

CNT

Chapter 1 to 3

Material :-

- ① Insulator :- valence band - conduction band
- ② Semiconductor :- ^{Gap between} valence band and conduction band
- ③ Conductor :- valence band conduction band overlap each other.

Charge carrier = Electrons

$$q = ne$$

n = number of electrons

e = electric charge

$$1.67 \times 10^{-19} \text{ C}$$

Ohm's law :-

$$i \propto V$$

$$i = kV$$

k = constant of proportionality

$$= \frac{1}{R}$$

$$i = \frac{V}{R} = GV$$

$$V = iR$$

G = Conductance

V = voltage

i = current

R = Resistance

$$V = iR = \frac{i}{G}$$

$$\text{ge drop} = -iR = -ve$$

$$\dot{z} = [M^0 L^0 T^0 A^1]$$

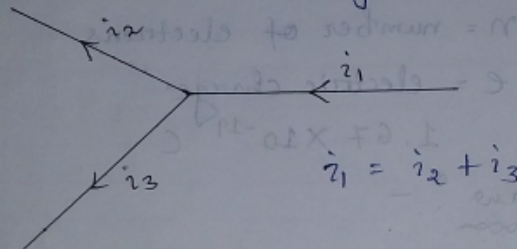
$$V = [M L^1 T^{-3} I^{-1}]$$

$$R = [M^1 L^2 T^{-3} A^{-2}]$$

Kirchhoff's law

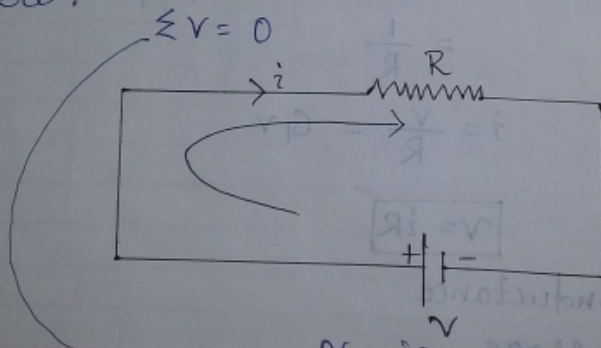
Kirchhoff's Current law (KCL)

The current meeting at a point is zero, i.e.
No accumulation of charge.



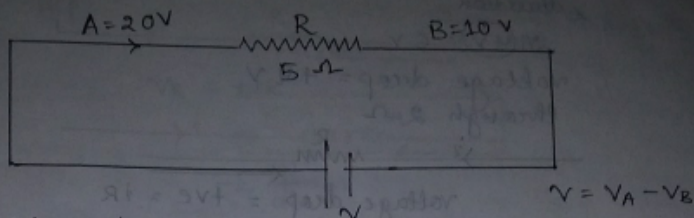
Kirchhoff's voltage law (KVL)

In a close loop the algebraic sum of the voltage is zero.



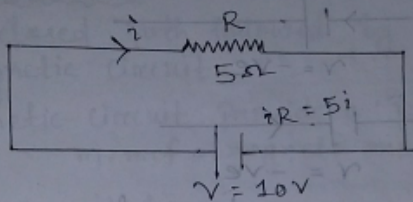
$$V - iR = 0$$

$$\sum V + \sum iR = 0$$



$$i = \frac{V_A - V_B}{R} = \frac{20V - 10V}{5\Omega} = \frac{10V}{5\Omega} = 2A$$

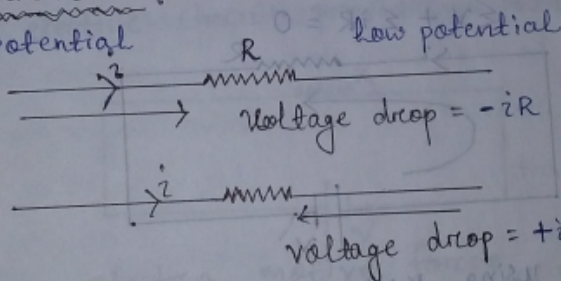
KVL :-



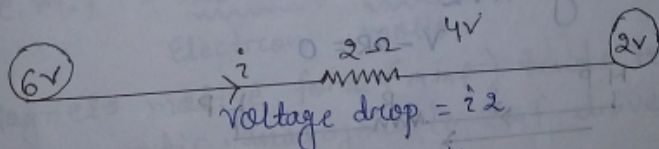
$$10V - 5i = 0$$

$$\Rightarrow i = \frac{10}{5} = 2A$$

Sign convention
high potential



Current flow
= potential flow



$$i = \frac{6 - 2}{2} = \frac{4}{2} = 2A$$

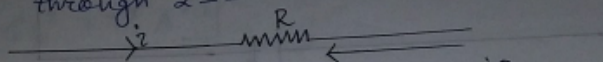
$$= 2 \times 2 = 4V$$

direction
voltage drop = $6V - 4V = 2V$
voltage drop = $-4V$, voltage drop = $-iR = -ve$

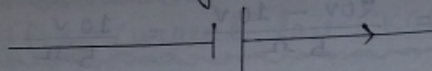
← direction

$$24(4V) = 6V$$

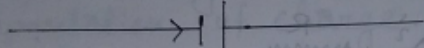
voltage drop = +4V
through 2Ω



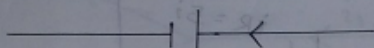
voltage drop = +ve = iR



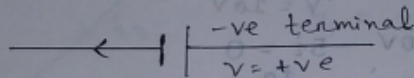
$V = +ve$



$V = -ve$



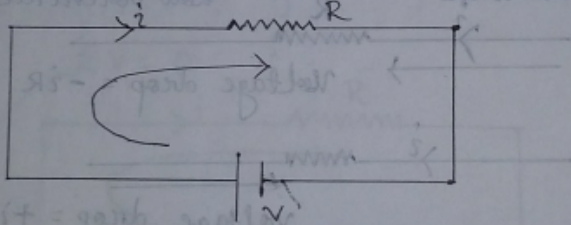
$V = -ve$



-ve terminal
 $V = +ve$

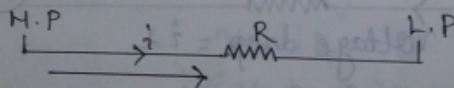
Kirchhoff's voltage law (KVL)

$$\sum V + \sum iR = 0$$

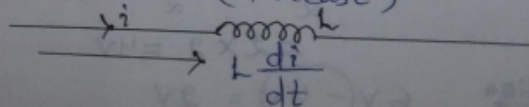


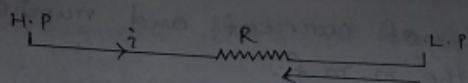
using KVL

$$V - iR = 0$$

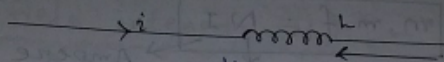


$V_R = -iR$ (decrease)

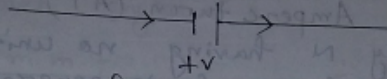




$$V_R = iR$$



$$-L \frac{di}{dt}$$



Magnetic Circuit :-

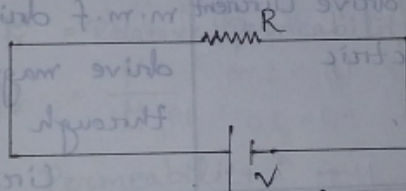
It is a closed path followed by magnetic flux is called magnetic circuit.

The magnetic circuit provide a path for magnetic flux.
m.m.f = magneto motive force

Electric Circuit :-

It is closed path through which electric current is flow.

Just as electric circuit provides a path for current flow.



e.m.f = Electro motive force
Electron motion

Magneto motive force (mmf) tends to drive motion in magnetic. analogous to 'emf' drives or tender drive current in electrons.

mmf or Magneto motive force
It drive or tends to drive magnetic flux in magnetic circuit.

The product of current and number of turn (N) gives the m.m.f.

$$\begin{array}{ccc} \text{m.m.f} = NI & & \text{Ampere} \\ \downarrow & & \downarrow \\ \text{unit} & \text{turn} & \end{array}$$

Ampere turn (AT)

usually N having no units.
Hence unit of m.m.f is generally takes as Ampere.

$$\begin{array}{l} \text{m.m.f} = NI \\ \text{unit} = AI \end{array}$$

It produces or tends to produce magnetic flux.

Electric circuit	Magnetic circuit
Emf	mmf
Electric motive force drives or tends to drive current through electric circuit.	Magneto motive force m.m.f drives or tends to drive magnetic flux through the magnetic circuit.

$$\text{mmf} = NI \text{ (Amp. turn)}$$

Magnetic flux :-

$$\phi = \vec{B} \cdot \vec{A}$$

$\vec{B}$ = Magnetic induction
or
Magnetic flux density
or
Magnetic field vector

flux :- Magnetic lines of force through certain area.

Magnetic field intensity (H) :-

Magnetic field intensity is the ratio of m.m.f to magnetic path length.

$$H = \frac{\text{m.m.f}}{\text{magnetic path length}} = \frac{NI}{l} \text{ (AT/m)}$$

The magnetic material to be have like magnet.

Magnetic material - Cobalt

$$B = \mu H$$

μ = permeability of material

$$B = \mu_0 H$$

μ_0 = Free space permeability

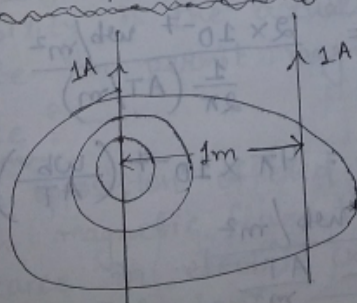
$$B = \mu_0 \mu_r H$$

$$\mu_r = \frac{\mu}{\mu_0}$$

μ_r = Relative permeability

$$\mu_r = \frac{\mu}{\mu_0}$$

Free Space Permeability :-



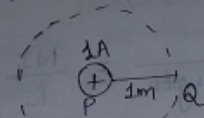
$$F = 2 \times 10^{-7} \text{ N/m}$$

then 1A

Consider a long straight conductor (P) carrying current 1A.

Consider a circle around the conductor 1m a part.

Take another conductor Q.



$$\begin{aligned} \text{m.m.f} &= NI \\ &= 1 \times 1 (\text{A}) \\ &= 1 (\text{AT}) \end{aligned}$$

$$H = \frac{\text{m.m.f}}{l} = \frac{1}{2\pi \times 1} = \frac{1}{2\pi} (\text{AT/m})$$

$$B = \mu_0 H$$

$$\mu_0 = \frac{B}{H}$$

Take another conductor Q at 1m a part carrying current 1A.

The force experienced by conductor Q, is given by $F = BIl = 2 \times 10^{-7} \text{ N/m}$

$$F = B \times 1A \times 1m$$

$$F = B = 2 \times 10^{-7} \text{ Wb/m}^2$$

$$B = \text{wb/m}^2$$

$$B = \mu_0 H$$

$$\mu_0 = \frac{B}{H} = \frac{2 \times 10^{-7} \text{ Wb/m}^2}{\frac{1}{2\pi} (\text{AT/m})}$$

$$= 4\pi \times 10^{-7} \left(\frac{\text{Wb}}{\text{AT}} \right)$$

$$\mu_0 = \frac{B}{H} = \frac{2 \times 10^{-7} \text{ Wb/m}^2}{\frac{1}{2\pi} \frac{\text{AT}}{\text{m}}}$$

$$= 2\pi \times 2 \times 10^{-7} \frac{\text{Wb}}{\text{m}^2} \times \frac{\text{m}}{\text{AT}}$$

$$= 4\pi \times 10^{-7} \left(\frac{\text{wb}}{\text{AT m}} \right)$$

$$\boxed{\mu_0 = 4\pi \times 10^{-7}} \rightarrow \text{Free Space permeability}$$

Relative Permeability (μ_r) :-

When a magnetomotive force (mmf) is applied the flux produced is very large as compared to air, vacuum or non magnetic material.

The ratio of flux density produced in ferromagnetic material to flux density produced in air, vacuum, Non-magnetic material is called μ_r .

$$\mu_r = \frac{\text{flux density produced in ferromagnetic material}}{\text{flux density produced in air}}$$

$$\mu_r = \frac{\mu}{\mu_0}$$

$$\mu_r = \frac{\mu}{\mu_0}$$

$$\mu = \text{Absolute permeability}$$

$$\mu = \mu_0 \mu_r$$

$$= \text{free space permeability} \times \text{Relative permeability}$$

Permeability :-

Permeability is the actual ability of a material to penetrate or permit magnetic flux through it.

Reluctance :-

It is the opposition offered by magnetic ckt to establish magnetic flux through it. It is analogous to resistance in electric ckt.

$$\text{Reluctance} \rightarrow \text{Resistance}$$

$$\text{mmf} = NI (AT)$$

To produce flux

$$H = \frac{\text{mmf}}{l} = \frac{NI}{l} \text{ (AT/m)}$$

$$B = \mu_0 \mu_r H$$

$$= \mu_0 \mu_r \frac{NI}{l}$$

$NI = \text{mmf}$ is analogous e.m.f. in electric ckt.

$$\phi = BA$$

$B = \text{Magnetic flux density}$

$\text{Magnetic induction}$

$\text{Magnetic field vector}$

$$B = \frac{\phi}{A} = \text{Magnetic flux per unit normal area.}$$

$$\phi = BA$$

$$\phi = \left(\mu_0 \mu_r \frac{NI}{l} \right) A$$

$$\phi = \mu_0 \mu_r \frac{NI}{l} A$$

$$= \frac{NI}{\left(\frac{l}{\mu_0 \mu_r A} \right)}$$

$$B = \mu H = \mu_0 \mu_r H$$

$$H = \frac{NI}{l}$$

$$= \mu_0 \mu_r \frac{NI}{l}$$

$$\phi = (B) A = \left(\frac{\mu_0 \mu_r NI}{l} \right) A$$

$$\phi = NI \left(\frac{\mu_0 \mu_r A}{l} \right)$$

$$\phi = \frac{NI}{\left(\frac{l}{\mu_0 \mu_r A}\right)}$$

$$i = \frac{V}{R} = \frac{\text{emf}}{\text{resistance}}$$

$$\text{flux } \phi = \frac{NI}{\text{Reluctance}} = \frac{\text{mmf}}{\text{Reluctance}}$$

$$\phi = \frac{NI}{\left(\frac{l}{\mu_0 \mu_r A}\right)}$$

$$(i) \text{ Reluctance } S = \frac{l}{\mu_0 \mu_r A}$$

$$S = \frac{l}{\mu A}$$

$$\phi = \frac{F}{S}$$

$$\frac{1}{S} = F = \text{mmf}$$

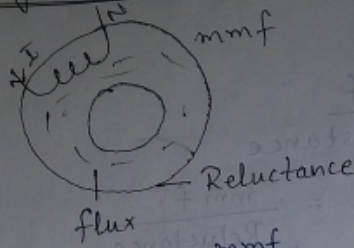
$S = \text{Reluctance}$

NI produces magnetisation in the magnetic ckt is known as magnets motive force (mmf).

It is analogous to emf in the electric ckt.

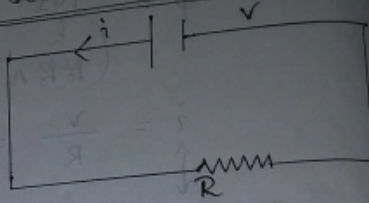
Comparison between Magnetic circuit and Electric Circuit.

Magnetic circuit



- ① flux $(\phi) = \frac{\text{mmf}}{\text{Reluctance}}$
- ② mmf $= NI (AT)$
- ③ flux ϕ in wb.
- ④ flux density $B = \frac{\phi}{A} \left(\frac{\text{wb}}{\text{m}^2} \right)$
- ⑤ Reluctance $(S) = \frac{l}{\mu A}$
- ⑥ permeance $= \frac{1}{\text{reluctance}}$
- ⑦ Reluctivity $= \frac{1}{\mu}$
- ⑧ permeability $= \frac{1}{\text{Reluctivity}}$
 $= \left(\frac{1}{\frac{1}{\mu}} \right) = \mu$

Electric circuit



- ① Current $i = \frac{\text{emf}}{\text{Resistance}}$
- ② emf $= E (\text{volt})$
- ③ Current I in Amp.
- ④ Current density $(j) = \frac{I}{A} (\text{Amp}/\text{m}^2)$
- ⑤ Resistance $R = \rho \frac{l}{a}$
- ⑥ Conductance $= \frac{1}{\text{Resistance}}$
- ⑦ Resistivity $\rho = \frac{1}{\sigma}$
- ⑧ Conductivity $\sigma = \frac{1}{\text{Resistivity}}$

Write down three similarity between Magnetic circuit and Electric circuit.

Difference between Magnetic ckt and Electric ckt.

- ① Electric current is ~~actual~~ flow of electron in electric ckt nothing flows in magnetic ckt because the magnetic flux lines are imaginary.
- ② There are certain good insulators of current so that current can be confined but there no certain insulators of magnetic flux to confine the flux in the ckt.
- ③ Flow of current in electric ckt due to continuous supply of electric energy, energy is required to produce magnetic flux but no energy is required to maintain it.

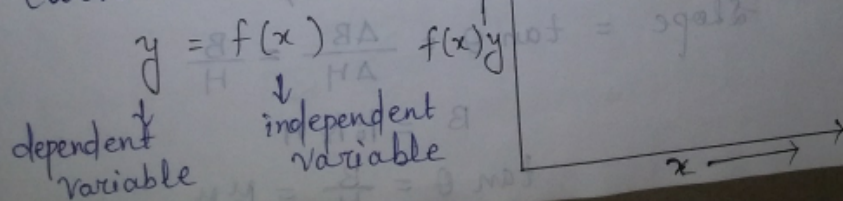
B-H curve :-

B = Magnetic induction
Magnetic flux density
or Magnetic field vector

H = Magnetic field intensity

B-H curve or Magnetisation curve is the relation between B and H .

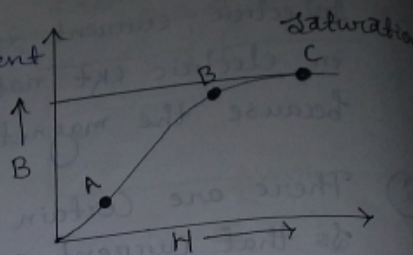
The graph between B and H is called B-H curve.



$$B = \mu_0 \mu_r H \rightarrow \text{independent}$$

↓
dependent

The B-H curve is divided into 4-part as shown in graph OA, AB, BC, Beyond C.

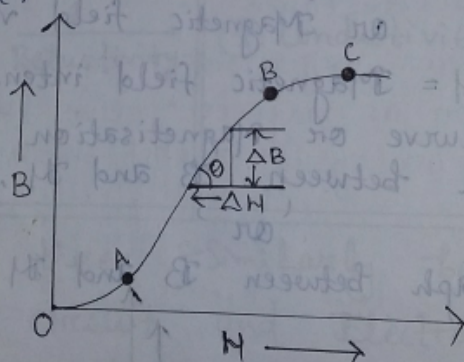


In region OA increase of magnetic flux density is with respect H is very small, so slope is small.

Again In region BC, increase of magnetic flux density is w.r.t H is small, slope is small.

In region beyond C, Magnetic flux density remains const. w.r.t H .

The Slope of the magnetic material is called saturation.



$$\text{Slope} = \tan \theta = \frac{\Delta B}{\Delta H} = \frac{B}{H}$$

$$B = \mu_0 \mu_r H$$

$$\tan \theta = \frac{B}{H} = \mu_0 \mu_r$$

$$\tan \theta = \frac{M}{H} = \text{slope}$$

$$\boxed{\mu_0 = \frac{1}{M} \tan \theta}$$

$$\mu_0 = \frac{1}{M} \tan \theta$$

$$\mu_0 = 4\pi \times 10^{-7} = \text{const.}$$

$$\frac{1}{\mu_0} = \text{const.}$$

$$\mu = k \tan \theta$$

$$\boxed{\mu \propto \tan \theta}$$

x axis = slope = 0
y axis = slope = ∞

Magnetic Hysteresis :-

It is defined as the lagging of the magnetic flux density (B) behind the magnetising force (H) or magnetic field intensity.

$$H \rightarrow B$$

$$B = \mu_0 \mu_r H$$

or

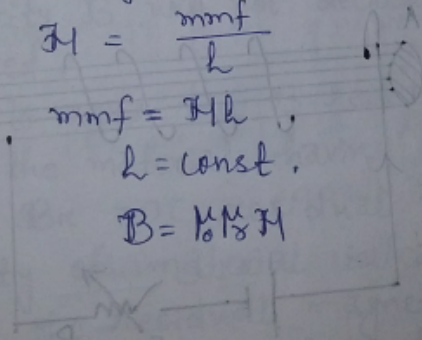
It may be defined as that the quality of magnetic substance due to which energy dissipate in it on the reversal of magnetisation.

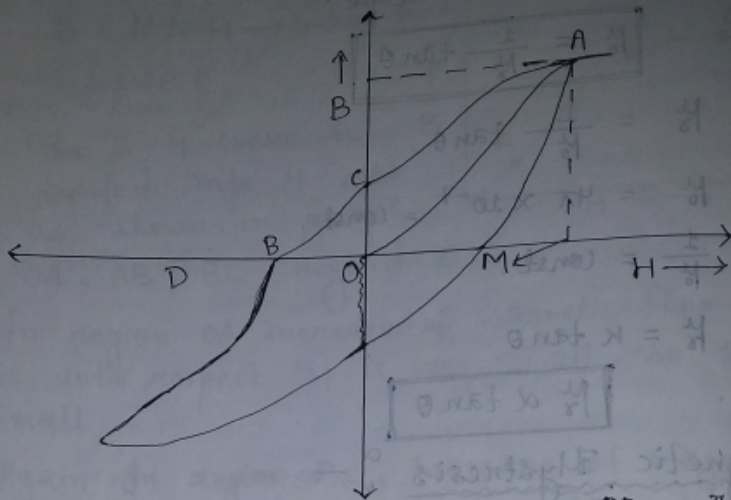
$$H = \frac{\text{mmf}}{l}$$

$$\text{mmf} = Hl$$

$$l = \text{const.}$$

$$B = \mu_0 \mu_r H$$





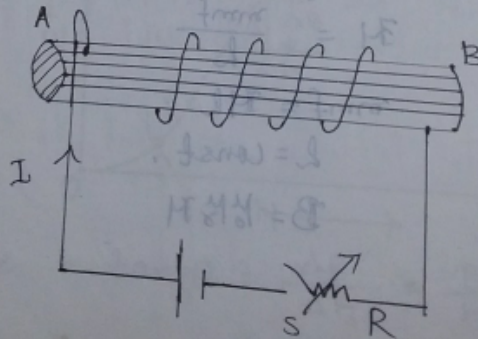
OP = B_{max}

OD = $-H$

ratio $\rightarrow$ flux density = B
 permeability

Consider an unmagnetised bar AB which is to be magnetised by placing it both in a field of solenoid. The solenoid produce a magnetic field intensity

$$H = \frac{NI}{l}$$

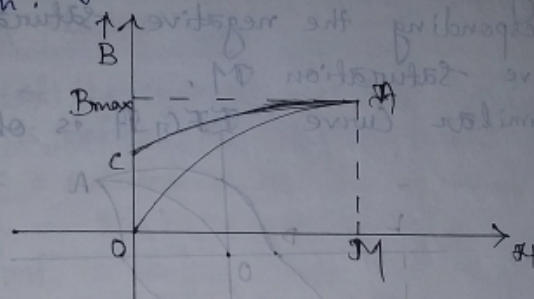


The value of H can be increased or decreased by increasing or decreasing the value of current.

The value of current can be managed by controlling the variable resistor R .

Let the value of H increased from zero to maximum step by step.

The corresponding values of B noted and plotted in a graph.



The material becomes magnetically saturated for $H = OH$.

Maximum flux density B_{max}

If H is now decreased gradually by decreasing solenoid current.

The flux density B will not decrease along HO as might expected.

H decreases to zero but B reaches OC .

That means the material having certain magnetic flux density $B_r = OC$ residual magnetism.

This property of material is called retentivity. To wipe out the residual magnetism, H will be provided in reverse direction by reversing the solenoid current.

Hysteresis loop :-

$$H = 0 \text{ D}$$

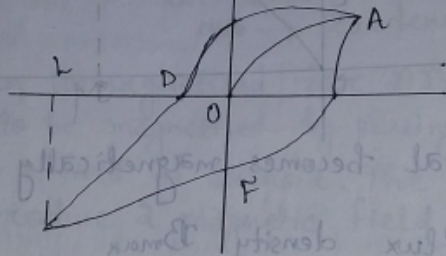
It is observed that the magnetisation reduces to zero.

If H further increased in the negative direction the iron bar reaches at

Magnetic Saturation at point E. If now taking back the value of H ,

Corresponding the negative saturation Oh, for positive Saturation M.

A similar curve EFGH is obtained.



Combining two curve a close path EFGHACDE is obtained. It is seen that always B lags behind M never and H simultaneously becomes zero.

The lagging of B behind H is given by Hysteresis loop.

$$\text{Hysteresis loss } H = \frac{NI}{L} = AT/m$$

①

Magnetic Circuits

The closed path followed by magnetic flux is called as Magnetic Circuit.

The magnetic ckt provides a path for magnetic flux, just as electric ckt provides a path for electric current.

Magnetomotive force (MMF) :-

MMF drives (or) tends to drive the flux through a magnetic ckt and corresponds to electromotive force (emf) in an electric ckt.

The product of the current and the number of turns of the coil is defined as magnetomotive force (MMF).

$$\text{MMF} = \text{Current} \times \text{Number of turns}$$

$$= I \times N \text{ (expressed in AT)}$$

Units of mmf is ampere turn (AT) but it is taken as ampere since N is dimensionless.

Magnetic field Intensity :-

It is defined as the magnetomotive force per unit length of the magnetic flux path.

It is denoted as H .

$$H = \frac{\text{mmf}}{\text{mean length of magnetic path}} = \frac{NI}{l}$$

Consider a solenoid of N turns, length L , carrying current I , then the magnetic field (or) flux density (B).

$$B = \mu H = \mu \frac{NI}{L}$$

②

$B = \mu_r \mu_0 H$, for any medium with relative permeability μ_r .

For Air medium $\mu_r = 1$

$$B = \mu_0 H \quad \text{--- (1)}$$

Free space permeability $\mu_0 = 4\pi \times 10^{-7} \text{ Tm/A}$

Consider a long straight conductor 'P' situated in vacuum and carrying a current of 1A.

Let us assume the return conductor is at a very large distance away so that it doesn't affect the magnetic field produced by the conductor 'P'.

The flux around 'P' is in the form of concentric circle.

Consider a flux path at a distance 1 metre from conductor 'P'.

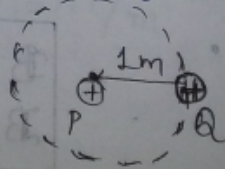
$$\text{MMF} = 1\text{N} = 1 \times 1 = 1\text{A} \quad \text{--- (2)}$$

Field intensity at distance of 1m. from the centre of conductor 'P'.

$$H = \frac{1\text{N}}{2\pi} = \frac{1}{2\pi} \text{ A/m} \quad \text{--- (3)}$$

Now consider another long straight conductor carrying current 1A situated 2 metre and parallel to P.

F_c = Force on conductor Q due to magnetic flux produced by P.



$$\textcircled{3} \quad F_c = B i l$$

$$= B \cdot 1 \cdot 1 = B$$

By definition of ampere, the force per metre on a
is 2×10^{-7} newton.

$$B = F_c = 2 \times 10^{-7} \text{ Tesla} \quad \textcircled{4}$$

From eqnⁿ $\textcircled{2}$ and $\textcircled{4}$

$$\frac{B}{H} = \frac{2 \times 10^{-7}}{\frac{1}{2\pi}} = 4\pi \times 10^{-7} \quad \textcircled{5}$$

Thus in vacuum air, or non magnetic material the
 B/H is a constant.

This constant is called the permeability of free space.

$$\mu_0 = \frac{B}{H} = 4\pi \times 10^{-7} \text{ H/m}$$

Relative Permeability —

when magneto motive force (mmf) is applied to a
ferromagnetic material, the flux produced is very
large compared with that in air, vacuum or non-
magnetic material.

The ratio of flux density (B) produced in material to
flux density produced in air, vacuum or non-magnetic
material by the same magnetic field intensity (H)
is called relative permeability.

$$\mu_r = \frac{\text{flux density in ferromagnetic material}}{\text{flux density in air}}$$

(4)

flux density in ferromagnetic material

$$= \mu_r \times \text{flux density in air}$$

$$= \mu_r \mu_0 H$$

$$\mu = \mu_r \mu_0 = \text{Absolute permeability}$$

Permeability :-

Permeability is actually the ability of a material for flux to penetrate or permeate through it.

Reluctance :-

The opposition offered by a magnetic circuit to the establishment of magnetic flux is called reluctance of the magnetic circuit.

It is analogous to the resistance of an electric ckt.

$$H = \frac{NI}{l} \text{ AT/m}$$

$$B = \mu_r \mu_0 H = \mu_r \mu_0 \frac{NI}{l} \text{ wb/m}^2$$

$$\text{Total flux } \phi = B A = \mu_r \mu_0 \frac{NI}{l} A$$

$$\phi = \frac{NI}{\left(\frac{l}{\mu_r \mu_0 A} \right)}$$

NI - produces magnetisation in the magnetic ckt is known as magnetomotive force (mmf) with a unit Ampere turn (AT).

It is analogous to emf in an electric ckt.

The denominator $\frac{l}{\mu_r \mu_0 A}$ is called as the reluctance.

$$\text{flux} = \frac{\text{mmf}}{\text{reluctance}}$$

⑤

$$\phi = \frac{F}{S}$$

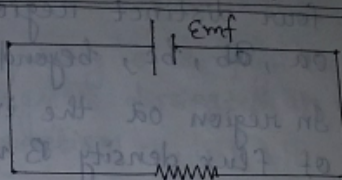
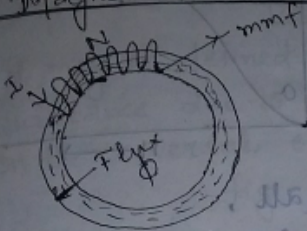
$F \rightarrow$ mmf

$S \rightarrow$ reluctance

Comparison between Magnetic and Electric ckt:-

Magnetic ckt

Electric ckt



Reluctance ($\mathcal{R}$)

① Flux = $\frac{\text{mmf}}{\text{Reluctance}}$

② MMF = NI (Amp. Turn)

③ Flux $\rightarrow \phi$ in wb

④ Flux density (B) = $\frac{\text{wb}}{\text{m}^2}$

⑤ Reluctance ($\mathcal{R}$) = $\frac{l}{\mu A}$

⑥ Permeance = $\frac{1}{\text{reluctance}}$

⑦ Reluctivity = $\frac{1}{\mu}$

⑧ Permeability = $\frac{1}{\text{reluctivity}}$
= μ

① Current = $\frac{\text{Emf}}{\text{resistance}}$

② Emf = E (volt)

③ Current I in Ampere

④ Current density (j) (A/m^2)

⑤ Resistance $R = j \frac{l}{A} = \frac{l}{\sigma A}$

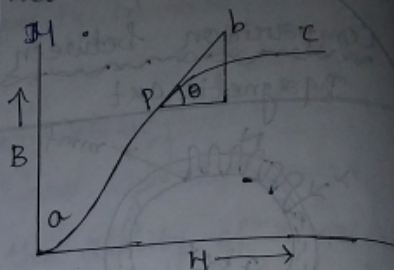
⑥ Conductance = $\frac{1}{\text{Resistance}}$

⑦ Resistivity $j = \frac{1}{\sigma}$

⑧ Conductivity, $\sigma = \frac{1}{\text{resistivity}}$

⑥ B-H curve or Magnetisation curve:-
 The B-H curve or magnetisation curve is a relation between B and H.

It can be divided into four distinct regions, oa , ab , bc , beyond c .



In region oa the increase of flux density B with it is very small. So slope is small.

In region ab flux density (B) increases linearly with H.

In region bc again increase flux density B is again small and region beyond c the flux density nearly constant.

The material is saturated and the point c is called the point of saturation for the material.

The slope of B-H curve at point P.

$$\tan \theta = \frac{B}{H}$$

$$B = \mu_0 \mu_r H$$

$$\Rightarrow \mu_r = \frac{1}{\mu_0} \frac{B}{H}$$

$$\boxed{\mu_r = \frac{1}{\mu_0} \times \tan \theta}$$

$$\mu_r \propto \tan \theta$$

⑦ Magnetic Hysteresis :-

It is defined as the lagging of magnetic flux density (B) behind the magnetising force (or) Magnetic field intensity (H).

OR

It may be defined as that quality of a magnetic substance due to which energy is dissipated in it on the reversal of its magnetism.

fig. 4.10 (a), (b)

Consider an unmagnetised bar of AB which is to be magnetised by placing it within the field of solenoid.

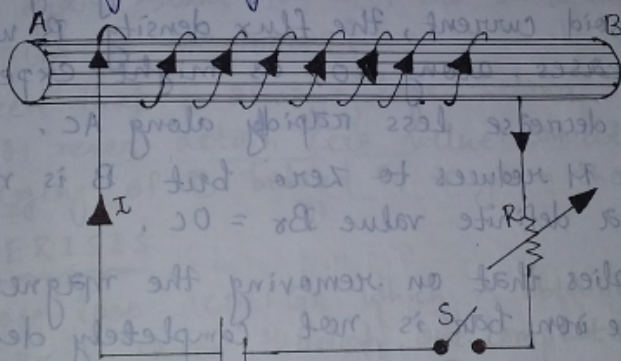


Fig. 4.10 (a)

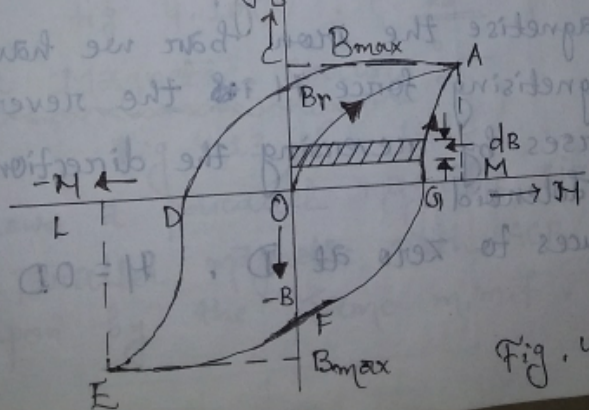


Fig. 4.10. (b)

(8)

The solenoid produces a magnetic field intensity

$$H = \frac{NI}{l}$$

H increases with increasing I and vice-versa.

The value of current in the solenoid changes by changing the variable resistor.

Plot graph between H - B .

The curve OA is obtained.

The material becomes magnetically saturated for $H = OM$ and maximum flux density B_{max} .

If it is now decreased gradually by decreasing solenoid current, the flux density B will not decrease along AO, as might be expected.

But decrease less rapidly along AC.

when H reduces to zero but B is not, but has a definite value $B_r = OC$.

It implies that on removing the magnetising force H , the iron bar is not completely demagnetised.

$B_r = OC$ = Residual flux density called retentivity.

To demagnetise the iron bar we have to apply the magnetising force H in the reverse direction.

H reverses by reversing the direction of current in the solenoid.

B_r reduces to zero at D. $H = OD$.

(d). c.c.p. p.p

④ The value of H required to wipe off residual magnetism is known as coercive force (H_c). It measures the coercivity of material. With the value of $H = 0D$, it is observed that magnetisation reduces to zero. If H further increased in the negative direction or reverse direction, the iron bar again reaches a state of magnetitic saturation represented by point E.

If now taking H back from ~~its~~ value corresponding to negative saturation or to its value for positive saturation OM , a similar curve $EFGA$ is obtained. If we again start from G , the same curve $GACDEFGA$ is obtained.

It is seen that B always lags behind H . Both B and H never attain zero value simultaneously. This lagging of B behind H is given the name MYSTERISIS.

The close loop $ACDEFGA$ which is obtained when iron bar is taken through one complete cycle of magnetisation is known as Hysteresis loop.

fig. 4.10 (a) . P. 280

Parallel Magnetic Circuits :-

Fig 4.13 (i) (ii)

Fig shows a parallel magnetic circuits consisting of two parallel magnetic path ACB and ADB acted upon by the same m.m.f.

⑩

Each magnetic path has an average length
 $= 2(l_1 + l_2)$

The flux produced by the coil wound on the central core is divided equally at point A between the two outer parallel paths.

The reluctance offered by the two parallel paths is = half the reluctance of each path.

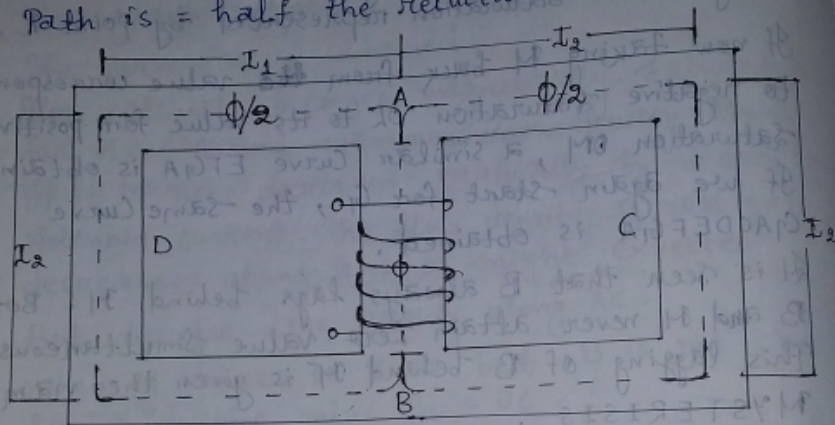


Fig 4.13.C.i

Series - Parallel Magnetic Circuits

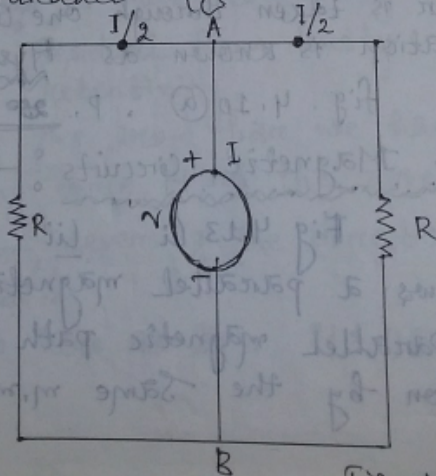


Fig. 4.13.C.ii

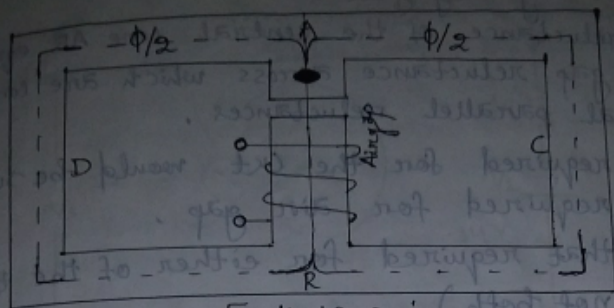


Fig 4.13.D.i

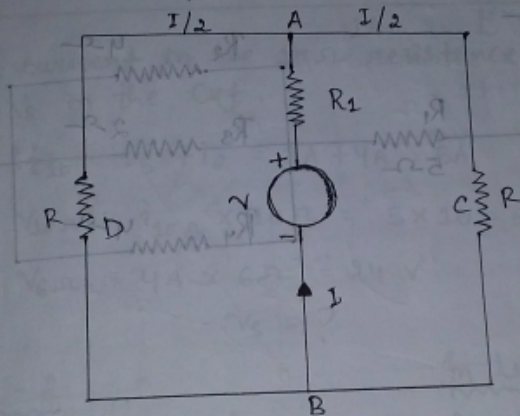


Fig 4.13.D.ii

Series - Parallel Circuits

Such cut shown in fig.

Two parallel magnetic cut, ACB and ACD. Connected across the common magnetic path AB which contains an air gap of length l_g .

Flux ϕ in the common core is divided equally at point A between two parallel paths which have equal reluctance.

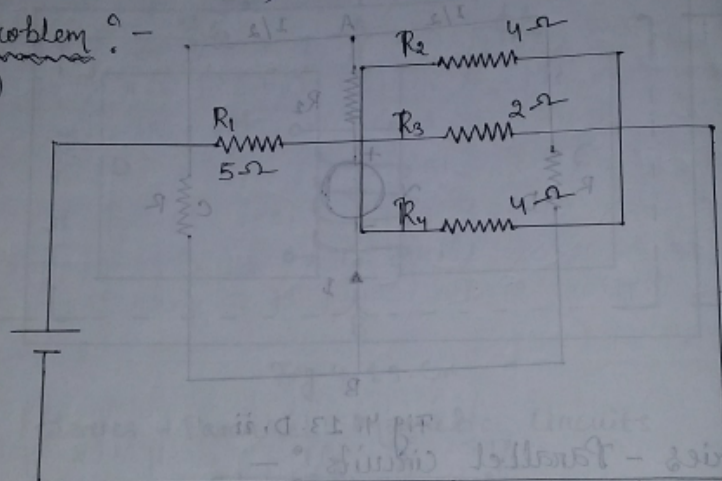
The reluctance of path AB consists of

- (i) air gap reluctance
- (ii) the reluctance of central core which

- 12) Comparatively negligible.
Hence reluctance of the central core AB equals only the air gap reluctance across which are connected two equal parallel reluctances.
M.M.F required for the cut would be sum of
(a) required for air gap.
(b) that required for either of the two paths (not both)

Problem :-

①



Determine the total current in the cut.

Soln :-

$$R_2 \parallel R_3 \parallel R_4$$

$$\frac{1}{R_{eq}} = \frac{1}{4} + \frac{1}{2} + \frac{1}{4}$$

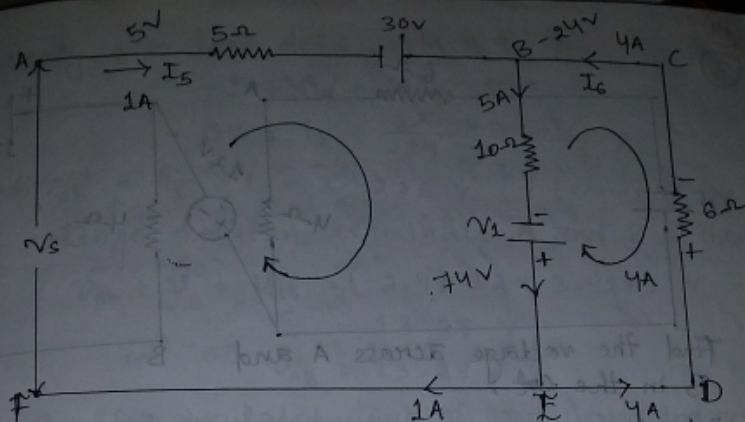
$$= \frac{2}{4} + \frac{1}{2} = \frac{1}{2} + \frac{1}{2} = \frac{2}{2} = 1 \Omega$$

$$R_{eq} = 1 \Omega$$

R_1 in series with $(R_2 \parallel R_3 \parallel R_4)$

$$R_{eq} = 5 \Omega + 1 \Omega = 6 \Omega$$

$$I = \frac{V}{R} = \frac{30 \text{ V}}{6 \Omega} = 5 \text{ A}$$



find the current in the 10Ω resistance V_1 and source voltage V_s in the ckt.

Solⁿ:- $i_{10} = i_5 + i_6 = 1A + 4A = 5A$

$V_{10\Omega} = i_{10\Omega} \times 10\Omega = 5 \times 10 = 50V$

$V_{6\Omega} = 4A \times 6\Omega = 24V$

$V_1 = ?$

$V_s = ?$

In Loop - 2

$$-V_1 + 10(i_5 + i_6) + 6i_6 = 0$$

$$\Rightarrow -V_1 + 10(1+4) + 6 \times 4 = 0$$

$$\Rightarrow -V_1 + 10(5) + 24 = 0$$

$$\Rightarrow -V_1 + 50 + 24 = 0$$

$$\Rightarrow -V_1 = -74$$

$$\Rightarrow V_1 = 74V$$

In Loop - 1

$$V_s + i_5 \times 5 + 30 - 10(i_5 + i_6) + V_1 = 0$$

$$\Rightarrow V_s - 1 \times 5 + 30 - 10(1+4) + V_1 = 0$$

$$\Rightarrow V_s - 5 + 30 - 10(5) + V_1 = 0$$

$$\Rightarrow V_s + 25 - 50 + 74V = 0$$

$$\Rightarrow V_s + 25 + 74V = 0$$

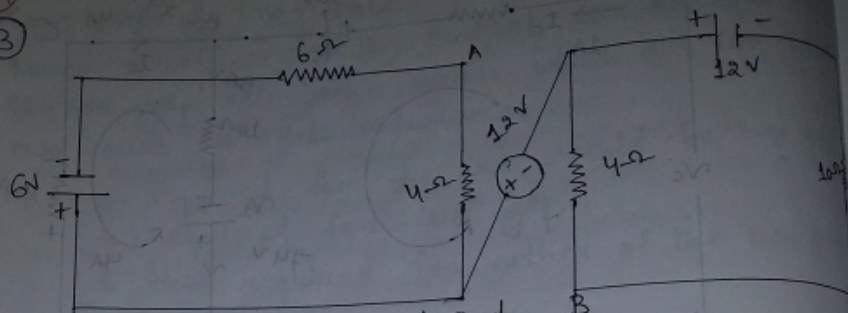
$$\Rightarrow V_s + 49V = 0$$

$$\Rightarrow V_s = -49V$$

Because of 10Ω resistance branch of both of loop, so total current will be

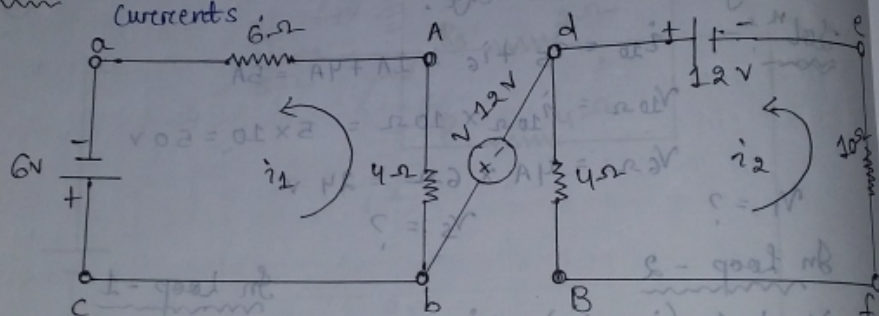
$$i_5 + i_6 = 1 + 4 = 5A$$

14
3



Find the voltage across A and B in the circuit.

Solⁿ:- Let us redraw the circuit with designated loop currents



In loop aAbc, KVL gives

$$-6 + 4i_1 + 6i_1 = 0$$

$$\text{OR, } i_1 = \frac{6}{10} = \frac{3}{5} \text{ A.}$$

$$V_{bA} = -V_{Ab} = 4i_1$$

(drop across 4Ω resistor)

$$= 4 \times \frac{3}{5} = 2.4 \text{ V}$$

(A terminal -ve as the current i_1 flows from b to A)

⑮ Similarly, in loop defB,

$$-12 + 4i_2 + 10i_2 = 0$$

$$\text{Or, } i_2 = \frac{12}{14} = \frac{6}{7} \text{ A}$$

$$\text{and } V_{dB} = \frac{6}{7} \times 4 = 3.4285 \text{ V. (d terminal +ve)}$$

The voltage between terminals A and B is then

$$V_{AB} + V + V_{dB} = (-2.47 - 12 + 3.428) \text{ V}$$

$$= 13.28 \text{ V}$$

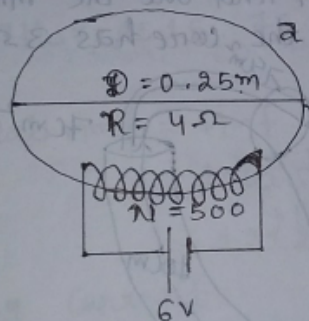
$$V_{AB} = 13.28 \text{ V}$$

④ A coil of a insulated wire of 500 turns and resistance 4Ω is closely wound on an iron ring. The ring has mean diameter 0.25 m and uniform cross sectional area 700 mm^2 calculate total flux in the ring when d.c source of 6 V is applied.

$$\mu_r = 550$$

$$a = 700 \text{ mm}^2$$

Solⁿ:-



$$H = \frac{NI}{l}$$

$$I = \frac{V}{R} = \frac{6 \text{ V}}{4\Omega} = 1.5 \text{ A}$$

$$NI = 500 \times 1.5 = 750 \text{ AT}$$

$$l = 2\pi r = \pi D = (\pi \times 0.25) \text{ m}$$

$$H = \frac{NI}{l} = \frac{750 \text{ AT}}{(\pi \times 0.25) \text{ m}} = 955 \text{ AT/m}$$

(16)

$$B = \mu_0 \mu_r H$$

$$= 4\pi \times 10^{-7} \times 550 \times 955$$

$$B = 0.66 \text{ T}$$

$$\phi = BA = 0.66 \text{ T} \times 700$$

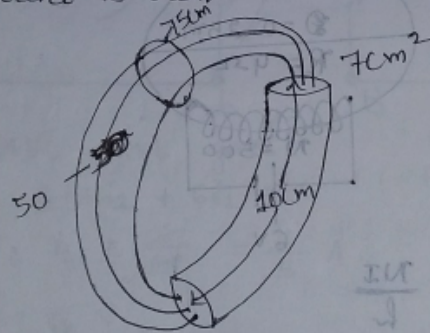
$$A = 700 \text{ mm}^2 = 700 \times (10^{-3} \text{ m})^2$$

$$\left(\begin{array}{l} 1 \text{ m} = 100 \text{ cm} = 1000 \text{ mm} \\ 1 \text{ m} = 10^3 \text{ mm} \\ 1 \text{ mm} = 10^{-3} \text{ m} \end{array} \right)$$

$$A = 700 \times 10^{-6} \text{ m}^2 = 7 \times 10^{-4} \text{ m}^2$$

- (5) A ring shaped core shown in fig. is made up of ferromagnetic material having $\mu_r = 600$. It is required to produce flux density 1.6 T in the thin section of the core. Find out the mmf (NI) and existing current if the core has 30 turns.

Solⁿ:-



$$\mu_r = 600$$

$$B = 1.6 \text{ T}$$

$$B = \mu_0 \mu_r H$$

$$H = \frac{B}{\mu_0 \mu_r} = \frac{1.6 \text{ T}}{4\pi \times 10^{-7} \times 600} = 2122.06 \text{ AT/m}$$

$$\text{mmf} = NI = HL$$

$$\textcircled{17} \quad H = \frac{NI}{L} = 2122.06 \times \frac{50}{100}$$

$$NI = Hl = 1061.03 \text{ AT}$$

mmf of thick section

$$B = \frac{\phi}{A}$$

$$\Rightarrow \phi = BA = 1.6 \times 5 \times 10^{-4}$$

$$B = \frac{\phi}{A} = \frac{1.6 \times 5 \times 10^{-4}}{7 \times 10^{-4}}$$

$$= 1.143 \text{ T}$$

$$H = \frac{B}{\mu_0 \mu_r}$$

$$= \frac{1.143}{4\pi \times 10^{-7} \times 600}$$

$$= 1515.76 \frac{\text{AT}}{\text{m}}$$

$$\text{mmf} = Hl = 1515.76 \times \frac{10}{100} = 151.57 \text{ AT}$$

$$\text{Total mmf} = \text{mmf} + \text{mmf}$$

$$= 1061.03 + 151.57$$

$$= 1212.61 \text{ AT}$$

Exciting current

$$= I = \frac{\text{mmf}}{N}$$

$$= \frac{1212.61 \text{ AT}}{300} = 4.042 \text{ A}$$

⑥ The area of a hysteresis loop material in 30 cm^2

$$1 \text{ cm} = 400 \text{ AT/m} = x$$

$$1 \text{ cm} = 0.4 \text{ wb/m}^2 = y$$

Determine the hysteresis power loss of 1.2×10^{-3} of the material is subjected to alternating flux of frequency 50 Hz .

Solⁿ :- Area of the hysteresis loop = Power loss

$$A = 30 \text{ cm}^2$$

$$\text{Power loss} = xy \times (\text{Area of the hysteresis loop})$$

$$\Rightarrow 400 \times 0.4 \times 30 \text{ m}^2$$

$$\Rightarrow 160 \times 30 = 48000 \text{ Joule/m}^2/\text{cycle}$$

Loss of watt

$$= 4800 \times 1.2 \times 10^{-3} \times 50$$

$$= 288 \text{ watt}$$

Induced current

$$\frac{7 \text{ mV}}{1} = I =$$

$$A \text{ and } P = \frac{7 \times 10^{-3} \times 1}{0.02} =$$

2nd chapter Coupled Circuit

It is defined as the interconnected loops of an electric network through the magnetic circuit.

There are two types of induced emf.

① Statically Induced emf.

② Dynamically Induced emf.

Faraday's Laws of Electro-Magnetic

Introduction →

First Law →

whenever the magnetic flux linked with a circuit changes, an emf is induced in it.

OR

whenever a conductor cuts magnetic flux an emf is induced in it.

Second law →

It states that the magnitude of induced emf is equal to the rate of change of flux linkages.

OR

The emf induced is directly proportional to the rate of change of flux and number of turns.

Mathematically :

$$e \propto \frac{d\phi}{dt}$$

$$e \propto N$$

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

where e = induced emf

N = NO. of turns

ϕ = flux

'-ve' sign is due to Lenz's law.

Inductance :-

It is defined as the property of the substance which opposes any change in current & flux.

Unit :- Henry

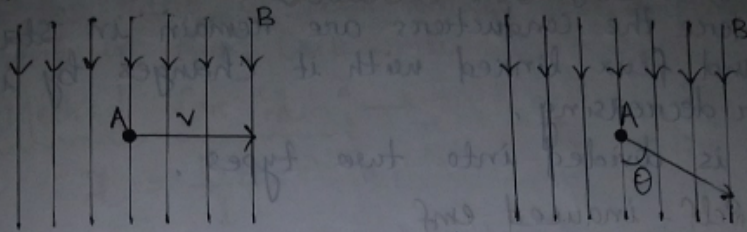
Fleming's right hand rule :-

If the forefinger points in the direction of the magnetic field and the thumb points in the direction of motion of conductor, then the middle finger shows the direction of induced current. This rule is called Fleming's right hand rule.

Lenz's law :-

It states that the direction of the induced current (emf) is such that it opposes the change of magnetic flux.

② Dynamically induced emf :-



In this case the field is stationary and the conductors are rotating in an uniform magnetic field at flux density ' B ' wb/m^2 and the conductor is lying perpendicular to the magnetic field. Let ' l ' is the length of the conductor and it moves a distance of ' dx ' in time ' dt ' second.

The area swept by the conductor = $l \cdot dx$

Hence the flux cut = $l dx \cdot B$.

change in flux in time ' dt ' second = $\frac{B l dx}{dt}$

$$\mathcal{E} = Blv$$

$$\text{where } v = \frac{dx}{dt}$$

If the conductor is making an angle ' θ ' with the magnetic field, then

$$\boxed{e = Blv \sin \theta}$$

① Statically Induced emf :-

Here the conductors are remain in stationary and flux linked with it changes by increasing or decreasing.

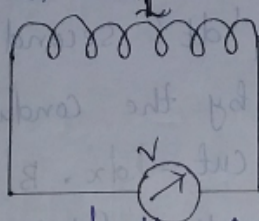
It is divided into two types.

(i) Self-induced emf

(ii) Mutually-induced emf.

① Self-induced emf :-

It is defined as the emf induced in a coil due to the change of its own flux linked with the coil.



If current through the coil is changed then the flux linked with its own turn will also change which will produce an emf is called Self-induced emf.

Self-Inductance :- (L)

It is defined as the property of the coil due to which it opposes any change of current or flux through it.

Co-efficient of Self-Inductance (L) :-

It is the ratio of flux linked per ampere of current in the coil.

1st Method for ' L ' :-

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

where L = Co-efficient of self-induction

N = number of turns

ϕ = flux

2nd Method for ' L ' :-

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

$$\Rightarrow LI = N\phi$$

$$\Rightarrow -LI = -N\phi$$

$$\Rightarrow -L \frac{dI}{dt} = -N \frac{d\phi}{dt}$$

$$\Rightarrow -L \frac{dI}{dt} = -N \frac{d\phi}{dt}$$

$$\Rightarrow -L \frac{dI}{dt} = -N \frac{d\phi}{dt}$$

$$\Rightarrow L \frac{dI}{dt} = N \frac{d\phi}{dt}$$

$$\Rightarrow L = \frac{-e_L}{\frac{dI}{dt}}$$

where L = Inductance

$e_L = -N \frac{d\phi}{dt}$ is known as self-induced emf.

when $\frac{dI}{dt} = 1 \text{ amp/sec}$

$$e = 1 \text{ volt}$$

$$L = 1 \text{ henry}$$

A coil is said to be a self-inductance of 1 Henry if 1 volt is induced in it, when the current through it changes at the rate of 1 amp/sec.

3rd method for L :-

$$L = \frac{\mu_0 \mu_r AN^2}{l}$$

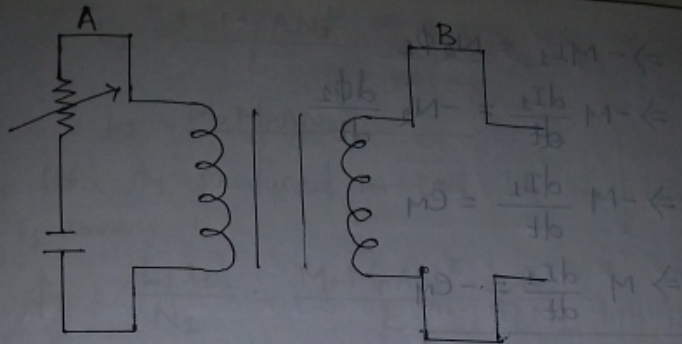
where A = Area of x-section of the coil

N = Number of turns

l = Length of the coil

(ii) Mutually Induced emf :-

It is defined as the emf induced in one coil due to change in current in other coil. Consider two coils 'A' and 'B' lying close to each other. An emf will be induced in coil 'B' due to change of current in coil 'A' by changing the position of the rheostat.



Mutual Inductance :-

It is defined as the emf induced in coil 'B' due to change of current in coil 'A' is the ratio of flux linkage in coil 'B' to 1 amp. of current in coil 'A'.
Co-efficient of Mutual Inductance (M).

Co-efficient of mutual inductance between the two coils is defined as the weber-turns in one coil due to one ampere current in the other.

1st method for 'M' :-

$$M = \frac{N_2 \phi_1}{I_1}$$

N_2 = number of turns

M = mutual inductance

ϕ_1 = flux linkage

I_1 = current in ampere

2nd method for M :-

$$M = \frac{N_2 \phi_1}{I_1}$$

$$\Rightarrow MI_1 = N_2 \phi_1$$

$$\Rightarrow -M I_1 = N_2 \phi_1$$

$$\Rightarrow -M \frac{dI_1}{dt} = -N_2 \frac{d\phi_1}{dt}$$

$$\Rightarrow -M \frac{dI_1}{dt} = e_M$$

$$\Rightarrow M \frac{dI_1}{dt} = -e_M$$

$$\Rightarrow M = \frac{-e_M}{\frac{dI_1}{dt}}$$

where $e_M = -N_2 \frac{d\phi_1}{dt}$ is known as mutually induced emf.

$$e_M = -1 \text{ volt}$$

then $M = 1 \text{ Henry}$

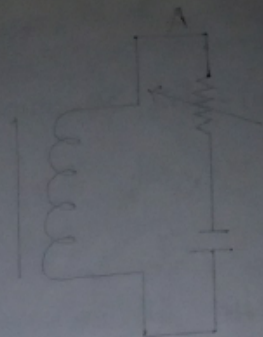
A coil is said to be a mutual inductance of 1 Henry when 1 volt is induced when the current of 1 amp/sec. is changed in its neighbouring coil.

3rd method for M :-

$$M = \frac{\mu_0 \mu_r AN_1 N_2}{l}$$

Co-efficient of Coupling :-

Consider two magnetically coupled coils having N_1 and N_2 turns respectively. Their individual Co-efficient of self-inductances are



$$L_1 = \frac{\mu_0 \mu_r AN_1^2}{l}$$

$$L_2 = \frac{\mu_0 \mu_r AN_2^2}{l}$$

The flux ϕ_1 produced in coil 'A' due to a current of I_1 ampere is

$$\phi_1 = \frac{L_1 I_1}{N_1} = \frac{\mu_0 \mu_r AN_1^2}{l} \times \frac{I_1}{N_1}$$

$$\phi_1 = \frac{\mu_0 \mu_r AN_1 I_1}{l}$$

Suppose a fraction of this flux i.e. $K_1 \phi_1$ is linked with coil 'B'

$$\text{Then } M = \frac{K_1 \phi_1}{I_1} \times N_2 = \frac{K_1 N_1 N_2}{l / \mu_0 \mu_r A} \quad \text{--- (1)}$$

Similarly, the flux ϕ_2 produced in coil 'B' due to I_2 amp. I_2

$$\phi_2 = \frac{\mu_0 \mu_r AN_2 I_2}{l}$$

Suppose a fraction of this flux i.e. $K_2 \phi_2$ is linked with coil 'A',

$$\text{Then } M = \frac{K_2 \phi_2}{I_2} \times N_1 = \frac{K_2 N_2 N_1}{l / \mu_0 \mu_r A} \quad \text{--- (2)}$$

Multiplying equation (1) & (2)

$$M^2 = \frac{K_1 K_2 N_1^2 N_2^2}{l^2 / \mu_0^2 \mu_r^2 A^2} \times N_1$$

$$= K^2 \left(\frac{\mu_0 \mu_r AN_1^2}{l} \right) \left(\frac{\mu_0 \mu_r AN_2^2}{l} \right)$$

$$[\because K_1 = K_2 = K]$$

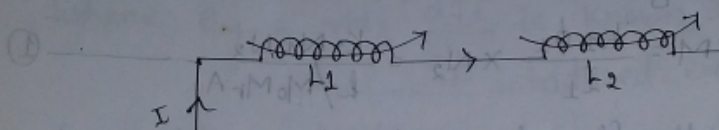
$$M^2 = K^2 \cdot L_1 \cdot L_2$$

$$K^2 = \frac{M^2}{L_1 \cdot L_2}$$

$$\Rightarrow K = \sqrt{\frac{M}{L_1 \cdot L_2}}$$

Where 'K' is known as the Co-efficient of coupling. Co-efficient of coupling is defined as the ratio of mutual inductance between two coils to the square root of their self-inductances.

Inductances in Series (Additive)



Fluxes are in the same direction

Let M = Co-efficient of mutual inductance

L_1 = Co-efficient of self-inductance of first

Coil.

L_2 = Co-efficient of self-inductance of second

Coil.

EMF induced in first coil due to self-inductance

$$e_{L_1} = -L_1 \frac{dI}{dt}$$

Mutually induced emf in first coil

$$e_{M_1} = -M \frac{dI}{dt}$$

EME induced in second coil due to self-inductance

$$e_{L_2} = -L_2 \frac{dI}{dt}$$

Mutually induced emf in second coil

$$e_{M2} = -M \frac{dI}{dt}$$

Total induced emf

$$e = e_{L1} + e_{L2} + e_{M1} + e_{M2}$$

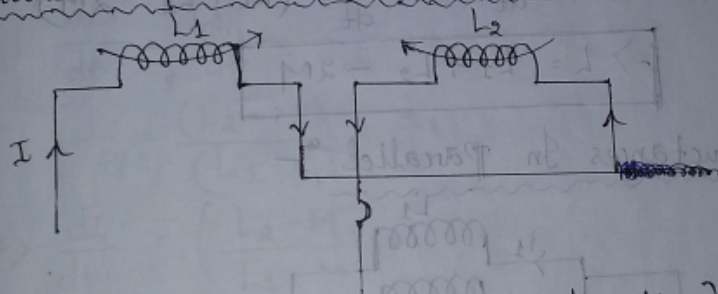
If 'L' is the equivalent inductance, then

$$-L \frac{dI}{dt} = -L_1 \frac{dI}{dt} - M \frac{dI}{dt} - L_2 \frac{dI}{dt} - M \frac{dI}{dt}$$

$$\Rightarrow -L \frac{dI}{dt} = - \frac{dI}{dt} (L_1 + L_2 + 2M)$$

$$\Rightarrow L = L_1 + L_2 + 2M$$

Inductances in series (Subtractive) :-



(Fluxes are opposite in direction)

Let M = Co-efficient of mutual inductance

L_1 = Co-efficient of self-inductance of first coil

L_2 = Co-efficient of self-inductance of second coil

Emf induced in first coil due to self-induction,

$$e_{L1} = -L_1 \frac{dI}{dt}$$

Mutually induced emf in first coil

$$e_{M1} = - \left(-M \frac{dI}{dt} \right) = M \frac{dI}{dt}$$

EMF induced in second coil due to self induction.

$$e_{L_2} = -L_2 \frac{dI}{dt}$$

Mutually induced emf in second coil

$$e_{M_2} = -\left(-M \frac{dI}{dt}\right) = M \frac{dI}{dt}$$

Total induced emf

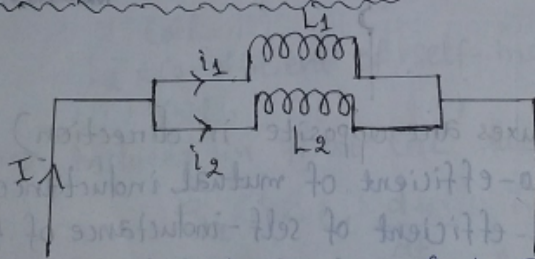
$$e = e_{L_1} + e_{L_2} + e_{M_1} + e_{M_2}$$

$$\text{Then } -L \frac{dI}{dt} = -L_1 \frac{dI}{dt} - L_2 \frac{dI}{dt} + M \frac{dI}{dt} + M \frac{dI}{dt}$$

$$\Rightarrow -L \frac{dI}{dt} = -\frac{dI}{dt} (L_1 + L_2 - 2M)$$

$$\Rightarrow L = L_1 + L_2 - 2M$$

Inductances In parallel:-



Let two inductances of L_1 & L_2 are connected in parallel.

Let the co-efficient of mutual inductance between them is M .

$$I = i_1 + i_2$$

$$\frac{dI}{dt} = \frac{di_1}{dt} + \frac{di_2}{dt} \quad \text{--- (1)}$$

$$e = L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}$$

$$M + \left(\frac{L_2}{M-L_1} + M \frac{di_1}{dt} \right) \left[1 + \left(\frac{M-L_1}{M-L_1} \right) \right]$$

$$\Rightarrow L_1 \frac{di_1}{dt} + M \frac{di_2}{dt} = L_2 \frac{di_2}{dt} + M \frac{di_1}{dt}$$

$$\Rightarrow (L_1 - M) \frac{di_1}{dt} = (L_2 - M) \frac{di_2}{dt}$$

$$\Rightarrow \frac{di_1}{dt} = \frac{(L_2 - M)}{(L_1 - M)} \frac{di_2}{dt} \quad \text{--- (2)}$$

$$\frac{dI}{dt} = \frac{di_1}{dt} + \frac{di_2}{dt}$$

$$= \frac{(L_2 - M)}{(L_1 - M)} \frac{di_2}{dt} + \frac{di_2}{dt}$$

$$\Rightarrow \frac{dI}{dt} = \left(\frac{L_2 - M}{L_1 - M} + 1 \right) \frac{di_2}{dt} \quad \text{--- (3)}$$

If 'L' is the equivalent inductance

$$e = L \frac{di}{dt} = L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}$$

$$L \frac{di}{dt} = L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}$$

$$\Rightarrow \frac{di}{dt} = \frac{1}{L} \left(L_1 \frac{di_1}{dt} + M \frac{di_2}{dt} \right) \quad \text{--- (4)}$$

Substituting the value of $\frac{di_1}{dt}$

$$\frac{di}{dt} = \frac{1}{L} \left[L_1 \frac{L_2 - M}{L_1 - M} + M \right] \frac{di_2}{dt} \quad \text{--- (5)}$$

Equating equation (3) & (5)

$$\left[\frac{L_2 - M}{L_1 - M} + 1 \right] \frac{di_2}{dt} = \frac{1}{L} \left[L_1 \left(\frac{L_2 - M}{L_1 - M} \right) + M \right] \frac{di_2}{dt}$$

$$\Rightarrow \frac{L_2 - M}{L_1 - M} + 1 = \frac{1}{L} \left[L_1 \left(\frac{L_2 - M}{L_1 - M} \right) + M \right]$$

$$\Rightarrow \frac{L_2 - M + L_1 - M}{L_1 - M} = \frac{1}{L} \left[\frac{L_1 L_2 - L_1 M + L_1 M - M^2}{L_1 - M} \right]$$

$$\Rightarrow \frac{L_1 + L_2 - 2M}{L_1 - M} = \frac{1}{L} \left[\frac{L_1 L_2 - M^2}{L_1 - M} \right]$$

$$\Rightarrow L_1 + L_2 - 2M = \frac{1}{L} [L_1 L_2 - M^2]$$

$$\Rightarrow L = \frac{L_1 L_2 - M^2}{L_1 + L_2 - 2M}$$

when mutual field assist.

$$L = \frac{L_1 L_2 - M^2}{L_1 + L_2 + 2M}$$

when mutual field opposes.

Self Inductance (L):

When a current changes in a ckt the magnetic flux linked to that ckt changes. So an emf is produced according to Faraday's law of electro magnetic induction.

$$e \propto \frac{di}{dt}$$

$$e = L \frac{di}{dt}$$

L = constant of proportionality or self inductance of the ckt.

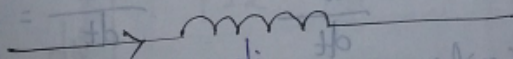
$$e \propto \frac{d\phi}{dt}, \quad \frac{d\phi}{dt} \propto \frac{di}{dt}$$

$$L = 1 \text{ henry}, \quad e = 1 \text{ volt}, \quad \frac{d\phi}{dt} = 1 \text{ amp}$$

$$L = \frac{N\phi}{i}$$

$$L = N \frac{d\phi}{di}$$

$$L = \frac{N\phi}{i}$$



$$e_1 = L \frac{di}{dt}$$

$$e_2 = N \frac{d\phi}{dt}$$

L = self inductance

$$i \propto \phi$$

$$\phi \propto i$$

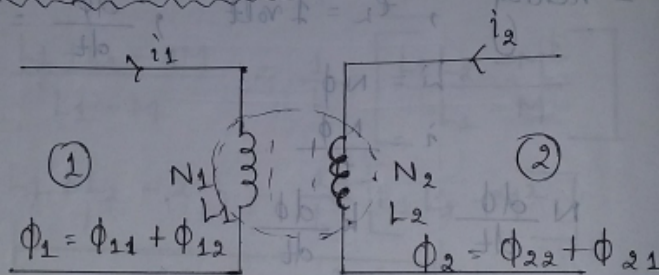
$$N\phi = Li$$

$$N\phi = Li$$

$$e_L = N \frac{d\phi}{dt} = L \frac{di}{dt}$$

$$L = N \frac{d\phi}{di}$$

Mutual Inductance



$$\phi_{12} = \phi_{21}$$

$$Q = L \frac{di}{dt} \quad L = 1 \text{ henry}$$

$$e_L = 1 \text{ volt}$$

$$L = \frac{e_L}{\frac{di}{dt}} \quad \frac{di}{dt} = 1 \text{ amp/sec}$$

when two coils are kept in such a way that their electrically isolated but magnetically coupled. There will be mutual induction between two coils. Hence, a portion of

magnetic flux which links with the other coil as well as due to magnetic coupled.

Let us consider two coils which are mutually coupled.

i_1 and i_2 are alternating current in coil 1 and 2 respectively.

ϕ_1 flux is produced by current i_1 .

$$\phi_1 = \phi_{11} + \phi_{12}$$

ϕ_{11} = flux produced by current i_1 and links to coil 1.

ϕ_{12} = flux produced by current i_1 and links to coil 2.

Total flux produced by current i_2 is ϕ_2 .

$$\phi_2 = \phi_{22} + \phi_{21}$$

ϕ_{22} = flux produced by current i_2 and links to coil 2.

ϕ_{21} = flux produced by current i_2 and links to coil 1.

$$L_1 = N_1 \frac{\phi_{11}}{i_1}$$

$$L_1 = N_1 \frac{d\phi}{di_1}$$

$$V_2 = L_1 \frac{di_1}{dt}$$

$$V_{L1} = N_1 \frac{d\phi_{11}}{dt}$$

$$\phi_{12} = \phi_{21}$$

$$L_2 = N_2 \frac{\phi_{22}}{i_2}$$

$$L_2 = N_2 \frac{d\phi_{22}}{di_2}$$

$$V_{L2} = L_2 \frac{d\phi_{22}}{dt}$$

$$V_{L2} = N_2 \frac{d\phi_{22}}{dt}$$

voltage induced in second coil

$$e_m = N_2 \frac{d\phi_{12}}{dt}$$

$$\frac{\phi_{12}}{N_2 \phi_{12}} = \frac{\alpha i_1}{Mi_1}$$

$$M_{12} = \frac{N_2 \phi_{12}}{i_1}$$

$$\phi_{12} \propto i_1$$

$$N_2 \phi_{12} \propto Li$$

$$N_2 \phi_{12} = M Li$$

$$M_{12} = \frac{N_2 \phi_{12}}{i_1} \quad (1)$$

Similarly $M_{21} = \frac{N_1 \phi_{21}}{i_2} \quad (2)$

But $M_{12} = M_{21} = M$

$$M = \frac{N_2 \phi_{12}}{i_1} = \frac{N_1 \phi_{21}}{i_2}$$

$$v_2 = N_2 \frac{d\phi_{12}}{dt} \quad (3)$$

$$v_2 \propto \frac{di_1}{dt}$$

$$v_2 = M \frac{di_1}{dt} \quad (4)$$

Equating eqⁿ (3) and (4)

$$M \frac{di_1}{dt} = N_2 \frac{d\phi_{12}}{dt}$$

$$M = N_2 \frac{d\phi_{12}}{dt} \quad \text{--- (5)}$$

voltage induced in first (n)

$$V_1 = N_1 \frac{d\phi_{21}}{dt} \quad \text{--- (6)}$$

$$V_1 \propto \frac{di_2}{dt}$$

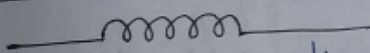
$$V_1 = M \frac{di_2}{dt} \quad \text{--- (7)}$$

Equating eqⁿ (6) and (7)

$$M \frac{di_2}{dt} = N_1 \frac{d\phi_{21}}{dt}$$

$$M = N_1 \frac{d\phi_{21}}{dt}$$

Self Inductance (L)



$$\frac{di}{dt} \quad e_L = L \frac{di}{dt}$$

$$i \propto \phi$$

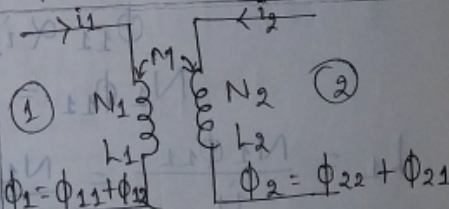
$$\phi \propto i$$

$$N\phi = Li$$

$$\text{Imp} \Rightarrow \boxed{L = \frac{N\phi}{i}} \quad \text{--- (1)}$$

$$e_L = N \frac{d\phi}{dt}$$

Mutual Inductance (M)



Electrical Contact - NO
Magnetically Contact - YES
Magnetically Coupled - YES

$$\frac{di}{dt} = \phi_1$$

$$L = N \frac{d\phi}{di} \quad \text{--- (2)}$$

Imp

$$i_1 \propto \phi_1$$

$$\phi_1 \propto i_1$$

ϕ_{11} = flux produced by current i_1 and links to coil 1,

ϕ_{12} = flux produced by current i_1 and links to coil 2,

$$\phi_{11} + \phi_{22} = \phi_1$$

ϕ_1 = Total flux produced by current i_1 .

Mutual process = Mutual inductance

Self inductance

1st coil

i_1, N_1, ϕ_1

ϕ_{11}

ϕ_{21}

$$\phi_{11} \propto i_1$$

$$N_1 \phi_{11} = L_1 i_1 \rightarrow \text{Self inductance}$$

$$L_1 = \frac{N_1 \phi_{11}}{i_1} = \frac{N_1 \phi_1}{i_1}$$

$$L_1 = N_1 \frac{d\phi_1}{di_1}$$

$$L_2 = \frac{N_2 \phi_{22}}{i_2} = \frac{N_2 \phi_2}{i_2}$$

$$L_2 = N_2 \frac{d\phi_2}{di_2}$$

$$e_L = L_1 \frac{di_1}{dt} = N_1 \frac{d\phi_1}{dt} \quad (\text{Faraday's Law})$$

2nd coil

i_2, N_2, ϕ_2

ϕ_{12}

ϕ_{22}

$$L_1 = N_1 \frac{d\phi_1}{di_1}$$

Mutual inductance

1st coil

2nd coil

ϕ_{12}

(N_1)

(N_2)

ϕ_{21}

$$\phi_{12} \propto i_1$$

$$N_2 \phi_{12} \propto i_1$$

$$N_2 \phi_{12} = M_{12} i_1$$

M_{12} = constant of proportionality or mutual inductance.

$$M_{12} = \frac{N_2 \phi_{12}}{i_1} \quad (2)$$

$$\phi_{21} \propto i_2$$

$$N_2 \phi_{21} \propto i_2$$

$$N_2 \phi_{21} = M_{21} i_2$$

$$M_{21} = \frac{N_1 \phi_{21}}{i_2} \quad (1)$$

$$M = \frac{N_2 \phi_{12}}{i_1}$$

$$M = \frac{N_1 \phi_{21}}{i_2}$$

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

M = mutual inductance of the coil.

Voltage induced in first coil :-

$$e = N_1 \frac{d\phi_{21}}{dt}$$

$$N_1 \phi_{21} \propto i_2$$

$$N_1 \phi_{21} = M i_2$$

differentiate both side w.r.t (i_2)

$$N_1 = \frac{d\phi_{21}}{di_2} = M$$

$$M = N_1 \frac{d\phi_{21}}{di_2} \quad (3)$$

voltage induced in 2nd coil :-

$$e = N_2 \frac{d\phi_{12}}{dt}$$

$$N_2 \phi_{12} \propto i_1$$

$$N_2 \phi_{12} = M i_1$$

Differentiating both side w.r.t

$$N_2 \frac{d\phi_{12}}{di_1} = M$$

$$M = N_2 \frac{d\phi_{12}}{di_1} \quad (4)$$

1st coil

$$L_1 = \frac{N_1 \phi_1}{i_1}$$

$$M = N_1 \frac{\phi_{21}}{i_2}$$

$$M = N_1 \frac{d\phi_{21}}{di_1}$$

2nd coil

$$L_2 = \frac{N_2 \phi_2}{i_2}$$

$$M = N_2 \frac{\phi_{12}}{i_1}$$

$$M = N_2 \frac{d\phi_{21}}{di_2}$$

Co-efficient of coupling (K) :-

$$K = \frac{\phi_{12}}{\phi_1}, \quad K = \frac{\phi_{21}}{\phi_2}$$

$$\phi_1 = \phi_{11} + \phi_{12}$$

$\downarrow$ $\downarrow$
 i_1 1st coil 2nd coil
 1st coil

$$\phi_2 = \phi_{22} + \phi_{21}$$

$\downarrow$ $\downarrow$ $\downarrow$
 i_2 2nd coil 1st coil
 2nd coil

1st total flux $\rightarrow$ 2nd coil
 It is the fraction of the flux links to the other coil divided by the other.

$$\Rightarrow \phi_{12} = K \phi_1 \quad \text{--- (5)} \quad \Rightarrow \phi_{21} = K \phi_2 \quad \text{--- (6)}$$

$$M = N_1 \frac{\phi_{21}}{i_2} \quad \text{--- (3)}$$

$$M = N_2 \frac{\phi_{12}}{i_1} \quad \text{--- (4)}$$

Multiplying eqn (3) and (4)

$$M^2 = \frac{N_1 \phi_{21}}{i_2} \times \frac{N_2 \phi_{12}}{i_1}$$

Putting value of ϕ_{12} and ϕ_{21} from eqn (5) & (6)

$$V_{\text{amp}} \quad M^2 = N_1 \frac{K \phi_1}{i_2} \quad N_2 \frac{K \phi_2}{i_1} \quad \left(\begin{array}{l} \phi_{21} = K \phi_2 \\ \phi_{12} = K \phi_1 \end{array} \right)$$

$$M^2 = K^2 \frac{N_1 \phi_2}{i_2} \frac{N_2 \phi_1}{i_1}$$

$$M^2 = K^2 \left(\frac{N_1 \phi_1}{i_1} \right) \left(\frac{N_2 \phi_2}{i_2} \right)$$

$$M^2 = K^2 L_1 L_2$$

$$K^2 = \frac{M^2}{L_1 L_2} \Rightarrow K = \frac{M}{\sqrt{L_1 L_2}}$$

$$K = \frac{M}{\sqrt{L_1 L_2}}$$

Self inductance

$$L = \frac{N \phi}{i}$$

$$L = N \frac{d\phi}{di}$$

Mutual inductance

$$M = \frac{N_2 \phi_{12}}{i_1}$$

$$M = \frac{N_1 \phi_{21}}{i_2}$$

$$M = N_2 \frac{d\phi_{12}}{di_1}$$

$$M = N_1 \frac{d\phi_{21}}{di_2}$$

Co-efficient of coupling (K)

$$K = \frac{\phi_{12}}{\phi_1} \quad K = \frac{\phi_{21}}{\phi_2}$$

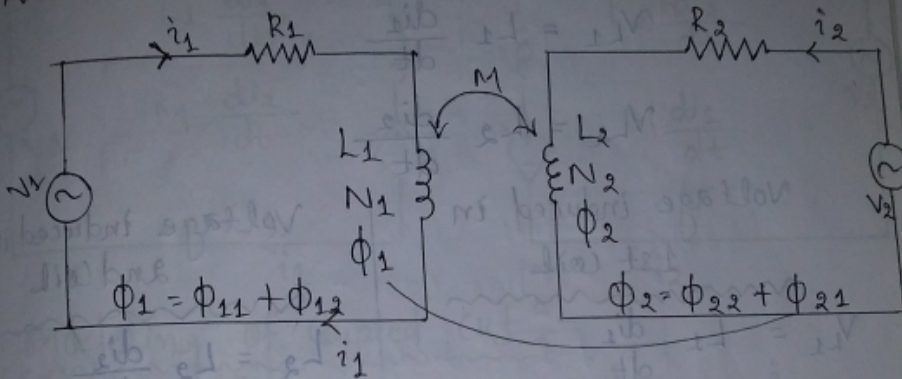
It is defined as the fraction of total flux link to other coil.

$$\phi_1 = \phi_{11} + \phi_{12}$$

1st coil 2nd coil

Dot convention :-

Modeling of a coupled circuit :-



First coil :-

$$V = L \frac{di}{dt}$$

$$\phi \propto i$$

$$N\phi \propto i$$

$$N\phi = Li$$

$$N \frac{d\phi}{dt} = L \frac{di}{dt}$$

$$Q = V_L = L \frac{di}{dt}$$

$$N_2 \phi_{12} \propto i_1$$

$$N_2 \phi_{12} = M i_1$$

$$N_2 \phi_{21} \propto i_2$$

$$N_2 \phi_{21} = M i_2$$

$$\left(N_2 \frac{d\phi_{12}}{dt} \right) = M \frac{di_1}{dt}$$

$$V_{M2} = M \frac{di_1}{dt}$$

$$N_2 \phi_{21} = M i_2$$

$$N_2 \frac{d\phi_{21}}{dt} = M \frac{di_2}{dt}$$

$$V_{M1} = M \frac{di_2}{dt}$$

$$V_{L1} = L_1 \frac{di_1}{dt}$$

$$V_{L2} = L_2 \frac{di_2}{dt}$$

Voltage induced in
1st coil

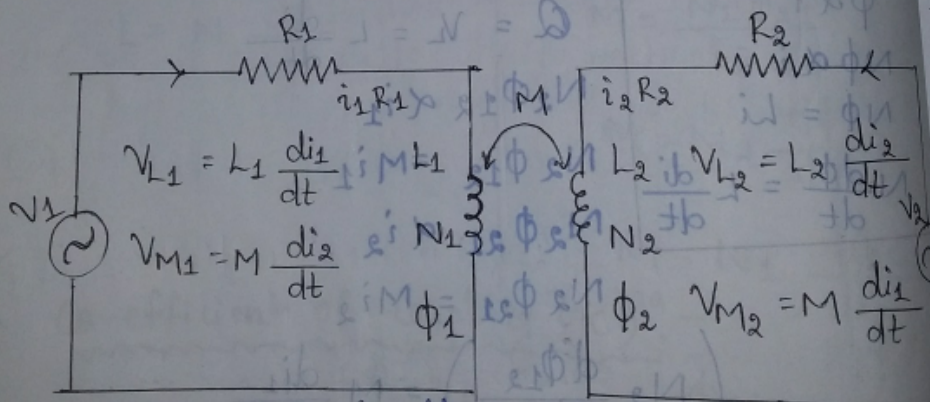
$$V_{L1} = L_1 \frac{di_1}{dt}$$

$$V_{M1} = M \frac{di_2}{dt}$$

Voltage induced in
2nd coil

$$V_{L2} = L_2 \frac{di_2}{dt}$$

$$V_{M2} = M \frac{di_1}{dt}$$

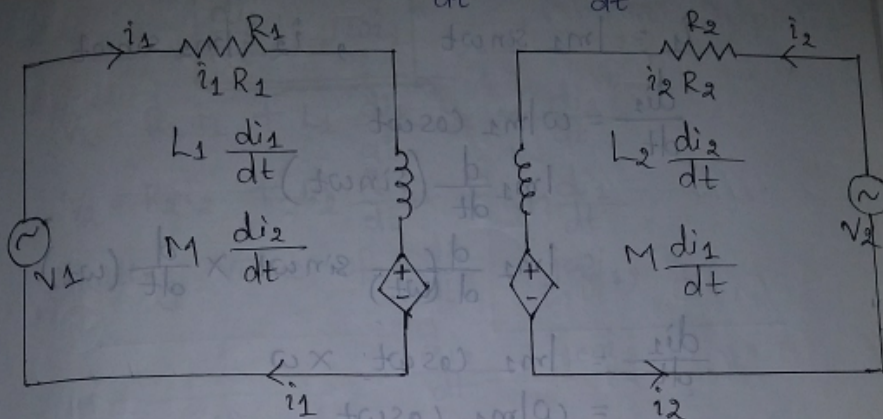


Applying KVL to the 1st coil,

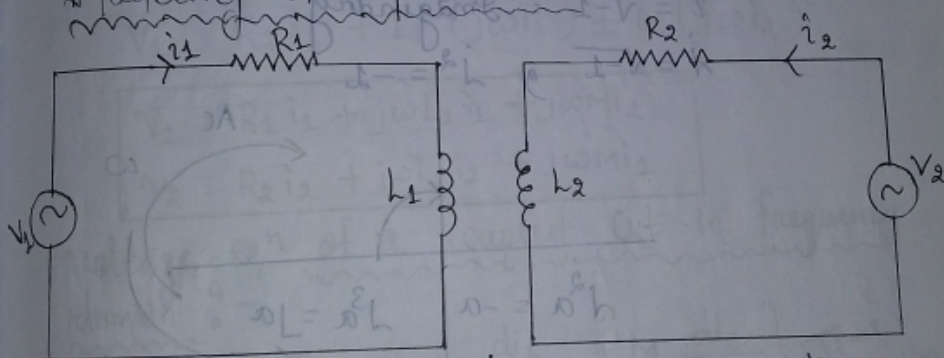
$$V_1 = i_1 R_1 + L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}$$

Applying KVL to the 2nd coil

$$V_2 = i_2 R_2 + L_2 \frac{di_2}{dt} + M \frac{di_1}{dt}$$



Modeling of coupled ckt^a -



$$V_1 = R_1 i_1 + L_1 \frac{di_1}{dt} \pm M \frac{di_2}{dt} \quad \left| \quad V_2 = R_2 i_2 + L_2 \frac{di_2}{dt} \pm M \frac{di_1}{dt} \right.$$

Equation of coupled ckt in time domain^a -

$$\begin{aligned} \text{(1st coil)} \quad & V_1 = R_1 i_1 + L_1 \frac{di_1}{dt} \pm M \frac{di_2}{dt} \quad (\text{Primary coil}) \\ \text{(2nd coil)} \quad & V_2 = R_2 i_2 + L_2 \frac{di_2}{dt} \pm M \frac{di_1}{dt} \quad (\text{Secondary coil}) \end{aligned}$$

$$V = V_m \sin \omega t$$

$$i = I_m \sin \omega t$$

$$i_1 = I_{m1} \sin \omega t, \quad i_2 = I_{m2} \sin \omega t$$

$$\frac{di_1}{dt} = \omega I_{m1} \cos \omega t$$

$$I_{m1} \frac{d}{dt} (\sin \omega t)$$

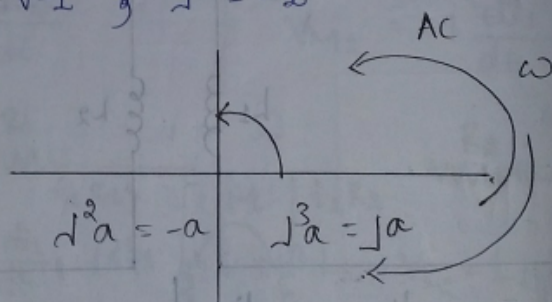
$$I_{m1} \frac{d}{d(\omega t)} \sin \omega t \times \frac{d}{dt} (\omega t)$$

$$\frac{di_1}{dt} = I_{m1} \cos \omega t \times \omega$$

$$= \omega I_{m1} \cos \omega t$$

$$i = \sqrt{-1} = \text{Imaginary}$$

$$j = \sqrt{-1} \quad , \quad j^2 = -1$$



$$\omega I_{m1} \sin (\omega t + \pi/2)$$

$$\sin(90^\circ + \theta) = \cos \theta$$

$$\sin(90^\circ + \omega t) = \cos \omega t$$

$$\sin(90^\circ + \omega t) = j \sin \omega t = \cos \omega t$$

$$\frac{\pi^c}{2} = 90^\circ$$

$$= \omega I_m \sin \omega t$$

$$= j\omega (I_m \sin \omega t)$$

$$\boxed{\frac{di_1}{dt} = j\omega i_1}$$

$$V_1 = R_1 i_1 + L_1 \frac{di_1}{dt} \pm M \frac{di_2}{dt}$$

$$V_2 = R_2 i_2 + L_2 \frac{di_2}{dt} \pm M \frac{di_1}{dt}$$

Equating value of $\frac{di_1}{dt} = j\omega i_1$

$$\frac{di_2}{dt} = j\omega i_2$$

in the above eqn

$$V_1 = R_1 i_1 + L_1 (j\omega i_1) \pm M (j\omega i_2)$$

$$V_1 = R_1 i_1 + j\omega L_1 i_1 \pm j\omega M i_2$$

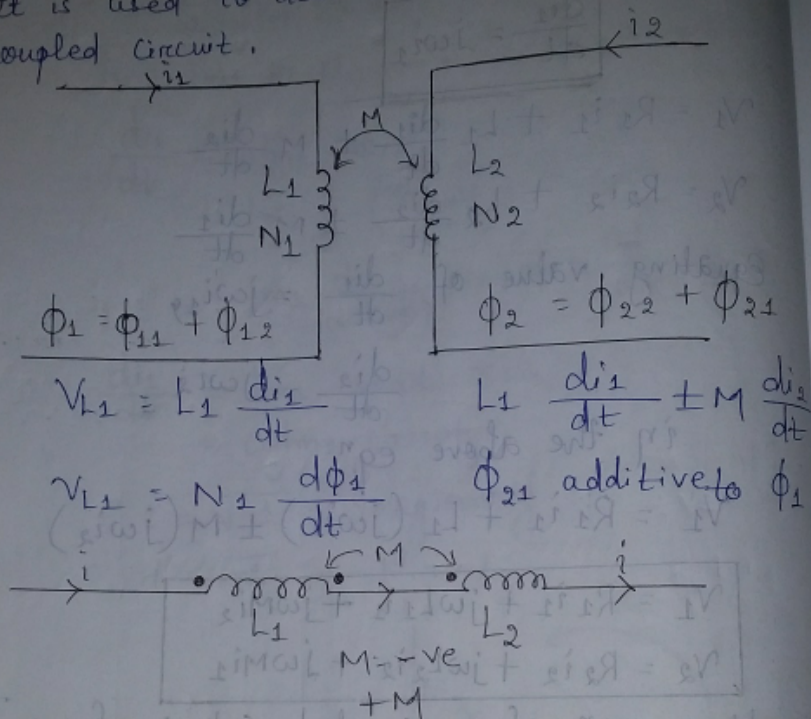
$$V_2 = R_2 i_2 + j\omega L_2 i_2 \pm j\omega M i_1$$

Voltage eqn of a coupled ckt in frequency domain :-

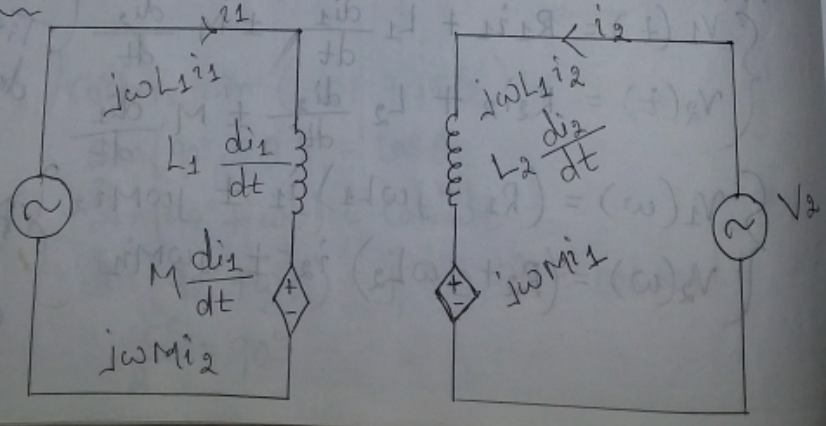
$$\left\{ \begin{array}{l} V_1(t) = R_1 i_1 + L_1 \frac{di_1}{dt} \pm M \frac{di_2}{dt} \\ V_2(t) = R_2 i_2 + L_2 \frac{di_2}{dt} \pm M \frac{di_1}{dt} \end{array} \right\} \text{Time domain eqn}$$

$$\left\{ \begin{array}{l} V_1(\omega) = (R_1 + j\omega L_1) i_1 \pm j\omega M i_2 \\ V_2(\omega) = (R_2 + j\omega L_2) i_2 \pm j\omega M i_1 \end{array} \right\} \text{Frequency domain eqn}$$

Dot Convention :-
It is used to determine the polarity of a coupled circuit.



Electrical equivalent of magnetically coupled Ckt :-



$$M = +ve$$

$$\begin{aligned} V_1 &= L_1 \frac{di_1}{dt} + M \frac{di_2}{dt} \\ V_2 &= L_2 \frac{di_2}{dt} + M \frac{di_1}{dt} \end{aligned} \quad \left. \vphantom{\begin{aligned} V_1 &= L_1 \frac{di_1}{dt} + M \frac{di_2}{dt} \\ V_2 &= L_2 \frac{di_2}{dt} + M \frac{di_1}{dt} \end{aligned}} \right\} \text{Time domain form}$$

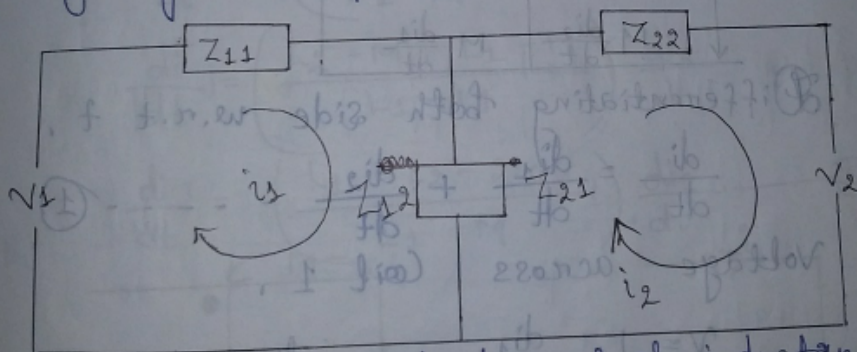
$$\frac{di_1}{dt} = j\omega i_1 \quad \frac{di_2}{dt} = j\omega i_2$$

$$\begin{aligned} V_1 &= j\omega L_1 i_1 + j\omega M i_2 \\ V_2 &= j\omega L_2 i_2 + j\omega M i_1 \end{aligned} \quad \left. \vphantom{\begin{aligned} V_1 &= j\omega L_1 i_1 + j\omega M i_2 \\ V_2 &= j\omega L_2 i_2 + j\omega M i_1 \end{aligned}} \right\} \text{Equivalent ckt in frequency domain}$$

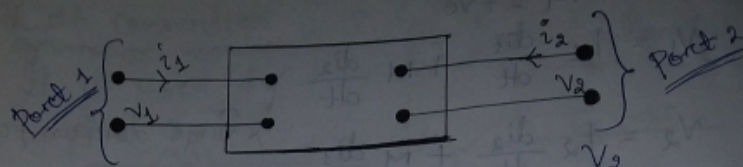
Electrical Equivalent ckt (Two types)

- ① Time domain ② Frequency domain

Conductively coupled ckt it doesn't involve any magnetic coupling.



Z_{12} or Z_{21} is called mutual inductance because, this inductance is common to both primary & secondary coil.



$$Z_{11} = \frac{V_1}{i_1}$$

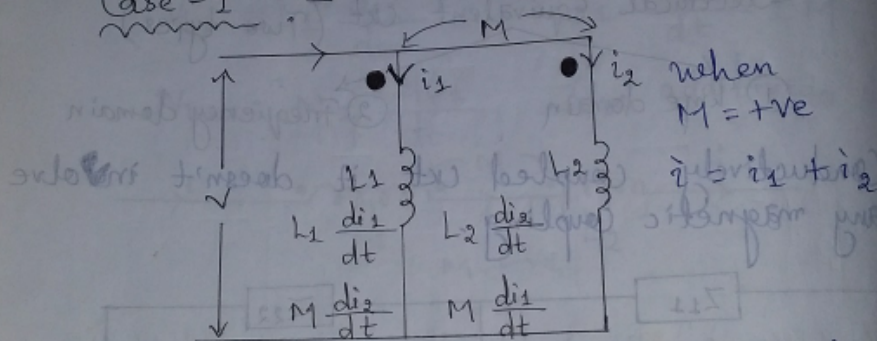
$$Z_{22} = \frac{V_2}{i_2}$$

$$Z_{12} = \frac{V_1}{i_2}$$

$$Z_{21} = \frac{V_2}{i_1}$$

Parallel Connection of coupled Ckt

Case - 1



Differentiating both side w.r.t t ,

$$\frac{di}{dt} = \frac{di_1}{dt} + \frac{di_2}{dt} \quad \text{--- (1)}$$

Voltage across Coil 1.

$$V = L_1 \frac{di_1}{dt} + M \frac{di_2}{dt} \quad \text{--- (2)}$$

Voltage across Coil 2.

$$V = L_2 \frac{di_2}{dt} + M \frac{di_1}{dt} \quad \text{--- (3)}$$

Equating Eqⁿ ② & ③

$$L_1 \frac{di_1}{dt} + M \frac{di_2}{dt} = L_2 \frac{di_2}{dt} + M \frac{di_1}{dt}$$

$$(L_1 - M) \frac{di_1}{dt} = (L_2 - M) \frac{di_2}{dt}$$

$$\frac{di_1}{dt} = \left(\frac{L_2 - M}{L_1 - M} \right) \frac{di_2}{dt} \quad \text{--- (4)}$$

Putting value of $\frac{di_1}{dt}$ from eqⁿ (4) into eqⁿ (1)

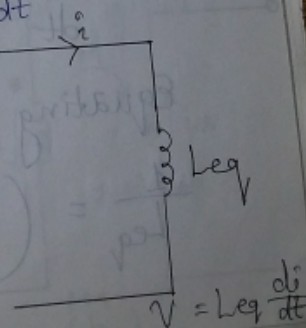
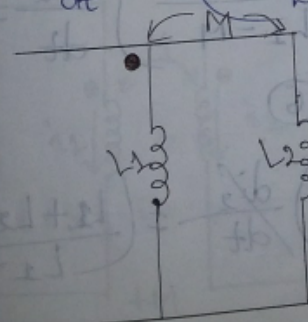
$$\frac{di}{dt} = \frac{di_1}{dt} + \frac{di_2}{dt}$$

$$\frac{di}{dt} = \left(\frac{L_2 - M}{L_1 - M} \right) \frac{di_2}{dt} + \frac{di_2}{dt}$$

$$\frac{di}{dt} = \left(\frac{L_2 - M}{L_1 - M} + 1 \right) \frac{di_2}{dt}$$

$$\frac{di}{dt} = \left(\frac{L_2 - M + L_1 - M}{L_1 - M} \right) \frac{di_2}{dt}$$

$$\frac{di}{dt} = \left(\frac{L_1 + L_2 - 2M}{L_1 - M} \right) \frac{di_2}{dt} \quad \text{--- (5)}$$



$$L_{eq} \frac{di}{dt} = L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}$$

$$= L_2 \frac{di_2}{dt} + M \frac{di_1}{dt}$$

$$L_{eq} \frac{di}{dt} = L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}$$

$$\frac{di}{dt} = \left(\frac{L_2 - M}{L_1 - M} \right) \frac{di_2}{dt}$$

$$L_{eq} \frac{di}{dt} = L_1 \left(\frac{L_2 - M}{L_1 - M} \right) \frac{di_2}{dt} + M \frac{di_2}{dt}$$

$$= \left[\left(\frac{L_1 L_2 - L_1 M}{L_1 - M} \right) + M \right] \frac{di_2}{dt}$$

$$L_{eq} \frac{di}{dt} = \left(\frac{L_1 L_2 - L_1 M + L_1 M - M^2}{L_1 - M} \right) \frac{di_2}{dt}$$

$$L_{eq} \frac{di}{dt} = \left(\frac{L_1 L_2 - M^2}{L_1 - M} \right) \frac{di_2}{dt}$$

$$\frac{di}{dt} = \frac{1}{L_{eq}} \left(\frac{L_1 L_2 - M^2}{L_1 - M} \right) \frac{di_2}{dt} \quad \text{--- (6)}$$

Equating Eqⁿ (5) & (6)

$$\frac{1}{L_{eq}} = \left(\frac{L_1 L_2 - M^2}{L_1 - M} \right) \frac{di_2}{dt} = \left(\frac{L_1 + L_2 - 2M}{L_1 - M} \right) \frac{di_2}{dt}$$

$$L_{eq} = \frac{L_1 L_2 - M^2}{L_1 + L_2 - 2M}$$

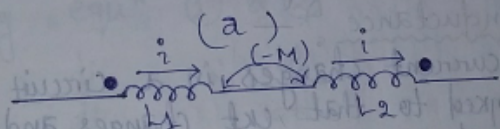
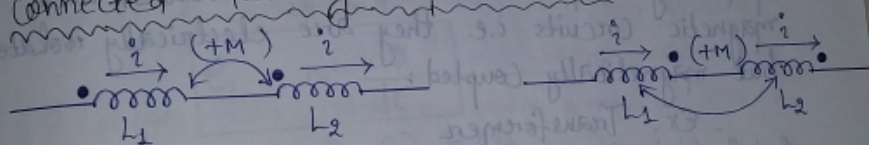
Case - 2

when $M = -ve$, $M^2 = +ve$

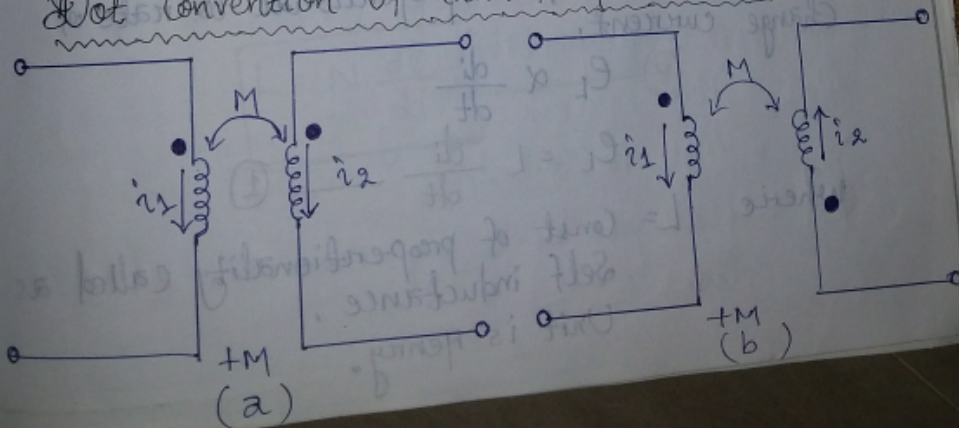
$$L_{eq} = \frac{L_1 L_2 - (-M)^2}{L_1 + L_2 - 2(-M)}$$

$$L_{eq} = \frac{L_1 L_2 - M^2}{L_1 + L_2 + 2M}$$

+ve and -ve dot convention for series connected mutually coupled coils.



Dot convention of transformer coils.



(b)

Chapter - 3

Network analysis

① Circuit :-

A circuit is a closed conducting path through which an electric current either flows or is intended to flow.

② Network :-

A combination of various electric elements, connected in any manner.

③ Node :-

It is an equipotential point at which two or more circuit elements are joined.

④ Junction :-

It is that point of a network where three or more circuit elements are joined.

⑤ Loop :-

It is a closed path in a circuit in which no element or node is accounted more than once.

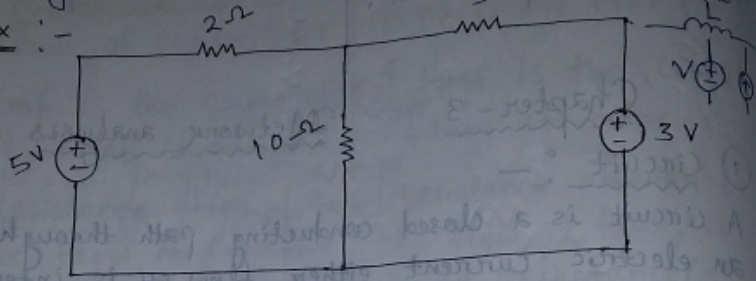
⑥ Mesh :-

It is a loop that contains no other loop within it.

Branch :-

It represents single circuit element such as voltage source, resistor etc.

Ex :-

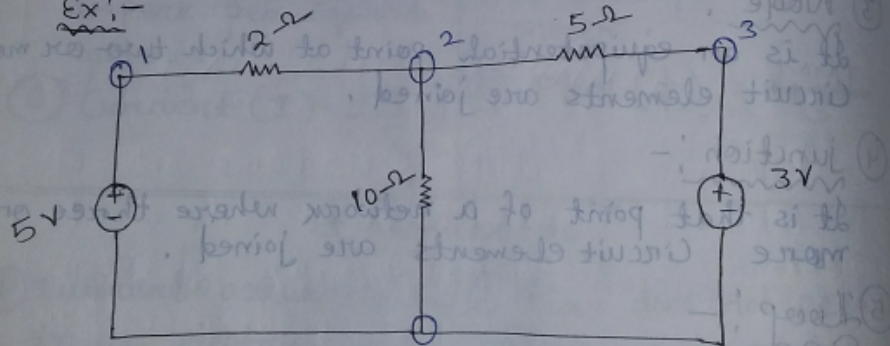


Branch = 5

Node :-

A point in a network where two or more elements are connected is called node.

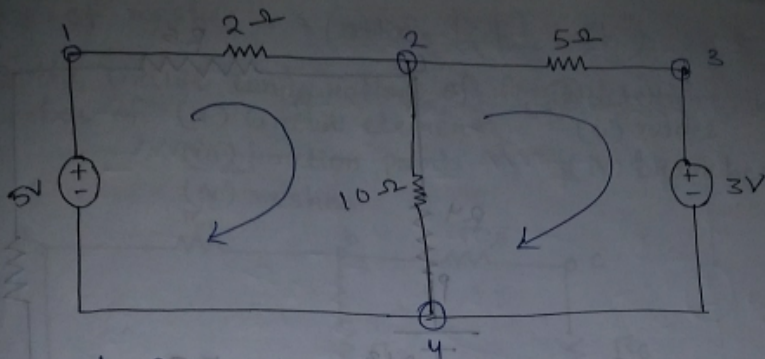
Ex :-



Node = 4

Loop and Mesh :-

Loop :- Any close path in electrical circuit is called loop.



1-2-4-1

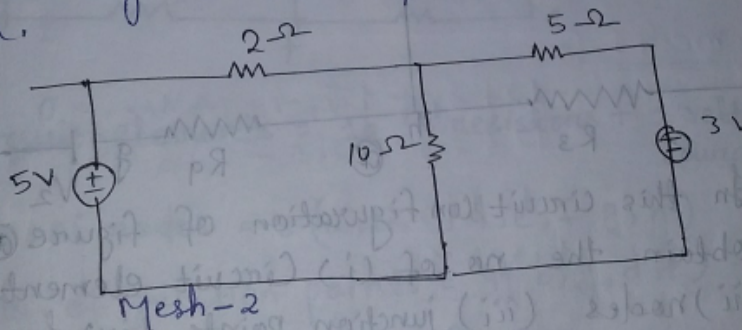
2-3-4-2

1-2-3-4-1

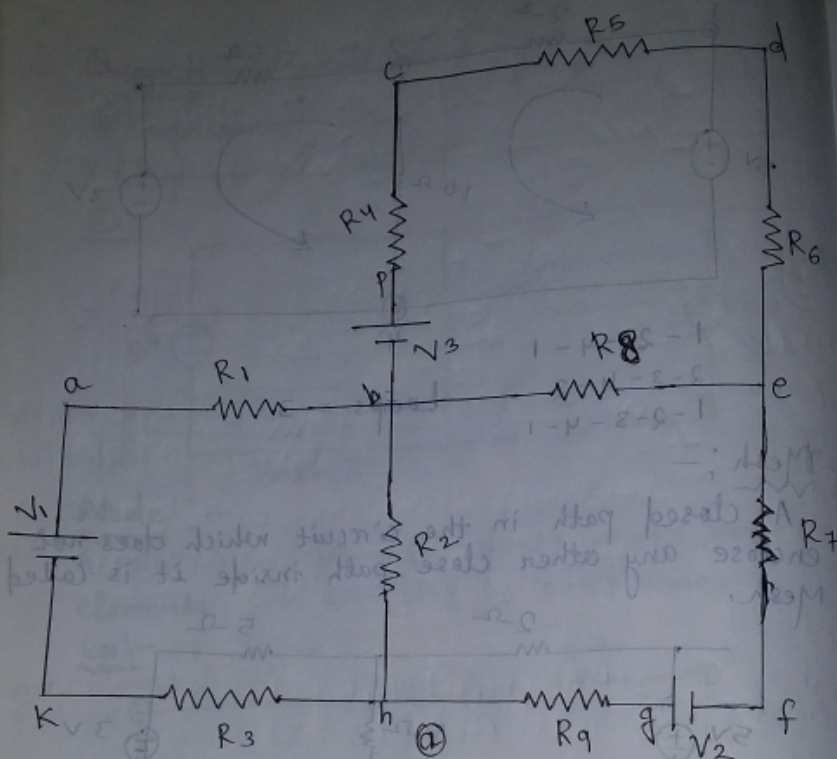
Loops = 3

Mesh:-

A closed path in the circuit which does not enclose any other closed path inside it is called Mesh.



- (i) no. of circuit elements = 13
 (ii) no. of meshes = 2
 (iii) no. of junction points = 3
 (iv) no. of branches = 5



- ① In this circuit configuration of figure a obtain the no. of (i) Circuit elements (ii) nodes (iii) junction points (iv) branches and (v) meshes.

Solⁿ:- (i) no. of circuit elements = 12
(9 resistors + 3 voltage sources)

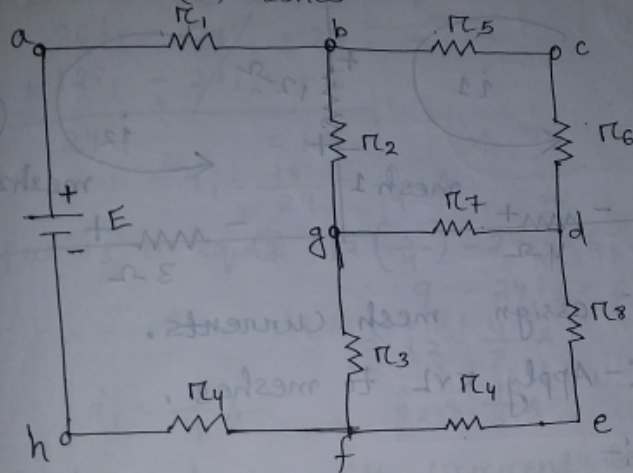
(ii) no. of nodes = 10 (a, b, c, d, e, f, g, h, k, p)

(iii) no. of junction points = 3 (b, e, h)

(iv) no. of branches = 5 (bcde, be, bh, begh, ba kh)

(v) No. of meshes = 3 (abhx, bcde, befgh)

② In the circuit configuration of fig ② determine, the number of (i) circuit element (ii) nodes (iii) junction points (iv) branches and (v) meshes



Soln:-

(i) circuit elements = 10 (9 resistors + 1 voltage source)

(ii) no. of nodes = 8 (a, b, c, d, e, f, g, h)

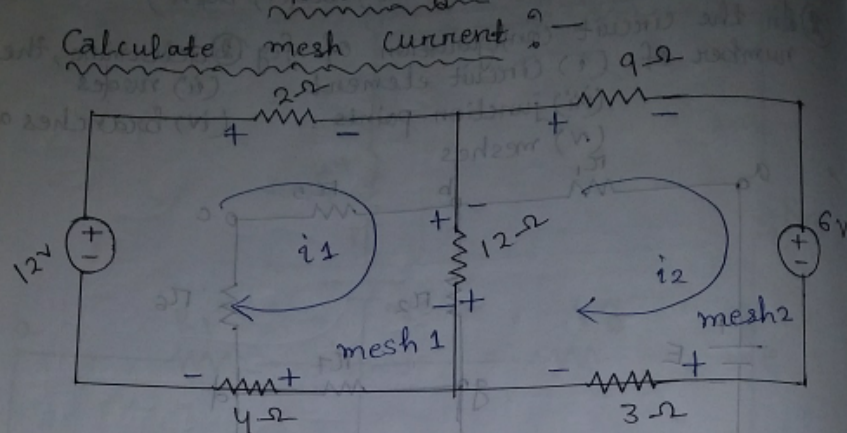
(iii) no. of junction points = 4 (b, g, d, f)

(iv) no. of branches = 6 ($R_2, R_7, R_3, (R_5 + R_6), (R_7 + R_8), (R_1 + R_4)$)

(v) no. of meshes = 3 (abfh, bcde, befgh)

Mesh analysis

Calculate mesh current



Step-1 :- assign mesh currents.

Step-2 :- Apply KVL to meshes.

mesh 1 :-

$$-12 + 2i_1 + 12(i_1 - i_2) + 4i_1 = 0$$

$$-12 + 2i_1 + 12i_1 - 12i_2 + 4i_1 = 0$$

$$= -12 + 18i_1 - 12i_2 = 0 \quad \text{or (i)}$$

$$= 18i_1 - 12i_2 = 12$$

$\div 12$

$$\boxed{\frac{3}{2}i_1 - i_2 = 1} \quad \text{eq (1)}$$

Mesh-2 :-

$$+6 + 3i_2 + 12(i_2 - i_1) + 9i_2 = 0$$

$$24i_2 - 12i_1 + 6 = 0$$

$$\text{Step-3 :- } \boxed{12i_1 - 24i_2 = 6} \quad \text{eq (2)}$$

Solve eq.s to obtain mesh currents.

$$\times 24 \rightarrow \text{eq (1)}$$

$$24\left(\frac{3}{2}i_1\right) - 24i_2 = 24$$

$$\boxed{36i_1 - 24i_2 = 24} \quad \text{--- eq (3)}$$

Subtract eq (2) and (3)

$$36i_1 - 24i_2 = 24$$

$$+ 12i_1 - 24i_2 = +6$$

$$\hline 24i_1 = 18$$

$$i_1 = \frac{18}{24} = \frac{3}{4} \text{ A}$$

Put i_1 in eq. (2) $12\left(\frac{3}{4}\right) - 24i_2 = 6$

$$9 - 24i_2 = 6$$

$$\Rightarrow i_2 = \frac{1}{8} \text{ A}$$

$$i_1 = \frac{3}{4} \text{ A}$$

$$i_2 = \frac{1}{8} \text{ A}$$

Mesh analysis with current source

2- possibilities

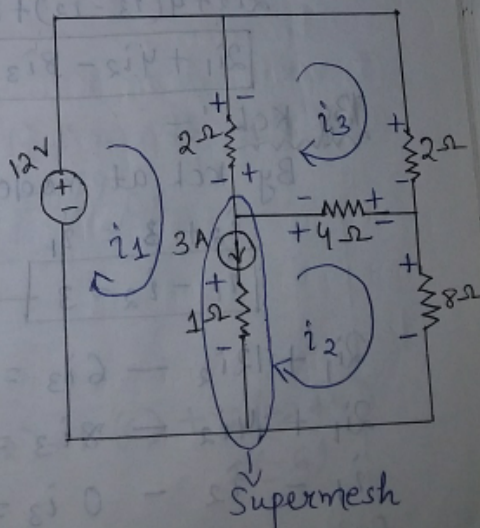
① I_s in only one mesh

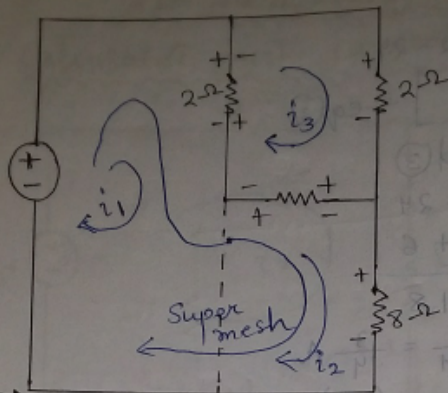
$$I_{\text{mesh}} = I_s$$

② I_s b/w two meshes

↓
Super mesh

↓
both KVL and KCL





By KVL :-
At supermesh :-

$$-12 + 2(i_1 - i_3) + 4(i_2 - i_3) + 8i_2 = 0$$

$$-12 + 2i_1 + 12i_2 - 6i_3 = 0$$

$$2i_1 + 12i_2 - 6i_3 = 12 \rightarrow \text{eq. (1)}$$

At mesh - 3 :-

$$2i_3 + 4(i_3 - i_2) + 2(i_3 - i_1) = 0$$

$$2i_1 + 4i_2 - 8i_3 = 0 \rightarrow \text{eq. (2)}$$

By KCL :-

By KCL at node o

$$i_2 + 3 = i_1$$

$$i_1 - i_2 = 3 \rightarrow \text{eq. (3)}$$

$$2i_1 + 12i_2 - 6i_3 = 12$$

$$2i_1 + 4i_2 - 8i_3 = 0$$

$$i_1 - i_2 - 0i_3 = 3$$

Cramer's rule :-

$$\begin{bmatrix} 2 & 12 & -6 \\ 2 & 4 & -8 \\ 1 & -1 & 0 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} 12 \\ 0 \\ 3 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 2 & 12 & -6 \\ 2 & 4 & -8 \\ 1 & -1 & 0 \end{vmatrix}$$

$$= 2(0-8) - 12(0+8) + (-6)(-2-4)$$

$$= -16 - 96 + 36$$

$$= -76$$

$$\boxed{\Delta = -76}$$

$$\Delta_1 = \begin{vmatrix} 12 & 12 & -6 \\ 0 & 4 & -8 \\ 3 & -1 & 0 \end{vmatrix} = 12(0-8) - 12(0+24) - 6(-12)$$

$$\boxed{\Delta_1 = -312}$$

$$\Delta_2 = \begin{vmatrix} 2 & 12 & -6 \\ 2 & 0 & -8 \\ 1 & 3 & 0 \end{vmatrix} = 2(24) - 12(8) - 6(6)$$

$$= 48 - 96 - 36$$

$$= -84$$

$$\boxed{\Delta_2 = -84}$$

$$\Delta_3 = \begin{vmatrix} 2 & 12 & 12 \\ 2 & 4 & 0 \\ 1 & -1 & 3 \end{vmatrix} = 2(12) - 12(6) + 12(-2+4)$$

$$= 24 - 72 + 12(-6)$$

$$\boxed{\Delta_3 = -120}$$

$$i_1 = \frac{\Delta_1}{\Delta} = \frac{-312}{-76}, \quad i_1 = 4.105 A$$

$$i_2 = \frac{\Delta_2}{\Delta} = \frac{-84}{-76}, \quad i_2 = 1.105 A$$

$$i_3 = \frac{\Delta_3}{\Delta} = \frac{-120}{-76}, \quad i_3 = 1.578 A$$

$$\text{Independent node} = n = j - 1$$

$$\text{mesh} = b - (j - 1)$$

Mesh(m)

$m > n$ mesh analysis

$n > m$ nodal analysis

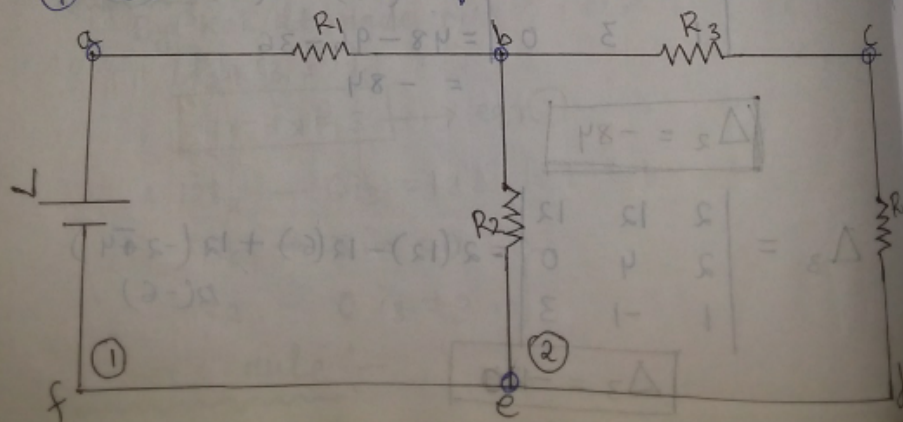
$$m = b - (j - 1)$$

$$= 5 - (3 - 1)$$

$$= 5 - 2 = 3$$

Condition

- ① Kkt must be planner,
- ② Assign the mesh current in a particular direction,
- ③ write down KVL for each mesh,
- ④ Solve the mesh eqn's to find the unknown.



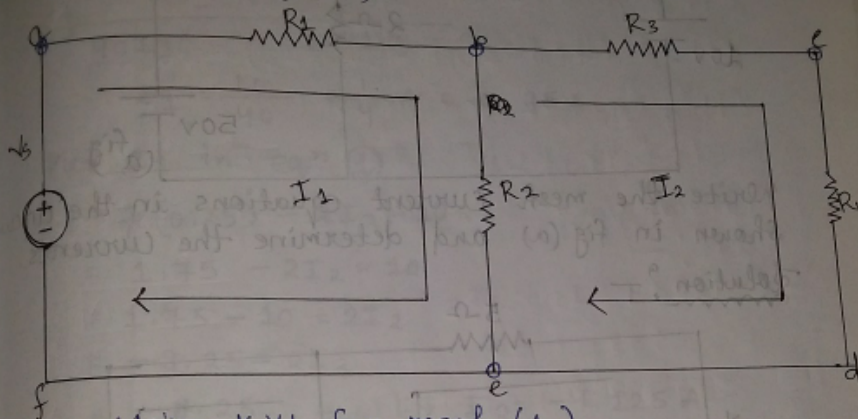
Nodes = 4

Junction = 2 (b, e)

Branch = 3

Mesh = $B - (J - 1)$

$$= 3 - (2 - 1) = 3 - 1 = 2$$



Using KVL for mesh (1)

$$V_s = I_1 R_1 + R_2 (I_1 - I_2) \quad \text{--- (1)}$$

$$V_s = I_1 (R_1 + R_2) - I_2 R_2$$

Using KVL for mesh (2)

$$R_2 (I_2 - I_1) + R_3 I_2 + R_4 I_2 = 0 \quad \text{--- (2)}$$

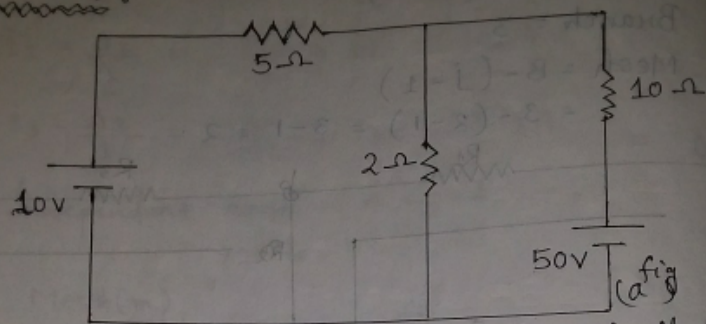
$$= -I_1 R_2 + (R_2 + R_3 + R_4) I_2 = 0$$

Branches = 5, Nodes = 4

$$M = B - (N - 1)$$

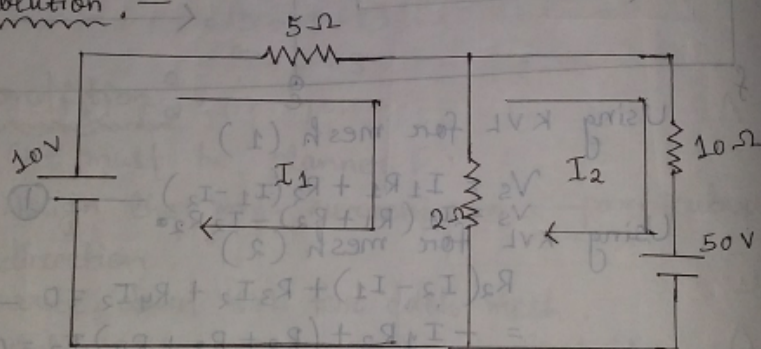
$$= 5 - (4 - 1) = 2$$

Problem :-



Write the mesh current equations in the circuit shown in fig (a) and determine the currents.

Solution :-



The mesh current equations are

$$5I_1 + 2(I_1 - I_2) = 10$$

$$= 5I_1 + 2I_1 - 2I_2 = 10$$

$$= 7I_1 - 2I_2 = 10 \quad \text{--- (1)}$$

$$10I_2 + 2(I_2 - I_1) + 50 = 0$$

$$= 10I_2 + 2I_2 - 2I_1 + 50 = 0$$

$$= 12I_2 - 2I_1 = -50 \quad \text{--- (2)}$$

$\times 6 \rightarrow \text{eq ①}$

$$42I_1 - 12I_2 = 60 \quad \text{--- ③}$$

Subtract eq ② and ③

$$42I_1 - 12I_2 = 60$$

$$-2I_1 + 1/2I_2 = 50$$

$$+ \quad \quad \quad +$$

$$40I_1 = 10 \Rightarrow I_1 = \frac{10}{40} = \frac{1}{4} \text{ A} = 0.25 \text{ A}$$

Put I_1 in eqn ②

$$= 7(0.25) - 2I_2 = 10$$

$$= 1.75 - 2I_2 = 10$$

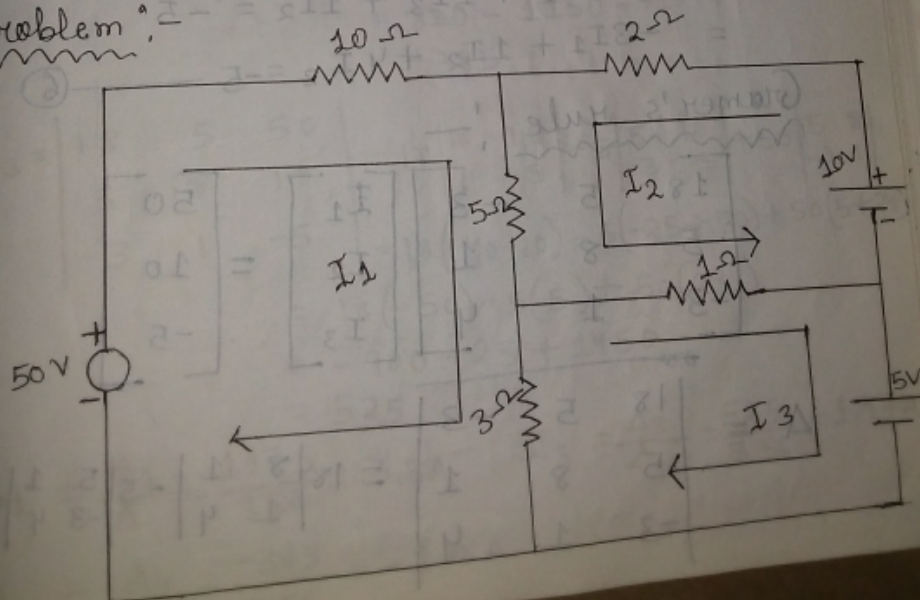
$$= 1.75 - 10 = 2I_2$$

$$= -8.25 = 2I_2$$

$$= \frac{-8.25}{2} = I_2 \Rightarrow I_2 = -4.125 \text{ A}$$

$$I_1 = 0.25 \text{ A and } I_2 = -4.125$$

Problem:-



Solution :-

Applying KVL for mesh (1)

$$10I_1 + 5(I_1 + I_2) + 3(I_1 - I_3) = 50 \quad \text{--- (1)}$$

Applying KVL for mesh (2)

$$2I_2 + 5(I_2 + I_1) + 1(I_2 + I_3) = 10 \quad \text{--- (2)}$$

Applying KVL for mesh (3)

$$3(I_3 - I_1) + 1(I_3 + I_2) = -5 \quad \text{--- (3)}$$

Rearranging the above equations we get :-

$$10I_1 + 5I_1 + 5I_2 + 3I_1 - 3I_3 = 50$$
$$= 18I_1 + 5I_2 - 3I_3 = 50 \quad \text{--- (4)}$$

$$2I_2 + 5I_2 + 5I_1 + 1I_2 + I_3 = 10$$
$$= 5I_1 + 8I_2 + I_3 = 10 \quad \text{--- (5)}$$

$$3I_3 - 3I_1 + 1I_3 + 1I_2 = -5$$
$$= -3I_1 + 1I_2 + 4I_3 = -5 \quad \text{--- (6)}$$

Cramer's rule :-

$$\begin{bmatrix} 18 & 5 & -3 \\ 5 & 8 & 1 \\ -3 & 1 & 4 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 50 \\ 10 \\ -5 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 18 & 5 & -3 \\ 5 & 8 & 1 \\ -3 & 1 & 4 \end{vmatrix} = 18 \begin{vmatrix} 8 & 1 \\ 1 & 4 \end{vmatrix} - 5 \begin{vmatrix} 5 & 1 \\ -3 & 4 \end{vmatrix} - 3 \begin{vmatrix} 5 & 8 \\ -3 & 1 \end{vmatrix}$$

$$= 18(32-1) - 5(20+3) - 3(5+24)$$

$$= 18(31) - 5(23) - 3(29)$$

$$= 558 - 115 - 87$$

$$= 356$$

$$\Delta_1 = \begin{vmatrix} 50 & 5 & -3 \\ 10 & 8 & 1 \\ -5 & 1 & 4 \end{vmatrix} = 50 \begin{vmatrix} 8 & 1 \\ 1 & 4 \end{vmatrix} - 5 \begin{vmatrix} 10 & 1 \\ -5 & 4 \end{vmatrix} - 3 \begin{vmatrix} 10 & 8 \\ -5 & 1 \end{vmatrix}$$

$$= 50(32-1) - 5(40+5) - 3(10+40)$$

$$= 50(31) - 5(45) - 3(50)$$

$$= 1550 - 225 - 150$$

$$= 1175$$

$$\Delta_2 = \begin{vmatrix} 18 & 50 & -3 \\ 5 & 10 & 1 \\ -3 & -5 & 4 \end{vmatrix} = 18 \begin{vmatrix} 10 & 1 \\ -5 & 4 \end{vmatrix} - 50 \begin{vmatrix} 5 & 1 \\ -3 & 4 \end{vmatrix} - 3 \begin{vmatrix} 5 & 10 \\ -3 & -5 \end{vmatrix}$$

$$= 18(40+5) - 50(20+3) - 3(-15+30)$$

$$= 18(45) - 50(23) - 3(15)$$

$$= 810 - 1150 - 45$$

$$= -385$$

$$\Delta_3 = \begin{vmatrix} 18 & 5 & 50 \\ 5 & 8 & 10 \\ -3 & 1 & -5 \end{vmatrix} = 18 \begin{vmatrix} 8 & 10 \\ 1 & -5 \end{vmatrix} - 5 \begin{vmatrix} 5 & 10 \\ -3 & -5 \end{vmatrix} + 50 \begin{vmatrix} 5 & 8 \\ -3 & 1 \end{vmatrix}$$

$$= 18(-40-10) - 5(-25+30) + 50(5+24)$$

$$= 18(-50) - 5(5) + 50(29)$$

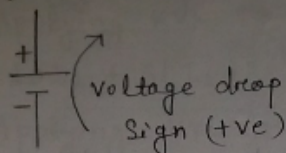
$$= -900 - 25 + 1450$$

$$= 525$$

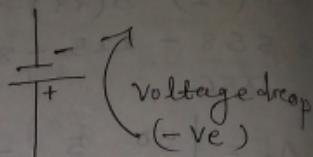
$$I_1 = \frac{\Delta_1}{\Delta} = \frac{1175}{356} = 3.3A \quad I_3 = \frac{\Delta_3}{\Delta} = \frac{525}{356} = 1.47A$$

$$I_2 = \frac{\Delta_2}{\Delta} = \frac{-385}{356} = -1.08A$$

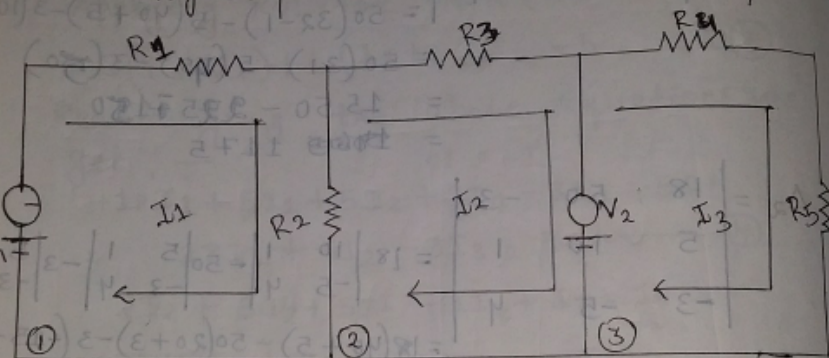
Mesh equations by inspection method:



lower potential to
higher potential



higher potential
to lower potential



The loop equations are ~~for~~ —

Applying KVL for mesh (1)

$$I_1 R_1 + R_2 (I_1 - I_2) = V_1$$

$$\Rightarrow I_1 R_1 + I_1 R_2 - I_2 R_2 = V_1$$

$$\Rightarrow I_1 (R_1 + R_2) - I_2 R_2 = V_1 \quad \text{--- (1)}$$

Applying KVL for mesh (2)

$$R_3 I_2 + R_2 (I_2 - I_1) = V_2$$

$$\Rightarrow R_3 I_2 + R_2 I_2 - R_2 I_1 = V_2$$

$$\Rightarrow I_2 (R_2 + R_3) - I_1 R_2 = -V_2 \quad \text{--- (2)}$$

Applying KVL for mesh (3)

$$\Rightarrow I_3 R_4 + I_3 R_5 = V_2 \quad \text{--- (2)}$$

$$\Rightarrow I_3 (R_4 + R_5) = V_2 \quad \text{--- (3)}$$

$$(R_1 + R_2) I_1 - R_2 I_2 + 0 \cdot I_3 = V_1 \quad \text{--- (4)}$$

$$-R_2 I_1 + (R_2 + R_3) I_2 + 0 \cdot I_3 = V_2 \quad \text{--- (5)}$$

$$0 \cdot I_1 + 0 \cdot I_2 + (R_4 + R_5) I_3 = V_3 \quad \text{--- (6)}$$

$$R_{11} I_1 \pm R_{12} I_2 \pm R_{13} I_3 = V_a \quad \text{--- (7)}$$

$$\pm R_{21} I_1 + R_{22} I_2 \pm R_{23} I_3 = V_b \quad \text{--- (8)}$$

$$\pm R_{31} I_1 \pm R_{32} I_2 + R_{33} I_3 = V_c \quad \text{--- (9)}$$

R_{11} = Self resistance of mesh (1)

R_{22} = Self resistance of mesh (2)

R_{33} = Self resistance of mesh (3)

$R_{12}, R_{13}, R_{21}, R_{23}, R_{31}, R_{32} \Rightarrow$ These are the mutual resistance between ~~two~~ ^{all} pairs of meshes.

V_a = Algebraic Sum of voltage of mesh (1)

V_b = Algebraic Sum of voltage of mesh (2)

V_c = Algebraic Sum of voltage of mesh (3)

$$R_{11} = R_1 + R_2, R_{12} = R_2, R_{13} = 0$$

$$(R_1 + R_2) I_1 - R_2 I_2 + 0 \cdot I_3 = V_1$$

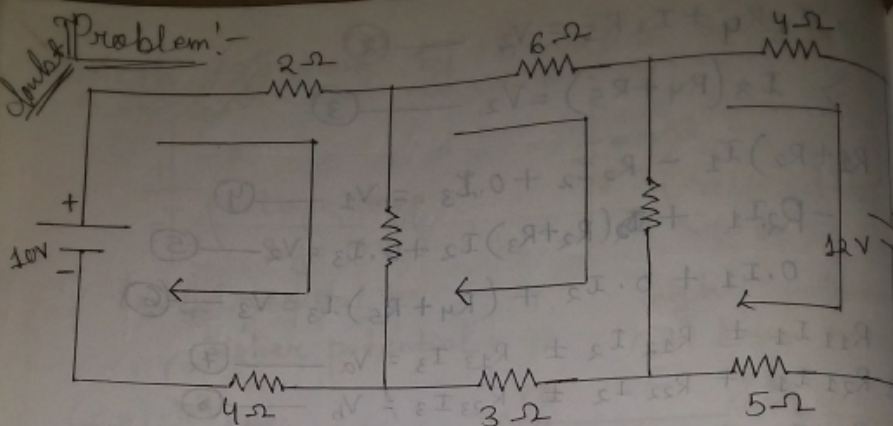
$$R_{21} = R_2, R_{22} = R_2 + R_3, R_{23} = 0$$

$$-R_2 I_1 + (R_2 + R_3) I_2 + 0 \cdot I_3 = V_2$$

$$R_{31} = 0, R_{32} = 0, R_{33} = R_4 + R_5$$

$$0 \cdot I_1 + 0 \cdot I_2 + (R_4 + R_5) I_3 = V_3$$

Problem:-



Soln:-

$$\begin{bmatrix} Z_{11} & Z_{12} & Z_{13} \\ Z_{21} & Z_{22} & Z_{23} \\ Z_{31} & Z_{32} & Z_{33} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 10 \\ 0 \\ -12 \end{bmatrix}$$

$$\begin{bmatrix} (2+3+4) & -(3) & 0 \\ -(3) & (6+6+3+3) & -(6) \\ 0 & -(6) & (4+6+5) \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 10 \\ 0 \\ -12 \end{bmatrix}$$

$$\begin{bmatrix} 9 & -3 & 0 \\ -3 & 18 & -6 \\ 0 & -6 & 15 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 10 \\ 0 \\ -12 \end{bmatrix}$$

[Z] [I] [V]

$$\Delta = 9(18 \times 15 - (-6 \times -6)) - (-3)(-3 \times 15)$$

$$= 9(270 - 36) + 3(-45)$$

$$= 9(234) + 3(-45) = 2106 - 135 = 1971$$

$$\Delta I_1 = \begin{vmatrix} 10 & -3 & 0 \\ 0 & 18 & -6 \\ -12 & -6 & 15 \end{vmatrix} = 10 \begin{vmatrix} 18 & -6 \\ -6 & 15 \end{vmatrix} - (-3) \begin{vmatrix} 0 & -6 \\ -12 & 15 \end{vmatrix}$$

$$= 10(270 - 36) + 3(-72)$$

$$= 10(234) + 3(-72)$$

$$= 2340 - 216 = 2124$$

$$\Delta I_2 = \begin{vmatrix} 9 & 10 & 0 \\ -3 & 0 & -6 \\ 0 & -12 & 15 \end{vmatrix} = 9 \begin{vmatrix} 0 & -6 \\ -12 & 15 \end{vmatrix} - 10 \begin{vmatrix} -3 & -6 \\ 0 & 15 \end{vmatrix}$$

$$= 9(-72) - 10(-45)$$

$$= -648 + 450 = -198$$

$$\Delta I_3 = \begin{vmatrix} 9 & -3 & 10 \\ -3 & 18 & 0 \\ 0 & -6 & -12 \end{vmatrix} = 9 \begin{vmatrix} 18 & 0 \\ -6 & -12 \end{vmatrix} - (-3) \begin{vmatrix} -3 & 0 \\ 0 & -12 \end{vmatrix} + 10 \begin{vmatrix} -3 & 18 \\ 0 & -6 \end{vmatrix}$$

$$= 9(-216) + 3(36) + 10(18)$$

$$= -1944 + 108 + 180$$

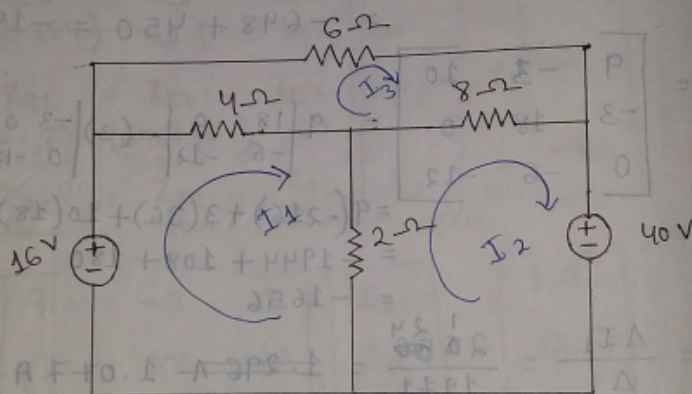
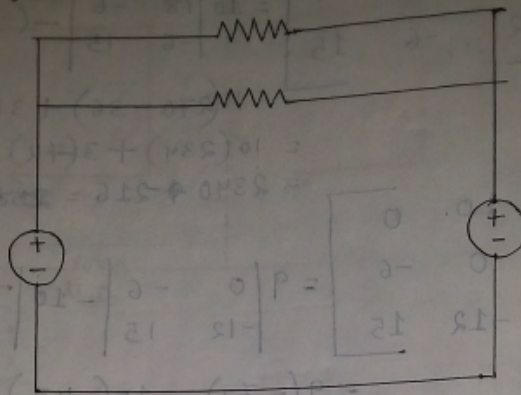
$$= -1656$$

$$I_1 = \frac{\Delta I_1}{\Delta} = \frac{2124}{1971} = 1.077 \text{ A}$$

$$I_2 = \frac{\Delta I_2}{\Delta} = \frac{-198}{1971} = -0.100 \text{ A}$$

$$I_3 = \frac{\Delta I_3}{\Delta} = \frac{-1656}{1971} = -0.840 \text{ A}$$

Problem 9 —



- ① Assign mesh currents.
- ② Find resistance matrix elements.
 - (a) $R_{ii} = \sum R \text{ mesh } i$
 - (b) $R_{ij} = -R \text{ shared by } i \text{ and } j$
- ③ Find mesh voltage (in the direction of the mesh current, sources only).
- ④ Set up the equations in matrix format and solve.

$$\Delta_3 = \begin{vmatrix} 6 & -2 & 16 \\ -2 & 10 & -40 \\ -4 & -8 & 0 \end{vmatrix} = 6 \begin{vmatrix} 10 & -40 \\ -8 & 0 \end{vmatrix} - (-2) \begin{vmatrix} -2 & -40 \\ -4 & 0 \end{vmatrix} + 16 \begin{vmatrix} -2 & 10 \\ -4 & -8 \end{vmatrix}$$

$$= 6(-320) + 2(-60) + 16(16 + 40)$$

$$= -1920 - 120 + 896$$

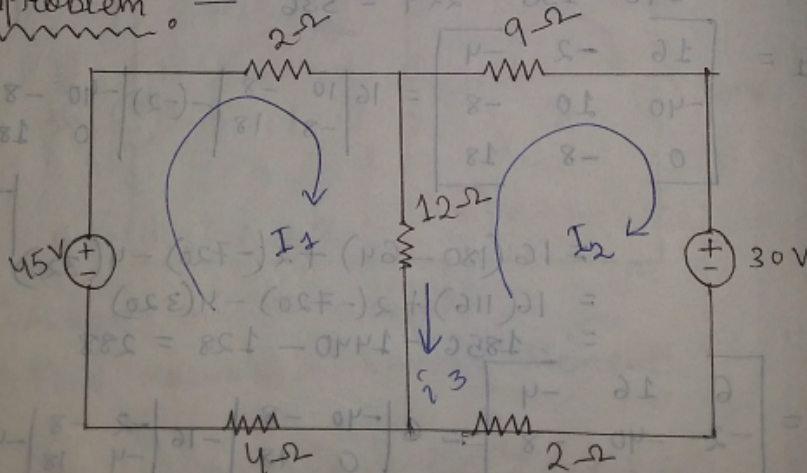
$$= -1144$$

$$I_1 = \frac{\Delta_1}{\Delta} = \frac{288}{336} = 0.857 \text{ A}$$

$$I_2 = \frac{\Delta_2}{\Delta} = \frac{-259.2}{336} = -7.714 \text{ A}$$

$$I_3 = \frac{\Delta_3}{\Delta} = \frac{-1144}{336} = -3.404 \text{ A}$$

Problem —



$$R_{11} = 2 + 12 + 4 = 18$$

$$R_{22} = 9 + 2 + 12 = 23$$

$$R_{12} = R_{21} = -12$$

$$\begin{bmatrix} 18 & -12 \\ -12 & 23 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 45 \\ -30 \end{bmatrix}$$

$$D = \begin{bmatrix} 18 & -12 \\ -12 & 23 \end{bmatrix} = 270$$

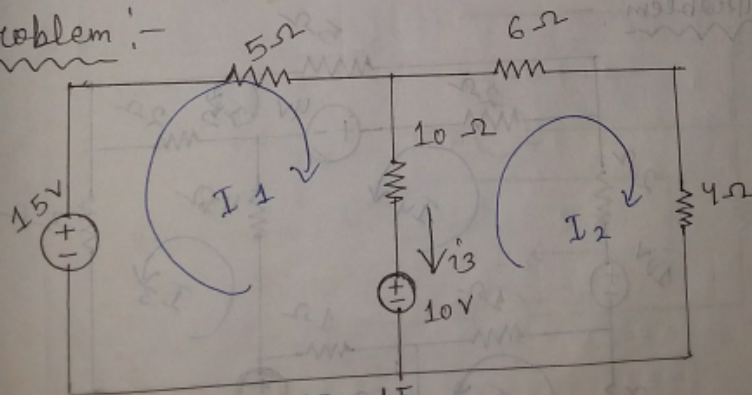
$$\textcircled{1} = \begin{bmatrix} 45 & -12 \\ -30 & 23 \end{bmatrix} = 675$$

$$\textcircled{2} = \begin{bmatrix} 18 & 45 \\ -12 & -30 \end{bmatrix} = 0$$

$$I_1 = \frac{\textcircled{1}}{D} = \frac{675}{270} = 2.5 \text{ A} \quad i_3 = I_1 - I_2 = 2.5 \text{ A} - 0 \text{ A} = 2.5 \text{ A}$$

$$I_2 = \frac{\textcircled{2}}{D} = \frac{0}{270} = 0 \text{ A}$$

Problem:-



$$R_{11} = 5 + 10 = 15$$

$$R_{22} = 6 + 4 + 10 = 20$$

$$R_{12} = R_{21} = -10$$

$$\begin{bmatrix} 15 & -10 \\ -10 & 20 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 5 \\ 10 \end{bmatrix}$$

$$D = \begin{bmatrix} 5 & -10 \\ -10 & 20 \end{bmatrix} = 300 - 100 = 200$$

$$\textcircled{1} = \begin{bmatrix} 5 & -10 \\ 10 & 20 \end{bmatrix} = 100 + 100 = 200$$

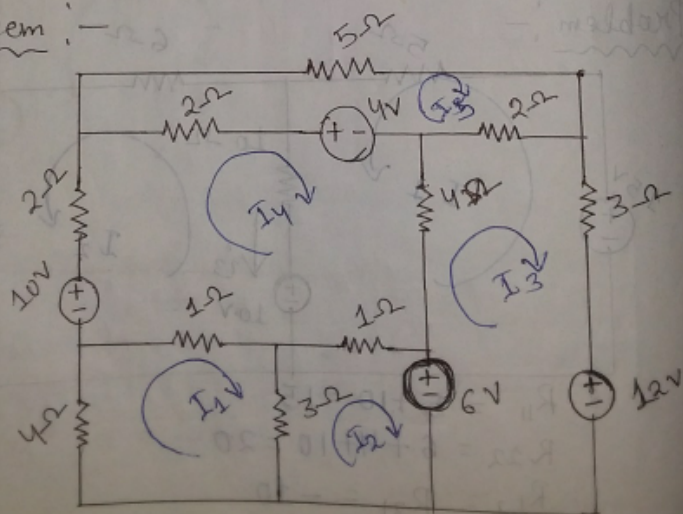
$$\textcircled{2} = \begin{bmatrix} 15 & 5 \\ -10 & 10 \end{bmatrix} = 150 + 50 = 200$$

$$I_1 = \frac{200}{200} = 1A$$

$$I_2 = \frac{200}{200} = 1A$$

$$I_3 = I_1 - I_2 = 1 - 1 = 0$$

Problem :-



$$R_{11} = 4 + 1 + 3 = 8$$

$$R_{22} = 3 + 1 = 4$$

$$R_{33} = 4 + 2 + 3 = 9$$

$$R_{44} = 1 + 2 + 2 + 4 + 1 = 10$$

$$R_{55} = 2 + 5 + 2 = 9$$

$$R_{21} = R_{12} = -3$$

$$R_{13} = R_{31} = 0$$

$$R_{14} = R_{41} = -1$$

$$R_{15} = R_{51} = 0$$

$$R_{23} = R_{32} = 0$$

$$R_{24} = R_{42} = -1$$

$$R_{25} = R_{52} = 0$$

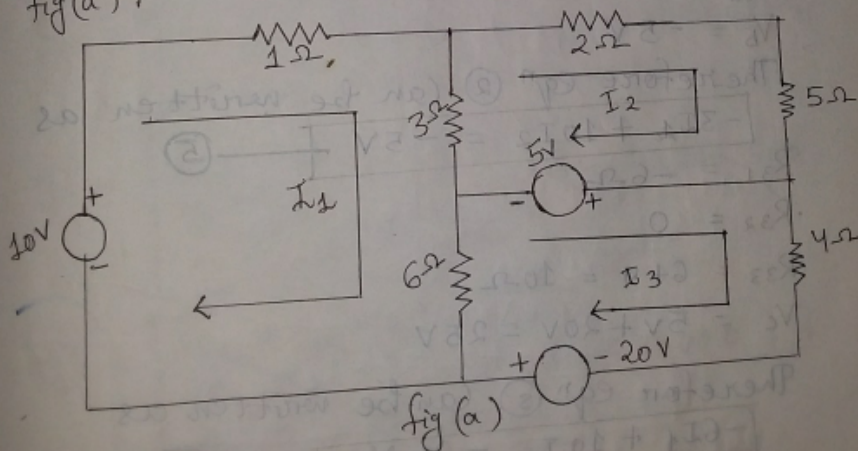
$$R_{34} = R_{43} = -4$$

$$R_{45} = R_{54} = -2$$

8	-3	0	-1	0	I_1	0
-3	4	0	-1	0	I_2	-6
0	0	9	-4	-2	I_3	-6
-1	-1	-4	10	-2	I_4	6
0	0	-2	-2	9	I_5	4

Example :-

Write the mesh equation for the circuit shown in fig(a).



Solⁿ: -

The general equation for three mesh equation are

$$R_{11}I_1 \pm R_{12}I_2 \pm R_{13}I_3 = V_a \quad \text{--- (1)}$$

$$\pm R_{21}I_1 + R_{22}I_2 \pm R_{23}I_3 = V_b \quad \text{--- (2)}$$

$$\pm R_{31}I_1 \pm R_{32}I_2 + R_{33}I_3 = V_c \quad \text{--- (3)}$$

$$R_{11} = 1\Omega + 3\Omega + 6\Omega = 10\Omega$$

$$R_{12} = -3\Omega$$

$$R_{13} = -6\Omega$$

$$V_a = 10V$$

Therefore eqⁿ (1) can be written as

$$10I_1 - 3I_2 - 6I_3 = 10V \quad \text{--- (4)}$$

$$R_{21} = -3$$

$$R_{22} = 3\Omega + 2\Omega + 5\Omega = 10\Omega$$

$$R_{23} = 0$$

$$V_b = -5V$$

Therefore eqⁿ (2) can be written as

$$-3I_1 + 10I_2 = -5V \quad \text{--- (5)}$$

$$R_{31} = -6\Omega$$

$$R_{32} = 0$$

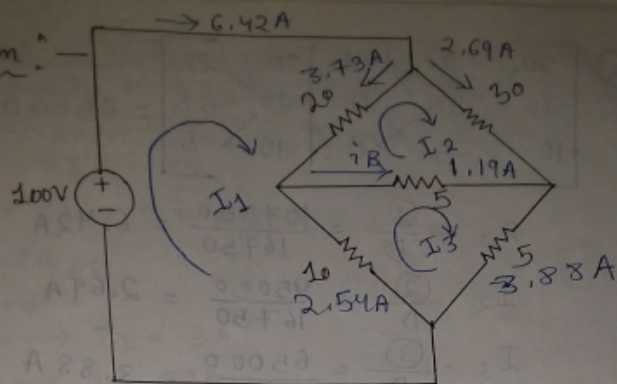
$$R_{33} = 6 + 4 = 10\Omega$$

$$V_c = 5V + 20V = 25V$$

Therefore eqⁿ (3) can be written as

$$-6I_1 + 10I_3 = 25V \quad \text{--- (6)}$$

Problem:



Solution:

$$R_{11} = 20 + 10 = 30 \quad R_{12} = R_{21} = -20$$

$$R_{22} = 20 + 30 + 5 = 55 \quad R_{13} = R_{31} = -10$$

$$R_{33} = 10 + 5 + 5 = 20 \quad R_{23} = R_{32} = -5$$

$$\begin{bmatrix} 30 & -20 & -10 \\ -20 & 55 & -5 \\ -10 & -5 & 20 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 100 \\ 0 \\ 0 \end{bmatrix}$$

$$D = \begin{vmatrix} 30 & -20 & -10 \\ -20 & 55 & -5 \\ -10 & -5 & 20 \end{vmatrix} = 16750$$

$$\textcircled{1} = \begin{vmatrix} 100 & -20 & -10 \\ 0 & 55 & -5 \\ 0 & -5 & 20 \end{vmatrix} = 107500$$

$$\textcircled{2} = \begin{vmatrix} 30 & 100 & -10 \\ -20 & 0 & -5 \\ -10 & 0 & 20 \end{vmatrix} = 45000$$

$$\textcircled{3} \begin{bmatrix} 30 & -20 & 10 & 0 & 30 & -20 \\ -20 & 55 & 0 & -20 & 55 & -5 \\ -10 & 5 & 0 & -10 & 5 & 0 \end{bmatrix} = 65000$$

$$I_1 = \frac{\textcircled{1}}{D} = \frac{107500}{16750} = 6.42 \text{ A}$$

$$I_2 = \frac{\textcircled{2}}{D} = \frac{45000}{16750} = 2.69 \text{ A}$$

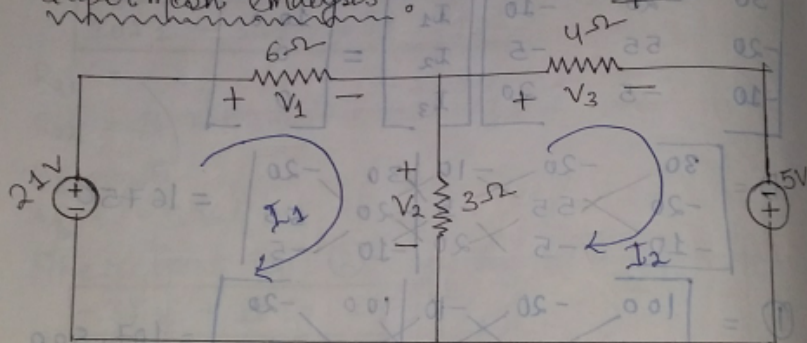
$$I_3 = \frac{\textcircled{3}}{D} = \frac{65000}{16750} = 3.88 \text{ A}$$

$$i_B = I_3 - I_2 = 3.88 - 2.69 = 1.19 \text{ A}$$

$$I_1 - I_3 = 6.42 - 3.88 = 2.54 \text{ A}$$

Super mesh Analysis

Mesh



Writing KVL at mesh 1

$$21 - V_1 - V_2 = 0$$

$$\therefore 21 = V_1 + V_2$$

$$= 6I_1 + 3(I_1 - I_2)$$

$$21 = 9I_1 - 3I_2 \quad \text{--- (1)}$$

Writing KVL at mesh 2

$$-V_3 + 5 + V_2 = 0$$

$$5 = V_3 - V_2$$

$$= 4I_2 - 3(I_1 - I_2)$$

$$5 = -3I_1 + 7I_2 \quad \text{--- (2)}$$

$$21 = 9I_1 - 3I_2 \quad \text{--- (1)}$$

$$5 = -3I_1 + 7I_2 \quad \text{--- (2)}$$

$$I_2 = 2A$$

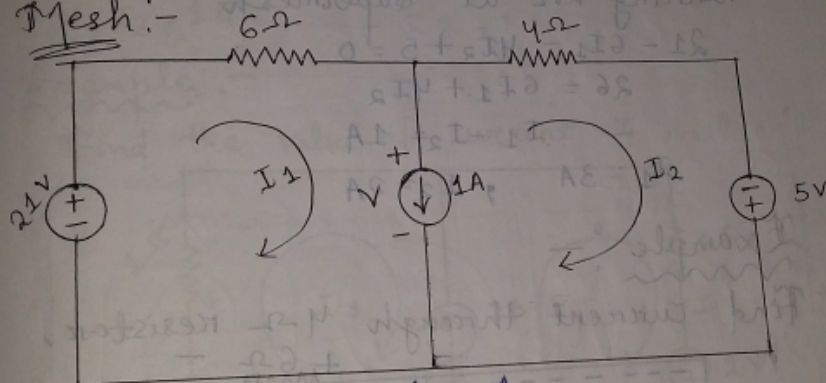
$$I_1 = 3A$$

$$6\Omega \rightarrow I_1 = 3A$$

$$4\Omega \rightarrow I_2 = 2A$$

$$3\Omega \rightarrow I_1 - I_2 = 1A$$

Mesh:-



KVL at mesh - 1

$$21 - 6I_1 - V = 0$$

$$V = 21 - 6I_1$$

KVL at mesh - 2

$$-4I_2 + 5 + V = 0$$

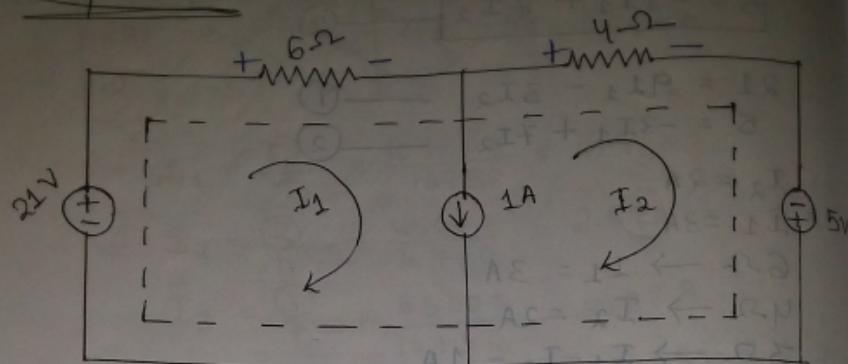
$$21 - 6I_1 = 4I_2 - 5$$

$$6I_1 + 4I_2 = 26 \quad \text{--- (1)}$$

$$I_1 - I_2 = 1 \quad \text{--- (2)}$$

$$I_1 = 3A$$

Supermesh :-



Writing KVL at Supermesh

$$2 - 6I_1 - 4I_2 + 5 = 0$$

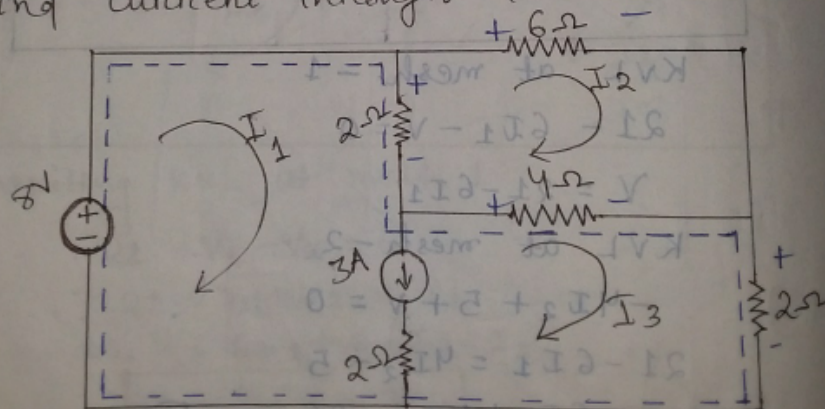
$$26 = 6I_1 + 4I_2$$

$$I_1 - I_2 = 1A$$

$$I_1 = 3A, I_2 = 2A$$

Example :-

Find current through 4Ω resistor,



Writing KVL at supermesh

$$8 - 2(I_1 - I_2) - 4(I_3 - I_2) - 2I_3 = 0$$