GIOPHYSICS ORIGINAL EXAMINATION SERIES

IB Physics

Mock examination pack

Two complete original papers with supplied-data graphs, generous working space, and a detailed teacher marking guide.

PAPERS	QUESTIONS	MARKS	TEACHER KEY
2	**20**	**260**	**Included**

INSIDE THIS PACK

PAPER 1

IB Physics · Extended Paper 1

180 minutes | 10 questions | 132 marks

A balanced original practice paper with long-form reasoning, calculations, and supplied-data graphs.

PAPER 2

IB Physics · Extended Paper 2

175 minutes | 10 questions | 128 marks

A balanced original practice paper with long-form reasoning, calculations, and supplied-data graphs.

Original practice - clearly independent

Every question and solution was independently written by GioPhysics. This pack is not an awarding-body document and does not reproduce a released examination question or mark scheme.

IB Physics · Extended Paper 1

A balanced original practice paper with long-form reasoning, calculations, and supplied-data graphs.

CANDIDATE NAME

CLASS / GROUP

DATE

PAPER	TIME	QUESTIONS	TOTAL MARKS
1	**180 min**	**10**	**132**

INSTRUCTIONS

- Answer every question and show all reasoning.
- State assumptions and use appropriate significant figures and units.
- Support evaluative conclusions with the supplied evidence and the relevant physics.
- Answer in the spaces provided and label any additional pages clearly.

INFORMATION

- The total mark for this paper is 132.
- Marks for each task are shown in brackets.
- The detailed marking guide begins after Paper 2.

GioPhysics original practice. Not an official MYP, Cambridge, College Board, or IB examination paper.

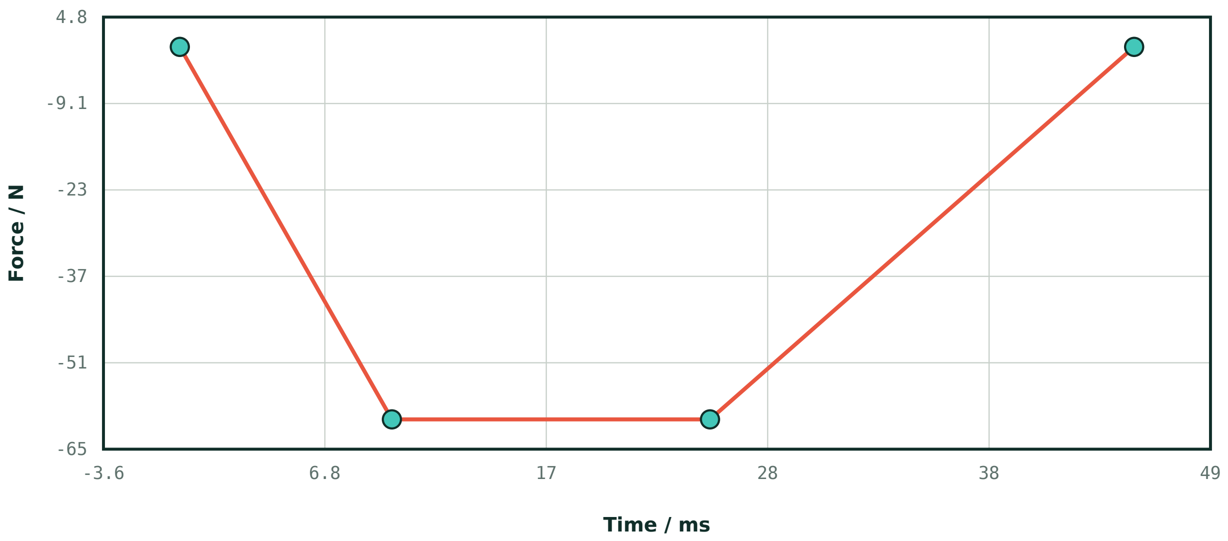
Impulse and rebound from force data

[13]

A 0.400 kg trolley moves right at 1.50 m s⁻¹ before striking a buffer. The measured horizontal force on it has coordinates (0 ms, 0 N), (10 ms, -60 N), (25 ms, -60 N), and (45 ms, 0 N), joined by straight lines. Determine the impulse, final velocity and kinetic-energy change. Explain whether momentum of the trolley alone is conserved, identify where the missing momentum goes, and evaluate one limitation of integrating sampled force data.

Measured buffer force

The four measured force-time coordinates from the prompt are connected linearly; signed area represents impulse.



ANSWER SPACE

Projectile prediction with uncertainty

[12]

A ball is launched from ground level at speed (18.0 ± 0.3) m s^{-1} and angle (35.0 ± 1.0)° above horizontal. Ignore drag and use g = 9.81 m s^{-2}. Calculate time of flight, maximum height and range from the central values. Estimate the percentage uncertainty in range using $R = u^2\sin(2\theta)/g$ and maximum-uncertainty addition, treating angular uncertainty in radians. Explain two reasons a measured range could be systematically shorter.

ANSWER SPACE

Muon survival and reference frames

[15]

Muons created 12.0 km above sea level travel downward at 0.998c. Their mean proper lifetime is 2.20 μs. Calculate the Lorentz factor, mean lifetime and mean travel distance in Earth's frame, and the atmosphere thickness in the muon frame. Estimate the survival fraction to sea level using exponential decay in either frame. Explain how the two descriptions agree without assigning an absolute time dilation.

ANSWER SPACE

Conduction and radiation through a wall

[13]

A 12.0 m^2 wall consists of 0.100 m brick with thermal conductivity 0.72 W m^{-1} K^{-1} and 0.060 m insulation with conductivity 0.040 W m^{-1} K^{-1}. Indoor and outdoor surface temperatures are 293 K and 273 K. Find the steady conductive power and interface temperature. If the outer surface has emissivity 0.85 and sees surroundings at 263 K, calculate its net radiative loss. Explain why simply adding that radiation to the conduction result may violate steady-state energy balance.

ANSWER SPACE

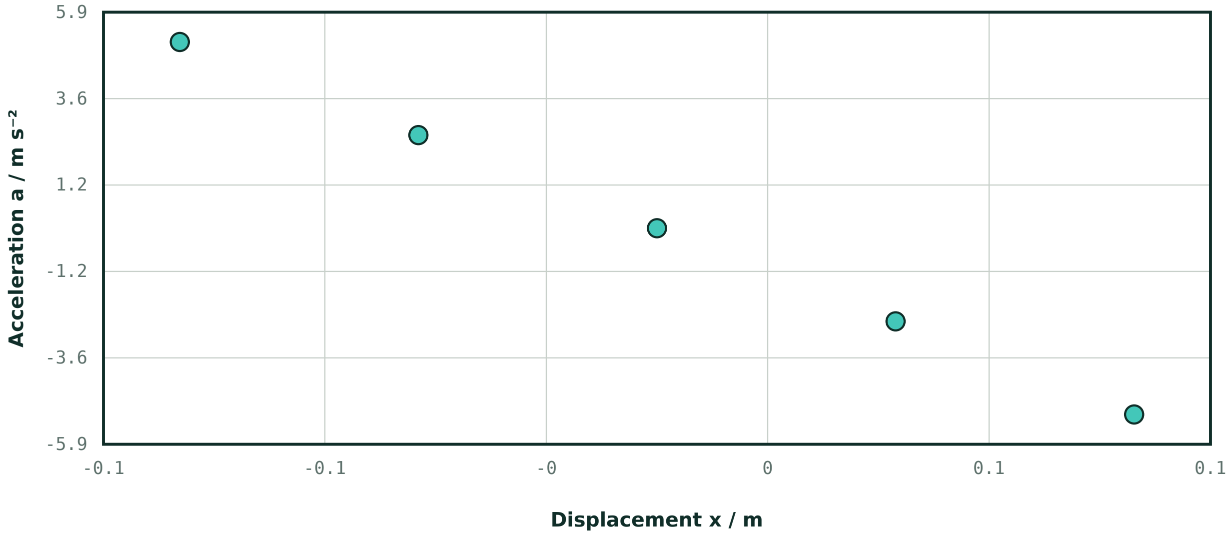
Test a simple-harmonic acceleration model

[13]

A motion sensor records acceleration against displacement for an oscillator: (-0.080 m, +5.12 m s^{-2}), (-0.040 m, +2.56 m s^{-2}), (0, 0), (0.040 m, -2.56 m s^{-2}), and (0.080 m, -5.12 m s^{-2}). Determine whether the data support SHM, find angular frequency and period, and calculate maximum speed and total energy for mass 0.250 kg. Evaluate how a constant acceleration-sensor zero offset would appear on the graph.

Acceleration against displacement

The five measured coordinates are listed in the prompt; their gradient, intercept and physical meaning are left for analysis.



ANSWER SPACE

Resolve wavelength and coherence from fringes

[13]

Two narrow slits separated by (0.300 ± 0.005) mm are illuminated by monochromatic light. On a screen (2.00 ± 0.01) m away, the distance across 10 fringe spacings is (42.0 ± 0.5) mm. Determine fringe spacing and wavelength with percentage uncertainty. Explain why measuring many spacings helps, predict what happens when one slit is widened substantially, and distinguish loss of visibility from a change in fringe spacing.

ANSWER SPACE

Electric potential along a dipole axis [14]

Charges +Q and -Q, with Q = 2.00 nC, lie at x = +0.0500 m and x = -0.0500 m respectively. At x = +0.200 m calculate electric potential and field. Find the work done by the electric field when a +1.00 nC test charge moves slowly from x = 0.200 m to x = 0.300 m. Derive the far-axis approximations for V and E in terms of dipole moment p = Qd and compare the exact potential at 0.200 m with the approximation.

ANSWER SPACE

Induction in a rotating coil

[13]

A 200-turn rectangular coil of area 3.00×10^{-3} m^2 rotates at 50.0 rad s^{-1} in a uniform 0.400 T field. At $t = 0$ its area vector is parallel to the field. Derive flux linkage and emf as functions of time, calculate peak and rms emf, and find the first time emf reaches its positive maximum. If connected to a 60.0 Ω resistor, find average power and mechanical torque averaged over a cycle for constant speed.

ANSWER SPACE

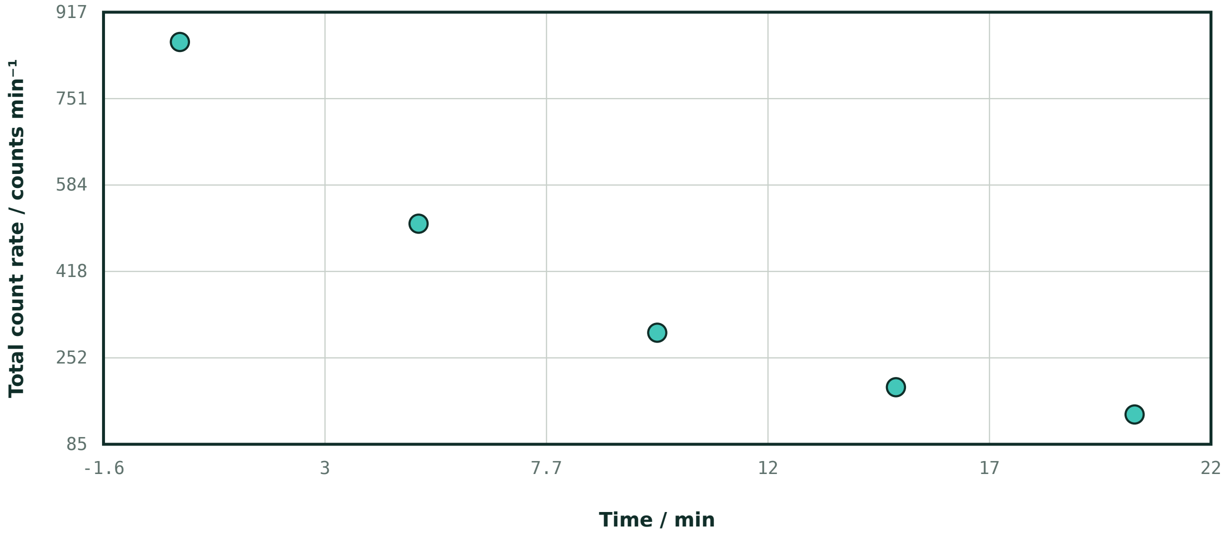
Infer half-life and background from count data

[14]

A detector records total count rate from a radioactive sample: (0 min, 860 counts min^{-1}), (5 min, 510), (10 min, 300), (15 min, 195), and (20 min, 142.5). A separate long background measurement gives 90.0 counts min^{-1}. Determine the corrected half-life and decay constant, predict the total count rate at 30 min, and explain how Poisson counting uncertainty and an incorrect background estimate affect a logarithmic analysis.

Measured total count rate

Total count rate includes the separately stated 90 counts per minute background; correction is part of the analysis.



ANSWER SPACE

Photoelectric energy and measurement design

[12]

Light of wavelength 400 nm illuminates a metal with work function 2.20 eV. Calculate photon energy, maximum photoelectron kinetic energy, stopping potential and maximum electron speed. Predict what changes when wavelength becomes 300 nm at the same photon rate, and outline how stopping potential should be measured without confusing it with the voltage that reduces current merely to a small nonzero value. Use $h = 6.626 \times 10^{-34}$ J s and electron mass 9.11×10^{-31} kg.

ANSWER SPACE

IB Physics · Extended Paper 2

A balanced original practice paper with long-form reasoning, calculations, and supplied-data graphs.

CANDIDATE NAME			
CLASS / GROUP		DATE	

PAPER	TIME	QUESTIONS	TOTAL MARKS
2	**175 min**	**10**	**128**

INSTRUCTIONS

- Answer every question and show all reasoning.
- State assumptions and use appropriate significant figures and units.
- Support evaluative conclusions with the supplied evidence and the relevant physics.
- Answer in the spaces provided and label any additional pages clearly.

INFORMATION

- The total mark for this paper is 128.
- Marks for each task are shown in brackets.
- The detailed marking guide begins after Paper 2.

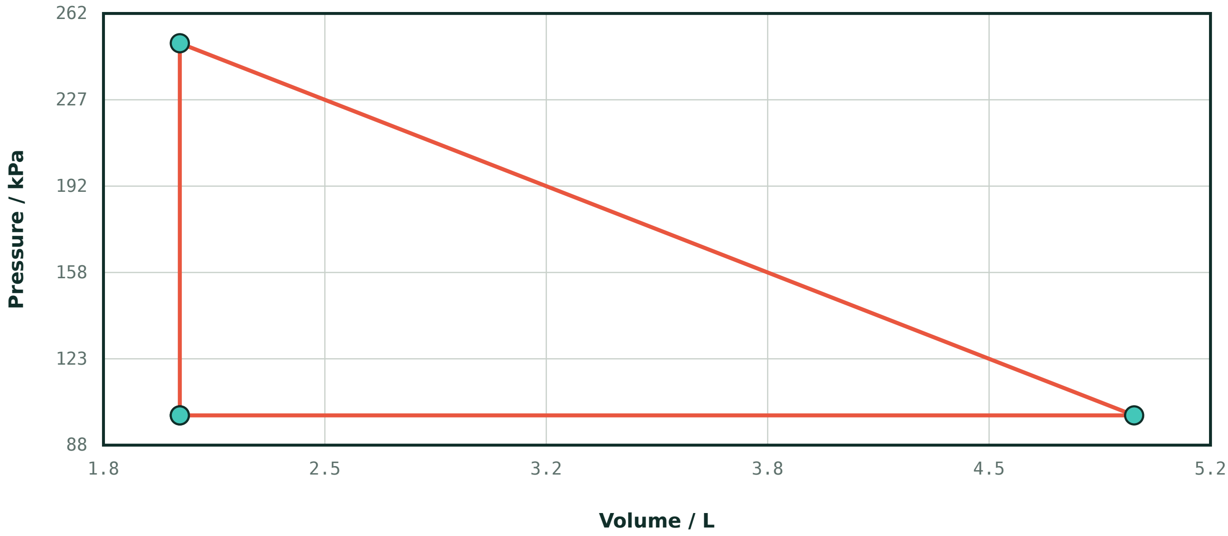
Analyse a triangular gas cycle

[14]

A monatomic ideal gas follows A(2.0 L, 100 kPa) → B(2.0 L, 250 kPa) → C(5.0 L, 100 kPa) → A, with B→C a straight line. Determine net work by the gas. Calculate temperatures at A, B and C for $n = 0.100$ mol, then find ΔU and Q on each leg. Use $R = 8.31$ J mol^{-1} K^{-1} and 1 kPa·L = 1 J. State whether the cycle operates as an engine.

Triangular ideal-gas cycle

The three state coordinates and return to A are exactly those stated in the prompt; straight segments define the paths.



ANSWER SPACE

Brake a rotating flywheel

[13]

A flywheel has moment of inertia 0.800 kg m^2 and rotates at 30.0 rad s^{-1}. A brake pad applies a constant tangential force of 12.0 N at radius 0.250 m until it stops. Determine torque, angular deceleration, stopping time, angle turned and thermal energy produced. If the measured stopping time is 9.0 s instead, infer the average additional resisting torque and discuss whether constant total torque is justified by one timing measurement.

ANSWER SPACE

Model a floating research buoy

[12]

A sealed cylindrical research buoy has mass 42.0 kg, external cross-sectional area 0.180 m^2 and total height 0.500 m. It floats upright in seawater of density 1025 kg m^{-3}. Calculate its submerged depth and freeboard. A 12.0 kg instrument is added centrally; calculate the new freeboard and decide whether the buoy remains safe if 0.080 m freeboard is required. Discuss stability information missing from this one-dimensional model.

ANSWER SPACE

Audit a claimed heat-engine performance [12]

An engine operates between reservoirs at 600 K and 300 K. Its manufacturer claims that each cycle absorbs 1200 J, produces 720 J of work and rejects 480 J. Check first-law consistency, calculate claimed efficiency and compare it with the Carnot limit. Calculate the total entropy change of the two reservoirs per claimed cycle and use it to diagnose the claim. State one way a real engine could legitimately produce 720 J of work per cycle.

ANSWER SPACE

Resonance in an open air column

[12]

An open pipe of physical length 0.840 m resonates at consecutive frequencies 200 Hz, 400 Hz and 600 Hz. Explain the mode pattern, infer wave speed if end correction is negligible, and calculate the end correction per end if an independent temperature measurement gives sound speed 343 m s^{-1}. Predict the first three resonances if one end is then closed but the same effective length applies. Discuss a limitation of that assumption.

ANSWER SPACE

Infer source speed from two Doppler readings

[12]

A stationary observer hears 680 Hz as a siren approaches and 612 Hz after it passes. Take sound speed as 340 m s^{-1} and model the source speed as constant, with no wind. Derive expressions for the two heard frequencies, determine source speed and emitted frequency, and explain how a steady wind from source toward observer would affect a naive calculation using ground-frame speed 340 m s^{-1}.

ANSWER SPACE

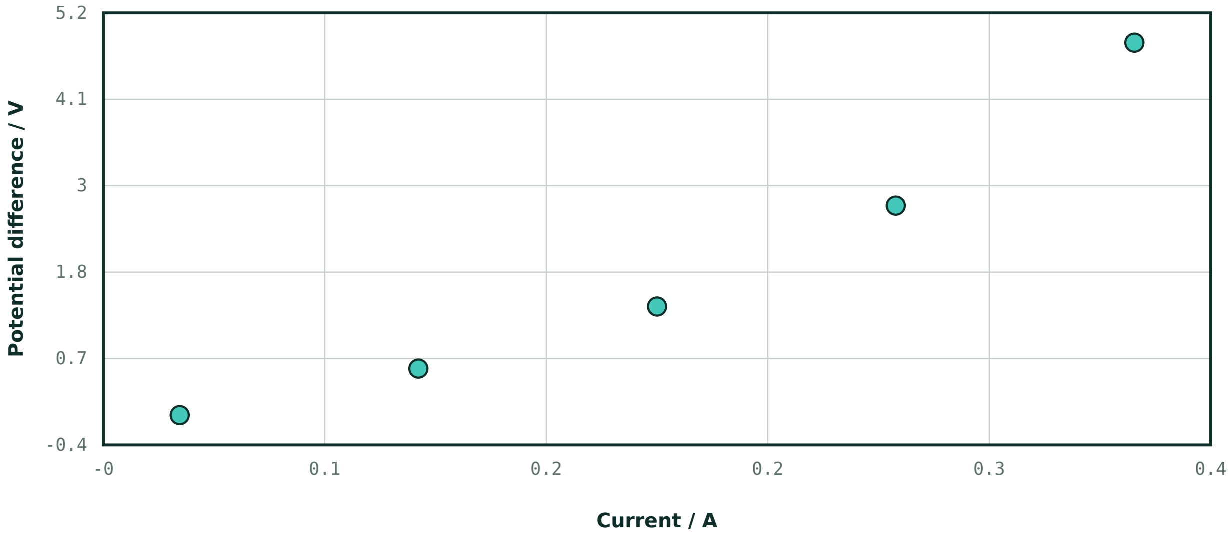
Diagnose a non-ohmic filament lamp

[13]

A filament lamp gives measured (current in A, potential difference in V) pairs (0, 0), (0.10, 0.60), (0.20, 1.40), (0.30, 2.70), and (0.40, 4.80). Determine the static resistance at 0.40 A and estimate dynamic resistance between 0.30 and 0.40 A. Explain the graph shape microscopically, calculate power at 0.40 A, and design a safe circuit and procedure to collect the data without overheating the lamp between readings.

Filament-lamp current-voltage observations

The five supplied measurements are shown without an extrapolation; static and local dynamic resistance must be distinguished.



ANSWER SPACE

Balance a current-carrying wire

[12]

A 0.300 m horizontal wire segment of mass 18.0 g lies perpendicular to a uniform horizontal magnetic field of 0.250 T. The wire is supported so that magnetic force may act vertically. Determine the current magnitude and direction needed for the magnetic force to balance its weight. If the current is 20% larger, find the initial vertical acceleration. Discuss why the complete circuit geometry matters and how a balance could measure B.

ANSWER SPACE

Mass defect and stellar fusion energy

[13]

In the net proton-proton chain, four hydrogen atoms ultimately form one helium-4 atom plus other products. Use atomic masses m_H = 1.007825 u and m_He = 4.002603 u; electron masses cancel in this atomic-mass comparison. Calculate mass defect and energy released per reaction in MeV and joules. Estimate reactions per second needed for luminosity 3.83×10^{26} W and mass converted to energy per second. Use 1 u = 931.5 MeV c^{-2} and 1 eV = 1.602×10^{-19} J.

ANSWER SPACE

Energy levels in an infinite quantum well [15]

An electron is confined to a one-dimensional infinite well of width L = 0.500 nm. Derive the allowed energies from standing-wave boundary conditions, then calculate E_1, E_2 and the photon wavelength for a 2→1 transition. Write the normalized ground-state wavefunction, state the number of nodes for n = 3, and explain why the electron does not have a single classical trajectory between walls. Use h = 6.626×10^{-34} J s and $m_e = 9.11 \times 10^{-31}$ kg.

ANSWER SPACE

TEACHER COPY

Detailed marking guide

IB Physics

How to use this guide

Award credit for equivalent correct physics expressed clearly. The numbered solution stages show a complete route, not the only valid route. Use the stated common mistake as feedback rather than as a penalty beyond the lost physics marks.

PAPERS	QUESTIONS	TOTAL MARKS
2	**20**	**260**

This guide is original GioPhysics material. It is not an official awarding-body mark scheme and must not be used to predict a grade boundary.

Impulse and rebound from force data

[13]

EXPECTED CONCLUSION

Impulse = -1.80 N s, final velocity = -3.00 m s⁻¹, and ΔK = +1.35 J. Trolley momentum is not conserved; the buffer and Earth receive the opposite impulse.

REASONING AND MARKING CHECKPOINTS

01

Impulse is signed area under F-t. The first triangle is -½(0.010)(60) = -0.300 N s, the rectangle is -0.900 N s, and the final triangle is -0.600 N s.

02

Total impulse is -1.80 N s. Initial momentum is (0.400)(1.50) = +0.600 kg m s^{-1}, so final momentum is -1.20 kg m s^{-1}.

03

Final velocity is p_f/m = -1.20/0.400 = -3.00 m s^{-1}. Kinetic energy changes from 0.450 J to 1.80 J, so ΔK = +1.35 J.

04

The trolley alone experiences an external impulse from the buffer and does not conserve momentum. In a larger trolley-buffer-Earth system, the buffer and Earth gain +1.80 N s, so total momentum remains conserved.

05

Straight-line integration assumes no narrow force peak occurs between samples. A higher sampling rate and calibrated force zero reduce missing-area and offset errors; repeating impacts quantifies random variation.

COMMON MISTAKE

Equating impulse with the unsigned area or claiming the trolley's momentum is conserved despite the clearly measured external buffer force.

Projectile prediction with uncertainty [12]

EXPECTED CONCLUSION

Time = 2.10 s, maximum height = 5.43 m, range = 31.0 m. Estimated range uncertainty ≈ 4.6%, or about ±1.4 m. Drag and a launch point below the assumed level can shorten the range.

REASONING AND MARKING CHECKPOINTS

01

Resolve velocity: $u_y = 18.0\sin 35° = 10.32$ m s^{-1} and $u_x = 18.0\cos 35° = 14.74$ m s^{-1}.

02

For equal launch and landing heights, $T = 2u_y/g = 2.10$ s. Maximum height is $u_y^2/(2g) = 5.43$ m.

03

Range is u_xT, equivalently $u^2\sin 70°/g = 31.0$ m. These two routes provide an algebraic cross-check.

04

For $R \propto u^2\sin 2\theta$, fractional maximum uncertainty is approximately $2\Delta u/u + |2\cot(2\theta)|\Delta\theta = 2(0.3/18.0) + 2\cot 70°(\pi/180) = 0.0460$.

05

Thus $\Delta R \approx 1.4$ m. Air drag reduces horizontal speed; a landing surface below or above the assumed equal level changes flight time. A launch-speed calibration bias or angle reference offset would also shift all trials systematically.

COMMON MISTAKE

Substituting the one-degree angular uncertainty directly into a calculus-based fractional expression without converting degrees to radians.

Muon survival and reference frames

[15]

EXPECTED CONCLUSION

γ = 15.82; Earth-frame lifetime = 34.8 μs and mean distance = 10.4 km; muon-frame atmosphere thickness = 0.759 km. Survival fraction ≈ exp(-12.0/10.4) = 0.316.

REASONING AND MARKING CHECKPOINTS

01

Lorentz factor is $\gamma = 1/\sqrt{(1-0.998^2)} = 15.82$. The muon lifetime is proper in its own rest frame.

02

Earth observers measure dilated mean lifetime $\gamma\tau_0$ = (15.82)(2.20 μs) = 34.8 μs and mean travel distance $v\gamma\tau_0$ = 10.4 km.

03

The survival probability over 12.0 km is $\exp[-t/(\gamma\tau_0)]$ with t = 12.0 km/(0.998c), giving exp(-12.0/10.4) = 0.316.

04

In the muon frame, atmospheric thickness is length-contracted: L' = 12.0 km/15.82 = 0.759 km. Travel time L'/(0.998c) compared with τ_0 gives the same exponential factor.

05

Earth describes a longer muon lifetime; the muon describes a shorter atmosphere. Lorentz transformations connect these frame-dependent intervals, so neither frame is an absolute privileged description and both predict the same arrival events.

COMMON MISTAKE

Applying both time dilation and length contraction in the same frame calculation, thereby counting the same relativistic transformation twice.

Conduction and radiation through a wall

[13]

EXPECTED CONCLUSION

Thermal resistance = 0.1366 K W^{-1}; conductive power = 146 W; interface temperature ≈ 291.3 K if brick is inside. Net outer radiation ≈ 445 W. The specified outer-surface temperature cannot remain fixed without a matching energy source.

REASONING AND MARKING CHECKPOINTS

01

Series thermal resistances are $R_{brick} = L/(kA) = 0.100/[0.72(12.0)] = 0.0116$ K W^{-1} and $R_{ins} = 0.060/[0.040(12.0)] = 0.125$ K W^{-1}.

02

Total resistance is 0.1366 K W^{-1}, so conductive power through the composite wall is $\Delta T/R = 20/0.1366 = 146$ W, not 12.2 W.

03

The brick temperature drop is $P R_{brick} = (146)(0.0116) = 1.69$ K. If brick faces indoors, the interface is therefore 293-1.69 = 291.3 K.

04

Net radiation is $\varepsilon\sigma A(T_s^4-T_{sur}^4) = 0.85(5.67 \times 10^{-8})(12.0)(273^4-263^4) \approx 445$ W.

05

The radiative loss exceeds the calculated conductive supply at the imposed temperatures, so the outer surface would cool unless convection or another source supplies the difference. A true steady-state solution must determine surface temperatures from simultaneous conduction, convection and radiation balances.

COMMON MISTAKE

Adding radiation to wall conduction while holding every surface temperature fixed, without checking that energy entering and leaving each surface can balance.

Test a simple-harmonic acceleration model

[13]

EXPECTED CONCLUSION

The linear negative gradient is -64.0 s^{-2}, so ω = 8.00 rad s^{-1} and T = 0.785 s. With A = 0.080 m, v_{max} = 0.640 m s^{-1} and E = 0.0512 J.

REASONING AND MARKING CHECKPOINTS

01

SHM requires $a = -\omega^2 x$: a straight acceleration-displacement graph through the origin with negative gradient. The supplied points satisfy this pattern.

02

Gradient is (-5.12-5.12)/(0.080-(-0.080)) = -64.0 s^{-2}. Therefore $\omega = \sqrt{64.0}$ = 8.00 rad s^{-1}.

03

Period is $T = 2\pi/\omega$ = 0.785 s. Taking the largest measured displacement as amplitude gives $v_{max} = \omega A$ = (8.00)(0.080) = 0.640 m s^{-1}.

04

The effective spring constant is $k = m\omega^2$ = (0.250)(64.0) = 16.0 N m^{-1}. Total energy is $\frac{1}{2}kA^2$ = 0.0512 J.

05

A constant acceleration zero offset adds the same value to every vertical reading. It preserves the gradient and inferred ω but shifts the line vertically so it no longer passes through the origin, creating an apparent nonzero acceleration at equilibrium.

COMMON MISTAKE

Using the gradient itself as angular frequency; in an a-x graph the gradient is $-\omega^2$, so its magnitude must be square-rooted.

Resolve wavelength and coherence from fringes

[13]

EXPECTED CONCLUSION

Fringe spacing = 4.20 mm; wavelength = 630 nm. Maximum fractional uncertainty ≈ 1.19% + 1.67% + 0.50% = 3.36%, so λ ≈ (630 ± 21) nm.

REASONING AND MARKING CHECKPOINTS

01

Ten spacings occupy 42.0 mm, so fringe spacing s = 4.20 mm. Measuring across many fringes makes the same endpoint-reading uncertainty a smaller fraction of one spacing.

02

For small angles, $s = \lambda D/d$. Hence $\lambda = sd/D = (4.20 \times 10^{-3})(0.300 \times 10^{-3})/2.00 = 6.30 \times 10^{-7}$ m.

03

Maximum fractional uncertainty is $\Delta s/s + \Delta d/d + \Delta D/D = 0.5/42.0 + 0.005/0.300 + 0.01/2.00 = 0.0336$.

04

Thus percentage uncertainty is 3.36% and absolute uncertainty is about 21 nm, giving λ = (630 ± 21) nm at matching precision.

05

Widening one slit changes relative amplitudes and may add a diffraction envelope, reducing visibility because minima no longer cancel perfectly. The geometric fringe spacing $\lambda D/d$ remains essentially unchanged while coherent path separation and wavelength are unchanged.

COMMON MISTAKE

Treating the measured 42.0 mm across ten spacings as one fringe spacing, producing a wavelength ten times too large.

Electric potential along a dipole axis

[14]

EXPECTED CONCLUSION

At 0.200 m, $V = 47.9$ V and $E = 512$ N C^{-1} toward +x. At 0.300 m, $V = 20.5$ V, so field work = $+2.74 \times 10^{-8}$ J. Far away $V \approx kp/x^2$ and $E \approx 2kp/x^3$; the potential approximation at 0.200 m is 44.9 V.

REASONING AND MARKING CHECKPOINTS

01

At $x = 0.200$ m, distances are 0.150 m to +Q and 0.250 m to -Q. Potential is $kQ(1/0.150-1/0.250) = 47.9$ V.

02

Both axial field contributions point toward +x there: $E = kQ[1/(0.150)^2-1/(0.250)^2] = 512$ N C^{-1}.

03

At 0.300 m, $V = kQ(1/0.250-1/0.350) = 20.5$ V. Electric-field work is $q(V_i-V_f) = 1.00 \times 10^{-9}(47.9-20.5) = 2.74 \times 10^{-8}$ J.

04

For x much larger than separation d, expand $1/(x\mp d/2)$ to first order. Their difference is approximately d/x^2, so $V \approx kp/x^2$ and $E = -dV/dx \approx 2kp/x^3$.

05

Here $p = Qd = 2.00 \times 10^{-10}$ C m, giving $V_{approx} = 44.9$ V. Its roughly 6% underestimate shows that $x/d = 2$ is only moderately within the far-field regime.

COMMON MISTAKE

Adding the two scalar potential contributions as positive magnitudes and forgetting that the negative source charge contributes negative potential.

Induction in a rotating coil

[13]

EXPECTED CONCLUSION

$N\Phi = 0.240\cos(50t)$ Wb-turn; $\varepsilon = 12.0\sin(50t)$ V; $\varepsilon_{rms} = 8.49$ V; first positive maximum at 0.0314 s. Average power = 1.20 W and average opposing torque = 0.0240 N m.

REASONING AND MARKING CHECKPOINTS

01

Flux per turn is $\Phi = BA\cos\omega t$. Flux linkage is $NBA\cos\omega t = 200(0.400)(3.00 \times 10^{-3})\cos(50t) = 0.240\cos(50t)$ Wb-turn.

02

Faraday's law gives $\varepsilon = -d(N\Phi)/dt = NBA\omega\sin\omega t = 12.0\sin(50t)$ V; the sign reflects Lenz's law for the chosen winding orientation.

03

Peak emf is 12.0 V and sinusoidal rms emf is $12.0/\sqrt{2} = 8.49$ V. First positive maximum occurs when $50t = \pi/2$, so $t = 0.0314$ s.

04

With a pure 60.0 Ω resistance, average power is $\varepsilon_{rms}^2/R = 8.49^2/60.0 = 1.20$ W.

05

At constant angular speed, average mechanical input equals electrical dissipation in the ideal model. Thus average torque magnitude is $P/\omega = 1.20/50.0 = 0.0240$ N m and acts opposite rotation.

COMMON MISTAKE

Using the peak voltage directly in $P = V^2/R$ for a sinusoidal source, which overestimates average power by a factor of two.

Infer half-life and background from count data

[14]

EXPECTED CONCLUSION

Corrected rates are 770, 420, 210, 105 and 52.5 counts min^{-1}; half-life from 10-20 min is 5.00 min, λ = 0.1386 min^{-1}, and predicted total at 30 min is about 103 counts min^{-1}.

REASONING AND MARKING CHECKPOINTS

01

Subtract background from every total reading. Corrected rates are 770, 420, 210, 105 and 52.5 counts min^{-1}.

02

The corrected rate halves from 210 to 105 in 5 min and again to 52.5 in the next 5 min, so the consistent later-data half-life is 5.00 min.

03

Decay constant is $\lambda = \ln 2/T_{half} = 0.6931/5.00 = 0.1386\ min^{-1}$.

04

At 30 min, two more half-lives after 20 min, corrected rate is 52.5/4 = 13.1 counts min^{-1}. Add background to predict total 103 counts min^{-1}.

05

Counts in a fixed interval have approximate standard uncertainty $\sqrt{N}$, so relative uncertainty grows as activity falls. A wrong background makes ln(corrected rate) curve, especially late when background is a large fraction; fit background and decay carefully rather than subtracting an arbitrary value.

COMMON MISTAKE

Taking half-life directly from total count rate without subtracting background, which makes the late decay appear artificially slow.

Photoelectric energy and measurement design

[12]

EXPECTED CONCLUSION

At 400 nm: photon energy = 3.10 eV, K_{max} = 0.900 eV, stopping potential = 0.900 V, and $v_{max} = 5.63 \times 10^5$ m s^{-1}. At 300 nm, K_{max} and stopping potential rise to about 1.93 eV and 1.93 V; saturation current is unchanged for equal photon rate and efficiency.

REASONING AND MARKING CHECKPOINTS

01

Photon energy is $hc/\lambda = (6.626 \times 10^{-34})(2.998 \times 10^8)/(400 \times 10^{-9}) = 4.966 \times 10^{-19}$ J = 3.10 eV.

02

Einstein's equation gives $K_{max} = hf - \Phi = 3.10 - 2.20 = 0.900$ eV, so stopping potential is K_{max}/e = 0.900 V.

03

Convert kinetic energy to joules and use $\frac{1}{2}mv^2$: $v = \sqrt{[2(0.900)(1.602 \times 10^{-19})/(9.11 \times 10^{-31})]} = 5.63 \times 10^5$ m s^{-1}.

04

At 300 nm photon energy is 4.13 eV, so $K_{max} \approx 1.93$ eV and stopping potential ≈ 1.93 V. Equal photon rate and unchanged quantum efficiency give the same saturation electron rate, not greater current merely because each photon is more energetic.

05

Reverse the collector voltage and extrapolate the photocurrent curve to zero current, correcting dark current and contact potential. Calling an arbitrary small-current voltage the stopping potential introduces detector-sensitivity bias.

COMMON MISTAKE

Assuming a shorter wavelength must increase photocurrent even when photon arrival rate is fixed; it raises electron energy, while current counts emitted electrons per second.

Analyse a triangular gas cycle

[14]

EXPECTED CONCLUSION

Net work = +225 J. Temperatures: 241 K, 602 K and 602 K. ΔU_{AB} = +450 J, ΔU_{BC} = 0, ΔU_{CA} = -450 J. Heats: +450 J, +525 J and -750 J. It is a heat engine.

REASONING AND MARKING CHECKPOINTS

01

The clockwise triangular area is W_{net} = ½(250-100)(5-2) = 225 kPa L = 225 J, positive for work done by the gas.

02

Using PV = nRT gives T_A = 200/[0.100(8.31)] = 241 K, T_B = 500/0.831 = 602 K and T_C = 500/0.831 = 602 K.

03

For a monatomic ideal gas $\Delta U = (3/2)nR\Delta T$. Thus ΔU_{AB} = +450 J, ΔU_{BC} = 0 and ΔU_{CA} = -450 J, summing to zero over the cycle.

04

Works are W_{AB} = 0, W_{BC} = average pressure times ΔV = [(250+100)/2](3) = 525 J, and W_{CA} = 100(2-5) = -300 J.

05

From $Q = \Delta U + W_{by}$, heats are +450 J, +525 J and -750 J. Net Q = +225 J equals net work, and positive cycle work means the device acts as a heat engine.

COMMON MISTAKE

Assuming internal energy changes with pressure alone; for an ideal gas it depends on temperature, and states B and C have the same PV and temperature.

Brake a rotating flywheel

[13]

EXPECTED CONCLUSION

Brake torque = 3.00 N m; α = -3.75 rad s^{-2}; stop time = 8.00 s; angle = 120 rad; thermal energy = 360 J. A 9.0 s stop implies total torque 2.67 N m, so another effect averages +0.333 N m in the direction of rotation.

REASONING AND MARKING CHECKPOINTS

01

The brake torque magnitude is $\tau = rF = (0.250)(12.0) = 3.00$ N m, opposite the angular velocity.

02

Using $\tau = I\alpha$ gives $\alpha = -3.00/0.800 = -3.75$ rad s^{-2}. Constant α gives stopping time $t = (0-30.0)/(-3.75) = 8.00$ s.

03

Angular displacement is the average angular speed times time: $\theta = (30.0+0)t/2 = 120$ rad.

04

Initial rotational energy $\frac{1}{2}I\omega^2 = \frac{1}{2}(0.800)(30.0)^2 = 360$ J becomes thermal energy. It also equals $\tau\theta = (3.00)(120)$ J.

05

A 9.0 s stop corresponds to $\alpha_{avg} = -3.33$ rad s^{-2} and $\tau_{total,avg} = -2.67$ N m, 0.333 N m less opposing than the nominal pad torque. One elapsed time determines only an average; angular-speed data throughout the stop are needed to test torque constancy.

COMMON MISTAKE

Multiplying the brake force by the wheel diameter instead of radius, or assigning the brake torque the same sign as the initial angular velocity.

Model a floating research buoy

[12]

EXPECTED CONCLUSION

Initial submerged depth = 0.228 m and freeboard = 0.272 m. With the instrument, submerged depth = 0.293 m and freeboard = 0.207 m, so it meets the 0.080 m requirement.

REASONING AND MARKING CHECKPOINTS

01

Floating equilibrium requires buoyant force equal weight: $\rho gAh = mg$. Gravity cancels, so $h = m/(\rho A)$.

02

Initially $h = 42.0/[1025(0.180)] = 0.228$ m. Freeboard is $0.500-0.228 = 0.272$ m.

03

With the instrument, total mass is 54.0 kg. Then $h = 54.0/[1025(0.180)] = 0.293$ m and freeboard is 0.207 m.

04

Because 0.207 m exceeds the required 0.080 m, the buoy passes the stated vertical-displacement criterion with 0.127 m margin.

05

This model says nothing about tipping. Safety also depends on centre of mass, centre of buoyancy, metacentric height, wave loading and whether the instrument shifts. A tall central mass can reduce rotational stability even while freeboard remains adequate.

COMMON MISTAKE

Using the buoy's entire external volume for displaced water even though a floating object displaces only the submerged volume required to balance its weight.

Audit a claimed heat-engine performance

[12]

EXPECTED CONCLUSION

Energy is conserved, but claimed efficiency 60% exceeds the 50% Carnot limit. Reservoir entropy change is -1200/600 + 480/300 = -0.400 J K^{-1}, violating the second law. More heat input or a hotter source/lower sink is required.

REASONING AND MARKING CHECKPOINTS

01

First-law accounting gives $Q_H = W + Q_C$: 1200 = 720 + 480 J, so the numerical energy balance is internally consistent.

02

Claimed efficiency is W/Q_H = 720/1200 = 0.600. The maximum reversible efficiency is $1-T_C/T_H$ = 1-300/600 = 0.500.

03

The hot reservoir entropy change is $-Q_H/T_H$ = -1200/600 = -2.00 J K^{-1}. The cold reservoir gains +480/300 = +1.60 J K^{-1}.

04

Total reservoir entropy change is -0.400 J K^{-1}. A cyclic engine returns to its own state, so it contributes no net entropy; the negative total violates the second law and confirms the claim is impossible.

05

At the same temperatures, even a reversible engine needs $Q_H \geq W/\eta_C$ = 720/0.5 = 1440 J. Alternatively, a hotter source or colder sink could raise the Carnot limit, subject to real irreversibility lowering actual efficiency.

COMMON MISTAKE

Accepting a heat engine merely because its joule totals balance; first-law conservation is necessary but does not guarantee second-law feasibility.

Resonance in an open air column

[12]

EXPECTED CONCLUSION

The open-pipe modes are n = 1, 2, 3 and imply 336 m s^{-1} without correction. Effective length for 343 m s^{-1} is 0.8575 m, so correction ≈ 8.75 mm per end. Closed-pipe resonances ≈ 100, 300 and 500 Hz under the same-length assumption.

REASONING AND MARKING CHECKPOINTS

01

An open pipe has displacement antinodes at both ends and frequencies $f_n = nv/(2L_{eff})$. Integer multiples 200, 400 and 600 Hz identify consecutive n = 1, 2 and 3 modes.

02

Ignoring end correction, $v = 2Lf_1 = 2(0.840)(200) = 336$ m s^{-1}.

03

Using independent v = 343 m s^{-1} gives $L_{eff} = v/(2f_1) = 343/400 = 0.8575$ m. The excess 0.0175 m shared by two open ends is 8.75 mm per end.

04

With one end closed, only odd harmonics occur: $f = v/(4L_{eff})$, $3v/(4L_{eff})$, $5v/(4L_{eff})$. The assumed same effective length gives 100, 300 and 500 Hz.

05

Closing an end changes the boundary geometry and its end correction; using the open-pipe effective length is therefore an approximation. Directly measure the new resonance series and check its odd-integer spacing.

COMMON MISTAKE

Assuming that a pipe closed at one end supports every integer harmonic, instead of only the odd sequence in the ideal model.

Infer source speed from two Doppler readings

[12]

EXPECTED CONCLUSION

For a moving source, $f_{app} = f\,c/(c-u)$ and $f_{rec} = f\,c/(c+u)$. The data give $u = 17.9$ m s⁻¹ and $f = 644$ Hz.

REASONING AND MARKING CHECKPOINTS

01

A moving source compresses wavelength ahead to $\lambda_{app} = (c-u)/f$ and stretches it behind to $\lambda_{rec} = (c+u)/f$. A stationary observer measures c divided by these wavelengths.

02

Thus $f_{app}/f_{rec} = (c+u)/(c-u)$. Solving gives $u = c(f_{app}-f_{rec})/(f_{app}+f_{rec})$.

03

Substitution gives $u = 340(680-612)/(680+612) = 17.9$ m s^{-1}.

04

Using either branch, $f = f_{app}(c-u)/c = 680(340-17.9)/340 = 644$ Hz; the receding branch provides the same value as a check.

05

Wind changes wave speed relative to the ground and can advect both source-generated wavefronts and observer. The simple still-air ground formula may bias inferred u; a consistent derivation must use velocities relative to the medium rather than replacing c in only one place.

COMMON MISTAKE

Using the moving-observer Doppler equation for a moving source; source motion changes wavelength, whereas observer motion changes the rate of meeting wavefronts.

Diagnose a non-ohmic filament lamp

[13]

EXPECTED CONCLUSION

Static resistance at 0.40 A is 12.0 Ω; interval dynamic resistance is 21.0 Ω; power is 1.92 W. Rising temperature increases lattice vibration and resistivity, so the slope grows.

REASONING AND MARKING CHECKPOINTS

01

Static resistance at an operating point is V/I = 4.80/0.400 = 12.0 Ω.

02

Dynamic resistance is the local gradient dV/dI. Over the final interval it is approximated by (4.80-2.70)/(0.40-0.30) = 21.0 Ω.

03

As current rises, electrical heating raises filament temperature. Stronger lattice vibrations increase electron scattering and resistivity, so the V-I graph becomes progressively steeper.

04

Power at 0.40 A is VI = (4.80)(0.400) = 1.92 W, consistent with I^2R using the static resistance at that operating point.

05

Use a low-voltage variable supply, series current-limiting resistor and switch, ammeter in series and voltmeter across the lamp. Increase current briefly, record simultaneous values, open the switch between readings, repeat in both directions, and do not exceed the rated current.

COMMON MISTAKE

Calling V/I the gradient of a curved graph; V/I is static resistance from the origin, while dynamic resistance is the tangent or local interval gradient.

Balance a current-carrying wire

[12]

EXPECTED CONCLUSION

Required current = 2.35 A, directed so I × B is upward. At 20% larger current the initial acceleration is 1.96 m s^{-2} upward.

REASONING AND MARKING CHECKPOINTS

01

For a straight segment perpendicular to B, magnetic force magnitude is F_B = BIL. Balance requires BIL = mg.

02

I = mg/(BL) = (0.0180)(9.81)/[(0.250)(0.300)] = 2.35 A. Use the vector rule I × B to choose whichever wire direction makes force upward.

03

At 1.20$I_{balance}$, magnetic force is 1.20mg. Net upward force is 0.20mg, so initial acceleration is 0.20g = 1.96 m s^{-2}.

04

Other circuit segments can experience magnetic forces too. Their directions, lengths within the field and mechanical supports determine whether they contribute to the measured vertical force or cancel.

05

Place the field segment on a balance, reverse current to remove constant offsets, and use half the difference in readings. A graph of force against IL has gradient B when the segment is perpendicular; control temperature because wire resistance and current can drift.

COMMON MISTAKE

Applying BIL to the whole wire length instead of only the portion inside the uniform field and perpendicular to it.

Mass defect and stellar fusion energy

[13]

EXPECTED CONCLUSION

Mass defect = 0.028697 u; energy ≈ 26.73 MeV = 4.282×10^{-12} J. About 8.94×10^{37} reactions s^{-1} and 4.26×10^{9} kg s^{-1} are required.

REASONING AND MARKING CHECKPOINTS

01

Initial atomic mass is 4(1.007825) = 4.031300 u. Subtracting helium mass gives Δm = 4.031300-4.002603 = 0.028697 u.

02

Energy is Δmc^2 = (0.028697)(931.5) = 26.73 MeV.

03

Convert to joules: 26.73×10^{6} eV multiplied by 1.602×10^{-19} J eV^{-1} gives 4.282×10^{-12} J per net reaction.

04

Reaction rate for luminosity L is L/E = $(3.83 \times 10^{26})/(4.282 \times 10^{-12}) = 8.94 \times 10^{37}$ s^{-1}.

05

Mass converted to radiant energy is $L/c^2 = 3.83 \times 10^{26}/(2.998 \times 10^{8})^2 = 4.26 \times 10^{9}$ kg s^{-1}. This is mass defect, not the much larger mass of hydrogen processed; neutrino losses would refine the luminosity link.

COMMON MISTAKE

Reporting the entire reacting hydrogen mass as destroyed; only the small mass defect is converted into released energy.

Energy levels in an infinite quantum well

[15]

EXPECTED CONCLUSION

$E_n = n^2h^2/(8mL^2)$. E_1 = 1.50 eV, E_2 = 6.02 eV; the 2→1 photon has energy 4.51 eV and wavelength about 275 nm. $\psi_1 = \sqrt{(2/L)}\sin(\pi x/L)$; n = 3 has two internal nodes.

REASONING AND MARKING CHECKPOINTS

01

Zero wavefunction at x = 0 and L requires an integer number of half wavelengths: $L = n\lambda/2$, so momentum magnitude $p = h/\lambda = nh/(2L)$.

02

Non-relativistic kinetic energy is $p^2/(2m)$, yielding $E_n = n^2h^2/(8mL^2)$. For L = 0.500 nm, $E_1 = 2.41 \times 10^{-19}$ J = 1.50 eV and $E_2 = 4E_1$ = 6.02 eV.

03

Transition energy is E_2-E_1 = $3E_1$ = 4.51 eV. Photon wavelength is $hc/\Delta E \approx 275$ nm.

04

Normalization gives $\psi_1(x) = \sqrt{(2/L)}\sin(\pi x/L)$ inside and zero outside. State n has n-1 internal nodes, so n = 3 has two.

05

The wavefunction provides a probability amplitude; $|\psi|^2$ predicts position distributions while energy states are stationary. A classical path with definite position and momentum at every instant is incompatible with the spatially extended state and uncertainty relation.

COMMON MISTAKE

Using n rather than n^2 for energy scaling, which makes the 2→1 photon energy E_1 instead of the correct $3E_1$.