PEARSON EDEXCEL A-LEVEL PHYSICS · 9PH0

PHYSICS



EXAM QUESTION PACK

TOPIC 6: FURTHER MECHANICS

CIRCULAR MOTION

SCORE	PERCENTAGE
/325	%

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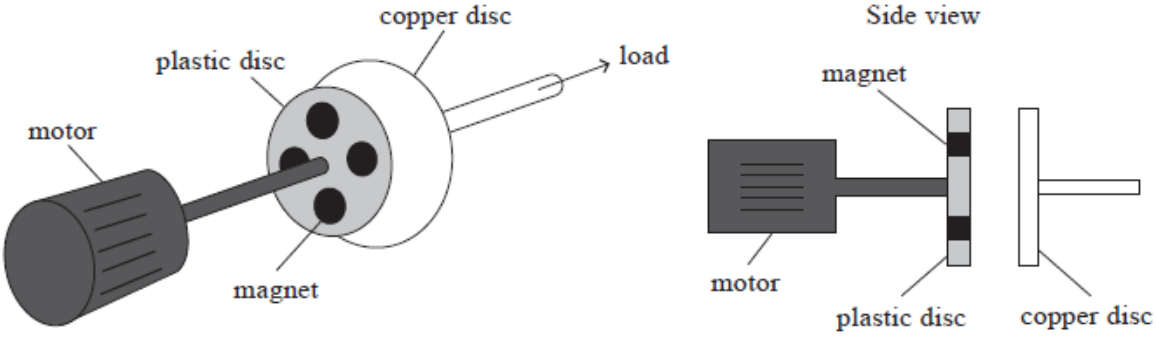
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Q1.

A device called a clutch can be used to connect a motor to a load. The diagram shows a design called an eddy current clutch.



Several magnets are embedded in the plastic disc and it is rotated by the motor.

The motor rotates at 500 revolutions per minute.

Calculate the angular speed ω of the motor.

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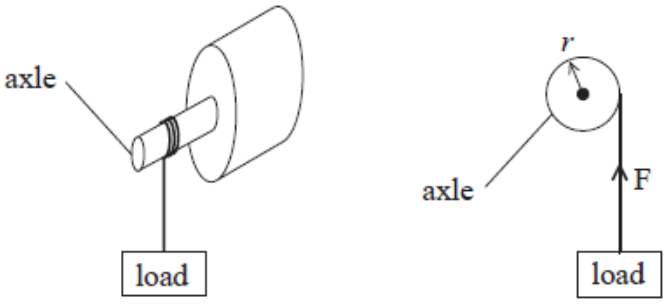
ω = ...

(Total for question = 2 marks)

Q2.

Motors usually have a rotating component which can do work *W*.

(a) A motor lifts a load in a time *t*. The axle of the motor has a radius *r* and exerts a force *F*.



The power produced by a motor can be calculated by using the following word equation.

Power = moment of the force exerted by the rotating axle × angular velocity

Derive this equation, starting with power $P = \frac{W}{t}$.

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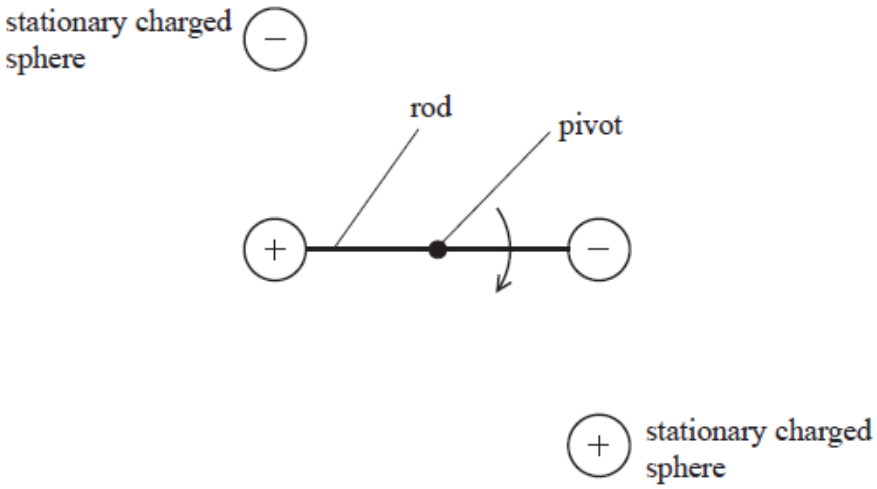
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(b) An electrostatic motor was first demonstrated by Benjamin Franklin in 1750.

The diagram shows a simplified version of part of this motor.

This consists of a rod, with an oppositely charged sphere at either end, which rotates around a fixed pivot. Two stationary charged spheres apply a force on the spheres at either end of the rod.

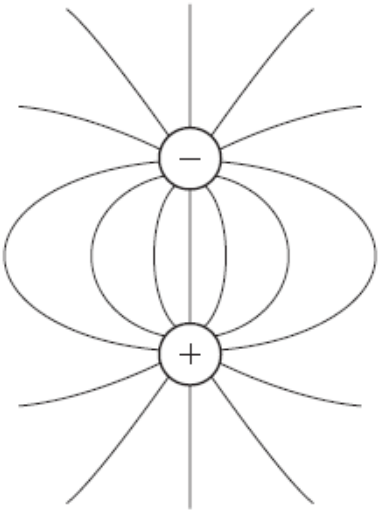


(i) In the diagram below, electric field lines have been drawn around one pair of these spheres.

Add to the diagram to show

- the directions of the field lines
- the lines of equipotential.

(3)



(ii) The distance between the centres of each charged sphere in this pair is 5.0 cm.

Show that the force between this pair of charged spheres is about 0.04 N.

charge on each sphere = 0.10 μC

(2)

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(c) The table shows the typical power and the corresponding angular velocity required for three different appliances.

	Power / W	Angular velocity / rad s^{-1}
Electric car	2.0×10^4	300
Vacuum cleaner	1.4×10^3	1000
Small pond pump	0.5	200

Deduce which of these appliances, in principle, could use the electrostatic motor in (b).

You should use the word equation in (a) and assume that the length of the rod in the electrostatic motor is 8.0 cm.

Assume that the electrostatic motor would deliver a constant force throughout one complete rotation.

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(Total for question = 13 marks)

Q3.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

The blade of a lawnmower rotates at a speed of 50 revolutions per second.

Which of the following is the angular speed of the blade in rads s^{-1}?

☒ **A** 7.96

☒ **B** 15.9

☒ **C** 157

☒ **D** 314

(Total for question = 1 mark)

Q4.

A particle moving in a circular path completes 8.0 revolutions in 5.0 s.
Its angular velocity in rad s^{-1} is

☒ **A** 1.6

☒ **B** 10

☒ **C** 40

☒ **D** 250

(Total for question = 1 mark)

Q5. A fairground roundabout makes 8 revolutions in 1 minute. The angular velocity of the roundabout is

☒ **A** 0.10 rad s^{-1}

☒ **B** 0.42 rad s^{-1}

☒ **C** 0.84 rad s^{-1}

☒ **D** 0.94 rad s^{-1}

(Total for Question = 1 mark)

Q6. The drum of a washing machine rotates with an angular velocity of 8.5 rad s^{-1}.

The time to complete 10 revolutions is

☒ **A** 0.85 s

☒ **B** 1.3 s

☒ **C** 3.7 s

☒ **D** 7.4 s

(Total for Question = 1 mark)

Q7.

Astronomers observing stars at the centre of our galaxy have suggested that many of them are orbiting a supermassive black hole. The mass of this black hole is 9.2×10^{36} kg.

Calculate the orbital period for a star in a circular orbit at a distance of 1.9×10^{14} m from a black hole of this mass.

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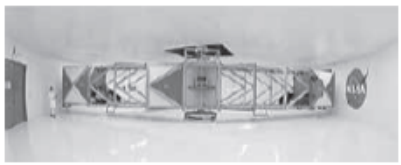
Orbital period = ...

(Total for question = 3 marks)

Q8.

A centrifuge is a machine which rotates.

The United States' space agency, NASA, uses a centrifuge to test whether equipment will operate when experiencing large forces. The equipment to be tested is attached to the end of the frame of the centrifuge, which rotates around a vertical axis at its centre.



(i) Show that the angular velocity of the centrifuge is about 5 rad s^{-1}.

(2)

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(ii) Explain how the centrifuge applies large forces to the equipment under test.

(2)

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(iii) The NASA website says the centrifuge can be used to test whether the equipment can withstand accelerations of up to about 25*g*.

Deduce whether this claim is correct.

(2)

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(Total for question = 6 marks)

Q9.

The International Space Station (ISS) orbits the Earth with a constant speed *v*. The orbit is circular and of radius *r*.

(i) The ISS completes one orbit in 92 minutes.

Calculate the centripetal acceleration of the ISS.

r = 6800 km

(3)

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Centripetal acceleration = ...

(ii) Astronauts in the ISS are often described as being "weightless".

Discuss whether the astronauts are "weightless" when they are orbiting the Earth in the ISS.

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(Total for question = 7 marks)

Q10.

The London Eye consists of a large vertical circle with 32 equally-spaced passenger cabins attached to it. The wheel rotates so that each cabin has a constant speed of 0.26 m s^{-1} and moves around a circle of radius 61 m.

(a) Calculate the time taken for each cabin to make one complete revolution.

(2)

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Time = ...

(b) Calculate the centripetal force acting on each cabin.

mass of cabin = 9.7×10^3 kg

(2)

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Centripetal force = ...

(c) (i) The diagram shows just the circle and the cabins. Draw arrows to show the direction of the centripetal force acting on a person in a cabin when the person is at each of positions **A**, **B** and **C**.

(3)

*(ii) As the person in a cabin moves around the circle, the normal contact force between the person and the cabin varies.

State the position at which this force will be a maximum and the position at which it will be a minimum. Explain your answers.

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(Total for question = 9 marks)

Q11.

The photograph is of a roundabout in a children's playground.



A child of mass 20 kg sits on the roundabout without holding the bars.

The distance from the centre of the roundabout to the centre of gravity of the child is 0.80 m. The maximum frictional force between the roundabout and the child is 0.35 × the weight of the child.

(a) Calculate the minimum time taken for one revolution of the roundabout if the child is not to slide off.

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Minimum time = ...

(b) State and explain how this time would change if a child of larger mass sat at the same place on the roundabout.

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(Total for question = 6 marks)

Q12.

The diagram shows a battery-powered clock on a wall. It has a minute hand and an hour hand.



(a) Calculate the average angular velocity of the minute hand.

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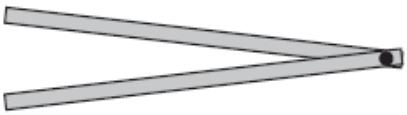
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Angular velocity = ...

(b) The diagram shows the position of the minute hand when the time is 1 : 44 and when the time is 1 : 46.



The diagram is not to scale.

Show that the work done against the force of gravity to move the minute hand from 1 : 44 to 1 : 46 is about 1 mJ.

mass of minute hand = 14 g

length of minute hand = 8.0 cm

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(c) The clock uses a 1.5 V cell and draws a maximum current of 8.0 μA.

After a time, the maximum power of the cell has reduced to 65% of its initial value making the clock run slowly.

Calculate the time taken for the minute hand to move from the 1 : 44 position to the 1 : 46 position.

(3)

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Time taken = ...

(Total for question = 10 marks)

Q13.

In 2015 the Messenger spacecraft crashed into the surface of the planet Mercury after four years in orbit observing the surface of Mercury.

Messenger's orbit was highly elliptical, varying between 200 km and 15 000 km above the surface of Mercury. Messenger completed one full orbit every 12 hours.

mass of Messenger spacecraft = 565 kg

mass of planet Mercury = 3.30×10^{23} kg
radius of planet Mercury = 2430 km

It has been suggested that the same orbital period of about 12 hours could have been achieved if Messenger was in a circular orbit 7690 km above the surface of Mercury.

(i) Determine whether this suggestion is correct.

(4)

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(ii) The elliptical orbit chosen had advantages over this circular orbit.

Explain **one** advantage.

(2)

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(Total for question = 6 marks)

Q14.

The first satellite weather picture was taken in 1960. Today more than 200 weather satellites are in use. Some of these satellites are in a geostationary orbit around the Earth, so that they remain at the same point above the Earth's surface all the time.

(a) (i) Show that the magnitude of the gravitational field strength g at a point outside of the Earth is given by

$$g = \frac{GM}{r^2}$$

where r is the distance of the point from the centre of the Earth and M is the mass of the Earth.

(2)

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(ii) Use this expression together with an expression for the centripetal acceleration to show that the radius of a satellite's orbit is given by

$$r^3 = \frac{GMT^2}{4\pi^2}$$

where T is the time for one orbit of the satellite.

(3)

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(iii) Hence calculate a value for the radius of the geostationary orbit.

$$M = 6.0 \times 10^{24} \text{ kg}$$

(3)

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Radius = ...

(b) State why all geostationary satellites are in an orbit above the Earth's equator.

(1)

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(Total for question = 9 marks)

Q15.

The photograph shows cars driving around a roundabout at a constant speed.



The resultant force *F* on a car causes it to follow a circular path.

Which of the following statements about *F* is **incorrect**?

☒ **A** *F* is equal to the product of the mass and angular velocity of the car.

☒ **B** *F* is equal to the product of the momentum and angular velocity of the car.

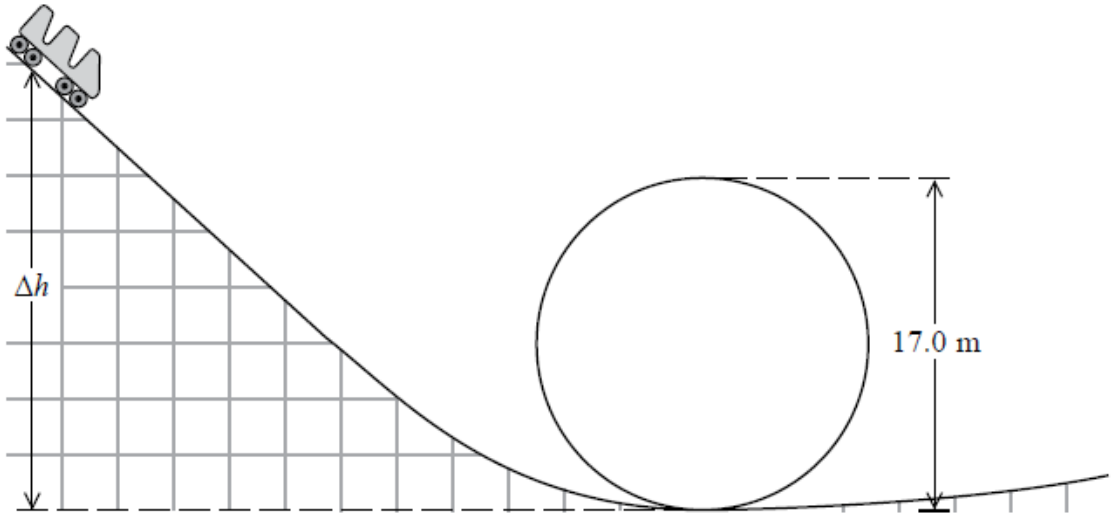
☒ **C** *F* is in the same direction as the acceleration of the car.

☒ **D** *F* is perpendicular to the momentum of the car.

(Total for question = 1 mark)

Q1.

The diagram shows the carriage of a rollercoaster about to enter a vertical loop of diameter 17.0 m. The carriage is initially at rest at a height Δh above the bottom of the loop.



During one particular ride, the speed of a car at the bottom of the loop was 22.5 m s^{-1}.

(i) Calculate the acceleration of the passenger at the bottom of the loop as a multiple of *g*, the acceleration due to gravity.

(2)

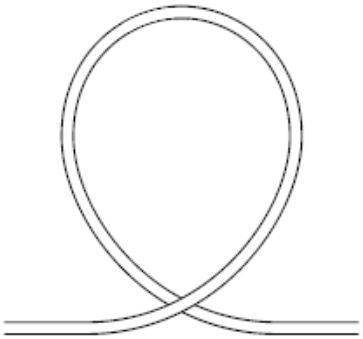
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Acceleration = ...

(ii) The maximum safe acceleration recommended for passengers is 4*g*. Most loop-the-loop rollercoasters do not have a circular loop. Instead, the radius of curvature of the loop varies.



Explain why making the radius of the loop vary in this way enables the acceleration at the bottom of the loop to be less than 4*g*.

(2)

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(Total for question = 10 marks)

Q2.

The International Space Station (ISS) orbits the Earth with a constant speed *v*. The orbit is circular and of radius *r*.

(i) The ISS completes one orbit in 92 minutes.

Calculate the centripetal acceleration of the ISS.

r = 6800 km

(3)

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Centripetal acceleration = ...

(ii) Astronauts in the ISS are often described as being "weightless".

Discuss whether the astronauts are "weightless" when they are orbiting the Earth in the ISS.

(4)

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(Total for question = 7 marks)

Q3.

In 2015 the Messenger spacecraft crashed into the surface of the planet Mercury after four years in orbit observing the surface of Mercury.

Messenger's orbit was highly elliptical, varying between 200 km and 15 000 km above the surface of Mercury. Messenger completed one full orbit every 12 hours.

mass of Messenger spacecraft = 565 kg
mass of planet Mercury = 3.30×10^{23} kg
radius of planet Mercury = 2430 km

It has been suggested that the same orbital period of about 12 hours could have been achieved if Messenger was in a circular orbit 7690 km above the surface of Mercury.

(i) Determine whether this suggestion is correct.

(4)

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(ii) The elliptical orbit chosen had advantages over this circular orbit.

Explain **one** advantage.

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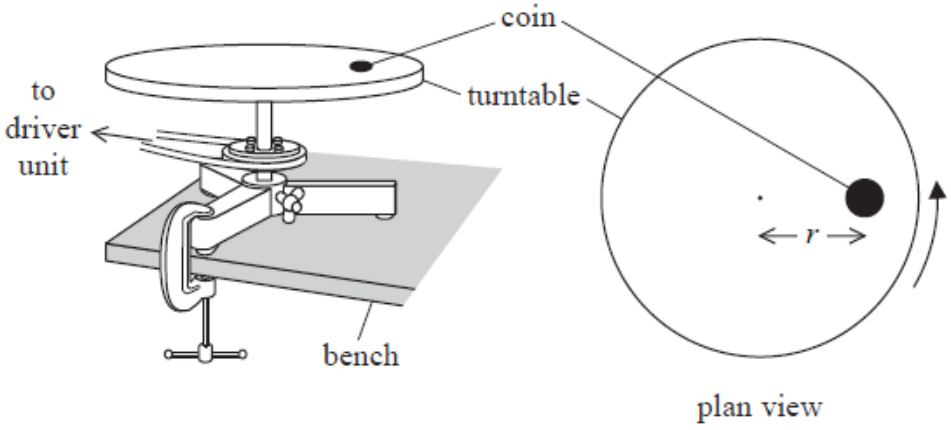
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(Total for question = 6 marks)

Q4.

A student was investigating the forces involved in circular motion.

He placed a small coin on a horizontal turntable as shown. The turntable was connected to a driver unit so that it could be rotated at a constant rate.



The student switched on the driver unit and increased the rate of rotation until the coin slid off the turntable. He read the angular velocity ω of the turntable from a digital display on the driver unit. He then replaced the coin in the original position on the turntable and repeated the procedure.

His results are shown.

ω / rad s^{-1}				
0.125	0.112	0.118	0.123	0.116

(i) The student used the results to calculate a mean value of ω.

State the purpose of calculating a mean.

(1)

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(ii) Calculate the percentage uncertainty in the mean value of ω.

(3)

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Percentage uncertainty = ...

(iii) The student used ω and r to calculate the centripetal acceleration of the coin at the instant it started to slide.

Calculate the percentage uncertainty in this centripetal acceleration.

(3)

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Percentage uncertainty = ...

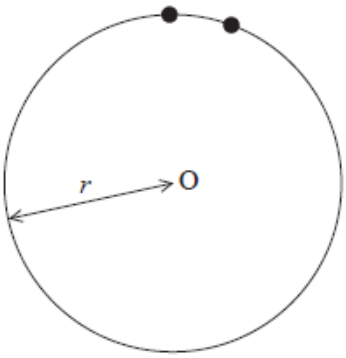
(Total for question = 7 marks)

Q5.

A centrifuge is a machine which rotates.

A particle in a centrifuge moves in a circle of radius r, centre O, with a constant speed v.

The diagram represents two positions of the particle.



Derive the equation for centripetal acceleration $a = \frac{v^2}{r}$ by considering the velocity at these two positions.

Your answer should include a vector diagram.

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(Total for question = 5 marks)

Q1.

The Starflyer is a fairground ride which operates 60 m above the ground. As it begins to spin, the chairs in which the riders sit move outwards.



Consider the chair and rider as a single object. By drawing a free-body force diagram and considering the forces acting, explain the following observations.

The angle to the vertical of the supporting ropes depends on the speed of rotation, but does not depend on the mass of the rider.

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(Total for question = 5 marks)

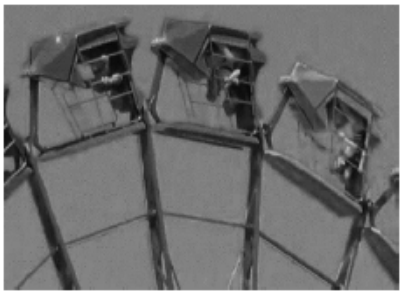
Q2.

The Enterprise is an amusement park ride. Riders sit in cars that are made to rotate in a vertical circle.

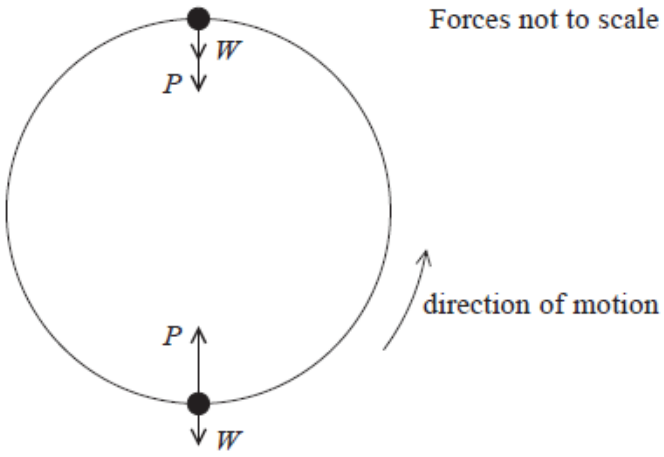
The ride starts by moving in a horizontal circle. The speed of rotation increases, and the frame tilts until the ride is rotating vertically as shown.



The photograph below shows riders at the top of the vertical circle. The riders are in contact with their seats at all times during the ride.



The diagram shows the weight *W* of a rider and the push *P* from the seat on the rider at the top and bottom of the circular path.



* The rider moves from the bottom to the top of the circular path.

Explain how the apparent weight experienced by the rider would change.

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(Total for question = 6 marks)

Q3.

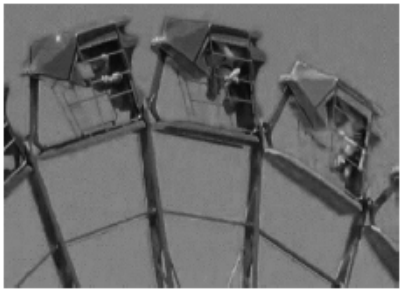
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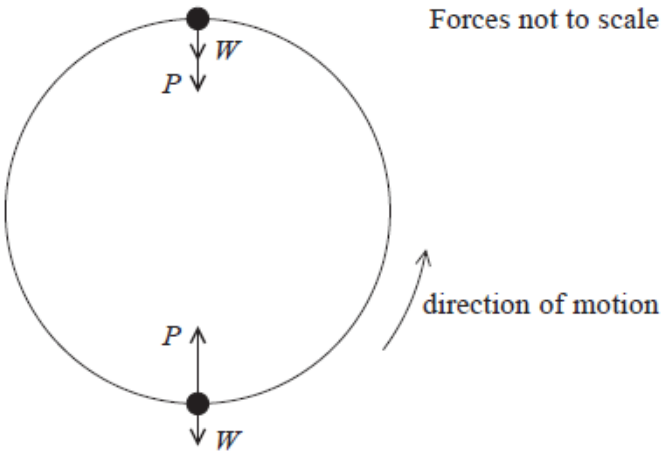
The ride starts by moving in a horizontal circle. The speed of rotation increases, and the frame tilts until the ride is rotating vertically as shown.



The photograph below shows riders at the top of the vertical circle. The riders are in contact with their seats at all times during the ride.



The diagram shows the weight *W* of a rider and the push *P* from the seat on the rider at the top and bottom of the circular path.



On the website of the amusement park it states

"The ride is perfectly safe without the need for safety harnesses for the riders. Centrifugal force ensures that the riders remain in their seats at all stages in the ride."

Assess the validity of this statement.

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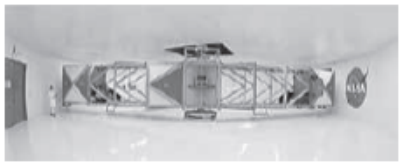
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(Total for question = 4 marks)

Q4.

A centrifuge is a machine which rotates.

The United States' space agency, NASA, uses a centrifuge to test whether equipment will operate when experiencing large forces. The equipment to be tested is attached to the end of the frame of the centrifuge, which rotates around a vertical axis at its centre.



(i) Show that the angular velocity of the centrifuge is about 5 rad s^{-1}.

(2)

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(ii) Explain how the centrifuge applies large forces to the equipment under test.

(2)

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(iii) The NASA website says the centrifuge can be used to test whether the equipment can withstand accelerations of up to about 25*g*.

Deduce whether this claim is correct.

(2)

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(Total for question = 6 marks)

Q5. A racing car of mass 1200 kg travels at 0.63 rad s^{-1} around a bend of radius 50 m. The force on the car necessary for this motion is

☒ **A** 2.4×10^4 N away from the centre of the circle.

☒ **B** 2.4×10^4 N towards the centre of the circle.

☒ **C** 3.8×10^4 N away from the centre of the circle.

☒ **D** 3.8×10^4 N towards the centre of the circle.

(Total for Question = 1 mark)

Q6.

The London Eye consists of a large vertical circle with 32 equally-spaced passenger cabins attached to it. The wheel rotates so that each cabin has a constant speed of 0.26 m s^{-1} and moves around a circle of radius 61 m.

(a) Calculate the time taken for each cabin to make one complete revolution.

(2)

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Time = ...

(b) Calculate the centripetal force acting on each cabin.

mass of cabin = 9.7×10^3 kg

(2)

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Centripetal force = ...

(c) (i) The diagram shows just the circle and the cabins. Draw arrows to show the direction of the centripetal force acting on a person in a cabin when the person is at each of positions **A**, **B** and **C**.

(3)

*(ii) As the person in a cabin moves around the circle, the normal contact force between the person and the cabin varies.

State the position at which this force will be a maximum and the position at which it will be a minimum. Explain your answers.

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(Total for question = 9 marks)

Q7. In order to make an object move around a circular path at a constant speed a resultant force must act on it.

(a) Explain why a resultant force is required and state the direction of this force.

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(b) When vehicles move around a bend on a level road, the resultant force is provided by friction between the tyres and the road. For a given vehicle and road surface there is a maximum value for this sideways frictional force.

Explain why roads designed for high-speed travel, such as motorways, do not have any sharp bends.

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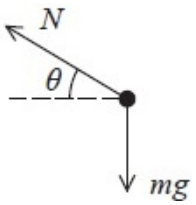
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(c) Some cycling tracks are banked. When cornering, a cyclist moves up the track until the sideways frictional force is zero.

The free-body force diagram for a cyclist and bicycle is shown. The normal contact force exerted by the track is N and the weight of cyclist and bicycle is mg.



(i) By considering the vertical and horizontal motion, show that

$$\tan\theta = gr/v^2$$

where r is the radius of the cyclist's path and v is the cyclist's speed.

(3)

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(ii) Calculate the value of θ for a cyclist travelling at 11.0 m s^{-1} around a bend of radius 18.7 m.

(2)

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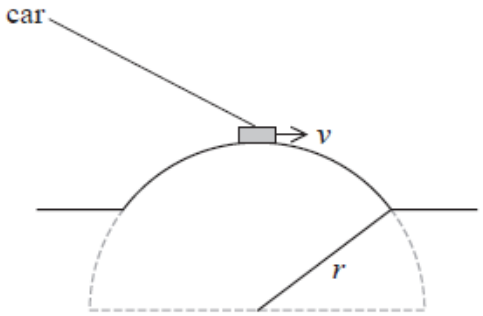
θ = ...

(Total for Question = 9 marks)

Q8.

Hump back bridges are sometimes found in country areas. The road surface is curved, describing an arc of a circle. If cars cross the bridge at too high a speed there is a danger they will lose contact with the road surface.





The responsibility for setting speed limits on many roads on which hump back bridges are found rests with the local traffic authority. One local traffic authority has suggested that a speed limit of 25 mph is appropriate for a hump back bridge with radius of curvature 10 m.

Assess the suitability of a speed limit of 25 mph for this bridge.

10 mph = 4.5 m s^{-1}

(5)

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(Total for question = 5 marks)

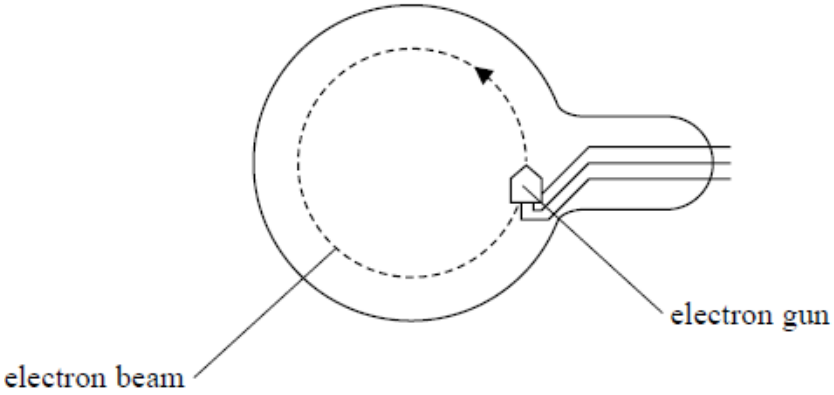
Q9.

An electron beam tube can be used to demonstrate the deflection of electrons in a uniform magnetic field. The tube contains a very low pressure gas so that electron paths can be seen.



(Source: http://www.klingereducational.com/images/products/thumbs/555571.jpg)

Electrons are emitted from the electron gun travelling vertically upwards into a region of uniform horizontal magnetic flux density.



Explain why the electrons follow a circular path.

(3)

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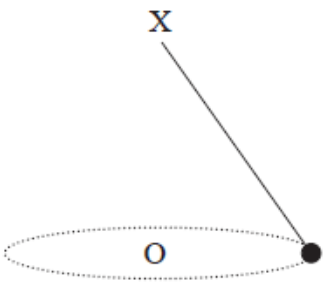
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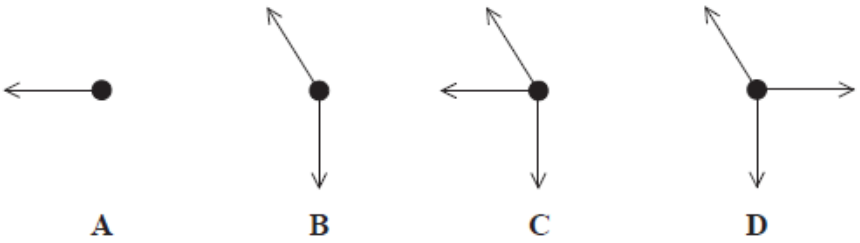
(Total for question = 3 marks)

Q10.

A mass is attached to a light thread which is fixed at X.
The mass is moving at constant speed in a horizontal circle, centre O.



Which of the following is a correct free-body force diagram for this mass?



(1)

- ☒ **A**
- ☒ **B**
- ☒ **C**
- ☒ **D**

(Total for question = 1 mark)

Q11.

The first satellite weather picture was taken in 1960. Today more than 200 weather satellites are in use. Some of these satellites are in a geostationary orbit around the Earth, so that they remain at the same point above the Earth's surface all the time.

(a) (i) Show that the magnitude of the gravitational field strength g at a point outside of the Earth is given by

$$g = \frac{GM}{r^2}$$

where r is the distance of the point from the centre of the Earth and M is the mass of the Earth.

(2)

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(ii) Use this expression together with an expression for the centripetal acceleration to show that the radius of a satellite's orbit is given by

$$r^3 = \frac{GMT^2}{4\pi^2}$$

where T is the time for one orbit of the satellite.

(3)

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(iii) Hence calculate a value for the radius of the geostationary orbit.

$$M = 6.0 \times 10^{24} \text{ kg}$$

(3)

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Radius = ...

(b) State why all geostationary satellites are in an orbit above the Earth's equator.

(1)

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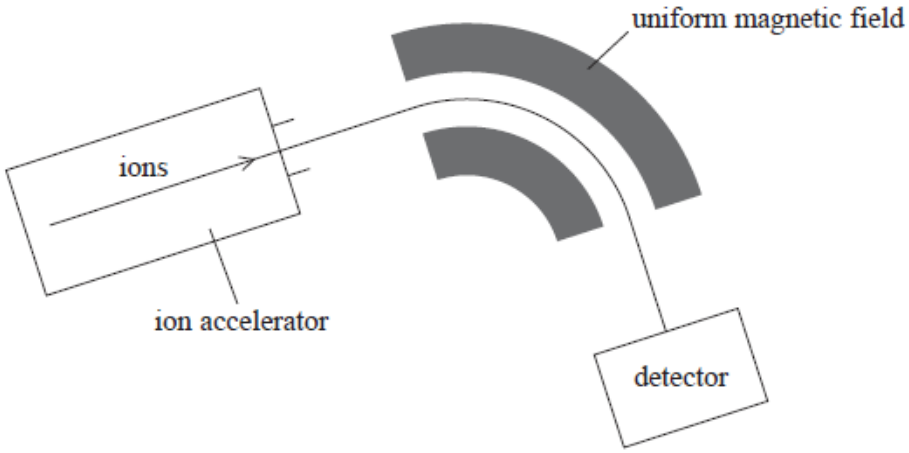
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(Total for question = 9 marks)

Q12.

Mass spectrometry is a technique used to separate ions based on their charge to mass ratio.

The atoms in a sample are ionised and then accelerated and formed into a fine beam. This beam is passed into a region of uniform magnetic field and the ions are deflected by different amounts according to their mass.



Analysis of mass spectrometer data shows that chlorine exists in nature as two isotopes, chlorine-35 and chlorine-37.

After passing through the velocity selector the ion beam enters a region of uniform magnetic flux density 0.35 T with the ions travelling at right angles to the field direction.

(i) Explain why the ions travel in a circular path.

(2)

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(ii) Calculate the radius of the circular path.

(2)

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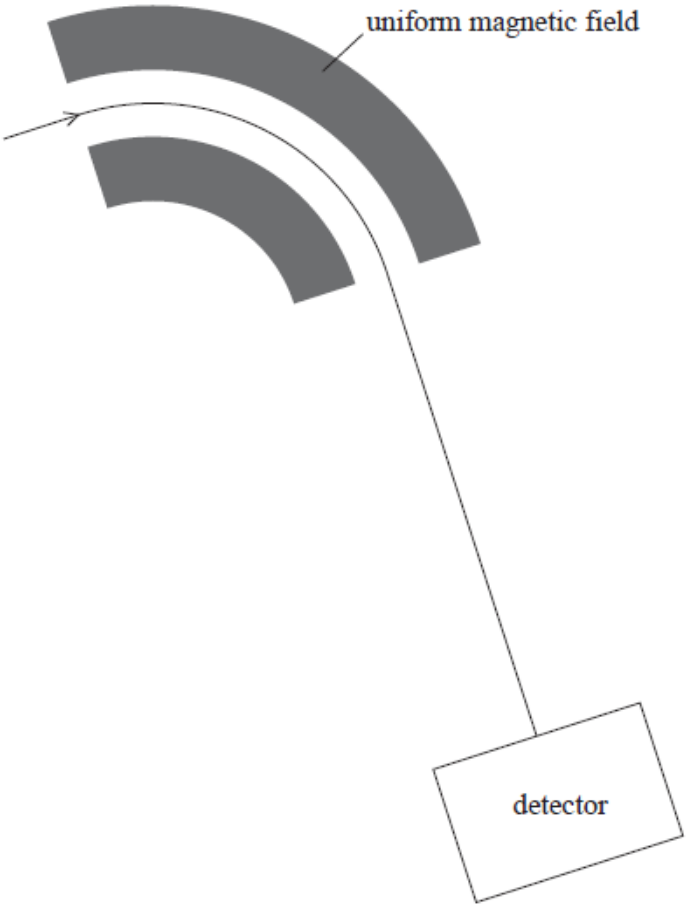
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Radius = ...

(iii) The diagram shows the path of the chlorine-35 ions in the field. Chlorine-37 ions enter the magnetic field with the same velocity.



1. Add another line to the diagram to show the path of these chlorine-37 ions.

(1)

2. Explain any differences in the paths.

(2)

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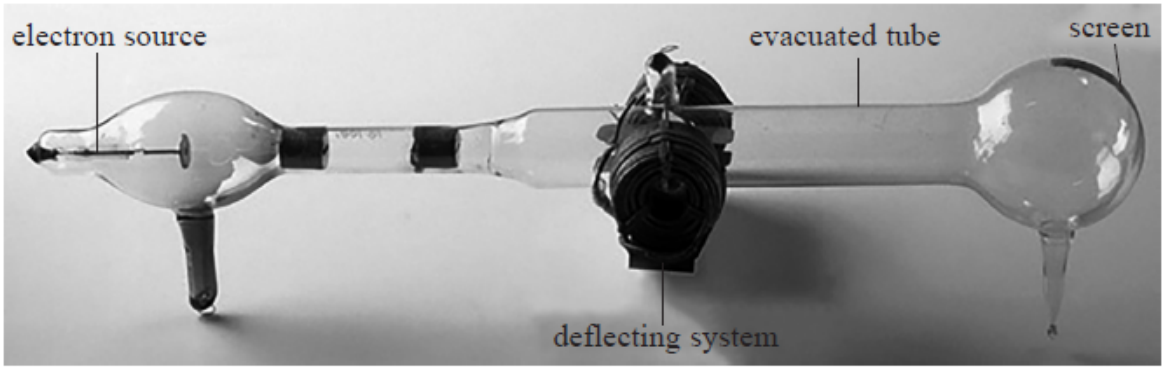
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(Total for question = 7 marks)

Q13.

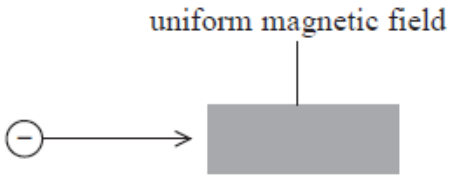
At the end of the 19th century, J.J. Thompson used electric and magnetic fields to deflect beams of charged particles. A photograph of his apparatus is shown.



© Science Museum London

Electrons were accelerated through a potential difference to produce a beam of high-energy electrons. The beam was then deflected in perpendicular directions by the magnetic and electric fields. The final position of the beam on the screen was determined by the charge and mass of the electrons.

An electron is travelling left to right and enters a region of uniform magnetic field as shown below. The direction of the magnetic field is perpendicular to the direction of travel of the electron.



(i) The magnetic field deflects the electron in the direction up the page.

Explain the direction of the magnetic field that would produce this deflection.

(2)

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(ii) Explain why the electron would travel in a circular path if no other forces acted on it.

(2)

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(Total for question = 4 marks)

Q14.

The photograph shows a model racing car set. The curved parts of the track are semicircular. The car makes electrical contact with the track using metal brushes underneath the car.



There is a maximum speed for the car to stay on the curved part of the track. Explain why the car will slip off the curved part of the track if the car exceeds the maximum speed.

(3)

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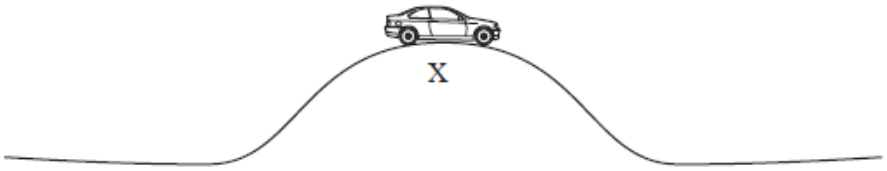
(Total for question = 3 marks)

Q15.

The photograph shows a bridge.



The diagram shows a car of mass 950 kg at the highest point X of the bridge.



The bridge forms part of a vertical circle of radius 20.0 m.

(a) Calculate the total upward force *R* of the road on the car:

(i) when the car is stationary at X,

(1)

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R = ...

(ii) when the car is passing point X at a speed of 12.0 m s^{-1}

(3)

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R = ...

(b) The car is repeatedly driven over the bridge at gradually increasing speeds. Above a certain speed the car loses contact with the road at X.

State why this happens.

(1)

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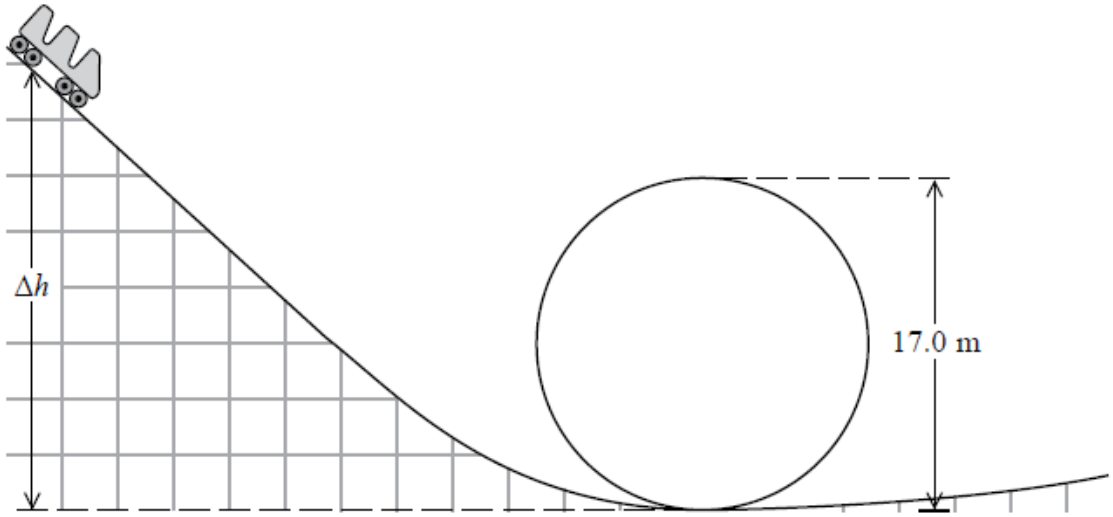
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(Total for question = 5 marks)

Q1.

The diagram shows the carriage of a rollercoaster about to enter a vertical loop of diameter 17.0 m. The carriage is initially at rest at a height Δh above the bottom of the loop.



(i) So that a passenger remains in contact with their seat at the top of the ride, show that the minimum speed of the car at the top of the loop is 9.1 m s^{-1}.

(3)

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(ii) Calculate the minimum value of Δh that will enable the passenger to remain in contact with their seat at the top of the loop.

(3)

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Δh = ...

(Total for question = 4 marks)

Q2.

The Starflyer is a fairground ride which operates 60 m above the ground. As it begins to spin, the chairs in which the riders sit move outwards.



Consider the chair and rider as a single object. By drawing a free-body force diagram and considering the forces acting, explain the following observations.

The angle to the vertical of the supporting ropes depends on the speed of rotation, but does not depend on the mass of the rider.

(5)

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(Total for question = 5 marks)

Q3.

Astronomers observing stars at the centre of our galaxy have suggested that many of them are orbiting a supermassive black hole. The mass of this black hole is 9.2×10^{36} kg.

Calculate the orbital period for a star in a circular orbit at a distance of 1.9×10^{14} m from a black hole of this mass.

(3)

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Orbital period = ...

(Total for question = 3 marks)

Q4.

In 1990, the Hubble Space Telescope (HST) was launched into a low Earth orbit above the Earth's atmosphere.

HST orbits the Earth in a circular orbit with a speed of 7.59 km s^{-1}.

mass of Earth = 5.97×10^{24} kg
radius of Earth = 6.37×10^{6} m

(i) Show that the height of HST above the surface of the Earth is about 6×10^5 m.

(3)

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(ii) Calculate the increase in the gravitational potential energy as HST is raised, from its initial position at the Earth's surface, to its orbital height.

mass of HST = 11 600 kg

(2)

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Increase in gravitational potential energy = ...

(iii) A student suggests that giving HST more energy than that required in (ii) would result in the satellite orbiting at a greater height and with a greater speed.

Assess the validity of the student's suggestion.

(4)

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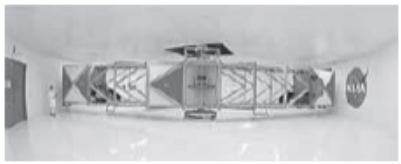
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(Total for question = 9 marks)

Q5.

A centrifuge is a machine which rotates.

The United States' space agency, NASA, uses a centrifuge to test whether equipment will operate when experiencing large forces. The equipment to be tested is attached to the end of the frame of the centrifuge, which rotates around a vertical axis at its centre.



(i) Show that the angular velocity of the centrifuge is about 5 rad s^{-1}.

(2)

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(ii) Explain how the centrifuge applies large forces to the equipment under test.

(2)

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(iii) The NASA website says the centrifuge can be used to test whether the equipment can

withstand accelerations of up to about 25*g*.

Deduce whether this claim is correct.

(2)

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(Total for question = 6 marks)

Q6. A racing car of mass 1200 kg travels at 0.63 rad s^{-1} around a bend of radius 50 m. The force on the car necessary for this motion is

☒ **A** 2.4×10^4 N away from the centre of the circle.

☒ **B** 2.4×10^4 N towards the centre of the circle.

☒ **C** 3.8×10^4 N away from the centre of the circle.

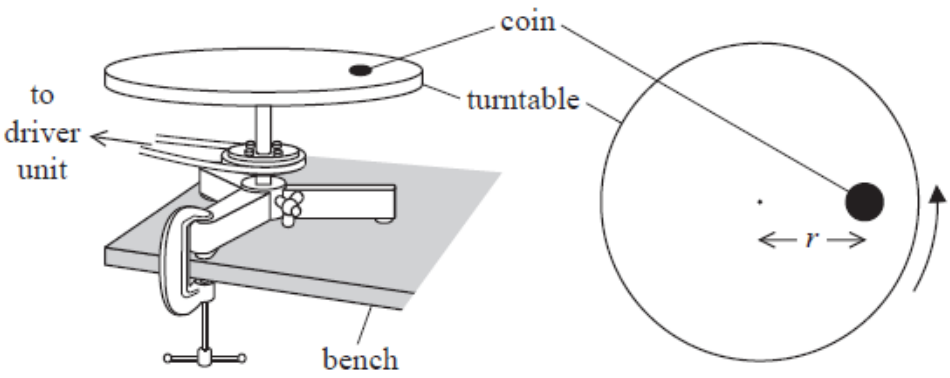
☒ **D** 3.8×10^4 N towards the centre of the circle.

(Total for Question = 1 mark)

Q7.

A student was investigating the forces involved in circular motion.

He placed a small coin on a horizontal turntable as shown. The turntable was connected to a driver unit so that it could be rotated at a constant rate.



The student repeated the procedure with different values of r.

Explain how the value of ω at which the coin started to slide varied as r increased.

(3)

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(Total for question = 3 marks)

Q8.

The London Eye consists of a large vertical circle with 32 equally-spaced passenger cabins attached to it. The wheel rotates so that each cabin has a constant speed of 0.26 m s^{-1} and moves around a circle of radius 61 m.

(a) Calculate the time taken for each cabin to make one complete revolution.

(2)

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Time = ...

(b) Calculate the centripetal force acting on each cabin.

mass of cabin = 9.7×10^3 kg

(2)

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Centripetal force = ...

(c) (i) The diagram shows just the circle and the cabins. Draw arrows to show the direction of the centripetal force acting on a person in a cabin when the person is at each of positions **A**, **B** and **C**.

(3)

*(ii) As the person in a cabin moves around the circle, the normal contact force between the person and the cabin varies.

State the position at which this force will be a maximum and the position at which it will be a minimum. Explain your answers.

(4)

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(Total for question = 9 marks)

Q9. In order to make an object move around a circular path at a constant speed a resultant force must act on it.

(a) Explain why a resultant force is required and state the direction of this force.

(2)

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(b) When vehicles move around a bend on a level road, the resultant force is provided by friction between the tyres and the road. For a given vehicle and road surface there is a maximum value for this sideways frictional force.

Explain why roads designed for high-speed travel, such as motorways, do not have any sharp bends.

(2)

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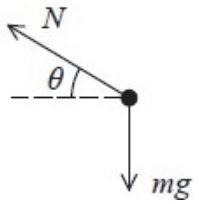
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(c) Some cycling tracks are banked. When cornering, a cyclist moves up the track until the sideways frictional force is zero.

The free-body force diagram for a cyclist and bicycle is shown. The normal contact force exerted by the track is N and the weight of cyclist and bicycle is mg.



(i) By considering the vertical and horizontal motion, show that

$$\tan\theta = gr/v^2$$

where r is the radius of the cyclist's path and v is the cyclist's speed.

(3)

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(ii) Calculate the value of θ for a cyclist travelling at 11.0 m s^{-1} around a bend of radius 18.7 m.

(2)

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θ = ...

(Total for Question = 9 marks)

Q10.

The photograph is of a roundabout in a children's playground.



A child of mass 20 kg sits on the roundabout without holding the bars.

The distance from the centre of the roundabout to the centre of gravity of the child is 0.80 m. The maximum frictional force between the roundabout and the child is 0.35 × the weight of the child.

(a) Calculate the minimum time taken for one revolution of the roundabout if the child is not to slide off.

(4)

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Minimum time = ...

(b) State and explain how this time would change if a child of larger mass sat at the same place on the roundabout.

(2)

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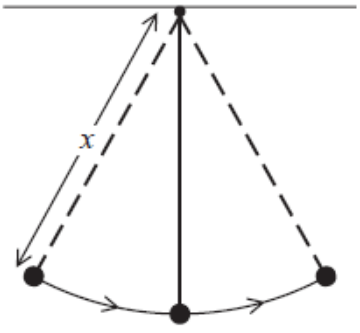
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(Total for question = 6 marks)

Q11.

A pendulum consists of a bob of mass m and a string of length x.

The diagram shows the pendulum swinging through the arc of a circle. At the bottom of its swing the tension in the string is T and the velocity of the bob is v.



Which of the following is correct for the bob at the bottom of the swing?

☒ **A** $T = \frac{mv^2}{x} - mg$

☒ **B** $T = \frac{mv^2}{x} + mg$

☒ **C** $T = mg - \frac{mv^2}{x}$

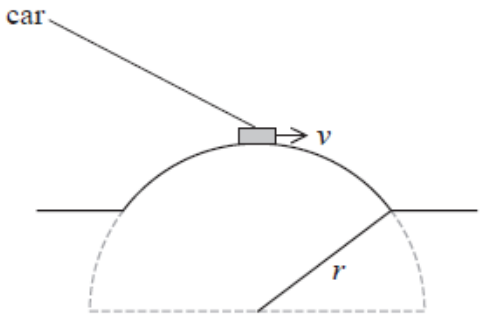
☒ **D** $T = \frac{mv^2}{x}$

(Total for question = 1 mark)

Q12.

Hump back bridges are sometimes found in country areas. The road surface is curved, describing an arc of a circle. If cars cross the bridge at too high a speed there is a danger they will lose contact with the road surface.





The responsibility for setting speed limits on many roads on which hump back bridges are found rests with the local traffic authority. One local traffic authority has suggested that a speed limit of 25 mph is appropriate for a hump back bridge with radius of curvature 10 m.

Assess the suitability of a speed limit of 25 mph for this bridge.

10 mph = 4.5 m s^{-1}

(5)

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(Total for question = 5 marks)

Q13.

In 2015 the Messenger spacecraft crashed into the surface of the planet Mercury after four years in orbit observing the surface of Mercury.

Messenger's orbit was highly elliptical, varying between 200 km and 15 000 km above the surface of Mercury. Messenger completed one full orbit every 12 hours.

mass of Messenger spacecraft = 565 kg
mass of planet Mercury = 3.30×10^{23} kg
radius of planet Mercury = 2430 km

It has been suggested that the same orbital period of about 12 hours could have been achieved if Messenger was in a circular orbit 7690 km above the surface of Mercury.

(i) Determine whether this suggestion is correct.

(4)

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(ii) The elliptical orbit chosen had advantages over this circular orbit.

Explain **one** advantage.

(2)

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(Total for question = 6 marks)

Q14.

The photograph shows a model racing car set. The curved parts of the track are semicircular. The car makes electrical contact with the track using metal brushes underneath the car.



The following measurements are made for a car starting at rest on a straight piece of track.

distance travelled = 1.2 m

time taken = 0.77 s

(i) Show that the final velocity of the car is about 3 m s^{-1}.

Assume the acceleration is constant.

(2)

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(ii) The final velocity calculated in (i) is the maximum velocity before the car slips off the track.

Calculate the maximum horizontal force between the curved part of the track and the car.

mass of car = 0.050 kg

radius of curved part of track = 0.042 m

(2)

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Maximum horizontal force = ...

(Total for question = 4 marks)

Q15.

The first satellite weather picture was taken in 1960. Today more than 200 weather satellites are in use. Some of these satellites are in a geostationary orbit around the Earth, so that they remain at the same point above the Earth's surface all the time.

(a) (i) Show that the magnitude of the gravitational field strength *g* at a point outside of the Earth is given by

$$g = \frac{GM}{r^2}$$

where *r* is the distance of the point from the centre of the Earth and *M* is the mass of the Earth.

(2)

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(ii) Use this expression together with an expression for the centripetal acceleration to show that the radius of a satellite's orbit is given by

$$r^3 = \frac{GMT^2}{4\pi^2}$$

where T is the time for one orbit of the satellite.

(3)

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(iii) Hence calculate a value for the radius of the geostationary orbit.

$M = 6.0 \times 10^{24}$ kg

(3)

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Radius = ...

(b) State why all geostationary satellites are in an orbit above the Earth's equator.

(1)

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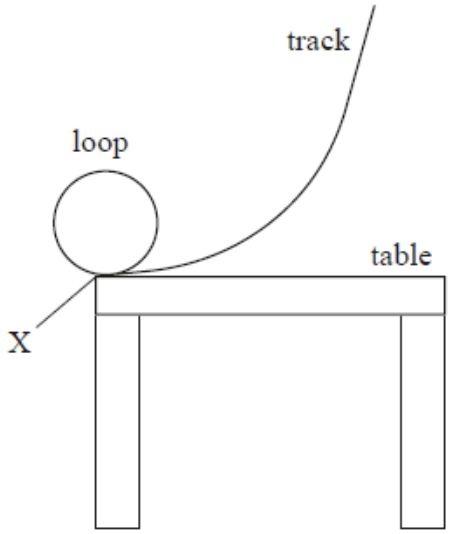
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(Total for question = 9 marks)

Q16.

A track for toy cars can be built with a circular loop as shown.



A toy car is placed on the track at various heights. It travels around the loop before leaving the track horizontally at X.

The loop has radius r and the mass of the toy car is m. It is possible for a toy car to complete the loop without losing contact with the inside of the track.

For this to occur the minimum speed of the toy car at the top of the loop v_{top} is given by

$$v_{top} = \sqrt{gr}$$

Explain why.

(2)

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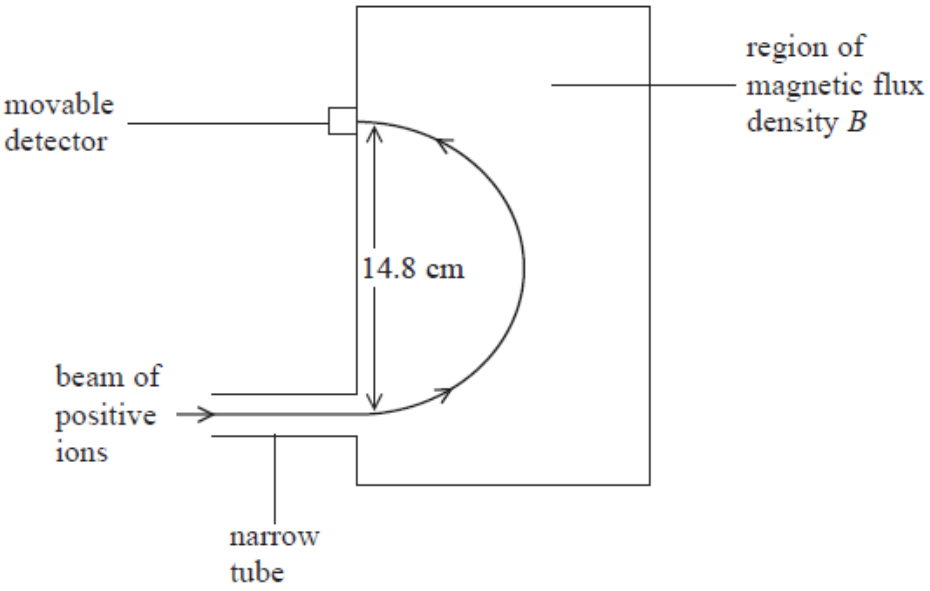
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(Total for question = 2 marks)

Q17.

A mass-spectrometer is an instrument that is used to measure the masses of molecules. Molecules of a gas are ionised and travel through a vacuum in a narrow tube. The ions enter a region of uniform magnetic flux density *B* where they are deflected in a semicircular path as shown.



(a) State why it is necessary for the molecules to be ionised.

(1)

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(b) State the direction of the magnetic field.

(1)

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(c) The ions have a charge of $+e$ and a speed of 1.20×10^5 m s^{-1}. When *B* has a value of 0.673 T, the ions are detected at a point where the diameter of the arc is 14.8 cm.

Calculate the mass of an ion.

(3)

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Mass of an ion = ...

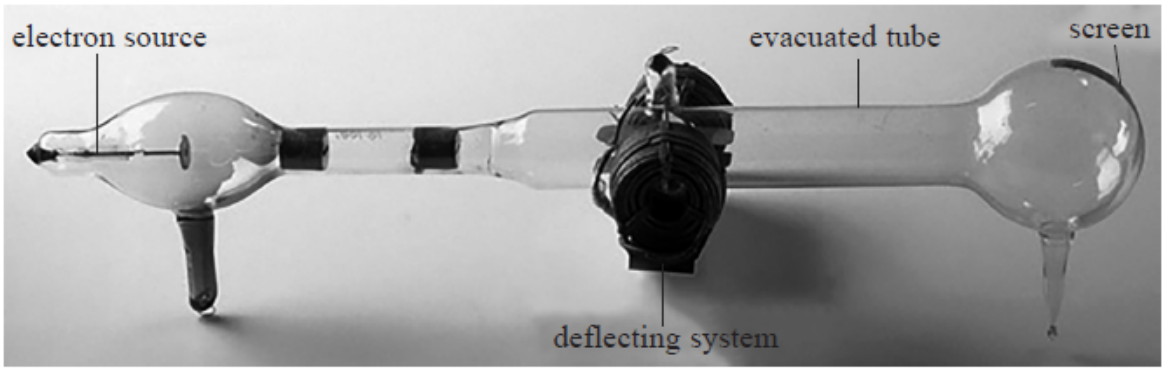
(d) Ions with a smaller mass but the same charge and speed are also present in the beam. On the diagram sketch the path of these ions.

(1)

(Total for question = 6 marks)

Q18.

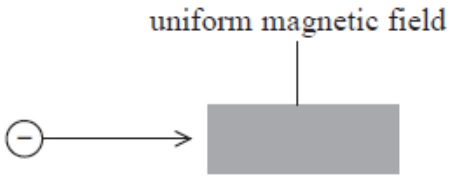
At the end of the 19th century, J.J. Thompson used electric and magnetic fields to deflect beams of charged particles. A photograph of his apparatus is shown.



© Science Museum London

Electrons were accelerated through a potential difference to produce a beam of high-energy electrons. The beam was then deflected in perpendicular directions by the magnetic and electric fields. The final position of the beam on the screen was determined by the charge and mass of the electrons.

An electron is travelling left to right and enters a region of uniform magnetic field as shown below. The direction of the magnetic field is perpendicular to the direction of travel of the electron.



(i) The magnetic field deflects the electron in the direction up the page.

Explain the direction of the magnetic field that would produce this deflection.

(2)

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(ii) Explain why the electron would travel in a circular path if no other forces acted on it.

(2)

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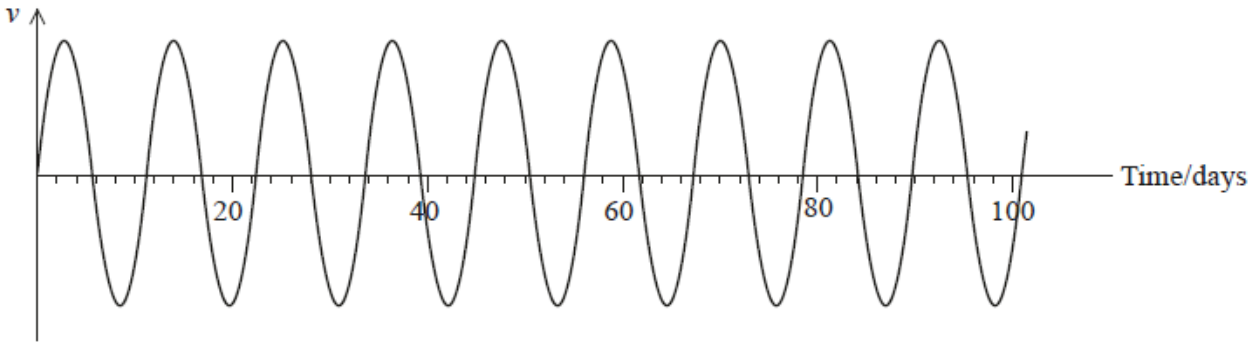
(Total for question = 4 marks)

Q19.

In 2016 astronomers announced the discovery of an Earth-like planet orbiting Proxima Centauri, the closest star to the Sun.

The planet was detected because of the small movement of the star as the planet orbited. The movement was detected using the Doppler shift in the frequency of light travelling to the Earth.

The graph shows how the component of the star's velocity *v* towards the Earth varied over time.



(i) Use the graph to show that the angular velocity of the planet is about 6×10^{-6} radian s^{-1}.

(3)

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(ii) The mass of Proxima Centauri is 0.12 times the mass of the Sun.

Determine the distance of the planet from Proxima Centauri.

mass of Sun = 1.99×10^{30} kg

(3)

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Distance = ...

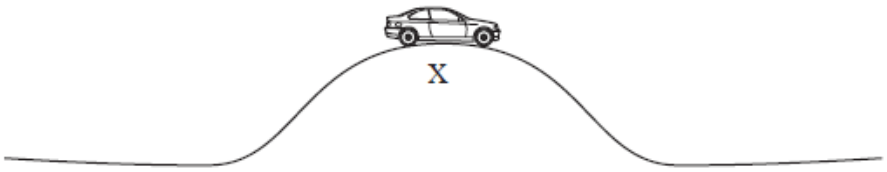
(Total for question = 6 marks)

Q20.

The photograph shows a bridge.



The diagram shows a car of mass 950 kg at the highest point X of the bridge.



The bridge forms part of a vertical circle of radius 20.0 m.

(a) Calculate the total upward force R of the road on the car:

(i) when the car is stationary at X,

(1)

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R = ...

(ii) when the car is passing point X at a speed of 12.0 m s^{-1}

(3)

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R = ...

(b) The car is repeatedly driven over the bridge at gradually increasing speeds. Above a certain speed the car loses contact with the road at X.
State why this happens.

(1)

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(Total for question = 5 marks)

Q21.

The photograph shows a model racing car set. The curved parts of the track are semicircular. The car makes electrical contact with the track using metal brushes underneath the car.



The cars are controlled separately and so can be raced, with one car on the inner lane and the other on the outer lane. The cars are identical. Each car is raced at its highest speed for that lane.

Explain why the outcome of the race is difficult to predict.

(3)

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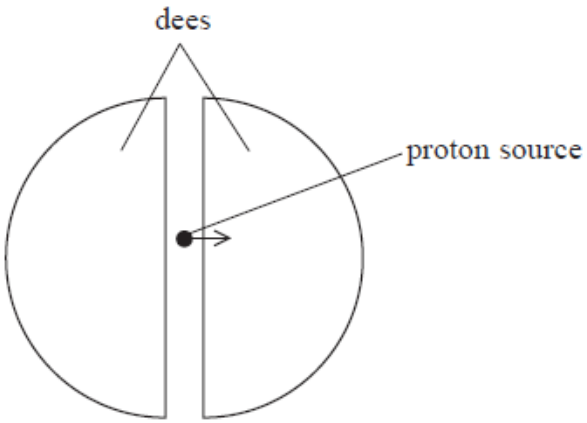
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(Total for question = 3 marks)

Q22.

A cyclotron is a particle accelerator which can be used to accelerate protons. The cyclotron consists of two semicircular electrodes called 'dees'. An alternating potential difference is applied across the gap between the dees. A uniform magnetic field is applied at right angles to

the plane of the dees.



(i) Complete the diagram to show the path of the protons.

(1)

(ii) State the direction of the magnetic field needed in order to produce the path you have sketched.

(1)

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(iii) Explain how the kinetic energy of the protons is increased as they follow the path you have shown.

(3)

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(iv) Show that the magnetic flux density B of the applied magnetic field is given by

$$B = \frac{2\pi f m}{e}$$

where f is the frequency of the alternating potential difference, m is the mass of the proton and e is the charge on the proton.

(3)

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(v) In a particular cyclotron B is 1.2 mT.
Calculate the frequency f of the alternating potential difference.

(2)

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f = ...

Q23.

The photograph shows cars driving around a roundabout at a constant speed.



The resultant force F on a car causes it to follow a circular path.

Which of the following statements about F is **incorrect**?

☒ **A** F is equal to the product of the mass and angular velocity of the car.

☒ **B** F is equal to the product of the momentum and angular velocity of the car.

☒ **C** F is in the same direction as the acceleration of the car.

☒ **D** F is perpendicular to the momentum of the car.

(Total for question = 1 mark)

Q24.

Scientists are developing a space station equipped with large solar panels. The space station would be located in a geostationary orbit. The space station would transfer energy to Earth as microwaves.

(i) A space station in a geostationary orbit is above the equator and has a period of 24 hours.

Explain one advantage of locating the space station in a geostationary orbit.

(2)

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(ii) Calculate the height h of the space station above the equator when it is in a geostationary orbit.

mass of Earth = 6.00×10^{24} kg

24 hours = 8.64×10^{4} s

(4)

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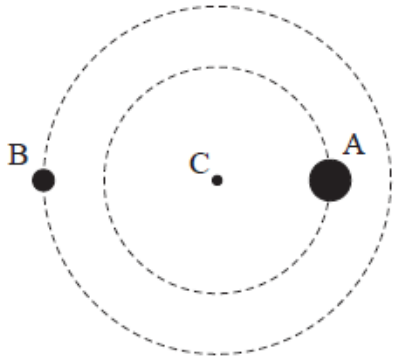
h = ...

(Total for question = 6 marks)

Q25.

The diagram shows two black holes, A and B, orbiting each other.

Assume that the centre of mass C of the system is the centre of a circular orbit for each black hole as shown in the diagram.



Black hole A is in an orbit of radius 2.9×10^{10} m and black hole B is in an orbit of radius 3.6×10^{10} m. Both orbit with the same period, so the total distance between them is 6.5×10^{10} m.

(a) Calculate the force between the black holes.

mass of Sun, $M_{\odot} = 1.99 \times 10^{30}$kg
mass of black hole A = $36M_{\odot}$
mass of black hole B = $29M_{\odot}$

(2)

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Force = ...

(b) By considering the orbit of one black hole about C, determine the period of the orbit.

(3)

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Period = ...

(Total for question = 5 marks)