1 Fig. 1 shows the velocity-time graph of a cyclist travelling along a straight horizontal road between two sets of traffic lights. The velocity, v, is measured in metres per second and the time, t, in seconds. The distance travelled, s metres, is measured from when $t = 0$.

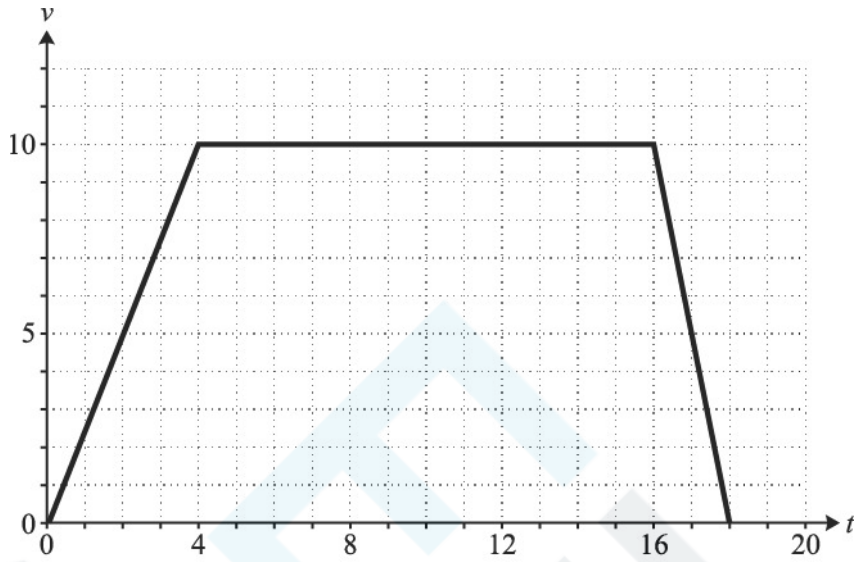


Fig. 1

(i) Find the values of s when $t = 4$ and when $t = 18$. **[3]**

(ii) Sketch the graph of s against t for $0 \leqslant t \leqslant 18$. **[3]**

2 **In this question you should take g to be 10 ms^{-2}.**

Piran finds a disused mineshaft on his land and wants to know its depth, d metres.

Local records state that the mineshaft is between 150 and 200 metres deep.

He drops a small stone down the mineshaft and records the time, T seconds, until he hears it hit the bottom. It takes 8.0 seconds.

Piran tries three models, A, B and C.

In model A, Piran uses the formula $d = 5T^2$ to estimate the depth.

(i) Find the depth that model A gives and comment on whether it is consistent with the local records.

Explain how the formula in model A is obtained.

[4]

In model B, Piran uses the speed-time graph in Fig. 6.

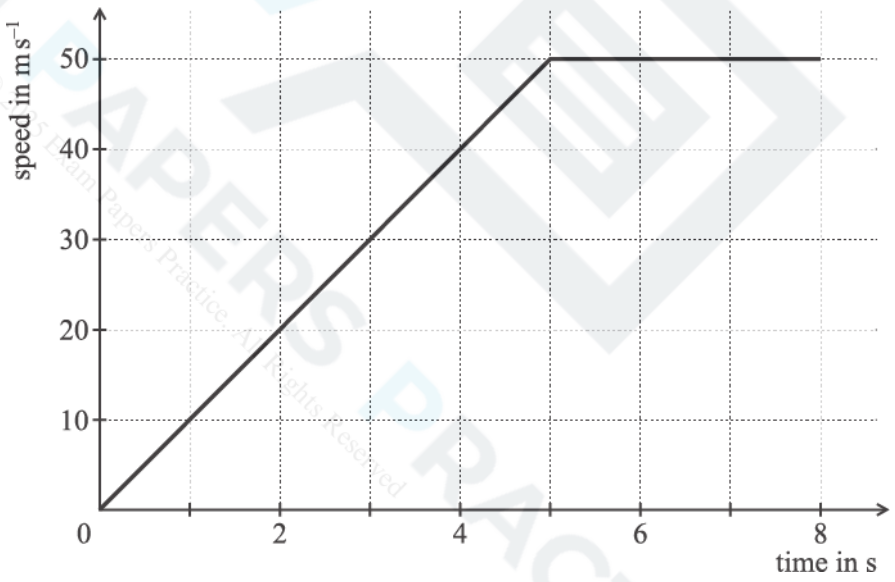


Fig. 6

(ii) Calculate the depth of the mineshaft according to model B.

Comment on whether this depth is consistent with the local records.

[4]

(iii) Describe briefly one respect in which model B is the same as model A and one respect in which it is different.

[2]

Piran then tries model C in which the speed, v ms^{-1}, is given by

$v = 10t - t^2$ for $0 \leqslant t \leqslant 5$,
$v = 25$ for $5 < t \leqslant 8$.

(iv) Calculate the depth of the mineshaft according to model C.

Comment on whether this depth is consistent with the local records.

[6]

(v) Describe briefly one respect in which model C is similar to model B and one respect in which it is different.

[2]

3 A car is usually driven along the whole of a 5 km stretch of road at a constant speed of 25 m s^{-1}. On one occasion, during a period of 50 seconds the speed of the car is as shown by the speed-time graph in Fig. 7; the rest of the 5 km is travelled at 25 m s^{-1}.

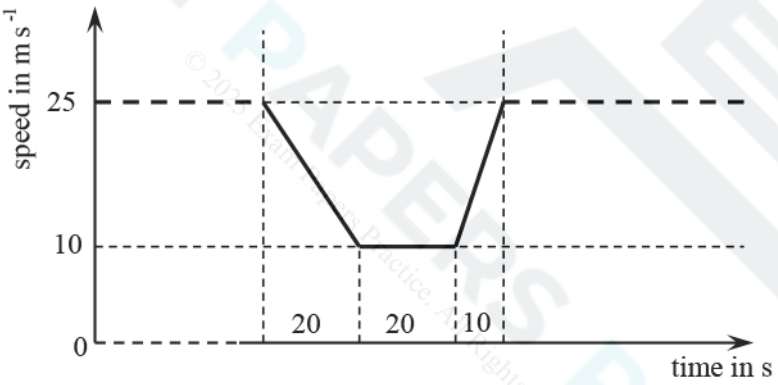


Fig. 7

How much more time than usual did the journey take on this occasion? Show your working clearly. [4]

4 A small package hangs from a balloon by means of a light inelastic string. The string is always vertical. The mass of the package is 15 kg.

Catherine initially models the situation by assuming that there is no air resistance to the motion of the package. Use Catherine's model to calculate the tension in the string if

(a) the package is held at rest by the tension in the string, [1]

(b) the package is instantaneously at rest and accelerating **upwards** at 2 m s^{-2}, [2]

(c) the package is moving **downwards** at 3 m s^{-1} and accelerating **upwards** at 2 m s^{-2}. [1]

Catherine now carries out an experiment to find the magnitude of the air resistance on the package when it is moving. At a time when the package is accelerating **downwards** at 1.5 m s^{-2}, she finds that the tension in the string is 140 N.

(d) Calculate the magnitude of the air resistance at that time. Give, with a reason, the direction of motion of the package. [5]

5 **In this question take $g = 10$.**

A small stone is projected from a point O with a speed of 26 ms^{-1} at an angle θ above the horizontal.

The initial velocity and part of the path of the stone are shown in Fig. 7. You are given that $\sin\theta = \frac{12}{13}$.

After t seconds the horizontal displacement of the stone from O is x metres and the vertical displacement is y metres.

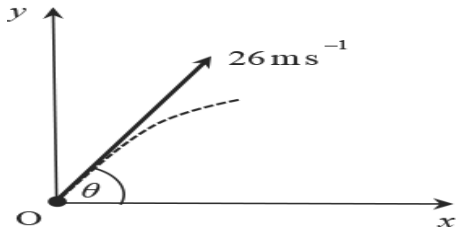


Fig.7

(a) Using the standard model for projectile motion,

- show that $y = 24t - 5t^2$,
- find an expression for x in terms of t. **[4]**

The stone passes through point A. Point A is 16m above the level of O.

(b) Find the two possible horizontal distances of A from O. **[4]**

A toy balloon is projected from O with the same initial velocity as the small stone.

(c) Suggest two ways in which the standard model could be adapted. **[2]**

6 In an experiment a small box is hit across a floor. After it has been hit, the box slides without rotation. The box passes a point A. The distance the box travels after passing A before coming to rest is S metres and the time this takes is T seconds. The only resistance to the box's motion is friction due to the floor.

The mass of the box is m kg and the frictional force is a constant F N.

(a) (i) Find the equation of motion for the box while it is sliding.

(ii) Show that $S = kT^2$ where $k = \frac{F}{2m}$. **[4]**

(b) Given that $k = 1.4$, find the value of the coefficient of friction between the box and the floor. **[4]**

7 **Fig. 15** shows a uniform shelf AB of weight W N.
The shelf is 180 cm long and rests on supports at points C and D. Point C is 30 cm from A and point D is 60 cm from B.

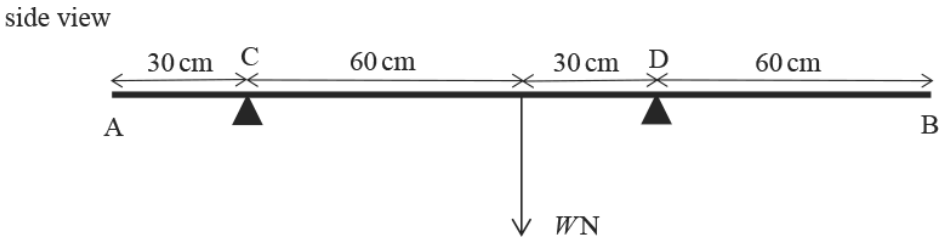


Fig. 15

Determine the range of positions a point load of 3 W could be placed on the shelf without the shelf tipping. **[6]**

8 A block of mass $5m$ kg is in equilibrium on a rough horizontal table. It is connected by horizontal light inextensible strings over smooth pulleys to particles of mass m kg and $2m$ kg which hang freely, as shown in Fig. 3.

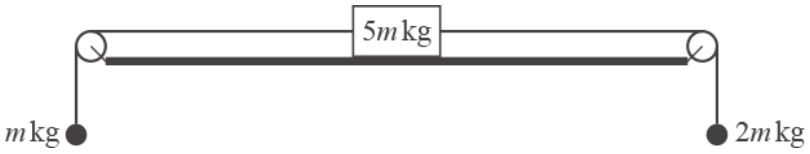


Fig. 3

Find the frictional force acting on the block, clearly indicating its direction. [3]

9 Two chess pieces are placed on a uniform straight ruler. The ruler balances horizontally on a pivot.

- The ruler AB is of length 30 cm.
- The pivot P is at the centre of the ruler.
- The first chess piece, of mass 20 grams, is at A.
- The second chess piece, of mass 50 grams, is x cm from B.

This is shown in Fig. 5.

Fig. 5

Calculate the value of x. [4]

10 Arjun is trying to hit a can with a stone. The can is standing on a narrow wall 4 m away from him. The can is 10 cm tall and its base is 1.9 m above the ground, which is level. Arjun throws the stone at the can with a speed of 8 ms^{-1} at an angle of 35° above the horizontal. The point of projection is 1 m above the ground.

Determine whether the stone hits the can. **[7]**

11 A non-uniform rod 0.8 m long rests horizontally on smooth pegs A and B at each end of the rod. The contact forces at A and B are 10 N and 15 N respectively, as shown in Fig. 2.

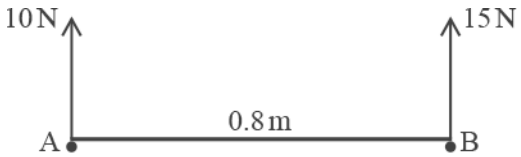


Fig. 2

Calculate the distance of the centre of mass of the rod from A. [3]

12 Fig. 9 shows a block of mass 2 kg resting on a rough horizontal table. It is attached to a ball of mass m kg by a light inextensible string that passes over a smooth pulley at the edge of the table. The ball hangs vertically below the pulley. The coefficient of friction between the block and the table is 0.6.

The system is held in equilibrium by a force of $5\sqrt{2}$ acting on the block at 45° above the horizontal. The block is on the point of sliding towards the pulley.

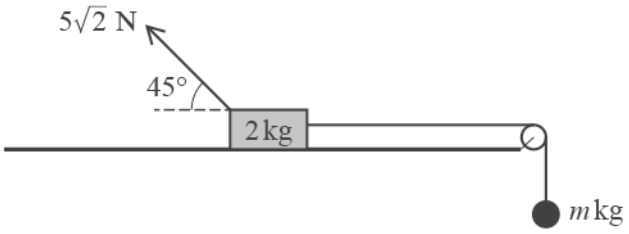


Fig. 9

(a) Complete the force diagram above to show all the forces acting on the block and the ball. [2]

(b) Calculate the frictional force acting on the block. **[4]**

(c) Calculate the value of m. **[4]**

13 The velocity of a car, v ms^{-1} at time t seconds, is being modelled. Initially the car has velocity 5 ms^{-1} and it accelerates to 11.4 ms^{-1} in 4 seconds.

In model A, the acceleration is assumed to be uniform.

(a) Find an expression for the velocity of the car at time t using this model. **[3]**

(b) Explain why this model is not appropriate in the long term. **[1]**

Model A is refined so that the velocity remains constant once the car reaches 17.8 ms^{-1}.

(c) Sketch a velocity-time graph for the motion of the car, making clear the time at which the acceleration changes. **[3]**

(d) Calculate the displacement of the car in the first 20 seconds according to this refined model. **[3]**

In model B, the velocity of the car is given by

$$v = \begin{cases} 5 + 0.6t^2 - 0.05t^3 & \text{for } 0 \leqslant t \leqslant 8, \\ 17.8 & \text{for } 8 < t \leqslant 20. \end{cases}$$

(e) Show that this model gives an appropriate value for v when $t = 4$. **[1]**

(f) Explain why the value of the acceleration immediately before the velocity becomes constant is likely to mean that model B is a better model than model A. **[3]**

(g) Show that model B gives the same value as model A for the displacement at time 20 s. **[3]**

14 A bus travelling on a straight road accelerates uniformly from 2.5 m s^{-1} to 7.5 m s^{-1} in 12 s. It then travels at 7.5m s^{-1} for 20 s before slowing uniformly to rest in 8 s.

(a) Sketch a velocity-time graph for the bus. **[3]**

(b) Calculate the average speed of the bus. **[4]**

15 A cyclist is travelling in a straight line. She has a velocity of $3ms^{-1}$ when passing O. After 4 s she reaches A which is 24 m from O. After a further 6 s she reaches B which is 80 m beyond A.

Determine whether modelling the motion as having constant acceleration is consistent with these values. **[5]**

16(a) A uniform ruler AB has mass 28 g and length 30 cm. As shown in Fig. 6, the ruler is placed on a horizontal table so that it overhangs a point C at the edge of the table by 25 cm.

A downward force of F N is applied at A. This force just holds the ruler in equilibrium so that the contact force between the table and the ruler acts through C.

Fig. 6

Complete the force diagram below, labelling the forces and all relevant distances. [2]

(b) Calculate the value of F. [2]

17 A particle is moving in a straight line. The acceleration α m s^{-2} of the particle at time t s is given by $\alpha = 0.8t + 0.5$. The initial velocity of the particle is 3 m s^{-1} in the positive x-direction.

Determine whether the particle is ever stationary. **[6]**

18(a) A block of mass 2 kg is placed on a rough horizontal table. A light inextensible string attached to the block passes over a smooth pulley attached to the edge of the table. The other end of the string is attached to a sphere of mass 0.8 kg which hangs freely.

The part of the string between the block and the pulley is horizontal. The coefficient of friction between the table and the block is 0.35. The system is released from rest.

Draw a force diagram showing all the forces on the block and the sphere. **[3]**

(b) Write down the equations of motion for the block and the sphere. **[2]**

(c) Show that the acceleration of the system is 0.35 m s^{-2}. **[4]**

(d) Calculate the time for the block to slide the first 0.5 m. Assume the block does not reach the pulley. **[2]**

19 A projectile is fired from ground level at 35 m s^{-1} at an angle of $\theta°$ above the horizontal.

State a modelling assumption that is used in the standard projectile model. **[1]**

20 In this question, the *x*, and y directions are horizontal and vertically upwards respectively.

A particle of mass 1.5 kg is in equilibrium under the action of its weight and forces $\mathbf{F}_1 = \begin{pmatrix} 4 \\ -2 \end{pmatrix}\text{N}$ and $\mathbf{F}_2$.

The force $\mathbf{F}_2$ is changed to $\begin{pmatrix} 2 \\ 20 \end{pmatrix}\text{N}$.

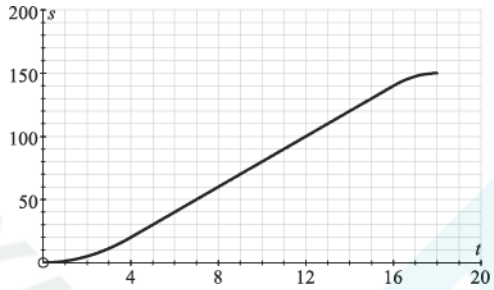
Find the acceleration of the particle. **[3]**

21 **In this question you must show detailed reasoning.**

A particle moves in a straight line. Its velocity $v$ms^{-1} after ts is given by $v = t^3 - 5t^2$.

Find the total distance travelled by the particle in the first 6 seconds. **[3]**

END OF QUESTION PAPER

Question			Answer/Indicative content	Marks	Guidance
1		i	When $t = 4$, $s = \frac{1}{2} \times 4 \times 10$		Finding the area of the triangle or equivalent.
		i	$s = 20$	B1	
		i	When $t = 18$, $s = \frac{1}{2} \times (18 + 12) \times 10$	M1	A complete method of finding the area of the trapezium or equivalent.
		i	$s = 150$	A1	CAO
		ii			
		ii	Graph joining (0,0), (4,20) and (18, 150)	B1	Allow FT for their (4,20) and (18, 150) Condone extension to (20, 150) with a horizontal line.
		ii	The graph goes through (16, 140)	B1	Allow SC1 for the first two marks if there is a consistent displacement from a correct scale, eg plotting (18,150) at (19, 150)
		ii	Curves at both ends	B1	The sections from $t = 0$ to $t = 4$ and from $t = 16$ to $t = 18$ are both curves **Examiner's Comments** This question, about interpreting a velocity-time graph, was well answered. It ended with a request to draw the equivalent distance-time graph, parts of which were curves; many candidates did not realise this and so lost the final mark.
			Total	**6**	
2		i	$d = 5 \times 8^2 = 320$, so 320 m	B1	
		i	This value is too great. It is not between 150 and 200 m.	B1	Accept “inconsistent“. Dependent on previous mark.
		i	$s = ut + \frac{1}{2}at^2$ with $s = d$, ($u = 0$), $a = 10$ and $t = T$	M1	

Question			Answer/Indicative content	Marks	Guidance
		i	Giving $d = \frac{1}{2} \times 10 \times T^2 = 5T^2$	A1	**Examiner's Comments** Question 6 was about modelling. It involved building up a model in three stages of increasing sophistication. At each stage candidates were asked to comment on which aspects of the model had changed and which had remained the same. The context was estimating the depth of a mine shaft from the time it took a stone to reach the bottom. Throughout the model was checked against local records. This question was very well answered. The question started with applying a simple model given by a formula and comparing the depth it gave to local records. It then went on to ask for an explanation of the model. Almost all candidates answered this fully correctly. Answer 320 m
		ii	Depth = Area under the graph	M1	oe
		ii	$= \frac{1}{2} \times 5 \times 50 + 3 \times 50$	A1	
		ii	= 275 m	A1	
		ii	Outside the 150 to 200 m interval so inconsistent	B1	A numerical comparison is required for this mark but may refer to values for it stated in part (i). Dependent on previous mark. **Special Case** Allow up to M1 A0 A1 B1 for a response in which the time at which v becomes constant is near but not equal to 5 (eg 4 or 4.5). **Examiner's Comments** The question then moved on to the second model which was given by a velocity time graph. Nearly all candidates obtained the correct distance but many lost a mark by not making a numerical comparison of their result with the local records. Answer 275 m

Question			Answer/Indicative content	Marks	Guidance
		iii	The same: initial constant acceleration (of 10 ms^{-2})	B1	Do not allow statements about the initial speed or the time taken
		iii	Different: two part motion with constant speed at end	B1	**Examiner's Comments** In this part candidates were asked to identify one respect in which the two models (so far) were the same and one in which they were different. Many candidates gave good answers. In both models the stone has acceleration of g for the first 5 second but then in model B it has constant velocity while in A it continues to accelerate. No marks were given for answers that referred to the conditions given in the question, such as that it takes 8 seconds, nor for answers that compared the mathematical presentation, for example algebra against a graph.
		iv	For $0 \geq t \geq 5$, the distance travelled is $\int_0^5 (10t - t^2)\mathrm{d}t$	M1	Or equivalent using indefinite integration
		iv	$= \left[5t^2 - \frac{t^3}{3}\right]_0^5$	A1	Limits not required for this mark
		iv	$5 \times 5^2 - \frac{5^3}{3}$ $(= 83\frac{1}{3})$	A1	A ☐ M
		iv	For $5 < t \leq 8$, the distance travelled is 25×3 (= 75)	B1	Seen or implied
		iv	$d = 83\frac{1}{3} + 75 = 158\frac{1}{3}$	A1	CAO

Question			Answer/Indicative content	Marks	Guidance
		iv	This is within the given interval.	B1	Dependent on previous mark **Examiner's Comments** The question then moved on to Model C where there was variable acceleration and so calculus had to be used. This was very well answered. Only a handful of candidates tried to use constant acceleration formulae. Most carried out the integration and did the appropriate substitution to find the distance covered in the first 5 seconds successfully, and then went on to add on the distance covered at constant velocity. All but few candidates handled the two stage motion correctly. The final mark required the distance found to be related to the local records and in this case it was necessary to identify the interval within which it lay. Many candidates did not do so and so scored 5 out of 6. Answer $158\frac{1}{3}$ m
		v v	Similar: constant speed for $< t \leq 8$ Different: acceleration is not constant for $0 \leq t \leq 5$.	B1 B1	**Examiner's Comments** This part was similar to part (iii) asking about how the model had developed. Those who had done well in part (iii) tended to do well here too. Both models involved terminal velocity but its value was different. In the new model the acceleration was variable for the first 5 seconds whereas it had been constant in the previous model.
			Total	18	

Question			Answer/Indicative content	Marks	Guidance	
3			Find how much less distance travelled in the 50 s	M1(AO3.1b)	Sensible attempt at method including finding distance as an area	
			Distance is the area (of trapezium and is) $\frac{(25-10)\times(50+20)}{2}=525\text{ m}$	A1(AO1.1)	cao. Need not be evaluated. Many correct routes.	
			This distance is made up at 25 m s^{-1} to give extra time	M1(AO3.4)		
			Extra time is $\frac{525}{25}=21$	A1(AO3.2a)	FT their area	
			Alternative method Find the distance travelled in the 50 s	M1(AO3.1b)	Sensible attempt at method including finding distance as an area	
			Find the time for the rest of the journey + 50 and subtract $\frac{5000}{25}=200$	M1(AO3.4)	May be scored later. oe	
			Distance travelled in the 50 s is 725 m	A1(AO1.1)	cao. Many correct routes to find area	
			Extra time is $\frac{(5000-725)}{25}+50-200=21$	A1(AO3.2a) [4]	FT their area. Many correct routes here.	Award full marks for 21 seen www
			Total	4		

Question			Answer/Indicative content	Marks	Guidance
4		a	No acceleration so we require the weight $15g$ (147 N)	B1(AO3.3) [1]	Accept $15g$, $15g$ N, 147 N etc
		b	Tension T N, N2L ↑ $T - 147 = 15 \times 2$ So $T = 177$ and tension is 177 N	M1(AO3.4) A1(AO1.1) [2]	Application of N2L
		c	177 N	B1(AO3.4) [1]	FT from (b)

Question			Answer/Indicative content	Marks	Guidance
		d	Let the air resistance be R ↑	M1(AO3.3)	
			N2L ↑ gives $R + 140 - 15g = 15\times(-1.5)$	M1(AO1.1)	Finding R using a and then T
			$R - 7 = -22.5$		
			$R = -15.5$	A1(AO1.1)	
			Hence magnitude is 15.5 N	A1(AO3.4)	
			R is downwards so motion of the package is upwards	E1(AO3.4)	
				[5]	
			Alternative method		
			Let the total upward force be F N and the air resistance R ↑		
			N2L ↑ gives $F - 147 = 15\times(-1.5)$	M1(AO3.3)	Finding F and hence R using a and then T
			So $F = 124.5$	A1(AO1.1)	
			Also $F = R + 140$ so $R = 124.5 - 140 = -15.5$	A1(AO1.1)	
			Hence magnitude is 15.5 N	A1(AO3.4)	
			R is downwards so motion of the package is upwards	A1(AO3.4)	
				[5]	
			Total	9	

Question			Answer/Indicative content	Marks	Guidance	
5		a	$y = ut\sin\theta - \frac{1}{2}gt^2$ stated and used $y = 26\times\frac{12}{13}t - 5t^2$ $= 24t - 5t^2$ $x = 26\times\frac{5}{13}t$ $= 10t$	M1(AO3.3) E1(AO2.1) M1(AO3.4) A1(AO1.1) [4]	AG Use of $\frac{5}{13}$ Accept any form	Given answer must be seen to score E1
		b	We require $16 = 24t - 5t^2$ Solving $5t^2 - 24t + 16 = 0$ $((5t-4)(t-4) = 0$ or ...) $t = 0.8$ or 4 Distances are $10 \times 0.8 = 8$ m and $10 \times 4 = 40$ m.	M1(AO3.4) M1(AO1.1) A1(AO1.1) B1FT(AO3.2a) [4]	Equating their y expression to 16 Method that could give 2 correct roots for their quadratic. Implied by 2 correct roots for their quadratic Cao FT only their t	
		c	E.g. Air resistance should be included E.g. The balloon should not be treated as a particle E.g. Horizontal force due to wind should be considered	B1(AO3.5c) B1(AO3.5c) [2]	Any two appropriate factors that would have an impact on the model.	
			Total	10		

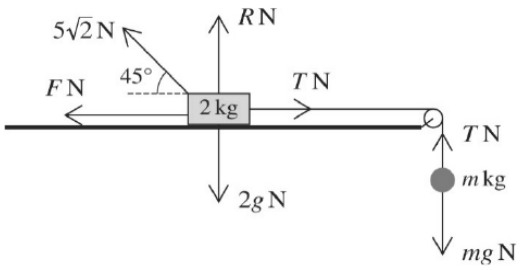
Question			Answer/Indicative content	Marks	Guidance
6		a	***A*** Let acceleration be *a* in the direction of motion. N2L in direction of motion gives $-F = ma$	M1(AO3.3)	Decide to use N2L to find acceleration
			so $a = -\frac{F}{m}$, which is constant.	A1(AO1.1)	No need to say 'constant'
		a	***B*** (As *a* constant) use *suvat* , giving $S = 0 \times T - \frac{1}{2} \times \left(-\frac{F}{m}\right) T^2$	B1(AO2.1)	Use appropriate (sequence of) *Suvat*
			so $S = \left(\frac{F}{2m}\right) T^2$, and $k = \frac{F}{2m}$	E1(AO2.4)	
				[4]	
		b	As sliding, friction is limiting and $F = \mu R$	M1(AO3.3)	
			$R = mg$	A1(AO3.4)	
			$k = \frac{F}{2m}$ so $k = \frac{\mu mg}{2m}$	M1(AO1.1)	In $F = \mu R$, substitute for F & R in terms of m and g
			Hence $\mu = \frac{2k}{g} = \frac{2 \times 1.4}{9.8} = \frac{2}{7}$	A1(AO2.2a)	Or 0.286 (3s.f.)
				[4]	
			Total	8	

Question			Answer/Indicative content	Marks	Guidance
7			Let the reactions of the supports on the shelf be U N at C and V N at D		
			Neither U nor V can be negative if the shelf does not tip	M1(AO2.2a)	May be implied
			Any position between C and D must give $U > 0$ and $V > 0$	B1(AO2.2a)	Need not show but must be stated
			Consider putting the load between A and C, x cm from C		
			cw moments about C	M1(AO3.1b)	moments about C
			If $V \geq 0$ then $W \times 60 \geq 3W \times x$	A1(AO1.1)	allow <
			so $x \leq 20$		
			Consider putting the load between D and B, y cm from D		
			anti-cw moments about D		
			If $U \geq 0$ then $W \times 30 \geq 3W \times y$	B1(AO3.1b)	
			so $y \leq 10$		allow <
			The load must be placed not closer than 10 cm to A and 50 cm to B oe	A1(AO3.2a)	Must be clear statement and include CD
				[6]	
			Total	6	
8			Let T_1 and T_2 be the tensions in the strings to m kg mass and $2m$ kg mass respectively		
			$T_1 = mg$ and $T_2 = 2mg$	B1(AO 3.3)	For values of tensions clearly stated or shown on the diagram
			$T_2 - T_1 - F = 0$	M1(AO 3.3)	
			$F = mg$ towards the m kg mass (to the left on the diagram)	A1(AO 2.2a)	
				[3]	
			Total	3	

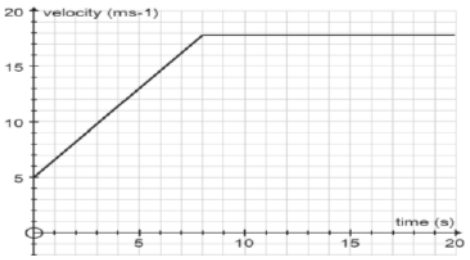
Question			Answer/Indicative content	Marks	Guidance	
9			Distance of 50 g piece from pivot is (15 – *x*) cm	B1(AO 3.3)	soi; may be on the diagram	
			Moments about pivot: 20 × 15 = 50 × (15 – *x*) oe	M1(AO 3.1b)	Allow any consistent units of weight (or mass) and length mass) and length	Condone e.g. 20*g* with no units for *g* stated
				A1(AO 2.1)	Correct (unsimplified) equation	
			x = 9	A1(AO 1.1b)		
				[4]		
			Total	4		

Question			Answer/Indicative content	Marks	Guidance
10			Horizontal motion: $x = (8\cos 35)t$	B1(AO 3.3)	
			Vertical motion: $y = (8\sin 35)t - 4.9t^2 + 1$	M1(AO 3.3)	Allow for RHS with first two terms only
			Time to wall: $(8\cos 35)t = 4$	M1(AO 3.1b)	Attempt to find t when $x = 4$
			$t = 0.6104$	A1(AO 1.1b)	Allow 0.61 or better
			Height at this time: $(8\sin 35)0.6104 - 4.9(0.6104)^2 + 1$	M1(AO 1.1a)	Substitute their value of t in their y
			$y = 1.975$	A1(AO 1.1b)	Allow 0.975 only if compared with 0.9
			This is between 1.9 and 2.0 so the stone hits the can	E1(AO 3.2a)	Comment must be supported by evidence
			Alternative method		
			Horizontal motion: $x = (8\cos 35)t$	B1	May be implied if trajectory eqn is quoted
			Vertical motion: $y = (8\sin 35)t - 4.9t^2 + 1$	M1	May be implied if trajectory eqn is quoted
			Trajectory: $y = (8\sin 35)\left(\frac{x}{8\cos 35}\right) - 4.9\left(\frac{x}{8\cos 35}\right)^2 + 1$	M1 A1	Allow without the '+1' if subsequent work is all consistent with origin at height 1
			Height at $x = 4$: $(8\sin 35)\left(\frac{4}{8\cos 35}\right) - 4.9\left(\frac{4}{8\cos 35}\right)^2 + 1$	M1	
			= 1.975	A1	
			This is between 1.9 and 2.0 so the stone hits the can	E1 [7]	Comment must be supported by evidence
			Total	7	

Question			Answer/Indicative content	Marks	Guidance
11			Vertical equilibrium: weight = 10 + 15 = 25 N Moments about A: $25x = 15 \times 0.8$ $x = 0.48$ m	B1(AO1.1a) M1(AO3.1b) A1(AO1.1b) [3]	soi or take moments about other points
			Total	3	

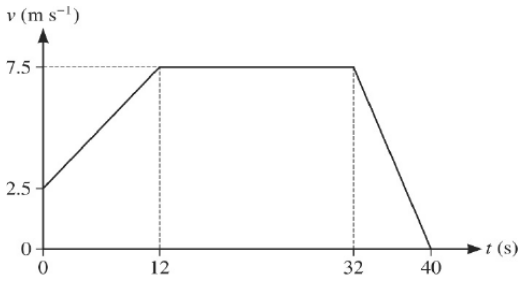
Question			Answer/Indicative content	Marks	Guidance	
12		a		B1(AO1.1a) B1(AO3.3) [2]	Weights and normal reaction labelled Tension correct in both parts of the string and friction in the correct direction	Condone absence of units N in diagram Friction force could be shown as μ*R* or 0.6*R* and tension could be shown as *mg*
		b	$R + 5\sqrt{2}\sin 45° = 2g$ $R = 2g - 5$ (= 14.6) $F = 0.6(2g - 5)$ $F = 8.76$ N	M1*(AO3.4) A1(AO1.1b) M1(AO1.1a)dep* A1(AO1.1b) [4]	Resolve vertically for the block Numerical evaluation not needed here Use of $F = \mu R$, but do not allow if $R = 2g$	Allow sin or cos here
		c	$T = F + 5\sqrt{2}\cos 45°$ $(= 13.76)$ $T = mg$ $m = \dfrac{13.76}{g} = 1.40$	M1(AO3.4) A1(AO1.1b) M1(AO1.1a) A1(AO1.1b) [4]	Resolve horizontally for the block Correct equation; evaluation not required for this mark Resolve vertically for the ball	Allow sin or cos here soi
			Total	10		

Question			Answer/Indicative content	Marks	Guidance
13		a	$u = 5$, $v = 11.4$, $t = 4$ $a = \frac{v-u}{t} = \frac{11.4-5}{4} = 1.6$ $v = 5 + 1.6t$	M1 (AO 3.1b) A1 (AO 1.1b) A1 (AO 3.3) [3]	Using suvat equation(s) leading to value for a Any form FT their a Examiner's Comments The key to this question was to calculate the acceleration of the car. The required expression is then found by substituting the values for u and a into the equation $v = u + a\,t$. Many fully correct answers were seen.
		b	The car would not be able to accelerate indefinitely – the velocity would become too large	E1 (AO 3.5b) [1]	Examiner's Comments Candidates were required to recognise the limitations of this model. Most successful answers stated that the velocity would eventually get much too big or that the car would have to slow down or stop at some point.

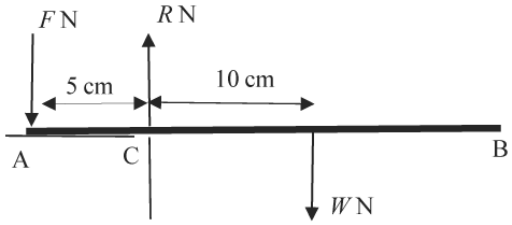
Question			Answer/Indicative content	Marks	Guidance	
		c	When $v = 17.8$ $t = \frac{17.8-5}{1.6} = 8$  	B1 (AO 1.1a) G1 (AO1.1a) G1 (AO 3.5c) [3]	Calculation or point on graph labelled at $t = 8$ Two line segments with one horizontal Axes labelled. (0, 5) and constant speed 17.8 clear on vertical scale	Mark intent for 17.8 – allow for a linear scale beyond 17.8 Examiner's Comments Most candidates correctly had a graph consisting of two line segments but a common error was to begin the graph at the origin when the initial velocity was 5 ms^{-1}. Some did not fully label their graph so lost a mark. AfL Make sure the axes are labelled and that all key points are clearly indicated on the graph.
		d	Dividing area into sections Area under trapezium $= \frac{1}{2}(5+17.8)\times 8 = 91.2$ Area rectangle 12 × 17.8 = 213.6 Total displacement = 304.8 m	M1 (AO 3.1b) A1 (AO 1.1a) A1 (AO 1.1b) [3]	May be found as sum of areas. May be implied by correct total FT their distance found for first 8s	FT their graph if linear for M1 A0 for a triangle or trapezium area 213.6 must be added to another distance Examiner's Comments Many candidates were successful in finding the area under their graph with only a few arithmetical errors.

Question			Answer/Indicative content	Marks	Guidance
		e	When $t = 4$ $v = 5 + 0.3 \times 4^2 - 0.05 \times 4^3 = 11.4$ ms^{-1} Which matches the given value	B1 (AO 3.4) [1]	Allow without comment Examiner's Comments This mark was credited for seeing the substitution of $t = 4$ into the equation. It would have been good to see this followed by a comment that the value was close to the given value.
		f	$\frac{dv}{dt} = 0.6 \times 2t - 0.05 \times 3t^2 \left[= 1.2t - 0.15t^2 \right]$ When $t = 8$ $v = 1.2 \times 8 - 0.15 \times 64 = 0$ Acceleration is zero at $t = 8$ which means that the car reaches its maximum speed without the sudden change in acceleration in model A.	M1 (AO 1.1a) A1 (AO 3.2a) E1 (AO 3.2a) [3]	Need not be simplified Must mention acceleration Must compare with model A Final mark can be awarded independently for a statement about change in acceleration as long as supported by some numerical evidence Examiner's Comments Some candidates were very vague in their answer here and were not credited many marks. There is a very clear instruction that it is the value of acceleration that is needed, so 2 of the 3 marks were given for finding this. Many candidates were able to comment that model B gives a gradual change in acceleration as it approaches the maximum speed avoiding the very sudden change seen in model A.

Question			Answer/Indicative content	Marks	Guidance	
		g	EITHER $\int_0^8 \left(5+0.6t^2-0.05t^3\right) \mathrm{d}t = \left[5t+0.2t^3-0.0125t^4\right]_0^8$ $=91.2$ m which is same as model A for the first 8 s Distance is the same for the remainder of the time So this is the same as model A at $t = 20$ OR $\int_0^8 \left(5+0.6t^2-0.05t^3\right) \mathrm{d}t = \left[5t+0.2t^3-0.0125t^4\right]_0^8$ = 91.2 m Distance at 17.8 ms^{-1} 213.6 Total distance 304.8m [which is the same as model A]	M1 (AO 2.1) A1 (AO 1.1b) E1 (AO 2.1) [3] M1 A1 A1	BC Must consider to $t = 20$ BC Must consider to $t = 20$	Allow for correct definite integral stated and calculator used. Also allow M1A1 for $5\times8 - 0.2\times8^3 - 0.0125\times8^4$ seen Allow for correct definite integral stated and calculator used.
					<u>Examiner's Comments</u> Many candidates realised that the distance was the definite integral that gave the distance travelled in the first 8s. It would have been sufficient to clearly write the integral with its limits and use a calculator to evaluate it. Most candidates decided to give a full solution with the substitution of limits made clear. Only a few candidates omitted the part of the journey beyond 8s.	
			Total	17		

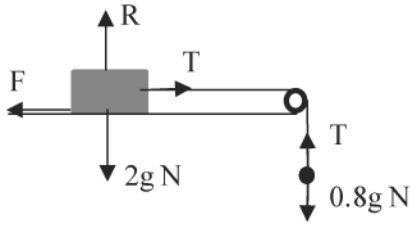
Question			Answer/Indicative content	Marks	Guidance
14		a		B1 (AO 3.3) B1 (AO 1.1) B1 (AO 1.1) [3]	Graph with three straight lines with positive, zero and negative gradients Vertical axis labelled with 2.5 and 7.5 marked Horizontal axis labelled with 12, 32 and 40 marked (oe, e.g.separate time intervals indicated)
		b	Total distance = area under graph $= \frac{1}{2}\times(2.5+7.5)\times12+(20\times7.5)+\frac{1}{2}\times8\times7.5$ = 240 m Average speed is $\frac{240}{40}$ = 6 m s^{-1}	M1 (AO 3.1b) A1 (AO 1.1) M1 (AO 1.1a) A1 (AO 1.1) [4]	Any complete method Dividing their distance by their total time FT
			Total	7	

Question			Answer/Indicative content	Marks	Guidance	
15			Use of $s = ut + \frac{1}{2}at^2$ to compare two accelerations			
			For OA: $24 = 3 \times 4 + \frac{1}{2} a \times 4^2$	M1 (AO 3.3)	Use formula with $u = 3$, $s = 24$, $t = 4$	
			$a = 1.5$	A1 (AO 1.1b)		
			For OB: $104 = 3 \times 10 + \frac{1}{2} a \times 10^2$	M1 (AO 3.3)	Use formula with $u = 3$, $s = 104$, $t = 10$ or (for AB) with $u = 9$, $s = 80$, $t = 6$	If AB considered do not allow $u = 3$; there must be an attempt to find the speed at A, e.g. via *suvat* for OA
			$a = 1.48$	A1 (AO 1.1b)	(or a = 1.44 using data for AB)	
			Similar values, so constant acceleration is a good model	A1 (AO 3.5a)	Clear comparison and conclusion. Allow alternative conclusion, i.e. that the model is not [exactly] consistent with the data	
			Alternative solution			Allow credit for any complete method
			Predicting a value and comparing with given figure			
			For OA: $24 = 3 \times 4 + \frac{1}{2} a \times 4^2$	M1	Find a for OA using $u = 3$, $s = 24$, $t = 4$	
			$a = 1.5$	A1		
			For OB: $s = 3 \times 10 + \frac{1}{2} \times 1.5 \times 10^2$	M1	Use of $a = 1.5$ for OB, oe	Do not allow $u = 3$ as initial speed for AB
			OB = 105 m	A1		
			Actual distance is 104 m, which is very close, so constant acceleration is a good model	A1	Clear comparison and conclusion Allow alternative conclusion, i.e. that the model is not [exactly] consistent with the data	
				[5]		
			Total	5		

Question			Answer/Indicative content	Marks	Guidance	
16	a			B1(AO1.1a) B1(AO1.1) [2]	F and their weight even if not labelled in roughly correct position Distances labelled. Allow for 5cm **and** any measurements that show that the weight is acting in the centre of the ruler.	R is already drawn in Printed Answer Booklet
	b		Take moments about C $10 \times 0.028g = 5F$ $F = 0.549$ N	M1(AO1.1a) A1(AO1.1) [2]	Moments about any point with all relevant forces seen. Allow their weight and one incorrect distance allow $\frac{7}{125}g$ oe	[Value of R is 0.8232 N]
			Total	**4**		

Question			Answer/Indicative content	Marks	Guidance	
17			$v = \int(0.8t + 0.5)\ dt = 0.4t^2 + 0.5t + c$	M1(AO3.1b)	Attempt to integrate, condone omission of +c	
			When $t = 0$, $v = 3$	M1(3.1b)	Attempt to evaluate c	
			$3 = 0.4 \times 0^2 + 0.5 \times 0 + c$	A1(AO1.1)	Any form	
			So $v = 0.4t^2 + 0.5t + 3$	M1(AO3.1b)	Forming an equation using their $v = 0$	
			Particle stationary when $v = 0$			
			$0.4t^2 + 0.5t + 3 = 0$	M1(AO3.1a)	Use of discriminant or completing the square, showing equation has complex roots or stating that the equation has no real roots	Allow this M mark for solving their equation if it has real solutions
			discriminant $0.5^5 - 4 \times 0.4 \times 3 = -4.55 < 0$			
			So the velocity is never zero and the particle never stationary.	E1(AO2.2a)	Clear conclusion in context consistent with their working. FT their v.	
			OR	[6]		
			$v = \int(0.8t + 0.5)\ dt = 0.4t^2 + 0.5t + c$	M1	Dependent on at least 1 method mark.	Ignore any reference to $t < 0$ but do not allow stationary at $t = 0$
			When $t = 0$, $v = 3$	M1	Attempt to integrate, condone omission of +c	
			$3 = 0.4 \times 0^2 + 0.5 \times 0 + c$	A1	Attempt to evaluate c	
			So $v = 0.4t^2 + 0.5t + 3$	M1	Uses the positivity of t to establish the positivity of v.	
			Clearly v is always positive therefore never sationary	M1	Argues that v is always positive	
			OR	E1	Clear conclusion in context consistent with their working. FT their v.	
			for $t > 0$ $a = 0.8t + 0.5 > 0$	M1	Dependent on at least 1 method mark.	

Question			Answer/Indicative content	Marks	Guidance	
			So v is an increasing function When $t = 0$, $v = 3 > 0$ v [> 3] > 0 for all values of t So the velocity is never zero and the particle never stationary.		Attempt to construct an argument based on the positivity of v. Uses the positivity of t aiming to establish the positivity of a Clear argument that $a > 0$ Uses the link between $a > 0$ and v Uses $v_0 = 3$ explicitly in their argument Convincing complete argument.	
			Total	6		

Question			Answer/Indicative content	Marks	Guidance	
18	a			B1(1.1a) B1(1.1a) B1(1.1a) [3]	both weights correct. common tension in the rigtht directions Friction and normal reaction and no extra forces	Allow weight of box and weight of sphere, but not if both marked weight. Allow T_1 and T_2 provided they are clearly shown equal to each other elsewhere. For *F,* allow 0.35R, 0.35 × 2 *g* 0.7g or 6.86 N
	b		$T - F = 2a$ $0.8g - T = 0.8a$	B1(AO1.1a) B1(1.1a) [2]	Allow any expression for F Allow distinct tensions if consistent with diagram	For *F,* allow 0.35*R*, 0.35 × 2*g* 0.7g or 6.86 N
	c		Vertically for the block $R = 2g$ Friction $F = 0.35R = 0.7g$ Add equations $0.8g - F = 2.8a$ $0.8g - 0.7g = 2.8a$ $a = 0.35$ m s^{-2}	M1(AO3.1b) A1(AO2.1) M1(AO2.1) A1(2.1) [4]	Attempt to use μ to evaluate friction Correct value for F Eliminate *T* from their equations AG must follow from correct work	Some of this work may already have been seen in previous part
	d		Use $s = 0.5$, $u = 0$, $a = 0.35$ $0.5 = \frac{1}{2} \times 0.35 \times t^2$ $t = 1.69$ s	M1(AO1.1a) A1(AO1.1) [2]	Using *suvat* equation(s) leading to a value for *t* Do not allow ±1.69	
			Total	**11**		
19			eg. Neglect air resistance Constant gravity Projectile is a particle	B1(AO1.2) [1]	One sensible statement.	Do not accept level ground
			Total	**1**		

Question			Answer/Indicative content	Marks	Guidance	
20			Newton's second law $\begin{pmatrix}0\\-1.5g\end{pmatrix}+\begin{pmatrix}4\\-2\end{pmatrix}+\begin{pmatrix}2\\20\end{pmatrix}=m\mathbf{a}$ $\mathbf{a}=\frac{1}{1.5}\begin{pmatrix}6\\3.3\end{pmatrix}=\begin{pmatrix}4\\2.2\end{pmatrix}$ m s^{-2}	M1(AO1.1a) A1(AO1.1) [2]	Addition of vectors. Allow if weight missing but other two forces and acceleration seen in equation Must be vector; any correct form.	Allow wrong weight only if given as a vector
			Total	1		
21			There is a change of direction when $t = 5$ $\int_0^5\left(t^3-5t^2\right)\mathrm{d}t=\left[\frac{t^4}{4}-\frac{5t^2}{3}\right]_0^5=-\frac{625}{12}$ $\int_5^6\left(t^3-5t^2\right)\mathrm{d}t=\frac{193}{12}$ Total distance $\frac{625+193}{12}=\frac{409}{6}=68.2$ m	M1(AO3.4) M1(AO3.4) A1(AO1.1) [3]	DR Considering signed areas either side of $t = 5$ s. Algebraic integration seen attempted Correct to at least 2 sf	SPECIAL CASE $\int_0^6\left(t^3-5t^2\right)\mathrm{d}t$ $=\left[\frac{t^4}{4}-\frac{5t^2}{3}\right]_0^6=-36$ SCM1 for algebraic integration seen attempted SCA1 for –36 m seen or distance 36 given
			Total	2		