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EDEXCEL A LEVEL PHYSICS: QUESTIONS BY TOPIC

Oscillations (13)

A Level Physics Topic 13

30 questions · 218 marks · Mark schemes included

A Level only content · Pearson Edexcel 8PH0 / 9PH0 papers, 2016–2025

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HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.

Click any row below to jump straight to that sub-topic or question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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3. Q10	A Level Paper 2 June 2019	1	6
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QUESTIONS

30 questions · 218 marks · 2 sub-topics



SUB-TOPIC 13.1

SIMPLE HARMONIC MOTION

Sub-topic 13.1 · 19 questions · 124 marks · lowest tariff first



3 A playground swing completes 24 oscillations in 1 minute.

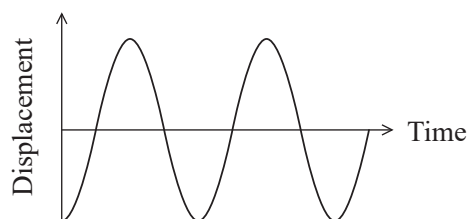
Which of the following is the frequency of the oscillations?

- ☐ **A** 0.042 Hz
- ☐ **B** 0.40 Hz
- ☐ **C** 2.5 Hz
- ☐ **D** 24 Hz

(Total for Question 3 = 1 mark)

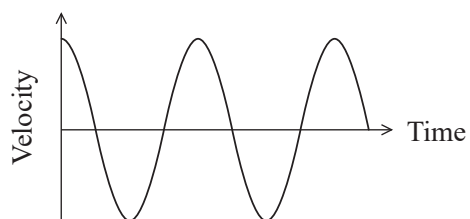


- 8 The graph shows how the displacement of a simple harmonic oscillator varies with time.

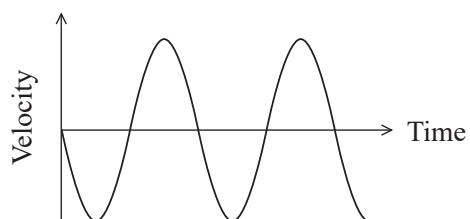


Which of the following graphs shows how velocity varies with time for the same oscillator, over the same time period?

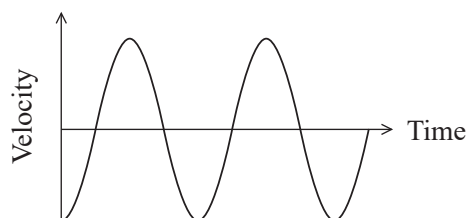
☐ A



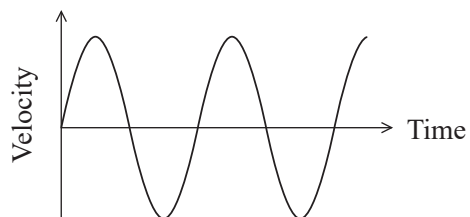
☐ B



☐ C



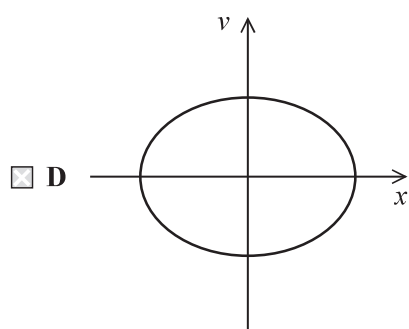
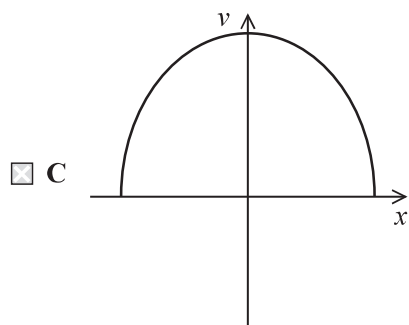
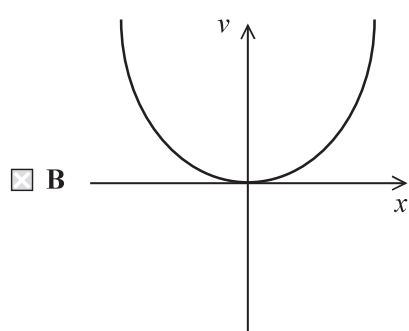
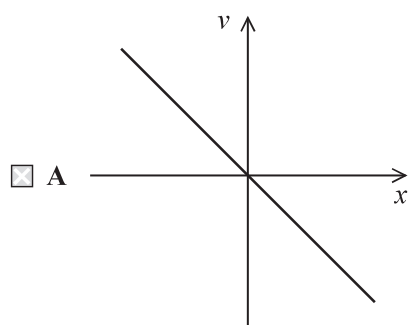
☐ D



(Total for Question 8 = 1 mark)

10 A mass at the end of a spring is set into small amplitude simple harmonic motion.

Which of the following graphs correctly shows the variation of velocity v of the mass with displacement x for one complete oscillation?



(Total for Question 10 = 1 mark)

7 A pendulum of length l with a bob of mass m oscillates with frequency f .

What is the frequency of a pendulum of length $4l$ with a bob of mass $2m$?

☐ A $4f$

☐ B $2f$

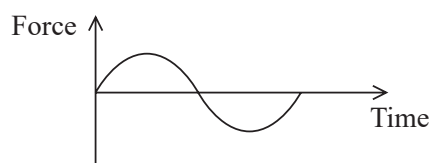
☐ C f

☐ D $\frac{f}{2}$

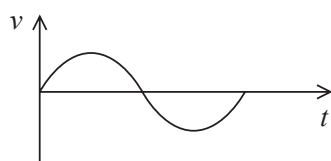
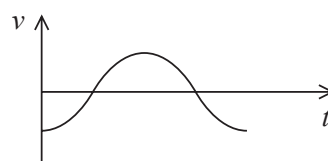
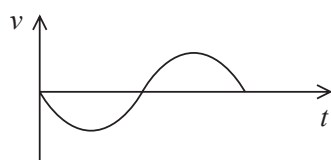
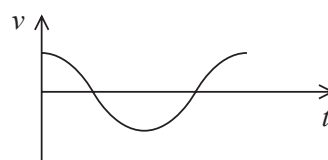
(Total for Question 7 = 1 mark)



- 9 A mass is suspended from a spring and allowed to come to equilibrium. The mass is displaced vertically and moves with simple harmonic motion. The graph shows how the resultant force on the mass varies with time.



Which of the following graphs shows how the velocity v of the mass varies with time t over the same time interval?

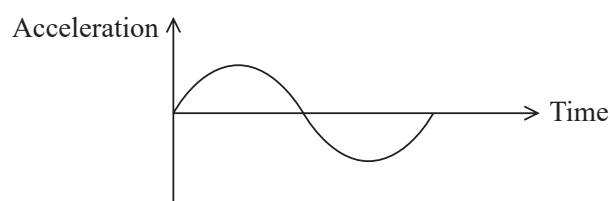
**A****B****C****D**

- ☐ A
- ☐ B
- ☐ C
- ☐ D

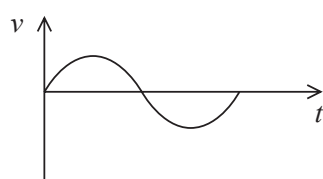
(Total for Question 9 = 1 mark)

- 9 A mass is suspended from a spring and displaced vertically. The mass performs simple harmonic motion.

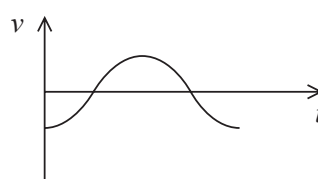
The graph shows how the acceleration of the mass varies with time over one oscillation.



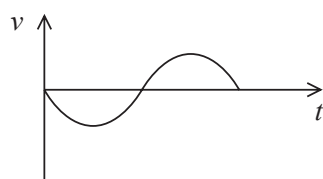
Which of the following graphs shows how the velocity v of the mass varies with time t over the same time interval?



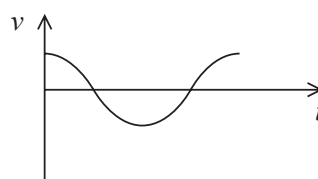
A



B



C



D

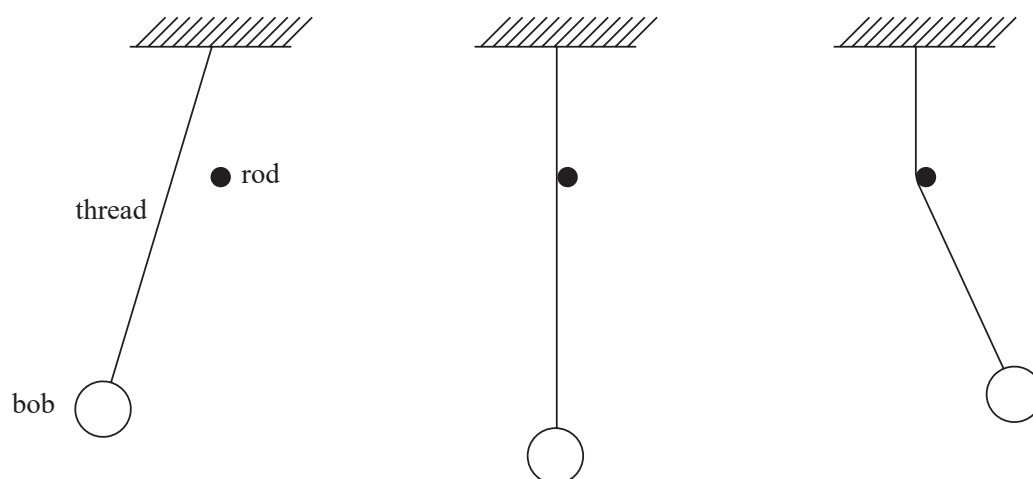
- ☐ A
- ☐ B
- ☐ C
- ☐ D

(Total for Question 9 = 1 mark)

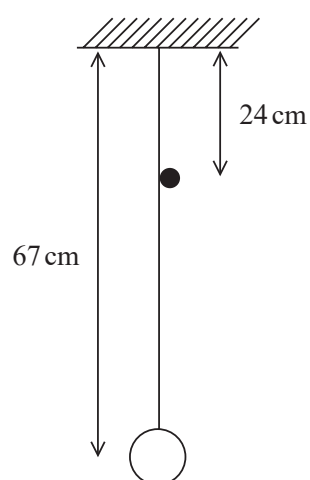
- 11 A simple pendulum consisting of a thread and a bob is set up next to a horizontal rod.

The bob is displaced to the left and released. When the bob reaches the equilibrium position the thread strikes the horizontal rod. For half of the cycle, only the lower part of the pendulum moves.

The diagram shows the swing of the pendulum.



The diagram below shows the dimensions of the pendulum.



Determine the frequency of the oscillations of the pendulum.

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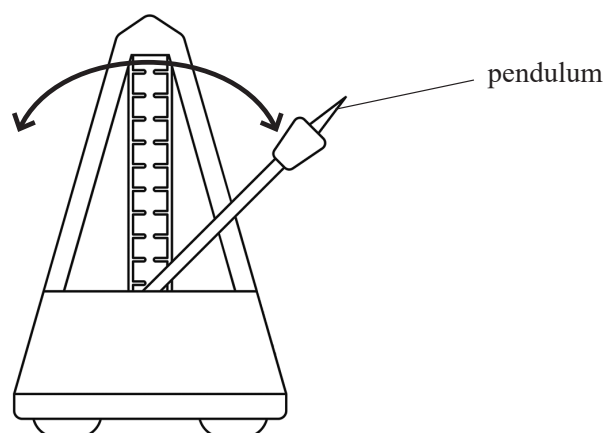
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Frequency = ...

(Total for Question 11 = 4 marks)



- 4 The diagram shows a metronome, which includes an inverted pendulum, used by musicians to set a tempo. The pendulum oscillates with simple harmonic motion and makes a loud click at regular intervals.



(Source: Getty Images)

A faulty metronome stopped making a clicking noise. A student tried to check the accuracy of the period T of the metronome, using a stopwatch. The student timed the pendulum as it moved from one extreme of the oscillation to the other.

Explain how the procedure used by the student to determine T could have been improved.

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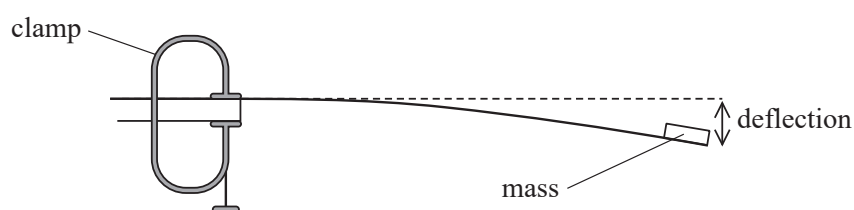
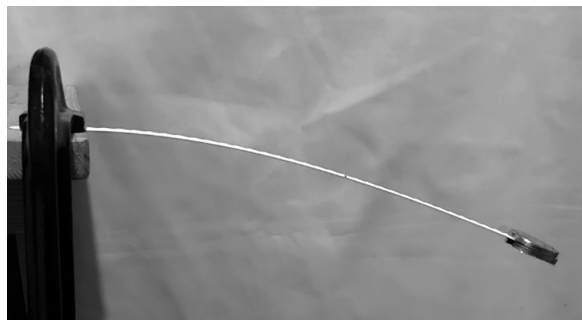
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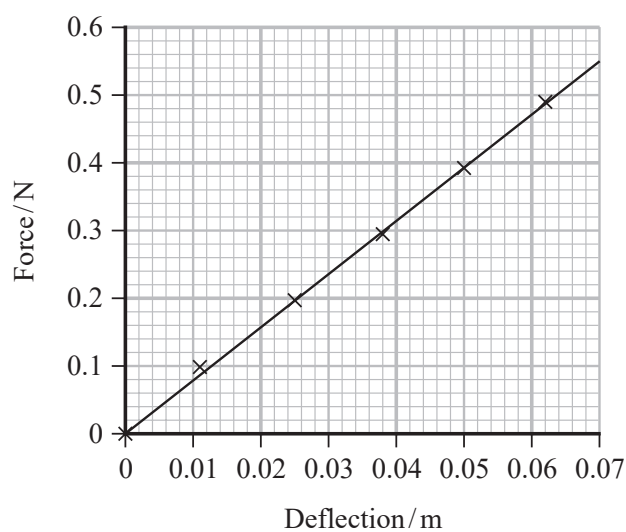
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(Total for Question 4 = 5 marks)

- 13 A student measured the deflection of a mass attached to the end of a thin strip of metal. The strip was clamped to a bench at one end as shown.



The student varied the force on the end of the strip by changing the mass attached. The deflection was measured each time when the mass was in its equilibrium position. The student obtained the following graph of deflection against force.



- (a) State why the mass will oscillate with simple harmonic motion when it is displaced slightly from its equilibrium position and released.

(2)

- (b) The student then investigated the oscillations of the mass on the metal strip. The student fixed different numbers of 10 g masses to the end of the metal strip.

The student noticed that the smaller the mass the higher the frequency of the oscillations. He estimated that the maximum number of oscillations he could count was two per second. He decided that the smallest mass he should use was 50 g.

Determine whether 50 g is the smallest mass he should use.

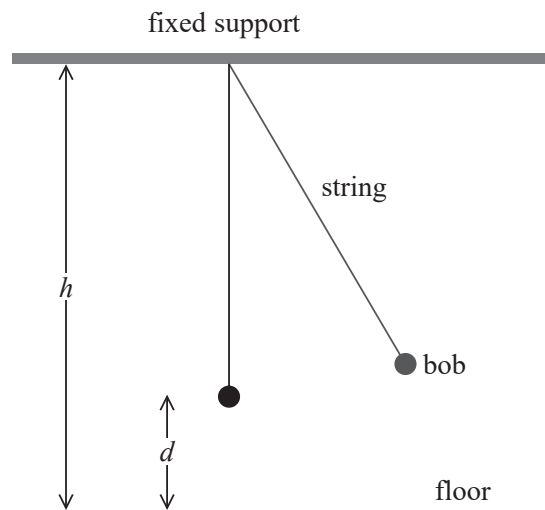
You may assume that the system acts in the same way as a mass on a spring.

(5)

(Total for Question 13 = 7 marks)



- 3 A student carried out an experiment with a pendulum hung from a fixed support. The fixed support was a distance h above floor level as shown.



As the student was unable to measure the length of the pendulum directly, she measured the distance d from the bob to the floor.

- (a) To determine the period T of the pendulum, the student used the following method:

- release the bob from its highest position and start a stopwatch
- stop the stopwatch when the bob reaches the same position again.

Criticise the student's method for measuring the period.

(2)

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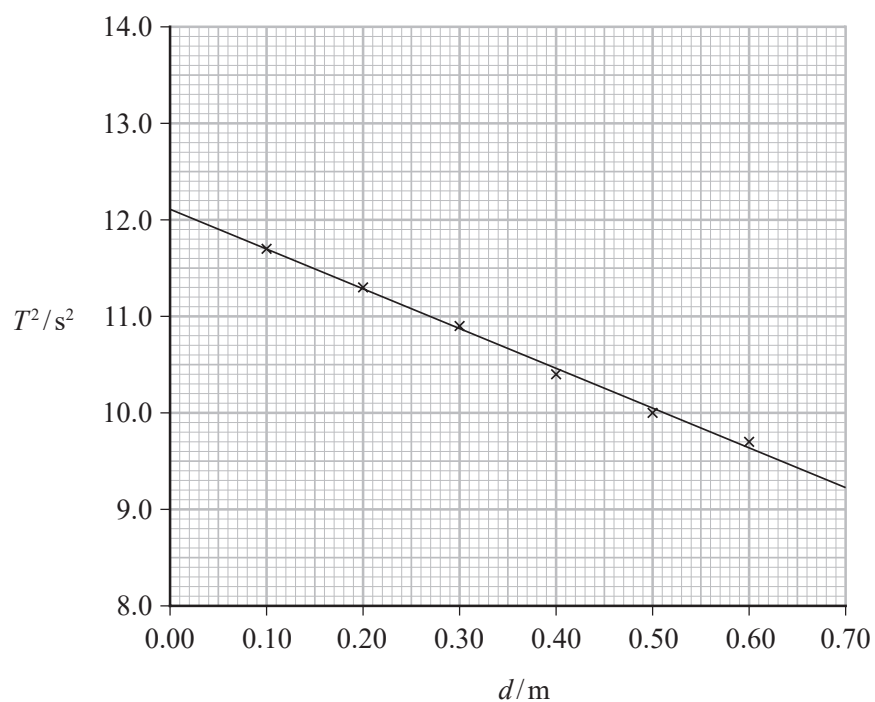
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(b) The student used her data to plot a graph of T^2 against d as shown below.



Determine a value for the acceleration due to gravity g .

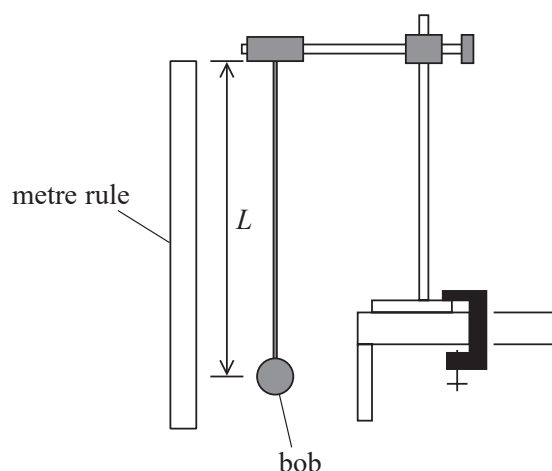
(5)

$g =$

(Total for Question 3 = 7 marks)



- 4 A student set up a “seconds pendulum”. This is a simple pendulum for which the time taken to move from the bob’s highest position on one side to its highest position on the opposite side is 1.00 s.



- (a) Calculate the length L required for the pendulum to be a “seconds pendulum”.

(2)

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$L =$

- (b) The student set the pendulum into oscillation. She used a stopwatch to check the accuracy of the pendulum’s period T .

Describe the procedure the student should have used to obtain an accurate value for T .

(2)

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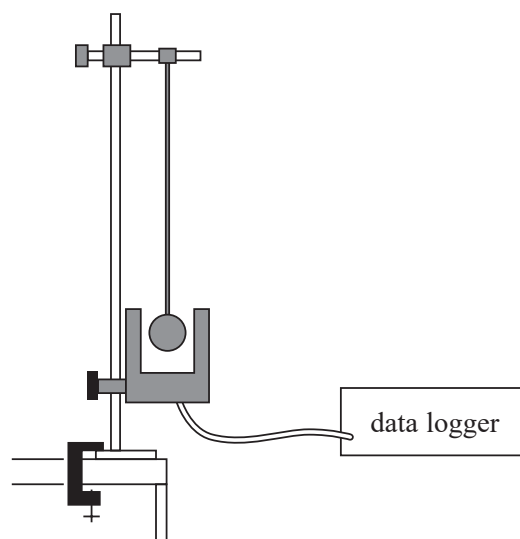
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- (c) Another student suggested that the uncertainty in the measurement of the time period of the pendulum could be reduced by using a light gate and a data logger. The data logger would record the time between successive interruptions of the light beam. Both the data logger and the stopwatch have a resolution of 0.01 s.



Comment on the student's suggestion of using a data logger rather than a stopwatch.

(4)

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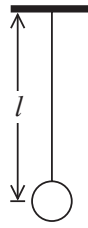
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(Total for Question 4 = 8 marks)

- 5 A student is using a simple pendulum to determine a value for the acceleration of free fall g .



- (a) She measures the length l of the pendulum four times with a metre rule and records the following values.

l / cm			
l_1	l_2	l_3	l_4
85.5	86.0	87.5	85.5

She calculates the mean length l_m of the pendulum using the following method:

$$l_m = \frac{85.5 + 86.0 + 87.5 + 85.5}{4} = 86.1 \text{ cm}$$

- (i) Calculate a more accurate value for l_m .

(2)

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$$l_m = \dots\dots\dots$$

- (ii) Determine the time period of the oscillations of this pendulum, using your calculated value for l_m .

(2)

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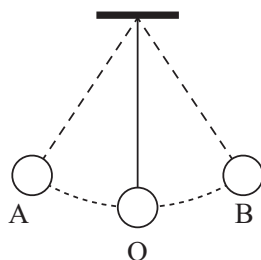
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Time period of oscillations = ...



- (b) She sets the pendulum into oscillations with small amplitude and uses a stopwatch to determine the time period.



The student releases the pendulum at A and simultaneously starts the stopwatch. She measures the time taken for 5 oscillations and divides the value by 5. She repeats the procedure twice and calculates a mean time period.

Explain two modifications to the student's method that would improve the value obtained for the time period.

(4)

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(Total for Question 5 = 8 marks)

- 11 The International Space Station (ISS) is in a low Earth orbit. Astronauts in ISS have an apparent weight of zero. In order to determine their mass, the astronauts must secure themselves to a platform which is set into oscillation and moves with simple harmonic motion.



- (a) Explain why the astronauts in the ISS have an apparent weight of zero.

(2)

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- (b) State what is meant by simple harmonic motion.

(2)

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(c) Describe how, using a stopwatch and a ruler, the following quantities could be determined for the oscillating platform:

(i) the frequency of oscillation

(2)

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(ii) the maximum speed of the platform.

(2)

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(d) The platform continues to move with simple harmonic motion at the same frequency, but its amplitude is doubled.

Explain how the maximum kinetic energy of the platform will change.

(2)

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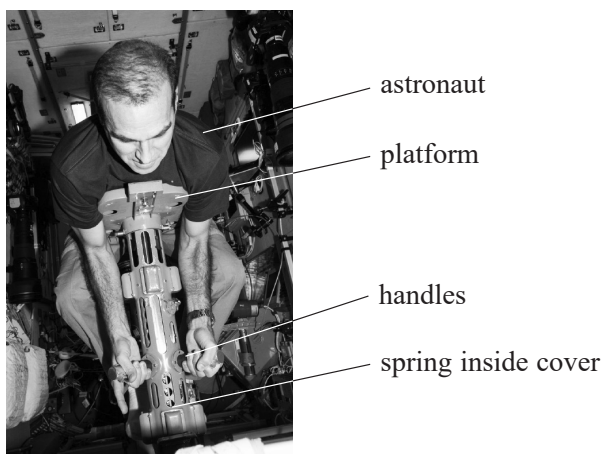
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(Total for Question 11 = 10 marks)



- 16** On the International Space Station (ISS), astronauts measure their mass once a month using a Body Mass Measurement Device (BMMD).

The BMMD is constructed from a large spring attached to the floor of the ISS, with a platform and handles attached to the spring. The spring is compressed and the astronaut puts his body onto the platform and holds onto the handles, as shown.



(Source: <https://www.nasa.gov/content/nasa-astronaut-rick-mastracchio-3>)

The spring is released and the astronaut and platform oscillate with simple harmonic motion.

An astronaut used the BMMD. The frequency of oscillation was 0.34 Hz.

- (a) Determine the mass of the astronaut.

spring constant = 350 N m^{-1}

mass of platform = 5.7 kg

(4)

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Mass of astronaut = ...

(b) The distance between the upper and lower points of the first oscillation is 0.29 m.

(i) Calculate the magnitude of the maximum acceleration of the astronaut.

(4)

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Magnitude of maximum acceleration = ...

(ii) Calculate the speed of the astronaut 3.5 s after the start of the oscillations.

(2)

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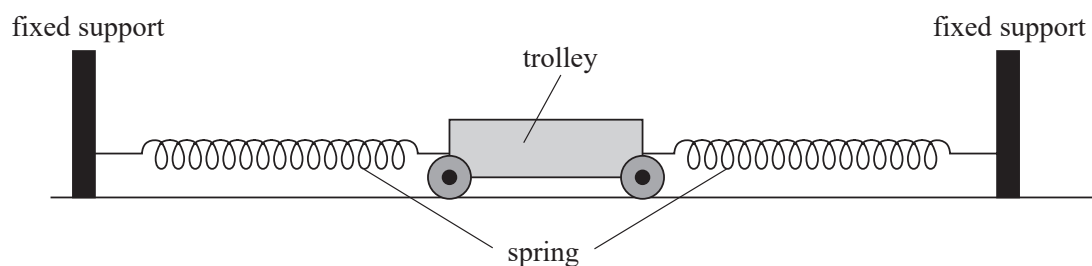
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Speed = ...

(Total for Question 16 = 10 marks)



- 5 A student used springs to attach a trolley between two fixed supports, as shown.



When displaced horizontally, the trolley oscillated with simple harmonic motion.

To determine the time period T of oscillation of the trolley, the student displaced the trolley from its equilibrium position and released it. As she released the trolley, she started a stopwatch. She stopped the stopwatch when the trolley had returned to its starting point.

- (a) Explain how the procedure used by the student to determine T could have been improved.

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- (b) The mass of the trolley was M . The student added a small mass m to the trolley and determined the new value of T . She repeated the procedure for a range of values of m .

She plotted a graph of T^2 against m .

Explain how she could use her graph to determine a value for M .

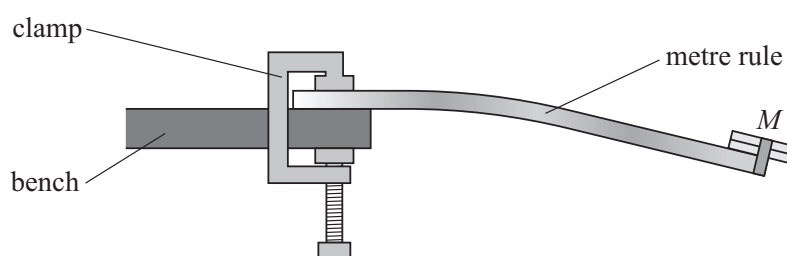
(4)

(Total for Question 5 = 10 marks)



9 A cantilever is a beam fixed at one end.

A student made a cantilever by clamping a metre rule to a bench and attached a mass M at the free end, as shown.



The student displaced the free end through a small distance. When the free end was released, the cantilever oscillated with simple harmonic motion of period T .

- (a) The student measured the time for 5 oscillations with an electronic stopwatch. This was repeated twice.

(i) Explain **one** modification to the apparatus which would improve the accuracy of the data the student obtained.

(3)

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(ii) Explain **one** modification to the student's method which would reduce the percentage uncertainty in her measurement of T .

(2)

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- (b) The length of the metre rule overhanging the bench was L . The period of oscillation T is related to L , M and the Young modulus E of the wood of the metre rule by the expression

$$T^2 \propto \frac{ML^3}{E}$$

The student repeated the timing measurements for a half-metre rule.

The half-metre rule had the same added mass M , width and thickness as the metre rule.

The metre rule was made from wood of Young modulus E_1 , and the half-metre rule was made from wood of Young modulus E_2 .

The student collected the following data.

	Young modulus	L/m	Time for 5 oscillations		
			t_1/s	t_2/s	t_3/s
Metre rule	E_1	0.95	14.69	14.64	14.76
Half-metre rule	E_2	0.45	5.33	5.40	5.24

The table below gives the Young modulus values of various types of wood.

Type of wood	Cedar	Spruce	Pine
Young modulus/GPa	7.7	9.6	10.1

Deduce the type of wood each rule is made from.

(6)

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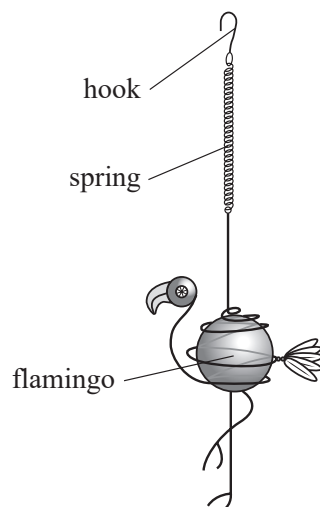
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(Total for Question 9 = 11 marks)

- 20 A garden ornament consists of a metal flamingo suspended from a spring as shown. The spring is hung from a support using the hook.



- (a) The mass of the flamingo is 65 g. When the flamingo is suspended vertically the spring extends by 8.5 cm.

The flamingo is pulled downwards by a small extra displacement and then released. The flamingo undergoes simple harmonic motion vertically.

The instructions state that the flamingo will oscillate with a frequency of 2.5 Hz.

Deduce whether this statement is correct.

(5)

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- (b) After being set into vertical oscillation, the flamingo comes to rest after a short time.

Explain why the flamingo comes to rest.

(2)

- (c) In a slight breeze the flamingo swings from side to side and behaves as a simple pendulum.

- (i) Show that the period of oscillation of the flamingo pendulum is about 2.2 s.

pendulum length = 1.25 m

(2)

- (ii) The amplitude of oscillation of the flamingo pendulum is 7.5 cm.

Calculate the maximum velocity of the flamingo pendulum.

(3)

Maximum velocity = ...

(Total for Question 20 = 12 marks)



16 The photograph shows an example of a Foucault pendulum.



This is a pendulum that consists of a massive sphere, suspended by a long wire from a high ceiling. Over time the vertical plane through which the pendulum swings appears to rotate because of the rotation of the Earth.

mass of sphere = 28.0 kg

(a) The pendulum makes 8 complete oscillations in 52.2 s.

Show that the length of the wire supporting the sphere is about 10 m.

diameter of sphere = 60.0 cm

(4)

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(b) During refurbishment, the pendulum is taken down and the wire is replaced.

Steel wires of the following diameters are available:

0.71 mm 0.91 mm 1.22 mm 1.63 mm 2.03 mm

(i) Explain which of these wires is the thinnest that could be used to support the sphere safely.

breaking stress of steel = $3.10 \times 10^8 \text{ N m}^{-2}$

(3)

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- (ii) The wire identified in part (i) is used for the pendulum, the unstretched length of the new wire is 11.2 m.

Calculate the extension of the new wire when the sphere is attached.

Young Modulus for steel = 200 GPa

(3)

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Extension = ...

- (c) To show the rotation of the Earth, the pendulum needs to oscillate for several hours.

Explain how using a heavy sphere is better than using a light sphere of the same diameter.

(3)

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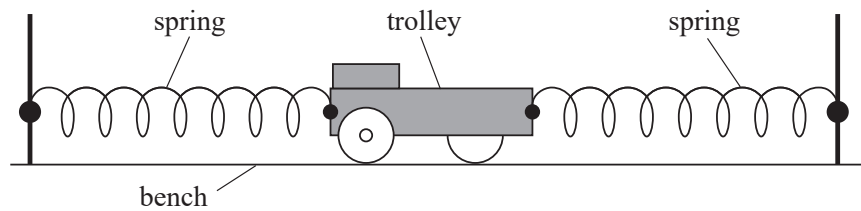
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(Total for Question 16 = 13 marks)



- 7 A trolley is attached to the ends of two springs as shown. When displaced from its equilibrium position, the trolley moves with simple harmonic motion.



- (a) A student has a stopwatch and metre rule available.

- (i) Explain the procedure that the student should follow to make an accurate determination of the time period T of the trolley.

(6)

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- (ii) Describe how the student should use her value of T to determine the maximum speed of the trolley.

(3)

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- (b) Another student suggests that a more accurate value for T could be obtained by using a position sensor and data logger.

Comment on this suggestion.

(1)

- (c) The student displaces the trolley a greater distance from the equilibrium position, so the amplitude of oscillation is doubled. The trolley still moves with simple harmonic motion.

Explain how the maximum kinetic energy of the trolley will change.

(3)

(Total for Question 7 = 13 marks)



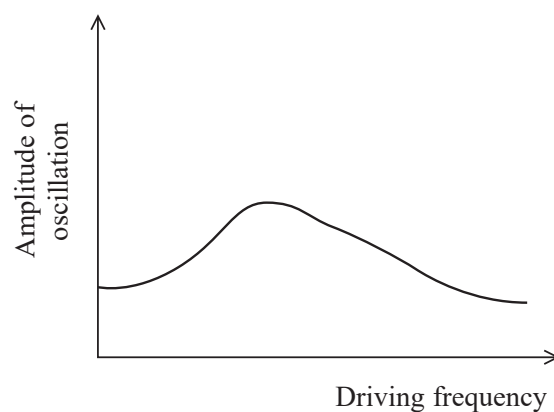
SUB-TOPIC 13.2

ENERGY IN SHM, DAMPING AND RESONANCE

Sub-topic 13.2 · 11 questions · 94 marks · lowest tariff first



- 5 A damped mass-spring system is driven into oscillation. The graph shows the amplitude of oscillation as the driving frequency is varied.



The damping is decreased.

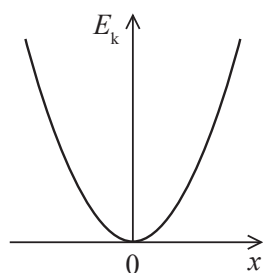
Which row of the table describes what happens to the maximum amplitude of oscillation and the driving frequency at which this occurs?

	Maximum amplitude	Frequency at which maximum amplitude occurs
☐ A	decreases	decreases
☐ B	decreases	increases
☐ C	increases	decreases
☐ D	increases	increases

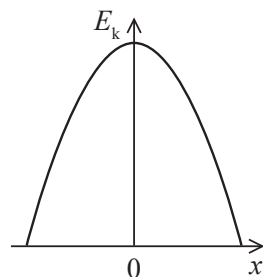
(Total for Question 5 = 1 mark)

- 9 An object oscillates with simple harmonic motion. The object has kinetic energy E_k and displacement x .

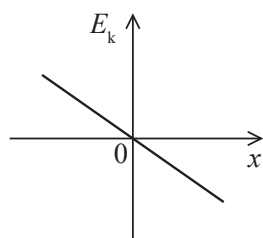
Which of the following graphs shows the variation of E_k with x for the object?



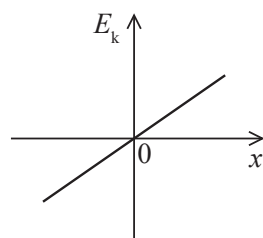
☐ A



☐ B



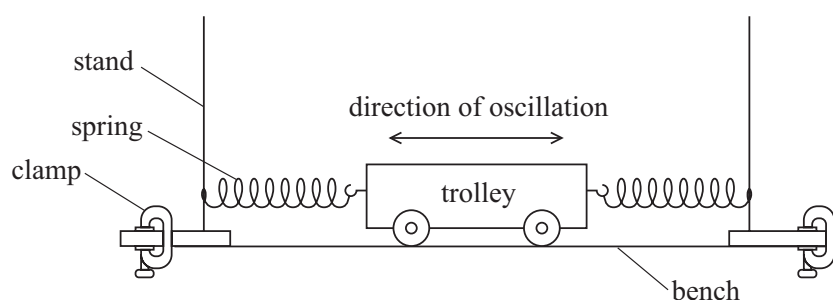
☐ C



☐ D

(Total for Question 9 = 1 mark)

- 6 A trolley is attached to two springs and set into horizontal oscillation, as shown.



The kinetic energy of the trolley is E_k , and the potential energy of the trolley is E_p .

Which row of the table is correct?

	Trolley at equilibrium position	Trolley at maximum displacement
☐ A	E_k is a maximum	E_p is minimum
☐ B	E_k is a maximum	E_p is a maximum
☐ C	E_k is zero	E_p is a maximum
☐ D	E_k is zero	E_p is minimum

(Total for Question 6 = 1 mark)

***13** The photograph shows a ‘singing bowl’.



When the handles are rubbed with both hands the bowl ‘sings’, producing a loud note with a frequency of 720 Hz.

A vibration generator is attached to the bowl and connected to a signal generator. The signal generator is adjusted to produce frequencies from 600 Hz to 800 Hz.

At all frequencies in this range the bowl produces a sound at the applied frequency. The sound is quiet for all frequencies except 720 Hz, when it is much louder.

Explain these observations.

(6)

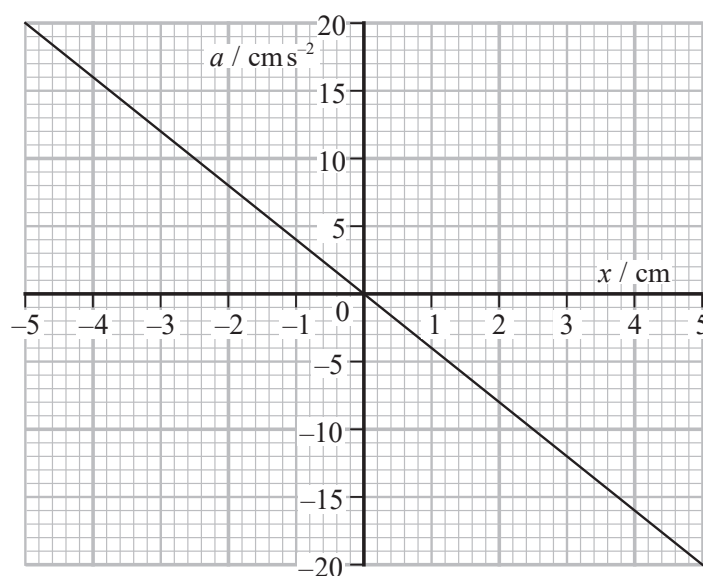
(Total for Question 13 = 6 marks)

- 10 A ‘jumperoo’ is a harness, suspended by a vertical spring, into which a baby can be placed, as shown.



The jumperoo is adjusted so that the baby’s feet are a few centimetres above the floor. If the baby is then displaced downwards and released, he oscillates vertically.

- (a) The graph shows how the acceleration a of the baby depends upon the displacement x of the baby from its equilibrium position.



For safety reasons, it is suggested that the maximum velocity of the baby should not exceed 0.5 m s^{-1} .

Assess whether it is safe for the baby to oscillate in the jumperoo with an amplitude of 22 cm.

(3)

- (b) The amplitude of the oscillations quickly decreases, so the baby has to push down on the floor to maintain the oscillations.

When the baby pushes at a particular frequency, the amplitude of oscillation increases to a maximum.

A baby of greater mass is placed in the jumperoo.

This baby pushes on the floor at a frequency that produces a maximum amplitude of oscillation.

Explain how this frequency compares with the frequency of pushing of the original baby.

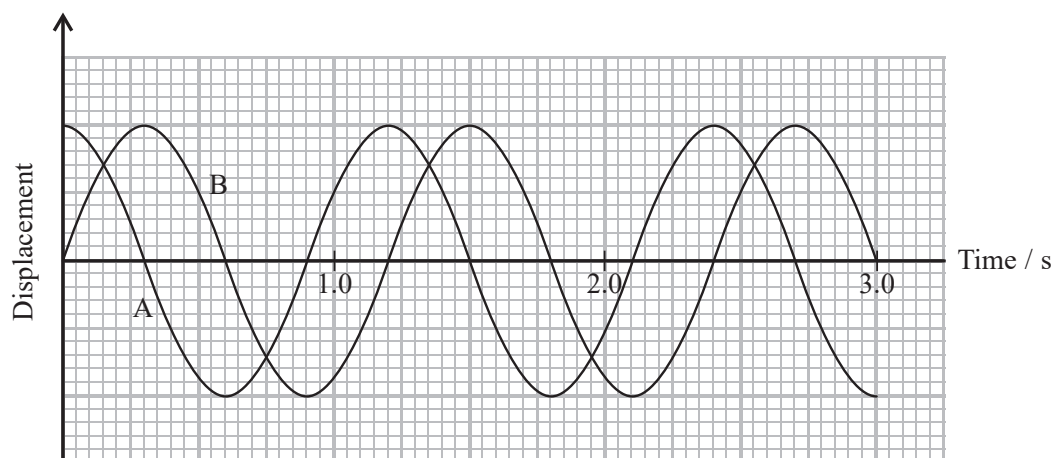
A calculation is not necessary.

(3)

(Total for Question 10 = 6 marks)



- (b) The graph shows how the displacement of each pendulum varies with time at one stage in the motion.



- (i) State the phase relationship between the two pendulums.

(1)

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- (ii) Determine the length of pendulums A and B.

(3)

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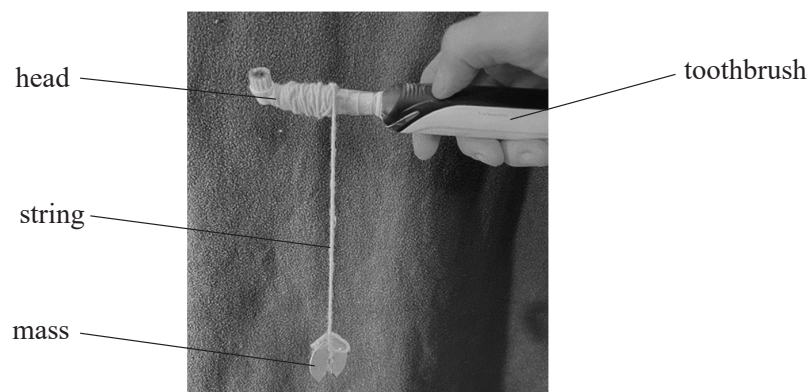
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Length = ...

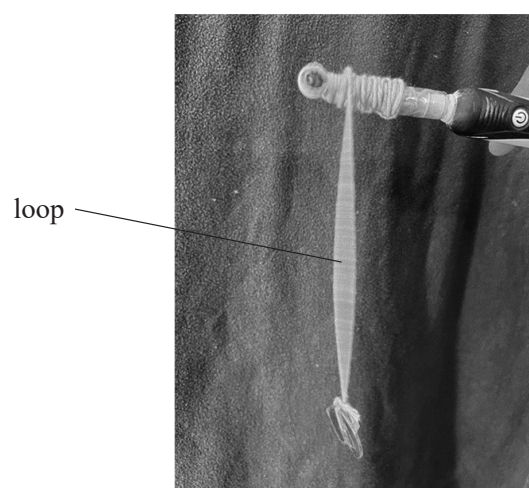
(Total for Question 16 = 10 marks)

- 15** A student wound a piece of string around the head of an electric toothbrush. The student attached a small mass to the other end of the string, as shown in Photograph 1.



Photograph 1

The toothbrush was switched on and the head started to vibrate. The student rotated the toothbrush slowly to unwind the string. At a particular length, large vibrations were observed on the string. The string formed a loop, as shown in Photograph 2.



Photograph 2

(a) Explain how the vibrations of the toothbrush head caused the loop to form.

(5)



- (b) The student continued to unwind the string and the loop disappeared. When the length of the unwound string was twice that shown in Photograph 2 two loops were seen. Three loops were seen when the unwound length was three times that shown in Photograph 2 and so on.

Determine the frequency of vibration of the toothbrush head.

unwound length of string with 4 loops = 0.69 m

mass on string = 0.010 kg

mass per unit length of string = $9.1 \times 10^{-4} \text{ kg m}^{-1}$

(5)

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Frequency = ...

(Total for Question 15 = 10 marks)



16 The suspension system in a car includes a spring attached to each wheel as shown.



(Source: © Macrovector/Shutterstock)

The car, of mass 1100 kg, is stationary. Each spring is compressed by 152 mm due to a quarter of the weight of the car. Each spring is well within both the limit of proportionality and the elastic limit.

(a) State what is meant by within the elastic limit.

(1)

(b) (i) Show that the stiffness of each spring is about $18\,000\text{ N m}^{-1}$.

(3)

- (ii) A force is applied to the car which results in a further small compression of each spring. The force is then removed, and the body of the car oscillates with simple harmonic motion.

Determine the frequency of the oscillations.

(3)

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Frequency = ...

- (c) State the conditions for simple harmonic motion.

(2)

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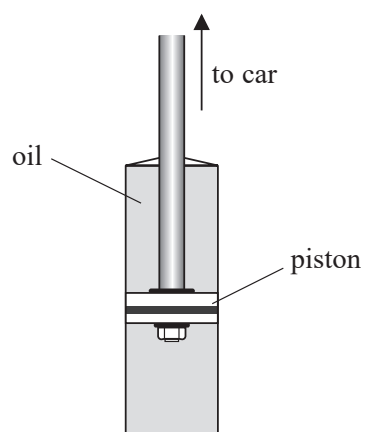
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- (d) The oscillations are heavily damped by a piston in the suspension system. The piston moves within a cylinder filled with oil, as shown. The oil has a high viscosity.



Explain why using oil of high viscosity will produce heavy damping.

(3)

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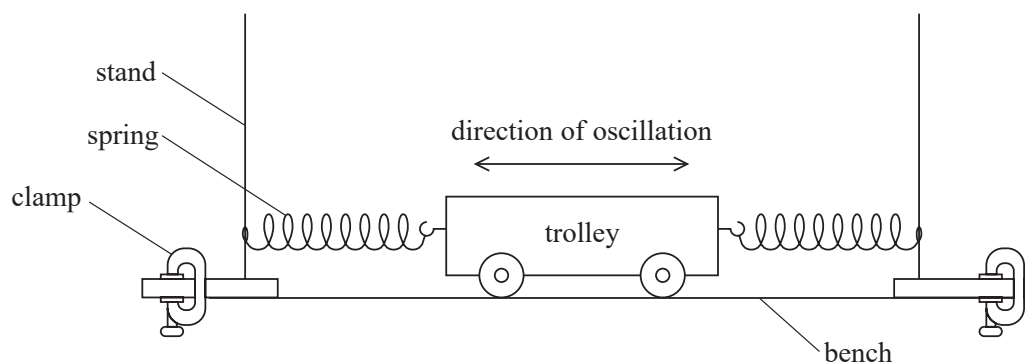
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(Total for Question 16 = 12 marks)

- 6 A student investigated the horizontal oscillations of a trolley between two springs, using the apparatus shown.



The student displaced the trolley from its equilibrium position. She then released the trolley and started a stopwatch. She stopped the stopwatch when the trolley had completed one oscillation.

- (a) Describe how the method used by the student could be improved to determine a more accurate value of the time period.

(4)

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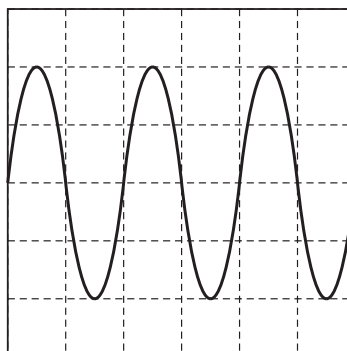
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- (b) The student displaced the trolley 6.0 cm from the equilibrium position. She recorded the velocity of the oscillating trolley using a sensor connected to a data logger.

The output from the data logger is shown below.



The time-base of the data logger output was set to 250 ms div^{-1} .

Determine the maximum velocity of the trolley.

(5)

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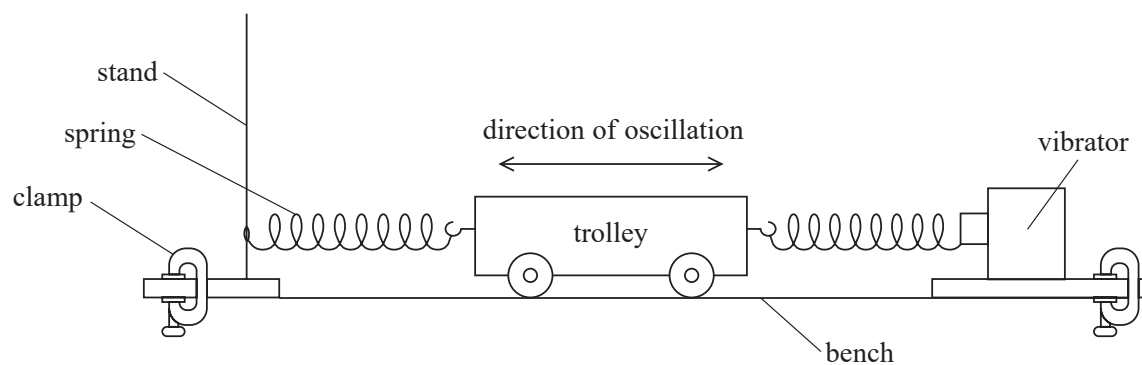
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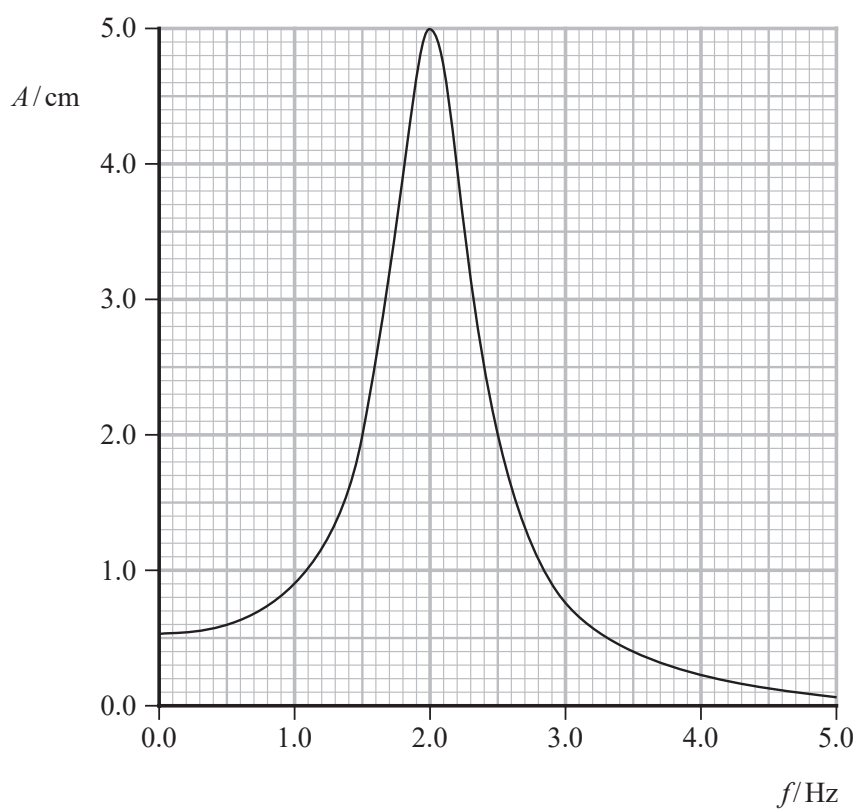
Maximum velocity of trolley = ...

- (c) The student modified the apparatus so that the trolley was driven into oscillation by a vibrator, as shown.

A sensor connected to a data logger recorded the amplitude A of the oscillations.



The graph shows how A varied as the student increased the frequency f of the oscillations.



(i) Explain the shape of the graph.

(4)

(ii) Determine the effective spring constant k of the oscillating trolley system.

mass of trolley = 0.87 kg

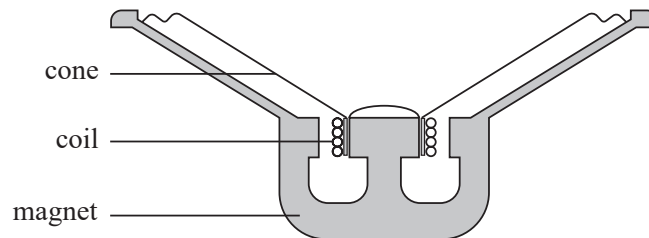
(2)

 $k = \dots\dots\dots$

(Total for Question 6 = 15 marks)



- 9 A simple loudspeaker consists of a cone, a coil of wire and a magnet. The cone and coil are attached to each other and are free to move. An alternating current in the coil causes the cone to oscillate. The loudspeaker is mounted in a wooden box. A cross-section through the loudspeaker is shown.



A student made the following observations:

- when an alternating potential difference (p.d.) is applied to the coil, the cone oscillates
- the frequency of oscillation is the same as the frequency of the p.d.
- at particular frequencies, the box vibrates with a large amplitude.

*(a) Explain these observations.

(6)

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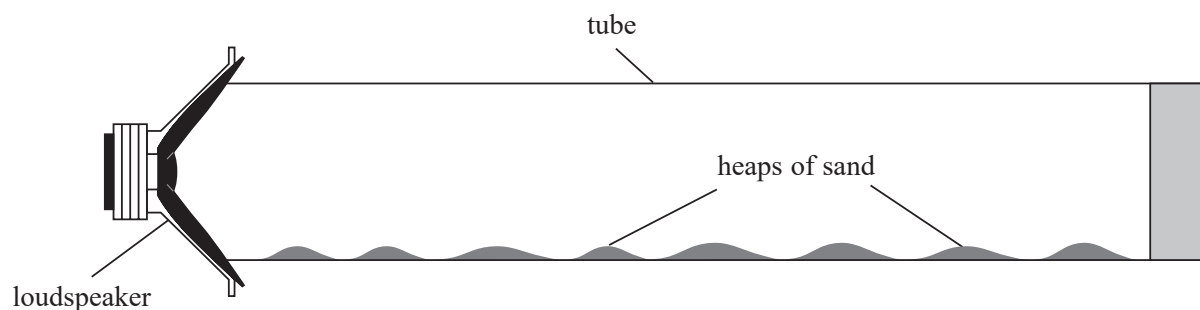
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- (b) The student connected a signal generator to the loudspeaker, and placed the loudspeaker near to one end of a long tube containing sand. The student adjusted the signal generator until the sand collected in small heaps as shown.



- (i) Explain why the sand collects in heaps.

(4)

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- (ii) The student determined the distance d between the centres of adjacent heaps. Describe the procedure she should follow to determine an accurate value for d .

(3)

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- (iii) Assess whether the experimental data is consistent with a value for the speed of sound of 340 m s^{-1} .

signal generator frequency = 3.25 kHz .

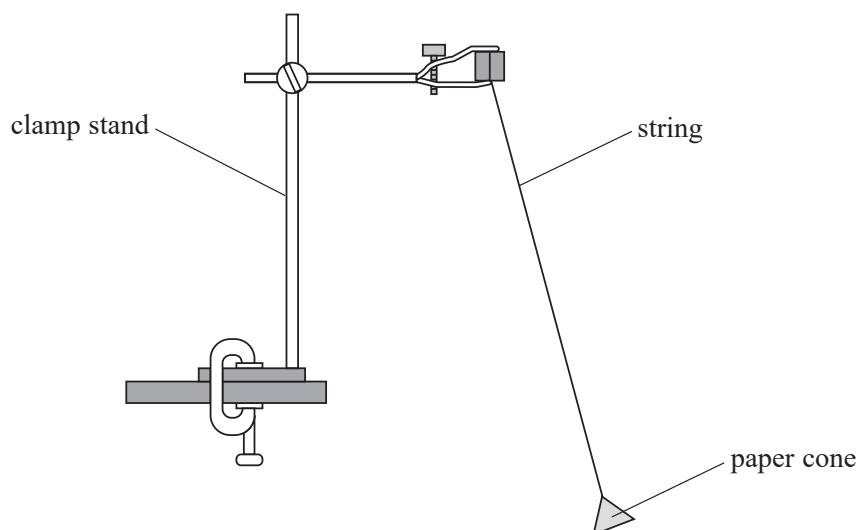
$d = 5.1 \text{ cm}$

(3)

(Total for Question 9 = 16 marks)



- 10 A student made a simple pendulum by connecting a paper cone to a piece of string. She attached the pendulum to a clamp as shown.



- (a) (i) The student displaced the pendulum through a small angle so that it oscillated. She determined the time period T as 2.50 s.

Calculate the length of the pendulum.

(2)

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Length of pendulum = ...

- (ii) Explain why the amplitude of oscillation of the pendulum did not stay constant.

(3)

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(b) The student recorded how the amplitude of oscillation varied over time.

(i) It is suggested that the relationship between amplitude A and time t is

$$A = A_0 e^{-\frac{kt}{T}}$$

where A_0 is the initial amplitude of the oscillation and k is a constant.

Explain why a graph of $\ln A$ against t would give a straight line.

(2)

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(ii) The table shows the student's data.

t/s	A/cm	
2.5	17.6	
5.0	14.3	
7.5	11.6	
10.0	9.4	
12.5	7.6	

Plot a graph of $\ln A$ against t on the grid opposite. Use the additional column to show your processed data.

(5)

(iii) Determine values for A_0 and k .

(4)

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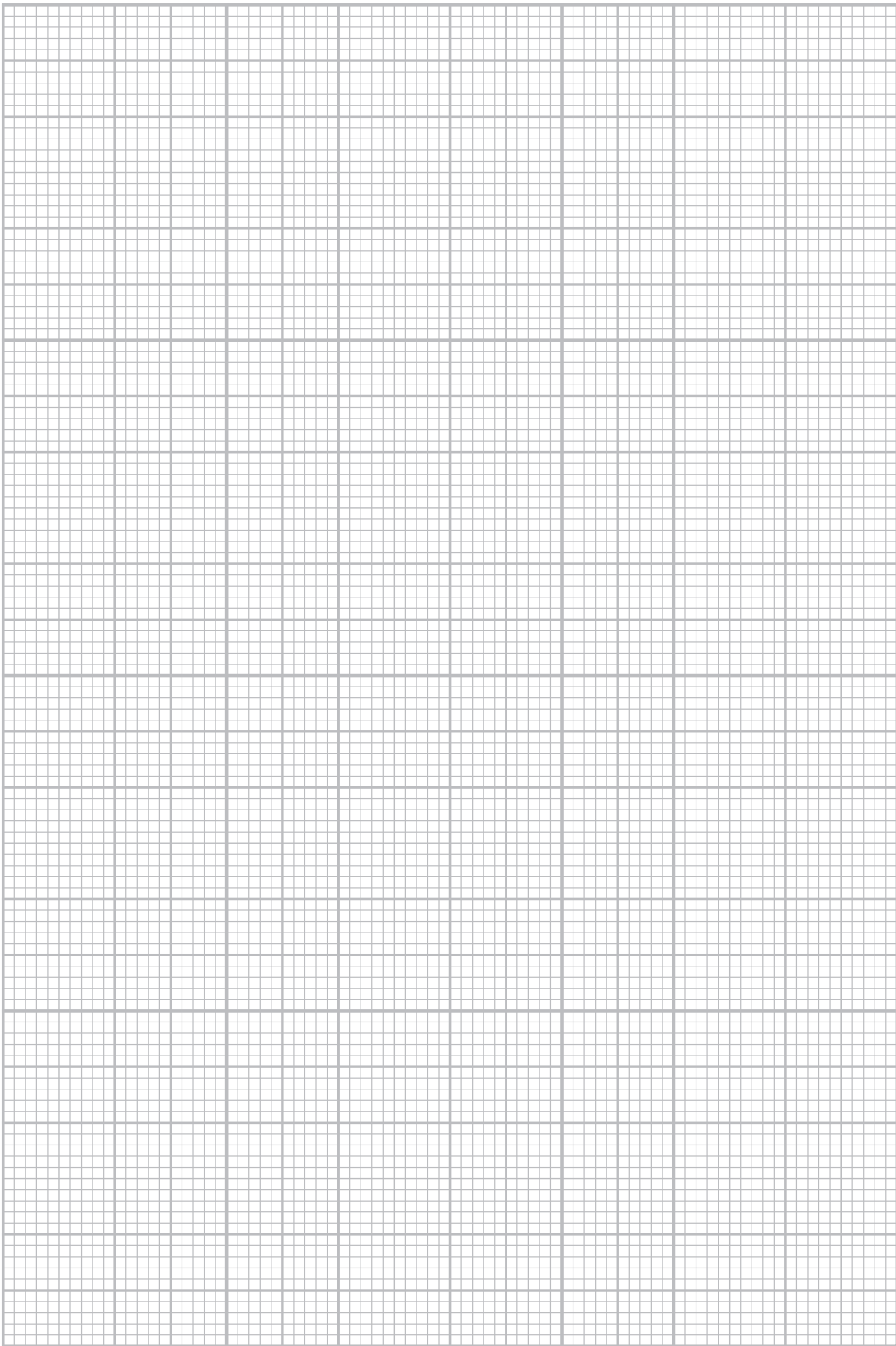
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$$A_0 = \dots\dots\dots$$

$$k = \dots\dots\dots$$





(Total for Question 10 = 16 marks)



MARK SCHEMES

official mark schemes



Question Number	Answer	Mark
3	B – 0.40 Hz Incorrect Answers: Correct method: $f = 24 \div 60 \text{ s} = 0.40 \text{ Hz}$ A – uses $1 \text{ minute} \div 24$ C – uses $60 \text{ s} \div 24$ D – uses $24 \div 1 \text{ minute}$	1



8	The only correct answer is D because velocity is equal to the gradient of the displacement-time graph A is not correct because velocity is equal to the gradient of the displacement-time graph, but here velocity is shown as proportional to -1 times the displacement B is not correct because velocity is equal to the gradient of the displacement-time graph, but here velocity is shown as -1 times the gradient C is not correct because velocity is equal to the gradient of the displacement-time graph, but here velocity is shown as proportional to the displacement		1
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10	D	The only correct answer is D : velocity is maximum when displacement is zero, and vice versa, and has positive and negative values since the direction reverses A is not correct because this shows maximum velocity when it should be minimum and vice versa B is not correct because this shows maximum velocity when it should be minimum and vice versa C is not correct because this does not show the change in direction of velocity during an oscillation	1
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(Total for Multiple Choice Questions = 10 marks)



7	D	The only correct answer is D because the frequency is inversely proportional to the square root of length and independent of the mass, so if length is quadrupled, frequency is halved to $f/2$ A is not the correct answer because it is $4f$ B is not the correct answer because it is $2f$ C is not the correct answer because it is f	1
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Question Number	Answer	Mark
9	The only correct answer is B because acceleration is proportional to force, so the acceleration graph would have the shape of the force graph. The acceleration at the start is zero, so the velocity graph must have an initial gradient of zero. For the acceleration to be positive in the first quarter cycle the velocity must be increasing. This graph has an initial gradient of zero and increasing velocity.	1
	A the initial gradient is not zero C the initial gradient is not zero D the velocity in the first quarter cycle is decreasing	



9	The only correct answer is B <i>A is not correct because the initial gradient is not zero. The acceleration at the start is zero, so the velocity graph must have an initial gradient of zero</i> <i>C is not correct because the initial gradient is not zero</i> <i>D is not correct because the velocity in the first quarter cycle is decreasing</i>	1
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Question Number	Acceptable answers	Additional guidance	Mark
11	- Use of $T = 2\pi\sqrt{l/g}$ (1) - Apply factor of 2 correctly for 2 half cycles (1) - Use of $f = 1/T$ (1) $f = 0.68 \text{ Hz}$ (1)	<u>Example of calculation</u> $T = 2\pi\sqrt{l/g}$ $T = 2\pi\sqrt{(0.43 / 9.81)}$ $= 1.32 \text{ s}$ $T = 2\pi\sqrt{(0.67 / 9.81)}$ $= 1.64 \text{ s}$ $T = (1.32 \text{ s} + 1.64 \text{ s}) / 2 = 1.48 \text{ s}$ $f = 1 / 1.48 \text{ s} = 0.68 \text{ Hz}$	4

(Total for Question 11 = 4 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
4	- Time a number of (complete) oscillations and divide this time by the number of (complete) oscillations (1) - This increases the total time recorded Or this reduces the effect of reaction time (Dependent on MP1) (1) - Time from the mid-point of the oscillation (1) - Use a marker to identify the mid-point of the oscillation Or pendulum is travelling fastest at the mid-point (1) - Each method reduces the (percentage) uncertainty (in the value for T) (1)	Allow: MP1: Use a light gate with a data logger Or video oscillation and play back frame by frame MP2: this reduces the effect of reaction time (Dependent on MP1) MP3: accept equilibrium point for mid-point MP5: can't be awarded on its own.	5

(Total for Question 4 = 5 marks)



Question Number	Acceptable answers	Additional guidance	Mark
13 (a)	☐ because the (resultant) force is (directly) proportional to displacement from equilibrium position (1) ☐ force is in the opposite direction to displacement or force is (always) acting towards the equilibrium position (1)		2
13 (b)	• use of graph to find gradient = k ($= F/x$) (1) • use of $T = 1/f$ (1) • use of $T = 2\pi\sqrt{\frac{m}{k}}$ (1) • $m = 0.05$ (kg) or k using 50 g and 2 Hz = 7.9 (N m⁻¹) or f using 50 g and k from graph = 2.0 (Hz) or T using 50 g and k from graph = 0.50 (s) (1) • Comparison and correct conclusion (dependent on MP4) (1)	<u>Example of calculation</u> $k = 0.55 \text{ N} / 0.07 \text{ m}$ $= 7.86 \text{ N m}^{-1}$ $T = \frac{1}{2} = 0.5 \text{ s}$ $0.5 \text{ s} = 2\pi\sqrt{\frac{m}{7.86 \text{ N m}^{-1}}}$ $m = 0.050 \text{ kg}$ (0.0498 kg) A smaller mass means a shorter period, so smaller than 0.05 kg would be a higher frequency than 2 Hz, so 50 g is smallest mass.	5

(Total for Question 13 = 7 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
3(a)	Any TWO from: - Should have used (a fiducial mark as) a reference point (1) - Should have timed from the equilibrium position of the bob Or Shouldn't time from the maximum displaced position of the bob (1) - Only timed one oscillation Or should have times more than one oscillation (1) - Should have allowed the pendulum to swing to and fro a few times before starting to time (as the first swing may be different from the others) (1)	Accept centre/vertical/undisplaced position for equilibrium position	2
3(b)	- Determination of gradient (1) - Re-arrangement of $T = 2\pi\sqrt{\frac{l}{g}}$ (1) - Algebra to show $T^2 = -\frac{4\pi^2}{g}d + \frac{4\pi^2}{g}h$ (1) - Gradient = $(-)\frac{4\pi^2}{g}$ (1) $g = 9.6 \text{ m s}^{-2}$ [accept $9.5 \rightarrow 9.7 \text{ m s}^{-2}$] (1)	$T^2 = \frac{4\pi^2}{g}l$ $T^2 = \frac{4\pi^2}{g}(h - d)$ $T^2 = -\frac{4\pi^2}{g}d + \frac{4\pi^2}{g}h$ <u>Example of calculation</u> $\text{gradient} = \frac{(12.1 - 9.2) \text{ s}^2}{(0.00 - 0.70) \text{ m}} = -4.1 \text{ s}^2\text{m}^{-1}$ $\therefore g = \frac{4\pi^2}{4.1 \text{ s}^2\text{m}^{-1}} = 9.6 \text{ m s}^{-2}$	5

(Total for Question 3 = 7 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
4(a)	- Use of $T = 2\pi\sqrt{\frac{L}{g}}$ (1) $L = 0.994 \text{ m}$ (1)	Example of calculation: $L = \frac{(2.00 \text{ s})^2 \times 9.81 \text{ m s}^{-2}}{4\pi^2} = 0.994 \text{ m}$	2
4(b)	A description that makes reference to the following points: - Record nT (where n is at least 5) and divide by n (to find T) (1) - Time oscillations from equilibrium position of bob using a (fiducial) marker (1) Or repeats timings for multiple oscillations and calculate mean (1)		2
4(c)	- Using the stopwatch there would be reaction time (1) - The uncertainty in the measurement of the time is larger with the stopwatch than with the data logger. (1) - Timing multiple swings (with stopwatch) reduces %U (1) - Light gates are difficult to use with a pendulum bob. (1)	MP2 dependent on MP1	4

(Total for Question 4 = 8 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
5(a)(i)	- discards value for l_3 (1) $l_m=85.7$ (cm) (1)	MP2: answer to 1 d.p. only <u>Example of calculation</u> $l_m = \frac{85.5+86.0+85.5}{3} = 85.7 \text{ cm}$	2
5(a)(ii)	- Use of $T = 2\pi\sqrt{\frac{\ell}{g}}$ (1) $T=1.86$ s (1)	ECF from (i) MP2: accept $T = 1.9$ s <u>Example of calculation</u> $T = 2\pi\sqrt{\frac{\ell}{g}} = 2\pi \times \sqrt{\frac{0.857 \text{ m}}{9.81 \text{ m s}^{-2}}} = 1.86 \text{ s}$	2
5(b)	Max 4 from 2 out of 3 pairs - The student should let the pendulum swing back and to before starting the stopwatch. (1) - The first swing may be affected by the student pushing the bob as they release it (1) - The student should use a (fiducial) marker at O (1) - Easier to determine when it passes O (1) - Time more oscillations (1) - A longer time reduces (%) uncertainty (in T) (1)	For each pair, the second marking point is dependent on the first marking point MP4: Accept the pendulum travelling fastest when it passes O	4

(Total for Question 5 = 8 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
11(a)	An explanation that makes reference to the following: - The astronauts are in free fall in the space craft Or The acceleration of the astronauts and the space station are the same (1) - So there is no contact/reaction force acting on them (1)	For MP2, accept a statement that the gravitational force (weight) is the only force acting upon them Or all of their weight is used to provide the centripetal force /acceleration	2
11(b)	The acceleration (of the platform) is: (directly) proportional to displacement from equilibrium position (1) (always) acting towards the equilibrium position Or the idea that acceleration is in the opposite direction to displacement (1) [An equation with symbols defined correctly is a valid response for both marks. e.g $a \propto -x$ or $F \propto -x$]	Accept towards undisplaced point/fixed point/central point for equilibrium position. Accept a definition in terms of the force i.e. the (resultant) force (on the platform) is: (directly) proportional to displacement from equilibrium position (always) acting towards the equilibrium position Or the idea that force is in the opposite direction to displacement	2
11(c)(i)	(Use the stopwatch to) time a large number of oscillations to determine the time period (1) - Calculate the frequency using $f = \frac{1}{T}$ (1)	MP1: At least 5 oscillations required	2
11(c)(ii)	(Use the metre rule to) measure the max displacement of the platform (from the equilibrium position) (1) - Calculate the maximum speed using $v_{\max} = 2\pi f x_{\max}$ (1)	MP2: allow use of $v_{\max} = \frac{2\pi}{T} x_{\max}$	2
11(d)	An explanation that makes reference to the following: $E_k = \frac{1}{2}mv^2$ and $v_{\max} = 2\pi f x_{\max}$ (1) - Max kinetic energy is quadrupled (1)		2

(Total for Question 11 = 10 marks)



Question Number	Acceptable answers	Additional guidance	Mark
16(a)	• Use of $f = 1 / T$ (1) • Use of $T = 2\pi \sqrt{m/k}$ (1) • Correct for mass of platform (1) • Mass of astronaut = 71 kg (1)	<u>Example of calculation</u> $T = 1 / 0.34 \text{ Hz} = 2.94 \text{ s}$ $2.94 \text{ s} = 2\pi \sqrt{m/350 \text{ N m}^{-1}}$ $m = 76.6 \text{ kg}$ mass of astronaut = $76.6 \text{ kg} - 5.7 \text{ kg}$ = 70.9 kg	4
16(b)(i)	• Determine amplitude (1) • Use of $\omega = 2\pi f$ (1) • Use of $\max a = (-) \omega^2 A$ (1) • Max acceleration = 0.66 m s^{-2} (1)	<u>Example of calculation</u> Amplitude = $0.29 \text{ m} / 2 = 0.145 \text{ m}$ $\omega = 2\pi \times 0.34 \text{ Hz} = 2.14 \text{ rad s}^{-1}$ $\max a = (2.14 \text{ rad s}^{-1})^2 \times 0.145 \text{ m}$ = 0.66 m s^{-2}	4
16(b)(ii)	• Use of $v = (-) A\omega \sin \omega t$ (1) • Speed = 0.29 m s^{-1} (ecf for ω and A from (b)(i)) (1)	<u>Example of calculation</u> $v = 0.145 \times 2.14 \text{ s}^{-1} \sin((2.14 \text{ s}^{-1} \times 3.5 \text{ s}) \text{ radian})$ = $0.145 \times 2.14 \text{ s}^{-1} \sin((2.14 \text{ s}^{-1} \times 3.5 \text{ s}) \times 360^\circ / 2\pi)$ Speed = 0.29 m s^{-1}	2

(Total for Question 16 = 10 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
5(a)	- Time a number of (complete) oscillations calculate a mean time period (1) - This reduces the effect of random error (dependent on MP1) (1) - Allow oscillation to settle before starting to time. (1) - Use a (fiducial) marker (so easier to see when trolley passes a point) (1) - Use the mid-point of the oscillation (for timing), (1) - Trolley is travelling fastest at mid-point, so effect of reaction time is reduced. (1)	Accept description of how to determine a mean – don't need to see the word "mean" Accept reaction time for random error, also accept reference to reducing percentage uncertainty Accept equilibrium/undisplaced position For MP6 allow use a datalogger to eliminate effect of reaction time [not dependent upon MP5]	6
5(b)	- Substitutes into equation for mass on spring to give $T = 2\pi \sqrt{\frac{M + m}{k}}$ (1) $T^2 = \frac{4\pi^2}{k}m + \frac{4\pi^2 M}{k}$ (1) - Identify gradient as $4\pi^2/k$ (and calculate a value for k) (1) - Identify y-intercept as $4\pi^2 M/k$ (and calculate a value for M) (1)		4

(Total for Question 5 = 10 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
9(a)(i)	An explanation that makes reference to the following points: • Use a (fiducial) marker (1) • Placed at the equilibrium position (of cantilever) (1) • (This will reduce timing errors) as end of cantilever is moving fastest at the equilibrium position (1)		3
9(a)(ii)	An explanation that makes reference to the following points: • Time a larger number of oscillations (1) • This will increase the total time recorded (1)		2



9(b)	- Calculation of average time (period) - Use of $T^2 \propto \frac{ML^3}{E}$ - Calculates $\frac{E_1}{E_2}$ - Calculates $\frac{E_{\text{spruce}}}{E_{\text{cedar}}}$ $\frac{E_1}{E_2} = 1.22$ and $\frac{E_{\text{spruce}}}{E_{\text{cedar}}} = 1.25$ - As 1.22 is close to 1.25, the metre rule must be made from spruce and half-metre rule from cedar Or Conclusion based on comparison of calculated values from using calculated ratio	(1) <u>Example of calculation</u> (1) $T_1 = \frac{14.69 \text{ s} + 14.64 \text{ s} + 14.76 \text{ s}}{3} = 2.94 \text{ s}$ (1) $T_2 = \frac{5.33 \text{ s} + 5.40 \text{ s} + 5.24 \text{ s}}{3} = 1.06 \text{ s}$ (1) $\left(\frac{T_1}{T_2}\right)^2 = \left(\frac{L_1}{L_2}\right)^3 \times \frac{E_2}{E_1} \quad \therefore \frac{E_1}{E_2} = \left(\frac{L_1}{L_2}\right)^3 \times \left(\frac{T_2}{T_1}\right)^2$ (1) $\therefore \frac{E_1}{E_2} = \left(\frac{0.95 \text{ m}}{0.45 \text{ m}}\right)^3 \times \left(\frac{1.06 \text{ s}}{2.94 \text{ s}}\right)^2 = 1.22$ (1) $\frac{E_{\text{spruce}}}{E_{\text{cedar}}} = \frac{9.6 \text{ GPa}}{7.7 \text{ GPa}} = 1.25$ (1) <u>Alternative MP4 and MP5</u> - Calculates $E_{\text{cedar}} \times \frac{E_1}{E_2} = E_{\text{spruce}}$ $\frac{E_1}{E_2} = 1.22$ and $E_{\text{spruce}} = 9.5$ (or $E_{\text{cedar}} = 7.9$)	6
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(Total for Question 9 = 11 marks)

Question Number	Acceptable answers	Additional guidance	Mark
20 (a)	- Use of $W = mg$ (1) - Use of $\Delta F = k\Delta x$ (1) - Use of $T = 2\pi\sqrt{\frac{m}{k}}$ (1) - Use of $f = \frac{1}{T}$ (1) $f = 1.7$ (Hz), so claim is incorrect. (1)	Example of calculation: $k = \frac{65 \times 10^{-3} \text{ kg} \times 9.81 \text{ N kg}^{-1}}{0.085 \text{ m}} = 7.50 \text{ N m}^{-1}$ $T = 2\pi\sqrt{\frac{65 \times 10^{-3} \text{ kg}}{7.50 \text{ N m}^{-1}}} = 0.585 \text{ s}$ $f = \frac{1}{T} = \frac{1}{0.585 \text{ s}} = 1.71 \text{ Hz}$	5
20 (b)	- There is damping Or resistive forces act on the flamingo (1) - Energy is removed from the oscillating system (and the amplitude decreases) (1)		2
20 (c)(i)	- Use of $T = 2\pi\sqrt{\frac{\ell}{g}}$ (1) $T = 2.24$ (s) (at least 3 sf) (1)	Example of calculation: $T = 2\pi\sqrt{\frac{1.25 \text{ m}}{9.81 \text{ m s}^{-2}}} = 2.24 \text{ s}$	2
20 (c)(ii)	- Use of $\omega = \frac{2\pi}{T}$ (1) - Use of $v = -A\omega \sin \omega t$ (1) $v = 0.21 \text{ m s}^{-1}$ (ecf from (i)) (1)	Example of calculation: $\omega = \frac{2\pi}{2.24 \text{ s}} = 2.80 \text{ rad s}^{-1}$ $v = -7.5 \times 10^{-2} \text{ m} \times 2.80 \text{ s}^{-1} \times 1 = 0.210 \text{ m s}^{-1}$	3

(Total for Question 20 = 12 marks)



Question Number	Acceptable answers	Additional guidance	Mark
16(a)	- Determine period, T (1) - Use of $T = 2\pi\sqrt{l/g}$ (1) - Subtracts radius of mass (1) - Length of wire = 10.3 (m) (1)	<u>Example of calculation</u> $T = 52.2 \text{ s} / 8$ $= 6.53 \text{ s}$ $6.53 \text{ s} = 2\pi\sqrt{l/9.81 \text{ N kg}^{-1}}$ Length of pendulum to centre of mass = 10.6 m Length of wire = 10.6 m – 0.3 m = 10.3 m	4
16 (b)(i)	- Use of (breaking) stress = F/A (1) - Use of $A = \pi r^2$ (1) - Diameter = 1.06 mm and choose 1.22 mm because it is the thinnest wire with stress lower than the breaking stress (1)	<u>Example of calculation</u> For max stress, $3.10 \times 10^8 \text{ N m}^{-2} = 28 \text{ kg} \times 9.81 \text{ N kg}^{-1}/A$ $A = 8.86 \times 10^{-7} \text{ m}^2$ $8.86 \times 10^{-7} \text{ m}^2 = \pi r^2$ $r = 5.3 \times 10^{-4} \text{ m}$ diameter = 1.06 mm	3
16 (b)(ii)	- Use of stress = F/A and $A = \pi r^2$ (ecf for radius from (b)(i)) (1) - Use of Young modulus = stress / strain and strain = $\Delta x/x$ (1) - Extension = 1.3 cm (1)	Allow ecf for radius of wire chosen in part (b)(i), but not for the calculated radius or area <u>Example of calculation</u> stress = $28 \text{ kg} \times 9.81 \text{ N kg}^{-1} / \pi (1.22 \times 10^{-3} \text{ m} / 2)^2$ strain = $2.34 \times 10^8 \text{ Pa} / 200 \text{ GPa} = 0.00117$ extension = $0.00117 \times 11.2 \text{ m} = 0.0132 \text{ m}$	3



16 (c)	• There is (damping due to) air resistance and this (damping) force is the same for both (since they have the same shape, area and speed initially) (1) • For large mass the force due to air resistance produces a smaller negative acceleration since $a = F/m$ (1) • The speed will decrease less for each swing, so there is less effect on the amplitude Or It will take longer for the (maximum) speed to decrease (to zero) so the pendulum will oscillate for a longer time (1) OR • There is air resistance and the force is the same for both • The work done by air resistance per swing is the same for both masses (1) • Initially the larger mass has greater quantity of energy shared between its kinetic and potential energy stores, so the proportion of KE transferred to the thermal energy store of the sphere and the surroundings is less per swing, so there is less effect on the amplitude Or Larger mass has greater total energy so fraction dissipated per swing is smaller so the pendulum will oscillate for a longer time (1)		3
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	OR There is air resistance and this force is the same for both (1) • For both masses the change in momentum per swing is the same (1) • The larger mass has greater initial momentum so it will take longer for the (maximum) momentum to decrease (to zero) so the pendulum will oscillate for a longer time (1)		
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(Total for Question 17 = 13 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
7(a)(i)	An explanation that makes reference to the following points: - Time n oscillations and divide by n, where n is a large number (1) - Increasing the time (measured) reduces the uncertainty (in T) (1) - Repeat timing and calculate a mean (1) - Use a (fiducial) marker to indicate the reference position (1) - Use equilibrium position as reference position (1) - The trolley is moving fastest at this point so the uncertainty in starting/stopping the stopwatch is least (1)	Where $n \geq 5$ For equilibrium allow centre/undisplaced	6
7(a)(ii)	- Use $\omega = 2\pi/T$ (to calculate a value for ω) Or use $\omega = 2\pi f$ with $f = 1/T$ (1) - Measure the maximum displacement of the trolley from the equilibrium position (with the metre rule) (1) - Use $v_{\max} = \omega A$ (to calculate a value for the maximum velocity of the trolley) (1)	For equilibrium allow centre/undisplaced [accept initial displacement for maximum displacement]	3



7(b)	(The sensor and data logger) eliminates reaction time Or data logger will not necessarily record the time with any greater resolution (1)		1
7(c)	An explanation that makes reference to the following points: $v_{\max} = \omega A$ and ω constant (1) - If A doubles, then $v_{\max}$ doubles (1) - Hence max E_k will quadruple, since $E_k = \frac{1}{2}mv^2$ [dependent upon MP2] (1) OR $\Delta E_{\text{el}} = \frac{1}{2}F\Delta x$ and $\Delta F = k\Delta x$ (1) $\Delta E_{\text{el}} \propto (\Delta x)^2$ since k is constant (1) - Hence max E_k will quadruple, since max $E_k = \max \Delta E_{\text{el}}$ (dependent upon MP2) (1)		3

(Total for Question 7 = 13 marks)



Question Number	Acceptable answer	Additional guidance	Mark
5	D	The only correct answer is D because when damping is decreased maximum amplitude increases and the frequency at which it occurs increases A is not correct because it states that they both decrease B is not correct because it states that the maximum amplitude decreases C is not correct because it states that the frequency decreases	1



9	The only correct answer is B A is not correct as $E_k = 0$ when $x = \text{amplitude}$ C is not correct as E_k is a scalar quantity D is not correct as E_k is a scalar quantity		1
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Question Number	Answer	Mark
6	The only correct answer is B, E_k is a maximum and E_p is a maximum A is not correct because E_p is a maximum when displacement is a maximum C is not correct because E_k is a maximum at the equilibrium position D is not correct because E_k is a maximum at the equilibrium position, and E_p is a maximum when displacement is a maximum	1



Question Number	Acceptable answers	Additional guidance	Mark																																
*13	This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table border="1"> <thead> <tr> <th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th><th>Max linkage mark available</th><th>Max final mark</th></tr> </thead> <tbody> <tr> <td>6</td><td>4</td><td>2</td><td>6</td></tr> <tr> <td>5</td><td>3</td><td>2</td><td>5</td></tr> <tr> <td>4</td><td>3</td><td>1</td><td>4</td></tr> <tr> <td>3</td><td>2</td><td>1</td><td>3</td></tr> <tr> <td>2</td><td>2</td><td>0</td><td>2</td></tr> <tr> <td>1</td><td>1</td><td>0</td><td>1</td></tr> <tr> <td>0</td><td>0</td><td>0</td><td>0</td></tr> </tbody> </table> The following table shows how the marks should be awarded for structure and lines of reasoning.	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	Max linkage mark available	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).	6
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	Max linkage mark available	Max final mark																																
6	4	2	6																																
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2	2	0	2																																
1	1	0	1																																
0	0	0	0																																



		Number of marks awarded for structure of answer and sustained line of reasoning		
	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2		
	Answer is partially structured with some linkages and lines of reasoning	1		
	Answer has no linkages between points and is unstructured	0		
	Indicative content 720 Hz is the natural frequency of the bowl - The generator/hand causes forced/driven oscillations - When they don't match the natural frequency they are quiet because little/less energy is transferred - The loudness (at 720 Hz) is because of resonance (Resonance occurs when) the driving frequency is equal/similar to the natural frequency (When resonance occurs) there is maximum transfer of energy so the amplitude is maximum Or (When resonance occurs) there is maximum transfer of energy so the amplitude increases		Do not accept 'resonant frequency' for 'natural frequency'	

(Total for Question 13 = 6 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
10(a)	- Use of $a = (-)\omega^2 x$ (1) - Use of $v = \omega A \sin \omega t$ (1) $v_{\max} = 0.44 \text{ m s}^{-1}$, so it is safe to oscillate at this amplitude (1)	No need to see $0.44 \text{ m s}^{-1} < 0.5 \text{ m s}^{-1}$, as conclusion includes credit for the correct value of v. <u>Example of calculation</u> $\omega = \sqrt{\frac{20.0 \text{ cm s}^{-2}}{5.0 \text{ cm}}} = 2.0 \text{ s}^{-1}$ $v_{\max} = 2.0 \text{ s}^{-1} \times 0.22 \text{ m} = 0.44 \text{ m s}^{-1}$	3
10(b)	An explanation that makes reference to the following points: - The (pushing) frequency must match the <u>natural</u> frequency (1) - The time period of oscillation increases, as $T = 2\pi \sqrt{\frac{m}{k}}$ (1) - So the frequency of pushing must decrease [dependent upon MP2] (1)		3

(Total for Question 10 = 6 marks)



Question Number	Acceptable Answers	Additional Guidance	Mark																																
*16(a)	This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table border="1"> <thead> <tr> <th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th><th>Max linkage mark available</th><th>Max final mark</th></tr> </thead> <tbody> <tr> <td>6</td><td>4</td><td>2</td><td>6</td></tr> <tr> <td>5</td><td>3</td><td>2</td><td>5</td></tr> <tr> <td>4</td><td>3</td><td>1</td><td>4</td></tr> <tr> <td>3</td><td>2</td><td>1</td><td>3</td></tr> <tr> <td>2</td><td>2</td><td>0</td><td>2</td></tr> <tr> <td>1</td><td>1</td><td>0</td><td>1</td></tr> <tr> <td>0</td><td>0</td><td>0</td><td>0</td></tr> </tbody> </table> The following table shows how the marks should be awarded for structure and lines of reasoning.	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	Max linkage mark available	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).	3
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	Max linkage mark available	Max final mark																																
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1	1	0	1																																
0	0	0	0																																



		Number of marks awarded for structure of answer and sustained line of reasoning	Indicative content		
	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2	• the pendulums have the same length, so they have the same time period/frequency		
	Answer is partially structured with some linkages and lines of reasoning	1	• the first pendulum		
	Answer has no linkages between points and is unstructured	0			
	causes forced oscillations of the second pendulum • The driving frequency equals the natural frequency • Resonance occurs, so there is maximum transfer of energy so the amplitude increases until all energy is transferred • The second pendulum then acts as a driver for the first pendulum Or the process repeats with energy transfer from B to A • When the lengths differ the driving frequency is not the natural frequency of the second pendulum so little energy transfer occurs				
16(b)(i)	• Pendulum A is $\pi/2$ ahead of pendulum B	(1)			1
16(b)(ii)	• $T = 1.2$ s from graph • Use of $T = 2\pi\sqrt{l/g}$ • $l = 0.36$ m	(1) (1) (1)	$T = 3.0$ s / 2.5 oscillations 1.2 s = $2\pi\sqrt{l/9.81 \text{ N kg}^{-1}}$ $l = 0.36$ m		3

(Total for Question 16 = 10 marks)



Question Number	Acceptable answers	Additional guidance	Mark
15(a)	EITHER - Waves are produced by the toothbrush and reflected (at the mass) (1) - Waves meet and superpose (1) - Constructive interference takes place where the waves are in phase (1) Or Destructive interference takes place where the waves are in antiphase - The string vibrates at the centre with maximum amplitude, forming an antinode in the centre (1) Or The string here has zero/minimum amplitude, forming nodes at the ends - Creating a standing/stationary wave (1) OR - The toothbrush causes the string to vibrate at its natural frequency (1) - There is a maximum/efficient transfer of energy from the toothbrush to the string (1) - Resonance occurs (1) - The string vibrates at the centre with maximum amplitude, forming an antinode in the centre (1) - Creating a standing/stationary wave (1)	Accept answer in terms of multiple 'loops' Accept reference to phase difference in terms of 2π, or 0 (radians) Accept reference to phase difference in terms of π (radians) Do not credit out of phase	5



15(b)	• Use of $W = mg$ • Use of $v = \sqrt{T/\mu}$ • Determination of wavelength • Use of $v = f\lambda$ • $f = 30 \text{ Hz}$	(1) (1) (1) (1) (1) <u>Example of calculation</u> $T = 0.010 \text{ kg} \times 9.81 \text{ N kg}^{-1} = 0.0981 \text{ N}$ $v = \sqrt{(0.0981 \text{ N} / 9.1 \times 10^{-4} \text{ kg m}^{-1})} = 10.4 \text{ m s}^{-1}$ $\lambda = 0.69 \text{ m} / 2 = 0.345 \text{ m}$ $f = 10.4 \text{ m s}^{-1} / 0.345 \text{ m}$ $= 30 \text{ Hz}$	5
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(Total for Question 15 = 10 marks)



Question Number	Acceptable answers	Additional guidance	Mark
16(a)	(Within the elastic limit,) if the load is removed the specimen/spring will return to its original shape / length Or above the elastic limit the specimen remains permanently deformed if the load is removed (1)	Or the converse for each	1
16(b)(i)	- Use of $W = mg$ (1) - Use of $F = kx$ (1) $k = 17700 \text{ (N m}^{-1}\text{)}$ (1)	<u>Example of calculation:</u> $275 \text{ kg} \times 9.81 \text{ N kg}^{-1} = 2700 \text{ N}$ $2700 \text{ N} = k \times 0.152 \text{ m}$ $k = 17\,748 \text{ N m}^{-1}$	3
16(b)(ii)	- Use of $T = 2\pi\sqrt{\frac{m}{k}}$ (1) - Use of $f = 1/T$ (1) $f = 1.3 \text{ Hz}$ (ecf from (b)(i)) (1)	<u>Example of calculation:</u> $T = 2\pi\sqrt{\frac{1100 \text{ kg}}{4 \times 17\,700 \text{ N m}^{-1}}}$ $f = 1 / 0.783 \text{ s}$ $f = 1.28 \text{ Hz}$	3
16(c)	(Resultant) force/acceleration is proportional to the displacement from the equilibrium position (1) (Resultant) force/acceleration is in the opposite direction to the displacement Or (resultant) force/acceleration is always directed towards the equilibrium position (1)		2
16(d)	An explanation that makes reference to the following points: - High viscosity oil will mean a large resistive force applied to the oscillations (1) (When piston moves) a large amount of work will be done (1) (Heavy damping so) energy of oscillation is quickly dissipated to the oil (1)	May refer to to $F = 6\pi\eta r v$ Mar refer to $\Delta W = F\Delta s$	3

(Total for Question 16 = 12 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
6(a)	- Time a number of (complete) oscillations and divide this time by the number of (complete) oscillations (1) - Repeat measurement (of time) and determine a mean value (1) - Use a (fiducial) marker (so easier to see when trolley passes a particular point) (1) - Time from the mid-point of the oscillation Or Wait for oscillation to settle before starting to time (1)	[Allow 1 mark for reference to using light gates and a data logger if no other marks awarded]	4
6(b)	T read from oscilloscope trace (1) - Use of time-base setting (1) - Use of $\omega = 2\pi / T$ Or Use of $f = 1/T$ (1) - Use of $v = (-)A\omega \sin \omega t$ (1) $v = 0.75 \text{ m s}^{-1}$ (1)	Use of $\omega = 2\pi f$ <u>Example of calculation</u> $T = 2 \text{ div} \times 250 \text{ ms div}^{-1} = 500 \text{ ms}$ $\omega = \frac{2\pi}{0.50 \text{ s}} = 12.6 \text{ rad s}^{-1}$ $v = 6.0 \times 10^{-2} \times 12.6 \text{ rad s}^{-1} = 0.754 \text{ m s}^{-1}$	5

6(c)(i)	An explanation that makes reference to the following points: • (As the frequency is increased) the amplitude increases to a maximum at a frequency of 2 Hz (and then decreases) (1) • This is the natural frequency (of oscillation) of the trolley (1) • When the vibrator drives the trolley at its natural frequency there is a maximum transfer of energy (from the vibrator to the trolley) (1) • This is resonance (1)		4
6(c)(ii)	• Use of $T = 2\pi\sqrt{\frac{m}{k}}$ (1) • $k = 140 \text{ N m}^{-1}$ (1)	<u>Example of calculation</u> $0.5 \text{ s} = 2\pi \times \sqrt{\frac{0.87 \text{ kg}}{k}}$ $\therefore k = \frac{4\pi^2 \times 0.87 \text{ kg}}{(0.5 \text{ s})^2} = 137 \text{ N m}^{-1}$	2

(Total for Question 6 = 15 marks)



Question Number	Acceptable Answer				Additional Guidance	Mark																				
9(a)	IC points	IC mark	Max linkage mark	Max final mark	This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The table shows how the marks should be awarded for indicative content and structure and lines of reasoning. <table><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr><tr><td>6</td><td>4</td></tr><tr><td>5–4</td><td>3</td></tr><tr><td>3–2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table> <table><tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr><tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></table> Alternative to first 3 indicative content points: IC1 Current in coil causes a magnetic field IC2 Current is alternating so field changes direction with current (same frequency) IC3 Field interacts with permanent magnet's field so coil experiences oscillating force IC6 Resonance occurs and the amplitude of vibration of the box increases	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	6	4	5–4	3	3–2	2	1	1	0	0		Number of marks awarded for structure of answer and sustained line of reasoning	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkages between points and is unstructured	0	
	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points																								
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	5–4	3																								
	3–2	2																								
	1	1																								
	0	0																								
		Number of marks awarded for structure of answer and sustained line of reasoning																								
	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2																								
	Answer is partially structured with some linkages and lines of reasoning	1																								
Answer has no linkages between points and is unstructured	0																									
6	4	2	6																							
5	3	2	5																							
4	3	1	4																							
3	2	1	3																							
2	2	0	2																							
1	1	0	1																							
0	0	0	0																							
Indicative content:																										
IC1 Alternating p.d. causes an alternating current in the coil																										
IC2 Current carrying conductor in a magnetic field experiences a force																										
IC3 Current is alternating, so force changes direction with current (same frequency)																										
Or the alternating current drives the cone at the frequency of the p.d.																										
IC4 The loudspeaker forces the box into oscillation																										
IC5 (At certain frequencies) the frequency of oscillation equals the natural frequency of oscillation of the air in the box																										
IC6 Maximum energy is transferred and the amplitude of vibration of the box increases																										

6



9(b)(i)	- A standing wave is set up in the tube Or interference (of sound waves) takes place in the tube (1) - Where constructive interference occurs the amplitude is a maximum Or at antinodes the amplitude is a maximum (1) - Where destructive interference occurs the amplitude is a minimum Or at nodes the amplitude is zero/minimum (1) - Sand is displaced from points of max amplitude to points of min amplitude Or sand is displaced from antinodes to nodes (1)		4
9(b)(ii)	- Measure over at least 3 heaps (1) - Divide by the number of gaps between the heaps (1) - Repeat measurement and calculate average (1)	i.e at least 2 gaps	3
9(b)(iii)	- Use of $d = \frac{\lambda}{2}$ (1) - Use of $v = f\lambda$ (1) $v = 330 \text{ (m s}^{-1}\text{)}$ and a comment on consistency with 340 m s^{-1} (1)	<u>Example of calculation:</u> $\lambda = 2d = 2 \times 5.1 \times 10^{-2} \text{ m} = 0.102 \text{ m}$ $v = 3.25 \times 10^3 \text{ Hz} \times 0.102 \text{ m} = 332 \text{ m s}^{-1}$	3

(Total for Question 9 = 16 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
10(a)(i)	- Use of $T = 2\pi\sqrt{\frac{\ell}{g}}$ (1) $\ell = 1.55 \text{ m}$ (1)	<u>Example of calculation</u> $\ell = \frac{(2.50 \text{ s})^2 \times 9.81 \text{ m s}^{-2}}{4\pi^2} = 1.55 \text{ m}$	2
10(a)(ii)	An explanation that makes reference to the following points: - Resistive forces act on the pendulum Or The oscillation is damped (1) - Work is done against the resistive/damping forces (1) - So the energy and amplitude of the oscillation/pendulum decreases (1)	Accept “energy is transferred from the system” for “energy decreases”	3
10(b)(i)	An explanation that makes reference to the following points: - Shows expansion $\ln(A) = -\left(\frac{k}{T}\right)t + \ln A_0$ (1) - Compares with $y = mx + c$ and states/indicates that gradient is $-\frac{k}{T}$ (which is a constant) (1) OR - Shows expansion $\ln(A) = \ln A_0 - \left(\frac{k}{T}\right)t$ (1) - Compares with $y = c + mx$ and states/indicates that gradient is $-\frac{k}{T}$ (which is a constant) (1)		2



10(b)(ii)	- Ln values correct and all to 2 decimal places Or Ln values correct and all to 3 decimal places (1) - Labels and unit (1) - Scales (1) - Plots (1) - Line of best fit (1)	<table border="1"> <thead> <tr> <th>t / s</th><th>A / cm</th><th>$\ln (A/cm)$</th><th>$\ln (A/cm)$</th></tr> </thead> <tbody> <tr> <td>2.5</td><td>17.6</td><td>2.868</td><td>2.87</td></tr> <tr> <td>5.0</td><td>14.3</td><td>2.660</td><td>2.66</td></tr> <tr> <td>7.5</td><td>11.6</td><td>2.451</td><td>2.45</td></tr> <tr> <td>10.0</td><td>9.4</td><td>2.241</td><td>2.24</td></tr> <tr> <td>12.5</td><td>7.6</td><td>2.028</td><td>2.03</td></tr> </tbody> </table>	t / s	A / cm	$\ln (A/cm)$	$\ln (A/cm)$	2.5	17.6	2.868	2.87	5.0	14.3	2.660	2.66	7.5	11.6	2.451	2.45	10.0	9.4	2.241	2.24	12.5	7.6	2.028	2.03	5
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10(b)(iii)	- Inverse ln of intercept determined (1) $A_0 = 22$ cm to 2 or 3 sf [Allow answers that round to 21 cm or 22 cm] (1) - Gradient determined using large triangle (1) $k = 0.21$ to 2 or 3 sf [Answers must round to 0.21] (1)	Only withhold mark for incorrect s.f. once in this part <u>Example of calculation</u> $\text{grad} = \frac{(3.08 - 2.00)}{(0 - 12.9) s} = -0.0837 s^{-1}$ $k = 0.0837 s^{-1} \times 2.50 s = 0.209$ $\ln A_0 = 3.08$ $A_0 = e^{3.08} = 21.8 \text{ cm}$	4																								

(Total for Question 10 = 16 marks)



