CLASS XII – PHYSICS (042)
STEP-BY-STEP SOLUTIONS AND MARKING SCHEME

Chapter 8: Electromagnetic Waves – Practice Paper (35 Marks)

Answer key – Section A

Q.	1	2	3	4	5	6	7	8	9
Ans.	(c)	(b)	(c)	(b)	(d)	(a)	(c)	(a)	(d)

Marks are shown in square brackets. Equivalent correct methods are acceptable. Take $c = 3 \times 10^8$ m s^{-1}, $\varepsilon_0 = 8.85 \times 10^{-12}$ SI units, $h = 6.6 \times 10^{-34}$ J s, $\pi = 3.14$, $\sqrt{2} = 1.41$.

SECTION A

Q.1 (c)

The displacement current is the continuation of the conduction current across the gap, so that the total current is continuous: $i_d = i_c = 3$ A. **[1]**

Q.2 (b)

The wave travels in the direction of E × B. With E along +y and B along +z, $\hat{y} \times \hat{z} = +\hat{x}$, so the wave travels along +x. **[1]**

Q.3 (c)

Region S lies on the long-wavelength side of the visible region (adjacent to the red end), between 700 nm and about 1 mm. This is the infrared region, produced by vibrating atoms and molecules; it is absorbed by water molecules and so is called heat waves. **[1]**

Q.4 (b)

From the graph one full wave occupies 6 m, so $\lambda = 6$ m and $\nu = c/\lambda = 3 \times 10^8/6 = 5 \times 10^7$ Hz = 50 MHz. The amplitude is $E_0 = 60$ V/m, so $B_0 = E_0/c = 60/(3 \times 10^8) = 2 \times 10^{-7}$ T. **[1]**

Q.5 (d)

Microwaves – klystron/magnetron valve (2); gamma rays – radioactive decay of the nucleus (1); X-rays – X-ray tubes / inner shell electrons (4); infrared – vibration of atoms and molecules (3). So P–2, Q–1, R–4, S–3. **[1]**

Q.6 (a)

The electric field is uniform over the plate area, so the displacement current through a coaxial area is proportional to that area: $i_d = i \times \pi r^2/\pi R^2 = i \times (1/2)^2 = i/4$. **[1]**

Q.7 (c)

$v = 1/\sqrt{(\mu_0 \mu_r \varepsilon_0 \varepsilon_r)} = c/\sqrt{(1 \times 4)} = c/2$. The frequency does not change at the boundary, so $\lambda = v/\nu = \lambda_0/2 = 300$ nm. **[1]**

Q.8 (a)

Both true. Between the plates the changing electric field gives a displacement current $i_d = \varepsilon_0 \, d\Phi_E/dt$, which produces a magnetic field exactly as a conduction current does (this is the Ampere–Maxwell law). R explains A. **[1]**

Q.9 (d)

A is false: a charge moving with uniform velocity constitutes a steady current and produces only a constant magnetic field; it does not radiate. R is true: only accelerated charges radiate. **[1]**

SECTION B

Q.10

(a) The displacement current between the plates equals the conduction current: $i_d = i = 0.885$ A. **[1]**

(b) $i_d = \varepsilon_0 \, d\Phi_E/dt = \varepsilon_0 A \, dE/dt$, so $dE/dt = i_d/(\varepsilon_0 A) = 0.885/(8.85 \times 10^{-12} \times 10^{-2}) = 1 \times 10^{13}$ V m^{-1} s^{-1}. ($A = 100$ cm$^2 = 10^{-2}$ m^2) **[1]**

Q.11

$B_0 = E_0/c = 45/(3 \times 10^8) = 1.5 \times 10^{-7}$ T; $k = 2\pi/\lambda = \pi$ rad m^{-1}; $\omega = ck = 3\pi \times 10^8$ rad s^{-1}. **[1]**
$E_x = 45 \sin(\pi z - 3\pi \times 10^8 t)$ V/m and $B_y = 1.5 \times 10^{-7} \sin(\pi z - 3\pi \times 10^8 t)$ T. (Numerical values k = 3.14 rad m^{-1}, $\omega = 9.42 \times 10^8$ rad s^{-1} are equally acceptable.) **[1]**

Q.12 (A)

P: microwaves (λ between 1 mm and 0.1 m, produced by magnetron/klystron); Q: X-rays (produced by high-energy electrons hitting a metal target); R: infrared (produced by vibration of atoms and molecules). (1 mark for identifying all three; award ½ mark if two are correct.) **[1]**
Uses (any one each): microwaves – radar, microwave oven; X-rays – medical diagnosis or treatment of some cancers; infrared – physical therapy, remote controls, satellite detectors. **[1]**

Q.12 (B)

(i) Ordinary glass absorbs ultraviolet radiation, which is what produces tanning (more melanin) in the skin, so no UV reaches the skin through a glass window. **[1]**
(ii) Water molecules present in most materials readily absorb infrared waves; on absorption their thermal motion increases, so the material heats up and warms its surroundings. **[1]**

Q.13

$hc = 6.6 \times 10^{-34} \times 3 \times 10^8 = 1.98 \times 10^{-25}$ J m. (a) Violet: $E = hc/\lambda = 1.98 \times 10^{-25}/(4 \times 10^{-7}) = 4.95 \times 10^{-19}$ J $= 4.95 \times 10^{-19}/1.6 \times 10^{-19} \approx 3.1$ eV. **[1]**
(b) Red: $E = 1.98 \times 10^{-25}/(7 \times 10^{-7}) = 2.83 \times 10^{-19}$ J ≈ 1.8 eV. The violet end (shorter wavelength, higher frequency) has photons of higher energy. **[1]**

SECTION C

Q.14

(a) $i_d = \varepsilon_0 \, d\Phi_E/dt = C \, dV/dt$ (since $\Phi_E = EA = VA/d$ and $C = \varepsilon_0 A/d$). Slope for 0–2 ms: 10 V/2 ms = 5000 V/s, so $i_d = 2 \times 10^{-6} \times 5000 = 10$ mA. **[1]**
2–4 ms: V is constant, dV/dt = 0, so $i_d = 0$. 4–6 ms: $dV/dt = (4 - 10)/(2 \times 10^{-3}) = -3000$ V/s, so $i_d = 2 \times 10^{-6} \times (-3000) = -6$ mA. **[1]**
(b) i_d is directed opposite to that in 0–2 ms (negative sign: the field is decreasing). Since $i_d = i_c$ in magnitude, the conduction current in the wires is 6 mA in the reversed direction: the capacitor is discharging. **[1]**

Q.15 (A)

(a) Ampere–Maxwell law: $\Sigma B \cdot \Delta l$ around a closed loop $= \mu_0(i_c + i_d) = \mu_0 i_c + \mu_0 \varepsilon_0 \, d\Phi_E/dt$, where the currents are those through any surface bounded by the loop. **[1]**
(b) For $r_1 = 3$ cm < R, only a part of the displacement current passes through the loop: $i_d(\text{enclosed}) = i \, r_1^2/R^2$. $B(2\pi r_1) = \mu_0 i \, r_1^2/R^2$, so $B = \mu_0 i \, r_1/(2\pi R^2) = (2 \times 10^{-7} \times 2 \times 0.03)/(25 \times 10^{-4}) = 4.8 \times 10^{-6}$ T. **[1]**
(c) For $r_2 = 10$ cm > R the loop encloses the whole displacement current $i_d = i = 2$ A: $B = \mu_0 i/(2\pi r_2) = (2 \times 10^{-7} \times 2)/0.1 = 4 \times 10^{-6}$ T. **[1]**

Q.15 (B)

Surface S_1 is crossed by the wire, so the current through it is i and Ampere's law gives $\Sigma B \cdot \Delta l = \mu_0 i$. Surface S_2 passes through the gap where no conduction current flows, so the same law gives $\Sigma B \cdot \Delta l = 0$ for the same loop: a contradiction. **[1]**
Maxwell noticed that an electric field $E = Q/(\varepsilon_0 A)$ changing with time exists in the gap; the flux through S_2 is $\Phi_E = Q/\varepsilon_0$ and $\varepsilon_0 \, d\Phi_E/dt = dQ/dt = i$. He called this the displacement current $i_d = \varepsilon_0 \, d\Phi_E/dt$, which equals i and removes the contradiction. **[1]**
Generalised (Ampere–Maxwell) law: $\Sigma B \cdot \Delta l = \mu_0 i_c + \mu_0 \varepsilon_0 \, d\Phi_E/dt$, i.e. the total current $i = i_c + i_d$ through any surface bounded by the loop is the source of B. **[1]**

Q.16

(a) $\lambda = c/\nu$. AM: $\lambda_{max} = 3 \times 10^8/(530 \times 10^3) \approx 566$ m; $\lambda_{min} = 3 \times 10^8/(1710 \times 10^3) \approx 175$ m. The AM band spans about 175 m to 566 m. **[1]**

(b) FM: $\lambda_{max} = 3 \times 10^8/(88 \times 10^6) \approx 3.4$ m; $\lambda_{min} = 3 \times 10^8/(108 \times 10^6) \approx 2.8$ m. The FM band spans about 2.8 m to 3.4 m. **[1]**

(c) The FM band needs the shorter antenna, because its wavelengths (a few metres) are much smaller than those of the AM band (hundreds of metres), and the antenna size should be comparable to the wavelength. **[1]**

SECTION D

Q.17 (Case study)

(i) **(b)** $\lambda = c/\nu = 3 \times 10^8/(2.45 \times 10^9) \approx 0.12$ m = 12 cm. **[1]**

(ii) **(c)** The frequency is selected to match the resonant frequency of water molecules, so energy from the waves is transferred efficiently to their kinetic energy. **[1]**

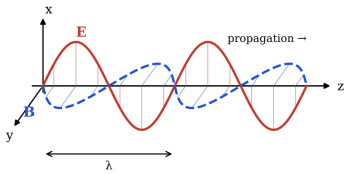
(iii) **(a)** Microwaves are produced by special vacuum tubes such as klystron or magnetron valves. **[1]**

(iv) **(b)** $E = h\nu = 6.6 \times 10^{-34} \times 2.45 \times 10^9 \approx 1.6 \times 10^{-24}$ J $= 1.6 \times 10^{-24}/1.6 \times 10^{-19} \approx 10^{-5}$ eV. **[1]**

OR (iv) (a) $B_0 = E_0/c = 600/(3 \times 10^8) = 2 \times 10^{-6}$ T. **[1]**

SECTION E

Q.18 (A)



Production: stationary charges produce only electrostatic fields and steady currents only constant magnetic fields; an accelerated (e.g. oscillating) charge produces an oscillating electric field, which produces an oscillating magnetic field, which in turn regenerates the electric field, and the wave propagates through space. Its frequency equals the frequency of oscillation of the charge. **[1]**

Nature: E and B are perpendicular to each other and to the direction of propagation (transverse waves), vary sinusoidally and in phase, and need no material medium (diagram as above). For propagation along z: $E_x = E_0 \sin(kz - \omega t)$, $B_y = B_0 \sin(kz - \omega t)$, with $k = 2\pi/\lambda$ and $\omega = ck$. **[1]**

$c = \omega/k = 1/\sqrt{(\mu_0\varepsilon_0)} = 3 \times 10^8$ m s^{-1} (speed of light, the same for all electromagnetic waves in vacuum) and $E_0/B_0 = c$. **[1]**

Numerical: $k = 2.1$ rad m^{-1} and $\omega = 6.3 \times 10^8$ rad s^{-1}. $\lambda = 2\pi/k = 6.28/2.1 \approx 3$ m; $\nu = \omega/2\pi = 6.3 \times 10^8/6.28 \approx 1 \times 10^8$ Hz = 100 MHz. **[1]**

$E_0 = cB_0 = 3 \times 10^8 \times 2 \times 10^{-7} = 60$ V/m. E is along y (since $\hat{y} \times \hat{z} = \hat{x}$): $E_y = 60 \sin(2.1\ x - 6.3 \times 10^8\ t)$ V/m. **[1]**

Q.18 (B)

1. Gauss's law for electricity: the total electric flux through a closed surface = Q/ε_0 (charges are the sources of E). **[1]**

2. Gauss's law for magnetism: the total magnetic flux through any closed surface = 0 (there are no magnetic monopoles). 3. Faraday's law: $\Sigma E \cdot \Delta l$ around a loop = $-d\Phi_B/dt$ (a changing magnetic flux produces an electric field). **[1]**

4. Ampere–Maxwell law: $\Sigma B \cdot \Delta l = \mu_0 i_c + \mu_0\varepsilon_0\, d\Phi_E/dt$ (conduction current and a changing electric flux produce a magnetic field). **[1]**

Numerical: $X_C = 1/\omega C = 1/(500 \times 80 \times 10^{-12}) = 2.5 \times 10^7\ \Omega$, so $I_{rms} = V/X_C = 150/(2.5 \times 10^7) = 6 \times 10^{-6}$ A = 6 μA. **[1]**

Peak current $i_0 = \sqrt{2}\, I_{rms} = 1.41 \times 6 = 8.46$ μA; this equals the peak displacement current. At r = 2 cm < R: $B_0 = \mu_0 i_0 r/(2\pi R^2) = (2 \times 10^{-7} \times 8.46 \times 10^{-6} \times 0.02)/(1.6 \times 10^{-3}) \approx 2.1 \times 10^{-11}$ T. **[1]**

— End of Solutions —