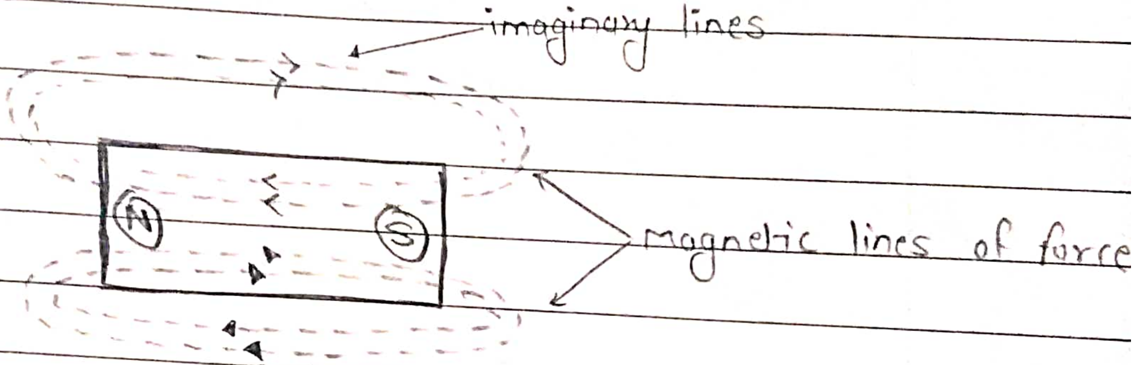
Date:

1. Electromagnetism

Important Terms

1) Magnetic field (Magnetic Lines of Force) :-
The region around magnet in which effect of magnetism can be experienced is called as MAGNETIC FIELD

To represent a magnetic field imaginary lines are considered around the magnet called Magnetic lines of force.



- Magnetic field lines are closed curves
- lines do not intersect with each other.

2) Magnetic Flux :- The total number of lines of force in a magnetic field, is called magnetic flux (Φ)
S.I. unit (Weber) $1\ Wb = 10^8$ lines of force

3) Magnetic field Intensity (Magnetising force) :- strength
The force experienced by a unit north pole, placed at any point in magnetic field is called as ....
(H) (N/Wb) (A/m) (AT/m)

$\frac{\text{Newton}}{\text{Weber}}$ $\frac{\text{Ampere}}{\text{meter}}$ $\frac{\text{Amper turns}}{\text{meter}}$

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

M T W T F S S

Page No.:

Date:

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4) Magnetic Flux Density :- The flux per unit area measured in a plane, perpendicular to the flux, is (B) $\frac{\text{Weber}}{\text{meter}^2}$ $\frac{Wb}{m^2}$ $B = \frac{\text{Total Flux}}{\text{Unit area}} = \frac{\Phi}{a}$ Tesla or

5) Pole Strength :- Amount of magnetic flux coming out from a given magnetic pole.

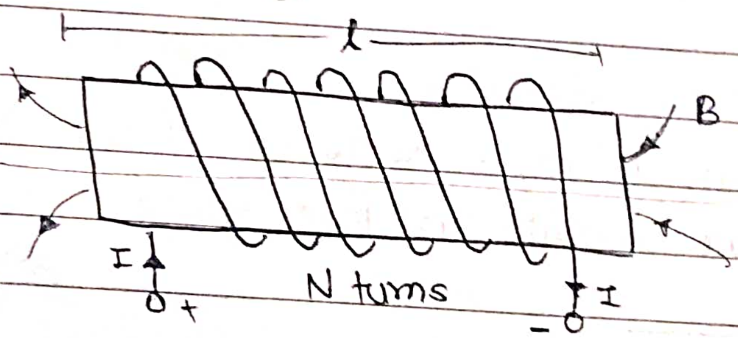
* Electromagnet :- An conductor wounded by wire and wire is carrying current in it (behave like magn

* Dot Convention :- ⊙ Current flowing towards obse

* Cross Convention :- ⊗ Current flowing away from obser

* Right Hand Thumb Rule :- "If a conductor is held in righ hand such that thumb indicates direction of current for flowing through conductor then remaining four fingers around the coductor indicates the direction of magnetic field lines". Thumb ⇒ Towards current
  Curled fingers ⇒ Direction of magnetic field

* Magnetic field ~~for~~ ~~[illegible]~~ due to Solenoid :-



$$B = \mu H = \frac{\mu N I}{l} = \mu K$$

B = Magnetic flux density (Tesla)
μ = Permeability of medium (H/m)
N = Number of turns
I = Current
l = length   K = sheet current density (A/m)

* **Permeability** :- Ability of a material to carry the magnetic flux lines in a given medium.

* **Absolute permeability** :- (μ) The ratio of magnetic flux density (B) to magnetic field strength (H)

$$\text{Absolute permeability} = \frac{\text{Magnetic flux density (B)}}{\text{Magnetic field strength (H)}}$$

$$\boxed{\mu = \frac{B}{H}} \quad H/m \quad \frac{\text{Henrie}}{\text{meter}}$$

* **Permeability of Vaccum or Free Space (μ_0)** :- When a magnet is placed in a vaccum or free space, ratio of B/H $\boxed{\mu_0 = 4\pi \times 10^{-7}}$ H/m

* **Relative Permeability** :- Ratio of flux density to magnetic flux density in free space

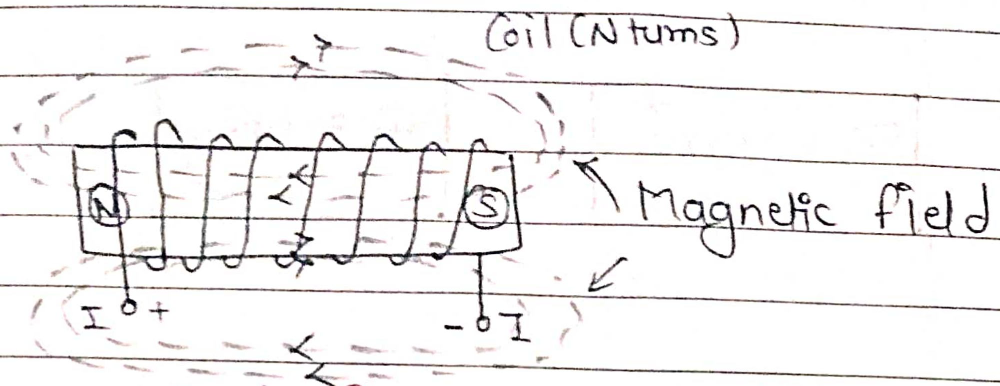
$$\boxed{\mu_r = \frac{B}{B_0}} \quad \text{unit less} \qquad \boxed{\mu_r \text{ air} = 1}$$

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

μ = Magnetic permeability
μ_0 = permeability of free space
μ_r = Relative permeability

Date:

* (MMF) Magnetomotive Force :-



The force required for generation / flow of magnetic flux in a magnetic circuit. N ⇒ turn

$I \Rightarrow$ Current

$$\boxed{MMF = NI}$$ Ampere Turns AT

* Reluctance :- Opposition to flow of magnetic flux by material called... (S)

$$\boxed{S = \frac{l}{\mu a}}$$

$l \Rightarrow$ Length
$a \Rightarrow$ Cross-sectional area m^2
$\mu \Rightarrow$ permeability

$$\boxed{S = \frac{l}{\mu_0 \mu_r a}}$$ $\frac{\text{Ampere Turns}}{\text{Weber}}$ $\frac{AT}{Wb}$

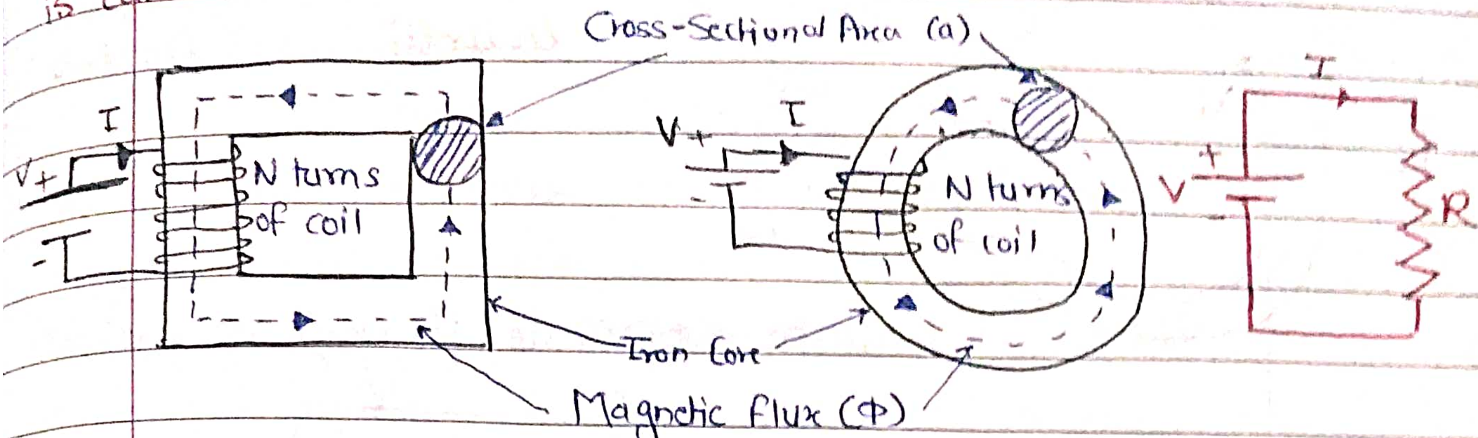
$$\boxed{S = \frac{mmf}{\Phi}}$$

$$\boxed{S = \frac{NI}{\Phi}}$$

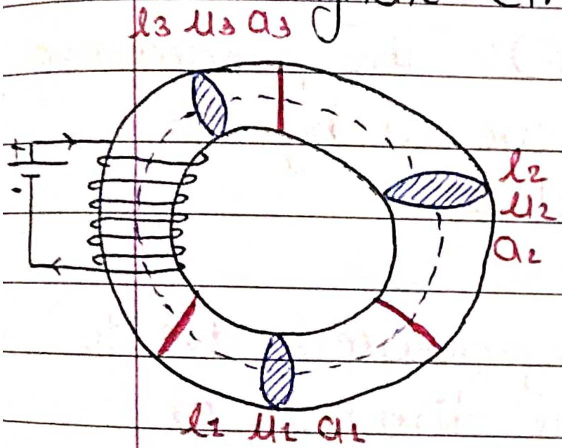
* Permeance :- Reciprocal of reluctance

$$\boxed{\text{Permeance} = \frac{1}{\text{Reluctance}}}$$ Wb/AT

* Magnetic Circuit :- A closed path followed by magnetic lines of force that means magnetic flux, is called as 'MAGNETIC CIRCUIT'.



* Series Magnetic Circuit :- same flux



$$\Phi = \frac{MMF}{S_T} \quad \text{------} \ (1)$$

$$S_T = \frac{l_1}{\mu_1 a_1} + \frac{l_2}{\mu_2 a_2} + \frac{l_3}{\mu_3 a_3} \quad \text{----} \ (2)$$

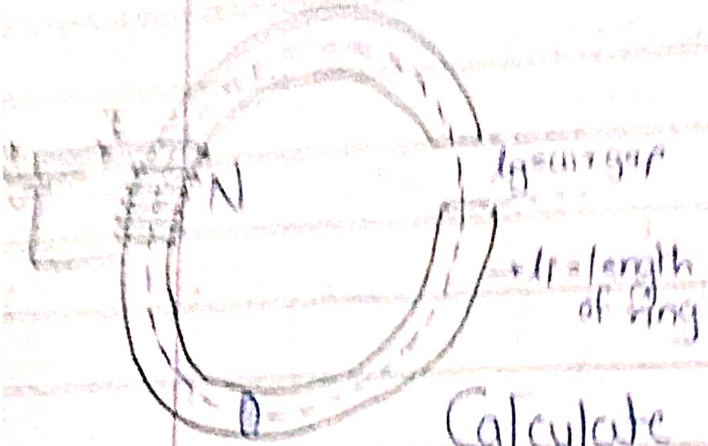
from (1) and (2)

$$\therefore MMF_T = [MMF]_1 + [MMF]_2 + [MMF]_3$$
$$= \Phi [S_1 + S_2 + S_3]$$
$$= \Phi \left[\frac{l_1}{\mu_1 a_1} + \frac{l_2}{\mu_2 a_2} + \frac{l_3}{\mu_3 a_3} \right]$$

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

$$\therefore MMF_T = H_1 l_1 + H_2 l_2 + H_3 l_3$$

* Series Magnetic Circuit with air gap:-



$S_i = \frac{l_i}{\mu_0 \mu_r a_i}$ $S_g = \frac{l_g}{\mu_0 \mu_r a_i}$

$\mu_r = 1$ .... air

Calculate seperate if gap is present

$\Phi = \frac{MMF}{S_T}$ $\boxed{S_T = \frac{l_i}{\mu_0 \mu_r a_i} + \frac{l_g}{\mu_0 \mu_r a_i}}$

* Electromagnetic Induction (EMF):- The phenomenon in which magnetic flux lines are cut by the conductor, to induce emf, is called as.......

* Lenz's Law:- When an emf is generated due to change in magnetic flux, the direction of induced emf is such that, it produces a current that opposes the cause responsible for inducing emf.

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

* Faraday's Law of Electromagnetic Induction :-

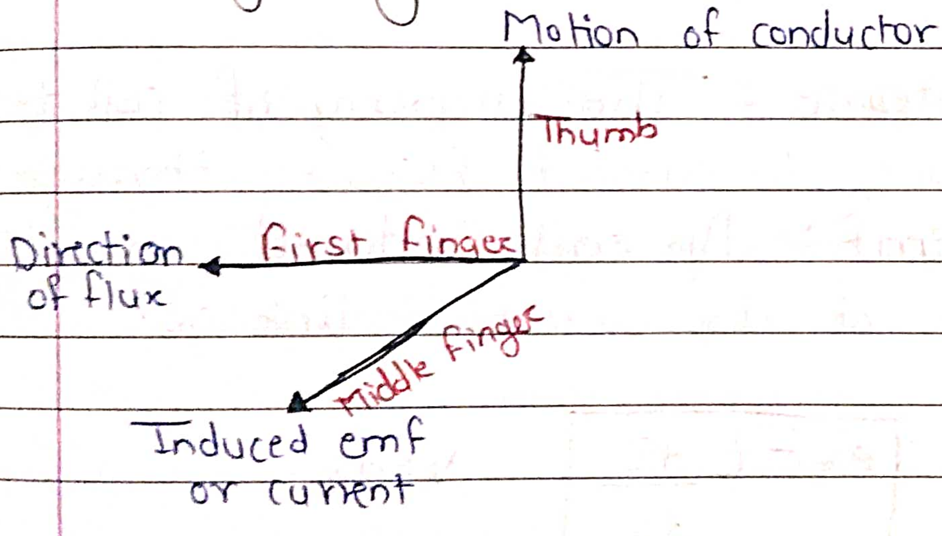
1st :- When ever the flux lines linking with a coil or conductor change ; an emf is induced in the coil or conductor.

2nd :- The magnitude of induced emf directly proportional to rate of change of flux linkage

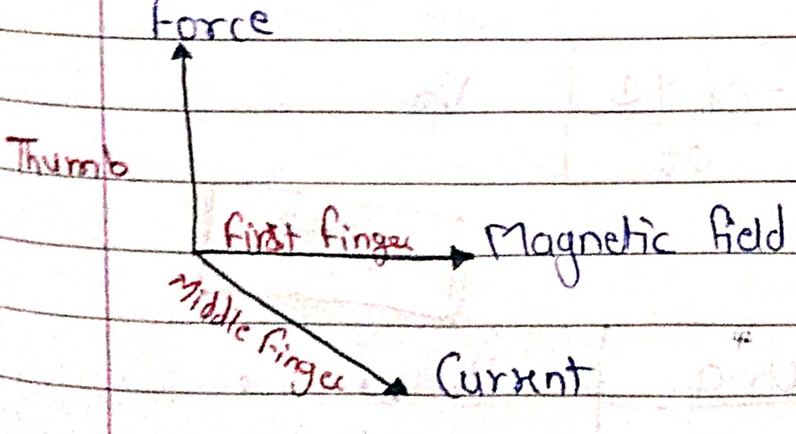
$$e = \underbrace{N}_{\text{Number of turns of coil}} \underbrace{\frac{d\Phi}{dt}}_{\text{Rate of change of flux}}$$

* laws to decide Direction of induced emf

① Fleming's Right Hand Rule :- ~~Conductor~~ Generator



② Fleming's Left Hand Rule :- ~~Generator~~ Motor



Page No.:
Date:

*1) Dynamically Induced EMF :- If an induced emf is due to physical movement of coil or magnet, then it is called......

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

*2) Statically Induced emf :- If an emf is induced without physical movement of coil or magnet, but due to changing current in a coil

$$\boxed{\frac{d\phi}{dt}}$$

*3) Self Inductance :- The property of coil to oppose the change in current flowing through

Self Induced emf :- An emf induced in coil due to change of its own flux linkage.

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

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

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

$L = \frac{N^2}{S}$ $$\boxed{L = \frac{N^2 \mu_0 \mu_r a}{l}}$$ Henry

* Force on a current carrying conductor placed in a magnetic circuit :-

$$\boxed{F = IBL\sin\theta}$$

Fleming's Right / Left Hand Rule

4) Mutual Inductance (M) :-

$$\boxed{e_2 = -M \frac{dI_1}{dt}}$$ Volts

$$M = \frac{N_2 \Phi_2}{I_1}$$

$$\boxed{M = \frac{N_2 k_1 \Phi_1}{I_1}}$$

$$\boxed{M = \frac{K_1 N_1 N_2}{S}}$$

$$\boxed{M = \frac{N_1 N_2 \mu_0 \mu_r a}{l}}$$

K_1 → fraction of flux

$$\boxed{\phi = \frac{N_1 I_1}{S}}$$

$$\therefore \boxed{M = \frac{N_1 N_2}{S}} \quad \ldots\ldots \text{ If } \boxed{K_1 = 1}$$

$$\boxed{P = e \times I}$$

Date:

~~Faraday's Laws of Electromagnetic Conduction~~

* IMP

Derivation of Coefficient of Coupling (k):

If coil A carries current I_1 and part of ϕ_1 gets linked in coil B then mutual inductance is

$$M = \frac{N_2 k_1 \phi_1}{I_1} \quad \text{------} \quad (1)$$

Coil B carries current I_2 produces main flux ϕ_2 and ϕ_2 gets linked with coil A then mutual inductance is

$$M = \frac{N_1 k_2 \phi_2}{I_2} \quad \text{------} \quad (2)$$

Multiply (1) and (2)

$$M^2 = \frac{N_2 k_1 \phi_1}{I_1} \cdot \frac{N_1 k_2 \phi_2}{I_2}$$

$$M^2 = k_1 k_2 \left[\frac{N_1 \phi_1}{I_1}\right] \left[\frac{N_2 \phi_2}{I_2}\right]$$

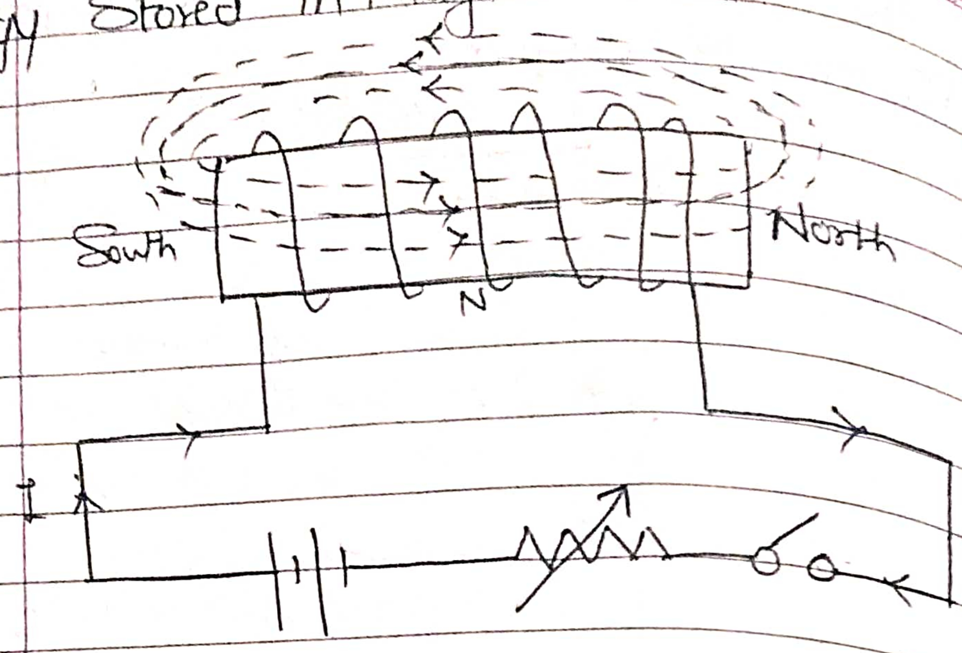
$$\therefore L = \frac{N\phi}{I}$$

$$M^2 = k_1 k_2 L_1 L_2$$

$$M = \sqrt{k_1 k_2 . L_1 L_2}$$

(Sollenoid)

* Energy Stored in Magnetic field :-



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

$$V = -e$$

$$V = -\left[-L\frac{dI}{dt}\right]$$

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

$$\text{Power} = V \times I$$

$$= L\frac{dI}{dt} \times I$$

Energy stored in the magnetic field dt

$$E = L\frac{dI}{dt} \times I \times dt$$

$$E = L\,dI\,I$$

integrating

$$\text{Energy stored} = \int_0^I L\,dI \times I$$

$$= L\int_0^I dI \times I$$

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

$$E = \frac{1}{2}LI^2 \text{ ---- Joules}$$

$$\therefore E = \frac{1}{2} L I^2$$

$$= \frac{1}{2} \frac{N\Phi}{\cancel{I}} \times I^{\cancel{2}}$$

$$E = \frac{1}{2} NI \times B \times a \quad \ldots\ldots \quad B = \frac{\Phi}{a} \quad \therefore B \times a = \Phi$$

$$E = \frac{1}{2} H \times l \times B \times a \quad \ldots \quad \therefore H = NI$$

$$E = \frac{1}{2} H \times B \times (l \times a) \quad \ldots \quad [\text{volume} = l \times a]$$

Energy stored per unit volume $= \frac{1}{2} HB$

$$= \frac{1}{2} \mu H^2 \quad \ldots\ldots \quad B = \mu H$$

Joules $/m^3$

$$= \frac{1}{2} \frac{B^2}{\mu} \text{ Joules}/m^3$$

Date:

$$Area = \frac{\pi d^2}{4} = \pi r^2$$

(1) An aircored solenoid 1m in length and 10 cm in diameter has 5000 turns calculate (1) self inductance (2) Energy stored in magnetic field when current of 2A flows in the solenoid.

→ Given:-

length = 1m

N = 5000 turns

diameter = 10 cm = 10×10^{-2} m

Current (I) = 2A

To find :- (1) Self inductance (2) Energy stored

Sol^n :- (1) Self inductance (L)

$$L = \frac{N^2 \mu_0 \mu_r a}{l} \quad \ldots\ldots \quad \mu_r = 1$$

$$= \frac{5000 \times 5000 \times 4\pi \times 10^{-7} \times 1 \times \pi \times (10 \times 1}{1 \quad\quad 4}$$

$= \cancel{98696044}$ 0.2467

(2) Energy stored = $\frac{1}{2} LI^2$

$$= \frac{1}{2} \times (0.2467) \times (2)^{2}$$

$= 0.4934$

M T W T F S S
Page No.
Date
YOUVA

(II) If a current of 5A flowing in coil with 1000 turns wound on a ring of fero magnetic material produces flux of 0.5m Wb in the ring calculate (1) self inductance of coil (2) EMF induced in coil when current is switched off and reaches zero value in 2ms. (3) Mutual induc- in coils if 2nd coil with 750 turns is wound uniformly over the 1st one

→ Given :- $I = 5A$ $\quad t = 2ms = 2 \times 10^{-3}$ sec

$N = 1000$ $\quad N_2 = 750$

$\Phi = 0.5 mWb = 0.5 \times 10^{-3}$ Wb

To find :- (1) L (2) EMF when $I=0$ (3) M

Soln :- (1) $L = \frac{N\Phi}{I} = \frac{1000 \times 0.5 \times 10^{-3}}{5} = 0.1$ Henery

(2) $e = -\frac{L dI}{dt} = \frac{-0.1 [0-5]}{2 \times 10^{-3}} = \frac{0.5}{2 \times 10^{-3}} = 250$ volts

(3) $M = \frac{N_2 \Phi_2}{I_1} = \frac{N_2 \Phi_1 K_1}{I_1}$ $\quad \because$ uniformly then $K_1 = 1$

$= \frac{750 \times 0.5 \times 10^{-3}}{5} = 0.075$ H