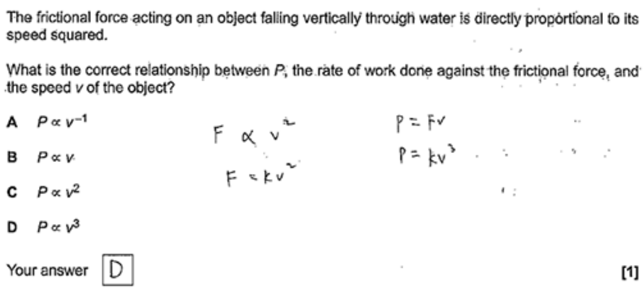
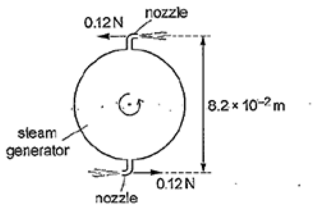
Mark scheme – Work, Energy and Power

Question			Answer/Indicative content	Marks	Guidance
1			work done = force × distance moved or displacement in the direction of the force	B1	
			Total	**1**	
2			**A**	**1**	
			Total	**1**	
3			A	1	
			Total	**1**	
4			B	1	
			Total	**1**	
5			C	1	
			Total	**1**	
6			B	1	**Examiner's Comments** All of the questions showed a positive discrimination, and the less able candidates could access the easier questions. The questions in Section A do require careful reading and scrutiny. Candidates are advised to reflect carefully before recording their response in the box. Candidates must endeavour to use a variety of quick techniques when answering multiple choice questions.
			Total	**1**	
7			B	1	
			Total	**1**	
8			C	1	**Examiner's Comments** All of the questions showed a positive discrimination, and the less able candidates could access the easier questions. The questions in Section A do require careful reading and scrutiny. Candidates are advised to reflect carefully before recording their response in the box. Candidates must endeavour to use a variety of quick techniques when answering multiple choice questions.
			Total	**1**	
9			C	1	
			Total	**1**	

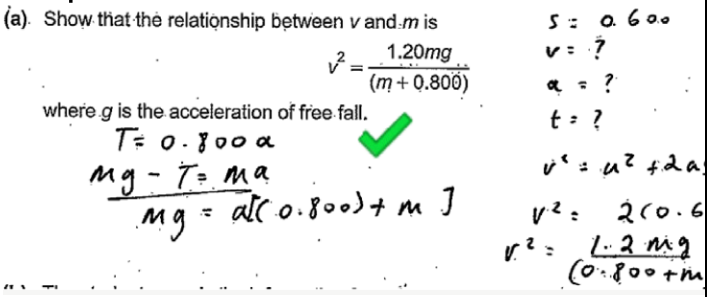
10			power or P: kg m^2 s^{-3}	B1	power = force × distance / time = force × velocity
			Total	**1**	
11			**D**	**1**	
			Total	**1**	
12			**B**	**1**	
			Total	**1**	
13	a		GPE loss = mgh = 0.60 × 9.81 × 0.050 = 0.29 J	A1	
	b		EPE = ½ F × = 0.50 × 5.88 × 0.05	M1	**Allow** answers to 2 s.f.
			= 0.147 J	A1	
			(or k = F / × = 5.88 / 0.050 = 118 N/m, EPE = ½ k x^2 = ½ × 118 × 0.050^2		
			= 0.147 J)		
	c		GPE → EPE + KE (when falling)	B1	
			EPE → GPE + KE (when rising)	B1	
			Some energy dissipated as heat as oscillates (because of air resistance / friction)	B1	
			Total	**6**	
14			B	1	
			Total	**1**	
15			C	1	
			Total	**1**	
16			C	1	**Examiner's Comments** All of the questions showed a positive discrimination, and the less able candidates could access the easier questions. The questions in Section A do require careful reading and scrutiny. Candidates are advised to reflect carefully before recording their response in the box. Candidates must endeavour to use a variety of quick techniques when answering multiple choice questions. The correct key was **C** and the most popular distractor was **A**. The kinetic energy of the ball at the ground was *K*. At maximum height, the ball just has horizontal component of velocity. The kinetic energy of the ball is proportional to speed². At the

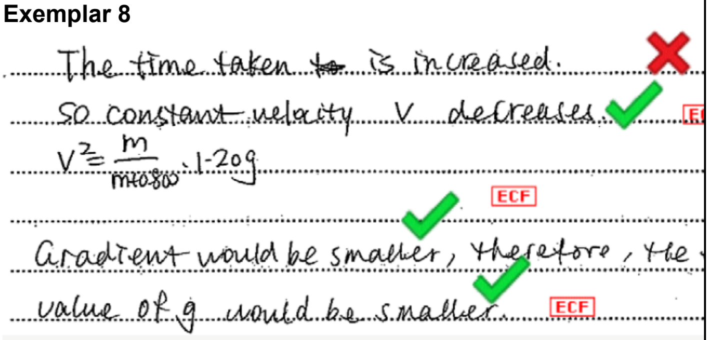
					maximum height the kinetic energy must therefore be $\cos^2 30° K = 0.75 K$.
			Total	**1**	
17			C	1	
			Total	**1**	
18			C	1	
			Total	**1**	
19			(KE = ½ × 0.900 × 2.0^2) kinetic energy = 1.8 (J)	**B1**	**Examiner's Comments** Most of the candidates answered this opening question extremely well, with the majority picking up the mark. The two most popular errors were omitting to square the speed of the trolley and using 900 g instead of 0.900 kg.
			Total	**1**	
20			A	1	
			Total	**1**	
21			A	1	**Examiner's Comments** The key to this question is to consider the GPE lost and equate it to the KE gained. The GPE lost here = mass × 9.81 × 0.20 = ½ × mass × v^2. The masses cancel (which is why the mass wasn't given). This makes $v^2 = 3.924$. The most common wrong answer was B, as candidates had forgotten to take the square root. The correct speed is 1.98 m s^{-1} giving the correct answer, A.
			Total	**1**	
22			A	1	
			Total	**1**	
23			**C**	1	
			Total	**1**	
24			**D**	1	**Examiner's Comments** This question is based on the equation $P = Fv$, which also appears in the Data, Formulae and Relationship Booklet. In the question, information is given about the frictional force F, which is directly proportional to v^2. Therefore, the rate of work done P must be proportional to v^3; making D as the answer. Most candidates struggled with this question, with all the distractors being equally popular. Less than a quarter of the candidates, mainly from the upper quartile, scored a mark in this question.

					The exemplar 2 below the correct response from a candidate. **Exemplar 2**  The frictional force acting on an object falling vertically through water is directly proportional to its speed squared. What is the correct relationship between *P*, the rate of work done against the frictional force, and the speed *v* of the object? **A** $P \propto v^{-1}$ **B** $P \propto v$ **C** $P \propto v^2$ **D** $P \propto v^3$ Your answer D **[1]** This candidate demonstrates how this question can be tackled with minimal amount of work. The key equation is on the script, as is the relationship between *F* and *v*. The final answer appears in the box; a perfect technique.
			Total	**1**	
25			**D**	1	
			Total	**1**	
26			**c**	1	
			Total	**1**	
27			**D**	1	**<u>Examiner's Comments</u>** This question was based on work done by a couple, and as such proved to be quite challenging. The work done by the couple is given by the expression below: work done = 2 × work done by each force = 2 × [0.12 × π × 8.2 × 10^{-2}] = 6.2 × 10^{-2} J The most popular answers turned out to be either A or C. The answer C was for the work done by one of the forces. This question was only accessible to the very top-end candidates. The exemplar 1 below shows an incorrect analysis that led to B being inserted into the answer box. **Exemplar 1**

					The diagram below shows a rotating steam generator.  The steam ejected from the nozzles provides a couple. The force at each nozzle is 0.12 N. The perpendicular distance between the nozzles is 8.2×10^{-2} m. What is the work done by the forces as the steam generator completes one revolution? **A** 0 J **B** 9.8×10^{-3} J **C** 3.1×10^{-2} J **D** 6.2×10^{-2} J Your answer B [1] The candidate has either written the equation for work done, or torque of a couple. Substitution shows that the torque has been calculated. Unfortunately, the response of 9.8×10^{-3} J was there as one of the options. This exemplar shows that if the starting point is incorrect, it can easily lead to what looks like a promising response.
			Total	**1**	
28			**B**	1	
			Total	**1**	
29			power × time = 2200 × 4.0 × 60 energy = 5.3×10^5 (J)	**C1** **A1**	**Note:** Answer to 3 s.f. is 5.28×10^5 (J) **Examiner's Comments** Virtually all candidates correctly found the total energy supplied, remembering to convert the time from minutes into seconds.
			Total	**2**	
30	a		work done = 400 × 0.80 work done = 320 (J)	C1 A1	**Examiner's Comments** This was answered correctly by most candidates; a tiny number did not convert from cm to m correctly.
	b		ratio of speeds = ratio of distances (since same time) **or** ratio = 80 / 2 ratio = 40	C1 A1	**Allow** 40:1 **Allow** 2 marks for ratio 29.4 (assuming p same) **Not** 1:40 for A1 **Examiner's Comments** Unsuccessful candidates tried to employ 'suvat' equations, although many candidates realised that the required ratio was also the ratio of the distances travelled in the same time period. Some credit was given for those candidates that assumed constant pressure and 100% efficiency.
	c		work done = 1200 × 9.81 × 0.02 (= 235.4)	C1 A1	**Note:** Using g =10 N kg^{-1} gives 75%: allow 1 mark max

			efficiency = 235.4 / 320 × 100 efficiency = 74 %		Possible ECF from **(a)** **Note:** 0.74 scores 1 mark **Allow** 2 marks for using 235/320 × 100 = 73% **Allow** use of 9.8 N kg^{-1} gives 73.5% for 2 marks **Allow** 1 mark for 71%, force = (1200*g* − 400) N used **Allow** 1 mark for 76%, force = (1200*g* + 400) N used **Examiner's Comments** The majority of candidates successfully calculated the work done on the car and hence the efficiency of the system.
			Total	**6**	
3 1			(Kinetic energy) reduces (with height) At maximum height, KE is minimum / non-zero	B1 B1	**Allow** idea that KE is transferred to GPE / KE store reduces and GPE store increases **Not** references to KE being a vector / having components for second mark
			Total	**2**	
3 2			$1.2 \times 10^6 = {}^1/_2 \times$ (mass per second) $\times 8.0^2$ mass per s = 3.8×10^4 (kg s^{-1})	**C1** **A1**	Answer is 3.75×10^4 (kg s^{-1}) to 3sf **Note:** 3.8 × 10n (kg s^{-1}) scores 1 for PoT error. **<u>Examiner's Comments</u>** A large majority of candidates got this right. Those that did not usually forgot to square the velocity.
			Total	**2**	
3 3			3000 × 9.8 × 12 / 0.60 = 588 kJ	C1 A1	
			Total	**2**	
3 4			$E_k = {}^1/_2 mv^2$ <u>and</u> $p = mv$ (Correct manipulation leading to) $E_k = {}^1/_2 p^2/m$	**M1** **A1**	**Allow:** any subject **Allow:** $E_k = p^2/(2m)$
			Total	**2**	
3 5			The force is towards the centre of the circle. The force is perpendicular to the motion or no component of force in direction of motion; hence no work is done on the particle.	B1 B1	
			Total	**2**	

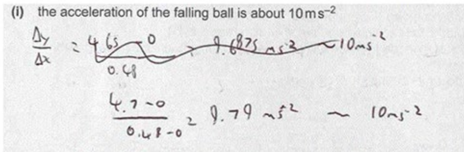
36	a		(change in) KE = (change in) GPE /AW ½$(m + 0.8)v^2 = 0.6\ mg$ (and hence equation as shown on	M1 A1	**allow** mgh = ½Mv^2 as long as it is clear that m and M are different, i.e. NOT mgh = ½mv^2 **allow** linear motion equation $v^2 = u^2 + 2as$ and $F = Ma$ $(W =)\ mg = (m + 0.8)a$; $u = 0$ and $s = 0.6$ **Examiner's Comments** The challenge to candidates in answering this *show that* question was to produce a convincing proof. More chose to use constant acceleration equations and $F = ma$ rather than loss of potential energy equates to gain in kinetic energy. The difficulty in the former method was justifying the statement $F = mg = (m + 0.800)\ a$. Most just quoted that $a = mg/\ (m + 0.800)$ which immediately gave the relationship shown in the question. The difficulty with the second method was that most candidates wrote $mgh = \pm$½mv^2 as the first line of their answer. In the next line one m became $(m + 0.800)$ without explanation to give the required relationship. Only candidates who gave more explanation were credited the marks. The candidate who wrote this perfect answer (exemplar 7) solved the problem in the first method of solution by introducing the tension in the string (labelled T on Fig. 4.1). **Exemplar 7**  (a) Show that the relationship between v and m is $v^2 = \frac{1.20mg}{(m + 0.800)}$ where g is the acceleration of free fall. T = 0.800 a mg − T = ma mg = a[(0.800) + m] s = 0.600 v = ? a = ? t = ? v² = u² + 2a v² = 2(0.6 v² = 1.2 mg / (0.800 + m
	b	i	$(v^2 =)$ 4.93 (±) 0.22	B1 B1	**allow** 4.9 (±) 0.2 (same number of decimal places)
		ii	Point (and error bar) plotted correctly Line of best-fit drawn through all points shown (use protractor tool at 49°)	B1 B1	tolerance ±½ small square; possible **ecf** from (b)**(i)** **allow ecf** from point plotted incorrectly or point omitted **Examiner's Comments** Most candidates calculated the value of v^2 to two decimal places successfully. Fewer were successful in giving the absolute uncertainty as ± 0.22. A popular distractor was ± 0.10. On the graph of Fig. 4.2 only the correct position of the point was required to gain the mark. The length of the uncertainty bar was ignored. A significant number of candidates forgot to draw the line of best fit on the graph.
	c	i	$v^2 = \frac{1.20mg}{(m + 0.800)}$ compared with $y = mx + c$	B1	**allow minimum of** gradient = $v^2/[m/(m + 0.8)] = 1.2$ g **or expect** $y = v^2$ and $x = m/(m + 0.800)$ so gradient = $1.20g$ **Examiner's Comments**

					The common successful method employed by the majority was to compare the given equation with standard form for a straight line $y = mx + c$. A simple rearrangement of the relationship without any explanation was not considered to be adequate.
		ii	one acceptable worst-fit line drawn large triangle used to determine gradient Gradient (used to determine 'worst' *g*) absolute uncertainty given to **one decimal place**	B1 B1 B1 B1	roughly between extremes of top and bottom error bars or by eye; consequential **ecfs** for rest of **(ii)** $\Delta x > 0.13$; **expect** steepest 12.5 ± 0.2 or shallowest 10.3 ± 0.2 if point from **bii** not plotted steepest line is 12.9 answer from ± 0.8 to 1.1(m s^{-2}); **allow ecf** from gradient value **<u>Examiner's Comments</u>** To avoid the problem of various lengths of error bar, candidates were judged to have drawn an acceptable worst fit line if it passed through opposite ends of the top and bottom bars on their graphs. Almost all gained the mark for using a triangle to determine the gradient of the line which spanned more than 0.13 on the *x* – scale. Most candidates were able to gain credit for finding the gradient of their graph correctly. The determination of the absolute uncertainty to one decimal place then proved to be too difficult a challenge for the majority.
	d		card appears shorter or time measured shorter calculated speed of trolley larger gradient of graph steeper **or** $v^2 \propto g$ /AW **so** calculated *g* is greater	B1 B1 B1 B1	**N.B.** each B mark is consequential on the previous statement; e.g. **ecf max** of 3 marks for correct consequences of stating card appears longer **or** time longer **<u>Examiner's Comments</u>** Candidates gave full and usually clear answers to this part. There were four consequential marking points in this answer. Each candidate was given credit for every point that followed logically from the previous one, even when that previous one was incorrect. In the example (exemplar 8) shown here the candidate stated that the card appeared longer, which is incorrect. There were still three marks available for stating that the speed would appear lower and deducing that g would appear smaller. By this method most candidates were credited with at least half of the available marks. **Exemplar 8** 
			Total	**15**	
37	a		(kinetic energy =) $1.6 \times 10^{-19} \times 300$	C1	

			$eV = \frac{1}{2}mv^2$	C1	
			$v = \sqrt{\frac{2\times1.6\times10^{-19}\times300}{9.11\times10^{-31}}}$	C1	**Note** 1.05×10^{14} scores 2 marks; omitted square rooting
			speed = 1.03×10^{7} (m s^{-1})	A0	**Examiner's Comments** Good candidates clearly showed the steps to determine the velocity. Weaker candidates found this question difficult. Clear substitution of numbers is required for these marks to be awarded.
	b		$\lambda = \frac{6.63\times10^{-34}}{9.11\times10^{-31}\times1.0\times10^{7}}$	C1	**Allow** ECF from the previous question part
			λ = 7.3×10^{-11} (m)	B1	**Allow** 2 marks for 7.1×10^{-11}, $v = 1.03 \times 10^{7}$ used **Examiner's Comments** This part was generally well answered although some candidates confused terms in the equation or could not deal with the powers of ten. Some candidates were confused and used $E=hc/\lambda$.
			Total	**5**	
38	a	i	**X** at closest point on orbit to the Sun	B1	**Allow X** on the orbit to the <u>left</u> of the Sun
		ii	(When the asteroid orbits the sun a) line segment joining the asteroid to the Sun sweeps out equal areas in equal time (intervals) Longer distance (in orbit for the same time)	B1 B1	**Allow** this mark on diagram (no labelling required) **Allow** 'equal area swept in same time'
	b	i	Work done per unit mass to move an object from infinity (to that point)	B1	**Not '** work done on 1 kg'
		ii	Manipulation of $V_{(g)} = (-)\ GM/r$	B1	
		iii	gradient = (−)30.4 or equivalent working candidate's gradient or expression = $6.67 \times 10^{-11} \times M$ <u>and</u> M calculated correctly from that gradient $M = 4.6 \times 10^{11}$ (kg)	C1 C1 A0	**Allow** ± 2 Possible ECF from incorrect gradient **Allow** any subject
	c		**Method 1:** Evidence of 2.3×10^{-3} <u>and</u> 600^{-1} or $(2.3 \times 10^{-3})^{-1}$ and 600 $\frac{1}{2} v^2 = 6.67 \times 10^{-11} \times 4.6 \times 10^{11} \times (2.3 \times 10^{-3} - 600^{-1})$ $v = 0.20$ (m s^{-1}) **Method 2:** Evidence of 7.0×10^{-2} <u>and</u> 5.1×10^{-2} from	C1 C1 A1 (C1)	Possible ECF from **(b)(iii)** for either value of GM or M **Allow** $\frac{1}{2} v^2 = 30 \times (2.3 \times 10^{-3} - 600^{-1})$ **Note** answer can be 0.19 or 0.20 or 0.2 m s^{-1} **Note** answer can be 0.19 or 0.20 or 0.2 m s^{-1} **Allow** correct use of one piece of data arriving at a value for v for 1 mark max

			graph $\frac{1}{2}v^2$ (= $\Delta V_{(g)}$) = $7.0 \times 10^{-2} - 5.1 \times 10^{-2}$ v = 0.19 (m s^{-1})	(C1) (A1)	
			Total	**10**	
39	a		energy input = $mc\Delta\theta$ = 0.327 × 4200 × 80 = 110 kJ	C1 M1	Allow 0.3 kg in the calculation
			energy input = power × time	C1	
			time = 220 (s)	A0	
	b		Thermal losses to kettle and surroundings	B1	
			Lagging the kettle	B1	
			Cover to prevent evaporation	B1	
			Total	**6**	
40	a		Arrow vertical down <u>and</u> an arrow opposite to the frictional force. Both arrows labelled correctly.	M1 A1	**Allow** weight / *mg* / W for the downward arrow <u>and</u> tension / *T* / 'force in rod' / 'force in tow bar' /'driving force' for the 'upward' arrow
	b		(W_s =) 1100 × 9.81 × sin 10° **or** 1100 × 9.81 × cos 80° (W_s = 1874 N or 1900 N)	C1 A0	**Allow** *g* instead of value
	c		force = 1900 + 300 force = 2200 (N)	 A1	**Allow** 1870 + 300 = 2170 (N)
	d		(distance =) 120 / sin 10° **or** 691 (m) (work done =) 2200 × 691 work done = 1.5 × 10^6 (J)	C1 C1 A1	**Allow** ECF from **(c)** **Allow** ECF from an incorrect attempt at first mark.
	e		(A =) π × 0.006^2 **or** 1.1 × 10^{-4} (m^2) (stress =) $\frac{2200}{\pi \times 0.006^2}$ <u>and</u> $2.0 \times 10^{11} = \frac{\text{stress}}{\text{strain}}$ x = 4.8 × 10^{-5} (m)	C1 C1 A1	**Allow** ECF from **(c)** **Allow** $x\ (=FL/EA) = \frac{2174\times0.5}{2.0\times10^{11}\times1.1\times10^{-4}}$ **Allow** 2 marks for 1.2 × 10^{-5}; 1.2 × 10^{-2} m used as radius **Allow** answer between 4.7 and 5.1 × 10^{-5} (m)
			Total	**10**	

4 1	a	i	$\frac{\Delta v}{\Delta t}$ <u>and</u> $\Delta t \geq 0.20$ s 9.8 m s^{-2}	M1 A0	**Allow** tolerance of ±½ a small square e.g. $\frac{4.7(-0)}{0.48(-0)} = 9.79$ **<u>Examiner's Comments</u>** This question was a "show" type question. Candidates needed to show their working logically. Ideally candidates would state that that the acceleration was equal to the gradient, and then show the substitution of the data values for the gradient calculation. It was expected that candidates would have gained an answer of 9.79 m s^{-2} **Exemplar 1**



(i) the acceleration of the falling ball is about 10 m s^{-2}

$\frac{\Delta y}{\Delta x} = \frac{4.7-0}{0.48-0} = 9.79$ m s^{-2} ~ 10 m s^{-2}

This candidate has clearly demonstrated from *Δy / Δx* that the gradient is to be determined. Co-ordinates are substituted into the gradient expression and it is clear that the candidate has used more than half the hypotenuse. The candidate then correctly evaluated the expression to give of 9.79 m s^{-2}. and then states that this is about 10 ms^{-2}.

AfL

Determining a gradient.

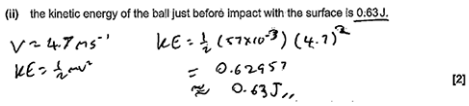
Candidates should clearly demonstrate the co-ordinates that are used to calculate the gradient. The co-ordinates must lie on the line. A common error is when a candidate uses a data point from a table of results. Candidates should be encouraged to read carefully the quantities from the axes and to pay attention to powers of ten and units.

The length of the hypotenuse used for the gradient calculation should be at least half the length of the line.

Candidates should clearly show the substitution of the co-ordinates and then evaluate the answer using the expression:

gradient $= \frac{y_2 - y_1}{x_2 - x_1}$.

The advantage of this method, it that negative gradients are automatically determined.

					AfL The gradient of a velocity-time graph is acceleration.
		ii	4.7 or $\frac{1}{2}$ x 0.057 x v^2 $\frac{1}{2}$ x 0.057 × 4.7^2 = 0.629565 0.63 J	M1 M1 A0	<u>**Examiner's Comments**</u> This was also a "show" type of question. Candidates needed to correctly read the maximum velocity (4.79 m s^{-1}) from the graph and change the mass of 57 g into kilograms. To gain the marks, clear substitution into the kinetic energy equation was needed with a correctly evaluated answer. **Exemplar 2**  (ii) the kinetic energy of the ball just before impact with the surface is 0.63 J. V ≈ 4.7 ms⁻¹ KE = ½ (57×10⁻³) (4.7)² KE = ½mv² = 0.62957 ≈ 0.63 J [2] In this two-mark answer, the candidate has clearly demonstrated the value from the graph as well as the equation that is going to be used. The candidate has correctly changed 57 g to kilograms effectively by using standard form. The candidate has then correctly evaluated the expression as 0.62957 before stating that this is approximately equal to 0.63 J. Candidates often find it helpful to underline relevant quantities. In this response the candidate has underlined 0.63 J.
	b	i	0.8 x 0.63 J (0.504 J) OR $v^2 = \frac{2 \times KE}{0.057}$ $v^2 = \frac{2 \times 0.504}{0.057}$ 4.2(1) (ms^{-1})	C1 C1 A1	**Allow** one mark for correct rearrangement of KE equation with incorrect KE 17.684 <u>**Examiner's Comments**</u> In this question, higher ability candidates initially determined the kinetic energy (0.504 J) as the ball leaves the surface, before rearranging the kinetic energy equation. A few candidates did not take the final square root.
		ii	Straight line from (0.48, –4.2) to *x*-axis <u>and</u> plotted to ±½ small square *x*-axis intercept at *t* = 0.91 ± 0.03 (s) from negative *v*	C1 A1	**Allow ECF** from **(b)(i)** **Allow** (0.49, –4.2) / (0.50, –4.2) / (0.51, –4.2) / (0.52, –4.2) **Allow ECF** for incorrect negative *v* <u>**Examiner's Comments**</u> In this question, a large number of candidates did not understand that velocity is a vector quantity and drew a line with a negative gradient back towards the x-axis. The velocity of the ball as it

					leaves the surface is in the opposite direction and is therefore –4.2 m s^{-1}. Candidates then needed to draw a parallel line to the initial line (since the acceleration is still the same). **AfL** Vector quantities have both a magnitude and a direction.
		iii	area under the graph = $\frac{1}{2}$ × 4.2 × 0.43 0.90 (m)	C1 A1	**Allow ECF** from **(i) and (ii)** **Allow** use of equation of motion: e.g. $s = \frac{4.2^2}{2 \times 9.81}$ or s = (–4.2 × 0.43) + $\frac{1}{2}$ × 9.81 × 0.43^2 (numbers must be seen) **Allow** use of loss of KE = gain in PE **Allow** one significant figure **Note** 0.84 for Δt = 0.40 to 0.97 for Δt = 0.46 **<u>Examiner's Comments</u>** There were many methods in which candidates could gain the marks in this question. It was helpful for clear methods to be demonstrated. The simplest was to determine the area under the velocity-time graph. Candidates also used the equations of uniform motion. Common errors seen included the incorrect velocity and when using the equations of motion but being confused about negative signs. Examiners on this occasion allowed an answer of 0.9 m which is one significant figure. Since the data used is to two significant figures, the final answer should also be to two significant figures. **AfL** The area under a velocity-time graph is displacement.
	c		Line will curve / be non-linear OR (magnitude of) gradient of line decreases (with increase in time) (Line will end with) a lower maximum/final velocity or hit the ground after a longer time	B1 B1	**Allow** sketch or gradient decreases / changes **Not** gradient is smaller / less steep / shallower / lower **Allow** ball will have a lower maximum/final velocity or hit the ground after a longer time)

					Examiner's Comments Candidates found this question challenging. Many candidates answered the question in terms of air resistance and terminal velocity. The question required candidates to explain how the graph would appear. Several candidates stated that the gradient would be smaller but did not clearly state that the gradient would decrease over time and not indicate that the line would curve. Candidates needed to also indicate that the line would indicate a lower maximum velocity at a longer time.
			Total	**12**	
42	a	i	1. *either* resultant force $F = ma - R$ *or* resultant force decreases as R increases	B1	**allow** for points 2 and 3 *when* $F = R$ appearing only once
		i	2. acceleration a decreases to zero when $F = R$	B1	
		i	3. velocity rises from zero to a terminal / maximum value when $F = R$	B1	
		ii	**1** initial acceleration is 40/120 = 0.33 (m s^{-2})	B1	
		ii	**2** from the graph Rv = 200 (W) so R = 40 N	C1	**or** forward force = 40 N so R = 40 N for constant
		ii	and terminal velocity v is 5 (m s^{-1})	A1	speed / zero acceleration
	b		p.e. / second = mgvsin θ = 120 × 9.81 × 5 × sin θ	C1	**allow** force downhill F = mgsin θ, extra power = Fv
			extra power= 200 (W)	C1	
			so sin θ = 1/29.4 giving × = 29 m	A1	
			Total	**9**	
43		i	$(\frac{1200}{300})$ 4.0	B1	**Allow** 1 SF
		ii	$180 = \frac{\rho \times 25}{6.7 \times 10^{-8}}$ $\rho = 4.8 \times 10^{-7}$ (Ω m)	C1 A1	**Note** answer is 4.82×10^{-7} to 3 SF
			Total	**3**	
44	a	i	There is friction. GPE is transferred to KE and heat or thermal (energy).	B1	
		ii	work done = (0.50 − 0.36) (J) or work done = 0.14 (J)	C1	
		ii	F × 0.90 = 0.14, therefore resistive force = 0.16 (N)	A1	
	b		Correct use of light-gate and timer **or** light-gate and data-logger **or** video technique to determine time interval.	B1	

			Speed determined by dividing length of car **or** interrupt card by time taken (to pass through light gate).	B1	
			Mass of car determined using scales and KE = ½ × mass × speed^2.	B1	
			Total	**6**	
45			(k.e. =) E = 5.0 × 10^6 × 1.6 × 10^{-19} v = √(2E/m) **or** = √(2 x 8.0 x 10^{-13} / 6.6 × 10^{-27}) = 1.6 x 10^7 (ms^{-1}) p (= mv) = 6.6 × 10^{-27} x 1.6 x 10^7 giving p = 1.1 × 10^{-19} (kg m s^{-1})	C1 C1 A1	E = 8(.0) × 10^{-13} J **or** (E = p^2/2m so) p = √(2mE) **Note:** A value of v = 1.6 x 10^7 (ms^{-1}) automatically scores both C1 marks even if the calculation for E is not shown **or** p (= √(2mE) = √(2 × 6.6 × 10^{-27} × 8.0 × 10^{-13}) giving p = 1.0 × 10^{-19} (kg m s^{-1}) Full substitution of values must be shown and answer (if calculated) must be correct **<u>Examiner's Comments</u>** This question provided an excellent opportunity for candidates to produce immaculate responses: identify the physics involved, select and write down the correct formula, do the necessary conversion (MeV to J), rearrange the formula, substitute correctly and then write the final response in standard form to a correct number of significant figures. Some of the common errors were: • forgetting to convert 5.0 MeV into J • not showing a full substitution of values (which is necessary for a 'show that' question) • not calculating the response to more than 1 s.f. (which is necessary for a 'show that' question).
			Total	**3**	
46		i	$(E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 0.16 \times 30.7^2)$ E_k = 75 (J)	B1	Possible ECF from **(iii)** **Examiner's Comments** This was generally well answered.
		ii	(E_p = mgh = 0.16 × 9.81 × 2.0 =) 3.1 (J)	B1	**Allow** $(E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 0.16 \times 6.3^2) = 3.2(J)$ **Examiner's Comments** Most candidates correctly calculated the gravitational potential energy although some weaker candidates used the answer from (i).
		iii	**(i)** − **(ii)**; (75 − 3.1) or $(E_k = \frac{1}{2} \times 0.16 \times 30^2)$ kinetic energy = 72 (J)	B1	Possible ECF from **(i)** and **(ii)** **Note:** Answer is 63 (J) when 28 (m s^{-1}) is used from **(ii)** **Examiner's Comments**

					Candidates either used the kinetic energy equation of subtracted the change in gravitational potential energy form their answer in (i). Common errors were either to state that the kinetic energy was zero or equal to the change in potential energy calculated in (ii).
			Total	**3**	
47	a		*Method 1: Momentum is conserved*		
			$1.7 \times 10^{-27} \times 500$ or $1.7 \times 10^{-27} \times (-)\ 420$ or $2.0 \times 10^{-26} \times v$	C1	
			$1.7 \times 10^{-27} \times 500 = 1.7 \times 10^{-27} \times -420 + 2.0 \times 10^{-26} \times v$	C1	
			$v = 78$ (m s^{-1})	A1	**Allow** 1 mark for 6.8 (m s^{-1}); + 420 used instead of − 420
			Method 2: Kinetic energy is conserved		
			$\frac{1}{2} \times 1.7 \times 10^{-27} \times 500^2$ or $\frac{1}{2} \times 1.7 \times 10^{-27} \times 420^2$ or $\frac{1}{2} \times 2.0 \times 10^{-26} \times v^2$	C1	**Allow** full credit for correct use of 'velocity of approach = −velocity of recession', e.g:
			$\frac{1}{2} \times 1.7 \times 10^{-27} \times 500^2 = \frac{1}{2} \times 1.7 \times 10^{-27} \times 420^2 + \frac{1}{2} \times 2.0 \times 10^{-26} \times v^2$	C1	'speed' of approach = (−) 'speed' of recession **C1** $500 = v + 420$ **C1** $v = 80$ (m s^{-1}) **A1**
			$v = 79$ (m s^{-1})	A1	**Examiner's Comments** This was a good discriminator with many of the top-end candidates scoring full marks. Most candidates opted to answer the question using the principle of conservation of momentum. A few candidates used ideas of conservation of kinetic energy for this perfectly elastic collision. It is good to report that most candidates coped well with powers of ten. The most common mistake was to use +420 m s^{-1} for the final velocity of the hydrogen atom, rather than −420 m s^{-1}; this gave the incorrect answer of 6.8 m s^{-1}. A small number of candidates used relative velocities before and after to arrive at an alternative correct answer of 80 m s^{-1}.
	b	i	Any two from: momentum, (total) energy and mass	B1	**Not**: kinetic energy Most candidates gained one mark for correctly stating two quantities from momentum, energy and mass. The most frequent incorrect answers were kinetic *energy* and *velocity*.
		ii	The force will have the same magnitude (at any time *t*)	B1	**Not** 'This is because action = reaction'
		ii	The force is in the opposite direction / has negative value	B1	**Not** Newton's third law **Allow** 1 mark for a correct graph if there is no description or

					explanation **Examiner's Comments** This question required knowledge and understanding of Newton's third law. Although many candidates were familiar with the law, they could not adequate describe or explain the force on the asteroid. There were vague answers such as *'The force goes up proportionally and then decreases exponentially'*. Some answers also focused unnecessarily on the transfer of momentum or kinetic energy but it was often the succinct answers such as *'The force on the asteroid is equal in magnitude but in opposite direction to the force F; NIII law' that scored full marks.*
			Total	**6**	
48	a		Photon(s) mentioned One-to-one interaction between photons and electrons Energy of photon is independent of intensity / intensity is to do with rate (of photons / photoelectric emission) / photon energy depends on frequency / energy of photon depends on wavelength / photon energy ∝ frequency / photon energy ∝ $1/\lambda$ energy of uv photon(s) > work function (of zinc) / frequency of uv > threshold frequency	**B1** **B1** **B1** **B1**	**Allow** 'photon absorbed by an electron' **Allow:** collide etc. for interaction **Allow** $E = hf$ or $E = hc/\lambda$ **Allow** energy of light photon(s) < work function (of zinc) / frequency of light > threshold frequency **Allow** ≥ instead of > here **Not** $f > f_0$ **Examiner's Comment** Many candidates wrote enthusiastically about photoelectric effect and understood the significance of work function energy (or threshold frequency) and the one-to-one interaction between photon and an electron. Some candidates did not mention 'photons' and this limited the marks they could acquire. The role of intensity was less understood. Many candidates thought it was linked to 'the *number of photons'* or *'the amount of electrons emitted.* The important term **rate** of the missing ingredient. Top-end candidates gave eloquent answers, typified by the response: *'intensity of visible light only affects the rate of photons incident on the plate but not the energy of each photon'.* Two common misconceptions were: • Photons were emitted from the negative plate. • Confusing threshold frequency and work function energy.
	b		$\phi = \dfrac{6.63\times10^{-34}\times3.0\times10^{8}}{2.9\times10^{-7}}$ or 6.86×10^{-19} (J) $E = 5.1 \times 1.60 \times 10^{-19}$ or 8.16×10^{-19} (J)	**C1** **C1**	**Note:** Using 5.1 and not 8.16×10^{-19} cannot score this mark or the next mark

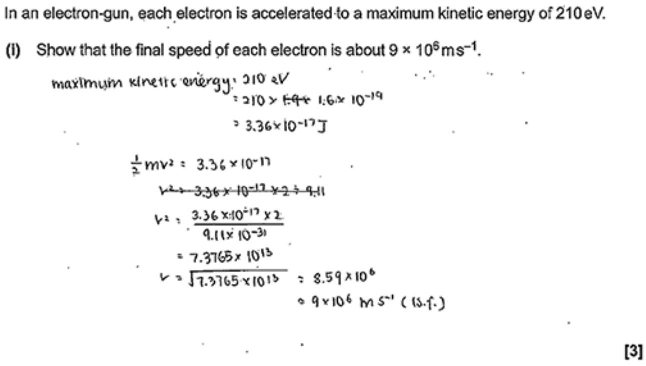
			max kinetic energy = (8.16 − 6.86) × 10^{-19} max kinetic energy = 1.3 × 10^{-19} (J)	**A 1**	**Allow** 2 marks for 0.81 eV **Examiner's Comment** This was a notable success for most of the candidates. Examiners were pleased to see a range of techniques being used to get the correct answer of 1.3 × 10^{-19} J. Many answers showed excellent structure, effortless conversion of energy from electronvolt to joule and excellent use of the calculator when dealing with powers of ten. Most candidates scored three marks. A small number of candidates left the final answer as 0.81 eV; the only thing missing was the conversion to J.
	c		Any <u>three</u> from: The electrons are repelled by **C** / electrons travel against the electric field (AW) The electrons are emitted with a 'range' of speed / velocity / kinetic energy (AW) As *V* increases the slow(er) electrons do not reach **C and** hence *I* decreases maximum KE in the range 2.1 <u>eV</u> to 2.2 <u>eV</u> or 3.36 × 10^{-19} <u>J</u> to 3.52 × 10^{-19} <u>J</u>	**B1× 3**	**Note** 'range' can be implied by 'highest' or 'lowest' **Allow** 'find p.d. when current is (just) zero, and then KE = *e* × *V* **Examiner's Comment** The electrons emitted from the metal plate have a **range** of kinetic energy. The emitted electrons are repelled by the negative electrode **C.** Fewer electrons reach **C** as the p.d. is increased. When the p.d. is about 2.2 V, and the current zero, the most energetic electron are stopped from reaching **C.** This makes the maximum kinetic energy of the electrons equal to 2.2 eV or 3.4 × 10^{-19} J. The question baffled most candidates. Some top-end candidates commented on *'the electrons repelled by* **C**' and the maximum kinetic energy of the emitted electrons being 2.2 eV. Such answers were rare. Too many candidates made guesses with answers such as *'the current drops because resistance increases'* and *'temperature increases and hence the current decreases'.*
			Total	**10**	
4 9		i	Using the graph to determine at least two ratios of the amplitudes.	M1	For example: 2.5/3.0 and 2.1/2.5
		i	Correct statement matching the ratios.	A1	For example: 'The statement is correct because 2.5/3.0 ≈ 2.1/2.5 ≈ constant. '
		ii	At time *t* = 0	M1	
		ii	Oscillator has maximum speed and hence the greatest friction. (AW)	A1	
			Total	**4**	
5 0		i	Q = 9.0 x 10-3 x 2 x 80 = 1.44 (C) *W* = (Q^2/2C =) 1.44^2/2 x 0.12 *W* = 8.6(4) (J)	C1 C1 A1	**ECF** for incorrect *Q* e.g. 2/3 for use of *Q* = 0.72(C) giving *W* = 2.2(J) **<u>Examiner's Comments</u>** The strongest answers were those where candidates set out their response in steps; first calculating the total charge and then using a correct formula to calculate the total energy stored. Many

					candidates performed the steps of their calculation randomly across the answer space, making it hard to determine their method.
		ii	(*W* = *Pt* so 8.6 = 0.050*t*) *t* = 8.6/0.050 = 170 (s)	A1	**ECF (b)(i)** for incorrect *W* **Examiner's Comments** Almost all candidates gained the mark for 3(b)(ii), as any incorrect answer to 3(b)(i) was accepted with error carried forward (ECF).
			Total	**4**	
5 1	a	i	At point P: path difference between slits and screen is a whole / integer number of wavelengths (for constructive interference) At point Q: path difference between slits and screen is an odd number of half wavelengths (for destructive interference)	**B1** **B1**	**Allow** n*λ* or λ **Not** phase difference **Allow** $(n + \frac{1}{2})\lambda$ **Not** *λ*/2 **Examiner's Comments** It was expected that candidates would describe the path difference in terms of the wavelength. Candidates often realised that the bright line would have a path difference of an integer number of wavelengths, this was often written as nλ. To explain the dark line many candidates struggled with the appropriate relationship in terms of *λ* or did not state an odd number of half wavelengths.
		ii	**1** *x* = 4.22 mm $\lambda = \frac{4.22 \times 10^{-3} \times 0.56 \times 10^{-3}}{4.50}$ 5.25 × 10^{-7} m $\frac{0.02}{4.5}$ or $\frac{0.02}{0.56}$ or $\frac{0.2}{42.2}$ $\left(\frac{0.02}{4.5} + \frac{0.02}{0.56} + \frac{0.2}{42.2}\right) \times 100 = 4.48\ \%$ Alternative max / min method: **2** $\lambda_{max} = \frac{4.24 \times 10^{-3} \times 0.58 \times 10^{-3}}{4.48} = 5.49 \times 10$ and/or $\lambda_{min} = \frac{4.20 \times 10^{-3} \times 0.54 \times 10^{-3}}{4.52} = 5.02 \times 10$ $\frac{\Delta\lambda}{\lambda} \times 100 = 4.4\%\ or\ 4.6\%$	**C1** **C1** **A1** **C1** **A1** **B1** **B1**	**Note x** = 42.2 mm or 4.2 × 10^{-2} m scores zero **Note x** = 3.84, 4.77 × 10^{-7} m may score max 2 **Allow** 4% or 5% with evidence of working **Ignore** significant figures **Examiner's Comments** Although candidates correctly identified the correct equation, a large number of candidates did not determine the fringe spacing correctly. Some candidates used 42.2 cm, others divided 42.2 cm by 11, 15 or 20. Furthermore, some candidates did not convert the slit separation from millimetres to metres. Candidates were able to identify the equation from the Data, Formulae and Relationships Booklet. Most candidates were able to determine at least one percentage uncertainty for the individual quantities correctly. Mistakes were

					made either on determining the other quantities or adding the percentage uncertainties. Some candidates attempted a maximum / minimum method – the common error with this method was not dividing maximum by minimum or minimum by maximum.
	b	i	$\frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{5.25 \times 10^{-7}} = \frac{1.989 \times 10^{-25}}{\mathbf{5\,b\,ii\,1}} = 3.79 \times$ $n = \frac{50 \times 10^{-3}}{3.79 \times 10^{-19}} = 2.5 \times 10^{23} \times \mathbf{5\,b\,ii\,1} = 1.3 \times 10$	**C1** **A1**	**Allow** ecf from **bii** **Examiner's Comments** Candidates found this question difficult. Many could not determine the energy of a photon correctly – an error carried forward was allowed from **5(b)(ii)1.** The question also required candidates to realise that 50.0 mW is equivalent to 50.0 mJ s^{-1}. A common error was to divide the power by the charge on an electron.
		ii	2.6 eV = 2.6 × 1.6 × 10^{-19}= 4.16 × 10^{-19} J ORA Energy of photon is less than work function so photoelectrons will not be emitted	**M1** **A1**	**Allow** photon has 2.37 eV of energy **Allow** conclusion based **5 c i** **Examiner's Comments** To explain whether photoelectrons will be emitted, candidates needed to convert the work function measured in electron volt to joule. A clear conclusion was needed.
			Total	**11**	
52		i	$E = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{380 \times 10^{-9}}$ or $\phi = 1.1 \times 1.6 \times$	C1	
		i	$\frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{380 \times 10^{-9}} = 1.1 \times 1.6 \times 10^{-19} + \frac{1}{2} \times 9.11 \times 10^{-31} v^{2}$	C1	This is substituting values into $\frac{hc}{\lambda} = \phi + \frac{1}{2}mv^{2}$
		i	speed = 8.7 × 10^{5} (m s^{-1})	A1	
		ii	The energy of a photon depends only on wavelength or frequency, so intensity does not change the maximum speed of the photoelectrons.	B1	
			Total	**4**	
53		i	$E = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{490 \times 10^{-9}}$ energy = 4.1 × 10^{-19} (J)	C1 A1	**Note** answer to 3 SF is 4.06 × 10^{-19}
		ii	(number of photons =) $\frac{0.230}{4.06 \times 10^{-19}}$ number of photons = 5.7 × 10^{17}	C1 A1	Possible ECF from **(b)(i)** **Note** answer is 5.6 × 10^{17} when 4.1 × 10^{-19} is used
			Total	**4**	

54	a		Graph correct shape and always positive and suitable scale on kinetic energy axis.	B1	
			Maxima occur at zero displacement times.	B1	
	b	i	Period from graph = 500/3.5 = 143 ms	C1	
		i	Acceleration = $\omega^2 A = (2\pi/0.143)^2 \times 0.006$ = 12 (ms^{-2})	A1	
		ii	KE = $0.5 \times 0.005 \times (2\pi / 0.143 \times 0.006)^2$	C1	
		ii	KE = 1.7×10^{-4} (J)	A1	
			Total	**6**	
55		i	Parallel and equidistant field lines.	B1	**Note**: Field lines must be right angle to the plates.
		i	Field direction is correct (from left to right).	B1	
		ii	work done = $1500 \times 1.6 \times 10^{-19} \times 1.2 \times 10^{-2}$ = 2.88×10^{-18} (J)	C1	
		ii	$\frac{1}{2} \times 9.11 \times 10^{-31} \times v^2 = \frac{1}{2} \times 9.11 \times 10^{-31} \times (5.0 \times 10^6)^2$	C1	Correct use of: final KE = initial KE − work done.
		ii	speed = 4.3×10^6 (m s^{-1})	A1	
			Total	**5**	
56		i	(surface area =) $4\pi \times (1.4 \times 10^9)^2$ **or** 2.46×10^{19} (m^2) (intensity = $\frac{P}{4\pi r^2}$) intensity = $\frac{2.7 \times 10^{27}}{4\pi \times (1.4 \times 10^9)^2}$ intensity = 1.1×10^8 (W m^{-2})	**C1** **C1** **A0**	**Allow** 2.5×10^{19} (m^2) **Note**: Using $\pi \times (1.4 \times 10^9)^2$ is wrong physics; hence no marks in this show question **<u>Examiner's Comments</u>** This was a demanding question designed for middle and top-end candidates. The radiant intensity is equal to the power transmitted per unit cross–sectional area. The area being that of a sphere of radius 1.4×10^9 m. The equation $4\pi R^2$ was appropriate here. The common errors, mainly from the low–scoring candidates, were using πR^2 and $\frac{4}{3}\pi R^3$. All the key steps in the calculations had to be structured well for
		ii	$E = \frac{3.00 \times 10^8 \times 6.63 \times 10^{-34}}{5.0 \times 10^{-7}}$ $E = 4.0 \times 10^{-19}$ (J)	**C1** **A1**	**Note**: Answer to 3 SF is 3.98×10^{-19} (J) **Allow** 4×10^{-19} (J) without any SF penalty **<u>Examiner's Comments</u>** Most candidates were familiar with the equation for the energy of the photon. Answers were generally well–structured and calculations were undertaken without much error in either rearranging the equation or powers of ten. The answer to two significant figures was 4.0×10^{-19} J, as in the general rule with such answers, 4×10^{-19} J was acceptable without any significant figure penalty.

		iii	(number per second = $\frac{2.7\times10^{27}}{4.0\times10^{-19}}$) number per second = 6.8×10^{45} (s^{-1})	B1	Possible ECF from **(b)(ii)** **Examiner's Comments** This was a successful end for the top–end candidates, who correctly divided the total output power of Procyon of 2.7×10^{27} W by the energy of each photon from **(b)(ii)**. The two common errors were dividing the intensity by the photon energy and changing the photon energy from joule (J) to electron–volt (eV).
			Total	**5**	
57		i	250 × 60 = 15000 J	C1	
		i	energy = $\frac{15000}{0.65}$ = 2.3×10^4 (J)	A1	
		ii	drag force = 0.4 × 6.0^2 = 14.4 N	C1	
		ii	forward force = power / velocity = 250/6.0 = 41.7 N	C1	
		ii	acceleration = $\frac{41.7 - 14.4}{85}$ = 0.32 m s^{-2}	A1	
			Total	**5**	
58		i	(*KE* =) 210 × 1.60 × 10^{-19} (J) **or** 3.36 × 10^{-17} (J) ½ × 9.11 × 10^{-31} × v^2 = 3.36 × 10^{-17} v = 8.6 × 10^6 (ms^{-1})	C1 C1 A1	**Note** using *KE* = 210 (J) is wrong physics XP **Note** the answer must be to more than 1 SF **Examiner's Comments** This was not a straight forward question but most candidates demonstrated excellent knowledge and application of physics here. The conversion of 210 eV was often done correctly. The K.E. equation was used successfully to show the final speed of the electrons to be about 8.6 × 10^6 m s^{-1}. The exemplar 11 below shows a model response from a top-end candidate. **Exemplar 11**

					 In an electron-gun, each electron is accelerated to a maximum kinetic energy of 210 eV. (i) Show that the final speed of each electron is about 9×10^6 m s^{-1}. maximum kinetic energy: 210 eV = 210 × ~~1.94~~ 1.6 × 10^{-19} = 3.36 × 10^{-17} J $\frac{1}{2}mv^2 = 3.36 \times 10^{-17}$ ~~$v^2 = 3.36 \times 10^{-17} \times 2 \div 9.11$~~ $v^2 = \frac{3.36 \times 10^{-17} \times 2}{9.11 \times 10^{-31}}$ $= 7.3765 \times 10^{13}$ $v = \sqrt{7.3765 \times 10^{13}} = 8.59 \times 10^6$ $\approx 9 \times 10^6$ m s^{-1} (1s.f.) [3] This exemplar shows a typical response produced by most of the candidates. The conversion from eV to J is very clear. The correct mass of the electron has been used to get the response of 8.6 × 10^6 ms^{-1}. It is good to report that very few candidates used 210 J to get the impossible response of 2.1 × 10^{16} ms^{-1}.
		ii	$\lambda = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 8.6 \times 10^6}$ λ = 8.5 × 10^{-11} (m)	C1 A1	Possible ECF from **(i)** **Allow** 2 marks for 8.1 × 10^{-11} (m); v = 9 × 10^6 ms^{-1} used **<u>Examiner's Comments</u>** The majority of the candidates effortlessly used the de Broglie equation and their answer from **(b)(i)**, or 9 × 10^6 m s^{-1}, to calculate the wavelength λ of the electron. ? **Misconception** The two common mistakes being made here were: • Using 3.0 × 10^8 m s^{-1} for the speed instead of 8.6 × 10^6 m s^{-1}. • Using the energy of the photon equation $E = \frac{hc}{\lambda}$ instead of $\lambda = \frac{h}{mv}$.
			Total	**5**	
59		i	F = GMm/r^2 = mv^2/r	C1	where r = 6.8 × 10^6 m
		i	v = (GM/r)$^{1/2}$ = (g/r)$^{1/2}$R (as g = GM/R^2)	C1	**N.B.** some working must be shown as a
		i	v = 7.7 (km s^{-1}).	A1	*show that* Q
		ii	total energy = ½mv^2 − GMm/r = −GMm/2r	M1	**no ecf from (i); allow** numerical values
		ii	E = −gR^{2}m/2r = −1.2(4) × 10^{13} (J)	A1	with no algebra if clear **no mark for** correct value without the minus sign
			Total	**5**	
60			**Level 3 (5 - 6 marks)** Clear determination of input energy,	B1 x 6	**Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2^ for 3 marks, etc.**

procedure and analysis

There is a well-developed line of reasoning which is clear and logically structured. The information presented is clear, relevant and substantiated.

Level 2 (3 – 4 marks)
Clear determination of input energy and procedure, but no analysis

or Clear analysis but limited determination of input energy and/or limited procedure

or Attempted determination of input energy, basic procedure, and an attempt at analysis

There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.

Level 1 (1 – 2 marks)
A limited selection from the scientific points worthy of credit.
There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant. **0 marks** No response or no response worthy of credit

Candidates can gain full credit for investigating the efficiency of either:
Method 1(M1): GPE (*nmgh*) to energy conversion in LED (*Pt*) or
Method 2(M2): GPE (*nmgh*) to energy stored in capacitor (½*CV*2 or ½Q2/*C*)
<u>L1 maximum for any answers which do not use GPE as input energy</u>

Indicative scientific points may include:

Determination of input energy

- record the number of inversions, *n*
- (use electronic / top pan balance to) measure mass of magnet *m*
- (use mm ruler to) measure tube length l_t and magnet length l_m
- calculate $h = l_t - l_m$
- calculate (GPE =) *nmgh*

Procedure

- invert torch n times (with torch switched off)
- make sure that the magnet falls the full height h between inversions
- M1 switch torch on and (use stopwatch to 0.1 s to) measure time *t* taken until LED goes out (use video with timer for greater accuracy)
- M1 use a darkened room or view LED through tube
- M2 (use voltmeter across capacitor to) measure final p.d. V_f
- M2 (with coulombmeter) measure final charge Q_f stored by capacitor
- repeat experiment for different *n*

Analysis of efficiency

- M1 calculate $W = Pt$ where P = 50 mW
- M2 calculate $W = \frac{1}{2}CV_f^2$ or $\frac{1}{2}Q_f^2/C$
- calculate efficiency = *W/nmgh*
- compare efficiency values for different *n*
- plot suitable graph e.g. efficiency against *n* / *W* against *nmgh*
- plot t against *n* (M1) / V^2 or Q^2 against *n* (M2) with justification
- discuss shape / gradient of graph

<u>Examiner's Comments</u>

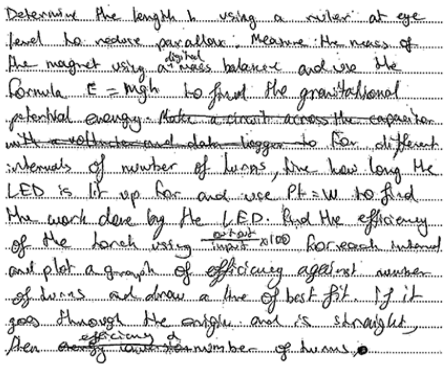
In level of response questions like 3(c), candidates must remember to refer closely to the stem of the question when planning their extended answer to make sure that they are addressing the question asked.

The challenge in this question was to design an experiment that would yield results leading to a valid conclusion. Candidates could gain full credit for investigating the efficiency of gravitational potential energy (GPE) to either:

- energy conversion in the LED (power x time) or
- energy stored in the capacitor (½CV^2 or ½Q^2/C)

Candidates were then expected to describe how the efficiency would be calculated, and how they could tell whether the efficiency depended on the number of times the torch is turned or inverted, n.
Many candidates were able to describe a valid graphical method, usually plotting efficiency against n, or output energy against input energy. Some candidates plotted time against number of inversions, which was able to score maximum credit provided that they clearly explained that t and n were proportional to output and input energy respectively.
The best responses were those where candidates had not just stated what to plot but had gone on to describe and explain the expected shape of the graph and what its gradient would show.

Exemplar 4


Determine the length h using a ruler at eye level to reduce parallax. Measure the mass of the magnet using a digital mass balance and use the formula E = mgh to find the gravitational potential energy. ~~Make a circuit across the capacitor with a voltmeter and data logger to~~ For different intervals of number of turns, time how long the LED is lit up for and use Pt = W to find the work done by the LED. Find the efficiency of the torch using $\frac{output}{input} \times 100$ for each interval and plot a graph of efficiency against number of turns and draw a line of best fit. If it goes through the origin and is straight, then ~~energy~~ efficiency ~~and~~ ∝ number of turns.

Exemplar 4 shows a typical Level 2 response. The candidate is correctly trying to find the efficiency of GPE converted to electrical energy in the torch, but their response lacks the clarity and detail needed for a Level 3 response. Also, their method will not yield correct results because they have

- not realised that GPE increases with the number of turns, so they need to use the formula GPE = nmgh.
- not specified that the length h is the distance that the magnet falls, rather than the length of the tube.
- not made clear which is the input and which the output energy in the (correct) efficiency formula.
- used incorrect graphical analysis for their graph of efficiency against n. We want to discover whether efficiency depends on n, not demonstrate that efficiency increases proportionally to n, which is impossible.

			Total	**6**	

6
1
	a		**Level 3 (5–6 marks)**
			Clear description and analysis.
			
			There is a well–developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.
			
			Level 2 (3–4 marks)
			Some description and some analysis.
			
			There is a line of reasoning presented with some structure. The information presented is in the most–part relevant and supported by some evidence.
			
			Level 1 (1–2 marks)
			Limited description and limited analysis
			or limited description
			or limited analysis
			
			There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.
			
			0 marks
			No response (NR) or no response worthy of credit (0).
				B1 x 6	**Indicative scientific points may include:**
					Description
					
					• Ruler used to determine *x*
					• Average readings to determine *x*
					• x recorded for various *v*
					• Suitable method for consistent *v* or varying *v* e.g.
					    • Released from same point on a track
					    • Ejected from a spring device with different compressions
					• Suitable method of determining point of impact e.g.
					    • trial run to get eye in approximate correct position
					    • carbon paper so that ball makes a mark on paper
					    • scale in frame of video recording
					    • tray of sand to catch ball
					• Suitable instrument used to determine *v* (light–gate / motion sensor / video techniques) or suitable description of inference of v from other measurements such as energy released from spring of known *k* and *x*
					• Ensuring the initial velocity of ball is horizontal
					
					Analysis
					
					• Horizontal velocity is constant
					• Time of fall is independent of *v*/horizontal velocity
					• Suggested relationship: e.g. $x \propto v$,x d.p. to V^2, etc
					• Plot a graph of *x* against *v* or graph consistent with candidate's suggested relationship
					• If relationship is correct, then a **straight line** through the **origin**.
					• Suggested relationship supported by correct physics or algebra.
					• Correct relationship supported by physics.
					
					Note:
					L1 is used to show 2 marks awarded and L1^ is used to show 1 mark awarded.

Examiner's Comments

Many candidates had plenty to say that was sensible. There was plenty of evidence that candidates had seen this experiment or had performed a similar one themselves. A few confused the question, instead describing how to find the time of flight or that the ball was falling vertically. Others described what they thought would happen to the vertical component of velocity when they changed the vertical distance that the ball dropped.

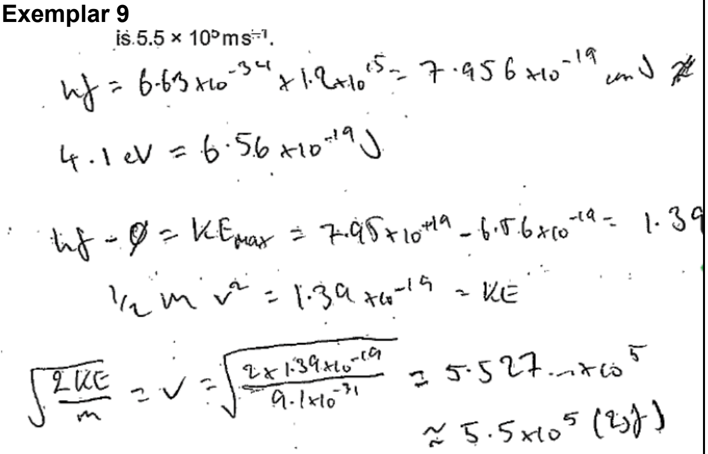
Exemplar 2

Use your knowledge of projectile motion to suggest the relationship between
how an experiment can be safely conducted to test this relationship and ho
analysed. make sure no one in

As in a projectile the horizontal
of velocity is constant given
is negligible then a equation of
would become $x = vt$ where x is
traveled v is velocity of ball and
time of flight therefor for a co
of flight it can be said $x \propto$
~~To test this it is very hard~~
~~time of flight constant as this~~
~~to its time of freefall~~
To test this a ball would
of a table at varying spe
calculate this speed a light
can be used passing through
center of the metal ball. As
travelled is equal to the diameter
ball, measured by a ruler, sp
be calculated using distance/time

					light gate. For safety the bal land in sand as not to sh land on someones foot. This also measuring x much easier as equal to the horizontal distance f edge of the table to the cra sand measured using a ruler. If taken to fall is kept constant by using a stop watch and by raising or lowering the point when v is plotted x on a graph it can be to be linear and pass thro origin. In the first paragraph, the candidate has made clear that the time of flight is constant and goes on to explain why towards the end of the response. This supports the prediction that $v \propto x$ In addition, the candidate takes time to explain how to obtain data for both the horizontal velocity and horizontal distance. It was pleasing to see light gates and motion sensors being employed, with the best answers explaining how to use the data provided by the sensors to calculate the velocity of projection. The exemplar response also includes the correct analysis. There is a graph of v against x and the resulting best fit straight line through the origin supports the idea that these two variables are directly proportional. Too many candidates did not mention the crucial statement about the line going through the origin, limiting their response to a high L1 or low L2.
	b	i	vertical component =30.0 sin(70°) or 30.0 cos(20°) vertical component = 28.2 (m s^{-1})	A1	**Allow** 2 SF answer of 28
		ii	Evidence of $v^2 = u^2 + 2as$ and $v = 0$ or $gh = \frac{1}{2} u^2$ $h = \frac{28.2^2}{2 \times 9.81}$ (Any subject)	C1 M1 A0	**Allow** *v* and *u* interchanged; a and g interchanged **Allow** use of candidate's answer for (a)(i) at this point **Ignore** sign **Allow** $h = \frac{28^2}{2 \times 9.81}$ or (30 sin(70))^2/(2 × 9.81) **No ECF from (a)(i) for the second mark**

			h = 40.5 (m)		
		iii	The ball has horizontal motion / velocity (AW)	**B1**	**Allow** idea of horizontal e.g. sideways, forwards **Not**: 'moving' unqualified
		iv	(horizontal velocity =) 30.0 cos 70° or 10.2.… (m s^{-1}) or 30.0 sin 20°. $E_k = {}^1/_2 \times 0.057 \times 10.26^2$ E_k = 3.0(J)	**C1** **A1**	**Allow** 1 SF answer **Not** 22 (J), v = 28 used **Not** 23 (J), v = 28.2 used **Not** 140 (J), v = 70 used **<u>Examiner's Comments</u>** Part (i) was particularly well answered by 95% of all candidates. Nine out of ten candidates scored full marks in part (a)(ii), as they remembered that the question asks to *show* that the maximum height is around 40m. Working for this type of question is essential. In part (a)(iii), three quarters of all candidates correctly talked about the ball still having a horizontal velocity (which wasn't zero) and therefore still possessing some KE. The key to this part (a)(iv), remembered by most candidates, was to use the horizontal component of velocity to find the KE at the maximum height. Some used the initial speed and others used the initial vertical velocity component found in part (a)(i).
			Total	**12**	
62		i	Any **THREE** from: Atoms of metal vibrate (about fixed points) Water molecules have translational KE The motion of the water molecules is random Metal atoms and water molecules have the same KE	B1×3	**Allow** particles for atoms / molecules throughout **Allow** idea that water particles move past each other **Not** idea that the water molecules have more KE than metal atoms
		ii	(E_{heater} =) 200 × 10 × 60 **or** 120000 (J)	C1 C1	

			(E_{water} =) 0.5 × 4200 × 40 **or** 84000 (J) (energy transferred = 120000 – 84000) energy transferred = 3.6×10^4 (J)	A1	
			Total	**6**	
6 3	i		$4.1\ eV = = 4.1 \times 1.6 \times 10^{-19}$ or 6.56×10^{-19} J OR $E_k = 6.63 \times 10^{-34} \times 1.2 \times 10^{15} - \phi$ $E_k = 6.63 \times 10^{-34} \times 1.2 \times 10\mathit{15} - 6.56 \times 10^{-19}$ $E_k = 1.39 \times 10^{-19}$ J $v = \sqrt{\frac{2 \times 1.39 \times 10^{-19}}{9.11 \times 10^{-31}}} = \sqrt{3.06 \times 10^{11}}$ 5.536×10^5 m s^{-1}	**C1** **C1** **C1** **C1** **A0**	**Allow** $f_0 = 9.9 \times 10^{14}$ Hz **Allow** $E_k = 6.63 \times 10^{-34} \times (1.2 \times 10^{15} - 9.9 \times 10^{14})$ **Allow** 1.4×10^{-19} J 3.06×10^{11} scores three marks **<u>Examiner's Comments</u>** Good candidates clearly showed the individual steps in this calculation, e.g. the conversion of electron-volt to joule for the work function, the energy of the photon calculated. It was important that candidates demonstrated that they had substituted the mass of the electron from the data booklet and correctly evaluated the square root term. Examiners expected to see 5.536×10^5 (m s^{-1}) for full credit so that it was clear that candidates had correctly calculated the powers of ten. **Exemplar 9**  In line 3 of the candidate's working, there is a rearrangement of the equation given at the beginning of the question. There is then clear substitution of the energy of a photon which was calculated in line 1 and the work function which had been converted from

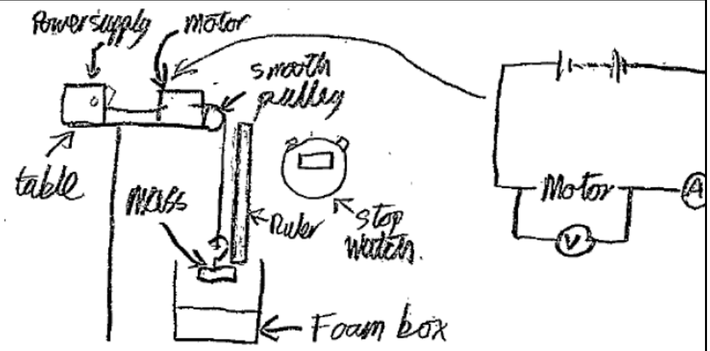
					electron volt to joule in line 2 to give a value for the maximum kinetic energy of the electrons. This scores three marks. In the final part the candidate correctly shows the rearrangement of the kinetic energy equation to give *v* as the subject and then correctly substitutes in the values including the mass of the electron from the data and formulae sheet. The final answer is given as 5.527 × 10*5* which is then shown to be approximately equal to 5.5 × 10*5* (ms^{-1}). This last part is essential in these show type questions.
		ii	Maximum energy is independent of intensity/(number of photons has increased but) energy of photon is the same/energy of a photon is <u>only</u> dependent on frequency/intensity affects the number of photons/electrons released <u>only</u>/frequency of photon has not changed No change in maximum speed	**M1** **A1**	**Not** "Does not increase" **<u>Examiner's Comments</u>** For this type of question, a clear explanation is needed before the mark for stating the change, if any. Candidates' descriptions were often vague, and few stated that the maximum energy was independent of intensity.
			Total	**6**	
6 4		i	$\varepsilon = eV = 12 \times 1.6 \times 10^{-19} = 1.92 \times 10^{-18}$ (J)	B1	
		i	$½mv^2 = 1.92 \times 10^{-18}$	C1	**Allow** ecf for energy value
		i	$v^2 = 2 \times 1.92 \times 10^{-18} / 9.1 \times 10^{-31} = 4.22 \times 10^{12}$	C1	
		i	$v = 2.05 \times 10^6$ (m s^{-1})	A1	
		ii	accelerates from 0 to v so use v / 2	C1	**ecf (i)**
		ii	$t = 5 \times 10^{-3} / 1 \times 10^6 = 5 \times 10^{-9}$ (s)	A1	**Allow** 1 mark for 2.5×10^{-9}s
			Total	**6**	
6 5			**Level 3 (5–6 marks)** Description and explanation of pattern changes **and** quantitatively explains link between de Broglie wavelength and potential difference. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.*	B1 ×6	**Indicative scientific points may include:** **Description of pattern changes** • Rings become closer (not just smaller) • Rings become brighter **Qualititative explanation of pattern changes in terms of de Broglie wavelength and potential difference**

			Level 2 (3–4 marks) Clear description of how pattern changes and explanation of pattern changes and qualitatively explains link between de Broglie wavelength and potential difference **or** limited description of how pattern changes and quantitatively explains link between de Broglie wavelength and potential difference. *There is a line of reasoning presented with some structure.* *The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description of how pattern changes and limited attempts to explain qualitatively the link between de Broglie wavelength and potential difference **or** qualitatively explains link between de Broglie wavelength and potential difference. *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.		• Electrons gain greater energy • Electrons have a greater speed • Electrons have a greater momentum • Implies smaller wavelength • Smaller wavelength means less diffraction • Shorter wavelength gives shorter path differences between areas of constructive and destructive interference **Quantitative explanation of pattern changes in terms of de Broglie wavelength and potential difference** • $eV = \frac{1}{2}mv^2$ • $p = mv$ • $v^2 \alpha V$ or $p^2 \alpha V$ • $\lambda = \frac{h}{p}$ or $\lambda \alpha \frac{1}{v}$ • $\lambda = \frac{h}{\sqrt{2meV}}$ or $\lambda \propto \frac{1}{\sqrt{V}}$ <u>**Examiner's Comments**</u> This question tested an understanding of electron diffraction. Many candidates gave a good qualitative explanation of how the pattern would change. High achieving candidates clearly demonstrated how the de Broglie wavelength λ was related to the potential difference V by equating the energy eV to kinetic energy, then using the definition of momentum and the de Broglie wavelength. Some candidates confused speed v with potential difference V. Many candidates gave a good qualitative explanation. Many candidates did not state that the rings would become brighter. **AfL** Candidates should be able to describe how to use light gates. In particular, candidates should be able to indicate the measurements that are needed to determine speed and acceleration. Candidates should state that the light gates should be connected to a timer or data-logger. **AfL** When analysing experimental data, candidates should be able to determine appropriate graphs to plot which will give a straight line (if the given relationship is true). Candidates should also be able to describe how unknown quantities may be determined using the gradient and / or *y*-intercept. **Misconception**

					There is some confusion between the equations to use for photoelectric effect and the equations to use when considering the de Broglie wavelength. For the de Broglie wavelength, a common misconception is to relate the energy to wavelength by the equation for the energy of a photon, $E = \frac{hc}{\lambda}$
			Total	**6**	
66	a	i	t = 0 to 1.5 s, constant force (of 30 N) causes constant acceleration	B1	or reference to N2
		i	t = 1.5 to 4.0 s zero (resultant) force so constant speed	B1	or reference to N1
		ii	acceleration = 30/65 = 0.46 (m s^{-2})	M1	
		ii	speed v at 1.5 s = at = 0.46 × 1.5 = 0.69 (m s^{-1})	A1	ecf acceleration value
		ii	distance = ½at^2 + vt' = 0.23 × 1.5^2 + 0.69 × 2.5	C1	ecf acceleration and speed values
		ii	s = 2.24 m	A1	
	b		power lost in circuit = 30^2 × 0.11	C1	Apply ecf rule as appropriate
			= 99(w)	C1	
			mechanical power = 640 × 0.70 = 448 (W)	C1	allow 3 marks for 53%
			electrical power input = 28 × 30 = 840 (W)	C1	
			input power to motor = 741 (W)	C1	
			efficiency = 448 / 741 = 0.60 or 60%	A1	
			Total	**12**	
67			**Level 3 (5–6 marks)** Clear description **and** correct calculations leading to value of total energy (must include the negative sign) *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some description and some correct calculations **or** Correct calculations (including the negative sign) *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.*	B1× 6	**Indicative scientific points may include:** **Description** • Orbit above the equator / equatorial orbit • Orbit from west to east/same direction of orbit as Earth's rotation • Orbital period is 24 hours / 1 (sidereal) day /23hrs 56mins (4 s) • Orbit is circular / above the same point on the Earth **Calculation** • $E = (-)\frac{GMm}{r}$ • $E = \frac{6.67\times10^{-11} \times 5.97 \times 10^{24} \times 2500}{4.22 \times 10^{7}}$ = (-)2.4 × 10^{10} J • $V = \frac{2\pi r}{T}$ ωr • $V = \frac{2\pi \times 4.22 \times 10^{7}}{24 \times 3600}$ = 3.07 × 10^3 m s^{-1} • $E = \frac{1}{2}mv^2$ • $E = \frac{1}{2} \times 2500 \times [3.07 \times 10^3]^2$ = 1.2 × 10^{10} J

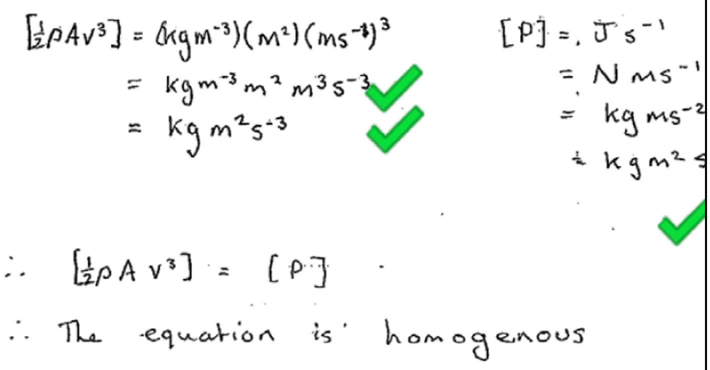
			Level 1 (1–2 marks) Limited description **or** Limited calculations *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.		• Total energy = - 2.4 × 10^{10} + 1.2 × 10^{10} = - 1.2 × 10^{10} J • Allow full credit for algebraic proof using $\frac{GMm}{r^2} = \frac{mv^2}{r}$, $E = (-)\frac{GMm}{r}$, $E = \frac{1}{2}mv^2$ and total energy = KE + PE Allow higher order answers in terms of Lagrange's Identity **<u>Examiner's Comments</u>** This part explored multiple ideas about geostationary orbits. It was accessible to most candidates, many of whom calculated the magnitude of the GPE correctly yet forgot that this value must be negative. Almost all candidates forgot that Gravitational Potential Energy is negative.
			Total	**6**	
6 8		i	GPE = (−) GMm/r GPE = (−) 6.67 × 10^{-11} × 2 × 10^{30} × 810/1.5 × 10^{11} GPE = (−) 7.2 × 10^{11} (J)	C1 C1 A0	Mark is for full substitution, including 6.67 × 10^{-11} for G
		ii	v = 2Πr/T = 2Π × 1.5 × 10^{11} / 3.16 × 10^7 (= 29.8 km s^{-1}) KE = ½mv^2 = 0.5 × 810 × (29.8 × 10^3)^2 KE = 3.6 × 10^{11} (J)	C1 M1 A1	**Allow** proof by algebraic method for full marks e.g. $mv^2/r = GMm/r^2$ so $mv^2 = GMm/r$ Therefore KE/GPE = ½mv^2/(GMm/r) =½
		ii i	total energy = (−) (7.2 × 10^{11} − 3.6 × 10^{11}) total energy = (−) 3.6 × 10^{11} (J)	M1 A0	working must be shown; **ECF (i) and (ii)**
			Total	**6**	
6 9			**Level 3 (5–6 marks)** Clear diagrams and procedure and measurements **and** analysis *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** A diagram, some procedure, some measurements and some analysis. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by*	**B1 × 6** **6**	**Indicative scientific points may include:** **Diagram and procedure** • labelled diagram • correct circuit diagram • description of procedure • use of cushion in case load falls • repeats experiment. **Measurements** • use of balance to measure load • use of ruler to measure height • use stopwatch to measure time • use of ammeter to measure current

			some evidence. **Level 1 (1–2 marks)** Limited procedure and limited measurements **or** limited analysis *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response or no response worthy of credit.		• use of voltmeter to measure p.d. **Analysis** • equation to determine input power/energy (*IV*/*IVt*) • equation to determine output power/energy (*mgh/t or mgh*) • equation to determine efficiency • use of gradient of appropriate graph **<u>Examiner's Comments</u>** This question is assessing candidates' abilities to plan an investigation. The question is set to help candidates e.g. "lift light loads" should have given the hint of gravitational potential energy. The stem of the question indicates that a suitable diagram should be drawn. Many candidates did not label their diagrams, or the diagrams were not workable. It was expected that there would be a workable circuit diagram with appropriate measuring instruments to determine the input power or energy; correct circuit symbols should be used. There also needed to be a diagram indicting how the useful power or energy could be determined. See Exemplar 1. When answering planning questions, candidates should identify the measurements that need to be taken and indicate appropriate measuring instruments. Candidates also needed to explain how the data would be analysed. This required them to give the appropriate equations using their measurements to determine the input power/energy, the output power/energy and the efficiency. Good candidates suggested the plotting of an appropriate graph and explained how the efficiency could be determined from the gradient. **Exemplar 1**

					 This candidate has drawn two diagrams – one diagram indicating clearly how the motor is connected to a cell with an ammeter and voltmeter which could be used to determine the input power. The left-hand diagram is an arrangement of the apparatus which indicates the basic set up and included a foam box for the mass to fall into if the experiment does not work properly. This candidate has also underlined key words from the question.
			Total	**6**	

7
0
			Level 3 (5–6 marks)
			Clear explanation of terms **and** explanation of results correctly comparing momentum and kinetic energy.
			
			There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.
			
			Level 2 (3–4 marks)
			Clear explanation of terms **and** limited explanation of results comparing momentum
			
			or limited explanation of terms and some explanation of results
			
			or correct comparison of momentum and kinetic energy.
			
			There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.
			
			Level 1 (1–2 marks)
			Has limited explanation of terms **or** limited comparison of momentum / kinetic energy.
			
			The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.
				B1 × 6	**Indicative scientific points may include:**
					Explanation of terms
					
					• $p = mv$
					• $E_k = \frac{1}{2}mv^2$
					• Total momentum conserved in all collisions
					• Total energy conserved in all collisions
					• E_k conserved in elastic collision
					• E_k NOT conserved in inelastic collision
					• Speed of approach = speed of separation in elastic collision
					
					Explanation of results
					
					• Initial p_A= 15 kg cm s^{-1} or 0.15 kg m s^{-1}
					• Initial E_{kA} = 0.015 J
					• Expt 1:
					  ○ Speed of separation = 0.150 + 0.050 = 0.200 m s^{-1}
					  ○ p_A after collision = (-) 0.375 kg m s^{-1}
					  ○ p_B after collision = 0.1875 kg m s^{-1}
					  ○ Total p after collision = 0.15 kg m s^{-1}
					  ○ E_{kA} after collision = 0.0009375 J
					  ○ E_{kB} after collision = 0.0140625 J
					  ○ Total E_k after collision = 0.015 J
					  ○ Collision is elastic since E_k conserved
					• Expt 2:
					  ○ p after collision = 0.15 kg m s^{-1}
					  ○ E_k after collision = 0.005625 J
					  ○ Collison is inelastic since E_k not conserved
					• Momentum conserved in both collisions

			0 marks No response or no response worthy of credit.		
			Total	**6**	
7 1		i	$E = \frac{1}{2}kx^2$ **or** E = mgh **or** 0.080 ×9.81 × 0.20 **or** $\frac{1}{2} \times 60 \times x^2$ 0.080 ×9.81 × 0.20 = $\frac{1}{2} \times 60 \times x^2$ *x* = 0.072 (m)	C1 C1 A1	
		ii	Time of flight is independent of speed/AW **1** Because distance of fall is the same **and** initial velocity vertically is zero / velocity is horizontal at **X** *D* increases as speed at **X** increases **2** because the time of flight is constant/AW *D* is directly proportional to speed at **X**	B1 B1 M1 A1	**Allow** algebraic answers that assume initial vertical velocity is zero/velocity is horizontal at X. **Allow** d = vt idea "*D* is directly proportional to speed at **X** because the time of flight is constant" scores 2. **Examiner's Comments** This part showed that many candidates thought that the time of flight of the car depended on the take-off speed of the car. Since the car is travelling horizontally the time of flight only depends on the height of the car above the horizontal track.
			Total	**7**	
7 2		i	tension = 850 kg × 9.81 = 8300 N	B1	
		ii	work done = *mgh* = 850 × 9.81 × 12	C1	
		ii	work done = 100 kJ	C1	
		ii	output power = 100 × 10^3 / 40 (=2501 W)	C1	
		ii	input power (= 2501 / 0.6) = 4200 (W)	A1	
		iii	Suggestion to reduce heat losses through friction in moving parts e.g. oil, bearings	B1	
		iii	Use a stiffer / stronger cable to reduce energy loss through stretching	B1	
			Total	**7**	
7 3		i	*A* → m^2 <u>and</u> *ρ* → kg m^{-3} *P* → kg m^2 s^{-3}	**M1** **M1**	**Note:** No mark for *v* → m s^{-1} since units are in (a) **Allow** *P* → kg m s^{-2} m s^{-1} (from *P* = *Fv* or P=Work done/t) **Note:** clear working includes m^3s^{-3} seen.

			Clear working to show units are equivalent on either side of equation	A1	**Examiner's Comments** **Exemplar 5**  Candidates generally made an excellent attempt at this question, although for many the working was difficult to follow. In the exemplar, the candidate has made it very clear that they are considering the two sides of the equation separately and have reduced each unit to its S.I. base units as required by the question. The use of square brackets to distinguish between a quantity rather than a base unit was helpful.
		ii	$1.2 \times 10^6 = {}^1/_2 \times 1.3 \times A \times 8.0^3$ or $A = 3600$ (m^2) seen $L = 34$ (m)	C1 A1	**Allow** volume $s^{-1} = 28846$ (m^3) using 3.75×10^4 (kg s^{-1}) or 29231 (m^3) using 3.8×10^4 (kg s^{-1}) **Allow** ECF from (a) **Note:** 3.4×10^n (m) scores 1 for PoT error. **Examiner's Comments** About two thirds of candidates got full marks on this item. By substituting the values into the formula, the area required is approximately 3600 m^2. Some candidates did not read the question and instead of thinking about area swept out being a circle, they took it to be square, giving the length of the blade to be $\sqrt{3600} = 60$ m.
		iii	(output power =) 0.42 × 1.2 / 0.504 (MW) (N = 50/0.504 = 99.2) N = 100	C1 A1	**Allow:** 50×10^6 / 0.42 = 119 MW and then 119 / 1.2 **Not** 99 **Note:** answer of 99.2 scores 1 mark max **Examiner's Comments** Rather more candidates got this item right. Some candidates mis–converted the unit and got values that could not be right i.e. 1 or 10^6 yet the majority arrived at 99.2 and correctly stated that the minimum number of required turbines must be 100 and not 99.
			Total	**7**	

74		i	($F = ma$ =) $190 \times 10^3 = 2.1 \times 10^5$ a a = 0.90 (m s^{-2})	M1 A0	a = 0.905 to 3 SF
		ii	($v^2 = u^2 + 2as$ gives) 36 = 2 × 0.90 × s s = 20 (m)	C1 A1	**Allow** any valid suvat approach; **allow ECF** from (i) **Note** using a = 1 gives s = 18(m)
		iii	**1** $P = Fv$ One correct calculation e.g. F = 100 × 10^3 and v = 42 gives P = 4.2 ×10^6 (W) Fv = constant **2** (P = VI = 4.2MW so) 4.2 × 10^6 = 25 × 10^3 × I I = 170 (A)	B1 B1 B1 C1 A1	Equation must be seen (not inferred from working) **Allow** any corresponding values of F and v; working must be shown. No credit for finding area below curve **Allow** F is proportional to 1/v or graph is hyperbolic *or* correct calculation of Fv at <u>two</u> points (or more) **Allow** P = 4MW or **ECF from (iii)1** Expect answers between 160 - 170 (A)
			Total	**8**	
75		i	From t = 0 to t = 2.0 s: a non–zero horizontal line From t = 2.0 to t = 3.5 s: line showing v = 0 From t = 3.5 to t = 4.0 s: non–zero horizontal line showing v is <u>opposite</u> in direction <u>and</u> magnitude larger than that of line drawn at t = 0 to t = 2.0.	**B1** **B1** **B1**	Judgement by eye
		ii	KE is constant. GPE increases linearly / proportional to t	**B1** **B1**	**Allow:** 'at constant rate' for 'linear' Not: unqualified 'constantly' **<u>Examiner's Comments</u>** Nearly four fifths of candidates completed 20a well, especially if they clearly stated the equations for momentum and kinetic energy. Those that did not generally forgot that the question required an expression with 'p' and 'm' in it. $^1/_2$ pv was a common wrong answer. 20bi was answered well, with some candidates either slightly misreading the graph when the velocity became negative or not spotting that the line was steeper for the last section of the movement than it was in the first. Most candidates spotted that the KE was constant because the velocity was constant. Rather fewer candidates explained that the GPE increased *at a constant rate*.
		iii	$V^2 = 0.80^2 + 2 \times 9.81 \times 0.40$ V = 2.9 (m s^{-1})	**C1** **A1**	

					Allow 1 mark for $(2 \times 9.81 \times 0.40)^{1/2} = 2.8$ (m s^{-1}) **Examiner's Comments** Many candidates selected the correct equation, although did not realise that the load was not at rest when it was released. The initial velocity was found from the graph on page 22 of the paper and was 0.80 ms^{-1}.
		iv	$F = 0.12 \times 2.9/0.025$ $F = 14$ (N)	C1 A1	Possible ECF from **(iii)1** **Note:** use of 2.8 m s^{-1} gives F = 13(.44 N) **Note:** 1.4×10^{n} (N) scores 1 mark **Examiner's Comments** Nearly three quarters of the candidates used the correct method for finding the average force acting on the load by considering the rate of change of momentum.
			Total	**9**	
76		i	$\frac{61000}{3600} = 16.944$ 17 ms^{-1}	M1 A0	**Note** *v* must be the subject **Examiner's Comments** This question was the first 'show' question of the paper. It is important that candidates show clearly their working. In this case it was expected to see 61 multiplied by 1000 and divided by 3600. Most candidates came up with an answer of 16.9.
		ii	**1** $\frac{1}{2} \times 1.9 \times 10^5 \times 17^2$ $2.7(5) \times 10^7$(J) **2** $0 = 17^2 + 2a \times 310$ OR $\boldsymbol{t} = \frac{\mathbf{310}}{\mathbf{8.5}} = \mathbf{36.}$ $a = (-)\frac{17^2}{2 \times 310} = (-)\frac{289}{620}$ OR $\boldsymbol{a} = \frac{\mathbf{17}}{\mathbf{36.5}}$ 0.47 (m s^{-2}) **3** 3 $1.9 \times 10^5 \times 0.47$	C1 A1 C1 C1 A1 C1 A1	**Allow** use of 16.9 gives 2.7×10^7(J) **Allow** $v^2 = u^2 + 2as$ with values stated correctly **Ignore** negative sign **Allow** use of 16.9 gives 0.46 **Not** 0.5 **Allow** ECF from **(b) (ii) 1** and **(b) (ii) 2** **Allow** $\frac{2.7 \times 10^7}{310}$ **Allow** $1.9 \times 10^5 \times 0.46$ **Allow** $\frac{1.9 \times 10^5 \times 17}{36.5}$ **Allow** alternatives 87100, 87400, 88000 **Examiner's Comments** Most candidates were able to correctly write down the equation

			89000(N)		for kinetic energy and substitute the numbers into it. Where mistakes were made, it was normally with candidates not squaring the speed. It was hoped that candidates would use a speed of 17 m s^{-1} from the previous part. Good candidates clearly indicated which equation they were going to use and then clearly showed the substitution of the numbers, with the acceleration as the subject of the formula. Some candidates attempted to determine the time taken for the train to stop. Often when this method was attempted, candidates incorrectly assumed that the speed of 17 m s^{-1} was the average speed and not the initial speed. A few candidates round their answer inappropriately to one significant figure. Candidates answered this question in a number of different ways. The majority of the candidates substituted in their answer to the previous part into *F* = *m a.* Other candidates either used their answer for kinetic energy and the distance travelled or determined the time for the train to stop and used force equals the rate of change of momentum.
		iii	Component of train's <u>weight</u> acts against the motion / down the incline / same direction as braking force OR some KE transferred to GPE <u>Smaller distance</u> because larger opposing forces / net force or greater deceleration or less work done by braking force	**B1** **B1**	**Not** gravity will slow it down **Not** down, parallel **Examiner's Comments** Candidates found this question requiring an explanation tough. There were many vague answers referring to "gravity" as opposed to the "force due to gravity" or "weight". Candidates should be encouraged to use correct scientific terms. There was also occasional reference to "faster" deceleration. Some candidates correctly answer this question in terms of the kinetic energy being transferred to an increase in gravitational potential energy. Few candidates were precise in discussing the component of the weight parallel to the incline.
			Total	**10**	
77	a	i	Missing data point and error bar plotted correctly.	B1	**Allow** ½ square tolerance.

		ii	Force measured by pulling back plate with a newton−meter.	B1	
		ii	Extension measured with a ruler (placed close to the transparent plastic tube).	B1	
		iii	Best fit line drawn correctly and gradient determined correctly.	B1	**Ignore** POT for this mark; gradient = 50 ± 4 (N m^{-1})
		iii	Worst fit line drawn correctly and its gradient determined correctly.	B1	**Note**: The line must have a greater/smaller gradient than the best fit line and must pass through all the error bars. **Ignore** POT for this mark.
		iii	$2k$ = 50 (N m^{-1}), therefore k = 25 (N m^{-1})	B1	Possible ECF.
		iii	Absolute uncertainty determined correctly.	B1	Possible ECF within calculation.
		iv	$F \propto x$ / straight line passing through the origin.	B1	
		v	energy stored = ½ × 50 × 0.12^2	C1	Possible ECF from **(iii)**
		v	½ × 50 × 0.12^2 = ½ × 0.39 × v^2	C1	**Allow** 1 mark for v = 0.96 m s^{-1}; used k for single spring
		v	v = 1.4 (m s^{-1})	A1	
	b		force constant of spring arrangement) = $\frac{2k}{3}$ $\frac{2k}{3}x = ma$	M1	
			$a = \frac{2}{3 \times 0.39}kx$	M1	
			a = 1.7 kx	A0	
			Total	**13**	
78		i	$-mV_g = ½mv^2$ or $½mv^2 + mV_g = 0$	B1	
		i	$V_g = -GM/R = -gR$	B1	
		i	$v = \sqrt{(2gR)}$	B1	Working must be shown
		ii	$v = \sqrt{(2 \times 9.81 \times 6.4 \times 10^6)} = 11 \times 10^3$ m s^{-1}	B1	allow 11(.2) km s^{-1}
		iii	$½mc^2 = 3/2\ kT$ where $m = (M/N_A) = 6.6 \times 10^{-27}$ kg	B1	**ecf (ii); allow** m = 4u or 4 × 1.67 × 10^{-27}
		iii	$T = 6.6 \times 10^{-27} \times 121 \times 10^6 / 3 \times 1.38 \times 10^{-23}$	C1	
		iii	$T = 1.9 \times 10^4$ (K)	A1	**allow** 2 or 2.0
		iv	1 random motion and elastic collisions of particles	B1	**max** 4 out of 5 marking points where answer is a logical progression
		iv	2 lead to distribution of kinetic energies/velocities among particles	B1 B1	

		iv	3 a very few will have very high velocities at top end of distribution 4 a long way from mean /r.m.s. velocity at 300 K 5 hence some able to escape	B1	
		v	helium nucleus is an α-particle	B1	**max** 2 out of 3 marking points
		v	so helium is generated by radioactive decay helium is found in (natural gas) deposits underground	B1	
			Total	**13**	