Electromagnetic Induction

- The magnetic flux through a surface of area **A** placed in a uniform magnetic field **B** is defined as,

  ΦB = **B**.**A** = BA cos θ

  where θ is the angle between **B** and **A**.

- Faraday's laws of induction imply that the emf induced in a coil of N turns is directly related to the rate of change of flux through it,

  $\varepsilon = -N(d\Phi_B/dt)$

  Here ΦB is the flux linked with one turn of the coil. If the circuit is closed, a current I = ε/R is set up in it, where R is the resistance of the circuit

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- Lenz's law states that the polarity of the induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produces it. The negative sign in the expression for Faraday's law indicates this fact.

- When a metal rod of length l is placed normal to a uniform magnetic field B and moved with a velocity v perpendicular to the field, the induced emf (called motional emf) across its ends is

  $\varepsilon = Bl\,v$

- Changing magnetic fields can set up current loops in nearby metal (any conductor) bodies. They dissipate electrical energy as heat. Such currents are called eddy currents.

- Inductance is the ratio of the flux-linkage to current. It is equal to $N\Phi/I$.

- A changing current in a coil (coil 2) can induce an emf in a nearby coil(coil 1). This relation is given by,

  $\varepsilon_1 = M_{12}(dI_2/dt)$

  The quantity M12 is called mutual inductance of coil 1 with respect to coil 2. One can similarly define M21. There exists a general equality,

  $M_{12} = M_{21}$

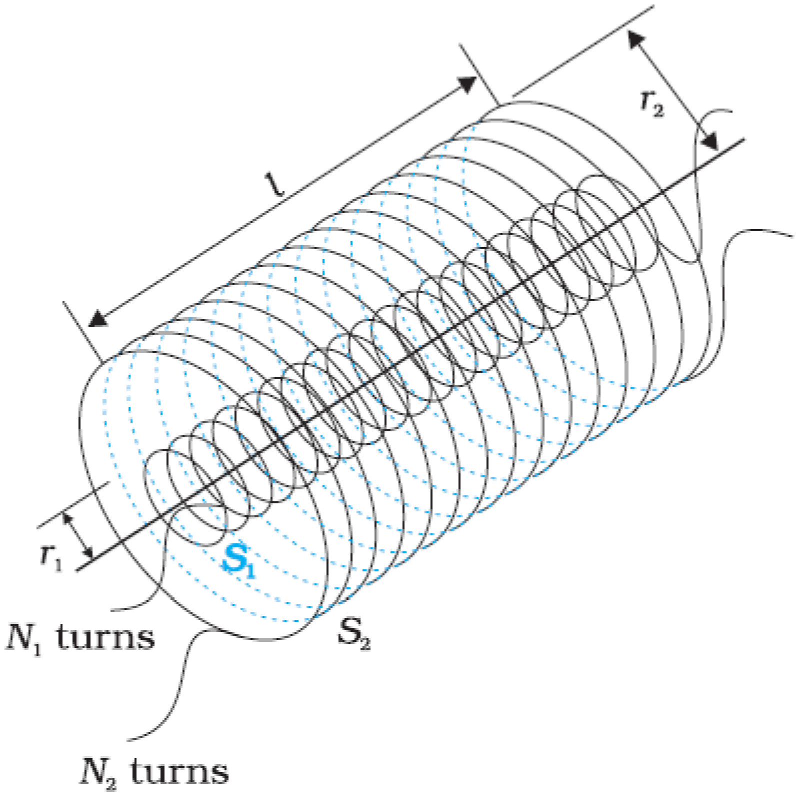
- When a current in a coil changes, it induces a back emf in the same coil. The self-induced emf is given by,

  $\varepsilon = L(dI/dt)$

  L is the self-inductance of the coil. It is a measure of the inertia of thecoil against the change of current through it.

- The self-inductance of a long solenoid, the core of which consists of amagnetic material of permeability μr, is given by

  $L = \mu_r \mu_0 n^2 Al$



where A is the area of cross-section of the solenoid, l its length and nthe number of turns per unit length.

- In an ac generator, mechanical energy is converted to electrical energyby virtue of electromagnetic induction. If coil of N turn and area A isrotated at ν revolutions per second in a uniform magnetic field B, thenthe motional emf produced is

  $\varepsilon = NBA\,(2\pi\nu)\,\sin(2\pi\nu t)$

  where we have assumed that at time t = 0 s, the coil is perpendicular tothe field.

Sample Examples

- A wheel with 10 metallic spokes each 0.5 m long is rotated with a speed of 120 rev/min in a plane normal to the horizontal component of earth's magnetic field HE at a place. If HE = 0.4 G at the place, what is the induced emf between the axle and the rim of the wheel?

  Note that 1 G = 10^{-4} T.

Solution

Induced emf = (1/2) ω B R^2

= (1/2) × 4π × 0.4 × 10–4 × (0.5)2

= 6.28 × 10–5 V

The number of spokes is immaterial because the emf's across the spokes are in parallel.

- A circular coil of radius 10 cm, 500 turns and resistance 2 Ω is placedwith its plane perpendicular to the horizontal component of the earth'smagnetic field. It is rotated about its vertical diameter through 180°in 0.25 s. Estimate the magnitudes of the emf and current induced inthe coil. Horizontal component of the earth's magnetic field at theplace is 3.0×10^{-5} T.

Solution

Initial flux through the coil,

Φ_B (initial) = BA cos θ

$= 3.0 \times 10^{-5} \times (\pi \times 10^{-2}) \times \cos 0^{\circ}$

$= 3\pi \times 10^{-7}$ Wb

Final flux after the rotation,

Φ_B (final) $= 3.0 \times 10^{-5} \times (\pi \times 10^{-2}) \times \cos 180^{\circ}$

$= -3\pi \times 10^{-7}$ Wb

Therefore, estimated value of the induced emf is,

$\varepsilon = N (\Delta\Phi / \Delta t)$

$= 500 \times (6\pi \times 10^{-7})/0.25$

$= 3.8 \times 10^{-3}$ V

$I = \varepsilon/R = 1.9 \times 10^{-3}$ A

Note that the magnitudes of ε and *I* are the estimated values. Their instantaneous values are different and depend upon the speed ofrotation at the particular instant.