BRAIN MAP

ELECTROMAGNETIC INDUCTION

Michael Faraday

A magnetic field can produce an electric field that can drive a current. This link between a magnetic field and the electric field is now known as Faraday's law of induction. The observations by Michael Faraday and other scientists which led to this law were at first just basic science. Today, however, applications of this basic science is everywhere.

MAGNETIC FLUX AND FARADAY'S LAW

- Magnetic flux $\phi_B = \vec{B}\cdot\vec{A} = BA\cos\theta$
- Faraday's Laws : It states that whenever magnetic flux linked with a coil changes, an emf is induced in the coil.

Induced emf, $\varepsilon = -N\dfrac{d\phi_B}{dt}$

Induced current, $I = \dfrac{\varepsilon}{R} = N\dfrac{(-d\phi_B/dt)}{R}$

Induced charge flow, $\Delta Q = I\Delta t = -N\dfrac{\Delta\phi_B}{R}$

- The polarity of induced emf is such that it tends to produce a current which opposes the change in magnetic flux that has produced it.

A wire moving in B produces emf

Motional emf

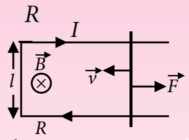
- On a straight conducting wire, $\varepsilon = Bvl$
- On a rotating conducting wire about one end $\varepsilon = \dfrac{B\omega l^2}{2}$

Here, $\vec{B}, \vec{v}(=\omega r\hat{v})$ and $\vec{l}$ are perpendicular to each other.

Quantitative idea behind motional emf

Energy Consideration in Motional emf

- Emf in the wire = Bvl
- Induced current, $I = \dfrac{\varepsilon}{R} = \dfrac{Bvl}{R}$
- Force exerted on the wire, $F = \dfrac{B^2l^2v}{R}$



- Power required to move the wire $P = \dfrac{B^2l^2v^2}{R}$

It is dissipated as Joule heat.

Special features of induced electric field

Induced Electric Field

- It is produced by change in magnetic field in a region. This is non-conservative in nature.

$$\oint \vec{E}\cdot d\vec{l} = -\frac{d\phi_B}{dt} = -A\frac{dB}{dt} \neq 0$$

- This is also known as integral form of Faraday's law.

Change in flux produces eddy current in a conducting plate

Eddy Current

- The currents induced in surface of bulk pieces of conductors when the magnetic flux linked with the conductor changes are known as Eddy currents. Slotting the conductor reduces the eddy current.
- Applications : Electromagnetic damping, Induction furnace, Electric power meter, Magnetic braking in trains.

Direction of induced emf/current is given by Lenz's law

Lenz's Law

- The direction of the induced current is such that it opposes the change that has induced it.
- If a current is induced by an increasing(decreasing) flux, it will weaken (strengthen) the original flux.
- It is a consequence of the law of conservation of energy.

Rotation of coil in B produces motional emf

Electric Generator

- Mechanical energy is converted into electrical energy by virtue of electromagnetic induction.
- Induced emf, $\varepsilon = NAB\omega \sin\omega t = \varepsilon_0 \sin\omega t$
- Current, $I = \dfrac{NBA\omega}{R}\sin\omega t = I_0 \sin\omega t$

Rate of change of current in the coil induces emf

Magnetic Energy

- Energy stored in an inductor $U_B = \dfrac{1}{2}LI^2$
- Energy stored in the solenoid, $U_B = \dfrac{1}{2\mu_0}B^2Al$
- Magnetic energy density, $u_B = \dfrac{U_B}{V} = \dfrac{B^2}{2\mu_0}$

Energy stored in the inductor (magnetic field)

Inductance

- Emf induced in the coil/conductor, $\varepsilon = -L\dfrac{dI}{dt}$
- Coefficient of self induction

$$L = \frac{N}{I}\phi_B = \frac{-\varepsilon}{dI/dt}$$

- Self inductance of a coil $L = \dfrac{1}{2}\mu_0\pi N^2 R$
- Self inductance of a long solenoid $L = \mu_0\mu_r n^2 Al = \dfrac{\mu_0\mu_r N^2 A}{l}$
- Mutual inductance, $M = \dfrac{N_2\phi_2}{I_1} = \dfrac{-\varepsilon_2}{(dI_1/dt)} = \dfrac{-\varepsilon_1}{(dI_2/dt)}$
- Mutual inductance of two closely wound circular coils, $M \propto N_1N_2$
- Mutual inductance of two long coaxial solenoids

$$M = \mu_0\mu_r\pi r_1^2 n_1 n_2 l = \frac{\mu_0\mu_r N_1N_2A_1}{l}$$

- Coefficient of coupling, $k = \dfrac{M}{\sqrt{L_1L_2}}$

For perfect coupling, $k = 1$ so, $M = \sqrt{L_1L_2}$

Required inductance can be achieved by

Combination of Inductors

- Inductors in series, $L_S = L_1 + L_2 \pm 2M$
- Inductors in parallel, $L_P = \dfrac{L_1L_2 - M^2}{L_1 + L_2 + 2M}$
- If coils are far away, then $M = 0$

So, $L_S = L_1 + L_2$ and $L_P = \dfrac{L_1L_2}{L_1 + L_2}$

Growth/decay of current in an inductor

L – R Circuit

- Current growth in L–R circuit $I = I_0(1 - e^{-t/\tau_L})$
- Current decay in L–R circuit

$I = I_0(e^{-t/\tau_L})$

Here, τ_L = Time constant = $\dfrac{L}{R}$

$I_0 = \dfrac{\varepsilon}{R}$