1(a)	(gravitational) force is (directly) proportional to product of masses	**B1**
	force (between point masses) is inversely proportional to the square of their separation	**B1**

1(b)(i)	force = $(6.67 \times 10^{-11} \times 4.0 \times 10^{30} \times 2.0 \times 10^{30}) / (3.3 \times 10^{12})^2$	**C1**
	$= 4.9 \times 10^{25}$ N	**A1**

1(b)(ii)	$a = F / m = (4.9 \times 10^{25}) / (4.0 \times 10^{30})$ $= 1.2 \times 10^{-5}$ m s^{-2}	**A1**

1(b)(iii)	$a = r\omega^2$ **and** $\omega = 2\pi / T$ **or** $a = v^2 / r$ **and** $v = (2\pi r / T)$	**C1**
	$r = (3.3 \times 10^{12}) / 3$	**C1**
	$T = 2\pi\,[(3.3 \times 10^{12}) / (3 \times 1.2 \times 10^{-5})]^{½}$ $= 1.9 \times 10^{9}$ s	**A1**

1(b)(iv)	acceleration: B greater than A	**B1**
	linear speed: B greater than A	**B1**
	period: B equal to A	**B1**

Question 1

(a) Generally, this question was answered well and most candidates were awarded full credit. Some candidates stated that the force was proportional to the 'masses' rather than the product of the masses. Some candidates stated the force was inversely proportional to the 'distance' or 'radius' squared, rather than the 'separation' or 'distance of separation' of the masses squared. A small number of candidates referred to 'indirect' rather than 'inverse' proportion regarding the separation squared or omitted 'squared'. A small number of candidates did not refer to force and gained no credit.

(b) (i) The majority of the candidates gained full credit. The most common error involved using the incorrect distance for the separation of the stars.

(ii) A large proportion of candidates gave the correct answer. Some candidates did not realise that the radius of the path of star A was one-third of the separation of the stars, and a small number of candidates did not correctly identify appropriate starting equations.

(iii) Candidates were guided to use their answer from **(b)(ii)**. Those who ignored this were generally unsuccessful in reaching the correct answer.

(iv) The majority of the candidates placed their ticks in the correct cells of the table. Almost all candidates were able to gain at least partial credit.

1(a)(i)	radius = $6.37 \times 10^6 \times \cos 52.2° = 3.90 \times 10^6$ m	**A1**

1(a)(ii)	period = 24 hours	**C1**
	$v = 2\pi r / T$ **or** $v = r\omega$ **and** $\omega = 2\pi / T$	**C1**
	$v = (2\pi \times 3.90 \times 10^6) / (24 \times 60 \times 60)$ $= 280$ m s^{-1}	**A1**

1(b)(i)	$F = mv^2 / r$	**C1**
	$= (58.6 \times 280^2) / (3.90 \times 10^6)$ $= 1.2$ N	**A1**

1(b)(ii)	arrow pointing horizontally to the left	**B1**

1(b)(iii)	arrow from student pointing along the dotted line, labelled 'weight'	**B1**
	upwards arrow from student pointing in a direction to the left of normal and above the tangent to the Earth, labelled 'contact force'	**B1**

Question 1

(a) (i) This question was generally well answered, with most candidates able to show the relevant trigonometry relating the radius of the Earth and the radius of the circle.

(ii) Stronger candidates had little difficulty with this question, but many of the weaker candidates found it difficult. Common mistakes were either to try to use an equation derived from equating gravitational force with resultant force, or to take the period of the circular motion as one year rather than one day.

(b) (i) Most candidates knew the correct starting equation for the resultant force $F = mv^2 / R$, and many were able to achieve full credit. Other than errors in arithmetic such as forgetting to square the speed, the common mistake of physics was to use the radius of the Earth rather than the radius of the circular motion.

(ii) Many candidates thought that the resultant force causing circular motion is towards the centre of the Earth rather than towards the centre of the circle.

(iii) Many candidates knew that one of the forces acting on the candidate is the weight towards the centre of the Earth. Very few candidates were able to deduce that the other force is the contact force from the surface of the Earth upwards from the surface and slightly to the left. Candidates were allowed credit for splitting this contact force into its normal and frictional components, provided those components were labelled correctly.

1(a)	velocity and acceleration both have constant magnitude	**B1**
	velocity is (always) perpendicular to acceleration	**B1**
1(b)(i)	$v = R\omega$	**A1**
1(b)(ii)	$a = R\omega^2$ **or** $a = v^2 / R$	**C1**
	$a = v\omega$	**A1**
1(c)(i)	$x = R \sin \theta$	**A1**
1(c)(ii)	$\theta = \omega t$	**A1**
1(c)(iii)	clear substitution of $\theta = \omega t$ into $x = R \sin \theta$ leading to $x = R \sin \omega t$	**A1**
1(c)(iv)	equation is of the form $x = x_0 \sin \omega t$ (so simple harmonic motion)	**B1**
1(d)(i)	amplitude = 0.46 / 2 = 0.23 m	**A1**

1(d)(ii)	$\omega = 2\pi / T$	**C1**
	period $= 2\pi / 1.9$ $= 3.3$ s	**A1**

1(d)(iii)	$a_0 = \omega^2 x_0$	**C1**
	$= 1.9^2 \times 0.23$ $= 0.83$ m s^{-2}	**A1**

1(e)	shadow on screen, labelled A, above left-hand edge of the circular path	**B1**

Question 1

(a) Most candidates appreciated that velocity and acceleration were always perpendicular to each other in circular motion. A smaller number of candidates appreciated that the magnitude of the velocity (speed) was constant. It was rarely written that the magnitude of the acceleration was also constant.

(b) (i) This question was generally answered correctly.

(ii) Most candidates understood the relationship between acceleration and either angular or linear velocity. Some candidates did not identify that the question required a relationship to be given that included all three of those quantities.

(c) (i) Most candidates recognised that a sine term needed to be used in the expression.

(ii) This question was generally answered correctly.

(iii) This 'show that' question required candidates to include both equations from the two earlier parts of **(c)** before they made the substitution to match the given answer.

(iv) Many candidates ignored the requirement to refer to the given equation in **(c)(iii)**. Instead, correct relationships were often given between acceleration and displacement. Such answers were not able to gain credit as they did not answer the question that was asked.

(d) (i) This question was generally answered correctly, with most candidates understanding what is meant by amplitude.

(ii) Most candidates knew the relationship between angular frequency/velocity and period.

(iii) Successful responses made clear that the acceleration and displacement were the maximum values, by the inclusion of a subscript (a_0, x_0) in the equation used.

(e) This question considered the movement of the shadow on the screen. Only the strongest candidates appreciated that drawing the shadow as a whole gave a greater opportunity to correctly identify the position of maximum positive acceleration. A significant minority of candidates did not follow the instruction in the question to label the shadow with the letter 'A'. Stronger candidates appreciated that the maximum positive acceleration would occur at the extreme left-hand edge of the movement of the shadow.

1(a)	angle (subtended at centre of a circle) when arc (length) = radius	**B1**

1(b)(i)	$v = r\omega$	**C1**
	ω = 17 / 0.46 = 37 rad s^{-1}	**A1**

1(b)(ii)	$T = 2\pi r / v$ **or** $T = 2\pi / \omega$	**C1**
	= $2\pi \times 0.46 / 17$ **or** $2\pi / 37$ = 0.17 s	**A1**

1(b)(iii)	distance = $2\pi \times 0.038$ = 0.24 m	**A1**

1(b)(iv)	angle = arc length / radius	**C1**
	= 0.24 / 0.15 = 1.6 rad	**A1**

1(c)	point X moves through a smaller distance in the same time **or** (linear) speed of movement of point X / chain decreases **or** (linear) speed of (circumference of) both cogs decreases	**B1**
	angular speed (of pedals) decreases	**B1**

Question 1

(a) The definition of the radian was generally well known and successfully stated by the majority of the candidates.

(b) (i) Most candidates knew that the starting equation for this question was $v = r\omega$, and many candidates calculated the correct angular velocity. A common mistake was to use the speed of the wheel of the bicycle with the radius of the small cog rather than the radius of the wheel.

(ii) Most candidates knew one or other of the valid starting equations, and many realised that they just needed to use the angular velocity calculated in **(b)(i)**. Weaker candidates attempted to find a different angular velocity before using $T = 2\pi / \omega$.

(iii) Most candidates realised that this question was effectively asking them to determine the circumference of the small cog, and were able to show that using the equation circumference = $2\pi r$. Some candidates used an incorrect answer to **(b)(ii)** together with the speed of the bicycle to obtain what was a numerically correct answer using speed = distance $\times$ time. The idea that the circumference of the small cog is related to the period of rotation via the speed of the bicycle was taken by examiners to be fundamentally incorrect physics.

(iv) This was another question in which most candidates knew the correct starting equation, $s = r\theta$. A smaller number of candidates realised that the correct radius needed to determine the angle turned by the large cog was the radius of the large cog.

(c) This was a challenging question set in the context of the effect of changing a bicycle's gear on the rate at which the pedals rotate. It discriminated well among the most able candidates, with the strongest candidates able to give very convincing explanations for the decrease in angular velocity of the pedals.

1(a)	arrow vertically downwards labelled 'weight' <u>and</u> arrow perpendicular to cone, inwards and upwards, labelled 'normal contact force'	**B1**

1(b)	vertical component of contact force = weight (so no resultant force vertically)	**B1**
	horizontal component of contact force is resultant force towards centre (of circle)	**B1**

1(c)	$a = v^2 / r$	**C1**
	$a = g \tan 52°$	**C1**
	$9.81 \times \tan 52° = v^2 / 0.15$ leading to $v = 1.4\ \mathrm{m\,s^{-1}}$	**A1**

1(d)	$v = r\omega$ <u>or</u> $a = r\omega^2$	**C1**
	$\omega = 1.4 / 0.15$ or $\sqrt{(9.81 \times \tan 52° / 0.15)}$ $= 9.3\ \mathrm{rad\,s^{-1}}$	**A1**

1(e)	same resultant force / same acceleration so v^2 is proportional to r (so if speed increases radius must also increase)	**A1**

Question 1

(a) A large proportion of candidates thought that centripetal force was one of the two forces acting on the sphere. Correct force diagrams were only seen from a small number of candidates. Some candidates drew diagrams that included more than two forces.

(b) Many candidates answered a different question from the one asked here. The question here was to explain how the two forces acting on the sphere result in the acceleration of the sphere being centripetal. Examiners were expecting to see discussion of horizontal and vertical components of the normal contact force, that the vertical component balances the weight and that the horizontal component is therefore effectively the resultant force that acts towards the centre of the circle. Most responses seen made no reference to the two forces acting at all.

(c) The general equation for acceleration in terms of speed and radius was generally well known. Candidates found it more difficult to use the trigonometry involved in getting to the magnitude of the resultant force from the weight of the sphere.

(d) This was the most successfully answered part of **Question 1**, with many candidates obtaining the correct answer.

(e) A very common misconception was that the angular frequency must remain unchanged, leading to direct proportionality between speed and radius. The candidates who fully appreciated the force analysis of the earlier parts of the question realised that the resultant force, and hence centripetal acceleration, cannot change, and thus the correct relationship is that radius is proportional to the square of speed.

1(a)(i)	$v = r\omega$	**C1**
	$= 0.85 \times 140$	**A1**
	$= 120\ \text{m s}^{-1}$	
1(a)(ii)	$a = r\omega^2$ **or** $a = v^2 / r$	**C1**
	$a = 0.85 \times 140^2$ **or** $120^2 / 0.85$	**A1**
	$= 1.7 \times 10^4\ \text{m s}^{-2}$	
1(b)(i)	direction of (induced) e.m.f.	**M1**
	is such as to (produce effects that) oppose the <u>change</u> that caused it	**A1**
1(b)(ii)	$T = 2\pi / \omega$	**A1**
	$= 2\pi / 140 = 0.045\ \text{s} = 45\ \text{ms}$	
1(b)(iii)	$\Phi = BA$	**C1**
	$= 0.18 \times \pi \times 0.85^2$	**C1**
	$= 0.41\ \text{Wb}$	**A1**
1(b)(iv)	$E = \Phi / t$	**C1**
	$= 0.41 / 0.045$	**A1**
	$= 9.1\ \text{V}$	

1(b)(v)	force (on spoke) must be anticlockwise, so current is from A to X (by Fleming's left hand rule), so X is at the higher potential	**B1**

Question 1

(a) (i) This question and **(ii)** were generally well answered by candidates that knew the basic equations for centripetal acceleration.

(ii) Some candidates who calculated the correct acceleration made an arithmetic error in rounding, to get a final answer of 1.6×10^4 m s^{-2}.

(b) (i) Lenz's law was only well known by the strongest candidates. To be awarded credit, candidates first needed to make it clear that Lenz's law is to do with the direction of the induced e.m.f. Confusion with Faraday's law was common, with many candidates giving responses in terms of the magnitude of the induced e.m.f.

(ii) This question was generally well answered, with most candidates able to show successfully that the period is 45 ms.

(iii) Many candidates knew the defining equation for magnetic flux. Some candidates did not know the correct formula for the area of a circle. Other candidates incorrectly included a factor of $\times$ 8 in the calculation.

(iv) Many candidates were awarded credit for realising that the magnitude of the e.m.f. is given by Faraday's law, but $\times$ 8 factors were common here too. Candidates should realise that the spokes are effectively in parallel, not in series, and so the $\times$ 8 factor is not applicable. Some candidates made a mistake with the unit conversion in the value of the time.

(v) This was a difficult question, with only the very strongest candidates demonstrating an ability to use Lenz's law correctly. The application of Lenz's law lay in realising that the cause of the induced e.m.f. is the rotation of the wheel. If current flows in the spokes, then it will cause a force on the wheel in the opposite direction to the rotation. Applying the left-hand rule then leads to a deduction that any current that flows will be from A to X. Finally, because current flows from low potential to high potential inside an e.m.f. source (and high to low potential around any external circuit), end X must be at the higher potential. A common misconception was that X is at the higher potential because it cuts more flux.

1(a)	angle (subtended at the centre of a circle) when arc (length) = radius	**B1**

1(b)(i)	arrow, labelled V, pointing in NE direction	**B1**

1(b)(ii)	arrow, labelled A, pointing in NW direction	**B1**

1(c)(i)	$v = r\omega$	**C1**
	$\omega = 0.68 / (0.093 - 0.012)$ $= 8.4 \text{ rad s}^{-1}$	**A1**

1(c)(ii)	$a = v^2 / r$ **or** $a = r\omega^2$	**C1**
	$a = 0.68^2 / (0.093 - 0.012)$ **or** $(0.093 - 0.012) \times 8.4^2$ $= 5.7 \text{ m s}^{-2}$	**A1**

1(d)	angular speed: same for both pieces	**B1**
	linear speed: less for second piece than first piece	**B1**
	acceleration: less for second piece than first piece	**B1**

Question 1

(a) The definition of the radian was well known by many candidates. It was important to note that this question asked for the definition of the unit, not the definition of the quantity 'angle' in radians.

(b) (i) Most candidates knew the general direction for the linear velocity of the modelling clay at the position shown, and examiners allowed a reasonable range for the precise direction in which the arrow was drawn. Some candidates did not take sufficient care to ensure that the direction was tangential to the circle at that point, and others drew curved arrows (implying that the velocity at that point has multiple directions).

(ii) Most candidates realised that the acceleration is centripetal and drew the arrow accordingly.

(c) (i) Most candidates used the correct starting equation, but only a minority correctly worked out the radius of the circle described by the modelling clay.

(ii) Many candidates were able to achieve full credit on this question, either by arriving at the correct answer or by the principle of error carried forward.

(d) The stronger candidates generally answered this question correctly, whereas weaker candidates largely appeared to guess.

5(a)	*any 2 points from*: • (angular) displacement • velocity • momentum • (centripetal) acceleration • (resultant) force	**B2**

5(b)(i)	$Bqv = mv^2 / r$	**M1**
	$v = 2\pi r / T$	**M1**
	completion of algebra leading to $B = 2\pi m / qT$	**A1**

5(b)(ii)	$B = (2\pi \times 4 \times 1.66 \times 10^{-27}) / (2 \times 1.60 \times 10^{-19} \times 2.5 \times 10^{-6})$	**C1**
	$= 0.052$ T	**A1**

5(b)(iii)	**either** the same because T is independent of r **or** the same because B, q and m are unchanged **or** the same because both radius and speed have doubled	**B1**

5(b)(iv)	$qE = Bqv$	**C1**
	$E = Bv = 0.052 \times 1.1 \times 10^6$ $= 5.7 \times 10^4$ N C^{-1}	**A1**

NOT FOUND:

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1(a)	angle (subtended at centre of circle) when arc length = radius	**B1**

1(b)	$\omega = 2\pi / T$	**C1**
	$= 2\pi / (1.0 \times 60 \times 60)$ $= 1.7 \times 10^{-3}$ rad s^{-1}	**A1**

1(c)(i)	angle $= 1.7 \times 10^{-3} \times 1400$ $= 2.4$ rad	**A1**

1(c)(ii)	L = arc length / angle $= 0.44 / 2.4$ **or** $L = 0.44 \times (3600 / 1400) / 2\pi$	**C1**
	$L = 0.18$ m	**A1**

1(c)(iii)	$a = r\omega^2$	**C1**
	$= 0.18 \times (1.745 \times 10^{-3})^2$ $= 5.5 \times 10^{-7}$ m s^{-2}	**A1**

1(d)	centripetal acceleration is negligible compared with acceleration of free fall **or** numerical comparison establishing answer to **(c)(iii)** $\ll$ 9.81	**B1**
	resultant force is negligible compared with weight (of modelling clay) (so variation is negligible) **or** force exerted by minute hand (approximately) equal (and opposite) to weight of modelling clay	**B1**

Question 1

(a) The definition of the radian was well known by many candidates. It was important to note that this question asked for the definition of the unit, not the definition of the quantity ‘angle’ in radians. Some weaker candidates defined the radian in terms of the degree to radian conversion.

(b) Most candidates knew the equation for calculation of angular speed from the period, and many were then able to use it to calculate the angular speed correctly. Some of the weaker candidates thought that the minute hand of a clock takes 1 minute, rather than 1 hour, to undergo one complete revolution.

(c) (i) Most candidates used their angular speed from **(b)** to calculate correctly a value for the angle moved through in the 1400 s time interval.

(ii) This question proved to be a little more challenging for some of the candidates, but stronger candidates were generally able to calculate the value of L correctly. There were two possible methods, using either the answer to **(b)** or the answer to **(c)(i)**. Full credit was available by the ‘error carried forward’ principle from incorrect previous answers, but this did occasionally result in values for L that were implausible. Candidates should be advised that a quick mental check on the plausibility of their answers can often help them to identify where they have made mistakes.

(iii) Most candidates knew the equation for calculating centripetal acceleration from angular speed and radius, but a significant minority of weaker candidates did not appreciate that the value of L is the radius of the circle. Many of them took the arc length 0.44 m as the radius.

(d) This was a challenging question. Some good responses were seen from the strongest candidates. The key advice to candidates is that quantities are very rarely ‘negligible’ in absolute terms; they are only negligible in relation to another quantity. Many candidates made the statement that the centripetal acceleration is negligible, but without any reference to a comparison. Examiners were looking for a comparison with the acceleration of free fall; this comparison then leads directly to the fact that the resultant force on the modelling clay is negligible in comparison with its weight, and hence the force exerted by the minute hand is approximately equal to the weight with negligible variation. Many of the weaker candidates attempted to explain why the force exerted by the minute hand is negligible, rather than explaining why its variation with time is negligible.

2(a)	horizontal force on sphere causes centripetal acceleration	**B1**
	weight of sphere is (now) equal to vertical component of tension **or** horizontal and vertical components (of force) (now) combine to give greater tension (in spring)	**B1**
	greater tension in spring so greater extension of spring	**B1**

2(b)(i)	$r = 10.8 \times \sin 27° = 4.9\,\text{cm}$	**A1**

2(b)(ii)	$T \cos \theta = mg$ **or** $T \cos \theta = W$ **and** $W = mg$	**C1**
	$T \cos 27° = 0.29 \times 9.81$ leading to $T = 3.2\,\text{N}$	**A1**

2(b)(iii)	$\Delta T = 3.2 - (0.29 \times 9.81)$	**C1**
	$k = \Delta T / \Delta x$ $= [3.2 - (0.29 \times 9.81)] / [10.8 - 8.5]$ $= 0.15\,\text{N cm}^{-1}$	**A1**

2(c)(i)	centripetal acceleration $= (T \sin \theta) / m$ $= (3.2 \times \sin 27°) / 0.29$	**C1**
	$= 5.0\,\text{m s}^{-2}$	**A1**

2(c)(ii)	$a = r\omega^2$ **and** $\omega = 2\pi / T$ **or** $a = v^2 / r$ **and** $v = 2\pi r / T$	**C1**
	$T = 2\pi \times \sqrt{(0.049 / 5.0)}$ $= 0.62$ s	**A1**

Question 2

(a) This question proved to be challenging. Many candidates did not refer to the components of the tension as required. Many referred to components of the weight or thought that the centripetal force was a third force acting, rather than the resultant of the tension and weight. A small number of candidates seemed to think the sphere was oscillating from side to side like a pendulum, rather than describing horizontal circles. The failure to realise the components of the tension at this stage often led to incorrect approaches to the numerical questions later on.

(b) (i) Most candidates were able to use basic trigonometry to show the value of the radius of the circle.

(ii) This 'show that' question proved to be challenging as candidates found it difficult to resolve forces correctly here. Some candidates did not show what they were doing clearly enough, with a numerical value for the weight appearing without the evidence that it was from the multiplication of mass $\times$ gravitational field strength.

(iii) Candidates also found this question difficult. Most candidates tried to apply $k = F / e$ but often did so incorrectly. The extra extension (10.8 cm – 8.5 cm) was not always used and the extra force (3.2 N – (0.29 $\times$ 9.81) N) was rarely used.

(c) (i) Many candidates tried to apply the equations of circular motion here. Only the strongest candidates used $F = ma$ and the horizontal component of the tension as F as necessary.

(ii) Candidates were more successful here, with many gaining credit. The use of circular motion equations, which many had unsuccessfully tried in **(c)(i)**, was necessary here.