ELECTROMAGNETIC INDUCTION

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Electromagnetic Induction

Magnetic flux

The magnetic flux through a small area $d\vec{A}$ placed in a magnetic field $\vec{B}$ is defined as: $d\phi = \vec{B}\cdot d\vec{A} = B(dA\cos\theta)$. The magnetic flux can be positive, negative or zero depending on the angle θ. The magnetic flux is taken as negative if field lines enter the area and positive if field lines leave the area. The SI unit of magnetic flux is weber. The cgs unit is maxwell. (1 weber = 10^8 maxwell). Also 1 weber = 1 Tesla-m^2.

1 If, the field is uniform and the area is plane, then the total magnetic flux through the area $\vec{A}$ is: $\phi = \vec{B}\cdot\vec{A} = BA\cos\theta$

2 The magnetic flux through a curved surface is given by the integral: $\phi = \int \vec{B}\cdot d\vec{A}$

3 The magnetic flux through a closed surface is always zero, i.e., . $\phi = \oint \vec{B}\cdot d\vec{A} = 0$. The statement that $\phi = \oint \vec{B}\cdot d\vec{A} = 0$ is the **Gauss' theorem for magnetostatics**. It is equivalent to the fact that isolated magnetic monopoles do not exist.

4 The magnetic flux is a measure of the total number of lines of $\vec{B}$ through a given area. The $\phi = \oint \vec{B}\cdot d\vec{A} = 0$ also means that lines of $\vec{B}$ are continuous, i.e., do not end at south pole of magnet but pass through the magnet coming out of the north pole.

Electromagnetic induction and Faraday's experiments

E.M. induction is the phenomenon of production of induced electric current and induced e.m.f in a conducting loop whenever the magnetic flux linked with the loop is changed. This phenomenon was discovered by Faraday.

Whenever there is a relative motion between coil and the magnet, induced e.m.f. is produced in the coil and induced current flows in the circuit. The induced current exists till there is a relative motion.

The magnitude of induced current or e.m.f. is large if relative velocity is large. The polarity of induced e.m.f. changes if the relative velocity is reversed in direction.

Laws of electromagnetic induction

First law: Whenever there occurs a change in the magnetic flux linked with a coil, there is an induced e.m.f. in the coil. The induced e.m.f. lasts so long as the change in flux is taking place. There is an induced current only when coil circuit is complete.

Second law: The magnitude of induced e.m.f. is directly proportional to the rate of change in the magnetic flux, i.e.

$e \propto (d\phi/dt)$. For N turns, $e \propto N(d\phi/dt)$.

Lenz's law: The direction of the induced current is such that it tends to oppose the cause producing it.

a. Combining the second and third law: $e = -N(d\phi/dt)$.

b. Lenz's law is based on law of conservation of energy.

Fleming's right hand rule: Stretch the thumb and two nearby fingers of your right hand in three mutually perpendicular directions such that if the forefinger points along the direction of magnetic field and thumb along the direction of motion of the conductor, then the central finger points in the direction of induced current.

1 Induced e.m.f. and induced current are in no way different from the e.m.fs. and currents provided by a battery connected to a conducting loop.

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2 The induced e.m.f. in a circuit does not depend on the resistance of the circuit as e = -(dϕ/dt). However, the induced current in the circuit does depend on the resistance. $I = \frac{e}{R} = -\frac{1}{R}\left(\frac{d\phi}{dt}\right)$

3 The induced charge that flows in the circuit depends on the change of flux only and not on how fast or slow the flux changes. $\frac{dq}{dt} = -\frac{1}{R}\left(\frac{d\phi}{dt}\right)$ or $dq = -\frac{d\phi}{R}$.

On integrating, the total charge that flows in the circuit is found to be: $q = \frac{(\phi_1 - \phi_2)}{R}$. Thus q does not depend on rate of change of the flux but it depends on total flux change and R in the circuit.

If the number of turns in the coil is N, then the charge that flows through the coil is: $q = \frac{N(\phi_1 - \phi_2)}{R}$

Induced E.M.F. across a conducting rod

Conducting rod moving in a uniform magnetic field: When a conducting rod of length l moves with a velocity v in a uniform magnetic field of induction B such that the l makes an angle θ with $\vec{B}$, then the magnitude of the average induced e.m.f. |e| is given by: $|e| = vBl \sin\theta$

Conducting rod rotating with angular velocity ω in a uniform magnetic field: When a rod of length l rotates with angular velocity ω in a uniform magnetic field B, then induced e.m.f. across the ends of the rotating rod is;

$e = (1/2)B\omega l^2 = B\pi f l^2 = BAf$ where $A = \pi l^2$ = area swept by the rod in one rotation and f is the frequency of rotation.

Metallic disc rotating with angular velocity ω in a uniform magnetic field: When a metallic disc of radius R rotates with angular velocity ω in a uniform magnetic field B, then induced e.m.f. across centre of disc and rim is $e = (1/2)B\omega R^2$

Self-inductance

When a current I flows through a coil, it produces a magnetic flux ϕ through it. Then $\phi \propto I$ or $\phi = LI$ where L is constant, called the coefficient of self-induction or self-inductance of the coil. The unit of L in MKS system is henry.

Further, e = -(dϕ/dt) = - d(LI)/dt == -L(dI/dt)

Self-inductance L of a solenoid of N turns, length l, area of cross-section A, with a core material of relative permeability μ_r is given by: $L = \frac{\mu_r \mu_o N^2 A}{l}$

Mutual inductance

When a current I flowing in the primary coil produces a magnetic flux ϕ in the secondary coil, then $\phi \propto I$ or $\phi = MI$, where M is a constant, called the coefficient of mutual induction or mutual inductance. The unit of M in MKS system is henry $e = -d\phi/dt = -d(MI)/dt = -M(dI/dt)$

Mutual inductance M of two co-axial solenoids is given by: $M = \frac{\mu_r \mu_o N_1 N_2 A}{l}$ where N_1 and N_2 represent the total number of turns in the primary coil and the secondary coil.

Series and parallel combination of inductances

1 Two inductors of self-inductances L_1 and L_2 are kept so far apart that their mutual inductance is zero. These are connected in series. Then the equivalent inductance is: $L = L_1 + L_2$

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2 Two inductors of self-inductances L_1 and L_2 are connected in series and they have mutual inductance M. Then the equivalent inductance of the combination is: $L = L_1 + L_2 \pm 2M$. The plus sign occurs if windings in the two coils are in the same sense, while minus sign occurs if windings are in opposite sense.

3 Two inductors of self-inductances L_1 and L_2 are connected in parallel. The inductors are so far apart that their mutual inductance is negligible. Then equivalent inductance is: $L = L_1L_2 / L_1 + L_2$ or $1/L = 1/L_1 + 1/L_2$

4 If two coils of self-inductances L_1 and L_2 are wound over each other, the mutual inductance is given by:

$M = K (L_1L_2)^{1/2}$ (where K is called coupling constant). The maximum coupling (K = 1) occurs when the two coils are wound over each other, over a ferromagnetic core.

Transformer

The transformer works on the principle of mutual induction and is used in AC only. It suitably changes the peak value of AC voltage. A transformer consists of a (a) primary coil of turns N_p, (b) secondary coil of turns N_S and (c) a laminated soft iron core.

1 If V_p and V_S, denote the voltage across the primary coil and the secondary coil respectively, then $(V_S/V_p) = (N_S/N_p)$.

2 In an actual transformer, Output power ≤ input power but in an ideal transformer, Output power = input power

i.e., $V_SI_S = V_p I_p$ (I_p and I_S are the currents in primary and secondary coils respectively)

or $\frac{V_S}{V_p} = \frac{I_p}{I_S} = \frac{N_S}{N_p}$

3 There are two types of transformers:

a. Step-up transformers: Here, $N_S > N_p$, so $V_S > V_p$ and $I_S < I_p$.

b. Step-down transformers: Here, $N_S < N_p$, so $V_S < V_p$ and $I_S > I_p$.

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Electromagnetic Induction Assignment

1 An induced emf is produced when a magnet is plunged into a coil. The magnitude of the induced emf is independent of

(a) the strength of the magnet

(b) the speed with which the magnet is moved

(c) the resistivity of the wire of the coil

(d) the number of turns in the coil.

2 A copper ring is held horizontally and a bar magnet is dropped through the ring with its length along the axis of the ring. The acceleration of the falling magnet is

(a) equal to that due to gravity

(b) less than that due to gravity

(c) more than that due to gravity

(d) depends on the diameter of the ring and the length of the magnet.

3 Two identical coaxial circular loops carry a current i each circulating in the same direction. If the loops approach each other the current in

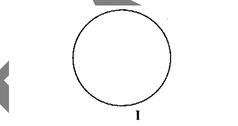
(a) each decreases

(b) each. increases

(c) each remains the same

(d) one increases whereas that in the other decreases.

4 A current-carrying wire is placed below a coil in its plane, with current flowing as shown. If the current increases



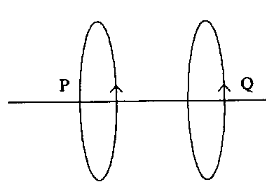
(a) no current will be induced in the coil

(b) an anticlockwise current will be induced in the coil

(c) a clockwise current will be induced in the coil

(d) the current induced in the coil will be first anticlockwise and then clockwise.

5 Two circular coils P and Q are arranged coaxially as shown. The sign convention adopted is that the currents are taken as positive whe n they flow in the direction of the arrows. Choose the correct statement.



(a) If P carries a steady positive current and it is moved towards Q, a positive current is induced in Q.

(b) If P carries a steady positive current and Q is moved towards P, a negative current is induced in Q.

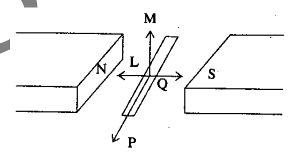
(c) If both the coils carry positive currents, the coils repeal each other,

(d) If a positive current flowing in P is switched off, a negative current is induced momentarily in Q.

6 A wire of length 1.0 m moves with a speed of 10 m/s perpendicular to a magnetic field. If the emf induced in the wire is 1.0 V, the magnitude of the field is

(a) 0.01 T (b) 0.1 T (c) 0.2 T (d) 0.02 T

7 An electric potential difference will be induced between the ends of the conductor shown in the diagram when it moves in the direction

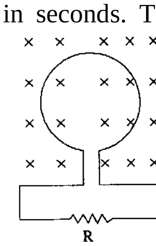


(a) P (b) Q (c) L (d) M

8 A coil of area 10 cm^2, 10 turns and resistance 20Ω is placed in a magnetic field directed perpendicular to the plane of the coil and changing at the rate of 10^8 gauss/second. The induced current in the coil will be

(a) 5 A (b) 0.5 A (c) 0.05 A (d) 50 A.

9 In the figure the flux through the loop perpendicular to the plane of the coil and directed into the paper is varying according to the rel ation $\phi = 6t^2 + 7t + 1$ where ϕ is in milliweber and t is in seconds. The magnitude of the emf induced in the loop at $t = 2$ s and the direction of induced current through R are



(a) 39 mV; right to left

(b) 39 mV; left to right

(c) 31 mV; right to left

(d) 31 mV; left to right

10 A solenoid has 2000 turns wound over a length of 0.3 m. Its cross-sectional area is 1.2 x 10^{-10} m^2. Around its central section a coil of 300 turns is wound. If an initial current of 2A flowing in the solenoid is reversed in 0.25 s, the emf induced in the coil will be

(a) 6.0 x 10^{-4} V (b) 6.0 x 10^{-2} V

(c) 4.8 x 10^{-4} V (d) 4.8 x 10^{-2} V

11 The current in a coil changes from 0 to 2A in 0.05 s. If the induced emf is 80 V, the self-inductance of the coil is

(a) 1 H (b) 0.5 H (c) 1.5 H (d) 2H

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12 When a wheel with metal spokes, 1.2 m long, is rotated in magnetic field of flux density 5×10^{-5} Wb/m^2 normal to the plane of the wheel, an emf of V is induced between the rim and the axle. The frequency of rotation of the wheel is

(a) 22 revolutions per second

(b) 44 revolutions per second

(c) $22/\pi$ revolutions per second

(d) $44/\pi$ revolutions per second.

13 A coil is rotated in a uniform magnetic field about an axis perpendicular to the field. The emf induced in the coil would be maximum when the plane of the coil is

(a) parallel to the field

(b) perpendicular to the field

(c) at 45° to the field

(d) in none of the above positions.

14 A coil having number of turns N and cross-sectional area A is rotated in a uniform magnetic field B with an angular velocity ω The maximum value of the emf induced in it is

(a) NBA/ω (b) $NBA\omega$

(c) NBA/ω^2 (d) $NBA\omega^2$

15 The mutual inductance of a pair of coils is 2 H. If the current in one of the coils changes from 10 A to zero in 0.1 s, the emf induced in the other coil is

(a) 2 V (b) 20 V (c) 0.2 V (d) 200 V.

16 Two inductors, each of inductance L, are connected in parallel but are well separated from each other. The effective inductance is

(a) L/4 (b) L/2 (c) L (d) 2L

17 Two different wire loops are concentric and lie in the same plane. The current in the outer loop is clockwise and increasing with time. The induced current in the inner loop then is

(a) clockwise

(b) zero

(c) counter clockwise

(d) in a direction that depends on the ratio of the loop radii.

18 Eddy currents are produced in a material when it is

(a) heated

(b) placed in a time varying magnetic field

(c) placed in an electric field

(d) placed in a uniform magnetic field.

19 The inductance of a coil is proportional to

(a) its length

(b) the number of turns

(c) the resistance of the coil

(d) the square of the number of turns.

20 In a step-down transformer the input voltage is 22 kV and the output voltage is 550 V. The ratio of the number of turns in the secondary to that in the primary is

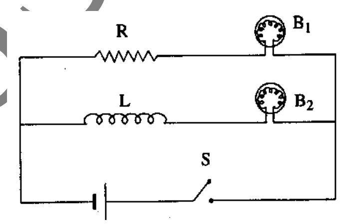
(a) 1 : 20 (b) 20 : 1

(c) 1 : 40 (d) 40 : 1

21 In a noiseless transformer an alternating current of 2 A is flowing in the primary coil. The number of turns in the primary and secondary coils are 100 and 20 respectively. The value of the current in the secondary coil is

(a) 0.08 A (b) 0.4 A (c) 5 A (d) 10 A

22 In the given circuit R is a resistor L is an inductor and B_1 and B_2 are two bulbs. If the switch S is turned off



(a) both B_1 and B_2 die out promptly

(b) both B_1 and B_2 die out with some delay

(c) B_1 dies out promptly but B_2 with some delay

(d) B_2 dies out promptly but B_1 with some delay.

23 A capacitor of 1 μF is charged and then connected across an ideal inductor of 10 mH. The angular frequency of oscillation of the charge in rad/s is

(a) 10^{-8} (b) 10^{8} (c) 10^{4} (d) 10^{-4}

24 A capacitor of 1μF initially charged to 10 V is connected across an ideal inductor of 0.1 mH. The maximum current in the circuit is

(a) 0.5 A (b) 1 A (c) 1.5 A (d) 2 A

25 A transformer is used to light a 140 W, 24 V bulb from a 240 V A.C. mains. The current in the main cable is 0.7 A. The efficiency of the transformer is

(a) 63.8% (b) 83.3% (c) 16.7% (d) 36.2%

26 In a step-up transformer, the turns ratio of primary and secondary is 1 : 2. A Laclanche cell of emf 1.5 V is connected across the primary. The voltage developed across the secondary would be

(a) zero (b) 3.0 V (c) 1.5 V (d) 0.75 V

27 Core of a dynamo is laminated because

(a) magnetic field increases

(b) magnetic saturation level in core increases

(c) residual magnetism in core decreases

(d) loss of energy in core due to eddy currents decreases.

Answers

1c ,2b ,3a ,4c ,5b ,6b ,7d ,8a ,9d ,10d ,11d ,12b
13a ,14b ,15d ,16b ,17c ,18b ,19d ,20c ,21d ,22c
23c ,24b ,25b ,26a ,27d

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