Class notes on Electricity and Magnetism paper (UNIT-II and III)

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0.1 Electromagnetic induction, emf induced in a coil due to magnet...

- **Magnetic flux:** The magnetic flux through any surface placed in a magnetic field is the total number of magnetic lines of force crossing this surface normally. It is measured as the product of the component of the magnetic field normal to the surface and the surface area.

  Magnetic flux is a scalar quantity, denoted by φ or φ_B. If a uniform magnetic field $\vec{B}$ passes normally through a plane surface area A, as shown in Fig. 1 (a), then the magnetic flux through this area is,

$$\varphi = BA \tag{1}$$

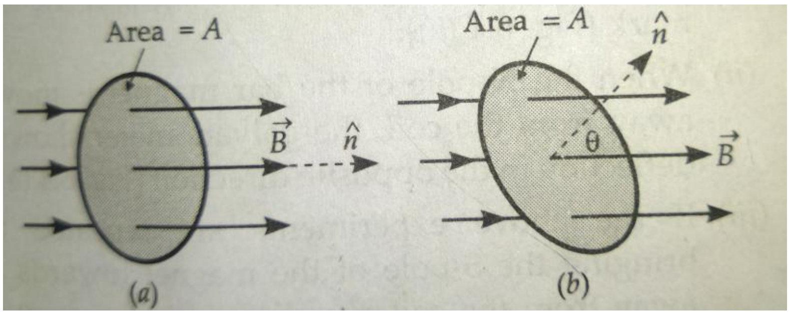

Figure 1: Magnetic flux through an area.

If the field $\vec{B}$ makes angle θ with the normal drawn to the area A, as shown in Fig. 1 (b), then the component of the field normal to this area will be $Bcos\theta$,

$$\begin{aligned} \varphi &= B\,cos\theta \cdot A \\ \Rightarrow \varphi &= BAcos\theta = \vec{B} \cdot \vec{A} \end{aligned} \tag{2}$$

Hence the direction of $\vec{A}$ is the direction of the outward drawn normal to the surface.

The flux through an area which is not uniform can be obtain by integrating,

$$\varphi = \int \vec{B} \cdot d\vec{A} \tag{3}$$

- SI unit of magnetic flux: SI unit of magnetic flux is weber. One weber is the flux produced when a uniform magnetic field of one tesla acts normally over an area of 1 m^2.

$$1weber = 1tesla \times 1metre^2$$
$$1Wb = 1Tm^2 \tag{4}$$

- **Positive and negative flux:** A to a plane can be drawn from either side. If the normal drawn to a plane points out in the direction of the field, then $\theta = 0^\circ$ and the flux is taken as positive. If the normal points in the points in the opposite direction of the field, then $\theta = 180^\circ$ and the flux is taken as negative.

- **Faraday's law of electromagnetic induction**
  Whenever the flux of magnetic field through the area bounded by a closed conducting loop changes, an emf is produced in the loop. The emf is given by,

$$\xi = -\frac{d\Phi}{dt} \tag{5}$$

Where $\Phi = \int \vec{B} \cdot d\vec{A}$ is the flux of the magnetic field through the area. Equation 55 is called Faraday's law of electromagnetic induction.
The negative sign indicates that the direction of the induced emf is such that it opposes the change in magnetic flux.

Lenz's law: Lenz's law states that the direction of induced current in a circuit is such that it opposes the cause or the change which produces it.

- **Self-induction**: When a current is established in a closed conducting loop, it produces a magnetic field. This magnetic field has its flux through the area bounded by the loop. If the current changes with time, the flux through the loop changes and hence an emf is induced in the loop. This process is called self-induction. The name is so chosen because the emf is induced in the loop by changing the current in the same loop. *Definition: the self-induction is the phenomenon of production of induced emf in a coil when a changing current passes through it.*

  The magnetic field at any point due to a current is proportional to the current. The magnetic flux through the area bounded by a current carrying loop is therefore, proportional to the current. We can write,

  $$\Phi = Li \tag{7}$$

  Where L is a constant depending on the geometrical construction of the loop. This constant is called self-inductance of the loop. The induced emf ξ, when the current in the coil changes, is given by,

  $$\xi = -\frac{d\Phi}{dt} \tag{8}$$

  Using Eqs. 7 and 8, we can write,

  $$\xi = -L\frac{di}{dt} \tag{9}$$

- **SI unit of L**: The SI unit of self-inductance L is weber/ampere.

- **Mutual induction:** Mutual inductance is the phenomenon of production of induced emf in one coil due to a change of current in the neighboring coil.

  As shown in Fig. 2, consider two coils P and S placed close to each other. The coil P is connected in series to a battery B and a rheostat Rh through a tapping key K. The coil S is connected to a galvanometer G. When a current flows through coil P, it produces a magnetic field which produces a magnetic flux through coil S. If the current in the coil P is varied, the magnetic flux linked with the coil S changes which induces an emf and hence a current in it, as seen in the galvanometer. The coil P is called the primary coil and the coil S, the secondary coil, because it is the former which causes an induced emf in the latter.

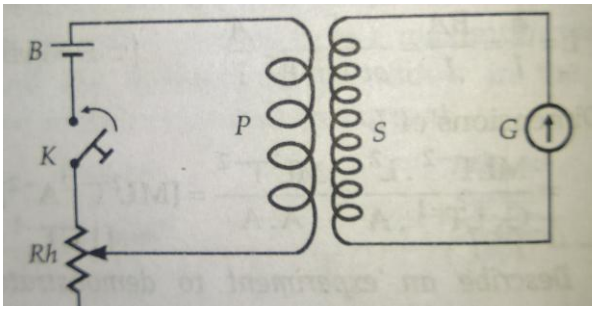

Figure 2: Mutual conductance.

At any instant, magnetic flux linked with the secondary coil is proportional to the current to the primary coil. i.e.,

$$\Phi \propto I$$
$$\Rightarrow \Phi = MI \tag{10}$$

The proportionality constant M is called the mutual inductance or the coefficient of mutual inductance of the two coils. Any change in the current I sets up an induced emf in the secondary coil which is given by,

$$\xi = -\frac{d\Phi}{dt} = -M\frac{dI}{dt} \tag{11}$$

- **Unit of mutual inductance**

$$M = -\frac{\xi}{dI/dt} \tag{12}$$

SI unit of mutual inductance= VsA^{-1}=henry.
The mutual inductance of two coils is said to be 1 henry if an induced emf of one volt is set up in one coil when the current in the neighboring coil changes at a rate of 1 ampere per second.

Eddy currents Currents can be induced, not only in conducting coils but also in conducting sheets or blocks. Whenever the magnetic flux link with a metallic sheets or block changes, an emf is induced in it. The induced currents flow in closed paths in planes perpendicular to the lines of force throughout the body of the metal. These currents looks like eddies or whirl-pools in water and so they are like eddy currents. Therefore, Eddy currents are the currents induced in solid metallic masses when the magnetic flux threading through them changes.

- **Fleming's right hand rule:** This rule gives the direction of induced current set up in a conductor moving perpendicular to a field and can be stated as follow:
If we stretch the thumb and the first two figures of our right hand in mutually perpendicular directions and if the forefinger points in the direction of the magnetic field, thumb in the direction of motion of the conductor; then the central finger points the direction of currents induced in the conductor.

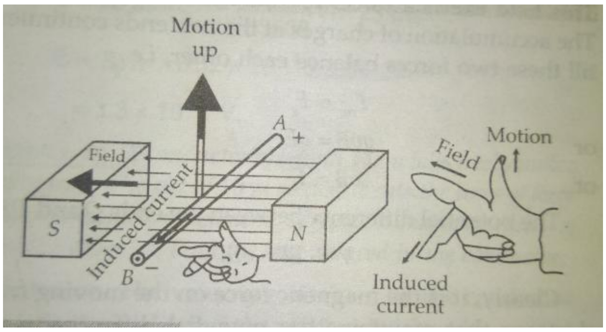

Figure 3: Fleming's right hand rule