# Basic Electrical Technology

## [ELE 1051]

***Electromagnetic induction***

# Faraday's Laws of Electromagnetic Induction

## First Law:

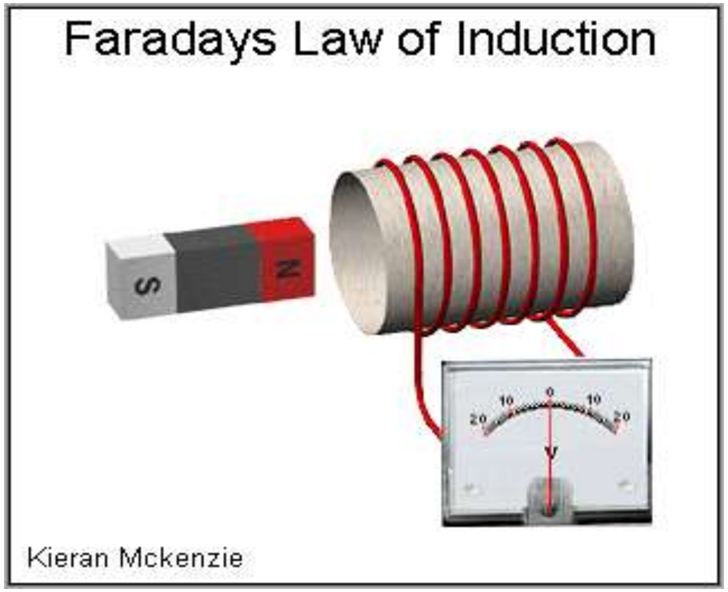
Whenever the magnetic field linking with a conductor changes, an EMF will be induced in that conductor

## Second Law:

The magnitude of the induced EMF is proportional to the rate of change of the magnetic flux linking the conductor

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

Where N = number of turns in the coil



# Lenz's Law

The electro-magnetically induced emf always acts in such a direction to set up a current opposing the motion or change of flux responsible for inducing the emf.

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

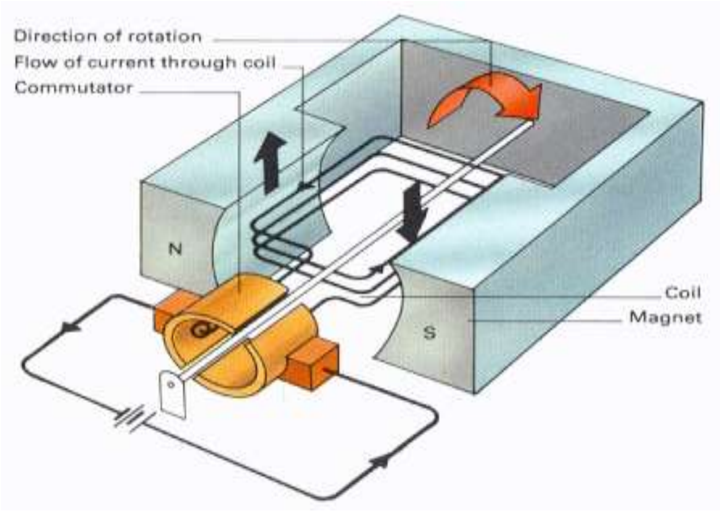
# Fleming’s Right Hand Rule

If the first, second and the thumb of the right hand are held at right angles to each other,
first finger indicates the direction of the magnetic flux
and
thumb finger indicates the direction of motion of the conductor relative to the magnetic field,
then
the second finger represents the direction of induced EMF.

# Types of induced EMF

## Dynamically induced EMF:

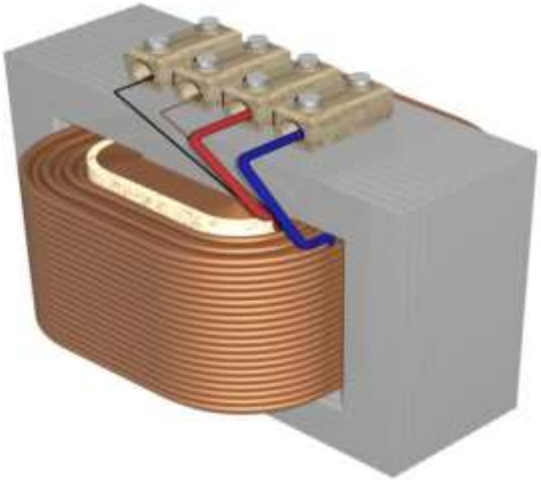
- **The voltage induced in the conductor due to relative motion of conductor and magnetic field**
- $e = B\, l\, v\, Sin\theta$
- **Either conductor or magnetic field is moving**
- **Principle of Electric generator**



# Types of induced EMF

## Statically Induced EMF:

- The voltage induced in the conductor due to change in the magnetic field
- Conductor is stationary
- Magnetic Field is changing in a stationary magnetic system
- Eg: Transformer

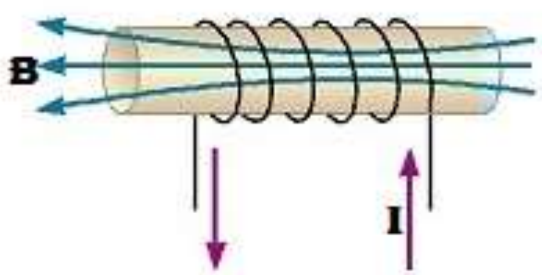


# Types of Statically induced EMF

## Self Induced Emf:

The induced emf in a coil proportional to the rate of the change of the magnetic flux passing through it due to its own current.

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




## Self Inductance L:

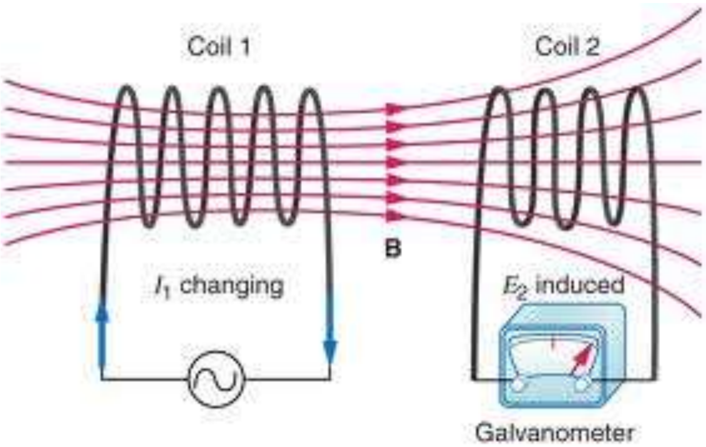
The proportionality constant is called the self inductance, L. Unit is Henry

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

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

## Mutually Induced Emf:

The induced emf in a coil due to the change of flux produced by the change of current in the nearby coil




## Mutual Inductance M:

This proportionality constant is called the mutual inductance, M

**If Coil 1 is excited:**

Mutually induced emf $e_2$ in Coil 2, $$e_2 = N_2 \frac{d\phi_{12}}{dt} = M \frac{di_1}{dt}$$

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

**If coil 2 is excited:** $$M = N_1 \frac{d\phi_{21}}{di_2}$$

# Coupling Coefficient (k)

Gives an idea about the degree of magnetic coupling between two coils.

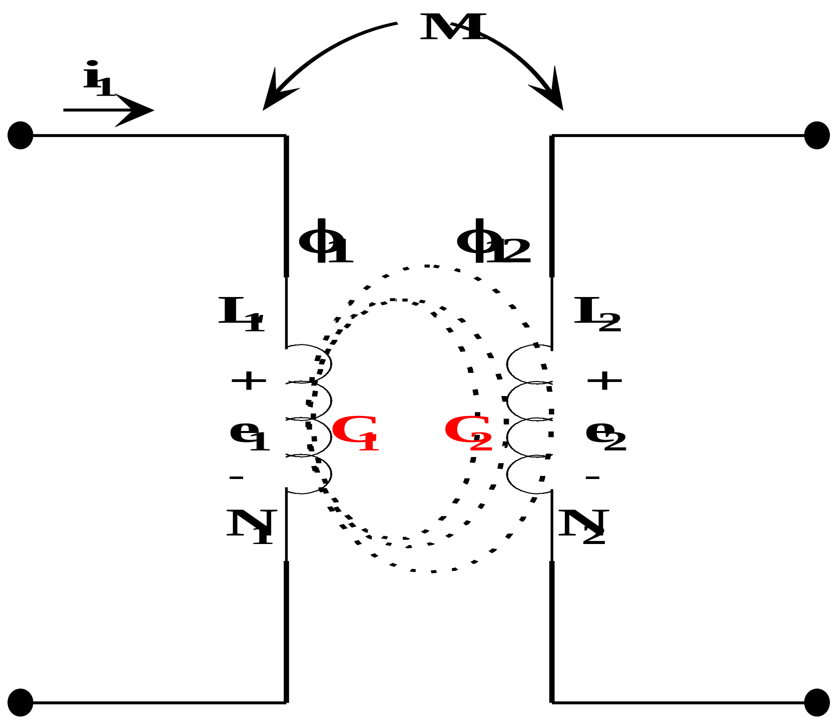
$$M = N_2\frac{d\phi_{12}}{di_1} = N_1\frac{d\phi_{21}}{di_2}$$

$$where, \phi_{12} = k\ \phi_1;\ \ \phi_{21} = k\ \phi_2$$

$$M^2 = \left(N_2 k\frac{d\phi_1}{di_1}\right)\left(N_1 k\frac{d\phi_2}{di_2}\right)$$

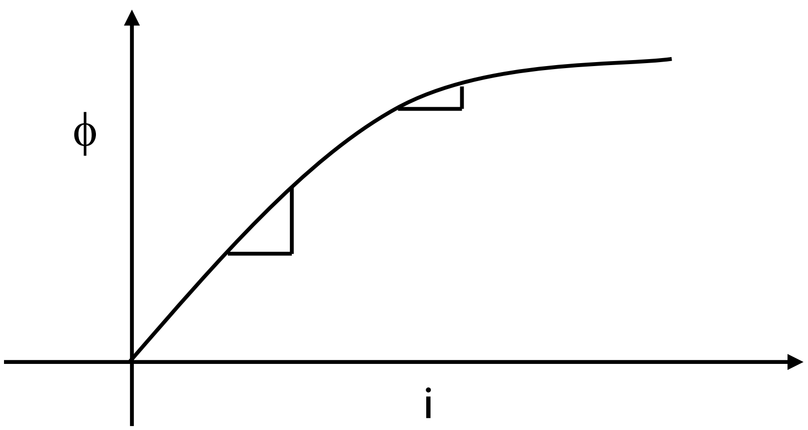
$$= k^2 L_1 L_2$$

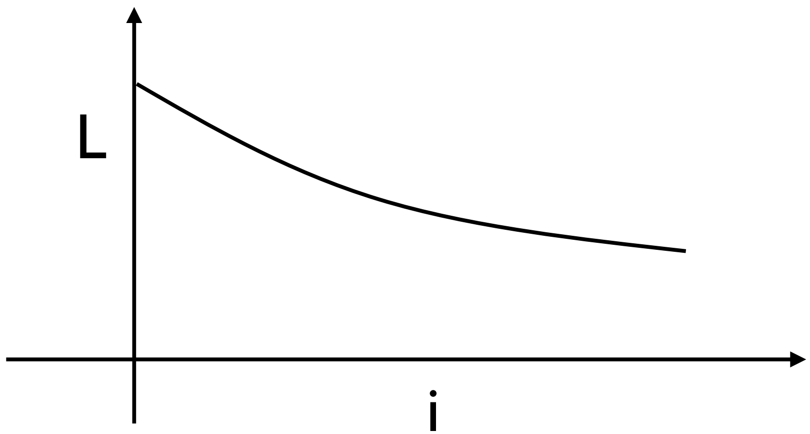
$$\boldsymbol{k = \frac{M}{\sqrt{L_1 L_2}}}$$



# Ferrite core inductor

- Ferrite core – used to reduce the size of the inductor
- $L = N\frac{d\phi}{di}$

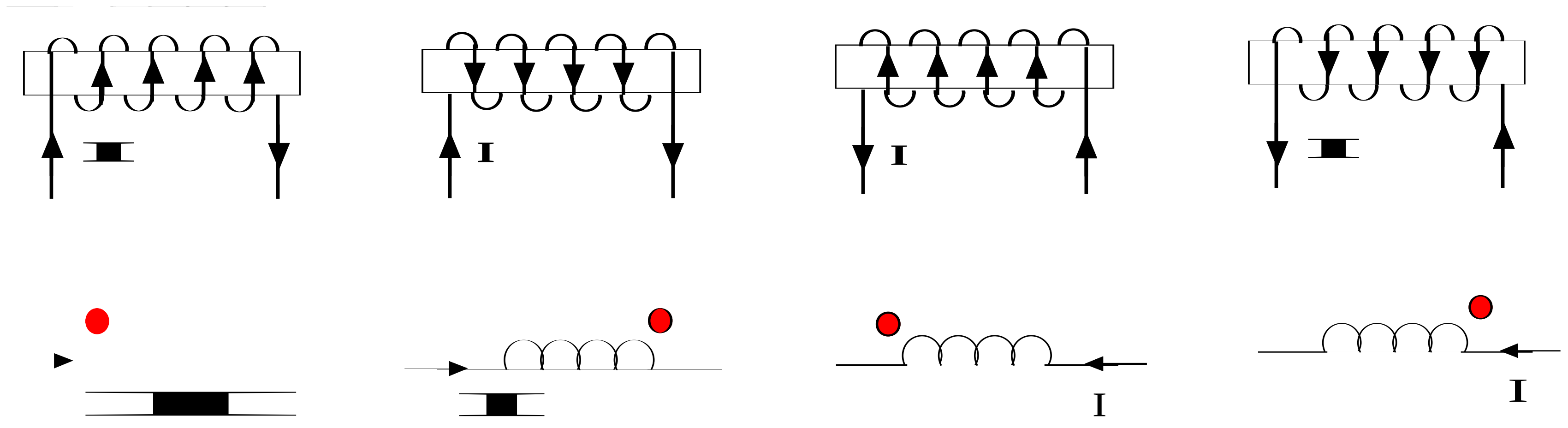


# Coupled Circuits

- Polarity of mutually induced emf depends on
  - current direction
  - physical construction of the coils
- Obtaining the dotted equivalent: Right Hand Grip Rule

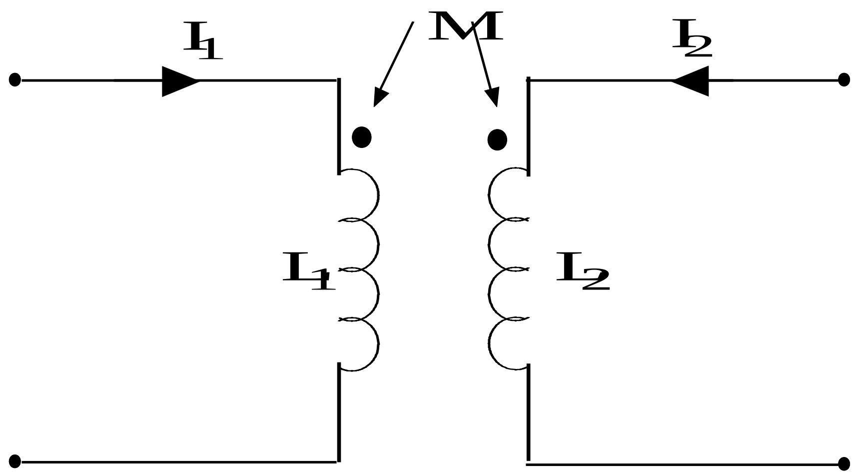
  Place the dot at the terminal directed by the thumb



# Dot Rule for coupled coils

- Dot Rule helps in determining the sign of mutually induced emf without going into the details of physical construction
- **Dot Rule:**
  - If currents enter (or leave) the dotted terminals in both the coils, the sign of mutually induced emf is same as that of sign of self induced emf. (Additive coupling)
  - If the current enters the dotted terminal in one coil and leaves the dotted terminal in the other coil, the sign of mutually induced emf is opposite to that of sign of self induced emf. (Subtractive coupling)

# Additive Coupling: (Fluxes are aiding)

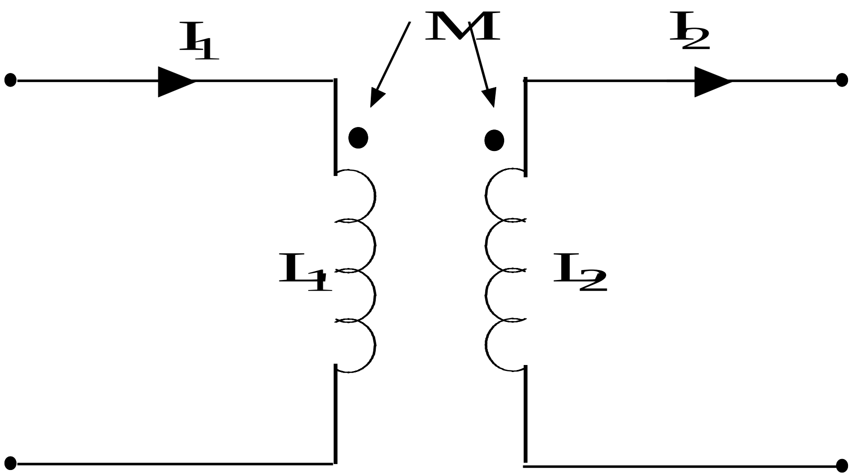



Self induced emf in $L_1$ = $-L_1 \dfrac{di_1}{dt}$

Mutually induced emf in $L_1$ = $-M \dfrac{di_2}{dt}$

Total induced emf in $L_1$ = $-\left( L_1 \dfrac{di_1}{dt} + M \dfrac{di_2}{dt} \right)$

# Subtractive Coupling: (Fluxes are opposing)

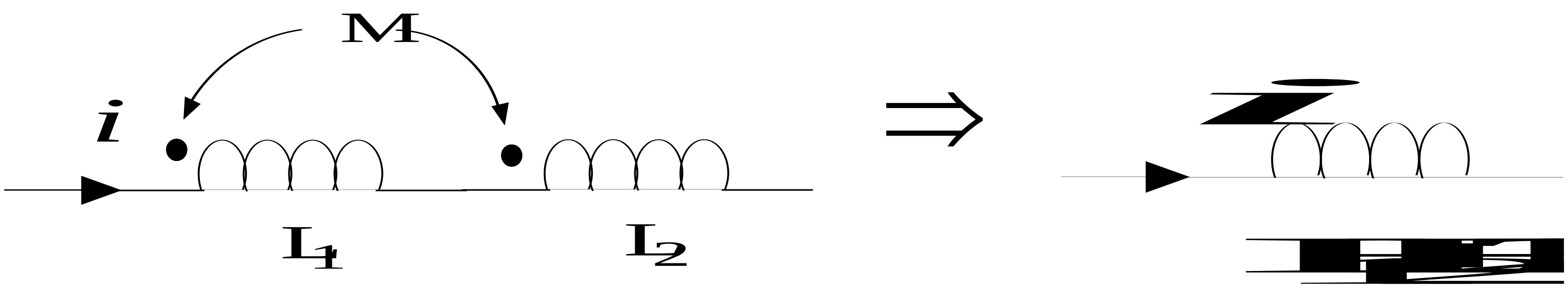



**Self induced emf in $L_1$ =** $$-L_1 \frac{di_1}{dt}$$

**Mutually induced emf in $L_1$ =** $$+M \frac{di_2}{dt}$$

**Total induced emf in $L_1$ =** $$\left(-L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}\right)$$

# Coupled coils in Series - Aiding



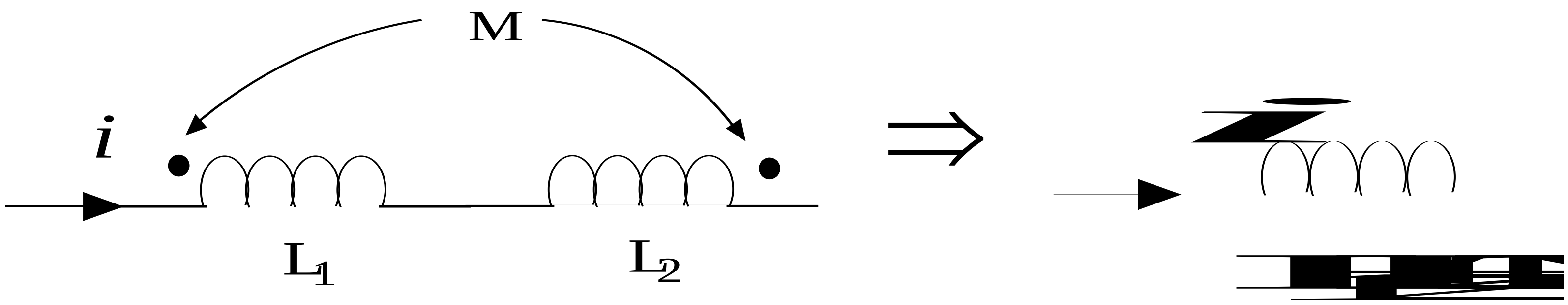

$$e_1 = L_1 \frac{di}{dt} + M \frac{di}{dt}$$

$$e_2 = L_2 \frac{di}{dt} + M \frac{di}{dt}$$

$$e = L_{eq} \frac{di}{dt} = e_1 + e_2 = (L_1 + L_2 + 2M) \frac{di}{dt}$$

$$L_{eq} = L_1 + L_2 + 2M$$

# Coupled coils in Series - Opposing




$$e_1 = L_1 \frac{di}{dt} - M \frac{di}{dt}$$

$$e_2 = L_2 \frac{di}{dt} - M \frac{di}{dt}$$

$$e = L_{eq} \frac{di}{dt} = e_1 + e_2 = (L_1 + L_2 - 2M) \frac{di}{dt}$$

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

# Example 1

For the circuit shown in the figure: L1 = 0.3 H, L2 = 0.2 H & k = 0.8

If the switch is closed at t = 0, find

a) Initial value of current in the circuit
b) Final value of current in the circuit
c) Time constant of the circuit