

Mark scheme – Work, Energy and Power

Question			Answer/Indicative content	Marks	Guidance
1			work done = force $\times$ 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	

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1 0			power or P: $\text{kg m}^2 \text{s}^{-3}$	B1	power = force $\times$ distance / time = force $\times$ velocity
			Total	1	
1 1			D	1	
			Total	1	
1 2			B	1	
			Total	1	
1 3	a		GPE loss = $mgh = 0.60 \times 9.81 \times 0.050 = 0.29 \text{ J}$	A1	
	b		EPE = $\frac{1}{2} F \times = 0.50 \times 5.88 \times 0.05$ = 0.147 J (or $k = F / x = 5.88 / 0.050 = 118 \text{ N/m}$, EPE = $\frac{1}{2} k x^2 = \frac{1}{2} \times 118 \times 0.050^2$ = 0.147 J)	M1 A1	Allow answers to 2 s.f.
	c		GPE $\rightarrow$ EPE + KE (when falling) EPE $\rightarrow$ GPE + KE (when rising) Some energy dissipated as heat as oscillates (because of air resistance / friction)	B1 B1 B1	
			Total	6	
1 4			B	1	
			Total	1	
1 5			C	1	
			Total	1	
1 6			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 <i>K</i>. At maximum height, the ball just has horizontal component of velocity. The kinetic energy of the ball is proportional to speed². At the

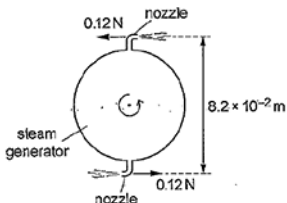
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				maximum height the kinetic energy must therefore be $\cos^2 30^\circ K = 0.75 K$.
			Total	1
1 7			C	1
			Total	1
1 8			C	1
			Total	1
1 9			(KE = $\frac{1}{2} \times 0.900 \times 2.0^2$) kinetic energy = 1.8 (J)	B1 Examiner's Comments Most of 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
2 0			A	1
			Total	1
2 1			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 $\times 9.81 \times 0.20 = \frac{1}{2} \times$ mass $\times v^2$. 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
2 2			A	1
			Total	1
2 3			C	1
			Total	1
2 4			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.

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				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 $P \propto v^{-1}$ $F \propto v^2$ $P = Fv$ B $P \propto v$ $F = kv^2$ $P = kv^3$ 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
2 5			D	1
			Total	1
2 6			c	1
			Total	1
2 7			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 = $2 \times$ work done by each force = $2 \times [0.12 \times \pi \times 8.2 \times 10^{-2}] = 6.2 \times 10^{-2} \text{ J}$ 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

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				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 $8.2 \times 10^{-2} \text{ m}$. What is the work done by the forces as the steam generator completes one revolution? A 0 J B $9.8 \times 10^{-3} \text{ J}$ C $3.1 \times 10^{-2} \text{ J}$ D $6.2 \times 10^{-2} \text{ J}$ Handwritten work: $W = F \cdot A$ $0.12 \times 8.2 \times 10^{-2} = 9.8 \times 10^{-3}$ 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 $9.8 \times 10^{-3} \text{ J}$ 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 $\times$ time = $2200 \times 4.0 \times 60$ energy = $5.3 \times 10^5 \text{ (J)}$	C1 A1	Note: Answer to 3 s.f. is $5.28 \times 10^5 \text{ (J)}$ 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 = $1200 \times 9.81 \times 0.02$ (= 235.4)	C1 A1	Note: Using $g = 10 \text{ N kg}^{-1}$ gives 75%: allow 1 mark max

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		efficiency = $235.4 / 320 \times 100$ efficiency = 74 %		Possible ECF from (a) Note: 0.74 scores 1 mark Allow 2 marks for using $235/320 \times 100 = 73\%$ Allow use of 9.8 N kg^{-1} gives 73.5% for 2 marks Allow 1 mark for 71%, force = $(1200g - 400) \text{ N}$ used Allow 1 mark for 76%, force = $(1200g + 400) \text{ N}$ 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		$1.2 \times 10^6 = \frac{1}{2} \times (\text{mass per second}) \times 8.0^2$ mass per s = $3.8 \times 10^4 \text{ (kg s}^{-1}\text{)}$	C1 A1	Answer is $3.75 \times 10^4 \text{ (kg s}^{-1}\text{)}$ to 3sf Note: $3.8 \times 10^4 \text{ (kg s}^{-1}\text{)}$ scores 1 for PoT error. Examiner's Comments A large majority of candidates got this right. Those that did not usually forgot to square the velocity.
		Total	2	
3 3		$3000 \times 9.8 \times 12 / 0.60$ = 588 kJ	C1 A1	
		Total	2	
3 4		$E_k = \frac{1}{2} mv^2$ <u>and</u> $p = mv$ (Correct manipulation leading to) $E_k = \frac{1}{2} p^2/m$	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	

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3 6	a	(change in) KE = (change in) GPE /AW $\frac{1}{2}(m + 0.8)v^2 = 0.6 mg$ (and hence equation as shown on	M1 A1	allow $mgh = \frac{1}{2}Mv^2$ as long as it is clear that m and M are different, i.e. NOT $mgh = \frac{1}{2}mv^2$ allow linear motion equation $v^2 = u^2 + 2as$ <u>and</u> $F = Ma$ ($W \Rightarrow mg = (m + 0.8)a$; $u = 0$ and $s = 0.6$) Examiner's Comments The challenge to candidates in answering this <i>show that</i> 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 $mgh = \pm \frac{1}{2}mv^2$ 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. $T = 0.800a$ $mg - T = ma$ $mg = a(m + 0.800) \Rightarrow a = \frac{mg}{m + 0.800}$ $s = 0.600$ $v = ?$ $a = ?$ $t = ?$ $v^2 = u^2 + 2as$ $v^2 = 2(0.6)$ $v^2 = \frac{1.2mg}{(0.800 + m)}$
	b i	($v^2 \Rightarrow$) 4.93 ($\pm$) 0.22	B1 B1	allow 4.9 ($\pm$) 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 $\pm \frac{1}{2}$ 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 $y = v^2$ <u>and</u> $x = m/(m + 0.800)$ so gradient $= 1.20g$ Examiner's Comments

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				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	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 $1.1(\text{m s}^{-2})$; allow ecf from gradient value Examiner's Comments 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	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 Examiner's Comments 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 The time taken to is increased.  so constant velocity V decreases  ECF $V^2 = \frac{m}{m+0.800} \cdot 1.20g$  ECF Gradient would be smaller, therefore, the value of g would be smaller.  ECF
			Total	15
3 7	a		(kinetic energy =) $1.6 \times 10^{-19} \times 300$	C1

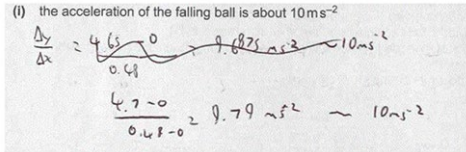
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			$eV = \frac{1}{2}mv^2$ $v = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 300}{9.11 \times 10^{-31}}}$ speed = 1.03×10^7 (m s⁻¹)	C1	
				C1	Note 1.05×10^{14} scores 2 marks; omitted square rooting
				A0	Examiner's Comments Good candidates clearly 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		$\lambda = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 1.0 \times 10^7}$ $\lambda = 7.3 \times 10^{-11}$ (m)	C1	Allow ECF from the previous question part
				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	
3 8	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	
			gradient = $(-)$ 30.4 or equivalent working	C1	Allow ± 2
		ii	candidate's gradient or expression = $6.67 \times 10^{-11} \times M$	C1	Possible ECF from incorrect gradient
		i	<u>and</u> M calculated correctly from that gradient		Allow any subject
			$M = 4.6 \times 10^{11}$ (kg)	A0	
	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

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		graph $\frac{1}{2} v^2 (= \Delta V_{(g)}) = 7.0 \times 10^{-2} - 5.1 \times 10^{-2}$ $v = 0.19 \text{ (m s}^{-1}\text{)}$	(C1) (A1)	
		Total	10	
3 9	a	energy input = $mc\Delta\theta = 0.327 \times 4200 \times 80 = 110 \text{ kJ}$	C1 M1	Allow 0.3 kg in the calculation
		energy input = power $\times$ 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	
4 0	a	Arrow vertical down <u>and</u> an arrow opposite to the frictional force.	M1	
		Both arrows labelled correctly.	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	$(W_s =) 1100 \times 9.81 \times \sin 10^\circ$ or $1100 \times 9.81 \times \cos 80^\circ$	C1	
		$(W_s = 1874 \text{ N or } 1900 \text{ N})$	A0	Allow g instead of value
	c	force = $1900 + 300$		
		force = 2200 (N)	A1	Allow $1870 + 300 = 2170 \text{ (N)}$
	d	(distance =) $120 / \sin 10^\circ$ or 691 (m)	C1	
		(work done =) 2200×691	C1	
		work done = $1.5 \times 10^6 \text{ (J)}$	A1	Allow ECF from (c) Allow ECF from an incorrect attempt at first mark.
	e	$(A =) \pi \times 0.006^2$ or $1.1 \times 10^{-4} \text{ (m}^2\text{)}$	C1	
		(stress =) $\frac{2200}{\pi \times 0.006^2}$ and $2.0 \times 10^{11} = \frac{\text{stress}}{\text{strain}}$	C1	Allow ECF from (c) Allow $x (=FL/EA) = \frac{2174 \times 0.5}{2.0 \times 10^{11} \times 1.1 \times 10^{-4}}$
		$x = 4.8 \times 10^{-5} \text{ (m)}$	A1	Allow 2 marks for 1.2×10^{-5} ; $1.2 \times 10^{-2} \text{ m}$ used as radius Allow answer between 4.7 and $5.1 \times 10^{-5} \text{ (m)}$
		Total	10	

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4 1	a i	$\frac{\Delta v}{\Delta t} \text{ and } \Delta t \geq 0.20 \text{ s}$ 9.8 m s^{-2}	Allow tolerance of $\pm\frac{1}{2}$ a small square e.g. $\frac{4.7(-0)}{0.48(-0)} = 9.79$ Examiner's Comments This question was a “show” type question. Candidates needed to show their working logically. Ideally candidates would state 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} This candidate has clearly demonstrated from $\Delta y / \Delta x$ 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 m s^{-2}. M1 A0  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: $\text{gradient} = \frac{y_2 - y_1}{x_2 - x_1}$ The advantage of this method, it that negative gradients are automatically determined.
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				 AfL The gradient of a velocity-time graph is acceleration.
		ii	4.7 or $\frac{1}{2} \times 0.057 \times v^2$ $\frac{1}{2} \times 0.057 \times 4.7^2 = 0.629565$ 0.63 J	Examiner's Comments 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 <u>0.63 J</u>. $v \sim 4.7 \text{ m s}^{-1}$ $KE = \frac{1}{2} (57 \times 10^{-3}) (4.7)^2$ $KE = \frac{1}{2} m v^2$ $= 0.62957$ <u>0.63 J</u> [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	$0.8 \times 0.63 \text{ J (0.504 J) OR } v^2 = \frac{2 \times KE}{0.057}$ $v^2 = \frac{2 \times 0.504}{0.057}$ 4.2(1) (ms^{-1})	Allow one mark for correct rearrangement of KE equation with incorrect KE 17.684 Examiner's Comments 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 $\pm \frac{1}{2}$ small square x-axis intercept at $t = 0.91 \pm 0.03 \text{ (s)}$ from negative v	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 Examiner's Comments 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

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				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.
		area under the graph = $\frac{1}{2} \times 4.2 \times 0.43$ 0.90 (m)	ii i 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 $s = (-4.2 \times 0.43) + \frac{1}{2} \times 9.81 \times 0.43^2$ (numbers must be seen) Allow use of loss of KE = gain in PE Allow one significant figure Note 0.84 for $\Delta t = 0.40$ to 0.97 for $\Delta t = 0.46$ <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)

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					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	
4 2	a	i	1. <i>either</i> resultant force $F = ma - R$ or resultant force decreases as R increases	B1	allow for points 2 and 3 <i>when</i> $F = R$ 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 $40/120 = 0.33 \text{ (m s}^{-2}\text{)}$	B1	
		ii	2 from the graph $Rv = 200 \text{ (W)}$ so $R = 40 \text{ N}$	C1	or forward force = 40 N so $R = 40 \text{ N}$ for constant
		ii	and terminal velocity v is $5 \text{ (m s}^{-1}\text{)}$	A1	speed / zero acceleration
	b		p.e. / second = $mgv \sin \theta = 120 \times 9.81 \times 5 \times \sin \theta$	C1	allow force downhill $F = mg \sin \theta$, extra power = Fv
			extra power = 200 (W)	C1	
			so $\sin \theta = 1/29.4$ giving $x = 29 \text{ m}$	A1	
			Total	9	
4 3		i	$\left(\frac{1200}{300}\right)$ 4.0	B1	Allow 1 SF
		ii	$180 = \frac{\rho \times 25}{6.7 \times 10^{-8}}$ $\rho = 4.8 \times 10^{-7} \text{ (}\Omega \text{ m)}$	C1 A1	Note answer is 4.82×10^{-7} to 3 SF
			Total	3	
4 4	a	i	There is friction. GPE is transferred to KE and heat or thermal (energy).	B1	
		ii	work done = $(0.50 - 0.36) \text{ (J)}$ or work done = 0.14 (J)	C1	
		ii	$F \times 0.90 = 0.14$, 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	

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			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 $KE = \frac{1}{2} \times \text{mass} \times \text{speed}^2$.	B1	
			Total	6	
4 5			(k.e. =) $E = 5.0 \times 10^6 \times 1.6 \times 10^{-19}$ $v = \sqrt{(2E/m)}$ or $= \sqrt{(2 \times 8.0 \times 10^{-13} / 6.6 \times 10^{-27})} = 1.6 \times 10^7 \text{ (ms}^{-1}\text{)}$ $p (= mv) = 6.6 \times 10^{-27} \times 1.6 \times 10^7$ giving $p = 1.1 \times 10^{-19} \text{ (kg m s}^{-1}\text{)}$	C1 C1 A1	$E = 8(.0) \times 10^{-13} \text{ J}$ or $(E = p^2/2m \text{ so } p = \sqrt{(2mE)})$ Note: A value of $v = 1.6 \times 10^7 \text{ (ms}^{-1}\text{)}$ automatically scores both C1 marks even if the calculation for E is not shown or $p (= \sqrt{(2mE)}) = \sqrt{(2 \times 6.6 \times 10^{-27} \times 8.0 \times 10^{-13})}$ giving $p = 1.0 \times 10^{-19} \text{ (kg m s}^{-1}\text{)}$ 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	
4 6		i	$(E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 0.16 \times 30.7^2)$ $E_k = 75 \text{ (J)}$	B1	Possible ECF from (iii) Examiner's Comments This was generally well answered.
		ii	$(E_p = mgh = 0.16 \times 9.81 \times 2.0 =) 3.1 \text{ (J)}$	B1	Allow $(E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 0.16 \times 6.3^2) = 3.2 \text{ (J)}$ Examiner's Comments Most candidates correctly calculated the gravitational potential energy although some weaker candidates used the answer from (i).
		ii i	(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

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					Candidates either used the kinetic energy equation or subtracted the change in gravitational potential energy from 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	
4 7	a				
				C1	
				C1	
				A1	Allow 1 mark for 6.8 (m s ⁻¹); + 420 used instead of – 420
				C1	Allow full credit for correct use of ‘velocity of approach = –velocity of recession’, e.g:
				C1	‘speed’ of approach = (–) ‘speed’ of recession C1 500 = v + 420 C1 v = 80 (m s ⁻¹) A1
					Examiner's Comments
				A1	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 <i>energy</i> and <i>velocity</i> .
		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

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					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 adequately describe or explain the force on the asteroid. There were vague answers such as <i>'The force goes up proportionally and then decreases exponentially'</i> . Some answers also focused unnecessarily on the transfer of momentum or kinetic energy but it was often the succinct answers such as <i>'The force on the asteroid is equal in magnitude but in opposite direction to the force F; NIII law'</i> that scored full marks.
			Total	6	
4 8	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 $\propto$ frequency / photon energy $\propto 1/\lambda$ 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 $\geq$ 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 <i>number of photons</i> ' or 'the <i>amount of electrons emitted</i> '. The important term rate of the missing ingredient. Top-end candidates gave eloquent answers, typified by the response: <i>'intensity of visible light only affects the rate of photons incident on the plate but not the energy of each photon'</i> . Two common misconceptions were: - Photons were emitted from the negative plate. - Confusing threshold frequency and work function energy.
	b		$\phi = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{2.9 \times 10^{-7}} \text{ or } 6.86 \times 10^{-19} \text{ (J)}$ $E_{19} = 5.1 \times 1.60 \times 10^{-19} \text{ or } 8.16 \times 10^{-19} \text{ (J)}$	C1 C1	Note: Using 5.1 and not 8.16×10^{-19} cannot score this mark or the next mark

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			max kinetic energy = $(8.16 - 6.86) \times 10^{-19}$ 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 <i>V</i> increases the slow(er) electrons do not reach C and hence / decreases maximum KE in the range 2.1 eV to 2.2 eV or 3.36×10^{-19} J to 3.52×10^{-19} J	B1×3	Note 'range' can be implied by 'highest' or 'lowest' Allow 'find p.d. when current is (just) zero, and then $KE = e \times V$ 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 '<i>the electrons repelled by C</i>' 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 '<i>the current drops because resistance increases</i>' and '<i>temperature increases and hence the current decreases</i>'.
			Total	10	
49	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 $2.5/3.0 \approx 2.1/2.5 \approx \text{constant}$.'
	ii		At time $t = 0$	M1	
	ii		Oscillator has maximum speed and hence the greatest friction. (AW)	A1	
			Total	4	
50	i		$Q = 9.0 \times 10^{-3} \times 2 \times 80 = 1.44$ (C) $W = (Q^2/2C) = 1.44^2/2 \times 0.12$ $W = 8.6(4)$ (J)	C1 C1 A1	ECF for incorrect <i>Q</i> e.g. 2/3 for use of $Q = 0.72$(C) giving $W = 2.2$(J) Examiner's Comments 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

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				candidates performed the steps of their calculation randomly across the answer space, making it hard to determine their method.
		ii	$(W = Pt \text{ so } 8.6 = 0.050t)$ $t = 8.6/0.050 = 170 \text{ (s)}$	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 <u>wavelengths</u> (for constructive interference) At point Q: path difference between slits and screen is an <u>odd number of half wavelengths</u> (for destructive interference)	Allow $n\lambda$ or λ Not phase difference Allow $(n + \frac{1}{2})\lambda$ Not $\lambda/2$ 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 $n\lambda$. 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	$x = 4.22 \text{ mm}$ 1 $\lambda = \frac{4.22 \times 10^{-3} \times 0.56 \times 10^{-3}}{5.25 \times 10^{-7} \text{ m}}$ $\frac{0.02}{4.5} \quad \text{or} \quad \frac{0.02}{0.56} \quad \text{or} \quad \frac{0.2}{42.2}$ $\left(\frac{0.02}{4.5} + \frac{0.02}{0.56} + \frac{0.2}{42.2}\right) \times 100 = 4.48 \%$ Alternative max / min method: 2 $\lambda_{\max} = \frac{4.24 \times 10^{-3} \times 0.58 \times 10^{-3}}{4.48} = 5.49 \times 10^{-7} \text{ m}$ and/or $\lambda_{\min} = \frac{4.20 \times 10^{-3} \times 0.54 \times 10^{-3}}{4.52} = 5.02 \times 10^{-7} \text{ m}$ $\frac{\Delta\lambda}{\lambda} \times 100 = 4.4\% \text{ or } 4.6\%$	Note $x = 42.2 \text{ mm}$ or $4.2 \times 10^{-2} \text{ m}$ scores zero Note $x = 3.84, 4.77 \times 10^{-7} \text{ m}$ may score max 2 C1 C1 Allow 4% or 5% with evidence of working Ignore significant figures A1 C1 A1 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

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					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	$\frac{6.63 \times 10^{-34} \times 3 \times 10^8}{5.25 \times 10^{-7}} = \frac{1.989 \times 10^{-25}}{5 \text{ b ii } 1} = 3.79 \times 10^{-19}$ $n = \frac{50 \times 10^{-3}}{3.79 \times 10^{-19}} = 2.5 \times 10^{23} \times 5 \text{ b ii } 1 = 1.3 \times 10^{24}$	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	
5 2		i	$E = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{380 \times 10^{-9}} \quad \text{or} \quad \phi = 1.1 \times 1.6 \times 10^{-19}$	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	
5 3		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	
			Total	4	

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5 4	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 = $500/3.5 = 143 \text{ ms}$	C1	
		i Acceleration = $\omega^2 A = (2\pi/0.143)^2 \times 0.006 = 12 \text{ (ms}^{-2}\text{)}$	A1	
		ii $\text{KE} = 0.5 \times 0.005 \times (2\pi / 0.143 \times 0.006)^2$	C1	
		ii $\text{KE} = 1.7 \times 10^{-4} \text{ (J)}$	A1	
		Total	6	
5 5	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 = $1500 \times 1.6 \times 10^{-19} \times 1.2 \times 10^{-2} = 2.88 \times 10^{-18} \text{ (J)}$	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 = $4.3 \times 10^6 \text{ (m s}^{-1}\text{)}$	A1	
		Total	5	
5 6	i	(surface area =) $4\pi \times (1.4 \times 10^9)^2$ or $2.46 \times 10^{19} \text{ (m}^2\text{)}$ (intensity = $\frac{P}{4\pi r^2}$) intensity = $\frac{2.7 \times 10^{27}}{4\pi \times (1.4 \times 10^9)^2}$ intensity = $1.1 \times 10^8 \text{ (W m}^{-2}\text{)}$	C1 C1 A0	Allow $2.5 \times 10^{19} \text{ (m}^2\text{)}$ 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 $1.4 \times 10^9 \text{ m}$. 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	$E = \frac{3.00 \times 10^8 \times 6.63 \times 10^{-34}}{5.0 \times 10^{-7}}$ $E = 4.0 \times 10^{-19} \text{ (J)}$	C1 A1	Note: Answer to 3 SF is $3.98 \times 10^{-19} \text{ (J)}$ Allow $4 \times 10^{-19} \text{ (J)}$ 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 $4.0 \times 10^{-19} \text{ J}$, as in the general rule with such answers, $4 \times 10^{-19} \text{ J}$ was acceptable without any significant figure penalty.

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			ii i (number per second = $\frac{2.7 \times 10^{27}}{4.0 \times 10^{-19}}$) number per second = $6.8 \times 10^{45} \text{ (s}^{-1}\text{)}$		Possible ECF from (b)(ii) <u>Examiner's Comments</u> B1 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	
5		i	$250 \times 60 = 15000 \text{ J}$	C1	
7		i	energy = $\frac{15000}{0.65} = 2.3 \times 10^4 \text{ (J)}$	A1	
		ii	drag force = $0.4 \times 6.0^2 = 14.4 \text{ N}$	C1	
		ii	forward force = power / velocity = $250/6.0 = 41.7 \text{ N}$	C1	
		ii	acceleration = $\frac{41.7 - 14.4}{85} = 0.32 \text{ m s}^{-2}$	A1	
			Total	5	
5					Note using $KE = 210 \text{ (J)}$ is wrong physics XP Note the answer must be to more than 1 SF
8		i	$(KE =) 210 \times 1.60 \times 10^{-19} \text{ (J) or } 3.36 \times 10^{-17} \text{ (J)}$ $\frac{1}{2} \times 9.11 \times 10^{-31} \times v^2 = 3.36 \times 10^{-17}$ $v = 8.6 \times 10^6 \text{ (ms}^{-1}\text{)}$	C1 C1 A1	<u>Examiner's Comments</u> 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 $8.6 \times 10^6 \text{ m s}^{-1}$. The exemplar 11 below shows a model response from a top-end candidate. Exemplar 11

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				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 $9 \times 10^6 \text{ ms}^{-1}$. maximum kinetic energy, 210 eV $= 210 \times 1.6 \times 10^{-19}$ $= 3.36 \times 10^{-17} \text{ J}$ $\frac{1}{2}mv^2 = 3.36 \times 10^{-17}$ $v^2 = \frac{3.36 \times 10^{-17} \times 2}{9.11 \times 10^{-31}}$ $= \frac{7.3765 \times 10^{13}}{9.11 \times 10^{-31}}$ $v = \sqrt{7.3765 \times 10^{13}} = 8.59 \times 10^6$ $\approx 9 \times 10^6 \text{ m s}^{-1} \text{ (1 s.f.)}$ [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 $8.6 \times 10^6 \text{ ms}^{-1}$. It is good to report that very few candidates used 210 J to get the impossible response of $2.1 \times 10^{16} \text{ ms}^{-1}$.
	ii	$\lambda = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 8.6 \times 10^6}$ $\lambda = 8.5 \times 10^{-11} \text{ (m)}$	C1 A1	Possible ECF from (i) Allow 2 marks for $8.1 \times 10^{-11} \text{ (m)}$; $v = 9 \times 10^6 \text{ ms}^{-1}$ used <u>Examiner's Comments</u> The majority of the candidates effortlessly used the de Broglie equation and their answer from (b)(i), or $9 \times 10^6 \text{ m s}^{-1}$, to calculate the wavelength λ of the electron. Misconception The two common mistakes being made here were: - Using $3.0 \times 10^8 \text{ m s}^{-1}$ for the speed instead of $8.6 \times 10^6 \text{ m s}^{-1}$. - Using the energy of the photon equation $E = \frac{hc}{\lambda}$ instead of $\lambda = \frac{h}{mv}$.
		Total	5	
5 9	i	$F = GMm/r^2 = mv^2/r$	C1	where $r = 6.8 \times 10^6 \text{ m}$
	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	$v = 7.7 \text{ (km s}^{-1}\text{)}.$	A1	<i>show that Q</i>
	ii	total energy = $\frac{1}{2}mv^2 - GMm/r = -GMm/2r$	M1	no ecf from (i); allow numerical values
	ii	$E = -gR^2m/2r = -1.2(4) \times 10^{13} \text{ (J)}$	A1	with no algebra if clear no mark for correct value without the minus sign
		Total	5	
6 0		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.

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		procedure and analysis <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is clear, relevant and substantiated.</i> 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 <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 – 2 marks) A limited selection from the scientific points worthy of credit. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant. 0 marks</i> No response or no response worthy of credit	Candidates can gain full credit for investigating the efficiency of either: Method 1(M1): GPE ($nmg h$) to energy conversion in LED (Pt) or Method 2(M2): GPE ($nmg h$) to energy stored in capacitor ($\frac{1}{2}CV^2$ or $\frac{1}{2}Q^2/C$) <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 =) $nmg h$ 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 $P = 50 \text{ mW}$ - M2 calculate $W = \frac{1}{2}CV^2$ or $\frac{1}{2}Q^2/C$ - calculate efficiency = $W/nmg h$ - compare efficiency values for different n - plot suitable graph e.g. efficiency against n / W against $nmg h$ - 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
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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 ($\frac{1}{2}CV^2$ or $\frac{1}{2}Q^2/C$)

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 mass balance and use the formula $E = mgh$ to find the gravitational potential energy. Make a circuit across the capacitor with a reflector and data logger to for different intervals of number of turns, 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 $\frac{\text{output}}{\text{input}} \times 100$ 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 conversion is proportional to 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.

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			Total	6	
6 1	a		Level 3 (5–6 marks) Clear description and analysis. <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 (3–4 marks) Some description and some analysis. <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 (1–2 marks) Limited description and limited analysis or limited description 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 (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 how it can be analysed.

As in a projectile the horizontal velocity is constant given is negligible then a equation of could become $x = vt$ where x is travelled i.e. is velocity of ball and time of flight. Therefore for a of flight it can be said x it. 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, so be calculated using distance time.

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				light gate. For safety the ball land in sand as not to shatter land on someone's foot. This also measuring x much easier as equal to the horizontal distance from edge of the table to the end sand measured using a ruler. If taken to fall is kept constant by using a stop watch and by raising or lowering the point where v is plotted x on a graph it can be to be linear and pass through 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 = $30.0 \sin(70^\circ)$ or $30.0 \cos(20^\circ)$ vertical component = $28.2 \text{ (m s}^{-1}\text{)}$	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 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 $(30 \sin(70^\circ))^2 / (2 \times 9.81)$ M1 No ECF from (a)(i) for the second mark A0

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			$h = 40.5 \text{ (m)}$		
		ii i	The ball has horizontal motion / velocity (AW)	B1	Allow idea of horizontal e.g. sideways, forwards Not: 'moving' unqualified
		i v	(horizontal velocity =) $30.0 \cos 70^\circ$ or $10.2\dots \text{ (m s}^{-1}\text{)}$ or $30.0 \sin 20^\circ$. $E_k = \frac{1}{2} \times 0.057 \times 10.26^2$ $E_k = 3.0\text{(J)}$	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 <i>show</i> 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	
6 2		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	$(E_{\text{heater}} =) 200 \times 10 \times 60$ or 120000 (J)	C1 C1	

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			$(E_{\text{water}} =) 0.5 \times 4200 \times 40 \quad \text{or} \quad 84000 \text{ (J)}$ $(\text{energy transferred} = 120000 - 84000)$ $\text{energy transferred} = 3.6 \times 10^4 \text{ (J)}$	A1	
			Total	6	
6	i		$4.1 \text{ eV} = 4.1 \times 1.6 \times 10^{-19} \text{ or } 6.56 \times 10^{-19} \text{ J OR}$ $E_k = 6.63 \times 10^{-34} \times 1.2 \times 10^{15} - \phi$ $E_k = 6.63 \times 10^{-34} \times 1.2 \times 10^{15} - 6.56 \times 10^{-19}$ $E_k = 1.39 \times 10^{-19} \text{ J}$ $v = \sqrt{\frac{2 \times 1.39 \times 10^{-19}}{9.11 \times 10^{-31}}} = \sqrt{3.06 \times 10^{11}}$ $5.536 \times 10^5 \text{ m s}^{-1}$	C1 C1 C1 C1 A0	Allow $f_0 = 9.9 \times 10^{14} \text{ Hz}$ Allow $E_k = 6.63 \times 10^{-34} \times (1.2 \times 10^{15} - 9.9 \times 10^{14})$ Allow $1.4 \times 10^{-19} \text{ J}$ Examiner's Comments 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 $5.536 \times 10^5 \text{ (m s}^{-1}\text{)}$ for full credit so that it was clear that candidates had correctly calculated the powers of ten. Exemplar 9 is $5.5 \times 10^5 \text{ ms}^{-1}$. $hf = 6.63 \times 10^{-34} \times 1.2 \times 10^{15} = 7.956 \times 10^{-19} \text{ J}$ $4.1 \text{ eV} = 6.56 \times 10^{-19} \text{ J}$ $hf - \phi = KE_{\text{max}} = 7.95 \times 10^{-19} - 6.56 \times 10^{-19} = 1.39$ $\frac{1}{2} m v^2 = 1.39 \times 10^{-19} = KE$ $\sqrt{\frac{2KE}{m}} = v = \sqrt{\frac{2 \times 1.39 \times 10^{-19}}{9.1 \times 10^{-31}}} = 5.527 \times 10^5$ $\approx 5.5 \times 10^5 \text{ (2sf)}$ 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

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				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 $5.5 \times 10^5 \text{ (ms}^{-1}\text{)}$. 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 Not "Does not increase" Examiner's Comments A1 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	$\epsilon = eV = 12 \times 1.6 \times 10^{-19} = 1.92 \times 10^{-18} \text{ (J)}$	B1	
	i	$\frac{1}{2}mv^2 = 1.92 \times 10^{-18}$	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	$v = 2.05 \times 10^6 \text{ (m s}^{-1}\text{)}$	A1	
	ii	accelerates from 0 to v so use $v / 2$	C1	ecf (i)
	ii	$t = 5 \times 10^{-3} / 1 \times 10^6 = 5 \times 10^{-9} \text{ (s)}$	A1	Allow 1 mark for $2.5 \times 10^{-9}\text{s}$
			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. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i>	B1 ×6	Indicative scientific points may include: Description of pattern changes • Rings become closer (not just smaller) • Rings become brighter Qualitative explanation of pattern changes in terms of de Broglie wavelength and potential difference

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	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. <i>There is a line of reasoning presented with some structure.</i> <i>The information presented is in the most-part relevant and supported by some evidence.</i> 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. <i>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.</i> 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 $eV = \frac{1}{2}mv^2$ $p = mv$ $v^2 \propto V$ or $p^2 \propto V$ $\lambda = \frac{h}{p}$ or $\lambda \propto \frac{1}{v}$ $\lambda = \frac{h}{\sqrt{2meV}}$ or $\lambda \propto \frac{1}{\sqrt{V}}$ Examiner's Comments 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
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					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	
6	a	i	t = 0 to 1.5 s, constant force (of 30 N) causes constant acceleration	B1	or reference to N2
6		i	t = 1.5 to 4.0 s zero (resultant) force so constant speed	B1	or reference to N1
		ii	acceleration = $30/65 = 0.46 \text{ (m s}^{-2}\text{)}$	M1	
		ii	speed v at 1.5 s = $at = 0.46 \times 1.5 = 0.69 \text{ (m s}^{-1}\text{)}$	A1	ecf acceleration value
		ii	distance = $\frac{1}{2}at^2 + vt = 0.23 \times 1.5^2 + 0.69 \times 2.5$	C1	ecf acceleration and speed values
		ii	s = 2.24 m	A1	
	b		power lost in circuit = $30^2 \times 0.11$ = 99(W)	C1	Apply ecf rule as appropriate
			mechanical power = $640 \times 0.70 = 448 \text{ (W)}$	C1	
			electrical power input = $28 \times 30 = 840 \text{ (W)}$	C1	allow 3 marks for 53%
			input power to motor = 741 (W)	C1	
			efficiency = $448 / 741 = 0.60$ or 60%	A1	
			Total	12	
6			Level 3 (5–6 marks) Clear description and correct calculations leading to value of total energy (must include the negative sign) <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 (3–4 marks) Some description and some correct calculations or Correct calculations (including the negative sign) <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>	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 $E = (-)\frac{GMm}{r}$ $E = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 2500}{4.22 \times 10^7}$ = $(-)\frac{2.4 \times 10^{10} \text{ J}}{2\pi r}$ $V = \frac{2\pi}{T} \omega r$ $V = \frac{2\pi \times 4.22 \times 10^7}{24 \times 3600} = 3.07 \times 10^3 \text{ m s}^{-1}$ $E = \frac{1}{2}mv^2$ $E = \frac{1}{2} \times 2500 \times [3.07 \times 10^3]^2 = 1.2 \times 10^{10} \text{ J}$

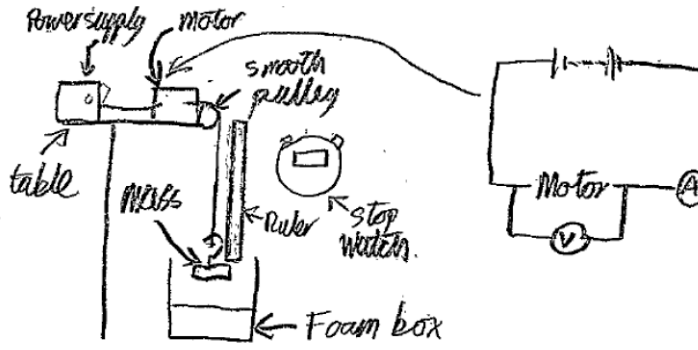
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		Level 1 (1–2 marks) Limited description or Limited calculations <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.		- Total energy = $-2.4 \times 10^{10} + 1.2 \times 10^{10} = -1.2 \times 10^{10} \text{ J}$ - 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 Examiner's Comments 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 = $(-)\frac{GMm}{r}$ GPE = $(-)\frac{6.67 \times 10^{-11} \times 2 \times 10^{30} \times 810}{1.5 \times 10^{11}}$ GPE = $(-)\frac{7.2 \times 10^{11}}{1}$ (J)	C1 C1 A0	Mark is for full substitution, including 6.67×10^{-11} for G
	ii	$v = 2\pi r/T = 2\pi \times 1.5 \times 10^{11} / 3.16 \times 10^7 (= 29.8 \text{ km s}^{-1})$ KE = $\frac{1}{2}mv^2 = 0.5 \times 810 \times (29.8 \times 10^3)^2$ 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 = $\frac{1}{2}mv^2/(GMm/r) = \frac{1}{2}$
	ii i	total energy = $(-)(7.2 \times 10^{11} - 3.6 \times 10^{11})$ total energy = $(-)\frac{3.6 \times 10^{11}}{1}$ (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 <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 (3–4 marks) A diagram, some procedure, some measurements and some analysis. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by</i>	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

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	<i>some evidence.</i> Level 1 (1–2 marks) Limited procedure and limited measurements 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.	• 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 indicating 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
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				 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	
70		Level 3 (5–6 marks) Clear explanation of terms and explanation of results correctly comparing momentum and kinetic energy. <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 (3–4 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. <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 (1–2 marks) Has limited explanation of terms or limited comparison of momentum / kinetic energy. <i>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.</i>	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 $p_A = 15 \text{ kg cm s}^{-1}$ or 0.15 kg m s^{-1} • Initial $E_{kA} = 0.015 \text{ J}$ • Expt 1: ○ Speed of separation = $0.150 + 0.050 = 0.200 \text{ m s}^{-1}$ ○ p_A after collision = $(-) 0.375 \text{ kg m s}^{-1}$ ○ p_B after collision = $0.1875 \text{ kg m s}^{-1}$ ○ 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 ○ Collision is inelastic since E_k not conserved • Momentum conserved in both collisions

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			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 $0.080 \times 9.81 \times 0.20$ or $\frac{1}{2} \times 60 \times x^2$ $0.080 \times 9.81 \times 0.20 = \frac{1}{2} \times 60 \times x^2$ $x = 0.072 \text{ (m)}$	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 <i>D</i> increases as speed at X increases because the time of flight is constant/AW 2 <i>D</i> 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 "<i>D</i> 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 = $850 \text{ kg} \times 9.81 = 8300 \text{ N}$	B1	
		ii	work done = $mgh = 850 \times 9.81 \times 12$	C1	
		ii	work done = 100 kJ	C1	
		ii	output power = $100 \times 10^3 / 40 (=2501 \text{ W})$	C1	
		ii	input power (= $2501 / 0.6$) = 4200 (W)	A1	
		ii	Suggestion to reduce heat losses through	B1	
		i	friction in moving parts e.g. oil, bearings		
		ii	Use a stiffer / stronger cable to reduce	B1	
		i	energy loss through stretching		
			Total	7	
7 3		i	$A \rightarrow \text{m}^2$ and $\rho \rightarrow \text{kg m}^{-3}$ $P \rightarrow \text{kg m}^2 \text{ s}^{-3}$	M1 M1	Note: No mark for $v \rightarrow \text{m s}^{-1}$ since units are in (a) Allow $P \rightarrow \text{kg m s}^{-2} \text{ m s}^{-1}$ (from $P = Fv$ or $P = \text{Work done}/t$) Note: clear working includes m^3s^{-3} seen.

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		Clear working to show units are equivalent on either side of equation	A1 <u>Examiner's Comments</u> Exemplar 5 $\begin{aligned} \left[\frac{1}{2}\rho A v^3\right] &= (\text{kg m}^{-3})(\text{m}^2)(\text{ms}^{-1})^3 \\ &= \text{kg m}^{-3} \text{m}^2 \text{m}^3 \text{s}^{-3} \\ &= \text{kg m}^2 \text{s}^{-3} \end{aligned}$ ✓✓ $[P] = \text{J s}^{-1}$ $= \text{N ms}^{-1}$ $= \text{kg ms}^{-2}$ $= \text{kg m}^2 \text{s}^{-3}$ ✓ $\therefore \left[\frac{1}{2}\rho A v^3\right] = [P]$ $\therefore$ The equation is homogenous 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	$1.2 \times 10^6 = \frac{1}{2} \times 1.3 \times A \times 8.03$ or $A = 3600$ (m ²) seen $L = 34$ (m)	C1 Allow volume s⁻¹ = 28846 (m³) using 3.75×10^4 (kg s⁻¹) or 29231 (m³) using 3.8×10^4 (kg s⁻¹) Allow ECF from (a) Note: 3.4×10^n (m) scores 1 for PoT error. <u>Examiner's Comments</u> About two thirds of candidates got full marks on this item. By substituting the values into the formula, the area required is approximately 3600 m². 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. A1
	ii i	(output power =) $0.42 \times 1.2 / 0.504$ (MW) ($N = 50/0.504 = 99.2$) $N = 100$	C1 Not 99 Note: answer of 99.2 scores 1 mark max <u>Examiner's Comments</u> A1 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

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7 4	i	$(F = ma \Rightarrow) 190 \times 10^3 = 2.1 \times 10^5 a$ $a = 0.90 \text{ (m s}^{-2}\text{)}$	M1 A0	$a = 0.905$ to 3 SF
	ii	$(v^2 = u^2 + 2as \text{ gives}) 36 = 2 \times 0.90 \times s$ $s = 20 \text{ (m)}$	C1 A1	Allow any valid suvat approach; allow ECF from (i) Note using $a = 1$ gives $s = 18\text{(m)}$
	ii i	1 $P = Fv$ One correct calculation e.g. $F = 100 \times 10^3$ and $v = 42$ gives $P = 4.2 \times 10^6 \text{ (W)}$ 2 $Fv = \text{constant}$ $(P = VI = 4.2\text{MW so}) 4.2 \times 10^6 = 25 \times 10^3 \times I$ $I = 170 \text{ (A)}$	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 $P = 4\text{MW}$ or ECF from (iii)1 Expect answers between 160 - 170 (A)
		Total	8	
7 5	i	From $t = 0$ to $t = 2.0 \text{ s}$: a non-zero horizontal line From $t = 2.0$ to $t = 3.5 \text{ s}$: line showing $v = 0$ From $t = 3.5$ to $t = 4.0 \text{ s}$: 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' Examiner's Comments 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. $\frac{1}{2}pv$ 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 <i>at a constant rate</i> .
	ii i	$V^2 = 0.80^2 + 2 \times 9.81 \times 0.40$ $V = 2.9 \text{ (m s}^{-1}\text{)}$	C1 A1	

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				Allow 1 mark for $(2 \times 9.81 \times 0.40)^{1/2} = 2.8 \text{ (m s}^{-1}\text{)}$ 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}.
		i v	$F = 0.12 \times 2.9/0.025$ $F = 14 \text{ (N)}$	Possible ECF from (iii) 1 Note: use of 2.8 m s^{-1} gives $F = 13(.44 \text{ N})$ Note: $1.4 \times 10^n \text{ (N)}$ 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
7 6		i	$\frac{61000}{3600} = 16.944$ 17 ms^{-1}	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 $\frac{1}{2} \times 1.9 \times 10^5 \times 17^2$ $2.7(5) \times 10^7 \text{ (J)}$ 2 $0 = 17^2 + 2a \times 310$ OR $t = \frac{310}{8.5} = 36.$ $a = (-) \frac{17^2}{2 \times 310} = (-) \frac{289}{620}$ OR $a = \frac{17}{36.5}$ $0.47 \text{ (ms}^{-2}\text{)}$ 3 $3 \times 1.9 \times 10^5 \times 0.47$	C1 Allow use of 16.9 gives $2.7 \times 10^7 \text{ (J)}$ A1 C1 Allow $v^2 = u^2 + 2as$ with values stated correctly C1 Ignore negative sign A1 Allow use of 16.9 gives 0.46 Not 0.5 Allow ECF from (b) (ii) 1 and (b) (ii) 2 C1 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

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			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.
		ii i	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 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	
7 7	a	i	Missing data point and error bar plotted correctly.	B1	Allow $\frac{1}{2}$ square tolerance.

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	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	
	ii i	Best fit line drawn correctly and gradient determined correctly.	B1	Ignore POT for this mark; gradient = $50 \pm 4 \text{ (N m}^{-1}\text{)}$
	ii i	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.
	ii i	$2k = 50 \text{ (N m}^{-1}\text{)}, \text{ therefore } k = 25 \text{ (N m}^{-1}\text{)}$	B1	Possible ECF.
	ii i	Absolute uncertainty determined correctly.	B1	Possible ECF within calculation.
	i v	$F \propto x$ / straight line passing through the origin.	B1	
	v	energy stored = $\frac{1}{2} \times 50 \times 0.12^2$	C1	Possible ECF from (iii)
	v	$\frac{1}{2} \times 50 \times 0.12^2 = \frac{1}{2} \times 0.39 \times v^2$	C1	Allow 1 mark for $v = 0.96 \text{ m s}^{-1}$; used k for single spring
	v	$v = 1.4 \text{ (m s}^{-1}\text{)}$	A1	
	b	force constant of spring arrangement) = $\frac{2k}{3}$	M1	
		$\frac{2k}{3}x = ma$	M1	
		$a = \frac{2}{3 \times 0.39}kx$	A0	
		$a = 1.7 \text{ } kx$		
		Total	13	
7 8	i	$-mV_g = \frac{1}{2}mv^2$ or $\frac{1}{2}mv^2 + mV_g = 0$	B1	
	i	$V_g = -GM/R = -gR$	B1	
	i	$v = \sqrt{(2gR)}$	B1	Working must be shown
	ii	$v = \sqrt{(2 \times 9.81 \times 6.4 \times 10^6)} = 11 \times 10^3 \text{ m s}^{-1}$	B1	allow 11(.2) km s^{-1}
	ii i	$\frac{1}{2}mc^2 = \frac{3}{2}kT$ where $m = (M/N_A) = 6.6 \times 10^{-27} \text{ kg}$	B1	ecf (ii); allow $m = 4u$ or $4 \times 1.67 \times 10^{-27}$
	ii i	$T = 6.6 \times 10^{-27} \times 121 \times 10^6 / 3 \times 1.38 \times 10^{-23}$	C1	
	ii i	$T = 1.9 \times 10^4 \text{ (K)}$	A1	allow 2 or 2.0
	i v	1 random motion and elastic collisions of particles	B1	max 4 out of 5 marking points where answer is a logical progression
	i v	2 lead to distribution of kinetic energies/velocities among particles	B1 B1	

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		i v	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	