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Electromagnetic Waves — 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 $c = 3 \times 10^8$ m/s, $\varepsilon_0 = 8.85 \times 10^{-12}$ C²/N m² and $\mu_0 = 4\pi \times 10^{-7}$ T m/A 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: Displacement current · Characteristics of electromagnetic waves · Transverse nature of electromagnetic waves · Electromagnetic spectrum · Applications of electromagnetic waves

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

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

1. A parallel-plate capacitor with circular plates of radius 5 cm is being charged by a current of 0.2 A. The displacement current through a circular area of radius 2.5 cm between the plates, coaxial with them and parallel to them, is (ignore edge effects)

(1) 0.2 A

(2) 0.1 A

(3) 0.05 A

(4) 0.4 A

2. A parallel-plate capacitor with circular plates of radius 5 cm is being charged by a current of 0.2 A. Ignoring edge effects, the ratio of the magnetic field between the plates at a distance of 2.5 cm from the axis to the magnetic field at a distance of 10 cm from the axis is

(1) 1 : 2

(2) 2 : 1

(3) 1 : 4

(4) 1 : 1

3. A plane electromagnetic wave travels through a non-magnetic glass of refractive index 1.5. The amplitude of its electric field in the glass is 6 V/m. The amplitude of its magnetic field in the glass is

(1) 1.3×10^{-8} T

(2) 3×10^{-8} T

(3) 2×10^{-8} T

(4) 9×10^{-8} T

4. The electric field of a plane electromagnetic wave in vacuum is $E = E_0 \sin(kz - \omega t)\,\hat{i}$. Its magnetic field is

(1) $B = (E_0/c)\sin(kz - \omega t)\,\hat{j}$

(2) $B = -(E_0/c)\sin(kz - \omega t)\,\hat{j}$

(3) $B = E_0 c \sin(kz - \omega t)\,\hat{j}$

(4) $B = (E_0/c)\sin(kz - \omega t)\,\hat{k}$

5. The electric field of an electromagnetic wave is $E_y = 60 \sin(5 \times 10^2\, x + 1.5 \times 10^{11}\, t)$ V/m, with x in metres and t in seconds. The wave travels

(1) along −x, with wavelength 1.26 cm

(2) along +x, with wavelength 1.26 cm

(3) along −x, with wavelength 2.0 mm

(4) along +x, with wavelength 4.0 mm

6. An electromagnetic wave of frequency 3 GHz passes from vacuum into a non-magnetic medium of relative permittivity 4. Its wavelength in the medium is

(1) 10 cm

(2) 5 cm

(3) 2.5 cm

(4) 20 cm

7. For a plane electromagnetic wave in vacuum, compare the average energy density of its electric field with that of its magnetic field:

(1) the electric part is c times the magnetic part

(2) the magnetic part is c times the electric part

(3) the electric part is twice the magnetic part

(4) the two are equal

8. The amplitude of the electric field of a plane electromagnetic wave in vacuum is 100 V/m. The average intensity of the wave is about

(1) 26.6 W/m²

(2) 6.6 W/m²

(3) 13.3 W/m²

(4) 1.3 W/m²

9. A 100 W lamp radiates 5% of its power as light, equally in all directions. The amplitude of the electric field of the light at a distance of 2 m from the lamp is about

(1) 4.3 V/m

(2) 12.2 V/m

(3) 8.7 V/m

(4) 6.1 V/m

10. Light of intensity 30 W/m² falls normally on a perfectly absorbing surface of area 10 cm² for 1 hour. The momentum delivered to the surface is

(1) 3.6×10^{-7} kg m/s

(2) 7.2×10^{-7} kg m/s

(3) 1.2×10^{-9} kg m/s

(4) 3.6×10^{-4} kg m/s

11. Light of intensity 1.2 kW/m² falls normally on a perfectly reflecting surface. The pressure it exerts is

(1) 4×10^{-6} Pa

(2) 8×10^{-6} Pa

(3) 2.4×10^{3} Pa

(4) 1.6×10^{-5} Pa

12. Which of the following lists electromagnetic radiations in order of increasing wavelength?

(1) X-rays, ultraviolet, microwaves, infrared

(2) gamma rays, infrared, ultraviolet, radio waves

(3) radio waves, microwaves, visible light, X-rays

(4) gamma rays, ultraviolet, infrared, microwaves

13. Match List I with List II.
List I: (A) Microwaves (B) Infrared (C) Ultraviolet (D) X-rays
List II: (I) Imaging of broken bones (II) Radar and cooking ovens (III) TV remote controls and thermal imaging (IV) Killing germs in water purifiers
Choose the correct answer from the options given below:

(1) A-I, B-II, C-III, D-IV

(2) A-II, B-IV, C-III, D-I

(3) A-III, B-II, C-I, D-IV

(4) A-II, B-III, C-IV, D-I

14. Electromagnetic radiation of frequency 5×10^{14} Hz in vacuum belongs to the

(1) visible region

(2) infrared region

(3) ultraviolet region

(4) microwave region

15. Which of the following statements about electromagnetic waves is NOT correct?

(1) Their electric and magnetic fields are perpendicular to each other and to the direction of travel

(2) They carry energy and momentum

(3) They need a material medium to travel through

(4) In vacuum they all travel with the same speed, whatever their frequency

16. The potential difference across a 2 μF capacitor is increasing at the rate of 5×10^4 V/s. The displacement current between its plates is

(1) 1 A

(2) 0.1 A

(3) 0.01 A

(4) 10 A

17. The amplitude of the electric field of a plane electromagnetic wave in vacuum is 50 V/m. The average total energy density of the wave is about

(1) 1.1×10^{-8} J/m³

(2) 2.2×10^{-8} J/m³

(3) 5.5×10^{-9} J/m³

(4) 4.4×10^{-8} J/m³

18. Electromagnetic waves are radiated by

(1) charges at rest

(2) charges moving with constant velocity

(3) accelerated charges

(4) steady currents

19. An X-ray and a gamma ray have the same wavelength. They differ in

(1) their speed in vacuum

(2) the energy of each photon

(3) their frequency

(4) their origin: gamma rays come from the nucleus

20. The magnetic field in a plane electromagnetic wave in vacuum is $B = 2 \times 10^{-7} \sin(kx - \omega t)$ T. The rms value of its electric field is about

(1) 60 V/m

(2) 42 V/m

(3) 85 V/m

(4) 30 V/m

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. A radio wave in vacuum has an electric field of amplitude 400 V/m. Its average intensity (in W/m²) is _____ (to the nearest integer).

Answer: _____

22. A 1.5 GHz radio wave travels through a non-magnetic medium of relative permittivity 2.25. Its wavelength in the medium (in mm) is _____ (to the nearest integer).

Answer: _____

23. The electric field between the plates of a parallel-plate capacitor of plate area 0.1 m² is changing at the rate of 2×10^{11} V m^{-1} s^{-1}. The displacement current (in mA) is _____ (to the nearest integer).

Answer: _____

24. A 30 mW laser beam falls normally on a mirror that reflects all of it. The force on the mirror is $x \times 10^{-11}$ N. The value of x is _____.

Answer: _____

25. A parallel beam of light of intensity 10 W/m² travels through vacuum. The electromagnetic energy (in pJ) contained in a 3 m long section of the beam with cross-sectional area 10 cm² is _____.

Answer: _____

END OF THE QUESTION PAPER

ANSWER KEY

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

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

Q21	Q22	Q23	Q24	Q25
212	133	177	20	100

WORKED SOLUTIONS

Q1. Answer (3). The total displacement current between the plates equals the conduction current, 0.2 A, and it is spread uniformly because the field is uniform. The fraction through the smaller area is $(2.5/5)^2 = 1/4$, so $I_d = 0.05$ A.

Q2. Answer (4). Ampère–Maxwell law: $B \times 2\pi r = \mu_0 \times$ (current enclosed). At 2.5 cm the enclosed displacement current is 0.05 A: $B = \mu_0 \times 0.05/(2\pi \times 0.025) = 4 \times 10^{-7}$ T. At 10 cm (beyond the plates) all 0.2 A is enclosed: $B = \mu_0 \times 0.2/(2\pi \times 0.1) = 4 \times 10^{-7}$ T. Ratio 1 : 1.

Q3. Answer (2). In a medium $E_0/B_0 = v$, the wave speed there: $v = c/n = 2 \times 10^8$ m/s. $B_0 = 6/(2 \times 10^8) = 3 \times 10^{-8}$ T. (2×10^{-8} T would be right in vacuum.)

Q4. Answer (1). The wave travels along +z (the phase $kz - \omega t$ is constant for z increasing with t). B is perpendicular to both E and the direction of travel, in phase with E, with E × B along the direction of travel: $\hat{i} \times \hat{j} = \hat{k}$, so B is along $+\hat{j}$, with amplitude E_0/c.

Q5. Answer (1). A phase $kx + \omega t$ stays constant if x decreases as t increases, so the wave travels along −x. $\lambda = 2\pi/k = 2\pi/500 \approx 1.26 \times 10^{-2}$ m. Check: $\omega/k = 1.5 \times 10^{11}/500 = 3 \times 10^8$ m/s = c.

Q6. Answer (2). $v = 1/\sqrt{(\mu_0\varepsilon_0\varepsilon_r)} = c/\sqrt{4} = 1.5 \times 10^8$ m/s. The frequency does not change, so $\lambda = v/f = 1.5 \times 10^8/(3 \times 10^9) = 0.05$ m = 5 cm (10 cm in vacuum).

Q7. Answer (4). $u_E = \frac{1}{2}\varepsilon_0 E^2$ and $u_B = B^2/(2\mu_0)$. With $B = E/c$ and $c^2 = 1/(\mu_0\varepsilon_0)$: $u_B = E^2/(2\mu_0 c^2) = \frac{1}{2}\varepsilon_0 E^2 = u_E$. The energy is shared equally.

Q8. Answer (3). I = average energy density × $c = \frac{1}{2}\varepsilon_0 E_0^2 c = \frac{1}{2} \times 8.85 \times 10^{-12} \times 10^4 \times 3 \times 10^8 \approx 13.3$ W/m².

Q9. Answer (3). $I = 5/(4\pi \times 2^2) = 0.0995$ W/m². $I = \frac{1}{2}c\varepsilon_0 E_0^2$, so $E_0 = \sqrt{(2I/(c\varepsilon_0))} = \sqrt{(0.199/(2.655 \times 10^{-3}))} \approx 8.7$ V/m. (6.1 V/m is the rms value.)

Q10. Answer (1). Energy absorbed $U = IAt = 30 \times 10^{-3} \times 3600 = 108$ J. For complete absorption $p = U/c = 108/(3 \times 10^8) = 3.6 \times 10^{-7}$ kg m/s. (A perfect reflector would receive twice this.)

Q11. Answer (2). Each second, momentum I/c arrives per unit area and the same leaves in the opposite direction, so the pressure is $2I/c = 2 \times 1200/(3 \times 10^8) = 8 \times 10^{-6}$ Pa.

Q12. Answer (4). In order of increasing wavelength: gamma rays, X-rays, ultraviolet, visible, infrared, microwaves, radio waves. Only gamma, ultraviolet, infrared, microwaves follows this order.

Q13. Answer (4). Microwaves: radar and ovens. Infrared: remote controls and thermal imaging. Ultraviolet: germicidal lamps in water purifiers. X-rays: imaging bones.

Q14. Answer (1). $\lambda = c/f = 3 \times 10^8/(5 \times 10^{14}) = 6 \times 10^{-7}$ m = 600 nm, which is in the visible range (about 400 to 700 nm): orange light.

Q15. Answer (3). Electromagnetic waves are self-sustaining oscillations of E and B and travel through vacuum, unlike sound. The other statements are true: they are transverse, carry energy and momentum (radiation pressure), and all travel at $c = 1/\sqrt{(\mu_0\varepsilon_0)}$ in vacuum.

Q16. Answer (2). $I_d = \varepsilon_0\, d\Phi_E/dt = \varepsilon_0 A\, d(V/d)/dt = (\varepsilon_0 A/d)\, dV/dt = C\, dV/dt = 2 \times 10^{-6} \times 5 \times 10^4 = 0.1$ A, equal to the charging current.

Q17. Answer (1). Averaged over a cycle, $u_E = \tfrac{1}{4}\varepsilon_0 E_0^2$ and u_B is equal to it, so $u = \tfrac{1}{2}\varepsilon_0 E_0^2 = \tfrac{1}{2} \times 8.85 \times 10^{-12} \times 2500 \approx 1.1 \times 10^{-8}$ J/m³. (5.5×10^{-9} J/m³ is the electric part alone.)

Q18. Answer (3). A charge at rest has only a static electric field and a steady current only a steady magnetic field. A charge moving uniformly carries its field along without radiating. An accelerated (for example oscillating) charge produces changing fields that travel outwards as an electromagnetic wave.

Q19. Answer (4). The same wavelength in vacuum means the same speed c, the same frequency c/λ and the same photon energy hc/λ. The two names describe the source: X-rays come from fast electrons or electron transitions in atoms, gamma rays from nuclei.

Q20. Answer (2). $E_0 = cB_0 = 3 \times 10^8 \times 2 \times 10^{-7} = 60$ V/m. For a sinusoidal field $E_{rms} = E_0/\sqrt{2} \approx 42$ V/m.

Q21. Answer 212. $I = \tfrac{1}{2}c\varepsilon_0 E_0^2 = \tfrac{1}{2} \times 3 \times 10^8 \times 8.85 \times 10^{-12} \times 1.6 \times 10^5 = 212.4$ W/m², i.e. 212.

Q22. Answer 133. $v = c/\sqrt{2.25} = 2 \times 10^8$ m/s, so $\lambda = v/f = 2 \times 10^8/(1.5 \times 10^9) = 0.1333$ m = 133 mm.

Q23. Answer 177. $I_d = \varepsilon_0 A\, dE/dt = 8.85 \times 10^{-12} \times 0.1 \times 2 \times 10^{11} = 0.177$ A = 177 mA.

Q24. Answer 20. The beam carries momentum P/c per second; reflection reverses it, so $F = 2P/c = 2 \times 0.03/(3 \times 10^8) = 2 \times 10^{-10}$ N = 20×10^{-11} N.

Q25. Answer 100. Energy density $u = I/c$. $U = uAL = (10/(3 \times 10^8)) \times 10^{-3} \times 3 = 10^{-10}$ J = 100 pJ. (Equivalently, the energy that crosses the area in the time $L/c = 10^{-8}$ s.)

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: displacement currents by differentiating the electric flux, fields from the Ampère–Maxwell law, intensities and energy densities by averaging the fields over a cycle, and wave directions by vector products.