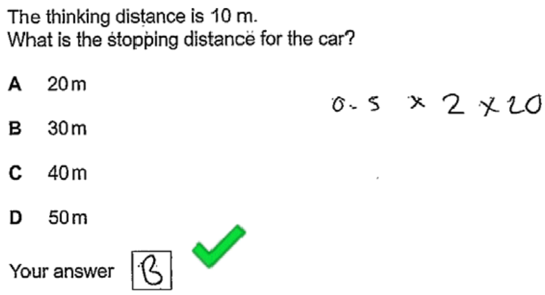
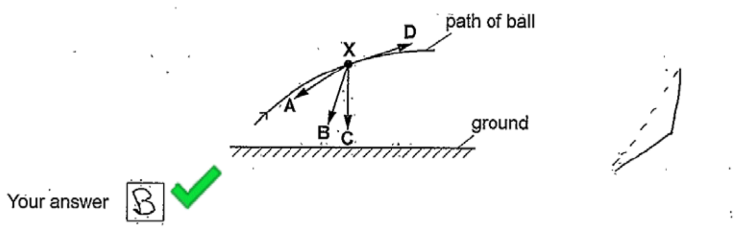
Mark scheme - Motion

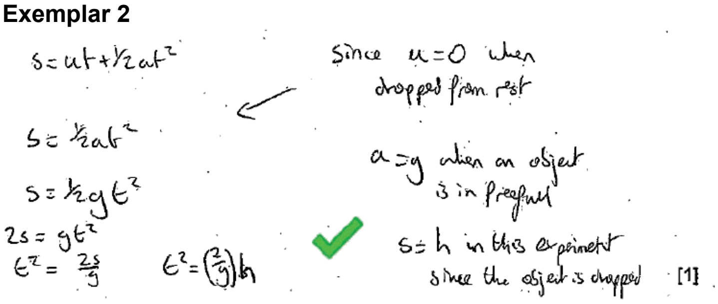
Question			Answer/Indicative content	Marks	Guidance
1			**B**	1	<u>**Examiner's Comments**</u> This question required understanding of *thinking, braking* and *stopping* distances together with an appreciation of the learning outcome 3.1.1(d). The total area under this velocity–time graph is equal to stopping distance. The area of the 'rectangle' is equal to thinking distance and the area of the 'triangle' is equal to the braking distance. The correct answer is **B**. The popular distractor was **A**, which just represented the braking distance. **Exemplar 4**  The thinking distance is 10 m. What is the stopping distance for the car? A 20 m B 30 m C 40 m D 50 m 0.5 × 2 × 20 Your answer B This exemplar illustrates how minimal work in a multiple–choice answer can produce dividends. The candidate has used the thinking distance and the 'reaction time' of 0.5 s to determine the initial speed of the car (20 m s^{-1}). This has then been used to calculate the braking distance. No interim values of distances are shown, but the candidate has done all the hard work by the substitution shown and labelling the vertical axis. A model answer from this high performing candidate.
			Total	**1**	
2			**D**	1	
			Total	**1**	
3			C	1	
			Total	**1**	
4			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**. The most popular distractor was **B**. This

					represented a point when the ball was just leaving the hard floor. The maximum height after the first bounce had to be when the ball was still accelerating and had zero velocity.
			Total	**1**	
5			**B**	1	
			Total	**1**	
6			A	1	
			Total	**1**	
7			Separation between droplets increases (further down)	B1	
			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. 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 speed^2. At the maximum height the kinetic energy must therefore be $\cos^2 30° K = 0.75 K$.
			Total	**1**	
9			**B**	1	**<u>Examiner's Comments</u>** The question requires knowledge and understanding of the forces acting on the ball in flight and resultant force. The path of the ball is shown. At **X**, the ball is travelling in the direction shown by the **D** arrow. The drag force will be in the opposite direction. Weight is other force acting on the ball – vertically downwards. Vectorially adding the weight and the small drag will produce a resultant in the direction shown by the **B** arrow. The answer (key) is therefore is **B**. The most popular distractors were **A** and **D**. **Exemplar 1**  The right–hand side of the exemplar has the jottings of a candidate and it does help to visualise the problem. This would certainly not qualify as an acceptable answer in Section B, but here, it

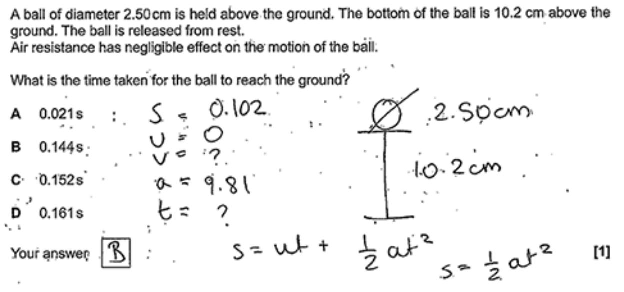
					demonstrates excellent technique; a vertical line for the *weight* and a slanting line for the *drag* and both being added to give the dotted line for the *resultant force*. This matches the arrow **B**.
			Total	**1**	
10			C	1	
			Total	**1**	
11	a		There is no contact force between the astronaut and the (floor of the) space station (so no method of measuring / experiencing weight)	B1	**Allow** astronaut and the space station have same acceleration (towards Earth) / floor is falling (beneath astronaut) **<u>Examiner's Comments</u>** **Misconception** Experiencing weightlessness is not the same as being in freefall There was a lack of understanding of the nature of feeling weightless. The sensation of 'weightlessness' is a lack of the physiological sensation of 'weight'. The skeletal and muscular systems are no longer in a state of stress. This sensation is caused by a lack of contact forces as a result of the ISS and the astronaut experiencing the same acceleration. Common incorrect responses included: • the astronaut is weightless because he is falling • there is no resultant force on the astronaut • gravity is too weak to have any effect on the astronaut • the ISS orbits in a vacuum where there is no gravity.
	b	i	$M = 5.97 \times 10^{24}$(kg) **or** ISS orbital radius $R = 6.78 \times 10^{6}$(m) **or** $g \propto 1/r^2$ (gr^2 = constant so) $g \times (6.78 \times 10^{6})^2 = 9.81 \times (6.37 \times 10^{6})^2$ $g = 8.66$ (N kg^{-1})	C1 C1 A1	**or** g (= GM/R^2) = $6.67 \times 10^{-11} \times 5.97 \times 10^{24} / (6.78 \times 10^{6})^2$ **Allow** rounding of final answer to 2 SF i.e. 8.7 (N kg^{-1}) **<u>Examiner's Comments</u>** The simplest method here was to use the fact that g is inversely proportional to r^2, so gr^2 = constant. If this was not used, a value for the mass of the Sun had to be calculated, which introduced a further step. Candidates who omitted this calculation and used a memorised value of the Sun's mass instead were unable to gain full marks, because they invariably knew it to 1 s.f. only, whereas 3 were required. Errors occurred when candidates used the incorrect distance in the formula for g. Common errors included:

					• forgetting to square the radius • using the Earth's radius rather than the orbital radius of the satellite • calculating ($6.37 \times 10^6 + 4.1 \times 10^5$) incorrectly.
		ii	$2\pi r / T = v$ **or** $T = 2 \times 3.14 \times 6.78 \times 10^6 / 7.7 \times 10^3$ $T = 5.5 \times 10^3$ s (= 92 min)	M1 A1	**ECF** incorrect value of R from **b(i)**
	c		$\frac{1}{2}Mc^2$ ($\frac{1}{2}N_Amc^2$) = $= \frac{3}{2}RT$ $c^2 = 3 \times 8.31 \times 293 / 2.9 \times 10^{-2} = 2.52 \times 10^5$ $\sqrt{c^2} = 500$ (m s^{-1}) (= 7.7×10^3 / 15)	C1 C1 A1 A0	**or** $\frac{1}{2}mc^2 = \frac{3}{2}kT$ **or** $c^2 = 3kT/m$ **or** $c^2 = 3 \times 1.38 \times 10^{-23} \times 6.02 \times 10^{23} \times 293/2.9 \times 10^{-2} = 2.52 \times 10^5$ **not** (7.7×10^3 / 15) = 510 (m s^{-1}) **Examiner's Comments** The success in this question depended on understanding the meaning of the term m in the formula $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$ given in the Data, Formulae and Relationship booklet. A significant number of candidates took m to be the mass of one mole (the molar mass, M) whereas m is actually the mass of one molecule. Candidates who used the formula $\frac{1}{2}M\overline{c^2} = \frac{3}{2}RT$ were usually more successful because the molar mass had been given in the question stem.
	d		power reaching cells (= IA) = $1.4 \times 10^3 \times 2500 = 3.5 \times 10^6$ W power absorbed = $0.07 \times 3.5 \times 10^6 = 2.45 \times 10^5$ W cells in Sun for (92 – 35 =) 57 minutes average power = $57/92 \times 2.45 \times 10^5 = 1.5 \times 10^5$ (W)	C1 C1 C1 A1	mark given for multiplication by 0.07 at any stage of calculation (90 – 35 =) 55 minutes using T = 90 minutes **ECF** value of T from **b(ii)** $55/90 \times 2.45 \times 10^5 = 1.5 \times 10^5$ (W) using T = 90 minutes **Examiner's Comments** Although this question looked daunting, it was actually quite linear and many candidates who attempted it were able to gain two or three marks even if they did not eventually get to the correct response. Candidates who set out their reasoning and working clearly were more liable to gain these compensatory marks.
			Total	**13**	
12			for thinking time t rider moves s = vt for (constant) deceleration from v to 0, $v^2 = 2as$ so total $s = d = v^2/2a + vt$	B1	
			Total	**1**	
13			min: 1.6 s; max: 2.2 s	B1	Need both for mark
			Total	**1**	

14	a		0.185 (s^2)	B1	**Examiner's Comments** This question was well answered. Since the raw data was given to three significant figures the calculated data should also have been given to three significant figures. Candidates did not score the mark for writing 0.1849 (four significant figures or 0.184 (truncating the data).
	b	i	Plots one missing plot to less than a half small square Draws straight line of best fit	B1 B1	**Allow** ECF from **(b)** **Allow** ECF Expect to be balance of points about line of best-fit. Judge straightness by eye. **Not** thick lines, multiple lines **Examiner's Comments** This question was again well answered with the majority of the candidates plotting the data point correctly. Sometimes the straight line of best fit did not have the points balanced. Candidates should be encouraged to plot graphs using a sharp pencil. It is helpful to use a clear 30 cm rule to draw the straight line of best fit. Thick plots and/or lines do not score marks.
		ii	Determines gradient correctly and gradient in the range 0.210 to 0.225	B1	Ignore significant figures. **Examiner's Comments** To determine the gradient of the straight line of best fit candidates are expected to identify two points (x_1, y_1) and (x_2, y_2) which are on the line and substitute them into $\text{gradient} = \frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x}$ The two points should be at least half the length of the drawn line apart. The advantage of this method is that it automatically allows for negative gradients. Common errors included the use data points from the table which are not on the line or just using one data point and assuming that the line passed through the origin.
	c	i	Evidence of use of $s = ut + \frac{1}{2}at^2$ (and $u = 0$) Manipulation leading to $t^2 = \left(\frac{2}{g}\right)h$		

				B1	**<u>Examiner's Comments</u>** For this type of question, candidates should start the answer by quoting the relevant equation of motion. It was then expected that candidates would state that *u* (or *ut*) = 0, that *a* = *g* and *s* = *h*. Some lower ability candidates did not clearly rearrange the equation correctly. **Exemplar 2**  This shows a reasoned answer with the relevant terms defined and clear working to demonstrate the rearrangement.
		ii	$g = \frac{2}{(c)ii}$ <u>and</u> given to 2 or 3 s.f.	B1 10	**Note:** Possible ecf from (c)(ii) **Ignore** rounding **<u>Examiner's Comments</u>** Candidates were required to identify from the equation given at the beginning of (d) (i) that the gradient was equal to 2/*g*. Candidates then needed to use the gradient value they calculated in 2 (c) (ii) to determine *g*. Some candidates incorrectly substituted data points from the table of results. To improve this skill candidates should practise comparing the *x* and *y* values from graphs with the equation of a straight line and then identifying the gradient and *y*-intercept values.
			Total	**6**	
15			Sum of <u>thinking distance</u> and the <u>braking distance</u>	B1	**Allow** the (total) <u>distance</u> travelled from when the driver sees a hazard to the vehicle stopping wtte **Examiner's Comments** The first question was incorrectly answered by a large number of

					candidates. The common error was only referring to braking distance.
			Total	**1**	
16			20 (m s^{-1})	B1	
			Total	**1**	
17			**C**	**1**	
			Total	**1**	
18			C	1	
			Total	**1**	
19			B	1	
			Total	**1**	
20			**B**	1	**Examiner's Comments** This question proved particularly straightforward and accessible to nearly all candidates.
			Total	**1**	
21			C	1	
			Total	**1**	
22			**A**	1	
			Total	**1**	
23			A	1	
			Total	**1**	
24			**B**	1	**Examiner's Comments** This question required knowledge and understanding of equations of motions. The simplest route to getting the correct answer was the equation $s = \frac{1}{2} at^2$ with the displacement s = 0.102 m. About two thirds of the candidates got the correct answer B. All the other distractors were based on using incorrect values for s. For example, the answer would have been D for s = 12.7 cm. The exemplar 3 below shows a typical working for a correct answer. **Exemplar 3**

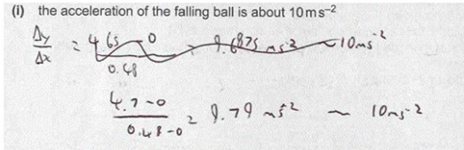
					 A ball of diameter 2.50 cm is held above the ground. The bottom of the ball is 10.2 cm above the ground. The ball is released from rest. Air resistance has negligible effect on the motion of the ball. What is the time taken for the ball to reach the ground? A 0.021 s B 0.144 s C 0.152 s D 0.161 s Your answer B [1] This exemplar illustrates relevant scribbling in a multiple choice answer can lead to the correct response. It is good to see that the candidate has focused on the correct distance of 0.102 m. The equation is there, as are the key numbers. The candidate had saved some time by finishing off the calculation on his/her calculator. A perfect technique from this candidate.
			Total	**1**	
25			**A**	1	**Examiner's Comments** This question was more challenging still. In this question, it was expected that candidates would use the idea that $v^2 = u^2 + 2aS$, hence realising that v^2 was directly proportional to the drop height, *h*, giving option A as the correct answer.
			Total	**1**	
26			C	1	
			Total	**1**	
27			A	1	
			Total	**1**	
28			C	1	
			Total	**1**	
29			**B**	**1**	
			Total	**1**	
30			B	1	
			Total	**1**	
31			C	1	
			Total	**1**	
32			A	1	

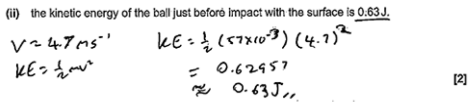
			Total	**1**	
33			**C**	1	**Examiner's Comments** This question was slightly more challenging.
			Total	**1**	
34	a		(u =) 68 sin 11° **or** 13.0 (m s^{-1}) t = 13.0 / 9.81 <u>and</u> t correctly evaluated t = 1.3(2) (s)	C1 C1 A0	**Not** t=90/(68cos(11)) =1.35 for zero marks. **Allow** any subject
	b		(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	**4**	
35			using y = mx + c d/v = v/2a + t gives an equation resulting in a straight line graph	B1	
			as a and t are constants.	B1	
			Total	**2**	
36			The steel ball not released straight away (because of the residual magnetism of the electromagnet) / The trapdoor does not open immediately. (AW)	B1	
			Increase distance of fall.	B1	
			Total	**2**	
37			**D**	1	
			Total	**2**	
38			($v^2 = 2as + u^2$); $v = (2 \times 9.81 \times 0.30)^{½}$ (Allow any subject) speed = 2.4 (m s^{-1})	**C1** **A1**	**Allow** ($s = ½ a t^2$) to give t = 0.247 and (v = at) gives 2.42 **Examiner's Comments** Examiners were pleased that nearly all candidates successfully employed Newton's equations of motion ideas to arrive at the correct answer. Those that did not either mis- substituted values or forgot to take a square root.
			Total	**2**	
39			Distance travelled from the moment the driver sees a hazard until the brakes are applied	B1	
			Distance proportional to speed (for constant thinking time)	B1	

			Total	**2**	
40	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) efficiency = 235.4 / 320 × 100 efficiency = 74 %	C1 A1	**Note:** Using g =10 N kg^{-1} gives 75%: allow 1 mark max 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 = (1200g − 400) N used **Allow** 1 mark for 76%, force = (1200g + 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**	
41			s = 0.5 (m) / t = 0.5 (s) $a = (-)\ \frac{2.0}{0.5}$ or $0 = 2.0^2 + 2 \times a \times 0.5$ deceleration = (−) 4.0 (m s^{-2})	**C1** **A1**	**Allow** other correct methods Possible ECF from **(b)** **Allow** 1 sf answer **Ignore** sign **Examiner's Comments** Most candidates were aware of what equation to use but only about half managed to gain one or two marks for their calculation. The simplest answers occupied a single line and the complex ones recalculated the initial velocity of the trolley from the graph and then used the equation $v^2 = u^2 + 2as$. There were no marks for using incorrect values for the time, or the displacement, during the deceleration stage. A significant number of candidates took the time for stopping to be either 0.80 s or 1.0 s.
			Total	**2**	

42	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 = $\frac{1}{2} \times 50 \times 0.12^2$	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 $v = 0.96$ 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**	
43	a		area under graph = 0.5 x 2.0 x 900 = 900 (N s) (mU = 900) U = 13 (m s^{-1})	C1 A1	**Not**: (initial force/mass) **<u>Examiner's Comments</u>** It was good to see that most candidates understood that Newton's second law of motion is more than the statement that $F=ma$. Many had successful attempts with some candidates missing that it is the rate of change of momentum, rather than the change of momentum that is required. About two-thirds of candidates also correctly indicated that the area under the graph represents the impulse or the change in momentum. In Question 20(b), some candidates assumed, incorrectly, that the maximum force multiplied by the time taken would give the change in momentum and so scored zero marks. Rather more simply

					divided the maximum force by the mass, which gave the right answer yet with incorrect physics. This approach also scored zero. In fact, more successful responses made it clear that the area of the triangle on the graph was the impulse and that that area gave a change in momentum of 900 Ns.
	b		The graph showing a (smooth) **curve** of continuously/always decreasing magnitude of gradient (with respect to time). **Curve** starts at (0,*U*) and stops at (2.0,0)	M1 A1	**Note:** curve must not be asymptotic at either end of the curve. **<u>Examiner's Comments</u>** Successful candidates spotted that the resultant force, the acceleration and hence the gradient of this speed- time graph decreased in magnitude with time. A constant gradient, ie a straight line between (0,U) and (2.0,0), can only be achieved by a constant decelerating resultant force. This gives a curve that starts off (0,U) with a steep negative gradient and finishes with a small negative gradient at (2.0,0).
			Total	**4**	
44			Deceleration is indicated by the <u>negative gradient/slope</u> (between t =1.5 to t =4.5) A straight line/constant (negative) gradient (between t =1.5 to t =4.5) (indicates constant deceleration)	**B1** **B1**	Constant negative gradient scores two marks **<u>Examiner's Comments</u>** This question was aimed to be a gentle introduction to the paper. It was expected that candidates would state that the **negative** gradient indicates the deceleration; many candidates simply referred to the gradient. The second part required candidates to refer to the straight line indicating that the deceleration is constant. Candidates may find it helpful to underline the key terms in the stem of the question, for example 'deceleration' and 'deceleration is constant'.
			Total	**2**	
45			Gradient of graph is equal to acceleration.	B1	
			The acceleration decreases as time increases.	B1	
			Total	**2**	
46	a	i	$\frac{\Delta v}{\Delta t}$ <u>and</u> $\Delta t \geq 0.20$ s	M1 A0	**Allow** tolerance of ±½ a small square e.g. $\frac{4.7(-0)}{0.48(-0)} = 9.79$

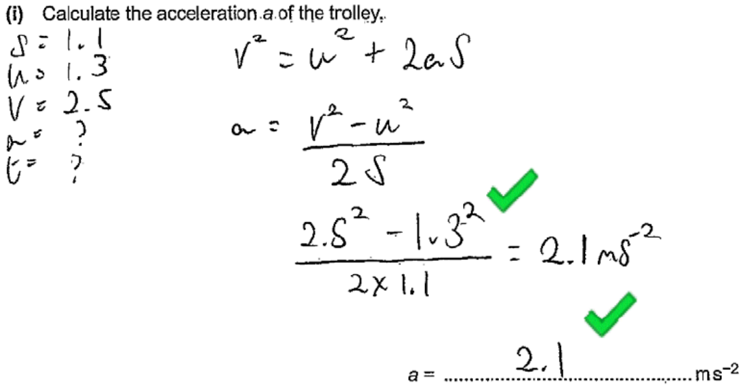
			9.8 m s^{-2}		**Examiner's Comments** This question was a "show" type question. Candidates needed to show their working logically. Ideally candidates would state that that the acceleration was equal to the gradient, and then show the substitution of the data values for the gradient calculation. It was 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} $\frac{\Delta y}{\Delta x} = \frac{4.65-0}{0.48} = 9.6875\ ms^{-2} \approx 10\ ms^{-2}$ $\frac{4.7-0}{0.48-0} = 9.79\ ms^{-2} \sim 10\ ms^{-2}$ 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**  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 Δ*t* = 0.40 to 0.97 for Δ*t* = 0.46 **Examiner's Comments** 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**	
47	a		(s =) 1.23 (m) **or** (**t** =) 0.50 (s) $v^2 = 2 \times 9.81 \times 1.23$ **or** $1.23 = 0.50 \times \frac{v}{2}$ **or** $1.23 = v \times 0.50 - ½ \times 9.81 \times 0.50^2$ **or** $v = 9.81 \times 0.50$ **or** $1.23 = ½ \times 9.81 \times t^2$; t = 0.50 (s) **and** $v = 9.81 \times 0.50$ v = 4.9 (m s^{-1})	C1 C1 A0	**Note** there are no marks for gradient calculations here **Allow** s between 1.22 (m) and 1.26 (m) **Allow** t between 0.495 (s) and 0.505 (s) Substitution into $v^2 = u^2 + 2as$ with u = 0 Substitution into $s = \frac{(v+u)}{2} \times t$ with u = 0 Substitution into $s = vt - ½ at^2$ Substitution into $v = u + at$ with u = 0 Substitution into $s = vt - ½ at^2$ and $v = u + at$ with u = 0 **Allow** g = 9.8 **Not** g = 10, unless already penalised in **21(c)(ii)** **Examiner's Comments** This question was generally well-answered with candidates using a range of equations of motion to show the speed to be 4.9 m s^{-1}. The most popular route was: v = 0 + (9.81 × 0.50) = 4.905 m s^{-1}.
	b		Correct tangent at t = 0.50 s with positive gradient Attempt at calculating the gradient of a tangent Gradient calculated in the range 3.20 to 3.80 (m s^{-1})	B1 M1 A1	**Note** must evidence for Δs and Δt values either here or on Fig. 22 **Allow** this M1 mark for tangent not drawn at t = 0.50 s **Note** this mark can only be scored if the tangent is drawn at t = 0.50 s and the calculated value falls in this range **Examiner's Comments** In this question, candidates had clear instructions on what to do. Most candidates drew adequate tangents at t = 0.50 s and did the correct analysis to determine the rebound speed of the ball. Most responses were in the range required (3.20 to 4.00 m s^{-1}) and most candidates scored 3 marks. About a quarter of the candidates drew tangents at times other than t = 0.50 s. This meant that they could only score a maximum of 1 mark for correctly calculating the gradient of their tangent.
	c		(Δv =) 4.9 + 3.5 **or** (Δv =) 8.4 (ms^{-1})	C1	Possible ECF from **(c)** **Allow** (Δp =) (4.9 + 3.5) × 0.056 **or** (Δp =) 0.47 (kg ms^{-1})

			force = $\frac{8.4 \times 0.056}{1.8 \times 10^{-3}}$ force = 260 (N)	A1	**Allow** 1 mark for 44 (N); Δv = 4.9 - 3.5 used **Ignore** sign **Examiner's Comments** The correct answer of 260 N eluded even many of the top-end candidates. The vector nature of velocity, or momentum, was overlooked, with many candidates calculating the magnitude of the force as follows: force = $\frac{\Delta p}{\Delta t} = \frac{0.056\,(4.9-3.5)}{1.8 \times 10^{-3}}$ = 44 N The magnitude of the change in the velocity of the ball 0.056(4.5 + 3.5), which would have given the correct answer of 260 N. **Misconception** Some examples of **incorrect** physics were: • force = weight of the ball = 0.056 × 9.81 • Using Δt = 0.50 s instead of 1.8 ms. • Using either 4.9 m s^{-1} or 3.5 m s^{-1} to calculate the force.
			Total	**7**	
48			horizontal component = 17 sin 30 or 17 cos 60 = 8.5 (m s^{-1})	B1	
			at highest point vertical component of velocity is zero.	B1	
			Total	**2**	
49	i		($v^2 = u^2 + 2as$) $2.5^2 = 1.3^2 + 2 \times 1.10 \times a$ (Any subject) a = 2.1 (m s^{-2})	**C1** **A1**	**Allow** other methods **Allow** this mark for t = 0.58 (s) **Note** answer to 3 SF is 2.07 (m s^{-2}) **Examiner's Comments** Most candidates demonstrated excellent understanding and application of equations of motion. The solutions were often well represented, calculations done correctly and the answer written to the correct number of significant figures (SF). A variety of routes were possible, but the most popular method was using the equation $v^2 = u^2 + 2as$. **Exemplar 5**

					 This exemplar from a grade E candidate shows flawless technique. The known and unknown quantities are written on the left-hand side. The equation is clear, as is the substitution and the final answer for the acceleration.
		ii	*ma* = *mg* sinθ **or** *a* = *g* sinθ **or** 2.07 = 9.81 × sinθ θ = 12°	**C1** **A1**	**Allow** 2.1 (m s^{-1}) **Allow** *g* = 9.8 **Note** using tan^{-1}(2.07/9.81) is **wrong physics**. Possible ECF from **(b)(i)** **Allow** *g* = 10 here; it gives the same answer to 2 SF **Allow** 1 mark for 78°
			Total	**2**	
50	a		Tangent drawn at *t* = 1.75 s (judge by eye) Gradient in the range 11.0 (m s^{-1}) to 13.0 (m s^{-1})	B1 B1	
	b		(After 0.75 s) gradient decreases with time Indicating velocity is decreasing / deceleration	M1 A1	**<u>Examiner's Comments</u>** In part (b) some candidates were vague in their responses, for example, stating that the gradient changes rather than stating that the gradient decreases. In part (c) most candidates were able to draw a reasonable tangent. Parts (d) and (e) were harder to answer. Part (d) required the correct time interval to be applied by interpreting the braking time and not including the thinking time. In part (e), high achieving candidates applied the halving of the initial speed to the effect this had on the thinking distance, the thinking time, the braking distance and the braking time.
			Total	**4**	
51			in time t_o car moves vt_o	B1	
			path lengths travelled by the two pulses differ by $c(t_o - t)$	M1	justified e.g. best solved by imagining first pulse takes time T_o and second time T and then $T_o - T = t_o$
			but this is twice the distance the car has moved as it is a reflected signal	A1	– t and / or drawing a space diagram.
			so $2vt_o = c(t_o - t)$.	A0	
			Total	**3**	

52			Tangent drawn correctly by eye Attempt made to determine the gradient of tangent acceleration = 1.3 (m s^{-2})	B1 C1 A1	**Allow** answer in range 1.2 to 1.4 (m s^{-2})
			Total	**3**	
53			(x =) 200 × 18 **or** (x =) 3600 (m) $(\lambda =)\frac{120 \times 3600}{2400}$ λ = 180 (m)	C1 C1 A1	**Not** $v = f\lambda$; $18 = \frac{1}{200} \times \lambda$ **or** λ = 3600 (m) **Allow** 3600 m from $v = f\lambda$ when used as x here **Note** using x = 1800 m is **XP** (this gives 90 m)
			Total	**3**	
54	a	i	1.30 ± 0.18 entered in table two points correctly plotted on graph with error bars Line of best fit; If points are plotted correctly then lower end of line should pass between (9.5, 1.3) and (10.5, 1.3) **and** upper end of line should pass between (34.0, 2.9) and (35.5, 2.9).	B1	allow ± 0.2 to ± 0.16 **ecf** value and error bar of first point **allow ecf** from points plotted incorrectly.
		i	Worst acceptable straight line.	B1	steepest or shallowest possible line that passes through all the error bars; should pass from top of top error bar to bottom of bottom error bar **or** bottom of top error bar to top of bottom error bar.
		ii	gradient of best fit line. should be about 0.065	B1	**allow ecf** values from graph in all values below
		ii	a = 1/(2 × gradient) giving a = 7.7 (m s^{-2})	B1	allow 7.3 to 7.7
		ii	y-intercept of best fit line; should be about 0.65 t = y-intercept so should be about 0.65 (s) uncertainty in gradient; should be about 0.010 to 0.012	B1	difference in worst gradient and gradient.
		ii	giving uncertainty in a to be about ± 1.1 to ± 1.2 uncertainty in y-intercept and t should be about ± 0.3	B1	difference in worst y-intercept and y-intercept both uncertainties correct for final mark.
	b		actual d/v values will be lower.	M1	
			so the y-intercept will be lower.	M1	
			hence the actual t (= y-intercept) will be smaller.	A1	

			Total	**9**	
55			• (initial) upward force unchanged • (initial) downwards force/weight increases • (initial) resultant force decreases • (initial) acceleration decreases • (initial) rate of change in momentum of rocket decreases • time taken to expel water increases • valid conclusion that the maximum height depends on more than one factor	B1 x 3	**Maximum 3** marks from 7 marking points: **Ignore** comments which assume an increase in pressure **Ignore** heavier **Allow** net or unbalanced or total for resultant **Allow** fuel for water e.g. the height depends on the bottle's velocity and its height when all the water has been expelled / the height depends on both the acceleration and the time taken to expel the water **Examiner's Comments** This question involved several factors and a conclusion was not required; hence the word 'discuss'. Candidates who performed well on this question realised that the weight of the rocket would increase, reducing the resultant force, and m would increase in the formula F = ma. These would both give a reduced initial acceleration and imply a smaller height. However, the time taken to expel the water would increase, meaning that the rocket would accelerate for longer. One common misconception was that the larger volume of water in the bottle would increase the pressure of the trapped air. However, as a pump was used to determine the pressure before lift-off, this argument was not given credit.
			Total	**3**	
56	a		(t =) 2 × 1.3 **or** 2.6 (s) (x =) 68 cos11° × 2.6 or 174 (m) horizontal distance = 174 – 90 horizontal distance = 84 (m)	C1 C1 A1	**Note** answer is 86 (m) if 1.32 s is used **Note** answer is 87 (m) if 1.3226… s is used **Allow** 1.3 × 68 cos11° for 1 mark **Allow** 3 or −3 m for 2 marks
	b	i	A collision in which kinetic energy is lost	B1	**Allow** KE is not conserved
		ii	Conservation of momentum Idea that velocity is to the right **and** velocity is very small / much smaller than 68 (m s^{-1})	B1 B1	**Not** 'goes backwards'
			Total	**6**	

5 7			18 x 0.5 or 9(.0) m $(a = \frac{v^2-u^2}{2s})$; $(a = \frac{v^2-u^2}{2s})$; (Any subject) Deceleration = 5.6 (m s^{-2})	C1 C1 A1	**Allow** 1 mark max for 4.26 or 4.3; (38 m used instead of 29 m) **Allow** 1 mark max for 3.4 or 3.45; (47 m used instead of 29 m) **Ignore** minus sign **Examiner's Comments** Many candidates use the stopping distance for the braking distance of the car, giving a deceleration that was too low and scoring 1 mark only. More successful candidates remembered to calculate the thinking distance involved (9 m) and subtract this from the stopping distance to give a braking distance of 29 m. Algebraic rearrangement, substitution and evaluation from then on was excellent.
			Total	**3**	
5 8			area under graph = displacement or distance $\frac{1}{2} \times 3 \times 14 = 21$ (m) 1 (m)	**C1** **M1** **A1** **5**	**ALLOW** $s = \frac{(u+v)}{2}t$ or $s = ut + \frac{1}{2}at^2$ and *a* = 14/3 $\frac{(14+0)}{2} \times 3$ × OR 7 × 3 **ALLOW** ECF for mis read of *t* or *v* **Do not accept** *t* = 4.5 **Ignore** "-" sign **Examiner's Comments** Candidates needed to understand that the car started decelerating when the brakes were applied. When answering this type question, candidates should be encouraged to show all their working. It was hoped that candidates would have written for the first mark that the area under the graph would be equal to the displacement. Then a clear calculation of the displacement was expected and then 21 m − 20 m to give the answer of 1 m. Other candidates correctly used $s = \frac{(u+v)}{2}t$ Some candidates attempted to use s = $ut + ½at^2$. To do this correctly candidates needed to determine the deceleration of the car and used this in the equation.
			Total	**3**	
5 9			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	**3**	
60		i	An arrow from trolley to ramp along the string (for the tension) and a downwards arrow from the trolley (for the weight).	B1	**Allow** arrows in correct directions anywhere on Fig. 21 **Not** arrow for the tension parallel to the ramp **Not** arrow perpendicular to the ramp for the weight **Not** two arrow heads in opposite directions along the string for the tension **Examiner's Comments** Most of the candidates answered this question well with two clearly drawn arrows for the weight of the trolley and the tension in the string. The most frequent mistake was to draw the tension arrow parallel to the ramp.
		ii	(s = ½ at^2); 0.80 = ½ × 3.0 × t^2 (Any subject)	C1	
		ii	t = 0.73 (s)	A1	**Note**: Apply SF penalty if 0.7 s is on the answer line or the final answer **Allow** 1 mark for 0.40 (s); 9.8 m s^{-2} used instead of 3.0 m s^{-2} **Allow** full credit for alternative methods, e.g: v^2 = 2 × 0.80 × 3.0; v = 2.19 (m s^{-1}) $t = \frac{2.19}{3.0}$ **C1** t = 0.73 (s) **A1** **Examiner's Comments** Candidates answered this question extremely well. The correct equation was identified, values substituted correctly and the final answer written to two significant figures. Some low-scoring candidates attempted to use the equation $x = vt$ or struggled with rearranging the equation s = ½ at^2. A disappointing number of candidates lost a mark for writing the answer to one significant figure on the answer line after correctly calculating the time t to be 0.73 s.
			Total	**3**	
61	a	i	u = 17 cos 30 = 14.7 (m s^{-1})	C1	
		i	h = ut − ½gt^2; = 14.7 × 1.5 − ½ × 9.81 × 1.5^2	C1	**or** use v^2 = u^2 – 2gs **or** s = (u + v)t/2
		i	h = 11 (m)	A1	**note**: if g = 10 is used, then maximum score is 2/3
		ii	s = 2 × 8.5 × 1.5	C1	**ecf 2a**

		ii	s = 26 (m)	A1	allow 25.5 m
	b		0 = 17 sin 30 t - ½ × 9.81 × t^2	C1	
			so t = 0 or 17/9.81 = 1.73	C1	
			s = 14.7 × 1.73 = 25.4 (m)	A1	allow s = 15 × 1.7 = 25.5 (accept 25 or 26 to 2 sf)
	c		the ball has the same speed (of 17 m s^{-1}) but is at different (either at 60° or 30°) angle to the horizontal.	B1	
			larger horizontal velocity (second trajectory) so travels further or higher bounce (first trajectory) so less drag from grass so travels further.	B1	accept any sensible answer, e.g. steeper bounce loses more energy in impact so slows more.
			Total	**10**	
62	a		Maximum of two from: (thinking) time is the same (braking) time is halved / 1.25 s total time is 2 s **AND** maximum of two from: (thinking) distance / displacement travelled (before braking) halved / 7.5 m (braking) distance / displacement quarters / 6.25 m total distance / displacement = 13.75 m	B1 ×3	
	b		Δtime = 1.75 – 0.75 OR 3.25 - 0.75	C1	**Allow** use of **(c)** and **(a)** **Allow** *a*= 8.0 m s^{-2} for $v^2=u^2+2as$ or $s=ut+ ½at^2$ methods **Not** ECF for incorrect time
			Using **(c)**: $F = 950 \times \frac{20-12}{1.75-0.75}$ or Using graph: $F = 950 \times \frac{20-0}{3.25-0.75}$ or $F = \frac{950 \times 20}{3.25-0.75}$	C1	
			7600 (N)	A1	**Ignore** sign
			Total	**6**	

6 3			$\frac{0.002}{0.1000}(\times 100)$ or $\frac{0.1}{1.4}(\times 100)$ or $g = \frac{1.4^2}{2 \times 0.100}$ (2 × 0.071 ...+ 0.02) or 0.1628 ... or 16.3 % absolute uncertainty = 1.6 (m s^{-2}) **OR** $g_{max} = \frac{1.5^2}{2 \times 0.098}$ (= 11.48) or $g_{min} = \frac{1.3^2}{2 \times 0.102}$ (= 8.28) range = 3.2 (m s^{-2}) absolute uncertainty = 1.6 (m s^{-2})	C1 C1 A1 C1 C1 A1	**Allow** 1SF answers here for uncertainties **Not** *g* = 9.8 for this C1 mark; must see working **Allow** 0.16 or 16% **Note**: The answer must be given to 2 SF **Ignore** value of *g* given on the answer line, e.g. 9.8 ± 1.6 **Note**: The answer must be given to 2 SF
			Total	**3**	
6 4			Distance / displacement / length measured using the (metre) rule **and** time measured using the stopwatch (S = ½ [*v* + *u*]*t* and *u* = 0) *v* = 2 × <u>average</u> velocity	**B1** **B1**	**Allow** this mark even if the measurements are taken after trolley has left the ramp **Note** *v* must be the subject **Allow** *v* = 2 × average speed **Allow** *v* = 2*x/t* without the terms defined (*x* can be *d*, *D* or s) **Not** s = ½ *vt* **Allow** *v* = *x/t*, where *x* = distance travelled along horizontal surface assuming it is smooth / negligible friction **Allow** 1 mark for the following where there is no mention of timing / stopwatch: Measure height / vertical distance with a (metre) rule **and** use *v* = √2*gh* (no need to define the terms) **<u>Examiner's Comments</u>** Most candidates struggled to gain full marks in this opening question. The first mark, for using a ruler to measure the length of the ramp and the stopwatch for the time taken to travel the length of the ramp, was gained by just over half of the candidates. The second mark required a clear statement that the **final** velocity was twice the **mean** velocity of the trolley. Equivalent statements were allowed. Unfortunately, many candidates opted to describe light-gates arrangements or using inappropriate equations of motion.
			Total	**4**	
6 5	a	i i i	weight; (tractive) force up slope; drag; (normal) reaction All forces in correct direction and correctly labelled.	B1	

		ii	14.4 + (85 × 9.81 × sin θ) = 41.7	C1	**ecf** from **(a)(ii)**
		ii	θ = 1.9 °	A1	
	b		any three from: • drag reduces velocity **or** increases time to cross **or** some kinetic energy of cyclist goes to heat. • longer crossing time results in cyclist at lower point on other side of gap. • moment on bicycle • rotation lowers height of front wheel.	B1 × 3	Allow argument based on: • very short crossing time (< 0.43s at speed of 6 ms^{-1} up slope). • energy changed to heat insignificant compared to KE • amount of rotation very small in short time.
					conclusion based on argument(s). So no change in maximum gap width.
			Conclusion based on argument(s). The maximum gap width is smaller.	B1	
			Total	**7**	
6 6		i	speed = $\frac{2 \times \pi \times 0.60}{20}$	C1	
		i	speed = 0.19 (m s^{-1})	A1	
		ii	Displacement is the direct distance of the locomotive from **A**, so the graph is symmetrical about t = 10 s.	B1	
		ii	At t = 20 s it returns back to **A** **or** at t = 10 s it is 1.2 m from **A** **or** at t = 10 s, it is at **C**.	B1	
			Total	**4**	
6 7		i	Circumference = (2 × 200) + (2π × 40) = 651.3 m	C1	
		i	Time for A to complete one lap = $\frac{651.3}{20}$ = 33 (	A1	accept 32.6
		ii	Distance moved by B = 23 × 32.6 = 749.8 m	C1	Accept calculation of relative speed followed by relative distance.
		ii	(B leads A by) 749.8 − 651.3 = 98.5 (m)	A1	accept 108 m for 33 s
			Total	**4**	
6 8			h measured with a metre rule/ruler	**B1**	**Allow** metre stick, tape measure
			(electronic) timer/data logger (started and stopped electronically)	**B1**	**Not** stopwatch
			Method to start timer (and release ball),	**B1**	**Allow** one mark for use light gates without reference to

			e.g. electromagnet or light gate to start timer Method to stop timer, e.g. trap door, second light gate	B1	timer/starting/stopping **Examiner's Comments** This question assessed candidates' knowledge and understanding of the techniques and procedures used to determine the acceleration of freefall. Most candidates were able to explain how the vertical distance could be measured using a metre rule. To measure the time, to the nearest 0.001 s, it was expected that candidates would describe either a method using an electromagnet and trap door or the use of light gates with a timer. Many candidates did not realise that the times were recorded to the nearest 0.001 s. Many candidates were vague in their responses, e.g. "use light gates" without an explanation. It was expected that candidates would state that the light gates would be connected to a timer or datalogger or computer and that the timer would start when the ball interrupts the first light beam and stops when the second light beam is crossed. Candidates should experience and be able to describe the techniques to determine velocity and acceleration using light gates
			Total	**4**	
69		i	$g = \frac{2s}{t^2}$ / $g = \frac{2\times 1.200}{0.50^2}$	C1	
		i	g = 9.6 (m s^{-2})	A1	
		ii	(% uncertainty in s) = 0.08 % or		
		ii	(% uncertainty in t) = 4.00 % % uncertainty in g = ((2 × 4.00) + 0.08)	C1	
		ii	% uncertainty in g = 8.08 (%)	A1	**Allow** 8.1% or 8 %
			Total	**4**	
70			Constant velocity from 0 to 0.3(0 s) / up to 0.3(0 s) / up to the crash / at the start	**B1**	**Allow** speed instead of velocity **Allow** 0.30 to 0.40
			Velocity decreases / deceleration from 0.3(0 s) to 0.8(0 s)	**B1**	**Allow** 0.30 to 0.40 and 0.76 to 0.80 **Allows** slows down
			Zero velocity / stationary after 0.8 (s) / towards the end	**B1**	Possible ECF
			gradient (of the graph) = velocity	**B1**	**Allow** slope instead of gradient **Allow** gradient is 2.0 (m s^{-1}) / gradient is constant (up to 0.30 s) /

					straight line (up to 0.30 s), so velocity / speed is constant **Allow** gradient decreases (between 0.30 s and 0.80 s), so velocity / speed decreases **Allow** gradient is zero (after 0.80 s), so velocity / speed is zero **Examiner's Comments** Most candidates gained two or more marks. Answers were often longer than required, but most candidates managed to analyse the displacement-time graph of the trolley extremely well. A few candidates lost marks for incorrect physics such as 'the *trolley decelerates at a constant speed between 0.3 s and 0.8* s'. The top-end candidates scored full marks for their descriptions and recognised that the velocity was equal to the gradient. A small number of candidates spoilt their answers by suggesting that the trolley *'bounced back'.*
			Total	**4**	
7 1			velocity = <u>gradient</u> **or** velocity = rate of change of displacement Any <u>three</u> from: • speed / (magnitude of) velocity increases (until 0.50 s / hits grounds) • speed / (magnitude of) velocity decreases after 0.50 (s) / hitting ground • direction (of velocity / motion) changes at / after 0.50 (s) / hitting ground • speed / (magnitude of) velocity after impact is smaller than the speed / (magnitude of) velocity before the impact	B1 B1×3	**Ignore** any statements about the motion before 0.2 s **Note** this must be clear statement - not implied **Allow** accelerates **Allow** decelerates **Allow** after hitting ground / 0.50 (s) the ball travels up / bounces (back / up) or change in direction (of velocity / motion) indicated by <u>change</u> in sign <u>**Examiner's Comments**</u> This question on displacement-time graph required clear interpretation and exposition of the physics. The question discriminated well, with the top-end candidates describing the motion of the ball in clear scientific terms. Terms such as acceleration and deceleration were used appropriately. Up to time t = 0.50 s, the ball was accelerating towards the ground – its velocity was increasing at a steady rate. The ball made impact with the ground at t = 0.50 s. The speed of the ball immediately after the impact was less than the speed just before the impact. This can be inferred from the gradient of the graph; the gradient being equal to velocity. The ball was moving away from the ground after t = 0.50 s and decelerating. It was only the very best candidate who mentioned that the gradient of the graph is equal to velocity of the ball. The two exemplars 8 and 9 show responses from top-end and low-end candidates.

Exemplar 8

Describe and explain the variation of the velocity of the ball from t = 0.20 s to t = 0.70 s.

No calculations are required.

From t = 0·20s to t = 0·50s, the ball is accelerating as it moves downwards. At t = 0·50s, the ball ~~di~~ collides with the ground and bounce back upwards. From t = 0·50s, to t = 0·70s, the ball is ~~acc~~ decelerating as it moves upwards from the ground. Gradient of the graph equals to velocity. The change in gradient (velocity) equals to acceleration. [4]

This is a response from a top-end candidate. The description is flawless. The last statement about the ‘change in gradient’ being equal to acceleration was ignored. It should have been **rate** of change in the gradient being equal to acceleration, however, the statement from the candidate was not an essential requirement. This candidate had picked up an elusive mark for mentioning that the gradient of the graph is equal to velocity.

Exemplar 9

Describe and explain the variation of the velocity of the ball from t = 0.20 s to t = 0.70 s.

No calculations are required.

Between 0s - 0·5s, velocity of the ball is increasing as it is accelerating at $9{\cdot}81\,ms^{-2}$. At exactly 0·5s, the velocity of the ball is zero m/s

~~Bu~~ Then from 0·5s - 0·7s, velocity increases but as time continues, the rate at which velocity is increasing ~~dec~~ slows down [4]

This is a response from a low-end candidate. It contains mistakes and misconceptions. The only mark obtained was for mentioning that the ball was accelerating before its impact with the ground.

?

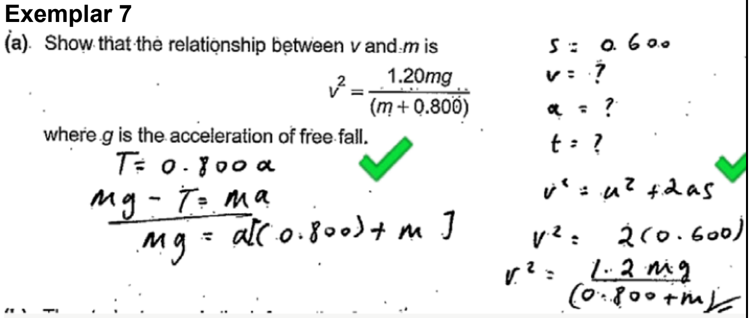
Misconception

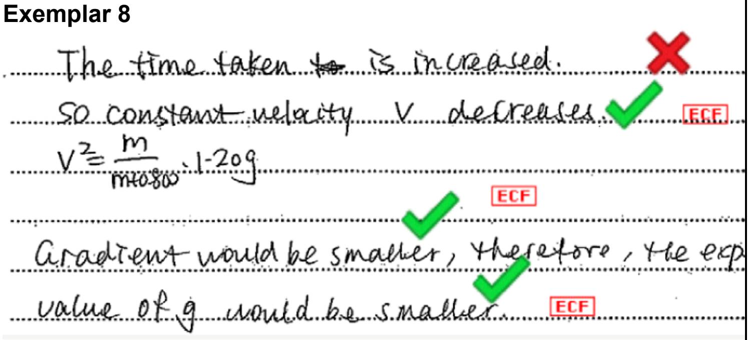
There were some missed opportunities, with some candidates using contradictory statements such as ‘*after t = 0.50 s, the ball is slowing down because it is acceleration upwards*’.

The three most common misconceptions are summarised below:

- The ball reaching **terminal velocity** just before the impact with the ground.
- The ball was **accelerating** again after t = 0.50 s.
- The displacement-time graph showed **projectile motion** of the ball.

			Total	4	
7 2		i	($v^2 = u^2 + 2as$) $(2.4 \times 10^6)^2 = (7.2 \times 10^6)^2 + 2 \times a \times 1.2 \times 10^{-2}$	C1	**Allow** other correct methods
		i	$a = (-)\ 1.9 \times 10^{15}$ (m s^{-2})	A1	**Allow** 1 mark for 1.9×10^{13}; distance left in cm **Note** answer to 3 s.f. is 1.92×10^{15} (m s^{-2}) **Ignore** sign
		ii	$E = F/Q$ and $F = ma$	C1	
		ii	$E = \frac{1.67 \times 10^{-27} \times 1.92 \times 10^{15}}{1.60 \times 10^{-19}}$	C1	Possible ECF from **(i)**
		ii	$E = 2.0 \times 10^7$ (N C^{-1})	A1	**Allow** 2 marks for 1.1×10^4; mass of electron used **Allow** 1 s.f. answer
			Total	4	
7 3		i	$(t =) \frac{6.3}{9.8(1)}$	M1	**Allow** other correct methods, e.g:
		i	(t =) 0.6(42....s)	A0	$(t) = \sqrt{\frac{2 \times 2.0}{9.8(1)}}$ or $(t) = \frac{2 \times 2.0}{6.3}$ **Not** a = 10 m s^{-2} **Note** t must be the unknown **Examiner's Comments** There were some convoluted answers. A number of candidates gained credit but wasted time by solving a quadratic equation. Some candidates assumed that the vertical velocity was an average and determined the time and then just multiplied by two without explanation – this did not gain credit. Clear explanations of the method are used to answer these types of "show" questions.
		ii	$(v_H =) \frac{18}{0.64}$ or $\frac{18}{0.6}$	M1	**Note** v must be the unknown
		ii	(v_H =) 28 (m s^{-1}) or 30 (m s^{-1})	A0	**Examiner's Comments** This part was answered better although some candidates tried using an equation with acceleration.
		iii	$v = \sqrt{6.3^2 + 30^2}$	C1	$v = \sqrt{6.3^2 + 28^2}$ **Allow** trigonometry methods
		iii	v = 31 (m s^{-1})	A1	v = 29 (m s^{-1}) **Note** 940 scores one mark **Examiner's Comments** A pleasing number of candidates determined the magnitude of the velocity correctly, Some correctly used trigonometry methods.
			Total	4	
7 4	a		(change in) KE = (change in) GPE /AW	M1	**allow** mgh = ½Mv^2 as long as it is clear that m and M are different, i.e. NOT mgh = ½mv^2

			½$(m + 0.8)v^2 = 0.6\,mg$ (and hence equation as shown on	A1	**allow** linear motion equation $v^2 = u^2 + 2as$ <u>and</u> $F = Ma$ $(W =)\ mg = (m + 0.8)a$; $u = 0$ and $s = 0.6$ **<u>Examiner's Comments</u>** 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 $mgh = \pm½mv^2$ 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 + 2as v² = 2(0.600) 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 **<u>Examiner's Comments</u>** 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 = $1.20g$ **<u>Examiner's Comments</u>** 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)** Δx > 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 α 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**	
7 5	a	i	0.22 and 0.26	B1	
		i	correct plotting of points on Fig. 2.2	B1	tolerance on each point ± 0.5 small scale division

		i	sensible line not through origin	B1	expect x-intercept at about 0.02
		ii	triangle with base at least half width of graph	B1	must have appropriate triangle on Fig. 2.2 or two sets of data lying on the line clearly shown
		ii	expected gradient close to 5	B1	ecf line; typical values (1.4 – 0)/(0.30 – 0.02)
	b	i	All points lie below the theoretical line	B1	accept quantitative answers e.g. error in s is half a square
		i	the error bars on each reading are not long enough to allow a worst line through the origin / AW	B1	and in t^2 is 3 to 4% as several readings averaged 2 marks for two valid points
		ii	s is too small	B1	Or s should be larger
		ii	same shift in all values so no change to gradient	B1	
		ii	t is too big	B1	
		ii	constant error in t leads to increasing error in t^2 so gradient is changed / steeper	B1	
		iii	sensible reason for t being too large or s too small	B1	e.g. electromagnet does not release instantaneously,trapdoor is stiff, faulty contacts,etc e.g. scale on ruler does not start at the end / AW
			Total	**12**	
76		i	Constant acceleration from 0 shown correctly followed by constant velocity.	B1	
		i	Constant velocity at 24 ms^{-1} starting at t = 16 s	B1	
		ii			Alternative method of equating areas.
		ii	Distance moved by B = (1/2 × 1.5 × 16^2) + 24(t − 16)	C1	Distance moved by B = (8 × 24) + (24(t − 16))
		ii	(1/2 × 1.5 × 16^2) + 24(t − 16) = 22t	C1	22t = (8 × 24) + 24(t − 16)
		ii	t = 96 (s)	A1	t = 96
			Total	**5**	
77			$eV = ½mv^2$ so $v^2 = 2eV/m$ $ma = eE$ so $a = eE/m$ $x = vt$ $d = ½at^2 = ½a(x/v)^2$ $d = (eE/2m).x^2.(m/2eV) = Ex^2/4V$ $x^2 = 4(d/E)V$	B1 B1 B1 B1 B1 A0	four equations are needed and some sensible substitution, etc. shown for the fifth mark
			Total	**5**	
78	a		arrow down through centre of ball labeled weight **or** W **or** mg **or** 1.2 N	**B1**	zero if any other arrows or forces present **Examiner's Comments** There were some carelessly drawn arrows on the diagram but otherwise this was done well. There were some arrows labelled *centripetal force*.

	b	i	(horizontally) mv^2/r **(or** $mr\omega^2$) = T sin θ **and** (vertically) W **or** mg = T cos θ (tan θ = v^2/rg **or** rw^2/g) tan θ = 0.045 × 4 × 9.87 × 2.2 / 9.81 **or** 0.48 / 1.2 (= 0.40) θ = 22°	**M1** **A1** **A0**	**accept** figures in place of algebra, r = 0.045 m v = 0.42 m s^{-1} ω = 3π rad s^{-1}; $r\omega^2$ = 4.0 m s^{-2} ; W = 1.2 N and m = 0.12 kg and $mr\omega^2$ = 0.48 N **accept** labelled triangle of forces diagram **N.B.** this is a *show that Q* ; sufficient calculation must be present to indicate that the candidate has not worked back from the answer
		ii	k = (mg / x_0 = 1.2 / 0.050) = 24 (N m^{-1}) (T = mg / cos θ = kx giving) x = 1.2 / 24 cos 22 x = 0.054 (m)	**C1** **C1** **A1**	**or** solution by ratios **Examiner's Comments** About half of the candidates completed the angle calculation successfully with a slightly smaller number finding the correct extension of the string.
	c		(y = ½gt^2 =) 0.18 = 0.5 × 9.81 × t^2 giving t = 0.19 (s) (x = vt =) 0.42 × 0.19 = 0.08 (m) distance = $\sqrt{(r^2 + x^2)}$ = √(0.0020 + 0.0064) = 0.092 (m)	**C1** **C1** **C1** **A1**	**alt:** projectile motion: x = vt, y = ½gt^2 y = ½$g(x / v)^2$ **ecf (b)i** for v; $x^2 = 2yv^2/g$ = 2 × 0.18 × 0.42^2/9.81 **Examiner's Comments** About half of the candidates found the time for the ball to fall to the bench. Most then managed to find the horizontal distance from the point of release, but half forgot that the point of reference in the question was the centre of rotation so failing to complete the calculation.
	d		T increases **or** string stretches **or** angle θ increases to provide / create a larger centripetal force	**M1** **A1**	**allow** mv^2/r **or** $mr\omega^2$ in place of *centripetal force* causality must be implied to gain the A mark **Examiner's Comments** About half of the candidates appreciated that the tension in the string increased or that the angle of the string to the vertical increased. Most answers gave the impression that the *centripetal force* was a *real* force rather than its provision being necessary for the ball to follow a circular path
			Total	**12**	
79		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 $gh = \frac{1}{2} u^2$	**C1**	**Allow** *v* and *u* interchanged; a and g interchanged **Allow** use of candidate's answer for (a)(i) at this point **Ignore** sign

			$h = \frac{28.2^2}{2 \times 9.81}$ (Any subject) h = 40.5 (m)	M1 A0	**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**
		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°. $E_k = \frac{1}{2} \times 0.057 \times 10.26^2$ 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 **Examiner's Comments** 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	**6**	
80			***Level 3 (5−6 marks)** Clear procedure, measurements and analysis. *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:** **Procedure** • Release ball and start timer. • Stop timer when ball reaches bottom of ramp. • Make distance as long as possible to reduce % uncertainty in timing.

			Level 2 (3−4 marks) 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 some evidence.* **Level 1 (1−2 marks)** Limited procedure and limited measurements or limited analysis. *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.		• Repeat measurement for *t* to get an average. • Mark the ramp at the set distance *d* to ensure release point is accurate. • Use a release mechanism to release ball. • Ensure the ball is not pushed when released. **Measurements** • Measure θ using protractor or calculate θ using trigonometry and correct distances. • Measure *t* using a stopwatch. • Measure the distance *d* using a ruler, from the leading-edge of the ball to the bottom of the ramp. **Analysis** • Plot a correct graph; e.g. *d* against t^2. • Gradient of best fit straight line determined. • Correct determination of *g* from the gradient.
			Total	**6**	
81		i	$\rho = m/V = m/Av$; so $m = A\rho v$	C1	
		i	$7.5 \times 10^{-5} \times 1000 \times v = 0.070$	A1	
		i	giving $v = 0.93$ (m s^{-1})	A0	
		ii	3.7 (m s^{-1})	A1	Accept 3.72
		iii	$F = \Delta(mv)/\Delta t = 0.070 \times (3.72 - 0.93)$	C1	**ecf (ii)**
		iii	$F = 0.195$ (N)	A1	accept 0.19 or 0.2(0)
		iv	arrow into the shower head perpendicular to its face.	B1	award mark for a reasonable attempt.
			Total	**6**	
82		i	$\varepsilon = eV = 12 \times 1.6 \times 10^{-19} = 1.92 \times 10^{-18}$ (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	$v = 2.05 \times 10^6$ (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**	
83	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 = $½at^2 + vt'$ = $0.23 \times 1.5^2 + 0.69 \times 2.5$	C1	ecf acceleration and speed values
		ii	s = 2.24 m	A1	
	b		power lost in circuit = $30^2 \times 0.11$	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**	

84			**Level 3 (5−6 marks)**
			Clear description of experiment **and** clear 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 of experiment 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 of experiment or limited analysis
			
			There is an attempt at a logical structure with a line of reasoning. The
				B1x6	Use level of response annotation in RM Assessor, e.g. L2 for 4 marks, L2^ for 3 marks etc.
					Indicative scientific points may include:
					Description
					
					• Ruler used to determine *x*
					• Balance used to determine mass of marble
					• x recorded for various *v*
					• Average readings to determine *x*
					• 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*, double average speed
					
					• Suitable method for consistent *v* or varying *v* e.g.
					  ○ Released from same point on a track or ramp
					  ○ Ejected from a spring with different compressions
					
					Analysis
					
					• Plot a graph of *x* against v^2 or graph consistent with suggested relationship e.g. v^2 against *x*; *v* against $\sqrt{x}$; $½ mv^2$ against *x*

information is in the most part relevant.

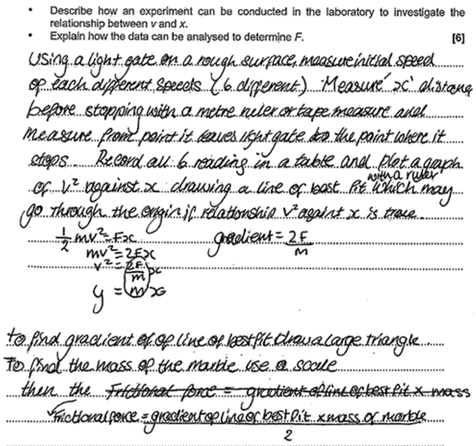
0 marks
No response or no response worthy of credit.

- If relationship is correct, then a **straight line** through the origin.
- Determination of gradient
- F determined by F = m/2 divided by (gradient of x against v^2 graph) or other relationship with F as the subject consistent with candidate's proposed graph.

Examiner's Comments

Most candidates made excellent attempts at describing this investigation. The analysis section was particularly well completed compared with previous sessions. Many of these investigations would have been successful had they been given as instructions to year 12 students as shown by Exemplar 6. The higher ability candidates distinguished themselves by being clear about how they were going to measure or calculate the speed of the marble and do that in a predictable way. This is shown best by exemplar 7.

Exemplar 6



- Describe how an experiment can be conducted in the laboratory to investigate the relationship between v and x.
- Explain how the data can be analysed to determine F. [6]

Using a light gate on a rough surface, measure initial speed of each different speeds (6 different) Measure 'x' distance before stopping with a metre ruler or tape measure and measure from point it leaves light gate to the point where it stops. Record all 6 reading in a table and plot a graph of v^2 against x drawing a line of best fit with a ruler which may go through the origin if relationship v^2 against x is true.

$\frac{1}{2}mv^2 = Fx$ gradient = $\frac{2F}{m}$

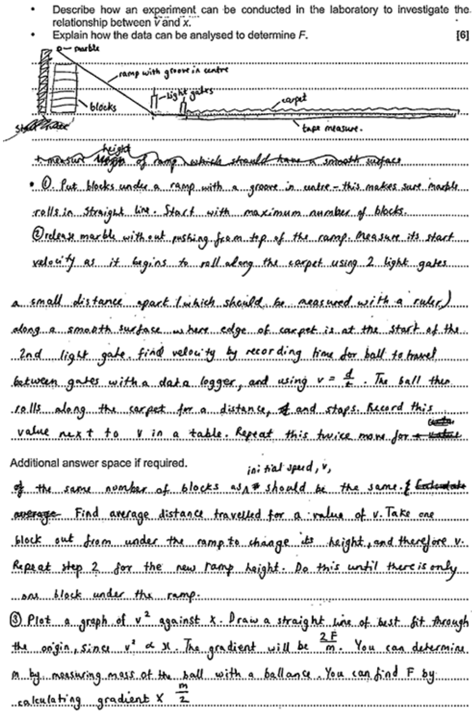
$mv^2 = 2Fx$

$v^2 = \frac{2F}{m}x$

$y = mx$

to find gradient of line of best fit draw a large triangle
To find the mass of the marble use a scale
then the ~~Frictional force = gradient of line of best fit x mass~~
Frictional force = $\frac{\text{gradient of line of best fit} \times \text{mass of marble}}{2}$

This response is a very good attempt. They have employed a light gate to measure the speed, without much explanation of how that device would calculate the speed itself. The analysis is sound, with a clear indication of what they would do with the data and how the relationship in the question matched up to a straight line of best fit. The candidate has made sure that they have explained how to calculate F from the gradient, rather than leaving it to the reader to work it out for themselves. This response scored Level 2.

					Exemplar 7  • Describe how an experiment can be conducted in the laboratory to investigate the relationship between *v* and *x*. • Explain how the data can be analysed to determine *F*. [6] marble; ramp with groove in centre; light gates; carpet; blocks; tape measure. ~~+ measure length of ramp which should have a smooth surface~~ height • ① Put blocks under a ramp with a groove in centre – this makes sure marble rolls in straight line. Start with maximum number of blocks. ② release marble without pushing from top of the ramp. Measure its start velocity as it begins to roll along the carpet using 2 light gates a small distance apart (which should be measured with a ruler) along a smooth surface where edge of carpet is at the start of the 2nd light gate. find velocity by recording time for ball to travel between gates with a data logger, and using $v = \frac{d}{t}$. The ball then rolls along the carpet for a distance, x and stops. Record this value next to v in a table. Repeat this twice more for ~~a value~~ of the same number of blocks as initial speed, v, should be the same. ~~Calculate average~~ Find average distance travelled for a value of v. Take one block out from under the ramp to change its height, and therefore v. Repeat step 2 for the new ramp height. Do this until there is only one block under the ramp. Additional answer space if required. ③ Plot a graph of v^2 against x. Draw a straight line of best fit through the origin, since $v^2 \propto x$. The gradient will be $\frac{2F}{m}$. You can determine m by measuring mass of the ball with a ballance. You can find F by calculating gradient × $\frac{m}{2}$ This response is similar in many ways to the previous exemplar. The difference is that the candidate has explained carefully how they will achieve different speeds and equally, how 2 light gates connected to a datalogger will measure the time of transit between the gates. The calculation of the speed *v* is easy to spot as the distance between the light gates divided by the time between them. Furthermore, there is reference to repeat readings for given *v* and an average distance for *x*. The analysis to find *F* is not quite as explicit as that in the previous exemplar, yet it is easily sufficient for a Level 3 response.
			Total	**6**	
8	5	i	Tangent drawn at t = 4.0 s Attempt at calculating the gradient v calculated from gradient and between 9.50 - 10.50 (m s^{-1}) **OR** s = 20 (m) and $s = ½ at^2$ 20 = ½ a × 4.0^2 **or** a = 2.5 (m s^{-2}) v = 2.5 × 4.0 **or** v^2 = 2 × 2.5 × 20 v = 10 (m s^{-1})	C1 C1 A1 C1 C1 C1 A0	**Allow** other correct methods **Note** working required for this mark
		ii	change in momentum = 1200 x 10 or 12000 (kg m s^{-1}) rate of change of momentum = 3000 unit: kg m s^{-2} or N **OR** F = 1200 X 2.5	C1 A1 B1 C1 A1 B1	**Allow** ECF from **(i)** **Allow** 2850 - 3150 **Allow** newton **Allow** ECF from **(i)** **Allow** newton

			rate of change of momentum = 3000 unit: kg m s^{-2} or N		
			Total	**6**	
8 6			**Level 3 (5–6 marks)** Detailed procedure including labelled diagram and measurements to be taken **and** detailed 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 **or** detailed analysis and limited procedure with limited diagram **or** detailed procedure including diagram and measurements to be taken and limited 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 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.	B1 ×6	**Indicative scientific points may include:** **Diagram and procedure** • labelled diagram • horizontal surface supported • description of procedure • method to release ball • method to identify position ball hits the ground • repeats experiment for each *v* • method to prevent ball rolling on floor in laboratory **Measurements** • measuring instruments to determine *v* • measurements to determine *v* e.g. *mgh* conversion or one light gate with diameter of ball measured or two light gates with distance between light gates measured • use of ruler to measure *R*. **Analysis** • equation to determine *v* • appropriate graph, e.g. plot *R* against *v* or plot R^2 against v^2 • Expect straight line passing through origin • $Q = g \times \text{gradient}^2$ or $Q = g \times \text{gradient}$ **Examiner's Comments** In Question 4, candidates were required to plan an experiment. A diagram should have been drawn which should indicate a workable experimental set-up. In this particular case, it was expected that candidates would include a method of support for the horizontal surface, a method to release the ball (e.g. a curved slope or a horizontal spring) and a method to determine the velocity as the ball left the horizontal surface. Most candidates indicated a rule to measure distance *R*. Candidates should also describe the method – perhaps indicating that *R* would be measured several times for same *v* and an average calculated. Safety precautions should also be included. Some candidates suggested good methods of identifying where the ball would land, e.g. use sand or add paint to the ball. High achieving candidates clearly described how the velocity of the ball as it left the horizontal surface could be determined. Some used an energy conversion either of gravitational potential energy to kinetic energy or elastic strain energy to kinetic energy. Others suggested the use of either one or two light gates connected to a data-logger. In the case of using one light, the diameter of the ball would need to be determined while for two light gates, the gates should be positioned close to each other and the distance between the two light gates would need to be measured.

					Most candidates suggested an appropriate graph to plot and then described how *Q* could be calculated using the gradient.
			Total	**6**	
8 7			**Level 3 (5–6 marks)** Clear description of experiment **and** measurements **and** clear 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 of experiment **and** 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 some evidence.* **Level 1 (1–2 marks)** Limited description of experiment **or** Limited measurements **or** Limited analysis *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.	B1×6	**Indicative scientific points may include:** **Description** • Release method • Ensure bob is not pushed • Repeat experiment for same *H* • Repeat for different H • Centre of mass of single bob and joined bob considered • Keep bob string taught **Measurements** • Measure heights *h* and *H* with ruler • Use centre of mass of bob or another suitable method • Use video camera to record motion • Use of datalogger and appropriate sensor to measure *H* and *h* • Measure mass with (top pan) **balance** **Analysis** • Construct a table of *h* and *H* • Plot graph of *h* against *H* • LoBF should pass through origin. • Determine gradient or calculate *h*/*H* ***repeatedly*** • gradient $= \left(\frac{M}{M+m}\right)^2$ (gradient must be consistent with the plot) • Masses substituted into above expression and checked against experimental gradient
			Total	**6**	
8 8		i	($g \rightarrow$) [m s^{-2}] **and** ($t \rightarrow$) [s] **or** ($gt^2 \rightarrow$) [m $s^{-2} \times s^2$] Clear evidence of working leading to m on both sides	M1 A1	
		ii	*s* / distance measured with a ruler / tape measure Timer mentioned for measuring *t* / time Measure distance from bottom of ball to (top of) trapdoor	B1 B1 B1 B1	

			Answer	Marks	Guidance
			Any <u>one</u> from: • Take repeated readings (for *t* for same *s*) to determine average *t* • Avoid parallax error when using the ruler		
			Total	**6**	
89		i	$(E=)\ \frac{4000}{0.080}$ $(F=)\ \frac{4000}{0.080}\times 1.6\times 10^{-19}$ $(a=)\ \frac{8.0\times10^{-15}}{9.11\times10^{-31}}$ **or** 8.78×10^{15} $a = 8.8\times10^{15}$	C1 C1 C1 A0	$E = 5.0\times10^{4}$ (V m^{-1}) $F = 8.0\times10^{-15}$ (N) **Allow** this mark if the working is shown. If only value is given, then the answer must be 3SF or more **<u>Examiner's Comments</u>** This question asks for a calculation to show the value of the vertical acceleration in an electric field. The magnitude of the electric field strength first needs to be calculated, followed by the acceleration from Newton's second law. Candidates are reminded that a **show** question needs to be answered in detail and that each stage should be clear. Roughly equal numbers of candidates scored full marks or zero on this question.
		ii	$(t=)\ \frac{0.12}{6.0\times10^{7}}$ ($t = 2.0\times10^{-9}$ s)	M1 A0	**<u>Examiner's Comments</u>** As with the previous question, there is the need to make sure that the calculation leading to the given answer is clearly set out.
		iii	$(x=)\ \frac{1}{2}\times 8.78\times10^{15}\times(2.0\times10^{-9})^{2}$ $x = 1.8\times10^{-2}$ (m)	C1 A1	**Allow** $a = 8.8\times10^{15}$ **<u>Examiner's Comments</u>** Most candidates appreciated the need to use an equation of motion in their solution, but a significant number of candidates used an initial horizontal velocity in the expression, leading to an incorrect answer. There were also an unusually large number who gave no response. Candidates should appreciate that if they have been given show questions, then it is likely that these values will be used in alter questions. **Misconception** Many candidates included an initial vertical velocity – it may be helpful to think of this process as analogous to that of projectile motion.
			Total	**6**	

90		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	**1** Time of flight is independent of speed/AW Because distance of fall is the same **and** initial velocity vertically is zero / velocity is horizontal at **X** **2** *D* increases as speed at **X** increases 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**	
91		i	22.1 ± 0.9	B1	value plus uncertainty both required for the mark allow ± 1.0
		ii	two points plotted correctly, including error bars;	B1	**ecf** value and error bar of first point
		ii	line of best fit worst acceptable straight line.	B1	**allow ecf** from points plotted incorrectly steepest or shallowest possible line that passes through all the error bars; should pass from top of top error bar to bottom of bottom error bar **or** bottom of top error bar to top of bottom error bar
		ii	gradient (= 4d / E) = 2.4 ± 0.4;	B1	**allow** 2.4 ± 0.5
		ii	E = 4 × 2.0 × 10^{-2} / 2.4 × 10^{-6} = 3.3 × 10^4	B1	
		ii	(3.3) ± 0.6 × 10^4	B1	0.1/4 + 0.4/2.4 = 0.192 × 3.3 = 0.63
		ii	V m^{-1} or N C^{-1}	B1	0.1/4 + 0.5/2.4 = 0.233 × 3.3 = 0.77 **allow** 3.3 ± 0.8 × 10^4
			Total	**7**	
92		i	(*F* = *ma* =) 190 × 10^3 = 2.1 × 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)

		ii i	**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**	
9 3		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*.
		ii i	$V^2 = 0.80^2 + 2 \times 9.81 \times 0.40$ 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}) **<u>Examiner's Comments</u>** 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**	
94		i	$a = F / m$ / $a = 8700 / 2300$	C1	
		i	$a = 3.8$	A1	**Note** answer is 3.78 to 3 s.f.
		ii	$D_{thinking} = u \times t = 22 \times 0.97 = 21.3$ (m)	C1	Allow 21.34
		ii	$D_{braking} = u^2 / 2a$ or $22^2 / (2 \times 3.8) = 64.0$ (m)	C1	Allow 63.98
		ii	stopping distance = $D_{thinking} + D_{braking}$ or 21.3 + 64.0	C1	Allow ecf
		ii	stopping distance = 85.3 (m)	A0	Allow 85.32
		iii	22 × 3600 / 1600 (= 49.5 mph)	B1	
		iv	Thinking distance for truck longer than in chart	B1	
		iv	Suggested reason e.g. tired	B1	Allow any relevant factor
		iv	Braking distance for truck longer than in chart	B1	
		iv	Suggested reason e.g. truck more massive than a car, truck's brakes are poor quality	B1	Ignore reference to road conditions
			Total	**10**	
95		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) × 10^7(J)	C1 A1	**Allow** use of 16.9 gives 2.7 × 10^7(J)
		2	$0 = 17^2 + 2a \times 310$ OR $t = \frac{310}{8.5}$ $a = (-)\frac{17^2}{2\times310} = (-)\frac{289}{620}$ OR $a = \frac{17}{36.5}$ 0.47 (m s^{-2})	C1 C1 A1	**Allow** $v^2 = u^2 + 2as$ with values stated correctly **Ignore** negative sign **Allow** use of 16.9 gives 0.46 **Not** 0.5
		3	3 1.9 × 10^5 × 0.47 89000(N)	C1 A1	**Allow** ECF from **(b) (ii) 1** and **(b) (ii) 2** **Allow** $\frac{2.7\times10^7}{310}$ **Allow** 1.9 × 10^5 × 0.46 **Allow** $\frac{1.9\times10^5\times17}{36.5}$ **Allow** alternatives 87100, 87400, 88000 **Examiner's Comments** Most candidates were able to correctly write down the equation 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 weight acts against the motion / down the incline / same direction as braking force OR some KE transferred to GPE Smaller distance 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**	