ELECTROMAGNETIC INDUCTION

INDUCTANCE

SELF INDUCTION

- Self-inductance is a phenomenon that occurs when an electromotive force (emf) is induced in a coil or circuit due to a change in its own current. This self-induced emf is proportional to the current and is quantified by a property called inductance (L). Let's delve into the details:

Total Flux and Inductance:

- The total magnetic flux ($N\Phi$) passing through a coil due to its own current is directly related to the current and can be expressed as $N\Phi = Li$. Here, 'L' is known as the coefficient of self-inductance or inductance.

- Inductance, represented by 'L,' is solely a geometric property of the coil. This means that we can determine the inductance value based on the shape, size, and number of turns of the coil, even if it is not connected within a circuit.

- In summary, inductance depends on the coil's geometric characteristics and is not influenced by the current passing through it.

Emf Induced Due to Current Change:

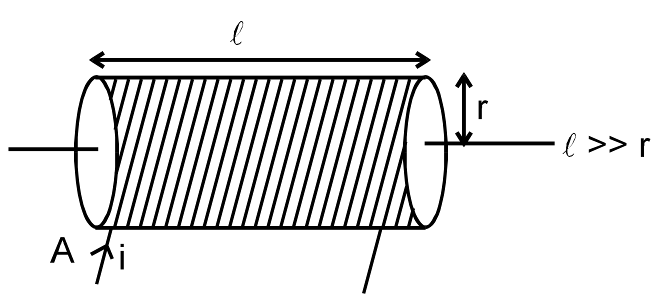
- When the current in the coil changes by ΔI within a time interval Δt, the average emf induced in the coil can be calculated using the formula: $\varepsilon = \Delta\Phi/\Delta t$.

- The instantaneous emf can also be expressed as $\varepsilon = d\Phi/dt$.

- The SI unit of inductance is the Weber per Ampere, also known as Henry (H).

- It's important to note that self-inductance, represented by 'L,' is a positive scalar quantity that depends on the geometry of the coil and the medium in which it is placed. Notably, it does not depend on the current passing through the coil.

SELF INDUCTANCE OF A SOLENOID:



- For a solenoid, we can calculate the self-inductance as follows:

- Let the volume of the solenoid be 'V' and the number of turns per unit length be 'n.'

- If a current 'I' flows through the solenoid, the magnetic field within the solenoid can be expressed as $B = \mu_0 ni$.

- The magnetic flux through one turn of the solenoid, $\Phi = \mu_0 niA$.

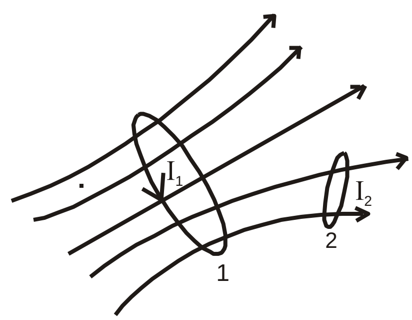
- The total magnetic flux through the solenoid, $N\Phi$, can be determined as $N\Phi = N\mu_0 niA = \mu_0 n^2 iA\lambda$.

- Thus, the self-inductance 'L' is found to be $L = \mu_0 n^2 V$, where 'V' represents the volume of the solenoid.

- The inductance per unit volume is $\mu_0 n^2$.

MUTUAL INDUCTANCE:

- Mutual inductance describes the interaction between two separate circuits. When a current flows in one circuit, it induces a magnetic field that affects the other circuit, leading to mutual induction. Mutual inductance is denoted as M.



- M21 represents the mutual inductance of circuit 2 with respect to circuit 1, while M12 is the mutual inductance of circuit 1 with respect to circuit 2. According to the Reciprocity Theorem, M21 is equal to M12.

- Mutual inductance is a geometric property, depending on factors such as the size, number of turns, relative position, and orientation of the two circuits.

- The SI unit of mutual inductance is the Henry (H), which is equivalent to a volt-second per ampere.

- If the current in one circuit changes by ΔI1 within a time interval Δt, it leads to a change in the magnetic flux linking the other circuit, resulting in an emf being induced in the second circuit. This emf can be represented as $\varepsilon = M\Delta I1$.

- Similarly, if the current in the second circuit changes by ΔI2 in a time interval Δt, an emf is induced in the first circuit, which can be expressed as $\varepsilon = M\Delta I2$.

- Notably, there is no direct physical connection between the two circuits; their interaction is solely due to the magnetic fields generated by their currents.

Example.

In summary, self-inductance involves the induction of emf in a circuit due to changes in its own current, which is quantified by inductance (L). Solenoids have their own self-inductance properties. Mutual inductance, on the other hand, describes the interaction between separate circuits and is quantified by the mutual inductance constant (M). Both self-inductance and mutual inductance are geometric properties dependent on factors like size, number of turns, and relative positioning.

Solution.

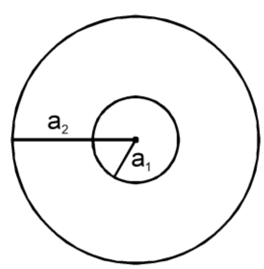
If a current I1 flows around the first wire then a uniform axial magnetic field of strength $B_1 = \frac{\mu_0 N_1 I_1}{\ell}$ is generated in the core. The magnetic field in the region outside the core is of negligible magnitude. The flux linking a single turn of the second wire is B1A. Thus, the flux linking all N2 turns of the second wire is

$$\phi_2 = N_2 B_1 A = \frac{\mu_0 N_1 N_2 A I_1}{\ell} = M I_1 \quad \therefore \quad M = \frac{\mu_0 N_1 N_2 A}{\ell}$$

As described previously, M is a geometric quantity depending on the dimensions of the core and the manner in which the two wires are wound around the core, but not on the actual currents flowing through the wires.

Example.

Determine the mutual inductance between two concentric coils with radii a_1 and a_2, where a_1 is significantly smaller than a_2, and the coils share the same plane.



Solution.

Let a current i flow in coil of radius a_2.

Magnetic field at the center of coil $= \frac{\mu_0 i}{2a_2} \pi a_1^2$

Or $Mi = \frac{\mu_0 i}{2a_2} \pi a_1^2$ or $M = \frac{\mu_0 \pi a_1^2}{2a_2}$