ELECTROMAGNETIC INDUCTION AND ALTERNATING CURRENT

Abstract

This Unit carries 08 marks,and is divided into two chapters *ELECTROMAGNETIC INDUCTION* and *ALTERNATING CURRENTS* both are equally important,marks wise.

INTRDUCTION: Electricity and magnetism are related,we had seen in the last chapter that moving charges(electric Current) produces magnetic field,in this chapter we see the converse i.e how magnetic field can be made to produce electric current.

Magnetic Flux ϕ_B: The magnetic flux linked with a surface held in a magnetic field is defined as the the number of magnetic field lines crossing the surface normally and is measured as the the product of the component of the magnetic field normal to the surface($B\,cos\theta$) and the surface area(A).Magnetic flux through a plane of area A placed in a uniform magnetic field (B) (Fig 1) can expressed as

$$\phi_B = \vec{B}.\vec{A} = BA\,cos\theta \tag{1}$$

where θ is the angle between $\vec{B}$ and $\vec{A}$.

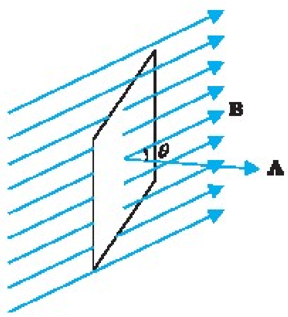

Figure 1: *magnetic flux definition*

If the magnetic field has different magnitudes and directions at various parts of a surface as shown in Fig2., then the magnetic flux through the surface is given by

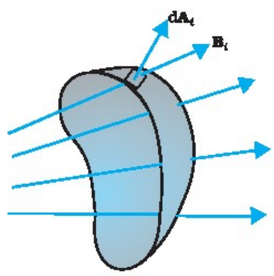

Figure 2: *Flux when $\vec{B}$ varies in magnitude and direction at different parts of the surface*

$$\phi_B = \vec{B}_1.\Delta\vec{A}_1 + \vec{B}_2.\Delta\vec{A}_2 + \vec{B}_3.\Delta\vec{A}_3 ... \vec{B}_i.\Delta\vec{A}_i = \sum_{all} \vec{B}_i.\Delta\vec{A}_i \tag{2}$$

where *all* stands for summation over all the area elements $\Delta\vec{A}_i$ comprising the surface and B_i is the magnetic field at the area element$\Delta\vec{A}_i$.If we consider the area elements to be infinitesimally small then the flux can be written in the integral form as:-

$$\phi_B = \oint \vec{B}.d\vec{A} = \oint B\, dA\, cos\theta \tag{3}$$

UNITS OF FLUX

Flux is a scalar quantity and the SI unit of magnetic flux is **weber (Wb)** or **tesla meter squared** (Tm^2).

FARADAY S EXPERIMENTS:

EXPERIMENT 1:

- When a bar magnet is pushed toward s a coil, the pointer in the galvanometer G deflects as shown in fig 3.

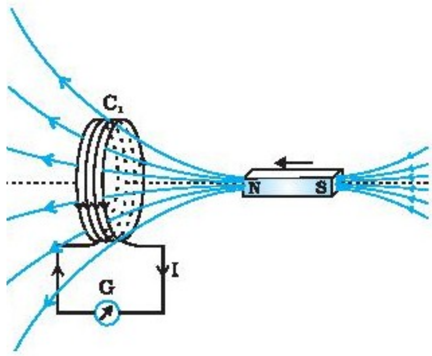

Figure 3: *An emf is induced in the coil when a magnet is pushed toward s the coil*

The following were observed from the experiment:-

1. The pointer in the galvanometer deflects,indicating the presence of electric current in the coil.
2. The deflection lasts as long as the bar magnet is in motion.The galvanometer does not show any deflection when the magnet is held stationary.
3. When the magnet is pulled away from the coil, the galvanometer shows deflection in the opposite direction, which indicates reversal of the currents direction.
4. When the South-pole of the bar magnet is moved toward s or away from the coil, the deflections in the galvanometer are opposite to that observed with the North-pole for similar movements.
5. The deflection (and hence current)is found to be larger when the magnet is pushed toward s or pulled away from the coil faster.
6. **All the above observations were true even if the magnet is held stationary and the coil was moved,this shows that it is the relative motion between the magnet and the coil that is responsible for generation (induction) of electric current in the coil**.

EXPERIMENT 2

- If two coils (with one connected to a battery and the other to a galvanometer) are moved relative to each other then the galvanometer shows deflection as shown in fig 4. *It is the relative motion between the coils that induces the electric current.*
  EXPERIMENT 3

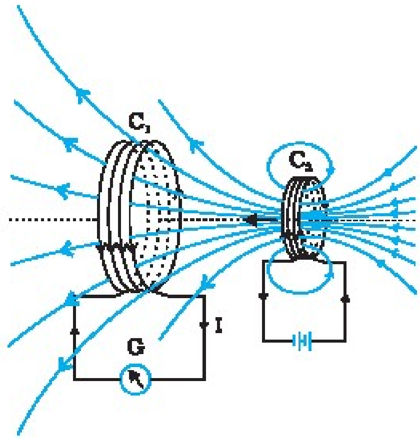

Figure 4: *the coil on the right behaves like a magnet(solenoid)*

- Fig 5 shows two coils C_1 and C_2 both held stationary. Coil C_1 is connected to a galvanometer G while the second coil C_2 is connected to a battery through a tapping key K.
  The following were observed from the experiment

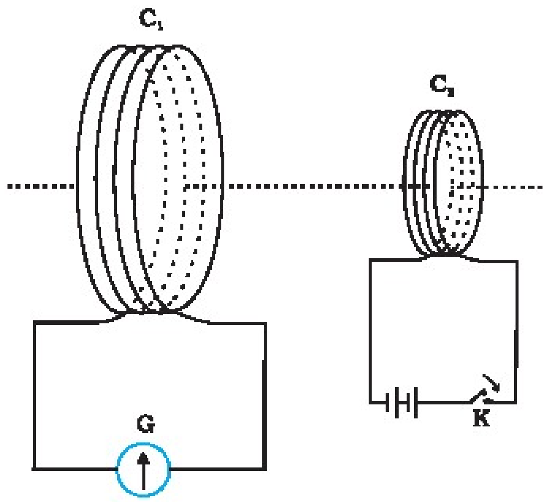

Figure 5: *The process of switching on and off induces current in the coil* C_1

1. The galvanometer shows a momentary deflection when the tapping key K is pressed,the pointer in the galvanometer returns to zero immediately.
2. After the initial deflection even If the key is held pressed continuously, there is no deflection in the galvanometer.
3. When the key is released, a momentary deflection is observed again, but in the opposite direction.
4. It is also observed that the deflection increases dramatically when an iron rod is inserted into the coils along their axis.

THE SERIES OF EXPERIMENTS CARRIED OUT BY FARADAY,CAN BE EXPLAINED USING FARADAY S LAWS.

FARADAYS LAW OF INDUCTION

Faraday s Law of electromagnetic Induction states that:-The magnitude of the induced emf in a circuit is equal to the time rate of change of magnetic flux through the circuit. Mathematically, the induced emf is given by

$$E = -\frac{d\phi_B}{dt} \tag{4}$$

The negative sign indicates the direction of current in a closed loop. (This will be discussed in detail using **conservation of energy** later.)In the case of a closely wound coil of N turns, change of flux associated with each turn, is the same. Therefore, the expression for the total induced emf is given by

$$E = -N\frac{d\phi_B}{dt} \tag{5}$$

EXPLANATION FOR FARADAYS EXPERIMENT USING FARADAYS LAWS

Flux is given by $\phi_B = B\,A\,cos\theta$ ***Changing*** B***,***A***,or*** θ ***can change the flux which will induce an emf.This is the basic concept of Faraday s law*** using this Faraday s experiments can be explained

Explanation for EXPERIMENT 1 and 2

The motion of a magnet toward s or away from coil C_1 in Experiment 1 and moving a current-carrying coil C_2 toward s or away from coil C_1 in Experiment 2, change the magnetic flux associated with coil C_1 this is because B changes with distance B is more when the magnet / coil is closer and less when away. The change in magnetic flux induces emf in coil C_1. It was this induced emf which caused electric current to flow in coil C_1 and through the galvanometer.

Explanation for EXPERIMENT 3

When the tapping key K is pressed, the current in coil C_2 (and the resulting magnetic field) rises from zero to a maximum value in a short time. Consequently, the magnetic flux through the neighboring coil C_1 also increases. It is the change in magnetic flux through coil C_1 that produces an induced emf in coil C1.When the key is held pressed, current in coil C_2 is constant(hence $d\phi_B/dt = 0$). Therefore,there is no change in the magnetic flux through coil C_1 and the induced current in coil C_1 drops to zero. When the key is released, the current in C_2 and the resulting magnetic field decreases from the maximum value to zero in a short time. This results in a decrease in magnetic flux through coil C_1 and hence again induces an electric current in coil C_1.

LENZ S LAW:

The polarity of induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produced it. The negative sign shown Faraday s Law (Equan. (4)) represents this effect.

LENZS LAW AND CONSERVATION OF ENERGY(Explanation for the negative sign in Faraday s law)

Lenz s law is a consequence of the law of conservation of energy(i.e energy can neither be created or destroyed but can only be trans formed from one form to another).For example when the north pole or the south pole of a magnet is pushed or pulled toward s or away from a coil an emf is induced in the coil this induced emf will produce a magnetic field which will oppose the motion of the magnet that is to induce an emf in the coil work has to be done against the force exerted by the magnetic field created by the induced emf(in the coil)against the magnet.Thus mechanical work has to be done to produce electrical energy,i.e electrical energy is not created but transformed from mechanical energy.

Application of LENZ'S LAW

We can understand Lenzs law by examining the following examples

(i)**NORTH POLE OF MAGNET IS MOVED TOWARDS A CONDUCTING LOOP**

In the figure below(fig. 6) the North-pole of a bar magnet is being pushed toward s the closed coil. As the North-pole of the bar magnet moves toward s the coil, the magnetic flux through the coil increases. Hence current is induced in the coil in such a direction that it opposes the increase in flux(Lenz's Law).This induced current produces its own magnetic field with the magnetic field oriented in such a direction as to oppose the motion of the magnet,this can happen only if the face of the loop facing North pole of the magnet behaves like the north pole (so that north pole north pole repel).The current carrying loop which is the equivalent of of a magnetic dipole behaves as the north pole only if the current flows anti-clock wise

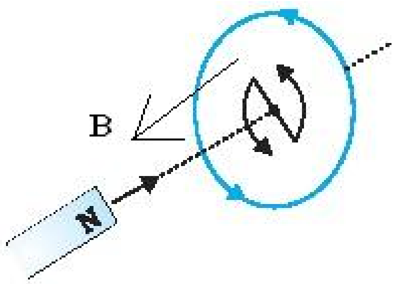

Figure 6: *Direction of current in the current loop using Lenz s law*

(ii)**NORTH POLE OF MAGNET MOVES AWAY FROM A CONDUCTING LOOP**

If the North pole of the magnet is being withdrawn from the coil(fig 6), the magnetic flux through the coil will decrease,hence an emf is induced To counter this decrease in magnetic flux, the induced current in the coil flows in clockwise direction and its South pole faces the receding North-pole of the bar magnet. This would result in an attractive force which opposes the motion of the magnet and the corresponding decrease in flux.

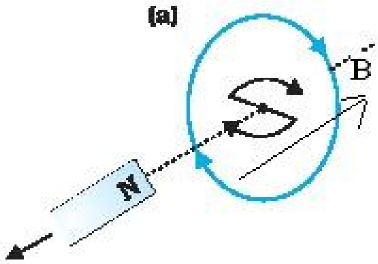

Figure 7: *the loop with current flowing clockwise*

(iii)**INDUCTION IN COILS** Consider two coils kept near each other as shown in figure 8.When the switch (key) in coil C_2 is switched on or off there is a momentary deflection in the galvanometer(after the switch is closed or after the switch is opened there is no deflection-the deflection or the flow of current in the coil exists only during the process of switching on or off.)When the current is switched on in C_2 the current in C_2 grows there by the magnetic field in C_2 grows. The induced current in C_1 will be in such a direction as to reduce the growth of the magnetic field inC_2 i.e to oppose the magnetic field of C_2.The field due to C_1 andC_2 are oppositely directed so as to reduce the growth of the magnetic field during switching.

When the current in the coil C_2 is switched off the current decays and hence the magnetic field also decays,the induced current in C_1 will be in such a way as to oppose the decay.

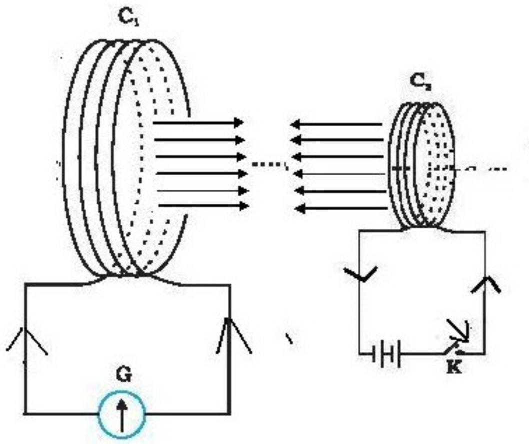

Figure 8: *Direction of induced current when switched on*

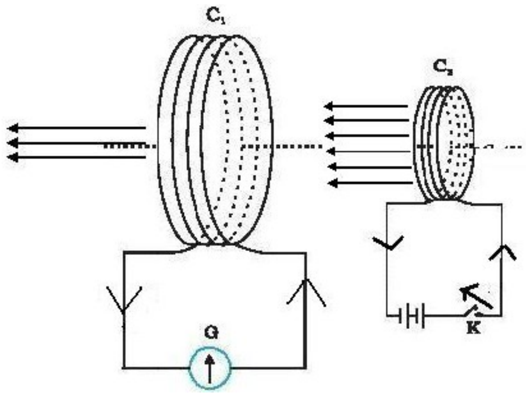

Figure 9: *Direction of induced current when switched off*

MOTIONAL ELECTROMOTIVE FORCE

Consider a straight conductor moving in a uniform magnetic field. shown in Figure 10. A rectan-

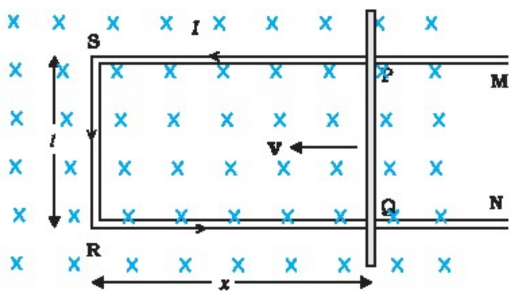

Figure 10: *motional emf*

gular conductor PQRS in which the conductor PQ is free to move. The rod PQ is moved toward s the left with a constant velocity v as shown in the figure. Assume that there is no loss of energy due to friction. PQRS forms a closed circuit enclosing an area that changes as PQ moves. It is placed in a uniform magnetic field B which is perpendicular to the plane of this system. If the length RQ $= x$ and RS $= l$, the magnetic flux B enclosed by the loop PQRS is given by:

$$\phi_B = B\,A\,cos\theta$$

$$\theta = 0$$

$$A = lx$$

$$\therefore \phi_B = BA = Blx$$

Since x is changing with time, the rate of change of flux ϕ_B will induce an emf given by using Faraday s Law:

$$E = -\frac{d\phi_B}{dt} = -\frac{Blx}{dt}$$

$$E = -Bl\frac{dx}{dt} = Blv \tag{6}$$

where $dx/dt = -v$ which is the speed of the conductor PQ. The induced emf Blv is called **motional emf**. *The induced emf is produced by moving a conductor instead of varying the magnetic field,*

MOTIONAL EMF IN TERMS OF LORENTZ FORCE

Consider any arbitrary charge q in the conductor PQ. When the rod moves with speed v, the charge will also be moving with speed v in the magnetic field B. The **Lorentz force** on this charge is qvB in magnitude, and its direction is toward s the point Q. All charges experience the same force, in magnitude and direction, irrespective of their position in the rod PQ.
The work done in moving the charge from P to Q is,

$$W = qvBl$$

Since emf is the work done per unit charge,

$$E = \frac{W}{q}$$

hence

$$E = Blv \tag{7}$$

Direction of MOTIONAL EMF-FLEMINGS RIGHT HAND RULE(optional)

The Flemings **Right** hand rule gives the direction of the induced current in the case of motional

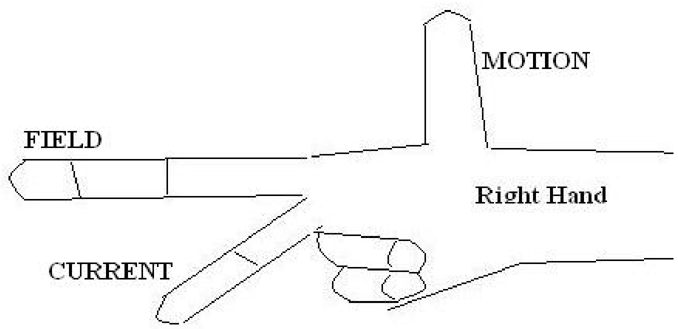

Figure 11: *Direction of motional emf*

emf

If we stretch our first finger, central finger and thumb of our right hand in a mutually perpendicular directions such that the first finger points along the direction of the magnetic field ,the thumb along the direction of motion of the conductor,then the central finger would give the direction of the induced current.

EMF INDUCED WHEN THE MAGNETIC FIELD IS CHANGING-USING LORENTZ FORCE

An emf is induced when a conductor is stationary and the magnetic field is changing (a fact which Faraday verified by numerous experiments.) In the case of a stationary conductor, the force on its charges is given by the Lorentz equation:

$$\vec{F} = q\vec{E} + q(\vec{v} \times \vec{B})$$

since $v = 0$.(the conductor is stationary)$\vec{F} = q\vec{E}$ Thus, any force on the charge arises from the electric field term E alone. In this case *The cause of induced emf or induced current, is that a time-varying magnetic field generates an electric field. A bar magnet in motion (or more generally, a changing magnetic field) can exert a force on the stationary charge. This is the fundamental significance of the Faradays discovery. Electricity and magnetism are related.*

ENERGY IN MOTIONAL EMF

Let r be the resistance of movable arm PQ of the rectangular conductor shown in Fig. 10. We assume that the remaining arms QR, RS and SP have negligible resistances compared to r.The current I in the loop is given by

$$I = \frac{E}{r} = \frac{Blv}{r} \tag{8}$$

Where E is the motional emf.

Due to the presence of the magnetic field there will be a force on the current carrying conductor given by:-

$$F = BIl$$

using equan (8) in the above equation we get

$$F = \frac{B^2 l^2 v}{r} \tag{9}$$

This force arises due to drift velocity of charges (responsible for current) along the rod.

The arm PQ is being pushed with a constant speed v,the power required to do this is,

$$P = Fv$$

Using equan (9)

$$P = \frac{B^2 l^2 v^2}{r}$$

This energy,which is mechanical is dissipated in the form of Joule heat

$$P_j = I^2 r$$

substituting equan. (8) we get

$$P_j = \frac{B^2 l^2 v^2}{r}$$

Which proves that mechanical energy is converted to heat energy(conservation of energy)

EMF INDUCED DUE TO THE ROTATION OF A CONDUCTING ROD IN A MAGNETIC FIELD Consider a metallic rod of length l is rotated with an angular frequency of ω, with one end hinged at the centre and the other end at the circumference of a circular metallic ring of radius l, about an axis passing through the centre and perpendicular to the plane of the ring (Fig. 12). A constant and uniform magnetic field B parallel to the axis is present everywhere,then the emf induce across the can be calculated as follows:-

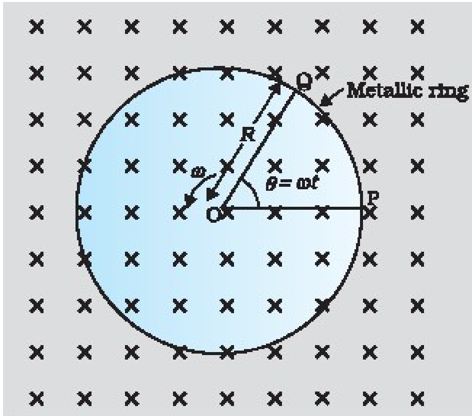

Figure 12: *Rod rotating in magnetic field*

Let P and Q be two points on the circular ring let θ be the angle between the radius and the rod at the point Q.as the rod rotates θ changes with time hence θ is a function of time.As the rod moves there is a change in area swept by the rod,and hence the flux changes and as per Faraday s law there is an induced emf hence the magnitude induced emf E is given by

$$E = \frac{d\phi_B}{dt} = B\frac{dA}{dt} \tag{10}$$

where A is the are of the sector OPQ.
Area of the sector OPQ A is given by

$$A = \pi\, l^2 \frac{\theta(t)}{2\pi} = \frac{1}{2} l^2 \theta(t)$$

Substituting for A in equan. (10) and differentiating we get

$$E = B\frac{d}{dt}(\frac{1}{2}l^2\theta(t)) = \frac{1}{2}Bl^2\frac{d\theta(t)}{dt} \;\; but$$

$$\frac{d\theta(t)}{dt} = \omega$$

$$\therefore E = Bl^2\omega$$

METHOD II (using the concept of motional emf)

Consider a small element of length dr in the rod then the *emf* induced in the element dE is given by(using E=Blv)

$$dE = Bdrv$$

$$v = r\omega$$

Hence

$$dE = B\omega r dr$$

Integrating between the limits 0 to l we get

$$E = \frac{Bl^2\omega}{2}$$

EDDY CURRENTS

Eddy currents are induced currents produced when bulk pieces of conductors are subjected to changing magnetic flux.These eddy currents are in the form of eddies or whirlpools.The direction in which these eddy currents whirl are given by Lenz s law.

Examples of eddy currents When a solid metal plate is swung between the poles of a strong

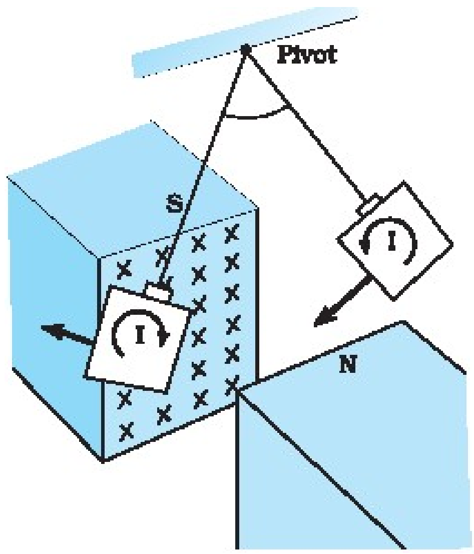

Figure 13: *Eddy currents are generated in the copper plate, while entering and leaving the region of magnetic field.*

magnet eddy currents are induced in the plate.These eddy currents produce the following effects

- the motion is damped and in a little while the plate comes to a halt in the magnetic field.
- Directions of eddy currents are opposite when the plate swings into the region between the poles and when it swings out of the region.

Ways to reduce eddy current damping
Eddy currents can be reduced by cutting slots in the plate as shown below
Reasons:-As magnetic moments($\vec{m} = I\vec{A}$) of the induced currents (which oppose the motion) depend upon the area enclosed by the eddy cutting slots reduces the area hence the plate moves more freely thereby reducing damping.
Ways of Minimising EDDY currents

Eddy currents are undesirable in some cases since they dissipate electrical energy in the form of heat. Eddy currents are minimised by:-

- By punching holes or having slots the effect of eddy currencs can be reduced
- By making the cores of electrical machinery(like the transformer) with thin sheets of laminated metal

Applications of Eddy currents

1. Electromagnetic brakes in trains
2. Speedometers

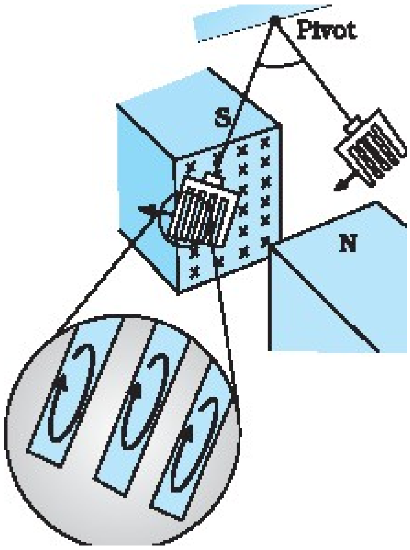

Figure 14: *Cutting slots reduce eddys*

3. Induction Furnace

4. Medical application like diathermy

INDUCTANCE

Self Inductance:-is the property by virtue of which a change in current I in a coil of n turns causes a change magnetic field produced by the coil(remember $B = \mu_o nI$),and hence a change in flux through the coil,this induces an emf in the coil in a direction which opposes the growth or decay of the current I.

Co-efficient of self inductance L

Consider a coil (a Long solenoid) carrying a current I and having N turns,then the flux through the coil is given by

$$\phi_B = NBA$$

as the geometry of the coil is constant we can say that

$$\phi_B \propto B$$

We know that

$$B \propto I$$

$$(\because B = \mu_o nI)$$

this implies that

$$\phi_B \propto I$$

or

$$\phi_B = LI \tag{11}$$

Here L is called the co-efficient of self inductance.L depends on the

1. The no of turns N

2. The geometry(shape, area etc) of the coil

3. The material of the core on which the coil is wound

4. The self inductance of a coil is similar to inertia in mechanics just as mass(inertia) of a body tends to oppose the force which tries to change the state of rest or motion,the self inductance offers opposition to the change in current(time varying) in the coil.In mechanics more the mass more the opposition to change ,more the inductance more opposition to current.

Unit of Coefficient of Self Inductance L
Inductance is a scalar quantity. It has the dimensions of $[ML^2T^{-2}A^{-2}]$(the dimensions are got from the equation $L = \frac{\phi_B}{I}$-check it out).The SI unit of self inductance is Henry (H) other units are

$$L = \frac{\phi_B}{I} \equiv \frac{Tm^2}{A} \equiv Webber\, A^{-1}$$

. **INDUCED EMF IN A COIL**
When the current is varied, the flux linked with the coil also changes and an emf is induced in the coil.From Faraday s law we know that

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

but

$$\phi_B = LI$$

$$\therefore E = -L\frac{dI}{dt} \tag{12}$$

where L is the self inductance of the coil.
COEFFECIENT OF SELF INDUCTANCE(L) OF A LONG SOLENOID(coil)
Consider a coil of length l,area of cross section A and having n turns/unit length ,if a current I is passed through the solenoid ,the magnetic field inside it is given by:-

$$B = \mu_o nI$$

Magnetic flux through each turn of the coil = $B\times$ Area of each turn = $\mu_o nIA$ Total magnetic flux linked with all turns $\phi = \mu_o nIAN$ Where N is the total no of turns

$$N = nl$$

$$\therefore \phi = \mu_o IAn^2l$$

using equan. (11) for ϕ we get

$$LI = \mu_o IAn^2l$$

$$\therefore L = \mu_o An^2l$$

If the core of the solenoid is having a material with permeability μ then

$$L = \mu An^2l = \mu_0\mu_r An^2l\, (\because \mu = \mu_0\mu_r)$$

SELF INDUCED EMF/BACK EMF:When a time varying current(I) flows in a coil it induces an emf in itself,the current due to this emfI_L) has direction which tends to oppose the time varying current(I).This emf is called the ***back emf or self induced emf***.
ENERGY STORED IN AN INDUCTANCE

Self induced emf or the back emf as opposes any change in the current in a circuit.(remember self-inductance L plays the role of inertia.)So, work needs to be done against the back emf (E) in establishing the current. This work done is stored as magnetic potential energy.
Power or rate of doing work is given by

$$\frac{dW}{dt} = |E|I \tag{13}$$

from equan.(12) we know that

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

substituting for E in equan. (13)we get

$$\frac{dW}{dt} = LI\frac{dI}{dt}$$

Total amount of work done in establishing the current I is

$$\int dW = W = \int_0^I LIdI = \frac{1}{2}LI^2 \tag{14}$$

MUTUAL INDUCTANCE

The phenomenon according to which an opposing emf is induced in one coil due to the change in current(and hence the magnetic flux) in the neighboring coil is called mutual Induction.

Co-efficient of MUTUAL INDUCTANCE M

If there are two coils P and Q (near each other) and if current I flows in one say P then the flux ϕ linked to S due to the current in P is directly proportional to I or

$$\phi \propto I$$

$$\phi = MI \tag{15}$$

Where M is the co-efficient of mutual inductance. note:Unit and dimensions of mutual Inductance is the same as self inductance

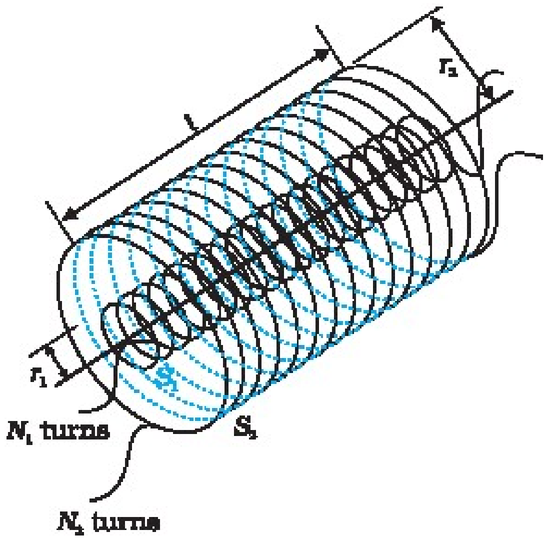

Figure 15: *Two co axial solenoids*

RELATION BETWEEN MUTUAL INDUCTACES OF 2 COILS ($M_{12} = M_{21}$)

Consider two long co-axial solenoids(fig.15)each of length l.The radius of the inner solenoid S_1 is r_1 and the number of turns per unit length is n_1. The corresponding quantities for the outer solenoid S_2 are r_2 and n_2, respectively. Let N_1 and N_2 be the total number of turns of coils S_1 and S_2, respectively. When a current I_2 is set up through S_2, it in turn sets up a magnetic flux ϕ_1 through S_1.The corresponding flux linkage with solenoid S_1 is

$$N_1\phi_1 = M_{12}I_2 \tag{16}$$

M_{12} is the constant of proportionality and is called the mutual inductance of coil S_1 w.r.t S_2.
NOTE:Remember if there is 1 turn flux is ϕ if there are N turns then it is $N\phi$
The induced emf in S_1 due to a time varying current I_2 flow in S_2 is given by using the Faraday s law ($E = -\frac{d\phi}{dt}$)

$$E_1 = -N_1\frac{d\phi_1}{dt} = -M_{12}\frac{dI_2}{dt}(\because \phi_1 = M_{12}I_2/N_1)$$

(refer equan.(16))
Calculation of mutual Inductance
Magnetic field due to current I_2 in S_2=$B_2 = \mu_o n_2 I_2$
Flux through S_1 due to current I_2 in S_2,is given by

$$\phi_1 = N_1B_2 \ \times \ area \ of \ S_1$$

$$\phi_1 = N_1B_2A = N_1\mu_o n_2 I_2 \pi r_1^2$$

AS $N_1 = n_1 l$

$$\phi_1 = n_1 l \mu_o n_2 I_2 \pi r_1^2$$

$$M_{12} = \frac{\phi_1}{I_2} = \mu_o n_1 n_2 \pi r_1^2 l \tag{17}$$

Consider the reverse case. A current I_1 is passed through the solenoid S_1 and the flux linkage with coil S_2 is,

$$N_2\phi_2 = M_{21}I_1 \tag{18}$$

M_{21} is called the mutual inductance of solenoid S_2 with respect to solenoidS_1.

The flux due to the current I_1 in S_1 can be assumed to be confined solely inside S_1 there are no magnetic fields outside S_1 since the solenoids are very long.The flux linked with S_2 due to current in S_1 is given by:-

$$\phi_2 = N_2B_1 \ \times \ Area \ of \ S_1$$

NOTE:the key thing to note is why the area os S_1 is used instead of S_2-check it out!

$$B_1 = \mu_o n_1 I_1$$

$$\therefore \phi_2 = N_2\mu_o n_1 I_1 \pi r_1^2$$

but$N_2 = n_2 l$

$$\therefore \phi_2 = n_2 l \mu_o n_1 I_1 \pi r_1^2$$

$$M_{21} = \frac{\phi_2}{I_1} = \mu_o n_1 n_2 \pi r_1^2 l \tag{19}$$

comparing equan.(17) and equan. (19) we find that

$$M_{12} = M_{21}$$

The following points are key

- Mutual inductance is between two(or more) coils
- Mutual inductance depends on the geometry of the coils
- Mutual Inductance depends on the magnetic properties of the material used as the core of the coil.

- $M_{12} = M_{21}$

AC GENERATOR
PRINCIPLE: An AC generator converts mechanical energy into electrical energy.The AC generator works on the principle ***Faraday s law***.The change in flux is produced by changing the effective area($Acos\theta$)of a coil exposed to the magnetic field by rotating the coil in a magnetic field,thus changing θ,hence the flux($\phi_B = A\,B\,cos\theta$).
CONSTRUCTION: An AC generator in shown in Fig.16. It consists of a coil mounted on a

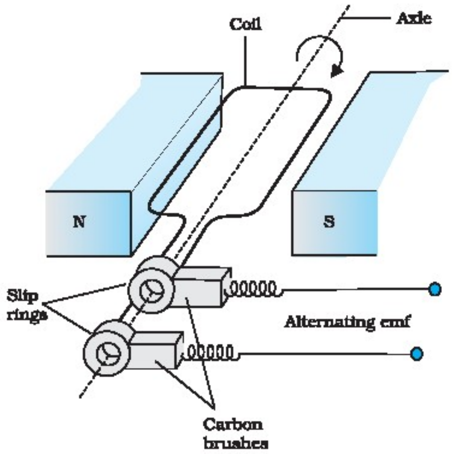

Figure 16: AC generator construction

rotor shaft. The axis of rotation of the coil is perpendicular to the direction of the magnetic field. The coil (called armature) is mechanically rotated in the uniform magnetic field by some external means(Say a Diesel engine). The rotation of the coil causes the magnetic flux through it to change, so an emf is induced in the coil. The ends of the coil are connected to an external circuit by means of ***slip rings*** and brushes to the load.
WORKING: When the coil is rotated with a constant angular speed ω, the angle θ between the magnetic field vector B and the area vector A of the coil at any instant t is $\theta = \omega t$(from defn. of angular velocity $\omega = \frac{\theta}{t}$) . As a result, the effective area of the coil exposed to the magnetic field lines changes with time, and from Eq.(1) , the flux at any time t is

$$\phi_B = BAcos\theta$$

if there are N turns in the coil then the flux is

$$\phi_B = NBAcos\theta$$

From Faradays law, the induced emf for the rotating coil of N turns is

$$E = -N\frac{d\phi_B}{dt} = -NBA\frac{d\,cos\theta}{dt}$$

differentiating and putting $\theta = \omega t$ we get the instantaneous emf E

$$E = -NBA\frac{dcos\omega t}{dt} = NBA\omega\,sin\omega t \qquad (20)$$

This($E = NBA\omega\,sin\omega t$), the ***instantaneous emf*** at the instant t(i.e the emf changes with time hence the E is the emf at the instant t).The ***maximum value of the emf*** E_o,also called the ***peak emf*** which occurs when $sin\,\omega t = \pm 1$.is given by

$$E_o = NBA\omega \qquad (21)$$

Note:$\omega = 2\pi f$,where f is the frequency of rotation of the coil.hence eqans.(21) and (20) become $E_o = NBA2\pi f$ and $E = NBA2\pi f\ sin2\pi ft$

Definition of Alternating current and its production

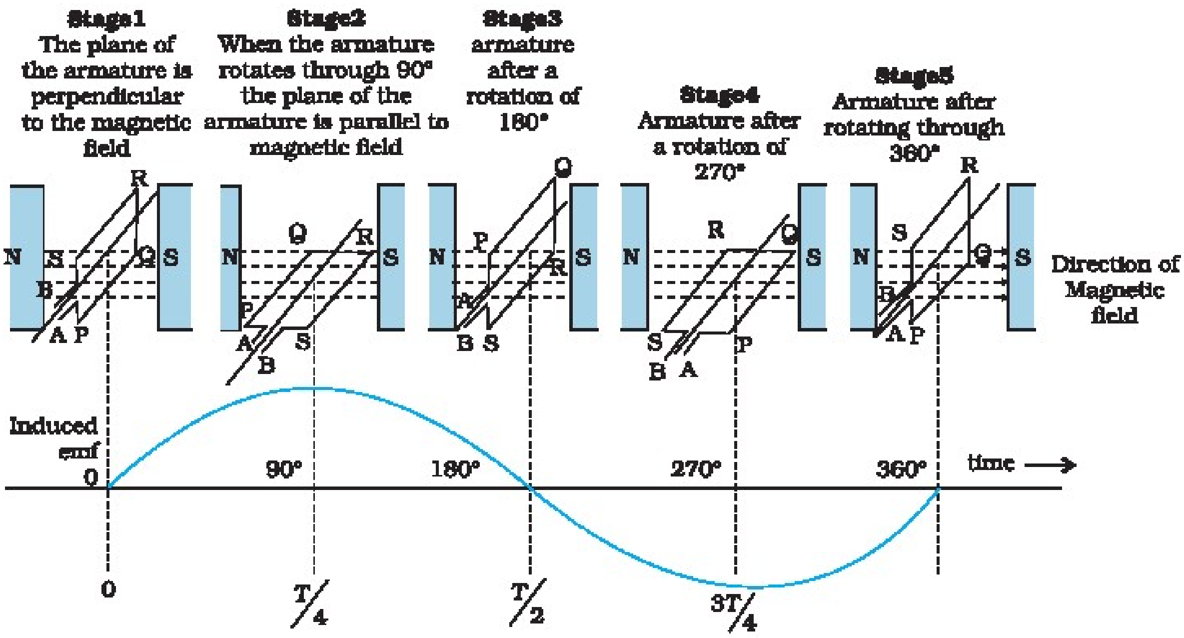

Figure 17: *Variation of emf sinusoidally*

Since the value of the sine function varies between +1 and-1, the sign, or polarity of the emf changes with time(and the instantaneous emf changes from $+E$ to$-E$). Note from Fig.17 that the emf has its maximum value when $\theta = 90^o$(positive maximum) or $\theta = 270^o$, as the change of flux is greatest at these points. **The direction of the current changes periodically and its magnitude varies sinusoidally therefore the current is called alternating current**.

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