Electromagnetic Induction

CHAPTER 6

EXAM DRILL

ANSWERS

1. (d) : Magnetic flux linked with a coil

$\phi = NBA\cos\theta$

Since, the magnetic field B is parallel to the area A,

i.e., $\theta = 90°$ ($\because$ Area vector is normal to the plane.)

$\therefore \quad \phi = 0$

2. (d) : Here, magnetic flux, $\phi = 3t^2 - 5t + 1$;

Resistance, $R = 10\ \Omega$

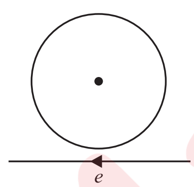
The induced emf is

$$\varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(3t^2 - 5t + 1) = -(6t - 5)$$

At $t = 0.253$ s, $\varepsilon = -(6 \times 0.253 - 5) = 3.482\ \text{V} \approx 3.5\ \text{V}$

$\therefore$ Induced current, $I = \frac{\varepsilon}{R} = \frac{3.5}{10} = 0.35\ \text{A}$

3. (a) : When an electron is moving from right to left, the flux linked with loop (which is going into the page) will first increase and then decrease as the electron passes by. So the induced current in the loop will be first clockwise and will change direction (*i.e.* will become anticlockwise) as the electron passes by.



4. (a) : Emf induced in the loop, $\varepsilon = BA\omega\cos\theta$

where θ is the angle between $\vec{B}$ and $\vec{A}$.

$|\varepsilon_{max}| = BA\omega$ for $\theta = 0°$ or $180°$

$\therefore$ The magnitude of induced emf in the loop is maximum when the plane of the loop is perpendicular to $\vec{B}$.

5. (c) : Reactance of inductor coil is $X_L \propto L$

$\therefore$ When divided in four equal parts, inductance of each part is $L/4$.

According to question, these four inductor coils are connected in parallel combination.

$$\Rightarrow \frac{1}{L'} = \frac{4}{L} + \frac{4}{L} + \frac{4}{L} + \frac{4}{L} = \frac{16}{L}$$

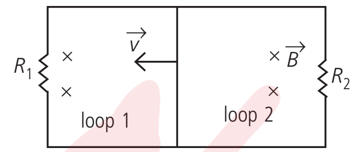
$$\therefore L' = \frac{L}{16}$$

6. (c) : The mutual inductance of the system is

$M = \mu_0 n_1 n_2 \pi a^2 L$

7. (b) : As the magnet moves towards the coil, the magnetic flux increases, also there is a change in polarity of induced emf when the magnet passes on the other side of the coil.

8. (c) : An external agent pulls the bar, area of loop 1, decreases and that of loop 2 increases. Magnetic flux decreases in loop 1 and increases in loop 2. As a result magnetic field should be increase in loop 1 and decrease in loop 2. So the induced current I_1, should be clockwise and I_2, anticlockwise.



9. (a) : Mutual inductance is the phenomenon according to which an opposing e.m.f. produce flux in a coil as a result of change in current or magnetic flux linked with a neighbouring coil. But when two coils are inductively coupled, in addition to induced e.m.f. produced due to mutual induction, also induced e.m.f. is produced in each of the two coils due to self-induction.

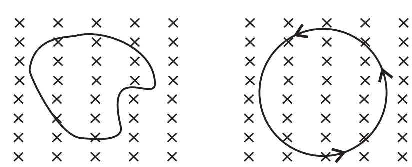
10. (a) : An induced current develop in a conductor cannot moved in a direction parallel to magnetic field. This is because when the conductor moved in a direction parallel to magnetic field, amount of flux linked with the conductor does not change. Thus the induced current develops only when conductor cuts the lines of magnetic force. The direction of flow of induced current can also be found by applying Fleming's right hand rule, when the direction of motion of conductor inside the magnetic field and the direction of magnetic field acting on it are known.

11. (c) : Induced current (emf) in a coil is directly proportional to the rate of change of magnetic flux linked with the coil. If there is no change in the flux, there is no induced current also.

12. (i) (d) : Lenz's law is a consequence of the law of conservation of energy.

(ii) (a) : Due to change in the shape of the loop, the magnetic flux linked with the loop increases. Hence, current is induced in the loop in such a direction that it opposes the increases in flux. Therefore, induced current flows in the anticlockwise direction.

(iii) (c) :



13. When see from the side of magnet, the induced current flows anticlockwise in the loop. The face of the loop towards the magnet developed north polarity and gets repelled away from the magnet.

14. As the loops are brought closer, the magnetic flux linked with them increases. An emf is induced in each loop opposes the change in flux, so current in each loop decreases.

15. As self inductance, $L = \frac{\phi}{I}$ = slope of the graph.

According to the question, slope for A is greater than slope for B.

$\therefore$ Inductor A has larger value of self inductance.

OR

The mutual inductance of the two coil is said to be 1 henry, if an induced emf of 1 volt is set up in one coil when the current in the other coil changes at the rate of 1 ampere per second.

16. When the circuit is switched off, induced current is in the same direction as the main current.

17. (i) By Lenz's law, the end of the coil closer to magnet develops s-polarity. The current induced in the coil flows clockwise when seen from the side of magnet.

Hence induced current flows from Y to X.

(ii) Similarly, according to Lenz's law, the ends of both the coil closer to the magnet develops s-polarity.

Therefore, in left coil, current flows from Y_1 to X_1 and in right coil current flows from Y_2 to X_2.

18. A moving conductor is equivalent to a battery of induced emf, $\varepsilon = Blv$

Here, total resistance $R_{eq} = R + \left(\frac{R \times R}{R+R}\right) = \frac{3R}{2}$

$\therefore\ i = \frac{\varepsilon}{R_{eq}} = \frac{2\varepsilon}{3R}$ or $i = \frac{2Blv}{3R}$

$\therefore\ i_1 = i_2 = \frac{i}{2} = \frac{Blv}{3R}$

19. Given, $B = B_0 \sin\omega t$

$\therefore\ \phi = NBA = NAB_0 \sin\omega t$

So, $\varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(NAB_0 \sin\omega t)$

or, $\varepsilon = -NA\omega B_0 \cos\omega t$

20.

	Self induction		Mutual induction
1.	Self inductance is the phenomenon by which the coil induces an emf by itself.	1.	Mutual inductance is the phenomenon when a coil induces an emf in itself due to another coil.
2.	It occurs in a single coil.	2.	It takes place in two coils.
3.	Basic circuit element is inductor.	3.	Circuit may contains inductor, as well as resistor and capacitor.

21. As $\varepsilon = Blv$

Here, two emfs are additive due to the relative velocity of each other.

So, $\varepsilon_{net} = 2Blv$

OR

When a current flows through a galvanometer, its coil suffers few oscillations before coming to rest in the final position. As the coil moves in the magnetic field, current is induced in the coil which opposes its motion and the oscillations occur in the coil. The oscillations of the coils are damped, called electromagnetic damping.

22. Here, motional emf $= B_1lv - B_2lv$

or, $\varepsilon = \frac{\mu_0 i}{2\pi\left(x - \frac{a}{2}\right)} \times lv - \frac{\mu_0 i}{2\pi\left(x + \frac{a}{2}\right)} \times lv$

or, $\varepsilon = \frac{\mu_0 ilv}{2\pi}\left[\frac{1}{\left(x - \frac{a}{2}\right)} - \frac{1}{\left(x + \frac{a}{2}\right)}\right]$

or, $\varepsilon = \frac{\mu_0 ilv}{\pi}\left[\frac{2x + a - 2x + a}{(2x - a)(2x + a)}\right]$ or, $\varepsilon = \frac{2\mu_0 ilva}{\pi}\left[\frac{1}{(4a^2 - x^2)}\right]$

23. (i) At any instant, the magnetic flux linked with a coil is proportional to the current flows through it.

$\phi \propto i$ or $\phi = Li$

where, L is the proportionality constant called coefficient of self inductance or coefficient of self induction.

$\therefore\ L = \phi/i$

(ii) The equivalent inductance is given by

$L = L_1 + \left(\frac{L_2 L_3}{L_2 + L_3}\right)$ or $L = 1 + \left[\frac{(0.75)^2}{(0.75 + 0.75)}\right]$

or $L = 1 + \frac{0.56}{1.5} = 1.37\,\text{H}$

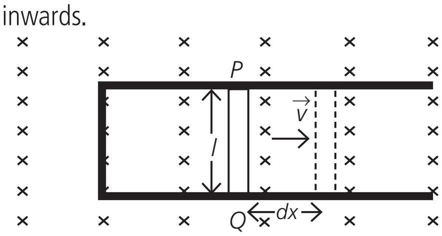
24. (i) Bulb lights up due to the induced current set up in the coil B due to alternating current in coil A.

(ii) Bulb gets dimmer when the coil B is moved upwards because the flux linked with coil B decreases and induced current also decreases.

(iii) When the copper sheet is inserted, eddy currents are set up in it, opposes the passage of magnetic flux. The induced emf in coil B decreases due to this brightness of the bulb decreases.

OR

This is based on Faraday's law. Let us consider a rod of length l moving with a uniform velocity $\vec{v}$ on two parallel imaginary conducting rails in the presence of uniform magnetic field which is directed inwards.



Let us consider in time dt, rod moves through a distance dx.

So, change in area of the loop, $dA = ldx$

$\therefore\ \phi = B \cdot A = BA\cos\theta = BA$ $[\because \theta = 0°]$

So, induced emf, $\varepsilon = \left|\frac{d\phi}{dt}\right|$ or $\varepsilon = B\frac{dA}{dt}$ or $\varepsilon = Bl\frac{dx}{dt}$

or $\varepsilon = Blv$

25. (i) Whenever the electric current passing through a coil or circuit changes, the magnetic flux linked with it will also change, due to this emf is induced in it which opposes the change that causes it. This phenomenon is called self induction.

The self inductance of a coil is said to be one henry if an induced emf of one volt is set up in it when the current in it changes at the rate of one ampere.

(ii) Self inductance of the coil depends upon

(a) the number of turns of the coil

(b) area of cross section of the coil

Similarly, mutual inductance of the coil depends upon

(a) number of turns of the two coils

(b) relative orientation of the two coils

26. (i) If two coils of self inductance L_1 and L_2 having mutual inductance M are connected in parallel and are far from each other, then

$$\frac{1}{L_2}=\frac{1}{L_1}+\frac{1}{L_2} \quad \text{or} \quad L_P=\left(\frac{L_1L_1}{L_1+L_2}\right)$$

When they are closed to each other, then

$$L_P=\frac{L_1L_2-M^2}{L_1+L_2\pm 2M}$$

27. (i) When a metallic rod held horizontally along east-west direction, is allowed to fall under gravity, then there will be an emf induced at its end because the horizontal component of earth's magnetic field is intercepted by it.

(ii) (a) When switch is closed, current in coil P increases, and induced current in the coil S opposes to decrease it. So, current in coil S flows in anticlockwise direction.

(b) When switch is open, current in coil P decreases, and induced current in coils oppose to increase it. So, the direction of current in coil S is in clockwise direction.

28. (i) It states that the direction of induced current is such that it opposes the cause which produces it, *i.e.*, it opposes the change in magnetic flux.

(ii) (a) The instantaneous value of induced emf in the wire is given by

$$\varepsilon = B_H\, l_v$$

where, B_H is the horizontal component of earth's magnetic field.

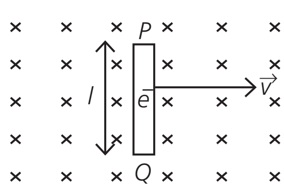
(b) Induced emf will be in the direction from west to east direction.

(c) As induced emf will be in the direction from west to east so that west end of the wire will be at higher potential and east end of the wire will be at lower potential.

29. (i) The emf induced across the ends of a conductor due to its motion in a magnetic field is called motional emf.

(ii) Let us consider a conducting rod of length l moving with a uniform velocity $\vec{v}$. Here velocity $\vec{v}$ is perpendicular to a uniform magnetic field $\vec{B}$ which is directed inwards or into the plane of page. Here, all three components length l, velocity $\vec{v}$ and magnetic field $\vec{B}$ perpendicular to each other.

Let us consider the conducting rod is moving along the right direction as shown in figure.



In this case conducting electrons present in the rod experiences a magnetic force, *i.e.*,

$$F_m = q(\vec{v}\times\vec{B})$$

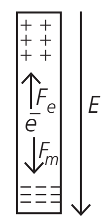
or $F_m = evB\sin\theta$ $\quad [\theta = 90°]$

or $F_m = evB$

After sometime, electrons accumulate at the end of Q-side of the rod, so at the end of P-side of the rod deficiency of electrons occurs. So, end P of the rod becomes positively charged while end Q becomes negatively charged, due to this an electric field is set up within the rod. So, force due to electric field is

$$F_e = qE$$

For electron. $F_e = eE$



With time, the number of electrons accumulate at the bottom and electric field increases, so F_e is also increase.

When $|F_e| = |F_m|$, electrons will be in equilibrium and this equilibrium state is called steady state.

So, $eE = evB$ or $E = vB$

Now, induced emf $= E \times l$

or $\varepsilon = Bvl$

OR

(i) It is the phenomenon of production of induced emf due to change of magnetic flux linked with a closed circuit.

(ii) Given, $N = 200$

$A = 15\text{ cm} \times 40\text{ cm}$

$= (15\times10^{-2})\times(40\times10^{-2}) = 6\times10^{-2}\text{ m}^2$

$B = 0.08\text{ Wb/m}^2$

$\omega = 2\pi f = 2\pi \times 50 = 100\,\pi$ rad/s

So, induced emf at any instance is given by

$$\varepsilon = NBA\,\omega\sin\omega t$$

If the plane of the coil makes an angle θ with the magnetic lines of force, then

$$\omega t = (90° - \theta)$$

So, when $\theta = 0°$, $\omega t = 90°$

$\therefore$ $\varepsilon = NBA\,\omega\sin 90°$

or $\varepsilon = 200\times0.08\times6\times10^{-2}\times100\pi\times1$

$= 301.6$ V

$\cong 301$ volt

When, $\theta = 60°$, $\omega t = (90° - \theta) = (90° - 60°) = 30°$

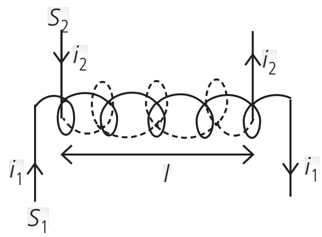
or $\varepsilon = NBA\,\omega\sin 30°$

$$=200\times0.08\times6\times10^{-2}\times100\pi\times\frac{1}{2}\simeq 150\text{ volt}$$

30. (i) The S.I. unit of mutual inductance is henry and denoted by H.

$1\text{ H} = 1\text{ V s A}^{-1}$

(ii) Let us consider two long co-axial solenoid S_1 and S_2 in which S_2 is wound over S_1. Let l be the length of each solenoid, r_1, r_2 be the radii of two solenoids and N_1, N_2 be the number of turns in the solenoids.



When i_2 passes through S_2, the magnetic field is produced inside S_2 due to i_2 which is given by

$$B_2 = \mu_2 n_2 i_2$$

So, total magnetic flux linked with inner solenoid S_1 is

$$\phi_1 = N_1 B_2 A \quad \text{or} \quad \phi_1 = N_1 \mu_0 n_2 i_2 A$$

Therefore, mutual inductance of S_1 with respect to S_2 is

$$M_{12} = \frac{\phi_1}{i_2} = N_1 \mu_0 n_2 A \text{ or } M_{12} = \frac{\mu_0 N_1 N_2 A}{l} \quad [\therefore N_2 = n_2 l]$$

When current i_1 flows through S_1, then

$$B_1 = \mu_0 n_1 i_1$$

Now total magnetic flux linked with the outer solenoid S_2 is given by

$$\phi_2 = B_1 A N_2 = \mu_0 n_1 i_1 A N_2$$

Therefore, mutual inductance on S_2 due to S_1 is

$$M_{21} = \frac{\phi_1}{i_1} = \frac{\mu_0 N_1 N_2 A}{l}$$

So, $M_{12} = M_{21} = M$ (say) $\therefore \; M = \dfrac{\mu_0 N_1 N_2 A}{l}$

OR

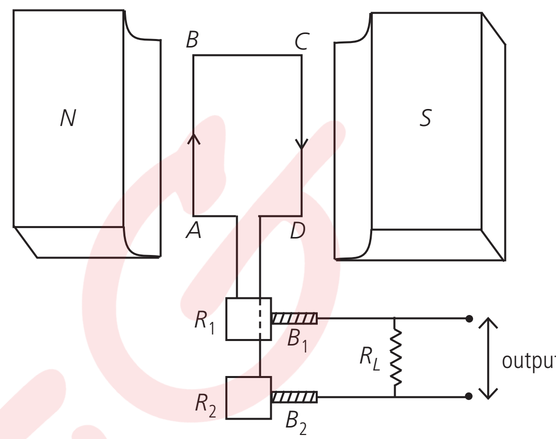
An electrical machine used to convert mechanical energy into electrical energy is known as a.c. generator.

Principle : It works on the principle of electromagnetic induction, *i.e.*, when a coil is rotated in a uniform magnetic field, emf is induced in it.

Construction : A.C. generator can be constructed by armature coil, strong field magnet, slip rings and brushes.

Here, the armature coil (say *ABCD*) consists of a large number of turns of insulated copper wire wound over a soft iron core. The strong permanent magnet or electromagnet are cylindrical in shape acts as a field magnet. In this case the armature coil rotates between the pole of these magnet. The uniform magnetic field is perpendicular to the axis of rotation of the coil.

Here, the two ends of the coil are connected to two slip rings (R_1 and R_2) which also rotate with the coil. Two brushes B_1 and B_2 here are fixed and are connected to the load through which the output is obtained.



Working : When the coil *ABCD* rotates in the strong magnetic field, it cuts the magnetic lines of force, so the magnetic flux linked with the coil changes hence emf is induced in the coil.

The current flows out through the brush B_1 in one direction of half of the revolution and through the Brush B_2 in the next half revolution in reverse direction and this process is repeated.

When the coil rotates with an angular velocity ω by an angle θ with time t, then

$$\theta = \omega t$$

$\therefore$ Magnetic flux, $\phi = BA \cos\omega t$

Now, emf produced in the coil is given by

$$\varepsilon = -\frac{d\phi}{dt} = \frac{-d}{dt}(BA\cos\omega t) \quad \text{or} \quad \varepsilon = BA\omega \sin\omega t$$

If the coil has N turns, then the total induced emf will be

$$\varepsilon = NBA\,\omega \sin\omega t$$

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