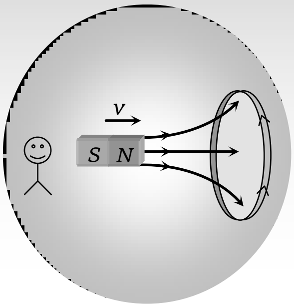
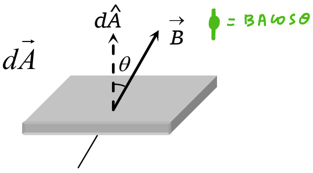
Focus on learning not on writing you will get Notes



Electromagnetic Induction

Magnetic Flux

The total number of magnetic lines of force passing normally through an area placed in a magnetic field is equal to the magnetic flux linked with that area.



For elementary area dA of a surface flux linked $d\phi = B\,dA\cos\theta$ or $d\phi = \vec{B}\cdot d\vec{A}$

So, Net flux through the surface $\boldsymbol{\phi = \oint \vec{B}\cdot d\vec{A} = BA\cos\theta}$

For N-turns coil $\phi = NBA\cos\theta$

$\phi = BA\cos\theta$ uniform , $\phi = \vec{B}\cdot\vec{A}$, $\phi = \int B\,dA\cos\theta$

(1) **Unit and Dimension**

Magnetic flux is a scalar quantity it's S.I. unit is *weber* (*wb*), CGS unit is *Maxwell* or *Gauss* × *cm*^{2}; $1\,wb = 10^8\,Maxwell$. Other units : *Tesla* × m^2 $= \dfrac{N\times m}{Amp} = \dfrac{Joule}{Amp} = \dfrac{Volt\times Coulomb}{Amp} = Volt\times sec$ = *Ohm* × *Coulomb* = *Henry* × *Amp*. It's dimensional formula $[\phi] = [ML^2T^{-2}A^{-1}]$

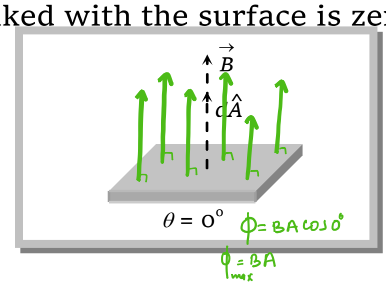
CGS unit is maxwell or Gauss × cm^2

$1\,wb = 10^8$ maxwell

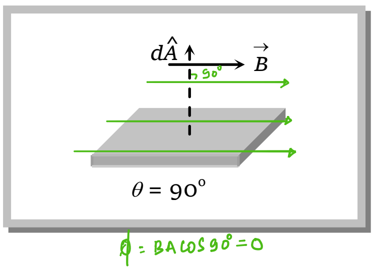
(2) **Maximum and Zero flux**

If $\theta = 0^\circ$, *i.e.* plane is held perpendicular to the direction of magnetic field then flux from the surface is maximum and if $\theta = 90^\circ$ *i.e.* plane is held parallel to the direction of magnetic field then flux linked with the surface is zero.

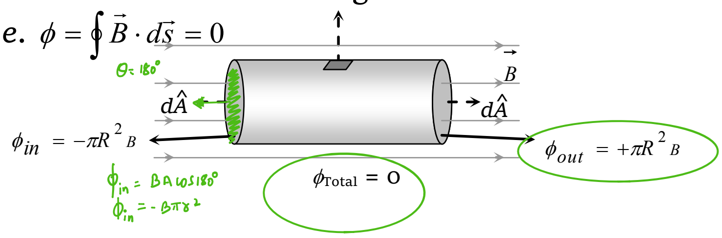
$\phi_{max} = BA$



$\phi = 0$

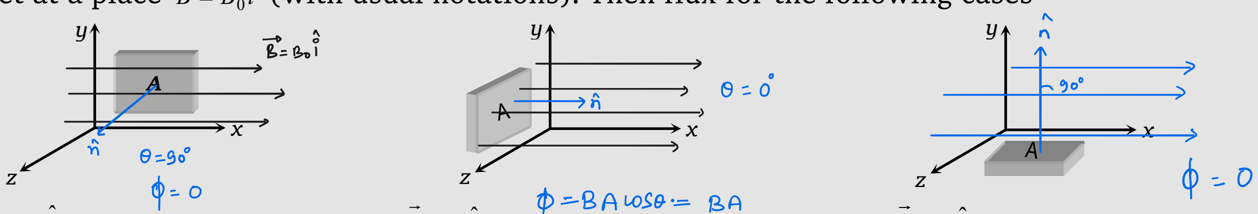


Note : ❐ In case of a body present in a field, either uniform or non-uniform, outward flux is taken to be positive while inward negative and Net flux linked with a closed surface is zero *i.e.* $\phi = \oint \vec{B} \cdot d\vec{s} = 0$



Specific example

Let at a place $\vec{B} = B_0\hat{i}$ (with usual notations). Then flux for the following cases



$\vec{A} = A\hat{k}$

$\phi = \vec{B} \cdot \vec{A} = (B_0\hat{i}) \cdot A\hat{k} = 0$

$\vec{A} = A\hat{i}$

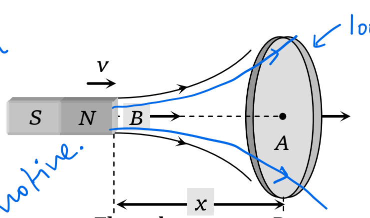
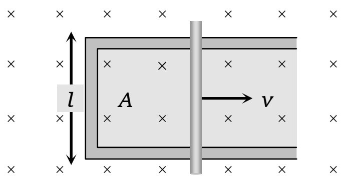
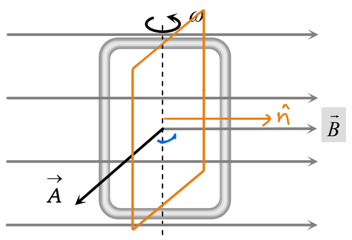
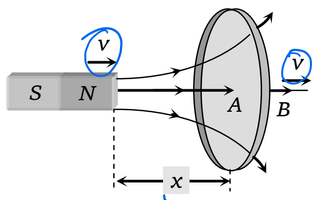
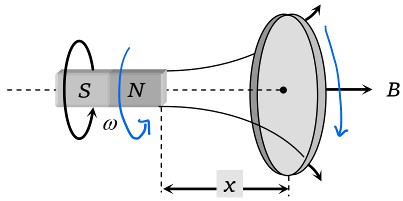
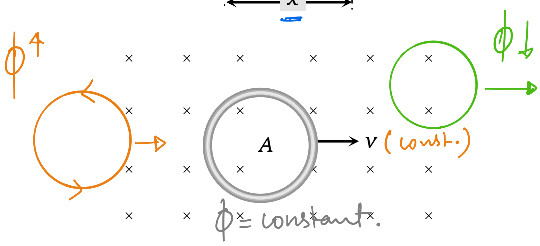
$\phi = \vec{B} \cdot \vec{A} = (B_0\hat{i}) \cdot A\hat{i} = B_0 A$

$\vec{A} = A\hat{j}$

$\phi = \vec{B} \cdot \vec{A} = (B_0\hat{i}) \cdot A\hat{j} = 0$

(3) **Variation of magnetic flux**

We know that magnetic flux linked with an area A is $\phi = BA\cos\theta$ *i.e.* ϕ will change if either B, A or θ will change

Flux changes	Flux not changes
flux will change when there is relative motive.  Flux changes as B  Flux changes as area (swept by rod)  Flux changes as θ changes	   In all these three cases flux ϕ will not change because B, A and θ doesn't change with time

Faraday's Experiment and Laws

(1) **Faradays first law**

Whenever the number of magnetic lines of force (magnetic flux) passing through a circuit changes (or a moving conductor cuts the magnetic flux) an emf is produced in the circuit (or emf induces across the ends of the conductor) called induced emf. The induced emf persists only as long as there is change or cutting of flux.

when flux changes emf will induce.

$$\text{emf} = -N\frac{d\phi}{dt}$$ ← rate of change of flux.

(2) **Faradays second law**

The induced emf is given by rate of change of magnetic flux linked with the circuit *i.e.* $e = -\frac{d\phi}{dt}$.

For N turns $e = -\frac{N\,d\phi}{dt}$; Negative sign indicates that induced emf (e) opposes the change of flux.

(i) **Other forms :**

We know that $\phi = BA\cos\theta$; Hence ϕ will change if either, B, A or θ will change

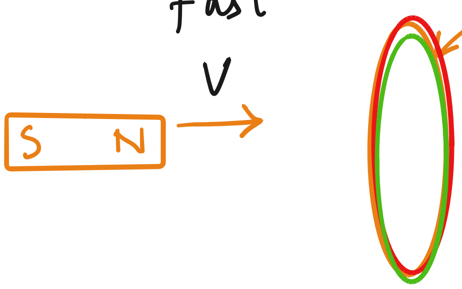
So $e = -N\frac{d\phi}{dt} = -\frac{N(\phi_2-\phi_1)}{\Delta t} = -\frac{NA(B_2-B_1)\cos\theta}{\Delta t} = -\frac{NBA(\cos\theta_2-\cos\theta_1)}{\Delta t}$

Note: ❒ Term $\frac{B_2-B_1}{\Delta t}$ = rate of change of magnetic field, it's unit is *Tesla/sec*

(ii) **Induced current :** If circuit is closed, then induced current is given by $i = \frac{e}{R} = -\frac{N}{R}.\frac{d\phi}{dt}$;
where R is the resistance of circuit

fast v

resistance = R



$$i = \frac{\text{emf}}{R} = \frac{-N\frac{d\phi}{dt}}{R}$$

$$\frac{dQ}{dt} = i = -\frac{N}{R}\frac{d\phi}{dt}$$

$\cancel{dt}$ $R\ \cancel{dt}$, $dQ = -\frac{N}{R} d\phi$

(iii) **Induced charge :** If dq charge flows due to induction in time dt then $i = \frac{dq}{dt}$; $dq = i\,dt = -\frac{N}{R} \cdot d\phi$ i.e. the charge induced does not depend on the time interval in which flux through the circuit changes. It simply depends on the net change in flux and resistance of the circuit.

$\Delta Q = \frac{N}{R}(\Delta \phi) \leftarrow$ indenpendent From time.

(iv) **Induced power :** It exists when the circuit is open or closed $P = ei = \frac{e^2}{R} = i^2 R = \frac{N^2}{R}\left(\frac{d\phi}{dt}\right)^2$.

It depends on time and resistance

$$\text{Power} = Vi = N\frac{d\phi}{dt} \times \frac{N}{R}\frac{d\phi}{dt}$$

$$(\text{Power})_{\text{induced}} = \frac{N^2}{R}\left(\frac{d\phi}{dt}\right)^2$$

(5) **Induced electric field**

It is non-conservative and non-electrostatic in nature.

Its field lines are concentric circular closed curves.

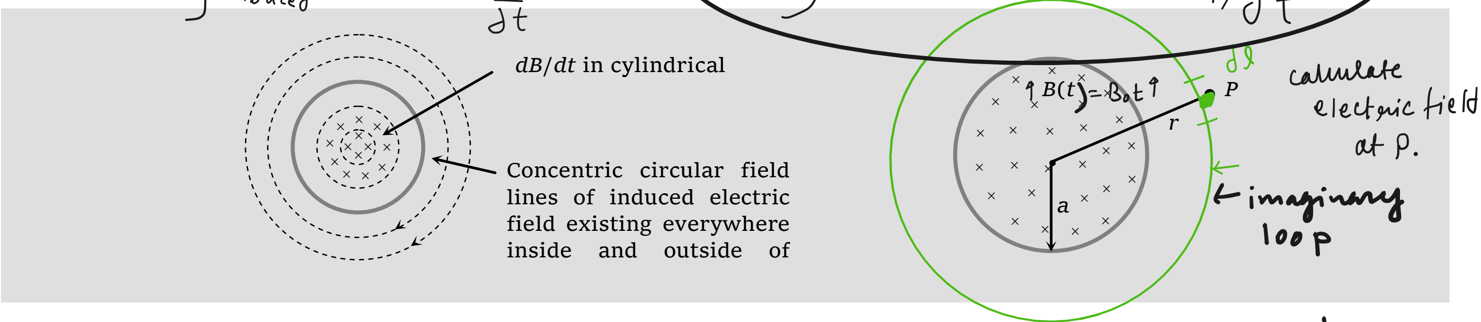
A time varying magnetic field $\frac{dB}{dt}$ always produced induced electric field in all space surrounding it.

Induced electric field is directly proportional to induced emf so $e = \oint \vec{E}_{in} \cdot d\vec{l}$ here $\vec{E}_{in}$ = induced electric field ......(i)

Also Induced emf from Faraday laws of EMI $e = -\frac{d\phi}{dt}$ ......(ii)

From (i) and (ii) $e = \oint \vec{E}_{in} \cdot d\vec{l} = -\frac{d\phi}{dt}$ This is known as integral form of Faraday's laws of EMI.

$\oint \vec{E}_{induced} \cdot \vec{dl} = -\frac{d\phi}{dt}$ $\qquad$ $\oint E\,dl\cos\theta = -d\phi/dt$



$E = \frac{\pi a^2 B_0}{2\pi r}$

$E = \frac{a^2 B_0}{2r}$

$\oint E\,dl\cos\theta = -\frac{d\phi}{dt} = -\frac{d(B\pi a^2)}{dt} = -\frac{d}{dt}\pi a^2 B_0 t$

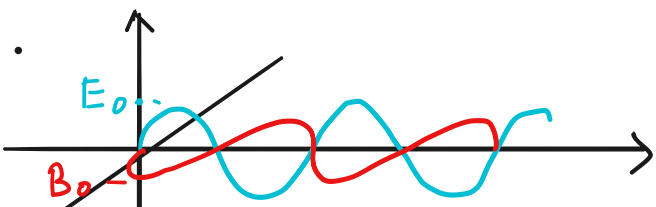
$E\oint dl = \pi a^2 B_0$

$E \times 2\pi r = \pi a^2 B_0$

So $\oint \vec{E}_{in} d\vec{l} = e = \frac{d\phi}{dt} = A\frac{dB}{dt}$ i.e. $E(2\pi r) = \pi a^2 \frac{dB}{dt}$ where $r \geq a$ or $E = \frac{a^2}{2r}\frac{dB}{dt}$; $\boldsymbol{E}_{\text{in}} \propto \frac{1}{r}$

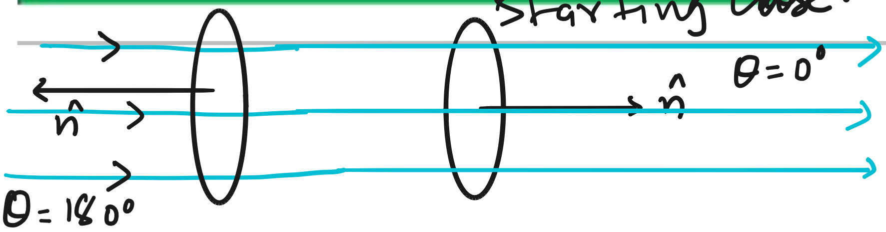
A time varying electric field creates Magnetic field and

A time varying magnetic field can create electric.



$\phi_f = NBA\cos 180^\circ = -NBA$

Starting case.



$\phi_i = NBA\cos 0^\circ = NBA$

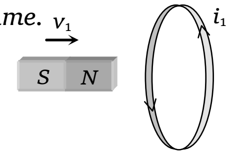
(6) **Change in induced parameter (*e*, *i* and *q*) with change in θ**

Suppose a coil having *N turns*, area of each turn is *A* placed in a transverse magnetic field *B* such that it's plane is perpendicular to the direction of magnetic field *i.e.* initially $\theta_1 = 0^\circ$. If *R* is the resistance of entire circuit and $\phi_1 = NBA\cos 0^\circ = NBA$, is initial flux linked with the coil then.

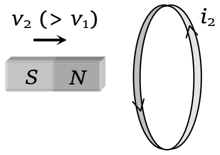
Change	**Final flux (ϕ_2)**	**Change in flux** $\Delta\phi = (\phi_2 - \phi_1)$	**Time taken (Δt)**	**Induced emf** $\lvert e \rvert = \left\lvert -\frac{\Delta\phi}{\Delta t} \right\rvert$	**Induced current** $i = \frac{e}{R}$	**Induced charge** $q = i\Delta t$
Coil turn through 180° (end to end)	$-NBA$	$-2NBA$	t	$\frac{2NBA}{t}$	$\frac{2NBA}{Rt}$	$\frac{2NBA}{R}$
Turn through 90°	Zero	$-NBA$	t	$\frac{NBA}{t}$	$\frac{NBA}{Rt}$	$\frac{NBA}{R}$
Taken out of the field	Zero	$-NBA$	t	$\frac{NBA}{t}$	$\frac{NBA}{Rt}$	$\frac{NBA}{R}$

Concepts

- *If a bar magnet moves towards a fixed conducting coil, then due to the flux changes an emf, current and charge induces in the coil. If speed of magnet increases then induced emf and induced current increases but induced charge remains same.*



Induced parameter : e_1, i_1, q_1



Induced parameter : $e_2\ (> e_1), i_2\ (> i_1), q_2\ (= q_1)$

- *Can ever electric lines of force be closed curve ? Yes, when produced by a changing magnetic field.*
- *It should be kept in mind that the total induced emf in a loop is not confined to any particular point but it is distributed around the loop in direct proportion to the resistance of it's parts.*

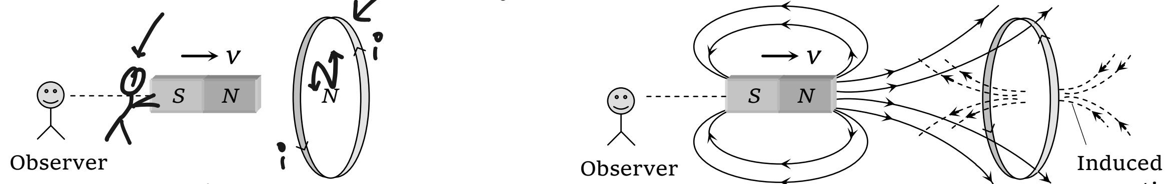
Lenz's law

This law gives the direction of induced emf/induced current. According to this law, the direction of induced emf or current in a circuit is such as to oppose the cause that produces it. This law is based upon law of conservation of energy. To understand the Lenz's law consider the followings.

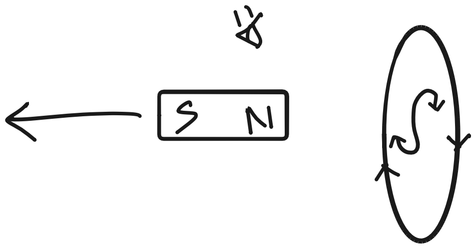
(1) **Motion of bar magnet towards a coil**

emf → current → Magnetic field

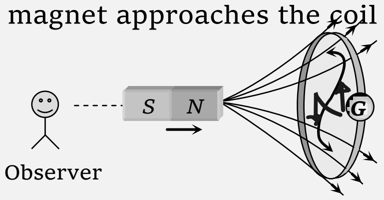
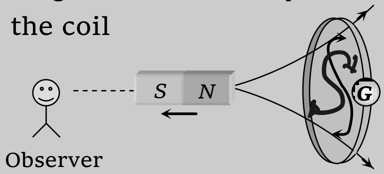
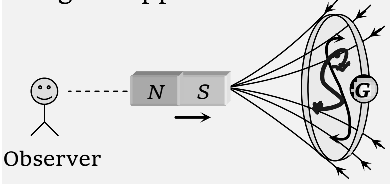
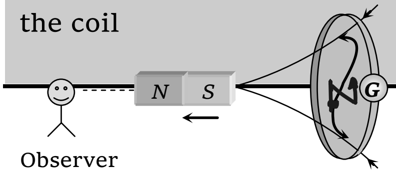
work efforts



(i) (ii)



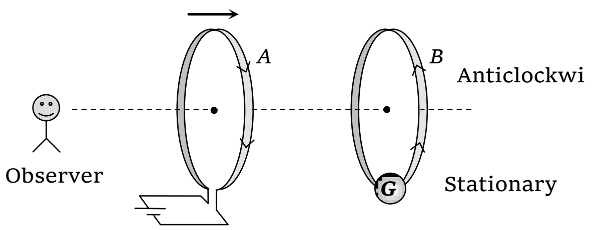
(2) **The various positions of relative motion between the magnet and the coil**

Position of magnet	**Direction of induced current**	**Behaviour of face of the coil**	**Type of magnetic force opposed**	**Magnetic field linked with the coil and it's progress as viewed from left**
When the north pole of magnet approaches the coil 	Anticlockwise direction	As a north pole	Repulsive force	Cross (×), Increases
When the north pole of magnet recedes away from the coil 	Clockwise direction	As a south pole	Attractive force	Cross (×), Decreases
When the south pole of magnet approaches the coil 	Clockwise direction	As a south pole	Repulsive force	Dots (·) Increases
When the south pole of magnet recedes away from the coil 	Anticlockwise direction	As a north pole	Attractive force	Dots (·) Decreases

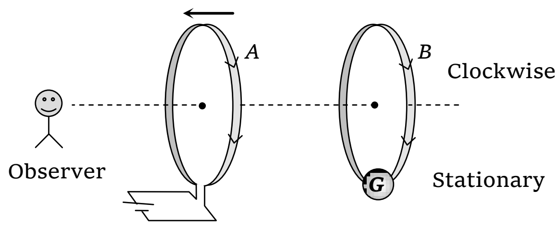
Some Standard Cases for Questions Based on Direction

(1) **Relative motion between co-axial circular coils**

(i) When a current carrying coil moves towards/away from a stationary coil



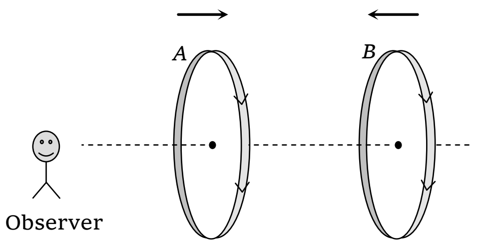
Induced current in coil B is opposite to the main current



Induced current in coil B is in the same direction to the main

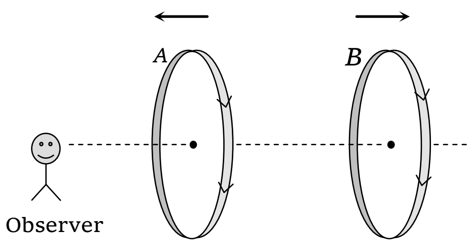
(ii) When two current carrying coils carries currents in the same direction and

Moves towards each other



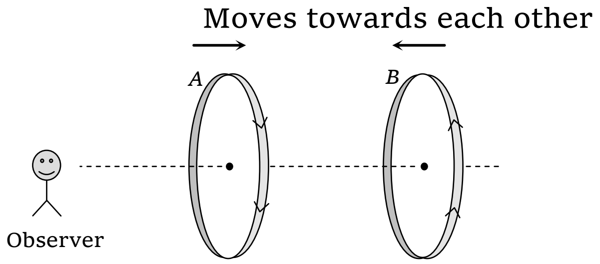
Induced current in both the coils opposite to that of main current so current through each coil decreases

Moves away from each other

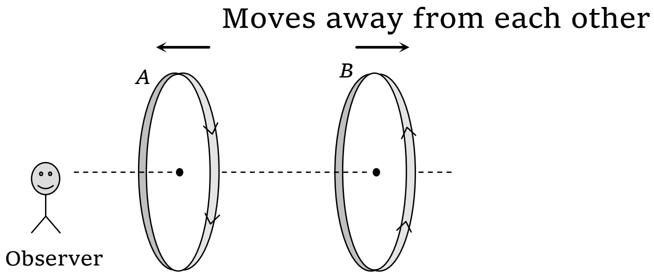


Induced current in both the coils assist the main current so current through each coil increases

(iii) When two current carrying coils carries currents in the opposite direction and



Induced current in coil A is clockwise and that in coil B is anti-clockwise *i.e.* in both the coils induced current flows in the direction of main current. Hence current through both the coil increases

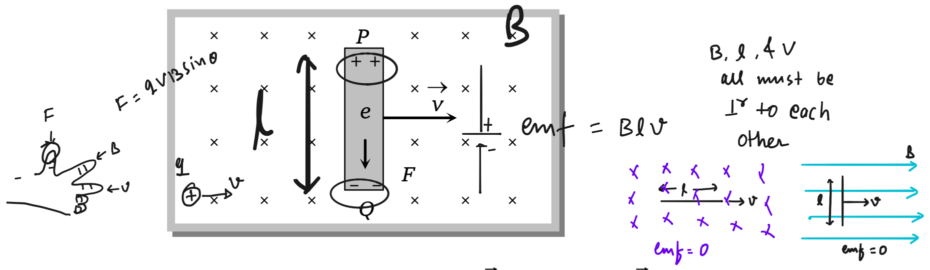


Induced current in coil A is anti-clockwise and that in coil B is clockwise *i.e.* in both the coils induced current flows in the direction opposite to main current. Hence current through both the coil decreases

Dynamic (Motional) EMI Due to Translatory Motion

When a conducting rod moves in a magnetic field, it cuts the magnetic field lines, this process is called flux cutting. Due to this a potential difference developed across the ends of the rod called Dynamic (motional) emf.

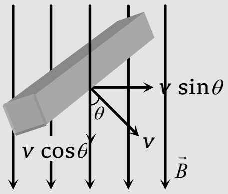
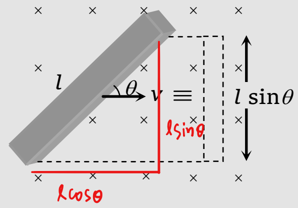
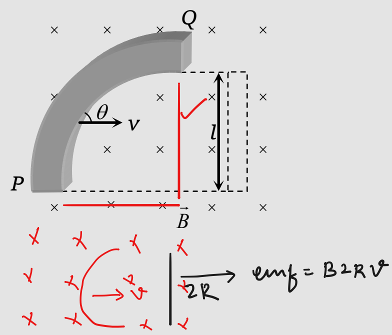
Consider a conducting rod of length l moving with a uniform velocity $\vec{v}$ perpendicular to a uniform magnetic field $\vec{B}$, directed into the plane of the paper. Let the rod be moving to the right as shown in figure. The conducting electrons also move to the right as they are trapped within the rod.



Conducting electrons experiences a magnetic force $\vec{F}_m = -e(\vec{v} \times \vec{B})$. In the present situation they experiences force towards Q, so they move from P to Q within the rod. The end P of the rod becomes positively charged while end Q becomes negatively charged, hence an electric field is set up within the rod which opposes the further downward movement of electrons *i.e.* an equilibrium is reached and in equilibrium electric force = magnetic force *i.e.* $eE = evB$ or $E = vB$

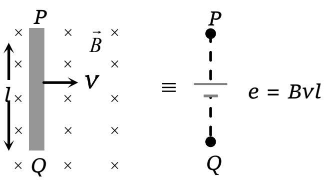
$\Rightarrow$ **Induced emf $e = El = Bvl$** $[E = \frac{V}{l}]$

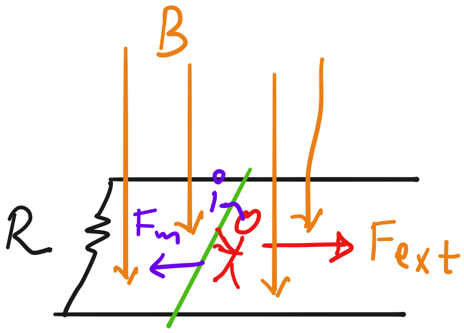
Important cases

If the rod does not translate in a plane perpendicular to the magnetic field or in other words rod is moving in a direction which is making an angle θ with the direction of magnetic field  This situation is equivalent to a straight conductor moving perpendicular to the magnetic field with a induced emf $e = B(v\sin\theta)l$ $\Rightarrow$ $\boldsymbol{e = Bvl\sin\theta}$	If the rod is moving perpendicular to the magnetic field but it's direction of motion is making an angle θ with it's length.  E = Blsinθv This situation is equivalent to a straight rod of length l sinθ perpendicular to it's direction of motion so induced emf across the rod $e = Bv(l\sin\theta) \Rightarrow \boldsymbol{e = Bvl\sin\theta}$	An arbitrary shaped conducting rod translating in a uniform magnetic field.  This rod can be replaced by a straight conductor whose length is equal to the projected length of the conductor on to a plane perpendicular to the direction of motion (dotted rod) so induced emf between P and Q $\boldsymbol{e = Bvl}$

Note : ❒ Vector form of motional emf : $e = (\vec{v} \times \vec{B}).\vec{l}$

❒ While solving the problems, flux cutting conducting rod can be treated as a single cell.





$$(Power)_{ext} = \frac{W}{t} = \frac{Fd\cos 0^\circ}{t}$$

$$(Power)_{ext.\ agent} = F_{ext} V = ilB v$$

$$(Power)_{ext.} = \left(\frac{Blv}{R}\right) lBv$$

$$(Power)_{ext} = \frac{B^2 l^2 v^2}{R}$$

electrical power

$$Power = i^2 R = \left(\frac{Blv}{R}\right)^2 R = \frac{B^2 l^2 v^2}{R}$$

$$F_{ext} = F_{magnetic} = ilB = \frac{Blv}{R}(lB)$$

$$F_{ext} = \frac{B^2 l^2 v}{R}$$

(1) **Induced current**

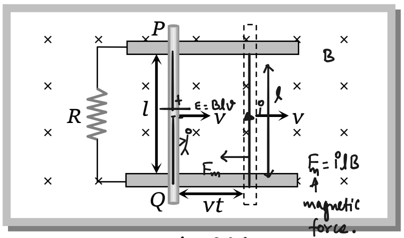
If conducting rod moves on two parallel conducting rails as shown in following figure then phenomenon of induced emf can also be understand by the concept of generated area (The area swept of conductor in magnetic field, during it's motion)

As shown in figure in time t distance travelled by conductor = vt

Area generated $A = lvt$

Flux linked with this area $\phi = BA = Blvt$

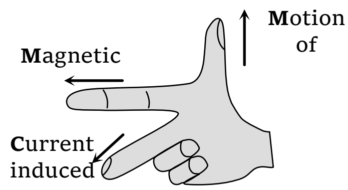
Hence induced emf $|e| = \frac{d\phi}{dt} = Bvl$ induced current $i = \frac{e}{R}$; $\boldsymbol{i = \frac{Bvl}{R}}$



$$i = \frac{emf}{R} = \frac{Blv}{R}$$

Direction of induced current can be found with the help of Flemings right hand rule.

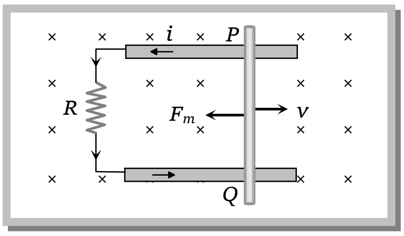
Fleming's right hand rule **:** According to this law, if we stretch the right hand thumb and two nearby fingers perpendicular to one another and first finger points in the direction of magnetic field and the thumb in the direction of motion of the conductor then the central finger will point in the direction of the induced current.



Note : ❒ Here it is worthy to note that the rod PQ is acting as a source of emf and inside a source of emf direction of current is from lower potential to higher potential; so the point P of the rod is at higher potential than Q though the current in the rod PQ is from Q to P.

(2) **Magnetic force on conductor**

Now current is set up in circuit (conductor). As we know when a current carrying conductor moves in a magnetic field, it experiences a force F_m = Bil (maximum) whose direction can be find with the help of Flemings left hand rule.

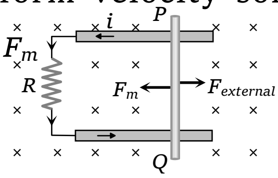


So, here conductor PQ experiences a magnetic force F_m = Bil in opposite direction of it's motion and $F_m = Bil = B\left(\frac{Bvl}{R}\right)l$; $F_m = \frac{B^2vl^2}{R}$

(As a result of this force (F_m) speed of rod decreases as time passes.)

Note : ❐ To move the rod with uniform velocity some external mechanical force is required and this is F_{ext} = – F_m

$\Rightarrow |F_{ext}| = \frac{B^2vl^2}{R}$



(3) **Power dissipated in moving the conductor**

For uniform motion of rod PQ, the rate of doing mechanical work by external agent or mech. Power delivered by external source is given as $P_{mech} = P_{ext} = \frac{dW}{dt} = F_{ext}.v = \frac{B^2vl^2}{R} \times v \Rightarrow$

$$P_{mech} = \frac{B^2v^2l^2}{R}$$

Also electrical power dissipated in resistance or rate of heat dissipation across resistance is given as

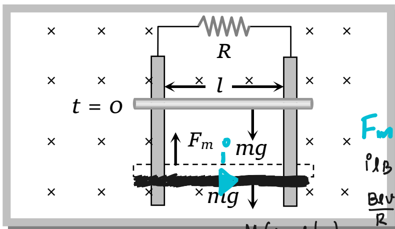
$$P_{thermal} = \frac{H}{t} = i^2R = \left(\frac{Bvl}{R}\right)^2 .R\ ; \quad P_{thermal} = \frac{B^2v^2l^2}{R}$$

Note : ❐ It is clear that $P_{mech.}$ = $P_{thermal}$ which is consistent with the principle of conservation of energy.

(4) **Motion of conductor rod in a vertical plane :** If conducting rod released from rest (at t = 0) as shown in figure then with rise in it's speed (v), induces emf (e), induced current (i), magnetic force (F_m) increases but it's weight remains constant.

Rod will achieve a constant maximum (terminal) velocity v_T if

So $\qquad \frac{B^2v_T^2l^2}{R} = mg$



$F_m = mg$

$ilB = mg$

$\frac{Bvl}{R} lB = mg$

v (const.)

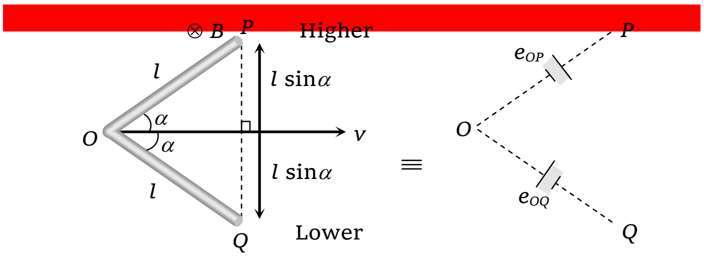
terminal vel.

$v = \frac{mgR}{B^2l^2}$

terminal vel.

$$\Rightarrow \qquad v_T = \frac{mgR}{B^2 l^2}$$

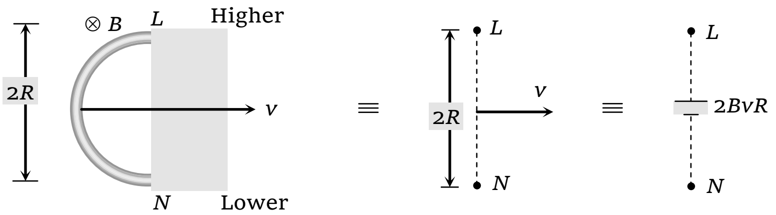
(i) Metal frame of different shape moves in uniform magnetic field



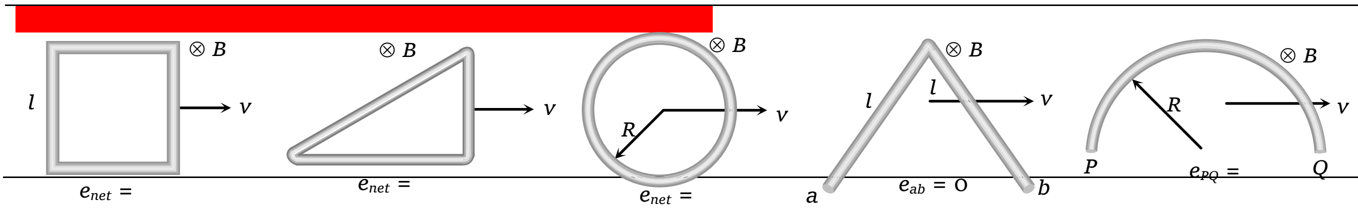
For part OP $e_{OP} = V_P - V_O = Bv\,(l\sin\alpha)$

For part QO $\quad e_{QO} = V_O - V_Q = Bv\,(l\sin\alpha)$

$$e_{QP} = V_P - V_Q = 2Bv\,(l\sin\alpha)$$



$$e_{LN} = 2BvR$$

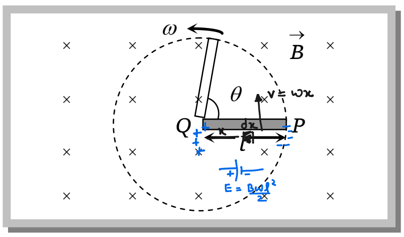


Motional EMI Due to Rotational Motion

(1) **Conducting rod**

$$\int d\,emf = \int B v\,dx = \int_0^{l} B\omega x\,dx$$

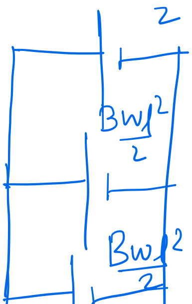
$$V_{PQ} = \frac{B\omega l^2}{2}$$

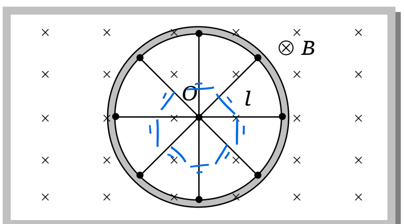


in parallel potential remains same.

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

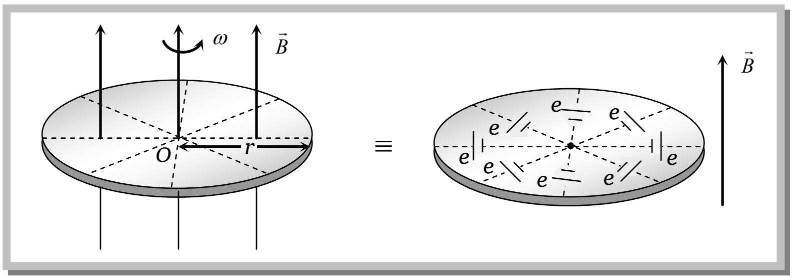
(2) **Cycle wheel**





(3) **Faraday copper disc generator**

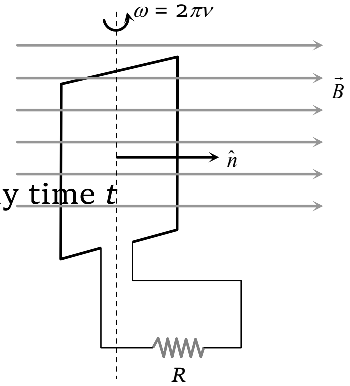
During rotational motion of disc, it cuts away magnetic field lines.



$$emf = \frac{B\omega R^2}{2}$$

Periodic EMI

Suppose a rectangular coil having N turns placed initially in a magnetic field such that magnetic field is perpendicular to it's plane as shown.



ω – Angular speed

ν – Frequency of rotation of coil

R – Resistance of coil

For uniform rotational motion with ω, the flux linked with coil at any time t

$\phi = NBA\cos\theta = NBA\cos\omega t$ (as $\theta = \omega t$)

$\phi = \phi_0 \cos\omega t$ where $\phi_0 = NBA$ = flux amplitude or maximum flux

(This relation shows that the flux changes in periodic nature)

$\phi = BA\cos\theta = BA\cos\omega t$

$\omega = \frac{\theta}{t}, \quad \theta = \omega t$

$emf = -\frac{d\phi}{dt} = -\frac{d}{dt} BA\cos\omega t$

$emf = NBA\omega \sin\omega t$

$(emf)_{max} = NBA\omega$

(1) **Induced emf in coil**

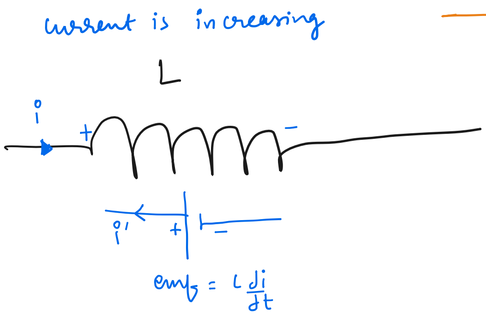
Induced emf also changes in periodic manner that's why this phenomenon called periodic EMI

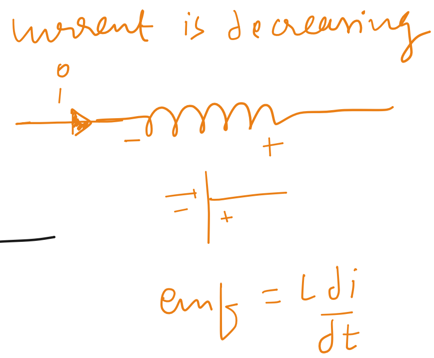
$e = -\frac{d\phi}{dt} = NBA\,\omega \sin\omega t \Rightarrow e = e_0 \sin\omega t$ where e_0 = emf amplitude or max. emf $= NBA\,\omega = \phi_0\omega$

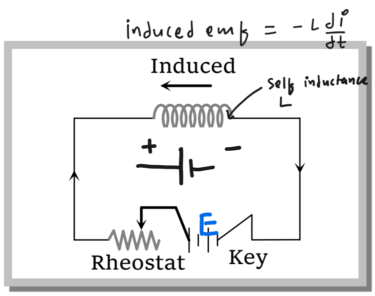
(2) **Induced current**

At any time t, $i = \frac{e}{R} = \frac{e_0}{R} \sin\omega t = i_0 \sin\omega t$ where i_0 = current amplitude or max. current $i_0 = \frac{e_0}{R} = \frac{NBA\,\omega}{R} = \frac{\phi_0\omega}{R}$

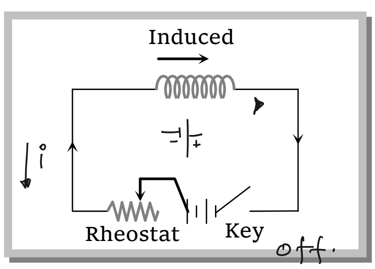
(1) Self-Induction







Main current



Main current

(i) **Coefficient of self-induction :** If no magnetic materials are present near the coil, number of flux linkages with the coil is proportional to the current *i*. *i.e.* $N\phi \propto i$ or $N\phi = Li$ (*N* is the number of turns in coil and $N\phi$ – total flux linkage) where $\boldsymbol{L} = \dfrac{\boldsymbol{N\phi}}{\boldsymbol{i}}$ = coefficient of self induction.

If *i* = 1*amp*, *N* = 1 then, *L* = ϕ *i.e.* the coefficient of self induction of a coil is equal to the flux linked with the coil when the current in it is 1 *amp*.

By Faraday's second law induced emf $e = -N\dfrac{d\phi}{dt}$. Which gives $\boldsymbol{e} = -\boldsymbol{L}\dfrac{\boldsymbol{di}}{\boldsymbol{dt}}$; If $\dfrac{di}{dt} = 1\ Amp\ /\ sec$ then $|e| = L$.

(ii) **Units and dimensional formula of '*L*'**

S.I. unit : $\dfrac{weber}{Amp} = \dfrac{Tesla \times m^2}{Amp} = \dfrac{N \times m}{Amp^2} = \dfrac{Joule}{Amp^2} = \dfrac{Coulomb \times volt}{Amp^2} = \dfrac{volt \times \sec}{amp} = ohm \times \sec$

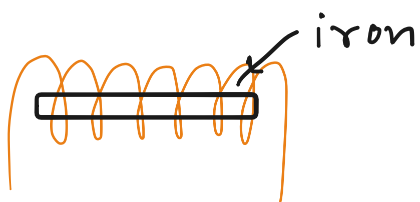
But practical unit is henry (***H***). It's dimensional formula $[L] = [ML^2T^{-2}A^{-2}]$

~~Note :~~ ❐ 1 *henry* = 10^9 *emu* of inductance or 10^9 *ab-henry*.

(iii) **Dependence of self inductance (*L*) :** '*L*' does not depend upon current flowing or change in current flowing but it depends upon number of turns (*N*), Area of cross section (*A*) and permeability of medium (μ). (Soft iron has greater permeability. Hence greater self inductance *L*)

'*L*' does not play any role till there is a constant current flowing in the circuit. '*L*' comes in to the picture only when there is a change in current.

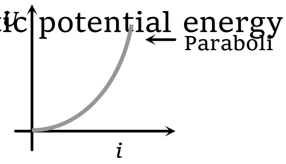
Solenoid →



$L = \mu_0 \pi r^2 n^2 l$ $\quad$ $L' = \mu \pi r^2 n^2 l$

$U = \frac{CV^2}{2}$

(iv) **Magnetic potential energy of inductor :** In building a steady current in the circuit, the source emf has to do work against of self inductance of coil and whatever energy consumed for this work stored in magnetic field of coil this energy called as magnetic potential energy (U) of coil



$$U = \int_0^i Li\,di = \frac{1}{2}Li^2;\ \text{Also}\ \ U = \frac{1}{2}(Li)i = \frac{N\phi i}{2}$$

Note : ❒ Energy density is given as $U = \frac{1}{2}\frac{B^2}{\mu_0}$.

$U = \frac{Li_0^2}{2}$

(v) **Calculation of self inductance for a current carrying coil :** If a coil of any shape having N turns, carries a current i, then total flux linked with coil $N\phi = Li$

Also $\phi = BA\cos\theta$; where B = magnetic field produced at the centre of coil due to it's current; A = Area of each turn; θ = Angle between normal to the plane of coil and direction of magnetic field.

$$\therefore L = \frac{N\phi}{i} = \frac{NBA\cos\theta}{i};\qquad \text{If } \theta = 0^\circ,\ \phi_{max} = BA \quad \text{So} \quad \boldsymbol{L = \frac{NBA}{i}}$$

Circular coil

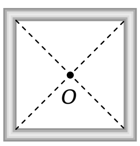
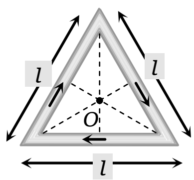
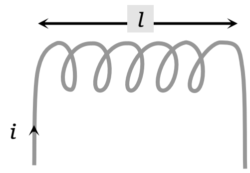
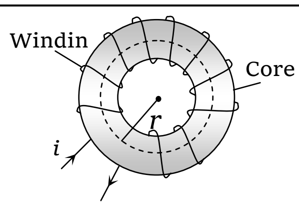
If a circular coil of N turns carrying current i and its each turn is of radius r then its self inductance can be calculated as follows as

Magnetic field at the centre of coil due to its own current $B = \frac{\mu_0}{4\pi} \cdot \frac{2\pi N i}{r}$ $\Rightarrow$

$$L = \frac{N\left(\frac{\mu_0}{4\pi} \cdot \frac{2\pi N i}{r}\right)(\pi r^2)}{i} = \frac{\mu_0 \pi N^2 r}{2}$$

$$\Rightarrow \quad \boldsymbol{L \propto N^2} \Rightarrow \frac{L_1}{L_2} = \left(\frac{N_1}{N_2}\right)^2 \quad \text{(For constant } r\text{)}$$

Other important cases

Square coil	Triangular coil	Solenoid	Toroid
			

$B=\frac{\mu_0}{4\pi}.\frac{8\sqrt{2}\,i}{a}N$ $L=\frac{N\left(\frac{\mu_0}{4\pi}.\frac{8\sqrt{2}Ni}{a}\right)a^2}{i}$ $L=\frac{2\sqrt{2}\mu_0 N^2 a}{\pi}$ $\Rightarrow L\propto N^2$	$B=\frac{\mu_0}{4\pi}.\frac{18\,Ni}{l}$ $L=\frac{N\left(\frac{\mu_0}{4\pi}\frac{18\,Ni}{l}\right)\times\left(\frac{\sqrt{3}}{4}l^2\right)}{i}$ $L=\frac{9\sqrt{3}\,\mu_0 N^2 l}{8\pi}$ $\Rightarrow L\propto N^2$	$B=\mu_0 ni=\frac{\mu_0 Ni}{l}$ $L=\frac{N\left(\frac{\mu_0 Ni}{l}\right).A}{i}$; $L=\frac{\mu_0 N^2 A}{l}$ $\Rightarrow L\propto N^2$ For iron cored solenoid $L=\frac{\mu_0\mu_r N^2 A}{l}=\frac{\mu N^2 A}{l}(\mu=\mu_0\mu_r)$	$B=\frac{\mu_0 Ni}{2\pi r}$ $L=\frac{N\left(\frac{\mu_0 Ni}{2\pi r}\right)\pi r^2}{i}=\frac{\mu_0 N^2 r}{2}$

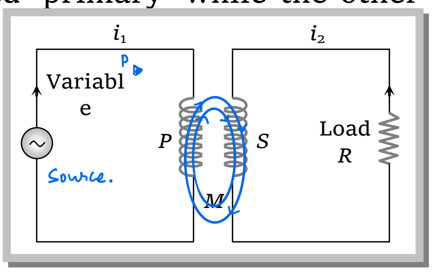
Note: ❒ Inductance at the ends of a solenoid is half of it's the inductance at the centre. $\left(L_{end}=\frac{1}{2}L_{centre}\right)$.

$$emf_s=\frac{-d\phi_s}{dt}=-\frac{d\,Mi_p}{dt}=-M\frac{di_p}{dt}$$

(2) **Mutual Induction** M

$$\phi_s\propto i_p\ ,\ \phi_s=M_{1,2}\,i_p$$

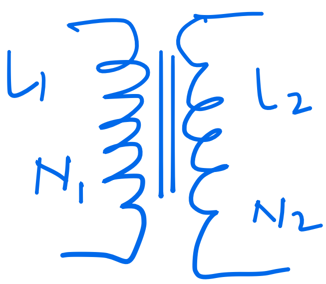
Whenever the current passing through a coil or circuit changes, the magnetic flux linked with a neighbouring coil or circuit will also change. Hence an emf will be induced in the neighbouring coil or circuit. This phenomenon is called ‘mutual induction’. The coil or circuit in which the current changes is called ‘primary’ while the other in which emf is set up is called ‘secondary’.



In case of mutual inductance for two coils situated close to each other, total flux linked with the secondary due to current in the primary is $N_2\phi_2$ and $N_2\phi_2 \propto i_1 \Rightarrow \boldsymbol{N_2\phi_2 = Mi_1}$ where N_1 - Number of turns in primary; N_2 - Number of turns in secondary; ϕ_2 - Flux linked with each turn of secondary; i_1 - Current flowing through primary; M-Coefficient of mutual induction or mutual inductance.

According to Faraday's second law emf induces in secondary $e_2 = -N_2\frac{d\phi_2}{dt}$; $\boldsymbol{e_2 = -M\frac{di_1}{dt}}$; If $\frac{di_1}{dt} = \frac{1\,Amp}{sec}$ then $|e_2| = M$. Hence coefficient of mutual induction is equal to the emf induced in the secondary coil when rate of change of current in primary coil is unity.

Units and dimensional formula of M are similar to self-inductance (L)



(i) **Dependence of mutual inductance**

(a) Number of turns (N_1, N_2) of both coils

(b) ~~Coefficient of self inductances~~ (L_1, L_2) of both the coils

(c) Area of cross-section of coils

(d) Magnetic permeability of medium between the coils (μ_r) or nature of material on which two coils are wound

(e) Distance between two coils (As $d\uparrow = M\downarrow$)

(f) Orientation between primary and secondary coil (for 90° orientation no flux relation $M = 0$)

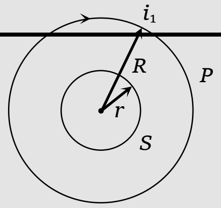
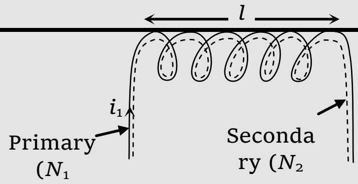
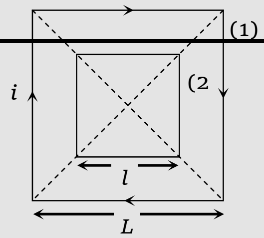
(g) Coupling factor 'K' between primary and secondary coil

(ii) **Calculation of mutual inductance between two coils**

If two coils (1 and 2) also called primary and secondary coils are placed close to each other (maximum coupling); N_1 and N_2 = Number of turns in primary and secondary coils respectively, ϕ_2 = Flux linked with each turn of secondary, $N_2\phi_2$ = Total flux linkage with secondary coils; M = Mutual inductance between two coil

So $N_2\phi_2 = Mi_1 \Rightarrow N_2(B_1A_2) = Mi_1 \Rightarrow M = \dfrac{B_1N_2A_2}{i_1}$

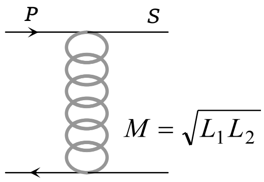
$M = K\sqrt{L_1L_2}$

Two concentric coplaner circular coils	Two Solenoids	Two concentric coplaner square coils
		

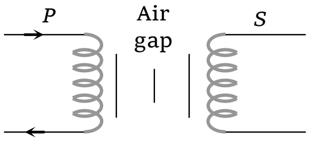
Magnetic field at the centre due to current in outer coil is $B_1 = \frac{\mu_0}{4\pi}.\frac{2\pi N_1 i_1}{R}$, From the above formula $M = \frac{\pi\mu_0 N_1 N_2 r^2}{2R} \Rightarrow \boldsymbol{M \propto \frac{r^2}{R}}$	If two air cored solenoid tightly wound to each other as shown : Magnetic field inside the primary solenoid $B_1 = \mu_0 n_1 i_1$ $\left\{n_1 = \frac{N_1}{l}\right.$ From the above formula {A = Area of each solenoid) $\boldsymbol{M = \frac{\mu_0 N_1 N_2 A}{l}}$	Magnetic field at the centre due to current in outer coil is $B_1 = \frac{\mu_0}{4\pi}.\frac{8\sqrt{2}\, N_1 i_1}{L}$ From the above formula $M = \frac{\mu_0 2\sqrt{2}\, N_1 N_2 l^2}{\pi L} \Rightarrow \boldsymbol{M \propto \frac{l^2}{L}}$

(iii) **Relation between M, L_1 and L_2**

For two magnetically coupled coils $M = k\sqrt{L_1 L_2}$; where k – coefficient of coupling or coupling factor which is defined as $k = \frac{\text{magnetic flux linked in secondary}}{\text{magnetic flux linked in primary}}$; $0 \le k \le 1$

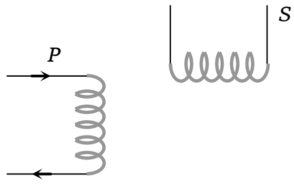


If coils are tightly coupled (k = 1)



(Normal

If coils are loosely coupled (0 < k < 1)

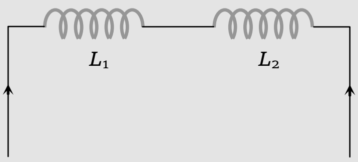
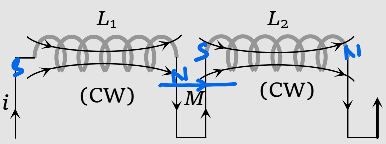
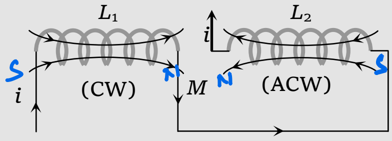


No coupling (k = 0)

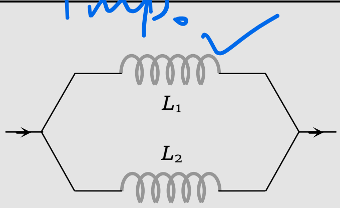
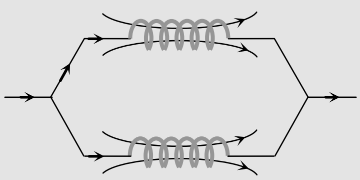
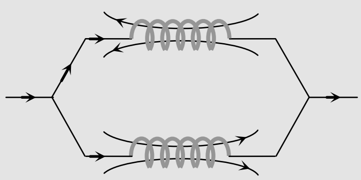
Note : ❒ Specially for Transformer in ideal case $M = \frac{N_2}{N_1} L_1$ and $M = \frac{N_1}{N_2} L_2$; $\frac{L_1}{L_2} = \left(\frac{N_1}{N_2}\right)^2$

(3) **Combination of inductance**

(i) **Series combination**

Mutual induction is absent (k = 0)	**Mutual induction is present and favours self inductance of coils**	**Mutual induction is present and opposes self inductance of coils**
 $\boxed{L_{eq} = L_1 + L_2}$	 $L_{eq} = L_1 + L_2 + 2M$ Current in same direction Winding nature same Their flux assist each other $L_{eq} = L_1 + L_2 + 2M$	 $L_{eq} = L_1 + L_2 - 2M.$ Current in opposite direction Opposite winding nature Their flux opposes each other $L_{eq} = L_1 + L_2 - 2M$

(ii) **Parallel combination**

Mutual induction is absent (k = 0)	**Mutual induction is present and favours self inductance of coils**	**Mutual induction is present and opposes self inductance of coils**
imp.  $L_{eq} = \dfrac{L_1 L_2}{L_1 + L_2}$	 $L_{eq} = \dfrac{L_1 L_2 - M^2}{L_1 + L_2 + 2M}$	 $L_{eq} = \dfrac{L_1 L_2 - M^2}{L_1 + L_2 - 2M}$

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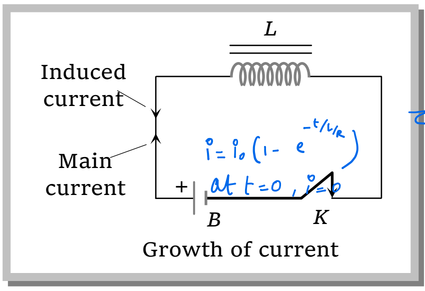
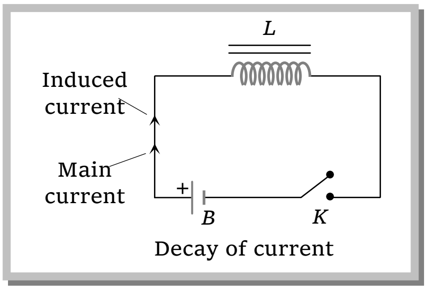
Growth and Decay of Current in *LR*-Circuit

If a circuit containing a pure inductor L and a resistor R in series with a battery and a key then on closing the circuit current through the circuit rises exponentially and reaches up to a certain maximum value (steady state). If circuit is opened from it's steady state condition then current through the circuit decreases exponentially.



Growth of current

time constant.
↓
$\tau = L/R$



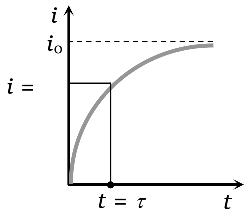
Decay of current

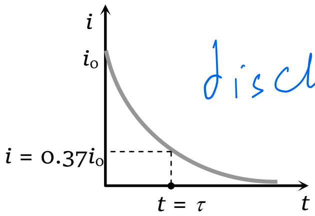
The value of current at any instant of time t after closing the circuit (*i.e.* during the rising of current) is given by $i = i_0\left[1 - e^{-\frac{R}{L}t}\right]$; where $i_0 = i_{max} = \frac{E}{R}$ = steady state current.

The value of current at any instant of time t after opening from the steady state condition (*i.e.* during the decaying of current) is given by $i = i_0 e^{-\frac{R}{L}t}$

(1) **Time constant (τ)**

In this circuit $\tau = \frac{L}{R}$; It's unit is *second*. In other words the time interval, during which the current in an inductive circuit rises to 63% of its maximum value at make, is defined as time constant or it is the time interval, during which the current after opening an inductive circuit falls to 37% of its maximum value.





discharging.

Changing

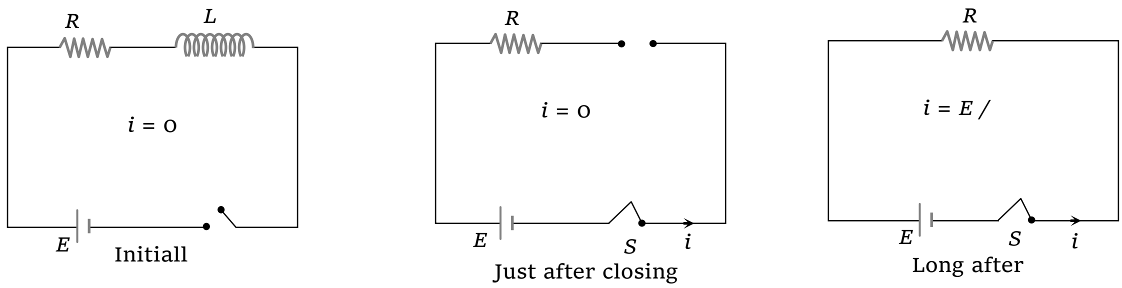
Note: ❒ The dimensions of $\frac{L}{R}$ are same as those of time *i.e.* $M^0L^0T^1$

❒ ***Half life (T)*** : In this time current reduces to 50% of its initial max value *i.e.* if $t = T$ then $i = \frac{i_0}{2}$ and again half life obtained as $T = 0.693\ \frac{L}{R}$ or T = 70% of time constant.

Now from $U = \frac{1}{2}Li^2$ so in half life time current changes from $i_0 \to \frac{i_0}{2}$ hence energy changes from $U_0 \to \frac{U_0}{4}$

(2) **Behaviour of inductor**

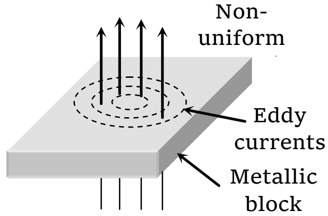
The current in the circuit grows exponentially with time from 0 to the maximum value $i\left(=\frac{E}{R}\right)$. Just after closing the switch as i = 0, inductor act as open circuit *i.e.* broken wires and long after the switch has been closed as $i = i_0$, the inductor act as a short circuit *i.e.* a simple connecting wire.



Application of EMI

(1) **Eddy current** heat.

When a changing magnetic flux is applied to a bulk piece of conducting material then circulating currents called eddy currents are induced in the material. Because the resistance of the bulk conductor is usually low, eddy currents often have large magnitudes and heat up the conductor.



These are circulating currents like eddies in water

Experimental concept given by Focault hence also named as "Focault current"

(i) **Disadvantages of eddy currents**

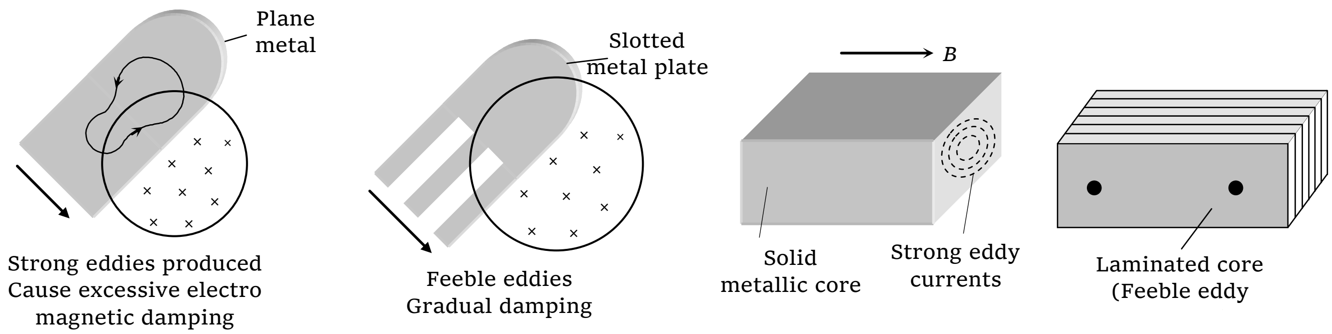
(a) The production of eddy currents in a metallic block leads to the loss of electric energy in the form of heat.

(b) The heat produced due to eddy currents breaks the insulation used in the electrical machine or appliance.

(c) Eddy currents may cause unwanted damping effect.

(ii) **Minimisation of losses due to eddy currents**

By Lamination, slotting processes the resistance path for circulation of eddy current increases, resulting in to weakening them and also reducing losses causes by them (slots and lamination intercept the conducting paths and decreases the magnitude of eddy currents and reduces possible paths of eddy currents)



(iii) **Application of eddy currents :** Though most of the times eddy currents are undesirable but they find some useful applications as enumerated below

(a) **Dead-beat galvanometer :** A dead beat galvanometer means one whose pointer comes to rest in the final equilibrium position immediately without any oscillation about the equilibrium position when a current is passed in its coil.

We know that the coil of a moving coil galvanometer is wound over a light aluminium frame. When the coil moves due to the torque produced by the current being measured, the aluminium frame also moves in the field. As a result the flux associated with the frame changes and eddy currents are induced in the frame. Eddy currents induced in aluminium frame as per Lenz's law always oppose the cause that produces them. Hence they damp the oscillation about the final steady position.

(b) **Electric-brakes :** When the train is running its wheel is moving in air and when the train is to be stopped by electric breaks the wheel is made to move in a field created by electromagnet. Eddy currents induced in the wheels due to the changing flux oppose the cause and stop the train.

(c) **Induction furnace :** Here a large amount of heat is to be generated so as to melt metal in it. To produce such a large amount of heat, a solid core of the furnace is taken (as against laminated core in situations where the heat produced is to be minimized).

(d) **Speedometer :** In the speedometer of an automobile, a magnet is geared to the main shaft of the vehicle and it rotates according to the speed of the vehicle. The magnet is mounted in an aluminium cylinder with the help of hair springs. When the magnet rotates, it produces eddy currents in the drum and drags it through an angle, which indicates the speed of the vehicle on a calibrated scale.

(e) **Diathermy :** Eddy currents have been used for deep heat treatment called diathermy.

(f) **Energy meter :** In energy meters, the armature coil carries a metallic aluminium disc which rotates between the poles of a pair of permanent horse shoe magnets. As the armature rotates, the current induced in the disc tends to oppose the motion of the armature coil. Due to this braking effect, deflection is proportional to the energy consumed.

(2) **dc motors**

It is an electrical machine which converts electrical energy into mechanical energy.

(i) **Principle :** It is based on the fact that a current carrying coil placed in the magnetic field experiences a torque. This torque rotates the coil.

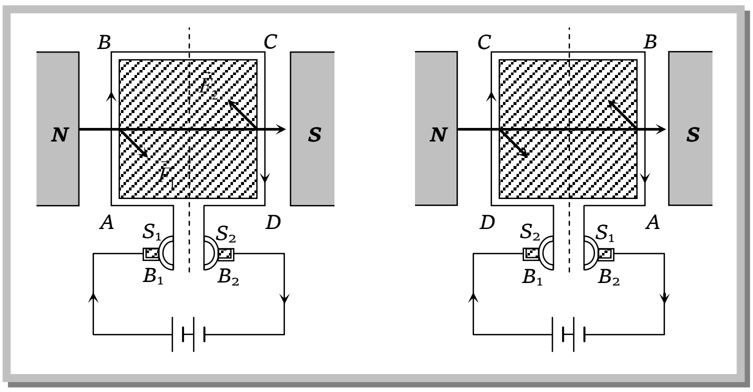
(ii) **Construction :** It consists of the following components figure.

$ABCD$ = Armature coil

S_1, S_2 = split ring comutators

B_1, B_2 = Carbon brushes

N, S = Strong magnetic poles



(iii) **Working :** Force on any arm of the coil is given by $\vec{F} = i(\vec{l} \times \vec{B})$ in fig., force on *AB* will be perpendicular to plane of the paper and pointing inwards. Force on *CD* will be equal and opposite. So coil rotates in clockwise sense when viewed from top in fig. The current in *AB* reverses due to commutation keeping the force on *AB* and *CD* in such a direction that the coil continues to rotate in the same direction.

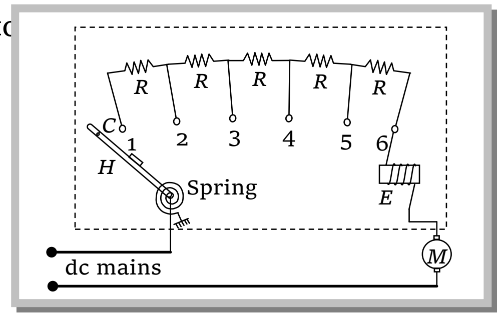
(iv) **Back emf in motor :** When the armature coil rotates in the magnetic field, an induced emf is set up in its windings. According to Lenz's law, this induced emf opposes the motion of the coil and its direction is opposite to the applied emf in the motor circuit. Hence the induced emf is known as back emf $\boldsymbol{e = E - iR}$

Value of back emf directly depends upon the angular velocity ω of armature and magnetic field *B*. But for constant magnetic field *B*, value of back emf *e* is given by $e \propto \omega$ or $\boldsymbol{e = k\omega}$ ($e = NBA\omega \sin\omega t$)

Let *e* = Magnitude of induced emf, *E* = Magnitude of the supply voltage, *R* = Resistance of the armature coil, *i* = Current in the armature. According to Ohm's law $i = \frac{E+(-e)}{R} = \frac{E-e}{R}$ or $iR = E - e$

(v) **Current in the motor :** $i = \frac{E-e}{R} = \frac{E-k\omega}{R}$; When motor is just switched on *i.e.* ω = 0 so *e* = 0 hence $i = \frac{E}{R} = \text{maximum}$ and at full speed, ω is maximum so back emf *e* is maximum and *i* is minimum. Thus, maximum current is drawn when the motor is just switched on which decreases when motor attains the speed.

Hence a starter is used for starting a dc motor safely. Its function is to introduce a suitable resistance in the circuit at the time of starting of the motor. This resistance decreases gradually and reduces to zero when the moto



The value of starting resistance is maximum at time *t* = 0 and its value is controlled by spring and electromagnetic system and is made to zero when the motor attains its safe speed.

Note : ❒ Small motor tends to have higher resistance then the large ones and do not normally need a starter.

(vi) **Mechanical power and Efficiency of dc motor :** Power supplied to the motor, $P_{in} = Ei$

and the power dissipated in the form of heat = i^2R

So remaining power = $Ei - i^2R$. This power is known as the mechanical power developed in the motor.

Hence mechanical power, $P_{mech.} = (E - iR)\, i = ei$

Efficiency of dc motor $\eta = \frac{P_{mechanical}}{P_{supplied}} = \frac{P_{out}}{P_{in}} = \frac{e}{E} = \frac{\text{Back e.m.f.}}{\text{Supply voltage}}$

Note : ❒ η will be maximum if ei = maximum. which obtained when $e = \frac{E}{2}$. So $\eta_{max.} = \frac{E/2}{E} \times 100 = 50\%$

(vii) **Uses of dc motors :** They are used in electric locomotives, electric ears, rolling mills, electric cranes, electric lifts, dc drills, fans and blowers, centrifugal pumps and air compressors, *etc.*

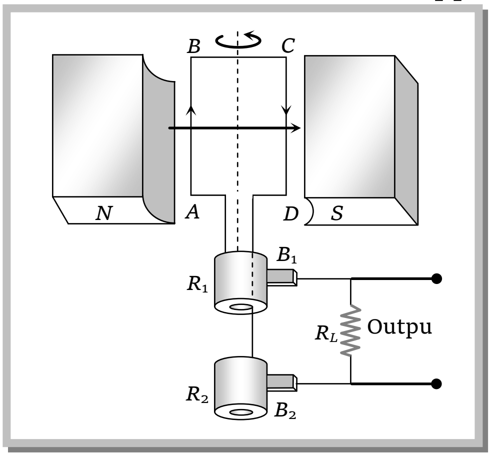
(3) **ac generator/Alternator/Dynamo**

An electrical machine used to convert mechanical energy into electrical energy is known as ac generator/alternator.

(i) **Principle :** It works on the principle of electromagnetic induction *i.e.*, when a coil is rotated in uniform magnetic field, an induced emf is produced in it.

(ii) **Construction :** The main components of ac generator are

(a) **Armature :** Armature coil ($ABCD$) consists of large number of turns of insulated copper wire wound over a soft iron core.



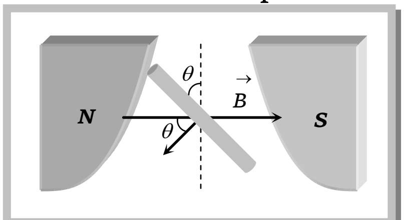
(b) **Strong field magnet :** A strong permanent magnet or an electromagnet whose poles (N and S) are cylindrical in shape in a field magnet. The armature coil rotates between the pole pieces of the field magnet. The uniform magnetic field provided by the field magnet is perpendicular to the axis of rotation of the coil.

(c) **Slip rings :** The two ends of the armature coil are connected to two brass slip rings R_1 and R_2. These rings rotate along with the armature coil.

(d) **Brushes :** Two carbon brushes (B_1 and B_2), are pressed against the slip rings. The brushes are fixed while slip rings rotate along with the armature. These brushes are connected to the load through which the output is obtained.

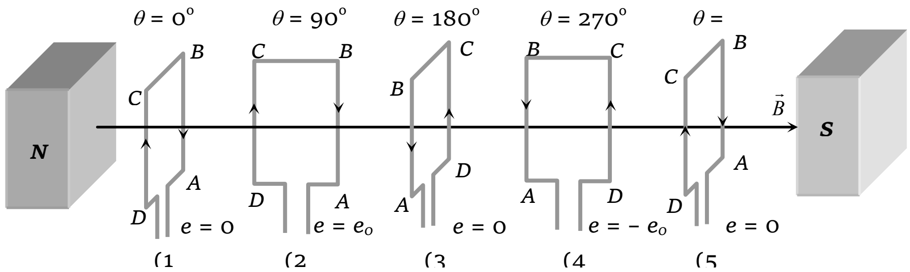
(iii) **Working :** When the armature coil $ABCD$ rotates in the magnetic field provided by the strong field magnet, it cuts the magnetic lines of force. Thus the magnetic flux linked with the coil changes and hence induced emf is set up in the coil. The direction of the induced emf or the current in the coil is determined by the Fleming's right hand rule.

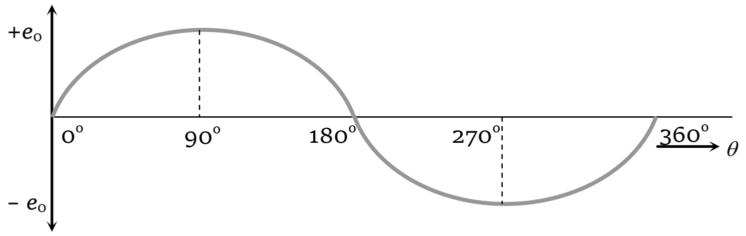
The current flows out through the brush B_1 in one direction of half of the revolution and through the brush B_2 in the next half revolution in the reverse direction. This process is repeated. Therefore, emf produced is of alternating nature.



$e = -\frac{Nd\phi}{dt} = NBA\,\omega \sin\omega t = e_0 \sin\omega t$ where $e_0 = NBA\omega$

$i = \frac{e}{R} = \frac{e_0}{R}\sin\omega t = i_0 \sin\omega t$ $R \to$ Resistance of the circuit





Note : ❒ Frequency of ac produced given by $[f_{AC}] = \frac{NP}{2}$, where P = Number of magnetic poles of field, N = Rotational frequency of armature coil in *rps* (rotations per *seconds*)

❒ For (a) Simple generator $P = 2 \Rightarrow f_{ac} = N$ (b) Multiple generator $P > 2 \Rightarrow f_{ac} > N$

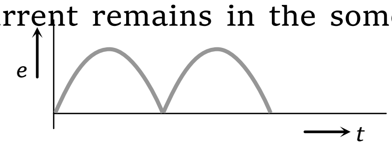
❒ To produce ac of given frequency, multiple generator is prove to be economical.

(4) **dc generator**

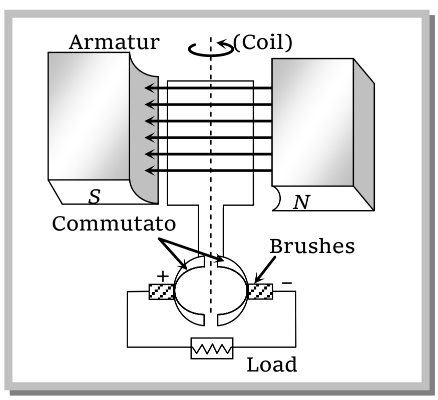
If the current produced by the generator is direct current, then the generator is called dc generator.

dc generator consists of (i) Armature (coil) (ii) Magnet (iii) Commutator (iv) Brushes

In dc generator commutator is used in place of slip rings. The commutator rotates along with the coil so that in every cycle when direction of '*e*' reverses, the commutator also reverses or makes contact with the other brush so that in the external load the current remains in the some direction giving dc



(Output of a single loop dc generator for one cycle of



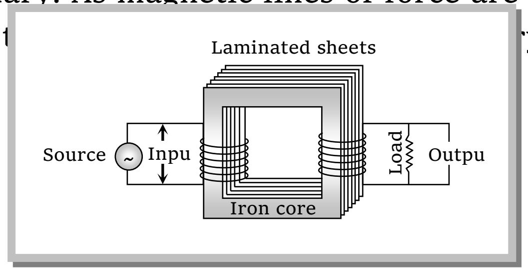
Note : ❒ Practical efficiencies of big generators are about 92% to 95%.

Concepts

- *dc motor is a highly versatile energy conversion device. It can meet the demand of loads requiring high starting torque, high accelerating and decelerating torque.*
- *Constructionally there is no basic difference between a dc generator and a dc motor. Infect the same dc machine can be used interchangeably as a generator or as a motor.*
- *All rating marked on dynamos and motors are for full loads. For example a 5 kW, 100 V, 1000 rpm dynamo delivers 5 kW electrical power at 100 V terminal voltage and it's speed of rotation at full load is 1000 rpm.*

Transformer

It is a device which raises or lowers the voltage in ac circuits through mutual induction. It consists of two coils wound on the same core. The coil which is connected to the source (*i.e.*, to which input is applied) is called primary while the other which is connected to the load (*i.e.*, from which output is taken) is called secondary. The alternating current passing through the primary creates a continuously changing flux through the core. This changing flux induces an alternating emf in the secondary. As magnetic lines of force are closed curves, the flux per turn of the primary must be equal t… y, *i.e.*,



(i) Transformer works on ac only and never on dc.

(ii) It can increase or decrease either voltage or current but not both simultaneously.

(iii) Transformer does not change the frequency of input ac.

(iv) There is no electrical connection between the winding but they are linked magnetically.

(v) Effective resistance between primary and secondary winding is infinite.

(vi) The flux per turn of each coil must be same *i.e.* $\phi_S = \phi_S$; $-\frac{d\phi_S}{dt} = -\frac{d\phi_P}{dt}$

(vii) If Suppose for a transformer –

N_P = number of turns in primary ; N_S = number of turns in secondary

V_P = applied (input) voltage to primary; V_S = Voltage across secondary (load voltage or output)

e_P = induced emf in primary ; e_S = induced emf in secondary

ϕ = flux linked with primary as well as secondary

i_P = current in primary; i_S = current in secondary (or load current)

R_P = resistance of primary; R_S = resistance of secondary

t_P = thickness of turn in primary; t_S = thickness of turn in secondary

As in an ideal transformer there is no loss of power *i.e.* $P_{out} = P_{in}$ and $e = V$

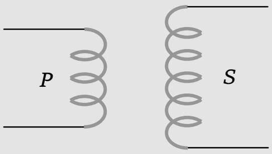
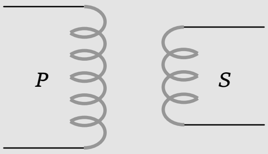
So $V_S i_S = V_P i_P$ and $V_P \approx e_P$, $V_S \approx e_S$

According to Faraday's law $e_S = -N_S \dfrac{d\phi}{dt}, e_P = -N_P \dfrac{d\phi}{dt}$

Hence $\dfrac{e_S}{e_P} = \dfrac{N_S}{N_P} = \dfrac{V_S}{V_P} = \dfrac{i_P}{i_S} = k$; k = Transformation ratio (or turn ratio)

From above discussions, it is clear that in transformers the side having greater number of turns will have greater voltage and lesser current. Since in increasing the voltage level, the current level decreases, therefore it can be concluded that voltage increases at the cost of current.

(viii) **Types of transformer** : Transformer is of two type

Step up transformer	**Step down transformer**
It increases voltage and decreases current	It decreases voltage and increases current
$V_S > V_P$	$V_S < V_P$
$N_S > N_P$	$N_S < N_P$
$E_S > E_P$	$E_S < E_P$
$i_S < i_P$	$i_S > i_P$
$R_S > R_P$	$R_S < R_P$
$t_S > t_P$	$t_S > t_P$
$k > 1$	$k < 1$
	

(ix) **Efficiency of transformer (η) :** Efficiency is defined as the ratio of output power and input power

i.e. $$\eta\% = \frac{P_{out}}{P_{in}} \times 100 = \frac{V_S i_S}{V_P i_P} \times 100$$

For an ideal transformer $P_{out} = P_{in}$ so $\eta = 100\%$ (But efficiency of practical transformer lies between 70% – 90%)

For practical transformer $P_{in} = P_{out} + P_{losses}$ so $\eta = \frac{P_{out}}{P_{in}} \times 100 = \frac{P_{out}}{(P_{out} + P_L)} \times 100 = \frac{(P_{in} - P_L)}{P_{in}} \times 100$

(x) **Losses in transformer :** In transformers some power is always lost due to, heating effect, flux leakage eddy currents, hysteresis and humming.

(a) ***Cu* loss (i^2R) :** When current flows through the transformer windings some power is wasted in the form of heat $(H = i^2Rt)$. To minimize this loss windings are made of thick *Cu* wires (To reduce resistance)

(b) **Iron loss :** If is further divided in two types

Eddy current loss : Some electrical power is wasted in the form of heat due to eddy currents, induced in core, to minimize this loss transformers core are laminated and silicon is added to the core material as it increases the resistivity. The material of the core is then called silicon-iron (steel).

Hystersis loss : The alternating current flowing through the coils magnetises and demagnetises the iron core again and again. Therefore, during each cycle of magnetisation, some energy is lost due to hysteresis. However, the loss of energy can be minimised by selecting the material of core, which has a narrow hysterisis loop. Therefore core of transformer is made of soft iron. Now a days it is made of "Permalloy" (*Fe*-22%, *Ni*-78%).

(c) **Magnetic flux leakage :** Magnetic flux produced in the primary winding is not completely linked with secondary because few magnetic lines of force complete their path in air only. To minimize this loss secondary winding is kept inside the primary winding.

(d) **Humming losses :** Due to the passage of alternating current, the core of the transformer starts vibrating and produces humming sound. Thus, some part (may be very small) of the electrical energy is wasted in the form of humming sounds produced by the vibrating core of the transformer.

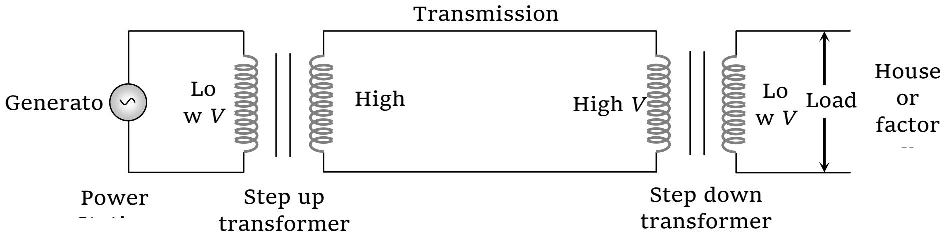
(xi) **Uses of transformer :** A transformer is used in almost all ac operations *e.g.*

(a) In voltage regulators for TV, refrigerator, computer, air conditioner etc.

(b) In the induction furnaces.

(c) Step down transformer is used for welding purposes.

(d) In the transmission of ac over long distance.



(e) Step down and step up transformers are used in electrical power distribution.

(f) Audio frequency transformers are used in radiography, television, radio, telephone *etc*.

(g) Radio frequency transformers are used in radio communication.

(h) Transformers are also used in impedance matching.