Unit - 1 [Electromagnetism and DC circuits].

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CHAPTER - 1 a) D.C Circuits.

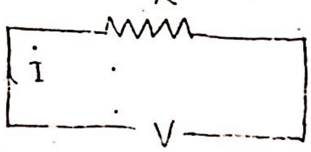
OHMS LAW:-

Statement:

Current flowing through a conductor is directly proportional to the potential difference across its ends, provided temperature remains constant.

Explanation:

Consider a circuit having a resistance 'R' ohms and 'V' be the voltage applied across it, then 'I' be the current flowing through it.



Applying Ohm's law to the above circuit. As per the statement

$I \propto V$

$\therefore I = GV$ (where G is conductance and unit is mho)

OR

$\boxed{I = \frac{V}{R}}$ (where $G = \frac{1}{R}$ and 'R' is resistance in ohms)

Limitations of ohm's law:-

1) Ohm's law holds good only at constant temperature.
2) Ohm's law can not be applied to non-linear devices like diodes, Zener diodes, voltage regulators etc.
3) Ohm's law does not holds good for non-metallic conductors such as Silicon Carbide.
4) Ohm's law can not be applied to arc lamps.

KIRCHOFF'S LAWS :→

KIRCHOFF'S CURREN LAW :—

Statement :-

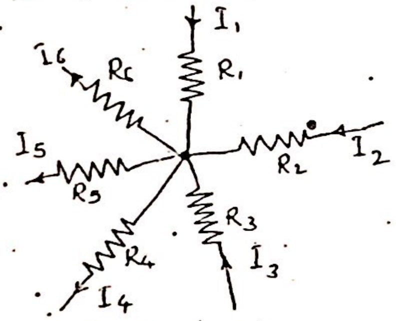
In a closed network, the algebraic sum of currents meeting at a node or junction is zero.

OR

The sum of currents entering the junction or node in a closed network is equal to the sum of currents leaving the junction or node.

Explanation :

Consider a junction or node 'O' in a closed network and Let I_1, I_2 and I_3 are currents entering the node 'O' and I_4, I_5 and I_6 are currents leaving the node 'O'.



Applying KCL to the node 'O',

$$I_1 + I_2 + I_3 - I_4 - I_5 - I_6 = 0$$

OR

$$I_1 + I_2 + I_3 = I_4 + I_5 + I_6$$

Sign Convention: Currents entering the node are taken as positive and Currents leaving the node are taken as negative

KIRCHOFF'S VOLTAGE LAW :→

Statement

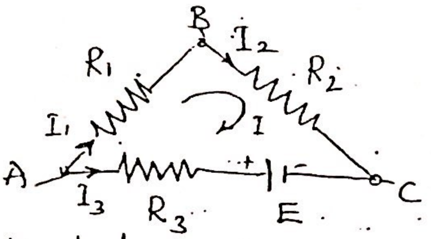
In any closed loop, the algebraic sum of products of currents and resistance (voltage drops) plus the algebraic sum of all the emf's in that loop is zero.

i.e. Algebraic sum of voltage drops + Algebraic sum of emf's = 0

In a closed loop (OR), the algebraic sum of product of currents and resistances (voltage drops) is equal to the algebraic sum of emf's present in the loop.

Explanation :

Consider a circuit, R_1, R_2 and R_3 are the resistances connected in the circuit as show with E be the emf present in the circuit.



Applying KVL to loop ABCA,

Lets assume an arbitary direction of current I in the loop.

$$-I_1R_1 - I_2R_2 + E + I_3R_3 = 0$$

Sign Convention: * If the current through a resistor is in the same direction as assumed current I, then product of resistance and current through it is taken as negative.

* If the current through a resistor is in the opposite direction as assumed current I, then product of resistance and current through it is taken as positive.

* If assumed current is passing through the battery from + to − terminal then emf of the battery is taken as '−' (negative).

* If the assumed current is passing through the battery from − to + terminal then emf of the battery is taken as '+' (positive).

Power: (Electrical Power)

The rate at which work is done in an electric Circuit is called as Power.

$$\text{Power} = \frac{\text{Work done}}{\text{Time}} = \frac{W}{t} = \frac{VIt}{t} = VI \text{ J/sec or Watts}$$

where $W = VIt$ Joules is the electric work.

$1 \text{ watt} = 1 \text{ Joule/sec}$

Power in an electric Circuit is found by

$P = V \cdot I$ or $P = \frac{V^2}{R}$ or $P = I^2R$

Electrical Energy:

Electrical energy is the total amount of electrical work done in an electrical Circuit.

Electrical Energy = Power × Time

$W = V.I \times t$

$\therefore W = VIt$ Joules or Watt-sec.

1 unit of electrical energy is Joules or watt-sec.

As watt-sec is a very small unit, Electrical energy is measured in larger units, they are

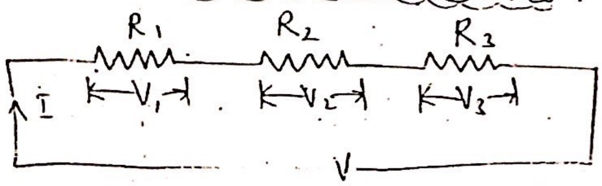
Watt-hours and Kilowatt-hour (kWh)

1 Watt-hour = 1 watt × 1 hours

$1 \text{ Wh} = 1 \text{ Watt} \times 3600 \text{ sec} = 3600 \text{ Watt-Sec or Joules}$

$\therefore 1 \text{ kWh} = 3600 \times 1000 = 3.6 \times 10^6 \text{ Joules}.$

Resistances Connected in Series:



The equivalent Resistance R_{eq} of the circuit is

$$R_{eq} = R_1 + R_2 + R_3$$

Proof:- Applying ohm's law.

$$I = \frac{V}{R_{eq}}, \quad \text{We know } V = V_1 + V_2 + V_3$$

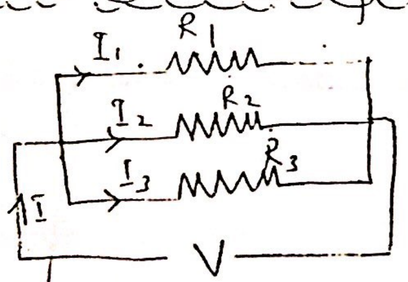
or $V = I(R_1) + I(R_2) + I(R_3)$

$$V = I(R_1 + R_2 + R_3)$$

$$\therefore I R_{eq} = I(R_1 + R_2 + R_3)$$

$$\boxed{R_{eq} = R_1 + R_2 + R_3}$$

Resistances Connected in Parallel:

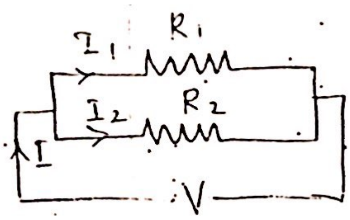


We know, $I = I_1 + I_2 + I_3$

$$\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\frac{\cancel{V}}{R_{eq}} = \cancel{V}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$\boxed{\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$



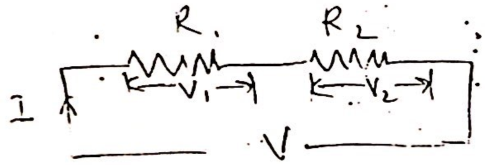
To find. I_1 & I_2: Current division rule can be used as

$$\boxed{I_1 = I \times \frac{R_2}{R_1+R_2}}$$

ll'y

$$\boxed{I_2 = I \times \frac{R_1}{R_1+R_2}}$$

Voltage Division rule to find voltage across branches:-



To find V_1 & V_2,

$$\boxed{V_1 = V \times \frac{R_1}{R_1+R_2}}$$

ll'y

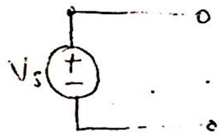
$$\boxed{V_2 = V \times \frac{R_2}{R_1+R_2}}$$

Energy Sources:-

Basically there are two types of energy Sources they are
1) Voltage Source 2) Current Source.

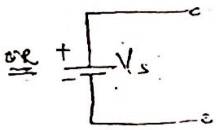
Voltage Source:

Ideal Voltage Source:- It is the energy Source which gives Constant voltage across its terminals irrespective of current drawn through its terminals.

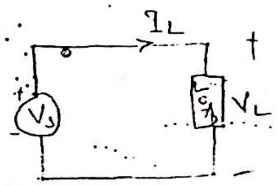


Symbol

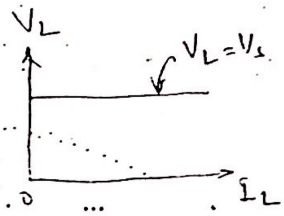
or



Symbol

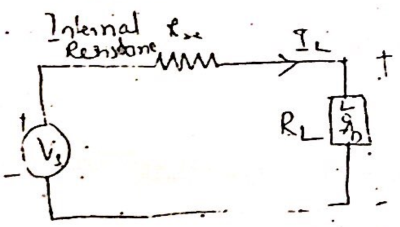


Connected in Circuit.

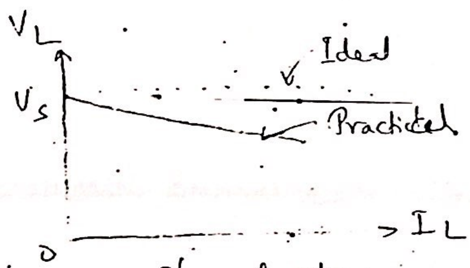


characteristics.

Practicle Voltage Source: It is that energy source which offers small internal resistance.

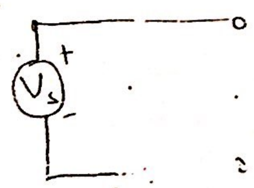


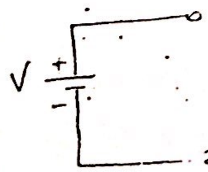
Connected in Circuit.



Characteristics.

Time Varient & Time Invarient Sources:





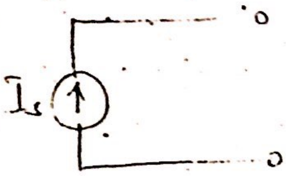
There are Time invarient source where Voltage is not varying with time. These are DC voltage Sources.

this is time varient Source where voltage is varying with time, these are AC voltage Sources.

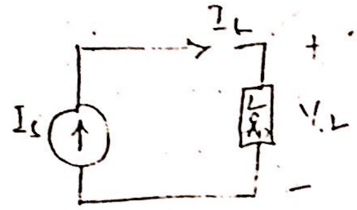
Current Sources:

Ideal Current Sources:-

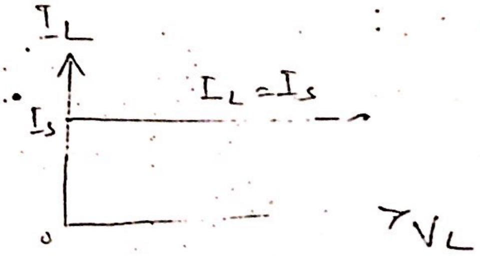
Ideal Current Sources are those which gives Constant Current irrespective of voltage appearing at its terminals.



Symbol

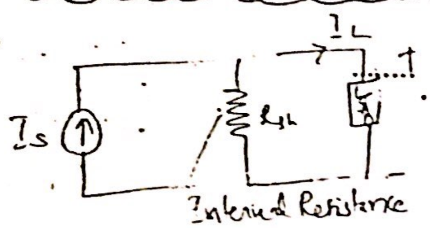


Connected in Circuit

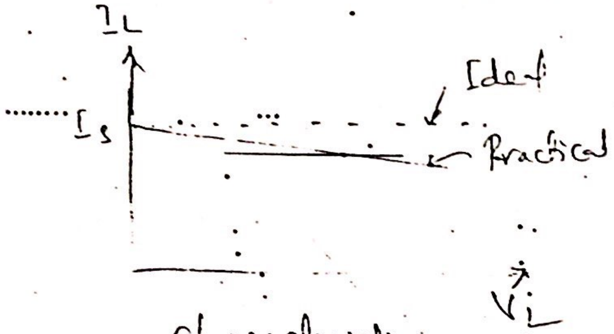


Characteristics

Practical Current Source:-

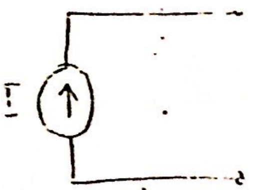


Connected in Circuit

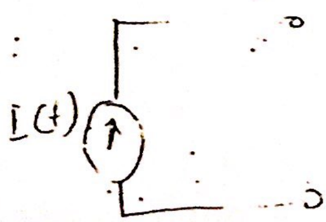


Characteristics

Time Variant & Invariant Sources:



This is time invariant Sources where Current does not vary with time. These are DC current Sources.



This is time variant Sources where Current Varies with time. These are AC Current Sources.

ELECTROMAGNETISM

Basic Terminology:

Magnetic Field:

The magnetic field of a magnet is defined as the area or place around the magnet within which the influence of magnet can be experienced is called magnetic field.

Magnetic Flux Density (B):

It can be defined as the number of magnetic flux lines passing through an unit area is called magnetic flux density.

$$\boxed{B = \frac{\Phi}{a} = \frac{Wb}{m^2} \text{ or Tesla}}$$

Magnetic Field Strength (H):

Magnetic field strength is defined as the force experienced by a unit N-pole when placed at any point in a magnetic field.

$$\boxed{H = \frac{\text{Ampere turns}}{\text{length}} = \frac{NI}{l} = AT/m}$$

Permeability:

The permeability is defined as the ability or ease with which the magnetic material forces the magnetic flux through a given medium.

Absolute Permeability: (μ)

The ratio of magnetic flux density B in a particular medium other than vaccum or air to the magnetic field strength H producing that flux density is called absolute permeability of that medium.

$$\boxed{\mu = \frac{B}{H}}$$

Permeability of Free Space or Vaccum (μ_0)

If the magnet is placed in a free space or Vaccum or in air then the ratio of flux density B and magnetic field strength H is called Permeability of free space or vaccum or air.

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

Relative Permeability (μ_r)

It is defined as the ratio of flux density produced in a medium other than free space to the flux density produced in free space

Magnetomotive force : (MMF or F)

It is defined as the force by the virtue of which establishes the flux in the magnetic circuit.

$$\boxed{mmf = NI \text{ ampere-turns}}$$

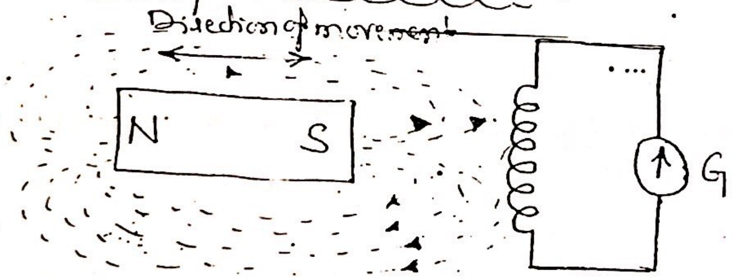
It is also defined as the work in joules on a unit magnetic pole in taking it once round closed magnetic circuit.

Reluctance (S):

It is the property of the magnetic material which opposes the establishment of flux in the magnetic circuit.

$$\boxed{S = \frac{l}{a\mu_0\mu_r} \text{ A/wb}} \quad \text{OR} \quad \boxed{S = \frac{NI}{\phi} \text{ A/wb}}$$

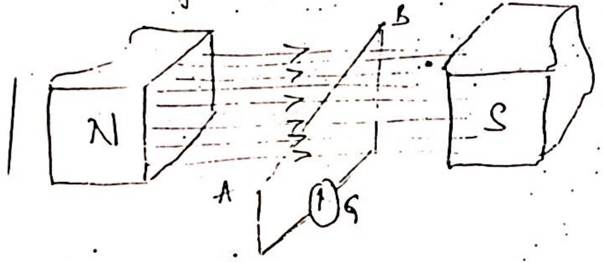
Electromagnetic Induction :→



Stationary Coil

Consider a coil having N numbers of turns connected to a galvanometer. Galvanometer indicates flow of current in the circuit. The permanent magnet is moved relative to coil, such that magnetic lines of force associated with coil get changed. Whenever there is motion of permanent magnet, galvanometer deflects indicating flow of current through the circuit. The deflection continues as long as motion of magnet exists. Now the deflection of galvanometer indicates flow of current, hence presence of emf. Hence such movement of flux lines with respect to coil changes, generates emf which drives current through the coil. This process of inducement of electricity due to movement of magnet is called as electromagnetic induction.

Consider a permanent magnet with magnetic lines starts from N-pole and terminates at S-pole. Consider a conductor of length AB is rotated in the magnetic field between N & S poles then flux linking with conductor changes causing an emf induced in the conductor. This process is also called as electromagnetic induction.



FARADAYS LAWS OF ELECTROMAGNETIC INDUCTION

Based on the electromagnetic induction process, Michael Faraday stated two laws of electromagnetic induction.

Faradays First Law: →

Whenever the number ~~of magnetic~~ lines of force (flux) linking with a coil or circuit changes an emf gets induced in that coil or circuit.

Therefore faradays first law deals with process of electromagnetic induction.

Faradays Second law: →

The average magnitude of the emf induced in the conductor or coil is directly proportional to rate of change of flux linkages.

The second law deals with magnitude of emf induced in the conductor or coil.

Consider a coil having N number of turns, the initial flux linking with coil is ϕ_1

$\therefore$ Initial flux linkages $= N\phi_1$

After a certain time interval 't', flux linking with the coil changes from ϕ_1 to ϕ_2

$\therefore$ Final flux linkages $= N\phi_2$

Now the rate of change of flux linkages $= \dfrac{N\phi_2 - N\phi_1}{t}$

Now as per the first law, because of change in flux linkages an emf will induce in the coil and as per second law magnitude of emf is proportional to the rate of change of flux linkages.

$$E \propto \frac{N\phi_2 - N\phi_1}{t}$$

$$\therefore E = \frac{N(\phi_2 - \phi_1)}{t}$$

$$\boxed{E = N\frac{d\phi}{dt}} \text{ volts}$$

Nature of the Induced EMF :⇒

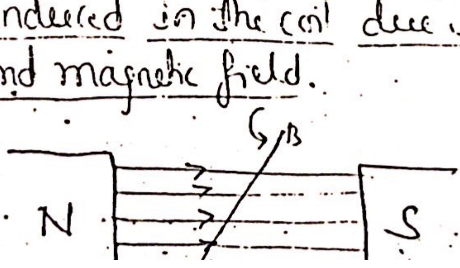
As we know, whenever there is change in flux linking with coil or conductor changes, an emf will induce in the coil or conductor. This change in flux linkage can be brought out in different ways. Based on the nature of methods, the induced emf is classified as

1) Dynamically induced emf
2) Statically induced emf.

Dynamically induced emf:

Consider a permanent magnet with N and S pole, and a conductor is rotated in the magnetic field between the poles, then conductor cuts the flux lines between the poles and hence the flux linking with conductor changes there by causing an emf induced in the conductor.

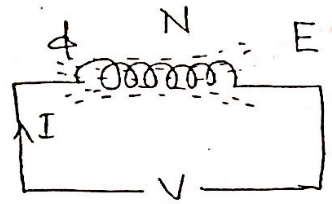
In this process, the change in flux linking with conductor or coil is brought out by the movement (rotation) of conductor relative to magnetic field. Hence dynamically induced emf can be defined as the emf induced in the coil due to relative motion between conductor and magnetic field.



Lenz's law: –

Statement: The direction of the emf induced in the coil or Conductor is such as to oppose the very cause producing it.

Explanation:



Consider a coil having 'N' number of turns with 'V' be the voltage applied and 'I' be the current flowing through it. Let the nature of applied voltage 'V' be varying hence current 'I' is also varying. The current (varying) flowing through the coil produces its own magnetic field around the coil. Let 'ϕ' be flux produced. Since current is varying, flux 'ϕ' will also be varying. therefore varying flux linking with stationary coil of 'N' turns changes causing an emf to be induced in coil. Let 'E' be the emf induced in coil.

To find the direction of emf induced in the coil Lenz's stated the law. Here the cause for producing 'E' is varying 'ϕ' and cause of varying 'ϕ' is varying 'I' and cause for varying 'I' is varying applied voltage. Therefore as per Lenz's law the cause for producing 'E' emf induced in coil is applied voltage V. Hence the direction of 'E' emf induced is opposite to the direction of the applied voltage.

Emf induced is given by

$$\boxed{E = -N\frac{d\phi}{dt}}$$

where – sign indicates opposition.

Derivation for Dynamically Induced emf :-

Consider a Conductor moving with velocity 'V' m/sec, 'B' be the flux density in wb/m². 'l' be the active length of Conductor in metres.

Let the Conductor is moved with distance of dx is a small time interval dt. Then area swept by Conductor is given by

$$= l \times dx \quad m^2$$

Flux cut by Conductor = Flux density × Area swept

$$\phi = B \times l \times dx \quad wb$$

As per Faradays law, magnitude of induced emf is proportional to rate of change of flux.

$$e = \frac{\text{flux cut}}{\text{time}} = \frac{d\phi}{dt}$$

$$= \frac{B\, l\, dx}{dt}$$

$\frac{dx}{dt}$ = rate of change of displacement

= Velocity of the conductor.

= V

$$\therefore e = B l v \quad \text{volts}$$

If Conductor is moving with a velocity 'V' but at a certain angle 'θ' measured w.r.t direction of magnetic field is given by

$$\boxed{e = B l v \sin\theta \text{ -- volts}}$$

FLEMING'S RULES :→

Fleming has stated two rules and they are
i) Flemings right hand rule ii) Flemings left hand rule.

Flemings right hand rule :- (For Generator)

Statement: Hold the right hand with thumb, fore finger and middle finger stretched mutually perpendicular to each other in the plane containing the hand. If thumb represents the direction of rotation of conductor in the magnetic field, If fore finger represents the direction of magnetic field then middle finger represents the direction of emf induced in the conductor.

Explanation:

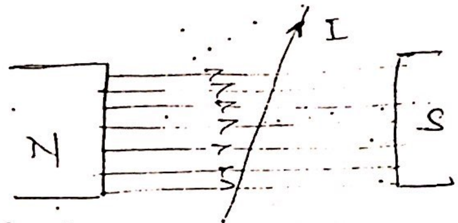
Consider a magnetic field with N and S poles, magnetic field lines start from N-pole and terminate at S-pole. when Conductor is rotated in the magnetic field, conductor cuts the flux and hence there will be change in flux linking with conductor causing an emf induced in the conductor. Thus generator working principle. Here we know the direction of magnetic field and direction of rotation of conductor in the magnetic field but the direction of induced emf in the conductor is not known. Thus to find the direction of emf induced in the conductor fleming has introduced flemings right hand rule.

Application: In generators to find the direction of emf induced in the coil.

Fleming's Left hand rule :- (For Motor)

Statement: Hold the left hand with thumb, fore finger and middle finger stretched mutually perpendicular to each other in a plane containing this hand. If fore finger represents the direction of magnetic field, middle finger represents the direction of current flowing in the coil, then thumb represents the direction of force exerting on the conductor tending to rotate in the

Explanation:



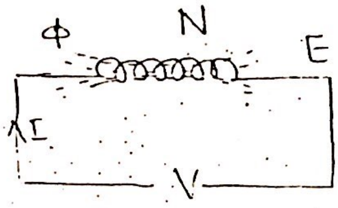
Consider a magnetic field with N and S poles and field lines starting from N and terminates on S. Consider a current carrying conductor to be placed in magnetic field. The current carrying conductor produces its own magnetic field around the conductor.
Let M_1 be the magnetic field of the already existing poles N & S and M_2 be the magnetic field produced due to current carrying conductor. Once two magnetic fields are brought in same region then the interaction (attraction or repulsion) between the magnetic fields causes a force exerting on the conductor tending to rotate in the magnetic field, thus motor working principle.
Here we know the direction of magnetic field (M_1), direction of current flowing through the conductor but we does not know the direction of force exerting on the conductor. Therefore Flemings left hand rule is used to find the direction of force exerting on conductor.

Application: In motors, to find the direction of force exerting on the conductor.

2) Statically Induced emf :→

Statically induced emf is defined as the emf induced in the coil or conductor due to variation of current in it.
There are two types of statically induced emf and they are
a) Self induced emf
b) Mutually induced emf.

Self Induced emf:



Consider a coil of N turns with V be the applied voltage and I be the current flowing through the coil. The nature of V & I are varying. The current I flowing through the coil produces its own magnetic field around the coil; as I is varying in nature then flux produced Φ is also varying in nature. The varying flux linking with N turns of stationary coil would cause change in flux linkage causing an emf induced in the coil. This emf is called as self induced emf.

Definition: Self induced emf is defined as the emf induced in the coil due to variation of current within the coil.

Derivation: From Faradays second law the emf induced is given by

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

Multiplying and dividing current I on RHS

$$E = N\frac{d\phi}{dt} \times \frac{I}{I}$$

$$= N\frac{dI}{dt} \cdot \frac{\phi}{I}$$

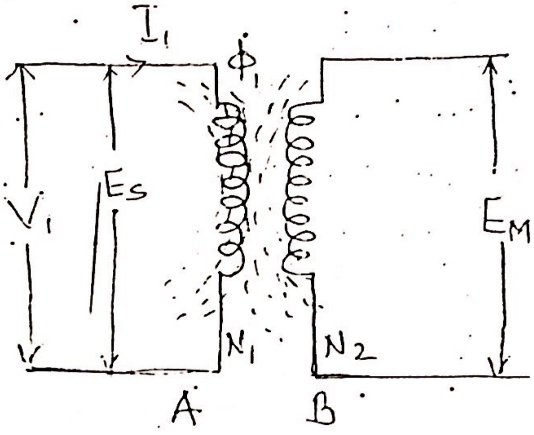
$$= N\left(\frac{\phi}{I}\right) \cdot \frac{dI}{dt}$$

$$\boxed{E_s = L\frac{dI}{dt}}$$ where L = Self inductance of the coil in Henry

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

Self inductance (L): It is defined as the property of the coil which opposes the variation of current in the coil.

Mutually induced emf :→



Consider two coils A and B with N_1 and N_2 be the number of turns of the coil A and B respectively. The coil A and B are kept very close to each other such that flux of one coil should link the other.

Let V_1 be the voltage applied to coil A and current be I_1 flowing through coil A. The voltage V_1 & current I_1 both are varying in nature hence varying current I_1 flowing through coil A will produce its own magnetic field around coil A. Then flux ϕ_1 produced by varying current I_1 is also varying in nature. Therefore varying flux ϕ_1 linking with N_1 turns of stationary coil A causes change in flux linkages and hence emf is induced in coil A called as self induced emf.

The varying flux ϕ_1 produced not only links coil A N_1 turns but also coil B N_2 turns causing change in flux linkages hence emf is induced in coil B also. (As coil A & B are kept close to each other). The emf induced in coil B is called as mutually induced emf.

Definition: Mutually induced emf is the emf induced in one coil due to variation of current in other coil.

Derivation:

The emf induced in coil is given by

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

Now emf induced in coil B is given by

$$E = N_2 \frac{d\phi_1}{dt}$$

Multiplying and dividing I_1 on RHS

$$E = N_2 \frac{d\phi_1}{dt} \cdot \frac{I_1}{I_1}$$

$$\therefore E = N_2 \frac{dI_1}{dt} \left(\frac{\phi_1}{I_1}\right)$$

$$\therefore E = N_2 \left(\frac{\phi_1}{I_1}\right) \cdot \frac{dI_1}{dt}$$

$$\boxed{E_M = M \frac{dI_1}{dt}}$$

where $M \rightarrow$ Mutual inductance between the coils and unit is Henry

$$\boxed{M = N_2 \left(\frac{\phi_1}{I_1}\right)}$$

Definition: Mutual inductance between two coils is defined as the flux linkages of the coil per ampere current in other coil.

Note:- If voltage is applied to coil B instead of Coil A then Mutually induced emf is given by

$$\boxed{E_M = M_1 \frac{dI_2}{dt}}$$

where $M = \frac{N_1 \phi_2}{I_2}$

The Self inductance of a coil is given by

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

But $\phi = \frac{NI}{S}$ $\therefore \frac{\phi}{I} = \frac{N}{S}$ where NI – ampere turns, S – Reluctance

Now $L = N \cdot \frac{N}{S}$ ($\because \frac{\phi}{I}$ is replaced by $\frac{N}{S}$)

$$\therefore L = \frac{N^2}{S}$$

$$\therefore L = \frac{N^2}{\frac{l}{a\mu_0\mu_r}} \quad \text{where } S = \frac{l}{a\mu_0\mu_r}$$

$$\therefore \boxed{L = \frac{N^2 a \mu_0 \mu_r}{l}} \text{ Henries.}$$

The mutual inductance between two coils is given by

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

But $\phi_1 = \frac{N_1 I_1}{S}$ $\therefore \frac{\phi_1}{I_1} = \frac{N_1}{S}$

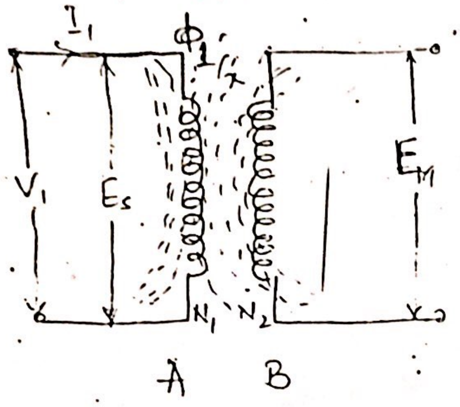
Now $M = N_2 \cdot \frac{N_1}{S}$ ($\because \frac{\phi_1}{I_1}$ is replaced by $\frac{N_1}{S}$)

$$\therefore M = \frac{N_1 N_2}{S}$$

$$\therefore M = \frac{N_1 N_2}{\frac{l}{a\mu_0\mu_r}} \quad \left(\because S = \frac{l}{a\mu_0\mu_r}\right)$$

$$\therefore \boxed{M = \frac{N_1 N_2 a \mu_0 \mu_r}{l}} \text{ Henries.}$$

Coefficient of Coupling :→



In mutual induction between two coils (A & B), the flux produced (ϕ_1) in coil A not only links coil A but also coil B. But in practice the entire flux produced (ϕ_1) will not effectively link coil B as there will be some percentage of total flux produced last nothing but will not link coil B effectively - that is called leakage flux. The flux which successfully links coil B is called useful flux.

In the above circuit the amount of flux linking coil B effectively is given by $x\phi$. where 'x' is the percentage of total flux produced which successfuly links coil B.

Now with reference to above explanation, the mutual inductance between coils A & B can be written as

$$M = \frac{N_2 x \phi_1}{I_1} \longrightarrow ① \quad \text{where 'x' is percentage of flux linking coil A}$$

Similarly if voltage is applied to coil B instead of coil A then

$$M = \frac{N_1 y \phi_2}{I_2} \longrightarrow ② \quad \text{where y is percentage of flux linking coil A}$$

Multiplying ① & ②

$$M^2 = N_2 \frac{x\phi_1}{I_1} \cdot N_1 \frac{y\phi_2}{I_2}$$

$$= N_1 \frac{\phi_1}{I_1} \cdot N_2 \frac{\phi_2}{I_2} \cdot xy$$

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

LIST OF FORMULE :⇒

1) Emf induced $E = N\frac{d\phi}{dt}$ volts

2) Dynamically induced emf : $E = Blv\sin\theta$ volts

3) Magnetic flux density : $B = \frac{\phi}{a}$ Wb/m²

4) Reluctance of magnetic circuit : $S = \frac{l}{a\mu_0\mu_r}$ A/wb

5) Magnetic field strength : $H = \frac{NI}{l}$ AT/m

6) Absolute Permeability : $\mu = \frac{B}{H}$ & for vaccum $\mu_0 = \frac{B}{H}$

7) Relative Permeability $\mu_r = \frac{\mu}{\mu_0}$

8) Self induced emf : $E_s = L\frac{dI}{dt}$ volts

9) Self inductance : $L = \frac{N\phi}{I}$ or $L = \frac{N^2 a\mu_0\mu_r}{l}$ Henry

10) Mutually induced emf : $E_M = M\frac{dI}{dt}$ Volts

11) Mutual inductance : $M = N_2\frac{\phi_1}{I_1}$ or $M = N_1\frac{\phi_2}{I_2}$ or $M = \frac{N_1N_2 a\mu_0\mu_r}{l}$ Henry

12) Coefficient of Coupling : $K = \frac{M}{\sqrt{L_1L_2}}$

13) Energy stored in magnetic field $E = \frac{1}{2}LI^2$ Joules