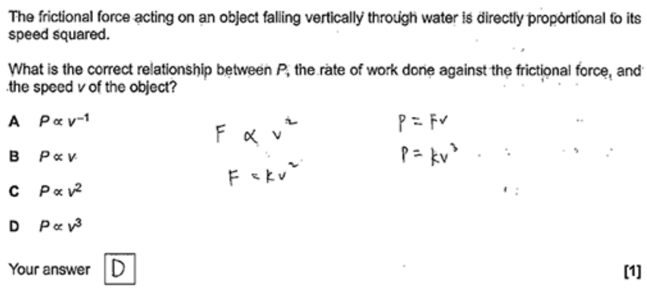
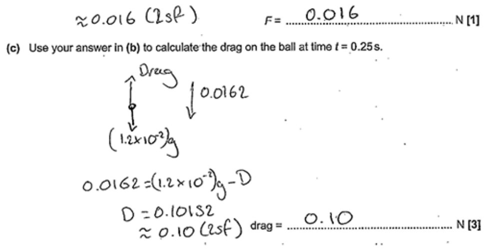
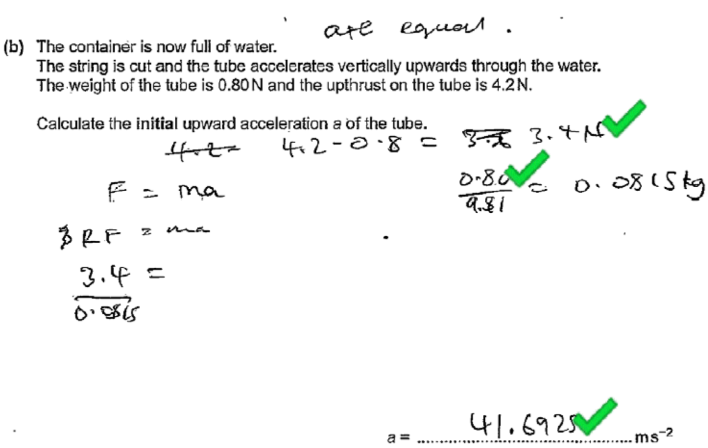
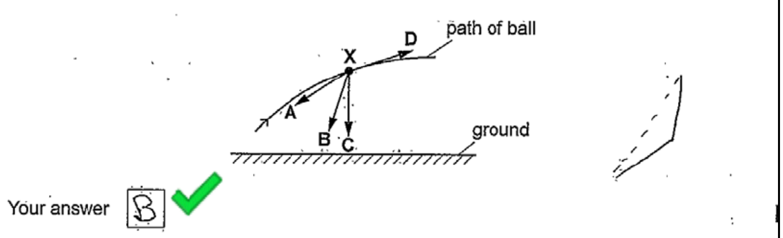
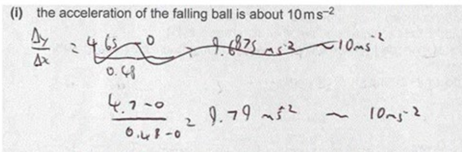
Mark scheme - Forces in Action Motion with non-uniform acceleration

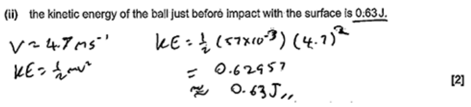
Question			Answer/Indicative content	Marks	Guidance
1			**D**	1	**Examiner's Comments** This question is based on the equation $P = Fv$, which also appears in the Data, Formulae and Relationship Booklet. In the question, information is given about the frictional force F, which is directly proportional to v^2. Therefore, the rate of work done P must be proportional to v^3; making D as the answer. Most candidates struggled with this question, with all the distractors being equally popular. Less than a quarter of the candidates, mainly from the upper quartile, scored a mark in this question. The exemplar 2 below the correct response from a candidate. **Exemplar 2**  The frictional force acting on an object falling vertically through water is directly proportional to its speed squared. What is the correct relationship between P, the rate of work done against the frictional force, and the speed v of the object? **A** $P \propto v^{-1}$ **B** $P \propto v$ **C** $P \propto v^2$ **D** $P \propto v^3$ Your answer D **[1]** This candidate demonstrates how this question can be tackled with minimal amount of work. The key equation is on the script, as is the relationship between F and v. The final answer appears in the box; a perfect technique.
			Total	**1**	
2			A	1	
			Total	**1**	
3	a		F (= ma = 1.2 x 10^{-2} x 1.3) = 0.016 (N)	B1	Possible ECF from (**a**) (1.2 x 10^{-2} x their answer) **Note** answer to 3 SF is 0.0156 (N)
	b		W = 1.2 x 10^{-2} x 9.81 or 0.118 (N) 0.0156 = 0.118 − drag (Any subject) drag = 0.10 (N)	C1 C1 A1	Possible ECF from (**b**) **Allow**: use of 'g' for 9.81 **Allow** 0.1 (N) **Examiner's Comments** Most candidates correctly calculated the ball's weight. They had calculated the resultant force on the ball, using F = ma. The resultant force from the previous question was checked, as error carried forward rules applied. Exemplar 3 shows an excellent way of planning out how to answer this sort of question.

					Exemplar 3  This candidate has drawn a free-body force diagram to make their intention clear. From it, they know that the resultant force must equal the weight minus the drag. From there they have found the drag force.
			Total	**4**	
4	a		(resultant force =) 4.2 − 0.8 **or** 3.4 (N) (*m* =) 0.8/9.81 **or** 0.0815 … (kg) ($a = \frac{3.4}{(0.8/9.81)}$) *a* = 42 (m s^{-2})	C1 C1 A1	**Allow** 0.082 (kg) **Not** 0.08 (kg) **Allow** 2 marks for F = 3.4 (N), m = 0.08 (kg) and hence a = 42.5 or **43** (m s^{-2}) **<u>Examiner's Comments</u>** The majority of the candidates scored full marks. Most answers showed good structure and reasoning. The data is given to two significant figures (SF). Answers given to more significant figures were condoned. However, if the answer was given to one SF, then this would have been penalised once only in the entire paper. **Exemplar 9**  This exemplar illustrates a decent solution from a grade C candidate. The physics is very easy to follow – resultant force determined, mass calculated from the weight and then the final value for the acceleration. As mentioned earlier, the answer is not given to two SF, but this was allowed in this specific question.

	b		There is (an increasing) friction / drag (acting on the tube)	**B1**	**Allow** (water) resistance / resistive force **Allow** upthrust decreases as tube comes out of water AW **Not** 'drag **and** upthrust', unless the upthrust is qualified asabove
			Total	**4**	
5			**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**	
6			**C**	1	
			Total	**1**	
7			C	1	
			Total	**1**	
8			**C**	**1**	
			Total	**1**	
9			B	1	
			Total	**1**	
1 0			A	1	
			Total	**1**	
1 1			C	1	

			Total	**1**	
12			C	1	
			Total	**1**	
13			B	1	**Examiner's Comments** Before the cone reaches terminal velocity, it is still accelerating downwards so there is still a resultant force downwards. Once the cone is at terminal velocity, the resultant force must be zero. This means that the resultant force has decreased, giving the correct answer B.
			Total	**1**	
14			**B**	1	
			Total	**1**	
15			C	1	
			Total	**1**	
16			D	1	
			Total	**1**	
17			The path is always below the original path	M1	
			The maximum height of path is reached before the front of the hockey goal	A1	**Examiner's Comments** Most candidates realised that the path was lower but few realised that it would reach a maximum height before the goal.
			Total	**2**	
18	a	i	$u = 17 \cos 30 = 14.7$ (m s^{-1})	C1	
		i	$h = ut - ½gt^2$; $= 14.7 \times 1.5 - ½ \times 9.81 \times 1.5^2$	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	$s = 2 \times 8.5 \times 1.5$	C1	**ecf 2a**
		ii	s = 26 (m)	A1	allow 25.5 m
	b		$0 = 17 \sin 30\ t - ½ \times 9.81 \times t^2$	C1	
			so t = 0 or 17/9.81 = 1.73	C1	
			$s = 14.7 \times 1.73 = 25.4$ (m)	A1	allow $s = 15 \times 1.7 = 25.5$ (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**	
19	a	i	$\frac{\Delta v}{\Delta t}$ <u>and</u> $\Delta t \geq 0.20$ s 9.8 m s^{-2}	M1 A0	**Allow** tolerance of ±½ a small square e.g. $\frac{4.7(-0)}{0.48(-0)} = 9.79$ **<u>Examiner's Comments</u>** This question was a "show" type question. Candidates needed to show their working logically. Ideally candidates would state that that the acceleration was equal to the gradient, and then show the substitution of the data values for the gradient calculation. It was expected that candidates would have gained an answer of 9.79 m s^{-2} **Exemplar 1**  This candidate has clearly demonstrated from $\Delta y / \Delta x$ that the gradient is to be determined. Co-ordinates are substituted into the gradient expression and it is clear that the candidate has used more than half the hypotenuse. The candidate then correctly evaluated the expression to give of 9.79 m s^{-2}. and then states that this is about 10 ms^{-2}. **AfL** Determining a gradient. Candidates should clearly demonstrate the co-ordinates that are used to calculate the gradient. The co-ordinates must lie on the line. A common error is when a candidate uses a data point from a table of results. Candidates should be encouraged to read carefully the quantities from the axes and to pay attention to powers of ten and units. The length of the hypotenuse used for the gradient calculation should be at least half the length of the line.

					Candidates should clearly show the substitution of the co-ordinates and then evaluate the answer using the expression: gradient $= \frac{y_2 - y_1}{x_2 - x_1}$. The advantage of this method, it that negative gradients are automatically determined. **AfL** The gradient of a velocity-time graph is acceleration.
		ii	4.7 or $\frac{1}{2}$ x 0.057 x v^2 $\frac{1}{2}$ x 0.057 × 4.7^2 = 0.629565 0.63 J	M1 M1 A0	**<u>Examiner's Comments</u>** This was also a "show" type of question. Candidates needed to correctly read the maximum velocity (4.79 m s^{-1}) from the graph and change the mass of 57 g into kilograms. To gain the marks, clear substitution into the kinetic energy equation was needed with a correctly evaluated answer. **Exemplar 2**  (ii) the kinetic energy of the ball just before impact with the surface is 0.63 J. $V \approx 4.7 ms^{-1}$ $KE = \frac{1}{2}(57\times10^{-3})(4.7)^2$ $KE = \frac{1}{2}mv^2$ $= 0.62957$ $\approx 0.63J$ [2] In this two-mark answer, the candidate has clearly demonstrated the value from the graph as well as the equation that is going to be used. The candidate has correctly changed 57 g to kilograms effectively by using standard form. The candidate has then correctly evaluated the expression as 0.62957 before stating that this is approximately equal to 0.63 J. Candidates often find it helpful to underline relevant quantities. In this response the candidate has underlined 0.63 J.
	b	i	0.8 x 0.63 J (0.504 J) OR $v^2 = \frac{2\times KE}{0.057}$ $v^2 = \frac{2\times 0.504}{0.057}$ 4.2(1) (ms^{-1})	C1 C1 A1	**Allow** one mark for correct rearrangement of KE equation with incorrect KE 17.684 **<u>Examiner's Comments</u>** In this question, higher ability candidates initially determined the kinetic energy (0.504 J) as the ball leaves the surface, before rearranging the kinetic energy equation. A few candidates did not take the final square root.

		ii	Straight line from (0.48, –4.2) to *x*-axis <u>and</u> plotted to ±½ small square *x*-axis intercept at *t* = 0.91 ± 0.03 (s) from negative *v*	C1 A1	**Allow ECF** from **(b)(i)** **Allow** (0.49, –4.2) / (0.50, –4.2) / (0.51, –4.2) / (0.52, –4.2) **Allow ECF** for incorrect negative *v* **<u>Examiner's Comments</u>** In this question, a large number of candidates did not understand that velocity is a vector quantity and drew a line with a negative gradient back towards the x-axis. The velocity of the ball as it leaves the surface is in the opposite direction and is therefore – 4.2 m s^{-1}. Candidates then needed to draw a parallel line to the initial line (since the acceleration is still the same). **AfL** Vector quantities have both a magnitude and a direction.
		iii	area under the graph = $\frac{1}{2}$ × 4.2 × 0.43 0.90 (m)	C1 A1	**Allow ECF** from **(i) and (ii)** **Allow** use of equation of motion: e.g. $s = \frac{4.2^2}{2 \times 9.81}$ or s = (–4.2 × 0.43) + $\frac{1}{2}$ × 9.81 × 0.43^2 (numbers must be seen) **Allow** use of loss of KE = gain in PE **Allow** one significant figure **Note** 0.84 for Δt = 0.40 to 0.97 for Δt = 0.46 **<u>Examiner's Comments</u>** There were many methods in which candidates could gain the marks in this question. It was helpful for clear methods to be demonstrated. The simplest was to determine the area under the velocity-time graph. Candidates also used the equations of uniform motion. Common errors seen included the incorrect velocity and when using the equations of motion but being confused about negative signs. Examiners on this occasion allowed an answer of 0.9 m which is one significant figure. Since the data used is to two significant figures, the final answer should also be to two significant figures. **AfL** The area under a velocity-time graph is displacement.

	c		Line will curve / be non-linear OR (magnitude of) gradient of line decreases (with increase in time) (Line will end with) a lower maximum/final velocity or hit the ground after a longer time	B1 B1	**Allow** sketch or gradient decreases / changes **Not** gradient is smaller / less steep / shallower / lower **Allow** ball will have a lower maximum/final velocity or hit the ground after a longer time) **<u>Examiner's Comments</u>** 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**	
20		i	Drag is the same (at a certain velocity) weight is greater or <u>resultant</u> force is larger)	B1 B1	**Allow** air resistance for drag **<u>Examiner's Comments</u>** Lots of candidates described the familiar ideas involving drag increasing with speed until the drag equals the weight's magnitude. The question was constructed to be simpler than this and asks to compare the forces on the 2 balls at a given speed. The weight of the sand-filled ball is larger. The 2 balls are identical in shape so at the same speed will have the same drag force. ***Know what is coming!*** Reading through to the end of the whole question is sensible. The answer candidates gave for Question 17(d)(i) would have formed part of the answer for Question 17(d)(ii), so valuable time can be saved by planning your answers for each part.
		ii	(TV requires) weight = drag **and** weight is greater Clear link to idea that greater speed gives greater drag (for same cross-sectional area)	B1 B1	**<u>Examiner's Comments</u>** The first mark here was for the knowing that the condition for terminal velocity was required, linked to the idea of the sand-filled ball having a larger weight. The second mark was more difficult to achieve, since a clear link between increased speed and increase drag was required.
			Total	**4**	
21		i	Using the graph to determine at least two ratios of the amplitudes.	M1	For example: 2.5/3.0 and 2.1/2.5

		i	Correct statement matching the ratios.	A1	For example: 'The statement is correct because 2.5/3.0 ≈ 2.1/2.5 ≈ constant. '
		ii	At time t = 0	M1	
		ii	Oscillator has maximum speed and hence the greatest friction. (AW)	A1	
			Total	**4**	
2 2		i	250 × 60 = 15000 J	C1	
		i	energy = $\frac{15000}{0.65}$ = 2.3 x 10^4 (J)	A1	
		ii	drag force = 0.4 × 6.0^2 = 14.4 N	C1	
		ii	forward force = power / velocity = 250/6.0 = 41.7 N	C1	
		ii	acceleration = $\frac{41.7 - 14.4}{85}$ = 0.32 m s^{-2}	A1	
			Total	**5**	
2 3			**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.* **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**	**B1 x6**	**Indicative scientific points may include:** **Procedure** • labelled diagram • long tube • method to determine <u>terminal</u> velocity • check for terminal velocity • safety precaution (tray to avoid spills / gloves / clamp tube) • method to remove sphere **Measurements** • measurement of diameter • use micrometer / calliper to measure diameter • averages diameter • measurements to determine v, e.g. stopwatch, ruler, light gate connected to timer, detailed use of video camera • repeats experiment for same r **Analysis** • $r = d / 2$ • determination of terminal velocity • plot a graph of v against r^2 • K = gradient. **Examiner's Comments** This question was the first level of response question on the paper. It involved candidates planning an investigation into the variation of

			No response or no response worthy of credit.		terminal velocity and the radius of a sphere. Candidates were expected to draw a labelled diagram and there were many tubes with elastic bands drawn. To gain the highest marks candidates were expected to explain carefully how they would measure the terminal velocity and to include how they would check that the terminal velocity had been achieved. Candidates were also expected to explain how their results could be used to give to determine the constant K. Good candidates suggested an appropriate graph that should be plotted and explained how K could be determined from the gradient. In general answers were better this year than last year.
			Total	**6**	
24		i	(g →) [m s^{-2}] **and** (t →) [s] **or** (gt^2 →) [m s^{-2} × 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 Any <u>one</u> from: • Take repeated readings (for t for same s) to determine average t • Avoid parallax error when using the ruler	B1 B1 B1 B1	
			Total	**6**	
25	a	i	1. *either* resultant force $F = ma - R$ *or* resultant force decreases as R increases	B1	**allow** for points 2 and 3 *when* $F = R$ appearing only once
		i	2. acceleration a decreases to zero when $F = R$	B1	
		i	3. velocity rises from zero to a terminal / maximum value when $F = R$	B1	
		ii	**1** initial acceleration is 40/120 = 0.33 (m s^{-2})	B1	
		ii	**2** from the graph Rv = 200 (W) so R = 40 N	C1	**or** forward force = 40 N so R = 40 N for constant
		ii	and terminal velocity v is 5 (m s^{-1})	A1	speed / zero acceleration

	b		p.e. / second = mgvsin θ = 120 × 9.81 × 5 × sin θ	C1	**allow** force downhill F = mgsin θ, extra power = Fv
			extra power= 200 (W)	C1	
			so sin θ = 1/29.4 giving × = 29 m	A1	
			Total	**9**	
26		i	weight / W / mg **and** downward arrow upthrust / U **and** upward arrow drag / D / friction **and** upward arrow	**B1** **B1** **B1**	**Allow** labels used in **(c)(i)** throughout **Ignore** arrow sizes. **Allow** '(water) resistance' for drag **Examiner's Comments** The forces referred to by name in module 3 of the specification are weight, drag, upthrust. tension, normal contact force and friction. Candidates should be aware that the three relevant forces in this example are upthrust, weight and drag (with friction as an acceptable alternative). A wide range of other options were provided by candidates, such as gravity, buoyancy, lift, pressure, impulse and air resistance, none of which were acceptable.
		ii	Resultant force decreases (with time or as cylinder descends) Upthrust remains constant / drag decreases (as speed decreases) / resultant force is upwards / At lowest point, drag is zero At lowest point, resultant force is upwards	**B1** **B1** **B1**	**Allow** 'At lowest point, upthrust > weight' **Note:** Any incorrect answer from the list will not score this point **Not** 'resultant force = 0' **Note:** Resultant force is <u>always</u> upwards' scores B1×2 **Examiner's Comments** Examiners would like to see an improvement in the understanding of the forces acting on objects in motion as this item on resultant forces was not answered well. A large proportion of candidates misunderstood the scenario, believing it to be a terminal velocity problem. This meant that many responses included the notion that the block would speed up and eventually have zero resultant force acting upon it. In this case, that would mean that the block would continue at constant velocity downwards rather than return to the surface. This item prompted the candidates by asking about the resultant force at the lowest point of the motion, which tying in with the ideas in previous parts of the question about density and floatation, should have hinted that the resultant force at the lowest point was upwards. Those candidates that did realise this often contradicted themselves to ensure an upwards resultant at the bottom of the motion. Typically, this was by stating, incorrectly, that the upthrust or the drag increased, at which point only one mark was possible.
			Total	**6**	