1. Fig. 4 shows two small blocks, Q of mass 8 kg and R of mass 6 kg. They are connected by a light string which passes over a pulley.

The pulley is light and smooth. It is rigidly suspended from the ceiling.

The system is released from rest with the two blocks at the same height.

Initially the blocks are 2 m above the floor and 3 m below the pulley.

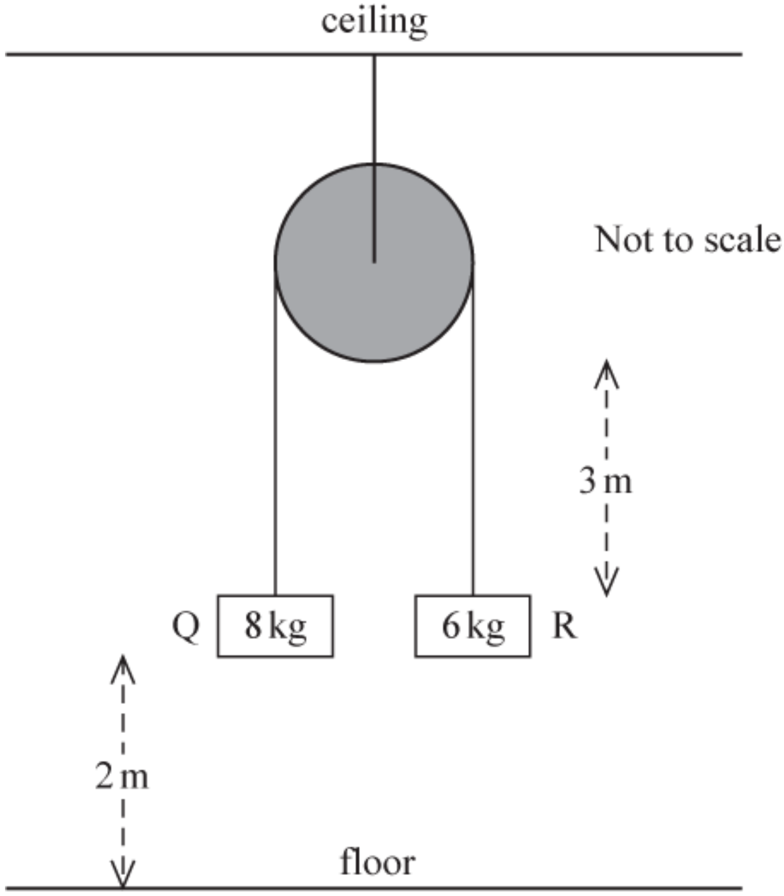


Fig. 4

(i) Draw diagrams showing the forces acting on each of the blocks Q and R. [1]

(ii) Write down the equations of motion of each of the blocks Q and R. [2]

(iii) Find the time between the system being released and one of the blocks reaching the floor. [4]

2. Fig. 4 shows a block of mass $4m$ kg and a particle of mass m kg connected by a light inextensible string passing over a smooth pulley. The block is on a horizontal table, and the particle hangs freely. The part of the string between the pulley and the block is horizontal. The block slides towards the pulley and the particle descends. In this motion, the friction force between the table and the block is $\frac{1}{2}mg$ N.

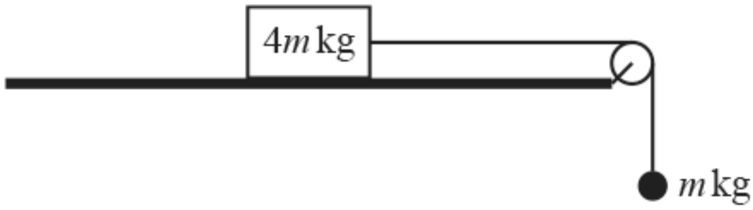


Fig. 4

Find expressions for

- the acceleration of the system,
- the tension in the string. [4]

3. A toy boat of mass 1.5 kg is pushed across a pond, starting from rest, for 2.5 seconds. During this time, the boat has an acceleration of 2 m s^{-2}. Subsequently, when the only horizontal force acting on the boat is a constant resistance to motion, the boat travels 10 m before coming to rest. Calculate the magnitude of the resistance to motion.

[6]

4. Fig. 5 shows blocks of mass 4 kg and 6 kg on a smooth horizontal table. They are connected by a light, inextensible string. As shown, a horizontal force F N acts on the 4 kg block and a horizontal force of 30 N acts on the 6 kg block.

The magnitude of the acceleration of the system is 2 ms^{-2}.

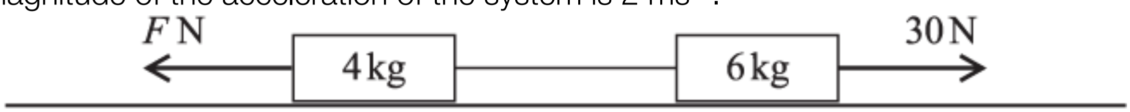


Fig.5

i. Find the two possible values of F.

[4]

ii. Find the tension in the string in each case.

[3]

5. Fig. 7 illustrates a train with a locomotive, L, pulling two trucks, A and B.

The locomotive has mass 90 tonnes and is subject to a resistance force of 2000 N.

Each of the trucks A and B has mass 30 tonnes and is subject to a resistance force of 500 N.

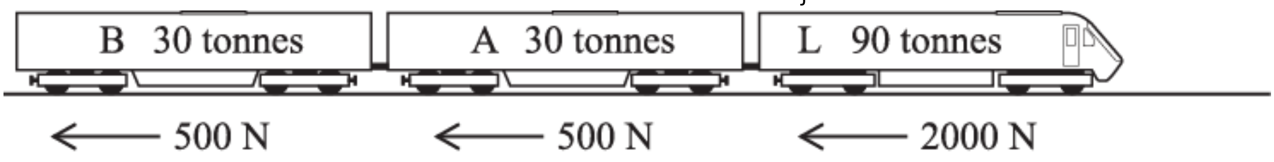


Fig. 7

Initially the train is travelling along a straight horizontal track. The locomotive is exerting a driving force of 12 000 N.

i. Find the acceleration of the train.

[3]

ii. Find the tension in the coupling between trucks A and B.

[3]

When the train is travelling at $10ms^{-1}$, a fault occurs with truck A and the resistance to its motion changes from 500 N to 5000 N.

The driver reduces the driving force to zero and allows the train to slow down under the resistance forces and come to a stop.

iii. Find the distance the train travels while slowing down and coming to a stop.

Find also the force in the coupling between trucks A and B while the train is slowing down, and state whether it is a tension or a thrust.

[7]

The fault in truck A is repaired so that the resistance to its motion is again 500 N. The train continues and comes to a place where the track goes up a uniformslope at an angle of α° to the horizontal.

iv. When the train is on the slope, it travels at uniform speed. The driving force remains at 12 000 N. Find the value of α.

[3]

v. Show that the force in the coupling between trucks A and B has the same value that it had in part **(ii)**.

[2]

6. Fig. 2 shows a 6 kg block on a smooth horizontal table. It is connected to blocks of mass 2 kg and 9 kg by two light strings which pass over smooth pulleys at the edges of the table. The parts of the strings attached to the 6 kg block are horizontal.

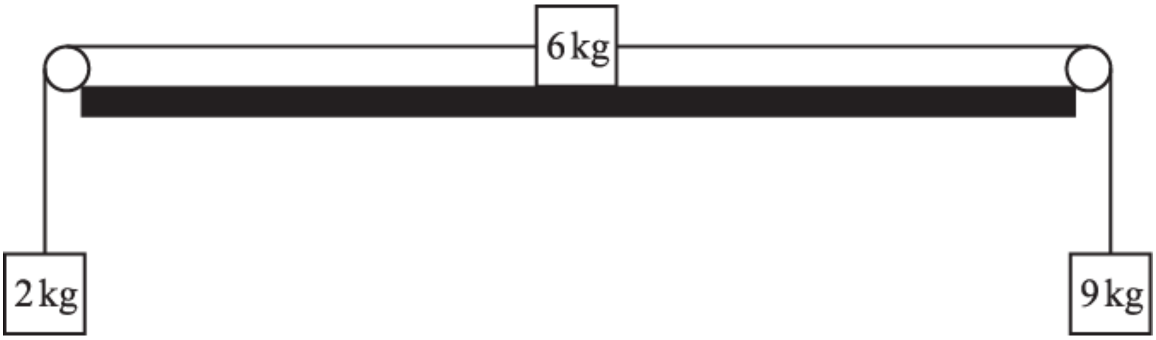


Fig. 2

i. Draw three separate diagrams showing all the forces acting on each of the blocks.

[3]

ii. Calculate the acceleration of the system and the tension in each string.

[5]

7. Fig. 3 shows a particle of weight 8 N on a rough horizontal table. The particle is being pulled by a horizontal force of 10 N. It remains at rest in equilibrium.

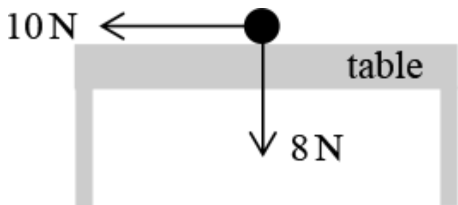


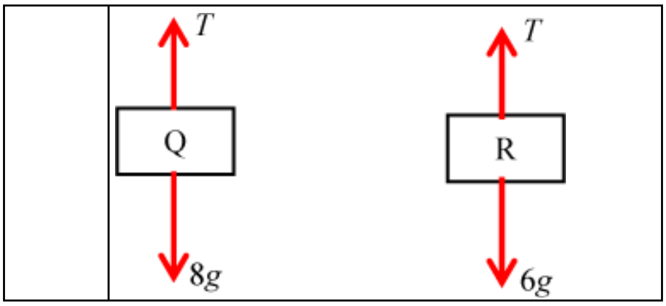
Fig. 3

(a) What information given in the question tells you that the forces shown in Fig. 3 cannot be the only forces acting on the particle? [1]

(b) The only other forces acting on the particle are due to the particle being on the table. State the types of these forces and their magnitudes. [2]

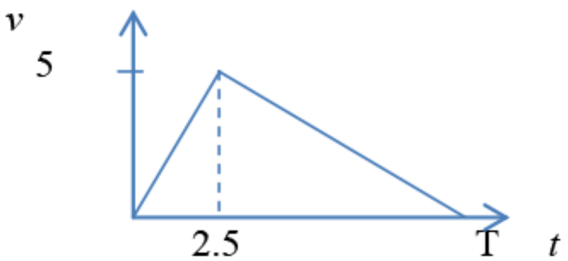
END OF QUESTION paper

Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1		i		B1 [1]	The same symbol for T must be used in both diagrams. **Examiner's Comments** Part (i) asked for force diagrams for the two connected particles, in this case blocks. A minority of candidates failed to get this right; the most common error was to mark different tensions for the different parts of the string.
		ii	Q: $8g - T = 8a$ R: $T - 6g = 6a$	B1 B1 [2]	Allow the equivalent equations with the direction of a reversed **Examiner's Comments** Part (ii) followed on from part (i) with a request for the equations of motion of the two blocks. This was not universally well answered; sign errors were common.
		iii	Adding the equations of motion $2g = 14a$ $a = \frac{2g}{14} \quad (= 1.4 \text{ m s}^{-2})$ For Q: $s = ut + \frac{1}{2}at^2$ $2 = \frac{1}{2} \times 1.4 \times t^2$ $\Rightarrow t = 1.690\ldots$ so the time is 1.69 s	M1 A1 M1 A1 [4]	Eliminating one variable from the two equations. May be implied by subsequent working. This answer must be consistent with the direction of a used in part (ii) Or an equivalent sequence of constant acceleration formulae Dependent on previous M mark. FT for their a but do not allow if it is g CAO **Examiner's Comments** In part (iii) the blocks were released and candidates were asked to find the time taken for one of them to reach the floor. This involved finding the acceleration of the system. Many, including those who has made mistakes in the earlier parts, did this using a whole system approach rather than working from the equations of motion.
			Total	7	

Question			Answer	Marks	Guidance
2			$T - \frac{1}{2}mg = 4ma$ $mg - T = ma$ $a = \frac{g}{10}$ m s^{-2} $T = \frac{9mg}{10}$ N	B1 (AO3.1b) B1 (AO3.1b) M1dep (AO1.1a) A1 (AO1.1b) [4]	Award for first of these two equations Signs consistent with first equation — M1 dependent on at least one B1 earned Attempting to solve the simultaneous equations leading to either *T* or *a* soi Both *T* and *a* needed simplified — Allow 0.98 m s^{-2}, and $T = \frac{441m}{50} = 8.82m$ N <u>Examiner's Comments</u> This question was a very standard question but many candidates did not correctly use Newton's 2nd law to form equations of motion. Those who attempted to write down a single equation for the whole system (the round-the-corner method) were rarely successful. Some wrongly included the weight of the object on the table in its equation of motion. Many candidates had fragments of working that were not clear - examiners used the mass to indicate which part(s) of the system was being considered and required the correct forces acting on that part. Some who had correct equations then lost a mark as they did not simplify their expressions for *a* and *T* fully. Prepare candidates to consider each part of the system separately and to identify which forces are acting on that object in the direction of its motion. There is evidence of candidates confusing mass and weight, essentially using *F* = *mga* instead of Newton's 2nd law.
			Total	4	

3	EITHER acceleration phase $v^2 = 0 + 2.5 \times 2 = 5$ m s^{-1} slowing phase $v^2 = u^2 + 2as$ $0 = 5^2 + 2a \times 10$ $a = -1.25$ m s^{-2} $[-R] = 1.5 \times (-1.25) = -1.875$ Magnitude of $R = 1.875$ N (1.88 to 3sf) OR acceleration phase $v = 0 + 2.5 \times 2 = 5$ m s^{-1} (graph below) using the distance to find the time it takes to stop *using areas* (second triangle): $\frac{1}{2}(T - 2.5) \times 5 = 10$ $T = 6.5$ so time to stop is 4 s. So $0 = 5 + 4a$ Giving $a = -1.25$ m s^{-2} $[-R] = 1.5 \times (-1.25) = -1.875$	M1 (AO3.1b) A1 (AO1.1b) M1 (AO3.1b) A1 (AO1.1b) M1 (AO1.1a) A1 (AO1.1b) [6] M1 A1 M1 A1 M1	Use of *suvat* equation(s) to find velocity. Do not allow if $s = 10$ used Use of *suvat* equation(s) with $s = 10$ to find acceleration FT their velocity. Must be correct sign. Use of Newton's second law. FT their a $a \neq 2$ Must be positive Use of *suvat* equation(s) to find velocity. Do not allow if $s = 10$ used Use of area and *suvat* equation(s) to find acceleration Must be correct sign	Must recognise two phases of motion for first 4 marks Consistent sign convention needed for full credit. Must recognise two phases of motion for first 4 marks

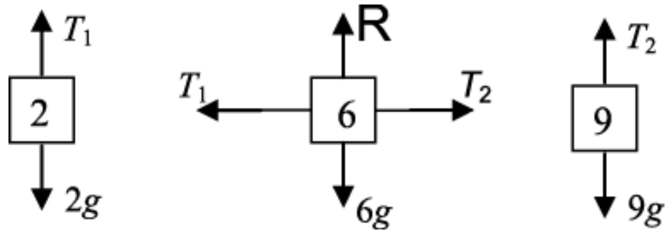


			Magnitude of R = 1.875 N (1.88 to 3sf)	A1 [6]	Use of Newton's second law. FT their a $a \neq 2$ Must be positive Consistent sign convention needed for full credit. Examiner's Comments Many good clear solutions were seen, however some candidates did not realise that this question covered two phases of motion and used all the numbers in the question in a single set of suvat equations. Some simply extracted the values of mass and acceleration from the first phase of motion and multiplied them together. Some candidates who obtained a negative value for resistance did not notice that it was the magnitude of the resistance that was required, so a positive answer was needed. Look out for two phases of motion and set up different equations for the two phases. Use the value of the velocity at the end of the first phase to link the two phases.
			Total	6	
4		i	If the acceleration is to the right		
		i	Overall $30 - F = (4 + 6) \times 2$	M1	Newton's 2nd Law in one direction. No extra forces allowed and signs must be correct.
		i	$F = 10$	A1	
		i	If the acceleration is to the left	M1	For considering second direction. No extra forces allowed and signs must be correct.
		i	$F = 50$	A1	Examiner's Comments This question was about connected particles, in the form of two blocks on a table. Part (i) was best answered treating the system as a whole. Both parts were correctly answered by many candidates. However, a few candidates did not realise that an acceleration of magnitude 2 could be in either direction, to the left or to the right.

		ii	6 kg block $30 - T = 6 \times 2$	M1	Newton's 2nd law with correct elements on either block
		ii	$\Rightarrow T = 18$	A1	CAO No follow through from part (i)
		ii	In the other case $T = 42$	A1	CAO No follow through from part (i) Examiner's Comments This question was about connected particles, in the form of two blocks on a table. Part (ii) asked for the tension in the connecting string and so required candidates to work with one of the blocks. A not uncommon mistake, particularly in part (ii), was to introduce extra forces into the equations of motion.
			Total	**7**	
5		i	Whole train: mass = 150 tonnes	B1	Both totals required.
		i	Total Resistance = 3000 N		
		i	$12000 - 3000 = 150000a$	M1	Correct elements must be present
		i	$a = 0.06$ The acceleration is 0.06 ms^{-2}	A1	CAO. Errors with units (eg not converting tonnes to kilograms) are penalised here but condoned where possible for the remainder of the question. Examiner's Comments This question was a good source of marks for many candidates. It was about the motion of a train and the forces in one of the couplings. Most candidates were able to answer the parts that involved considering the train as a whole. Fewer were successful when it came to working with part of the train to find the force in a particular coupling. Candidates were asked find the acceleration of the whole train and most were successful. A number failed to convert the mass of the train from tonnes into kilograms. This was penalised here but follow-through was then applied for all the marks in the next two parts and for the first two marks in part (iv).
		ii	Truck B: $T - 500 = 30000a$	M1	Correct elements must be present
		ii	$T - 500 = 30000 \times 0.06$	A1	Allow FT for a from part (i) if units are used consistently, for all the marks in this part
		ii	$T = 2300$	A1	
		ii	Between A and B, tension of 2300 N		
		ii	Alternative		

		ii	Rest of train: 12 000 − 2500 − T = 120 000a	M1	Correct elements must be present **Examiner's Comments** This question was a good source of marks for many candidates. It was about the motion of a train and the forces in one of the couplings. Most candidates were able to answer the parts that involved considering the train as a whole. Fewer were successful when it came to working with part of the train to find the force in a particular coupling. Candidates were asked to find the tension in the coupling between the two trucks. Most candidates answered this correctly but some introduced extraneous forces.
		ii	T = 12 000 − 2500 − 120 000 × 0.06	A1	
		ii	T = 2300	A1	
		iii	Treating the train as a whole − 2000 − 5000 − 500 = 150 000a	M1	Allow FT for the remaining A marks in part (iii) from an error in a Correct elements must be present. Alternative for rest of train: −T − 5000 − 2000 = 120 000 × −0.05 The sign of 1000 must be consistent with the direction of T. Dependent on previous M and A marks. Accept “compression”.
		iii	a = −0.05	A1	Allow FT for the remaining A marks in part (iii) from an error in a
		iii	$v^2 - u^2 = 2as$	M1	
		iii	$0^2 - 10^2 = 2 \times (-0.05) \times s$		
		iii	s = 1000 Stopping distance is 1000 m	A1	
		iii	B: T − 500 = 30000a	M1	Correct elements must be present. Alternative for rest of train: −T − 5000 − 2000 = 120 000 × −0.05
		iii	T = −1000	A1	The sign of 1000 must be consistent with the direction of T.
		iii	Between A and B, thrust of 1000 N	A1	Dependent on previous M and A marks. Accept “compression”. **Examiner's Comments** This question was a good source of marks for many candidates. It was about the motion of a train and the forces in one of the couplings. Most candidates were able to answer the parts that involved considering the train as a whole. Fewer were successful when it came to working with part of the train to find the force in a particular coupling. Carried 7 marks. The first four of these involved the motion of the train as a whole in a new situation and many candidates obtained all of these marks. The last three marks were for finding the new force in the coupling between the

					trucks. Most of those candidates who had been successful in part (ii) obtained these marks but others were unable to identify which forces were relevant and which were not.
		iv	Equilibrium parallel to the slope	M1	Correct elements must be present and there must be an attempt to resolve the weight. Condone omission of *g* for this mark.
		iv	$150000 \times 9.8 \times \sin\alpha + 3000 = 12000$	A1	
		iv	$\alpha = 0.35°$	A1	CAO **Examiner's Comments** This question was a good source of marks for many candidates. It was about the motion of a train and the forces in one of the couplings. Most candidates were able to answer the parts that involved considering the train as a whole. Fewer were successful when it came to working with part of the train to find the force in a particular coupling. Involved a new situation in which the train was on a slope. Candidates were asked to find the angle of the slope. While there were plenty of correct answers, many of them were not very well explained. Good force diagrams were something of a rarity.
		v	B: $T_2 - 500 - 30000 \times 9.8 \times \sin 0.35...° = 0$	M1	Correct elements must be present. Condone omission of g for this mark. Do not accept 1800 N for the component of the weight without justification. Alternative for rest of train: $12\,000 = T + 2500 + 120\,000 \times 9.8 \times \sin 0.35°$
		v	$T_2 = 2300$ Between A and B, tension of 2300 N, as in part (ii)	A1	This mark can only be awarded if the angle found in (iv) is correct. **Examiner's Comments** This question was a good source of marks for many candidates. It was about the motion of a train and the forces in one of the couplings. Most candidates were able to answer the parts that involved considering the train as a whole. Fewer were successful when it came to working with part of the train to find the force in a particular coupling. Provided the last two marks on the paper. It exemplified the interesting (and little known) result that the tensions between trucks when the train is going up a slope at constant speed are the same as those when it is accelerating on level ground, under the same driving force. In this part candidates were asked to do no more than find the same numerical answer as they had obtained in part (ii). Stronger candidates were successful on this but many others had failed to find the correct earlier results (the tension in part (ii) and the angle in part (iv)) that were needed here.
			Total	18	

6		i		B1	Diagrams for both 2 and 9 kg blocks. The tensions must be different from each other. No extra forces.
		i		B1	Tensions on 6 kg block. The tensions must be different from each other. No extra forces.
		i		B1	6*g* and *R* on 6 kg block. No extra forces. **Special Case** When the tensions are given as T_1, T_2, T_3, T_4 (or equivalent) award up to SC1 SC0 for the first two marks. **Examiner's Comments** Candidates were asked to draw separate diagrams showing the forces on the three objects. There were two strings and the tensions in them were different. However, many candidates treated them as the same and just marked them as *T*. This was obviously a serious mistake which undermined the whole question and so caused a large loss of marks both in part (i) and, if continued.
		ii	$9g - T_2 = 9a$	M1	First equation correct
		ii	$T_2 - T_1 = 6a$	M1	Both the remaining two equations correct.
		ii	$T_1 - 2g = 2a$		Do not give this mark if both tensions are shown as the same.
		ii	$a = \frac{7}{17}g = 4.04 \ (\text{m s}^{-2})$	A1	The final three marks are dependent on both M marks *a*, T_1 and T_2 may be found in any order and FT should be allowed from the first of these found
		ii	$T_1 = 27.7$ (N)	A1	
		ii	$T_2 = 51.9$ (N)	A1	
		ii	**Alternative: Whole system**		
		ii	$9g - 2g = 17a$	M1	
		ii	$a = \frac{7g}{17} = 4.04$	A1	
		ii	$T_1 - 2g = 2a$ and $9g - T_2 = 9a$	M1	Both equations correct. Oe.
		ii	$T_1 = 27.7$ (N)	A1	The final two marks are dependent on both M marks. T_1 and T_2 may be found in either order and FT should be allowed from their value for *a*.
		ii	$T_2 = 51.9$ (N)	A1	**Examiner's Comments**

					Candidates went on to find the acceleration of the system and the tensions in the two strings. Those who had drawn correct diagrams in part (i) usually got this completely correct but those who had not done so, rarely made much progress on this part.
		Total	8		
7	a	E.g. The particle is in equilibrium [and the given forces cannot sum to zero as at 90°]	B1(AO2.2a) [1]	oe	Accept "without another force present, the particle would be moving on a rough surface without a frictional force"
	b	Friction 10 N [to give horizontal resultant of 0] Normal reaction from table. 8 N [to give vertical resultant of 0] **Alternative method** One extra force that gives equilibrium. Components 10 N → and 8 N ↑ Components from Friction → and normal reaction ↑	B1(AO3.3) B1(AO1.2) B1(AO3.3) B1(AO1.2) [2]	oe Accept 'Because the surface is rough' for 'Friction' Oe oe Accept $\sqrt{164}$ at ≈ 39° to horizontal oe Accept 'because the surface is rough' for 'Friction'	
		Total	3		