Q1. (a) A simple pendulum is given a small displacement from its equilibrium position and performs *simple harmonic motion*.

State what is meant by simple harmonic motion.

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....

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(2)

(b) (i) Calculate the frequency of the oscillations of a simple pendulum of length 984 mm. Give your answer to an appropriate number of significant figures.

frequency .... Hz

(3)

(ii) Calculate the acceleration of the bob of the simple pendulum when the displacement from the equilibrium position is 42 mm.

acceleration .... ms^{-2}

(2)

(c) A simple pendulum of time period 1.90 s is set up alongside another pendulum of time period 2.00 s. The pendulums are displaced in the same direction and released at the same time.

Calculate the time interval until they next move in phase. Explain how you arrive at your answer.

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....

time interval .... s

(3)

(Total 10 marks)

Q2. (a) A spring, which hangs from a fixed support, extends by 40 mm when a mass of 0.25 kg is suspended from it.

(i) Calculate the spring constant of the spring.

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(ii) An additional mass of 0.44 kg is then placed on the spring and the system is set into vertical oscillation. Show that the oscillation frequency is 1.5 Hz.

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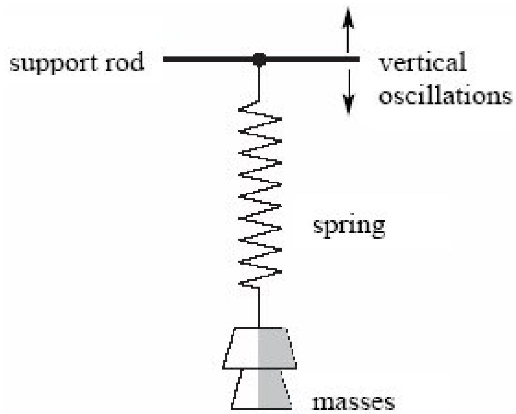
(4)

(b) With both masses still in place, the spring is now suspended from a horizontal support rod that can be made to oscillate vertically, as shown in the diagram below, with amplitude 30 mm at several different frequencies.



The response of the masses suspended from the spring to the vertical oscillations of the support rod varies with frequency. Describe and explain, as fully as you can, the motion of the masses when the support rod oscillates at a frequency of (i) 0.2 Hz, (ii) 1.5 Hz and (iii) 10 Hz.

The quality of your written answer will be assessed in this question.

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(6)
(Total 10 marks)

Q3. (a) A spring, which hangs from a fixed support, extends by 40 mm when a mass of 0.25 kg is suspended from it.

(i) Calculate the spring constant of the spring.

....

....

(ii) An additional mass of 0.44 kg is then placed on the spring and the system is set into vertical oscillation. Show that the oscillation frequency is 1.5 Hz.

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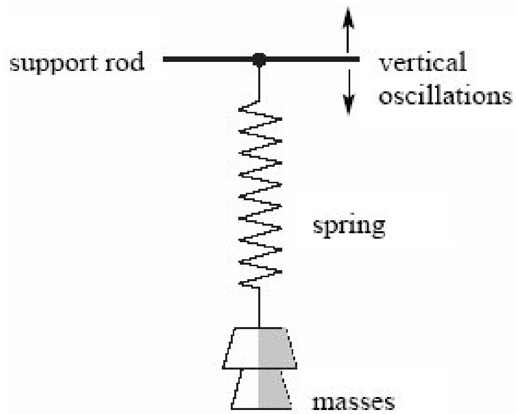
(4)

(b) With both masses still in place, the spring is now suspended from a horizontal support rod that can be made to oscillate vertically, as shown in the diagram below, with amplitude 30 mm at several different frequencies.



The response of the masses suspended from the spring to the vertical oscillations of the support rod varies with frequency. Describe and explain, as fully as you can, the motion of the masses when the support rod oscillates at a frequency of (i) 0.2 Hz, (ii) 1.5 Hz and (iii) 10 Hz.

The quality of your written answer will be assessed in this question.

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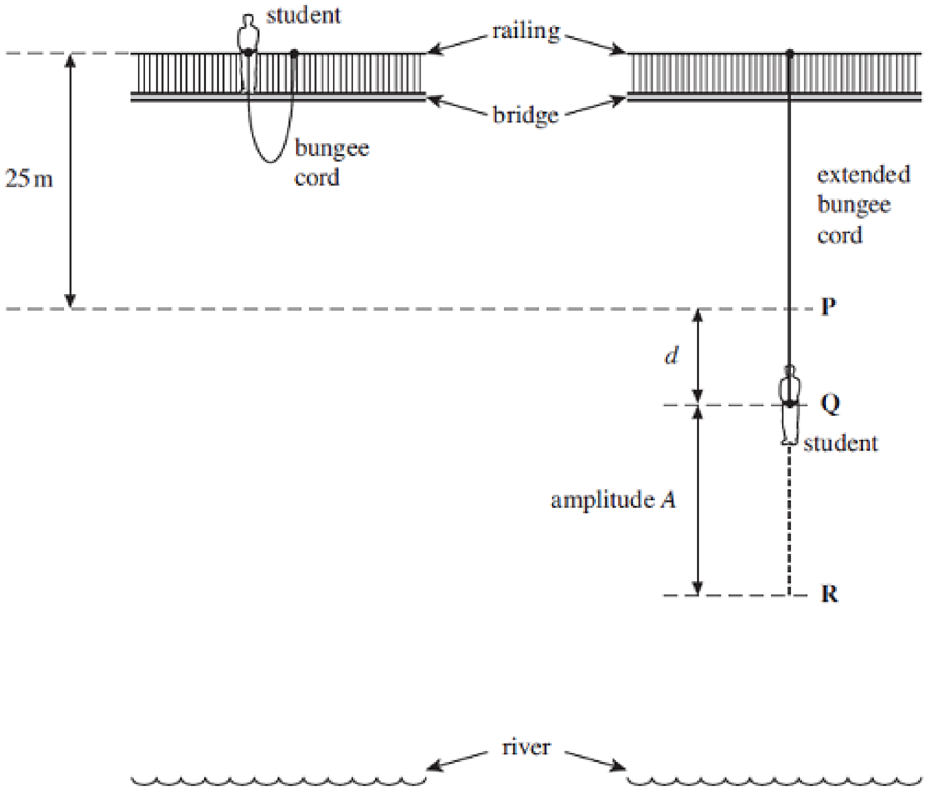
(6)
(Total 10 marks)

Q4. The two diagrams in the figure below show a student before and after she makes a bungee jump from a high bridge above a river. One end of the bungee cord, which is of unstretched length 25 m, is fixed to the top of a railing on the bridge. The other end of the cord is attached to the waist of the student, whose mass is 58 kg. After she jumps, the bungee cord goes into tension at point **P**. She comes to rest momentarily at point **R** and then oscillates about point **Q**, which is a distance *d* below **P**.

BEFORE **AFTER**



(a) (i) Assuming that the centre of mass of the student has fallen through a vertical distance of 25 m when she reaches point **P**, calculate her speed at **P**.
You may assume that air resistance is negligible.

answer = ... ms^{-1}

(2)

(ii) The bungee cord behaves like a spring of spring constant 54 Nm^{-1}.
Calculate the distance *d*, from **P** to **Q**, assuming the cord obeys Hooke's law.

answer = ... m

(2)

(b) As the student moves below **P**, she begins to move with simple harmonic motion for part of an oscillation.

(i) If the arrangement can be assumed to act as a mass-spring system, calculate the time taken for one half of an oscillation.

answer = ... s

(2)

(ii) Use your answers from parts (a) and (b)(i) to show that the amplitude *A*, which is the distance from **Q** to **R**, is about 25 m.

(3)

(c) Explain why, when the student rises above point **P**, her motion is no longer simple harmonic.

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(2)

(d) (i) Where is the student when the stress in the bungee cord is a maximum?

....

....

(1)

(ii) The bungee cord has a significant mass. Whereabouts along the bungee cord is the stress a maximum? Explain your answer.

....

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....

....

(2)
(Total 14 marks)

Q5. Which of the following is a possible unit for rate of change of momentum?

A N s

B N s^{-1}

C kg ms^{-1}

D kg ms^{-2}

(Total 1 mark)

Q6. The wheel of the London Eye has a diameter of 130 m and rotates at a steady speed, completing one rotation every 30 minutes. What is the centripetal acceleration of a person in a capsule at the rim of the wheel?

A 1.2×10^{-4} ms^{-2}

B 2.5×10^{-4} ms^{-2}

C 3.9×10^{-4} ms^{-2}

D 7.9×10^{-4} ms^{-2}

(Total 1 mark)

Q7. A small body of mass m rests on a horizontal turntable at a distance *r* from the centre. If the maximum frictional force between the body and the turntable is $\frac{mg}{2}$, what is the angular speed at which the body starts to slip?

A $\sqrt{\frac{gr}{2}}$

B $\frac{g}{r}$

C $\sqrt{\frac{g}{2r}}$

D $\frac{1}{2}\sqrt{\frac{g}{r}}$

(Total 1 mark)

Q8. A body of mass 0.50 kg, fixed to one end of a string, is rotated in a vertical circle of radius 1.5 m at an angular speed of 5.0 rad s^{-1}. What is the maximum tension in the string?

A 5.0 N

B 9.0 N

C 14 N

D 24 N

(Total 1 mark)

Q9. A particle of mass *m* oscillates in a straight line with simple harmonic motion of constant amplitude. The total energy of the particle is *E*. What is the total energy of another particle of mass 2*m*, oscillating with simple harmonic motion of the same amplitude but double the frequency?

A *E*

B 2*E*

C 4*E*

D 8*E*

(Total 1 mark)

Q10. When a mass suspended on a spring is displaced, the system oscillates with simple harmonic motion. Which one of the following statements regarding the energy of the system is **incorrect?**

A The potential energy has a minimum value when the spring is fully compressed or fully extended.

B The kinetic energy has a maximum value at the equilibrium position.

C The sum of the kinetic and potential energies at any time is constant.

D The potential energy has a maximum value when the mass is at rest.

(Total 1 mark)

Q11. When a mass M attached to a spring X, as shown in **Figure 1**, is displaced downwards and released it oscillates with time period *T*. An identical spring is connected in series and the same mass M is attached, as shown in **Figure 2**.

What is the new time period?

Figure 1

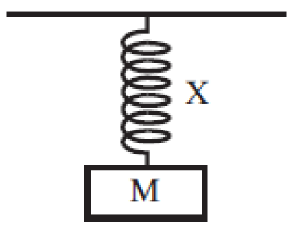
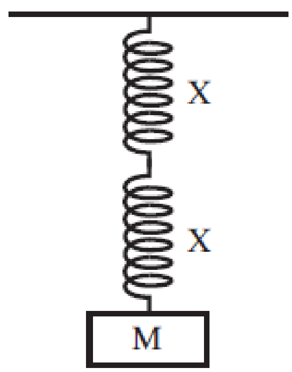


Figure 2



A $\frac{T}{2}$

B $\frac{T}{\sqrt{2}}$

C $\sqrt{2T}$

D $2T$

(Total 1 mark)

Q12. For a particle moving in a circle with uniform speed, which one of the following statements is **incorrect?**

A There is no displacement of the particle in the direction of the force.

B The force on the particle is always perpendicular to the velocity of the particle.

C The velocity of the particle is constant.

D The kinetic energy of the particle is constant.

(Total 1 mark)

Q13. A revolving mountain top restaurant turns slowly, completing a full rotation in 50 minutes. A man is sitting in the restaurant 15 m from the axis of rotation. What is the speed of the man relative to a stationary point outside the restaurant?

A $\frac{\pi}{100}$ m s^{-1}

B $\frac{3\pi}{5}$ m s^{-1}

C $\frac{\pi}{200}$ m s^{-1}

D $\frac{\pi}{1500}$ m s^{-1}

(Total 1 mark)

Q14. A particle of mass 0.20 kg moves with simple harmonic motion of amplitude 2.0×10^{-2} m. If the total energy of the particle is 4.0×10^{-5}J, what is the time period of the motion?

A $\frac{\pi}{4}$ seconds

B $\frac{\pi}{2}$ seconds

C π seconds

D 2π seconds

(Total 1 mark)

Q15. A simple pendulum and a mass-spring system are taken to the Moon, where the gravitational field strength is less than on Earth. Which line, **A** to **D**, in the table correctly describes the change, if any, in the period when compared with its value on Earth?

	period of pendulum	**period of mass-spring system**
A	increase	no change
B	increase	increase
C	no change	decrease
D	decrease	decrease

(Total 1 mark)

Q16. A mass on the end of a spring undergoes vertical simple harmonic motion. At which point (s) is the magnitude of the resultant force on the mass a minimum?

A at the centre of the oscillation

B only at the top of the oscillation

C only at the bottom of the oscillation

D at both the top and bottom of the oscillation

(Total 1 mark)

Q17. A baby bouncer consisting of a harness and elastic ropes is suspended from a doorway. When a baby of mass 10 kg is placed in the harness, the ropes stretch by 0.25 m. When the baby bounces, she starts to move with vertical simple harmonic motion. What is the time period of her motion?

A 1.0 s

B 2.1 s

C 2.3 s

D 3.1 s

(Total 1 mark)

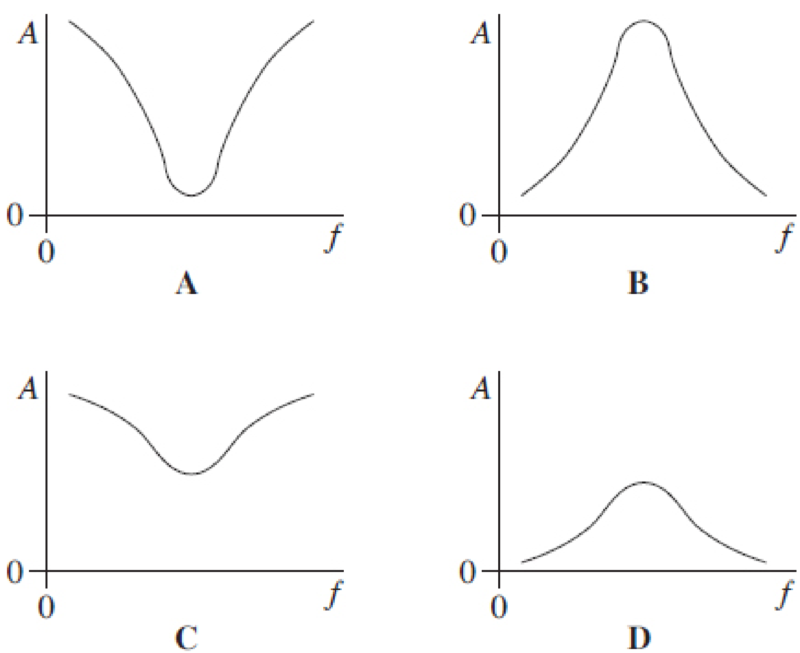
Q18. A simple pendulum and a mass-spring system both have the same time period T at the surface of the Earth. If taken to another planet where the acceleration due to gravity is twice that on Earth, which line, **A** to **D**, in the table gives the correct new time periods?

	simple pendulum	**mass-spring**
A	$T\sqrt{2}$	$\frac{T}{\sqrt{2}}$
B	$T\sqrt{2}$	T
C	$\frac{T}{\sqrt{2}}$	T
D	$\frac{T}{\sqrt{2}}$	$T\sqrt{2}$

(Total 1 mark)

Q19. An oscillatory system, subject to damping, is set into vibration by a periodic driving force of frequency f. The graphs, **A** to **D**, which are to the same scale, show how the amplitude of vibration A of the system might vary with f, for various degrees of damping.

Which graph best shows the lightest damping?



(Total 1 mark)

Q20. Which one of the following statements is true when an object performs simple harmonic motion about a central point O?

A The acceleration is always directed away from O.

B The acceleration and velocity are always in opposite directions.

C The acceleration and the displacement from O are always in the same direction.

D The graph of acceleration against displacement is a straight line.

(Total 1 mark)

Q21. A mechanical system is oscillating at resonance with a constant amplitude. Which one of the following statements is **not** correct?

A The applied force prevents the amplitude from becoming too large.

B The frequency of the applied force is the same as the natural frequency of oscillation of the system.

C The total energy of the system is constant.

D The amplitude of oscillations depends on the amount of damping.

(Total 1 mark)

Q22. For a particle moving in a circle with uniform speed, which one of the following statements is correct?

A The kinetic energy of the particle is constant.

B The force on the particle is in the same direction as the direction of motion of the particle.

C The momentum of the particle is constant.

D The displacement of the particle is in the direction of the force.

(Total 1 mark)

Q23. A young child of mass 20 kg stands at the centre of a uniform horizontal platform which rotates at a constant angular speed of 3.0 rad s^{-1}. The child begins to walk radially outwards towards the edge of the platform. The maximum frictional force between the child and the platform is 200 N. What is the maximum distance from the centre of the platform to which the child could walk without the risk of slipping?

A 1.1 m

B 1.3 m

C 1.5 m

D 1.7 m

(Total 1 mark)

Q24. A particle travels at a constant speed around a circle of radius *r* with centripetal acceleration *a*. What is the time taken for ten complete rotations?

A $\frac{\pi}{5}\sqrt{\frac{a}{r}}$

B $\frac{\pi}{5}\sqrt{\frac{r}{a}}$

C $20\pi\sqrt{\frac{a}{r}}$

D $20\pi\sqrt{\frac{r}{a}}$

(Total 1 mark)

Q25. The frequency of a body moving with simple harmonic motion is doubled. If the amplitude remains the same, which one of the following is also doubled?

A the time period

B the total energy

C the maximum velocity

D the maximum acceleration

(Total 1 mark)

Q26. The time period of a pendulum on Earth is 1.0 s. What would be the period of a pendulum of the same length on a planet with half the density but twice the radius of Earth?

A 0.5 s

B 1.0 s

C 1.4 s

D 2.0 s

(Total 1 mark)

Q27. Which one of the following statements always applies to a damping force acting on a vibrating system?

A It is in the same direction as the acceleration.

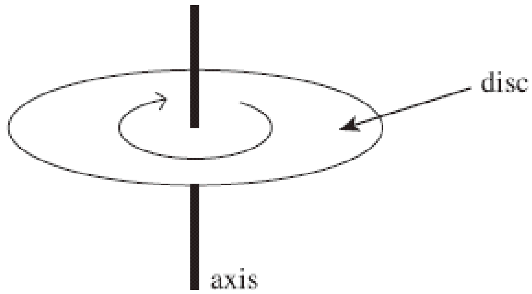
B It is in the same direction as the displacement.

C It is in the opposite direction to the velocity.

D It is proportional to the displacement.

(Total 1 mark)

Q28. The diagram shows a disc of diameter 120 mm that can turn about an axis through its centre.



The disc is turned through an angle of 30° in 20 ms. What is the average speed of a point on the edge of the disc during this time?

A 0.5π m s^{-1}

B π m s^{-1}

C 1.5π m s^{-1}

D 2π m s^{-1}

(Total 1 mark)

Q29. A particle of mass *m* moves in a circle of radius *r* at a uniform speed with frequency *f*. What is the kinetic energy of the particle?

A $\frac{mf^2r^2}{4\pi^2}$

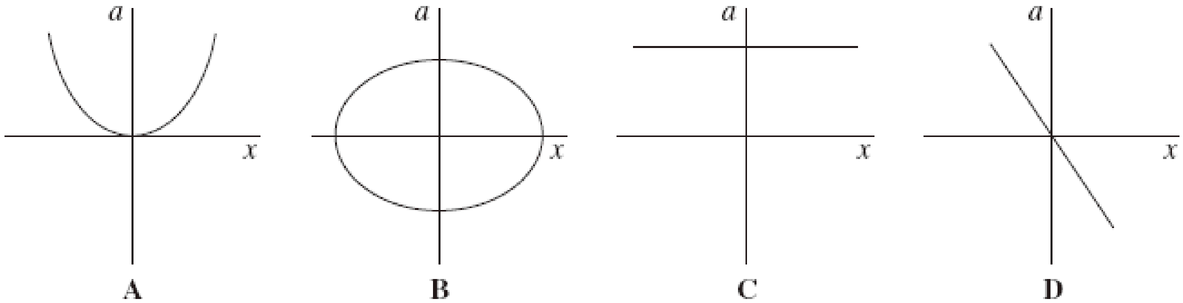
B $\frac{mf^2r}{2}$

C $2\pi^2 mf^2r^2$

D $4\pi^2 mf^2r^2$

(Total 1 mark)

Q30. Which one of the following graphs shows how the acceleration, *a*, of a body moving with simple harmonic motion varies with its displacement, *x*?



(Total 1 mark)

Q31. A body moves with simple harmonic motion of amplitude A and frequency $\frac{b}{2\pi}$.
What is the magnitude of the acceleration when the body is at maximum displacement?

A zero

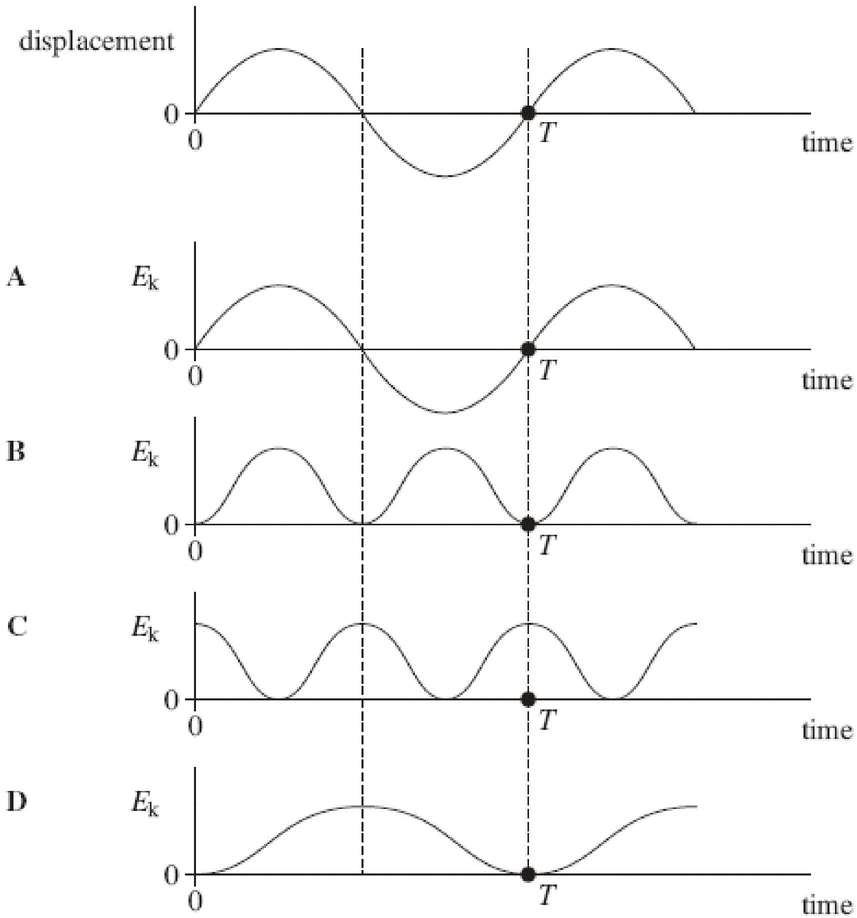
B $4\pi^2 Ab^2$

C Ab^2

D $\frac{4\pi^2 A}{b^2}$

(Total 1 mark)

Q32. An object oscillating in simple harmonic motion has a time period T. The first graph shows how its displacement varies with time. Which of the subsequent graphs, **A** to **D**, show how the kinetic energy, E_k, of the object varies with time?



(Total 1 mark)

Q33. The period of vertical oscillation of a mass-spring system is T when the spring carries a mass of 1.00 kg. What mass should be added to the 1.00 kg if the period is to be increased to 1.50 T?

A 0.25 kg

B 1.00 kg

C 1.25 kg

D 2.00 kg

(Total 1 mark)

Q34. A particle of mass *m* moves in a circle of radius *r* at uniform speed, taking time ***T*** for each revolution. What is the kinetic energy of the particle?

A $\dfrac{\pi^2 mr}{T^2}$

B $\dfrac{\pi^2 mr^2}{T^2}$

C $\dfrac{2\pi^2 mr^2}{T}$

D $\dfrac{2\pi^2 mr^2}{T^2}$

(Total 1 mark)

Q35. A particle of mass *m* moves in a circle of radius *r* at uniform speed, taking time ***T*** for each revolution. What is the kinetic energy of the particle?

A $\dfrac{\pi^2 mr}{T^2}$

B $\dfrac{\pi^2 mr^2}{T^2}$

C $\dfrac{2\pi^2 mr^2}{T}$

D $\dfrac{2\pi^2 mr^2}{T^2}$

(Total 1 mark)

M1. (a) acceleration is proportional to displacement (from equilibrium) ✓

Acceleration proportional to negative displacement is 1st mark only.

acceleration is in opposite direction to displacement

or towards a fixed point / equilibrium

Don't accept "restoring force" for accln.

position ✓

2

(b) (i) $f\left(=\frac{1}{2\pi}\sqrt{\frac{g}{l}}\right)=\frac{1}{2\pi}\sqrt{\frac{9.81}{0.984}}$ ✓ $= 0.503\ (0.5025)\ (\text{Hz})$ ✓

3SF is an independent mark.

[**or** $T\left(=2\pi\sqrt{\frac{l}{g}}\right)=2\pi\sqrt{\frac{0.984}{9.81}}$ ✓ (= 1.9(90) (s))

When g = 9.81 is used, allow either 0.502 or 0.503 for 2nd and 3rd marks.

$f\left(=\frac{1}{T}\right)=\frac{1}{1.990} = 0.503\ (0.5025)\ (\text{Hz})$ ✓]

***Use of g = 9.8** gives 0.502 Hz: award only 1 of first 2 marks if quoted as 0.502, 0.503 0.50 or 0.5 Hz.*

answer to **3SF** ✓

3

(ii) $a\left(=-(2\pi f)^2 x\right)=(-)(2\pi\times 0.5025)^2\times 42\times 10^{-3}$ ✓

*Allow ECF from **any** incorrect f from (b)(i).*

= 0.42 (0.419) (m s^{-2}) ✓

2

(c) recognition of 20 oscillations of (shorter) pendulum

and / or 19 oscillations of (longer) pendulum ✓

Explanation: difference of 1 oscillation or phase change of 2 π

or Δt = 0.1 so *n* = 2 / 0.1 =20, **or** other acceptable point ✓

time to next in phase condition = 38 (s) ✓

Allow "back in phase (for the first time)" as a valid explanation.

[**or** (*T* = 1.90 s so) (*n* + 1) × 1.90 = *n* × 2.00 ✓

gives *n* = 19 (oscillations of longer pendulum) ✓

minimum time between in phase condition = 19 × 2.00 = 38 (s) ✓]

3

[10]

M2. (a) (i) $mg = ke$ **(1)**

$$k = \left(\frac{0.25 \times 9.81}{40 \times 10^{-3}}\right) = 61(.3)\ \text{N m}^{-1}\ \textbf{(1)}$$

(ii) $T = \left(= 2\pi\sqrt{\frac{m}{k}}\right) = 2\pi\sqrt{\frac{0.69}{61.3}}$ **(1)** (= 0.667 s)

$f\left(= \frac{1}{T}\right) = \frac{1}{0.667}$ **(1)** (= 1.5(0) Hz)

4

(b) The marking scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC). There are no discrete marks for the assessment of QWC but the candidates' QWC in this answer will be one of the criteria used to assign a level and award the marks for this part of the question.

Level	**Descriptor** an answer will be expected to meet most of the criteria in the level descriptor	**Mark range**
Good **3**	– answer supported by appropriate range of relevant points – good use of information or ideas about physics, going beyond those given in the question – argument well structured with minimal repetition or irrelevant points – accurate and clear expression of ideas with only minor errors of spelling, punctuation and grammar	**5-6**
Modest **2**	– answer partially supported by relevant points – good use of information or ideas about physics given in the question but limited beyond this – the argument shows some attempt at structure – the ideas are expressed with reasonable clarity but with a few errors of spelling, punctuation and grammar	**3-4**
Limited **1**	– valid points but not clearly linked to an argument structure – limited use of information or ideas about physics – unstructured – errors in spelling, punctuation and grammar or lack of fluency	**1-2**
0	– incorrect, inappropriate or no response	**0**

examples of the sort of information or idea that might be used to support an argument

- forced vibrations (at 0.2 Hz) **(1)**
- amplitude fairly large (≈ 30 mm) **(1)**
- in phase with driver **(1)**
- resonance (at 1.5 Hz) **(1)**
- amplitude very large (> 30 mm) **(1)**
- oscillations may appear violent **(1)**
- phase difference at 90º **(1)**
- forced vibrations (at 10 Hz) **(1)**
- small amplitude **(1)**
- out of phase with driver or phase lag of π on driver **(1)**

[10]

M3. (a) (i) $mg = ke$ **(1)**

$$k = \left(\frac{0.25 \times 9.81}{40 \times 10^{-3}}\right) = 61(.3)\ \mathrm{N\ m^{-1}}$$ **(1)**

(ii) $T = \left(= 2\pi\sqrt{\frac{m}{k}}\right) = 2\pi\sqrt{\frac{0.69}{61.3}}$ **(1)** (= 0.667 s)

$f\left(= \frac{1}{T}\right) = \frac{1}{0.667}$ **(1)** (= 1.5(0) Hz)

4

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- forced vibrations (at 10 Hz) **(1)**
- small amplitude **(1)**
- out of phase with driver or phase lag of π on driver **(1)**

[10]

M4. (a) (i) speed at P, v (= $\sqrt{2gh}$) = $\sqrt{2 \times 9.81 \times 25}$ ✓

= 22(.1) (m s^{-1}) ✓

2

(ii) use of $F = k\Delta L$ gives $d \left(= \frac{F}{K}\right) = \frac{58 \times 9.81}{54}$ ✓

= 11 (10.5) (m) ✓

2

(b) (i) period $T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{58}{54}}$ ✓ (= 6.51 s)

time for one half oscillation = 3.3 (3.26) (s) ✓

2

(ii) frequency $f \left(= \frac{1}{T}\right) = \frac{1}{6.51}$ ✓ (= 0.154 (Hz))

use of $v = \pm 2\pi f \sqrt{A^2 - x^2}$ when x = 10.5 m and v = 22.1 m s^{-1} gives $22.1^2 = 4\pi^2 \times 0.154^2 (A^2 - 10.5^2)$ ✓

from which A = 25.1 (m) ✓

[alternatively, using energy approach gives $\frac{1}{2} m v_P^2 + mg\Delta L = \frac{1}{2} k(\Delta L)^2$ ✓

$\therefore (29 \times 22.1^2) + (58 \times 9.81 \times \Delta L) = 27 (\Delta L)^2$

solution of this quadratic equation gives ΔL = 35.7 (m) ✓

from which A = 25.2 (m) ✓]

3

(c) bungee cord becomes slack ✓

student's motion is under gravity (until she returns to **P**) ✓

has constant downwards acceleration **or** acceleration is not ∝ displacement ✓

2

(d) (i) when student is at **R** or at bottom of oscillation ✓

1

(ii) at uppermost point **or** where it is attached to the railing ✓

because stress = *F/A* and force at this point includes weight of whole cord ✓

[accept alternative answers referring to mid-point of cord because cord will show thinning there as it stretches **or** near knots at top or bottom of cord where A will be smaller with a reference to stress = *F/A*]

2

[14]

M5. D

[1]

M6. D

[1]

M7. C

[1]

M8. D

[1]

M9. D

[1]

M10. A

[1]

M11. C

[1]

M12. C

[1]

M13. A

[1]

M14. D

[1]

M15. A

[1]

M16. A

[1]

M17. A

[1]

M18. C

[1]

M19. B

[1]

M20. D

[1]

M21. A

[1]

M22. A

[1]

M23. A

[1]

M24. D

[1]

M25. C

[1]

M26. B

[1]

M27. C

[1]

M28. A

[1]

M29. C

[1]

M30. D

[1]

M31. C

[1]

M32. C

[1]

M33. C

[1]

M34. D

[1]

M35. D

[1]

E1. Except for part (c), this question was on material familiar to most candidates, so the marks awarded were generally high. In part (a) definitions of simple harmonic motion, in terms of the two features of the acceleration of a body moving with shm, were generally well known. Part (b)(i) presented a greater challenge for candidates who were unsure about how to handle significant figures. All the data required to complete the calculation in this question was available to 3SF. Therefore all the working should have been to at least 3SF and the answer should be quoted to 3SF. Candidates who used g = 9.8 instead of g = 9.81 lost a mark, and a further mark was lost if the final answer was not expressed to 3SF. Some of the weaker candidates did not appear to know the difference between period and frequency. Part (b)(ii) required a straightforward application of a = (–) $(2\pi f)^2$ × and presented few problems.

The solution of the question in part (c), involving the minimum time period between 'in phase' positions of two pendulums of different frequencies, could not be arrived at by a standard method that most candidates would have encountered. Consequently the explanations of how the answer had been arrived at were often unsatisfactory. Trial and error seemed to be a popular approach, sometimes leading to the correct answer of 38s without any working at all.

Probably the most satisfactory solution is to recognise that the *shorter* pendulum must make one more oscillation than the longer pendulum in the required time, hence the number of oscillations of the *longer* pendulum is given by $(n + 1) \times 1.9 = n \times 2.0$. Another successful approach follows from appreciating that Δt = 0.1s, so the number of oscillations required of the shorter pendulum is 2.0 / 0.1 = 20 (alternatively 1.9 / 0.1 gives 19 oscillations of the longer pendulum). This approach sometimes led to an incorrect conclusion, such as 19 × 1.9 = 36.1s, or 20 × 2.0 = 40s.

E4. This question, based on bungee jumping, tested simple harmonic motion in an unfamiliar context and at the same time to provide a synoptic test of some AS content. Examiners were pleased to see that a high proportion of the students were able to cope competently with this unfamiliar situation.

Application of energy conservation, or of the equations for uniformly accelerated motion under gravity, led to a high proportion of correct answers in part (a) (i). The equation representing Hooke's law was well known in part (a) (ii) but a few students showed confusion between mass and weight.

Part (b) (i), which required the time for half of an oscillation, only caused problems for the small number of students who misinterpreted the wording and determined the time for one-and-a-half oscillations. Part (b) (ii) was much more challenging and turned out to be a question that many students returned to answer on a supplementary sheet. The most direct solution came by applying the equation $v = \pm 2\pi f\sqrt{A^2 - x^2}$, with careful choice of the earlier values obtained for v and x, and of the derived value for f. Most students seemed to think a quick solution could be arrived at by applying $v_{max} = 2\pi fA$, but this is incorrect. It is possible to reach a correct solution from energy considerations; this needs particular care over the balance of gravitational pe lost, ke gained and elastic pe gained at some consistent point in the motion. Nevertheless, a few correct solutions using this approach were seen.

In part (c) most students realised that the bungee cord would cease to exert a force on the bungee jumper once she was higher than point P. Few went on to mention that her motion was then purely under gravity or that her acceleration became constant, although references to the fact that acceleration would no longer be proportional to displacement were quite common.

Almost all students gave the correct answer – point R – in part (d) (i). The responses in part (d) (ii) revealed a widespread misunderstanding of the significance of centre of mass, with statements such as 'the stress is a maximum at the centre of the cord because that is where the weight acts' seen. Acceptable answers included at the point where the cord is attached to the railing (where the greatest weight is supported) and (because of possible thinning) half way along the cord. It was expected that students would show that they understood what is meant by stress when formulating their reason, whichever point in the cord they gave.

E5. It is surprising that only 49% of the candidates arrived at the correct answer in this question. Identifying the rate of change of momentum with force, and the unit of force with (mass × acceleration), ought to be relatively straightforward piece of physics for candidates at the end of an A level course. Distractors A and C (where in each case the answer is a unit of momentum) were both chosen by about 20% of the candidates.

E6. 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.

E7. 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* $mg / 2$.

E8. 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.

E9. This question on simple harmonic motion was one of the most demanding questions in the test. Candidates should have realised that the total energy E of the oscillating particle is equivalent to its maximum kinetic energy $\frac{1}{2} m v_{max}^2$, and that $v_{max} = 2\pi fA$. When the amplitude A is constant it follows that E is proportional to mf^2. Doubling both m and f therefore produces an eightfold increase in E. Only 42% of the candidates selected the correct response. Almost inevitably, distractor C – a fourfold increase in E – was the second most popular choice with 32% of the responses. This question was also a good discriminator.

E10. This question was about the energies in a mass-spring system and was much more straightforward than the previous question. It required the selection of an *incorrect* statement. It produced a correct response from two-thirds of the candidates. 25% of the responses were for distractor D; those who made this choice must have thought that the potential energy of the system is *not* a maximum when the oscillating mass is stationary.

E11. This question was the most demanding question in the test, which asked candidates to consider the time period of an oscillating mass when two identical springs are connected in series. When this is done, the extension produced by the same mass must be twice as big, so the effective spring constant k is half of that for one spring. Applying $T = 2\pi\sqrt{m / k}$ should then show that the new time period is $\sqrt{2}$ times greater than the original value. Just 38% of the candidates gave the correct answer. 35% chose distractor B, where the original time period is divided by $\sqrt{2}$ instead of multiplied by $\sqrt{2}$.

E12. 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.

E13. 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.

E14. This question involved a two-stage calculation on the connection between the energy of a particle moving with simple harmonic motion, its mass and the time period. This proved to be demanding, as it had been when the question last appeared in an examination. On the previous occasion slightly fewer than half of the candidates gave the correct answer, whereas this time it was slightly more than half. The question discriminated between the abilities of candidates better than any other in this test. Perhaps it was an inability to translate from $\omega = 1$ to $T = 2\pi/1$ that caused almost a quarter of the candidates to select distractor B, where the answer was $\pi / 2$ instead of 2π.

E15. Candidates now appear to be much more familiar with the effects of the local value of gravitational field strength on the time periods of pendulums and mass-spring systems than was once the case. In this question, which was concerned with these effects on the Moon and on Earth, was answered correctly by almost 90% of the candidates; when used in an examination eleven years ago this question attracted only 67% of correct responses.

E16. This question required students to identify the point (or points) at which the resultant force is a *minimum* when a mass on a spring moves with simple harmonic motion. Almost 60% of them recognised that this could only be at the central point of the oscillation. The most common incorrect response was distractor D (top and bottom of the oscillation), suggesting that there was confusion between the *minimum* and the *maximum* resultant force.

E17. This question was a fairly direct test of $T = 2\pi(m/k)^{1/2}$ for a mass-spring system, but the spring constant k had to be determined first. The question turned out to be remarkably easy, with over 80% of students giving the correct response. When this question was pre-tested, only half of the students had done so.

E18. This question about removing a simple pendulum and a mass-spring system from the Earth to another planet and determining the revised time periods, was a re-banked question from an earlier examination. Its facility in 2012 was 63%, which was a substantial improvement over the previous occasion, but its discrimination was slightly worse this time. Distractor B, chosen by 20% of the students, was the most popular incorrect choice.

E19. This question presented students with four amplitude–frequency graphs for a resonant system, from which they were to select the best illustration of light damping. Around half of the students had this correct; incorrect answers were evenly distributed around the distractors.

E20. This question also re-banked questions, were about features of simple harmonic motion. Their facilities were 67% and 61% respectively, both significant improvements on the previous results.Those who chose distractor D in Question 7 (22% of students) clearly realised that the graph of kinetic energy against distance should be curved, but they chose the wrong shape of curve.

E21. This question required students to choose an incorrect statement about a mechanical system oscillating at resonance. The question had been used in a 2004 examination when it was found to be easy. It proved to be slightly easier this time, with 72% of responses correct. None of the three distractors attracted a response that was significantly higher than the others.

E22. This question, on circular motion, had been used in a previous examination. The facility this time was 62%, an increase of 7% over the previous result. The most common incorrect choices were distractors C and D, each getting 15% of the responses. The popularity of C was probably caused by a failure to understand that momentum is a vector.

E23. Knowledge of circular motion was tested in this question, where familiarity with $F = m\omega^2 r$, was the key to success. This turned out to be the easiest question on the paper, with 83% of the candidates giving correct responses; when pre-tested only 44% of answers were correct.

E24. This question was a sterner test of motion in a circle, because it was a two-stage calculation with algebraic distractors. Just over half of the candidates arrived at the correct result by combining $a = v^2/r$ and $T = 2\pi r/v$. Almost a quarter of the responses were for distractor C, in which the squarerooted expression (r /a) is inverted. This is likely to have been caused by careless rearrangement of the algebra.

E25. Simple harmonic oscillation was the topic tested by this question (which had been used before). 79% of the responses were correct, which was 8% better than when it was last used. This shows that $v_{max} = 2\pi fA$ is well known.

E26. This question was much more demanding because it required application of the relationship between mass and density for a uniform sphere, as well as $g = GM\, IR^2$. Just 41% of the responses were correct.

E27. Candidates for this test were slightly less familiar with the direction of the damping force acting on a vibrating system, required in this question, than those in 2005 when this question was last used. On both occasions about three-fifths of candidates made the right choice. Incorrect responses were fairly evenly spread across the other distractors.

E28. This question required candidates to find the linear speed of a point on the edge of a spinning disc. This is a two-stage calculation involving $\omega = \theta/t$ and $v = \omega r$. Candidates also had to appreciate that 30° is equivalent to p/6 rad, and that the radius of a disc is half of its diameter. 49% the candidates arrived at the correct response, whilst a quarter of them chose distractor B, indicating confusion between d and *r*.

E29. This question was the first of the re-banked questions from a previous examination. Three-quarters of the candidates were able to correctly combine $v = 2\pi fr$ with $E_k = ½\ m\ v^2$ to arrive at the required algebraic result. Distractor D attracted one in eight responses, suggesting that the factor of ½ had been overlooked.

E30. In this question candidates had to know how the acceleration-displacement relationship for a simple harmonic oscillator translates into a graph; linear but having a negative gradient. Slightly less than half of the candidates chose the correct response. Almost as many chose distractor A, which would be the potential energy-displacement graph.

E31. This question was concerned with simple harmonic motion. Candidates found the question, which had appeared in a previous examination, slightly easier than last time; three-quarters of them successfully applied $a = (2\pi f)^2 A$ to give the correct answer. This was the most discriminating question in the examination.

E32. This question was another easy question, the correct kinetic energy-time graph being recognised by over 80% of the candidates.

E33. Calculation of the *additional* mass to be placed on a vertical spring in order to increase the period of oscillations by half was the task in this question. 66% of the candidates did this correctly. Distractor A (where the value was 0.25 kg instead of the correct 1.25 kg) was the most popular alternative; it was chosen by about one-sixth of candidates.

E34. Candidates found the quantitative content of this question on circular motion more to their liking, because 63% of them chose the correct answer. Both of these questions gave statistics which were very similar to those obtained when last used.

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