of magnet is opposed. The mechanical energy spent in overcoming this opposition is converted in to electrical energy produced in coil. Therefore Lenz'z law is in accordance with law of conservation of energy.

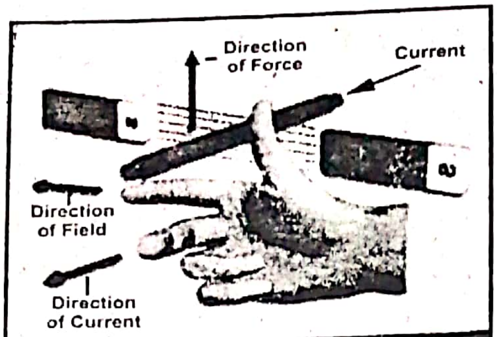
Fleming's Right Hand Rule and Direction:

To find the direction of the induced e.m.f. and hence current, Fleming's right hand rule may also be used. When the conductor moves at right angle to a stationary magnetic field then the direction of induced current is from right to left s shown in figure. If the motion of the conductor is downward, then the direction of induced current will be from left to right.

It may be stated as under:

- **Stretch out of forefinger, middle finger and thumb** of your right hand so that they are at right angles to one another.

If the forefinger points in the direction of magnetic field, thumb in the direction of motion of the conductor, then the middle finger will point in the direction of **induced current.**



Fleming's Right Hand Rule

INDUCED EMF:

The e.m.f produced in a conductor by its changing magnetic flux is called induced e.m.f.

By Faraday's law whenever a conductor is placed in a varying magnetic field, EMF is induced in the conductor and this emf is called induced emf.

But as the varying magnetic field can be brought about in two ways, therefore induced emf is of two types.

Dynamically induced emf:

The e.m.f produced in a conductor by moving it across a stationary magnet is called dynamically induced emf. It is so called because emf is induced in the conductor which is in motion.

For example the emf induced in a dc generator).

Statically induced emf:

The e.m.f produced in a conductor by moving a magnet across a stationary conductor is called static induced emf.

When the conductor is stationary and the magnet is moving or magnetic field is changing. Then the emf induced in this way is called statically induced emf (as in a transformer). It is called because the emf is induced in a confuctor which is stationary.

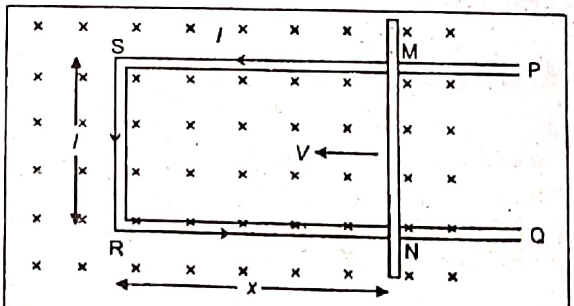
Q.5 Define Motional emf. Derive an expression for it.

Motional emf

The emf induced by the motion of a conductor across the magnetic field is called motional emf.

In order to study the dynamically induced emf in details, consider a conductor NM moving in a magnetic field. Fig shows a conductor of length l in a uniform magnetic field $\vec{B}$ perpendicular to the plane of the figure, directed into the page.

Suppose that the conductor is a part of a closed circuit so that induced current I flows in it. When the conductor is moved towards left with constant velocity $\vec{v}$ then the charge particle q in the conductor experiences a force equal to



The arm MN is moved to the left side, thus decreasing the area of the rectangular loop. This movement induces a current I as shown.

$$F = q(v \times B).$$

Since the conductor is carrying current and is in the uniform magnetic field, it will experience a force of magnitude BIl. By Fleming right hand rule, the direction of this force F.

$$F = BIl.$$

The applied force is doing work against the force BI l.

$\therefore$ Rate of work done = $Fv = (BIl)v$

Rate of work done = $BIlv$ ....(1)

P=F.v
P=VI

The work being done is converted into electrical energy.

Rate of production of electrical energy = ε *l*. ....(2)

The emf produced induced in this case in an example of dynamically induced emf.

According to the principle of conservation of energy, the rate of work done is equal to the rate of production of electrical energy therefore comparing Eq 1 and 2

$$\varepsilon I = BIlv$$

Or

$$\varepsilon = Bvl$$

The above equation is valid as long as B, I and v are mutually perpendicular. If they are not, then their mutually perpendicular components are used.

This is the expression for motional emf. However, if the angle between v and B is θ, then

$$\boxed{\varepsilon = vBl\sin\theta}$$

The above equation shows that no current is induced if the rod is stationary.

MCQ's From Past Board Papers

1. **If we make the magnetic field stronger, the value of Induced current is:**
   (A) Decreased (B) Increased (C) Vanished (D) Kept constant
2. **The induced current in a loop can be increased by:**
   (A) Using strong magnetic field (B) Moving the loop faster
   (C) Replacing loop by a coil (D) All of these
3. **The Lenz's Law fulfils:**
   (A) Law of conservation of energy (B) Law of conservation of charge
   (C) Law of conservation of Momentum (D) Kirchhoff's law
4. **Lenz's law is in accordance with law of conservation of**
   (A) Mass (B) momentum (C) Charge (D) energy
5. **joule/ampere is the unit of:**
   (A) Magnetic Induction (B) magnetic Flux density (C) Magnetic Flux (D) Potential Gradient
6. **The Lenz's law refers to:**
   (A) Induced Current (B) Induced Potential (C) Motional emf (D) All of these
7. **The direction of induced current is always so as to oppose the change which causes the current is:**
   (A) Faraday's law (B) Lenz's law (C) Ohm's law (D) Kirchoff's 1st rule
8. **If velocity of a conductor moving through a magnetic field 'B' is made zero, then motional emf is:**
   (A) -vBL (B) $-\frac{v}{BL}$ (C) $-\frac{BL}{v}$ (D) zero
9. **Lenz's law is in accordance with the Law of Conservation of:**
   (A) Momentum (B) Energy (C) Charge (D) Angular momentum
10. **The self inductance of solenoid is:-**
    (A) $L = \mu_o n Al$ (B) $L = \mu_o N^2 Al$ (C) $L = \mu_o n^2 Al$ (D) $L = \mu_o N Al$
11. **Unit of self Inductance is**
    (A) Weber (B) Tesla (C) Henry (D) Farad
12. **The rod of unit length is moving at 30° through a magnetic field of 1 T. If velocity of rod is 1 m/s, then induced emf in the rod will be given by.**
    (A) 1 V (B) 0.25 V (C) 0.5 V (D) 0.6 V
13. **If the speed of rotation of a generator is doubled the output voltage will be:**
    (A) Remain Same (B) Double (C) Four Time (D) One Half
14. **The motional emf is given by**
    (A) qvB (B) iBL (C) eBL (D) vBL
15. **A changing electric flux creates**
    (A) Electric field (B) gravitational field (C) magnetic field (D) electric charge
16. **Lenz's law deals with:**
    (A) Magnitude of emf (B) Direction of emf
    (C) Direction of induced current (D) Resistance

17. A metal rod of 1m is moving at a speed of $1ms^{-1}$ in a direction making an angle 30° with 0.5T magnetic field. The emf produced is:
(A) 0.25N (B) 2.5N (C) 0.25V (D) 2.5V

18. The motional emf depends upon the
(A) Length of conductor (B) Speed of conductor (C) Strength of magnet (D) All of these

19. Lenz's Law deals with
(A) Direction of EMF (B) Magnitude of EMF (C) Direction of induced current (D) Resistance

20 Electromagnetic induction obeys law of conservation of
(A) Charge (B) Energy (C) Momentum (D) Mass

21 When a conductor move across a magnetic field, an emf is set up, this emf is called
(A) Variable emf (B) Constant emf (C) Back emf (D) Motional emf

Answers Key

1. B	2. D	3. A	4. D	5. A	6. A	7. B	8. D	9. B	10. C	11. C	12. C
13. B	14. D	15. D	16. D	17. C	18. D	19. C	20. B	21. D			

Q.6 What is self-induced emf. Explain the phenomena of self-induction. Define Self- inductance. Give its unit.

SELF-INDUCED EMF:

The e.m.f induced in a coil due to change of its own magnetic flux is called self-induced emf.

(OR)

The emf induced in a coil due to change in current of the same coil is called self-induced emf.

When the conductor is stationary and the magnetic field is changing then the emf induced in the conductor is called statically induced emf. If current in the coil changes, then the magnetic flux linking the coil also changes.

Hence an emf ($\varepsilon = N\,\Delta\Phi/\Delta t$) is induced in the coil.

This is known as self-induced emf.

The direction of this emf (By Lenz's Law) is such so, as to oppose the case producing it, namely the change of current (and hence magnetic field) in the coil.

The self-induced emf will persist so long as the current in the coil is changing. So it is concluded that when current in a coil changes, the self-induced emf opposes the change of current in the coil which is known as **self-inductance or inductance.**

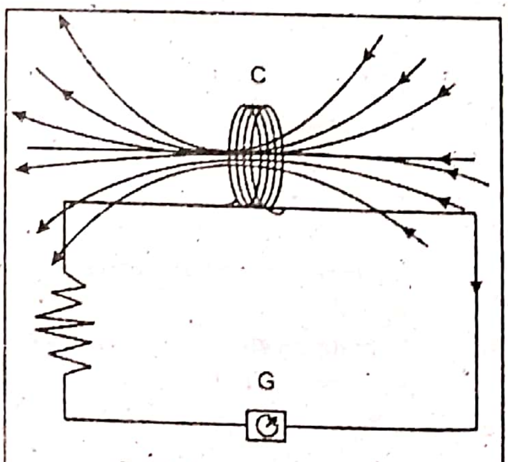
SELF-INDUCTANCE:

Self-induction: The phenomenon in which a changing current in a coil induces an emf in itself is called self-induction. The property of a coil that opposes any change in the amount of current flowing through it is called its self-inductance or inductance.

The inductance of a coil can be demonstrated by changing current in it, For example, if a steady direct current (DC) is flowing in a circuit, there will be no inductance.

When alternating current is flowing in the same circuit, the current is continuously changing and hence the circuit exhibits inductance.

This property (i.e. inductance) is due to the self-induced emf in the coil itself by the changing current.



Self-induced e.m.f in a coil

Self- inductance

Let ϕ be the flux passing through one loop of the coil then the total flux for N number of turns will be $N\phi$. Since the flux ($\phi = B.A$) is proportional to magnetic field and magnetic field ($B = \mu_o n I$) is proportional to current.

So, $N\phi \propto I$

or $N\phi = LI$ ....(1)

Where L is the constant of proportionality known as self-inductance. According to Faraday's law, the induced emf can be expressed as,

$$\varepsilon_L = -N\frac{\Delta\phi}{\Delta t}$$

or $$\varepsilon_L = -\Delta\left(\frac{N\phi}{\Delta t}\right) \quad \text{.........................(2)}$$

putting value of $N\phi$ from equation 1 in 2

or $$\varepsilon_L = \frac{-\Delta(LI)}{\Delta t}$$

But L is constant, so

$$\varepsilon_L = -L\frac{\Delta I}{\Delta t} \quad \text{———— (3)}$$

This equation shows that induced emf is directly proportional to the rate of change of current in the coil. The negative sign shows that self- induced emf must oppose the change that produces it.

From equation (3), we have

$$\boxed{L = \frac{\varepsilon_L}{\Delta I/\Delta t}} \quad \text{———— (4)}$$

Definition

Self- inductance of a coil may be defined as *the ratio of induced emf produced in a coil to rate of change of current in the same coil.*

Unit

SI unit of self-inductance is $V\,s\,A^{-1}$ which is equal to henry (H).

Henry

The self- inductance of a coil is said to be one henry if current changes at the rate of one ampere per second through it produces an induced emf one volt in the same coil.

Self- induced emf as back emf

As $$\varepsilon_L = -L\frac{\Delta I}{\Delta t}$$

The negative sign shows that the self-induced emf opposes the change which produces it. This is why self-induced emf is also called back emf.

This is according to Lenz's law. If the current is increased the self-induced emf tries to decrease the current and similarly when the current is decreased the induced emf tries to increase the current.

$$N\phi = LI$$

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

Factors affecting inductance:

Inductors play a great role in electronic, electrical, electromechanical, wireless circuit etc. To study the properties of inductance let us consider a coil of N turns.

When an emf is induced in a coil due to increasing current then its direction is always opposite to the increasing current i.e. direction of self-induced emf is opposite to the applied voltage. On the other hand when an emf is produced in a coil due to decreasing current then its direction is always opposite to the decreasing current i.e. direction of self-induced emf will be same as that of the applied voltage. Thus by increasing the self- induced emf, increases the self-inductance of the coil and the opposition to the changing current. The design of the inductor also plays an important role in determining the value of inductance of a coil. Hence, the inductance of a coil depends upon the following factors,

i. Shape and number of turns (N).
ii. Relative permeability of the material surrounding the coil.
iii. The rate of change of flux ($\Delta\Phi/\Delta t$) linking the coil.

In fact, any thing that affects magnetic field also affects the inductance of the coil.

- Thus, increasing the number of turn of a coil increasing its inductance.
- Similarly, by substituting an iron core increase its inductance.

Q.7 Explain the phenomena of Mutual Induction and Mutual Inductance and define its unit. Give Factors affecting the Mutual Inductance.

MUTUALLY INDUCED EMF:

The phenomenon in which changing current in one coil induces an emf in another coil, is called mutual induction.

Let us consider two coil A and B placed adjacent to each other as shown in figure. When the current flows in the coil A then magnetic field produced around it. A part of the magnetic flux produced by coil A passes through or links with coil B. If current in coil A is varied, the magnetic flux also varies and hence emf is induced in both the coils. The emf induces in coil B is known as mutually induced emf.

The mutually induced emf in coil B persists so long as the current in coil A is changing.

If current in coil A becomes steady, the mutual flux also becomes steady and mutually induced emf drop to zero.

The magnitude of mutually induced emf is given by Faraday's law i.e.,

$$\varepsilon = N_B \Delta\Phi_m/\Delta t$$

where N_B = number of turns of coil B

and $\Delta\Phi_m/\Delta t$ = rate of change of mutual flux i.e., flux common to both the coil.

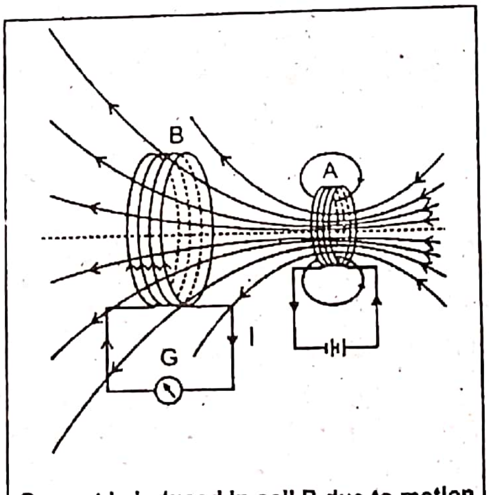
The direction of mutually induced emf (by Lenz's law) is always such so as to oppose the cause producing it. The cause producing the mutually induced emf in coil B is the changing mutual magnetic flux produced by coil A.

Hence The direction of induced current (when the circuit is completed) in coil B will be such that the magnetic flux set up by it will oppose the changing mutual flux produced by coil A.

The emf induced in a coil due to the changing current in the neighboring coil is called mutually induced emf.

MUTUALLY INDUCTANCE:

When the two coils are placed near each other then, changing current in one coil will induce an emf in the other coil. Figure shows two coils A and B placed near each other. If a current I_1 flows in the coil A, a flux is set up and a part of this flux links the coil B. The two coils being magnetically linked. When the current in the coil A, changes, the flux linking the coil B also changes and emf is induced in the coil B. The emf in coil B is termed as mutually induced emf.



Current Is Induced In coil B due to motion of the current carrying coil A.

According to Faraday's laws of electromagnetic induction, induced voltage in a coil depends upon the number of turns (N) and the rate of change of flux ($\Delta\Phi/\Delta t$) linking the coil. The larger the rate of change of current in coil A, the greater is the emf induced in coil B. In other words, mutually induced emf in coil B is directly proportional to the rate of change of current in coil A i.e.

Mutually induced emf in coil B ∝ Rate of change of current in coil A

$$\varepsilon \propto \frac{\Delta I}{\Delta t}$$

$$\varepsilon = M\frac{\Delta I}{\Delta t} \quad (1)$$

Where M is a constant called mutual inductance between the two coils.

$$\boxed{M = \frac{\varepsilon}{\frac{\Delta I}{\Delta t}}}$$

Mutual inductance is defined as ***the ratio of average emf induced in the secondary coil to the time rate of change of current in the primary coil.***

Factors on which Mutual Inductance depends upon

(i) No. of turns of the coils
(ii) Area of cross section of coils
(iii) Closeness of coils
(iv) Nature of core material
(v) Orientation of the coils

Unit

Its SI unit is $V\,s\,A^{-1}$ known as henry (H).

henry

If rate of change of current of one ampere per second in the primary produces the emf of one volt in the secondary, then mutual inductance of pair of coils is said to be one henry.

The unit of mutual inductance is henry (H).

Putting $\varepsilon = 1V$, $\frac{\Delta I}{\Delta t} = 1$ A/s, in equation (1) then M= 1H.

Hence mutual inductance between two coils is 1 Henry if current changing at the rate of 1A/s in one coil induces an emf of 1 V in the other coil.

Also we know that $\varepsilon = \Delta\frac{MI}{\Delta t}$ ....(2)

$\varepsilon = N\frac{\Delta\Phi}{\Delta t}$

$\varepsilon = \Delta\frac{N\Phi}{\Delta t}$ ....(3)

Comparing equation (2) &(3) we have

$MI = N\,\Phi$

or $M = \frac{N\Phi}{I}$

Mutual inductance occurs when the two coils are placed close together in such a way that flux produced by one links the other. We say then that the two coils are coupled. Each coil has its own inductance but in addition, there is further inductance due the induced voltage produced by coupling between the coils. We call this further inductance as mutual inductance. We say that the two coils are coupled together by mutual inductance.

Q.8 What are eddy currents? Explain.

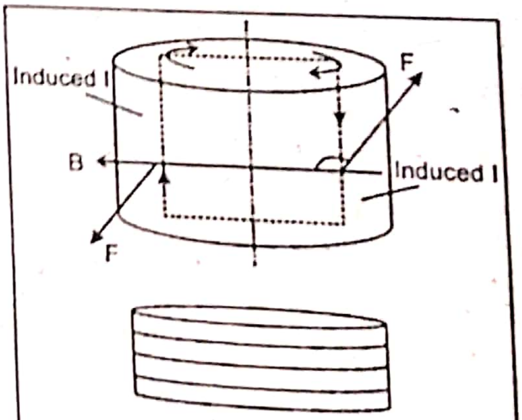
Eddy Currents:

The current induced in the iron core due to changing magnetic flux of iron core is called eddy current.

We have seen that an induced e.m.f is induced whenever a change of magnetic flux occurs. This e.m.f will be induced in any conductor experiencing change of flux, whether it is intended or not. The current that is induced because of this e.m.f is called an eddy current. Eddy currents are currents induced in metals moving in a magnetic field or metals that are exposed to a change magnetic field. Consider a solid metallic cylinder rotating in a magnetic field as shown:

1. A force resisting the rotation would be generated as shown.
2. Heat would be generated by the induced current in cylinder.

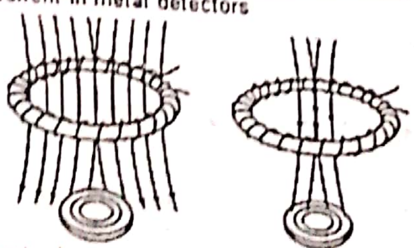
To reduce eddy currents, the solid cylinder could be replaced with a stack of "coins" with insulation between one another. The insulation between the coins increases resistance and reduces eddy current, thus reducing friction or heating.



Eddy current

For Your Information

Applications of eddy current in metal detectors



A van de Graaff generator is an electrostatic generator which uses a moving belt to accumulate very high amounts of electrical potential on a hollow metal globe on the top of the stand. A Van de Graaff generator operates by transferring electric charge from a moving belt to a terminal. First invented in 1929, the Van de Graaff generator became a source of high voltage for accelerating subatomic particle to high speeds, making it a useful tool for fundamental physics research.

MCQ's From Past Board Papers

1. In alternating current, inductors behave like
(A) Semi conductors (B) Inductors (C) Resistors (D) Insulators

2. When the current in a coil changes from 0 to 10 A in 0.025s, an average emf induced in a neighboring coil is 600V, the Mutual inductance for two coils is:
(A) 1.5 Henry (B) 12.5 Henry (C) 6 Henry (D) 10 Henry

3. Milli-henry is the unit of
(A) Mutual Induction (B) Self-inductance (C) Electro-magnetic induction (D) All of them

4. The S.I unit of mutual inductance is
(A) $V.A^{-1}.s^{-1}$ (B) $V\,A\,s^{-1}$ (C) $VA^{-1}s$ (D) $V^{-1}\,A\,s$

5. The mutual induction between two coils depends upon:
(A) Area of the coils (B) Number of the turns (C) Distance between the coils (D) All of these

6. If we make the magnetic field stronger, the value of induced current is:
(A) Decreased (B) Increased (C) Vanished (D) Kept constant

7. The inductance can be increased by winding the wire around a core made of:
(A) Copper (B) Silicon (C) Iron (D) Aluminum

8. One Henry is equal to·
(A) $Vs^{-1}A^{-1}$ (B) $Vs^{-1}A$ (C) $Vs\,A^{-1}$ (D) VsA

9. Alternating current generator converts which type of energy into electrical energy?
(A) mechanical energy (B) chemical energy (C) solar energy (D) potential energy

10. The self -inductance of along solenoid with a turns per unit length is
(A) $L=\frac{\mu_0 nA}{\ell}$ (B) $L=\frac{\mu_0 n^2 A}{\ell}$ (C) $L=\mu_0 n^2 A\ell$ (D) $L=\frac{\mu_0 n^2 \ell}{A}$

11. A coil has an inductance 5.0 H. If current through it changes at the rate of $5As^{-1}$, the emf induced in the coil will be ________.
(A) 2.5 V (B) 25 V (C) 1.0 V (D) $\frac{1}{25}$ V

12. Self inductance does not depend upon:
(A) Number of turns of the coil (B) Area of cross-section of the core
(C) Nature of material of the core (D) Current through inductor

13. henry is SI Unit of:-
(A) Current (B) Resistance (C) Flux (D) Self induction

14. Self induced emf is sometimes called as
(A) Motional emf (B) Constant emf (C) Back emf (D) Variable emf

15. Mutual Induction has a practical role in the performance of the:
(A) Radio Choke (B) Transformer (C) A.C. Generator (D) D.C. Generator

16. The SI unit of magnetic induction is
(A) Weber (B) tesla (C) Newton (D) Weber per meter

17. The mutual inductance between two coils depends upon their
(A) number of turns (B) Core material (C) Separation between coils (D) all

18. The self-induction is given by:
(A) $NL = \phi I$ (B) $NI = L\phi$ (C) $N\phi = LI$ (D) $N = LI$

19. SI unit of mutual inductance is
(A) $\frac{V.sec}{A}$ (B) $\frac{V.A}{sec}$ (C) $\frac{A}{V.sec}$ (D) V

20. The S.I unit of self inductance or mutual inductance is:
(A) Maxwell (B) Weber (C) henry (D) Tesla

21. ________ expressions for mutual inductance is correct.
(A) $M=\frac{N_S\,\phi_S}{I_P}$ (B) $M=\frac{\phi_S}{N_S\,I_P}$ (C) $M=\frac{I_P}{N_S\,\phi_S}$ (D) $M=\frac{N_S}{I_P\,\phi_S}$

22. "henry" may be written as:
(A) Weber (B) VsA^{-1} (C) $Vs^{-1}A^{-1}$ (D) $Vs\,A^{-1}\,T^{-1}$

23. The inductance of a coil can be increased by
(A) air as core material (B) iron as core material (C) copper as core material (D) bismuth as core material

Answers Key

1. C	2. A	3. B	4. C	5. D	6. B	7. C	8. C	9. A	10. C	11. B	12. D
13. D	14. C	15. B	16. B	17. D	18. C	19. A	20. C	21. A	22. B	23. B	

Q.9 Discuss the Principle, Construction and Working of an alternating Current Generator. Also find expression for induced emf and current.

Alternating Current Generator

The device which converts the mechanical energy into alternating current signal is called alternating current generator.

Principle

The **Faraday's law of electromagnetic induction** is the basic principle of working of an A.C generator.

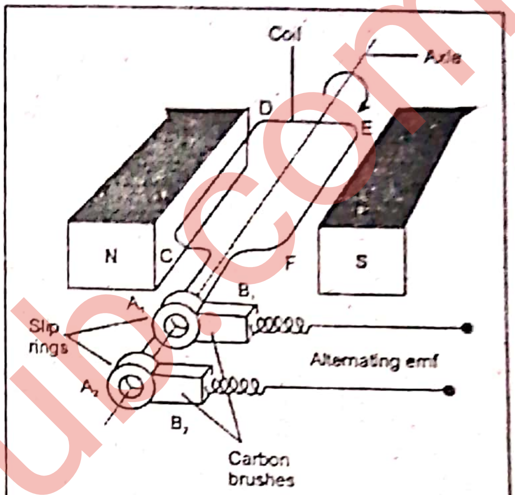
When a coil is rotated in magnetic field through by some mechanical means, magnetic flux through the coil changes. So, an emf is induced in the coil.

Construction

An A.C generator consists of following parts;

- **Armature:** It consists number of coil CDEF wounded on an iron cylinder.
- **Permanent Magnet** to provide magnetic field to armature.
- **Slip Rings:** Two copper slip rings A_1 and A_2 connected to two ends of the coil
- **Carbon Brushes:** Two carbon rods B_1 and B_2 to which an external circuit is connected.
- **Mechanical Source** to rotate coil about fixed axis.

A_1 is connected to the side CD of the coil and A_2 to the side EF as shown in fig. A_1 is always in contact with the brush B_1 and A_2 with the brush B_2.



AC Generator

AC generator

Working:

When the side CD moves upward Fleming's Right-hand rule shows that the direction of the current is form C to D and E to F. Thus the current enters the circuit at B_1 and leaves at B_2.

After half revolution later FE will be in the position previously occupied by CD and the current direction is reversed, i.e. it is from F to E and D to C. The current now enters the circuit at B_2 and leaves at B_1. Thus the direction of the induced electromotive force and the current changes every half revolution.

These vary not only in direction however, they also vary in magnitude. The graph of electromotive force against time is shown in Fig. The time taken for one revolution T is called the period and frequency f, is the number of revolutions per second. Hence

$$f = \frac{1}{T}$$

The domestic electricity supply has a frequency of 50 hertz, which means that the generator m fifty revolutions each second. The graph of current against time has the same shape as that of electromotive force against time, but the magnitude of the current depends upon the resistance of the external circuit. Fig. shows the positions of the coil that correspond to various points on the graph.

The coil has the maximum number of lines of force passing through it when it is in vertical position, and hence the maximum number of flux linkages.

- Therefore the induced electromotive force is a maximum when the coil is horizontal and a minimum when the coil is vertical.

The induced electromotive force, is determined by the rate at which the number of flux linkages changes. Form fig. it is clear that there is very little change in the number of flux linkages when the coil is near the vertical position and consequently no, or very little induced electromotive force. Another way of looking at the problem is to consider the sides CD and EF of the coil which are responsible for the induced electromotive force. When the coil is horizontal sides CD and EF is moving perpendicular to the magnetic field and so the induced electromotive force is a maximum; when the coil is perpendicular to the field side CD and EF are moving parallel to the magnetic field and so the induction electromotive force is zero. The magnitude of induced emf can be determined by finding the rate of change of flux through the coil.

Angular velocity of coil= ω

Magnetic field=B

Number of turns in the coil= N

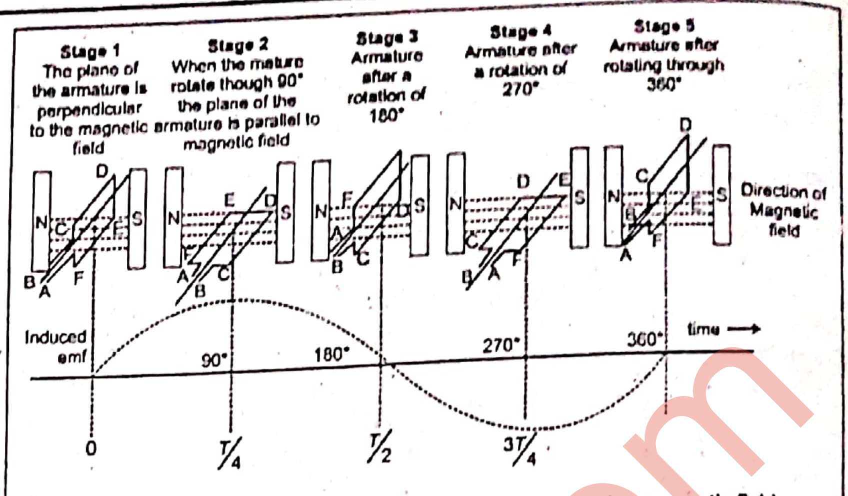
Area of coil= A

Magnetic flux of N turns of coil is

$$\Phi = BAN = NAB\cos\theta$$

Putting $\therefore\ \theta = \omega t$

$$\phi = NAB\ \cos\omega t \ldots\ldots\ldots\ (1)$$



An alternating emf is generated by a loop of wire rotating in a magnetic field.

The induced emf is

$$\varepsilon = -\frac{\Delta\Phi}{\Delta t} \ldots\ldots\ldots\ (2)$$

putting value of Φ from Eq (1)*in* (2)

$$\varepsilon = -\frac{\Delta}{\Delta t}(NAB\cos\omega t)$$

$$\varepsilon = -NAB\lim_{\Delta t\to 0}\frac{\Delta(\cos\omega t)}{\Delta t} \quad \text{As} \quad \lim_{\Delta t\to 0}\frac{\Delta(\cos\omega t)}{\Delta t} = -(\omega\sin\omega t) = NAB(\omega\sin\omega t)$$

For maximum value of induced emf $\sin\omega t = 1$,

so $\varepsilon_{max} = N\omega AB$

Hence induced emf at any instant of time is:

$$\varepsilon = \varepsilon_{max}\sin\omega t$$

$$\varepsilon = \varepsilon_{max}\sin(2\pi ft) \ldots\ldots\ldots (3)$$

S.NO	Time	Angle $\theta=\omega t=2\pi ft$	$\varepsilon = \varepsilon_{max}\sin(2\pi ft)$
1	0	0	0
2	T/4	$\pi/2 = 90^0$	ε_{max}
3	T/2	$\pi = 180^0$	0
4	3T/4	$3\pi/2 = 270^0$	$-\varepsilon_{max}$
5	T	$2\pi = 360^0$	0

Induced current

If R is the resistance of the coil, by ohm's law, the induced current in the wire will be

$$I = \frac{\varepsilon}{R}$$

Putting value of ε, we get

$$I = \frac{\varepsilon_o}{R}\sin\omega t$$

so $$I = I_o\sin\omega t \ \_\_\_\_\_\_\_\_\_\_\ (4)$$

$$\left[\text{where } \frac{\varepsilon_o}{R} = I_o\right]$$

Q.10 What is a A.C. motor? Describe its Principle, Construction and Working.

Ans.

AC Motor:

The device which converts the electrical energy into mechanical energy is called a motor.

Principle

Current- carrying coil is placed in a magnetic field experiences a torque which is given by

$$\tau = NIAB\cos\alpha$$

Construction

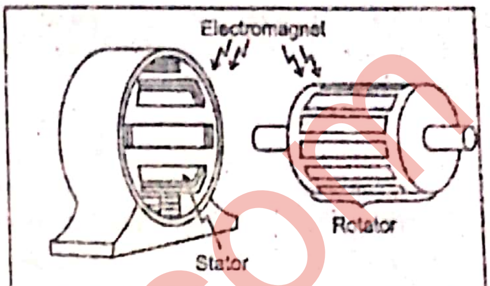
An AC motor has two basic electrical parts:

Stator:

The stator is the stationary part of the motor. The stator consists of a group of individual electromagnetic arranged in such a way that they form a hollow cylinder, with one pole of each magnet facing toward the center of the group. It also consists of a group of electromagnets arranged around a cylinder, with the poles facing toward the stator poles.

Rotor:

The rotor is the rotating part of the motor, obviously, is located inside the stator and is mounted on the motor's shaft. The objective of these motor components is to make the rotor rotate which in turn will rotate the motor shaft. The rotor consists of coils wound on a laminated iron armature mounted on an axle. The rotor coils are not connected to the external power supply, and an induction motor has neither commutator nor brushes.

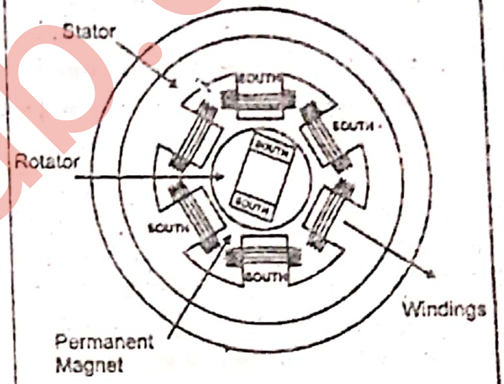


Basic electrical components of an AC motor.

An induction motor is so named because eddy currents are induced in the rotor coils by the rotating magnetic field of the stator.

The eddy currents produce magnetic field which interact with the rotating field of the stator to exert a torque on the rotor in the direction of rotation of the stator field.

- In order to understand the principle on which it works. Let at time t_1 the S-pole of the rotor is attracted by the two N-poles of the stator and the N-pole of the rotor is attracted by the two south poles of the stator.
- At time t_2, when the polarity of the stator poles is changed then it forces the rotor to rotate 60 degrees to line up with the stator poles as shown in figure 14.15.
- At time t_3, the polarity of the stator poles is changed so that the rotor is further rotate 60 degrees to line up with the stator poles. Similarly at time t_4 it further rotates 60 degrees.



The S pole of the rotor is attracted by the two N poles of the stator and the N-pole of the rotor is attracted by the two south poles of the stator.

As each change is made, the poles of the rotor are attracted by the opposite poles on the stator. Thus, as the magnetic field of the stator rotates, the rotor is also forced to rotate with it.

Q.11 What is Back EMF in Motors? Also describe relation between EMF and current.

Back EMF in Motors

A motor is just like a generator running in reverse.

When the coil of the motor rotates across the magnetic field by the applied potential difference, an emf is induced in it. The induced emf is in such a direction to oppose the applied emf. This is the reason that the induced emf is called back emf of the motor.

Relation between back EMF and current

Let

Applied potential difference = V

emf induced in the coil = ε

Resistance of the coil = R

Current drawn by the motor = I

Since V and ε are opposite in polarity, so

Net emf in the circuit = $V - \varepsilon$.

Now, by Ohm's law,

$$I = \frac{V - \varepsilon}{R}$$

Or $$IR = V - \varepsilon$$

Or $$V = \varepsilon + IR$$

Special Cases

- **If the motor is just started,** back emf is almost zero and a large current pass through the coil.
- **If the motor is running at normal speed,** the back emf ($\varepsilon_o = N\omega AB$) becomes maximum and the current become minimum, but it is sufficient to give the torque on the coil to drive the load and overcome the frictional losses.

If the motor is over loaded, it slows down. As a result, the back emf decreases and allows the motor to draw more current. If the motor is over loaded beyond a certain limit.

MCQ's From Past Board Papers

1. **When a motor is over loaded, then the magnitude of back emf:**
(A) Increase (B) decrease (C) remain constant (D) Zero
2. **When the motor is just started back emf is:**
(A) Maximum (B) minimum (C) Almost zero (D) Equal to current
3. **The devices in the circuit that consume electrical energy are known as:**
(A) Dissipaters (B) Generators (C) Load (D) Motors
4. **Commutator was invented by:**
(A) Henry (B) Oersted (C) William Sturgeon (D) Maxwell
5. **With the speed of motor magnitude of back e.m.f.**
(A) Remains same (B) Increases (C) decreases (D) First increases then decreases
6. **The winding of the electromagnet in motor are usually called:**
(A) Magnetic coils (B) Field coils (C) Electric coils (D) Electric-o-electric coils
7. **Commutators was invented in:**
(A) 1736 (B) 1834 (C) 1935 (D) 1885
8. **Component in generator which consumes energy is called.**
(A) Commutator (B) Split rings (C) Capacitor (D) Load
9. **Which one of the following is not present in A.C. generator?**
(A) Armature (B) Magnet (C) Slip rings (D) Commutator
10. **Maximum emf generated in a generator is:**
(A) $\varepsilon_0 = \varepsilon \sin\theta$ (B) $\varepsilon = \varepsilon_0 \sin\theta$ (C) $\varepsilon = N\omega AB \sin\theta$ (D) $\varepsilon_0 = N\omega AB$
11. **A device which converts electrical energy into mechanical energy is called:**
(A) Transformer (B) AC generator (C) DC motor (D) DC generator
12. **Eddy currents produced in the core of transformer are responsible for:**
(A) heat loss (B) step-up process (C) step-down process (D) induction phenomenon
13. **The principle of an alternating current generator is based on:**
(A) Coulomb's law (B) Ampere's law (C) Faraday's law (D) Lenz's law
14. **If we make the magnetic field stronger, the value of induced current is:**
(A) Decreased (B) Increased (C) Vanished (D) Kept constant
15. **A.C. generator based upon the**
(A) Lenz's law (B) Maxwell's relation
(C) Faraday's law of electromagnet induction (D) Mutual induction
16. **When the back emf in a circuit is zero, it draws:**
(A) Zero current (B) Maximum current (C) Minimum current (D) Average current
17. **When motor is just started, back emf is almost:–**
(A) Maximum (B) Zero (C) Minimum (D) Infinite
18. **The winding of the electromagnet in motor are usually called:**
(A) Magnetic coils (B) Field coils (C) Electric coils (D) Electric-o-electric coils
19. **Which one is not present in A.C generator?**
(A) armature (B) magnet (C) slip rings (D) commutator
20. **Commutators are used in**
(A) D.C generators (B) A.C generators (C) A.C motor (D) A.C rotator
21. **With the speed of motor, magnitude of black e.m.f.**
(A) remains same (B) Increases (C) decreases (D) first increases then decreases
22. **Which one is not present in AC generator?**
(A) Carbon brush (B) Coil (C) Magnetic field (D) Split ring
23. **With the increase in speed of motor, the magnitude of back emf:**
(A) Remains same (B) Increases (C) Decreases (D) First increases then decreases

24. When back emf in motor is zero, it draws:-
(A) Zero current (B) Minimum current (C) Maximum current (D) Steady current

25. ________ is not present in A.C. generator.
(A) Armature (B) Magnet (C) Slip-rings (D) Commutator

26. Induced emf in A.C. generator can be increased by:
(A) Decreasing area (B) Decreasing magnetic field (C) Increasing area of coil (D) Slowing down speed of coil

27. The jerks in D.C motor are created by use of
(A) Armature (B) Commutators (C) Slip ring (D) source of emf

28. Induced emf of A.c generator is
(A) vBL sin θ (B) IBL sin θ (C) NωAB sin θ (D) NIAB sin θ

29. If D.C is input for a step up transformer, then its output is
(A) zero (B) high (C) low (D) may be high or low

30. In D.C generator splits ring act as
(A) Capacitor (B) commutator (C) Inductor (D) Resistor

Answers Key

1. B	2. C	3. C	4. C	5. B	6. B	7. B	8. D	9. C	10. B	11. C	12. A
13. C	14. B	15. C	16. C	17. B	18. B	19. D	20. A	21. B	22. D	23. B	24. C
25. D	26. C	27. A	28. C	29. A	30. B						

Q.12 What is Transformer? Describe its Principle Construction and Working in Detail. What is an Ideal Transformer? Explain the Power Losses of a Transformer.

Transformer is an electrical device which changes a given AC voltage into a larger or smaller AC voltage.

Principle: The transformer is based on two principles: first, that an electric current can produce a magnetic field (electromagnetism),

- **Mutual induction**-between two coils wound on same iron core

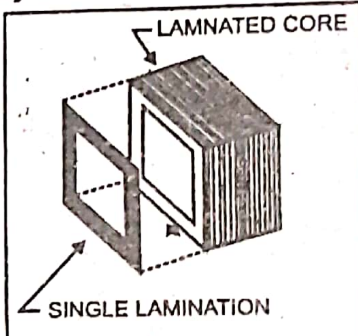
Construction

It consists of two coils of copper wire which are **magnetically** linked to each other (no electrical connection).

Primary coil: The coil to which A. C in put power is supplied is called primary coil

Secondary coil: The coil which delivers power to the output circuit is called secondary coil.

- A laminated iron core connecting the two coils



Laminated iron core

INDUCTION

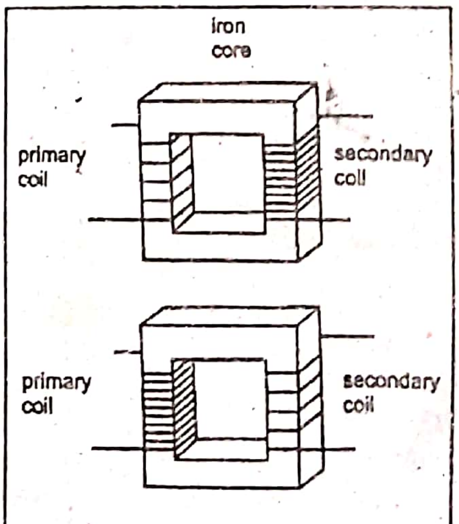
Current passing through the primary coil creates a magnetic field. The primary and secondary coil are wrapped around a core of high magnetic permeability, such as iron, so that most of the magnetic flux passes through both the primary and secondary coils. So the flux through the primary and secondary coil is same. The changing magnetic flux through the primary coil give rise to an induced e.m.f V_s in the secondary coil.

Number of turns of the primary coil= N_p

Number of turns of the secondary coil= N_s

According to Faraday's law of electromagnetic induction the emf induced across the secondary coil is,

$$V_s = N_s \frac{\Delta\phi}{\Delta t} \qquad (1)$$



Step up and step down transformer.

Since same magnetic flux passes through primary and secondary coil in an ideal transformer ,therefore voltage across primary coil is given by

$$V_p = N_p \frac{\Delta\phi}{\Delta t} \qquad (2)$$

Transformation Ratio

Dividing equation (2) by (1)

$$\frac{V_s}{V_p} = \frac{N_s \frac{\Delta\phi}{\Delta t}}{N_p \frac{\Delta\phi}{\Delta t}}$$

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

This equation is called transformation ratio.

Types of Transformer

Step Up Transformer

A transformer in which voltage across the secondary is greater than primary voltage is called a step up transformer.

Condition for step up transformer

Number of turns in the secondary coil is greater than number of turns in primary coil. ie. $N_s > N_p$. In this case $V_s > V_p$

Step Down Transformer

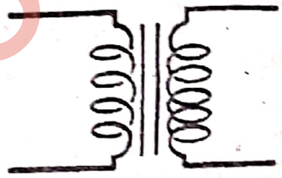
A transformer in which voltage across the secondary is less than primary voltage is called a step down transformer.

Condition for step down transformer

Number of turns in the secondary coil is less than number of turns in primary coil. ie. $N_s < N_p$. In this case $V_s < V_p$

The efficiency of practical transformer is about 90 %

For an ideal transformer,



Transformer symbol

Principle for transmission

Power input = Power output

$$V_s I_s = V_p I_p$$

$$\frac{V_s}{V_P} = \frac{I_p}{I_s}$$

This relation shows that currents are inversely proportional to the respective voltage, therefore in step up transformer

- When V_s increases, current i_s decreases:

This is the principle which is used for the electrical supply network, where transformer increases the voltage and reduces the current, so it can be transmitted over long distance without much power loss.

How to reduce power loss during transmission

When the current I passes through resistance R then the power loses due to heating effect is I^2R. Power loss can be decreased with the decrease in value of resistance. It requires a thick copper wire which is not economical, so it can be achieved by reducing I.

So in power generating stations, the step up transformer are used to step up the voltage up to several thousand volts and by decreasing current I and power is transmitted without much power losses. But a step down transformer is used to decrease the voltage up to safe value at the end of line before use of a consumer. While in house, step down transformer are used to change the 220volts to 9volts for the operation of radio transmitter or ringing bell etc.

Q.13 What are the causes of power Losses in a Transformer?

Ans.

ENERGY Losses in Transformer

i. **Flux leakage**

There is always some flux leakage means that all the flux of primary coil does not link to the secondary coil.

- This loss is due to either poor design of core or air gap in core.
- It can be reduced by winding the primary and secondary coils one over the other.

ii. **Copper wire loss**

The energy is lost due to resistance of wire used for the primary and secondary Coils. Heat produces in wire due to resistance of wire.

- As $R \propto \frac{1}{4}$

This type of loss of energy can be minimized by using thick copper wire

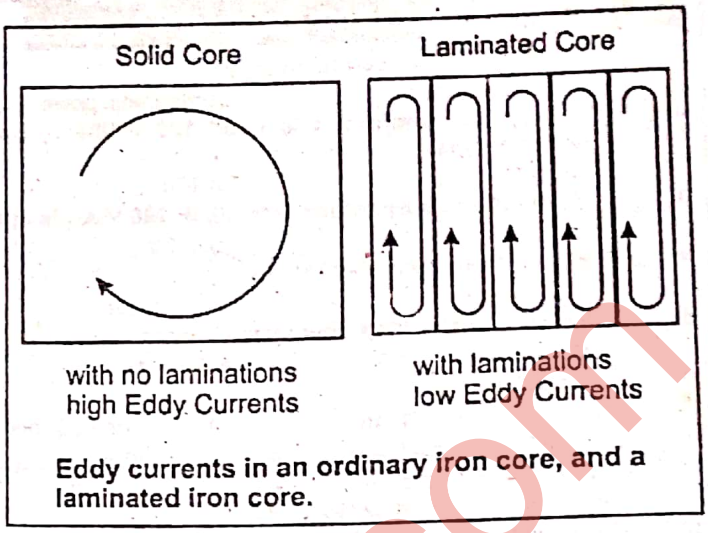
iii. **Eddy Currents loss**

The induced currents are setup due to change in magnetic flux of iron core of transformer. The induced currents are setup in a direction perpendicular to the flux so as to oppose the cause that produces them and are known as eddy currents.

These eddy currents cause the energy loss in the core due to heat produced in it.

Reduction in loss due to eddy currents

Such a loss can be reduced by using laminated core of large number of thin core sheets with insulation between the layers of lamination sheets, which stops the flow of eddy currents.



Eddy currents in an ordinary iron core, and a laminated iron core.

iv. **Hysteresis Loss**

This loss is due to repeated magnetization and demagnetization of core due to flow of alternating current.

Reduction in loss due to hysteresis

This loss can be reduced by use of soft iron core.

Q.19 How can the efficiency of a Transformer be improved?

Efficiency of a Transformer

Due to these power losses the actual transformer is far from being an ideal transformer. However its efficiency can be expressed as,

$$\text{Efficiency.} = \frac{\text{output power}}{\text{input power}} \times 100$$

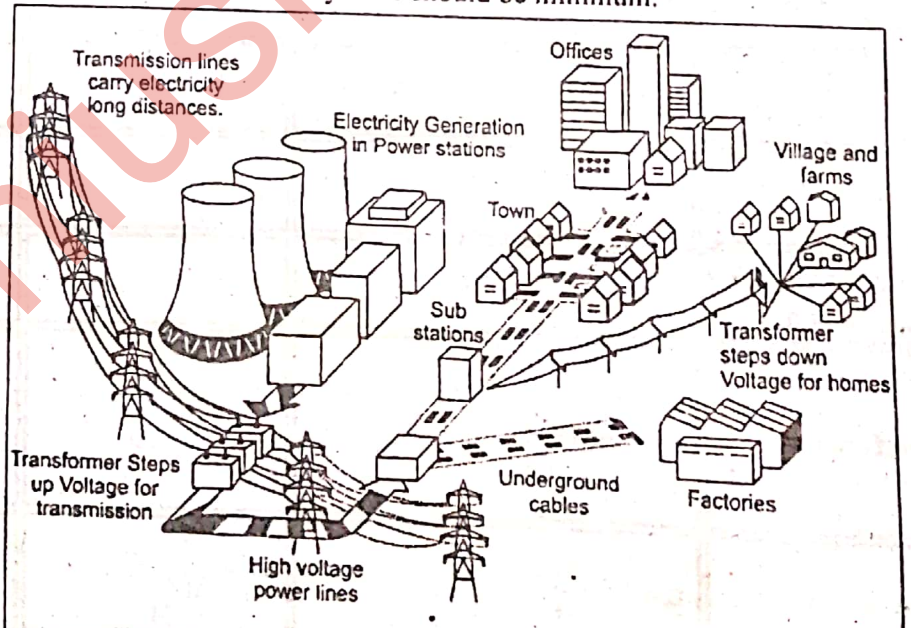
The efficiency of a transformer can be improved by.

i. The core should be made by soft iron, so that the energy loss due to magnetization and demagnetization should be minimum.

ii. The core should be assembled from laminated sheets of material to stop the eddy currents.

iii. The primary and secondary coils should be kept in such a way that flux coupling between them is maximum to reduce the flux losses.

iv. The resistance of the primary and secondary coils should be minimum.



Illustrations of electricity transmission from power station to homes

MCQ's From Past Board Papers

1. Transformer is used to change:
(A) electric power (b) magnetic power (C) alternating voltage (D) phase of A. C
2. A step us transformer is used 120 V line to provide 240 V. If primary coil has 100 turns. The number turns in secondary is
(A) 50 (b) 100 (C) 150 (D) 200
3. Turn ratio of a transformer is 50. IF 220 V AC is applied to its primary coil, voltage in the secondary coil will be:
(A) 440 V (b) 4.4 V (C) 220 V (D) 11000 V
4. Mutual induction play role in:
(A) Generator (b) D.C motor (C) Galvanometer (D) Transformer
5. To construct a step down transformer:
(A) $N_s < N_p$ (b) $N_P < N_s$ (C) $N_s = N_p$ (D) $N_s . N_p = I$
6. A transformer
(A) works on A.C. only (B) works on D.C. only (C) works on both A.C. and D.C (D) none of these
7. "Eddy Currents" are set up in a direction ________.
(A) Parallel to the flux (B) Anti parallel to the flux
(C) At an angle of 45° to the flux (D) Perpendicular to the flux
8. A real transformer does not change:
(A) Voltage level (B) Current level (C) Frequency level (D) Power level
9. Efficiency of transformer is not affected by:
(A) Input voltage (B) Core of transformer (C) Insulation between sheets (D) Resistance of coils
10. Eddy currents is one cause of energy loss in
(A) A.C generator (B) Transformer (C) D.C motor (D) D.C generator
11. A device which converts low voltage or current to high voltage or current is called
(A) Transformer (B) AC-generator (C) Rectifier (D) Amplifier
12. The working principle of transformer is:
(A) Self induction (B) Faraday's law (C) Mutual induction (D) Electromagnetic induction
13. Out put of D.C motor is
(A) A.C energy (B) mechanically energy (C) chemical energy (D) D.C energy
14. On what principle does a transformer work?
(A) electrostatic induction (B) electromagnetism (C) Ohm's law (D) Mutual induction

Answers Key

1. C	2. D	3. D	4. D	5. A	6. A	7. D	8. C	9. A	10. B	11. A	12. C

FORMULAE

1	Motional emf	$\varepsilon = -vBL\sin\theta$		
2	Motional emf (maximum)	$\varepsilon = -vBL$		
3	Faraday's law	$\phi = -N\frac{\Delta\phi}{\Delta t}$		
4	Magnetic flux through a current carrying coil	$N\phi = LI$		
5	Mutual inductance	$\varepsilon_s = -M\frac{\Delta I_p}{\Delta t}$	$M = \frac{\varepsilon_s}{\Delta I_p/\Delta t}$	
6	Self inductance	$\varepsilon = -L\frac{\Delta I}{\Delta t}$	$L = \frac{\varepsilon}{\Delta I/\Delta t}$	

7	Mutual Induction	$N_s\phi_s = MI_p$	$M = \frac{N_s\phi_s}{I_p}$	$\varepsilon_s = -M\frac{\Delta I_p}{\Delta t}$
8	Mutual Inductance	$M = \frac{\varepsilon_s}{\left(\frac{\Delta I_p}{\Delta t}\right)}$		
9	Energy stored in inductors	$U_m = \frac{1}{2}LI^2$		
10	Self inductance of a coil	$L = \mu_o n^2 A\ell$		
11	Energy stored in magnetic field	$U_m = \frac{1}{2}\frac{B^2}{\mu_o}(A\ell)$		
12	Energy density of magnetic field	$u_m = \frac{1}{2}\frac{B^2}{\mu_o}$		
13	emf produced by generator	$\varepsilon = N\omega AB\sin\theta$	$\varepsilon = N\omega AB\sin\omega t$	$\varepsilon = N\omega AB\sin 2\pi ft$
14	Maximum emf produced by generator	$\varepsilon_o = N\omega AB$	$\varepsilon = \varepsilon_o \sin\omega t$	$\varepsilon = \varepsilon_o \sin 2\pi ft$
15	Current induced by generator	$I = \frac{\varepsilon}{R}$	$I = I_o \sin\omega t$	$I = I_o \sin 2\pi ft$
16	Back emf effect in motors	$I = \frac{V-\varepsilon}{R}$	$V = \varepsilon + IR$	
17	Transformation ratio in transformer	$\frac{N_s}{N_p} = \frac{V_s}{V_p}$		
18	Power transmission in transformer	$V_pI_p \approx V_sI_s$	$\frac{V_s}{V_p} = \frac{I_p}{I_s}$	
19	Efficiency of a transformer	$E = \frac{\text{output power}}{\text{input power}} \times 100$		

UNITS

1	Mutual Inductance	VsA^{-1}	henry	WbA^{-1}
2	Self Inductance	VsA^{-1}	henry	WbA^{-1}

Key Points

- When the magnetic flux linking a conductor changes and e.m.f is induced in the conductor this phenomenon is known as electromagnetic induction.
- The basic requirement for electromagnetic induction is the change in flux linking the conductor (or coil).
- The e.m.f and hence the current in this conductor (or coil) will persist so long as this change is taking place.
- If the change of magnetic flux is due to a variation in the current flowing in the same circuit, the phenomenon is known as self-induction; if it is due to a change of current flowing in another circuit it is known as mutual induction.
- When the coil of electric motor rotates in a magnetic field by applying it with a battery of potential difference V and induced emf ε is produced. This induced emf is produced in such a direction so as to oppose the emf V of battery which is known as back emf.
- Lenz's proposed that the induced current will flow in such a direction so as to oppose the cause that produces it. When the conductor is moved in a stationary magnetic field in such a way that the flux linking it changes in magnitude. The e.m.f. induced is called dynamically induced e.m.f.
- When the conductor is stationary and the magnetic field is moving or changing. The e.m.f. induced is called statically induced e.m.f.
- The ability to produce an electromotive force by changing the magnetic field inside a coil is used to generate electricity. *Generator is a device which converts Mechanical energy into electrical energy.*
- A transformer is a device which is used to transform electrical power from one voltage and current level to another.
- The transformer is based on two principles: first, that an electric current can produce a magnetic field, and, second that a changing magnetic field within a coil of wire induces a voltage across the ends of the coil.
- One of the best ways to overcome difficulties of heating in transformers is to reduce the size of the eddy currents.

Solved Examples

Example 14.1:

A coil of 100 turns is linked by a flux of 20 m Wb. If this flux is reversed in a time of 2 ms, calculate the average e.m.f. induced in the coil.

Solution:

Changing in flux, $\Delta\Phi = 20-(-20) = 40\,\text{mWb} = 40\times10^{-3}\,\text{Wb}$

Time taken for the change, $\Delta t = 2\,\text{ms} = 2\times10^{-3}\,\text{s}$

$$\varepsilon = N\frac{\Delta\Phi}{\Delta t} = 100\times\frac{40\times10^{-3}}{2\times10^{-3}}$$

$$= 2000\,\text{V}$$

Example 14.2:

At what rate would it be necessary for a single conductor to cut the flux in order that a current of 1.2 mA flows through it when 10 Ω resistor is connected across its ends?

Solution:

$$\varepsilon = N\frac{\Delta\Phi}{\Delta t}$$

Here $\varepsilon = IR = 1.2\times10^{-13}\times10^{-2}\,\text{V}$;

$$\frac{\Delta\Phi}{\Delta t}=?$$

$$\frac{\Delta\Phi}{\Delta t}=\frac{\varepsilon}{N}=\frac{1.2\times10^{-2}}{1}$$

$$=1.2\times10^{-2}\,Wb/s$$

Example 14.3:

A coil of mean area 500 cm² and having 1000 turns is held perpendicular to a uniform field of 0.4 gauss. The coil is turned through 180° in 1/10 s. Calculate the average induced e.m.f.

Solution:

$$\Phi = NBA\cos\theta$$

When the plane of the coil is perpendicular to the field, $\theta = 0°$. When the coil is turned though 180°, $\theta = 180°$.

Therefore, initial flux linked with the coil is $\Phi_1 = NBA\cos\theta = NBA$

Flux linked with col when turned through $180° = -NBA$

Change in flux linking the coil is

$$\Delta\Phi = \Phi_2 - \Phi_1 = (-NBA)-(NBA) = -2NBA$$

∴ Average induced e.m.f., $\varepsilon = \frac{\Delta\Phi}{\Delta t} = \frac{2NBA}{\Delta t}$

Here $N = 1000$; $B = 0.4$ $B = 0.4\ G = 0.4\times10^{-4}\ T$

$; A = 500\times100^{-4}\,m^2;$

$\Delta t = 0.1s$

$$\varepsilon = \frac{2\times1000\times(0.4\times10^{-4})\times500\times10^{-4}}{0.1}$$

$$=0.04V$$

Example 12.4:

A loop of resistance $0.1\,\Omega$ is placed in a magnetic field of 2T. If a conductor of length 0.2m. is sliding along a loop with a velocity of $0.2ms^{-1}$. Find 9a) the e.m.f. produced in the conductor if the motion of a conductor is perpendicular to the field (b) current though the loop (c) the electrical power generated (d) the input mechanical power.

Solution:

(a) The motional e.m.f ε

$vBL = 0.2\times2\times0.2 = 0.08V$

(b) The current through the loop is $= I = \varepsilon / R$

$$=\frac{0.08V}{0.1\Omega}=0.8A$$

(c) Electrical power generated is $= P = IV =$

$$=0.08\times0.8=0.064W$$

The magnetic force exerted on the current carrying loop of length L is $F = BIL = 2\times0.8\times0.2 = 0.32\,N$

The power necessary to move the loop against magnetic force F is

$$P = Fv = 0.32\times0.2 = 0.064\ W$$

Text Book Exercises

Q.1 Select the correct answer of the following questions.

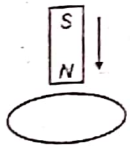
(i) For inducing emf in a coil the basic requirement is that:

(a) Flux should link the coil
(b) Change in flux should link the coil
(c) Coil should form a closed loop
(d) both (b) and (c) are true

(ii) The device in which induced emf is statically induced emf is:

(a) transformer (b) ac generator (c) alternator (d) dynamo

(iii) The north pole of a magnet is brought near a metallic ring as shown in the fig. The direction of induced current in the ring will be:



(a) anticlockwise
(b) clockwise
(c) first anti-clockwise and then clockwise
(d) first clockwise and then anti-clockwise

(iv) What is the coefficient of mutual inductance, when the magnetic flux changes by 2×10^{-2} Wb, and change in current is 0.01 A?

(a) 2H (b) 3H (c) 1/2 H (d)zero

(v) The induced emf in a coil is proportional to:

(a) magnetic flux through the coil
(b) rate of change of magnetic flux through the coil
(c) area of the coil
(d) product of magnetic flux and area of the coil

(vi) In a coil current change from 2 to 4 A in 0.5 s. If the average induced emf is 8V hen coefficient of self-inductance is:

(a) 0.2 henry (b) 0.1 henry (c) 0.8 henry (d) 0.04 henry

(vii) Which of the following quantities remain constant in step up transformer?

(a) current (b) voltage (c) power (d) heat

(viii) Step-up transformer has a transformation ratio of 3:2. What is the voltage in secondary, if voltage in primary is 30 V?

(a) 45 V (b) 15 V (c) 90 V (d) 300 V

(ix) Eddy current is produced when:

(a) A metal is kept in varying magnetic field
(b) a metal kept in steady magnetic field
(c) a circular coil is placed in a steady magnetic field
(d) a current is passed through a circular coil

No.	Option	ANSWER	EXPLANATION
(i)	(b)	Change in flux should link the coil	According to Faraday's law $\varepsilon = \frac{-N\Delta\phi}{\Delta t}$ The cause of emf is only the change in flux whereas for induced current the loop must also be closed which is not required for induced emf
(ii)	(a)	Transformer	Because in transformer, both primary and secondary coils are stationary (static)
(iii)	(a)	Anticlockwise	According to Lenz law in order to oppose the change in flux, the direction of induced current is anti clock. So that the top of the loop will be north pole.

(iv)	(a)	2H	$\Delta N\phi_s = 2\times10^{-2}$ Wb, $\Delta I_P = 0.01A$ As $M = \frac{N_s\phi_s}{I_P}$ Or $M = \Delta\frac{N_s\phi_s}{\Delta I_P}$ $(\because N_s\phi_s \propto I_P)$ $M = \Delta\frac{N_s\phi_s}{\Delta I_P}$ $M = \frac{2\times10^{-2}}{0.01}$ $M = 2$ H
(v)	(b)	rate of change of magnetic flux through the coil	By Faraday's Law $\varepsilon = -N\frac{\Delta\phi}{\Delta t}$ $\varepsilon \propto \frac{\Delta\phi}{\Delta t}$
(vi)	(a)	0.2 henry	$\Delta I = 4-2 = 2A$, $\Delta t = 0.05$ s $\varepsilon = 8V$, $L = ?$ As $\varepsilon = L\frac{\Delta I}{\Delta t}$ $L = \frac{\varepsilon\Delta t}{\Delta I} = \frac{8\times0.05}{2}$ $L = 0.2$ H
(vii)	(c,d)	Power , Heat	For ideal transformer, no power is lost, so no heat loss also. When a transformer may step up or down the voltage or current. For ideal transformer $P_{in} = P_{out}$
(viii)	(a)	45 V	$\frac{N_S}{N_P} = \frac{3}{2}$, $V_S = ?$ $V_P = 30$ As $\frac{N_S}{N_P} = \frac{V_S}{V_P}$ $\frac{3}{2} = \frac{V_S}{30} \Rightarrow V_S = 45V$
(ix)	(a)	A metal is kept in varying magnetic field	As eddy currents are also the induced current. So they will produce due to time varying magnetic field.

Comprehensive Question's

Q.2 Write short answers of the following questions.

1. **Describe electromagnetic induction with simple experiments. Explain the factors effecting magnitude and direction of induced emf.**

Ans: See Theory Question No. 1

2. **State faradays law of electromagnetism. Also explain statically and dynamically induced emf with experiments.**

Ans: See Theory Question No. 2 & 3

3. **Describe Lenz's law. Show that this law is a manifestation of conservation of energy.**

Ans: See Theory Question No. 4

4. Explain the phenomenon of mutual induction. Define the coefficient of mutual induction and units.

Ans: See Theory Question No. 7

5. Explain the phenomenon of self-induction. Define the coefficient of self-induction and units.

Ans: See Theory Question No. 6

6. Explain motional emf. Show that motional induced emf is $\varepsilon = Blv$.

Ans: See Theory Question No. 5

7. What is dc generator? Explain how alternating emf is generated by a loop of wire rotating in a magnetic field.

Ans: See Theory Question No. 9

8. What is AC motor? Explain the construction and working of AC motor.

Ans: See Theory Question No. 10

9. What is transformer? Give its principle, mathematical relationship. Also explain why laminated iron core is used instead of solid one.

Ans: See Theory Question No. 12

10. Explain the back emf in an electric motor.

Ans: See Theory Question No. 11

11. Explain eddy current with suitable example. How eddy current can be minimized.

Ans: See Theory Question No. 8

Conceptual Questions

1. Make list of similarities and differences between the motor effect and electromagnetic induction in a moving wire (the dynamo effect).

Ans: Differences:

Motor Effect	Electromagnetic Induction
• It is used to convert the electrical energy into mechanical energy. • In motor, the input is some electric source • In motor, the torque is used to rotate the load (such as fan's wings) • Its working principle is $\tau = NIAB\cos\alpha$	• It is used to convert the mechanical energy into electrical energy • In electromagnetic induction, the input is provided by some mechanical mean. • In electromagnetic induction, the electrical output is used to operate some load • Its working principle is Faraday's law of electromagnetic induction $\varepsilon = -N\frac{\Delta\phi}{\Delta t}$

Similarities:

- Both of these phenomenon are used for energy conversion from one form to another.
- Both of them require some magnetic field.

2. For a simple motor, why must the back e.m.f. always be smaller than the applied potential difference?

Ans: In motors, the back emf is smaller to maintain the rotation of armature coil

Explanation:

Back emf is always smaller then applied potential difference V. Because back emf depends upon the speed of coil of the motor. When the motor is just started, back emf is almost zero and it increases with the increase in speed of coil. As the back emf opposes the applied voltage. So the current can be expressed as,

$$I = \frac{V - \varepsilon}{R}$$

So the ε can never exceeds the applied emf

3. What factors limit the size of the back e.m.f.?

Ans: The motor works, the emf induces in the coil due to change in flux which is often called back emf.

Explanation:

The induced emf produced in an armature of motor is given by as;

$$\varepsilon = N\omega AB\sin\omega t$$

As for a given motor, the number of turns of the coil, area of the coil and strength of the magnetic field are constants so induced emf is directly proportional to the rotational speed or the motor.

4. Why does back e.m.f. tend to decrease as the rate of doing work increases?

Ans: **Reason:**

In motor, when rate of doing work increases, means we connect the load to the motor, sc the speed of rotation of coil decreases. This results as their decrease in rate of change in magnetic flux. So according to faraday's law of electromagnetic induction (i.e $\varepsilon = -N\frac{\Delta\phi}{\Delta I}$), the induced emf will also decrease. So according to formula,

$$I = \frac{V - \varepsilon}{R}$$

It will draw more current

Where V and ε are the applied and induced voltages and R is the applied load.

5. Explain from $\varepsilon = -\frac{\Delta\Phi}{\Delta t}$ why it possible to say that $\varepsilon = -\frac{\Delta I}{\Delta t}$.

Ans: **Proof:**

According to Faraday's law of electromagnetic in diction

$$\varepsilon = \frac{\Delta\phi}{\Delta t}$$

Also the self induced emf can be expressed as

$$\varepsilon = n^2\mu_o A\ell\frac{\Delta I}{\Delta t}$$

Where $n = \frac{N}{\ell}$ (number of turns per unit length)

$$\varepsilon = \Delta\frac{(n\mu_o I)\, n A\ell}{\Delta t} = \frac{\Delta(BA)\left(\frac{N}{\ell}\right)\ell}{\Delta t} \qquad \because B = n\mu_o I$$

$$\varepsilon = N\frac{\Delta\phi}{\Delta t} \qquad \because \Delta\phi = \Delta(BA)$$

For single loop N = 1

$\varepsilon = \frac{\Delta\phi}{\Delta t}$ (hence proved)

6. Show that the relationship $\varepsilon = -\frac{\Delta\Phi}{\Delta t}$ is dimensionally correct.

Ans: $\varepsilon \rightarrow [\varepsilon] = [\text{volts}] = [JC^{-1}] = [Nm]\,[As]^{-1} = [kgm^2s^{-2}]\,[As]^{-1}$

L.H.S. = $[kgm^2s^{-2}]\,[A^{-1}\,s^{-1}]$

L.H.S. = $[kgm^2s^{-3}A^{-1}]$

L.H.S. = $[ML^2T^{-3}A^{-1}]$

$$\frac{\Delta\phi}{\Delta t} \rightarrow \left(\frac{\Delta\phi}{\Delta t}\right) = \left(\frac{Wb}{s}\right) = \left(\frac{NmA^{-1}}{s}\right) = \frac{(kgm^2s^{-2}A^{-1})}{(s)}$$

R.H.S. = $[kgm^2s^{-3}A^{-1}]$

R.H.S. = $[ML^2T^{-3}A^{-1}]$

Hence proved

7.	**Give the formulae for the flux linkage in terms of angular orientation.**

Ans: The formula for flux linkage will be

$$\phi' = N\phi = NBA\cos\omega t$$

Proof:

As flow through the coil of N turns is

$$\phi' = N\phi$$

Since $\phi = NBA\cos\theta$,

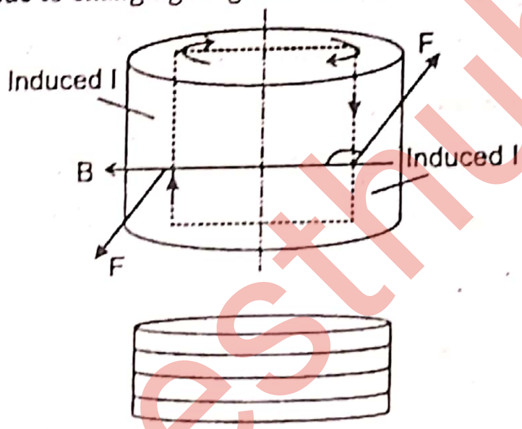
As ω *is the constant angular speed so* $\theta = \omega t$

$$\phi = NBA\cos\omega t$$

Which represents the flow linkage in terms of angular orientation.

8.	**Explain the eddy current in terms of Lenz's law. Also by drawing a suitable diagram show the direction of eddy current and the polarity produced in the sheet as a result of magnetic field.**

Ans: The induced currents in metal due to changing magnetic flow are called **eddy currents.**



According to Lenz's law, the induced current will always oppose the cause (i.e changing flux).

Consider a solid metallic cylinder static in magnetic field. A force opposing the rotation will cause to produce the heating effect. The solid cylinder could be replaced by stack of coins with insulation between them, will avoid the eddy currents.

9.	**How electromagnetic brake work? Explain.**

Ans: Electromagnetic braking means to applying brakes by using electronic and magnetic power.

By using principle of electromagnetism, we achieve the frictionless braking which help us to increase the life span, reliability and decrease the maintenance cost.

For working of electromagnetic brakes, a magnetic flow is passed perpendicularly to the rotating direction of wheel. So the eddy current flows in the opposite to the direction of rotation. This will produce a force to oppose the rotation of wheel. Hence the speed will slow down and may finally be stopped. So this is better braking system for future automobiles.

10.	**A bar magnet is dropped inside a long vertical tube. If it is made of metal, the magnet quickly approaches a terminal speed, but if the tube is made of cardboard, the magnet falls with constant acceleration. Explain why the magnet falls differently in the metal tube than it does in the cardboard tube.**

Ans: **Reason:**

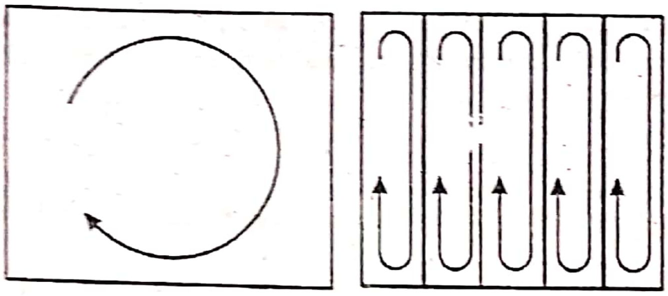
As bar magnet is dropped into hollow metallic tube, then according to principle of electromagnetic induction, induce currents known as eddy currents, will set up and by Lenz law it will oppose the change in flux. As this opposing force will soon be equal to weight of magnet, so it will achieve the terminal velocity, (uniform)

Whereas when magnet falls through tube of cardboard then no emf will include in it. Therefore no eddy current flow through it. Consequently no opposing force is experienced by the magnet and it will continue to fall with constant acceleration.

11. The transformer suffers from eddy current loss (a) Explain how eddy currents arise. (b) State the features of transformer designed to minimize eddy currents.

Ans: Eddy current:

(a) A transformer has an iron core to achieve the maximum possible inductive coupling between the primary and secondary coils. As the changing flux intersects the core, eddy currents are induced in the iron. Heating occurs because of the rather high resistance of the iron to the eddy currents.



(b) **Desiging:** Transformer cores are made of laminated iron, that is, many thin sheets of iron pressed together but separated by thin insulating layers. This limits the circulation of any eddy currents to the thickness of one lamina, rather than the whole core, thus reducing the overall heating effects.

12. Analyze information to explain how induction is used in cook tops in electric ranges?

Ans: It is the result of back emf

Induction cookers we coils placed beneath a glass ceramic cook top to generate heat for cooking.

Alternating current in the coils set up an alternating magnetic field which changes magnetic flux and hence induce eddy current in the metal pots. These eddy current produce extra heat in the metal pots and hence heat the food in it.

13. (a) Explain what is meant by the term back emf in any electric motor operation.

Ans: Explanation:

As the angular frequency of the as armature increases, the rate of change in flux will also increase. So according to Faraday's law, the back emf will increase, which will decrease the net voltage. So the current through armature will also decrease

$$I = \frac{V - \varepsilon}{R}$$

13. (b) Explain why it is an advantage for the armature to rotate in a radial magnetic field rather than a uniform one?

Ans: The radial magnetic field confirms that the plane of the coil rotating within the magnetic field, as in DC motor, is always parallel with in the external magnetic field so the torque produced will be maximum. i.e If N is the number of turns of the coil and A is the area then the torque due to the deflecting couple is given by

$$\tau = NIBA \cos \alpha$$

Since the pole pieces of magnet are made concave to make the field radial, therefore the plane of the coil is always parallel to field, so $\alpha = 0°$

$$\tau = NIBA \cos 0°$$

$$\tau = NIBA\ (1)$$

14. If the armatures rotating freely then explain, in terms of electromagnetic principles (a) why the current in the armatures progressively decreases as the angular velocity of the armature increase (b) why a maximum angular velocity is eventually reached?

Ans: Explanation:

As the angular frequency of the as armature increases, the rate of charge in flow will also increase. So according to Faraday's law, the back emf will increase, which will decrease the net emf. So the current through armature will also decrease.

a) When the armature of motor rotates across the magnetic field by applied potential difference V, then emf ε will also induces due to change in flux. So the net emf is equal to $V-\varepsilon$.

When motor is just started then back emf ε is almost zero and large current passes through the coil. As angular speed of the armature increases the back emf also increases and the current become smaller.

b) When motor is started, the armature is at rest and back emf ε is zero. The maximum current passes through the armature is given by

$$I = \frac{V-\varepsilon}{R}$$

Where R is the resistance of the coil. So the maximum torque acts on the coil

$$\tau = NIBA$$

Due to this maximum torque the angular velocity ω will reach to its maximum value.

15. Transformer cores can be made from a variety of materials. What are the main features that you would require of material to make a good transformer core? Suggest how well each of the following materials would perform; iron, solid soft iron, laminated soft iron, aluminum.

Ans: Transformer may step up or step down the alternating voltage. In transformers, there are two main sources of power loss.

Eddy Currents

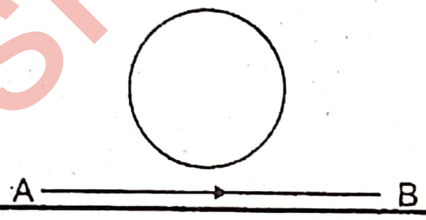
The constantly changing magnetic flux induces eddy current in the core of transformer which causes heating effect. This effect is reduced by having laminated core of soft iron.

Hysteresis loss

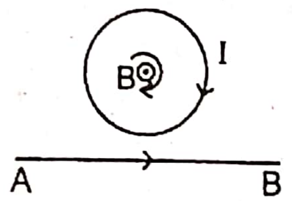
The energy loss during magnetization and demagnetization of core of transformer is called hysteresis loss. This loss of energy during each cycle of A.C can be reduced by using such a material for the core whose hysteresis area is small like soft iron.

In order to minimize above mentioned losses the core must me made by such material which will be suitable to reduce the eddy currents and hysteresis losses.

16. Current is increasing in magnitude from A to B as shown in fig: What is the direction of induced current, if any, in the loop?



Ans: The direction of current in the loop is clock wise



Explanation:

When the current increases in the straight conduction then its magnetic field will also increase. As the magnetic flow through the loop is also changing to by Faradays low emf will also induced in it. Which will also induces the current through it. So the loop's north pole will face us (out of paper). By Lenz's law, as the direction of induced current will be such as to oppose this increasing flux. So due to induced current the north pole is should face into the paper. Hence according to right hand rule the induced current must be clock – wise.

Numerical Problems

1. Two identical coils A and B of 500 turns each has on parallel planes such that 70% of flux produced by one coil links with the other. A current of 6 A flowing in coil A produces a flux of 0.06m Wb in it. If the current in coil A changes from 10A to –10 A in .03s, calculate 9a) the mutual inductance and 9b) the e.m.f. induced in coil B.

Given Data:

Number of turns N = 500

Primary magnetic flux = $\phi_1 = 0.06\text{m Wb} \times 10^{-3}$ Wb

Secondary magnetic flux = $\phi_2 = 70\%\ \phi_1 = \frac{70}{100} \times 0.06 \times 10^{-3}$ Wb $= 0.042 \times 10^{-3}$ Wb

Current in primary coil $I_P = 6A$

Initial current $I_i = 10A$

Final current $I_f = -10A$

Time taken for change $\Delta t = 0.03s$

To find:

(a) Mutual inductance M = ?

(b) emb 'ε' induced in coil B = ?

Solution:

(a)

The mutual induction is $M = \frac{N\phi_{BS}}{I_P}$

Since secondary coil here is ϕ_2, therefore

$$\phi_{BS} = \phi_2$$

or $$M = \frac{N\phi_2}{I_P}$$

Putting values: $$M = \frac{500 \times 0.042 \times 10^{-3}\ \text{Wb}}{6A}$$

∴ $$\boxed{M = 3.5 \times 10^{-3}\ H = 3.5\ mH}$$

(b)

The mutual induced emf is

$$\varepsilon_s = -M \times \frac{\Delta I}{\Delta t}$$

Or $$\varepsilon_s = -3.5 \times 10^{-3} \times \frac{(-10 - 10)}{0.03s}$$

$$\varepsilon_s = -3.5 \times 10^{-3} \times \frac{(-20)}{0.03}$$

$$\boxed{\varepsilon_s = 2333.33 \times 10^{-3}\ V = 2.33\ V}$$

2. A wheel with 12 metal spokes each 0.6 long is rotated with a speed of 180 r.p.m in plane normal to earth's magnetic field at a place. If the magnitude of the field is 0.6 G, what is the magnitude of induced e.m.f. between the axle and rim of the wheel?

Given Data:

Length $L = \frac{2\pi}{12 \times 0.6m} = 0.314m$

Radius $r = 0.6m$

Angular velocity $\omega = 180rpm = 6\pi rad/s$

Magnetic field $B = 0.6G = 0.6 \times 10^{-4}$ T

To find:

Induced emf $\varepsilon = ?$

Solution:

The motional emf is $\varepsilon = BLv \longrightarrow (i)$

The relation between linear and angular velocity is $v = r\omega \longrightarrow (ii)$

Putting equation (ii) in equation (i), we get

$$\varepsilon = BLr\omega$$

Putting values: $\varepsilon = 0.6 \times 10^{-4} T \times 0.314m \times 0.6m \times 6 \times 3.14 rad/s$

$$\boxed{\varepsilon = 2.129 \times 10^{-4} V}$$

3. A circuit has 1000 turns enclosing a magnetic circuit 20cm² in section with 4A current, the flux density is 1 Wbm⁻² and with 9A current, it is 1.4Wbm⁻². Find the mean value of the inductance between these current limits and the induced e.m.f. if the current falls from 9A to 4A in .05s.

Given Data:

Number of turns $N = 1000$

Area $A = 20m^2 = 20 \times (10^{-2})^2 m^2 = 20 \times 10^{-4} m^2$

Initial magnetic flux density $B_i = 1Wbm^{-2}$

Final magnetic flux density $B_f = 1.4Wbm^{-2}$

Initial current $I_i = 4A$

Initial current $I_f = 9A$

Time taken for change $\Delta t = 0.05$ sec

To find:

(a) Self-induction $L = ?$,

(b) Induced emf $\varepsilon = ?$

Solution:

(a) The self-induction can be given by relation

$$L = \frac{N\Delta\phi}{\Delta I} \longrightarrow (i)$$

The magnitude flux is defined as

$$\Delta\phi = \Delta BA = A\Delta B \longrightarrow (ii)$$

Putting equation (ii) in equation (i), we get

$$L = NA\frac{\Delta B}{\Delta I}$$

$$L = NA\frac{B_f - B_i}{I_f - I_i}$$

Putting values: $L = 100 \times 20 \times 10^{-4} m^2 \frac{(1.4 - 1.0)}{9A - 4A} \Rightarrow \boxed{L = 0.16H}$

(b)

The self-induction relation is $L = \frac{\varepsilon\Delta t}{\Delta I}$

or $\varepsilon = L\frac{\Delta I}{\Delta t}$

Hence, $\varepsilon = 0.16\frac{(9-4)}{0.05}$

$\varepsilon = 0.16 \times 100$

Therefore, $\boxed{\varepsilon = 16 V}$

4. A coil of resistance 100 Ω is placed in a magnetic field of 1mWb. The coil has 100 turns and a galvanometer of 400 Ω resistance is connected in series with it find the average emf and the current if the coil is moved in 1/10th s from the given field to a field of 0.2m Wb.

Given Data:

Number of turns N = 100

Initial magnetic flux ϕ_1 = 1m Wb = 1×10^{-3} Wb

Final magnetic flux ϕ_2 = 0.2m Wb = 0.2×10^{-3} Wb

Resistance of coil R_1 = 100 Ω

Resistance of galvanometer R_2 = 400 Ω

Time taken for change $\Delta t = \frac{1}{10s} = 0.1s$

To find:

Average current I = ?

Solution:

By Faraday's law

$$\varepsilon = -N\frac{\Delta\phi_B}{\Delta t}$$

or

$$\varepsilon = -N\frac{\phi_f - \phi_i}{\Delta t}$$

Putting values:

$$\varepsilon = -100 \times \frac{0.2 \times 10^{-3}\ Wb - 1.0 \times 10^{-3}\ Wb}{0.1s}$$

$$\varepsilon = 0.8\ V$$

As galvanometer is connected in series. So $R_{eq} = R_1 + R_2$

So

$$I = \frac{V}{R_{eq}} = \frac{\varepsilon}{R_{eq}}$$

$$I = \frac{0.8\ V}{500\ \Omega} = 0.0016A = 1.6\ mA$$

5: A horizontal straight wire 10 m long extending from east to west is falling with a speed of 5.0 m s^{-1}, at right angles to the horizontal component of the earth's magnetic field, 0.30×10^{-4} Wb m^{-2} (a) what is the instantaneous value of the emf induced in the wire?

(b) What is the direction of the emf?

(c) Which end of the wire is at the higher electrical potential?

Given Data:

Length L = 10m

Magnetic field B = 0.30×10^{-4} Wbm^{-2}

Falling speed v = 5.0 ms^{-1}

To find:

(a) Induced emf ε = ?

(b) Direction = ?

(c) End at higher potential = ?

Solution:

(a) The motional emf is $\varepsilon = B\ell v$

Putting values: $\varepsilon = 0.30 \times 10^{-4}\ Wbm^{-2} \times 10m \times 5.0\ ms^{-1}$

$$\boxed{\varepsilon = 1.5 \times 10^{-3}\ V = 1.5\ mV}$$

(b) If the central figure, fore finger and thumb finger of right hand are stretched mutually perpendicular to each other and the fore finger to magnetic field, the central finger points to the direction of induced current in the conductor which in this case is from west to east.

(c) Since the current is flowing from west to east therefore western end of wire is at higher potential.

6. Current in a circuit falls from 5.0 A to 0 A in 0.1 s. If an average emf of 200 V induced, give an estimate of the self-inductance of the circuit.

Given Data:

Average emf $\varepsilon = 200V$

Initial current $I_i = 5A$

Final current $I_f = 0A$

Time taken for change $\Delta t = 0.1s$

To find:

Self inductance $= L = ?$

Solution:

The self-inductance relation is $L = \dfrac{\varepsilon \Delta t}{\Delta I}$

or $L = \dfrac{\varepsilon \Delta t}{I_f - I_i}$

Putting values: $L = \dfrac{200 \times 0.1s}{5A - 0A}$

$$\Rightarrow L = \frac{200 \times 0.1}{5} \Rightarrow L = 4\ H$$

Therefore $\boxed{L = 4H}$

7. A long solenoid with 15 turns per cm has a small loop of area 2.0 cm² placed inside the solenoid normal to its axis. If the current carried by the solenoid changes steadily from 2.0 A to 4.0 A in 0.1 s, what is the induced emf in the loop while the current is changing?

Given Data:

Number of turns 15 turns / cm = 1500 turn / m

Turns per unit length n = 1500

Area $A = 2.0cm^2 = 2.0 \times (10^{-2})^2\ m^2 = 2.0 \times 10^{-4}\ m^2$

Initial current $I_i = 2A$, Final current $I_f = 4A$

Time taken for change $\Delta t = 0.1s$

To find:

Induced emf $\varepsilon = ?$

Solution:

For solenoid

$$\Delta B = \mu_o n \Delta I$$
$$= (4\pi \times 10^{-5})(1500)(4 - 2)$$
$$= 4 \times 3.14 \times 10^{-7} \times 1500 \times 2$$
$$\Delta B = 3.77 \times 10^{-5}\ T$$

From Faraday's law:

$$\varepsilon = \left(\frac{\Delta\phi}{\Delta t}\right) = \frac{(\Delta B)(A)}{\Delta t}$$

$$\Rightarrow \varepsilon = \frac{(3.77 \times 10^{-3})(2 \times 10^{-4})}{2}$$

$$\Rightarrow \varepsilon = 7.54 \times 10^{-5}\ V$$

8. A rectangular wire loop of sides 8 cm and 2 cm with a small cut is moving out of a region of 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 1 cm s^{-1} 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?

Given Data:

Length of loop L = 8cm = 0.08m
Width of loop W = 2cm = 0.02m
Magnetic field = 0.3T
Velocity of loop v = $1 cms^{-1}$ = $0.01\ ms^{-1}$

To find:

(a) emf induced in longer side ε_L = ?
(b) emf induced in shorter side ε_S = ?
(c) Time taken in both cases Δt = ?

Solution:

(a)

The motional emf is $\varepsilon_L = B\ell v$

Putting values: $\varepsilon_L = 0.3T \times 0.08m \times 0.01\ ms^{-1}$

$$\boxed{\varepsilon_L = 2.4 \times 10^{-4}\ V}$$

(b)

The motional emf is $\varepsilon_S = BWv$

Putting values: $\varepsilon_S = 0.3 \times 0.02 \times 0.01$

$$\varepsilon_S = \boxed{0.6 \times 10^{-4}\ V}$$

(c)

Since the longer side moves along the width therefore the time taken for longer side will be

$$t_L = \frac{W}{v} \quad (\because S = vt)$$

Putting values: $t_L = \frac{0.02}{0.01}$

Hence, $\boxed{t_L = 8s}$

9. A 90-mm length of wire moves with an upward velocity of 35 ms^{-1} between the poles of a magnet. The magnetic field is 80 mT directed to the right. If the resistance in the wire is 5.00 mΩ, what are the magnitude and direction of the induced current?

Given Data:

Length of loop L = 90mm = 0.09 m
Magnetic field = 80mT = 80×10^{-3} T
Velocity of loop v = 35 ms^{-1}
Resistance of wire R = 5.00 m Ω = $5.00 \times 10^{-3}\ \Omega$

To find:

Induced current I = ? (Magnitude and direction)

Solution:

By Ohm's law $I = \frac{V}{R} = \frac{\varepsilon}{R} \longrightarrow$ (i)

The motional emf is $\varepsilon = B\ell v \longrightarrow$ (ii)

Putting equation (ii) in equation (i), we get

$$I = \frac{B\ell v}{R}$$

Putting values:

$$I = \frac{80 \times 10^{-3} \times 0.09 \times 35\ ms^{-1}}{5.00 \times 10^{-3}}$$

$$I = \frac{252 \times 10^{-3}}{5.00 \times 10^{-3}}$$

therefore, $\boxed{I = 50.4\ A}$

The direction for the induced current will be determined by the Fleming's right-hand rule, which in this into the plane of paper.

10. A pair of adjacent coils has a mutual inductance of 1.5 H. If the current in one coil changes from 0 to 20 A in 0.5 s, what is the change of flux linkage with the other coil.

Given Data:

Mutual induction $M = 1.5H$

Initial current $I_i = 0A$,

Final current $I_f = 20A$

Time taken for change $\Delta t = 0.5s$

To find:

Change in magnetic flux $\Delta\phi = ?$

Solution:

By Faraday's law $\varepsilon = \frac{\Delta\phi_B}{\Delta tg} \longrightarrow$ (i)

The emf induced as mutual inductance $\varepsilon = M\frac{\Delta I}{\Delta t} \longrightarrow$ (ii)

Comparing equation (i) and equation (ii), we get

$$\frac{\Delta\phi}{\Delta t} = M\frac{\Delta I}{\Delta t}$$

$$\Delta\phi = M\Delta I$$

$$\Delta\phi = M(I_f - I_i)$$

Putting values: $\Delta\phi = 1.5 \times (20 - 0)$

or $\boxed{\Delta\phi = 30\ Wb}$

11. The back emf in motor in 120V when the motor is turning at 1680 rev/min. What is the back emf when the motor turns at 3360 rev/min ?

Given Data:

Initial back emf $\varepsilon = 120V$

Initial angular velocity $\omega_1 = 1680$ rev/min

Final angular velocity $\omega_f = 3360$ rev / min

To find:

Final back emf $\varepsilon_f = ?$

Solution:

Initial back emf is $\varepsilon_i = NBA\ \omega_i \longrightarrow$ (i)

Final back emf is $\varepsilon_f = NBA\ \omega_f \longrightarrow$ (ii)

Dividing equation (ii) by equation (i), we get

$$\frac{\varepsilon_f}{\varepsilon_i} = \frac{NBA\ \omega_f}{NBA\ \omega_i}$$

or $\frac{\varepsilon_f}{\varepsilon_i} = \frac{\omega_f}{\omega_i}$

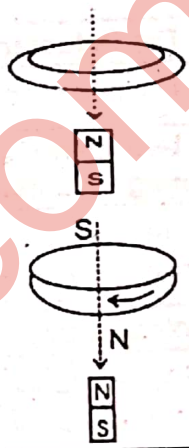
Hence, $\varepsilon_f = \varepsilon_i \frac{\omega_f}{\omega_i}$

Putting values: $\varepsilon_f = 120V \frac{3360 \text{ rev/min}}{1680 \text{ rev/min}}$

$\boxed{\varepsilon_f = 240V}$

Additional Conceptual Short Questions With Answers

1. A light metallic ring is released from above into a vertical bar magnet (Fig. Q.15.3). Viewed from above, does current flow clockwise or anticlockwise in the ring?



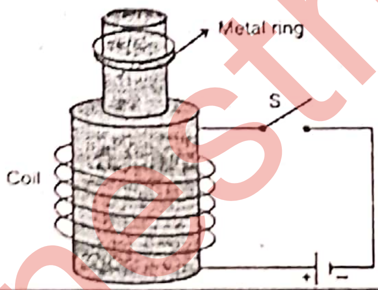
Ans. The induced current flows ***clockwise*** in the ring.(as viewed from above)

Reason:

When the metallic ring the released, the magnetic flux passing through ring changes and an emf is induced in the ring.

According to ***Lenz' law***, the direction of induced current is such that is opposes the downward motion of ring. It is possible only when the face of ring towards magnet act as north pole. Thus, according to right hand rule, the induced current must be clockwise as seen from above.

2. When the switch in the circuit is closed a current is established in the coil and the metal ring jumps upward. Why?



Ans. Reason:

When the switch is closed, the current through coil increases from zero to a maximum steady value. So, the magnetic flux through ring is ***increased*** which produces an emf in the ring (By Faraday's law)

According the Lenz's law, this induced emf acts to ***decrease*** the magnetic flux through ring. That is why ring jumps upward.

3. When the primary of a transformer is connected to a.c mains the current in it.
(a) is very small if the secondary circuit is open, but
(b) increase when the secondary circuit closed. Explain these facts.

Ans. Reason

(a) In a transformer,

power input = power output

OR $V_P I_P = V_S I_S$

If secondary circuit is open then $I_S = 0$

$\Rightarrow V_P I_P \approx 0$

$\therefore \quad V_P \neq 0$ therefore $I_P \approx 0$

Reason:

(b) When the secondary circuit is closed, the output power is increased. Since, in a transformer input power is nearly equal to output power. Therefore input power is also increased.

Now, Power input = $V_P I_P$

$\therefore \quad V_P$ = constant, So to increase the input power I_P should be increased.

4. Wearing a metal bracelet in a region of strong magnetic field can be hazardous. Discuss

Ans. If for any reason magnetic field change rapidly, a large emf produce in it. If bracelet is a continuous band, the induced emf would produce induce current and heat can produce due to flow of current.

5. The inductance coils are made of thick copper wire. Why?

Ans. The thick copper wire has small resistance and hence induced current will be large.

6. Two identical loops, one of copper and another of nickrome are rotated with same speed in a magnetic field. In which case will the induced (a) emf (b) current greater?

Ans. The emf in both the loops will be same but current is different. The current in the loop having small resistance is greater i.e. copper loop.

7. What is physical significance of self inductance?

Ans. The self inductance is called the electrical inertia of the coil or circuit just as mass is a measure of inertia in mechanical motion. If inductance is large, The induced emf is high and greater is the opposition to the change in current. To overcome this inertia the coil should be connected to an external voltage source.

8. What happen to the self inductance of a coil if the number of turns per metre length in it is doubled?

Ans. $L = \frac{\mu_o N^2 A}{\ell} = \left(\mu_o \left(\frac{N}{\ell}\right)^2 A\right)\ell$

$L = \mu_o n^2 A \ell \longrightarrow (1)$

When number of turns per metre length is doubled

$n' = 2n$

$L' = \mu_o n'^2 A \ell 1$

$L' = \mu_o (2n)^2 A \ell 1$

$L' = \mu(\mu_o n^2 A \ell 1)$

Putting value from eq (1)

$L' = 4L$

When number of turns per metre length is doubled then self inductance increases four times.

Self-Assessment Paper 1

Q.No.1 Encircle the correct option.

1. **Energy stored in a magnetic field is given by ________**

   (a) L^2I (b) $\frac{1}{2}L^2I$ (c) $\frac{1}{2}LI^2$ (d) IL^2

2. **The emf induced in a coil by a changing magnetic flux may have unit as ________**

   (a) $ms^{-1}A$ (b) $ms^{-2}A^{-1}$ (c) $kgms^2A^{-1}$ (d) $kgm^2s^{-3}A^{-1}$

3. **Self inductance of a long solenoid is ________**

   (a) $\mu_o n^2 lA$ (b) $\mu_o n^2 A/l$ (c) $\mu_o N^2 lA$ (d) BA

4. **One henry is equal to:**

   (a) V_sA^{-1} (b) NmA^{-1} (c) $V^{-1}{}_s.A$ (d) $Nm^{-1}A^{-1}$

5. **The winding of the electromagnet in motor are usually called:**

   (a) magnetic coils (b) field coils (c) electric coils (d) electromagnetic coils

6. **If we make magnetic field stronger the value of induced current is:**

   (a) decreased (b) increase (c) vanishes (d) remains constant

7. **The mutual inductance between two coils depends upon:**

   (a) area of coils (b) number of turns of the coil
   (c) distance between the coils (d) all of these

8. **joule/ampere is the unit of:**

   (a) magnetic induction (b) magnetic flux density (c) magnetic flux (d) potential gradient

9. **A coil has an inductance of 5.0 H. If current through it changes at the rate of $5As^{-1}$, the emf induced in the coil will be ________**

   (a) 2.5 V (b) 25 V (c) 1.0 V (d) $\frac{1}{25}$ V

10. **When the current in a coil changes from 0 to 10 A in 0.025 s, an average emf induced in a neighboring coil is 600 V, the mutual inductance for two coils is:**

    (a) 1.5 henry (b) 12.5 henry (c) 6 henry (d) 10 henry

Q.No.2 Write Short Answers any SIX of the following questions.

1. Show that $\frac{\Delta\Phi}{\Delta t}$ have the same units as ε
2. Analyze information to explain how inductions used in cook tops in electrical rangs
3. Does the induced emf in a circuit depend on the resistance of the circuit? Does the induced current depend on the resistance of the circuit?
4. How electromagnetic brakes works?
5. When an electric motor such as an electric drill, is being used, does it also act as a generator? If so what is the consequence of this?
6. What are hysteresis and eddy current losses of a transformer?
7. Can an electric motor be used to drive an electric generator with the output from the generator being used to operate the motor?

Q.No.3 Extensive Question.

Q. (a) What is motional emf? Derive its expression, how would the steady current is attained by induced emf?

(b) The current in a coil of 1000 turns placed in the magnetic field of 1 mWb. The coil has 100 turns and galvanometer of 400 ohms is connected in series with it. Find the average emf and the current if the coil is removed in 1/10 th from the given field of z that ?

Self-Assessment Paper 2

Q.No.1 Encircle the correct option.

1. **Eddy currents produced in the core of transformer are responsible for:**
   (a) heat loss (b) step up process (c) step down process (d) induction phenomenon
2. **Eddy currents are set up in a direction ________.**
   (a) parallel to the flux (b) anti parallel to the flux
   (c) at an angle of 45° to the flux (d) perpendicular to the flux
3. **Self induction depends upon**
   (a) number of turns of the coil (b) core material
   (c) area of cross section (d) all of these
4. **Mathematical form of Faraday's law is**
   (a) $\varepsilon = -N\dfrac{\Delta\Phi}{\Delta t}$ (b) $\sum_{i=1}^{i=N}\Sigma(\vec{B}.\vec{\Delta L})_i = \mu_0 I$ (c) $\varepsilon_s = -M\dfrac{\Delta I_p}{\Delta t}$ (d) $B = \mu_o nI$
5. **A metal rod of length 25 cm is moving at a speed of 0.5 ms^{-1} in a direction perpendicular to a 0.25T magnetic field, the e.m.f produced in the rod is**
   (a) 0.031V (b) 0.31 V (c) 3.1 V (d) 31 Volt
6. **The principle of an electric generator is based upon**
   (a) Coulumb's law (b) Ampere's law (c) Faraday's law (d) Lenz's law
7. **Eddy currents produced in the core of transformer are responsible for**
   (a) heat loss (b) step up process (c) step down process (d) induction phenomenon
8. **The self inductance of a long solenoid with n turns per unit length is**
   (a) $L = \dfrac{\mu_o nA}{l}$ (b) $L = \dfrac{\mu_o n^2 A}{l}$ (c) $L = \mu_o n^2 Al$ (d) $L = \dfrac{\mu_o n^2 l}{A}$
9. **The ratio of average induced emf to the rate of change of current in the coil is**
   (a) self inductance (b) mutual inductance (c) self induction (d) mutual induction
10. **An inductor may store energy in**
    (a) its magnetic field (b) its electric field (c) its coils (d) a neighboring circuit

Q.No.2 Write Short Answers any SIX of the following questions.

In a certain region the earth's magnetic field point vertically down. When plane flies due north, which wingtip is positively charged?

How can we reduce the power loses of a transformer?

Is it possible to change both the area of the loop and the magnetic field passing through the loop and still not have an induced emf in the loop?

State Faraday's law and Lenz's law.

Can a step up transformer increases the power level?

What are the different methods for production of induced emf?

A suspended magnet is oscillating freely in a horizontal plane. The oscillations are quickly damped out when a metal plate is placed under the magnet. Explain why this occurs?

Q.No.3 Extensive Questions.

(a) Determine the energy stored in an inductor.

(b) When current through a coil changes from 100mA to 200mA in 0.005 s, an induced emf of 40mV is produced in the coil. Find the increase in energy in the stored coil.