Mark schemes

1 (a) $\omega \left(= \frac{2\pi}{T}\right) = \frac{2\pi}{97 \times 60}$ [or $\omega \left(= \frac{360}{T}\right) = \frac{360}{97 \times 60}$]

$= 1.1 \times 10^{-3}$ (1.08×10^{-3}) **(1)** [$= 6.2$ (6.19) $\times 10^{-2}$]

rad s^{-1} [accept s^{-1}] **(1)** [degree s^{-1}]

3

(b) (i) $\frac{GMm}{r^2} = m\omega^2 r$ **or** $r^3 = \frac{GM}{\omega^2}$ **(1)**

gives $r^3 = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{(1.08 \times 10^{-3})^2}$ **(1)**

$\therefore r = 6.99 \times 10^6$ (m) **(1)**

3

(ii) F (= $m\omega^2 r$) = $1.1 \times 10^4 \times (1.08 \times 10^{-3})^2 \times 6.99 \times 10^6$ **(1)**

$= 9.0 \times 10^4$ (8.97×10^4) (N) **(1)**

[**or** $F\left(= \frac{GMm}{r^2}\right) = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24} \times 1.1 \times 10^4}{(6.99 \times 10^6)^2}$ **(1)**

$= 9.0 \times 10^4$ (8.98×10^4) (N) **(1)**]

2

[8]

2 (a) (i) change of momentum (= 0.44 × 32) = 14(.1) kg m s^1 **(1)**

(ii) (use of $F = \frac{\Delta(mv)}{\Delta t}$ gives) $F = \frac{14.1}{9.2 \times 10^{-3}}$ **(1)**

$= 1.5(3) \times 10^3$N **(1)**

(allow C.E. for value of $\Delta(mv)$ from (i)

3

(b) (i) deceleration = $\frac{24 - 15}{9.2 \times 10^{-3}}$ = 9.8×10^2m s^{-2} **(1)**

(9.78×10^2m s^{-2})

(ii) (use of $a = \frac{v^2}{r}$ gives)

centripetal acceleration = $\frac{24^2}{0.62}$ = 9.3×10^2m s^{-2} **(1)**

(9.29×10^2 m s^{-2})

(iii) before impact: radial pull on knee joint due to centripetal acceleration of boot **(1)**
during impact: radial pull reduced **(1)**

4

[7]

3 (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 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]

4 (a) kinetic energy = mgh **(1)** = 0.37 J **(1)**

(b) $v = \sqrt{\frac{2E}{m}}$ **(1)** = 2.22 ms^{-1} **(1)**

(c) $F_c = 2.9$ N [or 3.0 N if $g = 10$ used] **(1)**

(d) $T = F_c + W = 4.4$ N **(1)**

[6]

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

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

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

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

[5]

6

(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]

7 C **[1]**

8 D **[1]**

9 B **[1]**

10 D **[1]**

11 C **[1]**

12 D **[1]**

13 C **[1]**

14 A

[1]

Examiner reports

1 This question as a whole was very rewarding for the candidates who were sufficiently familiar with the principles of gravitation to understand the mathematical conditions for a satellite in stable orbit, as required in part (b) (i). These candidates made good progress with all parts of the question, whereas many other candidates were only able to score well on parts (a) and (b) (ii). In part (a), the correct conversion of the orbital time of the Hubble satellite into seconds followed by correct use of $\omega = 2\pi/T$, with a correct unit for angular speed, brought full marks for the majority of the candidates. Confusion of angular speed ω with linear speed v continues to be a problem, and giving the unit of ω as m s^{-1} inevitably caused the loss of one mark.

Part (b) (i) required candidates to appreciate that the radius of the orbit of a satellite can be found from the orbit equation $GMm/r^2 = m\omega^2 r$. The angular speed ω had been determined in part (a), whilst the values for G and the Earth's mass M could be taken from the *Data and Formulae Booklet*. Because the question had indicated that the Hubble telescope is in orbit close to the Earth, some candidates assumed that the radius of its orbit would be that of the Earth, 6.37×10^6 m.

Another common unsuccessful response was to attempt to determine the answer using the orbit relationship T^2/r^3 = constant, incorrectly treating the surface of the Earth as a satellite orbit and using T = 24 hours and r = 6.37×10^6 m.

Candidates who used $F = m\omega^2 r$, or $F = GMm/r^2$, had very little difficulty in part (b) (ii), where both marks were still accessible to those who had worked out wrong values for ω and/or r in the earlier parts of the question. Attempts at this part using $F = mv^2/r$ were often incorrect because of inability to correctly work out the linear speed, v.

2 In part (a) most candidates calculated the momentum correctly, although N s^{-1} was commonly given as the unit of momentum. Many correct answers were seen in part (ii), although a significant number of candidates misread the impact time as 9.2 s. The final answer was often presented with too many significant figures.

Many correct calculations were seen in part (b) (i) although some candidates attempted to use $v^2 = u^2 + 2as$ with s = 0.62 m. In part (ii), most candidates calculated the centripetal acceleration correctly. In both parts, incorrect units or provision of answers with too many significant figures were not uncommon. In part (iii), few candidates realized that the radial force pulled on the knee joint although a significant number of candidates knew that the force after impact was less because the speed was less. Many candidates failed to confine their answer to the limits set by the question and discussed features not relevant to the question.

3 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.

4 Candidates failing to equate kinetic energy with change in potential energy in part (a) made little useful headway. Such candidates attempted to use the expression for the velocity of a particle performing harmonic motion in terms of amplitude and angular frequency. Since the amplitude of the oscillator is equal to 90° the mass does not perform harmonic motion and such a calculation is invalid.

In part (b) the velocity of the mass is easily determined from the kinetic energy.

Most candidates were able to determine the magnitude of the centripetal force in part (c).

In part (d) the magnitude of the tension in the string is equal to the sum of the centripetal force and the weight of the oscillating mass. Many candidates assumed, incorrectly, that the tension in the string was equal to the weight of the mass.

5 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.

6 (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.

7 This question had a facility of 65%, up from 59% when used previously. Its subject was angular speed and its effect on the linear displacement of a model car moving around a circle. In 6.0 s, the car would travel through an angular displacement of 3π radians, taking it round the circle 1½ times and therefore to the opposite end of a diameter. An incorrect answer of 2.4π m (the distance travelled) would have been understandable, but it was not on the list of distractors. The common incorrect answers were distractors B (the distance travelled after 1.0 s) and D (the distance travelled after 4.0 s).

8 In this question most students realised that the centripetal force on the mass acts towards the centre of the circle in which it moves, and very few were distracted by the weight of the mass. 73% of the responses were correct. This question had been used in a 2010 examination, when 9% fewer students chose the correct answer.

9 This question, on circular motion in a vertical circle, produced correct responses form almost 70% of the students. The most popular incorrect choice was distractor C, made by 26%. This error follows from the wrong resolution of forces when applying $F_{res} = ma$. $T = mg + mv^2 / r$ leads to T = 17N whereas $T + mg = mv^2 / r$ gives T = 13N.

10 This question was a fairly direct test of centripetal acceleration $a = (2\pi f)^2 r$, although it did also need a time in minutes to be converted to seconds, together with $f = 1 / T$ and the realisation that r = 65m. This proved to be the easiest question in the test, because 86% of the candidates selected the correct response. The remaining 14% were fairly evenly spread across the other three distractors. The question had appeared in an earlier Unit 4 test; on that occasion its facility was 15% lower but the question was more discriminating.

11 This question had also appeared in a previous Unit 4 test. The facility was 65% in 2013 whereas it was 5% lower when last used. Equating $m\omega^2 r$ with $mg / 2$ readily leads to the correct expression for the angular speed. 27% of the responses were for distractor A, probably caused by confusing speed with angular speed and therefore equating mv^2 / r *with* $mg / 2$.

12 This question involved applying the mechanics of circular motion to a body moving in a vertical circle. The tension in the support string will be a maximum when the body is at the lowest point of the path, where $T - mg = m\omega^2 r$. Just over half of the candidates did this correctly. Distractor C was the most common incorrect answer, probably caused by applying Newton's second law incorrectly by assuming that $T + mg = m\omega^2 r$. This was the most discriminating question in the test.

13 Motion at constant speed in a circle was the subject of this question, which had appeared in a previous examination. This time over 80% of the responses were correct, candidates realising that velocity is not constant because of the constant change of direction. Perhaps this question illustrates better than any other the need for candidates to read the statements very carefully when asked to choose an *incorrect* statement, because distractor A (which clearly is a *correct* statement) was selected by 12% and was the most popular wrong choice.

14 In this question, which was also a re-used question, could be solved by combining $v = \omega r$ and $\omega = 2\pi / T$. Three quarters of the responses were correct, and this question discriminated well. The most common incorrect choice was distractor D, where the answer is the angular speed ω instead of the linear speed v.