Class 12 Physics · Chapter 8: Electromagnetic Waves

Answer key and marking scheme · 20 marks · about 40 minutes · based on NCERT

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1. The uniform electric field between the plates of a capacitor, each of area 0.020 m^2, is increasing at the rate of 2.0×10^{12} V m^{-1} s^{-1}. Taking $\varepsilon_0 = 8.85 \times 10^{-12}$ C^2 N^{-1} m^{-2}, the displacement current between the plates is [1]

(a) 35 A
(b) 0.18 A
(c) 0.35 A
(d) zero, as no charge crosses the gap

Answer: (c) $i_d = \varepsilon_0 \, d\Phi_E/dt = \varepsilon_0 \, A \, dE/dt = 8.85 \times 10^{-12} \times 0.020 \times 2.0 \times 10^{12} \approx 0.35$ A. 0.18 A halves it; 35 A slips two powers of ten; no charge crosses the gap, but a changing field carries a displacement current.

2. One common way of producing X-rays is to [1]

(a) bombard a metal target with high-energy electrons
(b) heat a filament to a very high temperature
(c) pass a current through a semiconductor diode
(d) decay radioactive nuclei

Answer: (a) X-rays are commonly generated by bombarding a metal target with high-energy electrons, as in an X-ray tube. Hot bodies give infrared and visible light; a semiconductor diode (an LED) gives infrared or light; radioactive nuclei emit gamma rays.

3. The displacement current through a surface across which the electric flux is Φ_E is [1]

(a) $(1/\varepsilon_0) \, d\Phi_E/dt$
(b) $\mu_0\varepsilon_0 \, d\Phi_E/dt$
(c) $\varepsilon_0 \, d\Phi_B/dt$
(d) $\varepsilon_0 \, d\Phi_E/dt$

Answer: (d) $i_d = \varepsilon_0 \, d\Phi_E/dt$, the rate of change of electric flux times ε_0. $\mu_0\varepsilon_0 \, d\Phi_E/dt$ is the term as it appears in the Ampere–Maxwell law, μ_0 times the current; the magnetic flux Φ_B belongs to Faraday's law.

4. The frequency of the microwaves in a microwave oven is chosen so that [1]

(a) it matches the frequency of visible light, which food absorbs strongly
(b) the microwaves are reflected by the water in the food
(c) it matches the resonant frequency of water molecules, which take up the energy as kinetic energy
(d) it ionises the molecules of the food

Answer: (c) The oven's frequency is selected to match the resonant frequency of water molecules, so energy goes efficiently into their kinetic energy and any food containing water heats up. Microwaves are far below visible frequencies and do not ionise molecules.

5. Ritu sits all afternoon in a sunlit room behind closed glass windows, yet her skin does not tan. This is because ordinary glass [1]

(a) absorbs infrared radiation
(b) absorbs ultraviolet radiation
(c) reflects all visible light
(d) absorbs X-rays from the sun

Answer: (b) Tanning is the skin's response to ultraviolet: exposure induces more melanin. Ordinary glass absorbs ultraviolet, so the radiation that would tan her does not reach her; visible light clearly passes, since the room is sunlit.

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6. Write the Ampere–Maxwell law and state what each of the two current terms on its right side stands for. [2]

$\oint B \cdot dl = \mu_0 i_C + \mu_0 \varepsilon_0 d\Phi_E/dt$. i_C is the conduction current, the current of flowing charges, through a surface bounded by the loop; $\varepsilon_0 d\Phi_E/dt$ is the displacement current, ε_0 times the rate of change of electric flux through the same surface.

- $\oint B \cdot dl = \mu_0 i_C + \mu_0 \varepsilon_0 d\Phi_E/dt$ (1)
- i_C conduction current of moving charges; $\varepsilon_0 d\Phi_E/dt$ displacement current from the changing electric flux (1)

7. Taking $\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1} and $\varepsilon_0 = 8.85 \times 10^{-12}$ C^2 N^{-1} m^{-2}, calculate $1/\sqrt{(\mu_0 \varepsilon_0)}$ and state the significance of the result. [2]

$\mu_0 \varepsilon_0 = 4\pi \times 10^{-7} \times 8.85 \times 10^{-12} = 1.11 \times 10^{-17}$ s^2 m^{-2}; $1/\sqrt{(1.11 \times 10^{-17})} \approx 3.0 \times 10^8$ m s^{-1}. This is the speed c of electromagnetic waves in vacuum given by Maxwell's equations, equal to the measured speed of light: light is an electromagnetic wave.

- $1/\sqrt{(\mu_0 \varepsilon_0)} \approx 3.0 \times 10^8$ m s^{-1} (1)
- equals the speed of light: light is an electromagnetic wave (1)

8. Name a device that produces the microwaves in a microwave oven, and explain why the oven heats food that contains water. [2]

A magnetron (a klystron, another special vacuum tube, is also used for microwaves). The oven's frequency is chosen to match the resonant frequency of water molecules, so the energy of the waves goes efficiently into the kinetic energy of the water molecules, raising the temperature of any food containing water.

- magnetron (or klystron) (1)
- frequency matches the resonant frequency of water molecules; energy goes into their kinetic energy (1)

9. Identify the part of the electromagnetic spectrum to which each wavelength belongs, and name one detector for each: (a) 2 cm, (b) 5 µm, (c) 100 nm. [3]

(a) 2 cm lies between 0.1 m and 1 mm: microwaves, detected by point contact diodes. (b) 5 µm lies between 1 mm and 700 nm: infrared, detected by thermopiles, a bolometer or infrared photographic film. (c) 100 nm lies between 400 nm and 1 nm: ultraviolet, detected by photocells or photographic film.

- (a) microwave; point contact diode (1)
- (b) infrared; thermopile or bolometer (1)
- (c) ultraviolet; photocell or photographic film (1)

10. A capacitor is being charged by a time-varying current i(t). Using two surfaces bounded by the same circular loop round the connecting wire, show that Ampere's circuital law, $\oint B \cdot dl = \mu_0 i$, gives contradictory results. How did Maxwell remove the contradiction? [3]

Take a loop of radius r round the wire at a point P near the capacitor. For a flat surface bounded by the loop and pierced by the wire, the current through it is i(t), so $B(2\pi r) = \mu_0 i(t)$: there is a field at P. For a pot-shaped surface with the same rim whose bottom lies between the plates, no conduction current passes through it, so the law gives $B(2\pi r) = 0$. The same loop gives two answers. Maxwell added the displacement current $\varepsilon_0 d\Phi_E/dt$: through the pot-shaped surface the electric flux between the plates changes, and $\varepsilon_0 d\Phi_E/dt$ equals i, so both surfaces carry the same total current and give the same B.

- flat surface: $B(2\pi r) = \mu_0 i(t)$ (1)
- pot-shaped surface between the plates: no conduction current, B = 0, a contradiction (1)
- displacement current $\varepsilon_0 d\Phi_E/dt = i$ through the second surface restores consistency (1)

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11. A capacitor with circular plates of radius R is being charged by a current i, the electric field between the plates being uniform. Using the Ampere–Maxwell law, obtain the magnetic field at a distance r ($r \le R$) from the axis, between the plates. How does it vary from the axis to the rim? [3]

Take a circular loop of radius r coaxial with the plates. No conduction current crosses it; the displacement current through it is the fraction r^2/R^2 of the total i, since E is uniform over the plate area. So $B(2\pi r) = \mu_0 \, i \, r^2/R^2$, $B = \mu_0 \, i \, r/(2\pi R^2)$. B is zero on the axis and rises linearly with r to $\mu_0 i/(2\pi R)$ at the rim, equal to the field just outside the plates.

- displacement current through the loop = $i \, r^2/R^2$ (1)
- $B = \mu_0 \, i \, r/(2\pi R^2)$ (1)
- zero on the axis, linear rise to $\mu_0 i/(2\pi R)$ at the rim (1)

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