PEARSON EDEXCEL A-LEVEL PHYSICS · 9PH0

PHYSICS



MARK SCHEME

TOPIC 6: FURTHER MECHANICS

CIRCULAR MOTION

SCORE	PERCENTAGE
/325	%

STEMUP

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Q1.

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)

Q2. 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)

Mark Scheme

Q1.

Question Number	Answer	Mark
	B	1

Q2.

Question Number	Answer	Mark
	C	**1**

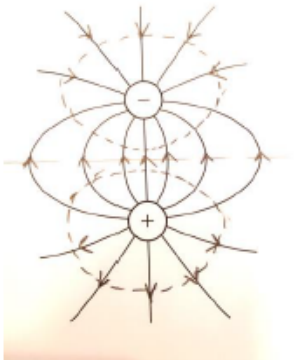
Mark Scheme

Q1.

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

Q2.

Question Number	Acceptable answers		Additional guidance	Mark
(a)	• Replace Work W by force × distance	(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
	• Replace distance ÷ time by velocity v	(1)		
	• Use $v = r \times$ Angular velocity	(1)		
	• Recognise $F \times r$ is the moment of F	(1)		

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

Question Number	Acceptable answers	Additional guidance	Mark
(b)(ii)	• Use of $F = \frac{Q_1 Q_2}{4\pi\varepsilon_o r^2}$ (1) • $F = 0.036$ (N) (1)	Example of calculation: $F = 8.99\times10^{9}\,\text{Nm}^2\text{C}^{-2}\,\frac{(0.1\times10^{-6}\text{C})^2}{(0.05\text{m})^2}$ $F = 0.036\text{N}$	2

Question Number	Acceptable answers	Additional guidance	Mark
(c)	• Use of moment = Fx (1) • Expression for correct moment (1) • Use of power = moment of force x angular velocity (1) • Only realistic possibility is pond pump and $P = 0.6$W (calculated answer could also be force and then comparison with b(i)) (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 $= 2.89\times10^{-3}\,\text{N m}\times200\text{s}^{-1} = 0.58\text{W}$	4

Q3.

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

Q4.

Question Number	Answer	Mark
	B	1

Q5.

Question Number	Answer	Mark
	C	**1**

Q6.

Question Number	Answer	Mark
	D	**1**

Q7.

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

Q8.

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

Q9.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• Use of $v = \frac{2\pi r}{T}$ or $\omega = \frac{2\pi}{T}$ **(1)** • Use of $a = \frac{v^2}{r}$ or $r\omega^2$ **(1)** • $a = 8.8\ \text{m s}^{-2}$ **(1)**	Example of calculation $v = \frac{2\pi 6800000\text{m}}{92\times 60\text{s}} = 7740\ \text{m s}^{-1}$ $a = \frac{7740^2(\text{m s}^{-1})^2}{6800000\ \text{m}} = 8.81\ \text{m s}^{-2}$ or $\omega = \frac{2\pi}{92\times 60\ \text{s}} = 1.14\times 10^{-3}\ \text{rad s}^{-1}$ $a = 6800000\ \text{m} \times (1.14\times 10^{-3}\ \text{rad s}^{-1})^2$ $a = 8.81\ \text{m s}^{-2}$	3
(ii)	• The astronauts have weight or not weightless **(1)** **Or** Earth's gravitational field = 8.8 N kg^{-1} on ISS (ECF from (b)(i)) • Earth's gravitational field keeps astronauts/ISS in circular motion **(1)** **Or** Weight provides the centripetal force • Our notion of "weight" is reaction force acting on us from the ground/floor **(1)** • There are no reaction forces from the ISS on the astronauts so they "feel" weightless **(1)**		4

Q10.

Question Number	Answer		Mark
(a)	Use of $v = 2\pi r/t$ **Or** $v = r\omega$ **and** $T = 2\pi/\omega$ $t = 1.5 \times 10^3$ s [24.6 minutes] Example of calculation $t = 2\pi r/v$ $t = (2\pi \times 61\text{ m}) / 0.26\text{ m s}^{-1}$ $t = 1473$ s	**(1)** **(1)**	**2**
(b)	Use of $F = mv^2/r$ $F = 11$ N Example of calculation $F = 9.7 \times 10^3\text{ kg} \times (0.26\text{ m s}^{-1})^2 / 61\text{ m}$ $F = 10.7$ N	**(1)** **(1)**	**2**
(c)(i)	Three arrows all pointing to the centre of the circle (accept free hand and lines of varying length)	**(1)**	**1**
* **(c)(ii)**	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) Maximum at C / bottom **and** Minimum at A / top At C contact/reaction force (R) greater than weight (accept $R - W = mv^2/r$ or $R = W + mv^2/r$) At A contact/reaction force is less than the weight. (accept $W - R = mv^2/r$ or $R = W - mv^2/r$) Any statement that centripetal force / acceleration is provided by weight/reaction **Or** centripetal force is the resultant force This is a qwc question so a bald statement of the equations can score the marks but to get full marks there must be clear explanation in words.	**(1)** **(1)** **(1)** **(1)**	**4**

Q11.

Question Number	Answer		Mark
(a)	Evidence of frictional force = $(0.35 \times mg)$ Use of $F = mr\omega^2$ **Or** $F = mv^2/r$ Use of $\omega = 2\pi/T$ **Or** $v = 2\pi r/T$ $t = 3.0$ s Example of calculation frictional force = 0.35×20 kg $\times 9.81$ m s^{-2} = 68.7 N $F = mr\omega^2$ $\omega = \sqrt{}$ (68.7 N / (20 kg $\times$ 0.80 m) ω = 2.1 rad s^{-1} $t = 2\pi/2.1$ rad s^{-1} $t = 3.0$ s	(1) (1) (1) (1)	4
(b)	There would be no difference Both expressions for force depend on mass **Or** algebraic equation for ω or T derived (could be in the working for (a)) showing ω or T independent of m **Or** statement that masses cancel if supported by evidence in (a)	(1) (1)	2
	Total for question		6

Q12.

Question Number	Acceptable Answer	Additional guidance	Mark
(a)	• use of $T = \frac{2\pi}{w}$ (1) • 1.7×10^{-3} rad s^{-1} or $\frac{\pi}{1800}$ rad s^{-1} (1)	Example of calculation: $w = \frac{2\pi}{(60 \times 60)\ s}$	**(2)**

Question Number	Acceptable Answer	Additional guidance	Mark
(b)	• recognises weight acts halfway along hand (1) • uses correct angle between the two positions (1) • determines change in vertical height (= 0.008 m) (1) • use of $\Delta E = mg\Delta h$ (1) • work done = 1.1 (mJ) (1)	Example of calculation: $W = 0.014\ \text{kg} \times 9.81\ \text{N kg}^{-1} \times (2 \times 0.04 \sin 6^\circ\ \text{m})$ $W = 1.1 \times 10^{-3}\ \text{J}$	**(5)**

Question Number	Acceptable Answer	Additional guidance	Mark
(c)	• use of $P = VI$ (1) • use of $P = \frac{W}{t}$ AND 65% (1) • t = 141 s (1)	Example of calculation: $P = 1.5\ \text{V} \times 8.0 \times 10^{-6}\ \text{A} = 1.2 \times 10^{-5}\ \text{W}$ $t = \frac{1.1 \times 10^{-3}\ \text{J}}{0.65 \times 1.2 \times 10^{-5}\ \text{W}} = 141\ \text{s}$	**(3)**

Q13.

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 Example of calculation $T^2 = 4\pi^2r^3 / G m_1$	4
	• use of $T = 2\pi/\omega$ **Or** use of $T = 2\pi r/v$	(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	
	• 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	2
	• 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)		
	OR • Satellite varies distance from surface	(1)		
	• So it can take wide-angle and close-up pictures of the planet	(1)		

Q14.

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)	3
	Example of calculation: $\omega^2 r = \frac{GM}{r^2}$ $\left(\frac{2\pi}{T}\right)^2 = \frac{GM}{r^3}$ $r^3 = \frac{GMT^2}{4\pi^2}$		
(a)(iii)	See T = 24 hours	(1)	
	T converted into s	(1)	
	$r = 4.2 \times 10^7$ m	(1)	3
	Example of calculation: $T = 24 \times 60 \times 60$ s = 86 400 s $r^3 = \frac{GMT^2}{4\pi^2} = \frac{6.67\times10^{-11}\ \text{N m}^2\ \text{kg}^{-2} \times 6.0\times10^{24}\ \text{kg} \times (86400\ \text{s})^2}{4\pi^2} = 7.57\times10^{22}\ \text{m}^3$ $r = \sqrt[3]{7.57\times10^{22}\ \text{m}^3} = 4.23\times10^7\ \text{m}$		
(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

Q15.

Question Number	Answer	Mark
	A	1

Mark Scheme

Q1.

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**

Q2.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• Use of $v = \frac{2\pi r}{T}$ **(1)** or $\omega = \frac{2\pi}{T}$ • Use of $a = \frac{v^2}{r}$ **(1)** or $r\omega^2$ • $a = 8.8\ \text{m s}^{-2}$ **(1)**	Example of calculation $v = \frac{2\pi 6800000\text{m}}{92\times 60\text{s}} = 7740\ \text{m s}^{-1}$ $a = \frac{7740^2(\text{m s}^{-1})^2}{6800000\ \text{m}} = 8.81\ \text{m s}^{-2}$ or $\omega = \frac{2\pi}{92\times 60\ \text{s}} = 1.14\times 10^{-3}\ \text{rad s}^{-1}$ $a = 6800000\ \text{m} \times (1.14\times 10^{-3}\ \text{rad s}^{-1})^2$ $a = 8.81\ \text{m s}^{-2}$	**3**
(ii)	• The astronauts have weight or not weightless **(1)** **Or** Earth's gravitational field = 8.8 N kg^{-1} on ISS (ECF from (b)(i)) • Earth's gravitational field keeps astronauts/ISS in circular motion **(1)** **Or** Weight provides the centripetal force • Our notion of "weight" is reaction force acting on us from the ground/floor **(1)** • There are no reaction forces from the ISS on the astronauts so they "feel" weightless **(1)**		**4**

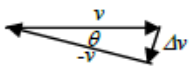
Q3.

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 Example of calculation $T^2 = 4\pi^2r^3 / G\,m_1$	4
	• use of $T = 2\pi/\omega$ **Or** use of $T = 2\pi r/v$	(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	
	• 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	2
	• 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)		
	OR • Satellite varies distance from surface	(1)		
	• So it can take wide-angle and close-up pictures of the planet	(1)		

Q4.

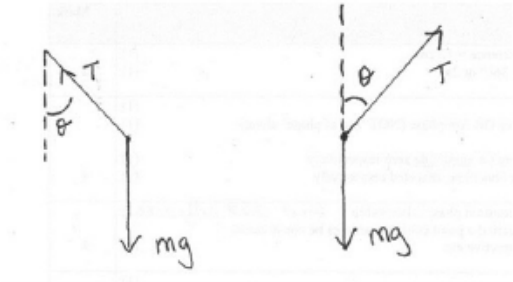
Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• To reduce the effect of random errors (1)		1
(ii)	• Use of data to calculate mean value (1) • Use of half range **Or** Use of greatest deviation from mean (1) • % uncertainty in range 5 % to 6% consistent with student's working (1 or 2 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

Q5.

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

Mark Scheme

Q1.

Question Number	Answer		Mark
	Free body force diagram showing 2 forces only Weight/W/mg Tension / T (Each additional forces e.g. horizontal component or resultant force, 1 mark penalty) **If θ is angle to the vertical then**: (Resolving vertically): $T\cos\theta = mg$ (Resolving horizontally): $T\sin\theta = mv^2/r$ **Or** $T\sin\theta = mr\omega^2$ Derives $\tan\theta = v^2/rg$ **and** links to observations **Or** Derives $\tan\theta = r\omega^2/g$ **and** links to observations If angle to horizontal is used candidates can score MP3 and 4.[then sin and cos swop over and tan of angle will be reciprocal of above] <u>Examples of free body force diagrams</u>  (full credit for the last 3 marks can be given to candidates who draw a vector triangle and derive $\tan\theta = T_{horzt}/mg$ and then $\tan\theta = r\omega^2/g$ **and** observation)	**(1)** **(1)** **(1)** **(1)** **(1)**	**5**
	Total for question		**5**

Q2.

Question Number	Acceptable Answer	Additional Guidance	Mark
*	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. **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	Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning Accept "the rider experiences a centripetal force"	6

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

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

Q3.

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"	

Q4.

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 $22.5g$ Allow reverse argument starting with $25g$ to $\omega = 5.28$ rads^{-1} <u>Example of calculation</u> $a = 8.8$ (m) $\times$ 5.24^2 (rads^{-1})^2 $a = 238$ (ms^{-2}) $\div 9.81$ (ms^{-2}) $= 24.6 \times g$	**2**
	• $a = 25g$ **and** appropriate comment	(1)		

Q5.

Question Number	Answer	Mark
	B	**1**

Q6.

Question Number	Answer		Mark
(a)	Use of $v = 2\pi r/t$ **Or** $v = r\omega$ **and** $T = 2\pi/\omega$ $t = 1.5 \times 10^3$ s [24.6 minutes] Example of calculation $t = 2\pi r/v$ $t = (2\pi \times 61\text{ m}) / 0.26\text{ m s}^{-1}$ $t = 1473$ s	**(1)** **(1)**	**2**
(b)	Use of $F = mv^2/r$ $F = 11$ N Example of calculation $F = 9.7 \times 10^3\text{ kg} \times (0.26\text{ m s}^{-1})^2 / 61\text{ m}$ $F = 10.7$ N	**(1)** **(1)**	**2**
(c)(i)	Three arrows all pointing to the centre of the circle (accept free hand and lines of varying length)	**(1)**	**1**
* **(c)(ii)**	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) Maximum at C / bottom **and** Minimum at A / top At C contact/reaction force (R) greater than weight (accept $R - W = mv^2/r$ or $R = W + mv^2/r$) At A contact/reaction force is less than the weight. (accept $W - R = mv^2/r$ or $R = W - mv^2/r$) Any statement that centripetal force / acceleration is provided by weight/reaction **Or** centripetal force is the resultant force This is a qwc question so a bald statement of the equations can score the marks but to get full marks there must be clear explanation in words.	**(1)** **(1)** **(1)** **(1)**	**4**

Q7.

Question Number	Answer		Mark
(a)	Velocity/direction changing **Or** (object is) accelerating Force towards centre of circle	**(1)** **(1)**	**2**
(b)	High(er) speed means large(r) force **Or** small(er) radius means large(r) force (For sharp bends) centripetal/resultant/required <u>force</u> would need to be greater than maximum frictional force **Or** (for sharp bends) friction cannot provide the (required) centripetal/resultant force	**(1)** **(1)**	**2**
(c)(i)	Resolving forces vertically $\underline{N} \sin \theta = mg$ Resolving forces horizontally $\underline{N} \cos \theta = mv^2/r$ Division of vertical equation by horizontal equation to get correct answer	**(1)** **(1)** **(1)**	**3**
(c)(ii)	Use of $\tan \theta = gr/v^2$ $\theta = 57°$ <u>Example of calculation</u> $\tan \theta = (9.81 \text{ m s}^{-2} \times 18.7 \text{ m})/ (11.0 \text{ m s}^{-1})^2$ $\theta = 56.6°$	**(1)** **(1)**	**2**
	Total for question		**10**

Q8.

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

Q9.

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**

Q10.

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		

Q11.

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)	3
	Example of calculation: $\omega^2 r = \frac{GM}{r^2}$ $\left(\frac{2\pi}{T}\right)^2 = \frac{GM}{r^3}$ $r^3 = \frac{GMT^2}{4\pi^2}$		
(a)(iii)	See T = 24 hours	(1)	
	T converted into s	(1)	
	$r = 4.2 \times 10^7$ m	(1)	3
	Example of calculation: $T = 24 \times 60 \times 60\ \text{s} = 86\,400\ \text{s}$ $r^3 = \frac{GMT^2}{4\pi^2} = \frac{6.67\times10^{-11}\ \text{N m}^2\ \text{kg}^{-2} \times 6.0\times10^{24}\ \text{kg} \times (86400\ \text{s})^2}{4\pi^2} = 7.57\times10^{22}\ \text{m}^3$ $r = \sqrt[3]{7.57\times10^{22}\ \text{m}^3} = 4.23\times10^7\ \text{m}$		
(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

Q12.

Question Number	Acceptable Answer		Additional Guidance	Mark
(i)	• The ions experience a force perpendicular to their velocity (and the magnetic field)	(1)	For velocity accept direction of motion or direction of travel	
	• 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)		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
(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 (1) • ions have the same charge so the radius of the path would be greater (1)		2

Q13.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• (Perpendicularly) out of the page (1) • The force is perpendicular to the magnetic field and the direction of (conventional) current **Or** an application of Fleming's Left-Hand Rule (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 (1) • Causing an acceleration towards the centre of a circle (1)	Accept reference to centripetal force for MP1	2

Q14.

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

Q15.

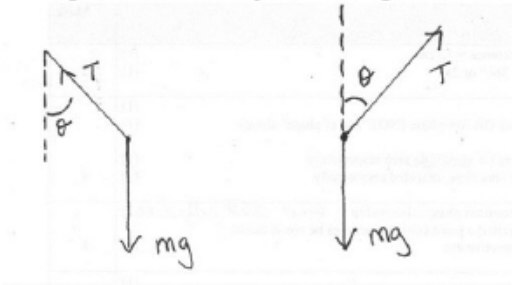
Question Number	Answer	Mark
(a)(i)	$R = 9.32$ kN (1) Example of answer $R = 950\ \text{kg} \times 9.81\ \text{m s}^{-2}$ $R = 9320$ N	1
(a)(ii)	Use of $F = mv^2/r$ (1) $R = mg - mv^2/r$ (1) $R = 2480$ N ecf their value of R (1) Example of calculation $R = 9320\ \text{N} - (950\ \text{kg} \times 12.0^2\ \text{m}^2\ \text{s}^{-2} / 20.0\ \text{m})$ $R = 2480$ N	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

Mark Scheme

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)** • $v = 9.1\ \text{m s}^{-1}$ **(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	Answer	Mark
	Free body force diagram showing 2 forces only Weight/W/mg **(1)** Tension / T **(1)** (Each additional forces e.g. horizontal component or resultant force, 1 mark penalty) **If θ is angle to the vertical then**: (Resolving vertically): $T\cos\theta = mg$ **(1)** (Resolving horizontally): $T\sin\theta = mv^2/r$ **Or** $T\sin\theta = mr\omega^2$ **(1)** Derives $\tan\theta = v^2/rg$ **and** links to observations **Or** Derives $\tan\theta = r\omega^2/g$ **and** links to observations **(1)** If angle to horizontal is used candidates can score MP3 and 4.[then sin and cos swop over and tan of angle will be reciprocal of above] <u>Examples of free body force diagrams</u>  (full credit for the last 3 marks can be given to candidates who draw a vector triangle and derive $\tan\theta = T_{horz}/mg$ and then $\tan\theta = r\omega^2/g$ **and** observation)	**5**
	Total for question	**5**

Q3.

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**

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Q4.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• Use of $F = \frac{GMm}{r^2}$ with $F = \frac{mv^2}{r}$ (1) • Correct substitutions to calculate r (1) • $h = 5.4\times10^5$ m (1) **OR** • Use of $g = \frac{GM}{r^2}$ to find value of g at orbit height (1) • Use of $a = \frac{v^2}{r}$ with value of g at orbit height (1) • $h = 5.4\times10^5$ m (1)	Example of calculation: $\frac{GMm}{r^2} = \frac{mv^2}{r}$ $r = \frac{GM}{v^2}$ $r = \frac{6.67\times10^{-11}\text{N m}^2\text{kg}^{-2}\times5.97\times10^{24}\text{ kg}}{(7.59\times10^3\text{ m s}^{-1})^2}$ $r = 6.91\times10^6$m $\therefore h = (6.91\times10^6 - 6.37\times10^6)$ m $= 5.42\times10^5$m	3
(ii)	• Use of $GPE = \frac{GMm}{r}$ (1) • GPE = 5.7×10^{10} J (ecf from (a)(i)) (1)	Example of calculation: $GPE = GMm\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$ $\therefore$GPE$= 6.67\times10^{-11}\text{Nm}^2\text{kg}^{-2}\times5.97\times10^{24}\text{ kg}\times11600\text{ kg}\left(\frac{1}{6.37\times10^6\text{m}} - \frac{1}{6.91\times10^6\text{m}}\right)$ $\therefore$GPE$= 5.67\times10^{10}$J	2

Question Number	Acceptable Answer	Additional Guidance	Mark
(iii)	• This would bring the gravitational potential energy closer to zero (1) • This would mean that the satellite would orbit at a greater height as $GPE \propto \frac{1}{r}$ (1) • To remain in orbit the centripetal acceleration must equal the gravitational field strength at the orbit height **Or** Since gravitational force smaller, $\frac{mv^2}{r}$ would be reduced (1) • (Hence) r is greater so v must be smaller **Or** $v^2 = \frac{GM}{r}$ and satellite would orbit at lower speed (1) **OR** • HST will have more kinetic energy at the original orbit height (1) • The centripetal force will be too small to keep it in this orbit (1) • The satellite would be travelling too fast, so it would move to a higher orbit (1) • (Hence) r is greater so v must be smaller **Or** $v^2 = \frac{GM}{r}$ and satellite would orbit at lower speed (1)		4

Q5.

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

Q6.

Question Number	Answer	Mark
	B	1

Q7.

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) • $F = m\omega^2 r$ so as r increased ω decreased (1)	For MP3 accept ω^2 for ω	3

Q8.

Question Number	Answer		Mark
(a)	Use of $v = 2\pi r/t$ **Or** $v = r\omega$ **and** $T = 2\pi/\omega$ $t = 1.5 \times 10^3$ s [24.6 minutes] Example of calculation $t = 2\pi r/v$ $t = (2\pi \times 61\text{ m}) / 0.26\text{ m s}^{-1}$ $t = 1473$ s	**(1)** **(1)**	**2**
(b)	Use of $F = mv^2/r$ $F = 11$ N Example of calculation $F = 9.7 \times 10^3\text{ kg} \times (0.26\text{ m s}^{-1})^2 / 61\text{ m}$ $F = 10.7$ N	**(1)** **(1)**	**2**
(c)(i)	Three arrows all pointing to the centre of the circle (accept free hand and lines of varying length)	**(1)**	**1**
* **(c)(ii)**	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate) Maximum at C / bottom **and** Minimum at A / top At C contact/reaction force (R) greater than weight (accept $R - W = mv^2/r$ or $R = W + mv^2/r$) At A contact/reaction force is less than the weight. (accept $W - R = mv^2/r$ or $R = W - mv^2/r$) Any statement that centripetal force / acceleration is provided by weight/reaction **Or** centripetal force is the resultant force This is a qwc question so a bald statement of the equations can score the marks but to get full marks there must be clear explanation in words.	**(1)** **(1)** **(1)** **(1)**	**4**

Q9.

Question Number	Answer		Mark
(a)	Velocity/direction changing **Or** (object is) accelerating Force towards centre of circle	**(1)** **(1)**	**2**
(b)	High(er) speed means large(r) force **Or** small(er) radius means large(r) force (For sharp bends) centripetal/resultant/required <u>force</u> would need to be greater than maximum frictional force **Or** (for sharp bends) friction cannot provide the (required) centripetal/resultant force	**(1)** **(1)**	**2**
(c)(i)	Resolving forces vertically $\underline{N} \sin \theta = mg$ Resolving forces horizontally $\underline{N} \cos \theta = mv^2/r$ Division of vertical equation by horizontal equation to get correct answer	**(1)** **(1)** **(1)**	**3**
(c)(ii)	Use of $\tan \theta = gr/v^2$ $\theta = 57°$ <u>Example of calculation</u> $\tan \theta = (9.81 \text{ m s}^{-2} \times 18.7 \text{ m})/ (11.0 \text{ m s}^{-1})^2$ $\theta = 56.6°$	**(1)** **(1)**	**2**
	Total for question		**10**

Q10.

Question Number	Answer		Mark
(a)	Evidence of frictional force = $(0.35 \times mg)$ Use of $F = mr\omega^2$ **Or** $F = mv^2/r$ Use of $\omega = 2\pi/T$ **Or** $v = 2\pi r/T$ $t = 3.0$ s <u>Example of calculation</u> frictional force = $0.35 \times 20 \text{ kg} \times 9.81 \text{ m s}^{-2} = 68.7 \text{ N}$ $F = mr\omega^2$ $\omega = \sqrt{}(68.7 \text{ N} / (20 \text{ kg} \times 0.80 \text{ m})$ $\omega = 2.1 \text{ rad s}^{-1}$ $t = 2\pi/2.1 \text{ rad s}^{-1}$ $t = 3.0$ s	**(1)** **(1)** **(1)** **(1)**	**4**
(b)	There would be no difference Both expressions for force depend on mass **Or** algebraic equation for ω or T derived (could be in the working for (a)) showing ω or T independent of m **Or** statement that masses cancel if supported by evidence in (a)	**(1)** **(1)**	**2**
	Total for question		**6**

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Q11.

Question Number	Answer	Mark
	B	1

Q12.

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)	Example of calculation: $mg = \frac{mv^2}{r}$ $v = \sqrt{rg} = \sqrt{10\,\text{m} \times 9.8\,\text{ms}^{-2}} = 9.9\,\text{ms}^{-1}$ 25 mph = $\left(\frac{25}{10}\right) \times 0.45\,\text{ms}^{-1} = 11.25\,\text{ms}^{-1}$	(5)

Q13.

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 Example of calculation $T^2 = 4\pi^2r^3 / G m_1$	4
	• use of $T = 2\pi/\omega$ **Or** use of $T = 2\pi r/v$	(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	
	• 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	2
	• 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)		
	OR			
	• Satellite varies distance from surface	(1)		
	• So it can take wide-angle and close-up pictures of the planet	(1)		

Q14.

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

Q15.

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) Example of calculation: $\omega^2 r = \frac{GM}{r^2}$ $\left(\frac{2\pi}{T}\right)^2 = \frac{GM}{r^3}$ $r^3 = \frac{GMT^2}{4\pi^2}$	3
(a)(iii)	See T = 24 hours (1) T converted into s (1) $r = 4.2 \times 10^7$ m (1) Example of calculation: $T = 24 \times 60 \times 60 \text{ s} = 86\,400 \text{ s}$ $r^3 = \frac{GMT^2}{4\pi^2} = \frac{6.67\times10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 6.0\times10^{24} \text{ kg} \times (86400 \text{ s})^2}{4\pi^2} = 7.57\times10^{22} \text{ m}^3$ $r = \sqrt[3]{7.57\times10^{22} \text{ m}^3} = 4.23\times10^7 \text{ m}$	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

Q16.

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)

Q17.

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 $mv^2/r = Bqv$ $m = Bqr/v = (0.673\ T \times 1.6 \times 10^{-19}\ C \times 7.40 \times 10^{-2}\ m) / 1.20 \times 10^{5}\ m\ s^{-1}$ $m = 6.64 \times 10^{-26}$ kg	(1) (1) (1)	3
(d)	Semicircle drawn starting from same initial point and a smaller radius	(1)	1
	Total for question		6

Q18.

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

Q19.

Question Number	Acceptable answers	Additional guidance	Mark
i	• Use of $\omega = 2\pi/T$ (1) • For at least 2 full cycles (1) • $\omega = 6.5 \times 10^{-6}$ (radian s^{-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 $v = 2\pi r/T$ (1) • Correct rearrangement and substitution (e.g. in $r^3 = Gm_1/\omega^2$) (1) • $r = 7.2 \times 10^9$ m (ecf from (b)(i)) (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

Q20.

Question Number	Answer	Mark
(a)(i)	$R = 9.32$ kN (1) Example of answer $R = 950$ kg $\times$ 9.81 m s^{-2} $R = 9320$ N	1
(a)(ii)	Use of $F = mv^2/r$ (1) $R = mg - mv^2/r$ (1) $R = 2480$ N ecf their value of R (1) Example of calculation $R = 9320$ N $- (950$ kg $\times 12.0^2$ m^2 s^{-2} / 20.0 m) $R = 2480$ N	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 (1) • inner lane has a smaller radius of curvature (1) • (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)		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 (1) 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 (1) 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)	3
(iv)	$Bev=mv^2/r$ **Or** $r=p/Be$ (1) $v=2\pi r/T$ (1) $T=1/f$ (seeing $f=v/(2\pi r)$ scores MP2 & 3) (1) **Or** $Bev=mr\omega^2$ (1) $v=r\omega$ (1) $\omega=2\pi f$ (seeing $v/r=2\pi f$ scores MP2 & 3) (1)	3
(v)	Use of $B=2\pi fm/e$ with mass of proton (1) $f=1.8\times10^4$ Hz (1) Example of calculation $f=eB/2\pi m$ $f=(1.6\times10^{-19}\text{ C}\times1.2\times10^{-3}\text{ T})/(2\pi\times1.67\times10^{-27}\text{kg})$ $f=1.8\times10^4$ Hz	2

Q23.

Question Number	Answer	Mark
	A	1

Q24.

Question Number	Acceptable Answer		Additional Guidance	Mark
(i)	• Satellite would always be above the same point on the Earth's surface • So that contact/communication with the space station would be maintained at all times	(1) (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)	Example of calculation: $m\omega^2 r = \frac{GMm}{r^2}$ $\therefore \left(\frac{2\pi}{T}\right)^2 = \frac{GM}{r^3}$ $\therefore r = \sqrt[3]{\frac{GMT^2}{4\pi^2}}$ $r = \sqrt[3]{\frac{6.67\times10^{11}\text{N m}^2\text{ kg}^2\times6.00\times10^{24}\text{kg}\times(8.64\times10^4\text{s})^2}{4\pi^2}}$ $r = 4.23 \times 10^7$m $h = r - R_E = 4.23 \times 10^7 - 6.4 \times 10^6$m $= 3.59 \times 10^7$m	4

Q25.

Question Number	Acceptable answers		Additional guidance	Mark
(a)	• use of $F = Gm_1m_2/r^2$ • force = 6.5×10^{31} N	(1) (1)	Example of calculation $F = 6.67 \times 10^{-11}$ N m^2 kg^{-2} $\times$ 29 $\times$ 1.99×10^{30} kg $\times$ 36 $\times$ 1.99×10^{30} kg / $(6.5 \times 10^{10}$ 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 $F = mv^2/r = m(2\pi r/T)^2/r$ $T^2 = 4\pi^2 mr/F$ $= 4\pi^2 \times 29 \times 1.99 \times 10^{30}$ kg $\times 3.6 \times 10^{10}$ m / 6.5×10^{31} N $= 1.21 \times 10^{12}$ s^2 $T = 1.12 \times 10^6$ s = 18700 min = 312 hours = 13 days	**3**