Chapter = 15

ELECTROMAGNETIC INDUCTION

In 1820 Oerested discovered the electric current produce magnetic field.
In 1831, Joseph Henry and Michal Faraday observed that when field is changed then emf is produced.

Electromagnetic induction: "If the magnetic field through a circuit changes, an emf and current are induced in the circuit, this phenomenon is called Electromagnetic induction".

Induced current and induced emf: If a conductor moves through a magnetic field then due to change of magnetic flux current flows through circuit which is called induced current and emf produced is called induced emf

Factors induced current depends: Induced current depends upon

i. Speed of loop
ii. Resistance of loop

Factors which increased the induced current: Induced current can be increased by

i. Using a stronger field
ii. Moving the loop faster
iii. Using a coil of many turn
iv. Increasing the area of loop

Induced current can be produced: The induced current can be produced by the relative motion of the magnet or loop i.e. by moving either the loop or the magnet.

Methods to produce induced emf: There are following methods to produce induced emf

i. Relative motion of bar magnet and coil of wire:
ii. Changing area of coil
iii. Rotating the coil
iv. Mutual induction and electromagnet

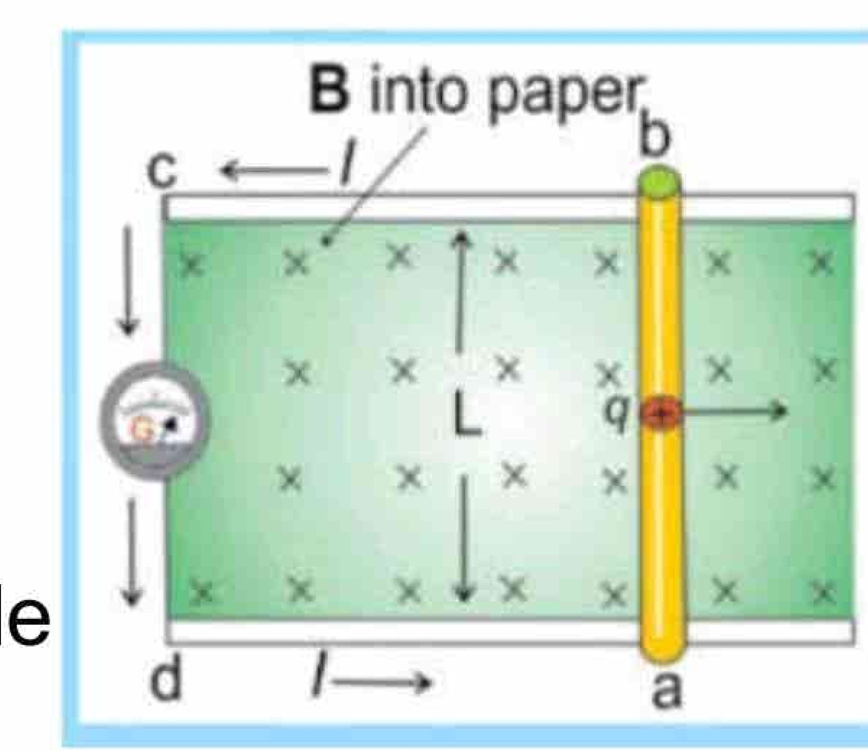
What is Motional emf? Derive its relation.

Definition:"The emf induced by the motion of conductor across the magnetic field is called motional emf".

Formula: $\varepsilon = -vBL\sin\theta$.

Explanation: Consider a conducting rod of length 'L' placed on two parallel metals rails separated by a distance L.

A galvanometer is connected b/w its ends of rails. This forms a complete conducting loop as shown in fig.



A uniform magnetic field is applied directed into the paper, when the rod is pulled to the right with constant velocity v, the galvanometer indicates a current flowing through loop.
Moving rod is acting as a source of emf $E=V_b-V_a=\Delta V$.
When the rod moves, a charge q within rod also moves with same velocity v and experience force
$F=q(v \times \bar{B})$ =qvB sinΘ= qvBsin90°=qvB, by using right hand rule
Force is directed from a to b in rod

And electric field is induced along the rod $E=\frac{F}{q}=\frac{qvB}{q}$ =vB ……………….. (1)

Also we know that electric field intensity E $=\frac{-V}{r}=\frac{-V}{L}=\frac{-\varepsilon}{L}$ ……………….(2)

Comparing eq(1) and eq(2) $\frac{-\varepsilon}{L}$=vB

We get ε =-vBL, if Θ is angle b/w v and B then ε =-vBLsinΘ, this is relation for motional emf.

Motional emf can be increased by:

(a) Increasing the speed of rod

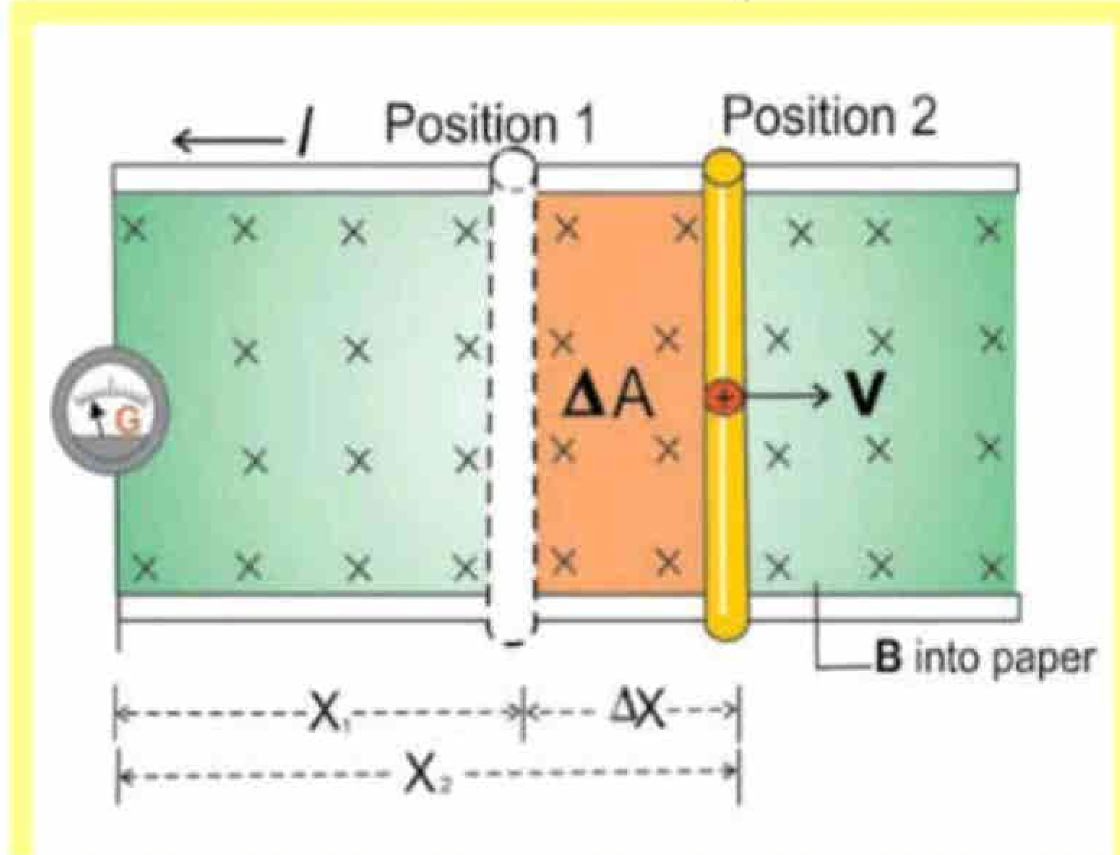
(b) Using the stronger magnetic field

State and explain Faraday Law of Electromagnetic induction

Statement: "The average emf induced in a conducting coil of N loops is equal to the negative of the rate at which magnetic flux through the coil is changing with time"

Equation: $\varepsilon = -N\frac{\Delta\varphi}{\Delta t}$.

Explanation: Consider a conducting rod of length L moves from a position 1 to position 2 and covers a distance



$\Delta x = x_2 - x_1$

the velocity of rod is given $v = \frac{\Delta x}{\Delta t}$

the emf produced in rod is $\varepsilon = -vBL$, putting the value of v

$\varepsilon = -\frac{\Delta x}{\Delta t}BL = -\frac{(\Delta x.L)}{\Delta t}B$ as we $\Delta x.L = \Delta A$

$\varepsilon = -\frac{(\Delta A)}{\Delta t}B = -\frac{(B\Delta A)}{\Delta t}$ $\Delta\varphi = B\Delta A$

$\varepsilon = -\frac{\Delta\varphi}{\Delta t}$, if coil has N turns then emf is $\varepsilon = -N\frac{\Delta\varphi}{\Delta t} \Rightarrow$ Faraday law of electromagnetic induction

Reason of negative sign in Faraday law: Negative sign shows that the direction of induced emf is such that it oppose the change it.

State and explain Lenz's law.

Statement: **"The direction of induced current is always such as to oppose the change which causes the current"**

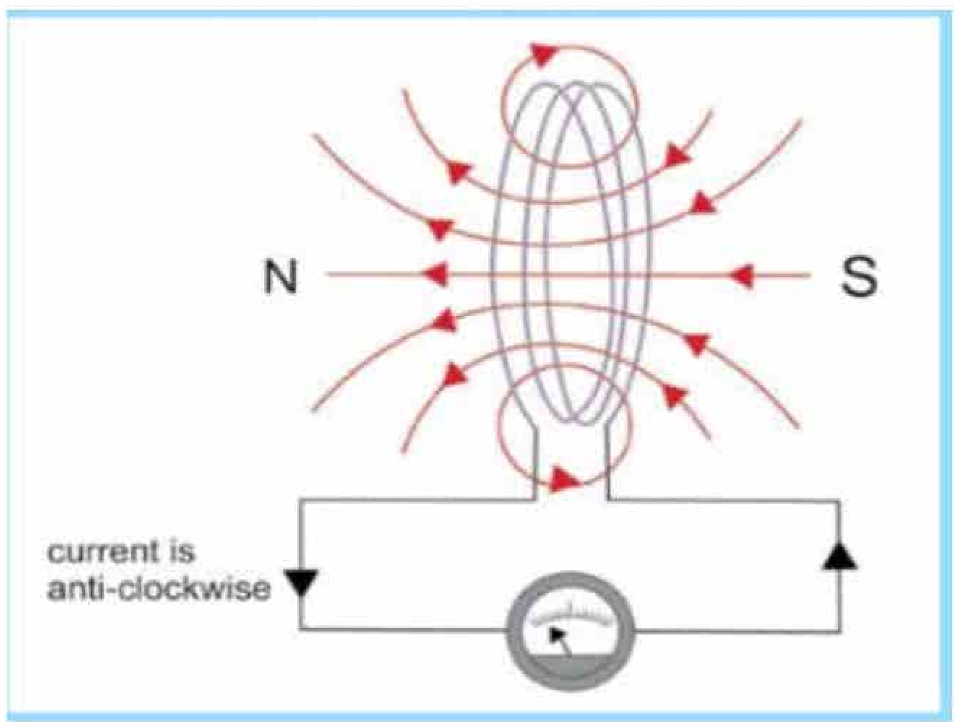
Lenz's law is used to find the direction of induced current which was given by Heinrich Lenz in 1834.

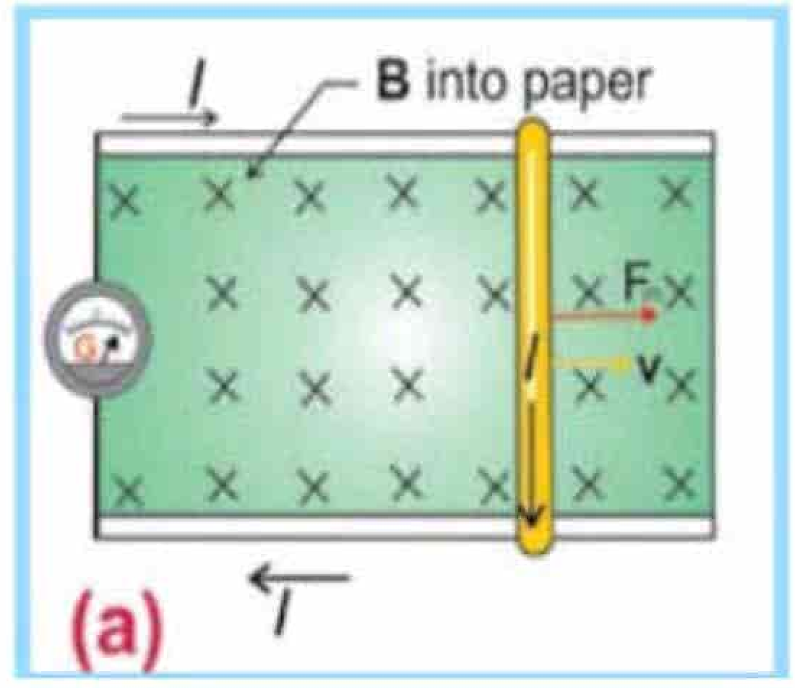
Experiment: let us consider a coil in which current is induced by the movement of bar magnet due to magnetic effect of current. One face of the coil acts as North Pole while the other one as the South Pole. If the coil is to oppose the motion of bar magnet, the face of the coil towards the magnet must become a north pole, the two north poles will repel each other, and then by using right hand rule direction of induced current is anti-clock wise.

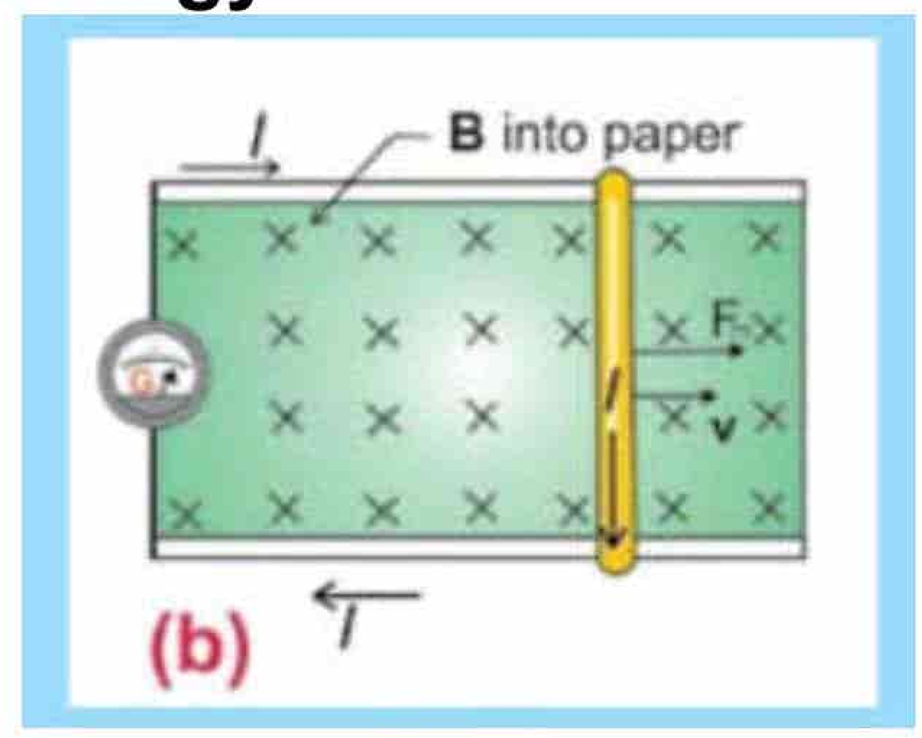
According to Lenz law the "push" of magnet is the "Change" that produces the induced current which tend to oppose the "push". Similarly if we "pull" the magnet away from the coil, the induced current oppose the "pull" by creating South Pole towards the bar magnet. As shown in fig a

Lenz's law and law of conservation of Energy: Let us consider rod moves towards right in uniform magnetic field, emf is induced it and induced current flows through the loop in anti-clock direction and rod experience a magnetic force whose direction is opposite to v, so it tend to stop the rod. If we consider the direction of current in clock wise direction then magnetic force will in the direction of v so this force would accelerate the rod increasingly. Hence the process becomes self-perpetuating which is against the law of conservation of energy.As shown in fig b and c

Lenz's law is in accordance to law of conservation of energy.







Multiple choice questions

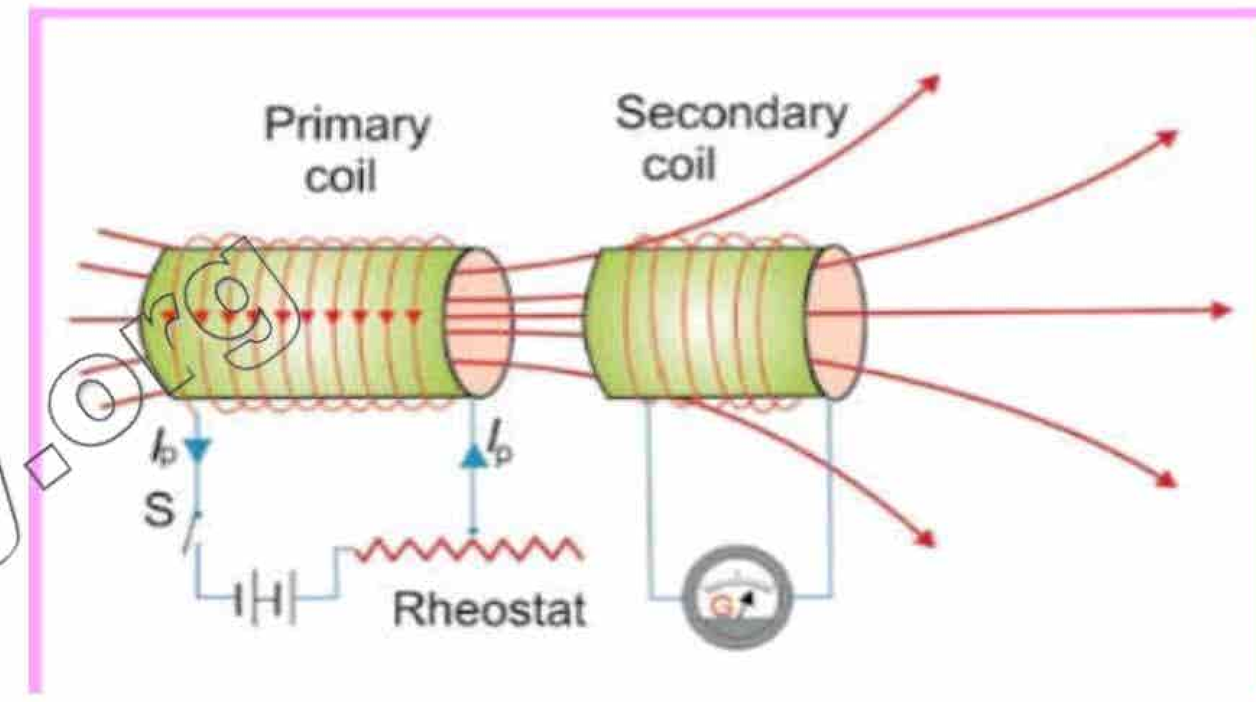
1	Lenz law is actually the law of conservation of	Charge	Mass	**Energy**	Momentum
2	If velocity of a conductor moving through a magnetic field B is made zero then motional emf is	-vBL	-v/BL	-BL/v	**Zero**
3	"The direction of induced current is always so as to oppose the change which causes the current" is statement of	Faraday law	**Lenz law**	Ohm law	None
4	If we make the magnetic field stronger then value of induced current is	Decreased	**Increased**	Vanished	Kept constant
5	A metal rod of length 1m is moving at a speed of 1m/s in a direction making an angle of 30˚with 0.5T the emf produced	0.25N	**0.25V**	2.5V	25V

6	When a loop of wire is moved across a magnetic field. The current produced in it which is called	Eddy current	DC current	Photo electric current	**Induced current**
7	A rod of length 20m is moving with velocity 20m/s in a direction perpendicular to magnetic field of 20T what is value of emf	2000V	4000V	6000V	**8000V**
8	SI unit of induced emf is	Ohm	Tesla	Henry	**Volt**
9	When a conductor is moved across magnetic field then emf produced is called	Variable emf	Constant emf	**Induced emf**	Back emf
10	Heater operates on the principle of	conduction	Electrostatic Induction	**Electromagnetic Induction**	None
11	Max motional emf is vBL. At what angle conductor moves in field so that it becomes half maximum value	0	45	**30**	60
12	Web/sec is equal to	Ampere	Tesla	**Volt**	Henry
13	Lenz law is used to find the direction of	Induced emf	**Induced current**	Force	Acceleration

What is Mutual Induction and derive the relation for mutual inductance.

Definition:"**The phenomenon in which changing the current in one coil induces an emf in another coil, is called mutual induction**".
Explanation: Lets us consider two coils placed to each other as shown in fig
Primary coil and Secondary coil: A coil connected with a battery through a switch and rheostat is called primary coil and the coil connected to a galvanometer is called secondary coil.
If the current in primary coil is changed by the changing the resistance by rheostat then magnetic flux through primary coil changes and emf is induced in secondary coil whose value is $\varepsilon_s = -N_s \frac{\Delta\varphi_s}{\Delta t}$

Mutual inductance: If φ_s = flux across secondary and N_s = No of turns across secondary



Magnetic flux φ_s and N_s is directly proportional to I_p

$N_s\varphi_s \propto I_p$

$N_s\varphi_s = M\, I_p$

Where M = Constant of proportionality known as mutual inductance

Now by Using Faraday law $\varepsilon = -Ns\frac{\Delta\varphi s}{\Delta t} = -\frac{\Delta(Ns\varphi s)}{\Delta t}$

$\varepsilon_s = -\frac{\Delta(M\, Ip)}{\Delta t} = -M\frac{\Delta Ip}{\Delta t}$, This shows that induced emf is proportional to rate of change of current current in primary coil

$M = \frac{\varepsilon_s}{\frac{\Delta Ip}{\Delta t}}$ = Mutual inductance

Mutual inductance: The ratio of average of induced emf in the secondary to the time rate of change of current in the primary coil is called mutual inductance. $M = \frac{\varepsilon_s}{\Delta I_p/\Delta t}$ Its unit is henry.

Henry: If the rate of change current one ampere per second in primary coil produces the emf of one volt in the secondary then mutual inductance will be one henry. VsA^{-1} = henry (H).

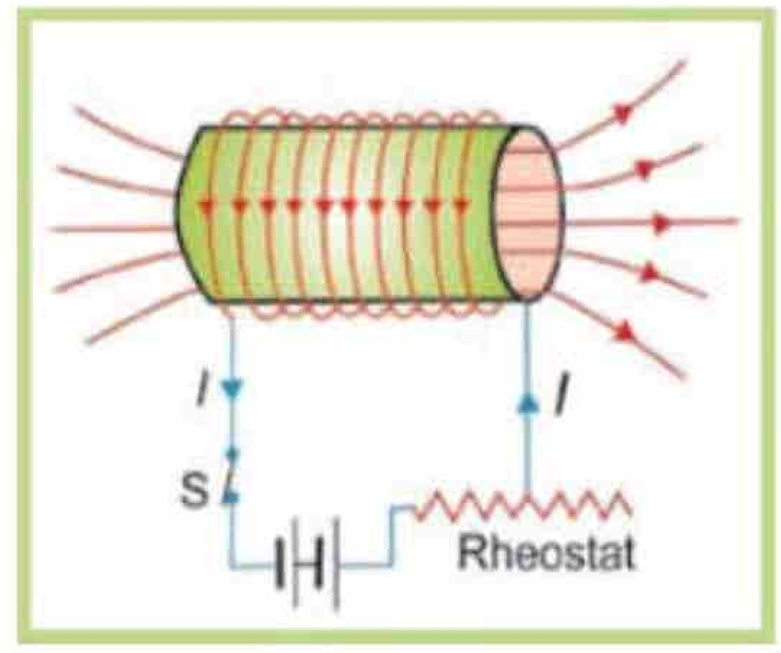
Factors on which mutual inductance depend:

i. No of turns of the coils
ii. Area of cross section of coils
iii. Closeness and orientation of coils
iv. Nature of core material

What is Self-induction? Derive its relation.

Self-induction: "The phenomemenon in which changing current in in a coil induces an emf in itself is called self-ininduction".
Explanation: Consider a coil cconnected in series with a battery anand a rheostat as shown in fig. when a current paspass passes through the coil, magnetictic flux is produce.

If the current is changed by varying the rheostat, magnetic flux through coil changes that caused an induced emf in coil such an emf is called self-induced emf or back emf.



Magnetic flux φ and N is directly proportional to I

$N\varphi \propto I$

$N\varphi = LI$

Where L = Constant of proportionality known as self inductance

Now by Using Faraday law $\varepsilon = -N\frac{\Delta\varphi}{\Delta t} = -\frac{\Delta(N\varphi)}{\Delta t}$

$\varepsilon = -\frac{\Delta(LI)}{\Delta t} = -L\frac{(\Delta I)}{\Delta t}$, This shows that induced emf is proportional to rate of change of current current in primary coil

$L = \frac{\varepsilon}{\frac{\Delta I}{\Delta t}}$ = Self inductance

Self-inductance: The ratio of induced emf produced in a coil to the rate of change of current in the same coil. $L = \frac{\varepsilon_L}{\Delta I/\Delta t}$ Its unit is henry (VsA^{-1}).

As induced emf must oppose the change that produced it, so according to Lenz's law self-induced emf is called back emf.By winding the coil around a ferromagnetic (iron) core, the magnetic flux and inductance can be increased.

PRACTICE MCQS

1	If an inductor has N turns of a coil and Ø is magnetic flux through each turn when current I is flowing in it, then self inductance is given by	I/N Ø	**N Ø/I**	NI/ Ø	Ø/NI
2	In choke of inductance L and resistance R	**L is large and R is small**	L is small and R is large	Both R&L are large	Both R&L are small
3	Inductance is measured in	volt	Ampere	**Henry**	Ohm
4	The ratio of average induced emf to rate of change of current in a	**Self-inductance**	Mutual inductance	Self-induction	Mutual induction

	coil is called				
5	One henry is equal to	VSA	VSA^2	**VSA^{-1}**	None
6	Mutual inductance depends upon	Density of coil	Material	**Geometry**	Stiffness
7	Self inductance of long solenoid with n turns per unit length is L=?	$\mu_o nA/l$	$\mu_o n^2A/l$	**$\mu_o n^2Al$**	$\mu_o n^2l/A$
8	The practical application mutual induction is	Electric motor	**Transformer**	Generator	None
9	SI unit of mutual and self-induction are	**Same**	Different	No unit	None of these
10	Inductance is more in self-induction in	Air cored coil	**Iron cored coil**	Tungsten cored	Steel cored
11	Mutual induction between two coils depends upon	Area of coils	Number of turns	Distance between coils	**All of these**
12	The inductance can be increased by winding the wire around a core made of	Copper	Silicon	**Iron**	Aluminum
13	Henry is the SI unit of	Current	Resistance	Flux	**Self-inductance**
14	SI unit of mutual inductance is	VSA	VSA^2	**VSA^{-1}**	None

15	The self-induction is given by	NL=φI	NI=Lφ	**Nφ=LI**	N=LI
16	The current in one coil changes from 0 to 2A in 0.05s, if the induced emf is 80V, self inductance will	1H	0.5 H	**2H**	1.5
17	What is mutual inductance when magnetic flux changes by $2*10^{-2}$web and change in current is 0.01 A and emf is 1 volt	**½ henry**	2 henry	Zero henry	10 henry
18	If coil is wound on an iron core, magnetic flux will	**Increase**	Zero	Decrease	Infinite
19	A coil has self inductance 5H, if current changes at the rate of 5A/s, self induced emf	**25V**	50 V	75V	2.5 V
20	Induction in coil can be increased by using	**Ferromagnetic substance**	Paramagnetic Substance	Diamagnetic Substance	Ferromagnetic substance

Calculate the Energy stored in an Inductor in terms of magnetic field.

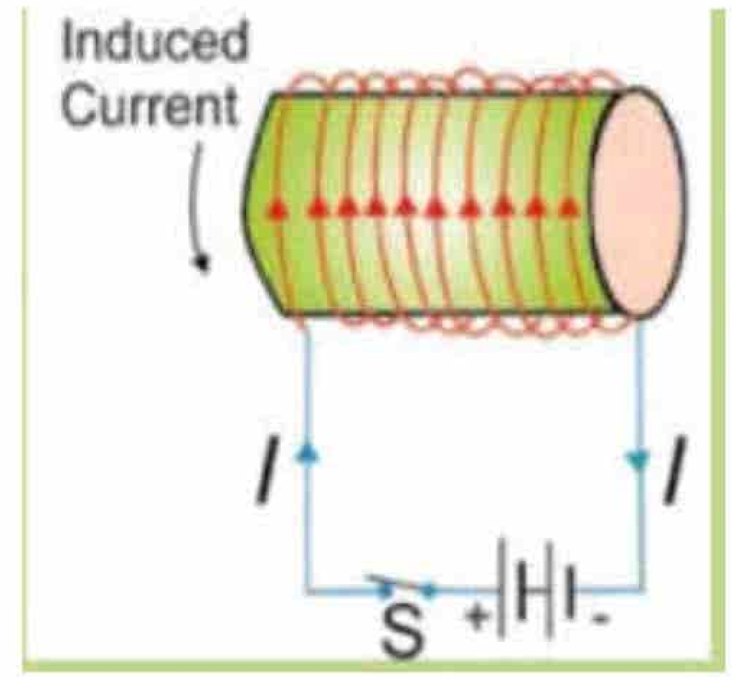
Inductor: **"Such a device which store energy in magnetic field is called inductor"**.

Derivation: Consider a coil connected to a battery and a switch in series as shown in fig. when the switch is turned on voltage is applied across the ends of coil and current increases from zero to maximum value. Due to change of current, an emf is induced, which is opposite to that of battery, work is done by battery to move charges against the induced emf.

Work done by the battery in moving small charge Δq

$$\Delta W = \varepsilon_L \Delta q \text{ ---------------(1)} \quad \text{as } \varepsilon_L = \frac{\Delta W}{\Delta q}$$

in case of self induced emf in inductor $\varepsilon_L = L\frac{\Delta I}{\Delta t}$ putting in eq (1)



$$\Delta W = L\frac{\Delta I}{\Delta t}\Delta q = L\frac{\Delta q}{\Delta t}\Delta I \text{ ------(2)}$$

As average current is $I = \frac{\Delta q}{\Delta t} = \frac{I_{max} + I_{min}}{2} = \frac{I+0}{2} = \frac{I}{2}$

$\Delta I = I_{max} - I_{min} = I - 0 = I$ putting in eq (2)

$\Delta W = L(\frac{I}{2})(I) = \frac{1}{2}LI^2$ This work is stored in form of P.E inductor which is

$U_m = \frac{1}{2}LI^2$ --------(a) This is energy stored in inductor

<u>Energy in terms of magnetic field/Energy density</u>: As inductor stored energy in magnetic field so the above equation (a) can be written in form of magnetic field B. As inductor is like solenoid of n turn per unit length of area A

For calculation of L consider Magnetic field inside solenoid $= B = \mu_o nI$, $n = N/L$

flux through coil is $= \phi = BA = \mu_o nI A$

as we know that $N\phi = LI$

$$L = \frac{N\phi}{I} = \frac{N\mu_o n I A}{I} = (nL)\mu_o n \ A = \mu_o n^2 (AL) \text{ ----(2)}$$

and I for solenoid $I = \frac{B}{\mu_o n}$ -----(3) putting the values of 2 and 3 in (a)

$$U_m = \frac{1}{2}\mu_o n^2 (AL)(\frac{B}{\mu_o n})^2 = \frac{1}{2}\mu_o n^2 (AL)(\frac{B^2}{\mu_o{}^2 n^2}) = \frac{1}{2}\frac{B^2}{\mu_o}(AL) = \text{Energy stored in terms of } \vec{B}$$

Energy density : Energy stored in inductor per unit volume is called energy density.

$$\frac{U_m}{AL} = \frac{1}{2}\frac{B^2}{\mu_o} \Rightarrow$$

$u = \frac{1}{2}\frac{B^2}{\mu_o}$ this is the formula for energy density in magnetic field, which is proportional to square of field.

What is AC Generator? Describe its principle construction and working. Also derive equation of induced current and induced emf.

<u>Definition</u>: **"A device which converts mechanical energy into electrical energy and output is in alternating current form is called AC generator"**.

<u>Principle of AC generator</u>: AC generator works on the principle of Faraday law of electromagnetic induction.

When a coil is rotated in magnetic field, magnetic flux through coil changes so an emf is induced in coil.

<u>Construction</u>: let us consider a rectangular wire of AC generator which has three major parts of AC generator

Armature: Number of coils wounded on an iron cylinder is called armature. The magnetic field is usually provided by an electromagnet.
Slip rings: slip rings are concentric with axis of loop and rotate with it.
Carbon brushes: carbon brush connected the slips rings to external circuit.
Working and Expression for induced emf and induced current of AC generator: consider the position of coil which is rotating anti clock wise. The vertical side ab and cd of loop is moving with velocity v and and field $\bar{B}$ and angle b/w is Θ, same value of current is flowing through both sides.

$\varepsilon_{ab} = vBL\sin\theta, \quad \varepsilon_{cd} = vBL\sin\theta$

And no contribution of sides $\varepsilon_{bc} = \varepsilon_{da} = 0$ because the force acting on the charges is not along the wire

$\varepsilon = \varepsilon_{ab} + \varepsilon_{cd} = vBL\sin\theta + vBL\sin\theta = 2vBL\sin\theta$

If the loop is replaced by N turns, the total emf in coil is

$\varepsilon = 2NvBL\sin\theta$

The linear speed of vertical wire is related to angular speed ω, $v = r\omega$

$\varepsilon = 2N(\omega r)BL\sin\theta = N\omega(2rL)B\sin\theta$ As $A = 2rL$

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

$\varepsilon = N\omega AB\sin(\omega t)$ ------(1)

This show that induced emf changes sinusoidally with time

for maximum value $\sin 90^\circ = 1$ $\varepsilon = N\omega AB\sin 90^\circ = N\omega AB$

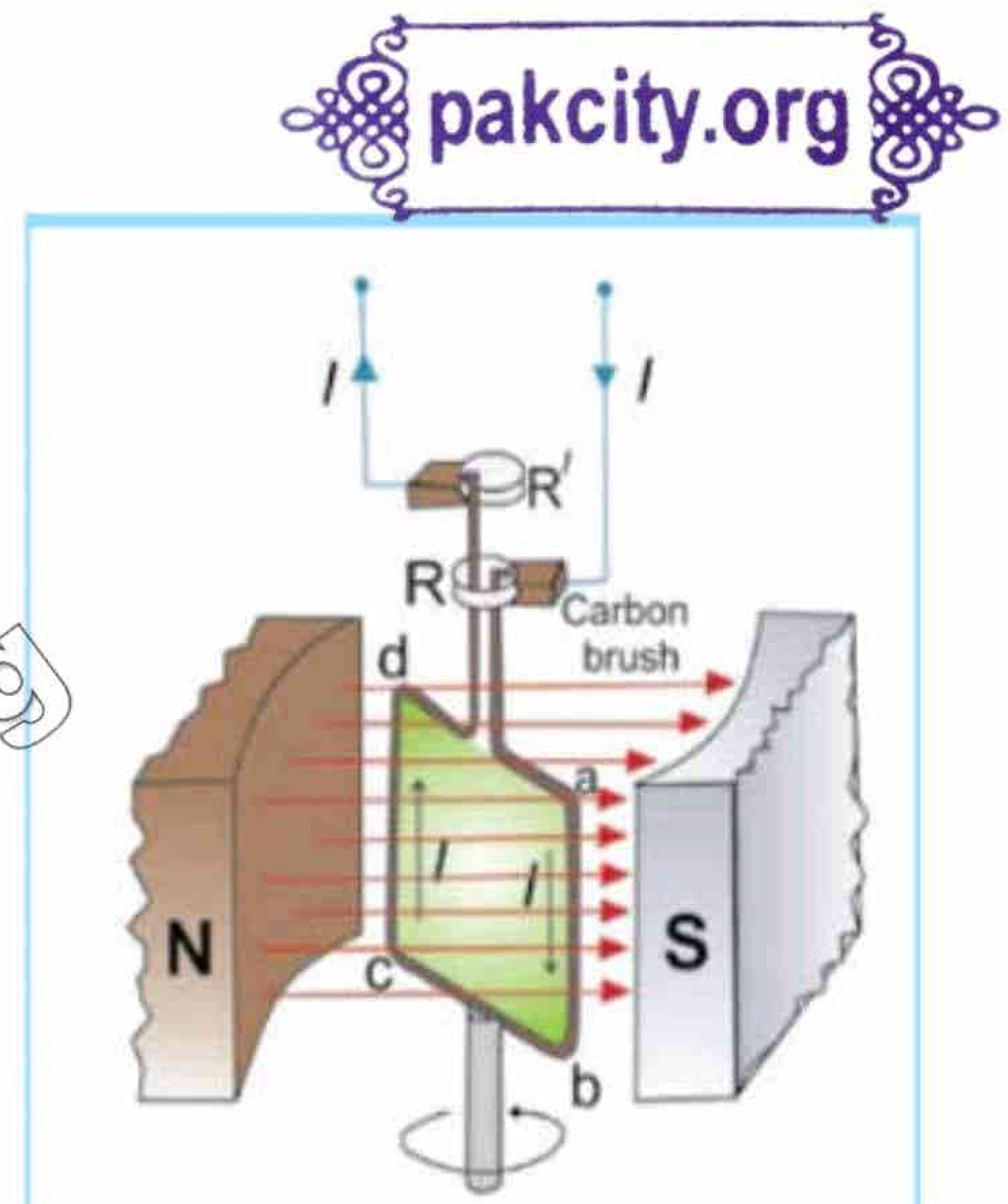
$\varepsilon_o = N\omega AB$

equation (1) is $\varepsilon = \varepsilon_o\sin(\omega t)$,

if the resistance of coil then by Ohm.'s law induced current will be

$I = \frac{\varepsilon}{R} = \frac{\varepsilon_o\sin(\omega t)}{R} = \frac{\varepsilon_o}{R}\sin(\omega t) = I_o\sin(\omega t)$ if angular speed $\omega = 2\pi f$

$\varepsilon = \varepsilon_o\sin(2\pi ft)$, $I = I_o\sin(2\pi ft)$ shows that variation of emf and current as function of $\theta = 2\pi ft$



As current alternates its direction once in one cycle so such current is called alternating current.

Multiple choice questions

1	If magnetic field is doubled then magnetic energy density becomes	**Four times**	Two times	Three times	Six times
2	A 50mH coil carries a current of 2A. The energy stored in B is	0.05 J	**0.1 J**	10 J	50 J
3	The value of emf induced in armature of N turns and area	**2πf NAB**	2πfN2AB	NIfAB	4πf2NAB

	A rotating in magnetic field B with frequency f is given by				
4	Energy stored in inductor is given by	½ cV^2	**½ LI^2**	½ BL^2	None
5	Which converts the mechanical energy into electrical energy	Transformer	Galvanometer	**Ac generator**	D.C motor
6	An inductor may store energy in its	Electric field	**Magnetic field**	Coils	Neighboring circuit
7	Maximum value of induced emf in the coil of A.C generator is	NBA/W	**NωAB**	BA	NIAB
8	Energy density of inductor is	$B^2/2\mu o^2$	μo/2B	$\mu o/2B^2$	**$B^2/2\ \mu o$**
9	The principle of AC generator is	Coulomb law	Ampere law	**Faraday law**	Lenz law
10	Energy stored per unit volume inside a solenoid is called	Electric flux	**Energy density**	Work	Volume charge density
11	Alternating current generator converts which type of energy into electrical energy	**Mechanical energy**	Chemical energy	Solar energy	Potential energy
12	Magnetic potential energy	Under root	Cube root of	**Square of**	None

	stored in an inductor depends upon	of current	current	**current**	
13	The work stored in inductor as a	Kinetic energy	Elastic potential energy	**Magnetic potential energy**	Gravitational potential energy
14	Which of the following is not present in alternating current generator	Armature	Magnet	Slip rings	**Commutator**
15	The most common source of AC voltage is	Motor	Cell	**Generator**	Thermocouple
16	AC generator uses	Coiled rings	Split rings	**Slip rings**	Solenoid rings
17	In AC inductor behaves as	Capacitor	**Resistor**	Commutator	Transistor
18	A device which convert mechanical energy into electrical energy is called	Dc motor	**Generator**	Capacitor	Inductor
19	Principle of AC generator is	Self induction	**Electromagnetic induction**	Mutual induction	All of these
20	If 10A current passes through 100mH inductor, then energy stores is	100 J	**5J**	20J	Zero
21	If magnetic field/current is doubled then energy stored in inductor	Becomes two times	**Becomes four times**	Becomes half	Becomes zero

22	Assembly of coil and cylinder is called	Generator	**Armature**	Router	Solenoid
23	If speed of rotation of AC generator becomes double, then output voltage	Remains same	**Becomes double**	Becomes half	Becomes zero

What is DC generator? Write its principle, construction and working.

DC generator: "A device which converts mechanical energy into electrical energy and gives direct current at its output is called DC generator".

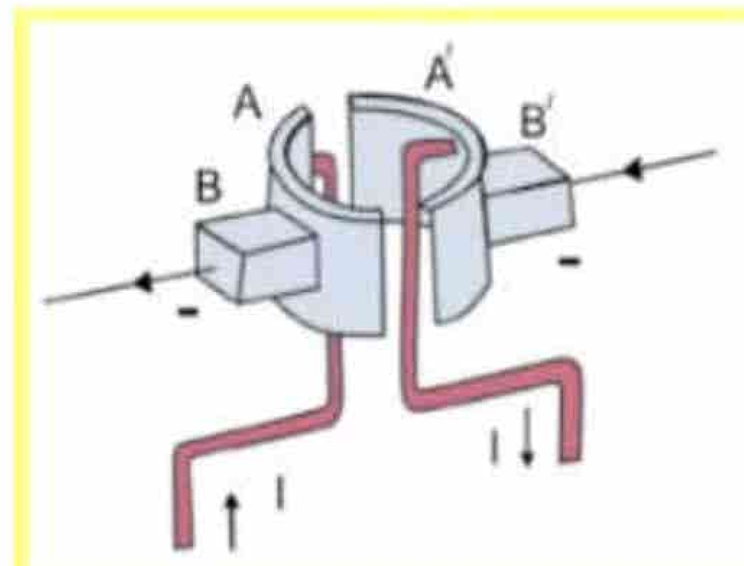
Principle of DC generator: DC generator works on the principle of Faraday law of electromagnetic induction.

Major parts of DC generator: There are following major parts

i. Armature

ii. Split rings (commutator):

Two halves of a rings/split rings which prevents
The direction of current from changing is called commutator.
William Sturgeon invented the commutator In 1834



iii. Carbon brushes

Working: When the current in the coil is zero and is about to change the direction, the split rings also changes the contact with carbon brushes, in this way the output remains in same direction although the current is not constant in magnitude, the curve is similar to sine curve with lower half inverted.

Fluctuations in output of DC can be reduced by: It can be reduced by using many coils rather than a single coil and each coil is connected to separate commutator to get maximum output.

What is Difference b/w AC generator and DC generator?

Both generators convert mechanical energy into electrical energy differences are following

AC generator	DC generator
Its output in AC form	Its output in DC form
It uses slip rings	It uses split rings

Both workon same principle "Faraday law of electromagnetic induction".

What is Back motor effect in generator?

How a turbine run : In order to run a turbine, the shaft of turbine is attached to the coil which rotates in magnetic field, it converts the mechanical energy of driven turbine to electrical energy. the generator supplies current to external circuit.

Back motor effect:

An effect produced by the forces acting on the coil placed in the magnetic field that opposes the rotational motion of coil is called back motor effect.

Load:

The generators supplies current to devices in external circuit is called load, greater the load, larger is the current supplied by generator. For open circuit generator does not supply electrical energy, for closed circuit current is drawn.

Write a note on DC Motor.

DC motor: "An electrical device which converts electrical energy into mechanical energy is called DC motor".

Principle: DC motor works on the principle "A current carrying conductor placed in magnetic field experience a force".

Construction: A DC motor is similar to DC generator in construction having magnetic field, commutator and armature, instead of rotating coil electric current is applied to coil which rotate in magnetic field. In DC motor, the brushes are connected to DC supply or battery.

Working: When current flows in the coil the force on the conductor produce a torque that rotate the coil. The amount of torque depends upon the current, the strength of field, the area of coil and number of turns. The magnetic field in motor is provided by a permanent magnet or electromagnet.

Field coils: The windings of electromagnet are called field coils. It may be series or in parallel to armature coils.

How jerks in smooth running of armature can be reduced: It is overcome by using more than one coil wrapped around a soft iron core which produces more steady torque.

What is DIFFERENCE B/W MOTOR AND GENERATOR?

Generator	Motor
It converts mechanical into electrical energy	It converts electrical into mechanical energy
It may uses slip and split rings	It uses only split rings
Mechanical work is input	Mechanical work is output
Electric current is output	Electric current is input

What is BACK EMF IN MOTOR

Back emf in motor: An emf induced in the motor which opposes the actual emf is called back emf in motor.

Relation b/w back emf and current: Since V and ε are opposite in polarity, then net emf will be V-ε so the value of current will be $I = \frac{V - \varepsilon}{R}$, $IR = V - \varepsilon$, $V = \varepsilon + IR$

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Why induced emf is called back emf of motor: When the coil of motor rotates across the magnetic field by applied potential difference, an emf induced in it, this induced emf is in such a direction to oppose the applied emf, that's why induced emf is called back emf.

Important points about back emf:

- ✓ If motor is just started back emf is almost zero and large current pass through coil.
- ✓ If motor is running at normal speed back emf becomes maximum and current becomes minimum.
- ✓ If motor is overloaded back emf decreases and allow the motor to draw more current
- ✓ If motor is overloaded beyond its limit the current could be so high that it may burn out the motor.

What is Transformer? Explain its principle, construction and working.

Definition: "**An electrical device which changes a given AC voltage into larger or smaller AC voltage is called transformer**".

Principle of transformer: Transformer works on the principle of **Mutual induction** b/w two coils. A changing current in the primary coil induce an emf in the secondary coil.

Construction: There are two coils used in transformer

Primary coil: The coil to which AC power is supplied

Secondary coil: The coil which delivers power to output. Both coils are magnetically linked.

Working: When an alternating emf is supplied to primary the, if at the some instant t the flux in primary is change then there will be back emf induced in primary which oppose the applied voltage.

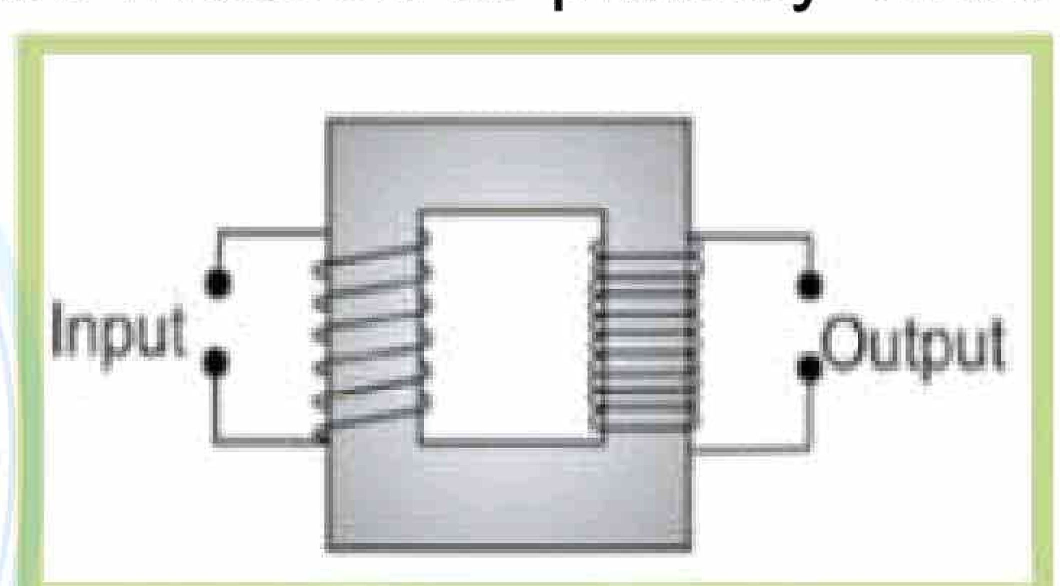


Fig.15.21 (a) Step up transformer

$$\text{Self induced emf} = -N_p\frac{\Delta\phi}{\Delta t},\ \text{If resistance of coil is negligible then}$$

$$Vp = -\text{back emf}$$

$$Vp = -\left(-N_p\frac{\Delta\phi}{\Delta t}\right) \Rightarrow Vp = \left(N_p\frac{\Delta\phi}{\Delta t}\right) ----------(1)$$

As change of flux in primary coil and secondary coil is same so

$$Vs = \left(N_s\frac{\Delta\phi}{\Delta t}\right) ---------------(2)$$

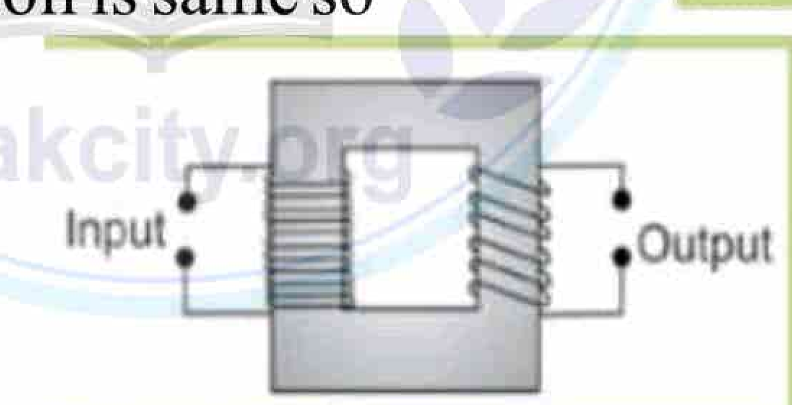
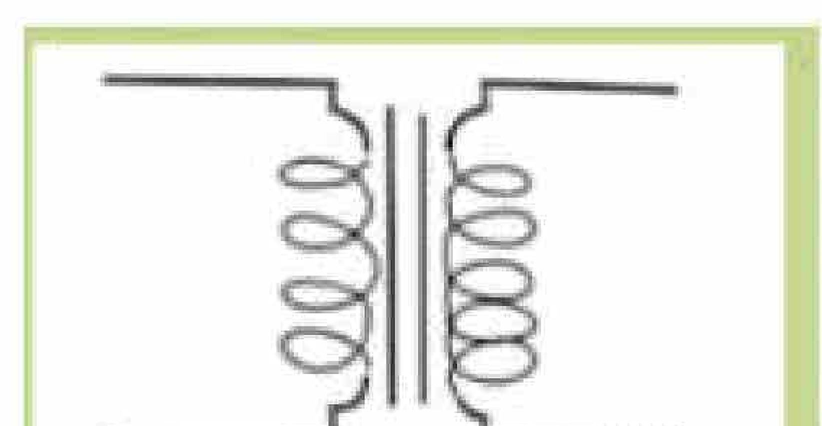


Fig.15.21 (b) Step down transformer

For transformation ratio dividing (2) by (1)

$$\frac{Vp}{Vs} = \frac{\left(N_p\frac{\Delta\phi}{\Delta t}\right)}{\left(N_s\frac{\Delta\phi}{\Delta t}\right)} = \frac{Np}{Ns} \Rightarrow or\ \frac{Vs}{V_p} = \frac{Ns}{Np},\ \text{This is transformation ratio equation}$$


Transformer symbol

Types of Transformer: There are are following types of transformer

Step-up transformer: Such a trtransformer in which voltage across thethe secondary is greater than primary voltage is cacalled step up transformer as Ns>Np p so Vs>Vp. **Step-down transformer:**Such uch a transformer in which voltage acrossoss the secondary is less then primary voltage is callecalled step down transformer. Ns<Np, Vp, Vs<Vp.

In Ideal transformer: The out power is equal to input power Power input= power output $V_pI_p=V_sI_s$ $V_p/V_s=I_s/I_p$

For an actual transformer the output power is always less than input power due to power losses.

Main causes of power loss in transformer: There are two main causes of power loss in transformer.

Eddy currents: The induced current which is setup in direction perpendicular to flux so as oppose the cause that produce them is called eddy current Eddy current cause the energy loss in core due to heat produced in it.

Such a loss can be reduced by using laminated core with insulation b/w layers of lamination sheets

Hysteresis loss: The energy used to magnetize and demagnetize the core material in each cycle of Ac is called hysteresis loss.This loss can be reduced by using soft iron core

Efficiency of transformer: $E = \frac{\text{outputpower}}{\text{inputpower}} \times 100$

Multiple choice questions

1	An ideal transformer obey the law of conservation of	Flux	Momentum	**Energy**	Charge
2	The device which converts electrical energy into mechanical energy is called	Transformer	Galvanometer	Ac generator	**D.C motor**
3	The core of transformer is made of iron because of	High melting point	Good conductor of electricity	Good conductor of heat	**Magnetic material**
4	The frequency of AC in Pakistan is	30Hz	40Hz	**50Hz**	100Hz
5	Which one is correct relation for transformer is	Ns/Np=Vp/Vs	Is/Ip=Vs/Vp	Ns/Np=Ip/Is	**$I_s/I_p=V_p/V_s$**
6	The power loss in transformer due to	Eddy current	Magnetic field	Hysteresis	**Both A&C**
7	When motor is just started, back emf is almost	Maximum	**zero**	Minimum	Infinite
8	Turn ratio of transformer is 50 if the 220V is applied to its primary coil . voltage in secondary coil will be	44V	**4.4V**	220V	1100V
9	A transformer works on	**A.C only**	D.C only	Both A&B	Has no

					loss
10)	Eddy current produced in the core of transformer are responsible for	**Heat loss**	Step up process	Step down process	Induction phenomenon
11)	In non ideal transformer, which quantity remains unchanged?	Power	**Frequency**	Current	Voltage
12)	The practical application mutual induction is	Electric motor	**Transformer**	Generator	None
13)	To construct a step down transformer	**Ns<Np**	Ns>Np	Ns=Np	None
14)	Inductance of coil in transformer is increased by using	Paramagnetic core	Diamagnetic core	**Ferromagnetic core**	Anti-ferromagnetic core
15)	Hysteresis produced in transformer is responsible for	**Energy loss**	Step up process	Step down process	EM induction
16)	If motor is overloaded then the magnitude of back emf	Increases	**Decrease**	Constant	Becomes zero
17)	Which of the following is not present in alternating current generator	Armature	Magnet	Slip rings	**Commutator**
18)	When back emf is zero it draws current	Minimum	**Maximum**	Zero	Steady
19)	When back emf in the generator is maximum it draw	Maximum current	Steady current	**Zero current**	None
20)	Eddy current are produced in a material when it is placed in	**Time varying field**	Moving	At rest	None
21)	Which of the following is correct step up transformer?	Np>Ns	**Np<Ns**	Np=Ns	None
22)	Commutators are used in	**DC generator**	AC generator	AC motor	AC rotator
23)	Commutator was invented in	1736	**1834**	1935	1885

24)	Working principle of transformer is	Self induction	Faraday law	**Mutual induction**	EM induction
25)	The winding of electromagnet in motor are usually called	Magnetic coils	**Field coils**	Electric coils	None
26)	A simple device which prevents the direction of current from changing is	Capacitor	Resistor	**Commutator**	Inductor
27)	If a step up transformer were 100% efficient, the primary and secondary windings would have same	Current	**Power**	voltage	Direction

EXERCISE SHORT QUESTIONS

1.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?**

a)No, induced emf does not depend upon the resistance of circuit. Because According to Faraday law $\varepsilon = -N\frac{\Delta\varphi}{\Delta t}$ induced emf depends upon rate of change of flux.

b)Yes, induced current depends upon resistance of circuit, as I=ε/R so induced current is inversely proportional to resistance.

2. A square loop of wire is moving through a uniform magnetic field. The normal to the loop is oriented parallel to the magnetic field. Is a emf induced in the loop? Give a reason for your answer.

No, emf is not induced in square loop. Because in this case the magnetic flux through loop is constant so rate of change of flux is zero and induced emf is directly proportional to rate of change of flux, so it will be zero.

$\varepsilon = -N\frac{\Delta\varphi}{\Delta t} = -N\frac{(0)}{\Delta t} = 0$

3. A light metallic ring is released from above into vertical bar magnet viewed for above for above, does the current flow clockwise or anticlockwise in the ring?

When viewed from above, the current in the ring is clockwise: and according to Lenz's law direction of induced current is opposing the downward motion of ring so face of ring towards magnet acts as north pole, so according to right hand rule induced current must be clock wise

4.*What is the direction of the current through resistor R when switch S is (a) closed (b) opened

a) The direction of current through Resistor R is from left to right when switch is closed the primary coil increases from zero to maximum steady value.
b) In this case direction of current through R from right to left.

5.Does the induced emf always act to decrease the magnetic flux through a circuit?**

No, it always opposes the change in magnetic flux through a circuit. According to Lenz's law the induced emf always opposes the cause that produces it. So if magnetic flux is decreasing through circuit induced emf acts to increase the magnetic flux through circuit and vice versa.

6. When the switch in the circuit is closed a current is established in the coil and the metal ring jumps upward why? Describe what would happen to the ring if the battery polarity were reversed?

The induced magnetic field in the ring opposes the magnetic field of the coil (according to Lenz's law). Therefore the ring experience a force of repulsion and jumps up. The same event occurs even if the polarity of the battery is reversed.

7. The Fig shows a coil of wire in the xy plane with a magnetic field directed along the y-axis. Around which of the three coordinate axes the coil should be rotated in order to generate an emf and a current in the coil?

If the coil is rotated about x-axis, then there is a change of magnetic flux passing through a coil. So only in this case, an emf is induced in the coil.

8. **How would you position a flat loop of wire in a changing magnetic field so that there is no emf induced in the loop?

If the plane of loop of wire is placed parallel to changing magnetic field i.e.,, then no flux through it will change. Hence no emf will be induced through the loop as

$$\varepsilon = -N\frac{\Delta\varphi}{\Delta t} = -N\frac{(0)}{\Delta t} = 0$$

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

When the plane flies due north in the earth magnetic field directed vertically downward, then electrons will experience force in east direction. Thus west wingtip of the plane is positively charged.

10. Show that ε and $\frac{\Delta\Phi}{\Delta t}$ have the same units?**

$$\text{unit of } \varepsilon = \text{volt} = \frac{\text{J}}{\text{C}} ----(1)$$

$$\text{unit of } \frac{\Delta\varphi}{\Delta t} = \frac{\text{web}}{\text{sec}} = \frac{\text{NmA}^{-1}}{\text{sec}} = \frac{Nm}{A\,\text{sec}} = \frac{J}{C} --(2)$$

As Nm = J and Asec = C   Hence, proved.

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11. 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?

Yes it acts like a generator.
When the coil of motor rotates in magnetic field, the magnetic flux through coil changes so emf is induced which oppose the applied emf. It limits the current flowing through coil of motor.

12. Can a D.C motor be turned into a D.C generator? What changes are required to be done?**

Yes, a DC motor be turned into a DC generator
In order to convert DC motor into a DC generator, two changes are to be done

i. Electromagnet is replaced by permanent magnet
ii. An arrangement to rotate the coil armature should be provided

13. 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?
Yes. If the plane of the loop is kept parallel to the direction of the magnetic field, no emf will be induced in the loop either by changing its area or by changing the magnetic field.

14. Can an electric motor be used to drive an electric generator with the output from the generator being used to operate the motor?**
No it is not possible. Because if it is possible, it will be a self-operating system without getting energy from some external source and this is against the law of conservation of energy.

15. A suspended magnet is oscillating freely in a horizontal plane. The oscillations are strongly damped when a metal plate is placed under the magnet. Explain why this occurs?
When the metal plate is placed under the magnet, a changing magnetic flux passes through the plate which produces an emf, according to Lenz law these eddy current oppose the free oscillations of magnet hence the oscillations of magnets are damped strongly.

16. Four unmarked wires emerge from a transformer. What steps would you take to determine the turn's ratio?**
There are following steps to find turn ratio

i. Coils are separated as primary and secondary by ohmmeter
ii. AC voltage is supplied to primary coil and induced emf is measured
iii. The turn ratio is determined by $\frac{Ns}{Np} = \frac{Vs}{Vp}$

15.17 (a) Can a step-up transformer increase the power level?**
No it cannot increase power level. In case of an ideal transformer, the power output is equal to the power input. In actual transformer, due of dissipation of energy in the coil, the output power is always less than input power. Therefore, a step-up transformer can't increase power level

b) Transformer, there is no transfer of charge from the primary to the secondary. How is, then the power transferred?
The two coils of transformer are magnetically linked i.e., the change of flux through one coil is linked with the other coil.

18. 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) increases when the secondary circuit is closed. Explain these facts.

a) In a transformer power input=power output
$V_pI_p=V_sI_s$ if secondary circuit is open $I_s=0$ then $V_p=0$.

a) When the secondary circuit is closed, the output power increases. To produce this power, transformer will draw large current from the A.C. mains to increase its primary power (V_pI_p).

Chapter = 15

NUMERICALS

15.1: An emf of 0.45V is induced between the ends of a metal bar moving through amagnetic field of 0.22T. What field strength would be needed to produce an emf of 1.5V between the ends of the bar, assuming that all other factors remain the same?

Given Data : $\varepsilon_1 = 0.45\text{V}, B_1 = 0.22\text{T}, \varepsilon_2 = 1.5\text{V}, B_2 = ?$

Using the formula $\varepsilon_1 = vB_1L\sin\theta$ ----- (1) $\varepsilon_2 = vB_2L\sin\theta$ ----- (2) Dividing both eqs.

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{vB_1L\sin\theta}{vB_2L\sin\theta} = \frac{B_1}{B_2} \Rightarrow B_2 = \frac{B_1 * \varepsilon_2}{\varepsilon_1} = \frac{0.22*1.5}{0.45} = 0.73T$$

15.2: The flux density B in a region between the pole faces of a horseshoe magnet is 0.5 Wbm^{-2} directed vertically downward. Find the emf induced in a straight wire 5.0 cm long, perpendicular to B when it is moved in a direction at an angle of 60^{o}with the horizontal with a speed of 100 cms^{-1}.

Given data : $B = 0.5\text{ web/m}^2, L = 5\text{ cm} = 5*10^{-2}\text{ m}$, Angle $= \theta_h = 60^o, \theta_v = 90^o - 60^o = 30^o, v = 100cm/s = 1m/s$

$$\varepsilon = vBL\sin\theta \Rightarrow \varepsilon = (1)(0.5)(5*10^{-2})\sin 30^o = 1.25*10^{-2}V$$

15.3: A coil of wire has 10 loops. Each loop has an area of $1.5\times10^{-3}m^2$. A magnetic field is perpendicular to the surface of each loop at all times. If the magnetic field is changed from 0.05T to 0.06T in 0.1, find the average emf induced in the coil during this time.

Given Data : $N = 10, A = 1.5*10^{-3}\text{m}^2, B_1 = 0.05\text{T}, B_2 = 0.06\text{T}, \Delta B = 0.06 - 0.05 = 0.01\text{T}, \Delta t = 0.1\sec, \varepsilon = ?$

$$\varepsilon = \frac{N\Delta\varphi}{\Delta t} = \frac{N\Delta BA}{\Delta t} = \frac{10*0.01*1.5*10^{-3}}{0.1} = 1.5*10^{-3}V$$

15.4: A Circular coil has 15 turns of radius 2cm each. The plane of the coil lies at 40^{o}to a uniform magnetic field of 0.2 T. If the field is increased by 0.5T in 0.2s, find the magnitude of the induced emf.

Given Data : $N = 15, r = 2\text{cm} = 2*10^{-2}\text{m}$, Angle b/w B and plane of coil $= \theta = 40^o$, Angle b/w A and B $= 90^o - 40^o = 50^o$

$B_1 = 0.2\text{T}, B_2 = 0.5\text{T}, \Delta B = 0.5 - 0.2 = 0.3\text{T}, \Delta t = 0.2\text{sec}$, induced emf $= \varepsilon = ?$

$$\varepsilon = \frac{N\Delta\varphi}{\Delta t} = \frac{NA\Delta B}{\Delta t} = \frac{N\Delta B(\pi r^2)}{\Delta t} = \frac{N\Delta\Delta B(r^2)}{\Delta t} = \frac{15*0.3(3.14*(2*10^{-2})^2)}{0.2} = 1.8*10^{-2}V$$

15.5: Two coils are placed side by side. An emf of 0.8 V is observed in one coil when the current is changing at the rate of 200 As^{-1} in the other coil. What is the mutual inductance of the coils?

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Given Data : emf $= \varepsilon_s = 0.8\text{V}$, Rate of change of current $= \frac{\Delta Ip}{\Delta t} = 200\text{A/sec}, M = ?$

$$M = \frac{\varepsilon}{\frac{\Delta Ip}{\Delta t}} = \frac{0.8}{200} = 40*10^{-3}H = 4mH$$

15.6: A pair of adjacent coils has a mutual inductance of 0.75 H. If the current in the primary changes from 0 to 10A in 0.025 s, what is the average induced emf in the secondary? What is the change in flux in it if the secondary has 500 turns?

Given Data : $M = 0.75\,H, \Delta Ip = 10A - 0A = 10A, \Delta t = 0.025sec, N = 500, \varepsilon_s = ? \Delta\varphi = ?$

$$\varepsilon_s = M\frac{\Delta Ip}{\Delta t} = 0.75*\frac{10}{0.025} = 300V$$

Using Faraday's law, $\varepsilon = N\frac{\Delta\varphi}{\Delta t} \Rightarrow \Delta\varphi = \frac{\varepsilon*\Delta t}{N} = 300*\frac{0.025}{500} = 0.015web = 1.5*10^{-2}\,weber$

15.7: A solenoid has 250 turns and its self-inductance is 2.4 mH. What is the flux through each turn when the current is 2 A? What is the induced emf when the current changes at 20As^{-1}?

Given Data : $N = 250$, Self inductance $= L = 2.5mH = 2.5*10^{-3}\,H, I = 2A, \frac{\Delta I}{\Delta t} = 20A/sec, \varphi = ?, \varepsilon = ?$

Using equation $N\varphi = LI \Rightarrow \varphi = \frac{LI}{N} = \frac{2.5*10^{-3}*2}{250} = 1.92*10^{-5}\,web$

$$\varepsilon = L\frac{\Delta I}{\Delta t} = 2.5*10^{-3}*20 = 48*10^{-3}\,V = 48mV$$

15.8: A solenoid of length 8.0cm and cross sectional area 0.5cm^2 has 520 turns. Find the self-inductance of the solenoid when the core is air. If the current in the solenoid increases through 1.5A in 0.2s, find the magnitude of induced emf in it.

Given Data : length $= l = 8\,cm = 8*10^{-2}\,m, A = 0.5cm^2 = 0.5*10^{-4}\,m^2\ N = 520, \Delta I = 1.5A, \Delta t = 0.2\,sec, L = ?\ \varepsilon = ?$

Using Equation $L = \mu_o n^2 lA = \mu_o (N/l)^2 lA = \mu_o (N^2/l)A = 4\pi*10^{-7}(520)^2*0.5*10^{-4}/8*10^{-2} = 2.12*10^{-4}\,H$

$$\varepsilon = L\frac{\Delta I}{\Delta t} = 2.12*10^{-4}*\frac{1.5}{0.2} = 1.6*10^{-3}\,volt$$

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

Given Data : $I_1 = 100mA, I_2 = 200mA, \Delta I = 200mA - 100mA = 100*10^{-3}\,A, \varepsilon = 40mV = 40*10^{-3}\,V, \Delta t = 0.005sec$

Self inductance = L = ? Increase in energy stored = ΔE = ?

$$L = \frac{\varepsilon}{\Delta I/\Delta t} = \frac{40*10-3}{0.1/0.005} = 2*10^{-3}\,H = 2mH$$

$$\Delta E = \frac{1}{2}L(\Delta E)^2 = \frac{1}{2}2*10^{-3}(100*10^{-3})^2 = 0.03*10-3J = 0.03mJ$$

15.10: Like any field, the earth's magnetic field stores energy. Find the magnetic energy stored in a space where strength of earth's fields is $7\times10^{-5}T$, if the space occupies an area of $10\times10^8\,m^2$ and has a height of 750m.

Given Data : $B = 7*10^{-5}\,T, A = 10*10^8\,m^2,\ L = 750m, Um = ?$

$$Um = \frac{1}{2}\frac{B^2}{\mu_o}(AL) = \frac{1}{2}\frac{(7*10^{-5})2}{4\pi*10^{-7}}(10*10^8*750) = 1.5*10^9\,J$$

15.11: A square coil of side 16cm has 200 turns and rotates in a uniform magnetic field of magnitude 0.05T. If the peak emf is 12V, what is the angular velocity of the coil?

Given Data : Side of square coil = 16cm, Area = $A = 16*16cm^2 = 256*10^{-4} m^2$, N = 200, B = 0.05T, $\varepsilon_o = 12V$, $\omega = ?$

$$\varepsilon_o = N\omega\omega A \Rightarrow \omega = \frac{\varepsilon_o}{NAB} = \frac{12}{200*256*10^{-4}*0.05} = 46.9 rad/sec = 47 rad/sec$$

15.12: A generator has a rectangular coil consisting of 360 turns. The coil rotates at420 rev per min in 0.14 T magnetic field. The peak value of emf produced by the generator is 50V. If the coil is 5.0 cm wide, find the length of the side of the coil.

given Data : $N = 360, \omega = \frac{420*2\pi}{60} = 43.96$ rad/sec, B = 0.14T, $\varepsilon_o = 50V$, width = b = 5cm = 5/100 = 0.05m

length of coil = L = ? using the formula $\varepsilon_o = N\omega\omega A = N\omega\omega(*b)B$

$$L = \frac{\varepsilon_o}{N\omega bB} = \frac{50}{0.14*360*43.96*0.05} = 0.45m$$

15.13: It is desired to make an a.c generator that can produce an emf of maximum value 5kV with 50 Hz frequency. A coil of area 1m² having 200 turns is used as armature. What should be the magnitude of the magnetic field in which the coil rotates?

Given Data : emf = ε_o = 5KV = 5000V, f = 50Hz, $A = 1m^2$, N = 200, B = ?

$$\varepsilon_o = N\omega AB \Rightarrow B = \frac{\varepsilon_o}{N\omega A} = \frac{\varepsilon_o}{N(2\pi f)A} = \frac{5000}{200(2\pi*50)*1} = 0.08T$$

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

Given Data : $\varepsilon_1 = 120V, \omega_1 = 1680 rev/min, \omega_2 = 3360 rev/min, \varepsilon_2 = ?$

As $\varepsilon_1 = N\omega_1 AB$ ----(1) $\varepsilon_2 = N\omega_2 AB$ ----(1) Dividing both eqs

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{N\omega_1 AB}{N\omega_2 AB} \Rightarrow \frac{\varepsilon_1}{\varepsilon_2} = \frac{\omega_1}{\omega_2} \Rightarrow \varepsilon_2 = \frac{\omega_2}{\omega_1}*\varepsilon_1 = \frac{3360}{1680}*120 = 240V$$

15.15: A D.C motor operates at 240 V and has a resistance of 0.5Ω. When the motor is running at normal speed, the armature current is 15A. Find the back emf in the armature.

Given Data : V = 240V, R = 0.5Ω, I = 15A, ε = ?

$$\varepsilon = V - IR = 240 - (15(0.5)) = 232.5 V$$

15.16: A copper ring has a radius of 4.0 cm and resistance of 1.0mΩ. A magnetic field is applied over the ring, perpendicular to its plane. If the magnetic field increases from 0.2T to 0.4T in a time interval of, what is the current in the ring during this interval?

Given Data : radius = r = 4cm = $4*10^{-2}$ m, R = 1mΩ = $1*10^{-3}$ Ω, $B_1 = 0.2T$, $B_2 = 0.4T$, $\Delta t = 5*10^{-3}$ sec

$N = 1, \Delta B = B_2 - B_1 = 0.4 - 0.2 = 0.2T$, I = ? As $I = \frac{\varepsilon}{R}$ ------(1)

$$\varepsilon = N\frac{\Delta\varphi}{\Delta t} = N\frac{\Delta BA}{\Delta t} = N\frac{\Delta B(\pi r^2)}{\Delta t} = 1*\frac{0.2*(3.14*(4*10^{-4})^2)}{5*10^{-3}} = 2.01*10^{-1} V, \text{put in}(1)$$

$$I = \frac{\varepsilon}{R} = \frac{2.01*10^{-1}}{1*10^{-3}} = 201A$$

15.17: A coil of 10 turns and 35cm^2 area is in a perpendicular magnetic field of 0.5T.The coil is 1.0s. Find the induced emf in the coil as it pulled out of the field.

Given Data : $N = 10, A = 35cm^2 = 35*10^{-4} m^2, \Delta B = 0.5 - 0 = 0.5T, \Delta t = 1sec, \varepsilon = ?$

$$\varepsilon = N\frac{\Delta\varphi}{\Delta t} = N\frac{\Delta BA}{\Delta t} = 10*\frac{0.5*35*10^{-4}}{1} = 175*10^{-4}V = 1.75*10^{-2}V$$

15.18: An ideal step down transformer is connected to main supply of 240V. It is desired to operate a 12V, 30W lamp. Find the current in the primary and the transformation ratio?

Given Data : Vp = 240 V, Vs = 12V, powerPo = 30W, Ip = ?, Ns/Np = ?

Ns/Np = Vs/Vp ⇒ 12/240 = 1/20

For an ideal transformer input power = output power ⇒ so $P_o = IpVp \Rightarrow Ip = Po/Vp = 30/240 = 0.125A$