OCR A Level Physics A (H556) Physics B (H557)

PAG 1: Investigating motion
Practice Exam Questions and Mark Scheme

1. A trolley is placed on a long ramp and is released from rest from the top of the ramp. It travels to the bottom of the ramp with a constant acceleration.

Describe how a metre rule and a stopwatch can be used to determine the **final** velocity v of the trolley at the bottom of the ramp.

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[2]

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2. Fig. 16.1 shows an arrangement used by a group of students to determine the acceleration of free fall *g* in the laboratory.

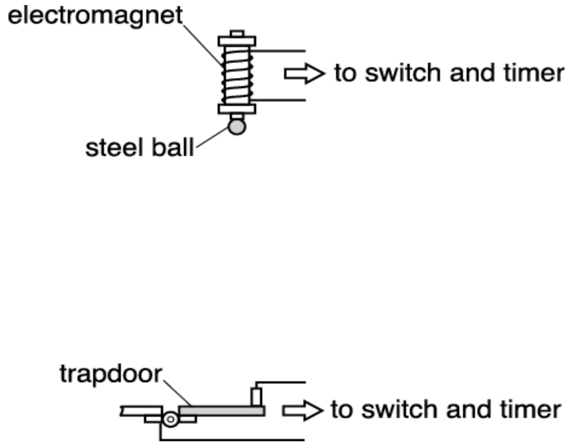

Fig. 16.1

An electromagnet is used to hold a small steel ball in position above a trapdoor. A timer starts as soon as the ball is released, and is stopped when the ball hits and opens the trapdoor. The clamp stands holding the trapdoor mechanism and the electromagnet are not shown in Fig. 16.1.

The distance between the bottom of the steel ball and the top of the trapdoor is 1.200 ± 0.001 m. The steel ball takes 0.50 ± 0.02 s to fall through this distance.

i. Calculate a value for *g* using these results.

g = ...m s^{-2} **[2]**

ii. Determine the percentage uncertainty in the value for *g*.

percentage uncertainty = ... % **[2]**

3. A student wishes to investigate how the terminal velocity v of a metal sphere varies with the radius r of the sphere as it travels through a liquid.

It is suggested that

$$v = Kr^2$$

where K is a constant.

Describe with the aid of a suitable diagram how an experiment can be safely conducted, and how the data can be analysed to determine K.

[6]

4(a). A student carries out an experiment to measure *g*, the acceleration due to gravity, by measuring the time *t* for a steel ball to fall a distance *s*.

The method is shown in **Fig. 2.1**

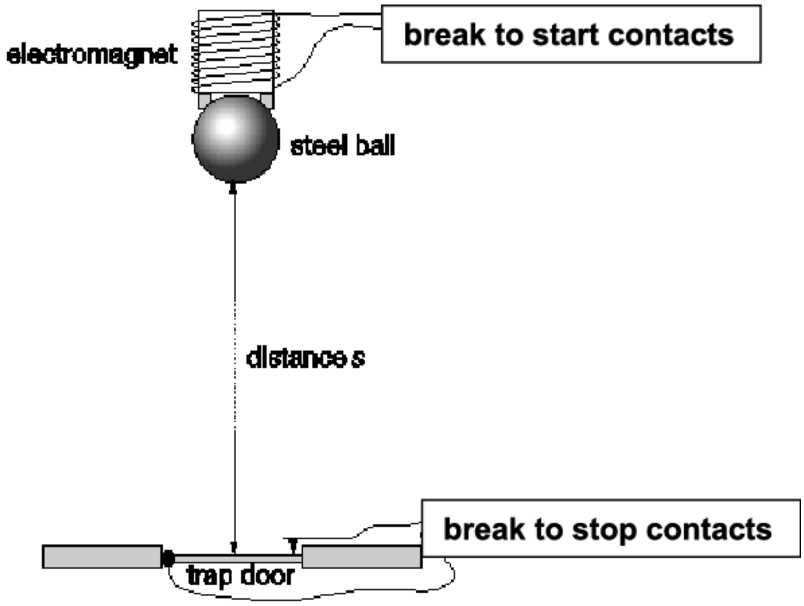

Fig 2.1

The break-to-start and break-to-stop contacts are connected to an electronic timer. As the steel ball is released from the electromagnet, the electronic timer starts. The ball falls a distance *s* before it hits a hinged metal 'trap door'. The trap door opens, breaks the circuit and stops the timer.

The student records the following data for a range of distances *s,* averaging the time *t* at each distance over several drops. He intends to plot a graph of *s* against t^2 so adds a third column to his table of results.

s/m	mean t/s	t^2/s^2
0.40	0.31	0.10
0.60	0.38	0.14
0.80	0.42	0.18
1.00	0.47	
1.20	0.51	
1.40	0.55	0.30

i.Complete the table. Add the final two points to the graph of **Fig. 2.2**. Draw a straight line of best fit on **Fig. 2.2**.

[3]

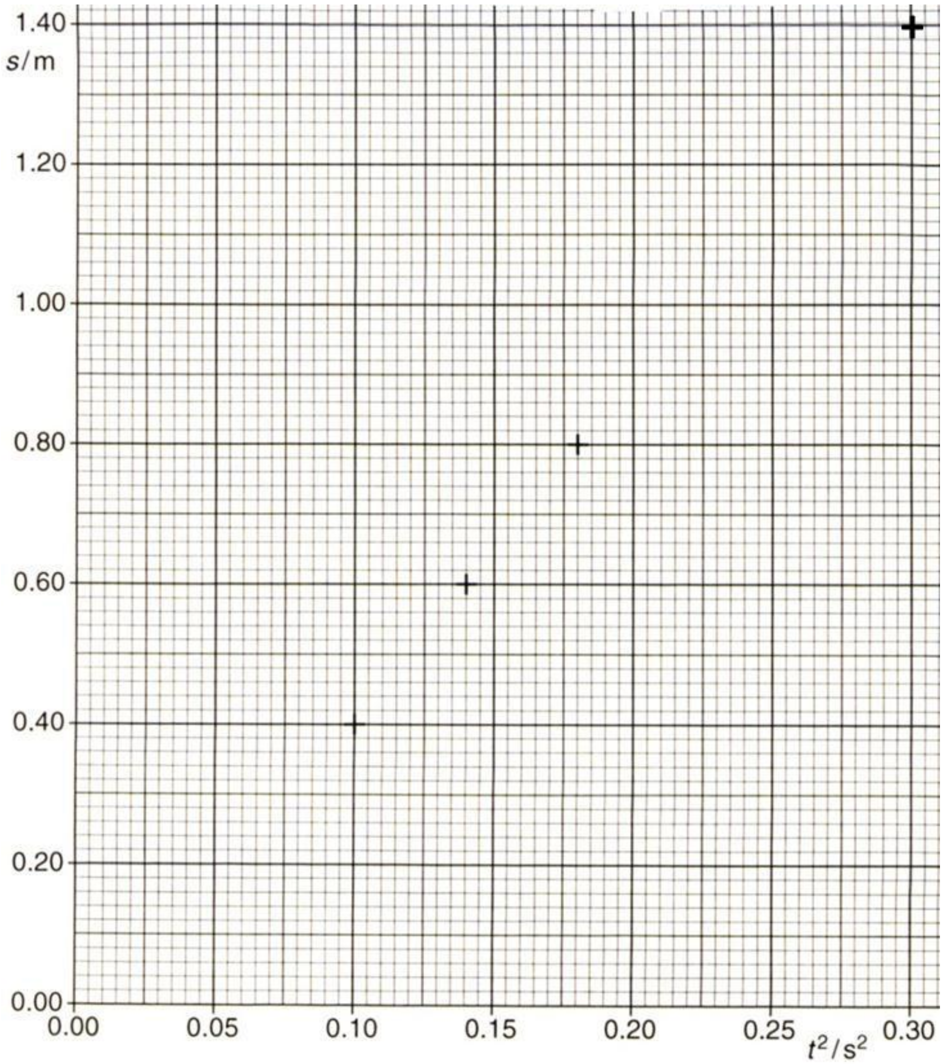

Fig 2.2

ii. Determine the gradient of the line. Show clearly your working.

gradient = ... m s^{-2} **[2]**

(b). The student expected the line to go through the origin and have a gradient of *g*/2. The timing device he used measures to within 0.01 s and the distance *s* was measured to within 0.01 m.

i. The fact that the line of best fit does not pass through the origin is unlikely to have been caused by random errors in his measurements. Justify this statement.

[2]

ii. Explain how a systematic error in each of the measured quantities could contribute to the line not passing through the origin and what effect, if any, each would have on the gradient of the line.

[4]

iii. Suggest one source of possible systematic error in the experiment.

[1]

5. *A group of students decide to determine the acceleration of free fall using the arrangement shown in Fig. 16.2.

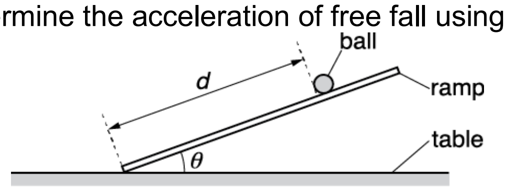

Fig. 16.2

The experiment uses a metal ball and a ramp.

The ball is at a distance *d* from the bottom of the ramp. The ramp makes an angle θ to the horizontal table. The ball is released from rest at time t = 0. The ball takes time t to travel the distance *d.*

The relationship between *d* and *t* is given by the equation

$$d = \frac{1}{2}(g\sin\theta)t^2.$$

Describe how you can conduct an experiment, and how the data can be analysed to determine the acceleration of free fall *g.*

[6]

6(a). Fig. 4.1 shows an arrangement used by a student to determine the acceleration of free fall.

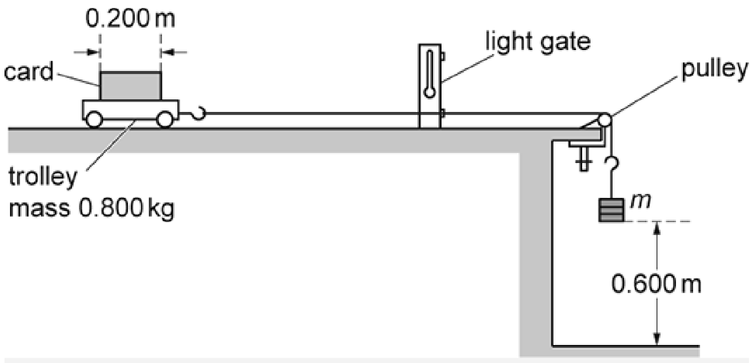

Fig. 4.1

A trolley is attached to a variable mass m by a string which passes over a pulley.

The mass m is released from rest and falls through a fixed height of 0.600 m accelerating the trolley of mass 0.800 kg. When the mass m hits the floor, the trolley then continues to move at a **constant** velocity v.

This constant velocity v is determined by measuring the time t for the card of length 0.200 m to pass fully through a light gate connected to a timer.

Frictional forces on the trolley and the falling mass m are negligible.

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.

[2]

(b). The student records the information from the experiment in a table. The column headings and just the last row for m = 0.600 kg from this table are shown below.

m / kg	t / 10^{-3} s	$\frac{m}{(m+0.800)}$	v / m s^{-1}	v^2 / m^2 s^{-2}
0.600	90 ± 2	0.429	2.22 ± 0.05	

i. Complete the missing value of v^2 in the table including the absolute uncertainty. **[2]**

ii. Fig. 4.2 shows some of the data points plotted by the student.

Plot the missing data for m = 0.600 kg on Fig. 4.2 and draw the straight line of best fit. **[2]**

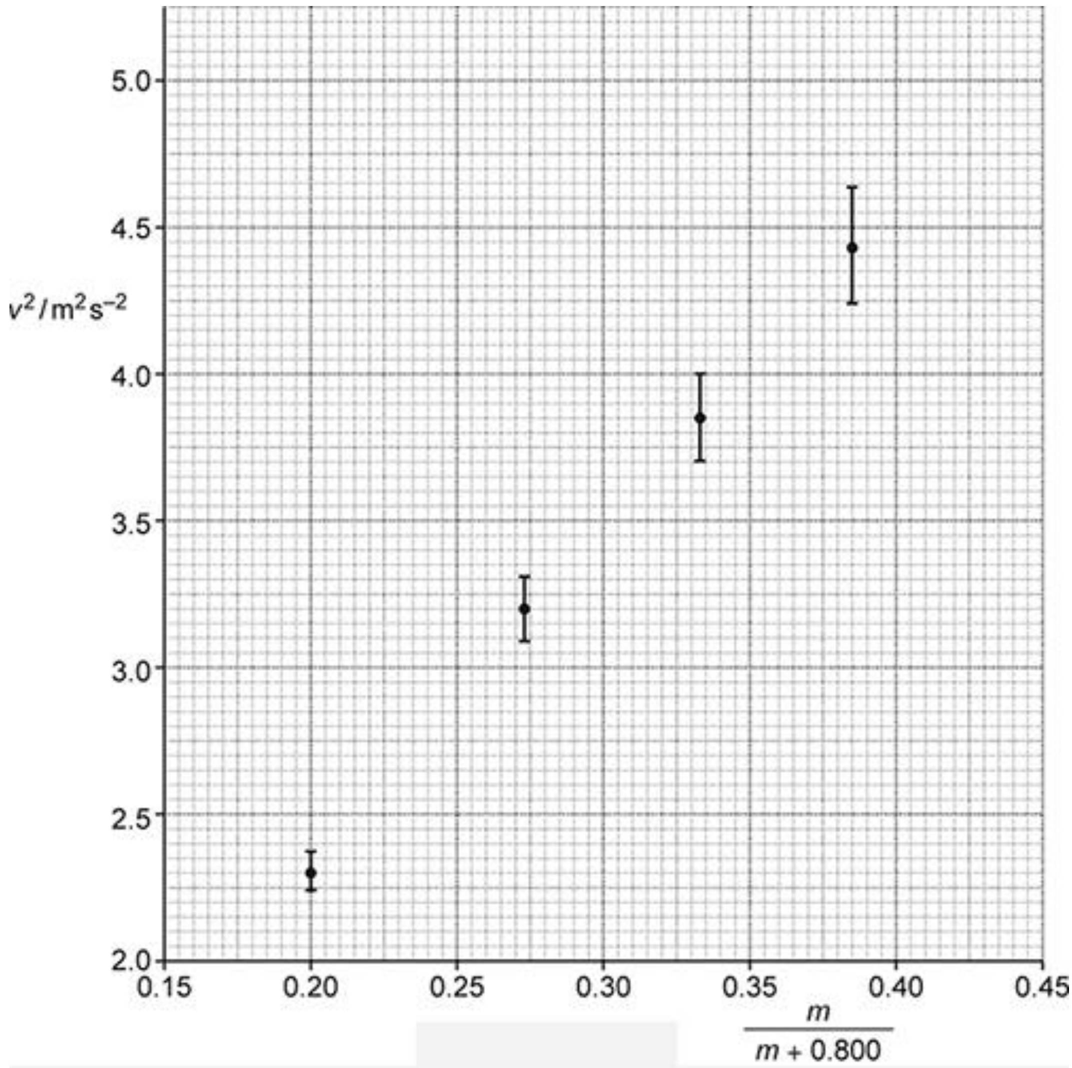

Fig. 4.2

(c).

i. Use the equation given in **(a)** to show that the gradient of the graph of v^2 against $\frac{m}{(m+0.800)}$ is equal to 1.20 g.

[1]

ii. Assume that the best-fit straight line through the data points gives 9.5 m s^{-2} for the experimental value of g.

Draw a worst-fit line through the data points on Fig. 4.2 and determine the absolute uncertainty in the value for g.

absolute uncertainty = ± ______________________ m s^{-2} **[4]**

(d). It is suspected that the card on the trolley did not pass at right angles through the light beam.

Discuss, without doing any calculations, the effect this may have on the experimental value for the acceleration of free fall g.

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____

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____

____

[4]

7. * A student rolls a marble at different speeds on a carpet to model the braking of a car.

The student wishes to investigate how the total distance x travelled before the marble stops (braking distance) depends on its initial speed v.
The speed v and distance x are related by the equation $\frac{1}{2}mv^2 = Fx$ where m is the mass of the marble and F is the constant frictional force acting on the marble.

- 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]

8(a). Carol and Jason are investigating momentum and energy changes in collisions.

They are using two trolleys on a table and measuring velocities with light gates connected to data-loggers. Each trolley has a pad of 'impact material' (rubber) attached to the front.

As each timing card passes through a light gate, it cuts a light beam and the attached data-logger records the time for which the beam has been cut. Fig. 8.1 shows the two trolleys approaching each other, having just passed through the light gates.

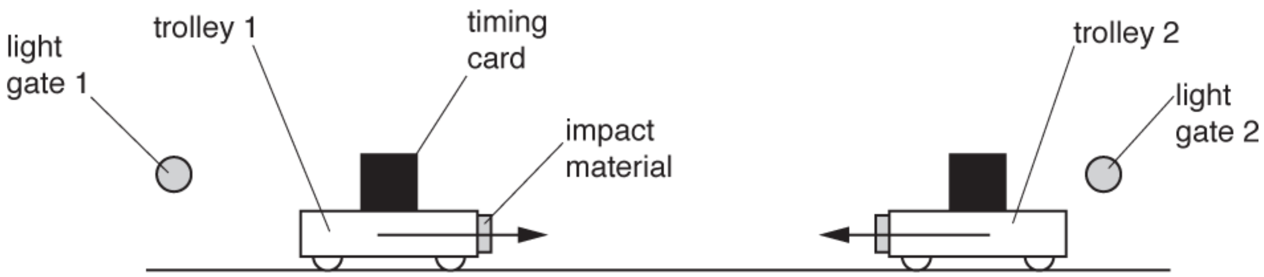

Fig. 8.1

The data-logger and light gate together have a timing uncertainty of 4 μs. Typical times recorded in the experiment are in the range 0.1 s to 1.0 s.

The timing cards are each cut to be 10.0 cm wide in the direction of motion, and the uncertainty in the card width is ± 0.1 cm.

i. Explain in terms of percentage uncertainty why the timing uncertainty can be ignored in this experiment.

[2]

ii. The time recorded by the data-logger when a trolley passes the light gate is 0.1453 s.

Calculate the mean speed of the trolley and its uncertainty.

Give both values to an appropriate number of significant figures.

mean speed = ________ ± ________ m s^{-1} **[3]**

(b). The data for one collision is given below. After the impact, the two trolleys reversed direction and moved back outwards. Each trolley has a mass of 0.800 kg.

trolley 1			trolley 2		
before or after collision?	before	after	before or after collision?	before	after
time / s	0.1233	0.1645	time / s	0.1052	0.2123
v / m s^{-1}	0.811	−0.608	v / m s^{-1}	−0.951	0.471
p / kg m s^{-1}	0.649	−0.486	p / kg m s^{-1}	−0.761	0.377

i. All the values of time are positive but some values of velocity and momentum are positive and some are negative. Explain this difference.

[1]

ii. Carol says, "These results seem to contradict the law of conservation of momentum."
Evaluate this comment.

[3]

iii. Show that kinetic energy is **definitely** not conserved in this collision and suggest why this is the case.

[2]

(c). After a few trials of this method, Jason says, “I think the results we are getting here are too variable. We need to set this up in a way that lets us have the same initial velocities each time, so that we can get repeat readings to give better estimates of energy and momentum and their uncertainties. I think our timing method could be improved, too.”

Evaluate Jason’s comments and suggest ways in which Jason’s concerns could be addressed in order to obtain more accurate results in this investigation of conservation of momentum and energy.

[6]

Note: Not all of the skills in the following question apply to the Physics A specification.

9(a). This question is about an experiment to find the terminal velocity of a large paper cake case, as shown in Fig. 29.1, falling in air.

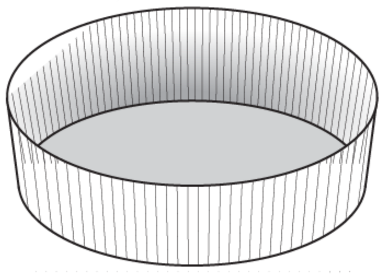

Fig. 29.1

The paper case is dropped from rest and falls a vertical distance of 1.85 m.
13 students use ± 0.1 s stop clocks to time the fall. Fig. 29.2 shows a dot plot of the data obtained.

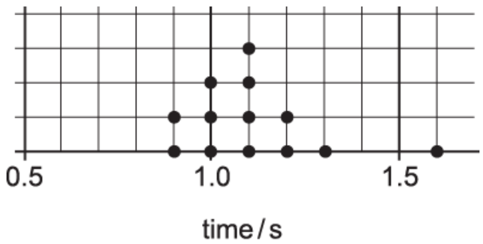

Fig. 29.2

i. The single 1.6 s reading was treated as an outlier.

Calculate the mean time of drop for the remaining data and estimate the uncertainty.

mean time of drop = ... ± ....s **[2]**

ii. Explain why the 1.6 s reading was treated as an outlier.

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[1]

iii. The vertical distance is measured as 1.85 ± 0.02 m due to the uncertainty in the release position.

Calculate your best estimate for the terminal velocity of the paper case and the uncertainty, using the data.

Make your method clear and justify how you estimated the uncertainty.

terminal velocity = ... ± .... m s^{-1} **[3]**

iv. Suggest **one** systematic error that exists in this method of finding the terminal velocity, and how it affects the estimate.

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[2]

(b). An improved method for finding the terminal velocity for the same falling paper case gives the data table and distance fallen against time graph shown in Fig. 29.3.

time / s	distance fallen / s	
0	0.43	
0.1	0.43	
0.2	0.43	
0.3	0.43	
0.4	0.44	
0.5	0.49	
0.6	0.60	
0.7	0.72	
0.8	0.94	
0.9	1.17	
1.0	1.38	
1.1	1.61	
1.2	1.84	
1.3	2.08	
1.4	2.28	
1.5	2.28	
1.6	2.28	

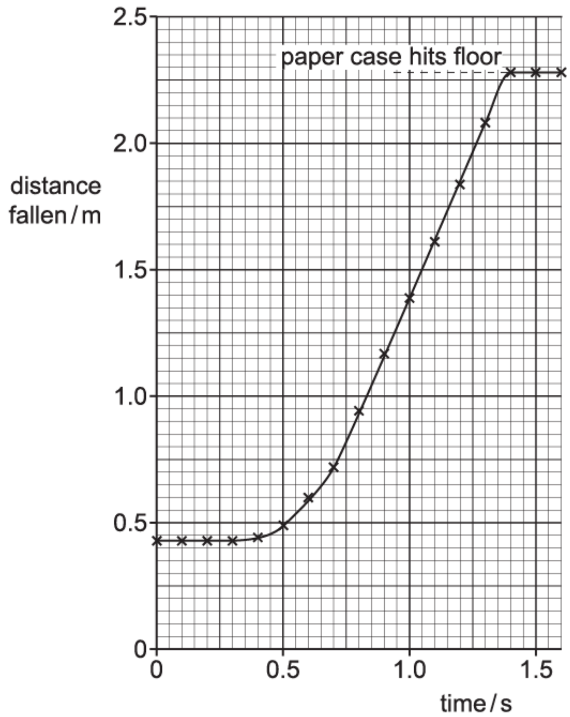

Fig. 29.3

i. Use the data from the table or the graph to make a new estimate for the terminal velocity. The table has a blank column for you to use, if required.
Make your method clear.

terminal velocity = ... m s^{-1}**[2]**

ii. Describe an experiment that could give the data in Fig. 29.3 and justify **one** way in which this method is better than that in **(a)**.

....

....

....

....

[3]

Total marks: 81

END OF QUESTION PAPER

Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1			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 = 2x/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 = √2gh (no need to define the terms)
			Total	**2**	
2		i	$g = \frac{2s}{t^2}$ / $g = \frac{2\times 1.20}{0.50^2}$ g = 9.6 (m s^{-2})	C1 A1	
		ii	(% uncertainty in s) = 0.08 % or (% uncertainty in t) = 4.00 % % uncertainty in g = ((2 × 4.00) + 0.08) % uncertainty in g = 8.08 (%)	 C1 A1	**Allow** 8.1% or 8 %
			Total	**4**	
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	**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

			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.		• repeats experiment for same *r* **Analysis** • $r = d / 2$ • determination of terminal velocity • plot a graph of v against r^2 • K = gradient.
			Total	**6**	
4	a	i	0.22 and 0.26 correct plotting of points on Fig. 2.2 sensible line not through origin	B1 B1 B1	 tolerance on each point ± 0.5 small scale division expect x-intercept at about 0.02
		ii	triangle with base at least half width of graph expected gradient close to 5	B1 B1	must have appropriate triangle on Fig. 2.2 or two sets of data lying on the line clearly shown ecf line; typical values (1.4 – 0)/(0.30 – 0.02)
	b	i	All points lie below the theoretical line the error bars on each reading are not long enough to allow a worst line through the origin / AW	B1 B1	accept quantitative answers e.g. error in s is half a square and in t^2 is 3 to 4% as several readings averaged 2 marks for two valid points
		ii	s is too small same shift in all values so no change to gradient t is too big constant error in t leads to increasing error in t^2 so gradient is changed / steeper	B1 B1 B1 B1	Or s should be larger
		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**	
5			***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*	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. • 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.

			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.		**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**	
6	a		(change in) KE = (change in) GPE /AW ½(m + 0.8)v^2 = 0.6 mg (and hence equation as shown on QP)	M1 A1	**allow** mgh = ½Mv^2 as long as it is clear that m and M are different, i.e. NOT mgh = ½mv^2 **allow** linear motion equation $v^2 = u^2 + 2as$ and $F = Ma$ $(W =)\ mg = (m + 0.8)a$; $u = 0$ and $s = 0.6$
	b	i	(v^2 =) 4.93 (±) 0.22	B1 B1	**allow** 4.9 (±) 0.2 (same number of decimal places)
		ii	Point (and error bar) plotted correctly Line of best-fit drawn through all points shown (use protractor tool at 49°)	B1 B1	tolerance ±½ small square; possible **ecf** from (b)**(i)** **allow ecf** from point plotted incorrectly or point omitted **Examiner's Comments** Most candidates calculated the value of v^2 to two decimal places successfully. Fewer were successful in giving the absolute uncertainty as ± 0.22. A popular distractor was ± 0.10. On the graph of Fig. 4.2 only the correct position of the point was required to gain the mark. The length of the uncertainty bar was ignored. A significant number of candidates forgot to draw the line of best fit on the graph.
	c	i	$v^2 = \dfrac{1.20mg}{(m + 0.800)}$ compared with $y = mx + c$	B1	**allow minimum of** gradient = v^2/[m/(m +0.8)] = 1.2 g **or expect** $y = v^2$ and $x = m/(m + 0.800)$ so gradient = 1.20g
		ii	one acceptable worst-fit line drawn large triangle used to determine gradient Gradient (used to determine 'worst' g)	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

			absolute uncertainty given to **one decimal place**	B1	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
	d		card appears shorter or time measured shorter calculated speed of trolley larger gradient of graph steeper **or** $v^2 \propto g$ /AW **so** calculated *g* is greater	B1 B1 B1 B1	**N.B.** each B mark is consequential on the previous statement; e.g. **ecf max** of 3 marks for correct consequences of stating card appears longer **or** time longer
			Total	**15**	

7			**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 information is in the most part relevant.
			
			0 marks
			No response or no response worthy of credit.
				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*
					• 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.

			Total	**6**	
8	a	i	percentage uncertainty in width = [0.1/10] × 100% = 1% ✓ and percentage uncertainty in *t* < [4 μs/0.1 s] × 100% (= 0.004 %) which is (very, very) much smaller ✓	2	Calculation of one percentage uncertainty = mp1; calculation of the other and comparison = mp2. Calculation can be implied by correct values 1% & / or 0.004%
		ii	mean = [0.10 m]/[0.1453 s] = 0.6882 m s^{-1} ✓	3	or e.g. 688.2 **mm s^{-1}** or 68.8 **cm s^{-1}**

			uncertainty Δv = 1% of own value of mean = 0.006882 / 6.882×10^{-3} ms^{-1} ✓ rounded Δv to 1 s.f. and rounded v to same no of d.p., = [0.688 ± 0.007] m s^{-1} ✓		or: $\Delta v = v_{max} - 0.6882 \times 10^{-3}$ m s^{-1} = [0.101 m]/[0.1453 s] − 0.6882×10^{-3} ms^{-1} = 0. 6951 m s^{-1} − 0.6882×10^{-3} m s^{-1} = 0.0069 m s^{-1} Allow [0.69 ± 0.01] m s^{-1}
	b	i	(*t* is a scalar but) ***v* and *p*** are **vectors** and so can go in + or − direction.	1	not just 'are vectors' without linking to the movement in Fig. 8.1 e.g. '(Time is scalar but) velocity and momentum are vectors so can go in a negative direction' is a minimum for the mark
		ii	Δp_1 = 0.649 N s + [−0.761 N s] = −0.112 N s Δp_2 = [−0.486] N s + 0.377 N s = −0.109 N s ✓ The difference (= 0.003 N s) is negligible (about 3% of either value) ✓ because percentage uncertainty of 1% for each of 4 readings (⇒4%) is more than this ✓	3	e.c.f own momenta providing values are not very different from each other
		iii	E_k before: ½ × 0.800 kg × [0.811 m s^{-1}]^2 + ½ × 0.800 kg × [−0.951 m s^{-1}]^2 = 0.6249 J = 0.625 J ✓ E_k after: ½ × 0.800 kg × [−0.608 m s^{-1}]^2 + ½ × 0.800 kg × 0.471 m s^{-1}]^2 = 0.2366 J = 0.237 J which (significantly) less than the initial kinetic energy so energy has been transferred to e.g. increased internal energy of trolleys ✓	2	Allow intermediate rounding to 2 s.f. in (b) (iii) m.p.2 needs a repeat calculation and a reasoned comment that this is significantly less than the original kinetic energy.
	c		**(Level 3) (5 – 6 marks)** Comments on improvement obtained by more results in terms of better means and quantified uncertainty with consequences for analysis of momenta and energies. Suggests a reasonable and detailed method of producing similar initial velocity and suggests a plausible way to measure *v* with greater precision. *There is a line of reasoning presented with some structure. 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)** Comments on improvement obtained by more results in terms of better means and quantified uncertainty. Suggests a reasonable method, possibly incomplete, of producing similar initial	6	**Indicative scientific points may include:** **Repeatable set-up** • catapult • weight / pulley with release • ramp • pull over marked distance with newton-meter at fixed setting **Advantages of repeated similar velocities** • allows calculation of mean and uncertainty in *v* • can calculate uncertainty in *p*, E_k • can quantify energy losses in the impact • can check on 'lost' *p* i.e. other unallowed-for forces **Improving timing method** • not a priority as current method is not the weakest link • cut card with greater precision • measure length with better resolution (e.g. travelling microscope)

			velocity. Comments on accuracy of velocity measurements. *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)** Suggests simple method of producing similar velocities without any physical justification. *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.		• longer card to reduce percentage error • ensure card cuts light-gate beam at right angles (e.g. by observing and discarding results where it doesn't) **Other suggestions** • use of linear air track • use of motion sensors (NOT tickertape) • can investigate p, E_k losses in trolley running along surface without collision to allow for these
			Total	**17**	
9	a	i	{(2 × 0.9)+(3 × 1.0)+ (4 × 1.1)+(2 × 1.2)+(1 × 1.3)} / 12 = 1.1 (s)✓ Uncertainty = 0.2 (s)	1 1	method **penalise** here if outlier is counted in – look for division by 13 **accept** 1.08 / 1.075 For second mark, decimal places in mean time and raw uncertainty must be max 2 and the same i.e. 1.1 ± 0.2 or 1.08 ± 0.20 **accept** 1.08 ± 0.22**allow** percentage uncertainty of 18% or 20% (2sf max) **accept** (14.5 /13) = 1.1 ± 0.4 (s) / 1.12 ± 0.35 (s) if outlier used for second mark only
		ii	(1.6 s is outlier) as further than 2 × spread from mean ✓	1	**NOT** outside of the range
		iii	v_{terminal} = 1.85 / 1.1 = 1.7 (m s^{-1})✓ % in t_{drop} is ± 18 % OR ± 20% and % in d ± 1% so use ± 18 % OR ± 20% ✓ ✓ (1.7 × 0.18) = ✓ 0.3 (m s^{-1}) alternative method for uncertainty:max v_{terminal} = 1.87 / 0.9 = 2.08 (second marking point) (or min v_{terminal} = 1.83 / 1.3 = 1.41) difference from mean = 2.08 − 1.7 = 0.38 (third marking point) (or difference from mean = 1.7 − 1.41 = 0.29)	1 1 1	evaluation for v_{terminal} value **accept** 1.68 (or 1.71 from t_{drop} = 1.08 or 1.72 from t_{drop} = 1.075 (m s^{-1}) **ecf** from 29(a) calculations and justification **allow** ecf on their ✓ value from (i) **accept** percentage errors combined / added (eg 19% or 21%) complete answer with uncertainty **accept** ± 0.34 / ± 0.4 (m s^{-1}) if correctly followed through from rounding no penalty here for difference in decimal places in terminal velocity and uncertainty **allow** ecf on their ± value from (i) accept ± 0.3 or ± 0.4 using this method **allow** using average of max and min differences values if both calculated
		iv	method assumes at v_{terminal} for whole drop / may not reach terminal velocity drop ✓ method underestimates the v_{termina} systematically ✓ **or** reaction time (at start and/or end) links smaller time to larger v_{terminal} or vice	1 1	**accept** time includes the time of acceleration up to v_{terminal} / not at v_{terminal} for whole of time period measured / **accept** estimate made is too small / low in value **NOT** human error in timing

			versa **or**incorrect height measurement due to plausible reason links smaller distance to smaller $v_{terminal}$ or vice versa		e.g. ruler at an angle, parallax, starting above ground answer must state clearly whether measured length is too short or too long for second mark
	b	i	using Δs / Δt from table or from graph ✓ evaluation **accept** in range 2.2 to 2.3 (m s^{-1})	1 1	method from gradient of linear section of graph (allow between 0.7 and 1.4) Δ*t* at least 0.3s e.g. (2.08 − 0.72) / (1.3 − 0.7) = 1.36 / 0.6 = 2.3 (2.27) (m s^{-1}) **or** from table of results (averaging at least 3 intervals) for interval from 0.7 s to 1.3 s (allow between 0.7 and 1.4) e.g. 2.2, 2.3, 2.1, 2.3, 2.3, 2.4 average gives 2.3 (2.27)(m s^{-1}) **MAX 1** if Δ*t* from graph < 0.3s or >3 intervals from table used bare answer in range max 1
		ii	Ultrasonic sensor motion with data-logger / position sensor with data-logger / video with ruler or tape / strobe photography with ruler or tape ✓ record data and review position every 0.1 s shows where $v_{terminal}$ is constant / smaller ± % uncertainty in time measurement / reduced to about ± 5% / eliminates reaction time systematic error ✓	1 1 1	apparatus and capture method **not** ticker-tape (inappropriate) **not** light gates (impractical) accept set pulse / frame rate to 0.1s **accept** shows acceleration phase uncertainty of velocity calculations from table is reduced to ≈ 1 part in 20 **ignore** references to reducing human error
			Total	**13**	
			Total marks	**81**	

