Chapter–6

Electromagnetic Induction

CBSE CLASS XII NOTES

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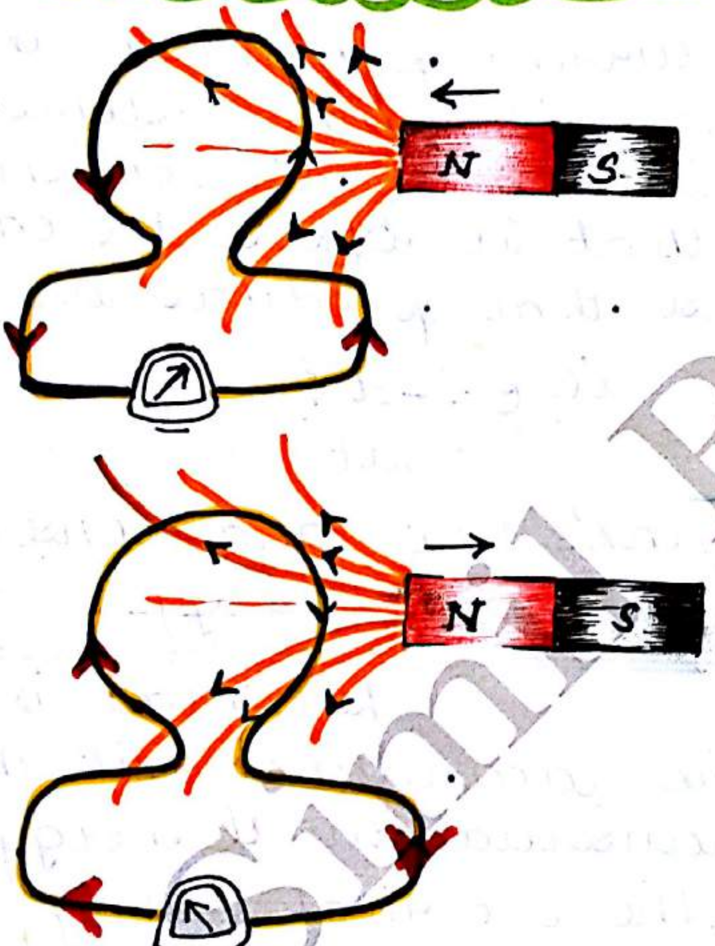
Electromagnetic Induction

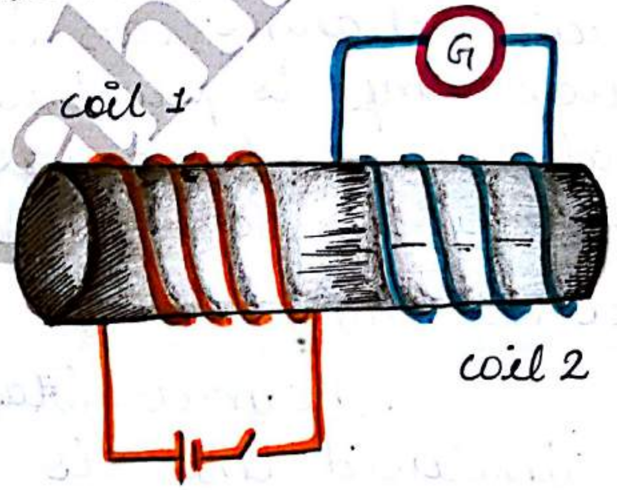
whenever magnetic flux linked with a conductor changes an emf is induced in the conductor.

Faradays Experiment



when a bar magnet is moved towards the loop of wire, the galvanometer shows deflection.

* If the magnet is moved towards the coil. Galvanometer shows deflection in one-direction
* If the magnet is moved away from the coil deflection is in opposite direction.
* If the magnet is kept stationary no deflection.
* If relative motion b/w magnet and coil increases more current will be induced.



Two wires are wound independently on a cylindrical support

* press key k in the coil 1. Galvanometer in coil 2 shows deflection in one direction.
* Release key k, G shows deflection in opposite direction.
* If continuously pressed (K); no deflection in G

as no change in magnetic flux.

conclusion: emf is induced when there is a change of magnetic flux.

Faraday's law of EMI

First law

whenever magnetic flux linked with a coil changes, an induced emf is produced and last as long as the change occurs.

second law

The magnitude of induced emf is directly proportional to the rate of change of magnetic flux in the coil.

i.e, emf = rate of change of magnetic flux

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

(-ve sign indicates the nature of emf e such that it opposes the cause which produces it.

for 'n' turns

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

* This is also known as faraday – Lenz's rule

Lenz's law.

The induced current produced in a coil always flows in such a direction that it oppose the cause that produces it.

i.e, $e = -\frac{d\phi}{dt}$

Lenz's law and conservation of energy.

Lenz's law is in accordance with the conservation of energy. The electrical energy produced in the form of induced 'emf' is at the expense of mechanical energy.

mechanical work (motion of magnet/coil) → Electrical energy

methods of producing induced emf.

$$\phi = BA\cos\theta$$

$$e = -\frac{d\phi}{dt} = -\frac{d}{dt}(BA\cos\theta)$$

emf can be induced by changing

(i) changing 'B'

(ii) changing 'A'.

(iii) changing 'θ'.

* methods of inducing emf by changing B.

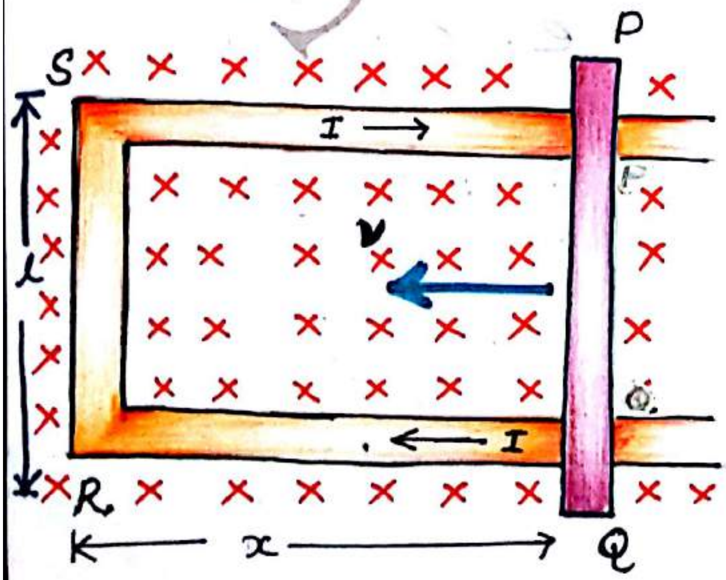
(i) Relative motion between a magnet and a coil.

(ii) switching 'on' and 'off' of the neighbouring circuit.

(iii) Relative motion between two coils.

Motional Emf

[Inducing emf by changing the area]



* Emf induced across the ends of a conductor due to its motion in a magnetic field is called motional emf.

consider a conductor PQ of length 'l' free to move on U-shaped conducting rails in a ⊥r B.

* loop PQRS ⊥r to B.
* PQ moves with uniform velocity v.
* Area of the loop associated with B changes.
* φ ↓ hence emf is set up across the ends of conductor PQ because of which an induced current flows in the circuit along the path PQRS.

$$\phi = BA\cos\theta \qquad \theta = 0^\circ$$

$$\phi = BA = Blx \qquad \{A = lx\}$$

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

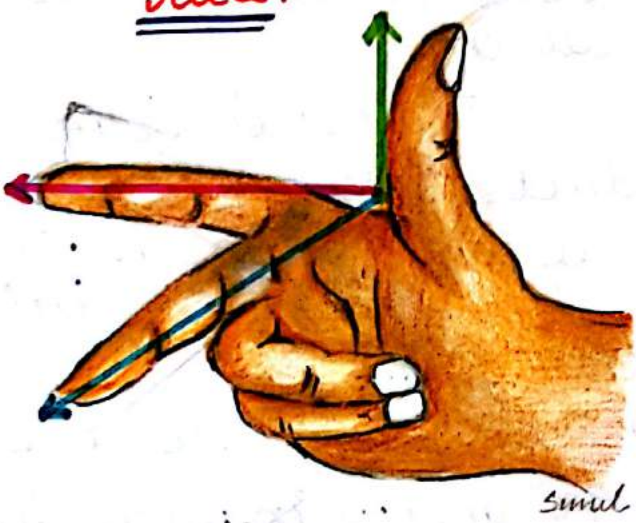
$$= -Bl\frac{dx}{dt}$$

x reduces with time

$$\therefore v = -dx/dt$$

$\therefore$ $e = Bl v$ (since $V = -\frac{dx}{dt}$)

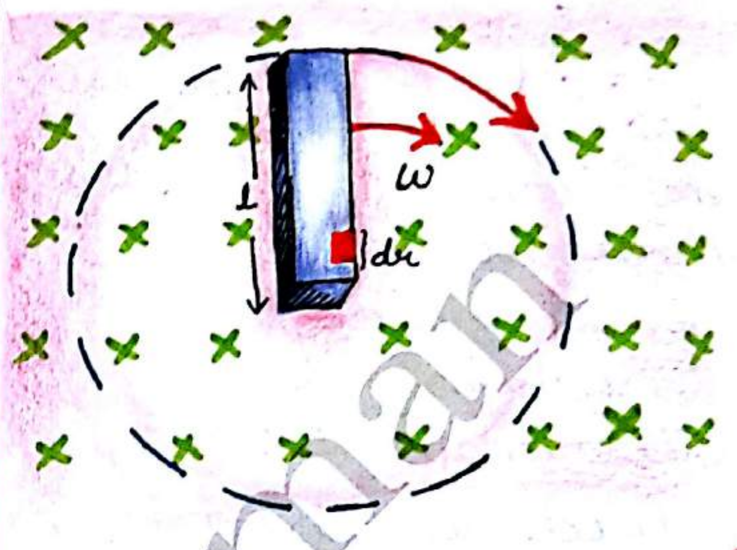
Fleming's Right hand rule.



If we stretch the thumb and first two fingres of our right hand in mutually ⊥r directions & if fore fingr points in the direction of the magnetic field, thumb in the direction of motion of the conductor, the central fingr points in the direction of current induced in the conductor.

Inducing emf in a rotating rod placed in a ⊥r Magnetic field.

consider a conducting rod OA of length 'l' rotating with uniform angular velocity 'ω' in ⊥r B.



motional emf $e = Blv$.

emf due to small element dr

$$de = B\,dr\,v$$

$$V = r\omega$$

$$\therefore de = B\,dr\,r\omega$$

$$de = Br\omega\,dr$$

total emf induced b/w ends of rod

$$\int de = \int_0^l Br\omega\,dr$$

$$e = B\omega\int_0^l r\,dr$$

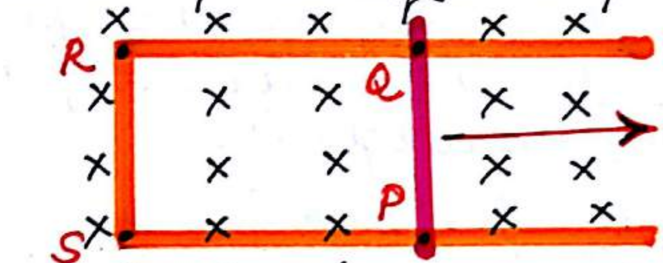
$$e = B\omega\left[\frac{r^2}{2}\right]_0^l$$

$$e = B\omega\frac{l^2}{2}$$

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

S.T $P = \frac{B^2 l^2 v}{R}$

when a rectangular loop is pulled out of uniform B



mechanical energy.
power delivered

$P = F \cdot V$

$P = BIl \sin\theta \cdot V$

$\theta = 90^\circ$

$P = BIlV$

$P = B\left(\frac{e}{R}\right)lV$

$P = B\left(\frac{BlV}{R}\right)lV$

$P = \frac{B^2 l^2 V^2}{R}$ ...... (1)

$P = \frac{W}{t}$

$P = \frac{F \cdot S}{t}$

$P = F \cdot V$

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

$V = e$

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

$e = BlV$

Electrical energy.

$P = I^2 R$

$P = \left(\frac{e}{R}\right)^2 R$

$= \left(\frac{BlV}{R}\right)^2 R$

$P = \frac{B^2 l^2 V^2}{R}$ ...... (2)

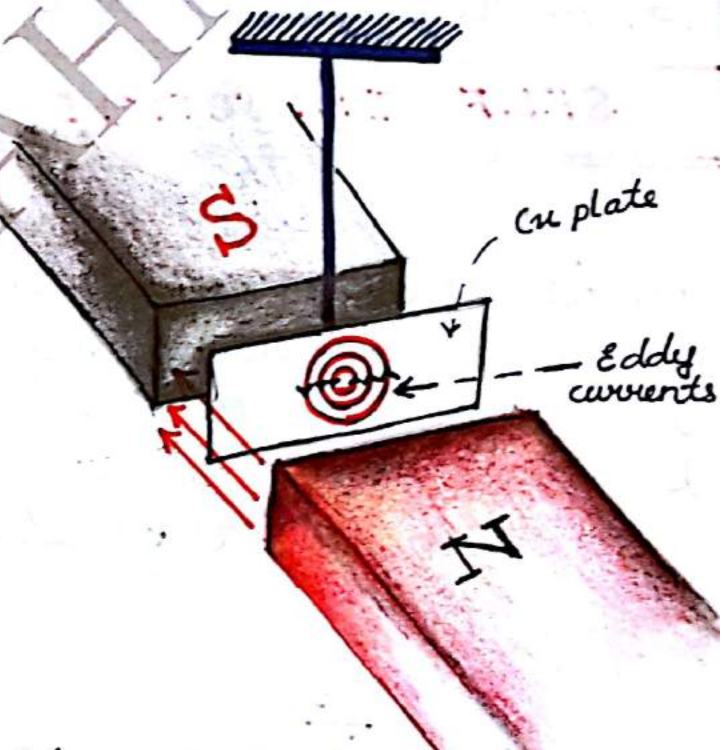
(1) = (2)

ie, mechanical energy is equal to electrical energy so energy is conserved.

③

EDDY CURRENTS

Eddy currents are the currents induced in a solid metallic masses when the magnetic flux through them changes.



* It produces heat energy
* It circulates inside the body.

Minimising eddy current

* By Increasing resistance of metal.
* By using lamination

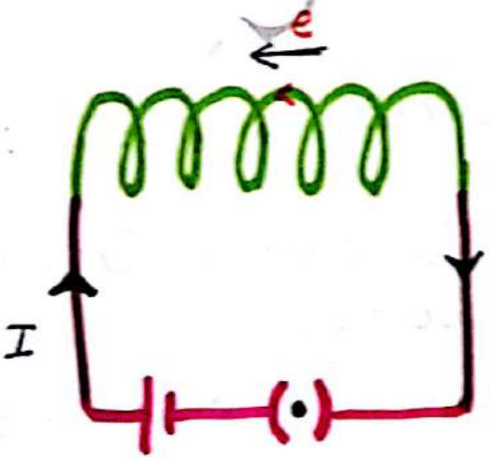
of metals (Eg; transformer)

application of eddy current.

(1) Electromagnetic damping
(2) Induction furnace.
(3) Electric brakes (magnetic braking in trains)
(4) speedometers.
(5) Induction motor.

SELF INDUCTION

Self Induction is the phenomenon of production of induced emf in a coil by changing the current passing through it.



coefficient of self-Induction.

The magnetic flux linked with the coil at any instant is directly proportional to the current passing through it.

ie; $\phi \propto I$

$$\phi = LI$$

where 'L' is the coefficient of self Induction [self Inductance]

$$L = \frac{\phi}{I} \qquad L = \phi \text{ when } I = 1A$$

ie, self inductance of a coil is numerically equal to the magnetic flux linked with the coil when a unit current flows through it. The induced emf

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

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

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

$L \rightarrow$ is called self Inductance.

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

If $\frac{dI}{dt} = \frac{1A}{1S}$

$L = -e$

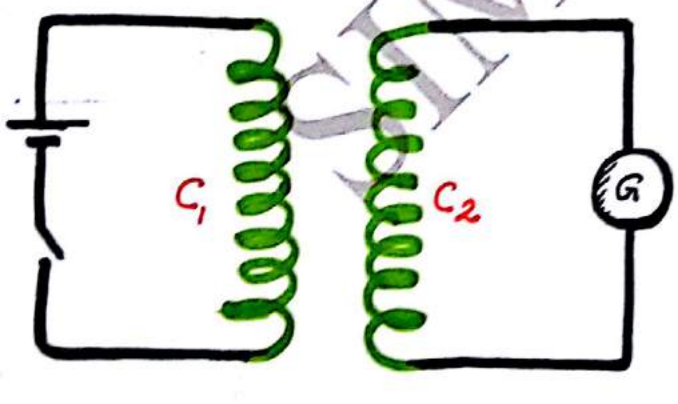
self inductance is equal to emf induced in a coil when current changes at the rate of 1 A/s in the same coil.

* S.I unit of self Inductance is henry (H)

Define one henry?

self Inductance of a coil is 1 henry when current changes at the rate of 1 A/s through the coil induces an emf of 1V in the coil.

MUTUAL INDUCTION



The phenomenon by which opposing induced emf is produced in a coil when there is change in the current or magnetic flux link the neighbouring coil is called mutual Induction.

co-efficient of Mutual Induction [Mutual Inductance]

The flux linked with the secondary coil is directly proportional to the current flowing through the primary coil.

$$\phi \propto I$$

$$\phi = MI$$

M - is the co-efficient of mutual Induction or mutual Inductance.

$\therefore M = \frac{\phi}{I}$ or $M = \phi$ when $I = 1A$

* mutual Inductance of a pair of coils is equal to the magnetic flux linked with one of the coil when a unit current passes through the coil.

the Induced emf

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

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

$$e = -M\frac{dI}{dt} \qquad M = \frac{-e}{dI/dt}$$

$$e = -M \quad \text{if} \quad \frac{dI}{dt} = 1\,A/s$$

mutual Induction is equal to Induced emf in a coil when current changes at the rate of 1 A/s in the other coil.

SI unit is H (henry)

Define 1 henry

mutual inductance of a coil is 1 henry when current changes at the rate of 1 A/s through one coil induces an emf of 1 V in the other coil.

SELF INDUCTANCE OF A LONG SOLENOID.

consider a solenoid of length l. let 'n' be the no of turns per unit length

∴ Total no of turns in the solenoid = nl

we have $\phi = BA$ .. ①

but $B = \mu_0 n I$ .. ②

for 'nl' turns, the total flux

$$① \Rightarrow \phi = (\mu_0 n I) A (nl)$$

$$\phi = \mu_0 n^2 l A I$$

$n = \frac{N}{l}$

but $\phi = LI$

$$LI = \mu_0 n^2 l A I$$

$$L = \mu_0 n^2 l A$$

or

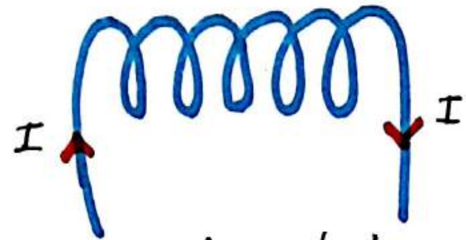
$$L = \frac{\mu_0 N^2 A}{l}$$

since $n = \frac{N}{l}$

If the core is of any other material

$$L = \mu_0 \mu_r n^2 l A$$

Energy stored in an Inductor



when 'I' flows through solenoid emf is induced which opposes the cause.

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

work must be done against this emf.

$$W = Vq$$

$$dW = e\,dq$$

$$dW = L\frac{dI}{dt}dq$$

$$dW = L\,I\,dI$$

$$\int dW = L\int_0^I I\,dI$$

$$W = L\int_0^I I\,dI.$$

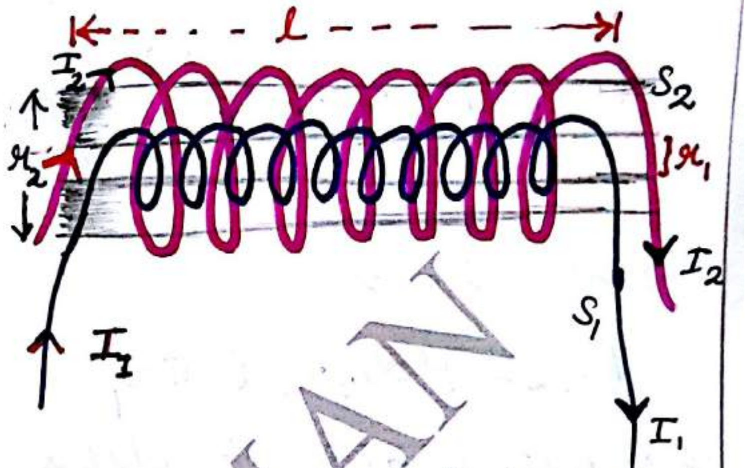
$$W = L\left[\frac{I^2}{2}\right]_0^I$$

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

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

This work is stored as energy.

Mutual Inductance of a pair of coil of different radii



consider two co-axial solenoids S_1 and S_2 of radii r_1 & r_2 let I_1 and I_2 be the currents flowing through S_1 and S_2 respectively. let 'l' be the length of the solenoid.

let n_1 be the no of turns per unit length of S_1 and n_2 be the no. of turns per unit length of S_2.

The magnetic flux linked with S_1 due to current flowing through S_2.

$$\phi_{12} = M_{12} I_2 \quad \text{--- (1)}$$

but we have $\phi_{12} = B_2 A_1$

$$\phi_{12} = (\mu_0 n_2 I_2)(\pi r_1^2)$$

for $(n_1 l)$ turns

$$\phi_{12} = (\mu_0 n_2 I_2)(\pi r_1^2)(n_1 l)$$

$$\phi_{12} = (\mu_0 n_1 n_2 l \pi r_1^2) I_2 \quad \ldots (2)$$

from (1) & (2)

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

* Now magnetic flux linked with S_2 due to current flowing through S_1

$$\phi_{21} = M_{21} I_1 \quad \ldots (3)$$

but $\phi_{21} = B_1 A_1$ [since magnetic flux due to I_1 in S_1 is confined within S_1]

∴ for $n_2 l$ turns

$$\phi_{21} = (\mu_0 n_1 I_1)(\pi r_1^2)(n_2 l)$$

$$\phi_{21} = (\mu_0 n_1 n_2 \pi r_1^2) I_1 \quad \ldots (4)$$

from (3) & (4)

$$M_{21} = \mu_0 n_1 n_2 l \pi r_1^2$$

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

** AC Generator. (v.imp)

[CBSE – 2008, 07, 06, 03, 06, 05, 04, D-2010 F-2012, 2011 (AI)]

A dynamo or generator is a device which converts mechanical energy into electrical energy.

Principle.

It works on the principle of electromagnetic Induction. i.e, emf is induced when magnetic flux linked with a coil changes.

Construction.

It consists of four main parts.

(i) Armature.

It consists of rectangular coil ABCD having large no of turns of insulated copper wire wound on a soft iron cylindrical core.

(ii) Field Magnet.

* It is a permanent magnet of the horse shoe shape in a small dynamo.
* In large or high power dynamo electromagnet is used.

(iii) Slip rings (S_1 and S_2)

Two hollow rings attached at the ends of armature. Slip rings are insulated brass rings.

(iv) Brushes (B_1, B_2).

Carbon brushes attached with S_1 and S_2, to connect with external circuits.

Source of energy.

The armature coil is rotated about its axis with the help of turbine or any other device connected to it. It is rotational K.E of the turbine which is ultimately converted into electrical energy by the ac generator.

Working

First half rotation

* plane of coil ⊥r to B
* AB front CD back

* coil rotates in anti clockwise direction (or clockwise)
* AB moves inward and CD moves outward.
* Apply flemings Right hand rule.
* current induced in AB from A to B and in CD from C to D
* In external circuit current flows from B_2 to B_1

Second half rotation

* AB is back and CD is front. AB moves outwards and CD moves inwards.
* The current induced induced in AB is from B to A and in CD is from D to C.
* Through external circuit current flows from B_1 to B_2
* This is repeated. Induced current in the external circuit changes direction after every half rotation of the coil. Hence the current induced is alternating in nature.

Expression for Induced emf.

N → No of turns in the coil

A → face area of each turn

B → magnitude of magnetic field.

θ → angle which normal to the coil makes with the field $\vec{B}$ at any instant 't'.

ω → Angular velocity with which the coil rotates

magnetic flux

$$\phi = NBA\cos\theta$$

$$\phi = NBA\cos\omega t \quad \text{(1)}$$

by faradays rule induced emf

$$E = -\frac{d\phi}{dt} \quad \text{(2)}$$

(1) in (2)

$$E = -\frac{d}{dt}(NBA\cos\omega t)$$

$$E = -NBA[-\sin\omega t]\omega$$

$$E = NBA\sin\omega t.\omega$$

$$E = NBA\omega.\sin\omega t$$

$$E = E_0\sin\omega t$$

$$I = \frac{E}{R} = \frac{E_0\sin\omega t}{R}$$

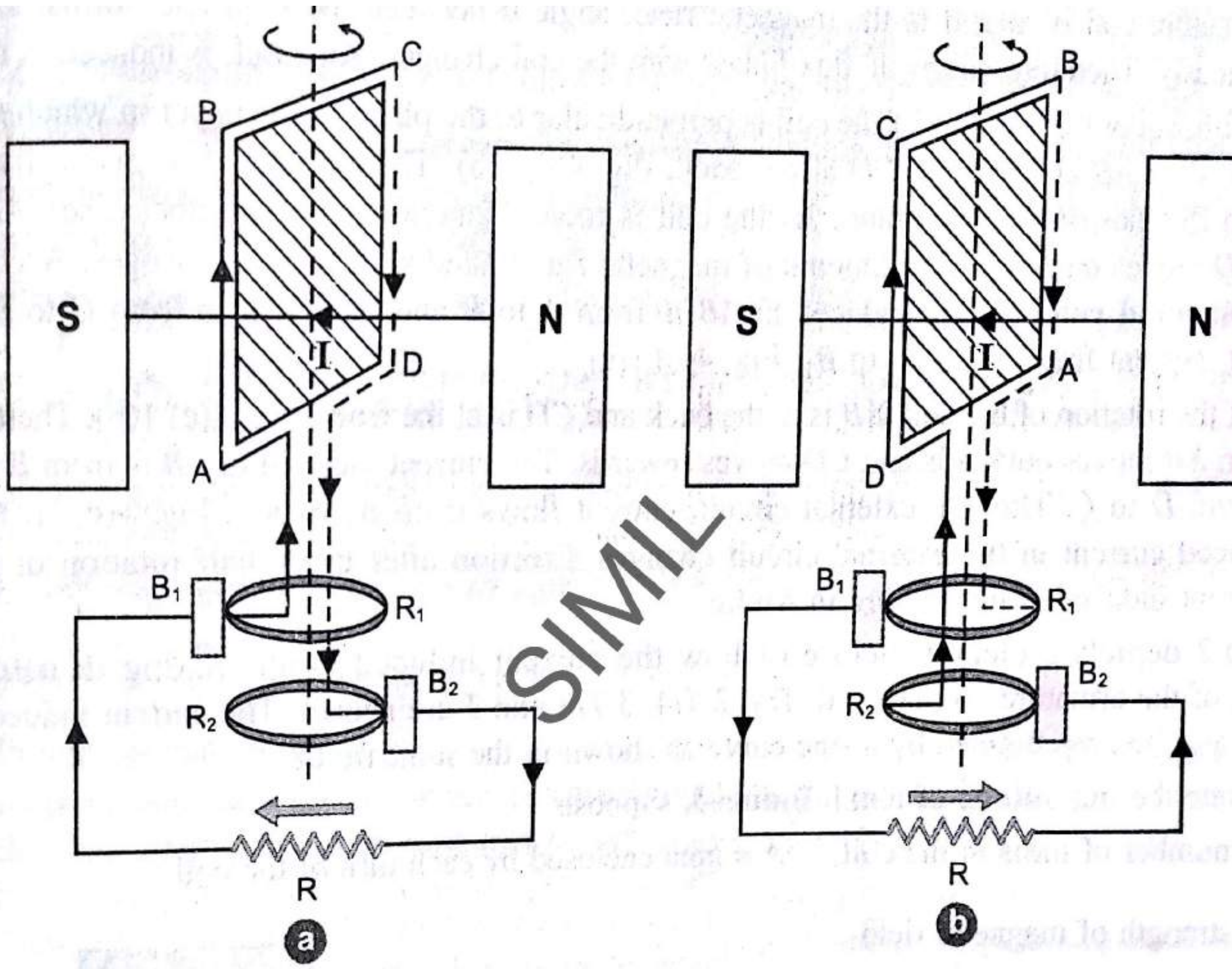
$$I = I_0\sin\omega t$$

$E_0 = NBA\omega \times 1$

$\sin\omega t = 1$

$\frac{E_0}{R} = I_0$

both E & V vary with time.


S
N
A
B
C
D
I
B_1
R_1
B_2
R_2
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B_2
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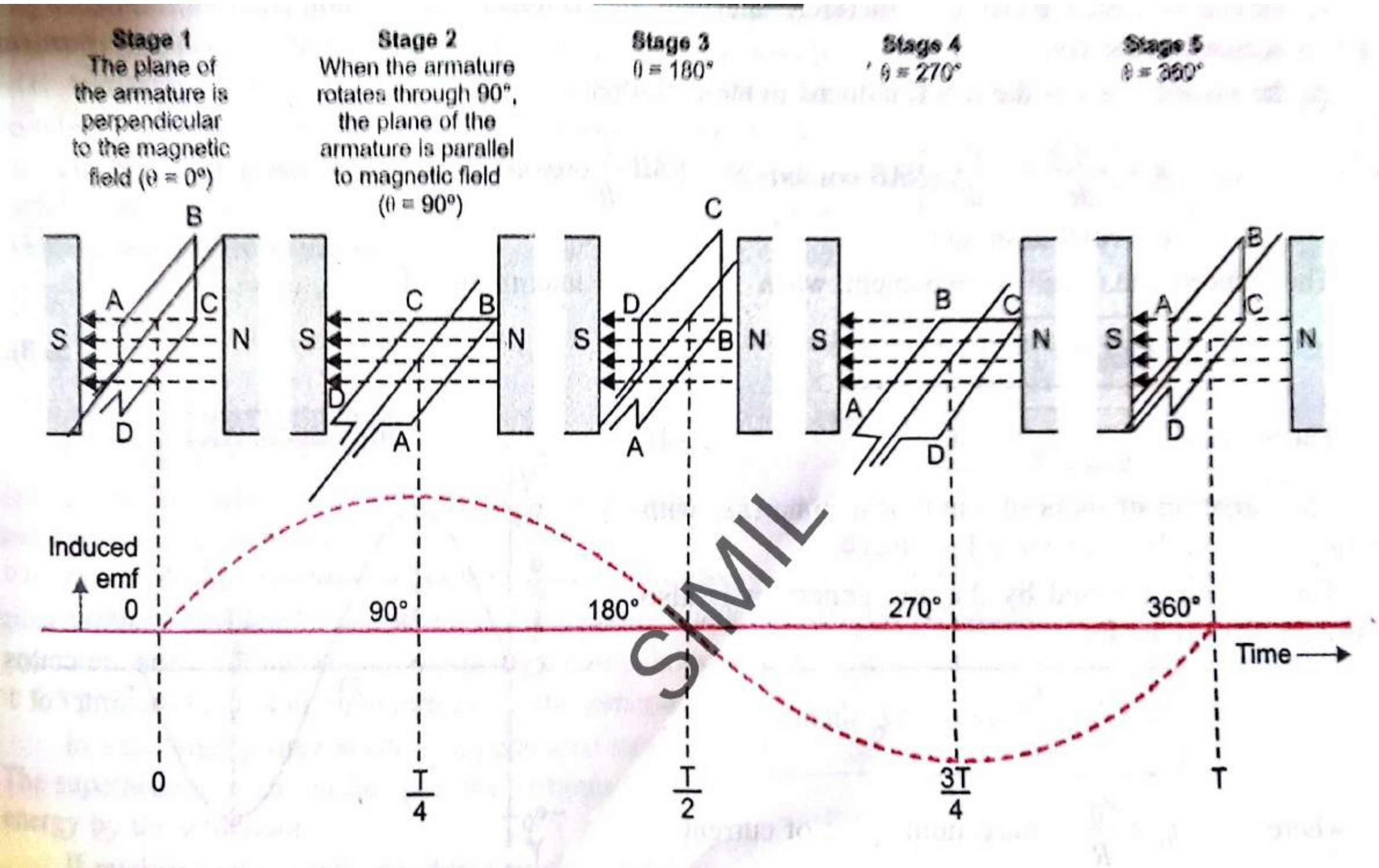
b



Stage 1
The plane of the armature is perpendicular to the magnetic field (θ = 0°)
Stage 2
When the armature rotates through 90°, the plane of the armature is parallel to magnetic field (θ = 90°)
Stage 3
θ = 180°
Stage 4
θ = 270°
Stage 5
θ = 360°
S
N
A
B
C
D
Induced emf
0
90°
180°
270°
360°
Time
0
T/4
T/2
3T/4
T