Name: ____

Topic 6: Further Mechanics Part 2

Date:

Time:

Total marks available:

Total marks achieved: ______

Questions

Q1.

(a) State what is meant by the de Broglie wavelength.

(2)

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(b) An electron is accelerated from rest, in a vacuum, through a potential difference of 500 V.

(i) Show that the final momentum of the electron is about 1×10^{-23} N s.

(3)

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(ii) Calculate the de Broglie wavelength for this electron.

(2)

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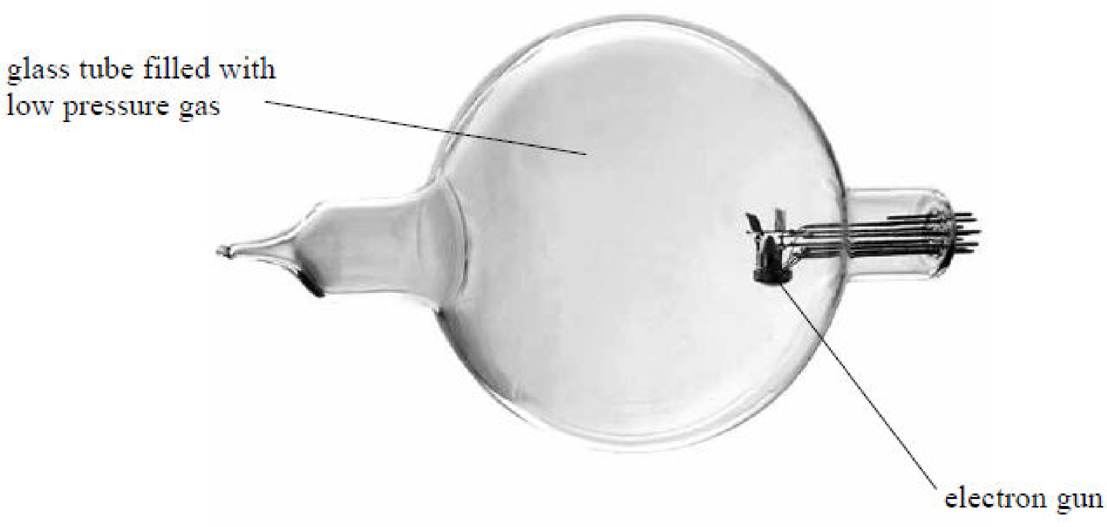
de Broglie wavelength = ...

(Total for question = 7 marks)

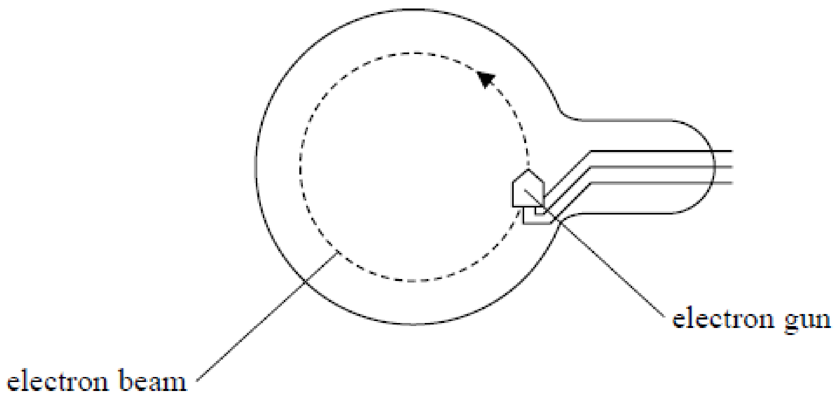
Q2.

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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(Total for question = 3 marks)

Q3.

Select the row of the table which correctly identifies the quantities conserved in an inelastic collision.

	Momentum	Kinetic energy	Total energy
☐ **A**	conserved	conserved	conserved
☐ **B**	conserved	not conserved	conserved
☐ **C**	conserved	not conserved	not conserved
☐ **D**	not conserved	not conserved	not conserved

(Total for question = 1 mark)

Q4.

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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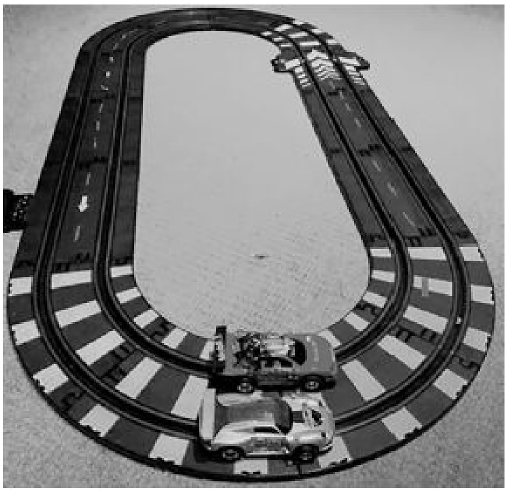
(Total for question = 6 marks)

Q5.

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)

Q6.

A footballer kicks a football from the penalty spot. A graph of force on the ball against time is drawn.

The area under the force-time graph represents

☒ **A** acceleration

☒ **B** change in kinetic energy

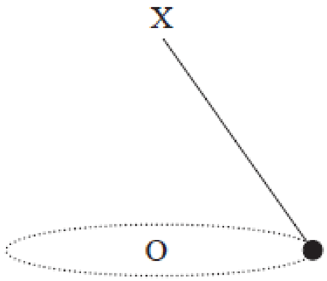
☒ **C** change in momentum

☒ **D** displacement

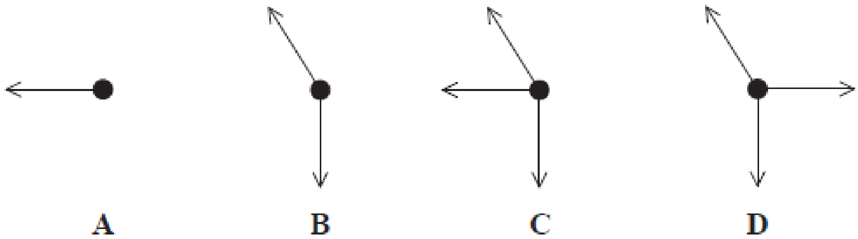
(Total for question = 1 mark)

Q7.

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)

Q8.

A 'Gauss gun' can be made from five ball bearings of equal mass and two magnets, as shown.

Pairs of ball bearings are placed to the right of two strong magnets. A single ball bearing is released from the left, as shown. The ball bearing is attracted to, and collides with, the first magnet. This and all subsequent collisions can be assumed to be elastic.

Explain what happens to make the last ball bearing on the right subsequently move off with a large velocity.

(3)

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(Total for question = 3 marks)

Q9.

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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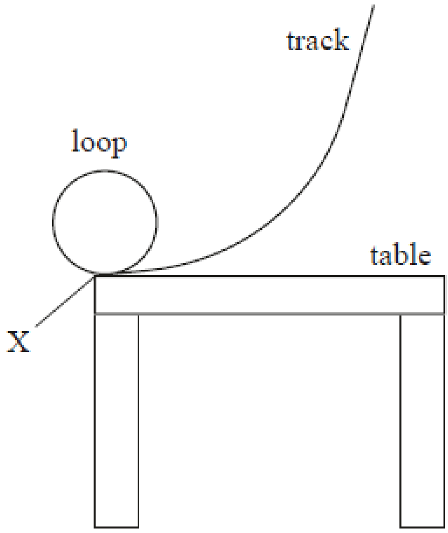
(Total for question = 9 marks)

Q10.

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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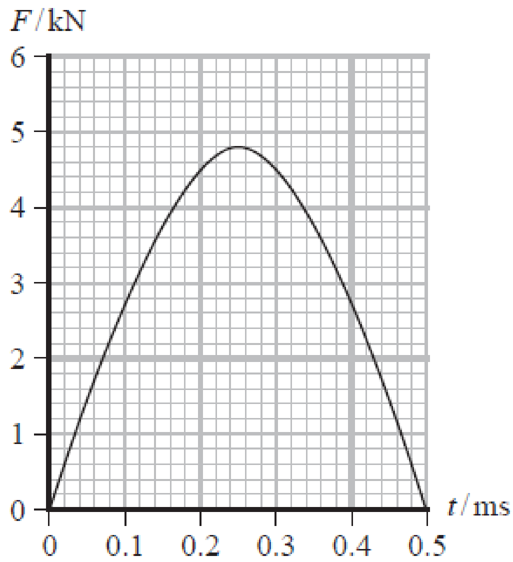
(Total for question = 2 marks)

Q11.

In the game of golf a stationary ball is hit by a club. One of the aims of the game is to land the ball on a patch of ground called the green.

The graph shows how the force F exerted by the club on the ball varies with time t as the ball is hit.



State why the area under the graph represents impulse.

(1)

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....

(Total for question = 1 mark)

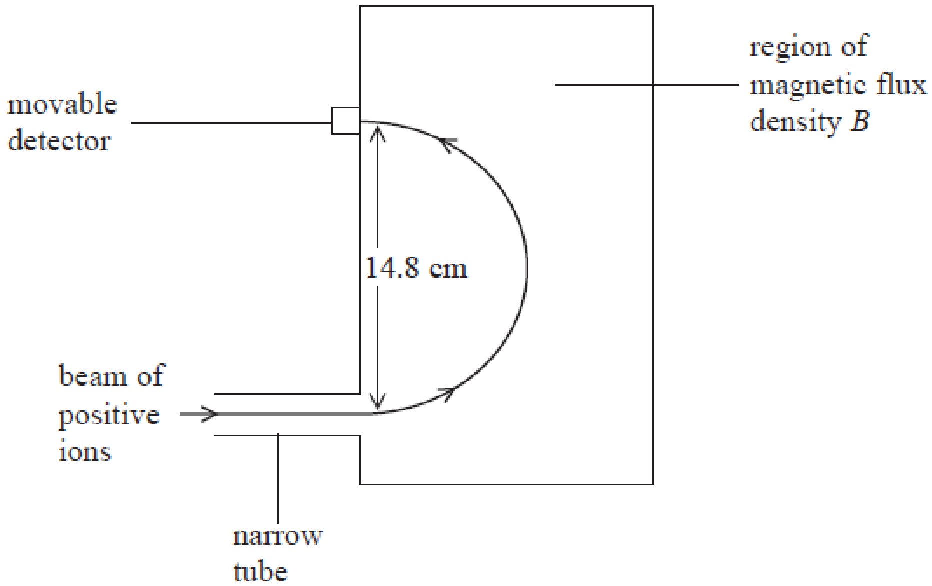
Q12. Select the row in the table that correctly identifies what happens in an inelastic collision.

		Momentum	Kinetic energy	Total energy
☒	**A**	conserved	conserved	conserved
☒	**B**	not conserved	conserved	conserved
☒	**C**	conserved	not conserved	conserved
☒	**D**	conserved	not conserved	not conserved

(Total for Question = 1 mark)

Q13.

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.

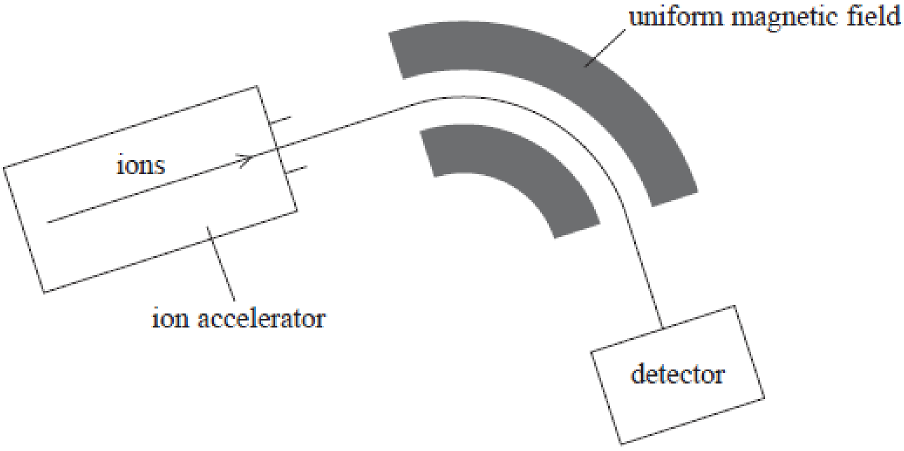
(1)

(Total for question = 6 marks)

Q14.

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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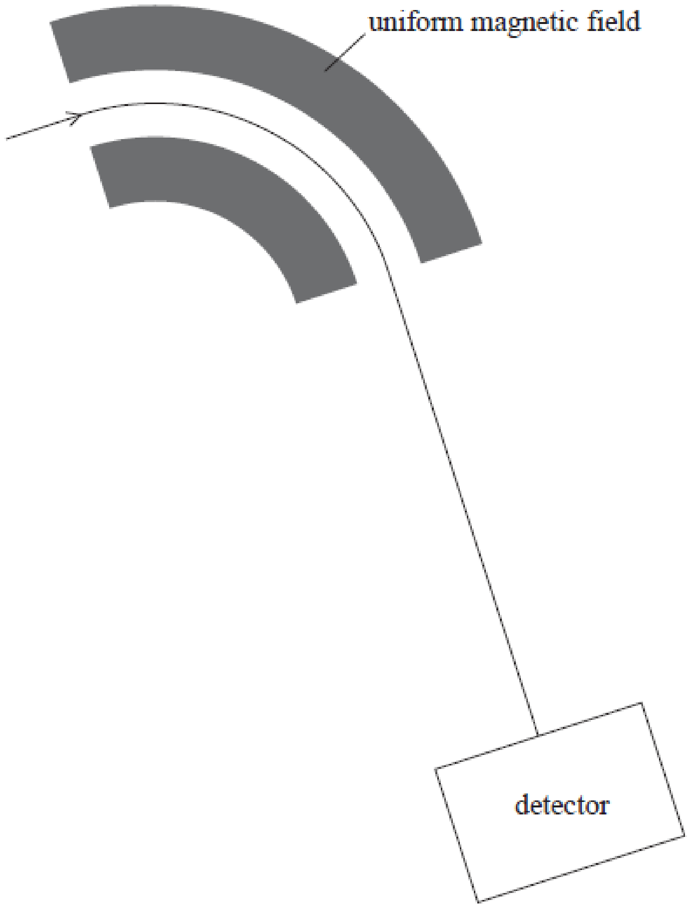
Radius = ...

(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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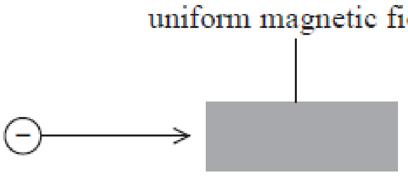
(Total for question = 7 marks)

Q15.

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.

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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....

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(Total for question = 4 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)

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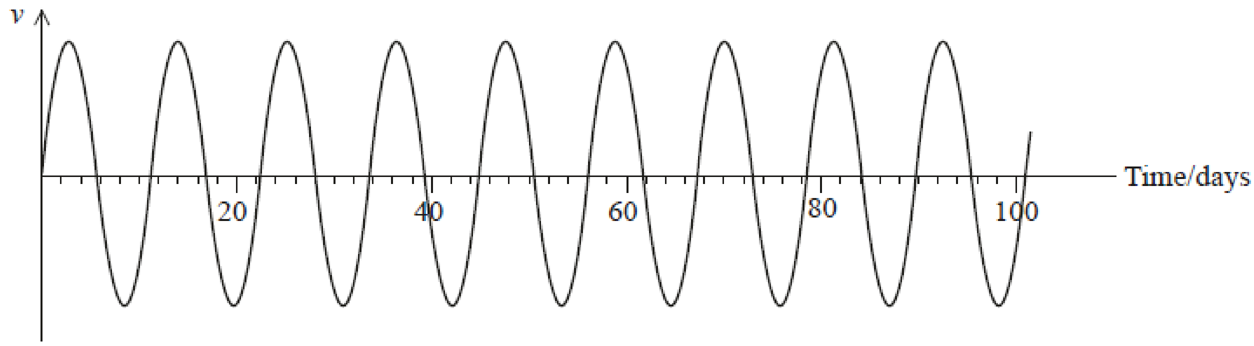
(Total for question = 3 marks)

Q17.

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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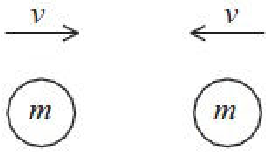
Distance = ...

(Total for question = 6 marks)

Q18.

Two identical spheres of mass *m* are both travelling with a speed *v* towards each other.



The spheres collide head-on.

Which of the following statements **must** be true after the collision?

☒ **A** total momentum = 2*mv*

☒ **B** total momentum = 0

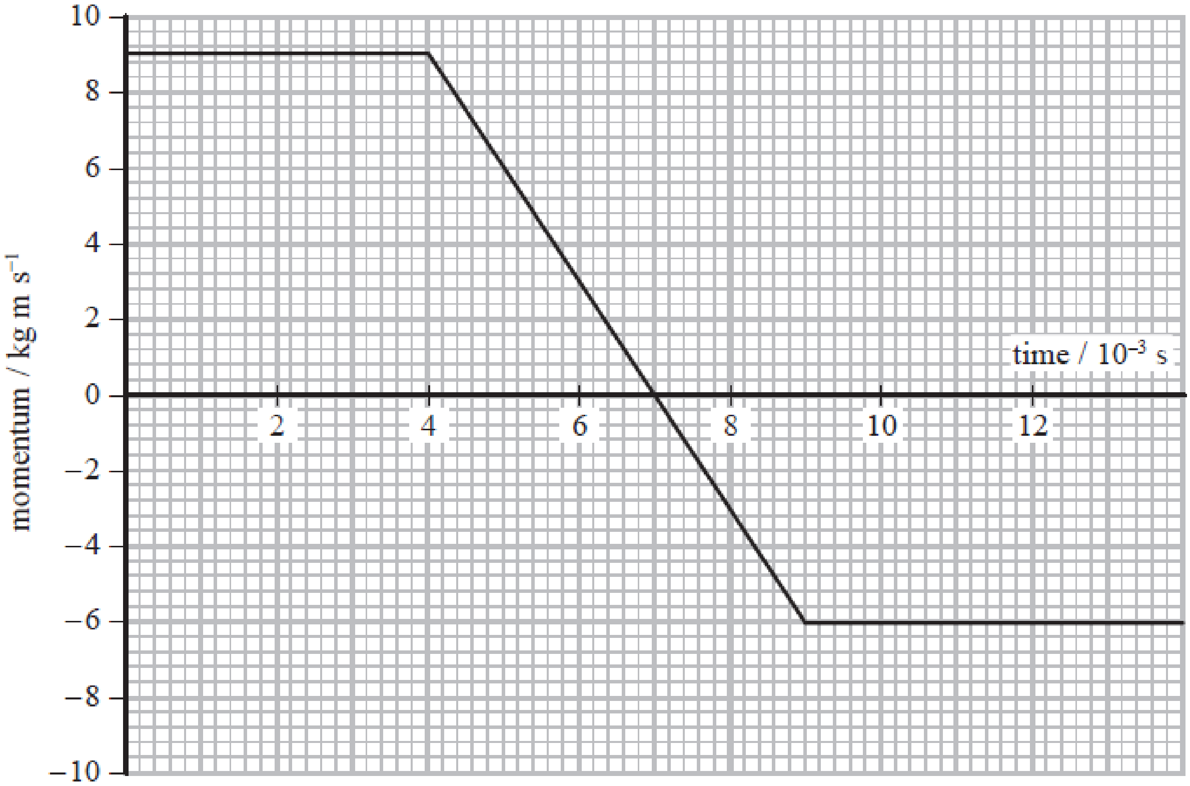
☒ **C** total kinetic energy = mv^2

☒ **D** total kinetic energy = 0

(Total for question = 1 mark)

Q19.

A football is kicked horizontally to hit a wall. Its momentum just before it hits the wall is 9.0 kg m s^{-1}.
It rebounds horizontally from the wall with a momentum of −6.0 kg m s^{-1}. The graph shows how the momentum of the football varies during the impact with the wall.



The force exerted by the wall on the football is

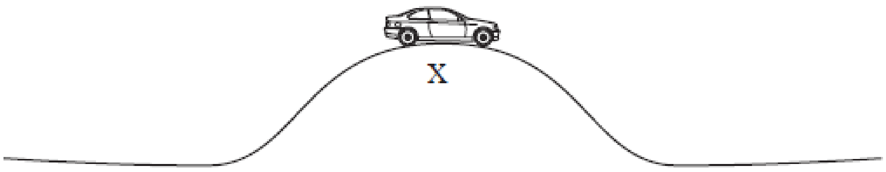
- **A** 3.0 N
- **B** 15 N
- **C** 600 N
- **D** 3000 N

(Total for question = 1 mark)

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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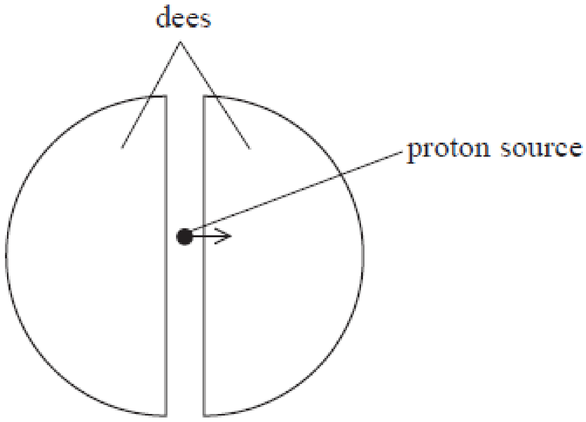
(Total for question = 3 marks)

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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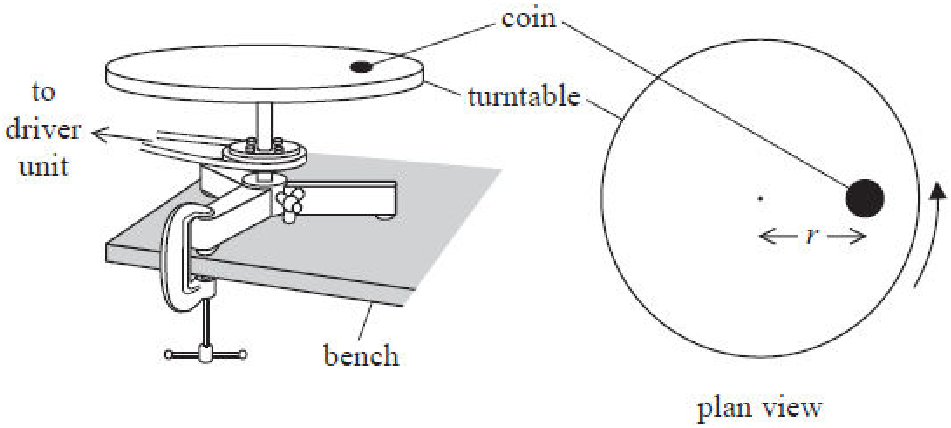
f = ...

Q23.

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)

Q24.

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)

Q25.

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)

Q26.

The discovery of the Higgs particle was an important contribution to our understanding of particle physics.

(a) Describe the standard model for subatomic particles. You should identify the fundamental particles and the composition of the particles we can observe.

(5)

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(b) The mass of the Higgs particle is 2.2×10^{-25} kg.

Calculate this mass in GeV/c^2.

(3)

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Mass = ... GeV/c^2

(c) The Higgs particle was discovered using the Large Hadron Collider (LHC) in 2012. Two beams of very high energy protons, moving in opposite directions, were made to collide.

(i) Explain the need for such high energy collisions.

(3)

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(ii) The beams of protons are contained within a ring of superconducting magnets.

Calculate the momentum of a proton in a beam.

(3)

magnetic field strength = 8.3 T
circumference of the ring = 27 km

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....

Momentum = ...

(iii) State the total momentum of the products of the collision between the two beams of protons.

(1)

Total momentum = ...

(d) A student used the equation $E_k = \frac{p^2}{2m}$ to predict the energy of a proton in the beam, using the momentum calculated in (c)(ii), but found the energy was far higher than 7 TeV.

Explain why.

(2)

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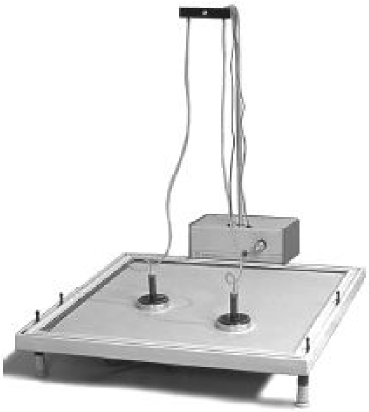
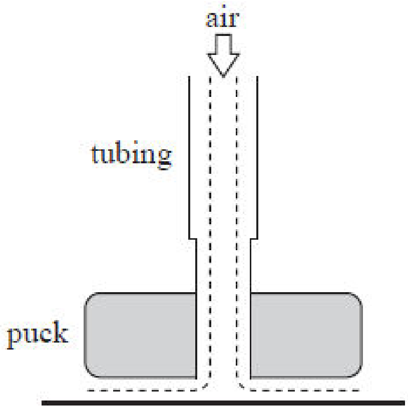
(Total for question = 17 marks)

Q27.

A teacher is demonstrating the principle of conservation of momentum using a flat glass surface and air pucks. Lightweight tubing supplies compressed air to the pucks which is forced out from the bottom of the pucks. This means that the pucks move with very little friction across the glass surface.





(a) Explain, using ideas about molecular movement, how the puck is able to hover a small distance above the glass surface.

(4)

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*(b) Applying Newton's 2nd and 3rd laws of motion to the collision between two pucks leads to the conclusion that momentum is conserved.

Justify this statement.

(6)

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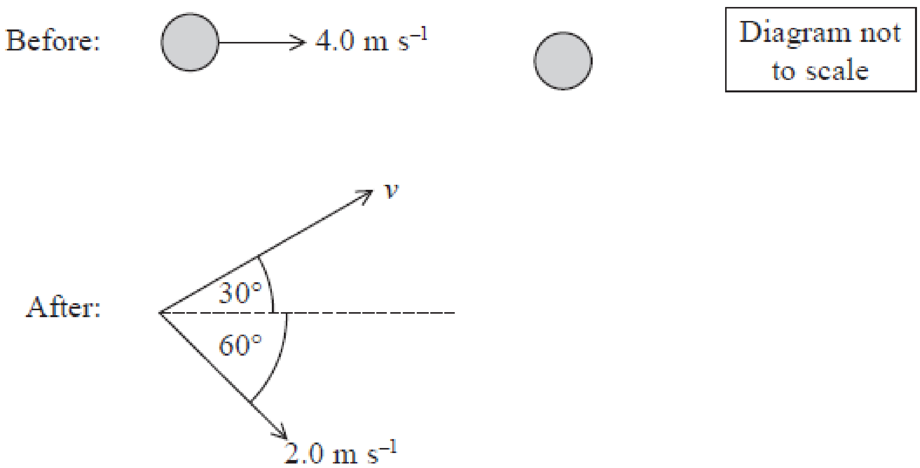
(c) The teacher uses two identical pucks to investigate collisions. In one collision, one puck moves with a velocity of 4.0 m s^{-1} and collides with a second puck that is stationary.
After the collision, the first puck has a velocity *v* at an angle of 30° to its original direction, and the second puck moves off with a velocity of 2.0 m s^{-1} at an angle of 60° to the original direction.



(i) Show that the magnitude of the velocity *v* of the first puck after the collision is about 3.5 m s^{-1}.

(3)

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(ii) Use the data to determine if the collision is elastic or inelastic.

(3)

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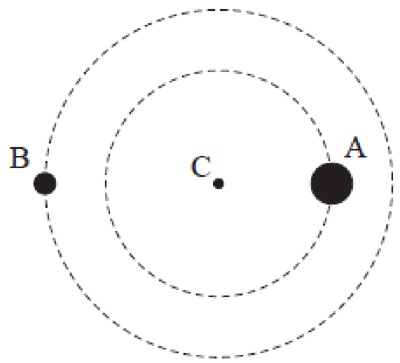
(Total for question = 16 marks)

Q28.

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)

Q29.

Astronauts on the 1971 Apollo 14 mission to the Moon brought back many rock samples. It is now believed that one of these contains a piece of rock that originated on Earth about 4 billion years (4×10^9 years) ago.

The piece of rock is believed to have been launched into space when an asteroid struck the Earth.

Four billion years ago, the Moon had a different orbital period, because it was closer to the Earth than it is today.

Calculate the period of the Moon's orbit four billion years ago, when the radius of its orbit was 1.34×10^8 m.

mass of Earth = 5.97×10^{24} kg

(3)

....

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Period = ...

(Total for question = 3 marks)

Q30.

Which of the following is a possible unit for rate of change of momentum?

☐ **A** kg m s^{-1}

☐ **B** kg m s^{-2}

☐ **C** N s

☐ **D** N s^{-1}

(Total for question = 1 mark)

Mark Scheme

Q1.

Question Number	Answer		Mark
(a)	The wavelength (associated) with a particle/electron with a given momentum **Or** $\lambda = h/p$ all terms defined	(1) (1) (1) (1)	**2**
(b)(i)	Use of $E_k = eV$ Use of $E_k = p^2/2m$ **Or** use of $E_k = mv^2/2$ **and** $p = mv$ Momentum = 1.21×10^{-23} kg m s^{-1} <u>Example of calculation</u> $E_k = 1.6 \times 10^{-19}$ C× 500 V $p^2 = 2\,m\,E_k = 2 \times 9.11 \times 10^{-31}$ kg × ($1.6 \times 10^{-19} \times 500$) J $p = 1.21 \times 10^{-23}$ kg m s^{-1}	(1) (1) (1)	**3**
(b)(ii)	Use of $\lambda = h/p$ $\lambda = 5.49 \times 10^{-11}$ m (ecf value of p from (i)) (show that value gives 6.63×10^{-11} m) <u>Example of calculation</u> $p = 6.63 \times 10^{-34}$ J s / 1.21×10^{-23} kg m s^{-1} $\lambda = 5.49 \times 10^{-11}$ m	(1) (1)	**2**
	Total for question		7

Q2.

Question number	Acceptable answers	Additional guidance	Mark
	An explanation that makes reference to: • The magnetic force on the electrons acts at right angles to the plane containing *B* and *v* **(1)** • Hence the force is always towards the centre of the circle **(1)** So providing a centripetal force on the electron or a centripetal acceleration that maintains circular motion **(1)**		**3**

Q3.

Question Number	Answer	Mark
	B	1

Q4.

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

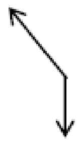
Q5.

Question Number	Acceptable answers		Additional guidance	Mark
i	• use of $s = \frac{(u+v)}{2} \times t$ • $v = 3.1$ (m s^{-1})	(1) (1)	Example of calculation: 1.1 m $= \frac{(0+v)}{2} \times 0.77$ s $v = 3.1$ m s^{-1}	2
ii	• use of $F = mv^2/r$ • $F = 11$ N (allow ecf from (i))	(1) (1)	Example of calculation: $F = \frac{0.050 \text{ kg} \times 3.1^2 (\text{m s}^{-1})^2}{0.042 \text{ m}}$ $F = 11.4$ N "show that value" gives $F = 10.7$ N	2

Q6.

Question Number	Answer	Mark
	C	1

Q7.

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		

Q8.

Question Marks	Acceptable Answers	Additional guidance	Mark
	• Magnet accelerates ball Or magnet increases ball's KE (1) • Momentum is conserved in the collision(s) (1) • (Since collisions are elastic) KE conserved so third ball moves off with the same velocity/KE as incoming ball hit magnet with (1)	Marks can be gained by discussing either set of balls	3

Q9.

Question Number	Answer	Mark
(a)(i)	See $F = GMm/r^2$ (1) Equated to mg to give required expression **Or** use of g = F/m (1)	**2**
(a)(ii)	Use of $g = \omega^2 r$ OR $g = v^2/r$ (1) Use of $\omega = 2\pi/T$ OR $v = 2\pi r/T$ (1) Correct algebra leading to expression given (1) <u>Example of calculation:</u> $\omega^2 r = \frac{GM}{r^2}$ $\left(\frac{2\pi}{T}\right)^2 = \frac{GM}{r^3}$ $r^3 = \frac{GMT^2}{4\pi^2}$	**3**
(a)(iii)	See T = 24 hours (1) T converted into s (1) $r = 4.2 \times 10^7$ m (1) <u>Example of calculation:</u> $T = 24 \times 60 \times 60$ s $= 86\,400$ s $r^3 = \frac{GMT^2}{4\pi^2} = \frac{6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2} \times 6.0 \times 10^{24}\ \text{kg} \times (86400\ \text{s})^2}{4\pi^2} = 7.57 \times 10^{22}\ \text{m}^3$ $r = \sqrt[3]{7.57 \times 10^{22}\ \text{m}^3} = 4.23 \times 10^7$ m	**3**
(b)	The satellite must rotate with the Earth **Or** the satellite must be in a geosynchronous orbit **Or** any non-equatorial orbit would cause the satellite to move N-S	**1**
	Total for question	**9**

Q10.

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

Q11.

Question Number	Acceptable answers	Additional guidance	Mark
	• Impulse is the product Ft which is area under this graph **(1)**		**1**

Q12.

Question Number	Answer	Mark
	C	**1**

Q13.

Question Number	Answer		Mark
(a)	Only (moving) charged particles are deflected by a magnetic field **Or** Only charged particles can be accelerated to produce a beam	(1) (1)	1
(b)	Into the page	(1)	1
(c)	Use of $F = mv^2/r$ **Or** use of $r = p/BQ$ Use of $F = Bqv$ **Or** use of $p = mv$ $m = 6.64 \times 10^{-26}$ kg Example of calculation $mv^2/r = Bqv$ $m = Bqr/v = (0.673\ \text{T} \times 1.6 \times 10^{-19}\ \text{C} \times 7.40 \times 10^{-2}\ \text{m}) / 1.20 \times 10^5\ \text{m s}^{-1}$ $m = 6.64 \times 10^{-26}$ kg	(1) (1) (1)	3
(d)	Semicircle drawn starting from same initial point and a smaller radius	(1)	1
	Total for question		**6**

Q14.

Question Number	Acceptable Answer		Additional Guidance	Mark
(i)	• The ions experience a force perpendicular to their velocity (and the magnetic field) • 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) (1)	For velocity accept direction of motion or direction of travel	2

Question Number	Acceptable Answer		Additional Guidance	Mark
(ii)	• Use of $r = \frac{mv}{BQ}$ • $r = 0.23$ m	(1) (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
(iii) 1	• 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
(iii) 2	• ions are more massive • ions have the same charge so the radius of the path would be greater	(1) (1)		2

Q15.

Question Number	Acceptable Answer		Additional Guidance	Mark
(i)	• (Perpendicularly) out of the page • The force is perpendicular to the magnetic field and the direction of (conventional) current **Or** an application of Fleming's Left-Hand Rule	(1) (1)	Accept movement of electrons for current	2
(ii)	An explanation that makes reference to the following points: • There would be a force (of constant magnitude) on the electron perpendicular to its direction of motion • Causing an acceleration towards the centre of a circle	(1) (1)	Accept reference to centripetal force for MP1	2

Q16.

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

Q17.

Question Number	Acceptable answers		Additional guidance	Mark
i	• Use of $\omega = 2\pi/T$ • For at least 2 full cycles • $\omega = 6.5 \times 10^{-6}$ (radian s^{-1})	(1) (1) (1)	For MP3, accept correctly rounded answers in range 6.5×10^{-6} radian s^{-1} to 6.6×10^{-6} radian s^{-1} Example of calculation $\omega = 5 \times 2\pi / (56 \times 24 \times 60 \times 60)$ s $= 6.49 \times 10^{-6}$ radian s^{-1}	3
ii	• Equates $F = Gm_1m_2/r^2$ and $F = m\omega^2r$ **Or** $F = Gm_1m_2/r^2$ and $F = mv^2/r$ with $v = 2\pi r/T$ • Correct rearrangement and substitution (e.g. in $r^3 = Gm_1/\omega^2$) • $r = 7.2 \times 10^9$ m (ecf from (b)(i))	(1) (1) (1)	Example of calculation $r^3 = 6.67 \times 10^{-11}$ N m^2 $kg^{-2} \times 0.12 \times 1.99 \times 10^{30}$ kg / $(6.5 \times 10^{-6}$ radian $s^{-1})^2$ $r = 7.2 \times 10^9$ m ($r = 7.6 \times 10^9$ m for 'show that' value)	3

Q18.

Question Number	Answer	Mark
	B	1

Q19.

Question Number	Answer	Mark
	D	1

Q20.

Question Number	Answer		Mark
(a)(i)	$R = 9.32$ kN <u>Example of answer</u> $R = 950\text{ kg} \times 9.81\text{ m s}^{-2}$ $R = 9320$ N	(1)	1
(a)(ii)	Use of $F = mv^2/r$ $R = mg - mv^2/r$ $R = 2480$ N ecf their value of R <u>Example of calculation</u> $R = 9320\text{ N} - (950\text{ kg} \times 12.0^2\text{ m}^2\text{ s}^{-2} / 20.0\text{ m})$ $R = 2480$ N	(1) (1) (1)	3
(b)	An answer that either states implicitly or implies that 'The required centripetal force > mg and so cannot be provided'.	(1)	1
	Total for question		**5**

Q21.

Question Number	Acceptable answers		Additional guidance	Mark
	• inner lane covers a smaller distance • inner lane has a smaller radius of curvature • (maximum horizontal force is the same for both cars) therefore maximum speed is greater for the car on the outside lane (so outcome unclear)	(1) (1) (1)		3

Q22.

Question Number	Answer		Mark
(i)	Outward spiral from centre in either direction, minimum of two complete loops	(1)	1
(ii)	Direction consistent with diagram: Clockwise path, field out of page Anticlockwise path, field into page	(1)	1
(iii)	Electric field/p.d. between dees causes (resultant) force/acceleration Proton makes half a revolution in half a cycle of the a.c. **Or** facing dee (always) negative when proton reaches gap. **Or** whenever the proton gets to a gap, the p.d. has reversed k.e./speed (only)increases each time the proton crosses the gap **Or** work done by the field in the gap increases the k.e.	(1) (1) (1)	3
(iv)	$Bev=mv^2/r$ **Or** $r=p/Be$ $v=2\pi r/T$ $T=1/f$ (seeing $f=v/(2\pi r)$ scores MP2 & 3) **Or** $Bev=mr\omega^2$ $v=r\omega$ $\omega=2\pi f$ (seeing $v/r=2\pi f$ scores MP2 & 3)	(1) (1) (1) (1) (1) (1)	3
(v)	Use of $B=2\pi fm/e$ with mass of proton $f=1.8\times10^4$ Hz <u>Example of calculation</u> $f=eB/2\pi m$ $f=(1.6\times10^{-19}\text{ C}\times1.2\times10^{-3}\text{ T})/(2\pi\times1.67\times10^{-27}\text{kg})$ $f=1.8\times10^4$ Hz	(1) (1)	2

Q23.

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

Q24.

Question Number	Answer	Mark
	A	1

Q25.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• Satellite would always be above the same point on the Earth's surface (1) • So that contact/communication with the space station would be maintained at all times (1)		2

(ii)	Use of $F = \frac{GMm}{r^2}$ with $F = m\omega^2 r$ Use of $\omega = 2\pi/T$ $r = 4.23 \times 10^7$ m $h = 3.6 \times 10^7$ m **OR** Use of $F = \frac{GMm}{r^2}$ with $F = \frac{mv^2}{r}$ Use of $v = 2\pi r/T$ $r = 4.23 \times 10^7$ m $h = 3.6 \times 10^7$ m	(1) (1) (1) (1) (1) (1) (1) (1)	<u>Example of calculation:</u> $m\omega^2 r = \frac{GMm}{r^2}$ $\therefore \left(\frac{2\pi}{T}\right)^2 = \frac{GM}{r^3}$ $\therefore r = \sqrt[3]{\frac{GMT^2}{4\pi^2}}$ $r = \sqrt[3]{\frac{6.67\times10^{11}\text{N m}^2\text{ kg}^2\times6.00\times10^{24}\text{kg}\times(8.64\times10^4\text{s})^2}{4\pi^2}}$ $r = 4.23 \times 10^7$ m $h = r - R_E = 4.23 \times 10^7 - 6.4 \times 10^6$ m $= 3.59 \times 10^7$ m	4

Q26.

Question Number	Acceptable Answers		Additional guidance	Mark
a	• fundamental – quarks and leptons • Baryons made of 3 q • Mesons made of quark and antiquark • 6 quark **Or** 6 leptons • Each particle has an antiparticle	(1) (1) (1) (1) (1)	MP2 and 3 could be given for a named particle and its quark composition Can be inferred if either set named	5

Question Number	Acceptable Answers		Additional guidance	Mark
b	• Use of $\Delta E = \Delta mc^2$ • Conversion of J to eV • mass = 120 GeV/c^2	(1) (1) (1)	Example of calculation: $E = 2.2 \times 10^{-25}\text{kg} \times (3.0 \times 10^8)^2 (\text{ms}^{-1})^2$ $E = 1.98 \times 10^{-8}$ J $E = 1.98 \times 10^{-8}\text{ J} \div 1.6 \times 10^{-19}\text{ JeV}^{-1}$ $E = 124 \times 10^9$ eV	3

Question Number	Acceptable Answers	Additional guidance	Mark
c(i)	• Energy (of protons) converted to mass (of Higgs) **Or** Energy is required to overcome electrostatic repulsion between protons (1) • Reference to $E = mc^2$ (can be written in any form) (1) • Because c^2 is very large (E must be large) **Or** Higgs particle is massive so needs a lot of energy to create it (1)	Alternative based on numerical values: Observation that Higgs mass is 120 GeV/c^2 This requires an energy of at least 120 GeV Each beam of protons would need an energy of at least 60 GeV	3
c(ii)	• Use of circumference = $2\pi r$ (1) • Use of $p = Bqr$ (1) • $p = 5.7 \times 10^{-15}$ Ns (1)	Example of calculation: $r = 27000 \div 2\pi$ $r = 4300$ m $p = 8.3\text{T} \times 1.6 \times 10^{-19}\text{C} \times 4300\text{m}$ $p = 5.7 \times 10^{-15}\text{Ns}$	3
ciii	0 (1)	zero	1

Question Number	Acceptable Answers	Additional guidance	Mark
d	• High speeds **Or** relativistic (1) • Mass (of proton) increases (1) • **Or** this equation is only valid at non-relativistic speeds	Alt: speeds close to speed of light	2

Q27.

Question Number	Acceptable Answer		Additional Guidance	Mark
(a)	An explanation that makes reference to the following: • air molecules make collisions with the puck and transfer momentum to the puck • according to Newton's 2nd law the change of momentum creates a force on the puck • the rate of change of momentum by air molecules colliding with bottom of puck is greater than that due to the collisions on the top of the puck • the net (upward) force balances the weight of the puck <u>OR</u> the greater air pressure below the puck allows the puck to be supported.	 (1) (1) (1) (1)		**(4)**

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

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

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

<table><tr><td>Number of indicative marking points seen in answer</td><td>Number of marks awarded for indicative marking points</td></tr><tr><td>6</td><td>4</td></tr></table></td><td>Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).</td><td></td></tr>
</table>

5 - 4	3
3 - 2	2
1	1
0	0

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

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

Indicative content:

- applying Newton's 3rd law one puck (A) exerts a force on the other puck (B) and vice versa (1)
- forces equal in magnitude and opposite and direction (1)
- forces act for same time (1)
- $F\Delta t_A$ = - $F\Delta t_B$ (1)
- applying Newton's 2nd law $F\Delta t = \Delta p$ since F is a resultant force on each puck (1)
- total change in momentum = zero, so momentum is conserved <u>OR</u> Δp for one puck = $-\Delta p$ for the other puck, so momentum is conserved (1)

(6)

Question Number	Acceptable Answer	Additional Guidance	Mark
(c)(i)	• resolve velocities to find forward/sideways component (1) • apply principle of conservation of momentum (1) • v = 3.46 m s^{-1} (1)	Example of calculation: Forwards velocity components: $v\cos30° = 0.866\,v$; $2\cos60° = 1\,\mathrm{m\,s^{-1}}$ $4m = m \times 0.866v + m \times 1$ $\therefore v = \frac{(4-1)\mathrm{m\,s^{-1}}}{0.866} = 3.46\,\mathrm{m\,s^{-1}}$	(3)
(c)(ii)	• use $KE = \frac{1}{2}mv^2$ (1) • show that final KE is equal to initial KE (1) • elastic collisions conserve KE, so collision is elastic (1)	Example of calculation: $KE_i = \frac{1}{2}m \times 4^2 = 8m$ $KE_f = \frac{1}{2}m \times 3.46^2 + \frac{1}{2}m \times 2^2$ $= 6m + 2m = 8m$	(3)

Q28.

Question Number	Acceptable answers	Additional guidance	Mark
(a)	• use of $F = Gm_1m_2/r^2$ (1) • force = 6.5×10^{31} N (1)	Example of calculation $F = 6.67 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}} \times 29 \times 1.99 \times 10^{30}\,\mathrm{kg} \times 36 \times 1.99 \times 10^{30}\,\mathrm{kg} / (6.5 \times 10^{10}\,\mathrm{m})^2$ force = 6.5×10^{31} N	2

Question Number	Acceptable answers	Additional guidance	Mark
(b)	**Either** • use of $F = mv^2/r$ ecf from (a) (1) • use of $v = 2\pi r/T$ (1) • $T = 1.1 \times 10^6$ s (1) **Or** • use of $F = m\omega^2 r$ ecf from (a) (1) • use of $\omega = 2\pi/T$ (1) • $T = 1.1 \times 10^6$ s (1)	Example of calculation $F = mv^2/r = m(2\pi r/T)^2/r$ $T^2 = 4\pi^2 mr/F$ $= 4\pi^2 \times 29 \times 1.99 \times 10^{30}\,\mathrm{kg} \times 3.6 \times 10^{10}\,\mathrm{m} / 6.5 \times 10^{31}\,\mathrm{N}$ $= 1.21 \times 10^{12}\,\mathrm{s^2}$ $T = 1.12 \times 10^6$ s = 18700 min = 312 hours = 13 days	3

Q29.

Question Number	Acceptable answers		Additional guidance	Mark
	• Use of $F = Gm_1m_2/r^2$ and $F = mv^2/r$	(1)	'Use of' can be with any mass m for the orbiting body, or by algebraic combination with no m	
	• Use of $v = 2\pi r/T$	(1)	Example of calculation	
	• T = 488 000 s = 5.7 days	(1)	$F = GMm/r^2 = mv^2/r$	
			$GM/r^2 = v^2/r$	
	OR		$v = 2\pi r/T$	
	• Use of $F = Gm_1m_2/r^2$ and $F = m\omega^2r$		$T^2 = 4\pi^2r^3 / GM$	
	• Use of $\omega = 2\pi/T$		$= 4\pi^2(1.34 \times 10^8 \text{ m})^3 / 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-1} \times 5.97 \times 10^{24} \text{ kg} = 2.39 \times 10^{11} \text{ s}^2$	
	• T = 488 000 s = 5.7 days		T = 488 000 s = 5.7 days	3

Q30.

Question Number	Answer	Mark
	B	1