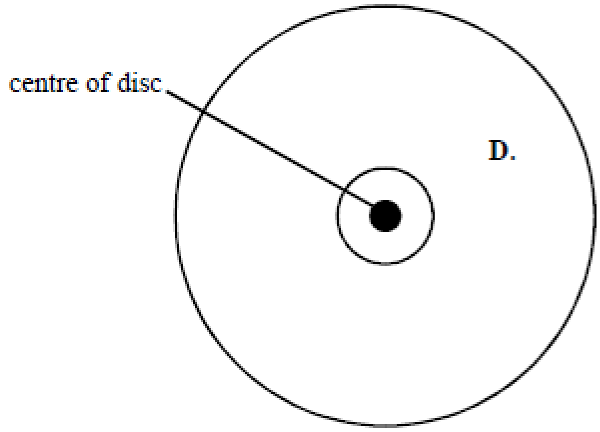
1 The figure below shows a dust particle at position **D** on a rotating vinyl disc. A combination of electrostatic and frictional forces act on the dust particle to keep it in the same position.



The dust particle is at a distance of 0.125 m from the centre of the disc. The disc rotates at 45 revolutions per minute.

(a) Calculate the linear speed of the dust particle at **D**.

(3)

(b) (i) Mark on the diagram above an arrow to show the direction of the resultant horizontal force on the dust particle.

(1)

(ii) Calculate the centripetal acceleration at position **D**.

(2)

(c) On looking closely at the rotating disc it can be seen that there is more dust concentrated on the inner part of the disc than the outer part. Suggest why this should be so.

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(3)

(Total 9 marks)

2 (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.

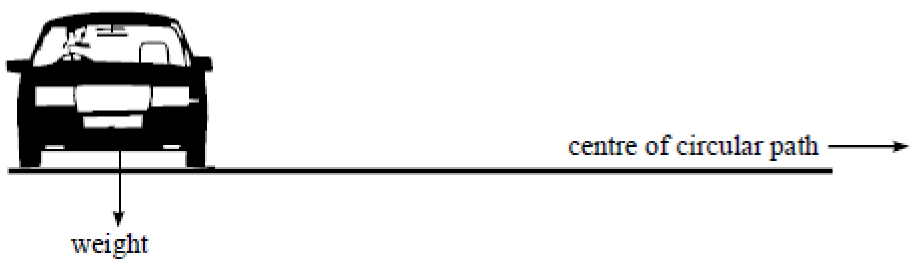


Figure 1

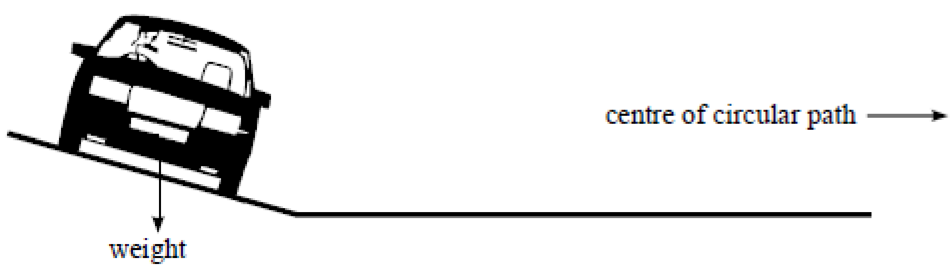


Figure 2

(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.

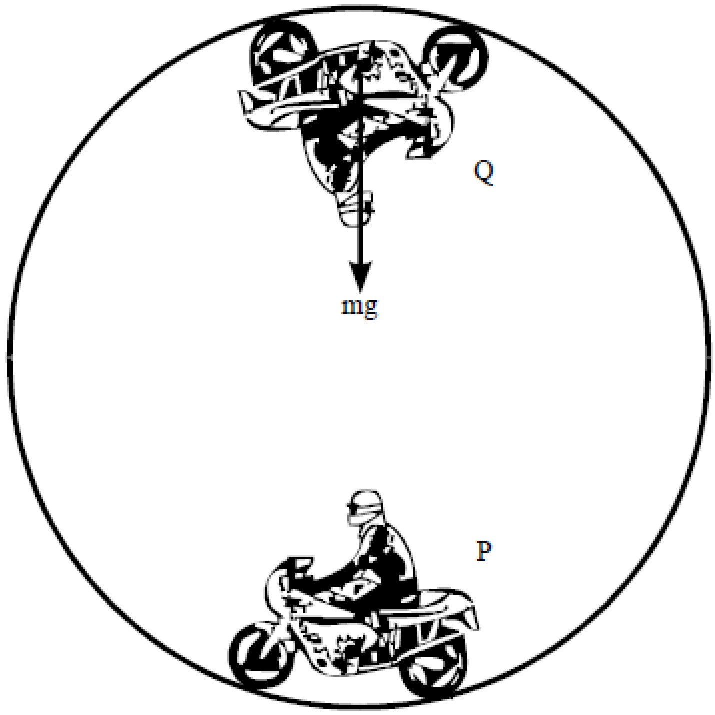


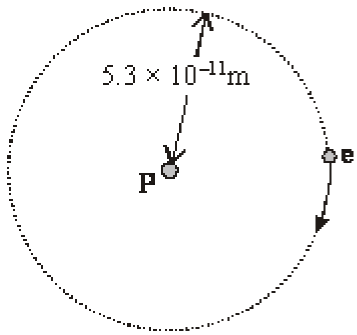
Figure 3

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)

3 The Bohr model of a hydrogen atom assumes that an electron **e** is in a circular orbit around a proton **P**. The model is shown schematically in **Figure 1**.

Figure 1



In the ground state the orbit has a radius of 5.3×10^{-11} m. At this separation the electron is attracted to the proton by a force of 8.1×10^{-8} N.

(a) State what is meant by <u>the ground state</u>.

____

____

(1)

(b) (i) Show that the speed of the electron in this orbit is about 2.2×10^{6} m s^{-1}.

mass of an electron = 9.1×10^{-31} k g

(3)

(ii) Calculate the de Broglie wavelength of an electron travelling at this speed.

Planck constant = 6.6×10^{-34} J s

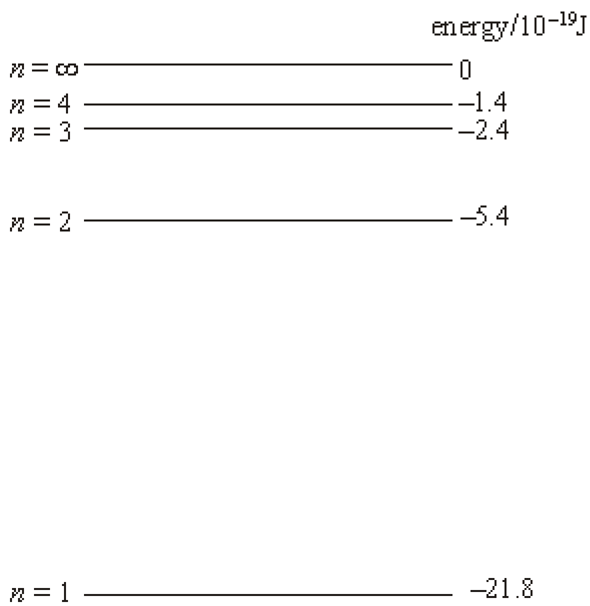
(2)

(iii) How many waves of this wavelength fit the circumference of the electron orbit? Show your reasoning.

(2)

(c) The quantum theory suggests that the electron in a hydrogen atom can only exist in certain well-defined energy states. Some of these are shown in **Figure 2**.

Figure 2



An electron **E** of energy 2.5×10^{-18} J collides with a hydrogen atom that is in its ground state and excites the electron in the hydrogen atom to the *n* = 3 level.

Calculate

(i) the energy that is needed to excite an electron in the hydrogen atom from the ground state to the $n = 3$ level,

(1)

(ii) the kinetic energy of the incident electron **E** after the collision,

(1)

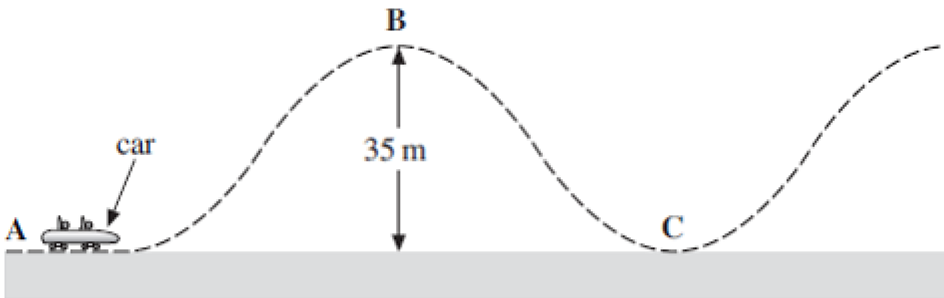
(iii) the wavelength of the lowest energy photon that could be emitted as the excited electron returns to the ground state.

speed of electromagnetic radiation = 3.0×10^8 m s^{-1}

(3)

(Total 13 marks)

4 The figure below shows a car on a rollercoaster track. The car is initially at rest at **A** and is lifted to the highest point of the track, **B**, 35 m above **A**.



The car with its passengers has a total mass of 550 kg. It takes 25 s to lift the car from **A** to **B**. It then starts off with negligible velocity and moves unpowered along the track.

(a) Calculate the power used in lifting the car and its passengers from **A** to **B**.
Include an appropriate unit in your answer.

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power________________________unit______________

(3)

(b) The speed reached by the car at **C**, the bottom of the first dip, is 22 ms^{-1}. The length of the track from **B** to the bottom of the first dip **C** is 63 m.

Calculate the average resistive force acting on the car during the descent.

Give your answer to a number of significant figures consistent with the data.

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resistive force ________________________ N

(4)

(c) Explain why the resistive force is unlikely to remain constant as the car descends from **B** to **C**.

(3)

(d) At **C**, a passenger of mass 55 kg experiences an upward reaction force of 2160 N when the speed is 22 ms^{-1}.

Calculate the radius of curvature of the track at **C**. Assume that the track is a circular arc at this point.

radius of curvature of the track ______________________ m

(3)

(Total 13 marks)

5 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 __________

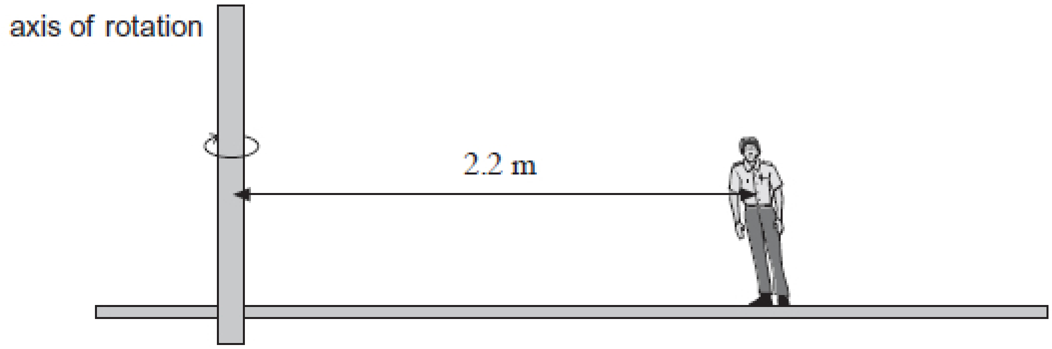
(3)

(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.

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(2)

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

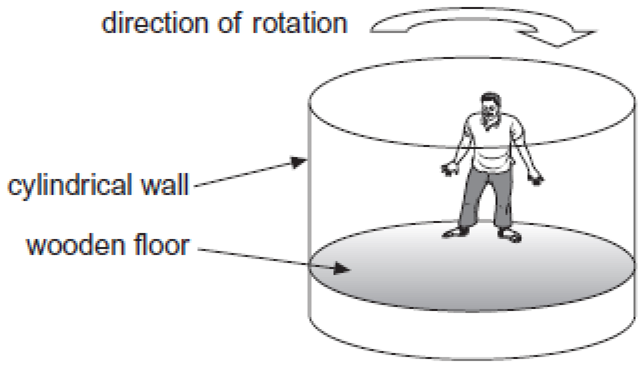
Which statement correctly describes and explains what happens to the coin?
Tick (✓) the correct answer in the right-hand column.

	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)

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

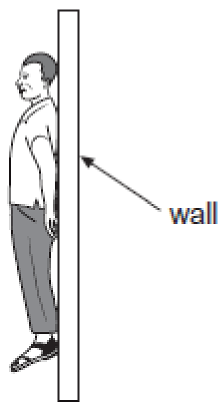
Figure 1



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.

(3)

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

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(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 2.1×10^5 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)

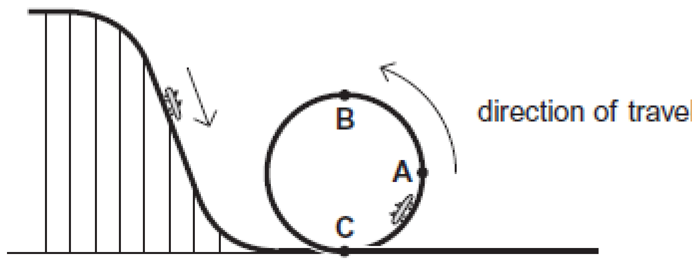
(iii) Calculate the centripetal force acting on a rider of mass 75 kg when the ride is moving at its maximum angular velocity.
Give your answer to an appropriate number of significant figures.

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 3*g*. 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.

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(2)
(Total 14 marks)

7 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)