Gujarat Technological University

Diploma in Electrical Engineering

Semester-1

D C Circuits - 4310901

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Rajkot

Unit – 5

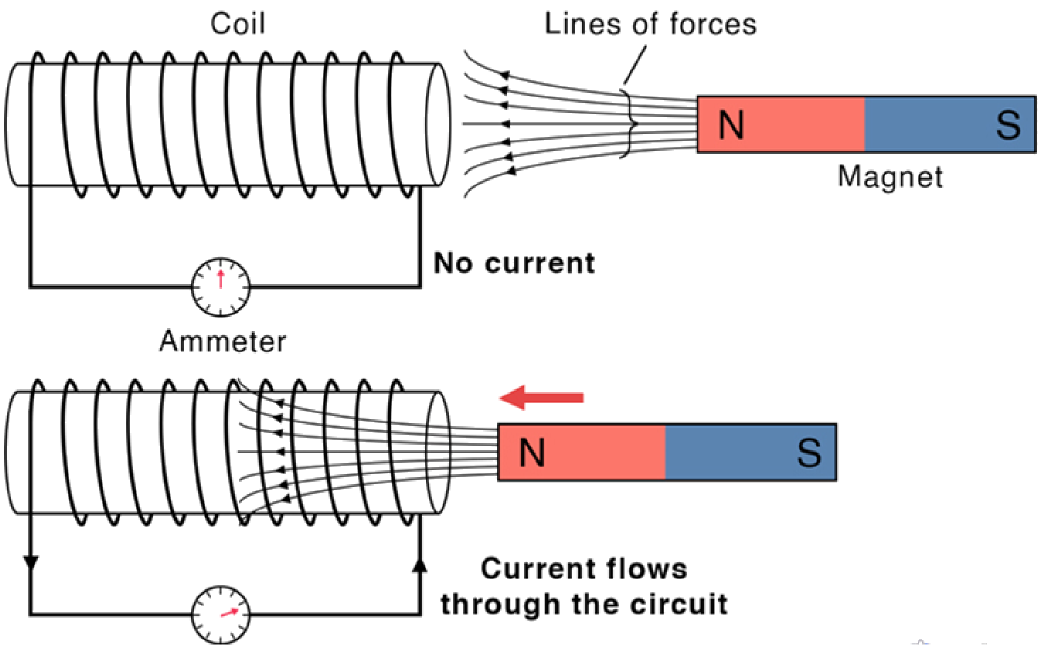
Magnetism
&
Electromagnetism

Topics

- Compare magnetic circuit with electric circuit
- Apply laws of electromagnetism to determine direction of flux, magnetic force, induced emf, flux density and field strength
- State Faraday's laws of electromagnetic induction, Flemings right- and left-hand rule and Lenz's law
- Compute equivalent inductance in various series-parallel combinations
- State applications of the given type of inductor
- Calculate the energy stored in the given inductor

Electromagnetic Induction

- **The phenomenon of production of e.m.f. and hence current in a conductor or coil when the magnetic flux linking the conductor or coil changes is called electromagnetic induction.**



Flux Linkages

- **The product of number of turns (N) of the coil and the magnetic flux (φ) linking the coil is called flux linkages.**

$$Flux\ Linkages = N\emptyset$$

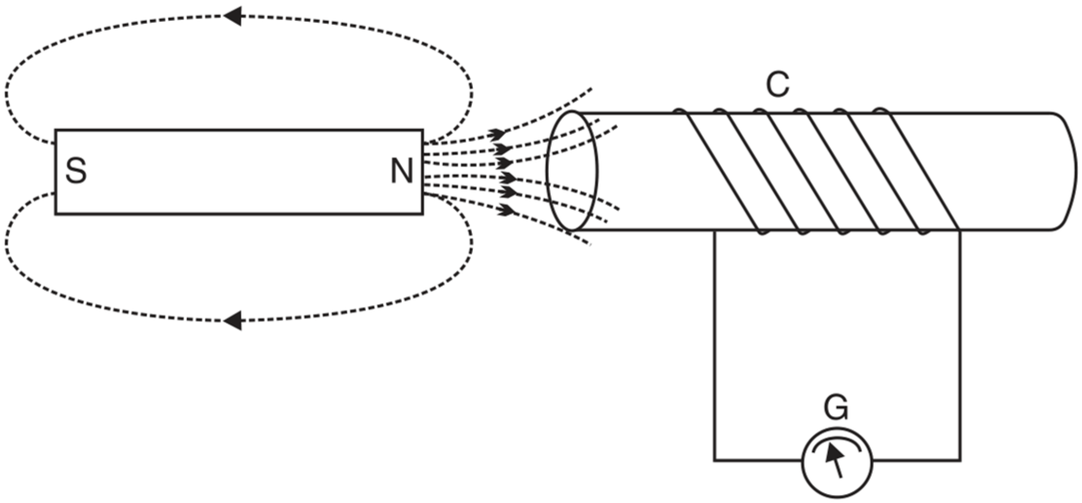
$$Induced\ EMF, e \propto Rate\ of\ change\ of\ flux\ linkages$$

$$e \propto \frac{N\emptyset_1 - N\emptyset_2}{t}$$

Faraday's Laws of Electromagnetic Induction

First Law

When the magnetic flux linking a conductor or coil changes, an e.m.f. is induced in it.



$$e \propto \frac{N\emptyset_1 - N\emptyset_2}{t}$$

Faraday's Laws of Electromagnetic Induction

Second Law

The magnitude of the e.m.f. induced in a conductor or coil is directly proportional to the rate of change of flux linkages.

$$e \propto \frac{N\emptyset_1 - N\emptyset_2}{t}$$

$$e = kN\frac{d\emptyset}{dt}$$

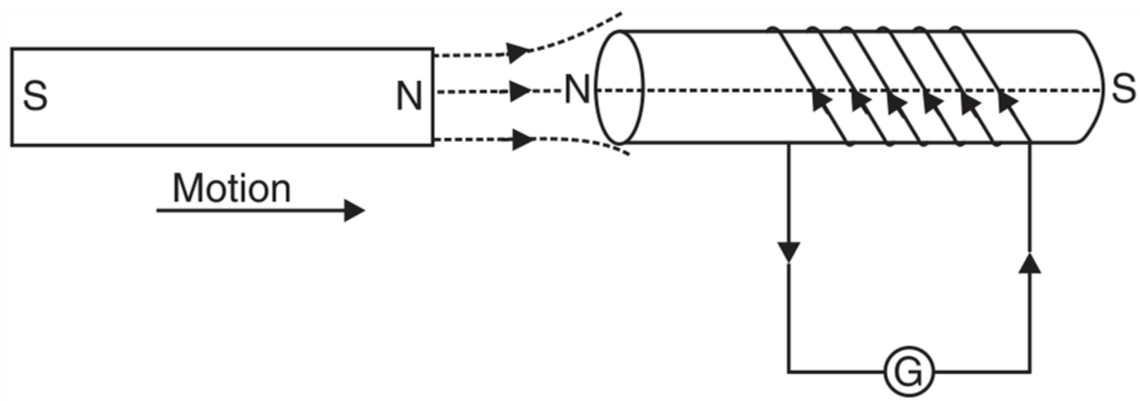
$$e = N\frac{d\emptyset}{dt} \qquad k = 1$$

Direction of Induced E.M.F. & Current

- **Lenz's Law**
- **Fleming's right-hand rule**

Lenz's Law

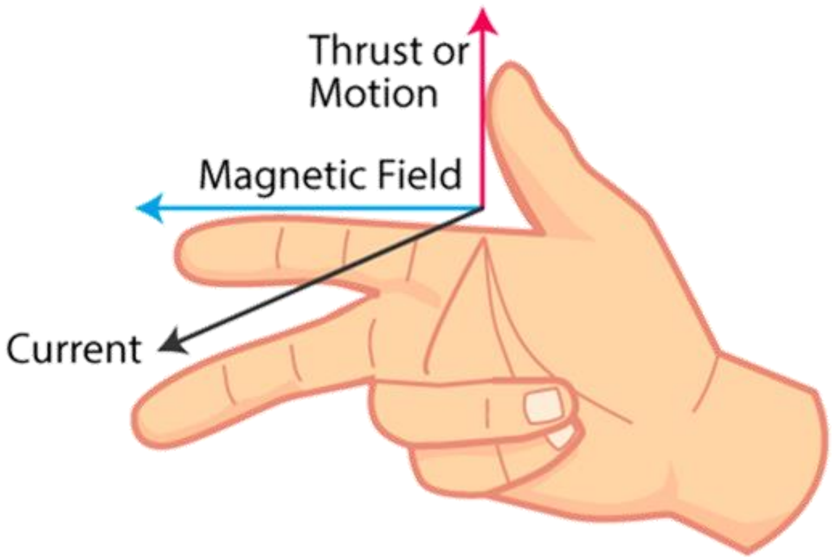
- ***The induced current will flow in such a direction so as to oppose the cause that produces it i.e. the induced current will set up magnetic flux to oppose the change in flux.***



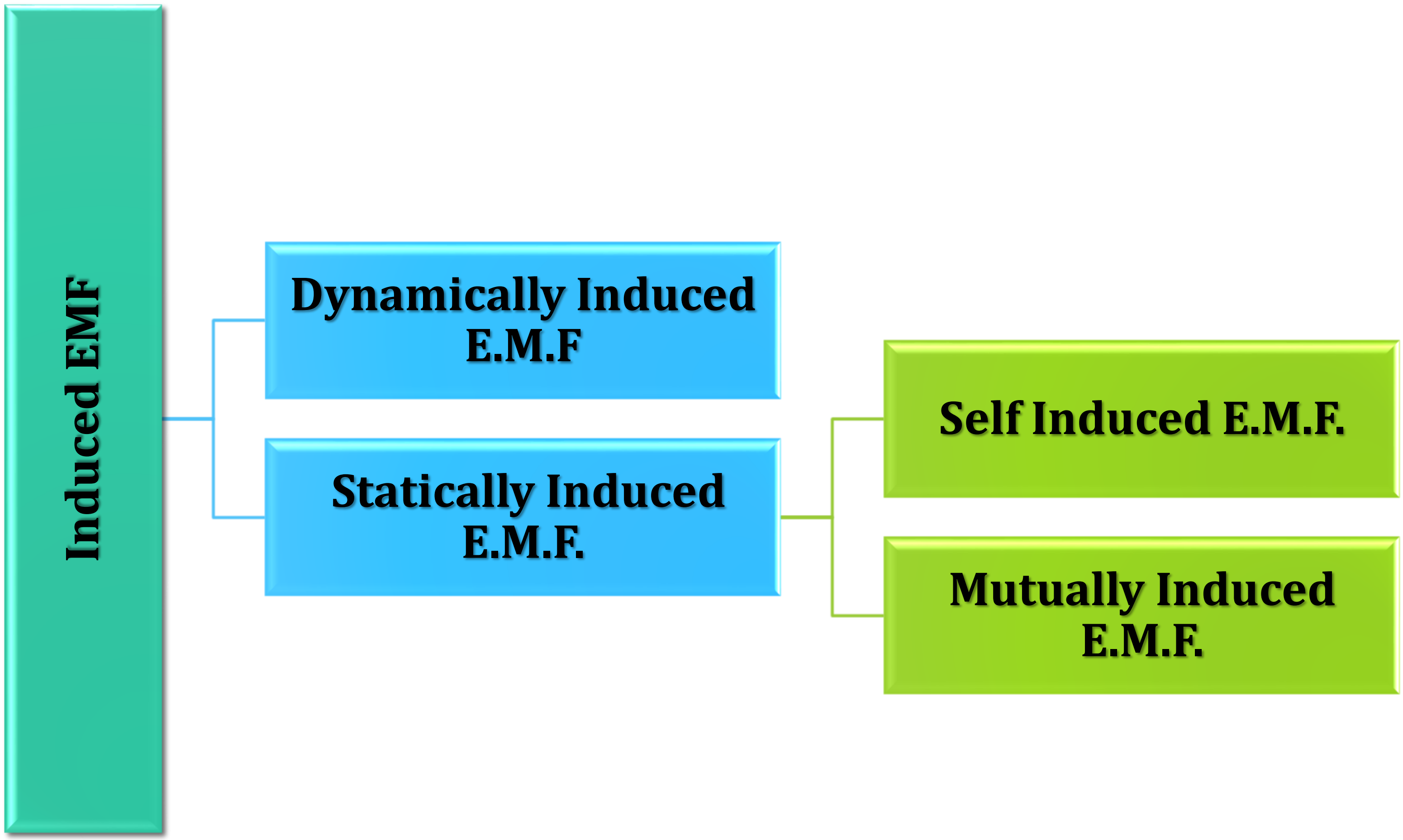
$$e = -N\frac{d\emptyset}{dt}$$

Fleming's right-hand rule

Stretch out the First finger, seCond finger and thuMb of your right hand so that they are at right angles to one another. If the First finger points in the direction of magnetic Field, thuMb in the direction of Motion of the conductor, then the seCond finger will point in the direction of induced Current.

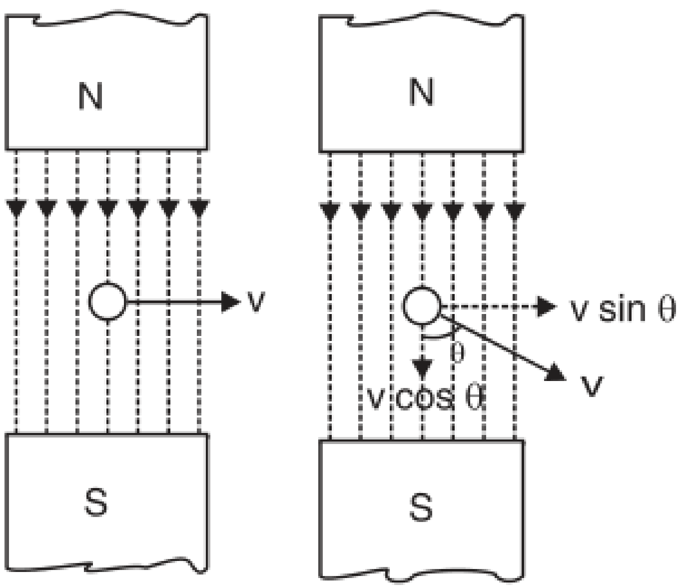


Classification of Induced E.M.F.



Dynamically Induced E.M.F

- ***The conductor is moved in a stationary magnetic field in such a way that the flux linking it changes in magnitude.***
- **The e.m.f. induced in this way is called dynamically induced**



$$Flux\ cut = Flux\ Density \times Area\ Swept$$

$$d\emptyset = B\,l\,dx$$

$$e = N\frac{d\emptyset}{dt}$$

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

$$e = B\,l\,v$$

$$N = 1 \qquad \frac{dx}{dt} = v$$

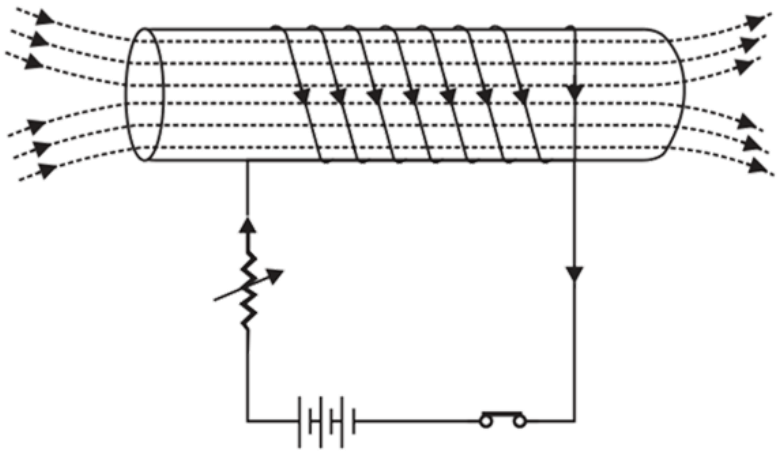
$$e = B\,l\,v\sin\theta$$

Statically Induced E.M.F

Self Induced E.M.F.

The e.m.f. induced in a coil due to the change of its own flux linked with it is called self-induced e.m.f.

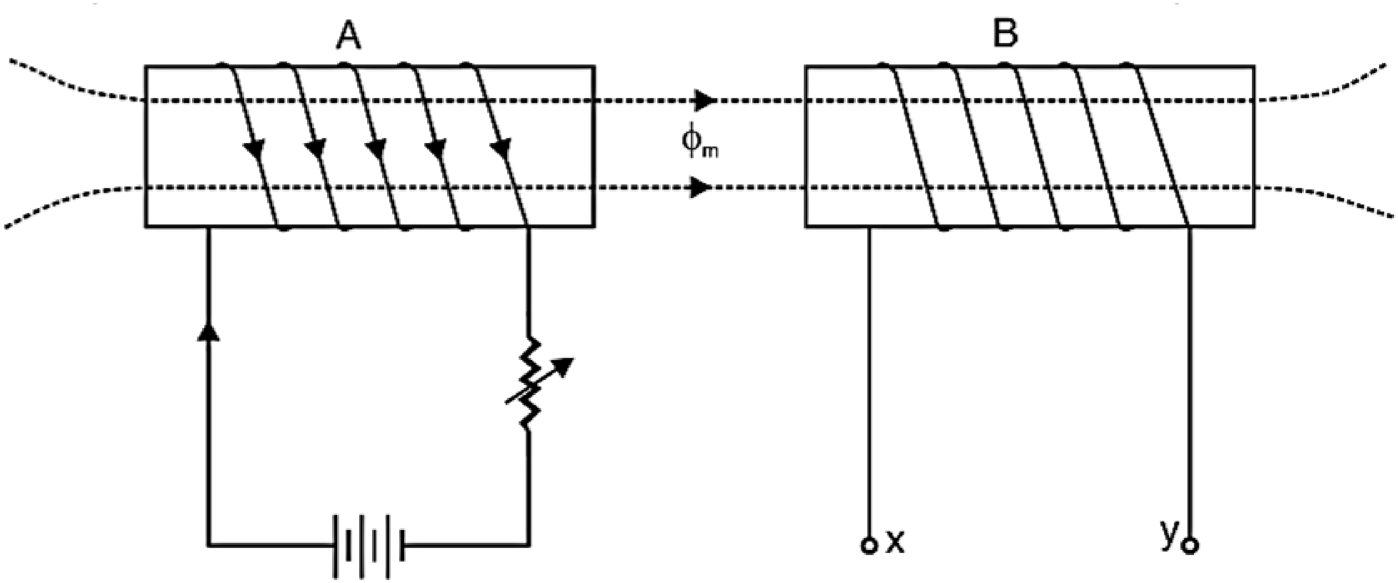
*When current in a coil changes, the self-induced e.m.f. opposes the change of current in the coil. This property of the coil is known as its **self-inductance** or **inductance.***



Statically Induced E.M.F

Mutually Induced E.M.F.

The e.m.f. induced in a coil due to the changing current in the neighbouring coil is called mutually induced e.m.f.



Self-inductance (L)

The property of a coil that opposes any change in the amount of current flowing through it is called its self-inductance or inductance.

The self-induced e.m.f. (and hence inductance) does not prevent the current from changing ; it serves only to delay the change.

Factors affecting inductance

- **Shape and number of turns**
- **Relative permeability of the material surrounding the coil**
- **The speed with which the magnetic field changes**

Magnitude of Self-induced E.M.F.

$$e = N\frac{d\emptyset}{dt} = \frac{d}{dt}(N\emptyset), \quad e = \frac{d}{dt}(N\emptyset) \propto \frac{dI}{dt}, \quad e = Constant \times \frac{dI}{dt},$$

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

Constant, L is known as Inductance

Unit of Inductance(L) is Henry (H)

Hence a coil (or circuit) has an inductance of 1 henry if an e.m.f. of 1 volt is induced in it when current through it changes at the rate of 1 ampere per second.

Expressions for Self-inductance

$$L = \frac{e}{(\frac{dI}{dt})}$$

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

Inductance depends upon the ratio φ/I

Inductance is constant only when the flux changes uniformly with current

$$L = \frac{N^2}{Reluctance(S)}$$

Inductance is directly proportional to turns squared and inversely proportional to the reluctance of the magnetic path

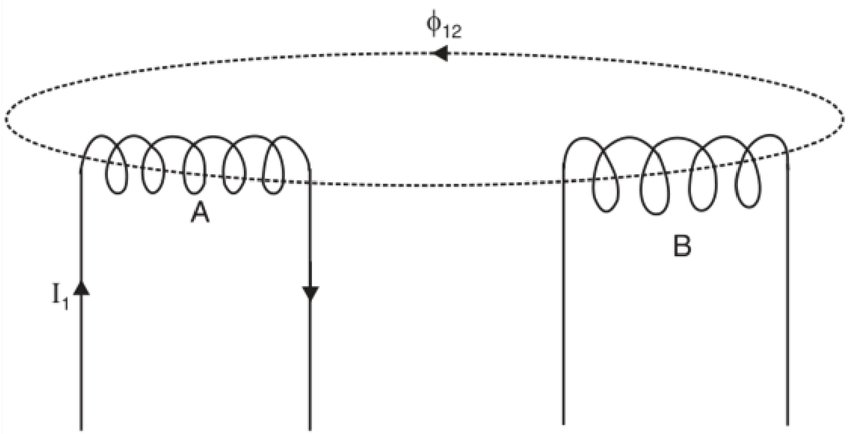
Magnitude of Mutually Induced E.M.F.

Mutually induced e.m.f. in coil B $\propto$ Rate of change of current in coil A

$$e_M \propto \frac{dI_1}{dt}$$

$$e_M = Constant \times \frac{dI_1}{dt}$$

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



M is a constant called mutual inductance between the two coils

Hence mutual inductance between two coils is 1 henry if current changing at the rate of 1 A/sec in one coil induces an e.m.f. of 1 V in the other coil.

Expressions for Mutual Inductance

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

$$e_M = \frac{d}{dt}(MI_1)$$

Also,

$$e_M = N_2\frac{d\emptyset_{12}}{dt} = \frac{d}{dt}(N_2\emptyset_{12})$$

From above two expressions, we have

$$MI_1 = N_2\emptyset_{12}$$

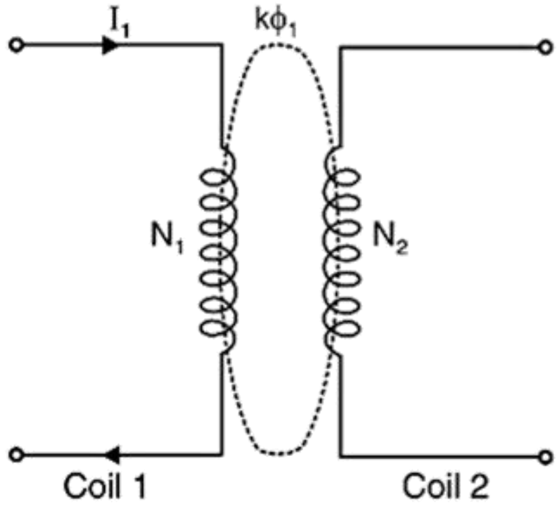
$$M = \frac{N_2\emptyset_{12}}{I_1}$$

Hence mutual inductance between two coils is 1 henry if a current of 1 A flowing in one coil produces flux linkages of 1 Wb-turn in the other.

Coefficient of Coupling

The coefficient of coupling (k) between two coils is defined as the fraction of magnetic flux produced by the current in one coil that links the other.

$$M = k\sqrt{L_1 L_2}$$



Coefficient of Coupling

$$L_1 = \frac{N_1 \emptyset_1}{I_1}$$

$$M_{12} = \frac{k \emptyset_1 N_2}{I_1}$$

$$L_2 = \frac{N_2 \emptyset_2}{I_2}$$

$$M_{21} = \frac{k \emptyset_2 N_1}{I_2}$$

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

$$M_{12} \times M_{21} = \frac{k \emptyset_1 N_2}{I_1} \times \frac{k \emptyset_2 N_1}{I_2}$$

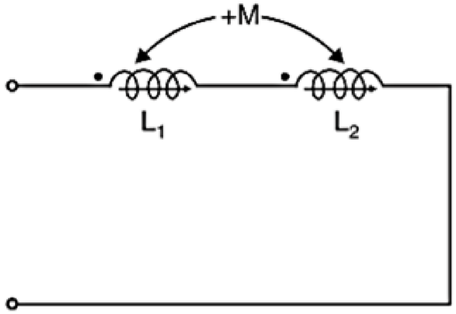
$$M^2 = k^2 L_1 L_2$$

$$M = k\sqrt{L_1 L_2}$$

Inductors in Series

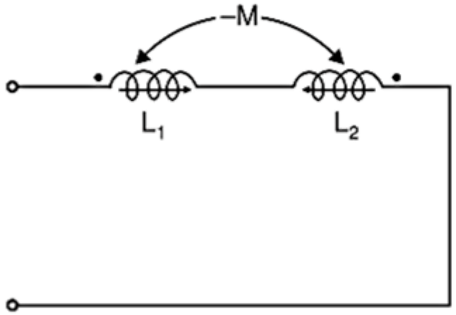
Series-aiding

$$L_T = L_1 + L_2 + 2M$$



Series-opposing

$$L_T = L_1 + L_2 - 2M$$



In General

$$L_T = L_1 + L_2 \pm 2M$$

Inductors in Parallel

Parallel-aiding

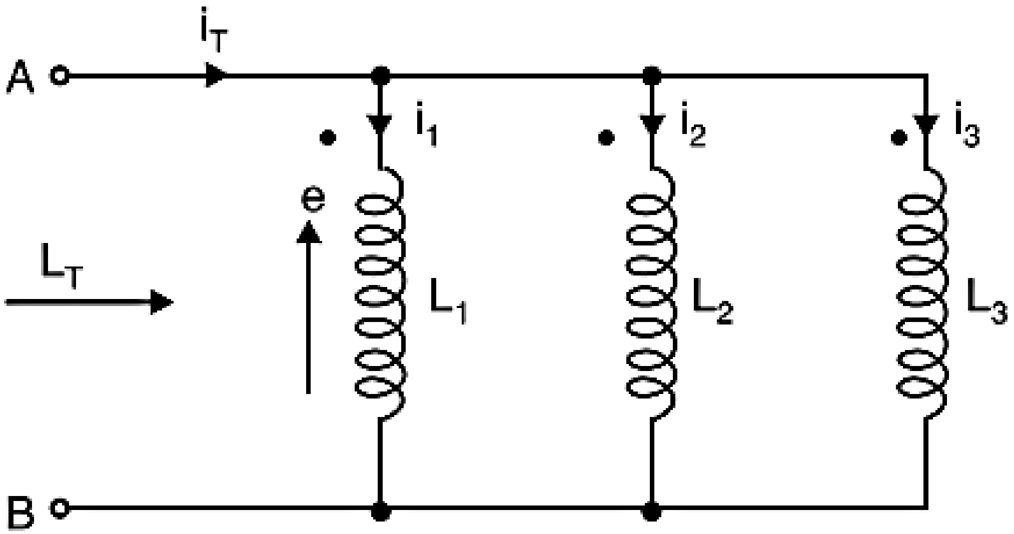
$$L_T = \frac{L_1 L_2 - M^2}{L_1 L_2 - 2M}$$

Parallel-opposing

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

In General

$$L_T = \frac{L_1 L_2 - M^2}{L_1 L_2 \mp 2M}$$



Energy Stored in Inductors

$$e = \frac{Ldi}{dt}$$

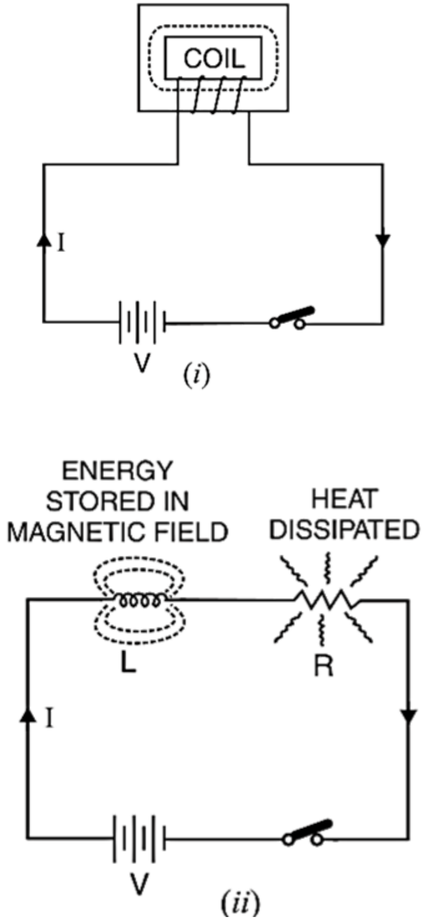
$$Instantaneous\ Power, p = ei$$

$$ei = Li\frac{di}{dt}$$

$$dw = p.dt = Li\frac{di}{dt}dt = Lidi$$

$$W = \int_0^I Lidi = \frac{1}{2}Li^2$$

$$E = \frac{1}{2}Li^2$$



References

Basic Electrical Engineering

by

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Thank You

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