Name: ______________________________________

Topic 13: Oscillations Part 2

Date:

Time:

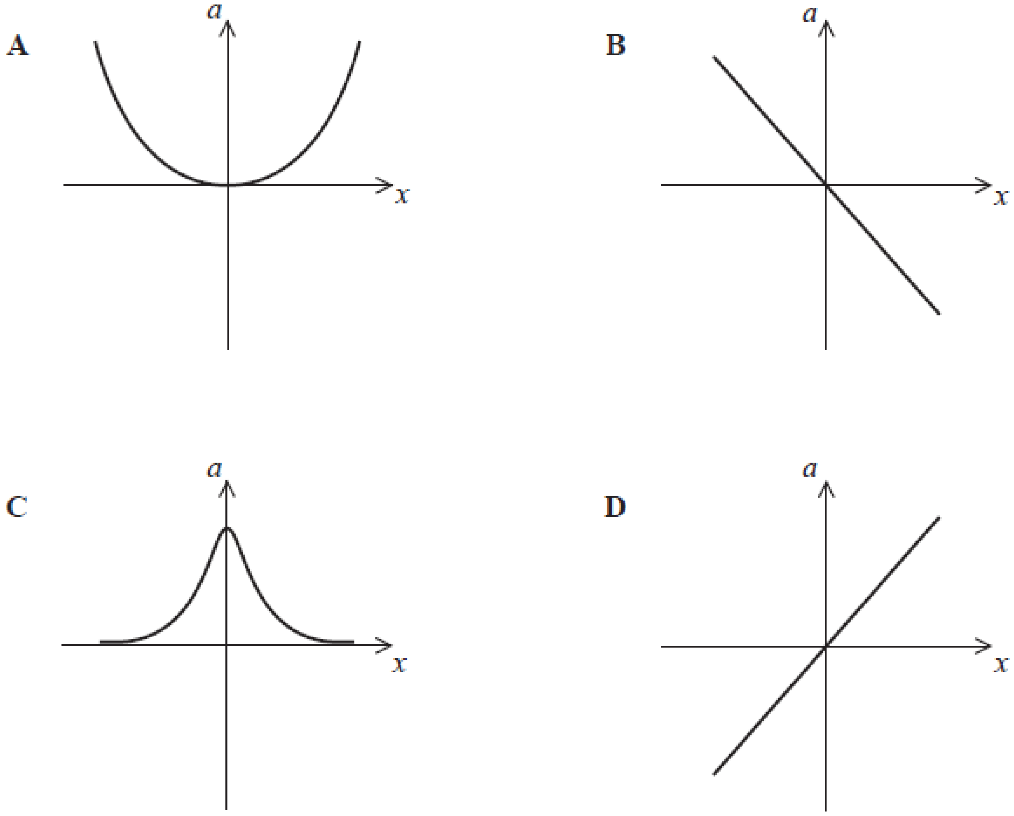
Total marks available:

Total marks achieved: ______

Questions

Q1.

Which of the following graphs correctly shows the relationship between acceleration *a* and displacement *x* for a simple harmonic oscillator?



☐ **A**

☐ **B**

☐ **C**

☐ **D**

(Total for question = 1 mark)

Q2.

A pendulum of length *l* oscillates with a frequency *f*. The length of the pendulum is doubled.

The frequency of oscillation will be

☒ **A** $\frac{f}{\sqrt{2}}$

☒ **B** $\frac{f}{2}$

☒ **C** $\sqrt{2}f$

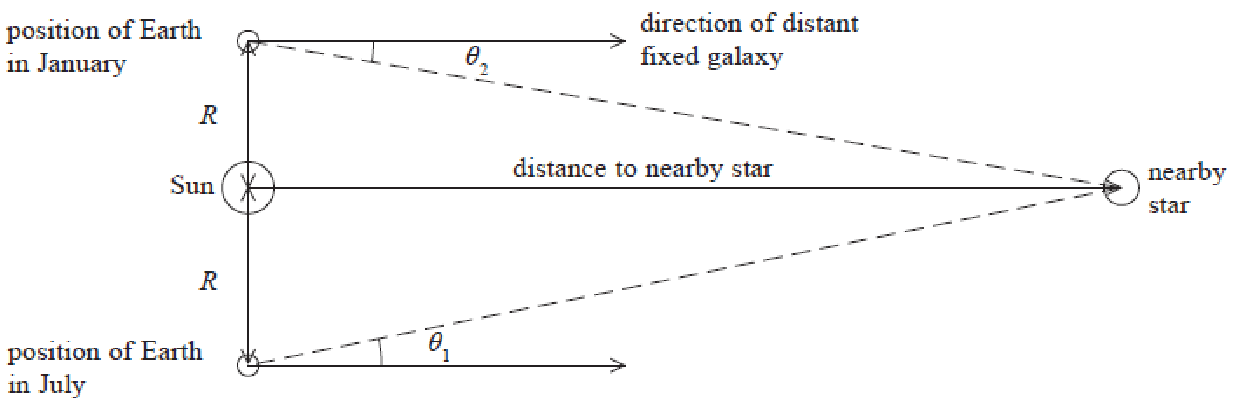
☒ **D** $2f$

(Total for question = 1 mark)

Q3.

Astronomers determine the distance to nearby stars using trigonometric parallax.

The diagram shows the measurements that an astronomer would take to determine this distance.



The distance to the nearby star is given by

☒ **A** $\frac{\tan(\theta_1 + \theta_2)}{R}$

☒ **B** $\frac{(\tan\theta_1 + \tan\theta_2)}{R}$

☒ **C** $\frac{R}{\tan\left(\frac{\theta_1 + \theta_2}{2}\right)}$

☒ **D** $\frac{R}{\tan(\theta_1 + \theta_2)}$

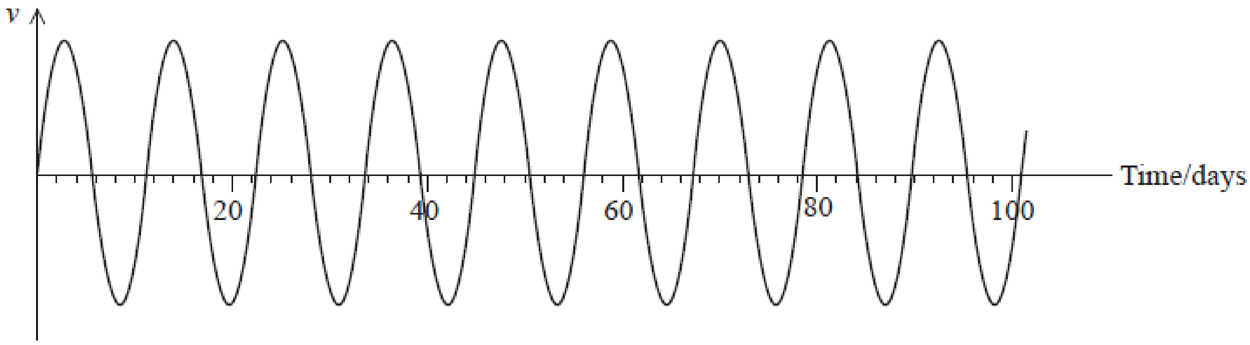
(Total for question = 1 mark)

Q4.

In 2016 astronomers announced the discovery of an Earth-like planet orbiting Proxima Centauri, the closest star to the Sun.

The planet was detected because of the small movement of the star as the planet orbited. The movement was detected using the Doppler shift in the frequency of light travelling to the Earth.

The graph shows how the component of the star's velocity *v* towards the Earth varied over time.



(i) Use the graph to show that the angular velocity of the planet is about 6×10^{-6} radian s^{-1}.

(3)

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(ii) The mass of Proxima Centauri is 0.12 times the mass of the Sun.

Determine the distance of the planet from Proxima Centauri.

mass of Sun = 1.99×10^{30} kg

(3)

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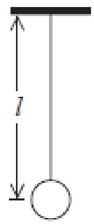
Distance = ...

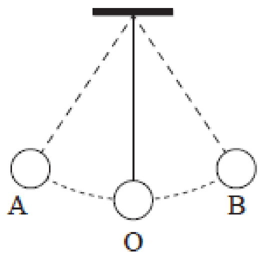
(Total for question = 6 marks)

Q5.

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



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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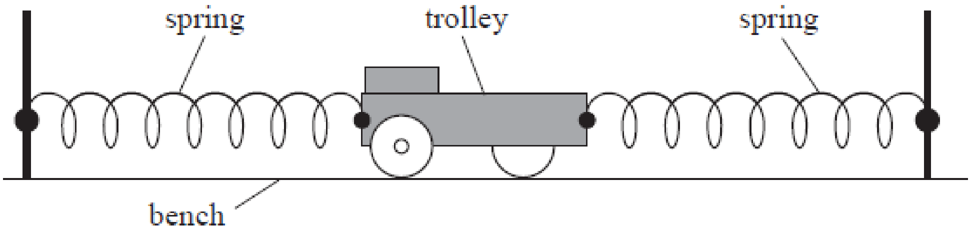
(Total for question = 4 marks)

Q6.

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 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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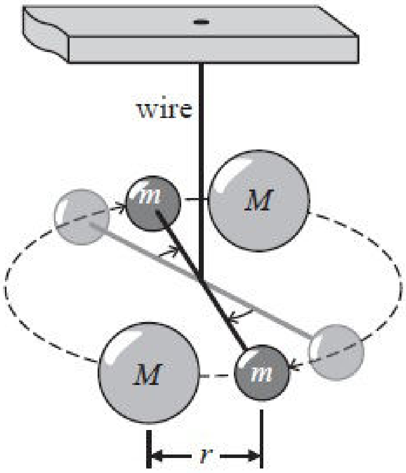
(Total for question = 9 marks)

Q7. In the 18th century Henry Cavendish devised an experiment to determine the average density of the Earth. This involved the first laboratory determination of the universal gravitational constant *G*.

A light horizontal rod with a small metal sphere at each end was hung from a fixed point by a very thin wire. Two large lead spheres were then brought close to the small spheres causing the rod to oscillate and then settle into a new position of equilibrium.



(a) In a modern version of the experiment the following data was obtained:

mass of large lead sphere M = 160 kg

mass of small sphere m = 0.75 kg

distance r = 0.23 m

gravitational force between adjacent large and small spheres $F = 1.5 \times 10^{-7}$ N.

Use this data to calculate a value for G.

(2)

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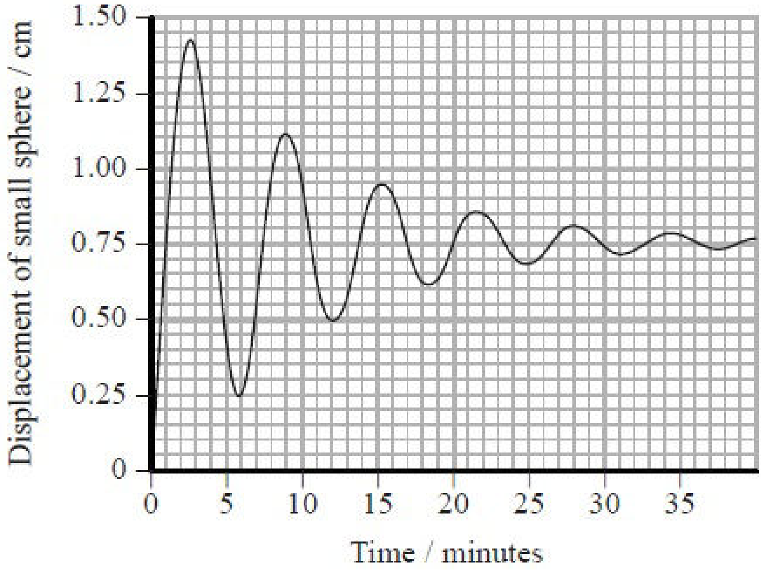
G = ...$\text{Nm}^2\ \text{kg}^{-2}$

(b) The graph shows how the displacement of one of the small spheres varies with time.



(i) Use the graph to determine the period of oscillation of the sphere.

(2)

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Period = ...

(ii) The amplitude of the oscillation decreases with each cycle.

Explain why this effect is observed.

(2)

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(iii) It is suggested that the decrease in amplitude is exponential. Use the graph to determine if this is approximately true.

(3)

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(Total for Question = 9 marks)

Q8.

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

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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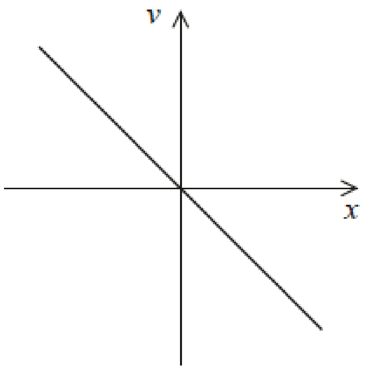
(Total for question = 4 marks)

Q9.

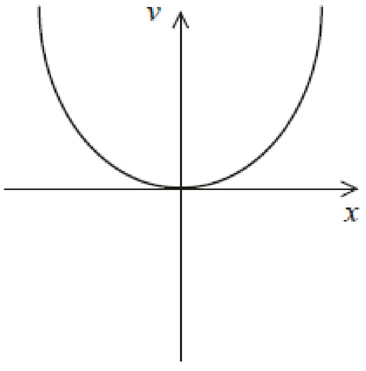
A mass at the end of a spring is set into small amplitude simple harmonic motion.

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

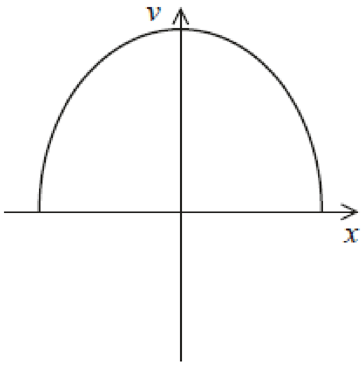
☐ **A**



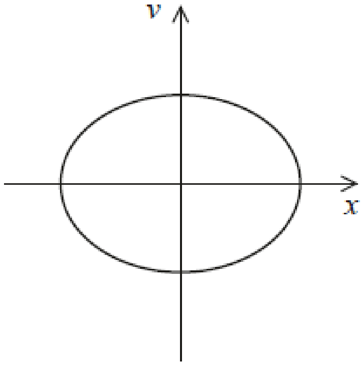
☐ **B**



☐ **C**



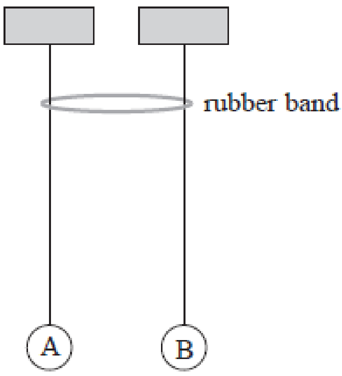
☐ **D**



(Total for question = 1 mark)

Q10.

The diagram shows two identical pendulums, A and B, side by side with a rubber band placed over both strings.



Pendulum A is displaced and starts to oscillate. As pendulum A oscillates, pendulum B starts to oscillate with the same time period, its amplitude increasing as the amplitude of pendulum A decreases. At one stage pendulum A is no longer oscillating and pendulum B has its maximum amplitude. Then pendulum A starts to oscillate again with increasing amplitude, as the amplitude of pendulum B decreases.

The apparatus is adjusted so that the pendulums do not have the same length as each other. When the first pendulum is set into oscillation, the second pendulum starts to oscillate, but with very small amplitude; the first pendulum does not stop oscillating.

* Explain this behaviour.

(6)

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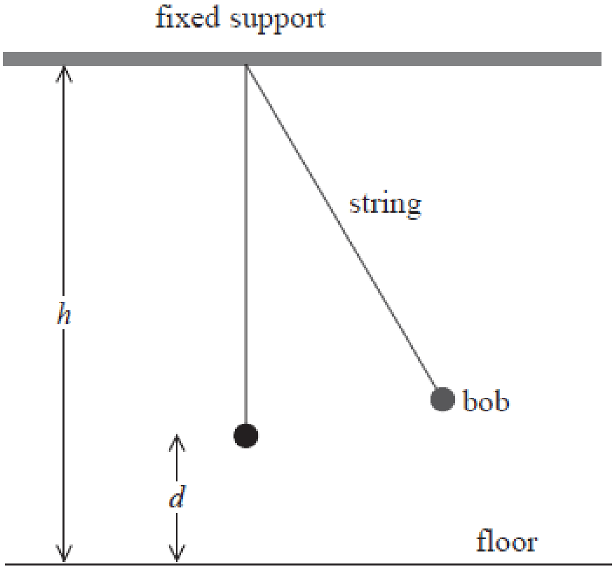
(Total for question = 6 marks)

Q11.

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.

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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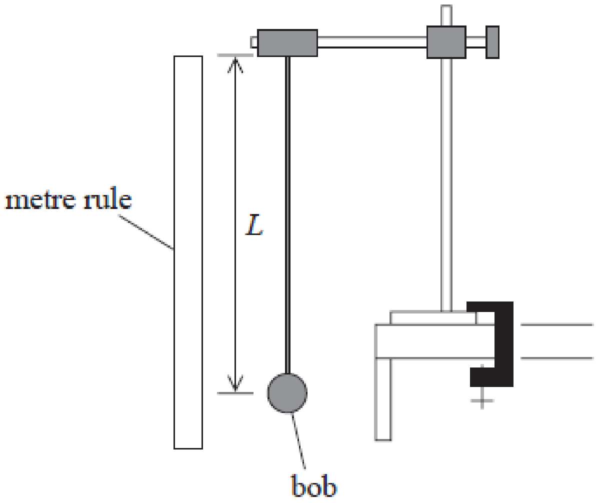
(Total for question = 2 marks)

Q12.

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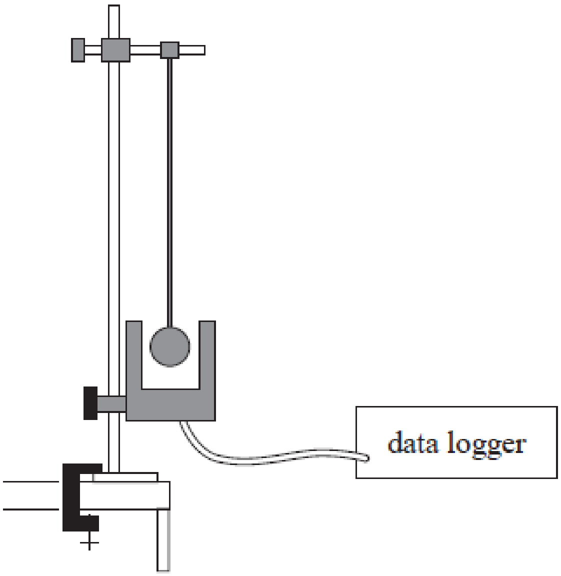
(c) Another student suggested that the uncertainty in the measurement of the time period of the pendulum could be reduced by using a light gate and a data logger. The data logger would record the time between successive interruptions of the light beam. Both the data logger and the stopwatch have a resolution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



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

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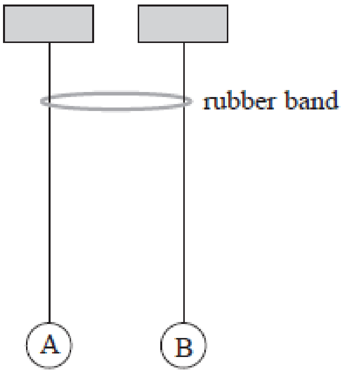
(Total for question = 8 marks)

Q13.

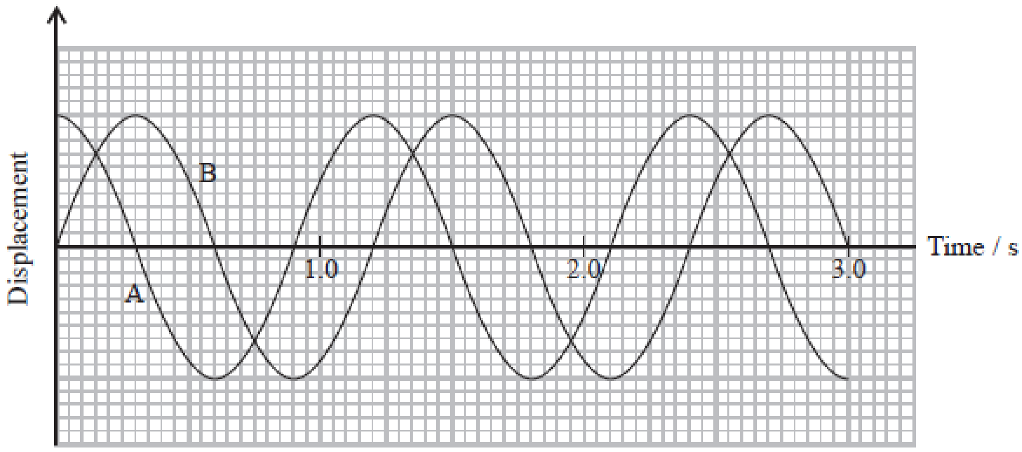
The diagram shows two identical pendulums, A and B, side by side with a rubber band placed over both strings.



Pendulum A is displaced and starts to oscillate. As pendulum A oscillates, pendulum B starts to oscillate with the same time period, its amplitude increasing as the amplitude of pendulum A decreases. At one stage pendulum A is no longer oscillating and pendulum B has its maximum amplitude. Then pendulum A starts to oscillate again with increasing amplitude, as the amplitude of pendulum B decreases.

The apparatus is adjusted so that the pendulums do not have the same length as each other. When the first pendulum is set into oscillation, the second pendulum starts to oscillate, but with very small amplitude; the first pendulum does not stop oscillating.

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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Length = ...

(Total for question = 4 marks)

Q14.

Figure 1 shows a wine glass being driven into oscillation at its natural frequency by a high-power loudspeaker. The loudspeaker is close to, but not touching, the glass. The loudspeaker is driven by a sine-wave generator.

Figure 1

Figure 2

In Figure 2, the amplitude of vibration of the glass has become so large that the glass shatters.

(a) (i) Name the effect being demonstrated.

(1)

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(ii) Explain why this effect occurs.

(2)

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(b) A rubber band may be placed around the glass to provide some damping. This would reduce the amplitude of vibration and prevent the glass from shattering.

Explain how a rubber band around the glass would provide damping.

(2)

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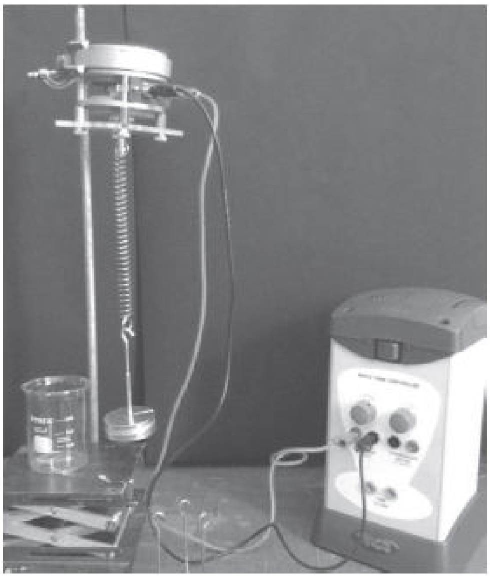
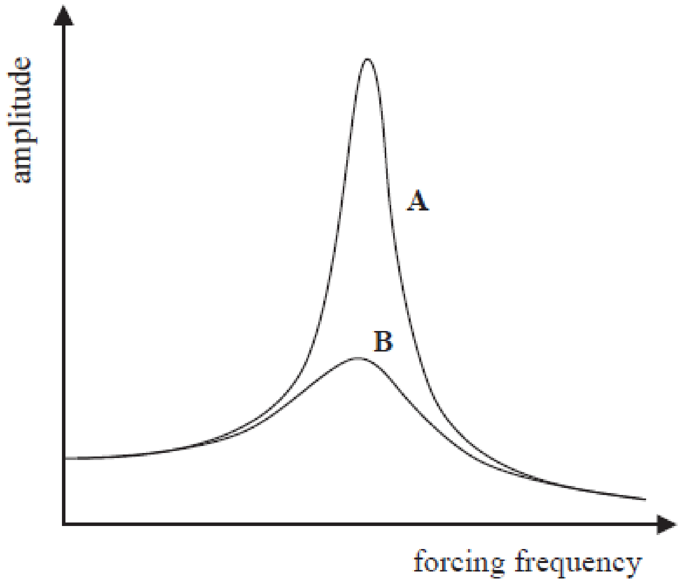
(Total for question = 5 marks)

Q15.

* A student uses the apparatus shown below to investigate the behaviour of a mass-spring system when it is forced into oscillation.



The graph shows how the amplitude of the oscillating mass varies over a range of forcing frequencies.



Curve A shows the results of the investigation using the apparatus as shown.

The student repeats the investigation with the oscillating mass in a beaker of water.
Curve B shows these results.

Making reference to important features in the graph, describe and explain the two sets of results.

(4)

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(Total for question = 4 marks)

Q16.

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)

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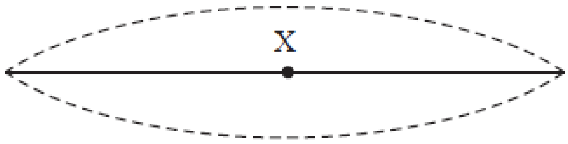
(Total for question = 6 marks)

Q17.

Guitar strings can oscillate with simple harmonic motion.

Shortly after the string is plucked, a standing wave exists on the string. The simplified diagram below shows a string in three positions of the standing wave.



(a) State what is meant by simple harmonic motion.

(2)

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(b) (i) Describe the acceleration of point X on the string as it moves between the extreme positions of its motion.

(2)

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(ii) Comment on the energy changes in the string as it moves between the extreme positions of its motion.

(3)

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(c) The oscillating string has a length of 0.53 m. Calculate the frequency of the sound emitted when the string oscillates as shown previously.

speed of the wave on the string = 270 m s^{-1}

(3)

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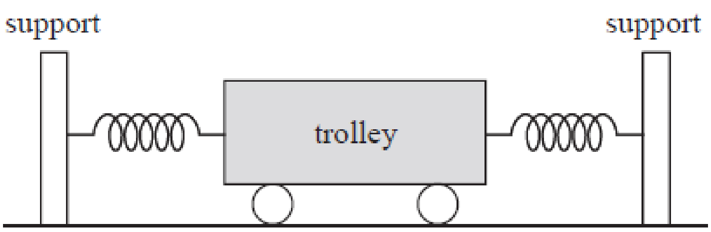
Frequency = ...

(Total for question = 10 marks)

Q18.

The diagram shows a mass-spring system that consists of a trolley held in equilibrium by springs attached to two fixed supports.



The trolley has a mass *m* and the spring arrangement has a force constant *k*.

(a) (i) The trolley is displaced towards one of the supports through a distance *x* and then released. Show that the initial acceleration of the trolley when it is released is given by $a = -\frac{kx}{m}$

and explain the significance of the minus sign.

(2)

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(ii) Use the expression in (i) to show that the trolley will oscillate with a time period T given by

$$T = 2\pi\sqrt{\frac{m}{k}}$$

(3)

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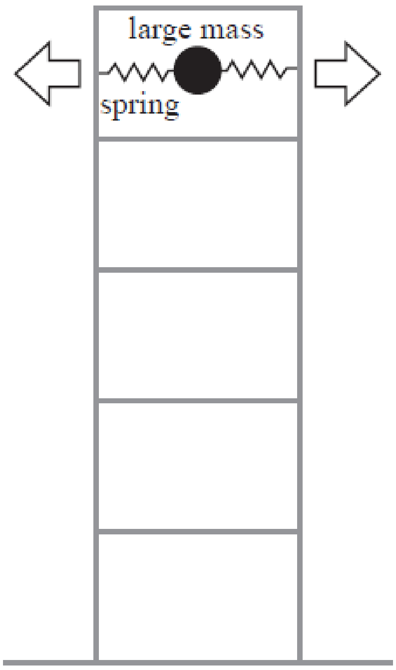
(b) Mass-spring systems are sometimes used in tall buildings to reduce the oscillation of the building due to strong winds.



As the top of the building moves the mass is set into oscillation. The mass-spring system is designed to have a natural frequency equal to that of the building.

(i) In one building a mass-spring system has a mass of 3.5×10^5 kg and the spring arrangement has a force constant of 4.8×10^6 N m^{-1}.

Show that the natural frequency of the mass-spring system is about 0.6 Hz.

(3)

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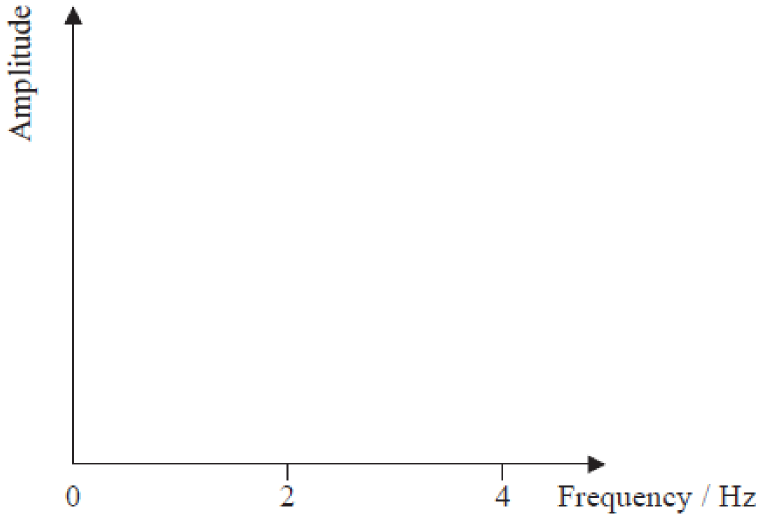
(ii) Sketch a graph to show how the amplitude of oscillation of the mass would vary with the frequency of movement of the building. Ignore the effects of damping.

(3)



(iii) In order to be effective the mass-spring system needs to be damped.

Explain what is meant by damping in this context and suggest why damping is a desirable feature of the mass-spring system in a tall building.

(3)

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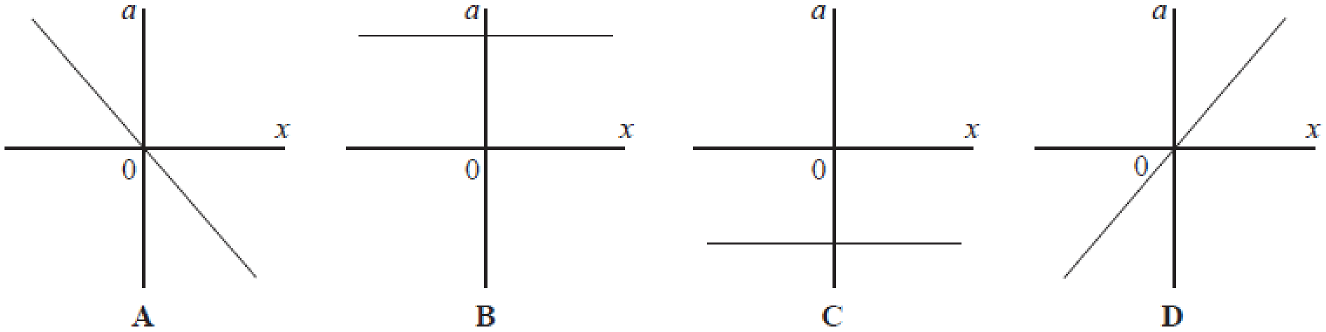
(Total for question = 14 marks)

Q19.

An object is undergoing simple harmonic motion.
Which graph shows how the acceleration *a* varies with displacement *x* from the equilibrium position?

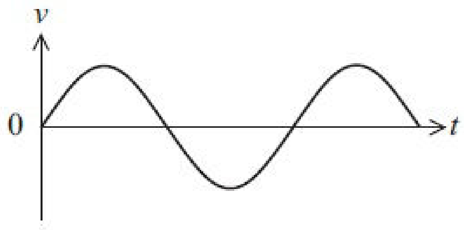


- A
- B
- C
- D

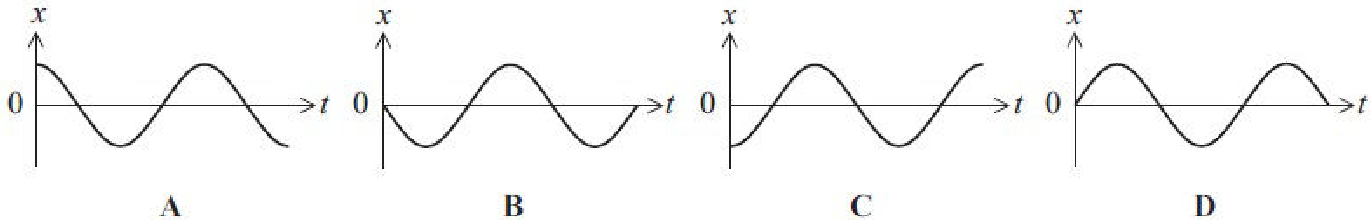
(Total for question = 1 mark)

Q20.

The graph below shows how the velocity varies with time for an object undergoing simple harmonic motion.



Which graph shows the variation of displacement with time?

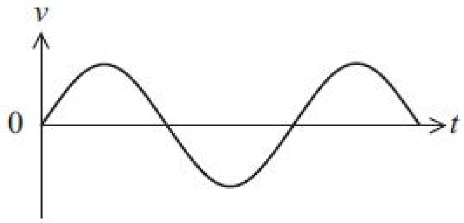


- A
- B
- C
- D

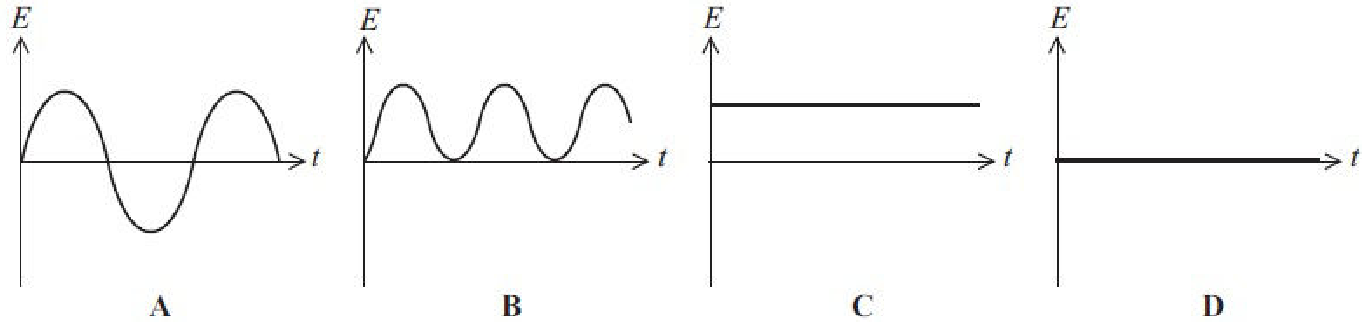
(Total for question = 1 marks)

Q21.

The graph below shows how the velocity varies with time for an object undergoing simple harmonic motion.



Which graph shows the variation of total energy with time?



☒ **A**

☒ **B**

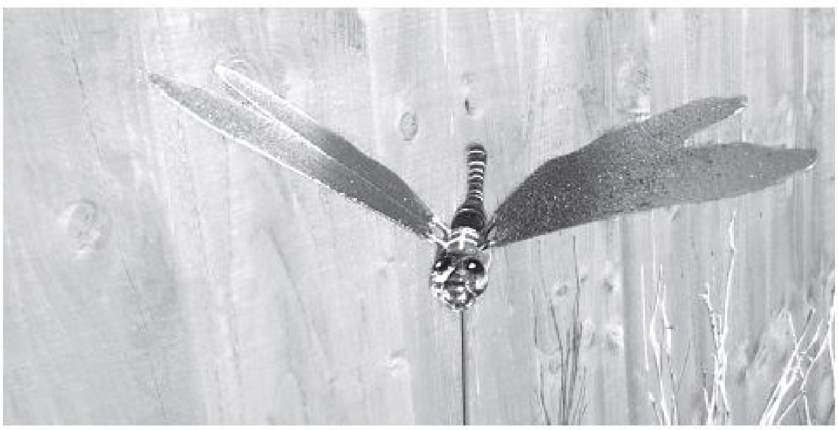
☒ **C**

☒ **D**

(Total for question = 1 marks)

Q22.

A garden ornament consists of a plastic dragonfly mounted on a stick. The dragonfly's wings are attached to the body with springs, and they flutter up and down in a gentle breeze.



(a) When the air is not moving and the wings are displaced through a small vertical distance, they oscillate. The time for 10 oscillations is recorded. This is repeated twice more.

Time / s		
t_1	t_2	t_3
6.2	6.6	6.9

(i) Calculate the frequency of oscillation of the wings

(3)

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Frequency = ...

(ii) The oscillation of the wings is thought to be simple harmonic motion.

State the conditions required for the oscillations to be simple harmonic.

(2)

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(b) The amplitude of the wings' oscillation dies down after only a small number of oscillations.

Explain why this happens

(2)

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(c) In certain breezy conditions the wings are seen to oscillate with a very large amplitude.

Name this effect and state the condition for it to occur.

(2)

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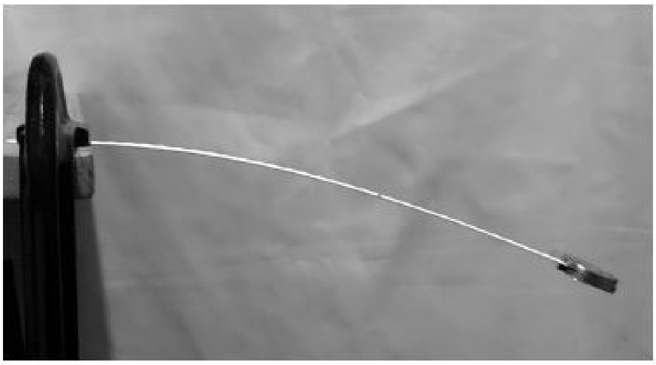
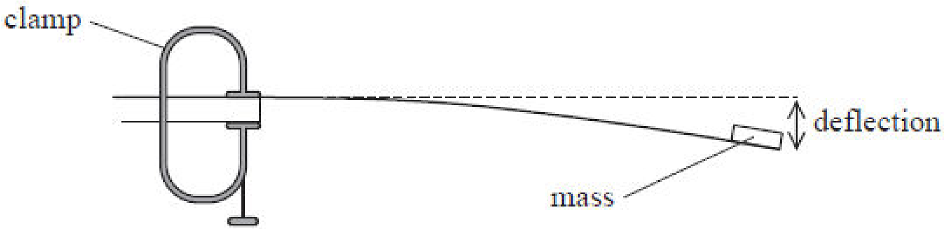
(Total for question = 9 marks)

Q23.

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.

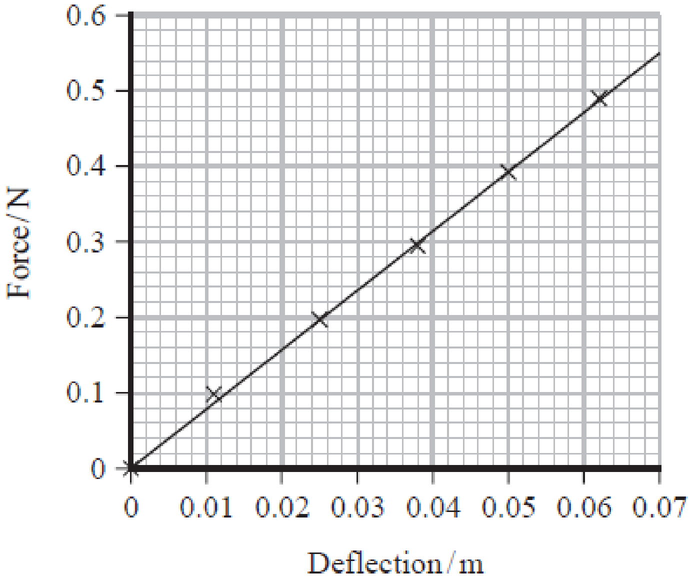




The student varied the force on the end of the strip by changing the mass attached.

The deflection was measured each time when the mass was in its equilibrium position.

The student obtained the following graph of deflection against force.



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

(2)

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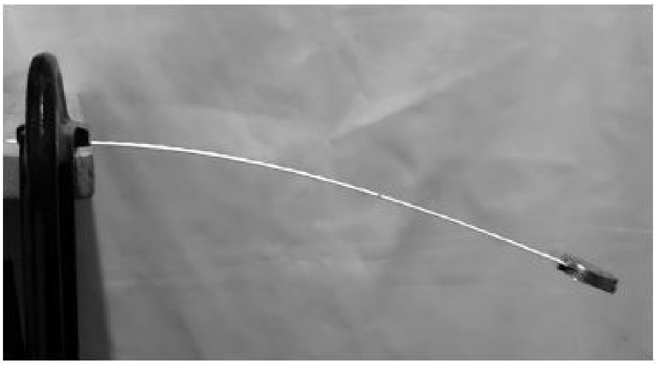
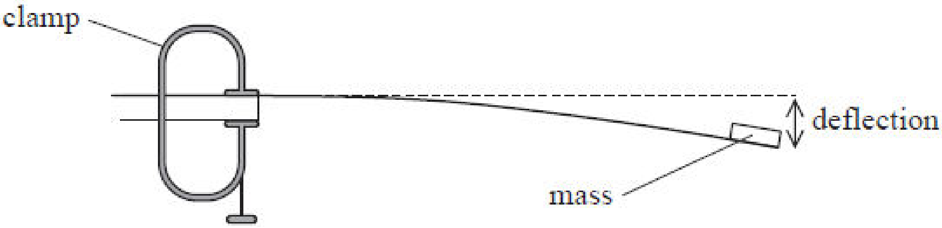
(Total for question = 2 marks)

Q24.

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.

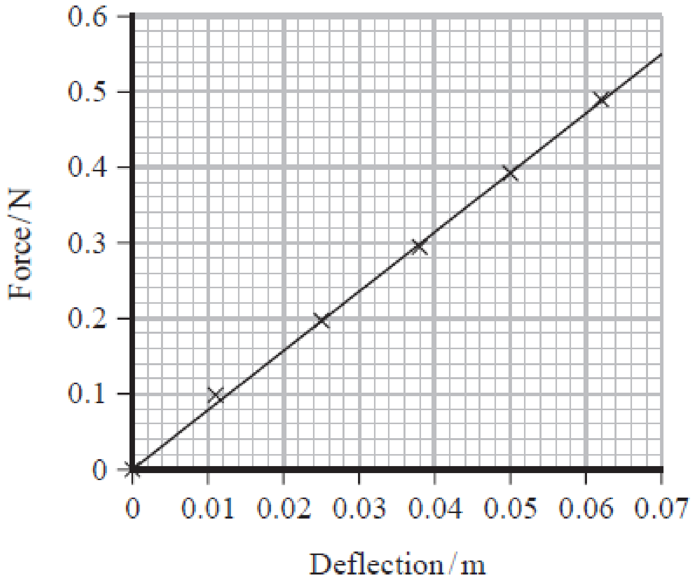




The student varied the force on the end of the strip by changing the mass attached.

The deflection was measured each time when the mass was in its equilibrium position.

The student obtained the following graph of deflection against force.



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)

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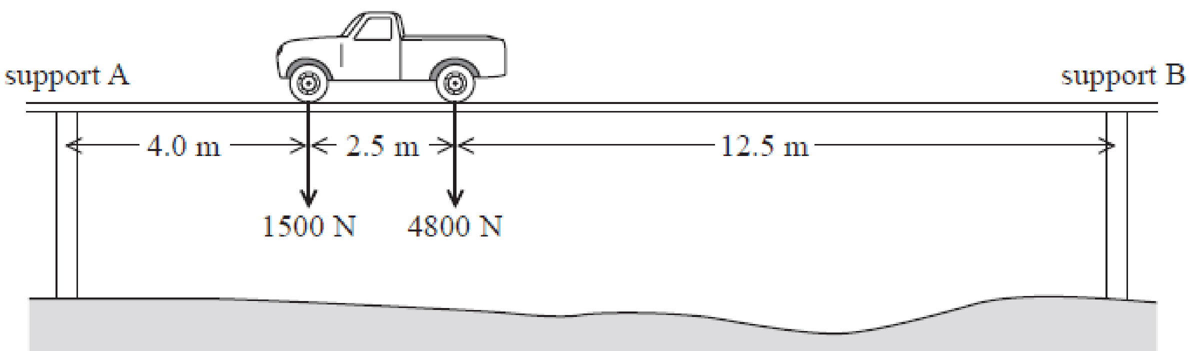
(Total for question = 5 marks)

Q25.

A beam bridge is a rigid structure that consists of one horizontal beam supported at each end.

The diagram shows a bridge with a uniform beam of mass 8 500 kg.

A small truck is crossing the beam bridge. The position of the truck and the forces of the truck on the bridge are shown, but are not drawn to scale.



(a) (i) State the conditions necessary for the bridge to be in equilibrium.

(2)

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(ii) Calculate the vertical forces at each of the bridge supports.

(5)

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Force at A = ...

Force at B = ...

The Volgograd Bridge is a concrete beam bridge across the River Volga in Russia.

In 2010 the bridge was closed to traffic due to windy conditions leading to resonance of the structure.

(i) Explain what is meant by resonance in this context.

(2)

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(ii) To suppress the oscillations of the bridge, dampers were installed.

Explain how damping resulted in the suppression of the oscillations of the bridge.

(3)

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(iii) Each damper contains an enclosure filled with a fluid. When this fluid is subjected to a magnetic field, the viscosity of the fluid greatly increases.

Describe how the behaviour of the fluid would change in a magnetic field and how this would be useful for the operation of the dampers.

(2)

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(Total for question = 14 marks)

Q26.

Whilst a car is being driven over a bridge, it sets the bridge into vibration. Which of the following terms definitely describes the oscillations of the bridge?

The oscillations of the bridge are

☐ **A** free.

☐ **B** forced.

☐ **C** natural.

☒ **D** resonant.

(Total for question = 1 mark)

Q27.

The Millennium Bridge is a pedestrian suspension bridge across the River Thames in London. The bridge had to be closed soon after its opening because of a large swaying motion created by people walking across it. A damping mechanism was installed to fix the problem.

The damping mechanism

☒ **A** increased the stiffness of the bridge.

☒ **B** increased the natural frequency of the bridge.

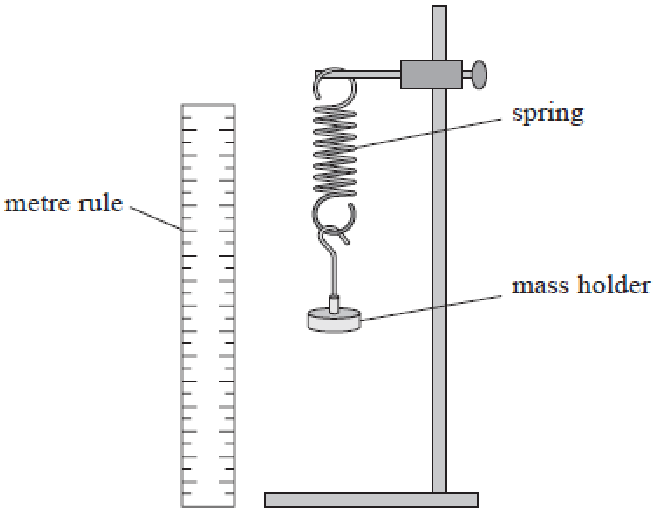
☒ **C** dissipated energy from the bridge.

☒ **D** decreased the forcing frequency on the bridge.

(Total for question = 1 mark)

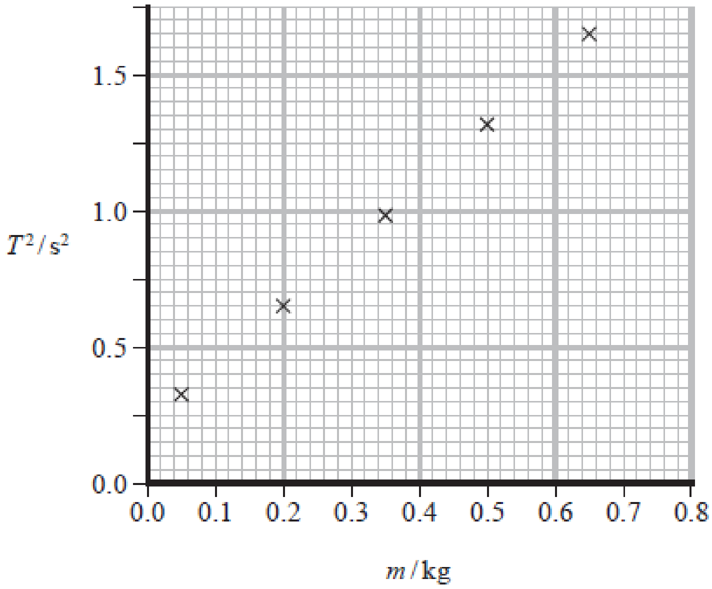
Q28.

A student investigated the behaviour of a spring under tension. The spring was hung vertically with a mass holder attached as shown.



In another experiment, the student displaced the mass vertically each time a mass was added to the spring. He used a stopwatch to determine the period of vertical oscillations of each mass.

The student used his data to plot a graph of T^2 against m as shown.



The student expected the graph to be a straight line through the origin. He thought that there may be systematic error due to reaction time.

(i) Give an example of another possible systematic error in this experiment.

(1)

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(ii) Another student suggests that to reduce the uncertainty in the value for the period, a data logger connected to a light gate could be used to measure time.

Comment on the student's suggestion.

(3)

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(iii) Determine a value for the stiffness of the spring.

(3)

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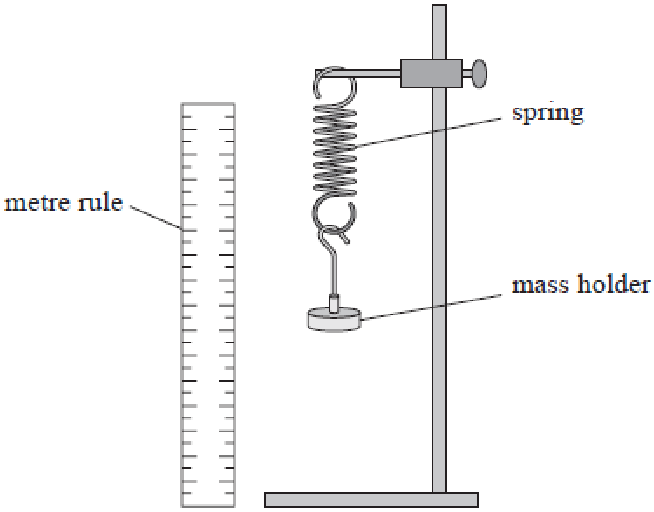
Stiffness of spring = ...

(Total for question = 7 marks)

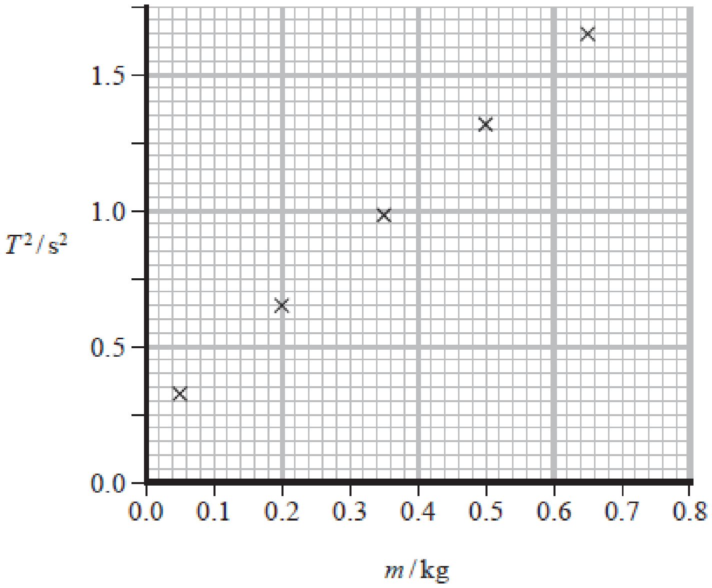
Q29.

A student investigated the behaviour of a spring under tension. The spring was hung vertically with a mass holder attached as shown.



In another experiment, the student displaced the mass vertically each time a mass was added to the spring. He used a stopwatch to determine the period of vertical oscillations of each mass.

The student used his data to plot a graph of T^2 against m as shown.



When determining the period of oscillation for each mass, the student measured the time for 20 oscillations. He repeated this measurement to obtain a mean time for 20 oscillations.

Explain how the student's procedure contributed to the accuracy of the measurement.

(3)

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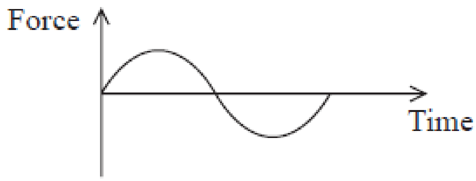
(Total for question = 3 marks)

Q30.

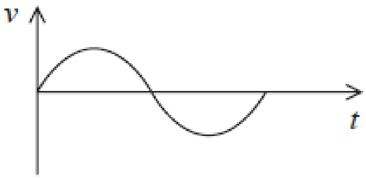
Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

A mass is suspended from a spring and allowed to come to equilibrium.

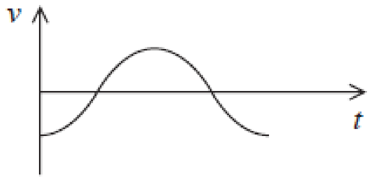
The mass is displaced vertically and moves with simple harmonic motion.
The graph shows how the resultant force on the mass varies with time.



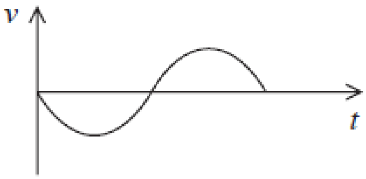
Which of the following graphs shows how the velocity *v* of the mass varies with time *t* over the same time interval?



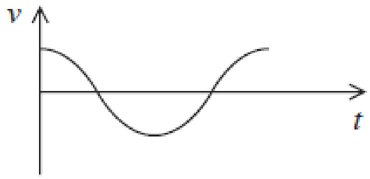
A



B



C



D

☐ **A**

☐ **B**

☐ **C**

☐ **D**

(Total for question = 1 mark)

Mark Scheme

Q1.

Question Number	Answer	Additional guidance	Mark
	B		**(1)**

Q2.

Question Number	Answer	Additional guidance	Mark
	A	$(\frac{f}{\sqrt{2}})$	**(1)**

Q3.

Question Number	Answer	Additional guidance	Mark
	C	$(\frac{R}{\tan(\frac{\theta_1+\theta_2}{2})})$	**(1)**

Q4.

Question Number	Acceptable answers		Additional guidance	Mark
i	• Use of $\omega = 2\pi/T$ • For at least 2 full cycles • $\omega = 6.5 \times 10^{-6}$ (radian s^{-1})	(1) (1) (1)	For MP3, accept correctly rounded answers in range 6.5×10^{-6} radian s^{-1} to 6.6×10^{-6} radian s^{-1} <u>Example of calculation</u> $\omega = 5 \times 2\pi / (56 \times 24 \times 60 \times 60)$ s $= 6.49 \times 10^{-6}$ radian s^{-1}	3
ii	• Equates $F = Gm_1m_2/r^2$ and $F = m\omega^2r$ **Or** $F = Gm_1m_2/r^2$ and $F = mv^2/r$ with $v = 2\pi r/T$ • Correct rearrangement and substitution (e.g. in $r^3 = Gm_1/\omega^2$) • $r = 7.2 \times 10^9$ m (ecf from (b)(i))	(1) (1) (1)	<u>Example of calculation</u> $r^3 = 6.67 \times 10^{-11}$ N m^2 $kg^{-2} \times 0.12 \times 1.99 \times 10^{30}$ kg / $(6.5 \times 10^{-6}$ radian $s^{-1})^2$ $r = 7.2 \times 10^9$ m ($r = 7.6 \times 10^9$ m for 'show that' value)	3

Q5.

Question Number	Acceptable Answer		Additional Guidance	Mark
	Max 4 from 2 out of 3 pairs		For each pair, the second marking point is dependent on the first marking point	
	• 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)	MP4: Accept the pendulum travelling fastest when it passes O	
	• The student should use a (fiducial) marker at O	(1)		4
	• Easier to determine when it passes O	(1)		
	• Time more oscillations	(1)		
	• A longer time reduces (%) uncertainty (in *T*)	(1)		

Q6.

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

Q7.

Question Number	Answer		Mark
(a)	Use of $F = \frac{G m_1 m_2}{r^2}$	(1)	2
	G = 6.6×10^{-11} (N m^2 kg^{-2}) [must see 6.6×10^{-11} when rounded to 2 sf]	(1)	
	Example of calculation $G = \frac{1.5\times10^{-7}\,\mathrm{N}\times(0.23\,\mathrm{m})^2}{160\,\mathrm{kg}\times0.75\,\mathrm{kg}} = 6.61\times10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$		
(b)(i)	Read (peak) times from graph for at least 3 cycles	(1)	2
	T = 6.4 min (±0.2 min) [T = (380 ±12) s]	(1)	
	[max 1 mark if correct answer shown without working]		
	Example of calculation $T = \frac{(28.0-2.5)\,\mathrm{min}}{4} = 6.38\,\mathrm{min}$		
(b)(ii)	Air resistance acts on the sphere [accept frictional forces **Or** (viscous) drag for air resistance]	(1)	2
	Energy is removed from the oscillation/system **Or** the oscillation/system is damped	(1)	
	[For mp 2 do not credit 'energy is lost' but accept 'energy is dissipated'; answer must indicate idea of transfer of energy]		
(b)(iii)	Evidence of values of at least 3 consecutive peaks read from graph [accept values of 3 points separated by equal time intervals]	(1)	3
	Attempt to obtain amplitudes, by subtracting 0.75	(1)	
	Calculation of two values of A_{n+1}/A_n with corresponding conclusion **Or** Calculation of two values of difference of ln A_{n+1} and ln A_n with corresponding conclusion	(1)	
	Or		
	Use peaks of graph to sketch curve	(1)	
	Use curve to determine "half-life" [accept other ratio]	(1)	
	Calculation of two values of "half-life" with corresponding conclusion	(1)	
	Example of calculation A_0 = 1.45-0.75 = 0.7, A_1 = 0.75-0.25 = 0.5, A_2 = 1.1-0.75 = 0.35, A_4 = 0.75 – 0.5 = 0.25		
	$\frac{A_1}{A_0} = \frac{0.50}{0.70} = 0.71$ $\frac{A_2}{A_1} = \frac{0.35}{0.50} = 0.70$ $\frac{A_3}{A_2} = \frac{0.25}{0.35} = 0.71$		
	Total for question		**9**

Q8.

Question Number	Acceptable answers	Additional guidance	Mark
	• 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)**	Example of calculation $T = 52.2\text{ s} / 8$ $= 6.53\text{ s}$ $6.53\text{ s} = 2\pi\sqrt{(l/9.81\text{ N kg}^{-1})}$ Length of pendulum to centre of mass = 10.6 m Length of wire = 10.6 m − 0.3 m = 10.3 m	4

Q9.

Question Number	Acceptable answer	Additional guidance	Mark
	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

Q10.

<table>
<tr><th>Question Number</th><th>Acceptable Answers</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>*</td><td>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>
<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></tr>
<tr><td>6</td><td>4</td><td>2</td></tr>
<tr><td>5</td><td>3</td><td>2</td></tr>
<tr><td>4</td><td>3</td><td>1</td></tr>
<tr><td>3</td><td>2</td><td>1</td></tr>
<tr><td>2</td><td>2</td><td>0</td></tr>
<tr><td>1</td><td>1</td><td>0</td></tr>
<tr><td>0</td><td>0</td><td>0</td></tr>
</table>
</td><td>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).</td><td>3</td></tr>
</table>

<table>
<tr><td></td><td>The following table shows how the marks should be awarded for structure and lines of reasoning.

<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</td><td>0</td></tr>
</table>
</td><td></td><td></td></tr>
</table>

	points and is unstructured **Indicative content** • The pendulums have the same length, so they have the same time period/frequency • The first pendulum 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		

Q11.

Question Number	Acceptable Answer	Additional Guidance	Mark
	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

Q12.

Question Number	Acceptable Answer		Additional Guidance	Mark
(a)	• Use of $T = 2\pi\sqrt{\frac{L}{g}}$	(1)	Example of calculation:	
	• $L = 0.994\ \text{m}$	(1)	$L = \frac{(2.00\ \text{s})^2 \times 9.81\ \text{m s}^{-2}}{4\pi^2} = 0.994\ \text{m}$	2

Question Number	Acceptable Answer		Additional Guidance	Mark
(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 **Or** repeats timings for multiple oscillations and calculate mean	(1)		2

Question Number	Acceptable Answer		Additional Guidance	Mark
(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)	MP2 dependent on MP1	
	• Timing multiple swings (with stopwatch) reduces %U	(1)		
	• Light gates are difficult to use with a pendulum bob.	(1)		4

Q13.

Question Number	Acceptable Answers		Additional Guidance	Mark
(i)	• Pendulum A is $\pi/2$ ahead of pendulum B	(1)		1
(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 $1.2\ \text{s} = 2\pi\sqrt{(l/9.81\ \text{N kg}^{-1})}$ $l = 0.36$ m	3

Q14.

Question Number	Answer		Mark
(a)(i)	Resonance / resonating / resonates	**(1)**	**1**
(a)(ii)	Loudspeaker/driving frequency close or equal to its natural frequency so energy transfer is maximised/large **Or** energy transfer is very efficient	**(1)** **(1)**	 **2**
(b)	Idea that energy would be transferred (from the glass) to the rubber band (as it deforms) **Or** work is done on the rubber band (by the glass) Some of the (transferred) energy becomes internal energy of rubber band **Or** some of the (transferred) energy is dissipated in the rubber band	**(1)** **(1)**	 **2**
	Total for Question		**5**

Q15.

Question Number	Answer		Mark
	MAX 3 Curve A: The system has a maximum amplitude at a particular frequency This is an example of resonance Resonance occurs when the forcing frequency is at (or near to) the natural frequency of the system At resonance there is an efficient/maximum transfer of energy (to the mass-spring system) **MAX 3** Curve B: B has a smaller amplitude than A (for a wide range of frequencies) The modified system has (greater) damping Energy is being removed from the system The frequency at which resonance occurs is lower for the damped system	 (1) (1) (1) (1) (1) (1) (1) (1)	 **4**
	Total for question		**4**

Q16.

Question Number	Acceptable answers	Additional guidance	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 following table shows how the marks should be awarded for indicative content.	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).	

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

The following table shows how the marks should be awarded for structure and lines of reasoning.

	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

Mark: 6

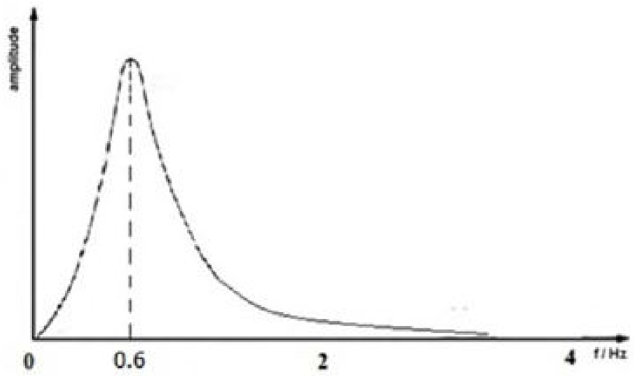
	• (Resonance occurs when) the driving frequency is equal/similar to the natural frequency • (When resonance occurs) there is maximum transfer of energy so the amplitude is maximum **Or** (When resonance occurs) there is maximum transfer of energy so the amplitude increases	Do not accept 'resonant frequency' for 'natural frequency'	

Q17.

Question Number	Answer		Mark
(a)	Force (or acceleration): • proportional to displacement from equilibrium/undisplaced/rest position • always acting towards the equilibrium/undisplaced/rest position **Or** always in the opposite direction to the displacement	(1) (1)	2
(b)(i)	Acceleration is a maximum at an extreme position (towards X) Acceleration decreases to zero at X	(1) (1)	2
(b)(ii)	**Max 3** Total energy remains constant (Elastic) potential energy is transferred to kinetic energy as string moves towards X Kinetic energy is zero at an extreme position and a maximum at X (Elastic) potential energy is a maximum at an extreme position and a minimum at X	 (1) (1) (1) (1)	3
(c)	Use of $\lambda = 2l$ Use of $v = f\lambda$ $f = 250$ Hz Example of calculation: $\lambda = 2 \times 0.53 \text{ m} = 1.06 \text{ m}$ $f = v/\lambda = 270 \text{ m s}^{-1}/1.06 \text{ m} = 254.7 \text{ Hz}$	(1) (1) (1)	3
	Total for question		**10**

Q18.

Question Number	Answer		Mark
(a)(i)	Use of Newton's 2nd law (F = ma) with F = –kx Acceleration/force is in opposite direction to the displacement from the equilibrium position **Or** acceleration/force is (always) towards the equilibrium/undisplaced/rest position <u>Example of calculation:</u> m a = - k x $a = -\frac{k}{m}x$	(1) (1)	2
(a)(ii)	See $a = -\omega^2 x$ Compare with $a = -\frac{k}{m}x$ to give $\omega^2 = \frac{k}{m}$ Substitute for ω using $\omega = \frac{2\pi}{T}$ <u>Example of calculation:</u> $a = -\omega^2 x$ and $a = -\frac{k}{m}x$ $\omega^2 = \frac{k}{m}$ and $\omega = \frac{2\pi}{T}$ $\left(\frac{2\pi}{T}\right)^2 = \frac{k}{m}$ $\therefore T = 2\pi\sqrt{\frac{m}{k}}$	(1) (1) (1)	3
(b)(i)	Use of $T = 2\pi\sqrt{\frac{m}{k}}$ Use of $f = \frac{1}{T}$ f = 0.59 Hz <u>Example of calculation:</u> $T = 2\pi\sqrt{\frac{3.5\times10^5\text{ kg}}{4.8\times16^6\text{ N m}^{-1}}} = 1.7\text{ s}$ $f = \frac{1}{T} = \frac{1}{1.7\text{ s}} = 0.588\text{ Hz}$	(1) (1) (1)	3

(b)(ii)	Correct shape Single sharp peak With the peak labelled at 0.6 Hz 	(1) (1) (1)	3
(b)(iii)	(Max) amplitude of oscillation is reduced as energy is transferred from the mass-spring system and then dissipated (in the surroundings)	(1) (1) (1)	3
	Total for question		**14**

Q19.

Question Number	Answer	Mark
	A	1

Q20.

Question Number	Answer	Mark
	C	1

Q21.

Question Number	Answer	Mark
	C	1

Q22.

Question Number	Answer		Mark
(a)(i)	Calculation of average time period [accept average time for 10T] Use of $f = \frac{1}{T}$ $f = 1.5$ Hz Example of calculation $T = \frac{t_1 + t_2 + t_3}{30} = \frac{(6.2 + 6.6 + 6.9)\text{s}}{30} = 0.657\text{ s}$ $f = \frac{1}{0.657\text{ s}} = 1.52\text{ Hz}$	(1) (1) (1)	3
(a)(ii)	Force (or acceleration): proportional to displacement from equilibrium position always acting towards the equilibrium position **Or** always in the opposite direction to the displacement [accept rest/centre point for "equilibrium position"] [both marks can be gained from an equation with terms clearly defined including a correct reference to the negative sign]	(1) (1)	2
(b)	There is (large) drag force [accept air resistance for drag] Producing a deceleration **Or** the oscillation is (heavily) damped **Or** energy is transferred/removed from the system [e.g. transferred to the surroundings.] [Do not accept "lost" for "transferred"]	(1) (1)	2
(c)	Resonance Driven at a frequency equal/near the natural frequency of the wings [accept their answer to (a) as a numerical value] [for "driven" accept "forced/made to oscillate"]	(1) (1)	2

Q23.

Question Number	Acceptable answers	Additional guidance	Mark
	☐ 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

Q24.

Question Number	Acceptable answers	Additional guidance	Mark
	• 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)	Example of calculation $k = 0.55$ N / 0.07 m = 7.86 N m^{-1} $T = ½ = 0.5$ s $0.5\text{ s} = 2\pi\sqrt{\frac{m}{7.86\text{ N m}^{-1}}}$ $m = 0.050$ 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

Q25.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)(i)	• no net force on bridge (1) • no net moment of force about any point (1)	Alternative wording that implies these 2 points will be accepted	**(2)**
(a)(ii)	• use of $W = mg$ to find the weight of the bridge (1) • use of moment = $F\,x$ (1) • applies principle of moments (1) • $F_A = 43610$ N (1) • applies equilibrium of forces or applies principle of moments about a different point to obtain $F_B = 45990$ N (1)	Example of calculation: W = mg = 8500 kg × 9.8 N kg^{-1}= 83300 N Taking moments about A, Clockwise moments = (1500 N × 4 m) + (4800 N × 6.5 m) + (83300 N × 9.5 m) Anticlockwise moments = F_A × 19 m 19 N × F_A = 828550 Nm F_A = 828550 Nm/19 m = 43610 N $F_A + F_B$ = 1500 N + 4800 N + 83300 N F_B = 89600 N − 43610 N = 45990 N	**(5)**

Question Number	Acceptable Answer		Additional Guidance	Mark
(b)(i)	• resonance occurs when the bridge is forced into oscillation at its natural frequency • this results in an increasing amplitude of oscillation of the bridge, which may damage the bridge	(1) (1)		**(2)**
(b)(ii)	• energy was transferred from the oscillating bridge to the dampers • this energy was dissipated in the dampers (and not returned to the bridge) • hence the amplitude of oscillation was kept small	(1) (1) (1)		**(3)**
(b)(iii)	• as the viscosity of the fluid increased the fluid would offer greater resistance to movement [accept reverse argument] • a greater resistance to movement would result in a greater energy dissipation	(1) (1)		**(2)**

Q26.

Question Number	Answer	Mark
	B	1

Q27.

Question Number	Answer	Mark
	C	1

Q28.

Question Number	Acceptable Answer		Additional Guidance	Mark
(i)	• Ignoring mass of holder / spring when determining the oscillating mass	(1)		1
(ii)	• Using a data logger (and light gate) would eliminate reaction time • So the uncertainty in the measurement (of the time) would be reduced • Not easy to measure timings for multiple swings/oscillations with a data logger	(1) (1) (1)		3
(iii)	• Identify gradient as $\frac{4\pi^2}{k}$ • Determine gradient of graph • $k = 17.8\ \text{N m}^{-1}$ [17.5 → 18.5]	(1) (1) (1)	Example of calculation Gradient = $2.21\ \text{s}^2\ \text{kg}^{-1}$ $k = \frac{4\pi^2}{2.21\ \text{s}^2\ \text{kg}^{-1}}$ $= 17.8\ \text{N m}^{-1}$	3

Q29.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• Timing a large number of oscillations minimised the percentage uncertainty in the measurement • Repeating each timing measurement and calculating a mean minimised the effect of random errors • Taking a repeat measurement allowed a check for gross timing errors.	(1) (1) (1)		3

Q30.

Question Number	Answer	Mark
	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. A the initial gradient is not zero C the initial gradient is not zero D the velocity in the first quarter cycle is decreasing	1