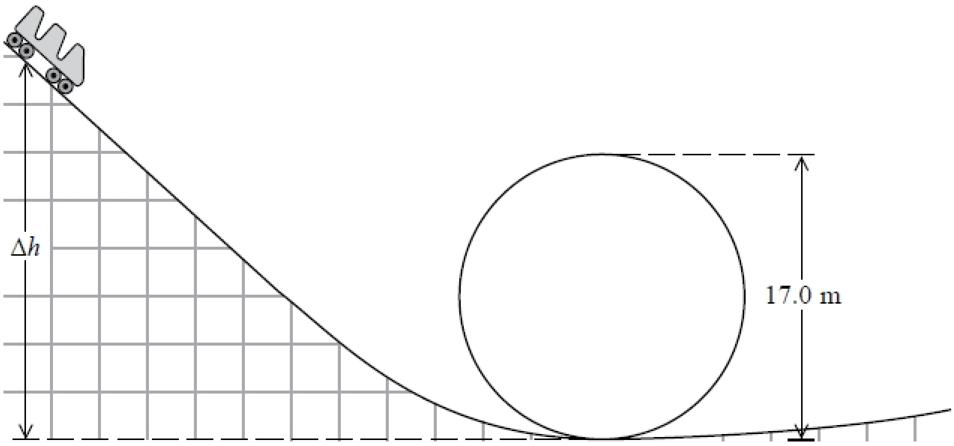
Circular Motion

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 Δ*h* 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)

....

....

....

....

....

....

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

(3)

....

....

....

....

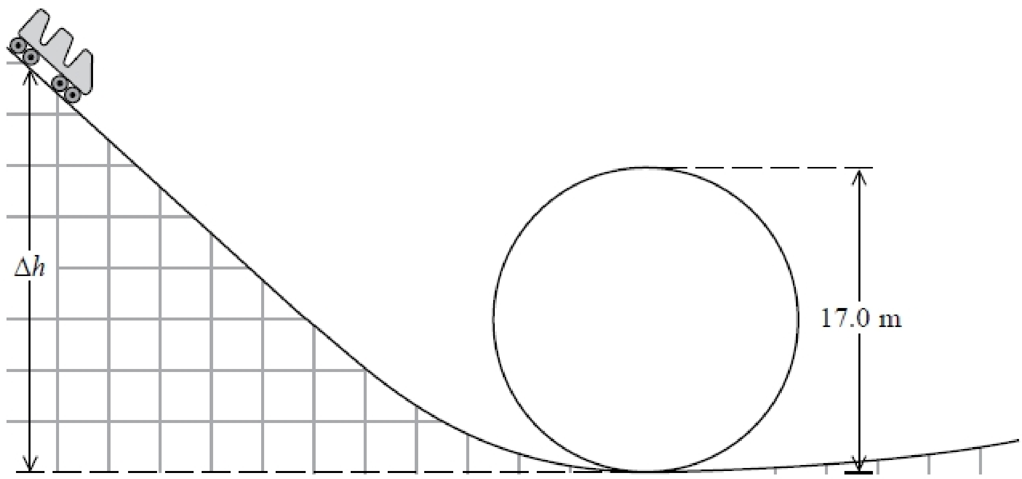
....

Δ*h* = ...

(Total for question = 4 marks)

Q2.

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)

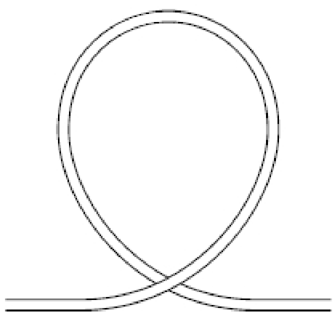
....

....

....

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)

....

....

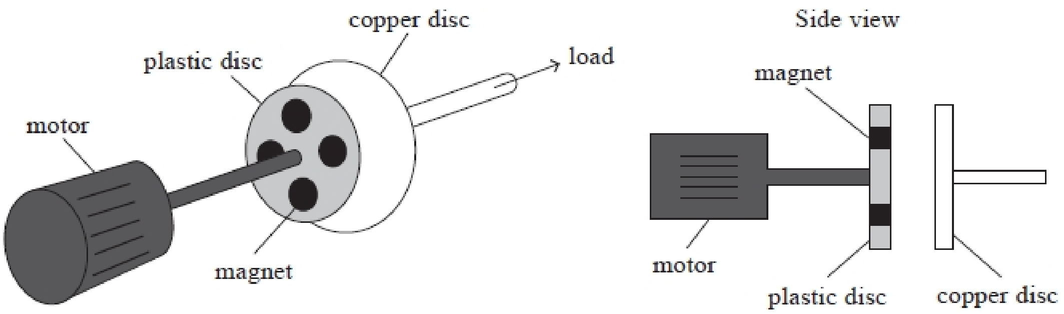
....

....

(Total for question = 10 marks)

Q3.

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.

(2)

....

....

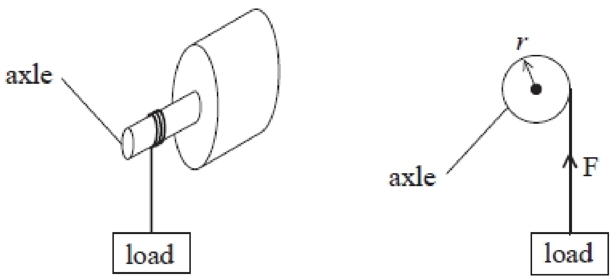
ω = ...

(Total for question = 2 marks)

Q4.

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 $P = \frac{W}{t}$.

(4)

....

....

....

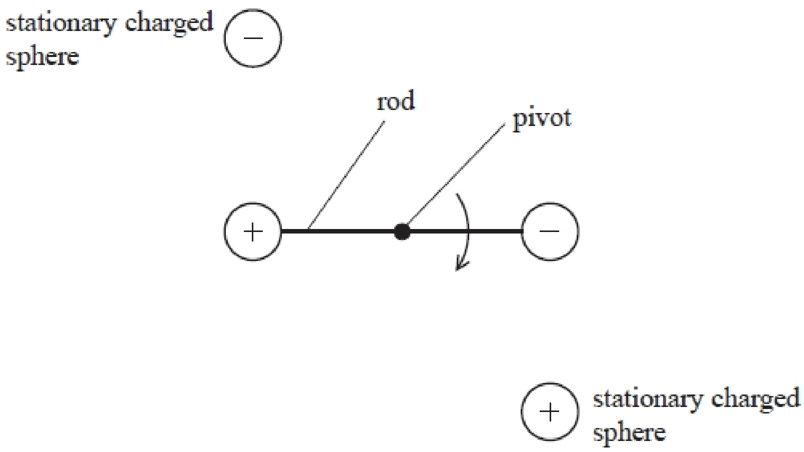
....

....

....

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

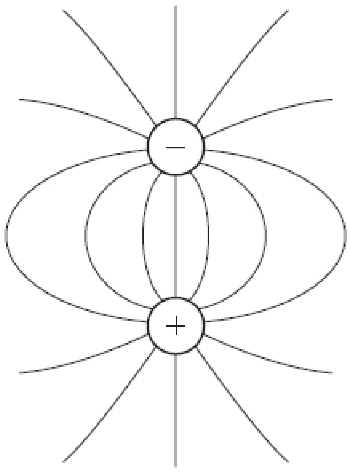
The diagram shows a simplified version of part of this motor.
This consists of a rod, with an oppositely charged sphere at either end, which rotates around a fixed pivot. Two stationary charged spheres apply a force on the spheres at either end of the rod.



(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)

....

....

....

....

....

(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.

(4)

....

....

....

....

....

....

....

....

(Total for question = 13 marks)

Q5.

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)

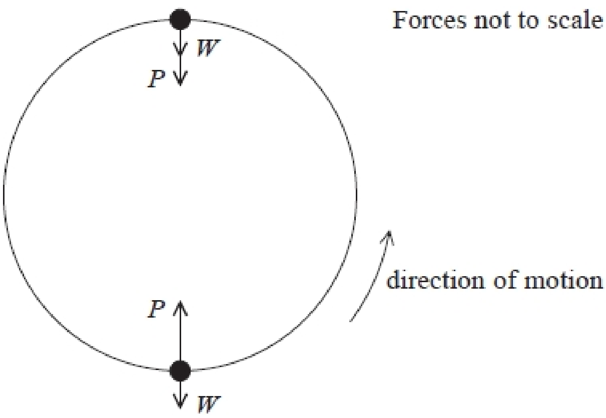
Q6.

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.

(6)

....

....

....

....

....

....

....

....

....

....

....

....

(Total for question = 6 marks)

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.

(3)

....

....

....

....

....

....

Orbital period = ...

(Total for question = 3 marks)

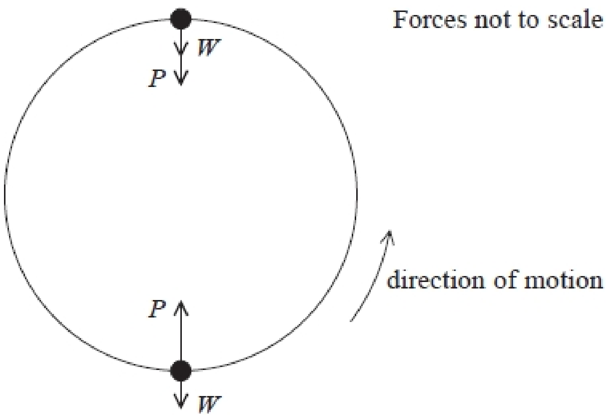
Q8.

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.



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.

(4)

....

....

....

....

....

....

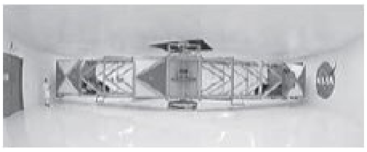
....

(Total for question = 4 marks)

Q9.

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)

....

....

....

....

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

(2)

....

....

....

....

....

(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)

....

....

....

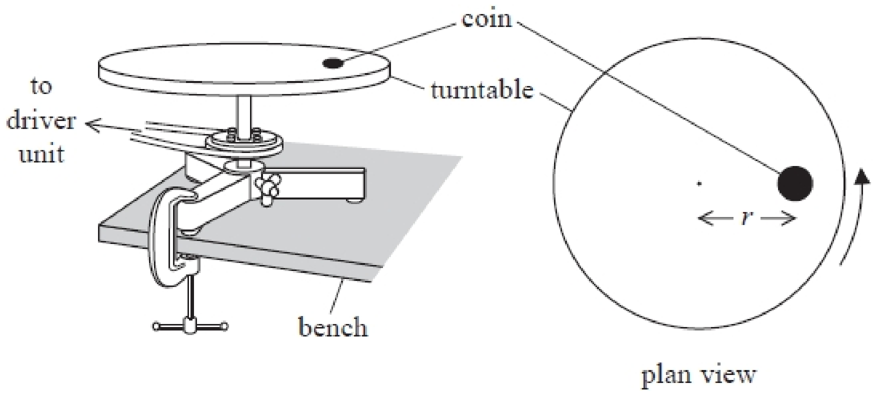
....

(Total for question = 6 marks)

Q10.

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)

....

....

....

....

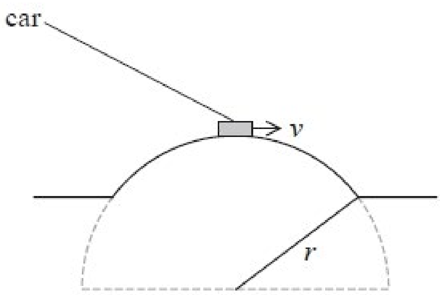
....

....

(Total for question = 3 marks)

Q11.

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)

....

....

....

....

....

....

....

....

....

....

....

....

(Total for question = 5 marks)

Q12.

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)

....

....

....

....

....

....

....

....

....

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

Explain **one** advantage.

(2)

....

....

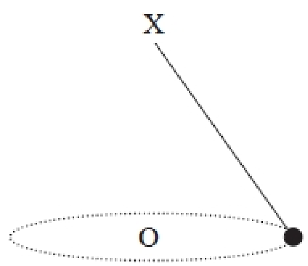
....

....

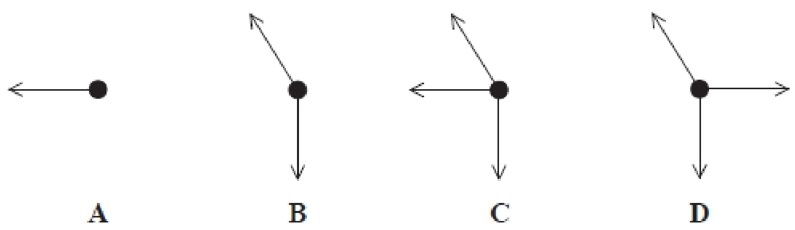
(Total for question = 6 marks)

Q13.

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**

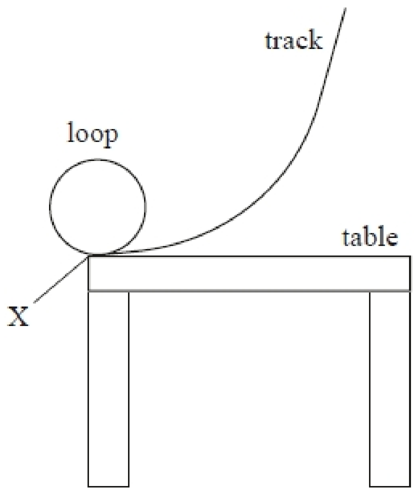
☐ **C**

☐ **D**

(Total for question = 1 mark)

Q14.

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)

....

....

....

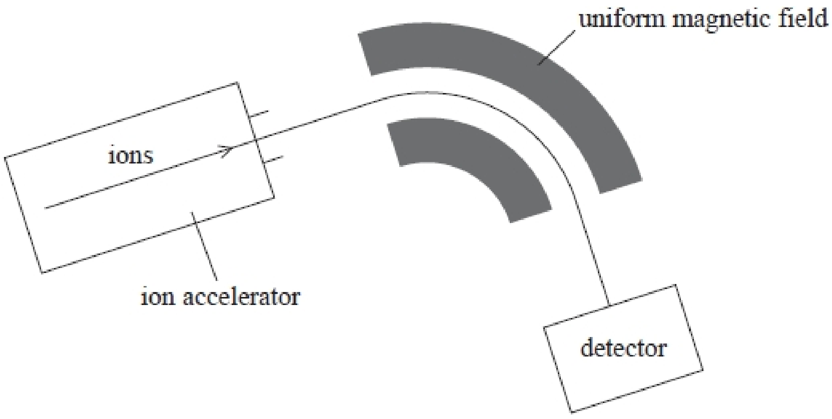
....

(Total for question = 2 marks)

Q15.

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)

....

....

....

....

....

(ii) Calculate the radius of the circular path.

(2)

....

....

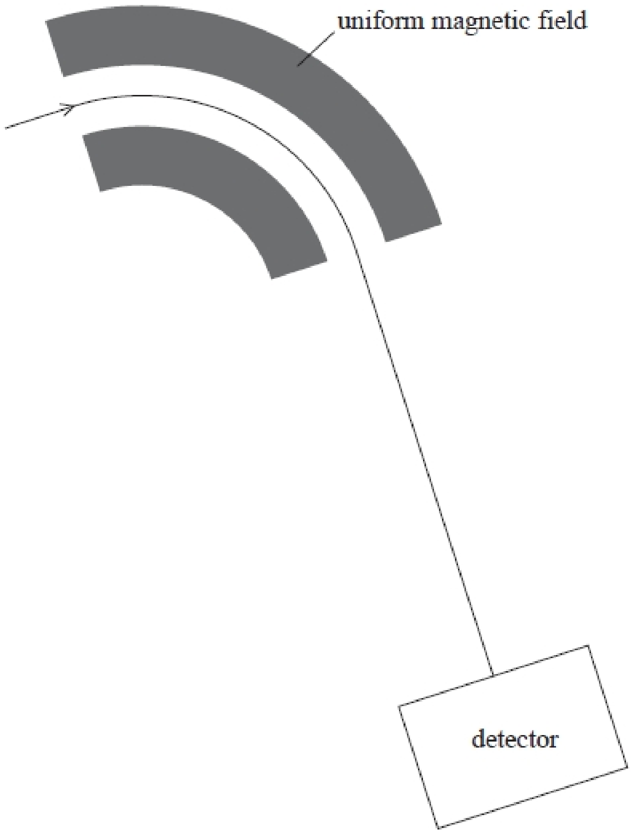
....

....

....

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)

....

....

....

....

....

(Total for question = 7 marks)

Q16.

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)

....

....

....

....

....

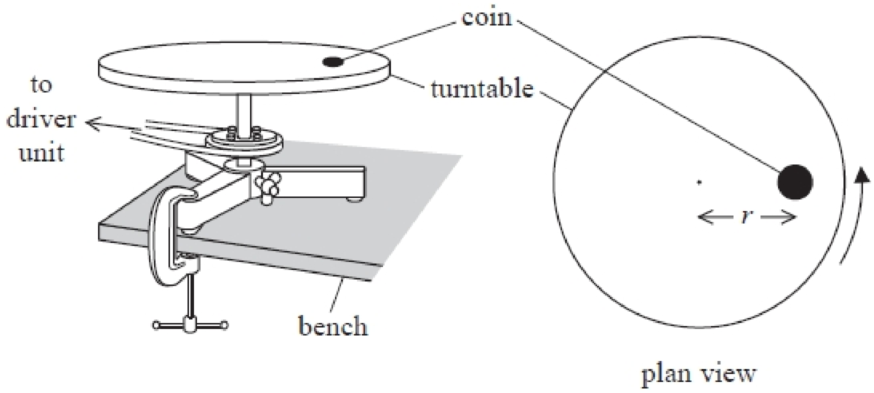
....

(Total for question = 3 marks)

Q17.

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)

....

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

(3)

....

....

....

....

....

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)

....

....

....

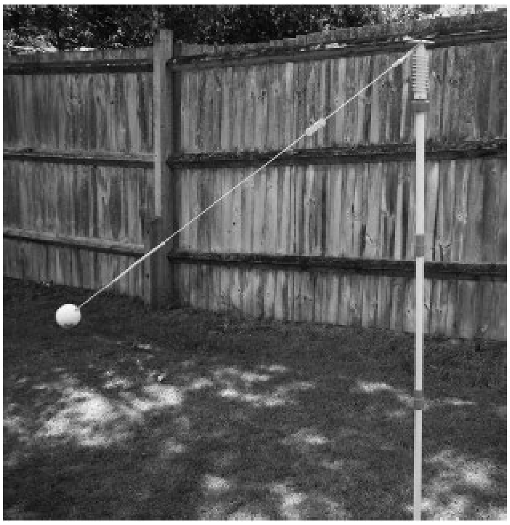
....

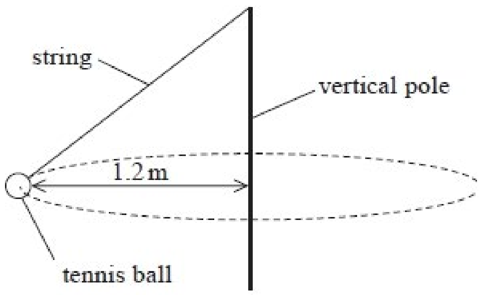
Percentage uncertainty = ...

(Total for question = 7 marks)

Q18.

A 'tennis trainer' consists of a tennis ball suspended by a string from the top of a vertical pole. When the ball is hit it travels in a horizontal circle around the pole, as shown in both the photograph and the diagram.





The radius of the path of the ball is 1.2 m and the speed of the ball is 3.8 m s^{-1}.

Deduce whether these values are consistent with the angle between the string and the vertical pole shown in the photograph.

(5)

....

....

....

....

....

....

....

....

....

....

....

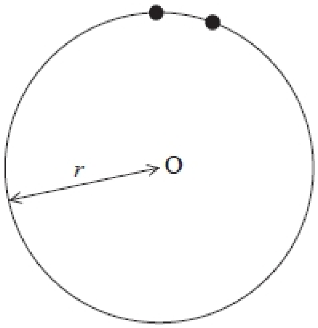
(Total for question = 5 marks)

Q19.

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.

(5)

....

....

....

....

....

....

....

....

....

....

(Total for question = 5 marks)

Mark Scheme – Circular Motion

Q1.

Question number	Acceptable answers	Additional guidance	Mark
(i)	• Recognise that for passenger to remain in their seat normal reaction $R \geq 0$ **(1)** **or** centripetal force >= weight **(1)** • Equate centripetal force and weight (for R=0) **(1)** • $v = 9.1$ m s^{-1} **(1)**	Example of calculation: $\frac{mv^2}{r} = mg$ $v = \sqrt{rg} = \sqrt{8.5\text{m} \times 9.81\text{m s}^{-2}} = 9.13\text{m s}^{-1}$	3
(ii)	• Equate decrease in gravitational potential energy to increase in kinetic energy at top of loop **(1)** • Adds this to 17.0 **(1)** • $\Delta h = 21.3$ m **(1)**	Example of calculation: $mgh = \frac{1}{2}mv^2$ $h = \frac{v^2}{2g} = \frac{(9.13\text{m s}^{-1})^2}{2 \times 9.81\text{m s}^{-2}} = 4.25\text{m}$ $\Delta h = 17 + 4.3 = 21.3$ m	3

Q2.

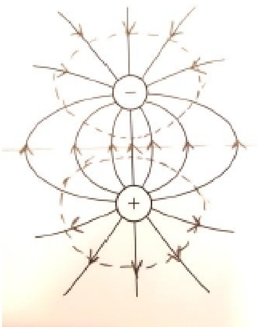
Question number	Acceptable answers	Additional guidance	Mark
(i)	• Use of $a = \frac{v^2}{r}$ **(1)** • $a = 6.1\text{g}$ **(1)**	Example of calculation: $a = \frac{v^2}{r} = \frac{(22.5\text{m s}^{-1})^2}{8.5\text{m}} = 59.6\text{m s}^{-2}$ $a = 59.6/9.8 = 6.1$ g	2
(ii)	An explanation that makes reference to: • Radius of curvature smallest at the top of the loop **(1)** **OR** radius larger at the bottom of the loop **(1)** • So acceleration at bottom is less for the same speed **(1)**		2

Q3.

Question Number	Acceptable answers	Additional guidance	Mark
	• convert to radians (1) • $\omega = 52$ rad s^{-1} (1)	Example of calculation $\omega = \frac{500 \times 2\pi}{60}$ $\omega = 52.4$ radians s^{-1}	2

Q4.

Question Number	Acceptable answers		Additional guidance	Mark
(a)	• Replace Work W by force × distance • Replace distance ÷ time by velocity v • Use $v = r$ × Angular velocity • Recognise $F \times r$ is the moment of F	(1) (1) (1) (1)	Alternative method: Consider one revolution of axle , Load rises $2\pi r$ Work done = $2\pi rF$ Time taken = $2\pi \div \omega$ Power = Work ÷ time= $2\pi rF \div 2\pi/\omega$ to give reqd eq	4

Question Number	Acceptable answers		Additional guidance	Mark
(b)(i)	• Arrow away from + charge **Or** arrow towards − charge • At least 3 Equipotential lines, perpendicular to field lines • Symmetrical about vertical/horizontal axis and not touching/crossing	(1) (1) (1)	MP3 dependent on lines being perpendicular in MP2 	3

Question Number	Acceptable answers		Additional guidance	Mark
(b)(ii)	• Use of $F = \dfrac{Q_1Q_2}{4\pi\varepsilon_o r^2}$ • $F = 0.036$ (N)	(1) (1)	Example of calculation: $F = 8.99 \times 10^9\ \text{Nm}^2\text{C}^{-2}\ \dfrac{(0.1\times10^{-6}\,\text{C})^2}{(0.05\text{m})^2}$ $F = 0.036\text{N}$	2

Question Number	Acceptable answers		Additional guidance	Mark
(c)	• Use of moment = $F x$ • Expression for correct moment • Use of power = moment of force x angular velocity • Only realistic possibility is pond pump and $P = 0.6$W (calculated answer could also be force and then comparison with b(i))	(1) (1) (1) (1)	Show that value gives 3.2×10^{-3} Nm and 0.64 W Example of calculation: Moment $= 0.036\text{N}\times0.04\text{m}\times2 = 2.89\times10^{-3}\,\text{Nm}$ Power $= 2.89\times10^{-3}\,\text{N m}\times 200\text{s}^{-1} = 0.58\text{W}$	4

Q5.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is D **314**	A, B and C all contain numerical errors	**1**

Q6.

Question Number	Acceptable Answer	Additional Guidance	Mark
*	(see below)	(see below)	**6**

Acceptable Answer:

This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully sustained reasoning.

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

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

Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points
6	4
5–4	3
3–2	2
1	1
0	0

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

Indicative content:

IC1 The rider experiences a resultant force acting towards the centre (of the circular path)

IC2 This (resultant) force is constant, as the rider has a constant (angular) velocity
Or the weight W is constant

IC3 At the bottom of the circle P and W act in opposite directions, so P must be greater than W

IC4 At the top of the circle P and W act in the same direction, and so P must be less (than at the bottom of the circle)

IC5 P is the weight the rider appears to have

IC6 The rider would feel heavier at the bottom of the circle
Or the rider would feel lighter at the top of the circle

Additional Guidance:

Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning

IC points	IC mark	Max linkage mark	Max final mark
6	4	2	6
5	3	2	5
4	3	1	4
3	2	1	3
2	2	0	2
1	1	0	1
0	0	0	0

Accept "the rider experiences a centripetal force"

Q7.

Question Number	Acceptable answers	Additional guidance	Mark
	Use of $F = mv^2 / r$ with $F = Gm_1 m_2 / r^2$ **(1)** Use of $v = 2\pi r / T$ **(1)** $T = 6.64 \times 10^8$ s (= 21 years) **(1)** **Or** Use of $F = m\omega^2 r$ with $F = Gm_1 m_2 / r^2$ Use of $\omega = 2\pi / T$ $T = 6.64 \times 10^8$ s (= 21 years)	<u>Example of calculation</u> $F = Gm_1 m_2 / r^2 = m_2 v^2 / r = (2\pi r)^2 m_2 / rT^2$ $T^2 = 4\pi^2 r^3 / G m_1$ $= 4\pi^2 \times (1.9 \times 10^{14}\ \text{m})^3 / (6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2} \times 9.2 \times 10^{36}\ \text{kg})$ $T = 6.64 \times 10^8$ s (= 21 years)	**3**

Q8.

Question Number	Acceptable Answer		Additional Guidance	Mark
	MAX 4			
	• The riders are most at risk of falling out of their seats when they are at the top of the circular path.	(1)		
	• But, as long as the contact/reaction force from the seat (*P*) is always greater than zero the riders will not fall out of their seats.	(1)		
	• The faster the ride rotates the larger the value of the contact/reaction force from the seat (*P*) needed to maintain the rider in a circular path	(1)		
	• So there is a minimum speed for the ride (when it is in vertical mode) **Or** the safety harness will be needed if the ride slows down or stops	(1)		4
	• It is the need for centripetal not centrifugal force that "keeps the riders in their seats"	(1)	Accept "there is no centrifugal force"	

Q9.

Question mark	Acceptable Answers		Additional Guidance	Mark
(i)	• Correct conversion to angle in radians	(1)	<u>Example of calculation</u> $\omega = 50 \times 2\pi / 60$ s $= 5.24$ rads^{-1}	2
	• $\omega = 5.2$ (rads^{-1})	(1)		
(ii)	• Reference to $F = mr\omega^2$	(1)		2
	• appreciation that r is large **Or** (the equipment) has a **high** (linear) velocity	(1)	Alt: mass (of equipment) could be large	
(iii)	• use of $r\omega^2$	(1)	Show that value gives 22.5*g* Allow reverse argument starting with 25*g* to ω=5.28 rads^{-1}	2
	• $a = 25g$ **and** appropriate comment	(1)	<u>Example of calculation</u> $a = 8.8$ (m) x 5.24^2 (rads^{-1})^2 $a = 238$ (ms^{-2}) ÷9.81 (ms^{-2}) $= 24.6 \times g$	

Q10.

Question Number	Acceptable Answer		Additional Guidance	Mark
	An explanation that makes reference to the following points:			
	• The centripetal force is provided by friction	(1)		
	• There is a max (frictional) force **Or** (frictional) force is the same when coin starts to slide	(1)	For MP3 accept ω^2 for ω	3
	• $F = m\omega^2 r$ so as r increased ω decreased	(1)		

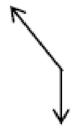
Q11.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• top of bridge identified as point at which car has greatest chance of losing contact. (1) • at the point which car loses contact with bridge push from bridge onto car becomes zero (1) **Or** resultant force on car = weight of car • Newton's 2nd law applied with $a = \frac{v^2}{r}$ (1) • v_{max} = 9.9 m s^{-1} (1) • 25 mph = 11.3 m s^{-1}, so speed limit is not suitable (1)	<u>Example of calculation:</u> $mg = \frac{mv^2}{r}$ $v = \sqrt{rg} = \sqrt{10\,\text{m} \times 9.8\,\text{m}\,\text{s}^{-2}} = 9.9\,\text{m}\,\text{s}^{-1}$ 25 mph = $\left(\frac{25}{10}\right) \times 0.45\,\text{m}\,\text{s}^{-1} = 11.25\,\text{m}\,\text{s}^{-1}$	**(5)**

Q12.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• use of $F = Gm_1m_2/r^2$ and use of $F = mr\omega^2$ **Or** use of $F = Gm_1m_2/r^2$ and use of $F = mv^2/r$ • use of $T = 2\pi/\omega$ **Or** use of $T = 2\pi r/v$ • T = 12 hours **Or** F = 120 N by gravitational approach and centripetal force approach **Or** $\omega = 1.45 \times 10^{-4}$ radians s^{-1} by gravitational approach and circular motion approach **Or** height of orbit = 7700 km • Comparative statement consistent with their value(s)	(1) (1) (1) (1)	MP3 and 4 - for force and angular velocity, both approaches required <u>Example of calculation</u> $T^2 = 4\pi^2 r^3 / G m_1$ $T^2 = 4\pi^2 \times (2\,430\,000 \text{ m} + 7\,690\,000 \text{ m})^3 / 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 3.30 \times 10^{23} \text{ kg}$ T = 43115 s = 11.98 hours	4
(ii)	**Max 2** • Allows satellite to get (much) closer to surface • So more detailed photographs/scans possible **OR** • Allows satellite to spend time further from the surface • So prevents exposure to prolonged heat from planet damaging probe **OR** • Satellite varies distance from surface • So it can take wide-angle and close-up pictures of the planet	 (1) (1) (1) (1) (1) (1)	For each, the second marking point is dependent on the first. Award second marking point for other sensible advantages	2

Q13.

Question Number	Acceptable answers	Additional guidance	Mark
	B The two forces acting on the mass are its weight (vertically down) and a tension in the thread.		1
	A assumes there is a centripetal force only C assumes there is an additional centripetal force D assumes the additional centripetal force acts away from the centre of the circle		

Q14.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $F = \frac{mv^2}{r}$ (1) • States that $F = mg$ only as reaction force is zero (1)	Example of derivation: $mg = \frac{mv^2}{r}$ $v = \sqrt{gr}$	(2)

Q15.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• The ions experience a force perpendicular to their velocity (and the magnetic field) (1) • The (resultant) force on the ions causes an acceleration at right angles to their velocity **Or** There is a magnetic force acting towards the centre of the path (1)	For velocity accept direction of motion or direction of travel	2

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	• Use of $r = \frac{mv}{BQ}$ (1) • $r = 0.23$ m (1)	Example of calculation: $r = \frac{mv}{BQ}$ $= \frac{(34.97 \times 1.66 \times 10^{-27})\,\text{kg} \times 2.2 \times 10^5\,\text{m s}^{-1}}{0.35\,\text{T} \times 1.6 \times 10^{-19}\,\text{C}} = 0.228\,\text{m}$	2

Question Number	Acceptable Answer	Additional Guidance	Mark
1 (iii)	• path drawn with less curvature (less overall deflection) (1)	MP1 awarded for path in the magnetic field	1

Question Number	Acceptable Answer	Additional Guidance	Mark
2 (iii)	• ions are more massive (1) • ions have the same charge so the radius of the path would be greater (1)		2

Q16.

Question Number	Acceptable answers	Additional guidance	Mark
	• A (resultant) force F is required to maintain circular motion (1) • This force is friction (between car/slider and track) (1) • As v increased F required increased until it exceeds friction and car slides off track (1)	alt: A (resultant) force acts to the centre of the circle.	3

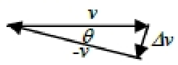
Q17.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• To reduce the effect of random errors (1)		1
(ii)	• Use of data to calculate mean value (1) • Use of half range **Or** Use of greatest deviation from mean (1) • % uncertainty in range 5 % to 6% consistent with student's working (1 or 2 SF) (1)	Example of calculation: $\omega_{av}=\frac{(0.112+0.116+0.118+0.123+0.125)}{5}$ $= 0.119 \text{ rad s}^{-1}$ Half range value $= \frac{0.125 \text{ mm} - 0.112 \text{ mm}}{2} = 0.0065$ $\therefore$ % uncertainty$= \frac{0.0065 \text{ mm}}{0.119 \text{ mm}} \times 100\ \% = 5.5\ \%$ Use of greatest deviation from mean gives 5.9 %	3
(iii)	• % uncertainty in ω is doubled (1) • Add % uncertainty in r (1) • % uncertainty = 11 % to 13% consistent with student's working (2 or 3 SF)(ecf from (b)(ii)) (1)	Don't penalise sf in both (ii) **and** (iii) Example of calculation: % uncertainty = 5% + 5% + 1% = 11%	3

Q18.

Question Number	Acceptable answers		Additional guidance	Mark
	• Measures angle at 52° +/- 2 °	(1)	Accept angle calculate from measured dimensions and trigonometry.	5
	• Uses $F = ma$ horizontally	(1)	<u>Example of calculation</u> $T\sin\theta = \frac{mv^2}{r}$	
	• Resolves forces vertically	(1)	$T\cos\theta = mg$	
	• Uses $a = v^2 / r$ **Or** $a = r\omega^2$	(1)	$\tan\theta = \frac{v^2}{rg}$	
	• Calculates the 51° and reaches a consistent conclusion	(1)	$\tan\theta = (3.8)^2 \text{ (m s}^{-1})^2 / 1.2 \text{ m} \times 9.81 \text{ m s}^{-2}$ $\theta = 50.8°$	

Q19.

Question mark	Acceptable Answers		Additional Guidance	Mark
	• vector velocities at two positions as part of a triangle and third side identified as Δv	(1)	<u>Example of diagram</u> 	
	• Acceleration $a = \Delta v/t$ (i)	(1)	Ignore arrow directions	
	• Use of trigonometry: $\Delta v/v \approx \sin\theta \approx \theta$ for small angles (ii)	(1)	Combine (i) and (ii) $a = v\theta / t$	
	• Use of $v = r\theta/t$ (iii)	(1)	Substitute for θ using (iii) a =	
	• Combine i, ii, iii to final equation	(1)	$\frac{v}{t} \times \frac{vt}{r}$ then "t"s cancel	5
	OR			
	• Diagram shows components of v with angle turned through	(1)	Allow other fully correct methods	
	• Acceleration $= 2v\sin\theta / t$	(1)		
	• Use of trigonometry: $\Delta v/v \approx \sin\theta \approx \theta$ for small angles	(1)		
	• $t = r2\theta / v$ and 2s cancel	(1)		
	• Simplify to final equation	(1)		