

PLUMI PRACTICE PACK

A Level Physics A

OCR-style practice pack (H556)

Mark scheme | Total 362 marks

Q	Section	Level	Topic	Specification	Marks
1	A	Easy	Projectile motion	3.1.5, 3.3.2	11
2	A	Medium	Upthrust and the ideal gas: a hot-air balloon	3.2.5, 5.1.3	11
3	A	Medium	Moments and equilibrium: a hinged beam	3.2.4, 2.3.2, 3.2.3	9
4	A	Medium	Circular orbits: the moons of Saturn	5.4.3, 5.2.2, 2.1.2	11
5	A	Hard	Gravitational orbits and signal timing: a GPS satellite	5.4.3, 5.4.4, 4.4.1	11
6	A	Hard	Oscillations practical: mass on a spring	5.3.1, 5.3.3, 1.1.4, 2.2.3	14
7	A	Hard	Momentum and impulse: an air-track collision	3.5.1, 3.5.2, 3.5.3, 3.5.4	16
8	A	Super hard	Circular motion and energy: a loop-the-loop	5.2.2, 3.3.2, 3.3.3	13
9	A	Super hard	Ideal gases practical: determining absolute zero	5.1.1, 5.1.3, 1.1.1, 1.1.4, 2.2.2	15
10	A	Super hard	Doppler shift and orbits: detecting an exoplanet	5.5.3, 5.4.3, 5.2.2, 3.5.2	13
11	B	Easy	Potential dividers: a light sensor	4.3.4, 4.2.2	8
12	B	Medium	Capacitor discharge: a clock back-up	6.1.3, 6.1.4, 6.1.2	11
13	B	Medium	Wave-particle duality: electron diffraction	4.5.3, 4.4.4	10
14	B	Medium	Medical imaging: X-ray production and attenuation	6.5.1, 6.5.2, 4.5.1	9
15	B	Hard	Uniform electric fields: separating plastics	6.2.3, 6.2.1, 3.1.3	12
16	B	Hard	Stationary waves: microwaves and a metal plate	4.4.6, 4.4.4, 2.2.3	14
17	B	Hard	The photoelectric effect: stopping potential	4.5.2, 4.5.1, 4.1.1	15
18	B	Super hard	Charged particles in fields: separating isotopes	6.3.2, 6.2.4, 6.4.1	12
19	B	Super hard	Capacitors practical: discharge through a voltmeter	6.1.3, 6.1.4, 1.1.1, 1.1.4, 2.2.3	15
20	B	Super hard	Annihilation and PET scanning	6.5.4, 6.4.1, 6.4.4, 4.5.1	14
21	C	Easy	Practical skills: the resistivity of a wire	4.2.4, 1.1.3, 1.1.4, 2.2.3, 2.2.4	8
22	C	Medium	Energy and electromagnetic induction: a hydroelectric generator	3.3.3, 3.3.4, 6.3.3, 6.3.4	12
23	C	Medium	Gravitational fields and kinematics: a lunar mass driver	5.4.2, 5.4.4, 3.1.3, 3.3.4	12
24	C	Medium	Thermal and electrical energy: an electric shower	5.1.2, 4.2.5, 4.2.4	11
25	C	Hard	Data analysis: a power law for the pendulum	5.3.1, 1.1.4, 2.2.3	13
26	C	Hard	Radioactivity and current: a smoke alarm	6.4.4, 6.4.2, 4.1.1	10
27	C	Hard	Stellar radiation: the radius of a star	5.5.2, 5.5.3, 4.4.1, 4.5.1	12
28	C	Super hard	Practical skills: the Planck constant from LEDs	4.5.1, 4.2.3, 1.1.1, 1.1.4, 2.2.3	14
29	C	Super hard	Stationary waves and materials: a guitar string	4.4.6, 4.4.1, 3.4.3, 3.4.5	13
30	C	Super hard	Momentum, energy and electricity: a hovering drone	3.5.1, 3.5.3, 3.3.4, 4.2.5, 4.1.1	13
Total (A: 124, B: 120, C: 118)					362

OCR-style practice written by Plumi. Not produced or endorsed by OCR. Every numerical answer, show-that, unit and significant-figure judgement in this scheme was checked by computer (exact and numerical calculation, dimensional analysis and simulation).



Annotations used in this mark scheme

Annotation	Meaning
M1	Method mark: a correct method applied to the values; it may be implied by later working.
A1	Accuracy mark: depends on the M (or C) mark before it. A correct answer from wrong working earns no A mark.
C1	Compensatory mark: awarded for a correct step, and implied by a correct final answer.
B1	Independent mark for a correct statement or result.
6 (*)	Level of Response item, marked by levels (see below).
ECF	Error carried forward: credit for correct work that uses an incorrect earlier answer.
AW, ORA	Alternative wording; or reverse argument.
allow / not / ignore	Answers that are acceptable / not acceptable / irrelevant and not penalised.
/	Alternative and acceptable answers for the same marking point.

Subject-specific marking instructions

- **Show that.** The working must be complete, and the final value must be given to at least one more significant figure than the value printed in the question. A bald 'which is about the given value' earns no accuracy mark.
- **Significant figures.** A final answer is accepted to any number of significant figures if it rounds to the value in the scheme, unless the question asks for an appropriate number of significant figures; only then is a separate mark shown. A show-that answer must have at least one more significant figure than the value printed in the question.
- **Error carried forward.** ECF is given for a correct method that uses an earlier incorrect value. ECF is not given where the method itself is wrong physics.
- **Units.** Where the unit is printed on the answer line it need not be repeated. Where the answer line has no unit, a unit is required only where the scheme says so.
- **Ranges.** Values read from graphs are accepted within the stated range; ECF applies to later parts.
- **Calculator use.** A correct answer with no working is given full credit unless the question says 'show that' or the scheme says otherwise; an incorrect answer with no working scores 0.

Level of Response items (*)

Read the whole answer. Decide the level from the science content against the level descriptors, then award the higher mark in the level if the communication statement for that level is met, otherwise the lower mark. The indicative scientific points are not a checklist; credit any valid physics. Level 0 (0 marks): no response, or no response worthy of credit.



SECTION A: MODELLING PHYSICS

Question 1 Modelling · Easy · Projectile motion

Question	Answer	Marks	Guidance
1(a)(i)	$18 \cos 35^\circ = 14.7 \text{ m s}^{-1}$	B1	Allow 15 m s^{-1}
1(a)(ii)	$18 \sin 35^\circ = 10.3 \text{ m s}^{-1}$	B1	Allow 10 m s^{-1}
1(b)	$s = ut + \frac{1}{2}at^2$ with $s = -42 \text{ m}$, $u = 10.3 \text{ m s}^{-1}$, $a = -9.81 \text{ m s}^{-2}$	C1	Any consistent sign convention. Allow a two-stage method: time to the top (1.05 s) plus time to fall from the highest point
	$4.905t^2 - 10.3t - 42 = 0$ solved, or $v = 30.5 \text{ m s}^{-1}$ downwards then $t = (10.3 + 30.5)/9.81$	C1	
	$t = 4.16 \text{ s}$	A1	Allow 4.2 s. Not 2.93 s (vertical component of initial velocity taken as zero: wrong physics, scores 0). 2.06 s (sign error in a) scores C1 only
1(c)	distance = 14.74×4.162 (unrounded values from (a)(i) and (b))	C1	ECF from (a)(i) and (b)
	61.4 m	A1	Allow 61 m; allow 61.1 to 61.4 m from rounded values
1(d)	No (resultant) horizontal force, so the horizontal component of velocity is constant	B1	Allow 'no horizontal acceleration'
	Weight / gravity gives a constant downward acceleration, so the vertical component changes (decreases upwards, then increases downwards); the direction of the velocity changes continuously	B1	Not 'gravity slows it down' alone
1(e)	$\frac{1}{2}mv^2 = \frac{1}{2}m(18)^2 + mg(42)$, so $v^2 = 18^2 + 2 \times 9.81 \times 42$	C1	Allow the component route: $v_y = 30.5 \text{ m s}^{-1}$, $v = \sqrt{14.7^2 + 30.5^2}$
	$v = 33.9 \text{ m s}^{-1}$	A1	Allow 34 m s^{-1}
Total		11	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Notes

(b) Most errors come from dropping the initial vertical velocity or mixing signs. A candidate who writes every vector with its sign and solves the quadratic gains full credit.

Question 2 Modelling · Medium · Upthrust and the ideal gas: a hot-air balloon

Question	Answer	Marks	Guidance
2(a)	$U = \rho Vg = 1.20 \times 2800 \times 9.81$	C1	
	$3.30 \times 10^4 \text{ N}$	A1	Allow $3.3 \times 10^4 \text{ N}$
2(b)	mass of air inside = $1.20 \times 2800 - 620 = 2740 \text{ kg}$	C1	Or weight of air inside = $3.30 \times 10^4 - 620 \times 9.81$



Question 2 continued

Question	Answer	Marks	Guidance
	$\rho = 2740/2800 = 0.979 \text{ kg m}^{-3}$	A1	Answer must be given to 3 s.f. or more. Not 0.98 with no further figure
2(c)	At constant pressure ρT is constant (from $pV = nRT$ with $n = m/M$, $\rho = pM/RT$)	C1	Allow $V \propto T$ for the same mass of air
	$T = 288 \times 1.20/0.979 = 353 \text{ K}$	C1	Temperatures must be in kelvin. Using 15 in place of 288 gives 18.4: wrong physics, scores 0
	80 °C	A1	Allow 79 to 81 °C. 353 K given as the final answer scores 2 marks
2(d)	$\Delta p = (\rho_{\text{out}} - \rho_{\text{in}})gh = (1.20 - 0.979) \times 9.81 \times 18$	C1	Allow $(620/2800) \times 9.81 \times 18$. One column only (212 Pa or 173 Pa) scores 0
	39 Pa	A1	Allow 38 to 40 Pa; ECF from (b)
2(e)	Upthrust ($\rho_{\text{out}} Vg$) is smaller, so the air inside must have a smaller mass / density for the balloon to lift off	B1	ORA
	At the same pressure, a smaller density needs a higher temperature (ρT constant)	B1	
	Total	11	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Notes

(c) The gas law is applied to density: no value of the molar mass is needed. The kelvin conversion is the commonest slip in reports on this topic.

(d) The pressure difference arises because pressure falls with height more slowly in the less dense air inside the envelope; the two pressures are equal at the mouth.

Question 3 Modelling · Medium · Moments and equilibrium: a hinged beam

Question	Answer	Marks	Guidance
3(a)	For a body in (rotational) equilibrium, the sum of the clockwise moments about any point is equal to the sum of the anticlockwise moments about the same point	B1	Both 'equilibrium' and 'about the same point' needed
3(b)	Weight of the beam acts at its centre: moment = $60 \times 0.90 = 54 \text{ N m}$	C1	Not drawn in Fig. 3.1; must be inferred from 'uniform'
	Moments about A: $T \sin 40^\circ \times 1.80 = 150 \times 1.80 + 54$ (= 324 N m)	C1	Allow $T \times 1.80 \sin 40^\circ$ (perpendicular distance)
	$T = 280.0 \text{ N}$	A1	Answer must be given to 3 s.f. or more. A candidate who omits the beam's weight (233 N) scores C0 C1 A0
3(c)	Horizontal component = $T \cos 40^\circ = 214.5 \text{ N}$	C1	ECF from (b); using 280 N gives the same values to 3 s.f.



Question 3 continued

Question	Answer	Marks	Guidance
	Vertical component = $210 - T \sin 40^\circ = 30.0 \text{ N}$ (upwards)	C1	Allow moments about B: $V \times 1.80 = 60 \times 0.90$
	$F = \sqrt{214.5^2 + 30.0^2} = 217 \text{ N}$	A1	Not 214 or 215 N (vertical component omitted)
3(d)	The moment of the tension about A must still be 324 N m, as the loads are unchanged	B1	Allow 'the vertical component of T must still be 180 N'
	$\sin 60^\circ > \sin 40^\circ$ (the perpendicular distance from A to the cable is larger), so a smaller tension gives this moment (208 N)	B1	
	Total	9	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Notes

(c) Two independent routes for the vertical component (resolving, or moments about B) both give 30.0 N; the agreement is a check that candidates can be taught to use.

Question 4 Modelling · Medium · Circular orbits: the moons of Saturn

Question	Answer	Marks	Guidance
4(a)	$15.9 \text{ days} = 15.9 \times 8.64 \times 10^4 = 1.37 \times 10^6 \text{ s}$	C1	
	$\frac{GMm}{r^2} = mr\omega^2 = mr \left(\frac{2\pi}{T} \right)^2$, so $M = \frac{4\pi^2 r^3}{GT^2}$	C1	Allow $T^2 = \frac{4\pi^2}{GM} r^3$ from the Data booklet
	$M = 5.69 \times 10^{26} \text{ kg}$	A1	Answer must be given to 3 s.f. or more
4(b)	$v = 2\pi r/T = 2\pi \times 1.22 \times 10^9 / 1.37 \times 10^6$	C1	Allow $v = \sqrt{GM/r}$
	$5.58 \times 10^3 \text{ m s}^{-1}$	A1	Allow $5.6 \times 10^3 \text{ m s}^{-1}$
4(c)	$T^2 \propto r^3$: $T = 15.9 \times (5.27 \times 10^8 / 1.22 \times 10^9)^{3/2}$	C1	Or $T = 2\pi \sqrt{r^3/GM} = 3.90 \times 10^5 \text{ s}$
	4.51 days	A1	Allow 4.5 days. $3.90 \times 10^5 \text{ s}$ not converted scores C1 only
4(d)	The gravitational force provides the centripetal force: $\frac{GMm}{r^2} = \frac{mv^2}{r}$, so $v = \sqrt{GM/r}$	B1	
	M is the same for both moons and Rhea's orbital radius is smaller, so its speed is greater	B1	Allow $v \propto 1/\sqrt{r}$
4(e)	$G = Fr^2/(Mm)$, and $N = \text{kg m s}^{-2}$	C1	Any correct equation for G
	$\text{kg m s}^{-2} \times \text{m}^2 \times \text{kg}^{-2} = \text{kg}^{-1} \text{ m}^3 \text{ s}^{-2}$	A1	Units left in N, or J, score A0
	Total	11	

Notes

(e) Only kg, m, s, A, K and mol may appear. Examiner reports note candidates who stop at $\text{N m}^2 \text{ kg}^{-2}$.



Question 5 Modelling · Hard · Gravitational orbits and signal timing: a GPS satellite

Question	Answer	Marks	Guidance
5(a)	$\frac{GMm}{r^2} = mr \left(\frac{2\pi}{T} \right)^2$	C1	
	$r^3 = \frac{GMT^2}{4\pi^2} = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times (4.31 \times 10^4)^2}{4\pi^2}$	C1	
	$r = 2.66 \times 10^7 \text{ m}$	A1	Answer must be given to 3 s.f. or more
5(b)	S is on the horizon, so SP is a tangent and is perpendicular to OP: $SP = \sqrt{r^2 - R^2} = 2.58 \times 10^7 \text{ m}$	C1	The hidden step. Using r for SP scores 0 for this mark
	distance when S is directly above P = $r - R = 2.02 \times 10^7 \text{ m}$	C1	
	$\Delta t = (2.58 - 2.02) \times 10^7 / 3.00 \times 10^8$	C1	ECF for their distances
	0.0186 s	A1	Allow 0.018 to 0.019 s; with $r = 2.7 \times 10^7 \text{ m}$ the answer is 0.0187 s
5(c)(i)	S must also be given kinetic energy, because it moves at its orbital speed in orbit	B1	
5(c)(ii)	Gain in GPE = $GMm \left(\frac{1}{R} - \frac{1}{r} \right) = 7.7 \times 10^{10} \text{ J}$	C1	Not $GMm/(r - R)$ or $mg(r - R)$ (wrong physics)
	Kinetic energy in orbit = $\frac{GMm}{2r}$ (or $\frac{1}{2}mv^2$ with $v = 2\pi r/T$) = $1.2 \times 10^{10} \text{ J}$	C1	
	minimum energy = $9.0 \times 10^{10} \text{ J}$	A1	Allow 8.9 to $9.1 \times 10^{10} \text{ J}$. Allow the total-energy route: $-\frac{GMm}{2r} - \left(-\frac{GMm}{R} \right)$
	Total	11	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Notes

Difficulty features: hidden physical model (the line of sight from P to a satellite on the horizon is a tangent, perpendicular to the radius OP; the right angle is not marked); several topics connected without announcing it (orbital mechanics, the speed of electromagnetic waves and gravitational potential energy in one situation); quantitative evaluation of a claim (the student's claim that only the gain in potential energy is needed); conditions and limiting cases (the rotation of the Earth is ignored, so the launch starts from rest).

(b) Fig. 5.1 deliberately does not mark the right angle at P. Candidates who see that a line to the horizon is a tangent have the whole method.

(c)(ii) Examiner reports repeatedly note candidates who put a difference in radius into one formula. Each potential energy must be found at its own radius and then subtracted.



Question 6 Modelling · Hard · Oscillations practical: mass on a spring

Question	Answer	Marks	Guidance
6(a)	Reduces the percentage uncertainty in T (the reaction-time uncertainty is shared over 20 periods)	B1	Allow 'more precise'. Not 'more accurate' alone
6(b)	$T = 0.990 \text{ s}$ and $T^2 = 0.980 \text{ s}^2$	B1	Both needed; allow 0.98 s^2
6(c)	Point plotted at (0.600, 0.980) to within half a small square	B1	ECF from (b)
	Single thin straight line of best fit with points balanced on either side; not forced through the origin	B1	
6(d)	gradient from a triangle covering at least half the line = $1.58 \text{ s}^2 \text{ kg}^{-1}$	C1	Allow 1.53 to $1.63 \text{ s}^2 \text{ kg}^{-1}$. Gradient from table values or a small triangle scores C0
	$T^2 = \frac{4\pi^2}{k}(m + m_s)$, so gradient = $4\pi^2/k$	C1	
	$k = 25 \text{ N m}^{-1}$	A1	Allow 24 to 26 N m^{-1} ; ECF from their gradient
6(e)	intercept on the T^2 axis = 0.032 s^2	C1	Allow 0.022 to 0.042 s^2 . Or extrapolates the line to $T^2 = 0$ and reads -0.020 kg on the m axis
	mass = $\frac{\text{intercept}}{\text{gradient}} = 0.032/1.58 = 0.020 \text{ kg}$	A1	Allow 0.013 to 0.028 kg ; ECF from their values
	The (effective) mass of the spring itself, part of which oscillates with the load	B1	Allow 'mass of the hanger' if justified as part of the oscillating mass
6(f)	% uncertainty in t (and T) = $0.2/8.72 \times 100 = 2.3\%$	C1	
	% uncertainty in $T^2 = 2 \times 2.29 = 4.6\%$	A1	Allow 4.5%. Not 2.3% (squared term not doubled)
6(g)	fraction = their mass from (e) / $0.060 = 0.0203/0.060$ (unrounded value from (e))	C1	ECF from (e); $0.020/0.060 = 0.33$ is also accepted
	0.34 (about one third of the spring's mass)	A1	Allow 0.2 to 0.5
	Total	14	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Notes

Difficulty features: representation change (the period is linearised as T^2 against m ; the gradient is $4\pi^2/k$ and the intercept must be interpreted); information to infer (the non-zero intercept shows that part of the spring itself oscillates; the student must deduce the extra mass from the graph); experimental design and uncertainty (timing many oscillations and doubling the percentage uncertainty for a squared quantity); quantitative evaluation of a claim ((g) compares the inferred extra mass with the measured mass of the spring: about one third of it oscillates).

(d) The question says only that M differs from m by a constant: candidates must recognise that the gradient is still $4\pi^2/k$ and the intercept carries the extra mass.

(e) An intercept read from a line forced through the origin scores 0.



Question 7 Modelling · Hard · Momentum and impulse: an air-track collision

Question	Answer	Marks	Guidance
7(a)	Impulse = change in momentum = area under the graph	C1	
	area = 0.15 N s (counting squares, or $\frac{1}{2} \times 3.0 \times 0.10$ by symmetry of the curve)	C1	Allow 0.14 to 0.16 N s
	$v = 0.15/0.250 = 0.60 \text{ m s}^{-1}$	A1	Allow 0.56 to 0.64 m s^{-1} from their area. Not $F_{\text{max}} \times \text{duration} = 0.30 \text{ N s}$ (wrong physics)
7(b)	Momentum conserved: $0.250 \times 0.60 = 0.250v_A + 0.250 \times 0.60$, so $v_A = 0$	C1	Or relative speed of approach (0.60) = relative speed of separation (0.60)
	kinetic energy before = $\frac{1}{2} \times 0.250 \times 0.60^2 = 0.045 \text{ J}$	C1	
	kinetic energy after = 0.045 J (B only moving), so kinetic energy is conserved: perfectly elastic	A1	Conclusion needed
7(c)	Same shape and duration, over the same time interval (0.010 s to 0.110 s)	B1	
	Below the time axis (negative), with a peak of -3.0 N	B1	Allow a mirror image of the given curve in the t-axis
7(d)	$0.250 \times 0.60 = 0.750v$, so $v = 0.20 \text{ m s}^{-1}$	C1	
	kinetic energy after = $\frac{1}{2} \times 0.750 \times 0.20^2 = 0.015 \text{ J}$	C1	
	$(0.045 - 0.015)/0.045 \times 100 = 67\%$	A1	ECF from their v . Not 33% (the percentage kept)
7(e)	Momentum is conserved in the collision (no external horizontal force)	B1	
	Total momentum before is 0.15 kg m s^{-1} , not zero, so the gliders must still be moving afterwards (at 0.20 m s^{-1})	B1	Allow 'momentum after would be zero, which is less than before'
7(f)	At the closest approach the two gliders have the same velocity (at $t = 0.060 \text{ s}$, the force peak)	C1	The hidden step
	$0.250 \times 0.60 = 0.500v$, so $v = 0.30 \text{ m s}^{-1}$; kinetic energy = $\frac{1}{2} \times 0.500 \times 0.30^2 = 0.0225 \text{ J}$	C1	
	energy stored = $0.045 - 0.0225 = 0.0225 \text{ J}$	A1	Allow 0.022 or 0.023 J; ECF from (b)
	Total	16	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Notes

Difficulty features: calculus-style trap (the impulse is the area under a curved force-time graph and must be estimated, not read as $F \times t$); information to infer (the force on A is equal and opposite to the force on B at every instant (Newton's third law), but is not drawn); competing plausible ideas (the student's claim that a softer putty could stop both gliders, against conservation of momentum); hidden physical model ((f): at closest approach the gliders move with the same velocity, and the missing kinetic energy is stored by the magnets).

(a) The force-time curve is not a triangle; the symmetry of the curve makes $\frac{1}{2} \times \text{peak} \times \text{duration}$ exact here, but candidates who count squares are equally credited.



Question 7 notes continued

(c) Examiner reports note that a generic statement of Newton's third law scores nothing; the sketch shows which body pushes which, at every instant.

Question 8 Modelling · Super hard · Circular motion and energy: a loop-the-loop

Question	Answer	Marks	Guidance
8(a)	At the top the car just stays in contact when the normal contact force is zero, so the weight alone provides the centripetal force: $mg = \frac{mv^2}{r}$, $v^2 = gr$	B1	The hidden step. Allow ' $N \geq 0$ at the top'
	Energy conservation from release to the top (height $2r$): $mgh = mg(2r) + \frac{1}{2}mv^2$	C1	
	$gh = 2gr + \frac{1}{2}gr$	C1	Substitutes the limiting speed
	$h = 2.5r$ (a larger h gives a larger speed at the top, so the contact force is then greater than zero)	A1	Using the bottom of the loop as the critical point, or $v = 0$ at the top, scores 0
8(b)	At the top: $\frac{1}{2}mv^2 = mg(3r - 2r)$, so $v^2 = 2gr$	C1	
	$N_{\text{top}} + mg = \frac{m(2gr)}{r}$, so $N_{\text{top}} = mg$	C1	Weight and contact force both towards the centre at the top
	At the bottom: $v^2 = 6gr$ and $N_{\text{bottom}} - mg = 6mg$, so $N_{\text{bottom}} = 7mg$	C1	Weight and contact force in opposite directions at the bottom
	ratio = 7	A1	Not 6 (weight omitted at both points)
8(c)	Energy needed at the top: $mg(2r) + \frac{1}{2}m(gr) = 2.5mgr$	C1	ECF from (a)
	Initial energy $3mgr$, so the greatest loss allowed is $0.5mgr$, which is 17% (one sixth)	C1	Allow 16.7%
	Claim not justified: a loss between 17% and 20% would let the car leave the track before the top	A1	Conclusion with a quantitative comparison
8(d)	The weight, the centripetal force (mv^2/r), the potential energy (mgh) and the kinetic energy ($\frac{1}{2}mv^2$) are all proportional to m	B1	
	so m cancels from the contact condition and the energy equation, and percentages of energy are ratios of quantities proportional to m	B1	
	Total	13	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Notes

Difficulty features: hidden physical model (staying in contact at the top of the loop means the contact force is at least zero, so the weight alone may provide the centripetal force); parameters instead of numbers (the release height and the ratio of contact forces must be found in terms of r , g and m , with no numbers given); conditions and limiting cases (the limiting case $N = 0$ at the top, and why larger heights also work); quantitative evaluation of a claim (the manufacturer's 20% energy-loss claim is tested against the allowed loss of one sixth); little scaffolding ((a) and (b) name neither the critical point nor the laws to combine, and no target value is given).

Question 8 notes continued

Indicative check: a numerical scan of the contact force round the loop (verify.py) confirms that $h = 2.49r$ loses contact and $h = 2.51r$ does not, for any mass and radius, and that the ratio in (b) is 7.

(a) A candidate who sets the speed at the top to zero has not identified the model and scores at most C1 for the energy equation.

Question 9 Modelling · Super hard · Ideal gases practical: determining absolute zero

Question	Answer	Marks	Guidance
9(a)*	Level 3 (5 or 6 marks) Clear description of how accurate readings are obtained and clear explanation of the analysis, including how absolute zero is found from the graph. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3 or 4 marks) Some description of how readings are obtained and some explanation of the analysis; or a clear description of the readings only; or a clear explanation of the analysis only. <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1 or 2 marks) Limited description of the readings or limited analysis. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response or no response worthy of credit.	6	Indicative scientific points may include: Readings - Flask (almost) completely under the water so all the air is at the water temperature - Short, narrow tube so that little air is outside the bath - Stir the water; wait until the thermometer and gauge readings are steady (thermal equilibrium) before reading - Heat in steps of about 10 to 15 °C over as wide a range as possible (for example ice-water to near 100 °C) - Read the thermometer at eye level, or use a digital thermometer; repeat while cooling and take means - Safety: hot water, clamp the flask, eye protection Analysis - Add atmospheric pressure to each gauge reading to obtain the pressure of the air - Plot p (y-axis) against θ (x-axis); expect a straight line, since $p \propto T$ at constant volume - Extrapolate the line to $p = 0$; the intercept on the θ-axis is absolute zero - Or: absolute zero = $-(y\text{-intercept})/(\text{gradient})$, from $p = m\theta + c$ - If the intercept is read from the graph, the θ-axis must extend to about -300 °C (no false origin on that axis)
9(b)	The pressure of the air is the gauge reading + 101.0 kPa (for example $2.6 + 101.0 = 103.6$ kPa)	C1	The hidden step. Extrapolating the gauge readings to zero gives 2.9 °C: scores the gradient mark only
	gradient = $(30.1 - 2.6)/(85.0 - 10.0) = 0.3667$ kPa °C ⁻¹	C1	Or a least-squares or graph gradient (0.366); the gradient is the same for gauge and absolute pressures
	absolute zero where the absolute pressure is zero: $\theta = 10.0 - 103.6/0.3667 = -272.5$ °C	C1	
	-272.5 °C (-273 °C)	A1	Allow -272 or -273 °C; allow -268 to -278 °C from a graph



Question 9 continued

Question	Answer	Marks	Guidance
9(c)	$T = 10.0 + 273 = 283 \text{ K}$	C1	Any row of the table; or uses the gradient: $nR/V = 367 \text{ Pa K}^{-1}$
	$n = \frac{pV}{RT} = \frac{103.6 \times 10^3 \times 2.50 \times 10^{-4}}{8.31 \times 283}$	C1	Absolute pressure in Pa. The gauge reading alone gives $2.8 \times 10^{-4} \text{ mol}$: C1 for T only
	$n = 0.0110 \text{ mol}$	A1	Allow 0.0108 to 0.0112 mol; allow 0.011 mol
9(d)	No change (the graph is the same)	B1	
	Gradient = nR/V ; doubling V at the same initial p and T doubles n , so n/V is unchanged	B1	Not 'halves' (n treated as fixed)
	Total	15	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Notes

Difficulty features: experimental design and uncertainty (the Level of Response plan: thermal equilibrium, air outside the bath, range of readings); hidden physical model (the gauge measures pressure above atmospheric, so absolute zero is where the gauge would read -101.0 kPa , not zero); representation change (the p against θ line is extrapolated to $p = 0$, and its gradient is interpreted as nR/V); little scaffolding ((b) and (c) give no method; any valid route is credited); competing plausible ideas (a larger flask seems to change the graph; the student must show that n/V , and so the gradient, is unchanged); information to infer (celsius to kelvin, and $\text{kPa per } ^\circ\text{C}$ to Pa per K , without prompting).

(b) The gauge readings plotted directly give a straight line of the same gradient, but its intercept on the θ -axis (about 3°C) is meaningless: the pressure of the air is never zero there.

(c) The gradient route and the single-row route give the same amount; neither is preferred.

(d) The tempting answer is that a bigger volume halves the gradient, which forgets that the bigger flask holds more air.

Question 10 Modelling · Super hard · Doppler shift and orbits: detecting an exoplanet

Question	Answer	Marks	Guidance
10(a)	The star orbits the centre of mass, so it moves alternately towards and away from the Earth	B1	
	Doppler effect: the wavelength increases when the star moves away (red shift) and decreases when it moves towards the Earth	B1	
10(b)	$\Delta\lambda_{\text{max}} = 1.23 \times 10^{-13} \text{ m}$ read from Fig. 10.1	C1	Allow 1.20 to $1.25 \times 10^{-13} \text{ m}$
	$v = c \frac{\Delta\lambda}{\lambda} = \frac{3.00 \times 10^8 \times 1.23 \times 10^{-13}}{656.28 \times 10^{-9}} = 56.2 \text{ m s}^{-1}$	A1	Answer to 3 s.f. or more (55.8 to 56.3 from readings 1.22 to 1.23). Allow the observed wavelength in the denominator (same answer)
10(c)	period from Fig. 10.1 = 4.23 days (several cycles) = $3.65 \times 10^5 \text{ s}$	C1	Allow 4.2 to 4.25 days



Question 10 continued

Question	Answer	Marks	Guidance
	For the planet: $\frac{GMm_p}{a^2} = m_p a \left(\frac{2\pi}{T}\right)^2$ with $M =$ mass of the star	C1	Planet's mass negligible compared with the star's
	$a^3 = \frac{GMT^2}{4\pi^2} = \frac{6.67 \times 10^{-11} \times 2.2 \times 10^{30} \times (3.65 \times 10^5)^2}{4\pi^2}$	C1	
	$a = 7.9 \times 10^9 \text{ m}$	A1	Allow 7.8 to $8.0 \times 10^9 \text{ m}$
10(d)	planet's speed $v_p = 2\pi a/T = 1.36 \times 10^5 \text{ m s}^{-1}$	C1	ECF from (c)
	Centre of mass stationary, so total momentum is zero: $Mv_s = m_p v_p$	C1	Allow $Mr_s = m_p a$ with $r_s = v_s T/2\pi$
	$m_p = 2.2 \times 10^{30} \times 56/1.36 \times 10^5 = 9.1 \times 10^{26} \text{ kg}$	A1	Allow 8.8 to $9.3 \times 10^{26} \text{ kg}$
10(e)	Only the component of the star's velocity along the line of sight causes a Doppler shift, so the measured speed is less than the star's orbital speed	B1	
	The planet's mass is proportional to the star's speed, so the true mass is larger than the value found	B1	
	Total	13	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Notes

Difficulty features: unfamiliar context disguising familiar physics (a periodic shift in a stellar absorption line is the star's orbital motion); several topics connected without announcing it (Doppler shift gives the star's speed, Kepler's third law gives the orbit, conservation of momentum gives the planet's mass; none is named); modelling decision (the planet's mass is negligible in the gravitational force law, and both bodies share one period); little scaffolding ((c) and (d) give no method); conditions and limiting cases (when the orbit is inclined, only the line-of-sight component is measured, so the mass is a lower limit).

(c) Reading the period over three cycles (12.7 days) and dividing by 3 is the expected practice; a single-cycle reading within the allowed range is also credited.

(d) The planet's mass found here is about half that of Jupiter: a 'hot Jupiter', close to its star.

SECTION B: EXPLORING PHYSICS

Question 11 Exploring · Easy · Potential dividers: a light sensor

Question	Answer	Marks	Guidance
11(a)	The resistance decreases	B1	
11(b)	$V_{\text{out}} = 9.0 \times \frac{10}{10 + 1.5}$	C1	Or $I = 9.0/11.5 \times 10^3$ then $V = IR$
	7.8 V	A1	Allow 7.83 V
11(c)	current = $1.0/10 \times 10^3 = 1.0 \times 10^{-4}$ A, and the p.d. across the LDR = $9.0 - 1.0 = 8.0$ V	C1	Or the divider ratio 8.0 : 1.0
	$R = 8.0/1.0 \times 10^{-4} = 8.0 \times 10^4 \Omega$	A1	Working must be seen; the given value alone scores 0
11(d)	The resistance of the LDR falls, so it takes a smaller share of the 9.0 V (or the total resistance falls and the current increases)	B1	Direction of each change needed
	so the p.d. across R increases (the p.d.s add to 9.0 V, or $V = IR$ with a larger I)	B1	
11(e)	Swap the LDR and R (or take the output across the LDR instead of across R)	B1	
	Total	8	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Question 12 Exploring · Medium · Capacitor discharge: a clock back-up

Question	Answer	Marks	Guidance
12(a)	$\tau = CR = 0.33 \times 30 \times 10^3$	C1	
	9.9×10^3 s	A1	Allow 9900 s
12(b)	$2.0 = 5.0e^{-t/9900}$, so $t = 9900 \ln(5.0/2.0)$	C1	
	9.1×10^3 s	A1	Allow 9.0 to 9.2×10^3 s
12(c)	$W = \frac{1}{2}C(5.0^2 - 2.0^2) = \frac{1}{2} \times 0.33 \times 21$	C1	Not $\frac{1}{2}C(5.0 - 2.0)^2 = 1.5$ J (wrong physics)
	3.5 J	A1	Allow 3.47 J
12(d)	6.0 hours = 2.16×10^4 s	C1	
	$t = CR \ln(5.0/2.0)$, so $C = \frac{2.16 \times 10^4}{3.0 \times 10^4 \times \ln 2.5}$	C1	Allow scaling their (b): $C = 0.33 \times 2.16 \times 10^4 / \text{their } t$
	0.79 F	A1	Allow 0.78 F
12(e)	The time halves (to 4.5×10^3 s)	B1	
	The resistance of the two clocks in parallel is 15 k Ω , so the time constant CR halves	B1	
	Total	11	



Question 12 notes continued

Notes

(c) Examiner reports on capacitors repeatedly note candidates who square a difference of p.d.s instead of subtracting two energies.

Question 13 Exploring · Medium · Wave-particle duality: electron diffraction

Question	Answer	Marks	Guidance
13(a)	$eV = \frac{1}{2}mv^2: v = \sqrt{2 \times 1.60 \times 10^{-19} \times 4000 / 9.11 \times 10^{-31}}$	C1	
	$3.75 \times 10^7 \text{ m s}^{-1}$	A1	
13(b)	$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 3.75 \times 10^7}$	C1	ECF from (a). Using c for v is wrong physics
	$1.94 \times 10^{-11} \text{ m}$	A1	
13(c)	$d \sin \theta = n\lambda$ with $n = 1: d = 1.94 \times 10^{-11} / \sin 9.1^\circ$	C1	
	$1.23 \times 10^{-10} \text{ m}$	A1	ECF from (b)
13(d)	Diffraction is a wave property	B1	
	The de Broglie wavelength is similar to the spacing between the atoms, so the electrons are diffracted by the graphite	B1	Allow: the rings appear at angles consistent with $\lambda = h/mv$
13(e)	Greater speed (momentum), so a shorter de Broglie wavelength	B1	
	so the angle of diffraction is smaller and the rings have a smaller diameter	B1	
	Total	10	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Question 14 Exploring · Medium · Medical imaging: X-ray production and attenuation

Question	Answer	Marks	Guidance
14(a)	$eV = \frac{hc}{\lambda}: \lambda = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^8}{1.60 \times 10^{-19} \times 80 \times 10^3}$	C1	Maximum photon energy = eV
	$1.55 \times 10^{-11} \text{ m}$	A1	
14(b)	41 W m^{-2}	B1	Allow 40 to 42 W m^{-2}
14(c)	$I = I_0 e^{-\mu x}: \mu = \ln(120/41)/6.0$	C1	ECF from (b)
	0.18 cm^{-1}	A1	Allow 0.17 to 0.19 cm^{-1} ; allow 18 m^{-1}
14(d)	$\frac{1}{2} = e^{-0.48x}, x = \ln 2 / 0.48$	C1	
	1.4 cm	A1	Allow 1.44 cm
14(e)	Barium has a high atomic (proton) number, so it absorbs X-rays strongly (large attenuation coefficient)	B1	



Question 14 continued

Question	Answer	Marks	Guidance
	so the intestines show up in contrast against the surrounding soft tissue, which has a similar attenuation coefficient to the intestine walls	B1	
	Total	9	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Question 15 Exploring · Hard · Uniform electric fields: separating plastics

Question	Answer	Marks	Guidance
15(a)	$E = V/d = 60 \times 10^3 / 0.60 = 1.0 \times 10^5 \text{ V m}^{-1}$	C1	
	$F = EQ = 4.0 \times 10^{-6} \text{ N}$	A1	
15(b)	$s = \frac{1}{2}gt^2: t = \sqrt{2 \times 1.5/9.81}$	C1	
	$t = 0.553 \text{ s}$	A1	Answer must be given to 3 s.f. or more
15(c)	horizontal acceleration = $F/m = 4.0 \times 10^{-6} / 3.0 \times 10^{-6} = 1.33 \text{ m s}^{-2}$	C1	Or the force ratio F/mg
	sideways displacement in the fall time = $\frac{1}{2} \times 1.33 \times 0.553^2$	C1	Or time to move 0.30 m sideways; or the drop while moving 0.30 m; or $x = 1.5 \times F/mg$
	0.20 m (or 0.67 s to reach a plate, or a drop of 2.2 m)	A1	
	0.20 m < 0.30 m (or 0.67 s > 0.55 s, or 2.2 m > 1.5 m), so the flake does not strike a plate	B1	Comparison with the half-separation, 0.30 m, needed
15(d)	The weight and the electric force are both constant, so the resultant force is constant in size and direction	B1	
	The flake starts from rest, so it accelerates along the direction of the resultant force (a fixed line)	B1	A parabola needs an initial velocity at an angle to the force
15(e)	PVC deflection = $0.20 \times 2.5/4.0 = 0.13 \text{ m}$ towards the other plate	C1	ECF from (c)
	separation = $0.20 + 0.13 = 0.33 \text{ m}$	A1	Not 0.07 m (same side)
	Total	12	

Notes

Difficulty features: hidden physical model (a flake starting from rest under two constant forces moves in a straight line along the resultant, not in a parabola); conditions and limiting cases (whether the flake reaches the bottom before it reaches a plate (0.20 m against 0.30 m)); several topics connected without announcing it (a uniform electric field combined with independent horizontal and vertical motion); parameters instead of numbers (the sideways displacement is proportional to the charge, so the PVC result follows by scaling).

(d) A numerical integration of the motion (verify.py) confirms the straight path and the 0.20 m deflection.



Question 16 Exploring · Hard · Stationary waves: microwaves and a metal plate

Question	Answer	Marks	Guidance
16(a)	Microwaves reflect at M and travel back towards T	B1	
	The incident and reflected waves (same frequency, travelling in opposite directions) superpose, giving nodes and antinodes	B1	Allow 'interfere'
16(b)	ten node spacings: node to node = $141/10 = 14.1 \text{ mm} = \lambda/2$	C1	
	$\lambda = 28.2 \text{ mm}$	C1	Using 14.1 mm as λ gives $2.13 \times 10^{10} \text{ Hz}$ (wrong physics: C1 only); 11 spacings gives $1.17 \times 10^{10} \text{ Hz}$ (C0 C1 A0)
	$f = c/\lambda = 3.00 \times 10^8 / 0.0282 = 1.06 \times 10^{10} \text{ Hz}$	A1	
16(c)	% uncertainty = $2/141 \times 100 = 1.4\%$	C1	The uncertainty in c is negligible
	$\pm 1.5 \times 10^8 \text{ Hz}$	A1	Allow $\pm 1.51 \times 10^8 \text{ Hz}$ or $\pm 0.015 \times 10^{10} \text{ Hz}$; ECF from (b)
16(d)(i)	0 (in phase)	B1	
16(d)(ii)	180° (π rad, antiphase)	B1	Not 225° (progressive-wave rule)
16(d)(iii)	The rule phase difference = $360^\circ \times (\text{distance}/\lambda)$ applies to a progressive wave	B1	
	In a stationary wave all points between adjacent nodes oscillate in phase (and points in adjacent loops in antiphase); it is the amplitude that varies with position	B1	
16(e)	At a maximum the amplitude is $A_i + A_r$; at a minimum it is $A_i - A_r$ (the waves no longer cancel completely)	C1	
	$(A_i + A_r)/(A_i - A_r) = 9.0$	C1	
	$A_r/A_i = 0.80$	A1	Allow 4/5. 0.64 of the intensity is reflected (not required)
	Total	14	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Notes

Difficulty features: competing plausible ideas (the progressive-wave rule for phase difference against the stationary-wave rule); experimental design and uncertainty (measuring across ten node spacings, and the absolute uncertainty in f); information to infer (the first to the eleventh minimum is ten node spacings, and node to node is half a wavelength); hidden physical model ((e): partial reflection; the maximum and minimum amplitudes are the sum and difference of the two amplitudes).

(d) Examiner reports name exactly this confusion: phase differences in a stationary wave are 0 or 180° only.

(c) Dividing the reading uncertainty by ten spacings is the point of the method; the percentage uncertainty is about ten times smaller than for one spacing.



Question 17 Exploring · Hard · The photoelectric effect: stopping potential

Question	Answer	Marks	Guidance
17(a)	One photon is absorbed by one electron; the photon energy is hf	B1	
	Below the threshold frequency hf is less than the work function, so no electron gains enough energy to escape; intensity only changes the number of photons	B1	
17(b)	gradient = h/e from a triangle covering at least half the line = $4.1 \times 10^{-15} \text{ V s}$	C1	$eV_s = hf - \phi$
	$h = e \times \text{gradient}$	C1	
	$6.6 \times 10^{-34} \text{ J s}$	A1	Allow 6.3 to $6.9 \times 10^{-34} \text{ J s}$
17(c)	Extrapolates the line to $V_s = 0$: $f_0 = 5.5 \times 10^{14} \text{ Hz}$; $\phi = hf_0/e$	C1	Or the intercept on the V_s axis at $f = 0$, by calculation from the line
	2.3 eV	A1	Allow 2.1 to 2.4 eV
17(d)	photons per second = $P/hf = 2.0 \times 10^{-3}/(6.63 \times 10^{-34} \times 8.0 \times 10^{14}) = 3.77 \times 10^{15} \text{ s}^{-1}$	C1	
	electrons per second = $3.77 \times 10^{15}/200 = 1.89 \times 10^{13} \text{ s}^{-1}$	C1	
	$I = 1.89 \times 10^{13} \times 1.60 \times 10^{-19} = 3.0 \times 10^{-6} \text{ A}$	A1	
17(e)(i)	No change: the maximum kinetic energy $hf - \phi$ depends on the frequency only, as each photon's energy is unchanged	B1	
17(e)(ii)	The current doubles: twice as many photons per second, so twice as many electrons per second	B1	
17(f)	V_s at $9.0 \times 10^{14} \text{ Hz} = 1.42 \text{ V}$ from the line, and $\frac{1}{2}mv^2 = eV_s$	C1	Allow 1.40 to 1.46 V
	$v = \sqrt{2 \times 1.60 \times 10^{-19} \times 1.42/9.11 \times 10^{-31}} = 7.1 \times 10^5 \text{ m s}^{-1}$	C1	Using c , or v from hf alone, is wrong physics
	$r = \frac{mv}{eB} = \frac{9.11 \times 10^{-31} \times 7.1 \times 10^5}{1.60 \times 10^{-19} \times 2.0 \times 10^{-3}} = 2.0 \times 10^{-3} \text{ m}$	A1	Allow 1.9 to $2.1 \times 10^{-3} \text{ m}$
	Total	15	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Notes

Difficulty features: representation change (the gradient of the stopping potential against frequency graph is h/e , and the intercept must be found by extrapolation); several topics connected without announcing it (photon flux, photoelectrons per second and current); competing plausible ideas (intensity changes the number of photons but not the maximum kinetic energy); information to infer ((f): the electrons' kinetic energy must be read from the stopping potential on the graph before the circular-motion step).



Question 18 Exploring · Super hard · Charged particles in fields: separating isotopes

Question	Answer	Marks	Guidance
18(a)	The magnetic force is always perpendicular to the velocity	B1	
	so no work is done on the ion (no component of force along its motion) and its kinetic energy and speed are constant	B1	
18(b)	$eV = \frac{1}{2}mv^2$ and $Bev = \frac{mv^2}{r}$	C1	Both relations needed; neither is given in the question
	$r = \frac{mv}{Be} = \frac{1}{B} \sqrt{\frac{2mV}{e}}$, so the landing distance $2r \propto \sqrt{m}$	C1	
	$m_{20} = 19.99 \times 1.661 \times 10^{-27} = 3.320 \times 10^{-26}$ kg and $m_{22} = 3.653 \times 10^{-26}$ kg	C1	
	$10.0 \times 10^{-3} = 2(r_{22} - r_{20}) = \frac{2}{0.20} \sqrt{\frac{2V}{1.60 \times 10^{-19}}} (1.9112 - 1.8222) \times 10^{-13}$	C1	Allow a numerical trial-and-improvement route
	$V = 1.0 \times 10^3$ V	A1	Allow 1010 V. Using the radius instead of the diameter gives 4.0×10^3 V: scores 4 marks
18(c)	separation $\propto \sqrt{V}/B$, so doubling B halves the separation at the same p.d.	B1	
	To keep a 10.0 mm separation V would have to be four times larger (4.0×10^3 V), so the suggestion is wrong: a smaller B allows a smaller V	B1	Allow $V \propto B^2$
18(d)	$r \propto \sqrt{m/q}$, so the radius for the 2+ ion is $r/\sqrt{2}$ (charge doubles both the energy gained and the force)	C1	
	$r_{20} = \frac{1}{0.20} \sqrt{\frac{2 \times 3.320 \times 10^{-26} \times 1010}{1.60 \times 10^{-19}}} = 0.102$ m	C1	Speed of the 1+ ion is 9.87×10^4 m s ⁻¹
	distance = $2r_{20}(1 - 1/\sqrt{2}) = 0.060$ m	A1	Not 0.10 m (charge doubled in the force only)
	Total	12	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Notes

Difficulty features: several topics connected without announcing it (an accelerating p.d. gives the speed, which sets the radius of the circular path in the magnetic field; neither link is named); parameters instead of numbers (the landing distance is $(2/B)\sqrt{(2mV/q)}$, so it scales as $\sqrt{m}$ and $\sqrt{(V/q)/B}$); little scaffolding ((b) asks only for the minimum p.d.: neither $eV = \frac{1}{2}mv^2$ nor $r = mv/BQ$ is prompted, and the $\sqrt{m}$ dependence must be found, not shown); quantitative evaluation of a claim (the engineer's suggestion to double B); cases and restrictions (a doubly charged ion gains twice the kinetic energy as well as twice the force).

(b) A numerical Lorentz-force integration (verify.py) confirms that a neon-20 ion lands $2r$ from the slit at constant speed.

(d) The trap is to double the force and forget that the 2+ ion also gains twice the kinetic energy from the same p.d.



Question 19 Exploring · Super hard · Capacitors practical: discharge through a voltmeter

Question	Answer	Marks	Guidance
19(a)*	Level 3 (5 or 6 marks) Clear description of the data collection and clear explanation of a graphical analysis that gives C, including the use of $R = 10.0 \text{ M}\Omega$. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3 or 4 marks) Some description of the data collection and some explanation of the analysis; or a clear description of the data collection only; or a clear analysis only. <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1 or 2 marks) Limited description of the data collection or a limited analysis. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response or no response worthy of credit.	6	Indicative scientific points may include: Data collection - Close S to charge the capacitor to 6.00 V; open S and start a stopwatch at the same instant - Record V at regular intervals (for example every 300 s) for at least one time constant (more than about 5000 s) - Or use a data logger connected across the capacitor to record V against t - Repeat and take mean values of V at each time - Only the voltmeter is connected while discharging; keep the circuit dry and clean so there is no other leakage path Analysis $V = V_0 e^{-t/RC}$, so $\ln V = \ln V_0 - t/RC$ - Plot $\ln V$ (y-axis) against t (x-axis): a straight line confirms exponential decay - gradient $= -1/RC$, so $C = -1/(\text{gradient} \times 10.0 \times 10^6)$ - Or plot V against t, find the time to halve, $t_{1/2} = RC \ln 2$, averaged over several halvings
19(b)	The capacitor discharges through the voltmeter: $V = V_0 e^{-t/RC}$	C1	Allow a $\ln V$ against t graph, gradient $-1.93 \times 10^{-4} \text{ s}^{-1}$
	e.g. $\ln(6.00/1.89) = \frac{6000}{RC}$, so $RC = 5.2 \times 10^3 \text{ s}$	C1	Any pair of rows
	$C = 5.2 \times 10^3 / 10.0 \times 10^6 = 5.2 \times 10^{-4} \text{ F}$	A1	Allow 500 to $540 \text{ }\mu\text{F}$
19(c)	$C = RC/R$, so $\pm 5\%$ in R gives $\pm 5\%$ in C : $519 \pm 26 \text{ }\mu\text{F}$, from $493 \text{ }\mu\text{F}$ to $545 \text{ }\mu\text{F}$	C1	ECF from (b); ignore the small uncertainty from the readings
	The label allows $470 \times 0.8 = 376 \text{ }\mu\text{F}$ to $470 \times 1.2 = 564 \text{ }\mu\text{F}$	B1	
	The whole of the student's range lies within the label's range, so the value is consistent with the label	B1	A comparison of $520 \text{ }\mu\text{F}$ alone with the label range scores this mark
19(d)	$E = \frac{1}{2} CV^2$, so $E \propto V^2 \propto e^{-2t/RC}$	C1	
	$\frac{1}{2} = e^{-2t/RC}$, so $t = \frac{1}{2} RC \ln 2$	C1	
	$t = 1.8 \times 10^3 \text{ s}$	A1	Allow 1.7 to $1.9 \times 10^3 \text{ s}$. Not $3.6 \times 10^3 \text{ s}$ (time for the p.d. to halve)



Question 19 continued

Question	Answer	Marks	Guidance
	Total	15	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Notes

Difficulty features: unfamiliar context disguising familiar physics (the voltmeter that measures the p.d. is itself the discharge resistor); experimental design and uncertainty (the Level of Response plan, and the capacitor's tolerance); representation change (exponential decay is linearised as $\ln V$ against t , with gradient $-1/RC$); quantitative evaluation of a claim (whether the measured value agrees with the label ' $470 \mu\text{F} \pm 20\%$ '); hidden physical model (the energy is proportional to V^2 , so it halves in half the time the p.d. takes).

(b) Every pair of rows in Table 19.1 gives a value between 500 and 540 μF (checked in verify.py).

(d) Candidates who halve the p.d. instead of the energy have not linked the energy to V^2 .

Question 20 Exploring · Super hard · Annihilation and PET scanning

Question	Answer	Marks	Guidance
20(a)(i)	The positron loses (almost) all its kinetic energy in the tissue before it annihilates, so the positron and electron have (almost) zero total momentum	B1	The hidden step: this is not stated in the question
	Momentum is conserved, so the photons have equal and opposite momenta (and so equal energies)	B1	
20(a)(ii)	The rest mass of both particles is converted: total energy = $2m_e c^2$, shared equally	C1	Kinetic energies negligible
	$E = 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2 = 8.20 \times 10^{-14} \text{ J}$	A1	Answer must be given to 3 s.f. or more (0.512 MeV)
20(b)	With annihilation time t_0 and distance d from D1: $t_0 + d/c = 1.63 \text{ ns}$ and $t_0 + (0.80 - d)/c = 2.03 \text{ ns}$	C1	Both photons leave X at the same instant; two equations in two unknowns
	Subtracting: $(0.80 - 2d)/c = 0.40 \text{ ns}$, so $0.80 - 2d = 3.00 \times 10^8 \times 0.40 \times 10^{-9} = 0.12 \text{ m}$	C1	Equivalent: X is 0.060 m from the midpoint, towards D1
	$d = 0.34 \text{ m}$	A1	Not 0.28 m (path difference not halved)
	$t_0 = 1.63 \text{ ns} - 0.34/3.00 \times 10^8 = 1.63 - 1.13 = 0.50 \text{ ns}$	B1	ECF from their d
20(c)	uncertainty in position = $c \times (\text{uncertainty in } \Delta t)/2 = 3.00 \times 10^8 \times 0.20 \times 10^{-9}/2$	C1	ECF from the method in (b)
	$= \pm 0.030 \text{ m} (\pm 3.0 \text{ cm})$	A1	
	3.0 cm is greater than 2 cm, so the claim is not justified (it would need a timing uncertainty of about $\pm 0.13 \text{ ns}$)	B1	
20(d)	$\lambda = \ln 2/110 = 6.30 \times 10^{-3} \text{ min}^{-1}$ (or $1.05 \times 10^{-4} \text{ s}^{-1}$)	C1	Or uses $(1/2)^{t/t_{1/2}}$ with $t/t_{1/2} = 120/110$
	$350 = A_0 e^{-6.30 \times 10^{-3} \times 120}$	C1	
	$A_0 = 746 \text{ MBq}$	A1	Allow 740 to 750 MBq; allow $7.5 \times 10^2 \text{ MBq}$
	Total	14	



Question 20 notes continued**Notes**

Difficulty features: hidden physical model (the positron has slowed to rest in the tissue (not stated), so zero initial momentum forces two equal photons travelling in opposite directions); several topics connected without announcing it (mass-energy, photons, arrival times and radioactive decay in one scan); information to infer (the annihilation point is displaced by half the path difference, $c\Delta t/2$); quantitative evaluation of a claim (the manufacturer's ± 2 cm claim against the timing uncertainty); little scaffolding ((b) gives two arrival times against a trigger and asks for both the position and the time of the annihilation, with no method); long chain of reasoning ((b) needs two simultaneous travel-time equations, then their difference and their sum).

(b) The commonest error is to use the whole path difference, $c\Delta t$, as the distance from the midpoint. Check: the photon to D2 travels 0.46 m in 1.53 ns, arriving at $0.50 + 1.53 = 2.03$ ns.



SECTION C: UNIFIED PHYSICS

Question 21 Unified · Easy · Practical skills: the resistivity of a wire

Question	Answer	Marks	Guidance
21(a)	The diameter may vary along the wire, so a mean of several readings is more representative (reduces the effect of random variations)	B1	Allow 'the wire may not be uniform'
21(b)	$d = 0.37 \text{ mm}$	B1	Mean to the same number of decimal places as the readings; allow 0.370
	uncertainty = half the range = $\pm 0.01 \text{ mm}$	B1	
21(c)	gradient = ρ/A from a large triangle on the line = $10.3 \Omega \text{ m}^{-1}$	C1	Allow 10.0 to $10.6 \Omega \text{ m}^{-1}$
	$A = \pi(0.37 \times 10^{-3})^2/4 = 1.08 \times 10^{-7} \text{ m}^2$	C1	Radius, not diameter, squared in πr^2
	$\rho = \text{gradient} \times A = 1.1 \times 10^{-6} \Omega \text{ m}$	A1	Allow 1.07 to $1.15 \times 10^{-6} \Omega \text{ m}$
21(d)	Resistance of the contacts or connecting leads (or a zero error on the meter) adds the same resistance to every reading: a systematic error	B1	The intercept is about 0.53Ω
	The gradient (ρ/A) is unchanged, so the resistivity is unaffected; only the intercept changes	B1	
	Total	8	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Question 22 Unified · Medium · Energy and electromagnetic induction: a hydroelectric generator

Question	Answer	Marks	Guidance
22(a)	rate of loss of GPE = mgh per second = $20 \times 9.81 \times 6.0$	C1	
	$1.18 \times 10^3 \text{ W}$	A1	Answer must be given to 3 s.f. or more
22(b)	$0.60 \times 1.18 \times 10^3$	C1	
	706 W	A1	Allow 700 to 720 W (720 W from 1.2 kW)
22(c)	greatest flux linkage = $NBA = 200 \times 0.25 \times 0.012 = 0.60 \text{ Wb}$ (turns), falling to zero after a quarter turn	C1	
	time for a quarter turn = $1/(4 \times 25) = 0.010 \text{ s}$	C1	
	average e.m.f. = change in flux linkage/time = $0.60/0.010 = 60 \text{ V}$	A1	Faraday's law. The rotating-coil peak e.m.f. formula is not required; a peak value (94 V) scores C1 C1 A0
22(d)	As the coil rotates, the flux linkage of the coil changes continuously	B1	
	The e.m.f. equals the rate of change of flux linkage (Faraday's law), which reverses direction every half turn	B1	



Question 22 continued

Question	Answer	Marks	Guidance
	The flux linkage changes fastest when it is zero, which is when the plane of the coil is parallel to the field	B1	Not 'when the flux linkage is greatest'
22(e)	Peak e.m.f. unchanged: the rate of change of flux linkage depends only on B , A , N and the rate of rotation	B1	
	Power available halves, because the input power (mgh per second) halves	B1	
	Total	12	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Question 23 Unified · Medium · Gravitational fields and kinematics: a lunar mass driver

Question	Answer	Marks	Guidance
23(a)	$g = \frac{GM}{r^2} = \frac{6.67 \times 10^{-11} \times 7.35 \times 10^{22}}{(1.74 \times 10^6)^2}$	C1	
	1.6 N kg^{-1}	A1	Allow 1.62 N kg^{-1}
23(b)	kinetic energy at launch = gravitational potential energy to be gained: $\frac{1}{2}mv^2 = \frac{GMm}{r}$	C1	
	$v = \sqrt{2 \times 6.67 \times 10^{-11} \times 7.35 \times 10^{22} / 1.74 \times 10^6}$	C1	
	$2.37 \times 10^3 \text{ m s}^{-1}$	A1	Answer must be given to 3 s.f. or more
23(c)	$v^2 = u^2 + 2as$ with $u = 0$ and $a = 200 \text{ m s}^{-2}$	C1	
	$1.41 \times 10^4 \text{ m}$	A1	Allow $1.4 \times 10^4 \text{ m}$
23(d)	time on the track $t = v/a = 11.9 \text{ s}$ (or force = $ma = 5000 \text{ N}$)	C1	
	kinetic energy gained = $\frac{1}{2} \times 25 \times (2.37 \times 10^3)^2 = 7.0 \times 10^7 \text{ J}$ (or mean speed = $v/2$)	C1	
	mean power = $5.9 \times 10^6 \text{ W}$	A1	Allow 5.8 to $6.1 \times 10^6 \text{ W}$
23(e)	No atmosphere on the Moon, so no air resistance or heating of the payload	B1	A second point about the atmosphere earns nothing more
	The escape speed from the Moon is much smaller (smaller GM/r), so a shorter track or smaller acceleration is needed	B1	
	Total	12	

Question 24 Unified · Medium · Thermal and electrical energy: an electric shower

Question	Answer	Marks	Guidance
24(a)	$I = P/V = 9000/230 = 39 \text{ A}$	B1	Allow 39.1 A
24(b)	$P = \frac{m}{t}c\Delta\theta$ with $\Delta\theta = 28 \text{ K}$	C1	
	$m/t = 9000/(4200 \times 28) = 0.0765 \text{ kg s}^{-1}$	C1	



Question 24 continued

Question	Answer	Marks	Guidance
	4.6 kg (each minute)	A1	0.0765 kg alone (per second) scores C1 C1 A0
24(c)	$R = V^2/P = 230^2/9000 = 5.88 \Omega$	C1	Or $R = V/I$
	$L = RA/\rho = 5.88 \times 1.5 \times 10^{-6}/1.1 \times 10^{-6}$	C1	
	8.0 m	A1	
24(d)	The current is large (39 A)	B1	
	A large cross-sectional area gives a small resistance, so the rate of heating (I^2R) in the cable is small and it does not overheat	B1	Allow 'less p.d. lost in the cable'
24(e)	$\Delta\theta = 40 - 5 = 35 \text{ K}$	C1	
	flow rate = $9000 \times 60/(4200 \times 35) = 3.7 \text{ kg per minute}$	A1	ECF from (b) method
	Total	11	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Question 25 Unified · Hard · Data analysis: a power law for the pendulum

Question	Answer	Marks	Guidance
25(a)	$\lg T = n \lg L + \lg k$, which has the form $y = mx + c$	B1	
	gradient = n ; intercept on the $\lg T$ axis (where $\lg L = 0$) = $\lg k$	B1	
25(b)	$\lg(L/m) = 0.079$ and $\lg(T/s) = 0.342$	B1	Both values
	Point plotted to within half a small square	B1	ECF from their table values
	Error bar from $\lg 2.15$ to $\lg 2.25$: ± 0.0098 (about one small square each way)	B1	
25(c)	Single thin straight line of best fit through the points	B1	
	$n = 0.50$	B1	Allow 0.48 to 0.52; gradient from a large triangle
25(d)	$\lg k = \text{intercept at } \lg L = 0: 0.30$, so $k = 10^{0.30} = 2.00 \text{ s m}^{-0.5}$	C1	Allow $\lg k$ 0.295 to 0.305. No false origin: $\lg L = 0$ is on the graph
	$k = \frac{2\pi}{\sqrt{g}}$, so $g = \frac{4\pi^2}{k^2}$	C1	
	$g = 4\pi^2/2.00^2 = 9.87 \text{ m s}^{-2}$, so 9.9 m s^{-2}	A1	Allow 9.6 to 10.2 m s^{-2}
25(e)	Draws the steepest and/or shallowest straight line passing through all the error bars	C1	
	gradients about 0.54 and 0.46, so $n = 0.50 \pm 0.04$	C1	Allow ± 0.02 to ± 0.05
	0.5 lies within this range, so the data support $n = 0.5$ ($T \propto \sqrt{L}$)	A1	ECF for a consistent conclusion from their range
	Total	13	



Question 25 notes continued

Notes

Difficulty features: representation change (a power law $T = kL^n$ becomes a straight line on a graph of $\lg T$ against $\lg L$; the gradient is n and the intercept is $\lg k$); experimental design and uncertainty (error bars on a logarithmic scale and the steepest and shallowest acceptable lines); quantitative evaluation of a claim (whether the data support $n = 0.5$).

(e) The error bar on $\lg T$ is about $0.434 \Delta T/T$, so it is largest for the shortest pendulum (± 0.023 at $T = 0.90$ s, more than two small squares) and smallest for the longest (± 0.0098).

(e) The steepest and shallowest lines quoted were found by linear programming through all six error bars (verify.py): gradients 0.46 and 0.54.

Question 26 Unified · Hard · Radioactivity and current: a smoke alarm

Question	Answer	Marks	Guidance
26(a)	Alpha particles are strongly ionising, so they produce many ion pairs and a measurable current	B1	
	Alpha particles have a short range (stopped by the casing), so none escape from the alarm; beta and gamma would	B1	
26(b)	ion pairs per alpha particle = $5.5 \times 10^6 / 35 = 1.57 \times 10^5$	C1	
	Fig. 26.1 shows the source on the surface of a plate, so only half the alpha particles enter the air: $\frac{1}{2} \times 3.7 \times 10^4 = 1.85 \times 10^4 \text{ s}^{-1}$	C1	The hidden step
	ion pairs per second = $1.85 \times 10^4 \times 1.57 \times 10^5 = 2.9 \times 10^9 \text{ s}^{-1}$	C1	ECF from their values
	$I = (\text{ion pairs per second}) \times e$: each ion pair passes a charge e round the circuit	M1	
	$I = 2.9 \times 10^9 \times 1.60 \times 10^{-19} = 4.7 \times 10^{-10} \text{ A}$	A1	Counting every alpha particle gives $9.3 \times 10^{-10} \text{ A}$: scores C1 C0 C1 M1 A0 (3 marks). Using $2e$ per pair scores M0
26(c)	Current is proportional to activity: $A/A_0 = (\frac{1}{2})^{10/432}$	M1	Or finds the time for the activity to fall to 75%
	$= 0.984$ after 10 years (or 179 years to fall to 75%)	C1	
	Concern not justified: a fall of about 2% is far less than the 25% needed	A1	Conclusion must follow from a calculation
	Total	10	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Notes

Difficulty features: information to infer (the source sits on a plate, so only the half of the alpha particles emitted upwards enter the air); several topics connected without announcing it (decay rate, ionisation energy and charge flow combine to give a current); quantitative evaluation of a claim (the householder's concern about the source decaying within ten years).

(b) Without the halving the scheme still rewards every correct step: the ion-pair count, the charge per pair and the final multiplication.

Question 27 Unified · Hard · Stellar radiation: the radius of a star

Question	Answer	Marks	Guidance
27(a)	$T = 2.90 \times 10^{-3} / 302 \times 10^{-9}$	C1	
	$9.6 \times 10^3 \text{ K}$	A1	Allow 9600 K
27(b)	$d = 1/0.130 = 7.69 \text{ pc} = 2.38 \times 10^{17} \text{ m}$	C1	
	$L = 4\pi d^2 I = 4\pi \times (2.38 \times 10^{17})^2 \times 2.3 \times 10^{-8} = 1.6 \times 10^{28} \text{ W}$	C1	
	$L = 4\pi R^2 \sigma T^4$ (Stefan's law)	C1	
	$R = \sqrt{L / (4\pi \sigma T^4)} = 1.6 \times 10^9 \text{ m}$	C1	ECF from (a)
	$2.4 \times \text{radius of the Sun}$	A1	Allow 2.3 to 2.5
27(c)	power entering the pupil = $2.3 \times 10^{-8} \times \pi(3.0 \times 10^{-3})^2 = 6.5 \times 10^{-13} \text{ W}$	C1	Radius 3.0 mm, not diameter
	photon energy = $hc/\lambda = 6.59 \times 10^{-19} \text{ J}$	C1	
	number per second = 9.9×10^5	A1	Allow 9.8×10^5 to 1.0×10^6
27(d)	L is measured independently of T , so $R \propto 1/T^2 \propto \lambda_{\text{max}}^2$	C1	
	4%	A1	Not 8% (T^4 applied to R); not 2%
	Total	12	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Notes

Difficulty features: several topics connected without announcing it (Wien's law, parallax, the inverse square law, Stefan's law and photon energy); little scaffolding ((b) gives no route from the measurements to the radius); information to infer (the luminosity must be found from the intensity at the Earth and the distance); competing plausible ideas (the radius depends on T^{-2} , not on T^{-4} , because the luminosity is measured).

(d) Examiner reports stress that the uncertainty in T counts four times in Stefan's law; here it is the radius that is asked for, and it depends on T^{-2} once L is fixed by measurement.



Question 28 Unified · Super hard · Practical skills: the Planck constant from LEDs

Question	Answer	Marks	Guidance
28(a)*	Level 3 (5 or 6 marks) Clear description of how V_0 is found, with a correct circuit, and clear explanation of the graphical analysis giving h. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3 or 4 marks) Some description of how V_0 is found and some analysis; or a clear method only; or a clear analysis only. <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1 or 2 marks) Limited description of the method or limited analysis; the circuit may be incorrect. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response or no response worthy of credit.	6	Indicative scientific points may include: Method • Circuit: d.c. supply with a potentiometer (or variable resistor) controlling the p.d. across the LED; protective resistor in series with the LED; voltmeter in parallel with the LED; ammeter (or milliammeter) in series • Increase the p.d. slowly from zero until the LED just emits light; view it through a tube, in a darkened room, to judge the threshold • Or: plot the I-V characteristic and extrapolate the straight part back to $I = 0$ • Repeat for each LED, increasing and decreasing the p.d.; take a mean • Wavelengths from the manufacturer's data or measured with a diffraction grating Analysis • $V_0 = (hc/e)(1/\lambda)$: plot V_0 against $1/\lambda$; a straight line is expected • gradient = hc/e, so $h = \text{gradient} \times e/c$ • Worst acceptable line through the error bars gives the uncertainty in the gradient and so in h
28(b)(i)	Best-fit line: thin, straight, balanced, passing through all the error bars	B1	
	Worst acceptable line: the steepest or shallowest straight line that passes through every error bar	B1	Not a line joining the first and last points
28(b)(ii)	gradient of best line = $1.20 \times 10^{-6} \text{ V m}$ ($1.20 \text{ V per } 10^6 \text{ m}^{-1}$)	C1	Allow 1.15 to $1.25 \times 10^{-6} \text{ V m}$; false origin: the gradient must come from the line, not from $V_0/(1/\lambda)$ for one point
	$h = \text{gradient} \times e/c = 1.20 \times 10^{-6} \times 1.60 \times 10^{-19}/3.00 \times 10^8 = 6.4 \times 10^{-34} \text{ J s}$	C1	
	gradient of the worst line (steepest 1.37 or shallowest $1.04, \times 10^{-6} \text{ V m}$) gives $h = 7.3 \times 10^{-34}$ (or 5.5×10^{-34}) J s	C1	
	absolute uncertainty = $ \text{worst} - \text{best} \approx 0.9 \times 10^{-34} \text{ J s}$	A1	Allow 0.3 to $1.0 \times 10^{-34} \text{ J s}$ from their lines
28(c)	Percentage difference = $(6.63 - 6.4)/6.63 \times 100 = 3.5\%$ (or the range is 5.5 to $7.3 \times 10^{-34} \text{ J s}$)	B1	ECF from (b)(ii)



Question 28 continued

Question	Answer	Marks	Guidance
	The accepted value lies within the student's uncertainty range, so the value is accurate (within its uncertainty)	B1	A conclusion based only on a 'small' percentage difference scores B0
	Total	14	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Notes

Difficulty features: experimental design and uncertainty (the Level of Response plan, error bars and the worst acceptable line); representation change ($eV_0 = hc/\lambda$ becomes a straight line of V_0 against $1/\lambda$ with gradient hc/e , on a false origin); quantitative evaluation of a claim (accuracy is judged by whether the accepted value lies within the uncertainty, not by the percentage difference alone); little scaffolding (no hint how h follows from the gradient or how to find its uncertainty); long chain of reasoning (threshold p.d. to graph, gradient, h , worst line, uncertainty, judgement).

(b)(ii) The extreme gradients 1.04 and $1.37 \times 10^{-6} \text{ V m}$ are the steepest and shallowest straight lines through all six error bars, found by linear programming in verify.py; hand-drawn worst lines will lie inside this range.

(c) Examiner reports repeatedly note candidates who call the gap from the accepted value an uncertainty.

Question 29 Unified · Super hard · Stationary waves and materials: a guitar string

Question	Answer	Marks	Guidance
29(a)	Waves travel along the string, reflect at the fixed ends and superpose with the waves travelling the other way	B1	
	The fixed ends are nodes; the fundamental has one loop, so node to node = $\lambda/2 = 0.648 \text{ m}$	B1	
29(b)	$v = f\lambda = 330 \times 1.296 = 428 \text{ m s}^{-1}$	C1	
	$A = \pi(0.127 \times 10^{-3})^2 = 5.07 \times 10^{-8} \text{ m}^2$	C1	
	$\mu = \rho A = 7800 \times 5.07 \times 10^{-8} = 3.95 \times 10^{-4} \text{ kg m}^{-1}$	C1	The hidden step: mass per unit length from density
	$T = \mu v^2 = 3.95 \times 10^{-4} \times 428^2 = 72.3 \text{ N}$	A1	Answer must be given to 3 s.f. or more
29(c)	stress = $T/A = 72.3/5.07 \times 10^{-8} = 1.43 \times 10^9 \text{ Pa}$	C1	
	strain = stress/ $E = 7.1 \times 10^{-3}$	A1	No unit
29(d)	With λ fixed, $f \propto v \propto \sqrt{T}$, so the tension must increase by a factor of 4 (to 289 N)	C1	
	stress = $4 \times 1.43 \times 10^9 = 5.7 \times 10^9 \text{ Pa}$ (or the highest frequency before breaking is $330 \times \sqrt{(2.2/1.43)} = 410 \text{ Hz}$)	C1	
	This is greater than the ultimate tensile strength ($2.2 \times 10^9 \text{ Pa}$), so the string would break: not possible	A1	
29(e)	stress = $T/A = \mu v^2/A = \rho v^2 = \rho(2Lf)^2$	B1	
	which does not depend on the diameter, so the stress is still $5.7 \times 10^9 \text{ Pa}$: the thicker string needs proportionally more tension	B1	ORA



Question 29 continued

Question	Answer	Marks	Guidance
	Total	13	

Marked by hand here. On iPad, Plumi marks questions like this one for you: tryplumi.app

Notes

Difficulty features: several topics connected without announcing it (stationary waves, wave speed and tension, then stress, strain and breaking stress); information to infer (the mass per unit length must be built from the density and the diameter); parameters instead of numbers (the stress is $\rho(2Lf)^2$, independent of the string's diameter); quantitative evaluation of a claim (whether the string can be tuned up an octave); competing plausible ideas (a thicker string seems stronger but needs proportionally more tension); long chain of reasoning (frequency to speed to tension to stress to strain).

(e) The result stress = $\rho(2Lf)^2$ (checked symbolically in verify.py) is why guitar strings have a highest playable pitch for a given scale length, whatever their gauge.

Question 30 Unified · Super hard · Momentum, energy and electricity: a hovering drone

Question	Answer	Marks	Guidance
30(a)	The rotors exert a downward force on the air, which gains downward momentum (Newton's second law: force = rate of change of momentum)	B1	
	By Newton's third law the air exerts an equal and opposite (upward) force on the rotors	B1	A generic 'action and reaction' statement scores B0
30(b)	swept area $A = 4 \times \pi \times 0.12^2 = 0.181 \text{ m}^2$; mass of air per second = ρAv	C1	
	force on the air = rate of change of momentum = $(\rho Av)v = \rho Av^2$	C1	The hidden step. $F = ma$ for the drone scores 0
	hovering: $\rho Av^2 = mg$, so $1.20 \times 0.181 \times v^2 = 1.20 \times 9.81$	C1	
	$v = 7.36 \text{ m s}^{-1}$	A1	Answer must be given to 3 s.f. or more
30(c)	power given to the air = kinetic energy per second = $\frac{1}{2}(\rho Av)v^2 = 43 \text{ W}$ (or $\frac{1}{2}mgv$)	C1	
	electrical power = $43/0.40 = 108 \text{ W}$	C1	
	battery energy = $QV = (5.000 \text{ A} \times 3600 \text{ s}) \times 11.1 \text{ V} = 1.8 \times 10^4 \text{ C} \times 11.1 \text{ V} = 2.0 \times 10^5 \text{ J}$	C1	
	$t = 2.0 \times 10^5 / 108 = 1.84 \times 10^3 \text{ s}$ (31 minutes)	A1	Allow 1.8 to $1.9 \times 10^3 \text{ s}$
30(d)	$v \propto \sqrt{m}$ and the power $\propto mv$, so the power $\propto m^{3/2}$ (the efficiency and battery are unchanged)	C1	
	time ratio = $(1.20/1.80)^{3/2} = 0.54$ (about $1.0 \times 10^3 \text{ s}$)	C1	Allow full recalculation with $m = 1.80 \text{ kg}$
	Claim not justified: the time falls to about 54% of the value in (c), not 67%; the claim overestimates the hovering time	A1	
	Total	13	



Question 30 notes continued**Notes**

Difficulty features: hidden physical model (the upward force is the rate of change of momentum of the air pushed down, not $F = ma$ for the drone); several topics connected without announcing it (momentum flow, the kinetic energy given to the air, and the energy stored in a battery); parameters instead of numbers ($v \propto \sqrt{m}$ and the power $\propto m^{3/2}$, so the hovering time $\propto m^{-3/2}$); quantitative evaluation of a claim (the manufacturer's claim, with an efficiency, that the time scales as $1/m$); modelling decision (the air is taken from rest to speed v through the swept area; its kinetic energy per second is the minimum power); information to infer (the battery's charge from its capacity in mA h).

(b) Examiner reports on thrust questions note that $F = ma$ with an invented acceleration is wrong physics; the force is the mass flowing per second times its change in velocity.

(c) A real rotor accelerates the air partly above the disc, so real drones need more power than this model; the model gives an upper limit for the hovering time.





Plumi

The iPad notebook for GCSE and A Level revision

Write your answers by hand. Each one is marked against that question's own mark scheme.

Stuck? The tutor nudges you with a hint before it gives anything away.

Practice adapts to you: the next question is chosen from what you have shown you can do.



Free on iPad · tryplumi.app

OCR-style practice written by Plumi. Not produced or endorsed by OCR.

