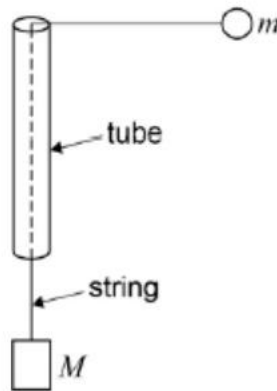


1

A string passes through a smooth thin tube. Masses m and M are attached to the ends of the string. The tube is moved so that the mass m travels in a horizontal circle of constant radius r and at constant speed v .



Which of the following expressions is equal to M ?

A $\frac{mv^2}{2r}$ ☐

B mv^2rg ☐

C $\frac{mv^2}{rg}$ ☐

D $\frac{mv^2g}{r}$ ☐

(Total 1 mark)

2

What is the angular speed of a car wheel of diameter 0.400 m when the speed of the car is 108 km h⁻¹?

A 75 rad s⁻¹

B 150 rad s⁻¹

C 270 rad s⁻¹

D 540 rad s⁻¹

(Total 1 mark)

3

A ball of mass 0.30 kg is attached to a string and moves in a **vertical** circle of radius 0.60 m at a constant speed of 5.0 m s^{-1} .

Which line, **A** to **D**, in the table gives the correct values of the minimum and maximum tension in the string?

	Minimum tension / N	Maximum tension / N
A	2.5	5.4
B	6.7	9.6
C	13	13
D	9.6	15

(Total 1 mark)

4

A roundabout in a fairground requires an input power of 2.5 kW when operating at a constant angular velocity of 0.47 rad s^{-1} .

(a) Show that the frictional torque in the system is about 5 kN m .

(3)

(b) When the power is switched off, the roundabout decelerates uniformly because the frictional torque remains constant. The roundabout takes a time of 34 s to come to rest.

(i) Calculate the moment of inertia of the roundabout.
Give an appropriate unit for your answer.

moment of inertia _____ unit _____

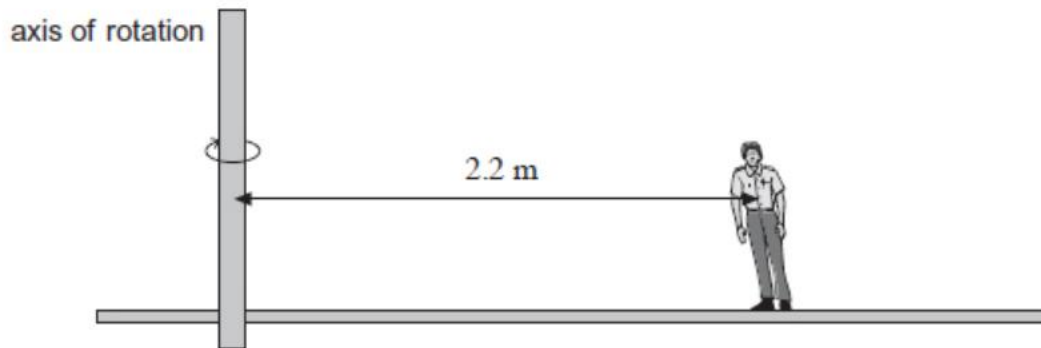
(3)

(ii) Calculate the number of revolutions that are made before the roundabout comes to rest.

number of revolutions _____

(3)

- (c) An operator of mass 65 kg is standing on the roundabout when the roundabout is rotating at an angular velocity of 0.47 rad s^{-1} . His centre of mass is 2.2 m from the axis of rotation. The diagram shows that his body leans towards the centre of the path.



- (i) Calculate the centripetal force needed for the operator to remain at this radius on the roundabout.

centripetal force _____ N

(2)

- (ii) State the origin of this centripetal force and suggest why the operator has to incline his body towards the centre of rotation to avoid falling over.

You may draw the forces that act on the operator in the diagram to help your answer.

(2)

- (iii) While the roundabout is moving, the operator drops a coin.

Which statement correctly describes and explains what happens to the coin?

Tick (✓) the correct answer in the right-hand column.

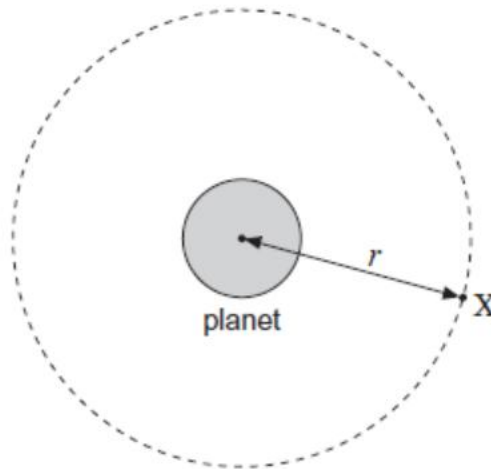
	Tick (✓)
There is no longer a centripetal force acting, so the coin falls vertically downwards and lands on the roundabout directly below the point at which it was dropped.	
The centripetal force causes the coin to have a horizontal component of velocity towards the centre of the roundabout, so that it follows a trajectory towards the centre of the roundabout.	
There is no longer a centripetal force acting, so there is a horizontal component of the coin's velocity directed away from the centre of the roundabout and it follows a trajectory directly away from the centre.	
There is no longer a centripetal force acting, so the coin has a horizontal component of its velocity tangential to its original path on the roundabout and it follows a trajectory along this tangent.	

(1)

(Total 14 marks)

5

A satellite **X** is in a circular orbit of radius r about the centre of a spherical planet of mass M .



Which line, **A** to **D**, in the table gives correct expressions for the centripetal acceleration a and the speed v of the satellite?

	Centripetal acceleration a	Speed v
A	$\frac{GM}{2r}$	$\sqrt{\frac{GM}{2r}}$
B	$\frac{GM}{2r}$	$\sqrt{\frac{GM}{r}}$
C	$\frac{GM}{r^2}$	$\sqrt{\frac{GM}{2r}}$
D	$\frac{GM}{r^2}$	$\sqrt{\frac{GM}{r}}$

(Total 1 mark)

- 6 A lead ball of mass 0.25 kg is swung round on the end of a string so that the ball moves in a horizontal circle of radius 1.5 m. The ball travels at a constant speed of 8.6 m s⁻¹.

- (a) (i) Calculate the angle, in degrees, through which the string turns in 0.40 s.

angle _____ degree

(3)

- (ii) Calculate the tension in the string.
You may assume that the string is horizontal.

tension _____ N

(2)

- (b) The string will break when the tension exceeds 60 N.
Calculate the number of revolutions that the ball makes in one second when the tension is 60 N.

number of revolutions _____

(2)

- (c) Discuss the motion of the ball in terms of the forces that act on it. In your answer you should:

- explain how Newton's three laws of motion apply to its motion in a circle
- explain why, in practice, the string will not be horizontal.

You may wish to draw a diagram to clarify your answer.

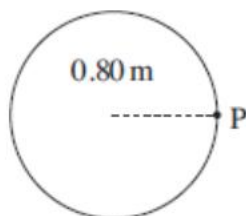
The quality of your written communication will be assessed in your answer.

(6)

(Total 13 marks)

7

A model car moves in a circular path of radius 0.80 m at an angular speed of $\frac{\pi}{2}$ rad s⁻¹.



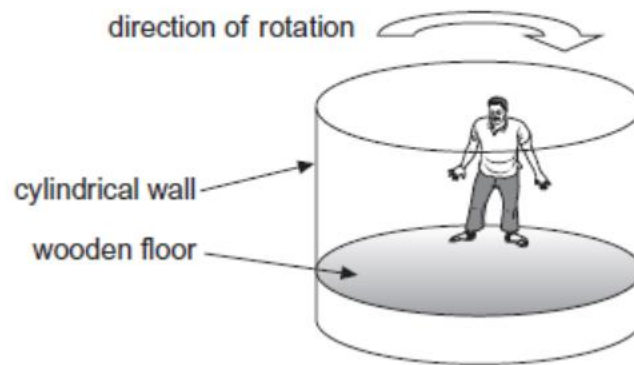
What is its displacement from point P 6.0 s after passing P?

- A** zero
- B** 0.4π m
- C** 1.6 m
- D** 1.6π m

(Total 1 mark)

Figure 1 shows a fairground ride called a Rotor. Riders stand on a wooden floor and lean against the cylindrical wall.

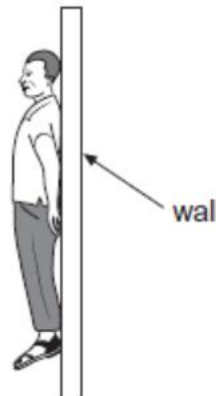
Figure 1



The fairground ride is then rotated. When the ride is rotating sufficiently quickly the wooden floor is lowered. The riders remain pinned to the wall by the effects of the motion. When the speed of rotation is reduced, the riders slide down the wall and land on the floor.

- (a) (i) At the instant shown in **Figure 2** the ride is rotating quickly enough to hold a rider at a constant height when the floor has been lowered.

Figure 2



Draw onto **Figure 2** arrows representing all the forces on the rider when held in this position relative to the wall.

Label the arrows clearly to identify all of the forces.

- (ii) Explain why the riders slide down the wall as the ride slows down.

(2)

A Rotor has a diameter of 4.5 m. It accelerates uniformly from rest to maximum angular velocity in 20 s.

The total moment of inertia of the Rotor and the riders is $2.1 \times 10^5 \text{ kg m}^2$.

- (b) (i) At the maximum speed the centripetal acceleration is 29 m s^{-2} .

Show that the maximum angular velocity of a rider is 3.6 rad s^{-1} .

(2)

- (ii) Calculate the torque exerted on the Rotor so that it accelerates uniformly to its maximum angular velocity in 20 s.
State the appropriate SI unit for torque.

torque _____ SI unit for torque _____

(3)

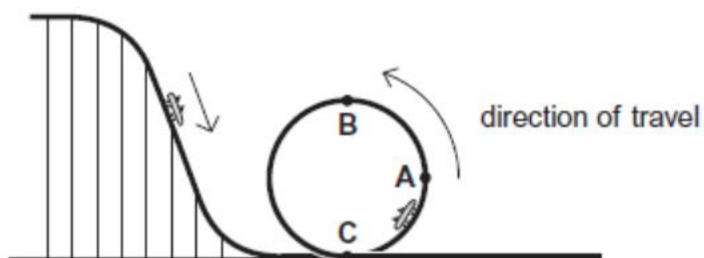
- (iii) Calculate the centripetal force acting on a rider of mass 75 kg when the ride is moving at its maximum angular velocity.
Give your answer to an appropriate number of significant figures.

centripetal force _____ N

(1)

- (c) **Figure 3** shows the final section of a roller coaster which ends in a vertical loop. The roller coaster is designed to give the occupants a maximum acceleration of $3g$. Cars on the roller coaster descend to the start of the loop and then travel around it, as shown.

Figure 3



- (i) At which one of the positions marked **A**, **B** and **C** on **Figure 3** would the passengers experience the maximum reaction force exerted by their seat?
Circle your answer below.

A

B

C

(1)

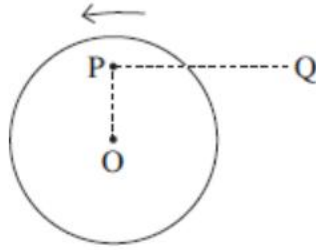
- (iii) Explain why the maximum acceleration is experienced at the position you have chosen.

(2)

(Total 14 marks)

9

A small mass is placed at P on a horizontal disc which has its centre at O. The disc rotates anti-clockwise about a vertical axis through O with constant angular speed.



Which one of the following describes the force which keeps the mass at rest relative to the disc when in the position shown?

- A the weight of the mass
- B a frictional force from P to Q
- C a frictional force directed away from O
- D a frictional force directed towards O

(Total 1 mark)

10

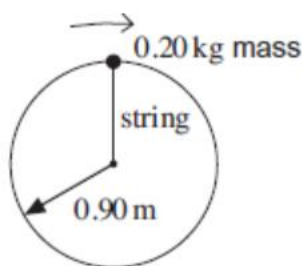
The wheel of the London Eye has a diameter of 130 m and rotates at a steady speed, completing one rotation every 30 minutes. What is the centripetal acceleration of a person in a capsule at the rim of the wheel?

- A $1.2 \times 10^{-4} \text{ ms}^{-2}$
- B $2.5 \times 10^{-4} \text{ ms}^{-2}$
- C $3.9 \times 10^{-4} \text{ ms}^{-2}$
- D $7.9 \times 10^{-4} \text{ ms}^{-2}$

(Total 1 mark)

11

A 0.20 kg mass is whirled round in a vertical circle on the end of a light string of length 0.90 m.



At the top point of the circle the speed of the mass is 8.2 m s^{-1} . What is the tension in the string at this point?

- A 10 N
- B 13 N
- C 17 N
- D 20 N

(Total 1 mark)

12

For a particle moving in a circle with uniform speed, which one of the following statements is **incorrect**?

- A There is no displacement of the particle in the direction of the force.
- B The force on the particle is always perpendicular to the velocity of the particle.
- C The velocity of the particle is constant.
- D The kinetic energy of the particle is constant.

(Total 1 mark)

13

A revolving mountain top restaurant turns slowly, completing a full rotation in 50 minutes. A man is sitting in the restaurant 15 m from the axis of rotation. What is the speed of the man relative to a stationary point outside the restaurant?

- A $\frac{\pi}{100} \text{ m s}^{-1}$
- B $\frac{3\pi}{5} \text{ m s}^{-1}$
- C $\frac{\pi}{200} \text{ m s}^{-1}$
- D $\frac{\pi}{1500} \text{ m s}^{-1}$

(Total 1 mark)

14

A particle moves in a circular path at constant speed. Which one of the following statements is correct?

- A The velocity of the particle is directed towards the centre of the circle.
- B There is no force acting on the particle.
- C There is no change in the kinetic energy of the particle.
- D The particle has an acceleration directed along a tangent to the circle.

(Total 1 mark)

15

A particle of mass m moves in a circle of radius r at uniform speed, taking time T for each revolution. What is the kinetic energy of the particle?

- A $\frac{\pi^2 mr}{T^2}$
- B $\frac{\pi^2 mr^2}{T^2}$
- C $\frac{2\pi^2 mr^2}{T}$
- D $\frac{2\pi^2 mr^2}{T^2}$

(Total 1 mark)

16

A mass on the end of a string is whirled round in a horizontal circle at increasing speed until the string breaks. The subsequent path taken by the mass is

- A a straight line along a radius of the circle.
- B a horizontal circle.
- C a parabola in a horizontal plane.
- D a parabola in a vertical plane.

(Total 1 mark)

17

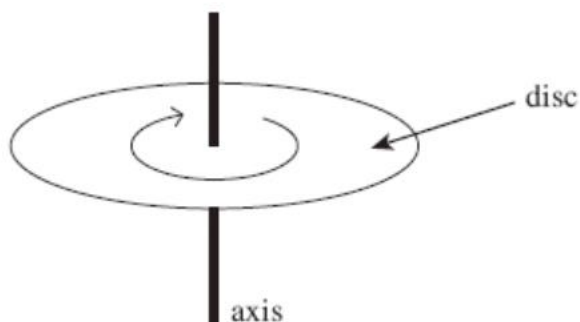
Which one of the following does **not** involve a centripetal force?

- A an electron in orbit around a nucleus
- B a car going round a bend
- C an α particle in a magnetic field, travelling at right angles to the field
- D an α particle in an electric field, travelling at right angles to the field

(Total 1 mark)

18

The diagram shows a disc of diameter 120 mm that can turn about an axis through its centre.



The disc is turned through an angle of 30° in 20 ms. What is the average speed of a point on the edge of the disc during this time?

- A $0.5\pi \text{ m s}^{-1}$
- B $\pi \text{ m s}^{-1}$
- C $1.5\pi \text{ m s}^{-1}$
- D $2\pi \text{ m s}^{-1}$

(Total 1 mark)

19

(a) **Figure 1** and **Figure 2** each show a car travelling in a horizontal circular path.

- (i) Draw and label on **Figure 1** and **Figure 2** arrows to indicate the other forces acting on the cars.

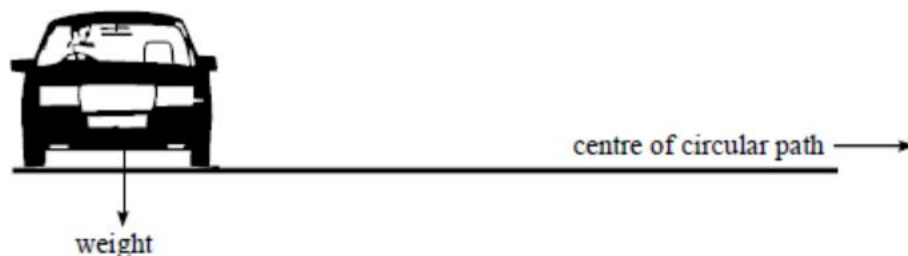


Figure 1



Figure 2

(2)

- (ii) State the possible origins of the centripetal force on the car in **Figure 2**.

(4)

- (b) **Figure 3** shows a motorcycle stunt rider travelling around a track in a vertical circle of radius 5.2 m. At position **Q**, when the speed is the minimum necessary to keep the motorcycle in contact with the track, the centripetal force is supplied by the weight of the motorcycle and rider. The combined mass of the motorcycle and rider is 220 kg.

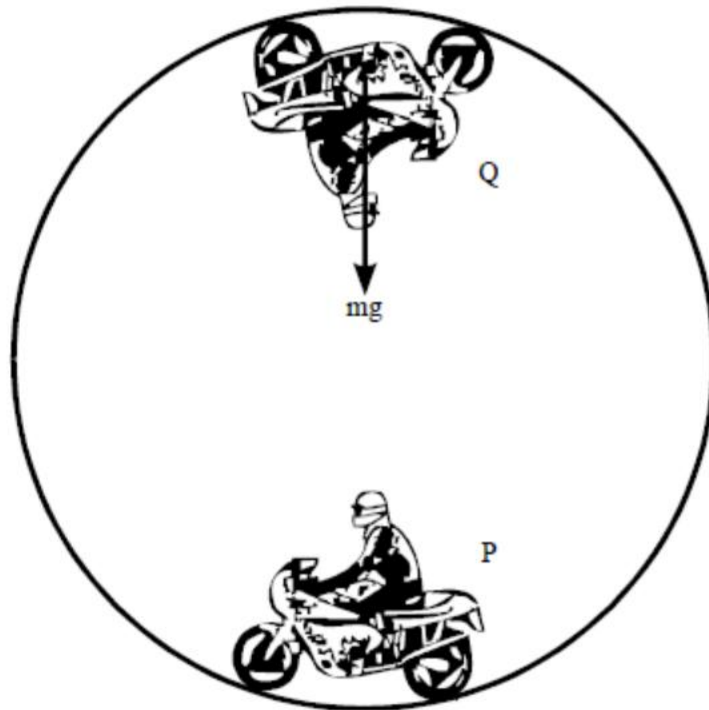
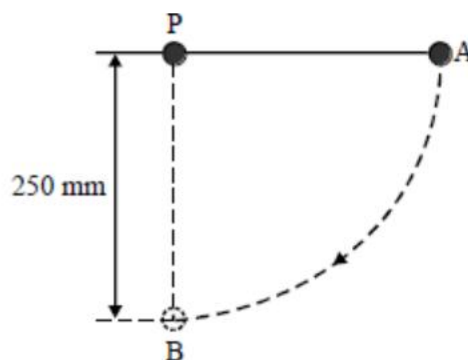


Figure 3

Calculate the minimum speed which will keep the motorcycle in contact with the track at position **Q**. The acceleration due to gravity, g , is 9.8 m s^{-2} .

(3)

(Total 9 marks)



A 150 g mass is attached to one end of a light inextensible string and the other end of the string is fixed at a point P as shown in the diagram above. The mass is held at point A so that the string is taut and horizontal. The mass is released so that it moves freely along a circular arc of 250 mm radius.

When the string moves through the vertical position, the mass is at point B. Neglecting the effect of air resistance, calculate

- (a) the kinetic energy of the mass,

- (b) the velocity of the mass,

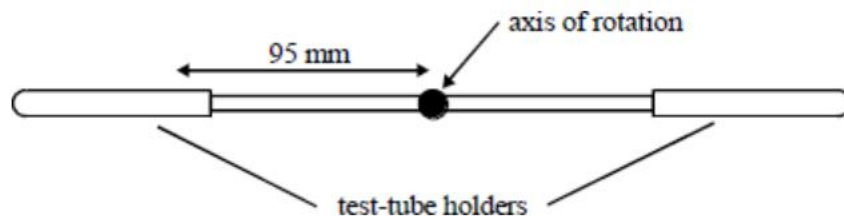
- (c) the centripetal force acting on the mass,

- (d) the tension in the string.

(Total 6 marks)

21

A chemical centrifuge consists of two test-tube holders which can be spun round in a horizontal circular path at very high speed as shown. The centrifuge runs at a steady speed of 3000 revolutions per minute and the test-tube holders are horizontal.



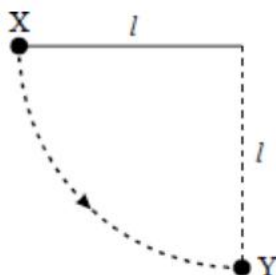
- (a) Calculate the angular speed of the centrifuge in rad s^{-1} .

- (b) Calculate the magnitude of the acceleration at a point on the centrifuge 95 mm from the axis of rotation.

- (c) State the direction of the acceleration in part (ii).

(Total 5 marks)

22



A ball of mass m , which is fixed to the end of a light string of length l , is released from rest at X. It swings in a circular path, passing through the lowest point Y at speed v . If the tension in the string at Y is T , which one of the following equations represents a correct application of Newton's laws of motion to the ball at Y?

A $T = \frac{mv^2}{l} - mg$

B $T - mg = \frac{mv^2}{l}$

C $mg - T = \frac{mv^2}{l}$

D $T + \frac{mv^2}{l} = mg$

(Total 1 mark)

23

For a particle moving in a circle with uniform speed, which one of the following statements is **incorrect**?

- A The velocity of the particle is constant.
- B The force on the particle is always perpendicular to the velocity of the particle.
- C There is no displacement of the particle in the direction of the force.
- D The kinetic energy of the particle is constant.

(Total 1 mark)

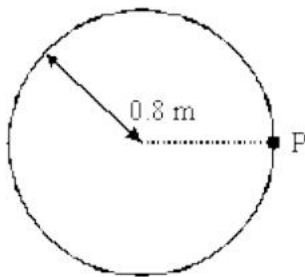
24

A girl of mass 40 kg stands on a roundabout 2.0 m from the vertical axis as the roundabout rotates uniformly with a period of 3.0 s. The horizontal force acting on the girl is approximately

- A zero.
- B 3.5×10^2 N.
- C 7.2×10^2 N.
- D 2.8×10^4 N.

(Total 1 mark)

25



A model car moves in a circular path of radius 0.8 m at an angular speed of $\frac{\pi}{2}$ rad s⁻¹.

What is its displacement from point P, 6 s after passing P?

- A zero
- B 1.6 m
- C 0.4π m
- D 1.6π m

(Total 1 mark)

1	C			[1]
2	B			[1]
3	D			[1]
4	(a)	T = power/ ω Torque = 2500/0.47 5320 N m value to 2 or more sf needed	3	
	(b) (i)	Deceleration= 0.47/34= 0.0138 (rad s ⁻²) moment of inertia = torque / angular deceleration =5000/0.0138 = 3.57 × 10 ⁵ kg m ² (Allow N m s ²) <i>3.8 × 10⁵ if 5320 used</i>	3	
	(ii)	Suitable equation of motion used with correct data but omitted minus sign 8.0 radian Allow (their $\omega/2\pi$) 1.27 revolutions <i>Condone 1 revolution</i> <i>(allowed for thinking question refers to complete revolutions)</i>	3	
	(c) (i)	F = 65 × 2.2 × 0.47 ² 32(31.6 N)	2	
	(ii)	Force produced by friction between the feet and the roundabout Centripetal force has to act through the centre of mass of the operator or The resultant of the frictional force and normal reaction has to pass through the centre of mass <i>Any indication (eg on diagram) of wrong direction = 0</i>	2	
	(iii)	Ticks 4 th box	1	

1

5

D

[1]

6

(a) (i) $\omega \left(= \frac{v}{r} \right) = \frac{8.6}{1.5} (= 5.73 \text{ rad s}^{-1}) \checkmark$

$$\theta (= \omega t) = 5.73 \times 0.40 = 2.3 \text{ (2.29) (rad)} \checkmark$$

$$= \frac{2.29}{2\pi} \times 360 = 130 \text{ (131) (degrees)} \checkmark$$

[or $s (= vt) = 8.6 \times 0.40 (= 3.44 \text{ m}) \checkmark$

$$\theta = \frac{3.44}{2\pi \times 1.5} \times 360 \checkmark = 130 \text{ (131) (degrees)} \checkmark]$$

Award full marks for any solution which arrives at the correct answer by valid physics.

3

(ii) tension $F (= m\omega^2 r) = 0.25 \times 5.73^2 \times 1.5 \checkmark = 12(.3) \text{ (N)} \checkmark$

[or $F \left(= \frac{mv^2}{r} \right) = \frac{0.25 \times 8.6^2}{1.5} \checkmark = 12(.3) \text{ (N)} \checkmark]$

Estimate because rope is not horizontal.

2

(b) maximum $\omega \left(= \sqrt{\frac{F}{mr}} \right) = \sqrt{\frac{60}{0.25 \times 1.5}} (= 12.6) \text{ (rad s}^{-1}) \checkmark$

$$\text{maximum } f \left(= \frac{\omega}{2\pi} \right) = \frac{12.6}{2\pi} = 2.01 \text{ (rev s}^{-1}) \checkmark$$

[or maximum $v = \sqrt{\frac{Fr}{m}} = \sqrt{\frac{60 \times 1.5}{0.25}} (= 19.0) \text{ (m s}^{-1}) \checkmark$

$$\text{maximum } f \left(= \frac{v}{2\pi r} \right) = \frac{19.0}{2\pi \times 1.5} = 2.01 \text{ (rev s}^{-1}) \checkmark]$$

Allow 2 (rev s⁻¹) for 2nd mark.

Ignore any units given in final answer.

2

- (c) **The student's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The student's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks

The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

The student appreciates that the velocity of the ball is not constant and that this implies that it is accelerating. There is a comprehensive and logical account of how Newton's laws apply to the ball's circular motion: how the first law indicates that an inward force must be acting, the second law shows that this force must cause an acceleration towards the centre and (if referred to) the third law shows that an equal outward force must act on the point of support at the centre. The student also understands that the rope is not horizontal and states that the weight of the ball is supported by the vertical component of the tension.

*A **high level** answer must give a reasonable explanation of the application of at least two of Newton's laws, and an appreciation of why the rope will not be horizontal.*

Intermediate Level (Modest to adequate): 3 or 4 marks

The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

The student appreciates that the velocity of the ball is not constant. The answer indicates how at least one of Newton's laws applies to the circular motion. The student's understanding of how the weight of the ball is supported is more superficial, the student possibly failing to appreciate that the rope would not be horizontal and omitting any reference to components of the tension.

*An **intermediate level** answer must show a reasonable understanding of how at least one of Newton's laws applies to the swinging ball.*

Low Level (Poor to limited): 1 or 2 marks

The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

The student has a much weaker knowledge of how Newton's laws apply, but shows some understanding of at least one of them in this situation. The answer conveys little understanding of how the ball is supported vertically.

*A **low level** answer must show familiarity with at least one of Newton's laws, but may not show good understanding of how it applies to this situation.*

References to the effects of air resistance, and/or the need to keep supplying energy to the system would increase the value of an answer.

The explanation expected in a competent answer should include a coherent selection of the following points concerning the physical principles involved and their consequences in this case.

- *First law:* ball does not travel in a straight line, so a force must be acting on it
- although the ball has a constant speed its velocity is not constant because its direction changes constantly
- because its velocity is changing it is accelerating
- *Second law:* the force on the ball causes the ball to accelerate (or changes the momentum of it) in the direction of the force
- the acceleration (or change in momentum) is in the same direction as the force
- the force is centripetal: it acts towards the centre of the circle
- *Third law:* the ball must pull on the central point of support with a force that is equal and opposite to the force pulling on the ball from the centre
- the force acting on the point of support acts outwards
- *Support of ball:* the ball is supported because the rope is not horizontal
- there is equilibrium (or no resultant force) in the vertical direction
- the weight of the ball, mg , is supported by the vertical component of the tension, $F \cos \theta$, where θ is the angle between the rope and the vertical and F is the tension
- the horizontal component of the tension, $F \sin \theta$, provides the centripetal force $m \omega^2 r$

Credit may be given for any of these points which are described by reference to an appropriate labelled diagram.

A reference to Newton's 3rd law is not essential in an answer considered to be a high level response. 6 marks may be awarded when there is no reference to the 3rd law.

max 6

[13]

7 C

[1]

8 (a) (i) Weight / W / mg – vertically downwards from some point on the body

B1

Friction – vertically upwards and touching both the wall and the body

B1

Centripetal force / normal reaction / R – horizontally to the left from the body

Each must be correct and correctly labelled

Minus one for each additional inappropriate force

B1

(ii) Centripetal force / reaction / R is smaller

B1

Frictional force reduces
Frictional force is less than weight
Resultant force is downward
Friction is proportional to (normal) reaction

B1

2

(b) (i) $r\omega^2 = 29$ or
 $v^2 / r = 29$

B1

Use of correct radius leading to $3.590 \text{ (rad s}^{-1}\text{)}$ to at least
3 sig figs

2.54 using wrong $r = 1$ mark

B1

2

(ii) Angular acceleration, $\alpha = 3.6 / 20$ OR $3.59 / 20$ or 0.18
or 0.1795

C1

$3.8 \text{ (3.77, 3.78)} \times 10^4 \text{ cao}$

A1

$\text{N m or kg m}^2 \text{ s}^{-2}$

B1

3

(iii) 2200 N cao

B1

1

(c) (i) C

B1

1

(ii) Speed greatest (as all PE turned to KE)

B1

Total reaction force = $mr\omega^2 + mg$ or $v^2/r + mg$ or R is largest or

$$R = ma + mg$$

OR

$$\text{Acceleration} = v^2 / r$$

B1

2

[14]

9

D

[1]

10

D

[1]

11

B

[1]

12

C

[1]

13

A

[1]

14

C

[1]

15

D

[1]

16

D

[1]

17

D

[1]

18

A

[1]

19

- (a) (i) a normal reaction shown and labelled on either diagram

B1

a frictional force correctly shown and labelled on either diagram (may be outward on second diagram)

deduct 1 mark for each wrong force (condone poor friction / reaction)

B1

(2)

- (ii) friction (between surface and wheel / tyre)

B1

(normal) reaction (at the surface)

B1

horizontal component of either force / component towards the centre

B1

sum of horizontal components

B1

(4)

- (b) use of $mg = mv^2 / r$ or $g = v^2 r$, centripetal force $= mv^2 / r$

C1

correct substitution $v^2 = 9.8 \times 5.2$

C1

7.1 m s^{-1}

A1

(3)

[9]**20**

- (a) kinetic energy $= mgh$ (1) $= 0.37 \text{ J}$ (1)

(b) $v = \sqrt{\frac{2E}{m}}$ (1) $= 2.22 \text{ ms}^{-1}$ (1)

(c) $F_c = 2.9 \text{ N}$ [or 3.0 N if $g = 10$ used] (1)

(d) $T = F_c + W = 4.4 \text{ N}$ (1)

[6]**21**

(a) $f = \frac{3000}{60} = 50 \text{ (Hz)}$ (1)

$\omega (= 2\pi f) = 314 \text{ (rad s}^{-1}\text{)}$ (1)

(b) $a = (r\omega^2) = 95 \times 10^{-3} \times 314^2 = 9.4 \times 10^3 \text{ m s}^{-2}$ (1)

- (c) (inwards) towards axis of rotation (1)

[5]

22

B

[1]

23

A

[1]

24

B

[1]

25

B

[1]