1 A lead ball of mass 0.25 kg is swung round on the end of a string so that the ball moves in a horizontal circle of radius 1.5 m. The ball travels at a constant speed of 8.6 m s^{-1}.

(a) (i) Calculate the angle, in degrees, through which the string turns in 0.40 s.

angle ____________________ degree

(3)

(ii) Calculate the tension in the string.
You may assume that the string is horizontal.

tension ____________________ N

(2)

(b) The string will break when the tension exceeds 60 N.
Calculate the number of revolutions that the ball makes in one second when the tension is 60 N.

number of revolutions ____________________

(2)

(c) Discuss the motion of the ball in terms of the forces that act on it. In your answer you should:

- explain how Newton's three laws of motion apply to its motion in a circle
- explain why, in practice, the string will not be horizontal.

You may wish to draw a diagram to clarify your answer.

The quality of your written communication will be assessed in your answer.

(6)

(Total 13 marks)

2 **Figure 1** shows three stages during the oscillations of a loaded spring. The positions shown are when the mass attached to the spring is at the top, equilibrium (middle) position and bottom of its motion.

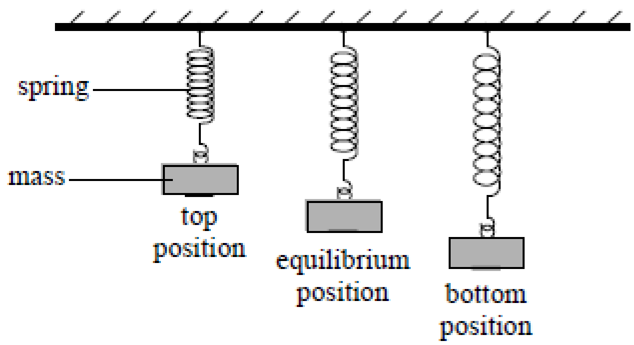


Figure 1

(a) (i) Describe what is meant by the *period* of this oscillation.

___

___

(1)

(ii) Mark and label the *amplitude* of the oscillation on **Figure 1**.

(1)

(b) Explain how you would determine an accurate value for the period of the oscillation.

___

___

___

___

___

___

(2)

(c) The mass is displaced from its equilibrium position in the air and then released. The graph in **Figure 2** shows the displacement-time graph from the moment of release. The mass-spring system is then submerged in water and set oscillating with the same initial displacement.

Sketch **on the same set of axes** the displacement-time graph for the motion in the water.

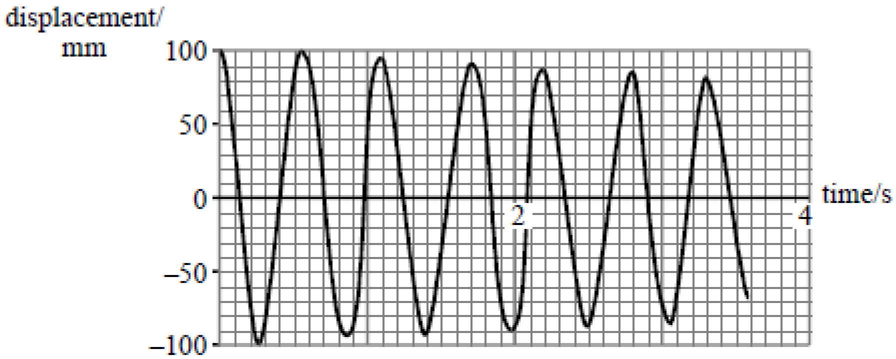


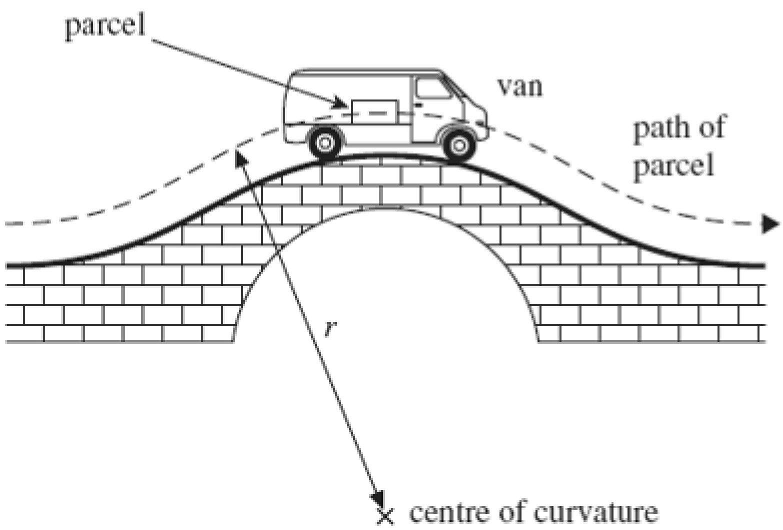
Figure 2

(2)

(Total 6 marks)

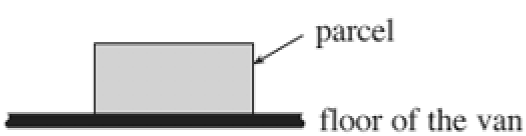
3 **Figure 1** shows a parcel on the floor of a delivery van that is passing over a hump-backed bridge on a straight section of road. The radius of curvature of the path of the parcel is r and the van is travelling at a constant speed v. The mass of the parcel is m.

Figure 1



(a) (i) Draw arrows on **Figure 2** below to show the forces that act on the parcel as it passes over the highest point of the bridge. Label these forces.

Figure 2



(1)

(ii) Write down an equation that relates the contact force, R, between the parcel and the floor of the van to m, v, r and the gravitational field strength, g.

____

____

(1)

(iii) Calculate R if m = 12 kg, r = 23 m, and v = 11ms^{-1}.

answer = ____________________ N

(2)

(b) Explain what would happen to the magnitude of *R* if the van passed over the bridge at a higher speed. What would be the significance of any van speed greater than $15 ms^{-1}$? Support your answer with a calculation.

___

___

___

___

___

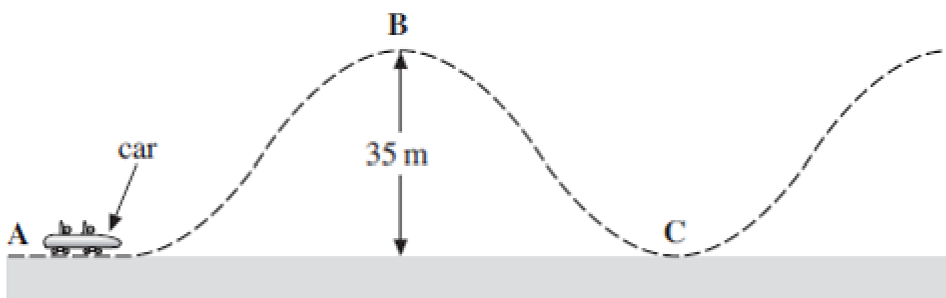
___

___

(3)

(Total 7 marks)

4 The figure below shows a car on a rollercoaster track. The car is initially at rest at **A** and is lifted to the highest point of the track, **B**, 35 m above **A**.



The car with its passengers has a total mass of 550 kg. It takes 25 s to lift the car from **A** to **B**. It then starts off with negligible velocity and moves unpowered along the track.

(a) Calculate the power used in lifting the car and its passengers from **A** to **B**. Include an appropriate unit in your answer.

___

___

___

___

power______________________unit_____________

(3)

(b) The speed reached by the car at **C**, the bottom of the first dip, is 22 ms^{-1}. The length of the track from **B** to the bottom of the first dip **C** is 63 m.

Calculate the average resistive force acting on the car during the descent.

Give your answer to a number of significant figures consistent with the data.

resistive force ______________________ N

(4)

(c) Explain why the resistive force is unlikely to remain constant as the car descends from **B** to **C**.

(3)

(d) At **C**, a passenger of mass 55 kg experiences an upward reaction force of 2160 N when the speed is 22 ms^{-1}.

Calculate the radius of curvature of the track at **C**. Assume that the track is a circular arc at this point.

____

____

____

____

____

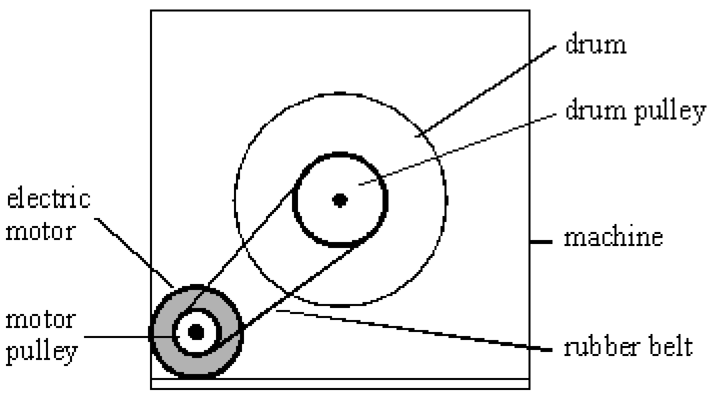
____

radius of curvature of the track ______________________ m

(3)

(Total 13 marks)

5 An electric motor in a machine drives a rotating drum by means of a rubber belt attached to pulleys, one on the motor shaft and one on the drum shaft, as shown in the diagram below.



(a) The pulley on the motor shaft has a diameter of 24 mm. When the motor is turning at 50 revolutions per second, calculate

(i) the speed of the belt,

____

____

____

____

(ii) the centripetal acceleration of the belt as it passes round the motor pulley.

(5)

(b) When the motor rotates at a particular speed, it causes a flexible metal panel in the machine to vibrate loudly. Explain why this happens.

(2)

(Total 7 marks)

6 (a) The equation that describes simple harmonic motion is

$$a = -\omega^2 x.$$

State the meaning of the symbol w in this equation and go on to explain the significance of the negative sign.

(2)

(b) **Figure 1a** shows a demonstration used in teaching simple harmonic motion. A sphere rotates in a horizontal plane on a turntable. A lamp produces a shadow of the sphere. This shadow moves with approximate simple harmonic motion on the vertical screen.

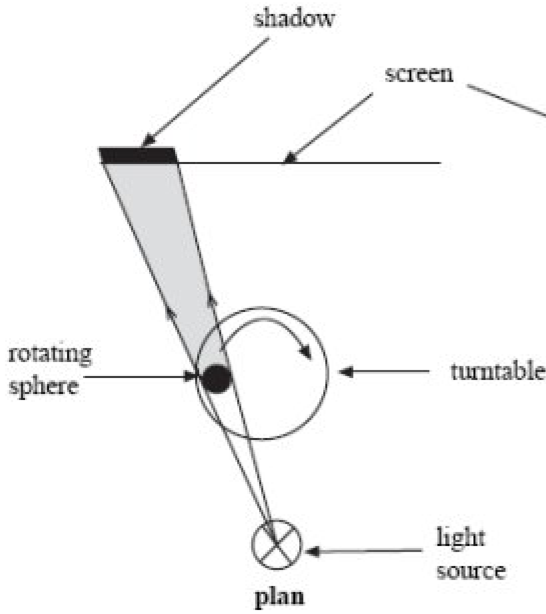


Figure 1a

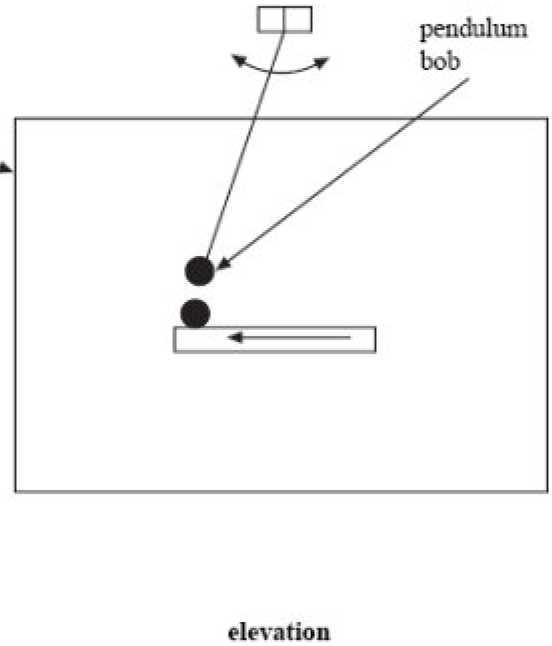


Figure 1b

(i) The turntable has a radius of 0.13 m and the teacher wishes the time taken for one cycle of the motion to be 2.2 s. The mass of the sphere is 0.050 kg.

Calculate the magnitude of the horizontal force acting on the sphere.

(2)

(ii) State the direction in which the force acts.

____

(1)

(c) **Figure 1b** shows how the demonstration might be extended. A simple pendulum is mounted above the turntable so that the shadows of the sphere and the pendulum bob can be seen to move in a similar way and with the same period.

(i) Calculate the required length of the pendulum.

acceleration due to gravity = 9.8 m s^{-2}

(1)

(ii) Calculate the maximum acceleration of the pendulum bob when its motion has an amplitude of 0.13 m.

(2)

(d) **Figure 2** includes a graph of displacement against time for the pendulum. Sketch, on the axes below, graphs of

(i) acceleration against time for the bob, and

(ii) kinetic energy against time for the bob.

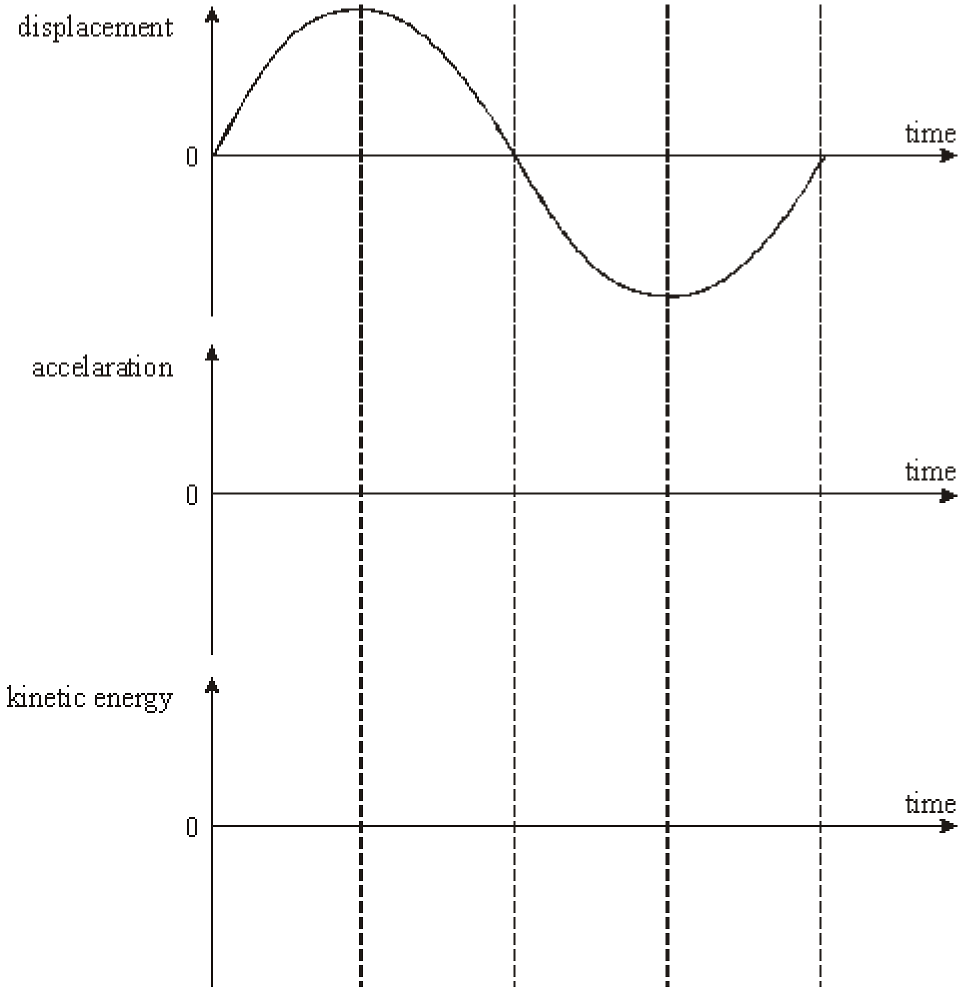
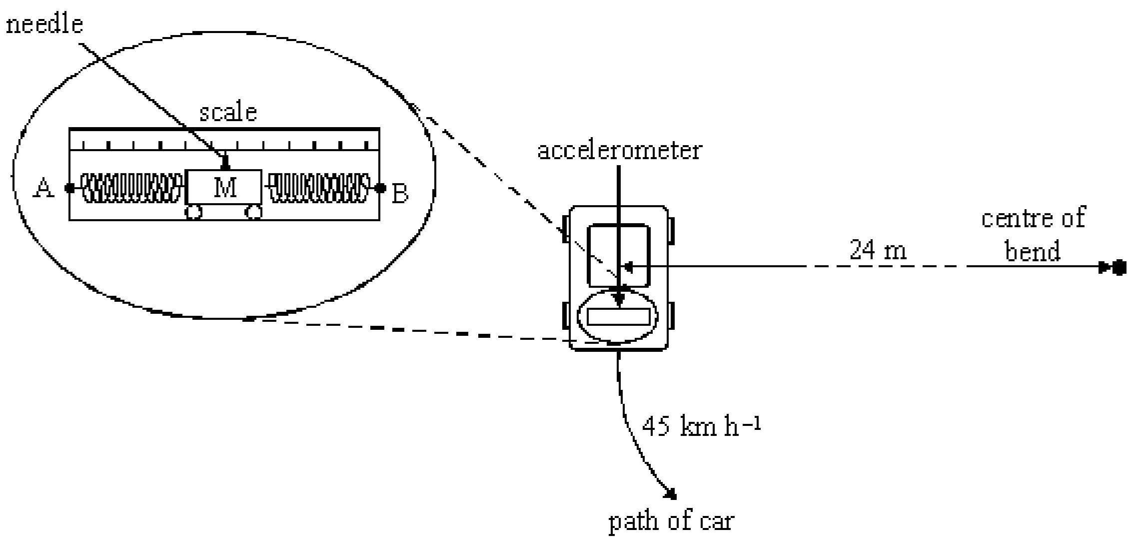


Figure 2

(4)
(Total 12 marks)

7 The diagram below shows a simple accelerometer designed to measure the centripetal acceleration of a car going round a bend following a circular path.



The two ends **A** and **B** are fixed to the car. The mass **M** is free to move between the two springs. The needle attached to the mass moves along a scale to indicate the acceleration.

In one instant a car travels round a bend of radius 24 m in the direction shown in the diagram above. The speed of the car is 45 km h^{-1}.

(a) State and explain the direction in which the pointer moves from its equilibrium position.

____

____

____

____

____

(3)

(b) (i) Calculate the acceleration that would be recorded by the accelerometer.

(2)

(ii) The mass **M** between the springs in the accelerometer is 0.35 kg. A test shows that a force of 0.75 N moves the pointer 27 mm.

Calculate the displacement of the needle from the equilibrium position when the car is travelling with the acceleration in part (i).

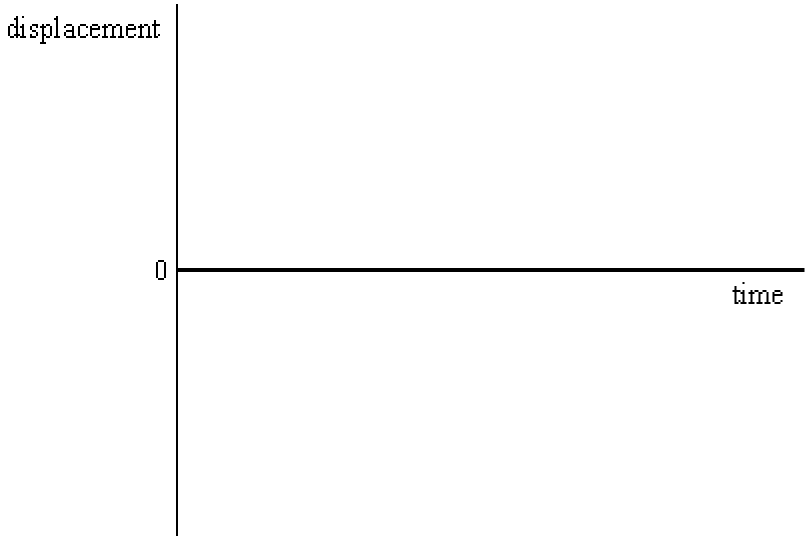
(2)

(c) When the car leaves the bend the accelerometer eventually returns to its zero reading after a few cycles of damped simple harmonic motion.

(i) Calculate the period of the oscillation of the mass **M**.

(3)

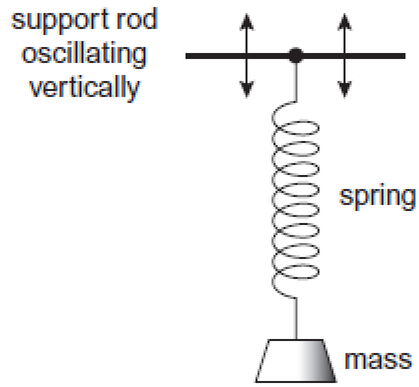
(ii) Sketch, on the axes below, a graph showing how the displacement of the mass varies with time from the instant the car leaves the bend. Include appropriate values on the axes of your graph.



(2)
(Total 12 marks)

8 (a) A mass is attached to one end of a spring and the other end of the spring is suspended from a support rod, as shown in **Figure 1**.

Figure 1



The support rod oscillates vertically, causing the mass to perform forced vibrations. Under certain conditions, the system may demonstrate resonance.

Explain in your answer what is meant by forced vibrations and resonance. You should refer to the frequency, amplitude and phase of the vibrations.

forced vibrations ____

____

____

____

____

____

resonance ____

____

____

____

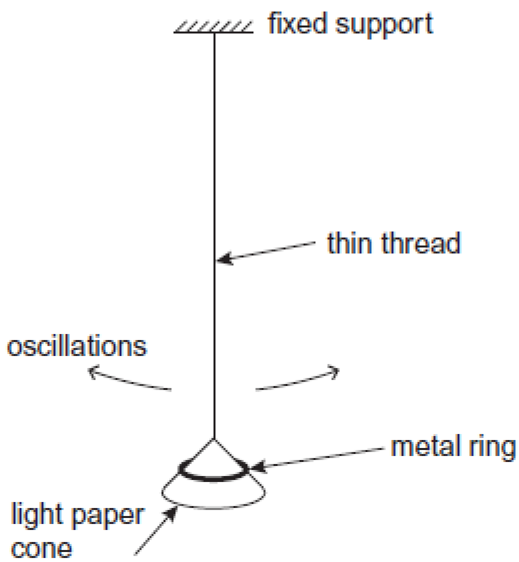
____

____

(4)

(b) A simple pendulum is set up by suspending a light paper cone (acting as the pendulum bob) on the end of a length of thin thread. A metal ring may be placed over the cone to increase the mass of the bob, as shown in **Figure 2**.

Figure 2



The bob is displaced and released so that it oscillates in a vertical plane. The oscillations are subject to damping.

(i) Are the oscillations of the pendulum more heavily damped when the cone oscillates with the metal ring on it, when it oscillates without the ring, or does the presence of the ring have no effect on the damping of the oscillations? Tick (✓) the correct answer.

cone oscillates with ring	
cone oscillates without ring	
ring has no effect	

(1)

(ii) Explain your answer to part (i).

____

____

____

____

____

____

____

____

(3)

(Total 8 marks)

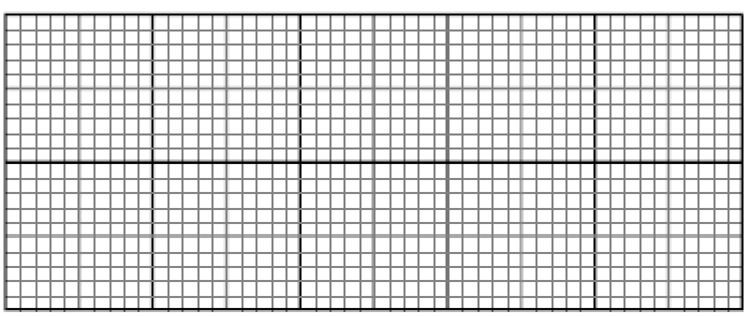
9 A spring, which obeys Hooke's law, hangs vertically from a fixed support and requires a force of 2.0 N to produce an extension of 50 mm. A mass of 0.50 kg is attached to the lower end of the spring. The mass is pulled down a distance of 20 mm from the equilibrium position and then released.

(a) (i) Show that the time period of the simple harmonic vibrations is 0.70 s.

____

____

(ii) Sketch the displacement of the mass against time, starting from the moment of release and continuing for two oscillations. Show appropriate time and distance scales on the axes.



(5)

(b) The mass-spring system described in part (a) is attached to a support which can be made to vibrate vertically with a small amplitude. Describe the motion of the mass-spring system with reference to frequency and amplitude when the support is driven at a frequency of

(i) 0.5 Hz,

___

___

___

(ii) 1.4 Hz.

___

___

___

(3)

(Total 8 marks)

10 A ball of mass 0.30 kg is attached to a string and moves in a **vertical** circle of radius 0.60 m at a constant speed of 5.0 m s^{-1}.

Which line, **A** to **D**, in the table gives the correct values of the minimum and maximum tension in the string?

	Minimum tension / N	Maximum tension / N
A	2.5	5.4
B	6.7	9.6
C	13	13
D	9.6	15

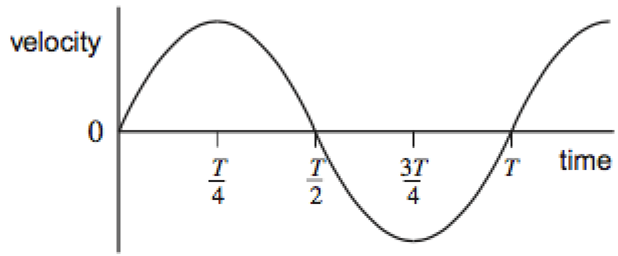
(Total 1 mark)

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

A The acceleration is always directed away from the central point.
B The acceleration and velocity are always 180° out of phase.
C The velocity and displacement are always in the same direction.
D Acceleration and displacement are always 180° out of phase.

(Total 1 mark)

12 The graph shows how velocity changes with time for a simple pendulum moving with simple harmonic motion.



Which one of the following statements related to the motion of the pendulum is **incorrect**?

A The acceleration is a minimum at $\frac{T}{4}$

B The acceleration is a maximum at $\frac{T}{2}$

C The kinetic energy is a maximum at $\frac{T}{2}$

D The restoring force is a minimum at $\frac{3T}{4}$

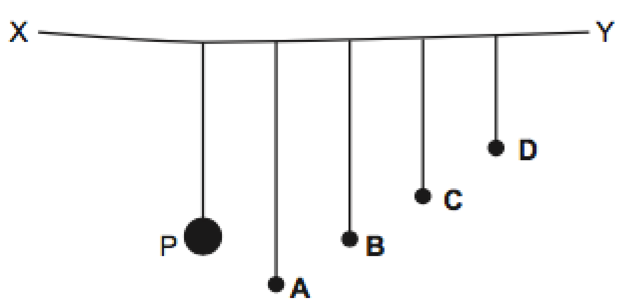
(Total 1 mark)

13 A mass hanging 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 both the top and bottom of the oscillation
B only at the top of the oscillation
C only at the bottom of the oscillation
D at the centre of the oscillation

(Total 1 mark)

14 The diagram shows a string XY supporting a heavy pendulum P and four pendulums **A**, **B**, **C** and **D** of smaller mass.



Pendulum P is set in oscillation perpendicular to the plane of the diagram.

Which one of the pendulums, **A** to **D**, then oscillates with the largest amplitude?

(Total 1 mark)

15 For a body performing simple harmonic motion, which one of the following statements is correct?

A The maximum kinetic energy is directly proportional to the frequency.

B The time for one oscillation is directly proportional to the frequency.

C The speed at any instant is directly proportional to the displacement.

D The maximum acceleration is directly proportional to the amplitude.

(Total 1 mark)

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) ✓

$\theta = \frac{3.44}{2\pi \times 1.5}$ × 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** $F\left(=\frac{mv^2}{r}\right) = \frac{0.25\times 8.6^2}{1.5}$ ✓ = 12(.3) (N) ✓]

Estimate because rope is not horizontal.

2

(b) maximum $\omega\left(=\sqrt{\frac{F}{mr}}\right) = \sqrt{\frac{60}{0.25\times 1.5}}$ (= 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 $v = \sqrt{\frac{Fr}{m}} = \sqrt{\frac{60\times 1.5}{0.25}}$ (= 19.0) (m s^{-1}) ✓

maximum $f\left(=\frac{v}{2\pi r}\right) = \frac{19.0}{2\pi \times 1.5}$ = 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 3 rd law is not essential in an answer considered to be a high level response. 6 marks may be awarded when there is no reference to the 3rd law.

max 6

[13]

2 (a) *period* time for one **complete** oscillation

B1

amplitude maximum displacement from undisturbed (equilibrium) position

B1

(2)

(b) clear description + repeat at least 10 times overall + averaging process

B1

beginning or end measurement at equilibrium / use of datalogger (explicit) / fiducial mark

B1

(2)

(c) same time period

B1

significant and gradual reduction in amplitude compared to original

B1

(2)

[6]

3 (a) (i) arrows to show *R* (or *N*) vertically up and *mg* (or *W*) vertically down and along the same line (within ± 2 mm) ✓

1

(ii) $mg - R = \frac{mv^2}{r} \therefore R = mg - \frac{mv^2}{r}$ ✓ $\left[= m\left(g - \frac{v^2}{r}\right)\right]$

1

(iii) **use** of $R = m\left(g - \frac{v^2}{r}\right)$ gives $R = 12(9.81 - \frac{11^2}{23})$ ✓

= 55 (54.6) (N) ✓

2

(b) *R* decreases (as *v* increases) ✓

because *mg* is unchanged but $\frac{mv^2}{r}$ is larger ✓

at higher speeds **R** becomes = 0 [**or** package is not in contact with the floor] ✓

supported by calculation eg when $v = 15$ m s^{-1}, $R = 0.33$ N (or ≈ 0) ✓

max 3

[7]

4 (a) attempt to use power = *mgh/t* or *P* = *Fv* and *v* = *s/t*

C1

7546/7550/7600

A1

W (allow J s^{-1} and condone N ms^{-1})

B1

3

(b) loss of GPE = 550 × 9.81 × 35 = 189 kJ

C1

gain in KE = $0.5 \times 550 \times 22^2$ = 133 kJ

C1

resistance force = their difference/63 (890 N if correct)

A1

answer to 2 sf (allow if answer is from working even if incorrect)

B1

4

(c) air resistance varies/increases

B1

frictional force varies/increases

B1

further detail: air resistance increases with speed/v or normal reaction force varies with angle of the slope

B1

3

(d) use of $F = mv^2/r$

C1

arrives at r = 12 m (ignoring the weight)

C1

16.4 m

A1

3

[13]

5 (a) (i) $r = 0.012$ (m) **(1)**
(use of $v = 2\pi fr$ gives) $v = 2\pi 50 \times 0.012$ **(1)**
$= 3.8$ 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)**

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

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

6 (a) $2\pi/T$ or $2\pi f$ **or** angular speed/velocity/frequency/$\Delta\theta \div \Delta t$ *with symbols defined*

B1

displacement direction opposite to acceleration vector/ acceleration towards central point/equilibrium point

B1

2

(b) (i) $\omega = 2\pi/T = 2.86$ rad/s *can appear as* $(2\pi/2.2)$ in

C1

subst
F = 0.053(1) N

A1

2

(ii) to centre of turntable/rotation/circle *not* 'towards centre'

B1

1

(c) (i) $l = [T^2g/4\pi^2] = 1.20$ m

A1

1

(ii) correct use of $a = \omega^2 A$

M1

or accel = v^2/r or F/m approach
a = 1.0 / 1.1 / 1.04 / 1.06 m s^{-2} [cao]

A1

2

(d) *a* origin at zero

C1

a in antiphase

A1

k.e always positive and start at maximum

C1

k.e. twice *f* and good shape

A1

4

[12]

7 (a) force is needed toward the centre or there is acceleration toward the centre

B1

movement to the left/toward A/away from the centre (or indicated on diagram)

M1

right hand spring (attached to **B)** has to stretch to provide force

A1

3

(b) (i) acceleration = v^2/r or speed = 12.5 m s^{-1}
or a = $r\,\omega^2$ and $v = r\omega$ or ω = 0.52 rad s^{-1} or $45^2/0.024$

C1

6.5 m s^{-2} 8.4 × 10^4 km h^{-2} unit essential

A1

2

(ii) Force on mass = 0.35 × (i) (2.28 N if correct)
or use of F = $mr\omega^2$ (0.35 × 24 × 0.52^2)

C1

0.82mm or 0.83 mm if (i) is correct;
Movement = 12.6 × (i) mm

A1

2

(c) (i) $T = 2\pi\sqrt{\frac{M}{k}}$ or a = $(2\pi f)^2 A$ or f = 1.4Hz or ω = 8.9 rad s^{-1}

C1

k = 27.8 N m^{-1} use of $T = 1/f$ or $2\pi/\omega$

C1

0.71 s (allow 0.70 s to 0.72 s)

A1

3

(ii) sketch showing amplitude reducing with time
starting at max ignore changing period

B1

labelled consistently with answers to (b)(ii) and (c)(i).
(0.71 s and initial displacement 82 mm)
condone only one period shown correctly

B1

2

[12]

8 (a) *forced vibrations:*

repeated upwards and downwards movement ✓

vibrations at frequency of support rod ✓

amplitude is small at high frequency **or** large at low frequency ✓

correct reference to phase difference between displacements of driving and forced vibrations ✓

Acceptable references to phase differences:

*Forced vibrations − when frequency of driver » frequency of driven, displacements are out of phase by (almost) π radians or 180° (**or** ½ a period) **or** when frequency of driver « frequency of driven, displacements are (almost) in phase. [Accept either].*

[Condone >, < for », «].

resonance:

frequency of support rod **or** driver is equal to natural frequency of (mass-spring) system ✓

large (or maximum) amplitude vibrations of mass ✓

maximum energy transfer (rate) (from support rod to mass-spring system) ✓

correct reference to phase difference between displacements of driving and driven vibrations at resonance ✓

*Resonance − displacement of driver leads on displacement of driven by π / 2 radians or 90° **or** ¼ of a period (or driven lags on driver by π / 2 radians or 90° **or** ¼ of a period).*

[Condone phase difference is π / 2 radians or 90°].

max 4

(b) (i) cone oscillates without ring *(ticked)*

Only one box to be ticked.

1

(ii) damping is caused by air resistance ✓

area is the same whether loaded or not loaded ✓

loaded cone has more kinetic energy **or** potential energy **or** momentum (at same amplitude) ✓

smaller <u>proportion</u> (or <u>fraction</u>) of (condone less) energy removed per oscillation from loaded cone (or vice versa) ✓

inertia of loaded cone is greater ✓

Award marks for correct physics even when answer to (b)(i) is incorrect.

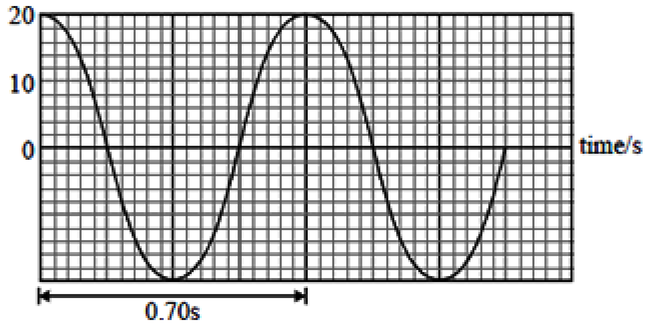
max 3

[8]

9

(a) (i) $k = \dfrac{2.0}{50 \times 10^{-3}}$ **(1)** $T = 2\pi\sqrt{\dfrac{0.5}{40}}$ **(1)** = 0.70 s

(ii)



a correct (= 20mm) **(1)**

x = ±20 mm at t = 0 **(1)**

T correct (= 0.70 s)**(1)**

(5)

(b) (i) vibrates at 0.5 Hz with low amplitude **(1)**

(ii) vibrates with high amplitude **(1)**
at natural frequency **(1)**
resonates **(1)**

(max 3)

[8]

10 **D** **[1]**

11 **D** **[1]**

12 **C** **[1]**

13 **D** **[1]**

14 **B** **[1]**

15 D **[1]**

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 (a) (i) Although many candidates scored the mark for describing the period of an oscillation, the level of explanation was not good with many references to ‘complete oscillations’ with no clear explanation of the true meaning of ‘complete’. It was clear to examiners that the terms *period* and *oscillation* are by no means well understood.

(ii) Amplitude markings on the diagram were well done by many candidates.

(b) The description of the method for determining an accurate value for period elicited half marks for many with a clear reference to the need for repeated measurements of many oscillations, but there were only a handful of references to the need for, or the use of, a fiducial mark. Poorer candidates often described a process of counting oscillations for a fixed time – ignoring the inevitable problem of fractional oscillations at the end of the time period.

(c) In the diagram candidates tended to draw either an appropriate period for the motion of the mass or an appropriately damped amplitude but rarely both.

3 The context of this question may have been unfamiliar to many candidates. Although most had some awareness of the ‘lift off’ sensation when a vehicle passes over a hump-backed bridge, relatively few were able to give good answers to explain the mechanics involved. Attempts at part (a)(i) were often muddled by the introduction of arrows marked ‘centripetal force’, ‘driving force’, ‘momentum’ and so on. In a correct answer, two labelled vertical arrows acting through the same point on the parcel were all that was expected; the weight downwards and the reaction upwards. Frictional forces were not expected but their inclusion did not nullify the answer. Poor understanding was revealed by labels such as ‘upthrust’ and ‘gravity’. The principal error in part (a)(ii) was to assume that the resultant (centripetal) force acts outwards, resulting in the incorrect equation $R - mg = mv^2/r$. Candidates doing this evidently did not understand that, for a body to move in a circular path, it has to experience a resultant force that acts towards the centre of the circle. This kind of incorrect response in part (ii) almost invariably meant that part (a)(iii) – where the calculation is based on the equation – would also be incorrect.

Some good answers were seen to part (b), but most only received partial credit. Good understanding of the mechanics of part (a) allowed more able candidates to see that at higher speeds, because mv^2/r increases but mg remains constant, R must decrease. They could then calculate R when v = 15 ms^{-1} and find it to be almost zero. The obvious deduction is that, with a slight increase in speed, R would become zero and the parcel would lose contact with the floor of the van. Very few candidates who carried out the calculation for speeds higher than 15 ms^{-1} were able to give a correct interpretation of the negative value they calculated for R. Less able candidates sometimes argued that the van would lift up vertically from the road surface at high speed because the upwards reaction would be greater than its weight. Candidates would be able to approach questions of this kind more successfully if more of them realised that ‘centripetal force’ (mv^2/r) really is ‘mass × acceleration towards centre’ rather than being an actual force, but that it is equal to the real resultant force ($mg - R$ here) acting towards the centre of the circle.

4 The most common error in part (a) was to omit *g.* A suitable unit was usually given. The unit .W. would have been the preferred response but J s.1 and N m s.1 were also accepted.

Many candidates showed poor understanding of physics in part (b). The solution required them to subtract ΔE_k from ΔE_p to find the work done against resistive forces and equate the difference to F_s.

The use of equations of uniformly accelerated motion was common although this clearly is not a case of uniform acceleration. Another common incorrect approach was to calculate the time to descend as being the 63/22, which is incorrect because of the acceleration, and then to use change in momentum = *Ft* to find *F.* Candidates who made a reasonable attempt and gave the answer to two significant figures gained the final mark but many felt that three significant figures was acceptable even though the data was provided to two.

In part (c), many referred to air resistance and went on to gain a further mark for why it should change.

Some of those who mentioned friction referred to friction 'between the wheels and the track' Although it is not a sliding situation, but there were many who appreciated the effect of the changing angle of the track on likely frictional forces within the system.

For part (d), most candidates who used $F = mv2/r$ ignored the effect of the gravitational force arrived at 12 m. The correct answer of 16.4 m was obtained by relatively few candidates.

5 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.

6 (a) Many candidates were able to state the meaning of ω clearly, usually in terms of angular velocity or speed and this gained full credit. A definition in terms of angular frequency, or $2\pi f$ or $2\pi T$ with symbols defined, would have been preferable however. Descriptions of the significance of the negative signs were much poorer with many ambiguous statements produced that involved vague references to 'the centre' with no statement of the centre of what.

(b) (i) The magnitude of the horizontal force was well calculated by many, but some could not progress beyond a calculation of the angular frequency.

(ii) Again, far too many candidates simply stated the direction of the force as being towards the centre without being clear about what they mean by this.

(c) (i) Almost all managed the simple task of calculating the required length of the pendulum from a formula provided on the data sheet.

(ii) This calculation was also well managed by almost all.

(d) (i) There were many good answers showing the correct starting position and correct phase for the acceleration–time graph. Most incorrect responses failed to gain any marks indicating that the candidate probably had little understanding of the relationship between displacement and acceleration in harmonic motion.

(ii) Completely correct drawings for the kinetic energy case were much more uncommon. There was a widespread failure to recognise the doubling of the frequency in the energy variation and the quality of the sketches was consistently poor. Examiners could not determine whether this was due to candidates failing to understand that kinetic energy varies sinusoidally or whether the candidates simply could not draw. There were many good quality but incorrect sketches showing cycloidal behaviour (rather than sinusoidal).

7

(a) Most candidates appreciated that a force was needed toward the centre when there was circular motion but many went on to suggest that this force moved the mass toward the centre (toward B). Relatively few made any reference to the way in which the difference in tensions of the two springs provided the necessary force.

(b) (i) There was a majority of correct answers but inability to convert from km h^{-1} to m s^{-1} was a problem for many and $45^2/24 = 84$ m s^{-2} was not uncommon. Many made life difficult by trying to use angular velocity equations.

(ii) Most candidates approached this part correctly but a significant proportion tried, inappropriately, to use simple harmonic motion equations to solve this. Many completely unrealistic answers went unquestioned (up to hundreds of kilometres!).

(c) (i) The majority of the candidates obtained correct values for the period using $T = 2\pi\sqrt{\frac{m}{k}}$. Some were unable to determine k correctly.

(ii) The majority drew a sketch that showed amplitude decreasing but fewer included acceptable scales, many omitting scales altogether. Candidates who failed to draw a graph that started at maximum displacement gained no marks here.

8 In part (a) most students knew far more about resonance than about forced vibrations. Relatively few were able to point out that the forced vibrations of the mass-spring system would have the same frequency as the oscillations of the support rod, and knowledge of the relative amplitudes and phases of the vibrations were rarely approached successfully. These features of a mass-spring system may be readily demonstrated by oscillating the system vertically at low and high frequencies by hand.

The main features of the resonating system were well known, but ambiguous expressions often limited the mark that could be awarded. An example of this was “the system oscillates at its natural frequency”. Without any reference to the driving frequency, this could mean free vibrations rather than resonant vibrations. The mark scheme adopted for part (a) meant that even those students who knew nothing about forced vibrations could score highly by their knowledge of resonance.

Part (b)(i), which was partly synoptic, proved to be a much sterner test than had been expected. Fewer than half of the students ticked the correct box, failing to realise that the cone without the ring would be the most heavily damped. The explanations presented in (b)(ii) revealed widespread misunderstanding. Many students were more concerned with the effect of the ring on the period of oscillation rather than on the decay of successive amplitudes. Resorting to the simple pendulum equation, where time period is independent of mass, led many to the conclusion that the mass of the ring would have no effect. Observation of simple experimental phenomena, such as looking at objects with different surface area-to-mass ratios falling through air, would readily demonstrate the effect of air resistance and the factors which affect the removal of energy from a moving body. Hardly any of the answers approached the most important aspects: that the loaded cone gains more kinetic energy after being given the same displacement, and that a *smaller proportion* of the energy of the oscillating system would be removed *per oscillation* from the loaded cone.

9 Part (a) was done well by the majority of candidates. Although some omitted the units on the graph axes, the only error of significance was to start the graph from the displacement origin.

The quality of answers given to part (b) varied widely. A small minority of candidates gave excellent and concise answers which showed a clear understanding of amplitude, natural frequency and resonance. Unfortunately, most answers were so badly expressed that it was difficult to award marks.

10 This question showed that motion in a vertical circle was well understood, because 80% of the answers were correct. However, 10% of the students considered the tension to be the same in both positions, that being the centripetal force (13N). The question discriminated very well.

11 Two-thirds of the students selected the correct answer in this question, concerning the characteristics of simple harmonic motion. Distractor B (acceleration out of phase with velocity by 180°) and distractor C (velocity always in the same direction as displacement) both attracted significant numbers of responses.

12 This question tested students’ interpretation of a velocity-time graph for simple harmonic motion. The question asked for the *incorrect* statement to be selected; this generally causes problems for students who read the questions too superficially. However on this occasion 70% of them gave the correct answer. Maybe the 13% of students who selected distractor D, which is clearly a *correct* statement, had forgotten the wording of the question by the time they reached it.

13 This was another re-used question from an earlier test paper. Its facility this time was 67%, up from 59% last time. 14% of the students thought the resultant force would be a minimum at both the top and the bottom of the oscillation (distractor A).

14 This question, on coupled pendulums, had appeared in the 2009 examination. The results on that occasion were surprisingly disappointing, with fewer than 40% of correct responses. In 2016 more of the students selected the correct resonant pendulum (B), but it was only 53% of them. One third of the students chose pendulum A, the longest one.

15 This question on simple harmonic motion, readily gave the correct answer to students who could apply $a = -(2\pi f)^2 x$: clearly therefore a_{max} is proportional to x_{max}, the amplitude. 78% of the responses were correct. Incorrect answers were fairly evenly distributed amongst the other three distracters.