Mark schemes

1

(a) (i) $\omega\left(=\frac{v}{r}\right)=\frac{8.6}{1.5}$ (= 5.73 rad s^{-1}) ✓

$\theta(=\omega t)$ = 5.73 × 0.40 = 2.3 (2.29) (rad) ✓

$=\frac{2.29}{2\pi}$ × 360 = 130 (131) (degrees) ✓

[**or** $s((=vt)$ = 8.6 × 0.40 (= 3.44 m) ✓

$\theta=\frac{3.44}{2\pi\times1.5}$ × 360 ✓ = 130 (131) (degrees) ✓]

Award full marks for any solution which arrives at the correct answer by valid physics.

3

(ii) tension $F(=m\omega^2 r)$ = 0.25 × 5.73^2 × 1.5 ✓ = 12(.3) (N) ✓

[**or** $F\left(=\frac{mv^2}{r}\right)=\frac{0.25\times8.6^2}{1.5}$ ✓ = 12(.3) (N) ✓]

Estimate because rope is not horizontal.

2

(b) maximum $\omega\left(=\sqrt{\frac{F}{mr}}\right)=\sqrt{\frac{60}{0.25\times1.5}}$ (= 12.6) (rad s^{-1}) ✓

maximum $f\left(=\frac{\omega}{2\pi}\right)=\frac{12.6}{2\pi}$ = 2.01 (rev s^{-1}) ✓

[**or** maximum $v=\sqrt{\frac{Fr}{m}}=\sqrt{\frac{60\times1.5}{0.25}}$ (= 19.0) (m s^{-1}) ✓

maximum $f\left(=\frac{v}{2\pi r}\right)=\frac{19.0}{2\pi\times1.5}$ = 2.01 (rev s^{-1}) ✓]

Allow 2 (rev s^{-1}) for 2nd mark.
Ignore any units given in final answer.

2

(c) **The student's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The student's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks

The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

The student appreciates that the velocity of the ball is not constant and that this implies that it is accelerating. There is a comprehensive and logical account of how Newton's laws apply to the ball's circular motion: how the first law indicates that an inward force must be acting, the second law shows that this force must cause an acceleration towards the centre and (if referred to) the third law shows that an equal outward force must act on the point of support at the centre. The student also understands that the rope is not horizontal and states that the weight of the ball is supported by the vertical component of the tension.

*A **high level** answer must give a reasonable explanation of the application of at least two of Newton's laws, and an appreciation of why the rope will not be horizontal.*

Intermediate Level (Modest to adequate): 3 or 4 marks

The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

The student appreciates that the velocity of the ball is not constant. The answer indicates how at least one of Newton's laws applies to the circular motion. The student's understanding of how the weight of the ball is supported is more superficial, the student possibly failing to appreciate that the rope would not be horizontal and omitting any reference to components of the tension.

*An **intermediate level** answer must show a reasonable understanding of how at least one of Newton's laws applies to the swinging ball.*

Low Level (Poor to limited): 1 or 2 marks

The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

The student has a much weaker knowledge of how Newton's laws apply, but shows some understanding of at least one of them in this situation. The answer coveys little understanding of how the ball is supported vertically.

*A **low level** answer must show familiarity with at least one of Newton's laws, but may not show good understanding of how it applies to this situation.*

References to the effects of air resistance, and/or the need to keep supplying energy to the system would increase the value of an answer.

The explanation expected in a competent answer should include a coherent selection of the following points concerning the physical principles involved and their consequences in this case.

- *First law:* ball does not travel in a straight line, so a force must be acting on it
- although the ball has a constant speed its velocity is not constant because its direction changes constantly
- because its velocity is changing it is accelerating
- *Second law*: the force on the ball causes the ball to accelerate (or changes the momentum of it) in the direction of the force
- the acceleration (or change in momentum) is in the same direction as the force
- the force is centripetal: it acts towards the centre of the circle
- *Third law*: the ball must pull on the central point of support with a force that is equal and opposite to the force pulling on the ball from the centre
- the force acting on the point of support acts outwards
- *Support of ball*: the ball is supported because the rope is not horizontal
- there is equilibrium (or no resultant force) in the vertical direction
- the weight of the ball, *mg*, is supported by the vertical component of the tension, $F\cos\theta$, where θ is the angle between the rope and the vertical and *F* is the tension
- the horizontal component of the tension, $F\sin\theta$, provides the centripetal force $m\omega^2 r$

Credit may be given for any of these points which are described by reference to an appropriate labelled diagram.

A reference to Newton's 3r 7) s not essential in an answer considered to be a high le\ ponse. 6 marks may be awarded when there is no reference to the 3rd law.

max 6

[13]

2

(a) $f = \frac{3000}{60}$ = 50 (Hz) **(1)**

ω (= $2\pi f$) = 314 (rad s^{-1}) **(1)**

(b) $\alpha = (r\omega^2) = 95 \times 10^{-3} \times 314^2 = 9.4 \times 10^3$ m s^{-2} **(1)**

(c) (inwards) towards axis of rotation **(1)**

[5]

3

(i) F = 65 × 2.2 × 0.47^2

32(31.6 N)

2

(ii) Force produced by friction between the feet and the roundabout

Centripetal force has to act through the centre of mass of the operator
or
The resultant of the frictional force and normal reaction has to pass through the centre of mass

Any indication (eg on diagram) of wrong direction = 0

2

(iii) Ticks 4th box

1

[14]

4 (a) (i) Weight / *W* / *mg* − vertically downwards from some point on the body

B1

Friction − vertically upwards and touching both the wall and the body

B1

Centripetal force / normal reaction / R − horizontally to the left from the body
Each must be correct and correctly labelled
Minus one for each additional inappropriate force

B1

(ii) Centripetal force / reaction / R is smaller

B1

Frictional force reduces
Frictional force is less than weight
Resultant force is downward
Friction is proportional to (normal) reaction

B1
2

(b) (i) $r\omega^2 = 29$ or
$v^2 / r = 29$

B1

Use of correct radius leading to 3.590 (rad s^{-1}) to at least 3 sig figs

2.54 using wrong r = 1 mark

B1
2

(ii) Angular acceleration, $\alpha = 3.6 / 20$ OR $3.59 / 20$ or 0.18 or 0.1795

C1

3.8 (3.77, 3.78) × 10^4 cao

A1

N m or kg m^2 s^{-2}

B1
3

(iii) 2200 N cao

B1
1

(c) (i) C

B1

1

(ii) Speed greatest (as all PE turned to KE)

B1

Total reaction force = $mr\omega^2 + mg$ or $v^2 / r + mg$ or R is largest or
$R = ma + mg$
OR
Acceleration = v^2 / r

B1

2

[14]

5

(a) $v = \omega r$ or $v = \frac{2\pi r}{T}$ or $v = 2\pi rf$

C1

$\omega = 2\pi \times 45 / 60$ or correct substitutions for v

C1

0.59 ms^{-1}

A1

(b) (i) radial arrow from D towards centre of disc

B1

(ii) $a = \frac{v^2}{r}$ or $a = \omega^2 r$ condone $a = \omega^2 x$ **but not** $a = -(2\pi f)^2 x$

2.78 m s^{-2} **but not if shm equation clearly used**

A1

(c) recognition that closer toward centre particles need smaller centripetal force

B1

support for this: $v \propto r$ or ω = constant along disc

B1

idea that friction / electrostatic forces are sufficient to meet the requirements of particles close to centre but not for those further away

B1

[9]

6 (a) (i) $r = 0.012$ (m) **(1)**

(use of $v = 2\pi fr$ gives) $v = 2\pi 50 \times 0.012$ **(1)**

$= 3.8\ \text{m s}^{-1}$ **(1)** ($3.77\ \text{m s}^{-1}$)

(ii) correct use of $a = \frac{v^2}{r}$ or $a = \frac{3.8^2}{0.012}$ **(1)**

$= 1.2 \times 10^3\ \text{m s}^{-2}$ **(1)**

[or correct use of $a = \omega^2 r$]

(allow C.E. for value of v from (i)

5

(b) panel resonates **(1)**

(because) motor frequency = natural frequency of panel **(1)**

2

QWC 2

[7]

Examiner reports

1 The rubric for the paper requires students to show their working and it is generally wise for a student to do so since otherwise credit cannot be given when an incorrect answer is obtained. This usually involves showing any equation used and the substitution of numerical values into it. When these steps are not shown, marks may not be gained even when the final answer is numerically correct and this led to some of the more careless students failing to gain some of the marks in part (a). There were several successful routes to the answer in part (i), using angular speed, linear speed and / or time period or frequency. The main causes of weaker answers were thinking that an answer in radians was the final answer in degrees, or not showing how a conversion from radians to degrees had been carried out.

The majority of answers for the tension in part (a)(ii) were correct, arrived at by the use of either $m\omega^2 r$ or mv^2 / r. Part (b), the maximum frequency of rotation, was also usually addressed successfully.

The final part of the question required an explanation of the mechanics of the rotated ball in terms of Newton's laws and an explanation of why the supporting string would not be horizontal. This part was used to assess the quality of the students' written communication by applying a standard 6-mark scheme. The understanding of circular motion traditionally presents difficulties for many, and the students in 2015 were no exception. It was at least satisfying to see a greater proportion of them attempting to address the bullet points than has often been the case previously. In order to achieve an intermediate level grading (3-4 marks) it was necessary for the answer to show knowledge and understanding of how at least one of Newton's laws applies. For a high level grading (5-6 marks) this was required for at least two of the laws, together with some understanding of the non-horizontal string. On the whole the students showed some familiarity with Newton's laws, particularly the second law and the third law. How they apply to circular motion was more demanding. Fundamental to any satisfactory explanation is the observation that although the speed of the ball is constant its velocity is not. It is therefore accelerated at right angles to the path and this requires a force to act in this same direction. Common misconceptions were that the ball continues at constant *speed* because no overall force acts on it (supposedly Newton I), or that the ball is in equilibrium in an orbit of constant radius because equal and opposite radial forces are acting (supposedly Newton III). The most able students were able to apply all of the laws correctly to the rotated ball and to explain the non-horizontal string by considering the weight of the ball being balanced by the vertical component of the tension.

2 This question on circular motion involving angular velocity caused less confusion than similar questions have done recently. A significant number of candidates, over a range of ability levels, were able to arrive at a correct answer. There was the usual confusion between orbital speed and angular velocity, but this was certainly not a major problem. The units for acceleration in part (ii) caused a few problems, with some of the better candidates giving the unit rad s^{-2}

Most candidates could say no more than "a polymer is a long chain molecule". The mention of monomers or cross-linking was quite rare.

3 (a) The majority of students gained full marks.

(b) (i) The calculation was generally well done but few could state the correct units kg m^2. The alternative N ms^2 was acceptable but those who included rad as N $mrads^2$ were penalised.

(ii) A common error was to use θ = ωt, thus giving an answer for constant speed. Many of those who used $\theta = \omega t + 1/2 \infty t^2$ did not use a negative value for the deceleration.

(c) (i) Most students had no problem here, however, a few took the angular speed to be the linear speed.

(ii) Many students demonstrated a lack of understanding of centripetal force. Some thought that its origin was the axis of rotation and others thought it acted outwards. Those who knew that it was provided by friction needed to indicate where the friction was acting. Some showed in pointing outwards on the diagram. Most students stated that the operator was leaning inwards to be nearer the axis and very few gave the correct reason.

4 (a) (i) Weight was drawn correctly by most candidates, but friction was usually drawn away from the wall and some drew force pointing to the right, presumably to "balance" the forces.

(ii) Some candidates believed that reaction force and centripetal force were not connected, and the relation between friction and reaction was not appreciated.

(b) (i) Easy question. Some used diameter instead of radius.

(ii) Many calculations erroneously used $T = I\omega$

Although N m for the unit was the majority answer, some gave the answer in kg, m and s, which if correct was credited, but answers which included rad were marked wrong, since rad is dimensionless.

(iii) A mark was thrown away by many candidates, who did not realise that the appropriate number of significant figures was 2.

(c) (i) Most plumped for **C**.

(ii) Very few mentioned the key fact that at **C** the speed is greater.

5

(a) Generally this was well answered; the most common mistake was in converting 45 rpm into a value for ω in rad s^{-1}.

(b) (i) Most candidates answered this correctly. Nevertheless radially outward forces were shown quite regularly as were tangential forces.

(ii) Although most candidates calculated the centripetal acceleration correctly many were penalised for clearly using the simple harmonic motion equation in the form $a = -2\pi f)^2 x$.

(c) Very few candidates gave complete explanations for this part. Many candidates appeared confused and the argument that "at a greater radius the centripetal force would be greater and would push the dust particles towards the centre of the disc" was commonplace, as was the idea that centripetal force decreases with increasing radius (from the equation $a = v^2 / r$). Those candidates recognising that the angular velocity is constant and then going on to use the $a = \omega^2 r$ tended to give the best answers. The expected argument took the form:

- as ω is constant the required centripetal force is proportional to r;
- for small r the friction electrostatic combination is sufficient to provide the required force;
- for large r this is not so and so the dust continues in a straight line and flies off tangentially.

6

Many candidates scored all three marks in part (a)(i), but some were careless and used the given value of diameter for the radius or did not include π in their calculations. A few candidates lost the final mark as a result of giving the answer to too many significant figures.

In part (ii), although some candidates confused speed with angular velocity, many correct answers were seen using $\frac{v^2}{r}$ or $\omega^2 r$. Candidates who repeated the error of using the value of the diameter rather than the radius were not penalised again.

In part (b) most candidates knew that the effect was due to resonance but not all of them were able to provide a clear explanation of why resonance occurred at a particular rotational speed of the motor.