University of Calcutta

Semester 2

PHYSICS

Paper: PHS-G-CC-2-2-TH (NEW SYLLABUS)

ELECTROMAGNETIC INDUCTION

SOLVED PROBLEMS

ASSIGNMENTS

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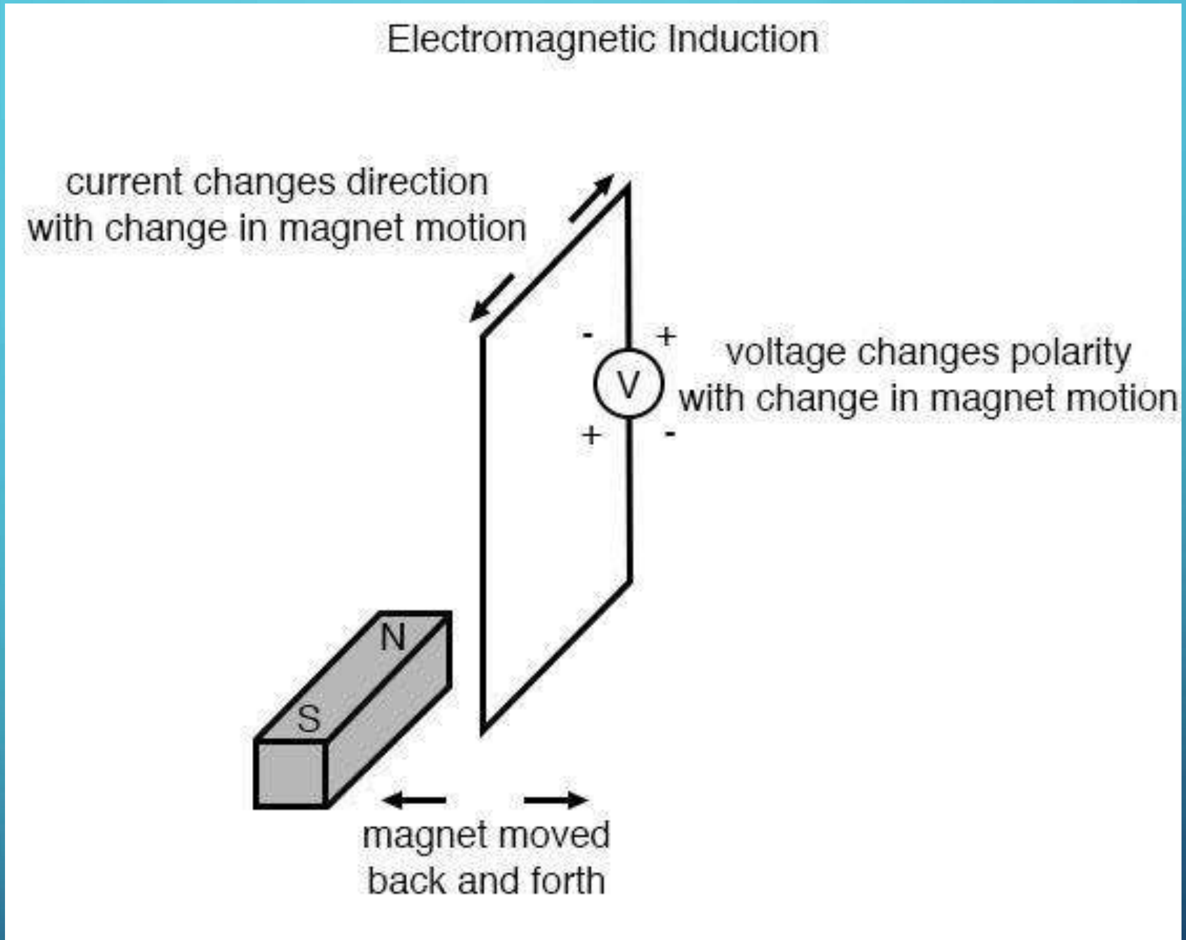
BASIC CONCEPT OF ELECTROMAGNETIC INDUCTION



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EXAMPLE OF ELECTROMAGNETIC INDUCTION

Suppose while shopping you go cashless and your parents use cards. The shopkeeper always scans or swipes the card. Shopkeeper does not take a photo of the card or tap it. Why does he swipe/scan it? And how does this swiping deduct money from the card? This happens because of the '**Electromagnetic Induction**'.

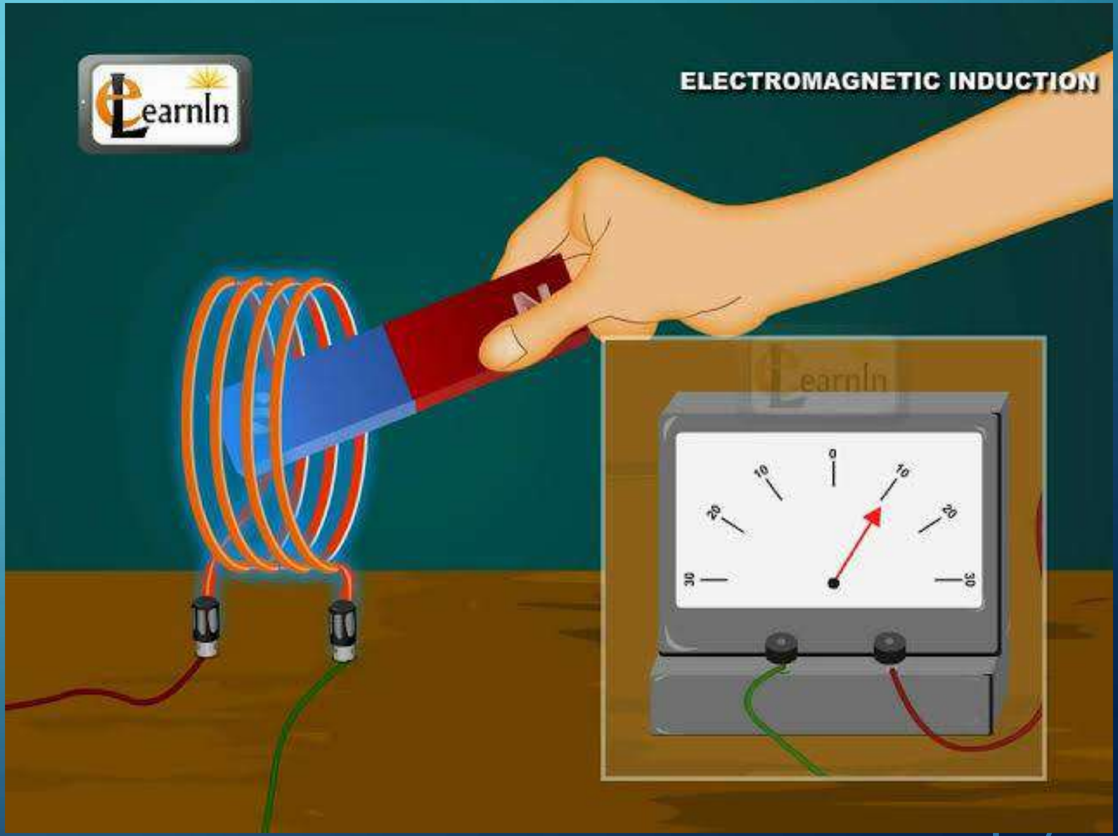
FARADAY'S LAWS

FIRST LAW

First Law of Faraday's Electromagnetic Induction state that whenever a conductor are placed in a varying magnetic field emf are induced which is called induced emf, if the conductor circuit are closed current are also induced which is called induced current.

Or

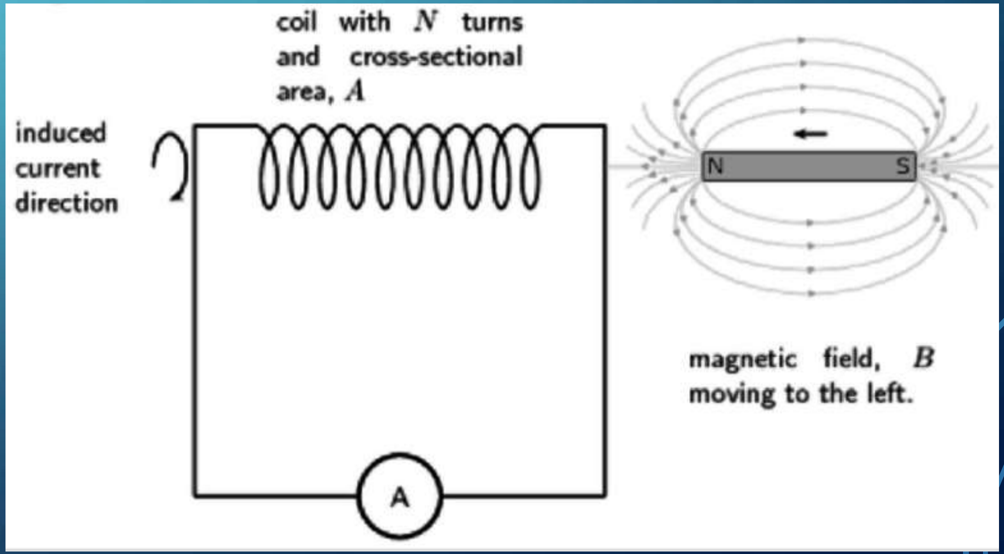
Whenever a conductor is rotated in magnetic field emf is induced which are induced emf.



FARADAY'S LAW

SECOND LAW

Second Law of Faraday's Electromagnetic Induction state that the induced emf is equal to the rate of change of flux linkages (flux linkages is the product of turns, n of the coil and the flux associated with it).



EXPLANATION

Initial flux linkages = $N\varphi1$

Final flux linkages = $N\varphi2$

Change in flux linkages= $N\varphi2 - N\varphi1$

$$= N((\varphi2-\varphi1)$$

If $(\varphi2-\varphi1) = \varphi$

Then change in flux linkages = $N\varphi$

Rate of change of flux linkages = $N\varphi/t$ wb/sec

Taking derivative of right hand side we get

Rate of change of flux linkages = $Nd\varphi/dt$ wb/sec

Rut according to Faraday's laws of electromagnetic induction, the rate of change of flux linkages equal to the induced emf, hence we can write

$$= Nd\varphi/dt \text{ volt}$$

Generally Faraday's laws is written as

$$e = -Nd\varphi/dt \text{ volt}$$

SIGNIFICANCE OF NEGATIVE SIGN

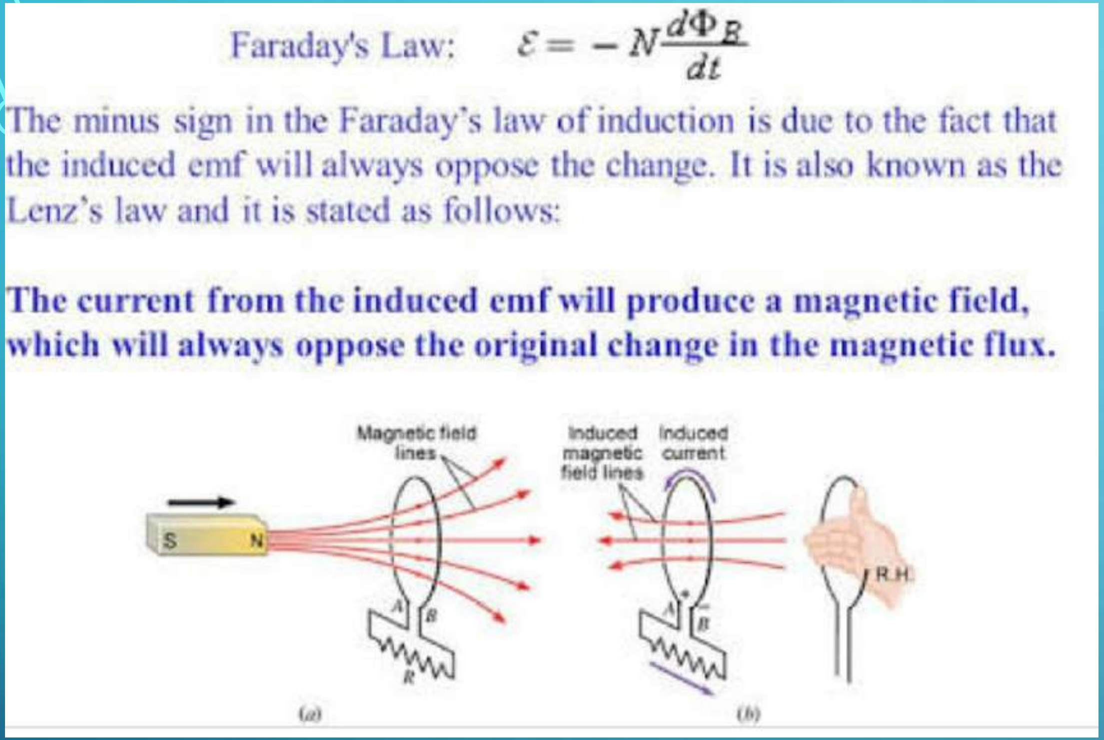
Where negative sign represents the direction of the induced current in the conductor will be such that the magnetic field produced by it will oppose the verb cause produce it.

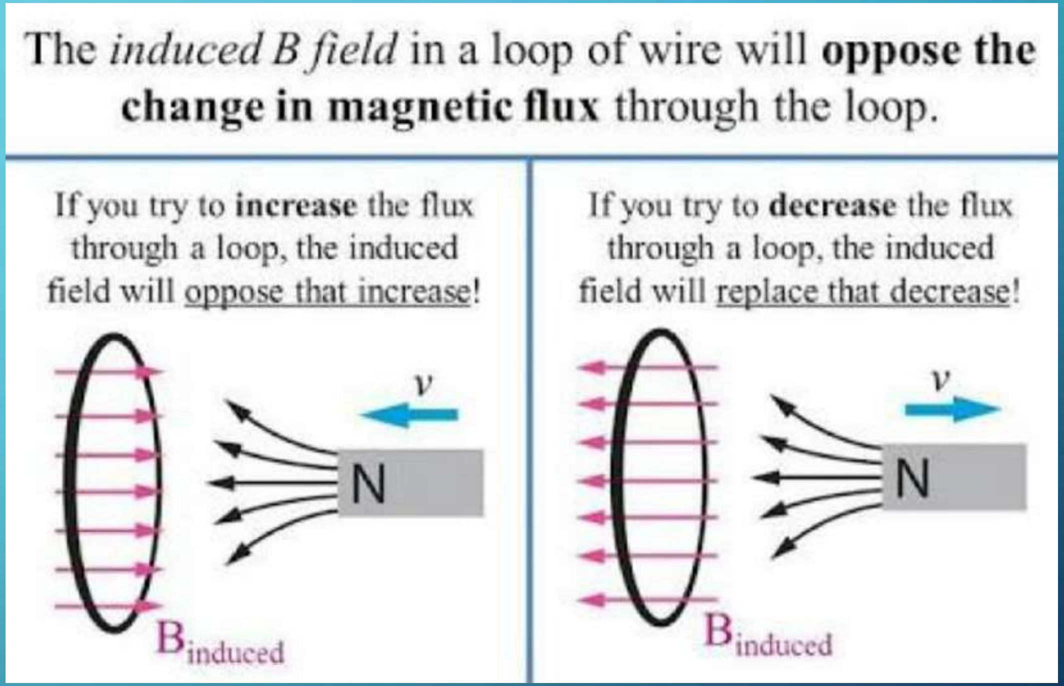
EXPLANATION

https://youtu.be/3HyORmBip-w

https://youtu.be/dm6iAts7cTM

LENZ’S LAW



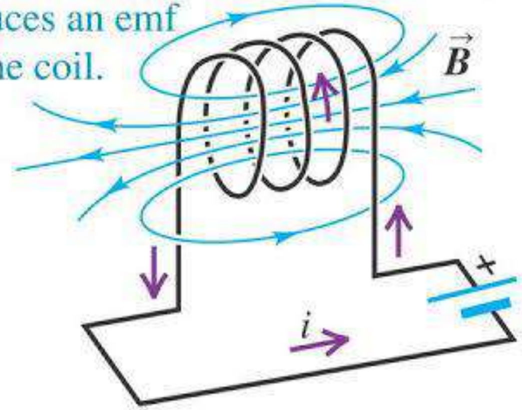


https://youtu.be/2_M83gNOOEg

SELF INDUCTANCE

Self-inductance

Self-inductance: If the current i in the coil is changing, the changing flux through the coil induces an emf in the coil.



$$\varepsilon = -N\frac{d\Phi}{dt},\; N\Phi = Li$$

$$\varepsilon = -L\frac{di}{dt},\; L = \frac{N\Phi}{i}$$

Self-inductance

- The self-induced emf ε_L is always proportional to the time rate of change of the current. (The emf is proportional to the flux change, which is proportional to the field change, which is proportional to the current change)

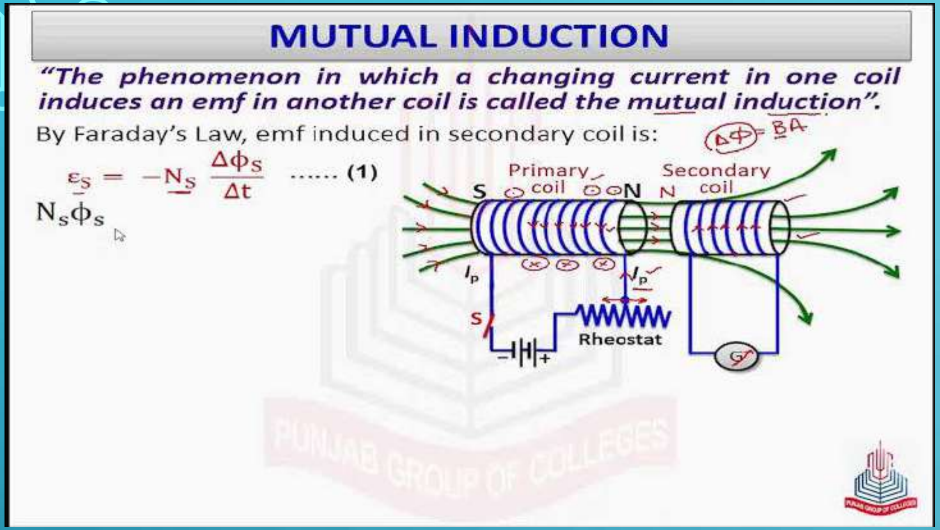
$$\varepsilon_L = -L\frac{dI}{dt}$$

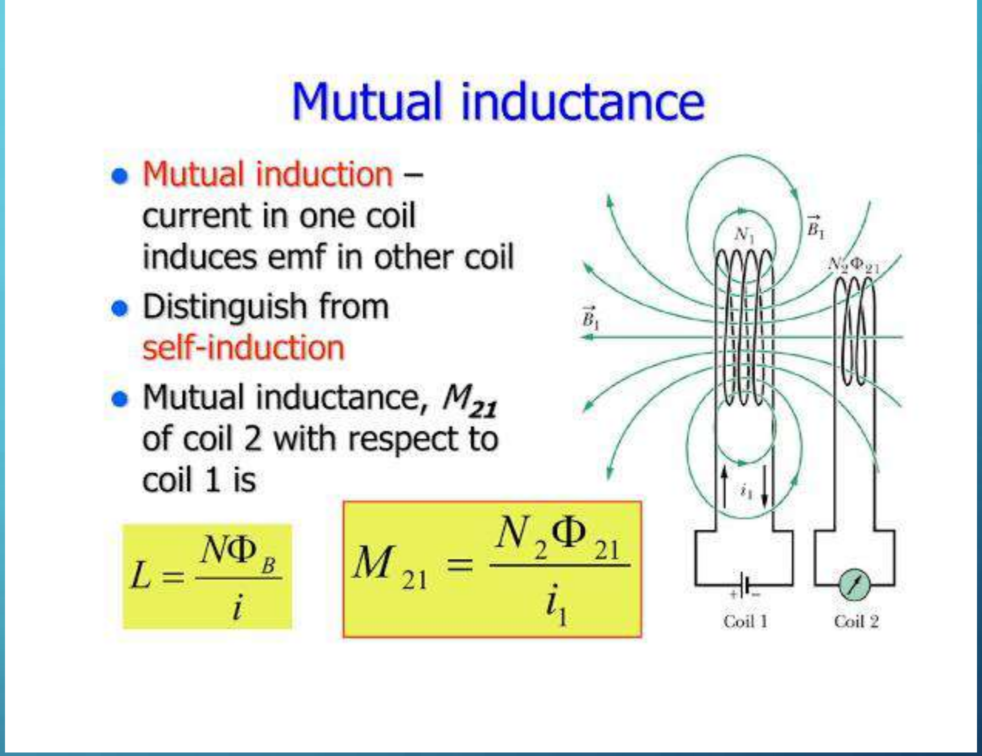
- L: inductance of a coil (depends on geometric factors)
- The negative sign indicates that a changing current induces an emf in opposition to that change
- The SI unit of self-inductance: Henry
- 1 H = 1 (V · s) / A

Joseph Henry
1797 – 1878

https://youtu.be/xl0xkQ3C5Sg

MUTIAL INDUCTANCE





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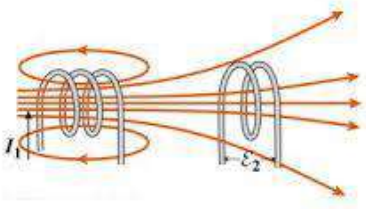
27.4. Inductance

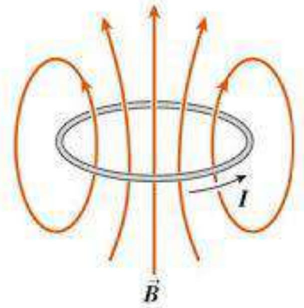
Inductance:



Mutual Inductance:
Changing current in one circuit induces an emf in the other.

Large inductance:
two coils are wound on same iron core.

Applications:
Transformers, ignition coil, battery chargers, …

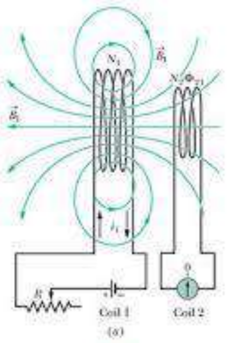


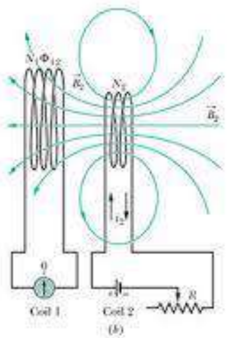
Self-Inductance:
Changing current induces emf in own circuit & opposes further changes.

Applications:
Inductors → frequency generator / detector …

$\Phi_B = L_{self}\, I$ [L] = T · m² / A = Henry

Mutual Induction





The mutual inductance M_{21} of coil 2 with respect to coil 1 as

$$M_{21} = \frac{N_2\Phi_{21}}{i_1}$$

Φ_{21} Is a magnetic flux through coil 2 associated with the current in coil 1

$$M_{21}i_1 = N_2\Phi_{21}.$$

$$M_{21}\frac{di_1}{dt} = N_2\frac{d\Phi_{21}}{dt}.$$

$$\varepsilon_2 = -\frac{d\phi_{21}}{dt}$$

$$\mathcal{E}_2 = -M_{21}\frac{di_1}{dt},$$

$$\mathcal{E}_1 = -M_{21}\frac{di_2}{dt}.$$

$$M_{21} = M_{12} = M,$$

$$\mathcal{E}_1 = -M\frac{di_2}{dt}.$$

$$\mathcal{E}_2 = -M\frac{di_1}{dt}$$

https://youtu.be/1TA_n8sVa9E

SOLVED PROBLEM-1

1. (a) *Determine the e.m.f. developed between the terminals of a straight conductor of length l moving with a constant velocity $\vec{v}$ at right angles to a uniform magnetic field $\vec{B}$.*

(cf. C.U. 1978)

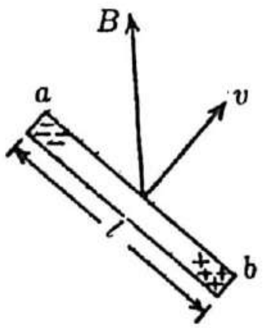


Fig.10.12. Figure for Problem 1

(b) *An aeroplane is moving due north with a velocity of 450 km per hour. Find the potential difference in volt between the ends of its wings, distant 35 meter from each other. Given, the earth's magnetic intensity is 0.35 Oe.*

Ans. (a) Each electron inside the conductor will experience a Lorentz force $-e\vec{v} \times \vec{B}$, $-e$ being the charge on an electron. The free electrons will, as a result, be deflected towards the end a of the conductor. There will be a charge separation leading to the development of an electric field $\vec{E}$ from the end b to the end a. In the steady state,

$$-e\vec{E} - e\vec{v} \times \vec{B} = \vec{0} \quad \text{or,} \quad \vec{E} = -\vec{v} \times \vec{B}.$$

The total e.m.f. induced in the conductor is

$$\mathcal{E} = |E|l = vBl.$$

(b) The induced e.m.f. is

$$\mathcal{E} = vBl,$$

where v = velocity = 450 km/hour = $\frac{450 \times 10^3}{3600}$ m/s, B = magnetic induction = $\mu_0 H = 4\pi \times 10^{-7} \times 0.35/(4\pi \times 10^{-3}) = 0.35 \times 10^{-4}$ tesla, and l = distance between the wings = 35 m. Therefore,

$$\mathcal{E} = \frac{450 \times 10^3}{3600} \times 0.35 \times 10^{-4} \times 35 = 0.153 \text{ volt}.$$

SOLVED PROBLEM-2

5. *A coil of self-inductance 100 mH is connected in series with another coil of self-inductance 169 mH. The effective inductance of the combination is found to be 70 mH. Determine the coefficient of coupling.*

Ans. Since the given effective inductance is less than the sum of the self-inductances of the two coils, the mutual flux must oppose the self-inductance fluxes. Therefore we can write for the effective inductance

$$L_{eff} = L_1 + L_2 - 2M.$$

Given, $L_1 = 100$ mH $L_2 = 169$ mH, and $L_{eff} = 70$ mH.

Therefore, $$M = \frac{L_1 + L_2 - L_{eff}}{2} = 99.5 \text{ mH}.$$

The coefficient of coupling is

$$k = \frac{M}{\sqrt{L_1 L_2}} = \frac{99.5}{\sqrt{100 \times 169}} = 0.765.$$

ASSIGNMENTS

1. (a) State the laws of electromagnetic induction. Calculate the self-inductance of a uniformly wound solenoid. (C.U. 1982)

(b) State Faraday's law of induction and express it in differential form. (C.U. 1989)

2. (a) What do you understand by 'self' and 'mutual' inductances ? Find an expression for the mutual inductance between the primary and the secondary of a standard solenoid. (C.U. 1987)

2. A metallic disc of radius 12 cm rotates at the rate of 1500 r.p.m. A uniform magnetic field of 30 gauss is applied perpendicular to the plane of the disc. Determine the e.m.f. induced between the centre and the edge of the disc. [Ans. 3.39 mV]

5. An air-cored solenoid of length 1 m and diameter 1 cm has 20 number of turns per cm. Calculate its self inductance. If a current I ampere varying with time t as $I = te^{-t}$ passes through the solenoid, calculate the induced e.m.f. in the solenoid at $t = 1$ s.

[**Ans.** 0.395 mH, 0]

ACKNOWLEDGEMENT

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