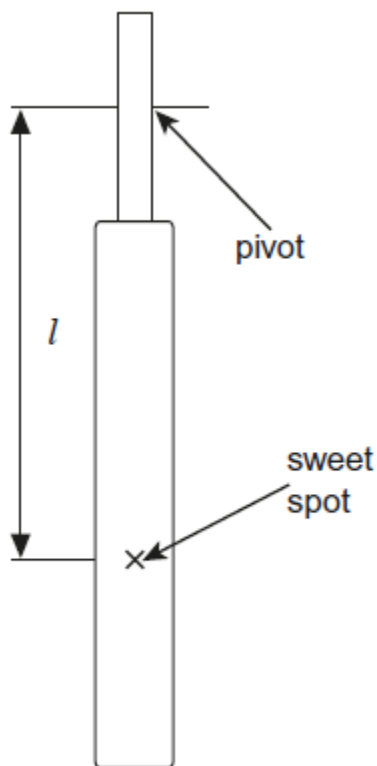


1

In a compound pendulum the mass is distributed along its length rather than being a 'point' mass as in a simple pendulum.

When used to strike a ball, a cricket bat behaves like a compound pendulum. The bat has a sweet spot. When the ball hits this spot there is a maximum momentum transfer from the bat to the ball and the bat oscillates in the batsman's hands.



The diagram above shows a cricket bat pivoted at the point at the centre of the batsman's grip. The position of the sweet spot is also marked on the bat.

It is suggested that the distance l between the pivot and the sweet spot is the same as the length of a simple pendulum with the same period of oscillation as the bat.

Describe how you would use the pivoted bat shown in the diagram to investigate whether the distance from the sweet spot to the pivot is equal to the length of the equivalent simple pendulum.

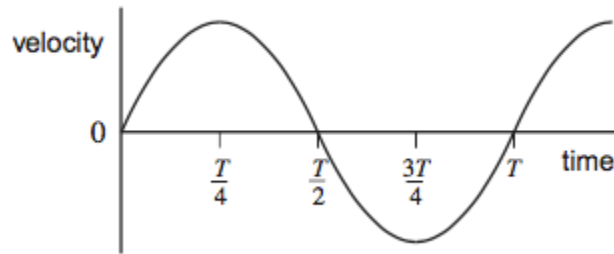
You should consider the uncertainties in the measurements for the bat and the pendulum in your answer

[illegible]

(Total 5 marks)

2

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)

3

Within certain limits, the bob of a simple pendulum of length l may be considered to move with simple harmonic motion of period T , where

$$T = 2\pi\sqrt{\frac{l}{g}}$$

- (a) State **one** limitation that applies to the pendulum when this equation is used.

(1)

- (b) Describe an experiment to determine the value of the Earth's gravitational field strength g using a simple pendulum and any other appropriate apparatus.

In your answer you should:

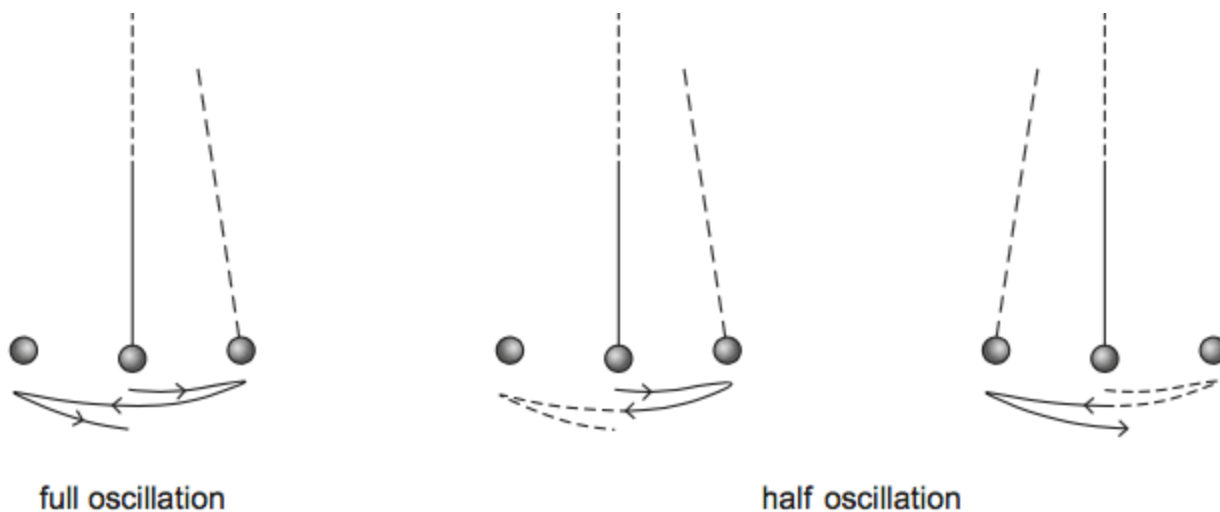
- describe how you would arrange the apparatus
- indicate how you would make the measurements
- explain how you would calculate the value of g by a graphical method
- state the experimental procedures you would use to ensure that your result was accurate.

You may draw a diagram to help you with your answer.

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

(6)

- (c) When carrying out the experiment in part (b), a student measures the time period incorrectly. Mistakenly, the student thinks that the time period is the time taken for half of an oscillation instead of a full oscillation, as illustrated in the diagram.



Deduce the effect this will have on the value of g obtained from the experiment, explaining how you arrive at your answer.

(3)

(Total 10 marks)

4

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?

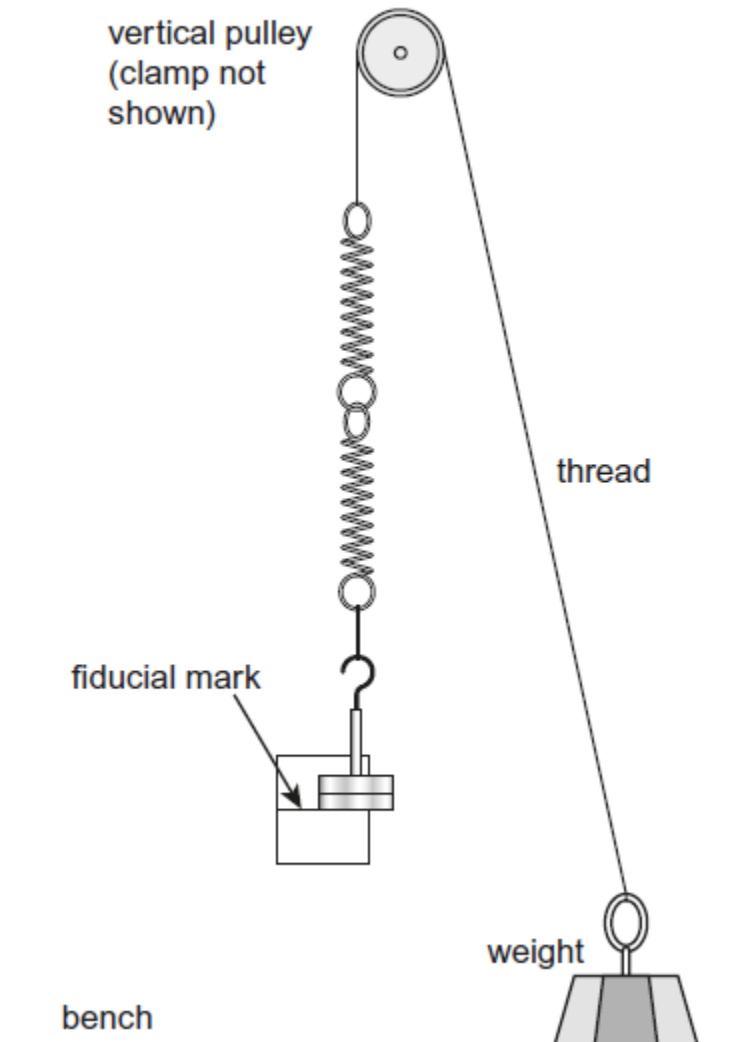
- A at both the top and bottom of the oscillation
- B only at the top of the oscillation
- C only at the bottom of the oscillation
- D at the centre of the oscillation

(Total 1 mark)

5

A student investigates the vertical oscillations of the mass–spring system shown in **Figure 1**.

Figure 1



The system is suspended from one end of a thread passing over a pulley.

The other end of the thread is tied to a weight.

The system is shown in **Figure 1** with the mass at the equilibrium position.

The spring constant (stiffness) is the same for each spring.

- (a) Explain why the position of the fiducial mark shown in **Figure 1** is suitable for this experiment.

The table below shows the measurements recorded by the student.

Time for 20 oscillations of the mass-spring system/s				
22.9	22.3	22.8	22.9	22.6

- (b) (i) Determine the percentage uncertainty in these data.

percentage uncertainty = _____

(3)

- (ii) Determine the natural frequency of the mass-spring system.

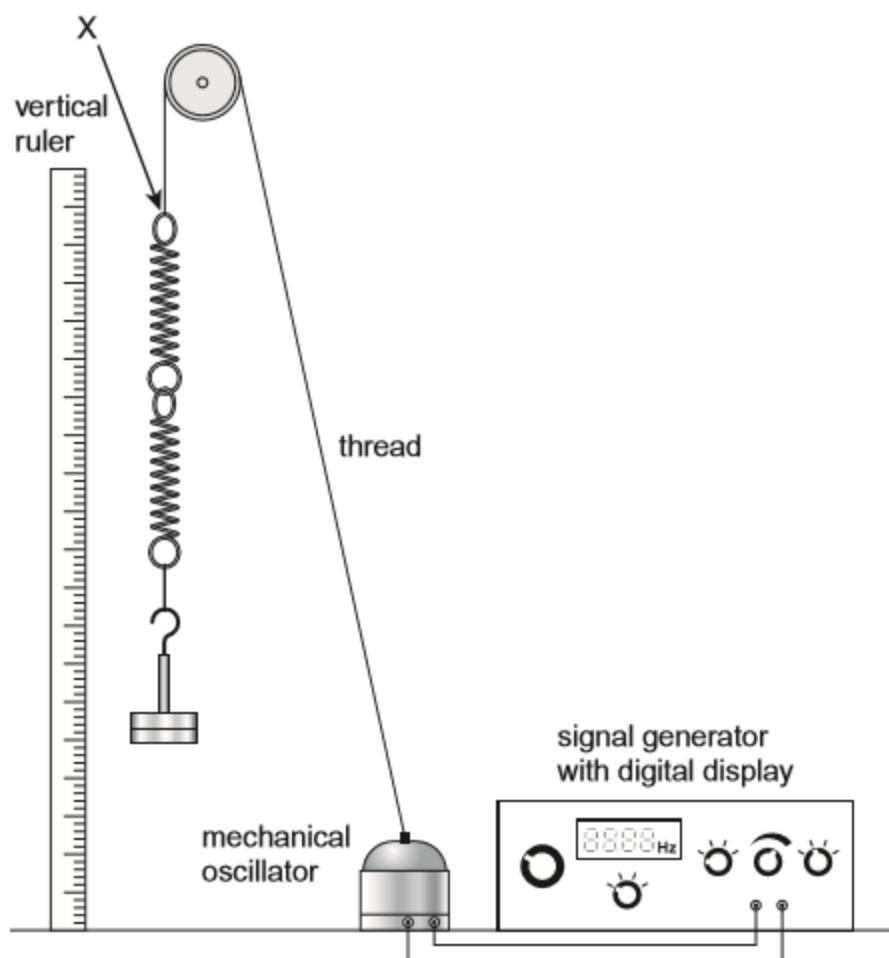
natural frequency = _____

(1)

- (c) The student connects the thread to a mechanical oscillator. The oscillator is set in motion using a signal generator and this causes the mass–spring system to undergo forced oscillations.

A vertical ruler is set up alongside the mass–spring system as shown in **Figure 2**. The student measures values of A , the amplitude of the oscillations of the mass as f , the frequency of the forcing oscillations, is varied.

Figure 2



A graph for the student's experiment is shown in **Figure 3**.

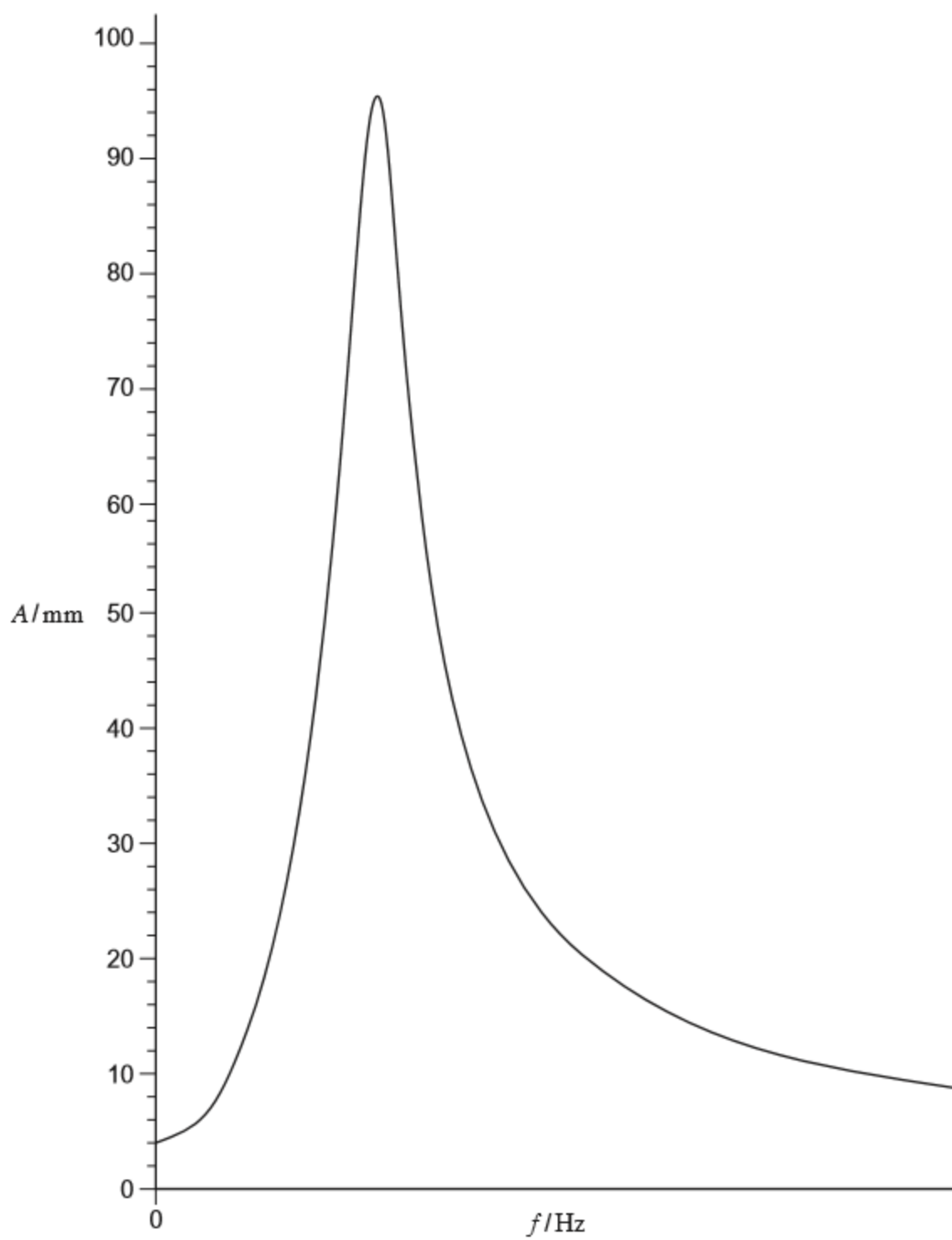
- (i) Add a suitable scale to the frequency axis.
You should refer to your answer in part **(b)(ii)** and note that the scale starts at 0 Hz.
- (ii) Deduce from **Figure 3** the amplitude of the oscillations of X, the point where the mass–spring system is joined to the thread.
You should assume that the length of the thread is constant.

(1)

amplitude of X = _____

(1)

Figure 3



- (d) (i) State and explain how the student was able to determine the accurate shape of the graph in the region where A is a maximum.

(2)

- (ii) The student removes one of the springs and then repeats the experiment.

Add a new line to **Figure 3** to show the graph the student obtains.

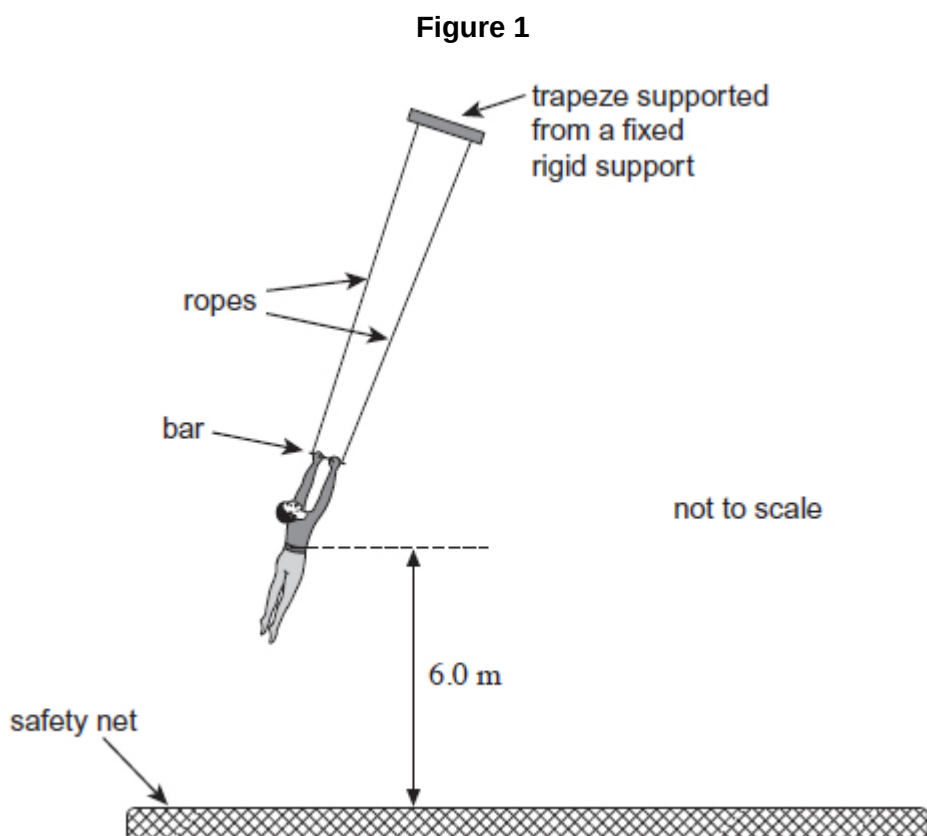
You may wish to use the equation $f = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$.

(2)

(Total 11 marks)

6

Figure 1 shows an acrobat swinging on a trapeze.



- (a) (i) State and explain how the tension in the ropes of the trapeze varies as the acrobat swings on the trapeze.

(3)

- (ii) The period of the oscillation of the acrobat on the trapeze is 3.8 s.

Calculate the distance between the point of suspension of the trapeze and the centre of mass of the acrobat.

Assume that the acrobat is a point mass and that the system behaves as a simple pendulum.

distance _____ m

(2)

- (b) At one instant the amplitude of the swing is 1.8 m. The acrobat lets go of the bar of the trapeze at the lowest point of the swing. He lands in a safety net when his centre of mass has fallen 6.0 m.

- (i) Calculate the speed of the acrobat when he lets go of the bar.

speed _____ m s^{-1}

(3)

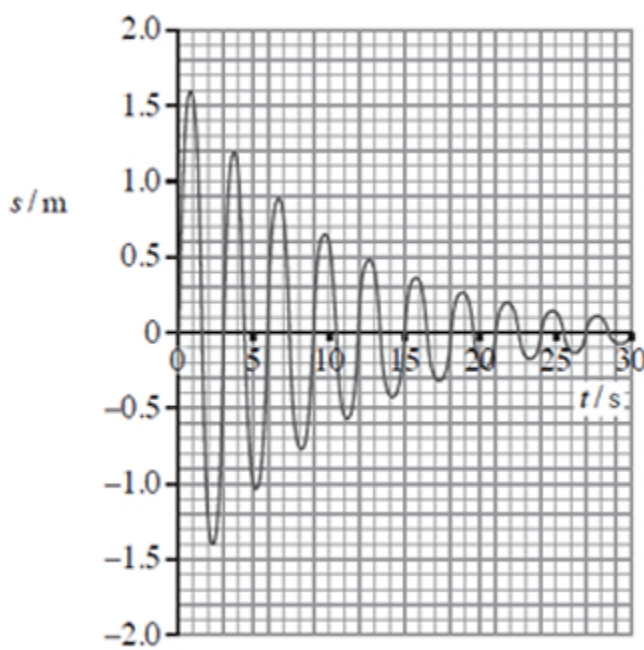
- (ii) Calculate the horizontal distance between the point of suspension of the trapeze and the point at which the acrobat lands on the safety net.

horizontal distance _____ m

(3)

- (c) **Figure 2** shows the displacement–time (s – t) graph for the bar of the trapeze after the acrobat has let go of the bar.

Figure 2



(i) Show that the amplitude of the oscillations decreases exponentially.

(3)

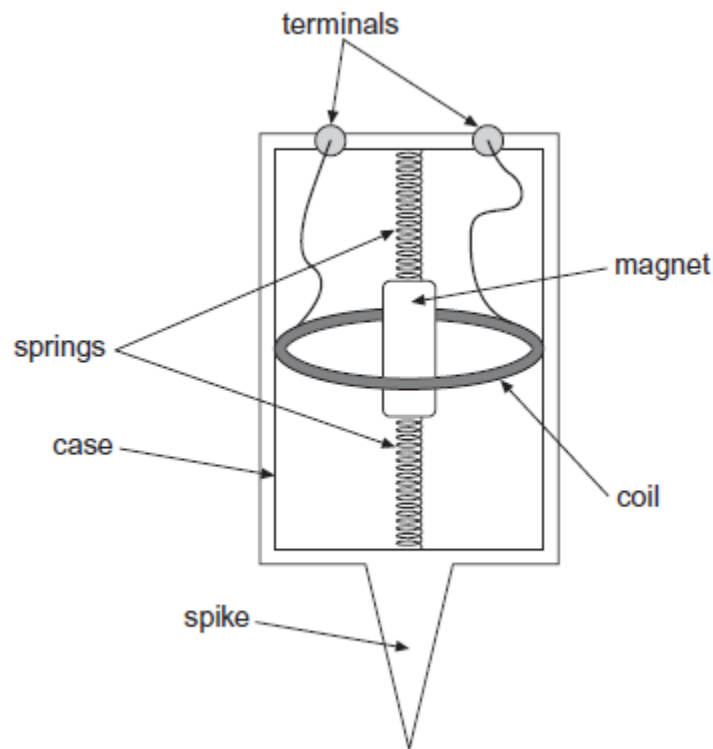
(ii) Explain why the period of the trapeze changes when the acrobat lets go of the bar.

(2)

(Total 16 marks)

7

The diagram below shows the main parts of a geophone.



The spike attaches the geophone firmly to the ground. At the instant an earthquake occurs, the case and coil move upwards due to the Earth's movement. The magnet remains stationary due to its inertia. In 3.5 ms, the coil moves from a position where the flux density is 9.0 mT to a position where the flux density is 23.0 mT.

- (a) The geophone coil has 250 turns and an area of 12 cm^2 .

Calculate the average emf induced in the coil during the first 3.5 ms after the start of the earthquake.

emf _____ V

(3)

- (b) Explain how the initial emf induced in the coil of the geophone would be affected:

if the stiffness of the springs were to be increased

if the number of turns on the coil were to be increased.

(2)

- (c) (i) The geophone's magnet has a mass of $8.0 \times 10^{-3} \text{ kg}$ and the spring stiffness of the system is 2.6 N m^{-1} .

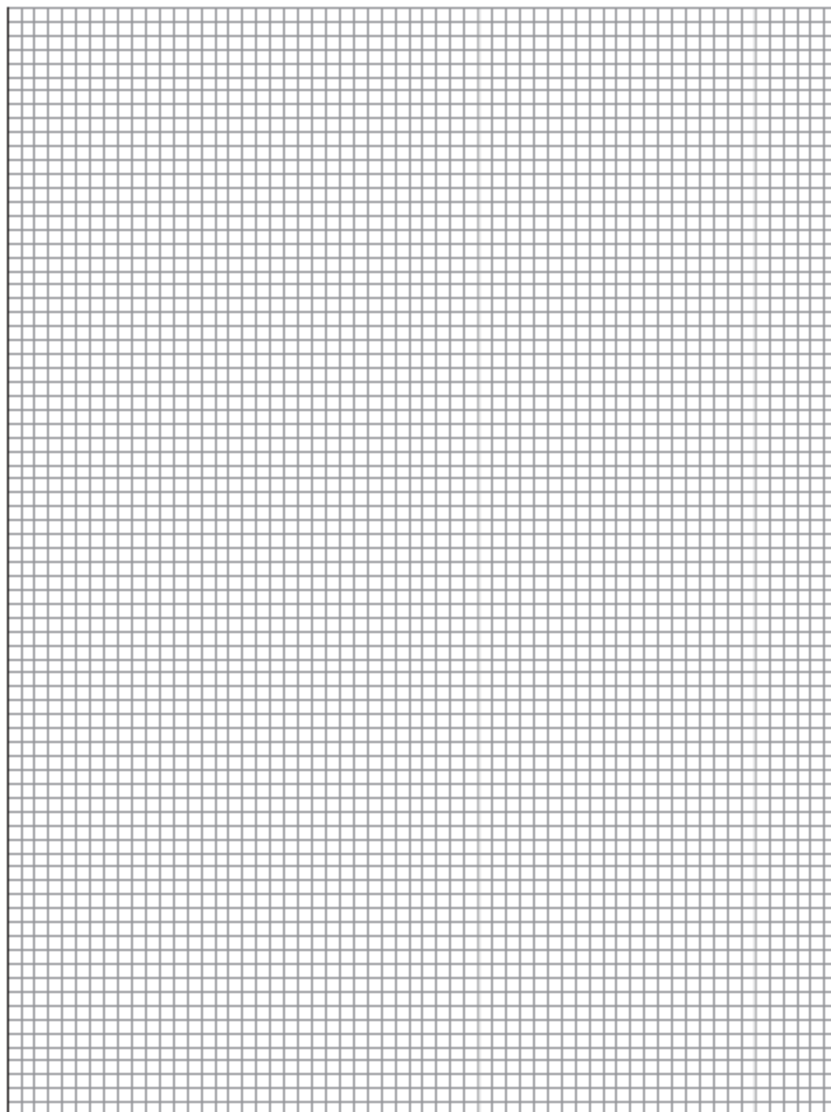
Show that the natural period of oscillation of the mass-spring system is approximately 0.35 s.

(2)

- (ii) At the instant that the Earth stops moving after one earthquake, the emf in the coil is at its maximum value of +8 V. The magnet continues to oscillate.

On the grid below, sketch a graph showing the variation of emf with time as the magnet's oscillation decays.

Show at least **three** oscillations.



(3)

(Total 10 marks)

8

The tip of each prong of a tuning fork emitting a note of 320 Hz vibrates in simple harmonic motion with an amplitude of 0.50 mm.

What is the speed of each tip when its displacement is zero?

- A zero
- B $0.32\pi \text{ mm s}^{-1}$
- C $160\pi \text{ mm s}^{-1}$
- D $320\pi \text{ mm s}^{-1}$

(Total 1 mark)

9

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**?

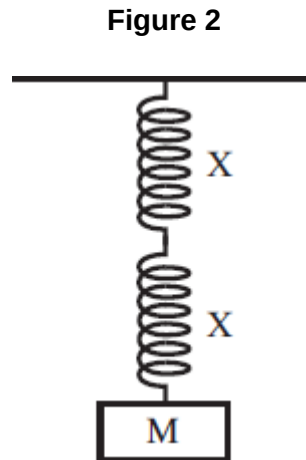
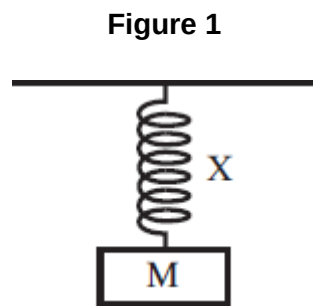
- A The potential energy has a minimum value when the spring is fully compressed or fully extended.
- B The kinetic energy has a maximum value at the equilibrium position.
- C The sum of the kinetic and potential energies at any time is constant.
- D The potential energy has a maximum value when the mass is at rest.

(Total 1 mark)

10

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?



- A $\frac{T}{2}$
- B $\frac{T}{\sqrt{2}}$
- C $\sqrt{2}T$
- D $2T$

(Total 1 mark)

11

- (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.

(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.

time interval _____ s

(3)

(Total 10 marks)

12

- (a) (i) Name the **two** types of potential energy involved when a mass–spring system performs vertical simple harmonic oscillations.

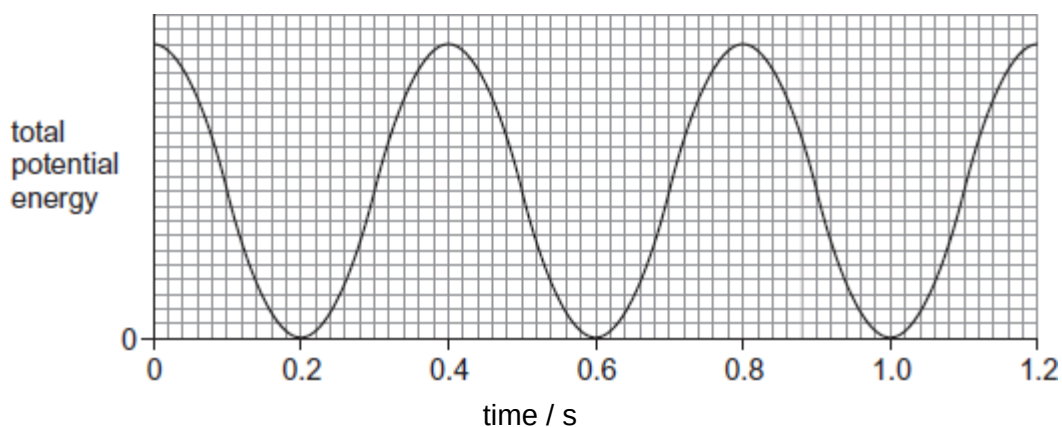
(1)

- (ii) Describe the energy changes which take place during one complete oscillation of a vertical mass-spring system, starting when the mass is at its lowest point.

(2)

- (b) **Figure 1** shows how the **total** potential energy due to the simple harmonic motion varies with time when a mass-spring system oscillates vertically.

Figure 1

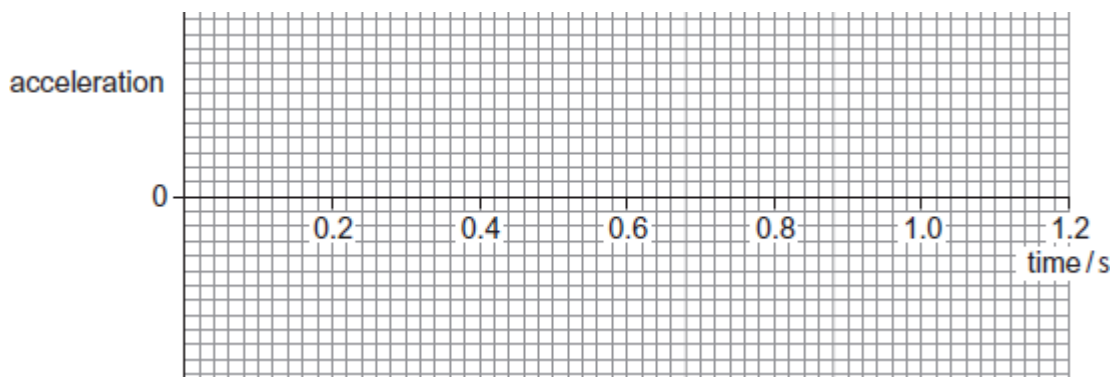


- (i) State the time period of the simple harmonic oscillations that produces the energy–time graph shown in **Figure 1**, explaining how you arrive at your answer.

(2)

- (ii) Sketch a graph on **Figure 2** to show how the acceleration of the mass varies with time over a period of 1.2 s, starting with the mass at the highest point of its oscillations. On your graph, upwards acceleration should be shown as positive and downwards acceleration as negative. Values are not required on the acceleration axis.

Figure 2



(2)

- (c) (i) The mass of the object suspended from the spring in part (b) is 0.35 kg. Calculate the spring constant of the spring used to obtain **Figure 1**. State an appropriate unit for your answer.

spring constant _____ unit _____

(3)

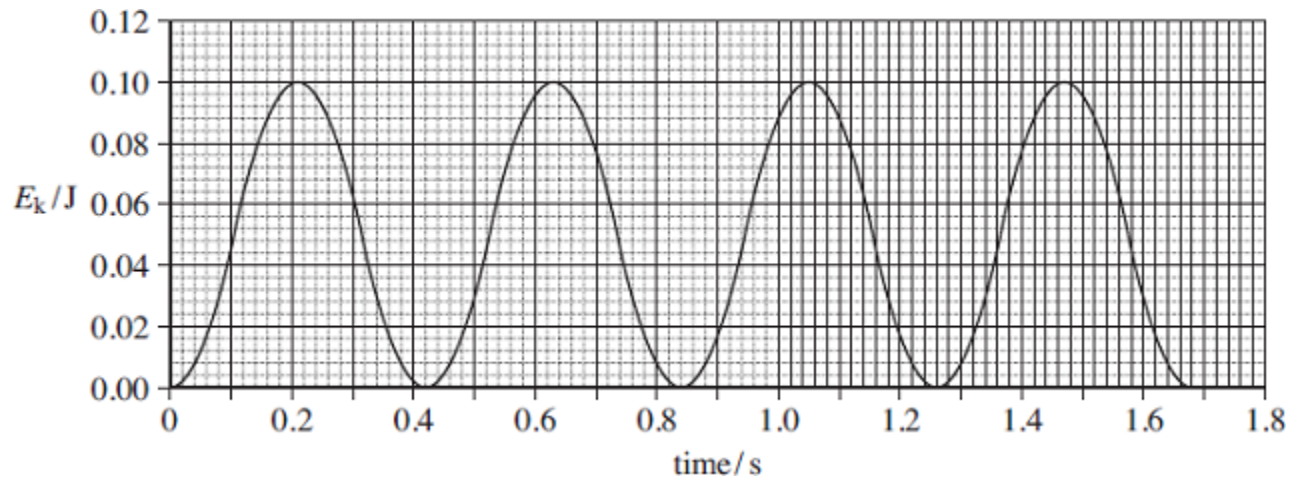
- (ii) The maximum kinetic energy of the oscillating object is 2.0×10^{-2} J. Show that the amplitude of the oscillations of the object is about 40 mm.

(4)

(Total 14 marks)

- (a) **Figure 1** shows how the kinetic energy, E_k , of an oscillating mass varies with time when it moves with simple harmonic motion.

Figure 1



- (i) Determine the frequency of the oscillations of the mass.

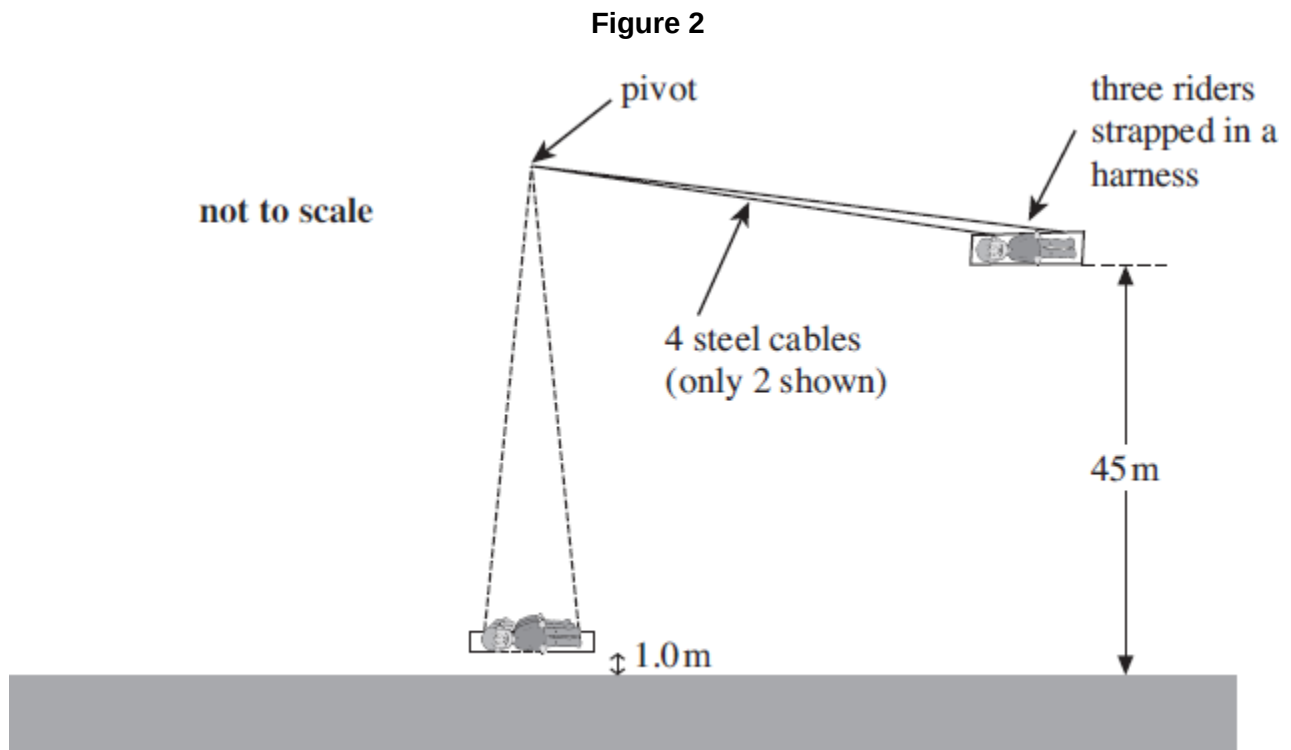
frequency of oscillation _____ Hz

(2)

- (ii) Sketch, on **Figure 1**, a graph showing how the potential energy of the mass varies with time during the first second.

(2)

(b) **Figure 2** shows a ride called a 'jungle swing'.



The harness in which three riders are strapped is supported by 4 steel cables. An advert for the ride states that the riders will be released from a height of 45 m above the ground and will then swing with a period of 14.0 s. It states that they will be 1.0 m above the ground at the lowest point and that they will travel at speeds of 'up to 120 km per hour'.

- (i) Treating the ride as a simple pendulum, show that the distance between the pivot and the centre of mass of the riders is about 49 m.

- (ii) The riders and their harness have a total mass of 280 kg.
Calculate the tension in each cable at the lowest point of the ride, assuming that the riders pass through this point at a speed of 120 km h^{-1} . Assume that the cables have negligible mass and are vertical at this point in the ride.

tension in each cable _____ N

(4)

- (iii) Show that the maximum speed stated in the advert is an exaggerated claim.
Assume that the riders are released from rest and neglect any effects of air resistance.

(4)

- (iv) The riders lose 50% of the energy of the oscillation during each half oscillation. After one swing, the speed of the riders as they pass the lowest point is 20 m s^{-1} .

Calculate the speed of the riders when they pass the lowest point, travelling in the same direction after two further complete oscillations.

speed of riders _____ ms^{-1}

(3)

(Total 17 marks)

14

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)

15

Two pendulums, P and Q, are set up alongside each other. The period of P is 1.90 s and the period of Q is 1.95 s.

How many oscillations are made by pendulum Q between two consecutive instants when P and Q move in phase with each other?

- A** 19
- B** 38
- C** 39
- D** 78

(Total 1 mark)

16

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?

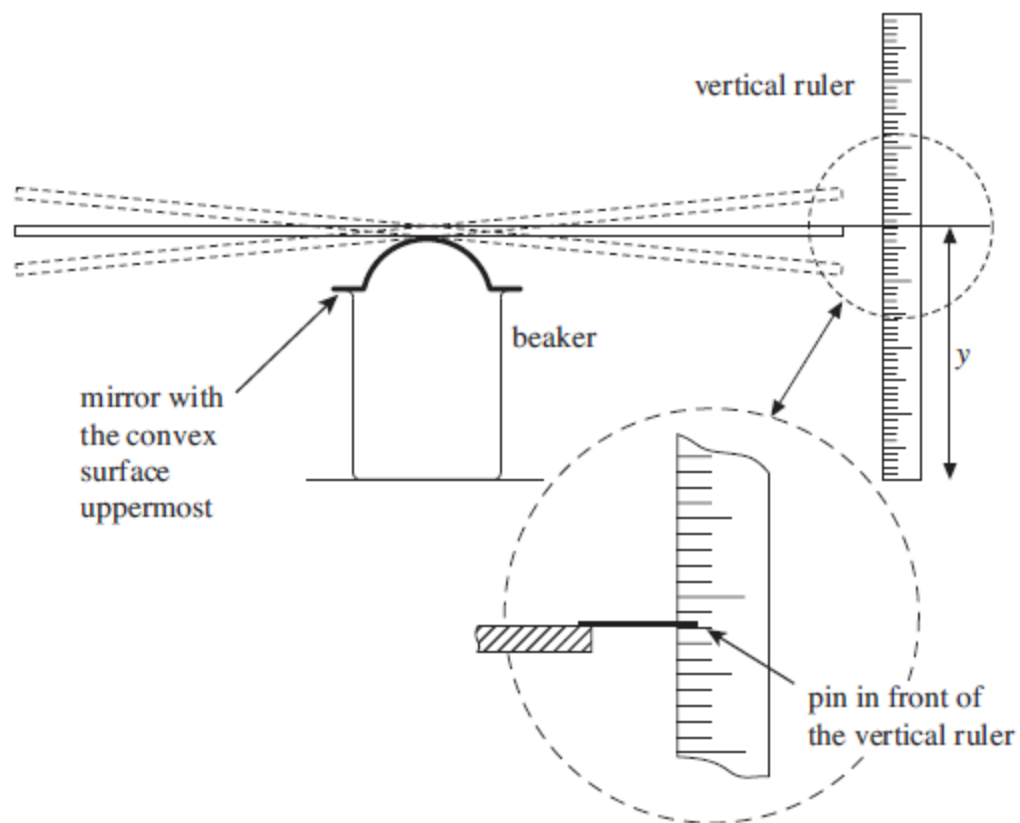
- A** at the centre of the oscillation
- B** only at the top of the oscillation
- C** only at the bottom of the oscillation
- D** at both the top and bottom of the oscillation

(Total 1 mark)

17

It is suggested to a student who is watching a metre ruler oscillating on the convex surface of a mirror that the amplitude of the oscillations decreases exponentially. The student is challenged to show whether or not this is true.

The student decides to record the motion of the ruler using a video camera. She attaches a pin to the end of the ruler and positions a vertical scale behind the tip of the pin, as shown in the diagram below.

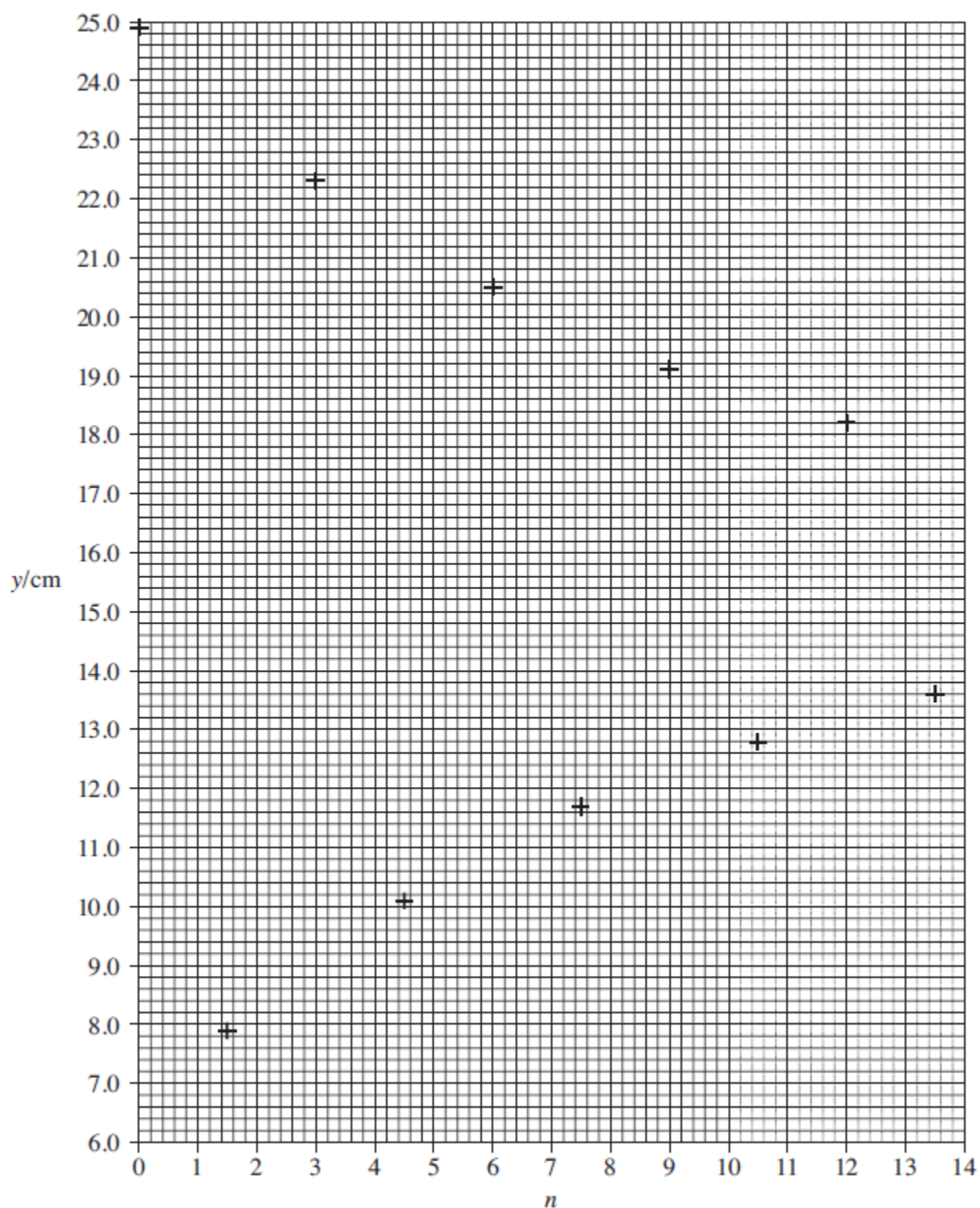


The student records the height above the bench of the tip of the pin at the top, y_t , and at the bottom, y_b , of its motion during several successive swings, n , of the ruler.

Her results are shown below.

n	0	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5
y_t/cm	24.9		22.3		20.5		19.1		18.2	
y_b/cm		7.9		10.1		11.7		12.8		13.6

(a) Her data points are plotted on the graph below.



On the graph draw

- (i) a line to show how y_t varies with n ,
- (ii) a line to show how y_b varies with n ,
- (iii) a line parallel to the horizontal axis to mark the position of the tip of the pin against the vertical scale when the ruler is at the equilibrium position.

- (b) Hence or otherwise, explain whether the student's data confirms the suggestion that the amplitude of the oscillations decreases exponentially.

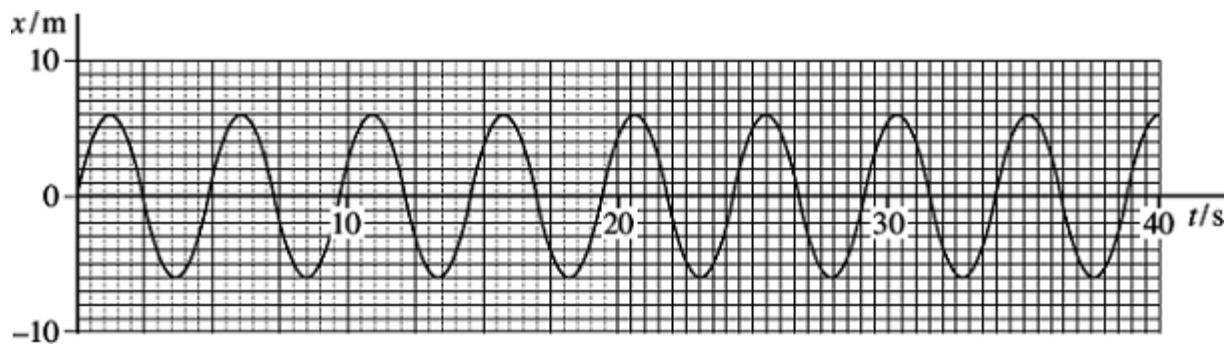
(3)

(Total 5 marks)

18

A pirate ship is a type of amusement park pendulum ride in which a gondola carrying passengers is made to oscillate. The ride can be modelled using a simple pendulum consisting of a mass on a string.

The figure below shows how the displacement x of the mass varies with time t .



- (a) (i) Define amplitude.

(1)

- (ii) Determine the amplitude of the oscillations of the mass.

amplitude _____ m

(1)

- (iii) Calculate the period of the pendulum.

period _____ s

(2)

- (b) Another model was constructed using a pendulum of frequency 0.25 Hz with the mass having an initial amplitude of 4.5 m.

- (i) Calculate the maximum velocity of the mass.

maximum velocity _____ ms^{-1}

(2)

- (ii) Calculate the maximum acceleration of the mass.

maximum acceleration _____ ms^{-2}

(2)

(iii) Calculate the length of the simple pendulum that has a frequency of 0.25 Hz.

length _____ m

(2)

- (c) To simplify the driving mechanism of the actual ride it is suggested that the gondola should be pushed each time it reaches the centre moving in one direction.
Explain why this would lead to large amplitude oscillations.

(2)

- (d) When the force is no longer applied the gondola will naturally come to rest. The time for this to happen will usually be too long to satisfy the ride operators. External dampers are used to reduce the time taken to stop the gondola.
Explain why the gondola would come to rest naturally and what feature of an energy efficient ride design would make this a lengthy process.

(3)

(Total 15 marks)

19

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)

20

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)

21

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?

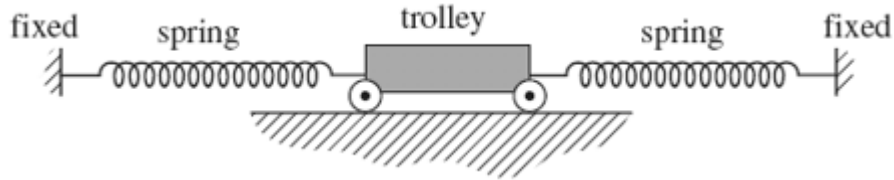
- A** 0.5 s
- B** 1.0 s
- C** 1.4 s
- D** 2.0 s

(Total 1 mark)

22

A trolley of mass 0.80 kg rests on a horizontal surface attached to two identical stretched springs, as shown in **Figure 1**. Each spring has a spring constant of 30 Nm^{-1} , can be assumed to obey Hooke's law, and to remain in tension as the trolley moves.

Figure 1



- (a) (i) The trolley is displaced to the left by 60 mm and then released. Show that the magnitude of the resultant force on it at the moment of release is 3.6 N .

(2)

- (ii) Calculate the acceleration of the trolley at the moment of release and state its direction.

answer = _____ m s^{-2}

direction _____

(2)

- (b) (i) The oscillating trolley performs simple harmonic motion. State the **two** conditions which have to be satisfied to show that a body performs simple harmonic motion.

(2)

- (ii) The frequency f of oscillation of the trolley is given by

$$f = \frac{1}{2\pi} \sqrt{\frac{2k}{m}}$$

where m = mass of the trolley

k = spring constant of one spring.

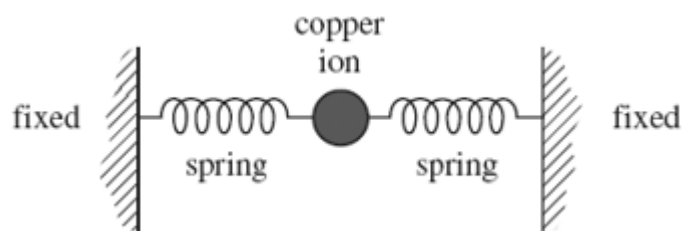
Calculate the period of oscillation of the trolley, stating an appropriate unit.

answer = _____

(3)

- (c) Copper ions in a crystal lattice vibrate in a similar way to the trolley, because the inter-atomic forces act in a similar way to the forces exerted by the springs. **Figure 2** shows how this model of a vibrating ion can be represented.

Figure 2



- (i) The spring constant of each inter-atomic 'spring' is about 200Nm^{-1} . The mass of the copper ion is $1.0 \times 10^{-25}\text{ kg}$. Show that the frequency of vibration of the copper ion is about 10^{13} Hz .

(1)

- (ii) If the amplitude of vibration of the copper ion is 10^{-11}m , estimate its maximum speed.

answer = _____ m s^{-1}

(1)

- (iii) Estimate the maximum kinetic energy of the copper ion.

answer = _____ J

(1)

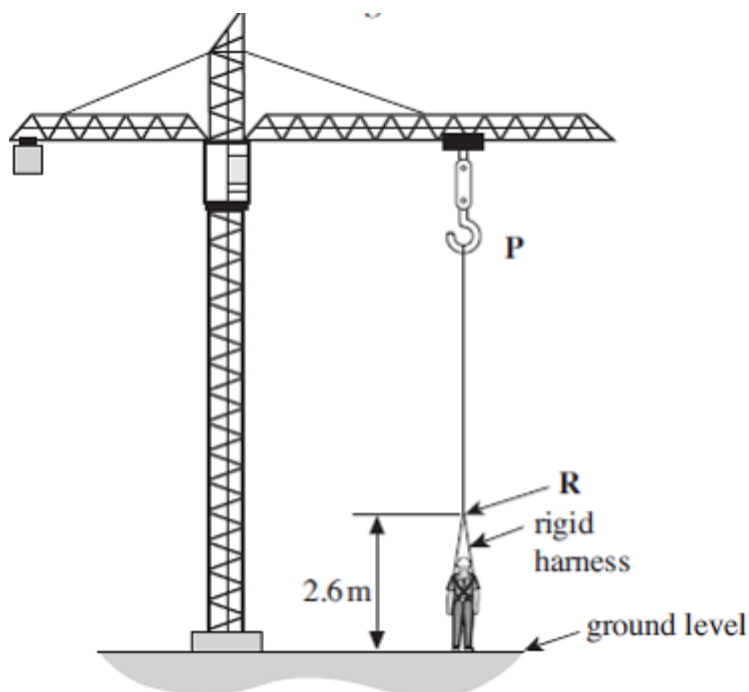
(Total 12 marks)

23

In a reverse bungee experience a 'rider' is catapulted high into the air. A designer creates a less extreme version for more timid participants, as shown in the figure below.

The rider is strapped into a rigid harness attached to one end of an elastic rope **PR**. The rider and the rope behave in the same way as a mass-spring system.

The rider is initially held at rest at ground level. The top end of the rope, **P**, is raised to stretch the rope. The rider is then released and moves upwards, reaching a maximum height when the rope is at its unstretched (natural) length. The rider then oscillates vertically until eventually coming to rest, suspended above the ground.



The rope has an unstretched length of 20 m. When stretched, the rope obeys Hooke's law and has a stiffness of 92 Nm^{-1} . In the following questions ignore the mass of the rope.

- (a) (i) The rider and harness have a total mass of 55 kg. Calculate the overall length of the rope when the rider comes to rest, suspended above the ground, at the end of the ride.

overall length _____ m

(3)

- (ii) At the start of the ride, the lower end of the rope **R** is attached to the rigid harness at a point which is 2.6 m above the ground.

The top end of the rope, **P**, has to be adjusted so that the rope just becomes unstretched when the rider is at the highest point of the ride.

Determine the height of **P** above the ground.

Neglect air resistance in this part of the question.

height of point **P** _____ m

(1)

- (b) (i) Show that the frequency of oscillation of the rider on the end of the rope is about 0.2 Hz.

(3)

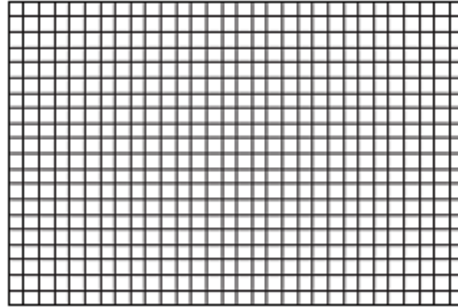
- (ii) Calculate the maximum speed reached by the rider when the amplitude of the oscillation is 4.2 m.

maximum speed _____ ms^{-1}

(2)

- (iii) In practice, air resistance has an effect. Sketch below, a graph showing how you would expect the velocity to vary with time over the first two complete oscillations, from the instant the rider was released from ground level. Take an upward velocity as being positive.

Label the time axis with a suitable scale. No scale is required on the velocity axis.



(3)

- (c) (i) A rider of greater mass now uses the ride. Explain how the height of **P** has to be changed to produce the same initial amplitude of oscillations as that for the previous rider.

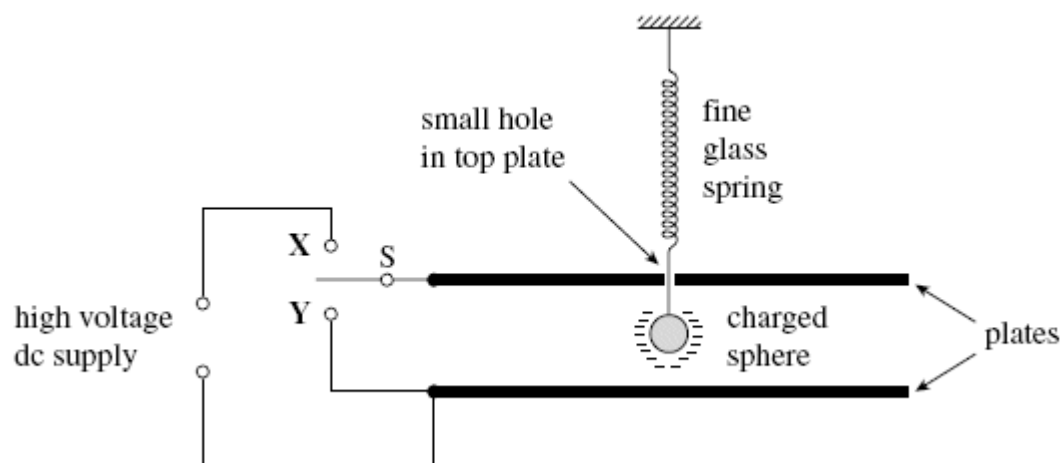
(3)

- (ii) A safety officer examines the design of the ride and thinks that, if the end **P** of the rope is raised too high so that the rope is stretched too much at the start, there is a risk that the rider could hit the ground after the first oscillation and suffer an injury. Describe what would happen to the rider during the ride in this case and explain why, even if air resistance is negligible, the safety officer's concerns are unfounded.

(3)

(Total 18 marks)

A small negatively charged sphere is suspended from a fine glass spring between parallel horizontal metal plates, as shown in the figure below.



- (a) Initially the plates are uncharged. When switch S is set to position X, a high voltage dc supply is connected across the plates. This causes the sphere to move vertically upwards so that eventually it comes to rest 18 mm higher than its original position.

(i) State the direction of the electric field between the plates.

(1)

- (ii) The spring constant of the glass spring is 0.24 N m^{-1} . Show that the force exerted on the sphere by the electric field is $4.3 \times 10^{-3} \text{ N}$.

(1)

- (iii) The pd applied across the plates is 5.0 kV. If the charge on the sphere is $-4.1 \times 10^{-8} \text{ C}$, determine the separation of the plates.

answer = _____ m

(3)

(b) Switch S is now moved to position Y.

(i) State and explain the effect of this on the electric field between the plates.

(2)

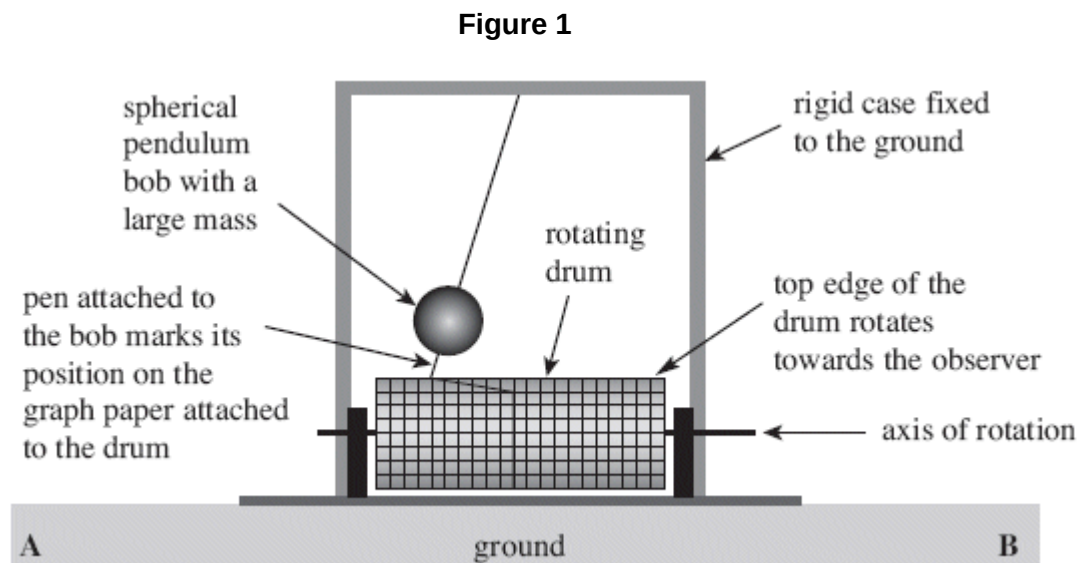
(ii) With reference to the forces acting on the sphere, explain why it starts to move with simple harmonic motion.

(3)

(Total 10 marks)

25

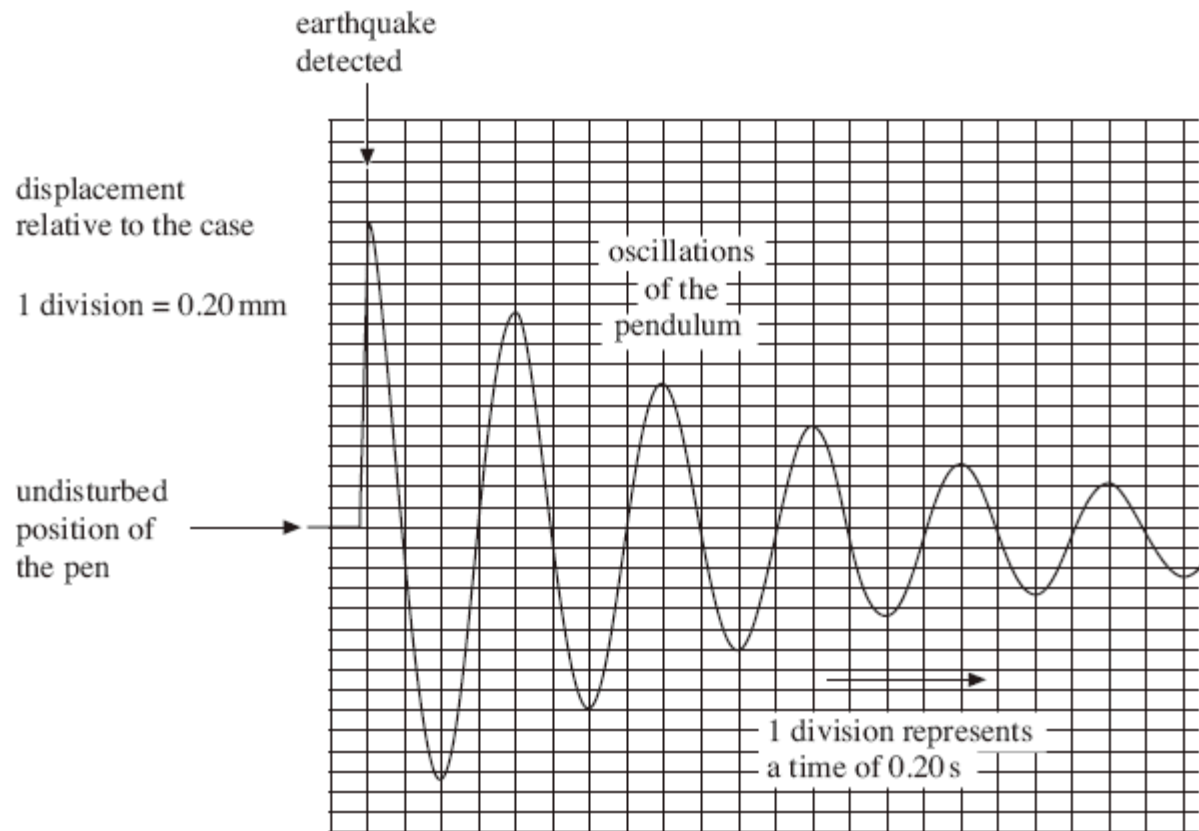
Figure 1 shows a seismometer used for detecting the horizontal movement of the ground caused by an earthquake.



The rigid case is fixed to the ground. When an earthquake occurs, the ground moves horizontally so the rigid case also moves horizontally. Initially, the heavy pendulum bob remains in its original position due to its high inertia. **Figure 1** shows the pendulum immediately after an earthquake is detected.

The rotating drum moves at a steady speed. **Figure 2** shows the trace produced on the graph paper that is attached to the rotating drum following the earthquake.

Figure 2



- (a) (i) State whether the ground has moved towards **A** or **B** to produce the situation shown in **Figure 1**.

(1)

- (ii) Determine the magnitude of the initial displacement of the ground that caused the trace in **Figure 2**.

(1)

- (b) (i) Use data from **Figure 2** to calculate the distance between the point of suspension of the pendulum and the centre of mass of the bob. Assume that the arrangement is a simple pendulum.

distance _____ m

(3)

- (ii) State and explain the effect of using a bob of the same radius but smaller mass on the initial displacement of the bob,

the period of oscillation of the bob.

(4)

- (c) (i) Determine whether the amplitude of the oscillations shown in **Figure 2** decreases exponentially.

(3)

- (ii) Explain why the amplitude of the oscillations of the bob decreases following the initial displacement.

(2)

- (iii) State and explain the effect of using a bob with the same radius but smaller mass on the time taken for the bob to come to rest following the initial disturbance.

(2)

(Total 16 marks)

26

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)

27

The time period of oscillation of a simple pendulum of length l is the same as the time period of oscillation of a mass M attached to a vertical spring. The length and mass are then changed. Which row, **A** to **D**, in the table would give a simple pendulum with a time period twice that of the spring oscillations?

	new pendulum length	new mass on spring
A	$2l$	$2M$
B	$2l$	$\frac{M}{2}$
C	$\frac{l}{2}$	$2M$
D	$\frac{l}{2}$	$\frac{M}{2}$

(Total 1 mark)

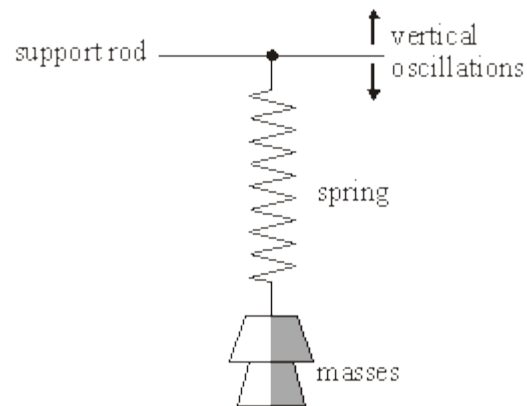
28

(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.

- (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 figure below, with amplitude 30 mm at several different frequencies.



Describe fully, with reference to amplitude, frequency and phase, the motion of the masses suspended from the spring in each of the following cases.

- (i) The support rod oscillates at a frequency of 0.2 Hz.

- (ii) The support rod oscillates at a frequency of 1.5 Hz.

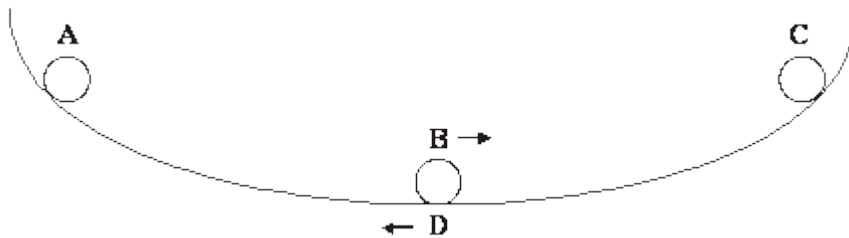
- (iii) The support rod oscillates at a frequency of 10 Hz.

(6)

(Total 10 marks)

29

A ball bearing rolls on a concave surface, as shown in the diagram, in approximate simple harmonic motion. It is released from **A** and passes through the lowest point **B** before reaching **C**. It then returns through the lowest point **D**. At which stage, **A**, **B**, **C** or **D**, does the ball bearing experience maximum acceleration to the left?



(Total 1 mark)

30

- (a) Give an equation for the frequency, f , of the oscillations of a simple pendulum in terms of its length, l , and the acceleration due to gravity, g .

State the condition under which this equation applies.

(2)

- (b) The bob of a simple pendulum, of mass 1.2×10^{-2} kg, swings with an amplitude of 51 mm. It takes 46.5 s to complete 25 oscillations. Calculate

- (i) the length of the pendulum,

- (ii) the magnitude of the restoring force that acts on the bob when at its maximum displacement.

(6)

(Total 8 marks)

31

A particle of mass m oscillates with amplitude A at frequency f . What is the maximum kinetic energy of the particle?

A $\frac{1}{2} \pi^2 m f^2 A^2$

B $\pi^2 m f^2 A^2$

C $2 \pi^2 m f^2 A^2$

D $4 \pi^2 m f^2 A^2$

(Total 1 mark)

32

The time period of a simple pendulum is doubled when the length of the pendulum is increased by 3.0 m. What is the original length of the pendulum?

A 1.0 m

B 1.5 m

C 3.0 m

D 6.0 m

(Total 1 mark)

Mark schemes

1

- (a) Time a minimum of ten oscillations in total including at least one repeat measurement **and then** calculate the mean period of oscillation, T , of the bat ✓

- (b) Measure the distance, l , from the pivot to the sweet spot ✓

- (c) Calculate the period, T_c , for a simple pendulum of length l using $T_c = 2\pi\sqrt{l/9.81}$ ✓

OR

A clear description of a simple pendulum experiment (length = l) to determine T_c ✓

- (d) Calculate the uncertainty in T from the repeat measurements ✓

- (e) The %uncertainty in $T_c = 0.5 \times$ the %uncertainty in l , if T_c was calculated ✓

OR

Calculate the %uncertainty in T_c from repeat timings, if T_c was found by experiment ✓

- (f) Compare T with T_c to see whether they agree within the calculated uncertainties. ✓

- (g) Allow 1 mark for any experimental detail designed to reduce uncertainties (but not more repeat readings) ✓

Award up to five marks of the 7 that are available.

Annotate the script with a tick and the appropriate code letter (e.g. ✓a) at each point where the candidate's answer matches a marking point.

[5 max]

2

C

[1]

3

- (a) amplitude (of bob) is small
[or (angular) amplitude is less than or = 10°]
[or $\sin \theta \approx \theta$ with θ explained] ✓

or string is inextensible (or of negligible mass)

or bob is a point mass

Ignore references to "air resistance".

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

The candidate'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 candidate describes the arrangement of the apparatus clearly. They identify correctly the measurements to be made, and indicate how these measurements would be made. They describe a valid method by which a straight line graph may be obtained and show how g would be calculated from their graph. They are also aware of precautions that should be taken during the experiment to ensure that the result is accurate.

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 candidate is less clear about the experimental arrangement, gives a reasonable account of the measurements to be made and indicates a valid method by which a straight line graph may be obtained. They are less clear about how the result would be calculated from the graph, and they know the precautions less well.

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 candidate gives a superficial account of the experimental arrangement, has some knowledge of the measurements to be made, but has only limited ability to show how a graphical method could be used to calculate the result. Some precautions may be known.

The description expected in a competent answer should include a coherent selection of the following points.

- Diagram or description showing a bob suspended from a fixed point, on which the length l may be labelled correctly.
- Length l of pendulum measured by ruler from fixed point of support to centre of mass of bob.
- Period T measured by stopwatch, by timing a number of oscillations.
- Measurement of T repeated for the same l and a mean value of T calculated.
- Measurements repeated for at least five different values of l .
- Graph of T^2 against l (or any other suitable linear graph) would be plotted.
- Graph is a straight line through origin, gradient is $4\pi^2/g$ (or correct expression for g from their graph).

Experimental measures such as the following are likely to be given:

- Small amplitude oscillations.
- Measure l to centre of mass of bob.

- Measure T from a large number of oscillations.
- Repeat timing for each length.
- Begin counting oscillations at nought when $t = 0$.
- Measure complete oscillations.
- Use of fiducial mark at centre of oscillations.
- Pendulum should swing in a vertical plane.
- Avoid very small values of l when repeating the experiment.

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

*A **high level** answer must include*

1. a description of the apparatus,
2. a correct statement of the measurements to be made,
3. a correct graph plot,
4. a correct indication of how g would be found from the graph,
5. at least two precautions.

*An **intermediate level** answer must include (at least)*

*1 and 2, **or** 1 and 3, **or** 2 and 3, above and at least one precaution.*

*A **low level** answer must include (at least) any one of 1,2,3,4 above.*

*An inappropriate, irrelevant or physically incorrect answer should be awarded **a mark of zero**.*

*If the experiment described relates to a **compound pendulum**, mark to max 2.*

If a log graph is plotted and explained, it may gain credit.

*If a correct graph is **not** used, then maximum mark awarded is 3.*

max 6

- (c) measured value of g will be $4 \times$ true value of g ✓

gradient of T^2 against l graph will be $\frac{1}{4}$ of expected value [**or** reference to $g \propto 1/T^2$ or equivalent] ✓

(T is halved so) T^2 is $\frac{1}{4}$ of true value ✓

2nd and 3rd marks may be covered by an analysis of the period equation.

3

[10]

4

D

[1]

5

- (a) (mark should be at the equilibrium position) since this is where the mass moves with greatest speed [transit time is least] ✓

1

- (b) (i) mean time for 20T (from sum of times $\div 5$) = 22.7 (s)₁ ✓
(minimum 3sf)

uncertainty (from half of the range) = 0.3 (s)₂ ✓ (accept trailing zeros here)

percentage uncertainty

$$\left(\text{from } \frac{0.3}{22.7} \times 100\right) \left[\frac{100}{5} \times \sum \frac{0.3}{20T}\right] = 1.3 (22)\%_3 \quad \checkmark$$

(allow full credit for conversion from 20T to T, e.g. $1.135 =$ ₁ ✓
 $0.015 =$ ₂ ✓ ecf for incorrect ₁ ✓ and / or ₂ ✓ earns ₃ ✓

3

- (ii) natural frequency (from $\frac{20}{22.7}$ and minimum 2 sf) = 0.88 (1)Hz [accept s⁻¹] ✓

(ecf for wrong mean 20T; accept ≥ 4 sf)

1

- (c) (i) linear scale with at least 3 evenly-spaced convenient values (i.e. not difficult multiples) marked; the intervals between 1 Hz marks must be 40 ± 2 mm (100 ± 5 mm corresponds to 2.5 Hz) ✓

(ecf for wrong natural frequency: 100 ± 5 mm corresponds to $\frac{2.5f}{0.88}$ Hz)

1

- (ii) 4 mm [allow ± 0.2 mm] ✓

1

- (d) (i) student decreased intervals [smaller gaps] between [increase frequency / density of] readings (around peak / where A is maximum) ✓ ✓

[student took more / many / multiple readings (around peak) ✓]

(reject bland 'repeated readings' idea; ignore ideas about using data loggers with high sample rates)

2

- (ii) new curve starting within ± 1 mm of A = 4 mm, f = 0 Hz with peak to right of that in Figure 3
(expect maximum amplitude shown to be less than for 2 spring system but don't penalise if this is not the case; likewise, the degree of damping need not be the same (can be sharper or less pronounced)
Peak at $\sqrt{2}$ value given in (b)(ii); expect 1.25 Hz so peak should be directly over 50 ± 5 mm but take account of wrongly-marked scale ✓

2

6

- (a) (i) Tension minimum at extremities or maximum at middle / bottom

Tension depends on (component of) weight and required centripetal force / velocity

Increases as acrobat moves downwards

Tension at bottom = $mg + mv^2/r$ or Tension = weight + centripetal force

Tension at extremity = $mg/\cos\theta$ (θ is angle between rope and vertical)

Max 3

3

- (ii) Use of $T = 2\pi\sqrt{l/g}$

3.6 (3.59) (m)

Allow for change of subject for use

2

- (b) (i) Frequency of swing = 0.26 Hz

Use of $v = 2\pi fA$

3.0 or 2.97 (m s^{-1})

alternative method

Change in pe = gain in ke

Calculating Δh by geometry from swing = 0.48 m

3.1 or 3.06 (m s^{-1})

3

- (ii) Use of $s = \frac{1}{2}at^2$

time to reach safety net = 1.11 s

$s = \text{their answer to (b)(i)} \times \text{their time to reach the net} = \text{answer}$

(answer is 3.3 m if all correct)

Allow for change of subject for use

3

(c) (i) Attempt at valid test:

Fractional change in amplitude for same time interval

or use of 'half life' method

or use of exponential formula ($A = A_0 e^{-kt}$) to show that k is constant

Correct calculation for one pair of amplitudes

Correct for second pair and conclusion

for half life method must see curve through peaks or other indication to find values between peaks

3

(ii) Period shorter

Centre of mass of trapeze artist was lower than the bar

Effective length of the pendulum is lower

Bar likely to be low mass now have a pendulum with distributed mass / no longer a simple pendulum / centre of mass is half way along suspending rope

Calculates new effective length of the pendulum (2 m)

Max 2

2

[16]

7

(a) $\text{emf} = \Delta(BAN) / t$

Change in flux = $A \times \Delta B$ or $12 \times (23 - 9)$ seen

C1

Substitution ignoring powers of 10

C1

1.2 V

A1

3

(b) Reduced

M0

Magnet will move (with the case)

A1

Increased

M0

Flux linkage increases or emf is proportional to N

A1

2

(c) (i) Formula used

$$2\pi \sqrt{\frac{8 \times 10^{-3}}{2.6}} \text{ seen}$$

B1

0.348 / 0.349 seen to at least 3 sf

B1

2

(ii) Period consistent at 0.35 s or $V_0 = 8 \text{ V}$

B1

Shape shows decreasing amplitude

M1

At least 3 cycles starting at 8 V

A1

3

[10]

8

D

[1]

9

A

[1]

10

C

[1]

11

- (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

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

3SF is an independent mark.

$$[\text{or } T \left(= 2\pi \sqrt{\frac{l}{g}} \right) = 2\pi \sqrt{\frac{0.984}{9.81}} \quad \checkmark \quad (= 1.9(90) \text{ (s)})]$$

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

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

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

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

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

$$= 0.42 \text{ (0.419) (m s}^{-2}\text{)} \quad \checkmark$$

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 2π

or $\Delta t = 0.1$ 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.

$$[\text{or } (T = 1.90 \text{ s so}) (n + 1) \times 1.90 = n \times 2.00 \quad \checkmark]$$

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

minimum time between in phase condition = $19 \times 2.00 = 38 \text{ (s)}$ ✓]

3

12

- (a) (i) elastic potential energy **and** gravitational potential energy ✓
For elastic pe allow "pe due to tension", or "strain energy" etc.

1

- (ii) elastic pe → kinetic energy → gravitational pe
 → kinetic energy → elastic pe ✓✓

[or pe→ke→pe→ke→pe is ✓ only]

[or elastic pe → kinetic energy → gravitational pe is ✓ only]

If kinetic energy is not mentioned, no marks.

Types of potential energy must be identified for full credit.

2

- (b) (i) period = 0.80 s ✓
 during one oscillation there are two energy transfer cycles
 (or elastic pe→ke→gravitational pe→ke→elastic pe in 1 cycle)
or there are two potential energy maxima per complete oscillation ✓
Mark sequentially.

2

- (ii) sinusoidal curve of period 0.80 s ✓
 – cosine curve starting at $t = 0$ continuing to $t = 1.2\text{s}$ ✓
For 1st mark allow ECF from T value given in (i).

2

- (c) (i) use of $T = 2\pi\sqrt{\frac{m}{k}}$ gives $0.80 = 2\pi\sqrt{\frac{0.35}{k}}$ ✓

$$\therefore k \left(= \frac{4\pi^2 \times 0.35}{0.80^2} \right) = 22 \text{ (21.6) } \checkmark \quad \text{N m}^{-1} \checkmark$$

Unit mark is independent: insist on N m^{-1} .

Allow ECF from wrong T value from (i): use of 0.40s gives 86.4 (N m^{-1}).

3

(ii) maximum ke = $(\frac{1}{2} m v_{\max}^2) = 2.0 \times 10^{-2}$ gives

$$v_{\max}^2 = \frac{2.0 \times 10^{-2}}{0.5 \times 0.35} \checkmark (= 0.114 \text{ m}^2 \text{s}^{-2}) \text{ and } v_{\max} = 0.338 \text{ (m s}^{-1}) \checkmark$$

$$v_{\max} = 2\pi f A \text{ gives } A = \frac{0.338}{2\pi \times 1.25} \checkmark$$

and $A = 4.3(0) \times 10^{-2} \text{ m} \checkmark$ i.e. about 40 mm

$$[\text{or maximum ke} = (\frac{1}{2} m v_{\max}^2) = \frac{1}{2} m (2\pi f A)^2 \checkmark$$

$$\frac{1}{2} \times 0.35 \times 4\pi^2 \times 1.25^2 \times A^2 = 2.0 \times 10^{-2} \checkmark$$

$$\therefore A^2 = \frac{2 \times 2.0 \times 10^{-2}}{4\pi^2 \times 0.35 \times 1.25^2} \checkmark (= 1.85 \times 10^{-3})$$

and $A = 4.3(0) \times 10^{-2} \text{ m} \checkmark$ i.e. about 40 mm]

$$[\text{or maximum ke} = \text{maximum pe} = 2.0 \times 10^{-2} \text{ (J)}$$

$$\text{maximum pe} = \frac{1}{2} k A^2 \checkmark$$

$$\therefore 2.0 \times 10^{-2} = \frac{1}{2} \times 21.6 \times A^2 \checkmark$$

$$\text{from which } A^2 = \frac{2 \times 2.0 \times 10^{-2}}{21.6} \checkmark (= 1.85 \times 10^{-3})$$

and $A = 4.3(0) \times 10^{-2} \text{ m} \checkmark$ i.e. about 40 mm]

First two schemes include recognition that $f = 1 / T$

i.e. $f = 1 / 0.80 = 1.25 \text{ (Hz)}$.

Allow ECF from wrong T value from (i) – 0.40s

gives $A = 2.15 \times 10^{-2} \text{ m}$ but mark to max 3.

Allow ECF from wrong k value from (i) – 86.4 Nm^{-1} gives

$A = 2.15 \times 10^{-2} \text{ m}$ but mark to max 3.

13

- (a) (i) correct period read from graph or use of $f=1/T$ 0.84 ± 0.01

C1

2.4 Hz gets C1

correct frequency 1.2 (1.18 – 1.25 to 3 sf)

A1

- (ii) correct shape (inverse)

B1

Crossover PE = KE

B1

- (b) (i) Use of $T = 2\pi \sqrt{\frac{l}{g}}$

C1

48.7 (49) m

A1

- (ii) $v = 120\,000 / 3600 = 33(.3) \text{ m s}^{-1}$

B1

Use of $F = m v^2/r$ (allow v in km h^{-1})

B1

Total tension = $6337 + (280 \times 9.81) = 9.083 \times 10^3 \text{ N}$
Allow their central force

B1

Divide by 4 $2.27 \times 10^3 \text{ N}$
Allow their central force

B1

- (iii) $mgh = \frac{1}{2} mv^2$

B1

Condone: Use of $v = 2\pi fA$ (max2)

$9.8 \times 44 = 0.5 v^2$ Allow 45 in substitution

B1

Condone 22 m s^{-1}

29.4 m s⁻¹ (Use of 45 gives 29.7)

B1

106 km h⁻¹ (their m s⁻¹ correctly converted)
Or compares with 33 m s⁻¹

B1

(iv) 1/16th(0.625) % of KE left if correct

M1

Allow 1/8 (0.125) or 1/32 (0.313)

KE at start = 5.6×10^4 J or states energy $\propto$ speed² so speed is $\frac{1}{4}$

M1

Allow for correct subⁿ $E = \frac{1}{2} 280 \times 20^2 \times$ factor from incorrect number of swings calculated correctly

Final speed calculated = 5 m s⁻¹

A1

Must be from correct working

[17]

14

A

[1]

15

B

[1]

16

A

[1]

17

(a) 2 smooth curves to show envelope of exponential decay waveform; lines to be continuous from first to fifth points, maximum deviation from best-fit lines through each set of 5 points must not be greater than 1 mm ✓

1

equilibrium position marked on grid with horizontal line at $A = 15.7 \pm 0.1$ cm ✓

1

- (b) evidence of **valid** working (using the line(s) and/or the equilibrium position) established in (a)(iii) to **test for** the exponential nature of the decay (working may be shown on the graph): do not penalise confusion between n and time either

evidence of relevant A values [$2A$ ie $A - (-A)$] measured from graph (correct to nearest mm) or deduced from difference between tabulated values and equilibrium position of pointer) **or 0/3** ₁ ✓

at least two half life measurements (expect evidence of working) ₂ ✓

values obtained giving $n_{1/2} = 6.3 \pm 0.3$ from **either or both** curves **confirming exponential decay** ₃ ✓

or

₁ ✓ as above; evaluates at least two ratios of successive amplitudes [or the fractional change in successive amplitudes], eg

$$\frac{A_0}{A_1} \text{ and } \frac{A_1}{A_2} \left[\frac{A_0 - A_1}{A_0} \text{ and } \frac{A_1 - A_2}{A_1} \right] \text{ }_2 \text{ } \checkmark; \text{ ratios obtained giving consistent results to}$$

$\pm 5\%$ **confirming exponential decay** ₃ ✓

or

₁ ✓ as above; evaluates difference between natural logs of at least two successive amplitudes, eg $\ln(A_0) - \ln(A_1)$ and $\ln(A_1) - \ln(A_2)$ ✓ differences obtained giving results consistent to $\pm 10\%$ **confirming exponential decay** ₃ ✓

3

5

18

- (a) (i) Maximum **displacement** (of carriage/pendulum from rest position)

B1

1

- (ii) 6.0 (m)

B1

1

- (iii) Clear evidence of what constitutes period

C1

4.8–4.9 (s)

A1

2

(b) (i) Use of $v = 2\pi fA$

C1

7.07 (ms^{-1})

A1

2

(ii) Use of $a = 4\pi^2 f^2 A$

C1

11.1 (ms^{-2}) ecf

A1

2

(iii) Substitution into or rearrangement of $T = 2\pi\sqrt{l/g}$

C1

3.98 (m)

A1

2

(c) Applied frequency = natural frequency

B1

Mention or clear description of resonance

B1

2

(d) Resistive/frictional/damping/air resistance forces

C1

due to friction in named place (eg in bearings)/air resistance acting on named part (allow ride/gondola here)

A1

low friction/large mass or inertia /streamline/smooth surface etc.

B1

3

[15]

19

C

[1]

20

A

[1]

21

B

[1]

22

- (a) (i) for one spring, change in force $\Delta F = k\Delta L = 30 \times 60 \times 10^{-3}$
 $= 1.8 \text{ (N)}$ ✓

resultant force $(= [F + \Delta F] - [F - \Delta F]) = 2\Delta F$ ✓

$(= 3.6 \text{ N})$

alternative using answer from (b) (ii)

$$a = (2\pi f)^2 x = (2\pi \times 1.38)^2 \times 60 \times 10^{-3} = 4.51 \text{ (m s}^{-2}\text{)} \checkmark$$

$$\text{resultant force} = ma = 0.80 \times 4.51 (= 3.6 \text{ N})$$

2

- (ii) acceleration $a \left(= \frac{F}{M} \right) = \frac{3.6}{0.8} = 4.5 \text{ (m s}^{-2}\text{)} \checkmark$
 to the right ✓

alternative for first mark using answer from (b) (ii)

$$a = (2\pi f)^2 x = (2\pi \times 1.38)^2 \times 60 \times 10^{-3} = 4.5 \text{ (m s}^{-2}\text{)} \checkmark$$

2

- (b) (i) acceleration is proportional to displacement
 (from equilibrium position) ✓

acceleration is in opposite direction to displacement

[or acceleration is towards a fixed point/equilibrium position] ✓

2

(ii) $f = \frac{1}{2\pi} \sqrt{\frac{2 \times 30}{0.80}} \checkmark = (1.38 \text{ Hz})$

$$\text{period } T \left(= \frac{1}{f} \right) = \frac{1}{1.38} = 0.73 \text{ (0.726)} \checkmark \text{ [or 730]}$$

s ✓ [ms]

3

$$(c) \quad (i) \quad f = \left(\frac{1}{2\pi} \sqrt{\frac{2k}{m}} \right) = \frac{1}{2\pi} \sqrt{\frac{2 \times 200}{1.0 \times 10^{-25}}} = 1.0(1) \times 10^{13} \text{ (Hz)} \checkmark$$

1

$$(ii) \quad v_{\max} (= 2\pi fA) = 2\pi \times 10^{13} \times 10^{-11} = 630 \text{ (628) (m s}^{-1}\text{)} \checkmark$$

1

$$(iii) \quad \max E_K (= \frac{1}{2} m v_{\max}^2) = \frac{1}{2} \times 1.0 \times 10^{-25} \times 628^2 = 2.0 \times 10^{-20} \text{ (J)} \checkmark$$

[or using $\frac{1}{2} kA^2$ approach]

1

[12]

23

(a) (i) use of $mg = k\Delta L$ or $F = k\Delta L$ **and** $F = mg$

C1

extension = 5.9 m

A1

total length = 25.9 m (allow 20 + their extension)

B1

3

(ii) 20 + twice (5.9) amplitude + 2.6; 34.4 m;
allow ecf from ai

B1

1

(b) (i) $T = 2\pi\sqrt{m/k}$ and $T = 1/f$ or $f = 1/2\pi\sqrt{k/m}$

B1

correct substitution: allow for calculation
of T (4.85 s)

B1

0.21 or 0.206 (Hz)

B1

3

(ii) substitutes data in $v_{\max} = 2\pi fA$

C1

5.4 ms⁻¹ (5.28 to 5.53)

A1

2

- (iii) two complete oscillations shown with positive and negative velocities and acceptable shape (condone more than 2)

B1

and two from

period of 5 s used in graph (allow ecf for T from earlier part)

B1

start at 0 and positive velocity change at $T = 0$ with positive and negative velocities shown

B1

max velocity shown decreasing

B1

3

- (c) (i) it would have to raised

B1

rest extension would be greater/rider would be nearer the ground if extension unchanged

B1

the rider has to move down a distance = to the amplitude (5.9 m) from the new rest position

or with same initial extension/energy stored in rope, the rider would reach a lower height
amplitude would be lower

or due to the larger mass more energy ($= mgh$) is needed to reach the same height

so initial extension would have to be increased

B1

3

- (ii) the rope would become slack at the top of the ride so the rider would go into free flight/rider would overshoot the highest point

B1

the rider would fall and, with negligible air resistance, the rope would again absorb the energy arriving back at the start point **or** rider is more likely to fail to reach the ground after one oscillation due to energy losses/air resistance

B1

the PE gained (at the top of the flight) can (at most) only be converted back to the elastic energy that was stored in the rope at the start

(allow a statement to the effect that to hit the floor would contravene conservation of energy or require an energy input)

B1

3

[18]

24

- (a) (i) (vertically) downwards [**or** top to bottom, or down the page] **(1)**

1

- (ii) force on sphere $F (= kx) = 0.24 \times 18 \times 10^{-3}$ **(1)** ($= 4.32 \times 10^{-3}$ N)

1

- (iii) **use of** $F = EQ$ gives $E = \frac{4.32 \times 10^{-3}}{41 \times 10^{-9}}$ **(1)** ($= 1.05 \times 10^5$ V m⁻¹)

use of $E = \frac{V}{d}$ gives separation $d = \frac{5.0 \times 10^{-3}}{1.05 \times 10^5}$ **(1)**

$= 4.8 \times 10^{-2}$ (m) **(1)** (4.76×10^{-2})

3

- (b) (i) electric field becomes zero (or ceases to exist) **(1)**

flow of charge (or electrons) from one plate to the other
[**or** plates discharge] **(1)**

(until) pd across plates becomes zero [**or** no pd across plates,
or plates at same potential] **(1)**

max 2

- (ii) net downward force on sphere (when E becomes zero)
[or gravitational force acts on sphere, or force is weight] **(1)**

this force extends spring **(1)**

force (or acceleration) is proportional to (change in)
extension of spring **(1)**

acceleration is in opposite direction to displacement
(or towards equilibrium) **(1)**

for shm, acceleration $\propto$ $(-)$ displacement
[or for shm, force $\propto$ $(-)$ displacement] **(1)**

max 3

[10]

25

- (a) (i) toward B

B1

1

- (ii) $15 \times 0.20 = 3 \text{ mm}$

B1

1

- (b) (i) period = 0.8 s

C1

use of $T = 2\pi\sqrt{L/g}$

C1

0.16 (0.159) m

A1

3

(ii) lower initial displacement

B1

lower inertia/more likely to begin moving as
the Earth moves

B1

no effect

B1

period of a simple pendulum is independent of the
mass of the bob/mass of bob is not in the formula
for the period of a simple pendulum/period only
depends on length (and g)

B1

4

(c) (i) clearly states consistency of ratios of successive
amplitudes as the
test

B1

one ratio of successive amplitudes correctly
determined

B1

two ratios correctly determined and conclusion

B1

3

(ii) the oscillations are damped/air resistance
mentioned/friction of pen against paper

B1

energy is lost because of air resistance/work is
done against air resistance/energy lost moving
air out of the way/giving air kinetic energy

B1

2

- (iii) it will come to rest quicker

M1

the bob loses a greater proportion of its energy during each oscillation

A1

2

or pendulum has lower inertia so damping force has greater effect

or oscillating pendulum (initially) has less energy

or air resistance (initially) is unchanged

[16]

26

C

[1]

27

B

[1]

28

(a) (i) $mg = ke$ (1)

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

$$T = 2\pi \sqrt{\frac{m}{k}} = 2\pi \sqrt{\frac{0.69}{61.3}} \text{ (1) (= 0.667 s)}$$

(ii) $f = \left(\frac{1}{T} \right) = \frac{1}{0.667} \text{ (1) (= 1.50 Hz)}$

4

- (b) (i) forced vibrations (at 0.2 Hz) (1)
amplitude less than resonance (≈ 30 mm) (1)
(almost) in phase with driver (1)

- (ii) resonance [or oscillates at 1.5 Hz] (1)
amplitude very large (> 30 mm) (1)
oscillations may appear violent (1)
phase difference is 90° (1)

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

Max 6

[10]

29

C

[1]

30

(a) $f = \frac{1}{2\pi} \sqrt{\frac{g}{l}}$ (1)

Oscillations must be of small amplitude (1)

2

(b) (i) $f = \frac{25}{46.5} = 0.53(8)(s^{-1})$ (1)

[or $T = \frac{46.5}{25} = 1.8(6) (s)$]

$l \left(= \frac{g}{4\pi^2 f^2} \right) = \frac{9.81}{4\pi^2 0.538^2}$ [or $l \left(= \frac{T^2 g}{4\pi^2} \right) = \frac{1.86^2 \times 9.81}{4\pi^2}$] (1)

$l = 0.85(9)m$ (1)

(allow C.E. for values of f or T)

(ii) $a_{\max} (= -(2\pi f)^2 A) = (2\pi \times 0.538)^2 \times 51 \times 10^{-3}$ (1)

(= 0.583 ms^{-2})

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

$F_{\max} (= ma_{\max}) = 1.2 \times 10^{-2} \times 0.583$ (1)

= $7.0 \times 10^{-3} \text{ N}$ (1)

($6.99 \times 10^{-3} \text{ N}$)

[or $F_{\max} (= mg \sin \theta_{\max})$ where $\sin \theta_{\max} = \frac{51}{859}$ (1)

= $1.2 \times 10^{-2} \times 9.81 \times \frac{51}{859}$ (1)

= $6.99 \times 10^{-3} \text{ N}$ (1)]

6

[8]

31

C

[1]

32

A

[1]