Physics (042)

CBSE Class 12 Board Examination 2027 – Practice Paper No. 1

Model Answer Paper

Time: 3 hours **Max. Marks: 70**

Model answers show one correct method; any other correct method gets full marks.

SECTION A Questions 1 to 16 carry 1 mark each. (Q.1–12 multiple choice; Q.13–16 assertion–reason) **[16]**

1. An electric dipole is held in a uniform electric field with its dipole moment **p** pointing exactly opposite to the field **E**. Which of the following is correct for the dipole in this position?

(A) Net force zero, torque zero; equilibrium is stable
(B) Net force zero, torque zero; equilibrium is unstable
(C) Net force non-zero, torque zero
(D) Net force zero, torque maximum (= pE)

Answer (1 mark)
(B) Net force zero, torque zero; equilibrium is unstable.
In a uniform field the forces qE and –qE cancel, so net force = 0. Torque $\tau = pE \sin 180° = 0$. The potential energy $U = -pE \cos 180° = +pE$ is maximum, so a slight tilt makes the dipole turn away: unstable equilibrium.

2. A parallel plate capacitor (air between the plates) is charged by a battery and then disconnected from it. Its stored energy is U. The gap is now completely filled with a dielectric slab of dielectric constant K = 4. The energy stored now is

(A) 4U
(B) U/4
(C) U
(D) 16U

Answer (1 mark)
(B) U/4
After disconnection the charge Q stays constant; C becomes KC = 4C. $U = Q^2/2C$, so $U' = Q^2/(2 \times 4C) = U/4$.

3. A copper wire is connected across a constant potential difference V. It is replaced by another copper wire of the same cross-section but three times the length, connected across the same V. The drift speed of the free electrons becomes

(A) 3 times
(B) one-third
(C) unchanged
(D) one-ninth

Answer (1 mark)
(B) one-third
$v_d = eE\tau/m$ and $E = V/l$. Same V, three times l ⇒ E becomes one-third ⇒ v_d becomes one-third (τ is unchanged for the same metal at the same temperature).

4. An electron and a proton enter the same uniform magnetic field with equal speeds, both moving perpendicular to the field. The ratio of the radius of the electron's circular path to that of the proton ($r_e : r_p$) is

(A) $m_p : m_e$
(B) $m_e : m_p$
(C) 1 : 1
(D) $\sqrt{m_e} : \sqrt{m_p}$

Answer (1 mark)
(B) $m_e : m_p$
$qvB = mv^2/r \Rightarrow r = mv/(qB)$. Same v, same $|q|$, same B $\Rightarrow r \propto m$.

5. A small bar of a material whose magnetic susceptibility is $\chi = -1.5 \times 10^{-5}$ is placed near one pole of a strong electromagnet (non-uniform field). The bar will

(A) move towards the stronger field; the field inside it is enhanced
(B) move towards the weaker field; the field inside it is slightly reduced
(C) be strongly attracted and remain magnetised after the current is switched off
(D) remain completely unaffected

Answer (1 mark)
(B) move towards the weaker field; the field inside it is slightly reduced.
Negative χ means a diamagnetic material: it develops a magnetic moment opposite to the applied field, so it is repelled from the strong-field region and the field lines inside it are slightly expelled.

6. An air-cored solenoid has self-inductance 2 mH. If the number of turns is doubled while its length and area of cross-section are kept the same, its self-inductance becomes

(A) 4 mH
(B) 8 mH
(C) 1 mH
(D) 16 mH

Answer (1 mark)
(B) 8 mH
$L = \mu_0 n^2 Al = \mu_0 N^2 A/l$. Doubling N (same l, A) makes L four times: 4 × 2 mH = 8 mH.

7. An ideal capacitor is connected to an ac source of fixed rms voltage and frequency 50 Hz; the rms current is 0.4 A. If the frequency of the source is changed to 200 Hz (same rms voltage), the rms current will be

(A) 0.1 A
(B) 0.4 A
(C) 0.8 A
(D) 1.6 A

Answer (1 mark)
(D) 1.6 A
$X_C = 1/(2\pi\nu C)$. Frequency × 4 $\Rightarrow X_C \div 4 \Rightarrow I = V/X_C$ becomes 4 × 0.4 A = 1.6 A.

8. Which part of the electromagnetic spectrum is used in LASIK eye surgery and is largely absorbed by the ozone layer of the atmosphere?

(A) Infrared
(B) Ultraviolet
(C) Microwaves
(D) Radio waves

Answer (1 mark)
(B) Ultraviolet
UV radiation (from very fine beams of UV lasers) is used in LASIK; most of the Sun's UV is absorbed by the ozone layer.

9. A thin convex lens of focal length 25 cm is placed in contact with a thin concave lens of focal length 40 cm. The power of the combination and its nature are

(A) +1.5 D, converging
(B) –1.5 D, diverging
(C) +6.5 D, converging
(D) –6.5 D, diverging

Answer (1 mark)
(A) +1.5 D, converging
$P = P_1 + P_2 = (100/25) + (100/(-40)) = 4 - 2.5 = +1.5$ D. Positive power ⇒ converging ($f \approx 66.7$ cm).

10. In a single-slit diffraction set-up, the slit width is halved and the light is changed from 600 nm to 450 nm. The angular width of the central maximum becomes

(A) 0.75 times
(B) 1.5 times
(C) 2 times
(D) 3 times

Answer (1 mark)
(B) 1.5 times
Angular width of central maximum = $2\lambda/a$. New/old = $(450/600) \times (a/(a/2)) = 0.75 \times 2 = 1.5$.

11. An electron and an α-particle have the same de Broglie wavelength. Which of them has the greater kinetic energy?

(A) The electron
(B) The α-particle
(C) Both have equal kinetic energy
(D) It depends on the sign of their charges

Answer (1 mark)
(A) The electron
$\lambda = h/p$, so equal $\lambda \Rightarrow$ equal momentum p. $K = p^2/2m$, so the lighter particle (electron) has the greater kinetic energy.

12. A pure silicon crystal is doped with a small amount of indium (a trivalent element). The doped crystal is

(A) n-type and negatively charged
(B) p-type and positively charged
(C) p-type and electrically neutral
(D) n-type and electrically neutral

Answer (1 mark)
(C) p-type and electrically neutral
Trivalent indium is an acceptor, so holes become majority carriers (p-type). Every added atom is neutral, so the crystal as a whole stays electrically neutral.

13. For Questions 13 to 16, two statements are given – one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer from the codes (A), (B), (C) and (D) as given below.
(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of Assertion (A).
(C) Assertion (A) is true, but Reason (R) is false.
(D) Both Assertion (A) and Reason (R) are false.

Assertion (A): Energy is released when two light nuclei such as deuterium nuclei fuse to form a heavier nucleus.
Reason (R): The binding energy per nucleon of the nucleus formed is greater than that of the fusing light nuclei.

(A) Both A and R true; R explains A
(B) Both A and R true; R does not explain A
(C) A true, R false
(D) Both A and R false

Answer (1 mark)
(A) Both A and R are true and R is the correct explanation of A.
For light nuclei, B.E. per nucleon increases with mass number; the product is more tightly

bound, and the difference in total binding energy is released.

14. **Assertion (A):** A hydrogen atom in its ground state can absorb a photon of energy 10.2 eV.
Reason (R): A hydrogen atom in its ground state can absorb a photon of any energy greater than 10.2 eV.

(A) Both A and R true; R explains A
(B) Both A and R true; R does not explain A
(C) A true, R false
(D) Both A and R false

Answer (1 mark)
(C) A is true but R is false.
$E_2 - E_1 = -3.4 - (-13.6) = 10.2$ eV, so A is true. Below the ionisation energy (13.6 eV) only photons whose energy exactly equals a level difference (10.2 eV, 12.09 eV, ...) are absorbed; e.g. an 11 eV photon is not absorbed. So R is false.

15. **Assertion (A):** The focal length of a concave mirror does not change when the mirror is immersed in water.
Reason (R): The speed of light in water is less than its speed in air.

(A) Both A and R true; R explains A
(B) Both A and R true; R does not explain A
(C) A true, R false
(D) Both A and R false

Answer (1 mark)
(B) Both A and R are true, but R is not the correct explanation of A.
$f = R/2$ depends only on the radius of curvature (law of reflection does not involve the medium), so A is true. R is a true fact, but it is about refraction and does not explain A.

16. **Assertion (A):** The work done in moving a charge between two points on an equipotential surface depends on the path followed.
Reason (R): Electric field lines are always parallel to an equipotential surface.

(A) Both A and R true; R explains A
(B) Both A and R true; R does not explain A
(C) A true, R false
(D) Both A and R false

Answer (1 mark)
(D) Both A and R are false.
$W = q(V_B - V_A) = 0$ for any path on an equipotential surface, so A is false. Field lines are always perpendicular (normal) to equipotential surfaces, so R is false.

SECTION B Questions 17 to 21 carry 2 marks each. **[10]**

17. A long, thin, straight wire carries a uniform linear charge density. The electric field at a point 25 cm from the wire is 7.2×10^4 N C^{-1}, directed away from the wire.
(i) Find the linear charge density λ of the wire.
(ii) What is the electric field at a point 75 cm from the wire?
(Take $1/4\pi\varepsilon_0 = 9 \times 10^9$ N m^2 C^{-2}.)

Answer (2 marks)
(i) For an infinitely long straight wire (Gauss's law): $E = \lambda/(2\pi\varepsilon_0 r) = 2k\lambda/r$
$\lambda = Er/(2k) = (7.2 \times 10^4 \times 0.25)/(2 \times 9 \times 10^9) = (1.8 \times 10^4)/(1.8 \times 10^{10}) = 1.0 \times 10^{-6}$ C m^{-1} = 1 μC m^{-1}.
Field points away from the wire ⇒ λ is positive: $\lambda = +1.0$ μC m^{-1}.
(ii) $E \propto 1/r$: at 75 cm (3 times farther), $E = 7.2 \times 10^4/3 = 2.4 \times 10^4$ N C^{-1}, directed away from the wire.

Marking: Formula $E = \lambda/2\pi\varepsilon_0 r$ – ½ · $\lambda = 1.0\ \mu C\ m^{-1}$ (positive) – ½ · Using $E \propto 1/r$ – ½ · $E = 2.4 \times 10^4\ N\ C^{-1}$ – ½

Examiner tip: Convert cm to m before substituting. Note the field of a line charge falls as $1/r$, not $1/r^2$.

18. Two cells of emf 1.5 V and 2.0 V, with internal resistances 0.5 Ω and 1.0 Ω respectively, are connected in parallel (positive terminal to positive terminal). This combination is connected across an external resistor of 3 Ω. Find
(i) the current through the 3 Ω resistor, and
(ii) the current through the 1.5 V cell.

Answer (2 marks)
(i) For cells in parallel:
$\varepsilon_{eq} = (\varepsilon_1 r_2 + \varepsilon_2 r_1)/(r_1 + r_2) = (1.5 \times 1.0 + 2.0 \times 0.5)/(0.5 + 1.0) = 2.5/1.5 = 5/3$ V
$r_{eq} = r_1 r_2/(r_1 + r_2) = 0.5/1.5 = 1/3\ \Omega$
$I = \varepsilon_{eq}/(R + r_{eq}) = (5/3)/(3 + 1/3) = (5/3)/(10/3) = 0.5$ A
(ii) Terminal voltage $V = IR = 0.5 \times 3 = 1.5$ V.
Current through the 1.5 V cell = $(\varepsilon_1 - V)/r_1 = (1.5 - 1.5)/0.5 = 0$. (The whole 0.5 A is supplied by the 2.0 V cell: $(2.0 - 1.5)/1.0 = 0.5$ A.)

Marking: ε_{eq} and r_{eq} – ½ + ½ · Current 0.5 A – ½ · Current in 1.5 V cell = 0 with reason – ½

Examiner tip: Kirchhoff's rules give the same result; many students forget to find the terminal voltage before finding each cell's current.

19. (A) A rod of a certain material has relative magnetic permeability $\mu_r = 1.0006$. It is placed in a uniform magnetising field of magnetic intensity $H = 5000\ A\ m^{-1}$.
(i) Find the magnetic susceptibility χ and name the type of magnetic material.
(ii) Find the magnetisation M of the rod and the magnetic field B inside it. ($\mu_0 = 4\pi \times 10^{-7}\ T\ m\ A^{-1}$)

OR

(B) State any two differences between the electric field lines of an electric dipole and the magnetic field lines of a bar magnet. Why can two magnetic field lines never intersect?

Answer (2 marks)
(A) (i) $\chi = \mu_r - 1 = 1.0006 - 1 = 6 \times 10^{-4}$. χ is small and positive ⇒ the material is paramagnetic.
(ii) $M = \chi H = 6 \times 10^{-4} \times 5000 = 3\ A\ m^{-1}$.
$B = \mu_0 \mu_r H = 4\pi \times 10^{-7} \times 1.0006 \times 5000 \approx 6.29 \times 10^{-3}$ T (about $2\pi \times 10^{-3}$ T).

OR
(B) Differences:
1. Electric field lines of a dipole start on the positive charge and end on the negative charge (open curves); magnetic field lines of a bar magnet form continuous closed loops (outside from N to S, inside the magnet from S to N).
2. Inside the dipole (between the charges) the electric field lines go from +q to –q, i.e. opposite to **p**; inside a bar magnet the magnetic field lines run from S to N, i.e. along **m**. (Equivalently: isolated charges exist, but isolated magnetic poles do not.)
Two field lines cannot intersect because at the point of intersection there would be two directions of the field (two tangents), which is impossible – the field has a unique direction at each point.

Marking: (A) $\chi = 6 \times 10^{-4}$ – ½; paramagnetic – ½; $M = 3\ A\ m^{-1}$ – ½; $B \approx 6.29 \times 10^{-3}$ T – ½ · (B) Two differences – ½ + ½; reason for no intersection – 1

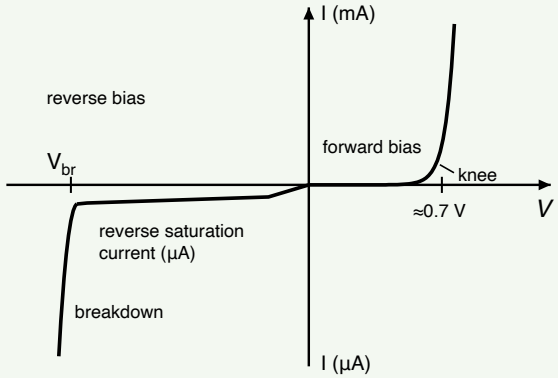
Examiner tip: Use $\mu_r = 1 + \chi$ and $M = \chi H$; do not confuse magnetisation M with magnetic moment m.

20. Draw the I–V characteristic of a silicon p-n junction diode for both forward and reverse bias. Mark the knee (threshold) voltage and the breakdown voltage. Why does the current under reverse bias remain almost constant as the reverse voltage is increased (up to breakdown)?

Answer (2 marks)

Graph: in forward bias the current is negligible up to about 0.7 V (knee voltage for Si), then rises steeply (mA). In reverse bias a very small current (μA) flows which remains nearly constant, until at the breakdown voltage V_{br} the reverse current increases suddenly.

Reason: The reverse current is due to **minority carriers** drifting across the junction. Their number depends on temperature (thermal generation), not on the applied voltage; even a small reverse voltage sweeps all of them across. So the current saturates (reverse saturation current) and stays almost constant until breakdown.



Marking: Forward characteristic with knee voltage – ½ · Reverse characteristic with breakdown voltage – ½ · Minority carriers / limited by their number – 1

Examiner tip: Use different scales: mA for forward current and μA for reverse current, and label both axes.

21. (A) Light of wavelength 414 nm falls on a metal surface whose work function is 2.0 eV. Calculate (i) the maximum kinetic energy of the emitted photoelectrons in eV, and (ii) the stopping potential.

OR

(B) An electron, initially at rest, is accelerated through a potential difference of 150 V. Calculate its de Broglie wavelength. How would the de Broglie wavelength of a proton accelerated through the same potential difference compare with it?

Answer (2 marks)

(A) Photon energy $E = hc/\lambda = (6.63 \times 10^{-34} \times 3 \times 10^{8})/(414 \times 10^{-9})$ J $= 4.80 \times 10^{-19}$ J $= (4.80 \times 10^{-19})/(1.6 \times 10^{-19})$ eV ≈ 3.0 eV

(i) $K_{max} = E - \phi_0 = 3.0 - 2.0 = 1.0$ eV

(ii) $eV_0 = K_{max} \Rightarrow V_0 = 1.0$ V

OR

(B) $\lambda = h/\sqrt{(2meV)} = 6.63 \times 10^{-34}/\sqrt{(2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 150)}$

$= 6.63 \times 10^{-34}/\sqrt{(4.368 \times 10^{-47})} = 6.63 \times 10^{-34}/(6.61 \times 10^{-24}) \approx 1.0 \times 10^{-10}$ m $= 0.1$ nm

(Using $\lambda = 1.227/\sqrt{V}$ nm $= 1.227/\sqrt{150}$ nm ≈ 0.10 nm.)

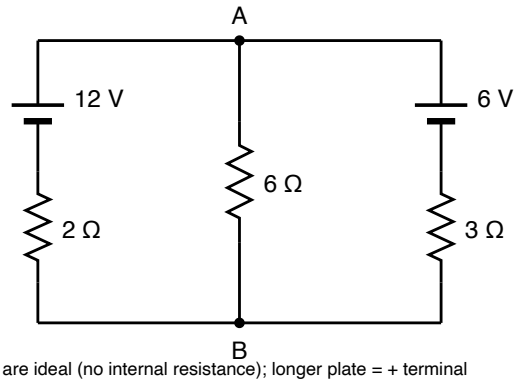
For a proton (same charge, same V): $\lambda \propto 1/\sqrt{m}$, and $m_p \gg m_e$, so the proton's wavelength is much smaller: $\lambda_p/\lambda_e = \sqrt{(m_e/m_p)} \approx 1/43$.

Marking: (A) Photon energy 3.0 eV – 1; $K_{max} = 1.0$ eV – ½; $V_0 = 1.0$ V – ½ · (B) Formula and substitution – ½ + ½; $\lambda \approx 0.1$ nm – ½; proton has smaller λ with reason – ½

Examiner tip: Convert joules to eV by dividing by 1.6×10^{-19}; stopping potential in volts equals K_{max} in eV.

SECTION C Questions 22 to 28 carry 3 marks each. **[21]**

22. In the circuit shown, the cells are ideal. Using Kirchhoff's rules, find (i) the current in each branch, stating its direction, and (ii) the potential difference $V_A - V_B$.



Cells are ideal (no internal resistance); longer plate = + terminal

For visually impaired candidates: Three branches are connected in parallel between two points A and B. Branch 1: an ideal 12 V cell (positive terminal towards A) in series with a 2 Ω resistor. Branch 2: a 6 Ω resistor only. Branch 3: an ideal 6 V cell (positive terminal towards A) in series with a 3 Ω resistor. Using Kirchhoff's rules, find the current in each branch (with direction) and $V_A - V_B$.

Answer (3 marks)

Let $V = V_A - V_B$. Take currents I_1 (up through the 12 V branch into A), I_3 (up through the 6 V branch into A) and I_2 (down through 6 Ω from A to B).

Loop/branch equations: $I_1 = (12 - V)/2$, $I_3 = (6 - V)/3$, $I_2 = V/6$

Junction rule at A: $I_1 + I_3 = I_2$

$(12 - V)/2 + (6 - V)/3 = V/6 \Rightarrow 36 - 3V + 12 - 2V = V \Rightarrow V = 8$ V

(i) $I_1 = (12 - 8)/2 = 2$ A, upward through the 12 V cell (it discharges).

$I_3 = (6 - 8)/3 = -2/3$ A $\Rightarrow$ 0.67 A flows **downward** through the 6 V cell (from + to – inside it; this cell is being charged).

$I_2 = 8/6 = 4/3$ A ≈ 1.33 A from A to B through 6 Ω.

Check: $2 - 2/3 = 4/3$ ✓

(ii) $V_A - V_B = 8$ V.

Marking: Junction rule and loop equations – 1 · Solving: V = 8 V / currents 2 A, 2/3 A, 4/3 A – 1½ · Directions (6 V cell being charged) – ½

Examiner tip: A negative answer only means the current flows opposite to the direction you assumed – state the actual direction.

23. (A) A moving coil galvanometer has a coil of resistance 99 Ω and gives full-scale deflection for a current of 10 mA.

(i) What shunt resistance is needed to convert it into an ammeter of range 0–1 A?

(ii) What resistance is needed, and how is it connected, to convert it into a voltmeter of range 0–5 V?

(iii) What is the resistance of the ammeter so formed?

OR

(B) Two long, straight, parallel wires 6 cm apart in air carry currents of 4 A and 9 A in opposite directions.

(i) Find the magnitude of the force per unit length between them and state whether it is attractive or repulsive.

(ii) Locate the point on the line joining the wires (in the plane of the wires) where the net magnetic field due to the two currents is zero. ($\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1})

Answer (3 marks)

(A) G = 99 Ω, I_g = 10 mA = 0.01 A

(i) Shunt $S = I_g G/(I - I_g) = (0.01 \times 99)/(1 - 0.01) = 0.99/0.99 = 1$ Ω, connected in parallel.

(ii) Series resistance $R = V/I_g - G = 5/0.01 - 99 = 500 - 99 = 401$ Ω, connected in series with the coil.

(iii) $R_A = GS/(G + S) = (99 \times 1)/(99 + 1) = 0.99$ Ω.

OR

(B) (i) $F/l = \mu_0 I_1 I_2/(2\pi d) = (4\pi \times 10^{-7} \times 4 \times 9)/(2\pi \times 0.06) = (2 \times 10^{-7} \times 36)/0.06 = 1.2 \times 10^{-4}$ N m^{-1}.

Currents are opposite ⇒ the force is repulsive.

(ii) Between the wires the fields of opposite currents are in the same direction, so they cannot cancel there. The null point lies outside, nearer the smaller current (4 A). Let it be at distance x from the 4 A wire (and x + 6 cm from the 9 A wire):

$\mu_0(4)/(2\pi x) = \mu_0(9)/(2\pi(x + 6)) \Rightarrow 4(x + 6) = 9x \Rightarrow x = 4.8$ cm.

The field is zero at 4.8 cm from the 4 A wire on the side away from the 9 A wire (10.8 cm from the 9 A wire).

Marking: (A) Shunt 1 Ω (parallel) – 1; 401 Ω in series – 1; ammeter resistance 0.99 Ω – 1 · (B) $F/l = 1.2 \times 10^{-4}$ N m^{-1} – ½ + ½ (repulsive); reasoning for region – ½; x = 4.8 cm – 1½

Examiner tip: State how the extra resistance is connected (shunt in parallel, multiplier in series) – this carries marks.

24. A rectangular coil of size 12 cm × 5 cm has 400 turns and a total resistance of 8 Ω. It is placed with its plane perpendicular to a uniform magnetic field directed into the plane of the page. The field decreases uniformly from 0.9 T to 0.3 T in 0.12 s. Find

(i) the magnitude of the induced emf,

(ii) the induced current and the total charge that flows through the coil, and

(iii) the direction of the induced current as seen by an observer looking at the page (field pointing away from the observer).

Answer (3 marks)

Area A = 0.12 m × 0.05 m = 6.0×10^{-3} m^2; ΔB = 0.9 – 0.3 = 0.6 T; Δt = 0.12 s

(i) $|\varepsilon| = N A \Delta B/\Delta t = 400 \times 6.0 \times 10^{-3} \times 0.6/0.12 = 12$ V

(ii) $I = \varepsilon/R = 12/8 = 1.5$ A

Charge $q = I\Delta t = 1.5 \times 0.12 = 0.18$ C (also $q = NA\Delta B/R = 400 \times 6.0 \times 10^{-3} \times 0.6/8 = 0.18$ C,

independent of how fast the field changes).
(iii) By Lenz's law the induced current opposes the decrease of the flux into the page, so it produces a field into the page inside the coil. A current that produces a field into the page (away from the observer) is **clockwise** as seen by the observer.

Marking: emf 12 V – 1 · I = 1.5 A and q = 0.18 C – ½ + ½ · Clockwise with Lenz's-law reasoning – 1

Examiner tip: Do not forget N (number of turns) in Faraday's law, and give a reason (Lenz's law) for the direction.

25. The magnetic field of a plane electromagnetic wave in vacuum is

$B_y = 2.0 \times 10^{-8} \sin(400\pi x - 1.2\pi \times 10^{11} t)$ T, with x in metre and t in second.

(i) Find the wavelength and frequency of the wave.
(ii) Find the amplitude of the electric field and state the axis along which the electric field oscillates.
(iii) Name the part of the electromagnetic spectrum to which the wave belongs and give one use of this radiation.

Answer (3 marks)

Compare with $B_y = B_0 \sin(kx - \omega t)$: $B_0 = 2.0 \times 10^{-8}$ T, $k = 400\pi$ m^{-1}, $\omega = 1.2\pi \times 10^{11}$ rad s^{-1}

(i) $\lambda = 2\pi/k = 2\pi/400\pi = 5 \times 10^{-3}$ m = 5 mm

$\nu = \omega/2\pi = 1.2\pi \times 10^{11}/2\pi = 6 \times 10^{10}$ Hz (check: $\nu\lambda = 6 \times 10^{10} \times 5 \times 10^{-3} = 3 \times 10^{8}$ m s^{-1} = c ✓)

(ii) $E_0 = cB_0 = 3 \times 10^{8} \times 2.0 \times 10^{-8} = 6$ V m^{-1}.

The wave travels along +x and **B** is along y; **E** must be perpendicular to both, so the electric field oscillates along the z-axis.

(iii) λ = 5 mm lies in the microwave region (about 1 mm to 0.1 m). Use: radar systems for aircraft navigation / microwave ovens / communication.

Marking: λ = 5 mm and $\nu = 6 \times 10^{10}$ Hz – ½ + ½ · E_0 = 6 V m^{-1} – ½; along z-axis – ½ · Microwaves – ½; one use – ½

Examiner tip: Read k and ω directly from the equation; E, B and the direction of propagation are mutually perpendicular.

26. A ray of monochromatic light passes through a glass prism of angle A. Draw a ray diagram showing the passage of the ray when the prism is in the position of minimum deviation, and derive the relation between the refractive index n of the glass, A and the angle of minimum deviation D_m.

A ray of light falls on one face of an equilateral glass prism at an angle of incidence of 45° and passes through the prism symmetrically (the emergent ray also makes 45° with the normal to the second face). Find the refractive index of the glass and the angle of minimum deviation.

Answer (3 marks)

Ray diagram: at minimum deviation the ray inside the prism is parallel to the base; i = e and $r_1 = r_2 = r$.

Derivation: In the quadrilateral formed by the two faces and the two normals, the angle between the normals = 180° – A, so in the triangle formed by the normals and the refracted ray: $r_1 + r_2 = A$.

Total deviation $\delta = (i - r_1) + (e - r_2) = i + e - A$.

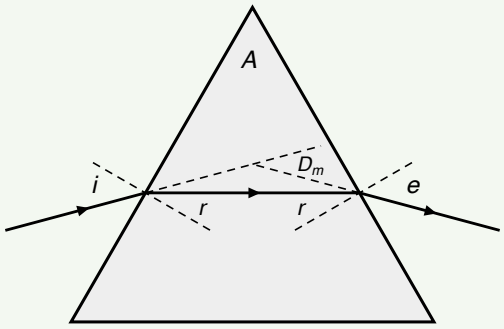
At minimum deviation i = e and $r_1 = r_2 = r \Rightarrow 2r = A \Rightarrow r = A/2$, and $D_m = 2i - A \Rightarrow i = (A + D_m)/2$.

Snell's law at the first face: $n = \sin i/\sin r = \sin[(A + D_m)/2]/\sin(A/2)$.

Numerical: symmetric passage (i = e = 45°) means the prism is in the position of minimum deviation, so r = A/2 = 30°.

$n = \sin i/\sin r = \sin 45°/\sin 30° = (1/\sqrt{2})/(1/2) = \sqrt{2} \approx 1.41$

$D_m = 2i - A = 2 \times 45° - 60° = 30°$.



i = e = 45°, r = A/2 = 30°, D_m = 30°; ray inside parallel to the base

Marking: Ray diagram at minimum deviation – ½ · $r_1 + r_2 = A$ and $\delta = i + e - A$ – ½ + ½ · Final relation – ½ · $n = \sqrt{2}$ – ½; $D_m = 30°$ – ½

Examiner tip: Show the ray inside the prism parallel to the base; write the steps $r = A/2$ and $i = (A + D_m)/2$ explicitly.

27. In a Young's double-slit experiment, the slits are 0.30 mm apart and the screen is 1.5 m from the slits. Light of wavelength 600 nm is used.
(i) Find the fringe width.
(ii) Find the distance between the second bright fringe on one side of the central bright fringe and the third dark fringe on the other side.
(iii) What will the fringe width be if the entire apparatus is immersed in water of refractive index 4/3?

Answer (3 marks)

$d = 0.30$ mm $= 3.0 \times 10^{-4}$ m, $D = 1.5$ m, $\lambda = 600$ nm $= 6.0 \times 10^{-7}$ m

(i) $\beta = \lambda D/d = (6.0 \times 10^{-7} \times 1.5)/(3.0 \times 10^{-4}) = 3.0 \times 10^{-3}$ m $= 3.0$ mm

(ii) Bright fringes are at $y = n\beta$, dark fringes at $y = (n - ½)\beta$ ($n = 1, 2, 3, \ldots$).
Second bright fringe: $2\beta = 6.0$ mm on one side; third dark fringe: $2.5\beta = 7.5$ mm on the other side.
Required distance $= 2\beta + 2.5\beta = 4.5\beta = 4.5 \times 3.0$ mm $= 13.5$ mm

(iii) In water the wavelength becomes $\lambda' = \lambda/n_w$, so $\beta' = \beta/n_w = 3.0$ mm $\times 3/4 = 2.25$ mm.

Marking: $\beta = 3.0$ mm – 1 · Positions 2β and 2.5β on opposite sides – ½; distance $4.5\beta = 13.5$ mm – ½ · $\beta' = 2.25$ mm with reason (λ decreases in water) – 1

Examiner tip: The first dark fringe is at $\beta/2$, so the third dark fringe is at $5\beta/2$, not 3β; fringes on opposite sides of the centre add.

28. In a hydrogen atom, the electron makes a transition from the orbit $n = 4$ to the orbit $n = 2$.
(i) Calculate the energy of the emitted photon in eV.
(ii) Calculate the wavelength of the emitted radiation and state the region of the spectrum.
(iii) Using Bohr's model, find the ratio of the radii and the ratio of the speeds of the electron in these two orbits ($r_4 : r_2$ and $v_4 : v_2$).

($E_n = -13.6/n^2$ eV)

Answer (3 marks)

(i) $E_4 = -13.6/16 = -0.85$ eV; $E_2 = -13.6/4 = -3.40$ eV

Photon energy $= E_4 - E_2 = -0.85 - (-3.40) = 2.55$ eV

(ii) $\lambda = hc/E = (6.63 \times 10^{-34} \times 3 \times 10^8)/(2.55 \times 1.6 \times 10^{-19}) = (1.989 \times 10^{-25})/(4.08 \times 10^{-19}) \approx 4.87 \times$

10^{-7} m ≈ 487 nm – visible region (blue-green light).

(iii) $r_n \propto n^2 \Rightarrow r_4 : r_2 = 16 : 4 = 4 : 1$

$v_n \propto 1/n \Rightarrow v_4 : v_2 = 2 : 4 = 1 : 2$

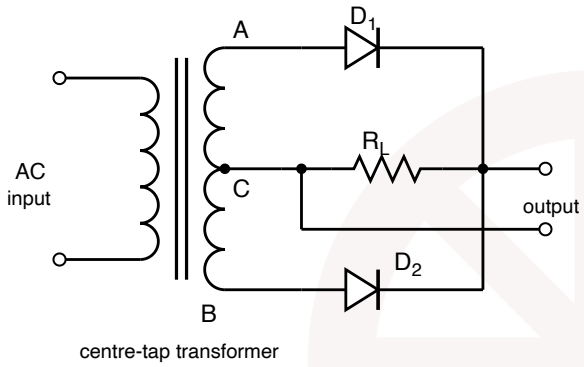
Marking: Photon energy 2.55 eV – 1 · $\lambda \approx 487$ nm, visible – ½ + ½ · $r_4 : r_2 = 4 : 1$ – ½; $v_4 : v_2 = 1 : 2$ – ½

Examiner tip: Energy of the photon is the difference of the two level energies; keep track of the negative signs.

SECTION D Questions 29 and 30 are case study based questions carrying 4 marks each. **[8]**

29. Read the following passage and answer the questions that follow.

Almost every phone charger, LED bulb driver and inverter in Indian homes converts the 230 V, 50 Hz ac mains into a low dc voltage. Inside, a step-down transformer is followed by a rectifier made of p-n junction diodes. A common design is the full-wave rectifier using a centre-tap transformer shown in the figure: the ends A and B of the secondary are connected to diodes D_1 and D_2, and the load R_L is connected between the joined diode outputs and the centre tap C. The rectified output is pulsating, so a large capacitor is connected across R_L to smooth it before it reaches the phone battery.



(i) During the half-cycle in which end A of the secondary is positive with respect to the centre tap C,

(A) D_1 is reverse biased and D_2 is forward biased

(B) D_1 is forward biased and D_2 is reverse biased

(C) both D_1 and D_2 are forward biased

(D) both D_1 and D_2 are reverse biased

(ii) When the forward bias voltage across a p-n junction is increased, the depletion layer

(A) becomes wider and the barrier potential increases

(B) becomes wider and the barrier potential decreases

(C) becomes narrower and the barrier potential decreases

(D) remains unchanged

(iii) A large capacitor is connected across the load R_L because

(A) it blocks the dc and passes only the ripple to the load

(B) it charges to nearly the peak voltage and discharges only slowly through R_L

(C) it increases the peak value of the output voltage above the peak of the secondary voltage

(D) it makes the diodes conduct during both half-cycles

(iv) In a charger built with this circuit, diode D_2 burns out and becomes an open circuit. Describe the output across R_L (without the capacitor) and state the frequency of the output pulses when the input is 50 Hz.

Answer (4 marks)

(i) (B) D_1 is forward biased and D_2 is reverse biased. (When A is positive w.r.t. C, B is negative w.r.t. C.)

(ii) (C) becomes narrower and the barrier potential decreases. (Forward bias opposes the built-in barrier.)

(iii) (B) The capacitor charges to nearly the peak voltage and, because the time constant CR_L is large, discharges only a little before the next pulse; so the output is nearly steady dc close to the peak value.

(iv) Only D_1 conducts (during the half-cycles when A is positive), so the circuit works as a half-wave rectifier: output pulses appear only in alternate half-cycles with gaps in between. The output pulses repeat at 50 Hz (instead of 100 Hz for the full-wave circuit).

Marking: (i) – 1 · (ii) – 1 · (iii) – 1 · (iv) Half-wave output – ½; 50 Hz – ½

Examiner tip: In the centre-tap circuit the two ends of the secondary are always in opposite phase with respect to the centre tap – only one diode conducts at a time.

30. Read the following passage and answer the questions that follow.

The Tarapur Atomic Power Station in Palghar district, Maharashtra, was India's first nuclear power station. In its reactors, a slow neutron is absorbed by a uranium-235 nucleus, which splits into two medium-mass fragments (for example barium and krypton) and two or three neutrons. About 200 MeV of energy is released in each fission, mostly as kinetic energy of the fragments, and is finally converted into heat that produces steam to run the turbines. The neutrons released can cause further fissions, and the rate of fission in the reactor is kept under control. The nuclei involved are held together by the nuclear force, and their sizes follow $R = R_0A^{1/3}$.

(i) How many fissions per second are needed to produce a thermal power of 160 MW, if each fission releases 200 MeV? (1 eV = 1.6×10^{-19} J)

(A) 5×10^{15}

(B) 5×10^{18}

(C) 8×10^{18}

(D) 2×10^{20}

(ii) Energy is released in the fission of a heavy nucleus like ^{235}U because

(A) the fragments have a larger binding energy per nucleon than the uranium nucleus

(B) the fragments have a smaller binding energy per nucleon than the uranium nucleus

(C) the total number of nucleons decreases in fission

(D) neutrons are converted completely into energy

(iii) Which of the following is **not** a property of the nuclear force?

(A) It is much stronger than the electrostatic force between protons at nuclear distances.

(B) It is short-ranged (a few femtometres).

(C) It acts only between protons and is absent between neutrons.

(D) It becomes repulsive when the nucleons are closer than about 0.8 fm.

(iv) What is the ratio of the nuclear mass densities of ^{235}U and a ^{92}Kr fragment? Give a reason.

Answer (4 marks)

(i) (B) 5×10^{18}

Energy per fission = $200 \times 10^6 \times 1.6 \times 10^{-19}$ J = 3.2×10^{-11} J; number per second = $160 \times 10^6/(3.2 \times 10^{-11}) = 5 \times 10^{18}$ s^{-1}.

(ii) (A) The medium-mass fragments lie near the peak of the B.E./A curve (about 8.5 MeV) while ^{235}U has about 7.6 MeV per nucleon; the increase in total binding energy is released.

(iii) (C) The nuclear force is (nearly) charge-independent: it acts between proton–proton, proton–neutron and neutron–neutron alike.

(iv) 1 : 1. Nuclear volume $\propto R^3 = R_0{}^3A$, and mass $\propto A$, so density = mass/volume is independent of A – all nuclei have (nearly) the same density.

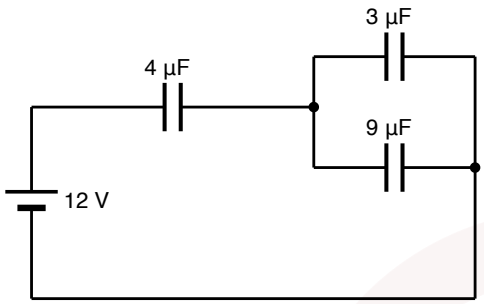
Marking: (i) – 1 · (ii) – 1 · (iii) – 1 · (iv) 1 : 1 – ½; reason – ½

Examiner tip: Convert MeV to joule before dividing the power by the energy per fission.

SECTION E Questions 31 to 33 carry 5 marks each. **[15]**

31. (A) (i) Derive an expression for the electric potential at a point at distance r from the centre of a short electric dipole of dipole moment p, the line joining the point to the centre making an angle θ with the dipole axis ($r \gg a$). Hence write the potential at a point on (a) the axial line and (b) the equatorial line.

(ii) In the network shown in the figure below, a 4 μF capacitor is connected in series with a parallel combination of 3 μF and 9 μF capacitors across a 12 V battery. Find the equivalent capacitance of the network and the charge on the 9 μF capacitor.



OR

(B) (i) Using Gauss's law, obtain the expression for the electric field due to a uniformly charged thin spherical shell of radius R carrying charge q at a point (a) outside the shell and (b) inside the shell.

(ii) A thin spherical shell of radius 10 cm carries a charge of 4.0 nC uniformly distributed over it. Find the electric field at points 6 cm and 30 cm from its centre, and the electric potential at its centre. (Take $1/4\pi\varepsilon_0 = 9 \times 10^9$ N m^2 C^{-2}.)

Answer (5 marks)

(A) (i) Let charges –q at A and +q at B, separation 2a, dipole moment p = q × 2a along A→B. P is at distance r from centre O, ∠POB = θ; r_1 = BP, r_2 = AP.

$V = (1/4\pi\varepsilon_0)(q/r_1 - q/r_2)$

$r_1{}^2 = r^2 + a^2 - 2ar\cos\theta$, $r_2{}^2 = r^2 + a^2 + 2ar\cos\theta$

For $r \gg a$ (keep terms of first order in a/r): $1/r_1 \cong (1/r)(1 + (a/r)\cos\theta)$, $1/r_2 \cong (1/r)(1 - (a/r)\cos\theta)$

$V = (q/4\pi\varepsilon_0) \times (2a\cos\theta)/r^2 = p\cos\theta/(4\pi\varepsilon_0 r^2)$ $(= \mathbf{p}\cdot\hat{\mathbf{r}}/4\pi\varepsilon_0 r^2)$

(a) Axial line (θ = 0° or 180°): $V = \pm p/(4\pi\varepsilon_0 r^2)$

(b) Equatorial line (θ = 90°): V = 0

(ii) 3 μF ∥ 9 μF = 12 μF. In series with 4 μF: $1/C = 1/4 + 1/12 = 4/12 \Rightarrow C_{eq} = 3$ μF.

Total charge $Q = C_{eq}V = 3$ μF × 12 V = 36 μC (same on 4 μF and on the 12 μF combination).

p.d. across the parallel pair = 36 μC/12 μF = 3 V ⇒ charge on 9 μF = 9 μF × 3 V = 27 μC.

OR

(B) (i) (a) Outside (r > R): take a concentric Gaussian sphere S_1 of radius r. By symmetry E is radial and has the same magnitude at every point of S_1.

Flux $= E \times 4\pi r^2 = q/\varepsilon_0 \Rightarrow E = q/(4\pi\varepsilon_0 r^2)$, directed radially outward for q > 0 – as if the whole

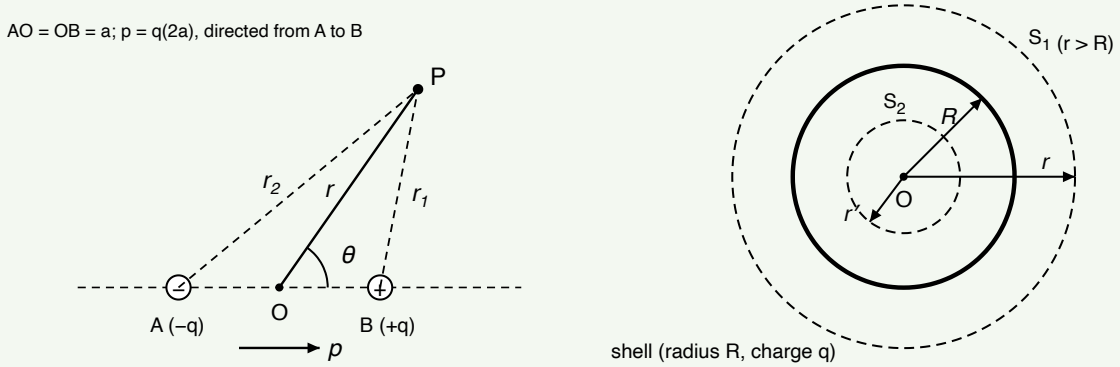
charge were at the centre.

(b) Inside ($r' < R$): Gaussian sphere S_2 of radius r' encloses no charge $\Rightarrow E \times 4\pi r'^2 = 0 \Rightarrow E = 0$ everywhere inside the shell.

(ii) 6 cm < R $\Rightarrow$ E = 0.

30 cm > R $\Rightarrow E = kq/r^2 = (9 \times 10^9 \times 4.0 \times 10^{-9})/(0.30)^2 = 36/0.09 = 400$ N C^{-1} (radially outward).

Inside the shell E = 0, so the potential is the same everywhere inside and equals that on the surface: $V_{centre} = kq/R = 36/0.10 = 360$ V.



Marking: (A)(i) Diagram and $V = (q/4\pi\varepsilon_0)(1/r_1 - 1/r_2)$ – 1; approximation and result $p\cos\theta/4\pi\varepsilon_0 r^2$ – 1½; axial and equatorial cases – ½ · (A)(ii) C_{eq} = 3 µF – 1; charge on 9 µF = 27 µC – 1 · (B)(i) Gaussian surface and flux for r > R – 1½; E = 0 inside – 1½ · (B)(ii) E = 0 and 400 N C^{-1} – ½ + ½; V = 360 V with reason – 1

Examiner tip: Draw the figure for every derivation and state the approximation $r \gg a$ clearly; in (ii) the 4 µF and 12 µF combination carry the same charge.

32. (A) (i) A spherical refracting surface of radius of curvature R separates a rarer medium of refractive index n_1 from a denser medium of refractive index n_2. With a ray diagram, derive the relation $n_2/v - n_1/u = (n_2 - n_1)/R$ for a point object on the principal axis in the rarer medium forming a real image in the denser medium.

(ii) A thin biconvex lens of glass (refractive index 1.5) has radii of curvature 20 cm and 30 cm. Find its focal length in air and when it is completely immersed in a transparent liquid of refractive index 1.25. Does it remain a converging lens?

OR

(B) (i) Draw a labelled ray diagram of a refracting astronomical telescope in normal adjustment (final image at infinity) and obtain the expression for its magnifying power.

(ii) A small refracting telescope has an objective of focal length 120 cm and an eyepiece of focal length 4 cm. Find its magnifying power and the separation between the objective and the eyepiece in normal adjustment. If the Moon subtends an angle of 0.5° at the objective, what angle does its final image subtend at the eye?

Answer (5 marks)

(A) (i) Let the convex surface have pole P and centre C. A ray from O strikes the surface at N, NM ⊥ principal axis; NC is the normal; the refracted ray meets the axis at I. Let ∠NOM = α, ∠NCM = β, ∠NIM = γ; i = angle of incidence, r = angle of refraction.

For small apertures: tan α ≈ α = MN/OM, β ≈ MN/MC, γ ≈ MN/MI.

In △NOC (exterior angle): i = α + β. In △NCI: β = r + γ $\Rightarrow$ r = β – γ.

Snell's law for small angles: $n_1 i = n_2 r \Rightarrow n_1(\alpha + \beta) = n_2(\beta - \gamma)$

$\Rightarrow n_1/OM + n_2/MI = (n_2 - n_1)/MC$

With M ≈ P (thin aperture) and the Cartesian sign convention: OM = –u, MI = +v, MC = +R:

$n_2/v - n_1/u = (n_2 - n_1)/R$

(ii) In air (lens maker's formula): $1/f = (n - 1)(1/R_1 - 1/R_2) = (1.5 - 1)(1/20 + 1/30) = 0.5 \times (5/60) = 1/24 \Rightarrow f = 24$ cm

In the liquid: relative index $n_{gl} = 1.5/1.25 = 1.2$.

$1/f_l = (1.2 - 1)(1/20 + 1/30) = 0.2 \times (1/12) = 1/60 \Rightarrow f_l = +60$ cm. Since $n_{glass} > n_{liquid}$, f is still positive: the lens remains converging (but weaker).

OR

(B) (i) Ray diagram: parallel rays from a distant object, inclined at angle α to the axis, are focused by the objective at A′B′ in its focal plane; A′B′ lies at the focus of the eyepiece, so the rays emerge parallel at angle β and the final image is at infinity.

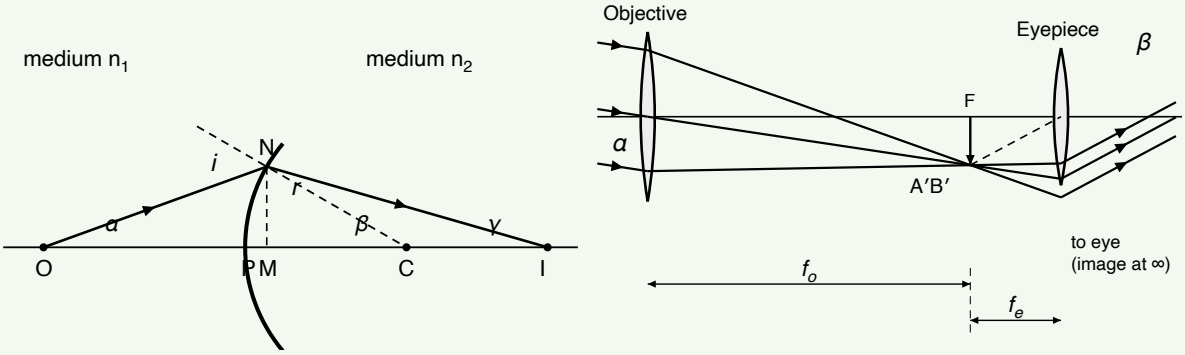
Magnifying power m = β/α. For small angles: $\alpha \approx \tan\alpha = h/f_o$, $\beta \approx \tan\beta = h/f_e$ (h = A′B′).

$m = \beta/\alpha = f_o/f_e$; length of telescope (tube) = $f_o + f_e$.

(ii) $m = f_o/f_e = 120/4 = 30$.

Separation = $f_o + f_e = 120 + 4 = 124$ cm.

Angle subtended by the final image $\beta = m\alpha = 30 \times 0.5° \approx 15°$ (small-angle approximation, $m = \beta/\alpha$).



Marking: (A)(i) Ray diagram – 1; angle relations and Snell's law – 1; final relation with sign convention – 1 · (A)(ii) f = 24 cm – 1; f_l = 60 cm, still converging – 1 · (B)(i) Labelled ray diagram – 1½; $m = f_o/f_e$ – 1½ · (B)(ii) m = 30 – ½; separation 124 cm – ½; angle ≈ 15° – 1

Examiner tip: In the derivation, apply the sign convention only at the end; in the liquid use the refractive index of glass relative to the liquid.

33. (A) (i) A resistor R, an inductor L and a capacitor C are connected in series to an ac source $v = v_m \sin\omega t$. Draw the phasor diagram (take $V_L > V_C$) and obtain the expression for the impedance of the circuit and the phase difference between the voltage and the current.

(ii) A series circuit has R = 400 Ω, L = 0.4 H and C = 10 μF. It is connected to an ac source of rms voltage 250 V and angular frequency 1000 rad s^{-1}. Find the impedance, the rms current, the power factor, the average power consumed, and the angular frequency at which resonance would occur.

OR

(B) (i) State the principle of an ac generator. With a labelled diagram, explain its working and show that the emf induced in its coil is $e = NBA\omega \sin\omega t$.

(ii) A rectangular coil of 100 turns, each of area 0.05 m^2, rotates at 50 revolutions per second about an axis perpendicular to a uniform magnetic field of 0.07 T. Find the peak value and the rms value of the induced emf. (Take π = 22/7.)

Answer (5 marks)

(A) (i) The same current $i = i_m \sin(\omega t - \phi)$ flows through R, L and C (ϕ = angle by which the voltage leads the current). Phasors: $V_R = i_m R$ in phase with I; $V_L = i_m X_L$ leading I by 90°; V_C =

$i_m X_C$ lagging I by 90°. V_L and V_C are opposite, so their resultant is $(V_L - V_C)$ perpendicular to V_R.

$v_m^2 = V_R^2 + (V_L - V_C)^2 = i_m^2[R^2 + (X_L - X_C)^2]$

$\Rightarrow i_m = v_m/Z$, with impedance $Z = \sqrt{[R^2 + (X_L - X_C)^2]}$, $X_L = \omega L$, $X_C = 1/\omega C$

Phase difference: $\tan\phi = (X_L - X_C)/R$; for $X_L > X_C$ the voltage leads the current by ϕ. (NCERT writes $i = i_m \sin(\omega t + \phi)$ with $\tan\phi = (X_C - X_L)/R$ – the same result.)

(ii) $X_L = \omega L = 1000 \times 0.4 = 400\ \Omega$; $X_C = 1/\omega C = 1/(1000 \times 10 \times 10^{-6}) = 100\ \Omega$

$Z = \sqrt{(400^2 + 300^2)} = 500\ \Omega$

$I_{rms} = 250/500 = 0.5$ A

Power factor $\cos\phi = R/Z = 400/500 = 0.8$ (current lags the voltage, since $X_L > X_C$)

$P = V_{rms} I_{rms} \cos\phi = 250 \times 0.5 \times 0.8 = 100$ W (check: $I^2R = 0.25 \times 400 = 100$ W ✓)

Resonance: $\omega_0 = 1/\sqrt{(LC)} = 1/\sqrt{(0.4 \times 10 \times 10^{-6})} = 1/(2 \times 10^{-3}) = 500$ rad s^{-1}.

OR

(B) (i) Principle: electromagnetic induction – when a coil rotates in a uniform magnetic field, the magnetic flux linked with it changes continuously and an emf is induced in it.

Construction/working: a coil (armature) is rotated about an axis perpendicular to a uniform field B between the poles of a magnet; its ends are connected to slip rings that rotate with it; carbon brushes pressing on the rings take the current to the external load. As the coil rotates, the induced current reverses direction every half rotation, giving alternating current.

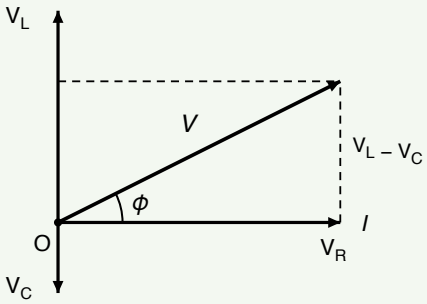
Derivation: if the normal to the coil makes angle $\theta = \omega t$ with B, flux linkage $\Phi_B = NBA\cos\omega t$.

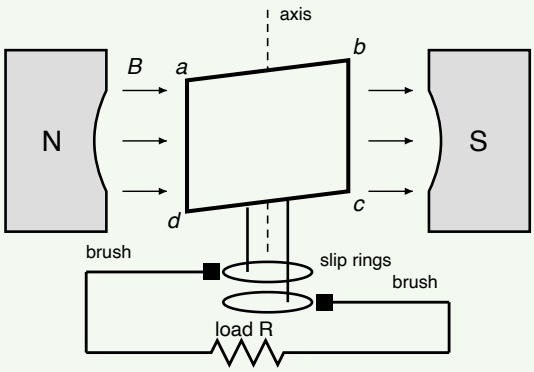
$e = -d\Phi_B/dt = NBA\omega \sin\omega t = e_0 \sin\omega t$, where $e_0 = NBA\omega$ is the peak emf (when the plane of the coil is parallel to B).

(ii) $\omega = 2\pi\nu = 2 \times (22/7) \times 50 = 2200/7$ rad s^{-1}

$e_0 = NBA\omega = 100 \times 0.07 \times 0.05 \times 2200/7 = 0.35 \times 2200/7 = 110$ V

$e_{rms} = e_0/\sqrt{2} = 110/1.414 \approx 77.8$ V





Marking: (A)(i) Phasor diagram – 1; $Z = \sqrt{(R^2 + (X_L - X_C)^2)}$ and $\tan\phi$ – 1 · (A)(ii) Z = 500 Ω and I = 0.5 A – 1; power factor 0.8 and P = 100 W – ½ + ½; resonance $\omega_0 = 500$ rad s^{-1} – 1 · (B)(i) Principle – ½; labelled diagram – 1; working – ½; derivation of $e = NBA\omega \sin\omega t$ – 1 · (B)(ii) $e_0 = 110$ V – 1½; $e_{rms} \approx 77.8$ V – ½

Examiner tip: Always show V_R along the current phasor; in numericals find X_L and X_C first, then Z.

All the best for your exam!