Physics

HSC Board Exam February–March 2027 – Practice Paper No. 2

Model Answer Paper

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

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

SECTION A – Q.1 Select and write the correct answer for the following multiple choice type of questions: **[10]**

(i) A kathak dancer spinning on one heel draws her arms close to her body, so that her moment of inertia becomes 3/4 of its initial value. Her rotational kinetic energy becomes _____ times its initial value.

(A) 3/4 (B) 4/3
(C) 9/16 (D) 16/9

Answer (1 mark)
(B) 4/3
No external torque, so angular momentum L is conserved. $K.E._{rot} = L^2/2I$. With $I' = 3I/4$, $K.E.' = L^2/(2 \times 3I/4) = (4/3)$ K.E.

(ii) A soap bubble and a liquid drop have the same radius R and the same surface tension T. The ratio of the excess pressure inside the soap bubble to that inside the liquid drop is _____.

(A) 1 : 2 (B) 2 : 1
(C) 1 : 1 (D) 4 : 1

Answer (1 mark)
(B) 2 : 1
A soap bubble has two free surfaces: excess pressure = 4T/R. A drop has one: excess pressure = 2T/R. Ratio = 2 : 1.

(iii) According to the law of equipartition of energy, the ratio $\gamma = C_p/C_v$ for a rigid diatomic ideal gas is _____.

(A) 5/3 (B) 7/5
(C) 4/3 (D) 9/7

Answer (1 mark)
(B) 7/5
A rigid diatomic molecule has 5 degrees of freedom (3 translational + 2 rotational): $C_v = 5R/2$, $C_p = C_v + R = 7R/2$, so $\gamma = 7/5$.

(iv) In an isochoric process, the heat supplied to an ideal gas is used _____.

(A) only to do external work (B) only to increase the internal energy
(C) partly to do work and partly to increase the internal energy (D) neither to do work nor to change the internal energy

Answer (1 mark)
(B) only to increase the internal energy
Volume is constant, so $W = p\Delta V = 0$ and the first law gives $Q = \Delta U$.

(v) For the air column in a pipe open at both ends, the frequencies of the first three harmonics are in the ratio _____.

(A) 1 : 3 : 5 (B) 1 : 2 : 3

(C) 1 : 2 : 4 (D) 1 : 4 : 9

Answer (1 mark)
(B) 1 : 2 : 3
Both ends are antinodes, so $n_p = pv/2L$ with p = 1, 2, 3, ... – all harmonics are present.

(vi) A point charge q is placed at the centre of a cube. The electric flux through any one face of the cube is _____.

(A) q/ε_0 (B) $q/6\varepsilon_0$

(C) $6q/\varepsilon_0$ (D) zero

Answer (1 mark)
(B) $q/6\varepsilon_0$
By Gauss' law the total flux through the closed cube is q/ε_0; by symmetry it divides equally among the 6 faces.

(vii) In a balanced Wheatstone's network, the positions of the cell and the galvanometer are interchanged. The balance _____.

(A) is disturbed (B) is not disturbed

(C) is disturbed only if the galvanometer resistance is large (D) is obtained only if all four resistances are equal

Answer (1 mark)
(B) is not disturbed
The balancing condition P/Q = R/S becomes P/R = Q/S after the interchange, which is the same condition.

(viii) A straight conductor moves perpendicular to a uniform magnetic field. If its speed is doubled and the magnetic induction is halved, the induced emf across its ends _____.

(A) is doubled (B) is halved

(C) remains unchanged (D) becomes four times

Answer (1 mark)
(C) remains unchanged
e = Blv; (B/2) × l × (2v) = Blv.

(ix) The lines of the Balmer series of the hydrogen spectrum lie mainly in the _____ region.

(A) ultraviolet (B) visible

(C) infrared (D) microwave

Answer (1 mark)
(B) visible
Balmer lines are emitted when the electron jumps to n = 2 from higher orbits; Hα (656 nm), Hβ, Hγ ... lie in the visible region.

(x) The output of a two-input NOR gate is 1 only when _____.

(A) both inputs are 1 (B) both inputs are 0

(C) only input A is 1 (D) the two inputs are different

Answer (1 mark)
(B) both inputs are 0
Y = NOT (A + B), the complement of A + B. A + B = 0 only for A = B = 0, so Y = 1 only then.

Q.2 Answer the following questions: **[8]**

(i) What is the coefficient of absorption (absorptive power) of a perfect blackbody?

Answer (1 mark)
a = 1
A perfect blackbody absorbs all the radiation incident on it (r = 0, t = 0).

(ii) Write the differential equation of linear S.H.M.

Answer (1 mark)
$d^2x/dt^2 + \omega^2 x = 0$ ($\omega^2 = k/m$).

(iii) What is the phase difference between any two points on the same wavefront?

Answer (1 mark)
Zero – all points on a wavefront vibrate in the same phase.

(iv) Write the SI unit of magnetic dipole moment.

Answer (1 mark)
A m^2 (ampere metre^2), equivalently J/T.

(v) What is the magnetic susceptibility of a superconductor?

Answer (1 mark)
$\chi = -1$ (a superconductor is a perfect diamagnet; $\mu_r = 0$).

(vi) What is the power factor of a purely resistive a.c. circuit?

Answer (1 mark)
1 (unity), since $\phi = 0$ and $\cos\phi = 1$.

(vii) Define threshold frequency.

Answer (1 mark)
Threshold frequency of a metal is the minimum frequency of incident radiation below which no photoelectrons are emitted from it, however intense the radiation may be.

(viii) Which type of breakdown occurs in a heavily doped Zener diode?

Answer (1 mark)
Zener breakdown (the depletion layer of a heavily doped diode is very narrow, so breakdown occurs at a low reverse voltage, below about 6 V).

SECTION B Attempt any EIGHT questions of the following: (2 marks each) **[16]**

Q.3 A flyover in Pune has a curved section of radius 90 m. The road is to be banked so that a car moving at 54 km/h can go round the curve without depending on friction. Find the required angle of banking. ($g = 10\ m/s^2$)

Answer (2 marks)
v = 54 km/h = 54 × 5/18 = 15 m/s
For a banked road (no friction): $\tan\theta = v^2/(rg)$

$\tan\theta = (15)^2/(90 \times 10) = 225/900 = 0.25$

$\theta = \tan^{-1}(0.25) \approx 14°2'$ (about 14°)

Marking: Conversion to 15 m/s and $\tan\theta = v^2/rg$ – 1 mark · $\tan\theta = 0.25$, $\theta \approx 14°$ – 1 mark

Examiner tip: Convert km/h to m/s before squaring; $54^2/(90 \times 10)$ gives a meaningless angle.

Q.4 State Bernoulli's principle. Using it, explain how an aeroplane wing gets an upward force (dynamic lift).

Answer (2 marks)

Bernoulli's principle: For the streamline flow of an ideal (incompressible, non-viscous) fluid, the sum of the pressure, the kinetic energy per unit volume and the potential energy per unit volume remains constant along a streamline:

$p + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$.

Dynamic lift: The wing (aerofoil) is curved more on its upper surface and is slightly tilted. The streamlines of air crowd together above the wing, so air flows faster above it than below it. The height difference is negligible, so by Bernoulli's principle the pressure above the wing is less than the pressure below it. This pressure difference multiplied by the wing area gives a net upward force called dynamic lift.

Marking: Statement of Bernoulli's principle (with equation) – 1 mark · Faster flow above → lower pressure above → upward force – 1 mark

Examiner tip: Say clearly WHERE the speed is higher and therefore where the pressure is lower; 'air pushes the wing up' alone earns nothing.

Q.5 Find (a) the average translational kinetic energy of a helium molecule at 27 °C and (b) the total translational kinetic energy of 2 mol of helium gas at that temperature. ($k_B = 1.38 \times 10^{-23}$ J/K, R = 8.31 J/mol K)

Answer (2 marks)

T = 27 + 273 = 300 K

(a) Average translational K.E. per molecule = $(3/2)\,k_BT = 1.5 \times 1.38 \times 10^{-23} \times 300$

$= 6.21 \times 10^{-21}$ J

(b) Total translational K.E. of n moles = $(3/2)\,nRT = 1.5 \times 2 \times 8.31 \times 300$

$= 7479\text{ J} \approx 7.48 \times 10^3$ J

Marking: (a) $(3/2)k_BT = 6.21 \times 10^{-21}$ J – 1 mark · (b) $(3/2)nRT = 7.48 \times 10^3$ J – 1 mark

Examiner tip: Use the absolute temperature 300 K, not 27.

Q.6 One mole of an ideal monatomic gas is heated at constant pressure from 300 K to 350 K. Find (a) the work done by the gas, (b) the increase in its internal energy and (c) the heat supplied to it. (R = 8.31 J/mol K)

Answer (2 marks)

$\Delta T = 50$ K

(a) At constant pressure, $W = p\Delta V = nR\Delta T = 1 \times 8.31 \times 50 =$ **415.5 J**

(b) For a monatomic gas $C_V = 3R/2$: $\Delta U = nC_V\Delta T = 1.5 \times 8.31 \times 50 =$ **623.25 J**

(c) First law: $Q = \Delta U + W = 623.25 + 415.5 =$ **$1038.75\text{ J} \approx 1.04 \times 10^3$ J**

Marking: $W = nR\Delta T = 415.5$ J – ½ mark · $\Delta U = (3/2)nR\Delta T = 623.25$ J – 1 mark · $Q = \Delta U + W = 1038.75$ J – ½ mark

Examiner tip: ΔU of an ideal gas always uses C_V, even when the process is at constant pressure.

Q.7 A block of mass 0.5 kg is attached to a light horizontal spring of force constant 50 N/m and oscillates on a smooth table. Find its period. What will the period be if the block is replaced by one of mass 2 kg? (π = 3.14)

Answer (2 marks)

$T = 2\pi\sqrt{(m/k)} = 2 \times 3.14 \times \sqrt{(0.5/50)} = 6.28 \times 0.1$

$T = 0.628$ s

$T \propto \sqrt{m}$: $T' = T\sqrt{(2/0.5)} = 0.628 \times 2$

$T' = 1.256$ s

Marking: $T = 2\pi\sqrt{(m/k)} = 0.628$ s – 1 mark · $T' = 1.256$ s – 1 mark

Examiner tip: The period depends on mass and force constant only, not on amplitude.

Q.8 Unpolarised light of intensity 32 W/m^2 falls on a polariser. The light coming out of it passes through an analyser whose transmission axis makes an angle of 30° with that of the polariser. (a) Find the intensity of light emerging from the analyser. (b) At what angle to the polariser's axis should the analyser be set so that the emerging intensity is 4 W/m^2?

Answer (2 marks)

After the polariser: $I_1 = I_0/2 = 32/2 = 16$ W/m^2

(a) Malus' law: $I = I_1 \cos^2\theta = 16 \times \cos^2 30° = 16 \times 3/4 =$ **12 W/m^2**

(b) $4 = 16 \cos^2\theta \Rightarrow \cos^2\theta = 1/4 \Rightarrow \cos\theta = 1/2 \Rightarrow$ **$\theta = 60°$**

Marking: $I_1 = I_0/2$ and $I = 12$ W/m^2 – 1 mark · $\theta = 60°$ – 1 mark

Examiner tip: The polariser halves the intensity of unpolarised light; Malus' law applies only after that.

Q.9 Capacitors of 6 μF and 3 μF are connected in series, and this pair is connected in parallel with a 4 μF capacitor. The combination is connected to a 12 V battery. Find (a) the equivalent capacitance and (b) the charge on the 6 μF capacitor.

Answer (2 marks)

(a) Series pair: $1/C_s = 1/6 + 1/3 = 1/2 \Rightarrow C_s = 2$ μF

Parallel with 4 μF: **$C_{eq} = 2 + 4 = 6$ μF**

(b) The series pair has 12 V across it; charge on each capacitor of the pair = $C_sV = 2 \times 12$

$Q = 24$ μC on the 6 μF capacitor (same as on the 3 μF).

Marking: $C_s = 2$ μF, $C_{eq} = 6$ μF – 1 mark · $Q = 24$ μC – 1 mark

Examiner tip: Capacitors in series carry the same charge; do not use 6 μF × 12 V.

Q.10 In a metre bridge experiment, an unknown resistance X is in the left gap and a 12 Ω resistance in the right gap. The null point is at 40 cm from the left end. Find X. Where will the null point be if X and the 12 Ω resistance are interchanged?

Answer (2 marks)

At balance: $X/R = l_X/(100 - l_X)$

$X = 12 \times 40/60 =$ **8 Ω**

After interchanging, $12/8 = l/(100 - l) \Rightarrow 12(100 - l) = 8l \Rightarrow l = 60$ cm

Null point at 60 cm from the left end (40 cm from the right end).

Marking: X = 8 Ω – 1 mark · Null point at 60 cm – 1 mark

Examiner tip: Lengths in the ratio must be measured from the ends of the gaps on the same sides as the resistances.

Q.11 The two long, straight, parallel conductors of a battery cable are 2.5 cm apart and carry currents of 25 A each in opposite directions. Find the force per unit length on each conductor and state whether it is attractive or repulsive. ($\mu_0 = 4\pi \times 10^{-7}$ Wb/A m)

Answer (2 marks)

$F/l = \mu_0 I_1 I_2/(2\pi d) = (4\pi \times 10^{-7} \times 25 \times 25)/(2\pi \times 0.025)$

$= 2 \times 10^{-7} \times 625/0.025$

$F/l = 5 \times 10^{-3}$ N/m

Currents are in opposite directions, so the force is **repulsive**.

Marking: Formula and substitution, $F/l = 5 \times 10^{-3}$ N/m – 1 mark · Repulsive (opposite currents) – 1 mark

Examiner tip: Like currents attract and unlike currents repel – the reverse of the rule for charges.

Q.12 A d.c. motor with armature resistance 2 Ω is connected to a 220 V d.c. supply. When running at normal speed it draws a current of 10 A. Find (a) the back emf at normal speed and (b) the current at the instant the motor is switched on.

Answer (2 marks)

(a) The back emf e_b opposes the supply voltage, so by Kirchhoff's voltage law for the armature circuit: $V - e_b = IR$

$e_b = 220 - 10 \times 2 =$ **200 V**

(b) At switching on, the armature is at rest, so $e_b = 0$:

$I = V/R = 220/2 =$ **110 A**

(This large starting current is why motors are started through a starter resistance.)

Marking: $e_b = 200$ V – 1 mark · Starting current 110 A ($e_b = 0$) – 1 mark

Examiner tip: Back emf is zero at start because it is produced only when the coil rotates.

Q.13 A capacitor of capacitance $(125/\pi)$ μF is connected to a 240 V, 50 Hz a.c. supply. Find (a) its capacitive reactance and the r.m.s. current. (b) At what frequency of a 240 V supply would the current be doubled?

Answer (2 marks)

(a) $X_C = 1/(2\pi fC) = 1/(2\pi \times 50 \times 125 \times 10^{-6}/\pi) = 1/(0.0125) =$ **80 Ω**

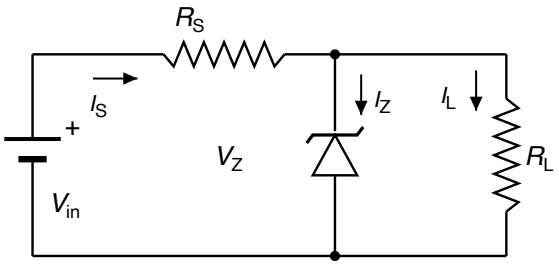
$I_{rms} = V_{rms}/X_C = 240/80 =$ **3 A**

(b) For double current X_C must be 40 Ω. $X_C \propto 1/f$, so f must be doubled: **f = 100 Hz**

Marking: $X_C = 80$ Ω and I = 3 A – 1 mark · f = 100 Hz – 1 mark

Examiner tip: Write μF as 10^{-6} F; the π in the data is meant to cancel the π in 2πf.

Q.14 In the Zener regulator circuit shown, $V_{in} = 15$ V, Zener voltage $V_Z = 6$ V, $R_S = 300$ Ω and load $R_L = 1.2$ kΩ. Find the currents I_S, I_L and I_Z.



Zener diode in reverse bias, R_L parallel to it

Answer (2 marks)

The Zener diode works in breakdown, so the voltage across $R_L = V_Z = 6$ V.

$I_L = 6/1200 =$ **5 mA**

Voltage across $R_S = 15 - 6 = 9$ V $\Rightarrow I_S = 9/300 =$ **30 mA**

At the junction (Kirchhoff's current law) $I_S = I_Z + I_L$, so $I_Z = I_S - I_L = 30 - 5 =$ **25 mA**

Marking: $I_L = 5$ mA – ½ mark · $I_S = 30$ mA – 1 mark · $I_Z = 25$ mA – ½ mark

Examiner tip: The voltage across the load equals V_Z, not V_{in}; the rest of the input voltage drops across R_S.

SECTION C Attempt any EIGHT questions of the following: (3 marks each) **[24]**

Q.15 State the theorem of parallel axes. A uniform wooden rod (lathi) of mass 0.5 kg and length 1.2 m is rotated about an axis perpendicular to its length and passing through a point 0.2 m from one end. Find its moment of inertia about this axis.

Answer (3 marks)

Theorem of parallel axes: The moment of inertia of a body about any axis is equal to the sum of its moment of inertia about a parallel axis passing through its centre of mass and the product of its mass and the square of the distance between the two axes: $I_O = I_C + Mh^2$.

About the transverse axis through the centre: $I_C = ML^2/12 = 0.5 \times (1.2)^2/12 = 0.06$ kg m^2

Distance of the given axis from the centre: $h = 0.6 - 0.2 = 0.4$ m

$I = 0.06 + 0.5 \times (0.4)^2 = 0.06 + 0.08$

$I = 0.14$ kg m^2

Marking: Statement with $I_O = I_C + Mh^2$ – 1 mark · $I_C = 0.06$ kg m^2 and $h = 0.4$ m – 1 mark · $I = 0.14$ kg m^2 – 1 mark

Examiner tip: h is measured from the centre of mass (0.6 m from the end), not from the end of the rod.

Q.16 State Stokes' law. Obtain an expression for the terminal velocity of a small sphere falling through a viscous fluid. When will the sphere move upward instead?

Answer (3 marks)

Stokes' law: The viscous force acting on a small sphere moving through a viscous fluid is directly proportional to the radius r of the sphere, its velocity v and the coefficient of viscosity η of the fluid: $F_v = 6\pi\eta rv$.

Let ρ = density of the sphere and σ = density of the fluid. Forces on the sphere (figure):

Weight $W = (4/3)\pi r^3\rho g$ (downward)

Upthrust $U = (4/3)\pi r^3\sigma g$ (upward)

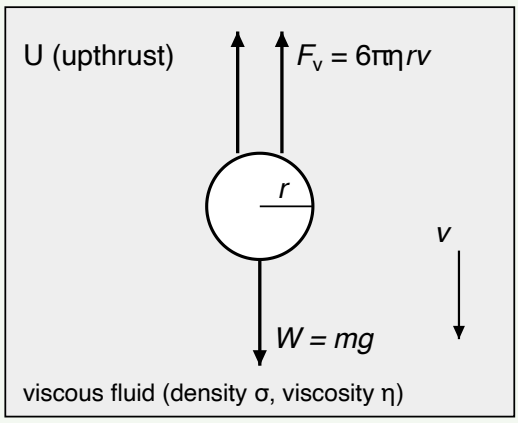
Viscous force $F_v = 6\pi\eta rv$ (upward, opposite to motion)

As v increases, F_v increases until the net force becomes zero; the sphere then moves with constant terminal velocity v:

$W = U + F_v \Rightarrow (4/3)\pi r^3(\rho - \sigma)g = 6\pi\eta rv$

$v = 2r^2(\rho - \sigma)g / 9\eta$

If $\sigma > \rho$ (e.g. an air bubble in water), v is negative: the body moves upward.



Marking: Statement of Stokes' law – 1 mark · Three forces correctly written – 1 mark · $v = 2r^2(\rho - \sigma)g/9\eta$ and the upward case – 1 mark

Examiner tip: Do not forget the upthrust; writing $W = F_v$ gives the wrong factor (ρ instead of $\rho - \sigma$).

Q.17 A string of an ektara is 60 cm long between its fixed ends and has a linear density of 5×10^{-3} kg/m. It is stretched by a tension of 72 N. Find (a) the frequency of its fundamental mode, (b) the frequency of its second overtone and (c) the tension needed to make the fundamental frequency 150 Hz.

Answer (3 marks)

Speed of transverse waves: $v = \sqrt{(T/m)} = \sqrt{[72/(5 \times 10^{-3})]} = \sqrt{14400} = 120$ m/s

(a) $n = v/2L = 120/(2 \times 0.6) =$ **100 Hz**

(b) Second overtone = third harmonic = 3n = **300 Hz**

(c) $n \propto \sqrt{T} \Rightarrow T' = T(n'/n)^2 = 72 \times (150/100)^2 = 72 \times 2.25 =$ **162 N**

Marking: v = 120 m/s and n = 100 Hz – 1 mark · Second overtone = 300 Hz – 1 mark · T′ = 162 N – 1 mark

Examiner tip: For a string fixed at both ends the second overtone is the THIRD harmonic (3n), not 2n.

Q.18 Light from a red laser of wavelength 630 nm falls normally on a single slit of width 0.18 mm. The Fraunhofer diffraction pattern is observed on a screen 1.2 m away. Find (a) the width of the central bright fringe, (b) the distance of the first secondary bright fringe from the centre and (c) the angular width of the central bright fringe.

Answer (3 marks)

$W = \lambda D/a = (630 \times 10^{-9} \times 1.2)/(0.18 \times 10^{-3}) = 4.2 \times 10^{-3}$ m = 4.2 mm

(a) Width of central bright fringe = $2\lambda D/a = 2W =$ **8.4 mm**

(b) n^{th} secondary bright fringe: $y = (n + ½)\lambda D/a$; for n = 1: $y = 1.5 \times 4.2 =$ **6.3 mm**

(c) Angular width = $2\lambda/a = 2 \times 630 \times 10^{-9}/(0.18 \times 10^{-3}) =$ **7×10^{-3} rad**

Marking: Central fringe width 8.4 mm – 1 mark · First secondary maximum at 6.3 mm – 1 mark · Angular width 7×10^{-3} rad – 1 mark

Examiner tip: The central bright fringe is twice as wide as the others; do not use the double-slit formula $\lambda D/d$ for it.

Q.19 State Gauss' theorem in electrostatics. Using it, obtain an expression for the electric field intensity at a point at distance r from an infinitely long, straight, uniformly charged wire of linear charge density λ placed in vacuum.

Answer (3 marks)

Gauss' theorem: The total electric flux through any closed surface is equal to $1/\varepsilon_0$ times the net charge enclosed by the surface: $\Phi = \oint E \cdot ds = q/\varepsilon_0$.

Imagine a coaxial Gaussian cylinder of radius r and length l around the wire, with point P on its

curved surface (figure).

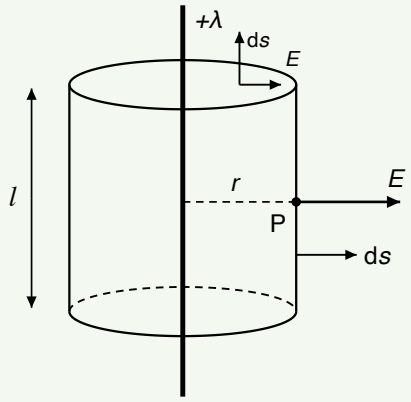
By symmetry E is radial, has the same magnitude at every point of the curved surface and is along the normal ds there (θ = 0). On the plane end caps, E is parallel to the caps (θ = 90°), so their flux is zero.

$\Phi = \oint E\,ds = E \times$ (area of curved surface) $= E(2\pi rl)$

Charge enclosed $q = \lambda l$. By Gauss' theorem:

$E(2\pi rl) = \lambda l/\varepsilon_0$

$E = \lambda/(2\pi\varepsilon_0 r)$, directed radially outward for positive λ (inward for negative λ).



Gaussian cylinder (radius r, length l)

Marking: Statement of Gauss' theorem – 1 mark · Gaussian cylinder; flux $E(2\pi rl)$, zero through caps – 1 mark · $E = \lambda/2\pi\varepsilon_0 r$ – 1 mark

Examiner tip: Show why the end caps contribute no flux; examiners look for that line.

Q.20 A moving coil galvanometer has a resistance of 199 Ω and gives full-scale deflection for a current of 5 mA. How will you convert it into (a) an ammeter reading up to 1 A and (b) a voltmeter reading up to 10 V?

Answer (3 marks)

$G = 199\ \Omega$, $I_g = 5\ \text{mA} = 5 \times 10^{-3}\ \text{A}$

(a) Ammeter: a shunt S is connected in parallel with the galvanometer.

$S = I_g G/(I - I_g) = (5 \times 10^{-3} \times 199)/(1 - 0.005) = 0.995/0.995$

S = 1 Ω in parallel

(b) Voltmeter: a high resistance X is connected in series.

$X = V/I_g - G = 10/(5 \times 10^{-3}) - 199 = 2000 - 199$

X = 1801 Ω in series

Marking: $S = I_g G/(I - I_g)$, value 1 Ω – 1 mark · 'in parallel' for ammeter – ½ mark · X = 1801 Ω – 1 mark · 'in series' for voltmeter – ½ mark

Examiner tip: State the connection (parallel/series) – a correct value with the wrong connection loses marks.

Q.21 State Ampère's circuital law. Using it, obtain an expression for the magnetic induction inside a toroid. A toroid of mean radius 12 cm has 600 turns and carries a current of 1.5 A. Find the magnetic induction inside its (air) core. ($\mu_0 = 4\pi \times 10^{-7}$ Wb/A m)

Answer (3 marks)

Ampère's circuital law: The line integral of magnetic induction around any closed path is equal to μ_0 times the net current enclosed by the path: $\oint B \cdot dl = \mu_0 I$.

Toroid: take an Amperian loop – a circle of radius r inside the core, coaxial with the toroid. By symmetry B is tangential and of the same magnitude everywhere on it:

$\oint B \cdot dl = B(2\pi r)$

Each of the N turns crosses the loop once, so current enclosed = NI:
$B(2\pi r) = \mu_0 NI \Rightarrow$ **$B = \mu_0 NI/(2\pi r) = \mu_0 nI$**, where $n = N/2\pi r$ is the number of turns per unit length.

Numerical: $B = (4\pi \times 10^{-7} \times 600 \times 1.5)/(2\pi \times 0.12) = (2 \times 10^{-7} \times 900)/0.12$

$B = 1.5 \times 10^{-3}$ T

Marking: Statement of Ampère's law – 1 mark · $B = \mu_0 NI/2\pi r$ – 1 mark · $B = 1.5 \times 10^{-3}$ T – 1 mark

Examiner tip: The enclosed current is NI, not I – the loop is pierced N times.

Q.22 Show that the orbital magnetic moment of an electron revolving in a circular orbit is $M = (e/2m)L$, where L is its orbital angular momentum. Using Bohr's quantisation condition, obtain the value of the Bohr magneton. ($e = 1.6 \times 10^{-19}$ C, $m = 9.1 \times 10^{-31}$ kg, $h = 6.63 \times 10^{-34}$ J s, $\pi = 3.14$)

Answer (3 marks)

Let the electron revolve with speed v in an orbit of radius r. Period $T = 2\pi r/v$.

Equivalent current: $I = e/T = ev/(2\pi r)$

Magnetic moment: $M = IA = (ev/2\pi r) \times \pi r^2 = evr/2$

Orbital angular momentum $L = mvr \Rightarrow vr = L/m$

$M = (e/2m)\,L$ (M is opposite to L because the electron is negative.)

Bohr's condition: $L = nh/2\pi$. For $n = 1$:

$M = (e/2m)(h/2\pi) = eh/4\pi m = \mu_B$ (Bohr magneton)

$\mu_B = (1.6 \times 10^{-19} \times 6.63 \times 10^{-34})/(4 \times 3.14 \times 9.1 \times 10^{-31})$

$\mu_B \approx 9.28 \times 10^{-24}$ A m^2

Marking: $I = ev/2\pi r$ and $M = evr/2$ – 1 mark · $M = (e/2m)L$ – 1 mark · $\mu_B = eh/4\pi m \approx 9.28 \times 10^{-24}$ A m^2 – 1 mark

Examiner tip: Write the equivalent current as charge ÷ period; many students write ev/r and lose the factor 2π.

Q.23 A red laser pointer emits light of wavelength 663 nm with a power of 3 mW. Find (a) the energy of each photon in joule and in eV, (b) the number of photons it emits per second and (c) the momentum of each photon. ($h = 6.63 \times 10^{-34}$ J s, $c = 3 \times 10^8$ m/s, 1 eV = 1.6×10^{-19} J)

Answer (3 marks)

(a) $E = hc/\lambda = (6.63 \times 10^{-34} \times 3 \times 10^8)/(663 \times 10^{-9})$ = **3×10^{-19} J**

$= 3 \times 10^{-19}/1.6 \times 10^{-19}$ = **1.875 eV**

(b) Number of photons per second $N = P/E = (3 \times 10^{-3})/(3 \times 10^{-19})$ = **10^{16} photons/s**

(c) $p = h/\lambda = (6.63 \times 10^{-34})/(663 \times 10^{-9})$ = **10^{-27} kg m/s**

Marking: $E = 3 \times 10^{-19}$ J = 1.875 eV – 1 mark · $N = 10^{16}$ per second – 1 mark · $p = 10^{-27}$ kg m/s – 1 mark

Examiner tip: Change nm to m ($\times 10^{-9}$) and mW to W ($\times 10^{-3}$) before substituting.

Q.24 Define mass defect and binding energy of a nucleus. Calculate the binding energy per nucleon of the neon nucleus $^{20}_{10}$Ne. (Mass of ^{20}Ne atom = 19.992440 u, mass of hydrogen atom m_H = 1.007825 u, mass of neutron m_n = 1.008665 u, 1 u = 931.5 MeV/c^2)

Answer (3 marks)

Mass defect: The difference between the sum of the masses of the constituent nucleons (in the free state) and the actual mass of the nucleus: $\Delta m = Zm_p + (A - Z)m_n - M$.

Binding energy: The energy equivalent of the mass defect, i.e. the minimum energy needed to separate the nucleus completely into its nucleons: B.E. = $\Delta m\, c^2$.

For $^{20}_{10}$Ne: Z = 10, N = 10 (atomic masses used, so electron masses cancel)

$\Delta m = 10m_H + 10m_n - M = 10(1.007825) + 10(1.008665) - 19.992440$

$= 10.078250 + 10.086650 - 19.992440 = 0.172460$ u

B.E. = 0.172460 × 931.5 ≈ 160.6 MeV

B.E. per nucleon = 160.6/20 ≈ 8.03 MeV

Marking: Definitions of mass defect and binding energy – 1 mark · Δm = 0.17246 u – 1 mark · B.E./nucleon ≈ 8.03 MeV – 1 mark

Examiner tip: Divide by the mass number A (20), not by Z (10).

Q.25 A coil of N turns, each of area A, rotates with uniform angular velocity ω about an axis perpendicular to a uniform magnetic field B. Show that the emf induced in it is $e = e_0 \sin \omega t$, where $e_0 = NAB\omega$. A coil of 50 turns, each of area 0.04 m^2, rotates at 1800 r.p.m. in a uniform magnetic field of 0.25 T. Find the peak emf. (π = 3.14)

Answer (3 marks)

Let the normal to the plane of the coil make angle θ = ωt with B at time t (θ = 0 at t = 0).

Flux linked with the coil: Φ = NBA cos θ = NBA cos ωt

By Faraday's law: e = –dΦ/dt = –NBA d(cos ωt)/dt = NBAω sin ωt

$e = e_0 \sin \omega t$, with $e_0 = NAB\omega$ (maximum when the plane of the coil is parallel to B).

Numerical: f = 1800/60 = 30 Hz ⇒ ω = 2πf = 2 × 3.14 × 30 = 188.4 rad/s

$e_0 = NAB\omega = 50 \times 0.04 \times 0.25 \times 188.4$

e_0 = 94.2 V

Marking: Φ = NBA cos ωt – 1 mark · e = NABω sin ωt – 1 mark · e_0 = 94.2 V – 1 mark

Examiner tip: Convert r.p.m. to rad/s: ω = 2π × (r.p.m./60).

Q.26 Define the coefficient of performance of a refrigerator. A cold storage for Nagpur oranges keeps its chamber at 7 °C while the outside temperature is 42 °C. Treating it as a Carnot refrigerator, find (a) its coefficient of performance, (b) the work needed to remove 4000 J of heat from the chamber and (c) the heat given out to the surroundings.

Answer (3 marks)

Coefficient of performance K of a refrigerator: the ratio of the heat Q_C removed from the cold reservoir to the work W done on the refrigerator: $K = Q_C/W$.

$T_C = 7 + 273 = 280$ K, $T_H = 42 + 273 = 315$ K

(a) Carnot refrigerator: $K = T_C/(T_H - T_C) = 280/35 =$ **8**

(b) $W = Q_C/K = 4000/8 =$ **500 J**

(c) $Q_H = Q_C + W = 4000 + 500 =$ **4500 J**

Marking: Definition $K = Q_C/W$ – ½ mark · K = 8 – 1 mark · W = 500 J – 1 mark · Q_H = 4500 J – ½ mark

Examiner tip: Use kelvin temperatures; 7/(42 – 7) gives a wrong K.

SECTION D Attempt any THREE questions of the following: (4 marks each) **[12]**

Q.27 (a) A small body tied to a string is whirled in a vertical circle of radius r under gravity. Using the principle of conservation of energy, obtain the minimum speeds of the body at the uppermost point, at the lowermost point and at a point where the string is horizontal. Show that the difference between the tensions at the lowermost and uppermost points is 6mg. [3]

(b) A farmer whirls a stone in a gofan (sling) in a vertical circle of radius 0.4 m. Find the minimum speed the stone must have at the top of the circle and the corresponding speed at the lowest point. (g = 10 m/s^2) [1]

Answer (4 marks)

(a) Uppermost point A: tension T_A and weight mg both act towards the centre:

$T_A + mg = mv_A^2/r$ ... (1)

The string just remains taut when $T_A = 0 \Rightarrow$ **$v_{A(min)} = \sqrt{(rg)}$**

Lowermost point B: $T_B - mg = mv_B^2/r$ ... (2)

Energy conservation between A and B (fall through 2r):

$\frac{1}{2}mv_B^2 = \frac{1}{2}mv_A^2 + mg(2r) \Rightarrow v_B^2 = v_A^2 + 4rg$ ... (3)

With $v_{A(min)}^2 = rg$: **$v_{B(min)} = \sqrt{(5rg)}$**

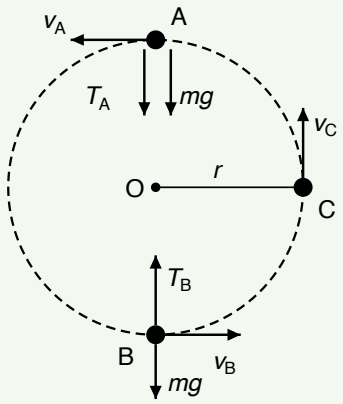
String horizontal (point C, fall r from A): $v_C^2 = v_A^2 + 2rg \Rightarrow$ **$v_{C(min)} = \sqrt{(3rg)}$**

Subtracting (1) from (2): $T_B - T_A = 2mg + m(v_B^2 - v_A^2)/r = 2mg + m(4rg)/r$

$T_B - T_A = 6mg$ (independent of the speed).

(b) $v_{top(min)} = \sqrt{(rg)} = \sqrt{(0.4 \times 10)} =$ **2 m/s**

$v_{bottom} = \sqrt{(5rg)} = \sqrt{20} \approx$ **4.47 m/s**



Marking: $v_{A(min)} = \sqrt{(rg)}$ from $T_A = 0$ – 1 mark · Energy equation, $v_{B(min)} = \sqrt{(5rg)}$, $v_{C(min)} = \sqrt{(3rg)}$ – 1 mark · $T_B - T_A = 6mg$ – 1 mark · (b) 2 m/s and 4.47 m/s – 1 mark

Examiner tip: At the top both tension and weight point towards the centre; at the bottom they are opposite. Mixing these up spoils every later step.

Q.28 (a) Obtain an expression for the energy stored in a charged capacitor and express it in three forms. Show that only half of the energy supplied by the charging battery is stored in the capacitor. [3]

(b) The flash unit of a camera has a 500 μF capacitor charged to 200 V. Find the energy delivered in one flash. [1]

Answer (4 marks)

(a) Let a capacitor of capacitance C be charged by a d.c. source. When it carries charge q′, the potential difference between the plates is $V' = q'/C$.

Work done to transfer a further small charge dq: $dW = V'dq = (q'/C)\,dq$

Total work to charge it from 0 to Q:

$W = \int_0^Q (q'/C)\,dq' = Q^2/2C$

This work is stored as electrostatic energy in the field between the plates. Using $Q = CV$:

$U = Q^2/2C = \frac{1}{2}CV^2 = \frac{1}{2}QV$

The battery moves the whole charge Q through its constant emf V, so the energy supplied by the battery = QV.

Energy stored = ½QV = half of QV. The other half is lost as heat in the connecting wires and the battery (and as electromagnetic radiation).

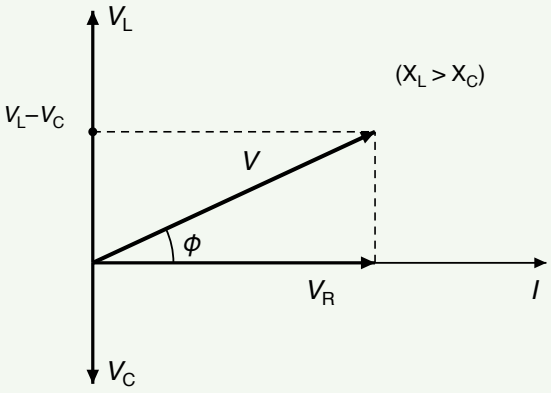
(b) $U = \frac{1}{2}CV^2 = \frac{1}{2} \times 500 \times 10^{-6} \times (200)^2 =$ **10 J**

Marking: $dW = (q/C)dq$ and integration – 1 mark · Three forms $Q^2/2C = \frac{1}{2}CV^2 = \frac{1}{2}QV$ – 1 mark · Battery supplies QV, half stored – 1 mark · (b) U = 10 J – 1 mark

Examiner tip: The potential difference rises from 0 to V while charging; using W = QV directly gives twice the stored energy.

Q.29 (a) Draw the phasor diagram for a series LCR circuit connected to an a.c. source (take $X_L > X_C$). Obtain expressions for its impedance and the phase angle between the voltage and the current. State the condition for resonance and obtain the resonant frequency. [3]
(b) Find the resonant frequency of a series LCR circuit with L = (1/π) H and C = (1/π) μF. [1]

Answer (4 marks)
(a) The same current $i = i_0 \sin \omega t$ flows through R, L and C (taken as the reference phasor).
$V_R = IR$ is in phase with I; $V_L = IX_L$ leads I by π/2; $V_C = IX_C$ lags I by π/2 (figure). V_L and V_C are opposite, giving a net $(V_L - V_C)$ along V_L.
Resultant: $V = \sqrt{[V_R^2 + (V_L - V_C)^2]} = I\sqrt{[R^2 + (X_L - X_C)^2]}$
Impedance $Z = V/I = \sqrt{[R^2 + (X_L - X_C)^2]}$
$\tan \phi = (X_L - X_C)/R$; the voltage leads the current by ϕ.
Resonance: when $X_L = X_C$, Z = R (minimum) and the current is maximum, in phase with the voltage.
$\omega L = 1/\omega C \Rightarrow \omega_r = 1/\sqrt{(LC)} \Rightarrow$ **$f_r = 1/(2\pi\sqrt{(LC)})$**
(b) $LC = (1/\pi)(10^{-6}/\pi) = 10^{-6}/\pi^2 \Rightarrow \sqrt{(LC)} = 10^{-3}/\pi$
$f_r = 1/(2\pi \times 10^{-3}/\pi) = 1/(2 \times 10^{-3}) =$ **500 Hz**



Marking: Phasor diagram – 1 mark · $Z = \sqrt{[R^2 + (X_L - X_C)^2]}$ and $\tan \phi$ – 1 mark · Resonance condition and $f_r = 1/2\pi\sqrt{(LC)}$ – 1 mark · (b) f_r = 500 Hz – 1 mark
Examiner tip: In the phasor diagram the current is the reference; draw V_L and V_C exactly opposite, both perpendicular to V_R.

Q.30 (a) Obtain expressions for the kinetic energy and the potential energy of a particle performing linear S.H.M. Hence show that its total energy is conserved. Draw a graph showing how these energies vary with displacement. [3]
(b) A particle performs S.H.M. of amplitude 10 cm. At what displacement from the mean position are its kinetic and potential energies equal? [1]

Answer (4 marks)
(a) Let a particle of mass m perform linear S.H.M. of amplitude A and angular frequency ω; force constant $k = m\omega^2$.
Kinetic energy: velocity at displacement x is $v = \omega\sqrt{(A^2 - x^2)}$
K.E. = $\frac{1}{2}mv^2 = \frac{1}{2}m\omega^2(A^2 - x^2) = \frac{1}{2}k(A^2 - x^2)$
Potential energy: the restoring force is F = –kx. Work done against it in displacing the particle

from 0 to x is stored as P.E.:

P.E. = $\int_0^x kx\,dx$ = **$\frac{1}{2}kx^2 = \frac{1}{2}m\omega^2x^2$**

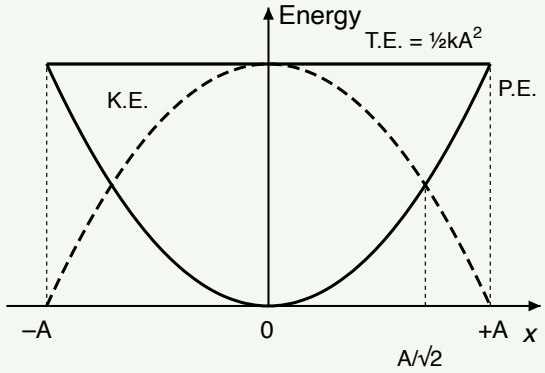
Total energy: T.E. = K.E. + P.E. = $\frac{1}{2}k(A^2 - x^2) + \frac{1}{2}kx^2$ = **$\frac{1}{2}kA^2 = \frac{1}{2}m\omega^2A^2$**

This is independent of x, so the total energy is constant (conserved) throughout the motion.

Graph: P.E. parabola, K.E. inverted parabola, T.E. horizontal line (figure).

(b) K.E. = P.E. $\Rightarrow \frac{1}{2}k(A^2 - x^2) = \frac{1}{2}kx^2 \Rightarrow x = A/\sqrt{2} = 10/1.414$

$x \approx \pm 7.07$ cm



Marking: K.E. = $\frac{1}{2}k(A^2 - x^2)$ – 1 mark · P.E. = $\frac{1}{2}kx^2$ by integration – 1 mark · T.E. = $\frac{1}{2}kA^2$ constant, with graph – 1 mark · (b) $x = A/\sqrt{2} \approx 7.07$ cm – 1 mark

Examiner tip: Label all three curves on the graph and mark ±A on the displacement axis.

Q.31 (a) Using Bohr's postulates, obtain an expression for the energy of the electron in the n^{th} orbit of the hydrogen atom. [3]

(b) The energy of the electron in the n^{th} orbit of hydrogen is $E_n = -13.6/n^2$ eV. Find the wavelength of the photon emitted when the electron jumps from the 5^{th} orbit to the 2^{nd} orbit. ($c = 3 \times 10^8$ m/s, $h = 6.63 \times 10^{-34}$ J s, 1 eV = 1.6×10^{-19} J) [1]

Answer (4 marks)

(a) Let the electron (charge –e, mass m) revolve round the nucleus (charge +e) in the n^{th} orbit of radius r_n with speed v_n.

The electrostatic attraction provides the centripetal force:

$mv_n^2/r_n = e^2/(4\pi\varepsilon_0 r_n^2)$ ... (1)

Bohr's quantisation condition: $mv_n r_n = nh/2\pi$ ... (2)

From (1) and (2): $r_n = \varepsilon_0 h^2 n^2/(\pi m e^2)$

K.E. = $\frac{1}{2}mv_n^2 = e^2/(8\pi\varepsilon_0 r_n)$ (from (1)); P.E. = $-e^2/(4\pi\varepsilon_0 r_n)$

Total energy E_n = K.E. + P.E. = $-e^2/(8\pi\varepsilon_0 r_n)$

Substituting r_n: **$E_n = -me^4/(8\varepsilon_0^2 h^2 n^2)$**

The negative sign shows that the electron is bound ($E_n \propto 1/n^2$).

(b) $\Delta E = 13.6(1/2^2 - 1/5^2) = 13.6 \times 21/100 = 2.856$ eV = $2.856 \times 1.6 \times 10^{-19}$ J

$\lambda = hc/\Delta E = (6.63 \times 10^{-34} \times 3 \times 10^8)/(4.570 \times 10^{-19})$

$\lambda \approx 4.35 \times 10^{-7}$ m = 435 nm

Marking: Eqs (1) and (2) – 1 mark · r_n, K.E. and P.E. – 1 mark · Final E_n – 1 mark · (b) $\lambda \approx 435$ nm – 1 mark

Examiner tip: E = K.E. + P.E. = –K.E.; dropping the minus sign of P.E. gives a wrong positive energy.

All the best for your exam!