Mark scheme – Circular Motion

Question			Answer/Indicative content	Marks	Guidance
1			B	1	
			Total	**1**	
2			B	1	
			Total	**1**	
3			(Resultant) Force acts perpendicularly to the direction of motion	B1	
			Total	**1**	
4	a		arrow down through centre of ball labeled weight **or** W **or** mg **or** 1.2 N	**B1**	zero if any other arrows or forces present **Examiner's Comments** There were some carelessly drawn arrows on the diagram but otherwise this was done well. There were some arrows labelled *centripetal force.*
	b	i	(horizontally) mv^2/r **(or** $mr\omega^2$) = T sin θ **and** (vertically) W **or** mg = T cos θ (tan θ = v^2/rg **or** rw^2/g) tan θ = 0.045 × 4 × 9.87 × 2.2 / 9.81 **or** 0.48 / 1.2 (= 0.40) θ = 22°	**M1** **A1** **A0**	**accept** figures in place of algebra, r = 0.045 m v = 0.42 m s^{-1} ω = 3π rad s^{-1}; $r\omega^2$ = 4.0 m s^{-2} ; W = 1.2 N and m = 0.12 kg and $mr\omega^2$ = 0.48 N **accept** labelled triangle of forces diagram **N.B.** this is a *show that Q* ; sufficient calculation must be present to indicate that the candidate has not worked back from the answer
		ii	k = (mg / x_0 = 1.2 / 0.050) = 24 (N m^{-1}) (T = mg / cos θ = kx giving) x = 1.2 / 24 cos 22 x = 0.054 (m)	**C1** **C1** **A1**	**or** solution by ratios **Examiner's Comments** About half of the candidates completed the angle calculation successfully with a slightly smaller number finding the correct extension of the string.
	c		(y = ½gt^2 =) 0.18 = 0.5 × 9.81 × t^2 giving t = 0.19 (s) (x = vt =) 0.42 × 0.19 = 0.08 (m) distance = √(r^2 + x^2) = √(0.0020 + 0.0064) = 0.092 (m)	**C1** **C1** **C1** **A1**	**alt:** projectile motion: x = vt, y = ½gt^2 y = ½g(x / v)^2 **ecf (b)i** for v; x^2 = $2yv^2/g$ = 2 × 0.18 × 0.42^2/9.81 **Examiner's Comments** About half of the candidates found the time for the ball to fall to the bench. Most then managed to find the horizontal distance from the point

					of release, but half forgot that the point of reference in the question was the centre of rotation so failing to complete the calculation.
	d		T increases **or** string stretches **or** angle θ increases to provide / create a larger centripetal force	**M1** **A1**	**allow** mv^2/r **or** $mr\omega^2$ in place of *centripetal force* causality must be implied to gain the A mark **Examiner's Comments** About half of the candidates appreciated that the tension in the string increased or that the angle of the string to the vertical increased. Most answers gave the impression that the *centripetal force* was a *real* force rather than its provision being necessary for the ball to follow a circular path
			Total	**12**	
5	a	i	{$v = \omega r$ **and** $\omega = 2\pi f$} **or** $v = 2\pi fr$ Comparison with $y = mx$ leading to gradient = $2\pi r$ **or** $\Delta v/\Delta f = 2\pi r$	B1 B1	**Allow** $v/f = 2\pi r$ **<u>Examiner's Comments</u>** This part tested ideas about investigative experiments: there was a solid focus on elements of data-taking and instruments that should be used. Typically at A Level, analysis should include an appropriate graph and a comparison between the line of best fit and the equation under test. Putting the general equation below the given equation would make it much clearer how the candidate linked the gradient or y-intercept with the required property.
		ii	Line of best fit drawn Gradient = 62.5 (m) $2\pi r = 62.5$ $r = 9.9$ (m)	B1 M1 M1 A0	 **Allow** ± 3 **Allow** ECF on gradient
		iii	$F = \frac{mv^2}{r}$ **or** $F = ma$ **and** $a =$ $F = \frac{1.7 \times 10^{-27} \times [2.0 \times 10^7]^2}{9.9}$ $F = 6.8 \times 10^{-14}$ (N)	C1 C1 A1	**Allow** use of candidate's answer for (ii) or use of '10' Expect answers of 6.8 or 6.9 × 10^{-14} (N)
	b		$r \propto v^2$ / speed increases by a factor of √2 maximum speed = 2.8×10^7 ($m\ s^{-1}$)	C1 A1	**Allow** substitution into correct equation with r doubled **Allow** recalculation from previous value of force in (a)(iii)
			Total	**10**	
6			The force is towards the centre of the circle.	B1	
			The force is perpendicular to the motion or no component of force	B1	

			in direction of motion; hence no work is done on the particle.		
			Total	**2**	
7			λ_1 = d sin 12.5 = 4.33 × 10^{-7} m giving 1/d = 5 × 10^5 or d = 2 × 10^{-6}	C1	or λ_2 = d sin 14.0 = 4.84 × 10^{-7} (m)
			λ_3 = sin 19.0/5 × 10^5 = 6.51 × 10^{-7} (m) **or** λ_1 = d sin 12.5 = 4.33 × 10^{-7} and λ_3 = d sin 19.0 so λ_3 = 4.33 × 10^{-7} sin 19.0/sin 12.5 = 6.51 × 10^{-7} (m)	A1	or use λ_2 = d sin 14.0 = 4.84 × 10^{-7} m sin 19.0/sin 12.5 = 0.326/0.216 = 1.50
			Total	**2**	
8			$mv^2/r = mg$ or $v^2/r = g$ $v^2 = 9.81 \times 0.25$ v = 1.6 (m s^{-1})	**C1** **C1** **A1**	**Allow:** $v^2/r = a$ <u>and</u> $a = g$ or $mv^2/r = ma$ <u>and</u> $a = g$ **Allow:** any subject **Allow:** any subject **Note:** qualified 2.21 (ms^{-1}) scores 2 marks. **<u>Examiner's Comments</u>** This question was answered well by those above the mean result. When the machine is switched off, the clothes are still in circular motion and at point B, the resultant force is still the weight of the clothes plus the normal contact force. This means at the critical speed when the clothes fall off at point B, the centripetal force will equal the weight of the clothes, since the question states that the normal contact force is zero.
			Total	**3**	
9			$F = m\omega^2 r$ **and** $\omega = 2\pi f$ $kmg = m\omega^2 r$ Clear algebra leading to $f^2 = \left(\frac{gk}{4\pi^2}\right) \times \frac{1}{r}$	M1 M1 A1	**Allow** $F = mv^2/r$ **and** $v = 2\pi fr$ **Allow** this mark for $kmg = mv^2/r$
			Total	**3**	
10		i	the uncertainty in the measurement of angle is the same for all angles and the bigger the angle measured the smaller the % error	B1	
		ii	n_{max} = d sin 90	C1	

		ii	$= 1/(5 \times 10^5 \times 4.33 \times 10^{-7}) = 4.6$ but n is an integer so n = 4	A1	
			Total	**3**	
11			centripetal force provided by BQv; hence $\frac{mv^2}{r} = BQv$	C1	
			$B = \frac{mv}{Qr} = \frac{9.11 \times 10^{-31} \times 5.0 \times 10^7}{1.6 \times 10^{-19} \times 0.018}$	C1	
			$B = 1.6 \times 10^{-2}$(T)	A1	
			Total	**3**	
12			$T = 60/1600$ or $T = 3.75 \times 10^{-2}$ (s) ($v = \pi \times 0.50/3.75 \times 10^{-2}$) speed = 42 (m s^{-1}) uncertainty = 3 (m s^{-1})	**C1** **A1** **A1**	**Allow:** f = 26.7 or $\frac{1600}{60}$ (Hz) or ω = 168 (s^{-1}) **Note:** v must be to 2 or more SF **Note:** uncertainty must be to 1 SF **Allow:** ecf on candidate's value for speed i.e. uncertainty = candidate's value / 16 (to 1 SF) **Allow for 2 marks max: 84 ± 5 (m s^{-1})** **<u>Examiner's Comments</u>** About half of the candidates got this item right or provided clear working to show where they were going. There was much confusion about which quantity was which. 1600 revolutions per minute refers to the frequency of the rotation, not the angular speed, angular frequency or the speed itself. The percentage error of the frequency was 6.25%, prior to rounding. Some candidates multiplied this by their value for the speed to get the correct absolute uncertainty, although good practice is to round uncertainties to 1 SF.
			Total	**3**	
13			$m = 650/g$ **or** $m = 650/9.81$ (= 66.3 kg) ($F = mr\omega^2$ gives) $d = 0.050 / m\omega^2 = 0.050 / 66.3 \times (3.5 \times 10^{-3})^2$ $d = 62$ (m)	C1 C1 A1	**Not** m = 650 kg or m = 65 kg **or** ($F = mv^2/r$ and $v = 2\Pi r/T$ gives) $d = 0.050 \times (30 \times 60)^2 / (4\pi^2 \times 66.3)$
			Total	**3**	
14		i	$F = 5.0 \times 4.8^2 / 1.5$	C1	
		i	$F = 77$ (N)	A1	**Allow** 76.8 (N)

		ii	$\omega = v / r = 4.8 / 1.5$	C1	**Allow** alternative e.g. $F = m\,\omega^2\,r$
		ii	$\omega = 3.2$ (rad s^{-1})	A1	
			Total	**4**	
15			$\lambda = \frac{\ln 2}{6600} = 1.050 \times 10^{-4}$ (s^{-1})	C1	Correct use of $A = \lambda N$
			$N = \frac{400 \times 10^6}{1.050 \times 10^{-4}} = 3.809 \times 10^{12}$	C1	
			mass of FDG = $\frac{3.809 \times 10^{12}}{6.02 \times 10^{23}} \times 0.018 \div 0.$	C1	
			mass of FDG = 1.15×10^{-12} (kg) or 1.2×10^{-12} (kg)	A1	
			Total	**4**	
16			$\omega^2 = k/m$ **or** 60/0.080 **or** $\omega^2 = 750$	C1	**Allow** correct algebraic expression for T
			$T = 2\pi/27.39$ **or** $T = 0.2295$ (s)	C1	**Allow** incorrect value for omega
			$t = ¼ \times 0.2295$	C1	**Allow** incorrect value of T
			$t = 0.057$ (s)	A1	
			Total	**4**	
17		i	3 downward arrows correctly labelled.	B1	longest being 4.33×10^{-7} (m)
		ii	ΔE = hc/λ	C1	
		ii	$\lambda = 6.63 \times 10^{-34} \times 3 \times 10^8 / 4.8 \times 10^{-20} = 4.1(4) \times 10^{-6}$ (m)	A1	
		ii	region: infra red	B1	**allow** ecf if wavelength calculation incorrect.
			Total	**4**	
18			*y*-intercept = − 0.45	C1	**Allow** ± 0.05
			$\frac{1}{2}\lg\left(\frac{gk}{4\pi^2}\right) = -0.45$	C1	**Allow** attempt at calculating y-intercept using gradient and a point **on the line.**
			$\left(\frac{gk}{4\pi^2}\right) = 10^{-0.9}$	C1	**Not** $e^{-0.9}$ wrong physics
			$k = \frac{0.126 \times 4 \times \pi^2}{9.81}$		
			$k = 0.51$	A1	Allow k in range 0.48 to 0.63 **Note** Answer must be to 2 SF
			Total	**4**	
19	a		There is no contact force between the astronaut and the (floor of the) space station (so no method of measuring / experiencing weight)	B1	**Allow** astronaut and the space station have same acceleration (towards Earth) / floor is falling (beneath astronaut) **<u>Examiner's Comments</u>**

					Misconception Experiencing weightlessness is not the same as being in freefall There was a lack of understanding of the nature of feeling weightless. The sensation of 'weightlessness' is a lack of the physiological sensation of 'weight'. The skeletal and muscular systems are no longer in a state of stress. This sensation is caused by a lack of contact forces as a result of the ISS and the astronaut experiencing the same acceleration. Common incorrect responses included: • the astronaut is weightless because he is falling • there is no resultant force on the astronaut • gravity is too weak to have any effect on the astronaut • the ISS orbits in a vacuum where there is no gravity.
	b	i	$M = 5.97 \times 10^{24}$(kg) **or** ISS orbital radius $R = 6.78 \times 10^{6}$(m) **or** $g \propto 1/r^2$ (gr^2 = constant so) $g \times (6.78 \times 10^6)^2 = 9.81 \times (6.37 \times 10^6)^2$ $g = 8.66$ (N kg^{-1})	C1 C1 A1	**or** g (= GM/R^2) = $6.67 \times 10^{-11} \times 5.97 \times 10^{24} / (6.78 \times 10^6)^2$ **Allow** rounding of final answer to 2 SF i.e. 8.7 (N kg^{-1}) **<u>Examiner's Comments</u>** The simplest method here was to use the fact that g is inversely proportional to r^2, so gr^2 = constant. If this was not used, a value for the mass of the Sun had to be calculated, which introduced a further step. Candidates who omitted this calculation and used a memorised value of the Sun's mass instead were unable to gain full marks, because they invariably knew it to 1 s.f. only, whereas 3 were required. Errors occurred when candidates used the incorrect distance in the formula for g. Common errors included: • forgetting to square the radius • using the Earth's radius rather than the orbital radius of the satellite • calculating ($6.37 \times 10^6 + 4.1 \times 10^5$) incorrectly.
		ii	$2\pi r/T = v$ **or** $T = 2 \times 3.14 \times 6.78 \times 10^6 / 7.7 \times 10^3$ $T = 5.5 \times 10^3$ s (= 92 min)	M1 A1	**ECF** incorrect value of R from **b(i)**
	c		$\frac{1}{2}Mc^2$ ($\frac{1}{2}N_A mc^2$) = $\frac{3}{2}RT$ $c^2 = 3 \times 8.31 \times 293 / 2.9 \times 10^{-2}$ =	C1 C1	**or** $\frac{1}{2}mc^2 = \frac{3}{2}kT$ **or** $c^2 = 3kT/m$ **or** $c^2 = 3 \times 1.38 \times 10^{-23} \times 6.02 \times 10^{23} \times 293/2.9 \times 10^{-2} = 2.52 \times 10^5$ **not** (7.7×10^3 / 15) = 510 (m s^{-1})

			2.52×10^5 $\sqrt{c^2}$ = 500 (m s^{-1}) (= 7.7×10^3 / 15)	A1 A0	**Examiner's Comments** The success in this question depended on understanding the meaning of the term *m* in the formula $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$ given in the Data, Formulae and Relationship booklet. A significant number of candidates took *m* to be the mass of one mole (the molar mass, *M*) whereas *m* is actually the mass of one molecule. Candidates who used the formula $\frac{1}{2}M\overline{c^2} = \frac{3}{2}RT$ were usually more successful because the molar mass had been given in the question stem.
	d		power reaching cells (= *IA*) = $1.4 \times 10^3 \times 2500 = 3.5 \times 10^6$ W power absorbed = $0.07 \times 3.5 \times 10^6 = 2.45 \times 10^5$ W cells in Sun for (92 – 35 =) 57 minutes average power = 57/92 × $2.45 \times 10^5 = 1.5 \times 10^5$ (W)	C1 C1 C1 A1	mark given for multiplication by 0.07 at any stage of calculation (90 – 35 =) 55 minutes using *T* = 90 minutes **ECF** value of *T* from **b(ii)** 55/90 × $2.45 \times 10^5 = 1.5 \times 10^5$ (W) using *T* = 90 minutes **Examiner's Comments** Although this question looked daunting, it was actually quite linear and many candidates who attempted it were able to gain two or three marks even if they did not eventually get to the correct response. Candidates who set out their reasoning and working clearly were more liable to gain these compensatory marks.
			Total	**13**	
20		i	$F = GMm/r^2 = mv^2/r$	C1	where r = 6.8×10^6 m
		i	$v = (GM/r)^{1/2} = (g/r)^{1/2}R$ (as $g = GM/R^2$)	C1	**N.B.** some working must be shown as a
		i	v = 7.7 (km s^{-1}).	A1	*show that* Q
		ii	total energy = $\frac{1}{2}mv^2 - GMm/r = -GMm/2r$	M1	**no ecf from (i); allow** numerical values
		ii	$E = -gR^2m/2r = -1.2(4) \times 10^{13}$ (J)	A1	with no algebra if clear **no mark for** correct value without the minus sign
			Total	**5**	
21		i	(For circular motion) there must (always) be a resultant force towards the centre The resultant force is not always vertical/sometimes has a horizontal component This can only be provided by friction/cannot be provided by *R* and W / *R* and W are always vertical/only *F* is horizontal	B1 x 2	any 2 from 3 marking points **Allow** *F* provides the horizontal (component of the) centripetal force

		ii	Sine wave with period 30 min and amplitude 0.050 (N) Correct phase, i.e. <u>negative</u> sine wave	B1 B1	Must start at the origin
		iii	F = 0.050 cos 40° F = 0.038 (N)	C1 A1	**Allow** alternative methods e.g. triangle of forces **Allow ECF** from graph if used
			Total	**6**	
2 2		i	$F = (mv^2/r =)\ 8.0 \times 1.5^2/2.0$ F = 9.0 (N)	C1 A1	**Allow** answer to 1s.f. **<u>Examiner's Comments</u>** Question 4(b)(ii) proved very difficult and highlighted poor understanding of circular motion. Almost all candidates described the centripetal force as an additional force that had appeared out of nowhere. This centripetal force 'pulled the suitcase inwards' (or, in some cases, outwards) or 'balanced the frictional force' or 'added to the frictional force' and so on. **Exemplar 5** At 'Y' the bag is moving in an arc, meaning that centripetal force is acting on it as well as weight, friction and the normal. In order to keep the bag in equilibrium friction has to increase and R has to decrease, as this centrifital force works against friction (F) and with R. The candidate who gave the response in Exemplar 5 clearly thinks that an additional force, called the centripetal force, now acts on the suitcase. The forces F and R have to adjust in order to keep the suitcase in equilibrium. They have not realised that the suitcase is no longer in equilibrium horizontally but is accelerating. This means that the available forces have to adjust in order to provide a resultant force towards the centre of the circle, while still balancing vertically. **Exemplar 6** The suitcase is now accelerating towards the center of the semicircle. This means there is a net force acting to the left (on the diagram). W has no component to the left so F must increase so that there is a component to the left allowing it to accelerate allowing it to stay on course. The centripetal force required is 9N so the horizontal component of F must be 9N bigger than the horizontal component of R. The suitcase must not move down or up though so their vertical components [4] must still add to 78.48N so F increases and R decreases. F In contrast, the candidate who wrote the response in Exemplar 6 has a much better grasp of the situation.

					AfL Rather than using the phrase 'centripetal force', candidates could be encouraged to think of motion in a circle as a special case of $F = ma$ where the resultant force F points towards the centre of the circle and the acceleration a is given by v^2/r. This should hopefully encourage them to think about which of the forces available in the situation could provide the resultant force for this motion to occur.
		ii	• Suitcase accelerates / changes its velocity / (constantly) changes direction / has a resultant force acting on it / is no longer in equilibrium • The resultant force must act (horizontally) towards centre of circle / to the left • The centripetal force can only be provided by (an increase in) *F* • Increased vertical component of *F* means the vertical component of *R* must decrease (in order to balance *W*) So *R* must decrease	B1 x 4 A0	Any answer that mentions **centrifugal** force scores 0/4 **Ignore** any statement that treats the centripetal force as an extra force **Allow** net or unbalanced or total for resultant throughout **or** $F\cos30^\circ - R\sin30^\circ$ increases (from 0 to 9.0 (N)) / the (magnitude of the) horizontal component of *F* must exceed the (magnitude of the) horizontal component of *R* **not** a resultant force acts towards **Y** e.g. Friction is the only force able to provide the centripetal force / only F has a component to the left **Allow** *F* provides the centripetal force **Not** the horizontal force must increase / increases **or** $F\sin30^\circ + R\cos30^\circ = W$ / *W* is the vector sum of *F* and *R* / $W = (F^2 + R^2)^{½}$ (and *F* increases while *W* remains constant) Total
			Total	**6**	
23			**Level 3 (5–6 marks)** Clear description **and** correct calculations leading to value of total energy (must include the negative sign) *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some description and some correct calculations **or** Correct calculations (including the negative sign) *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.*	B1×6	**Indicative scientific points may include:** **Description** • Orbit above the equator / equatorial orbit • Orbit from west to east/same direction of orbit as Earth's rotation • Orbital period is 24 hours / 1 (sidereal) day /23hrs 56mins (4 s) • Orbit is circular / above the same point on the Earth **Calculation** • $E = (-)\frac{GMm}{r}$ • $E = \frac{6.67\times10^{-11}\times 5.97\times10^{24}\times 2500}{4.22\times10^{7}}$ = (-)2.4 × 10^{10} J • $V = \frac{2\pi r}{T}\ \omega r$ • $V = \frac{2\pi\times 4.22\times10^{7}}{24\times 3600}$ = 3.07 × 10^3 m s^{-1} • $E = \frac{1}{2}mv^2$ • $E = \frac{1}{2}\times 2500\times[3.07\times10^{3}]^2$ = 1.2 × 10^{10} J • Total energy = - 2.4 × 10^{10} + 1.2 × 10^{10} = - 1.2 × 10^{10} J • Allow full credit for algebraic proof using $\frac{GMm}{r^2} = \frac{mv^2}{r}$, $E = (-)\frac{GMm}{r}$, $E = \frac{1}{2}mv^2$ and total energy = KE + PE

			Level 1 (1–2 marks) Limited description **or** Limited calculations *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.		Allow higher order answers in terms of Lagrange's Identity **Examiner's Comments** This part explored multiple ideas about geostationary orbits. It was accessible to most candidates, many of whom calculated the magnitude of the GPE correctly yet forgot that this value must be negative. Almost all candidates forgot that Gravitational Potential Energy is negative.
			Total	**6**	
24		i	Any sensible suggestion, e.g. Satellites used for global communication, instant access to news, weather forecasting etc.	B1	
		ii	$g = (6400/15300)^2 \times 9.81$	C1	
		ii	$g = 1.72$ (N kg^{-1})	A1	
		iii	Acceleration towards centre = 1.72 ms^{-2} or centripetal force = mass of satellite × 1.72 N	C1	ecf (b)(i)
		iii	$T^2 = 4 \times \pi^2 \times 1.53 \times 10^7 / 1.72$	C1	
		iii	$T = 1.87 \times 10^4$ (s)	A1	Allow 1.9
			Total	**6**	
25			**Level 3 (5–6 marks)** a structured combination of at least 6 statements taken from A, B and C or A and D a combination of at least 5 statements; script of a lower quality **N.B.** bonus given for any of E at any level *The ideas are well structured providing significant clarity in the communication of the science.* **Level 2 (3–4 marks)** a good combination of at least 4 statements taken from A and B or A and C or B and C or A and D a combination of at least 3 statements taken from two sections which are relevant together.	B1	**A initial scenario** • for circular orbit a centripetal force (of magnitude mv^2 / r) is required or AW in terms of accelerations • this is provided by the gravitational force GMm/r^2 **or** G force just pulls radially inwards sufficiently to maintain orbit • the speed in orbit $v = (GM/r)^{1/2}$ **B reverse thrust** • G force causes rocket to spiral towards Earth when rocket slowed; • rocket speeds up in process • v in orbit is larger when radius r is smaller; condition for faster lower orbit can be achieved **or** T smaller because either v is larger or r / circumference is smaller or both or $2\pi r/v$ is smaller **C forward thrust**

			There is partial structuring of the ideas with communication of the science generally clear. **Level 1 (1–2 marks)** at least 2 statements from A, B, C or D which are relevant together some attempt which is related to the question *The ideas are poorly structured and impede the communication of the science.* **Level 0 (0 marks)** Insufficient or relevant science.		• when rocket speeds up with engines fired forwards G force insufficient to hold orbit so spirals to larger orbit • slowing as it does so **D energy approach** • some p.e. goes to k.e. when rocket is slowed as it moves towards Earth • so v increases • vice versa when rocket is accelerated **E further comments** • extra corrections needed to obtain circular orbit after manoeuvre (not mentioned in passage) • any other relevant statement not included above
			Total	**6**	
26		i	Horizontal arrow pointing to the right.	**B1**	Judgement by eye **<u>Examiner's Comments</u>** The examiners were quite lenient in this series in terms of the precise direction of the arrow, which should point towards the centre of Mars.
		ii	$2.14 \times 10^3 = \frac{2\times\pi\times9380\times10^3}{T}$ $T = 2.75 \times 10^4$ (s)	**C1** **A1**	**Allow** 2SF answer **Note:** 2.75… × 10^n scores 1 mark. **<u>Examiner's Comments</u>** Around four fifths of candidates got this right. Those that did not either poorly converted the radius from km or used the area rather than the circumference of the orbit.
		iii	$\frac{GMm}{r^2} = \frac{mv^2}{r}$ or $v^2 = \frac{GM}{r}$ $(2.14 \times 10^3)^2 = 6.67 \times 10^{-11} \times M/9380 \times 10^3$ $M = 6.44 \times 10^{23}$ (kg)	**C1** **C1** **A1**	**Allow** ecf of answer for T from (a)(ii) **Allow** 2 SF answer **Note:** Use of 2.8 × 10^4 seconds gives 6.3 × 10^{23} (kg) for 3 marks. **Alternative Method for C1C1** • $M = 4\pi^2R^3/(T^2G)$ (Databook formula re–arranged with M as subject)

					• $M = 4\pi^2(9380 \times 10^3)^3/((2.75 \times 10^4)^2 \times 6.67 \times 10^{-11})$ (i.e. M as subject) **Note:** In alternative method, PoT error forgetting km–>m conversion gives 6.46×10^{14} (kg) for 2 marks. **<u>Examiner's Comments</u>** Many candidates successfully used the equation for Kepler's Third Law, which is encouraging. A quicker route was to find the Phobos's acceleration (from v^2/r) and equating that to the gravitational field strength at Phobos from Mars (GM_{mars}/r^2) and then rearranging to find the mass of Mars.
			Total	**6**	
27			* **Level 3 (5–6 marks)** A labelled diagram including all equipment required and a detailed description of the method leading to an appropriate analysis of data. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** A labelled diagram including most of the equipment required and a description of the method leading to an appropriate graph but with some misunderstanding of the relationship. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** A diagram is included with most of the equipment required and a description of the method leading to an attempt of identifying an appropriate graph or relationship. *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.*	B1 × 6	**Equipment / labelled diagram(E)** 1. String / cord (passed through a tube) with bung at one end and load at other (accept a labelled diagram) 2. Stopwatch to measure time period 3. Suitable scale / marker to measure radius **Method (M)** 1. Whirl bung with constant frequency and radius (in horizontal circle) 2. Measure time for several time periods 3. Measure radius either using cord markers or stopping the cord at the tube and measuring with a ruler 4. Vary frequency and new radius **Analysis (A)** 1. Expect $v^2 \propto r$, or $r \alpha T^{-2}$ 2. Plot graph; e.g r against T^{-2} 3. Expect straight line through origin

			Total	**6**	
28		i	(For circular orbit) <u>centripetal</u> force provided by <u>gravitational</u> force (of attraction) (Gravitational / centripetal) force is along line joining stars which must therefore be diameter of circle (AW)	**M1** **A1**	**<u>Examiner's Comments</u>** Only a minority of candidates related the gravitational force between the stars to the centripetal force required for circular motion to occur. This candidate has written the perfect answer (exemplar 5). There were two popular insufficient answers; that if the stars were not diametrically opposite they would collide and that the centre of mass of the system had to be at the centre of the orbit. **Exemplar 5** *. Their gravitational force to each other acts a the centripetal force. *. Gravitational force is directly towards their ce which means the centripetal ~~force~~ force is on the line of the Gravitational force so the center of orbit must be ~~seen~~ on the line of their centers as the di
		ii	$T = 20.5 \times 86400$ (= 1.77×10^6 s) **and** $R = 1.8 \times 10^{10}$ (m) $m = 16 \times \pi^2 \times (1.8 \times 10^{10})^3/G \times (20.5 \times 86400)^2$ giving $m = 4.4 \times 10^{30}$ so $m = 2.2\ M_\odot$	**C1** **C1** **A1**	values of T **and** R scores first mark; **both** incorrect 0/3 correct substitution allowing π^2 and G $m = 16 \times 9.87 \times 1.8^3 \times 10^{30}/6.67 \times 10^{-11} \times 1.8^2 \times 10^{12}$ using 2R gives $35.2 \times 10^{30} = 17.6\ M_\odot$ or using T = 1 day gives $1850 \times 10^{30} = 930\ M_\odot$ **award** 2/3 **<u>Examiner's Comments</u>** This question tested the candidates' ability to interpret and substitute data into an elaborate formula and then evaluate it. The most common error was to write the formula with the correct substitutions but then to omit the square symbol against T. Candidates should be encouraged to consider whether their answers are reasonable before moving on to the next question. In the calculation (exemplar 6) shown here, is it possible that these stars could be four million times the mass of the Sun? The correct answer of 2.2 Sun masses seems very plausible and should give candidates confidence. **Exemplar 6**

					1 day = 86400 s $M_\odot = 2.0 \times 10^{30}$ kg $m = \frac{16\pi^2 \times (1.8 \times 10^{10})^3}{6.67 \times 10^{-11} \times (20.5 \times 8.64 \times 10^4)}$ T^ $\doteq 7.795... \times 10^{36}$ kg $\frac{Ans}{2 \times 10^{30}} = 3.8977... \times 10^6$ $m = 3.9 \times 10^6$ $M_\odot$
		iii	$v = 2\pi R/T = 2 \times 3.14 \times 1.8 \times 10^{10} / 1.8 \times 10^6$ (giving $v = 6.3$ or 6.4×10^4) $\Delta\lambda = (v/c)\lambda = (6.3/3) \times 10^{-4} \times 656 = 0.14$ (nm)	C1 A1	**do not** penalise repeated error for R or T **ecf** for incorrect v, gives $\Delta\lambda = v \times 2.2 \times 10^{-6}$ $\Delta\lambda = 0.28$ for 2R; $\Delta\lambda = 2.9$ for 1 day and $\Delta\lambda = 5.7$ for both incorrect **Examiner's Comments** Most of the higher performing candidates completed this problem successfully. Two common errors among the remainder were to equate the formula for central force gravitational potential energy *(GMm/r)* to kinetic energy to find a value for the speed of the stars and to rewrite incorrectly metres in powers of 10 in nanometres.
			Total	**7**	