IB · DP · Physics

3 hours 14 questions

Structured Questions

9.1 Simple Harmonic Motion

9.1.1 The Defining Equation of SHM / 9.1.2 Energy Changes in SHM / 9.1.3 Calculating Energy Changes in SHM / 9.1.4 Examples of SHM

Easy (5 questions)	/67
Medium (5 questions)	/55
Hard (4 questions)	/37
Total Marks	**/159**

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Easy Questions

1 (a) State what is meant by the time period of an oscillation.

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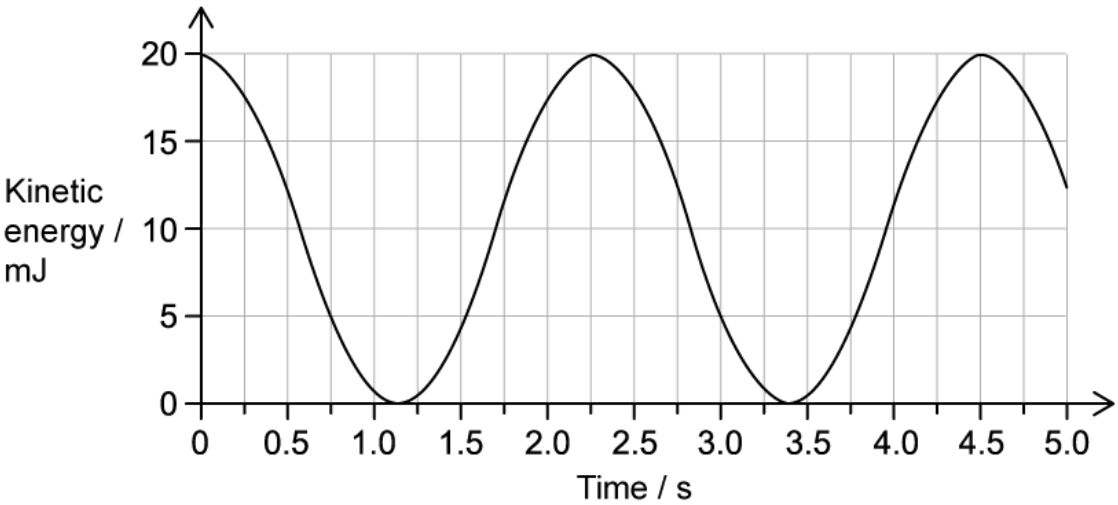
(1 mark)

(b) A small metal pendulum bob is suspended from a fixed point by a thread with negligible mass. Air resistance is also negligible.

The pendulum begins to oscillate from rest. Assume that the motion of the system is simple harmonic, and in one vertical plane. The graph shows the variation of kinetic energy of the pendulum bob with time.



Determine the time period of the pendulum.

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(1 mark)

(c) Label a point X on the graph where the pendulum is in equilibrium.

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(1 mark)

(d) The mass of the pendulum bob is 60×10^{-3} kg.

(i) Determine the maximum kinetic energy of the pendulum bob.

[1]

(ii) Hence or otherwise, show that the maximum speed of the bob is about 0.82 m s^{-1}.

[3]

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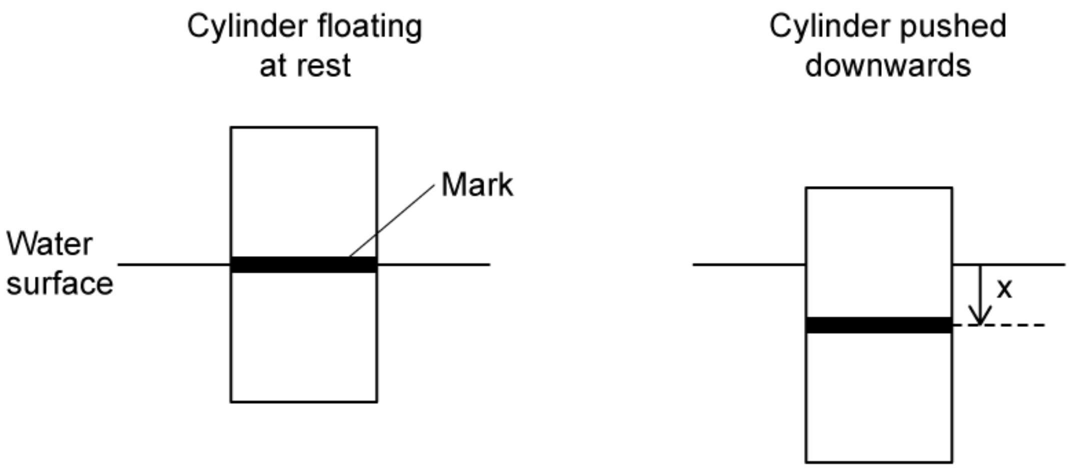
(4 marks)

2 (a) A solid vertical cylinder of uniform cross-sectional area A floats in water. The cylinder is partially submerged. When the cylinder floats at rest, a mark is aligned with the water surface. The cylinder is pushed vertically downwards so that the mark is a distance x below the water surface.



The cylinder is released at time $t = 0$. The resultant force on the cylinder is related to the displacement x by:

$$F = kx$$

(i) Define simple harmonic motion.

[2]

(ii) Outline why the cylinder performs simple harmonic motion when released.

[2]

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(4 marks)

(b) The mass, m, of the cylinder is 100 kg and the value of k is 3000 kg s^{-2}.

(i) Define angular frequency.

[1]

(ii) Show that the equation from part (a) can be related to an expression for angular frequency to give $-\omega^2 m = k$.

[3]

(iii) Hence, show that the angular frequency, ω of oscillation of the cylinder is 5.5 rad s^{-1}.

[2]

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(6 marks)

(c) The cylinder was initially pushed down by a displacement $x = 0.15$ m.

(i) Determine the force applied to the cylinder.

[1]

(ii) Determine the maximum kinetic energy E_{kmax} of the cylinder.

[3]

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(4 marks)

(d) Draw, on the axes below, the graph to show how the kinetic energy of the cylinder varies with time during one period of oscillation T.

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(2 marks)

3 (a) A vibrating guitar string is an example of an object oscillating with simple harmonic motion.

Give three other real-world examples of objects that oscillate with simple harmonic motion.

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(3 marks)

(b) The guitar string vibrates with simple harmonic oscillations at a frequency of 225 Hz.

Determine the time it takes to perform 15 complete oscillations.

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(3 marks)

(c) The amplitude of the oscillation is 0.4 mm.

Determine the maximum acceleration of the guitar string.

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(4 marks)

(d) Calculate the total energy in the string during this oscillation, given that the mass of the string is 3.3 g.

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(3 marks)

4 (a) The defining equation of simple harmonic motion is:

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

(i) Define each variable and give an appropriate unit for each.

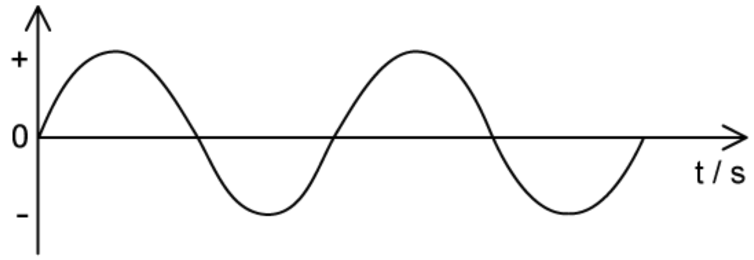
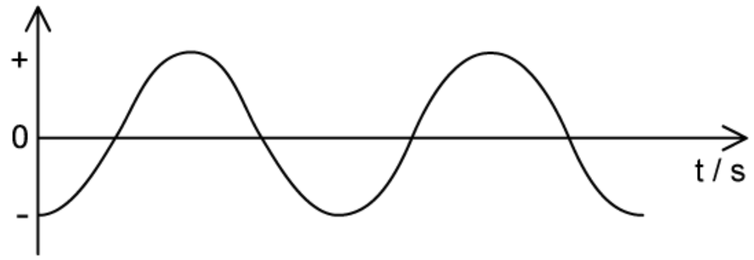
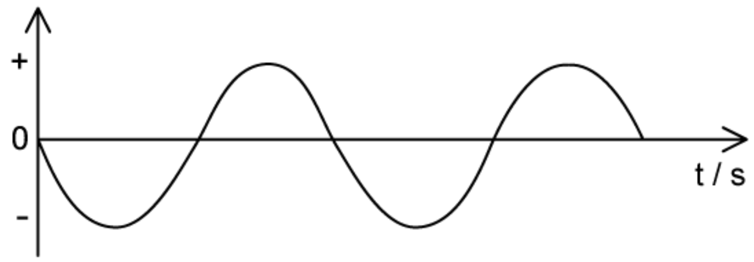
[3]

(ii) State the significance of the minus sign.

[1]

(4 marks)

(b) A mass on a spring begins oscillating from its equilibrium position. Time, t = 0 s is measured from where the mass begins moving in the negative direction. The motion of the oscillation is shown in the graphs below.

<table>
<tr><th>Graph</th><th>Variable on y-axis</th></tr>
<tr><td>
</td><td>Acceleration</td></tr>
<tr><td>
</td><td></td></tr>
<tr><td>
</td><td></td></tr>
</table>

Complete the table to show the correct variable on the *y*-axis of each graph.

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(3 marks)

(c) The period of the oscillation T = 1.84 s and the mass is 55 g. The mass-spring system oscillates with an amplitude of 5.2 cm.

Calculate the spring constant of the spring.

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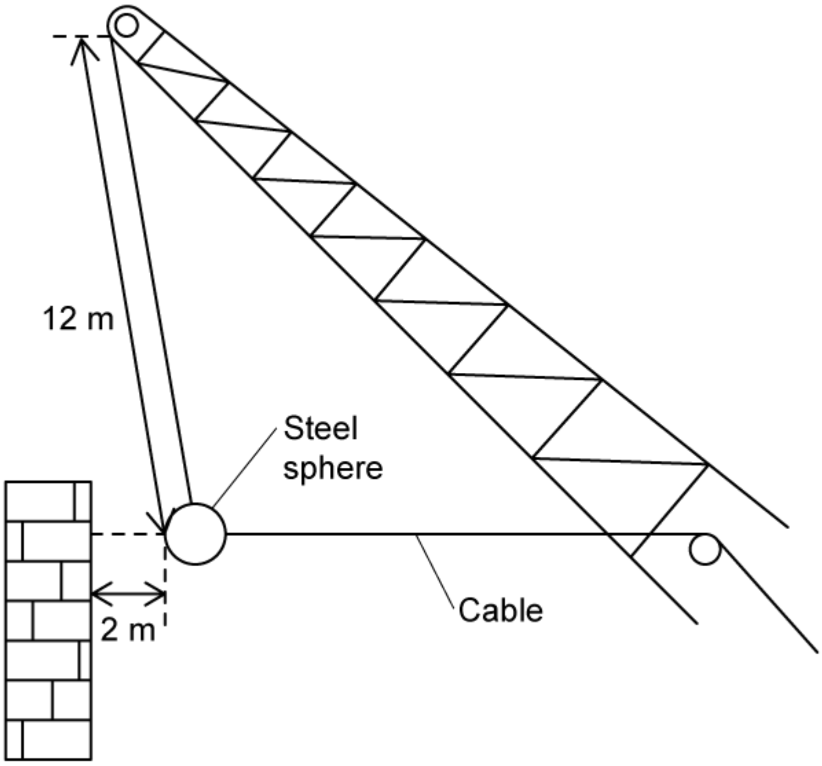
(3 marks)

(d) Determine the magnitude of the displacement of the mass at t = 1.2 s.

(4 marks)

5 (a) The diagram below shows a system used for demolishing buildings.



A 2750 kg steel sphere is suspended by a steel cable of length 12 m. The steel sphere is pulled 2 m to the side by another cable and then released.

When the wall is not in the way, the system performs simple harmonic motion.

Calculate the frequency of the oscillation.

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(4 marks)

(b) When the steel sphere hits the wall, the suspension cable is vertical.

Calculate the speed of the steel sphere when it hits the wall.

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(4 marks)

(c) Calculate the kinetic energy of the steel sphere as it hits the wall. Give your answer to an appropriate amount of significant figures.

(5 marks)

(d) Complete the following sentences using appropriate words to describe the effect on the kinetic energy of the sphere when doubling its mass and displacement.

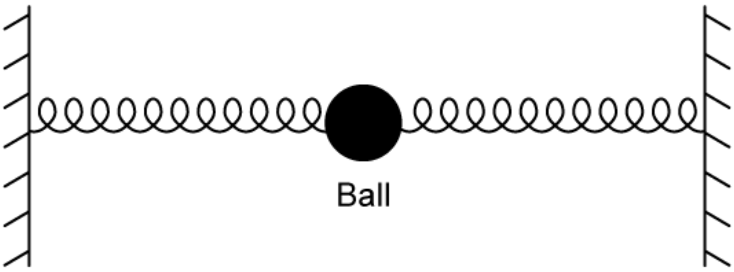
Doubling the mass of the steel sphere would cause the kinetic energy to __________ by a factor of ________. This is because kinetic energy is proportional to _________________.

Doubling the displacement of the steel sphere would cause the kinetic energy to __________ by a factor of ________. This is because the kinetic energy is proportional to ___________________.

(4 marks)

Medium Questions

1 (a) A ball within a ball-spring system oscillates about an equilibrium point.



Outline how the ball-spring system demonstrates simple harmonic motion.

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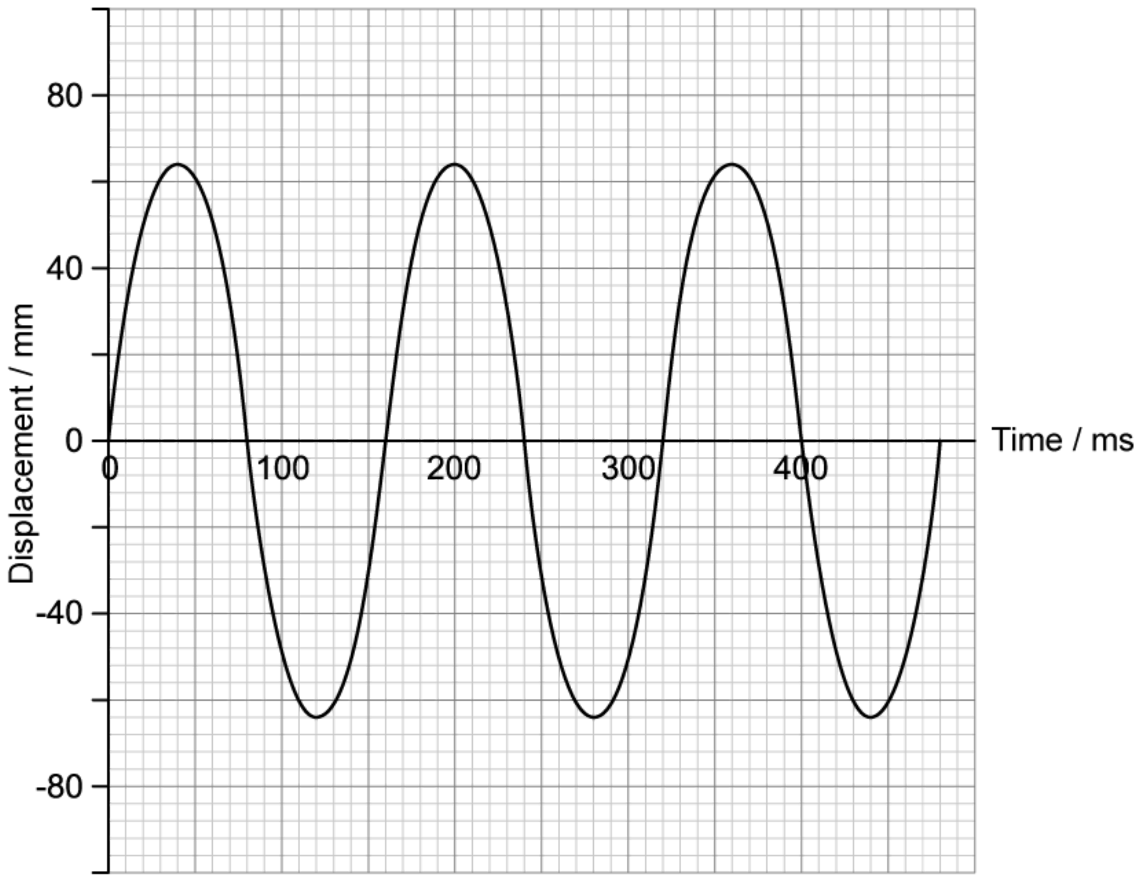
(2 marks)

(b) The ball is oscillating in simple harmonic motion. The graph shows the displacement of the ball over time.



Determine the maximum velocity of the ball.

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(2 marks)

(c) For the motion of the ball

(i) Show that the acceleration of the ball at 90 ms is 43 m s^{-2}.

[2]

(ii) On the graph, mark an X at a point where the resultant force acting on the ball is zero.

[1]

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(3 marks)

(d) On the axes provided, taking the oscillation as beginning at the positive amplitude when t = 0, sketch for the ball's motion:

(i) The variation of displacement with time, label this graph x

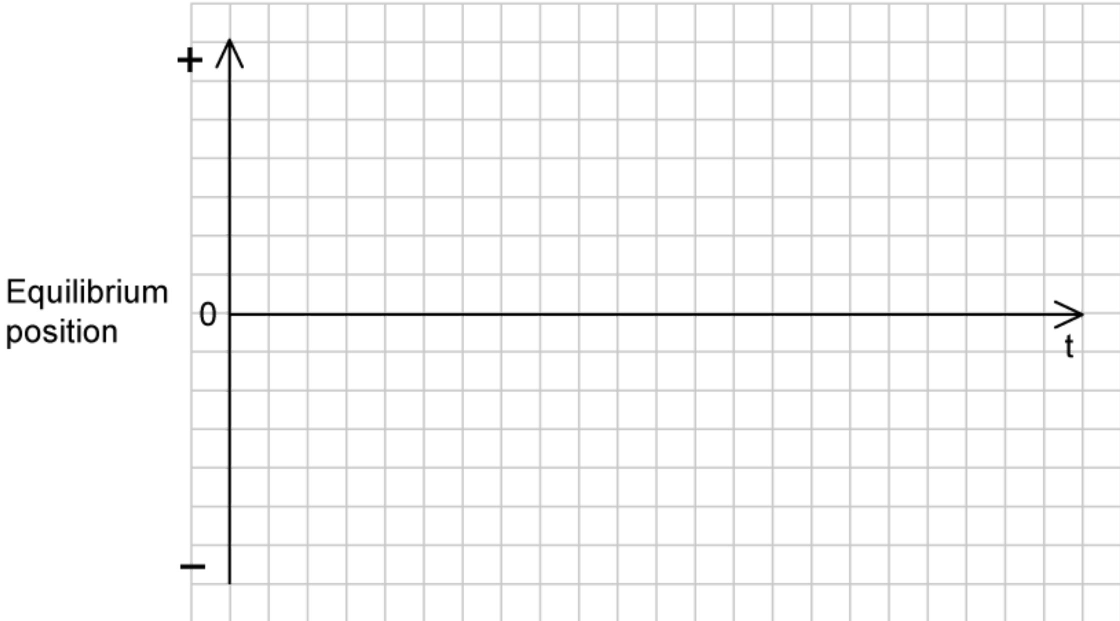
[1]

(ii) The variation of velocity with time, label this graph v

[1]

(iii) The variation of acceleration with time, label this graph a

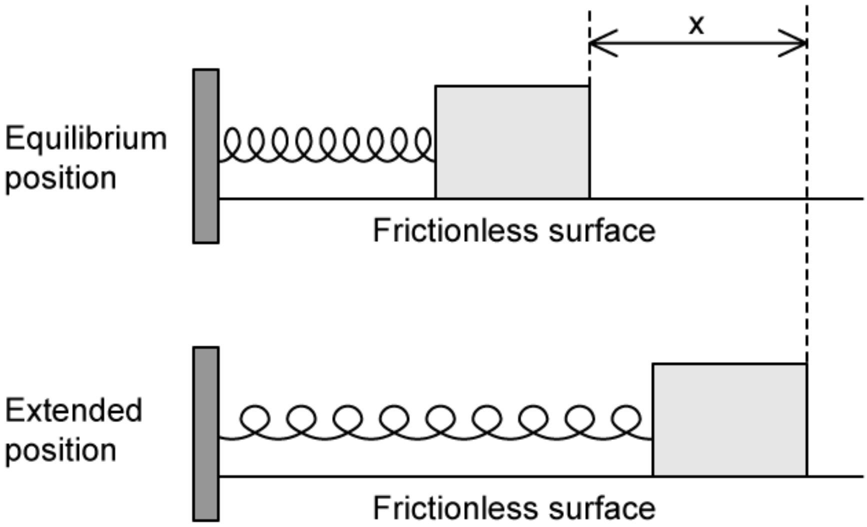
[1]



(3 marks)

A mass of 45 g on a spring undergoes simple harmonic motion with a period of 0.84 s. A wooden block attached to the same spring undergoes simple harmonic motion with a period of 0.64 s. The wooden block is displaced horizontally by 3.6 cm from the equilibrium position on a frictionless surface.

2 (a)



Determine the total energy in the oscillation of the wooden block.

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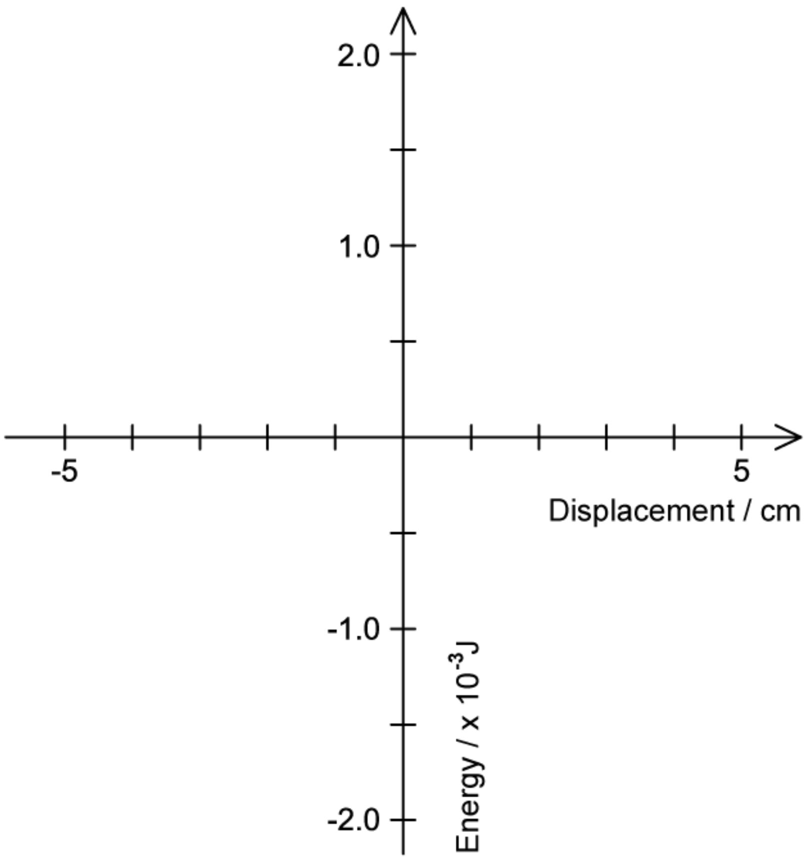
(4 marks)

(b) Using the information from part (a), sketch on the axes the kinetic, potential, and total energies of the oscillating wooden block as they vary with displacement.



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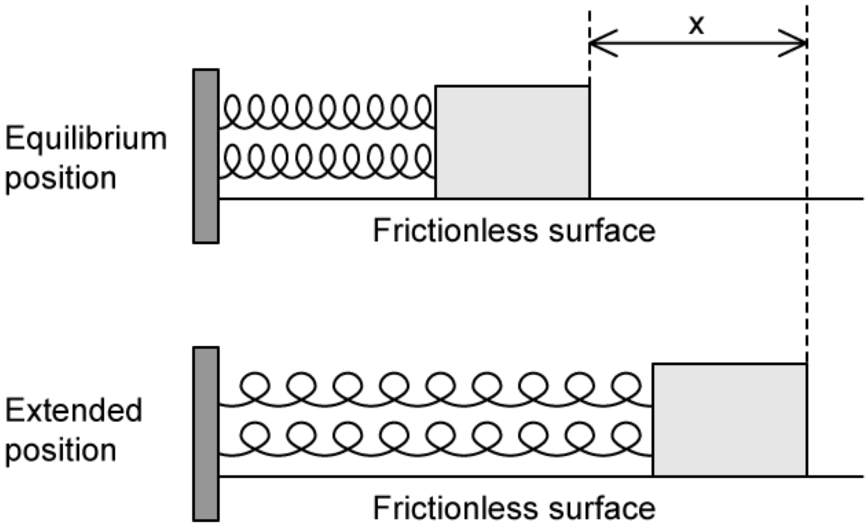
(3 marks)

(c) The investigation from part (a) is repeated. The same wooden block and spring are used, but a second identical spring is added in parallel.



Suggest how this change will affect the fractional uncertainty in the mass of the wooden block.

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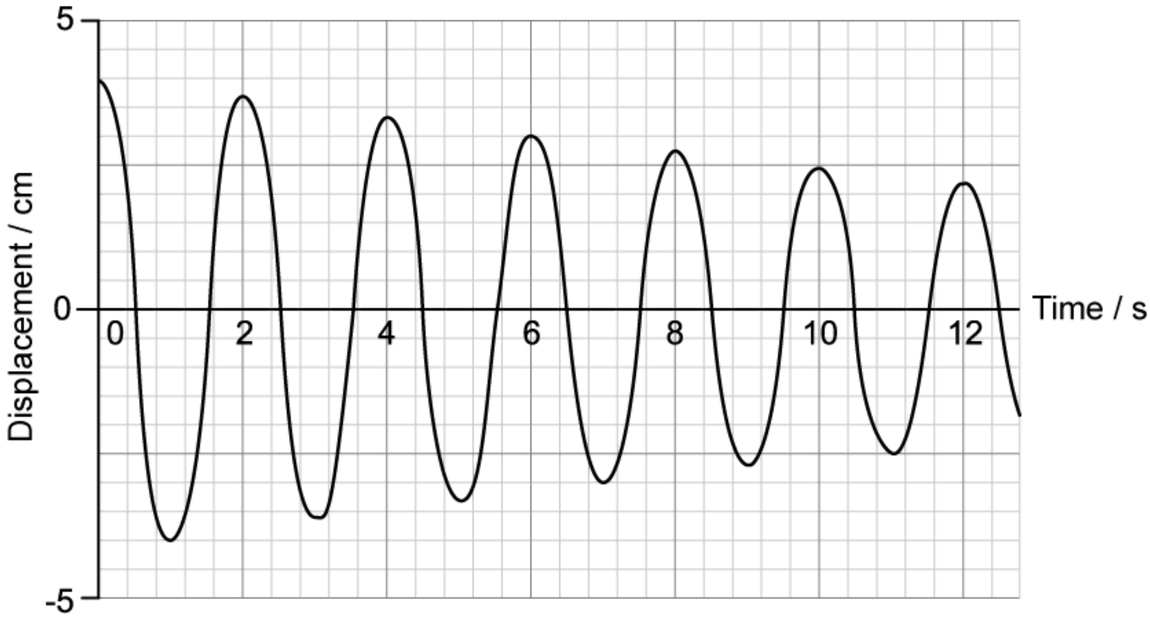
(3 marks)

(d) The spring from part (a) is attached to the mass in part (a), and oscillates freely in simple harmonic motion.

The graph shows the variation of displacement with time *t* of the mass on the spring.



For the new mass-spring system

(i) Describe the motion of the mass on the spring.

[1]

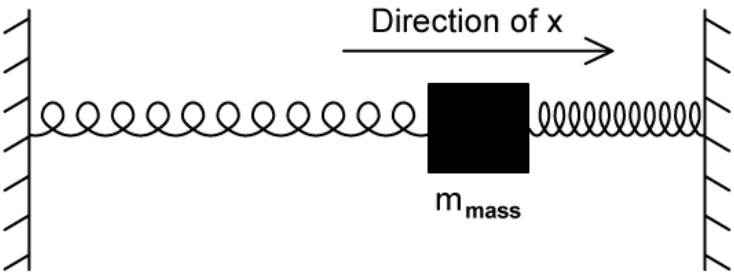
(ii) Determine the initial energy of the mass-spring system.

[2]

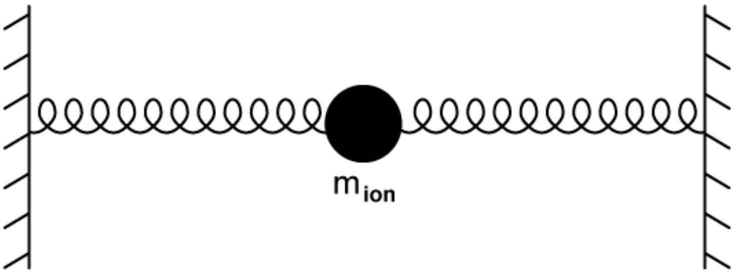
(3 marks)

3 (a) A mass of 75 g is connected between two identical springs. The mass-spring system rests on a frictionless surface. A force of 0.025 N is needed to compress or extend the spring by 1.0 mm.

The mass is pulled from its equilibrium position to the right by 0.055 m and then released. The mass oscillates about the equilibrium position in simple harmonic motion.



The mass-spring system can be used to model the motion of an ion in a crystal lattice structure.



The frequency of the oscillation of the ion is 8×10^{12} Hz and the mass of the ion is 6×10^{-26} kg. The amplitude of the vibration of the ion is 2×10^{-11} m.

For the oscillations

(i) Calculate the acceleration of the mass at the moment of release. [1]

(ii) Estimate the maximum kinetic energy of the ion.

[1]

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(2 marks)

(b) For the mass-spring system

(i) Calculate the total energy of the system.

[1]

(ii) Use the axes to sketch a graph showing the variation over time of the kinetic energy of the mass and the potential energy of the springs.

You should include appropriate values, and show the oscillation over one full period.

[2]

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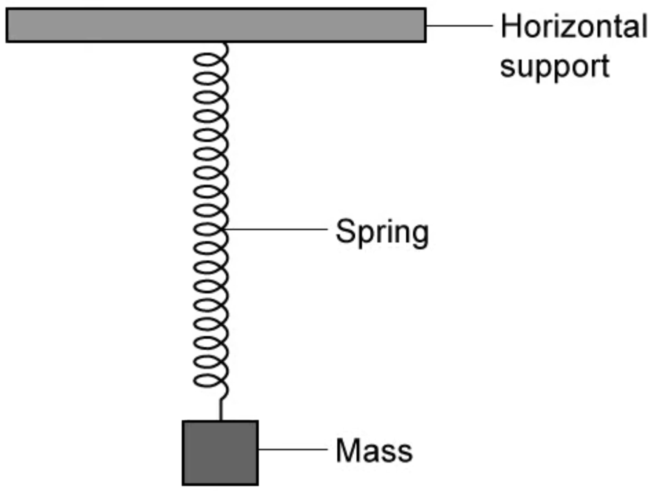
(3 marks)

(c) The same mass and a single spring from part (a) are attached to a rigid horizontal support.



The length of the spring with the mass attached is 64 mm. The mass is pulled downwards until the length of the spring is 76 mm. The mass is released, and the vertical mass-spring system performs simple harmonic motion.

For the new mass-spring system

(i) Determine the velocity of the mass 2 seconds after its release.

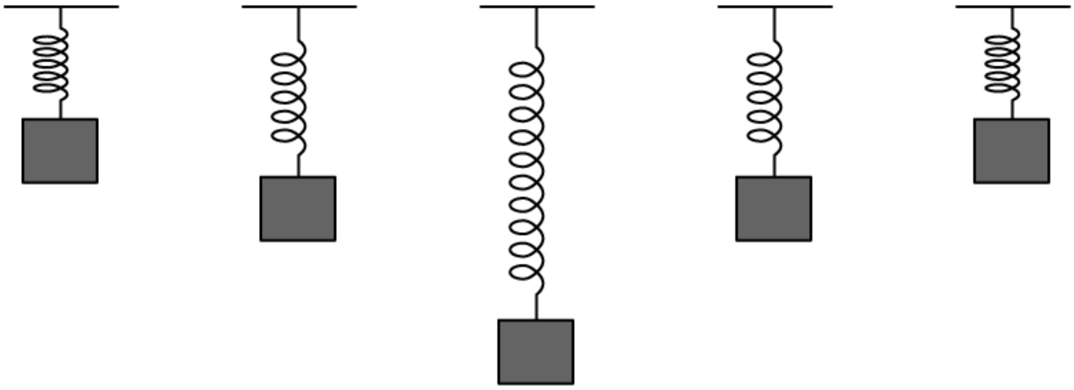
[1]

(ii) Determine the kinetic energy of the mass at this point.

[2]

(3 marks)

(d) The diagram shows the vertical spring-mass system as it moves through one period.



Annotate the diagram to show when:

E_p = max

E_k = max

v = 0

v = max

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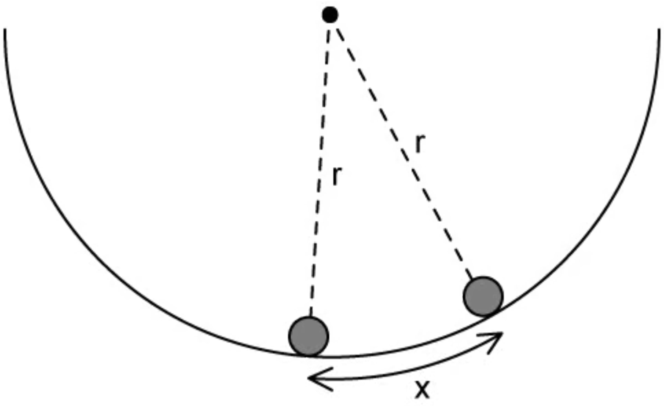
(2 marks)

4 (a) A ball is displaced through a small distance *x* from the bottom of a bowl and then released.



The frequency of the resulting oscillation is 1.5 Hz and the maximum velocity reaches 0.36 m s^{-1}. *r* is the radius of the bowl.

For the oscillating ball:

(i) Show that the radius of the bowl in which it oscillates is approximately 11 cm.

[1]

(ii) Calculate the amplitude of oscillation.

[1]

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(2 marks)

(b) For the ball

(i) Calculate the time taken for the displacement to fall to 0.01 m after it is released.

[2]

(ii) Determine the acceleration at 0.2 s after it is released.

[1]

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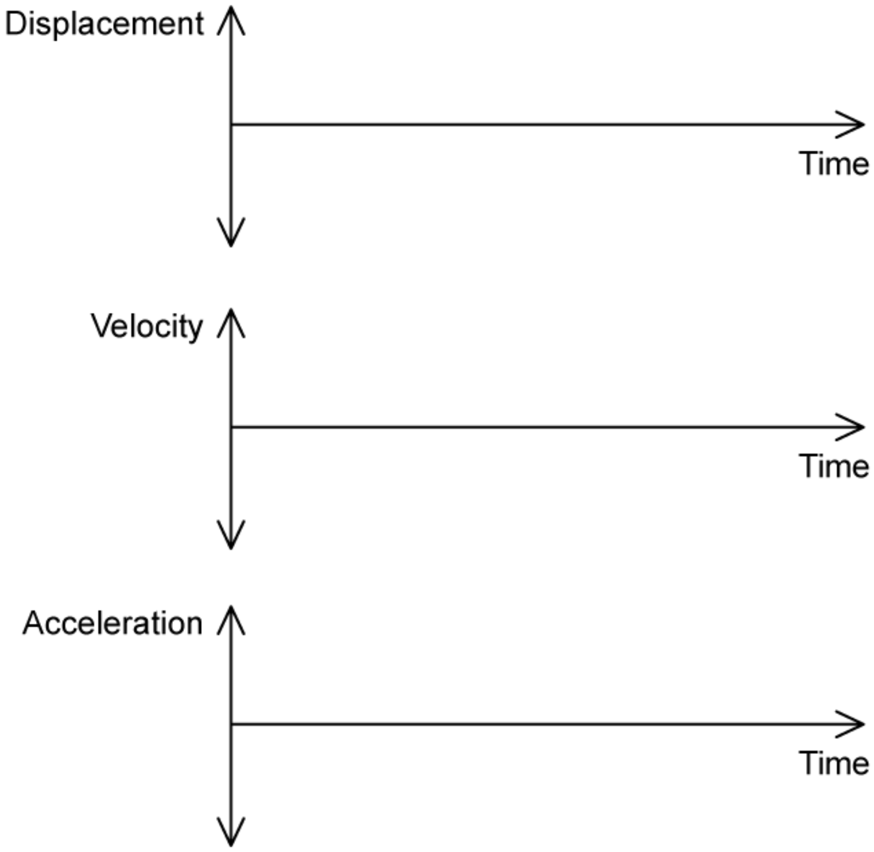
(3 marks)

(c) Sketch the graphs showing how the displacement, velocity and acceleration of the ball vary with time. You should include any relevant values.



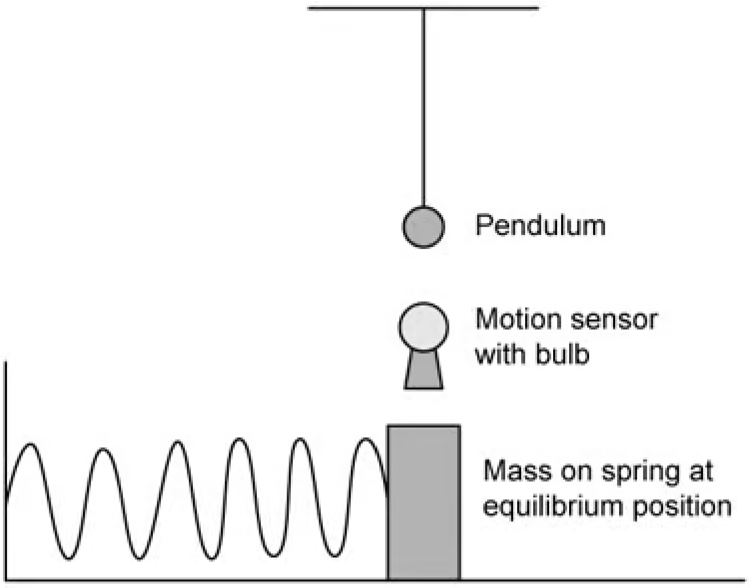
(4 marks)

(d) The ball was replaced by a ball of the same size, but with a greater mass.

Outline what effect this would have on the period of the oscillation.

(2 marks)

5 (a) An experiment is carried out on Planet Z using a simple pendulum and a mass-spring system. The block moves horizontally on a frictionless surface. A motion sensor is placed above the equilibrium position of the block which lights up every time the block passes it.



The pendulum and the block are displaced from their equilibrium positions and oscillate with simple harmonic motion. The pendulum bob completes 150 full oscillations in seven minutes and the bulb lights up once every 0.70 seconds. The block has a mass of 349 g.

Show that the value of the spring constant *k* is approximately 7 N m^{-1}.

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(2 marks)

(b) The volume of Planet Z is the same as the volume of Earth, but Planet Z is twice as dense.

For the experiment on Planet Z

(i) Show that the length of the pendulum, $l = \frac{4mg}{k}$

[2]

(ii) Calculate the value of l.

[2]

(4 marks)

(c) The angle that the pendulum string makes with the horizontal is 81.4 ° when the acceleration of the pendulum bob is at a maximum.

Determine the maximum speed reached my the pendulum bob.

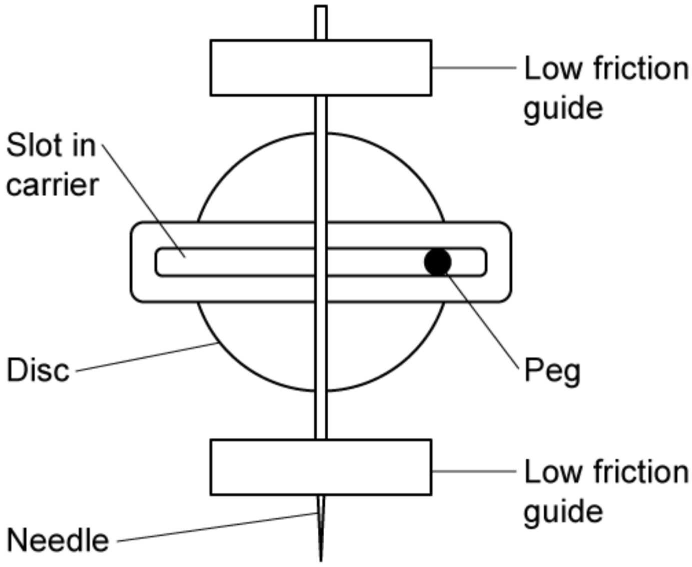
(3 marks)

(d) Compare and contrast how performing the experiment on Planet Z, rather than on Earth, affects the period of the oscillations of the pendulum and the mass-spring system.

(2 marks)

Hard Questions

1 (a) The needle carrier of a sewing machine moves with simple harmonic motion. The needle carrier is constrained to move on a vertical line by low friction guides, whilst the disk and peg rotate in a circle. As the disk completes one oscillation, the needle completes one stitch.



The sewing machine completes 840 stitches in one minute. Calculate the angular speed of the peg.

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(2 marks)

(b) The needle carrier has a mass of 23.9 g, and the needle has a mass of 0.7 g. The needle moves a distance of 36 mm between its extremities of movement.

Assuming that the fabric requires a negligible force for the needle to penetrate it:

(i) Calculate the maximum speed of the needle.

[1]

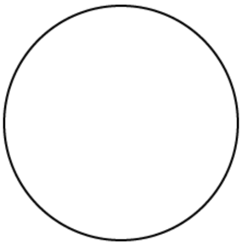
(ii) Determine the kinetic energy of the needle at this point.

[1]

(2 marks)

(c) For the needle-carrier system:

(i) Label, on the diagram, the position of the peg at the point of maximum velocity, and the point of maximum contact force of the peg on the slot.



Disc front view

[2]

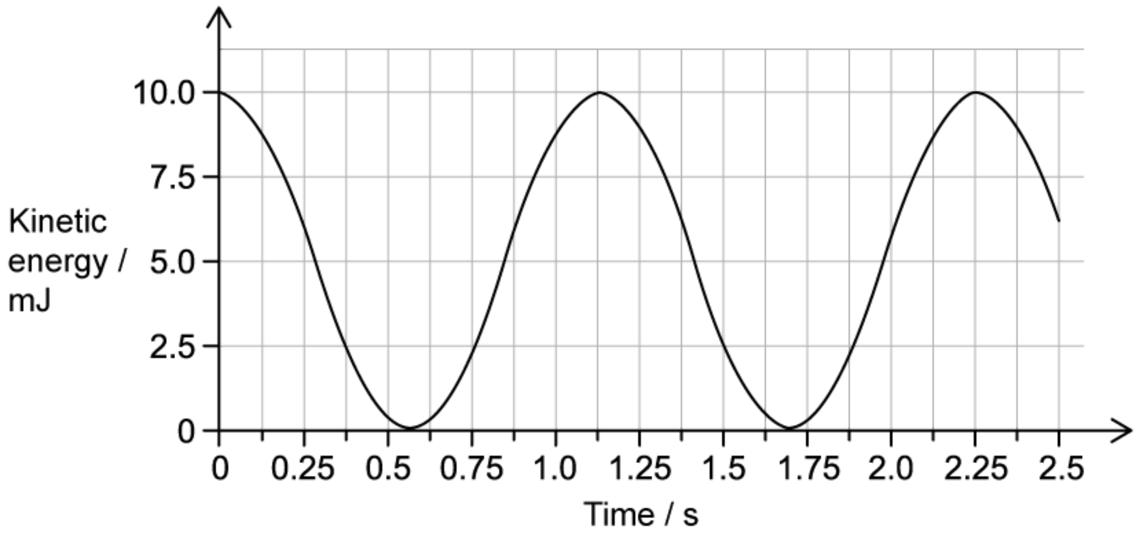
(ii) Calculate the maximum force acting on the peg by the slot.

[1]

(1 mark)

2 (a) A metal pendulum bob of mass 7.5 g is suspended from a fixed point by a length of thread with negligible mass. The pendulum is set in motion and oscillates with simple harmonic motion.

The graph shows the kinetic energy of the bob as a function of time.



Calculate the length of the thread.

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(2 marks)

(b) For the simple pendulum:

(i) Label the graph from part a with an A at the point where the restoring force is acting at a maximum.

[1]

(ii) Label the graph from part a with a B at the point where the speed of the pendulum is half of its initial speed.

[1]

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(2 marks)

(c) Show that the amplitude of the oscillation is around 0.6 m.

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(2 marks)

(d) An IB Physics class was discussing this experiment.

A student in the class said that increasing the mass of the pendulum bob would increase the period of the oscillation because increasing the mass would increase the inertia of the bob.

The teacher said the student was incorrect.

Discuss the teachers comments.

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(6 marks)

3 (a) A steel spring with an unstretched length of 33 cm is attached to a fixed point and a mass of 35 g is attached and gently lowered until equilibrium is reached and the spring has a length of 37.5 cm. The spring is then stretched elastically to a length of 42 cm and released.

Design a plan to investigate if the oscillation is simple harmonic motion.

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(5 marks)

(b) For the stretching of the spring:

(i) Calculate the gravitational potential energy lost by the mass. [1]

(ii) Determine the elastic potential energy gained by the spring. [2]

(iii) Explain why the two answers are different. [1]

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(4 marks)

(c) For the simple harmonic oscillation:

(i) Determine the resultant force acting on the load at the lowest point of its movement.

[2]

(ii) Calculate the maximum speed of the mass.

[2]

(4 marks)

4 (a) A student with mass 68 kg hangs from a bungee cord with a spring constant, k = 270 N m^{-1}. The student is pulled down to a point where the cord is 4.0 m longer than its unstretched length, and then released. The student oscillates with SHM.

For the student:

(i) Determine their position 15.7 s after being released.

[3]

(ii) Calculate their velocity 15.7 s after being released.

[1]

(iii) Explain where in the oscillation the student is at 15.7 s after being released. You may want to include a sketch diagram to aid your explanation.

[2]

(6 marks)

(b) A second student wants to do the bungee jump, however, they would like a greater number of bounces in their five minute session.

Evaluate the possibilities for facilitating the student's wishes.

(1 mark)