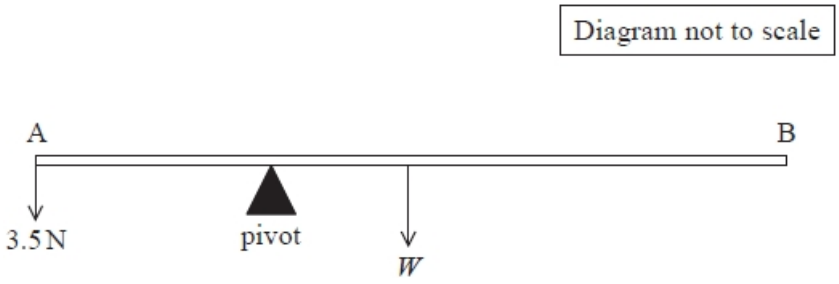
Moments

Q1.

A uniform rigid rod AB of length 1.50 m has a weight *W* of 6.5 N. A force of 3.5 N applied at A balances the rod on a pivot as shown.



Calculate the distance of the pivot from A when the rod is in equilibrium.

(2)

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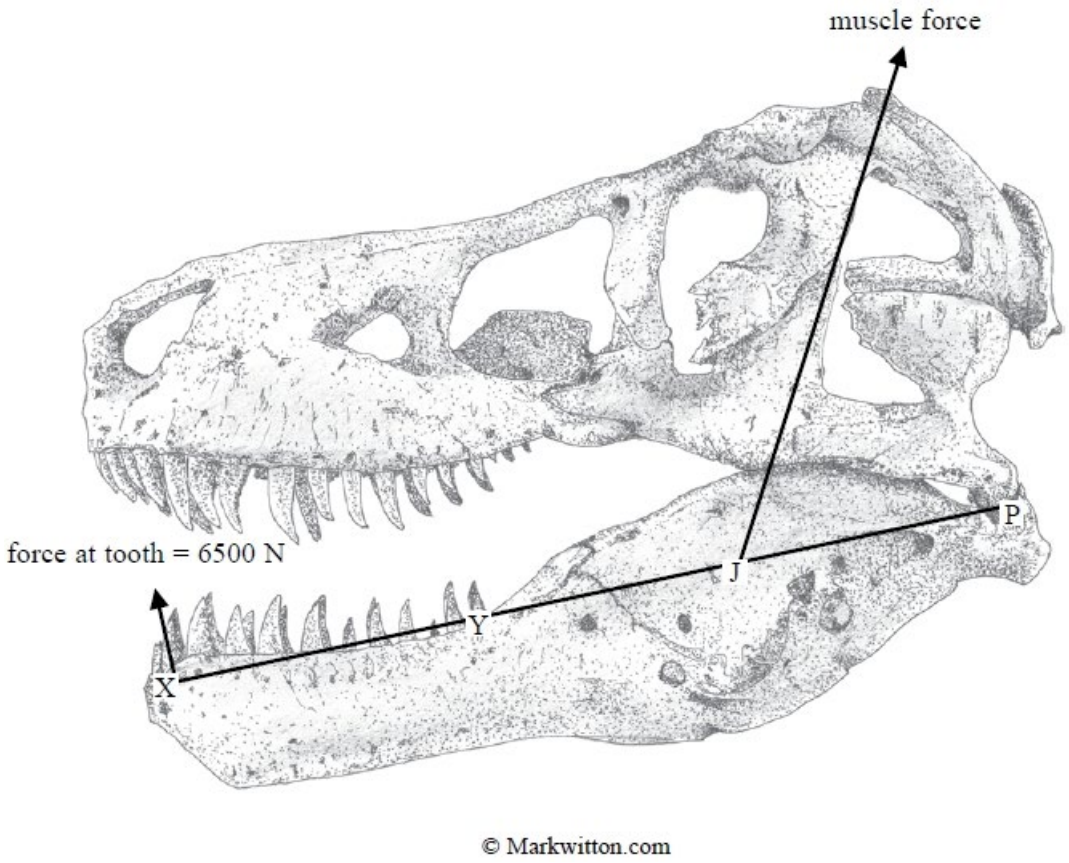
Distance of pivot from A = ...

(Total for question = 2 marks)

Q2.

Extinct animals can be studied by using their fossils. 70-million-year-old fossils from the *Tyrannosaurus rex* and *Triceratops* dinosaurs show that a *Triceratops* was sometimes eaten by a *Tyrannosaurus rex*.

The diagram shows a *Tyrannosaurus rex* skull.



On the diagram, the position of the main biting muscle is indicated by the line labelled 'muscle force'. The muscle is connected to the jaw at point J. This produces a moment about point P where the jaw is hinged. Teeth marks found in fossilised *Triceratops* bones show that the force exerted by a tooth at the front of the jaw X could reach 6500 N.

The skull is drawn to a scale of 1 to 10. The force arrows are **not** drawn to scale.

Take measurements from the diagram to determine the size of the muscle force when the force exerted by the tooth at X is 6500 N.

(5)

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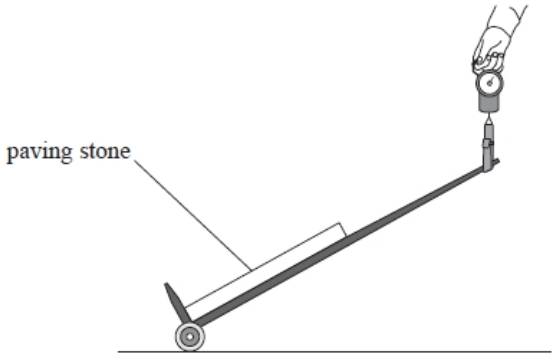
Muscle force = ...

(Total for question = 5 marks)

Q3.

A gardener used a trolley to move a paving stone.



A force meter was attached to the handle of the trolley.

The gardener recorded the following measurements when the trolley was at rest in the position shown in the diagram.

mass of trolley and paving stone = 18.5 kg

length of trolley = 97 cm

force on handle = 50 N

Determine the distance of the centre of gravity of the loaded trolley from the wheels.

(3)

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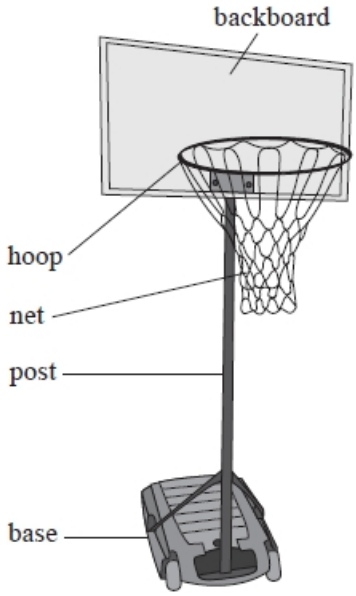
Distance = ...

(Total for question = 3 marks)

Q4.

A portable basketball set has a base and a post arrangement. The post arrangement consists of a post, backboard, hoop and net. The base can be filled with water to increase stability.



(a) The base has a capacity of 85.0 litres.

Show that the maximum weight of the base is about 870N.
mass of 1.00 litre of water = 1.00 kg
mass of base when empty = 3.50 kg

(2)

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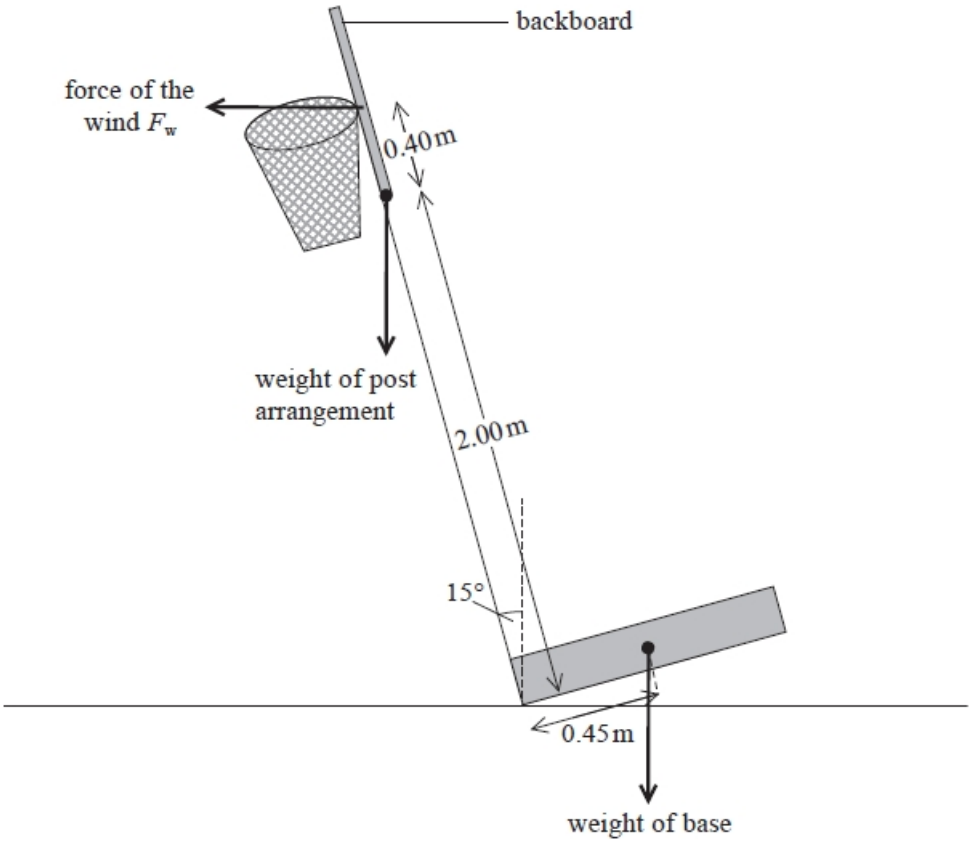
(b) Due to the large area of the backboard, the basketball set may topple over when the wind blows.



Calculate the minimum force of the wind F_w that will cause the basketball set to be blown over when it is at the angle shown. Ignore the effect of the wind on the base.
weight of post arrangement = 27.0 N

(5)

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Minimum force of the wind F_w = ...

(c) The base is filled with sand instead of water. The density of sand is greater than the density of water.

State and justify what would happen to the value of F_w calculated in part (b).

(3)

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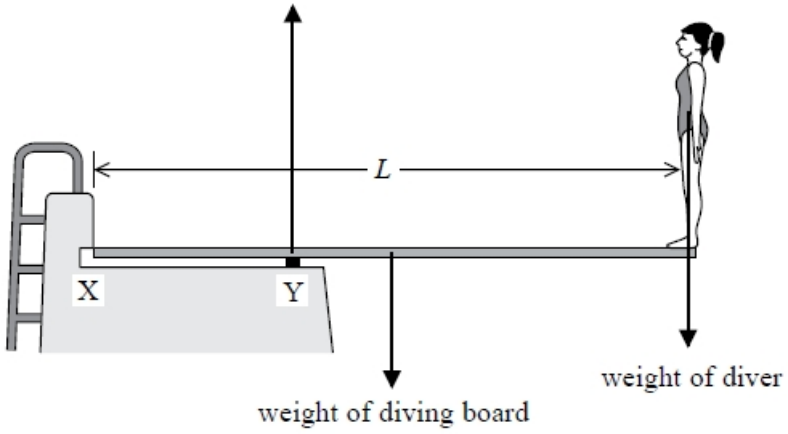
(Total for question = 10 marks)

Q5.

The diagram shows a diver of weight 680 N on a diving board.



The diving board has a length *L* of 3.6 m and is fixed at the end labelled X. It is supported at position Y which is 0.9 m from X. The diving board is uniform and has a weight of 390 N.

By taking moments about X, determine the upward force exerted by the support at Y on the diving board.

(5)

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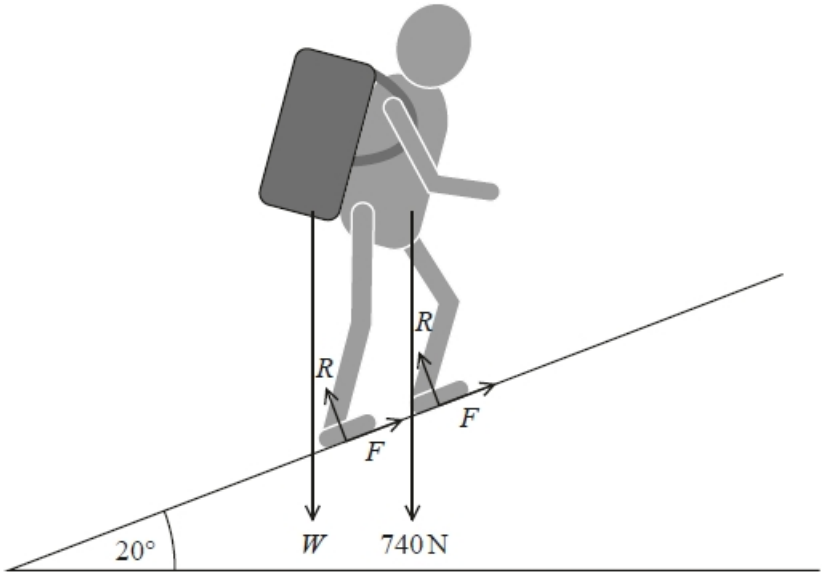
Force = ...

(Total for question = 5 marks)

Q6.

A hiker of weight 740N walks up a hill carrying a large bag of weight *W*. The hiker stops for a moment in the position shown.



The normal force *R* of the ground on the hiker is the same at each foot. The frictional force between each foot and the ground is *F*. The hill is at an incline of 20° to the horizontal.

The hiker repacks his bag, placing the heavier items at the bottom of the bag.

Explain why this may cause *R* on the front foot to decrease.

(2)

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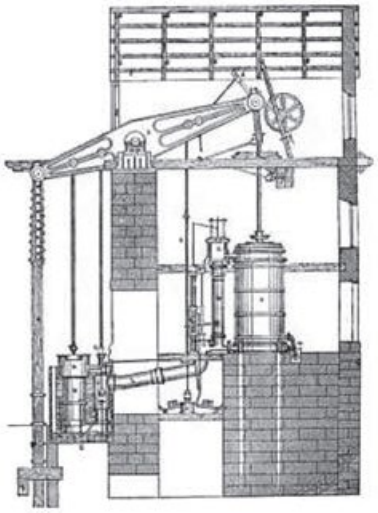
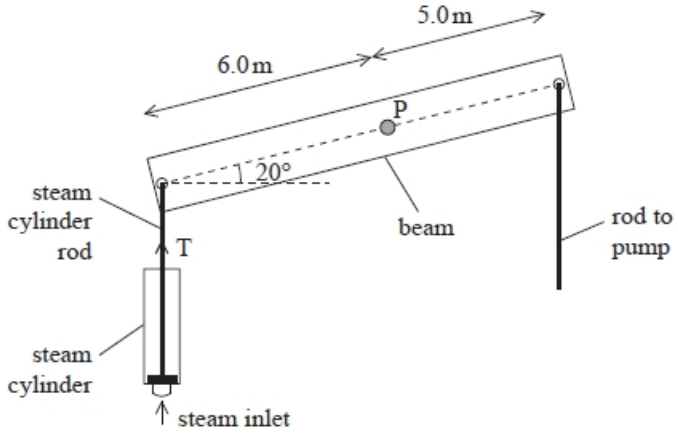
(Total for question = 2 marks)

Q7.

Beam engines contributed to powering the Industrial Revolution in Britain in the 18th century. A beam engine consisted of a beam which could rock to and fro around a well-oiled pivot. Attached to the beam there are two rods, one connected to a piston in a steam cylinder and the other connected to a pump.



The diagram below shows a simplified arrangement of a beam engine.



The beam has a constant thickness and a mass of 3.05×10^4 kg. The length of the beam is 11.0 m. The pivot P is positioned 6.0 m from the steam cylinder end of the beam.

In its resting position the steam cylinder rod is supported by the base of the steam cylinder with the beam at an angle of 20° to the horizontal.

The steam cylinder rod exerts a force *T* on the beam. The force exerted on the beam by the pump rod can be neglected.

Calculate the force *T*.

(4)

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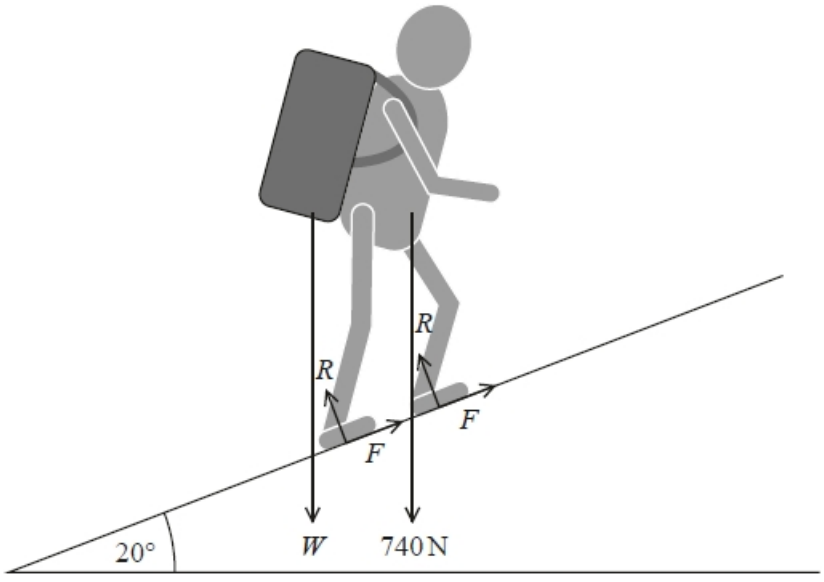
T = ...

(Total for question = 4 marks)

Q8.

A hiker of weight 740N walks up a hill carrying a large bag of weight *W*. The hiker stops for a moment in the position shown.



The normal force *R* of the ground on the hiker is the same at each foot. The frictional force between each foot and the ground is *F*. The hill is at an incline of 20° to the horizontal.

An expression for the components of force perpendicular to the ground acting on the hiker is

$$740\cos 20 + W\cos 20 - 2R = 0$$

(i) Explain why this expression is correct.

(2)

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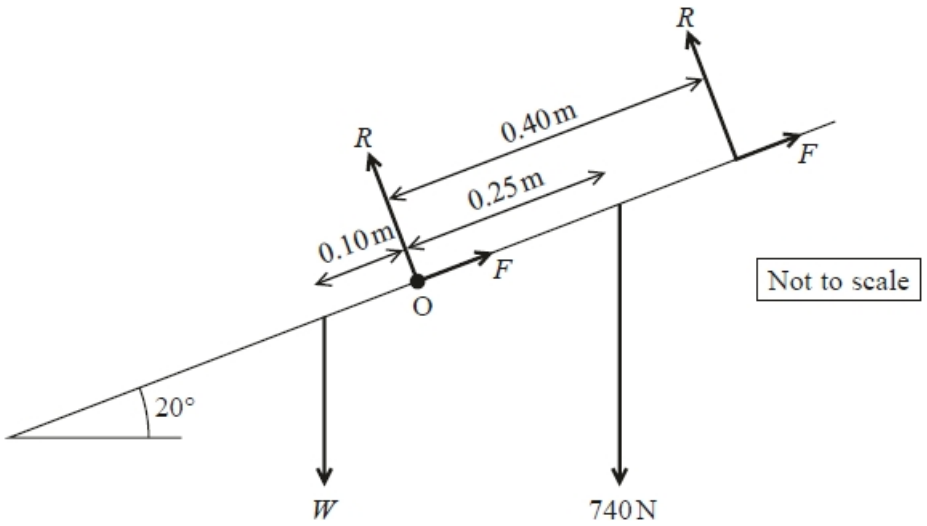
(ii) The diagram shows the lines of action of the forces acting on the hiker and backpack. Position O represents the middle of the back foot of the hiker.



Determine *W*. You should take moments about O.

(6)

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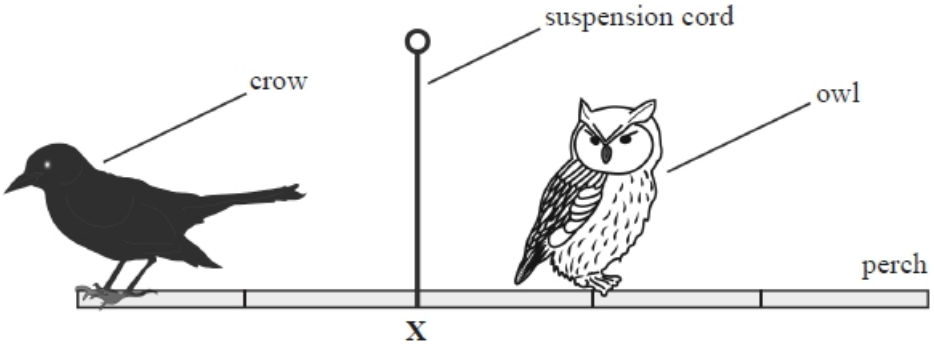
W = ...

(Total for question = 8 marks)

Q9.

In a 'balancing birds' puzzle, model owls and crows are each placed in one of six equally spaced positions marked on a perch. The perch has negligible mass, and is suspended from another of the six marked positions. With the birds placed, and the perch suspended, as shown, the puzzle is in equilibrium.



State what is meant by 'in equilibrium'.

(2)

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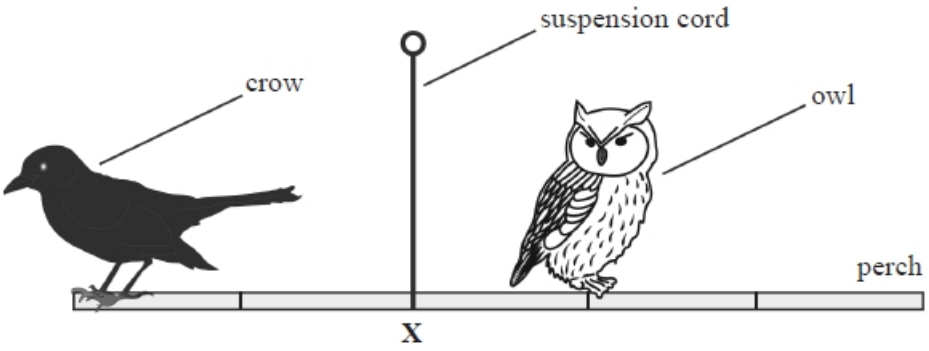
(Total for question = 2 marks)

Q10.

In a 'balancing birds' puzzle, model owls and crows are each placed in one of six equally spaced positions marked on a perch. The perch has negligible mass, and is suspended from another of the six marked positions. With the birds placed, and the perch suspended, as shown, the puzzle is in equilibrium.



(i) The owl has a mass 2*M* and the crow has a mass *M*. Show that the perch will balance when suspended as shown from position X.

(1)

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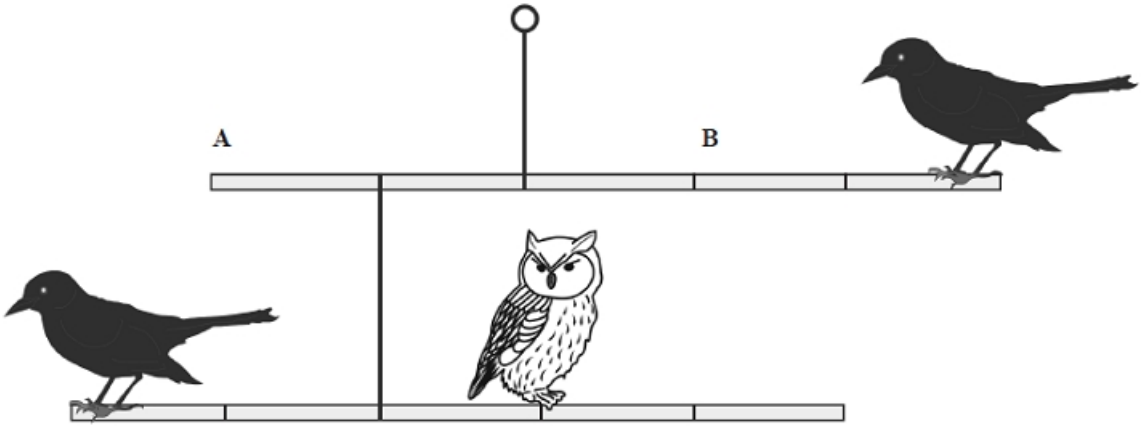
(ii) The perch is then attached to a second perch and suspended as shown. Two more birds, not shown, are placed at A and B, and the whole arrangement is in equilibrium. Each crow has the same mass *M*. The mass of an owl is 2*M*.



Explain, with the aid of a calculation, which type of bird sits at A and which type of bird sits at B to ensure the whole arrangement is in equilibrium.

(3)

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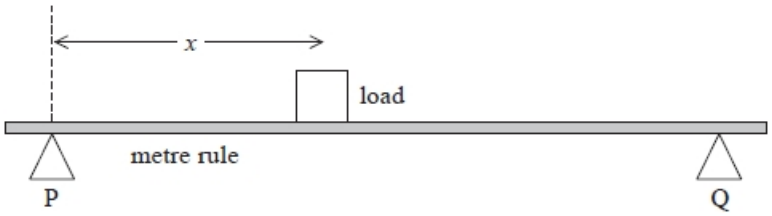
(Total for question = 4 marks)

Q11.

A student investigated how the supporting forces on a bridge vary as traffic moves across the bridge.

The student made a simple model of a bridge using a metre rule. The metre rule rested on two supports, P and Q, as shown.



The upward force on the metre rule at P was F_P. The upward force on the metre rule at Q was F_Q.

A load was placed on the metre rule a distance *x* from support P. Forces F_P and F_Q were measured for different values of *x*.

Explain how F_P and F_Q changed as *x* was increased.

(5)

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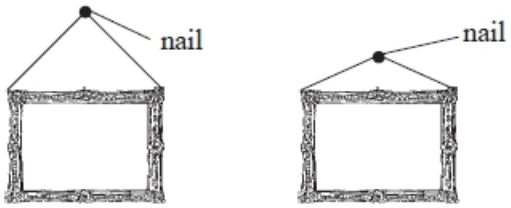
(Total for question = 5 marks)

Q12.

A thin wire of negligible mass is used to hang a picture on a wall. The wire is hung over a nail and can be attached to the picture using arrangement 1 or arrangement 2, as shown.



arrangement 1 arrangement 2

It was observed that if the wire was not hung with its midpoint over the nail, as in Diagram 1, the picture moved and then remained in the position shown in Diagram 2.

Diagram 1 Diagram 2

Use the idea of moments to explain why.

(3)

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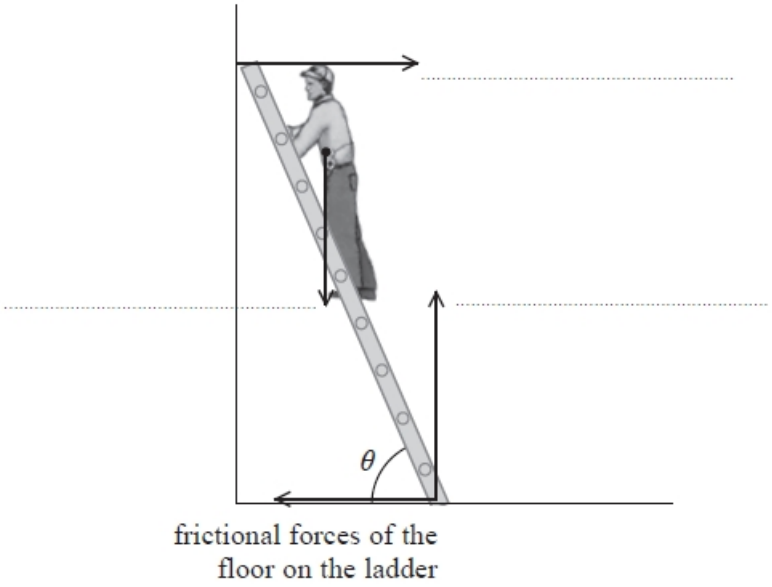
(Total for question = 3 marks)

Q13.

The photograph shows a person on a ladder which is propped up against a wall at an angle θ to the horizontal.

The ladder and the person form a system. The diagram shows four of the forces acting on the system, friction between the wall and the ladder can be neglected. One of the forces has been labelled.

- = centre of gravity of the system



(a) Complete the diagram by labelling the other three forces acting on the system.

(2)

*(b) Use the principle of moments to explain why the system is stable in the position shown, but will topple over if θ becomes too large.

(6)

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(Total for question = 8 marks)

Mark Scheme- Moments

Q1.

Question Number	Answer	Additional Guidance	Mark
	• Use moment = $F\,x$ **(1)** • $x = 0.49$ m **(1)**	Example of calculation $6.5\text{ N} \times (0.75\text{ m} - x) = 3.5\text{ N}\,x$ $4.875\text{ Nm} - 6.5\,x = 3.5\,x$ $x = \frac{4.875\text{ Nm}}{10\text{ N}} = 0.488\text{ m}$	**2**

Q2.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• Uses scale 1:10 **(1) OR** determines the ratio of lengths from the diagram **(1)** • Use of moment equation for tooth force = force × (perp) distance **(1)** • Use of moment equation for muscle force = force × sin (angle with jaw) × (perp) distance **(1)** • Moment of tooth force = moment of muscle force **(1)** • Muscle force = 24 000 N **(1)**		**5**

Q3.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of moment = force × perpendicular distance **(1)** • Use of clockwise moments = anticlockwise moments **(1)** • Position of centre of gravity = 27 cm from base **(1)**	MP1 not awarded if cos θ not used or sin θ not used Example of calculation $(18.5\text{ kg} \times 9.81\text{ N kg}^{-1}) \times x \cos\theta = 50\text{ N} \times 0.97\text{ m} \times \cos\theta$ $x = 0.27$ m	**3**

Q4.

Question Number	Acceptable Answer		Additional Guidance	Mark
(a)	• Use of $W = mg$ • $W = 868$ (N)	(1) (1)	Example of calculation Mass of water = 85.0 litres × 1 kg = 85.0 kg Mass of base and water = 85.0 kg + 3.50 kg = 88.5 kg Weight of base = 88.5 kg × 9.81 N kg^{-1} = 868.2 N	2

Question Number	Acceptable Answer		Additional Guidance	Mark
(b)	• See 868 N × 0.45 m × cos 15 (= 377.3 Nm) • See 27 N ×2.0 m × cos 75 (= 13.98 Nm) • See F_w ×2.4 m × cos 15 (= 2.31F_w) • Use of principle of moments e.g. substitution into: moment of weight of base = moment of weight of post arrangement + moment of wind • $F_w = 157$ or 158 N	(1) (1) (1) (1) (1)	MP1 accept sin75 for cos15 MP2 accept sin15 for cos75 MP3 accept sin75 for cos15 MP4, accept > correctly used in place of = to indicate the point at which it will tip and ecf for W from 11 (a) Example of calculation (using perpendicular forces) Moment of weight of base = 868 N × cos 15 × 0.45 m = 377.29 Nm Moment of the post arrangement = 27.0 N × cos 75 × (2.80 m – 0.80 m) = 13.98 Nm Moment of the wind = F_w × cos 15 × 2.40 m = 2.31 F_w 377.29Nm = 13.98 Nm + 2.31 F_w F_w = 157.28 N Example of calculation (using perpendicular distances) (868 N × 0.45 m × cos 15) = (27 N ×2.0 m × cos 75) + (F_w ×2.4 m × cos 15) F_w = 156.72 N	5

Question Number	Acceptable Answer		Additional Guidance	Mark
(c)	• F_w would increase • The weight of the base would be heavier/increase • This increases the clockwise moment **Or** this increases the moment of the (weight of the) base	(1) (1) (1)		3

Q5.

Question number	Acceptable answers	Additional guidance	Mark
	• Recognises that weight acts at midpoint of diving board 1.8 (m) from X **(1)** • Use of moment = perpendicular force x distance **(1)** • Total clockwise moment = 3150 Nm **(1)** • Recognises that clockwise moment = anticlockwise moment **(1)** • F=3500 N **(1)**	Example of calculation: Total clockwise moment = (680x3.6)+(390x1.8) = 3150 Nm F = 3150/0.9 = 3500 N	**5**

Q6.

Question Number	Acceptable answers	Additional guidance	Mark
	• The position of the centre of gravity moves to the left/backwards **Or** the perpendicular distance (from O) would be greater **(1)** • The moment of the bag (about O) increases so the moment of R (and the size of R) decreases to preserve equilibrium **(1)**	MP1: accept lower for to the left	**2**

Q7.

Question Number	Acceptable answers	Additional guidance	Mark
	• Take a correct moment about pivot P **(1)** • Converts the mass to weight of beam ie ×9.81 seen **(1)** • Appreciates centre of mass 0.5 m from P **(1)** • T = 25 kN **(1)**	eg T.6.cos20 or sin70 If cos20's are absent from both sides of equation then can still credit 4 marks Example of Calculation: $T \times 6(\text{m}) \times \cos 20 = 3.05 \times 10^{4}(\text{kg}) \times 9.81(\text{ms}^{-2}) \times 0.5(\text{m}) \times \cos 20$ $T = 24.9\text{kN}$	**4**

Q8.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	**MAX 2** • Statement describing 740cos20 as the (perpendicular) component of weight of the hiker **and** Statement describing Wcos20 as the (perpendicular) component of the weight of the bag • 2R is the push of the ground on the hiker • Use of $\Sigma F = 0$ with reference to hiker being stationary	(1) (1) (1)	Accept reaction force	2

Question Number	Acceptable answers		Additional guidance	Mark
(ii)	• See 740 N × 0.25 m × cos 20 (= 173.8 N m) • See W × 0.10 m × cos 20 (= 0.0940W N m) • See R × 0.40 m (= 0.40N N m) **Or** 0.5(740cos20 + Wcos20) • Use of principle of moments e.g. substitution into: moment of weight of man = moment of weight of bag + moment of R • Use of equation of the resultant force with the equation obtained in MP4 **OR** Use of principle of moments about another point with the equation obtained in MP4 • W = 120 N	(1) (1) (1) (1) (1) (1)	Example of calculation Moment of the weight of the man: 740 N × 0.25 m × cos 20 = 173.8 N m Moment of the weight of the bag: W × 0.10 m × cos 20 = 0.0940W N m Moment of R: R × 0.40 m = 0.40R N m 173.8 N m = 0.40R + 0.0940W N m Re-arranging to make R the subject of the equation: R = 435 N – 0.235W N Re-arranging the equation for the resultant force: R = 347.7 N + 0.470W 435 N – 0.235W N = 347.7 N + 0.470W 0.705W = 87.3 W = 124 N	6

Q9.

Question Number	Acceptable answers	Additional guidance	Mark
	• sum of moments (about any point) is zero **Or** resultant moment is zero (about any point) **(1)** • sum of the forces (in any direction) is zero **Or** resultant force is zero (in any direction) **(1)**		**2**

Q10.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• shows clockwise moment = anticlockwise **(1)**	Example of calculation M.2 = 2M.1	**1**
(ii)	• Moment of 3M associated with 1 **(1)** • Takes moments around suspension **(1)** • crow at A and owl at B **(1)** Alternative scheme for MP2 and MP3: • Show that, without the extra birds, it balances **(1)** • So added birds must be crow at A and owl at B, as in part (i) **(1)**	Example of calculation 3M.1 + x.2 = M.3 + y.1 2x = y So y must be an owl and x the crow	**3**

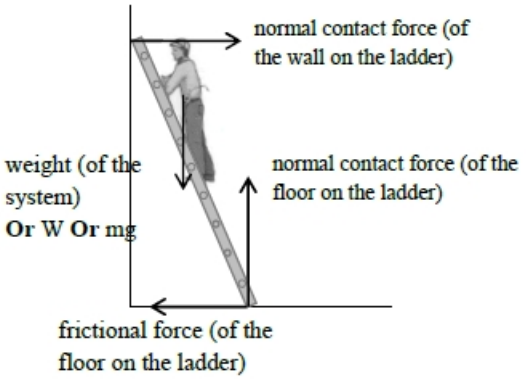
Q11.

Question Number	Acceptable answers	Additional guidance	Mark
	Either • As x increases, the (clockwise) moment of the load about P increases **(1)** • (For equilibrium) the clockwise moment and the anticlockwise moment about P must be equal **(1)** • So F_Q must increase (to increase the anticlockwise moment) **(1)** MP3 dependent on MP2. • (For equilibrium) the resultant vertical force must be zero **Or** As x increases, the (anticlockwise) moment of the load about Q decreases **(1)** • As F_Q increases F_P must decrease **(1)**		
	OR • As x increases, the (anticlockwise) moment of the load about Q decreases **(1)** • (For equilibrium) the clockwise moment and the anticlockwise moment about Q must be equal **(1)** • So F_P must decrease (to decrease the clockwise moment) **(1)** MP3 dependent on MP2 • (For equilibrium) the resultant vertical force must be zero **Or** As x increases, the (clockwise) moment of the load about P increases **(1)** • As F_P decreases F_Q must increase **(1)**		**5**

Q12.

Question Number	Acceptable answers		Additional guidance	Mark
	• The weight does not act through the nail/pivot **Or** the centre of gravity is not in line/below the nail/pivot **Or** there is a perpendicular distance between the weight and the nail/pivot	(1)	Accept centre of mass for centre of gravity (Allow annotations to a diagram with additional explanation for MP1/3)	3
	• There is now a moment of the weight **Or** the anticlockwise moment is greater than the clockwise moment	(1)		
	• The idea that the picture stops moving when the c of g is below the nail	(1)	MP3 Accept: the turning moment being 0 **Or** the clockwise moments equal to the anti-clockwise moments	

Q13.

Question Number	Acceptable Answer		Additional Guidance	Mark
(a)	• Both normal contact forces labelled	(1)	Example of Labels:  	**(2)**
	• Weight (of system) **Or** W **Or** mg	(1)		

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr>
<td>(b)*</td>
<td>This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The following table shows how the marks should be awarded for indicative content.

<table>
<tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5-4</td><td>3</td></tr>
<tr><td>3-2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
</td>
<td>Guidance on how the mark scheme should be applied:

The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning).</td>
<td></td>
</tr>
</table>

The following table shows how the marks should be awarded for structure and lines of reasoning.

	Number of marks awarded for structure of answer and sustained line of reasoning
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).

(6)

	Indicative content • the ladder is stable because the forces/ moments are in equilibrium • when in equilibrium/ stable the (clockwise) moment of the normal contact force at the wall is equal to the moment of the weight • reference to taking moments about the bottom of the ladder (may be implied in response) • If θ is large enough, centre of gravity (of system) is now to the right of the bottom of the ladder. • moment of weight is now clockwise • no anticlockwise moments **Or** Σclockwise moments> Σanticlockwise moments (so ladder will topple)	Ecf incorrect labels for the forces from part (a)	