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Electromagnetic Induction and Alternating Currents — JEE (Main) Pattern Topic Test

FREE SAMPLE TEST · PHYSICS · PATTERN OF JEE (MAIN)

DURATION	MAXIMUM MARKS	QUESTIONS	NAME / ROLL NO.
60 minutes	100	25 (20 + 5)	

GENERAL INSTRUCTIONS

1. This question paper has two sections, A and B. All 25 questions are compulsory.
2. Section A has TWENTY (20) multiple-choice questions. Each has FOUR options, (1), (2), (3) and (4), of which ONLY ONE is correct.
3. Section B has FIVE (05) questions whose answer is a numerical value. Enter the value rounded off to the nearest integer.
4. Marking scheme for both sections: +4 for a correct answer, −1 for an incorrect answer, 0 if the question is not attempted.
5. Take $\mu_0 = 4\pi \times 10^{-7}$ T m/A and g = 10 m/s² unless stated otherwise. Use of a calculator, log tables or any other aid is not allowed.
6. The answer key and worked solutions are at the end of this booklet. Attempt the paper in 60 minutes before you look at them.

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Topics covered: Faraday's law of induction · Lenz's law and eddy currents · Motional emf · Self-inductance · Mutual inductance · Peak and rms values of alternating current · Reactance and impedance · LCR series circuit and resonance · Power in AC circuits and wattless current · AC generator · Transformer

SECTION A (Q1–20) · Multiple choice · +4 / 0 / −1

Each question has FOUR options. ONLY ONE of them is correct.

1. A coil of 200 turns and area 0.01 m² is held perpendicular to a uniform magnetic field of 0.5 T. The field is reversed steadily in 0.1 s. The average emf induced in the coil is

(1) 10 V

(2) 20 V

(3) 40 V

(4) 0 V

2. A metal rod 1 m long rotates at 10 rad/s about an axis through one end, perpendicular to the rod and parallel to a uniform magnetic field of 0.4 T. The potential difference between the midpoint of the rod and its free end is

(1) 2 V

(2) 0.5 V

(3) 1 V

(4) 1.5 V

3. A conducting rod of length 0.5 m slides with a constant speed of 2 m/s along two parallel rails joined at one end by a 2 Ω resistor. A uniform magnetic field of 0.8 T acts perpendicular to the plane of the rails, and the rod and rails have negligible resistance. The force needed to keep the rod moving, and the power supplied by that force, are

(1) 0.16 N and 0.32 W

(2) 0.32 N and 0.64 W

(3) 0.16 N and 0.16 W

(4) 0.08 N and 0.16 W

4. A horizontal rod of mass 20 g and length 0.4 m slides without friction down two long vertical conducting rails joined at the top by a 0.5 Ω resistor. A uniform horizontal magnetic field of 0.5 T acts perpendicular to the plane of the rails. Neglecting other resistances, the terminal speed of the rod is

(1) 1.25 m/s

(2) 5 m/s

(3) 2.5 m/s

(4) 10 m/s

5. A strong bar magnet is dropped down a long vertical copper tube, without touching its walls. Which of the following is correct?

(1) It falls with acceleration g, because copper is not magnetic

(2) It falls with an acceleration greater than g

(3) It soon reaches a constant speed, because of currents induced in the tube

(4) It comes to rest inside the tube

6. The current in a coil of self-inductance 0.2 H rises steadily from 0 to 3 A in 0.1 s. The emf induced in the coil during this time, and the energy stored in it at the end, are

(1) 6 V and 0.9 J

(2) 6 V and 1.8 J

(3) 0.6 V and 0.9 J

(4) 60 V and 0.9 J

7. A long solenoid has 1000 turns per metre and a cross-sectional area of 4 cm². A coil of 50 turns is wound tightly round its middle. When the current in the solenoid changes at 100 A/s, the emf induced in the coil is about

(1) 25 mV

(2) 0.25 mV

(3) 2.5 μV

(4) 2.5 mV

8. A coil of inductance 2 H and resistance 4 Ω is connected to a 12 V battery of negligible internal resistance at t = 0. The current reaches half of its final value at about

(1) 0.69 s

(2) 0.35 s

(3) 0.5 s

(4) 0.17 s

9. The current in a wire is $i = (3 + 4 \sin \omega t)$ A. Its rms value is

(1) 5 A

(2) $\sqrt{17}$ A

(3) $7/\sqrt{2}$ A

(4) $(3 + 2\sqrt{2})$ A

10. A capacitor of capacitance $(100/\pi)$ μF and a 100 Ω resistor are connected in series across a 220 V, 50 Hz supply. The rms current is about

(1) 2.2 A

(2) 1.1 A

(3) 3.1 A

(4) 1.56 A

11. A series LCR circuit has L = 0.5 H, C = 20 μF and R = 10 Ω. It is driven by an AC source of variable frequency. The current is largest at a frequency of about

(1) 316 Hz

(2) 100 Hz

(3) 50 Hz

(4) 159 Hz

12. In a series LCR circuit the rms voltages across the resistor, the inductor and the capacitor are 40 V, 90 V and 60 V. The rms voltage of the source and the power factor of the circuit are

(1) 50 V and 0.8

(2) 190 V and 1

(3) 50 V and 0.6

(4) 70 V and 0.57

13. An AC circuit draws an rms current of 5 A from a 200 V (rms) supply, and the current lags the voltage by 60°. The average power drawn is

(1) 500 W

(2) 1000 W

(3) 866 W

(4) 250 W

14. The rms current in an AC circuit is 10 A and it lags the applied voltage by 37°. The wattless component of the current is (take sin 37° = 3/5)

(1) 8 A

(2) 10 A

(3) 6 A

(4) 0 A

15. A step-down transformer changes 2200 V to 220 V and delivers 4.4 kW to its load. Its efficiency is 80%. The current in its primary coil is

(1) 2 A

(2) 20 A

(3) 25 A

(4) 2.5 A

16. The coil of an AC generator has 100 turns, each of area 0.05 m^2, and rotates at 50 revolutions per second in a uniform magnetic field of 0.2 T. The peak emf generated is about

(1) 31.4 V

(2) 314 V

(3) 157 V

(4) 100 V

17. Which of the following is NOT a use of eddy currents?

(1) Electromagnetic braking of trains

(2) Induction furnaces

(3) Damping in dead-beat moving coil galvanometers

(4) Laminated transformer cores, which increase the eddy currents

18. A long solenoid has self-inductance L. It is rewound with twice as many turns on the same length and the same cross-section. Its self-inductance becomes

(1) 4L

(2) 2L

(3) L/2

(4) 8L

19. A long straight wire carries a steady current I upwards. A rectangular loop lies in the same plane, to the right of the wire, with two of its sides parallel to the wire, and moves steadily away from the wire. The induced current in the side of the loop nearer to the wire is

(1) opposite in direction to I

(2) zero

(3) in the same direction as I

(4) first along I and then opposite to it

20. A series LCR circuit with R = 5 Ω and $X_L = X_C = 50$ Ω at the supply frequency is connected to a 10 V (rms) source. The rms voltage across the inductor is

(1) 10 V

(2) 100 V

(3) 50 V

(4) zero

SECTION B (Q21–25) · Numerical value · +4 / 0 / −1

The answer to each question is a NUMERICAL VALUE. Enter it rounded off to the nearest integer.

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21. The magnetic flux through each turn of a 100-turn coil varies as $\Phi = (4t^2 + 2t)$ mWb, with t in seconds. The magnitude of the emf induced in the coil at t = 3 s (in mV) is _____.

Answer: _____

22. A coil of 500 turns and area 20 cm² is placed perpendicular to a magnetic field of 0.4 T, which is then reduced to zero. The total resistance of the coil circuit is 20 Ω. The charge (in mC) that flows round the circuit is _____.

Answer: _____

23. The capacitance (in μF) that must be connected in series with an inductor of 0.1 H so that the circuit is in resonance with a 50 Hz supply is _____ (take $\pi^2 = 10$).

Answer: _____

24. A voltage $v = 311 \sin(100\pi t)$ volt is applied across a 50 Ω resistor. The average power (in W) dissipated in it is _____ (to the nearest integer).

Answer: _____

25. An ideal transformer has 200 turns in its primary coil and steps 220 V down to 11 V. When the primary current is 0.5 A, the current (in A) in the secondary coil is _____.

Answer: _____

END OF THE QUESTION PAPER

ANSWER KEY

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
(2)	(4)	(1)	(3)	(3)	(1)	(4)	(2)	(2)	(4)

Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
(3)	(1)	(1)	(3)	(4)	(2)	(4)	(1)	(3)	(2)

Q21	Q22	Q23	Q24	Q25
2600	20	100	967	10

WORKED SOLUTIONS

Q1. Answer (2). The flux through each turn changes from +BA to −BA: $\Delta\Phi = 2 \times 0.5 \times 0.01 = 0.01$ Wb. emf $= N\Delta\Phi/\Delta t = 200 \times 0.01/0.1 = 20$ V. (10 V forgets that reversing the field changes the flux by 2BA.)

Q2. Answer (4). An element at distance r moves with speed ωr, so $d\varepsilon = B\omega r\, dr$. Between $r = L/2$ and $r = L$: $\varepsilon = \tfrac{1}{2}B\omega(L^2 - L^2/4) = \tfrac{1}{2} \times 0.4 \times 10 \times 0.75 = 1.5$ V. (2 V is the emf of the whole rod.)

Q3. Answer (1). $\varepsilon = BLv = 0.8 \times 0.5 \times 2 = 0.8$ V and $I = 0.8/2 = 0.4$ A. The magnetic force on the rod opposes its motion: $F = BIL = 0.8 \times 0.4 \times 0.5 = 0.16$ N, so this force is needed. Power $Fv = 0.32$ W, which equals $I^2R = 0.16 \times 2$.

Q4. Answer (3). At speed v the current is BLv/R and the upward magnetic force is B^2L^2v/R. Terminal speed when this equals mg: $v = mgR/(B^2L^2) = 0.02 \times 10 \times 0.5/(0.25 \times 0.16) = 2.5$ m/s.

Q5. Answer (3). The changing flux induces eddy currents in the tube. By Lenz's law their field opposes the motion of the magnet, with a force that grows with its speed. The magnet speeds up until this force balances its weight, then falls at a constant terminal speed. It cannot come to rest, since there is no opposing force at zero speed.

Q6. Answer (1). $\varepsilon = L\, di/dt = 0.2 \times 3/0.1 = 6$ V (opposing the rise). $U = \tfrac{1}{2}LI^2 = \tfrac{1}{2} \times 0.2 \times 9 = 0.9$ J.

Q7. Answer (4). $B = \mu_0 nI$ inside the solenoid, so the flux linkage of the coil is $N_2\mu_0 nIA$ and $M = \mu_0 nN_2A = 4\pi \times 10^{-7} \times 1000 \times 50 \times 4 \times 10^{-4} = 2.5 \times 10^{-5}$ H. $\varepsilon = M\, dI/dt = 2.5 \times 10^{-5} \times 100 = 2.5$ mV.

Q8. Answer (2). $i = (E/R)(1 - e^{(-t/\tau)})$ with $\tau = L/R = 0.5$ s. Half the final value when $e^{(-t/\tau)} = \tfrac{1}{2}$: $t = \tau \ln 2 = 0.5 \times 0.693 \approx 0.35$ s.

Q9. Answer (2). $i^2 = 9 + 24 \sin \omega t + 16 \sin^2 \omega t$. Over a cycle $\sin \omega t$ averages to 0 and $\sin^2 \omega t$ to $\tfrac{1}{2}$, so the mean of i^2 is $9 + 8 = 17$ and $i_{rms} = \sqrt{17} \approx 4.1$ A.

Q10. Answer (4). $X_C = 1/(2\pi fC) = 1/(2\pi \times 50 \times 10^{-4}/\pi) = 100\ \Omega$. $Z = \sqrt{(R^2 + X_C^2)} = 100\sqrt{2} \approx 141\ \Omega$, so $I = 220/141 \approx 1.56$ A.

Q11. Answer (3). At resonance $X_L = X_C$: $\omega_0 = 1/\sqrt{(LC)} = 1/\sqrt{(10^{-5})} \approx 316$ rad/s, so $f_0 = \omega_0/(2\pi) \approx 50$ Hz. (316 is ω_0 in rad/s, not a frequency in Hz.)

Q12. Answer (1). V_L and V_C are opposite in phase and both at 90° to V_R: $V = \sqrt{(40^2 + (90 - 60)^2)} = 50$ V. Power factor $\cos \varphi = V_R/V = 40/50 = 0.8$.

Q13. Answer (1). $P = V_{rms} I_{rms} \cos \varphi = 200 \times 5 \times \cos 60° = 500$ W. (1000 W is the apparent power, in volt-amperes.)

Q14. Answer (3). Resolve the current along and at right angles to the voltage. The part in phase, $I \cos \varphi = 8$ A, carries the power; the part at 90°, $I \sin \varphi = 10 \times 3/5 = 6$ A, does no work on average: it is the wattless current.

Q15. Answer (4). Input power $= 4400/0.8 = 5500$ W. $I_p = 5500/2200 = 2.5$ A. (2 A would be the primary current of an ideal transformer.)

Q16. Answer (2). $\Phi = NBA\cos\omega t$, so $\varepsilon = NBA\omega\sin\omega t$ and the peak emf is $NBA\omega = 100 \times 0.2 \times 0.05 \times 2\pi \times 50 \approx 314$ V.

Q17. Answer (4). Braking, induction heating and the damping of a galvanometer coil all rely on eddy currents. Transformer cores are laminated to cut the eddy currents down, because they only waste energy as heat there.

Q18. Answer (1). $B = \mu_0(N/l)I$ and the flux linkage is $NBA = \mu_0 N^2 AI/l$, so $L = \mu_0 N^2 A/l \propto N^2$. Doubling N gives 4L.

Q19. Answer (3). Moving away, the loop's flux (into the plane, on that side of the wire) decreases. By Lenz's law the induced current tries to keep it up, so it must itself make a field into the plane inside the loop: it flows clockwise, which is upwards (along I) in the nearer side. Parallel currents attract, which opposes the motion away.

Q20. Answer (2). At resonance the reactances cancel, $Z = R = 5\ \Omega$ and $I = 10/5 = 2$ A. $V_L = IX_L = 2 \times 50 = 100$ V, ten times the supply voltage (V_C is also 100 V, opposite in phase).

Q21. Answer 2600. $d\Phi/dt = (8t + 2)$ mWb/s $= 26$ mWb/s at $t = 3$ s. $\varepsilon = N\,d\Phi/dt = 100 \times 26$ mV $= 2600$ mV.

Q22. Answer 20. $q = \int i\,dt = \int (\varepsilon/R)\,dt = N\Delta\Phi/R$, whatever the time taken: $q = 500 \times 0.4 \times 20 \times 10^{-4}/20 = 0.02$ C $= 20$ mC.

Q23. Answer 100. Resonance: $\omega^2 LC = 1$, so $C = 1/(4\pi^2 f^2 L) = 1/(40 \times 2500 \times 0.1) = 10^{-4}$ F $= 100\ \mu$F.

Q24. Answer 967. $V_r ms = 311/\sqrt{2}$, so $P = V_r ms^2/R = 311^2/(2 \times 50) = 967.2$ W, i.e. 967.

Q25. Answer 10. For an ideal transformer $V_p I_p = V_s I_s$, so $I_s = 220 \times 0.5/11 = 10$ A. (The secondary has $200 \times 11/220 = 10$ turns.)

All questions are original and © Master Testing Agency. Free to download and use for personal practice; not for resale. Every answer in this paper was checked independently by computer: induced emfs by differentiating the flux numerically, moving rods and coils by step-by-step integration, AC values by averaging over a cycle or by complex impedances, and resonance by scanning the frequency.