Oscillations

1. A simple harmonic oscillator has maximum speed 24 m s^{-1} and amplitude 5.6 cm.

What is its angular frequency?

A 0.23 rad s^{-1}
B 21 rad s^{-1}
C 68 rad s^{-1}
D 430 rad s^{-1}

Your answer [1]

2. A pendulum is oscillating in air and experiences damping.

Which of the following statements is/are correct for the damping force acting on the pendulum?

1 It is always opposite in direction to acceleration.
2 It is always opposite in direction to velocity.
3 It is maximum when the displacement is zero.

A Only 1 and 2
B Only 2 and 3
C Only 3
D 1, 2 and 3

Your answer [1]

3. Which quantity has the unit hertz (Hz)?

A frequency
B acceleration
C phase difference
D angular frequency

Your answer [1]

4. Oscillations of an object can either be **free** or **forced**.

Which of the following is an example of a **forced** oscillation?

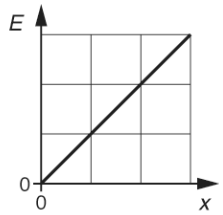
A A ball rolling to-and-fro on a curved track.
B A loudspeaker oscillating and producing a continuous note.
C A mass oscillating from the end of a suspended spring.
D A pendulum bob oscillating from the end of a fixed length of string.

Your answer ☐ **[1]**

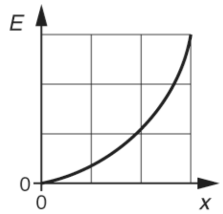
5. An object oscillates with simple harmonic motion.

Which graph **best** shows the variation of its potential energy E with distance x from the equilibrium position?

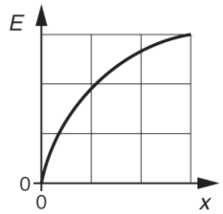
A



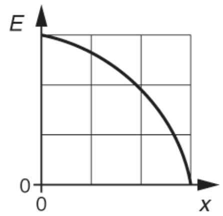
B



C



D



Your answer ☐ **[1]**

6. For a simple harmonic oscillator, the maximum speed is vmax when the amplitude is *A*. The frequency of the oscillations is *f*.

Which expression is correct for this oscillator?

A $v_{max} = fA$
B $v_{max} = 2\pi fA$
C $v_{max} = f^2A$
D $v_{max} = 4\pi^2 f^2 A$

Your answer ☐ **[1]**

7. The acceleration *a* of a simple harmonic oscillator is related to its displacement *x* by the equation

$$a = -25x.$$

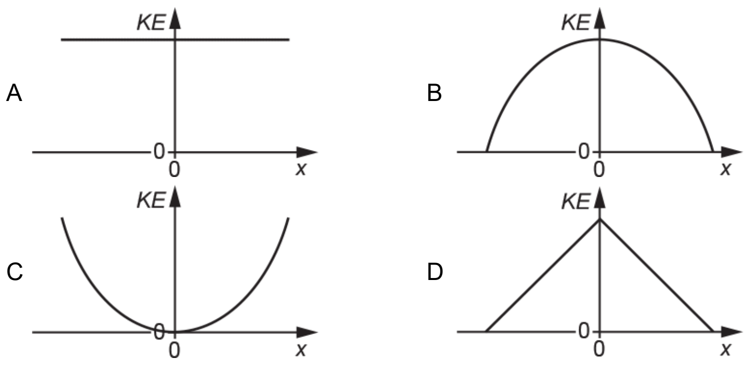
What is the frequency of the oscillator?

A 0.80 Hz
B 1.3 Hz
C 4.0 Hz
D 5.0 Hz

Your answer ☐ **[1]**

8. An oscillator is executing simple harmonic motion.

Which graph of kinetic energy *KE* against displacement *x* is correct for this oscillator?



Your answer ☐ **[1]**

9. An oscillator is in simple harmonic motion.

Which statement is **not** correct?

A The acceleration is directly proportional to the displacement.
B The acceleration is zero at maximum displacement.
C The maximum velocity is at zero displacement.
D The kinetic energy is zero at maximum displacement.

Your answer

[1]

10. The motion of an oscillator is simple harmonic.

Which statement is correct about the period of the oscillator?

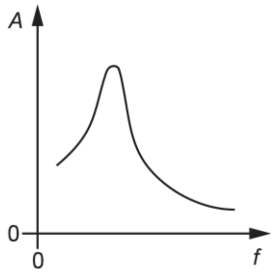
The period …

A. is independent of the amplitude.
B. depends on the displacement of the oscillator.
C. is independent of the frequency of the oscillator.
D. depends on the force acting on the oscillator.

Your answer

[1]

11. An oscillator is forced to oscillate at different frequencies.
The graph of amplitude *A* against driving frequency *f* for this oscillator is shown.



The damping on the oscillator is now **decreased** .

Which of the following statements is / are correct?

1. The amplitude of the oscillations at any frequency decreases.
2. The maximum amplitude occurs at a lower frequency.
3. The peak on the graph becomes thinner.

A Only 1
B Only 2
C Only 3
D 1, 2 and 3

Your answer

[1]

12. The 500 m tall Taipei 101 tower is shown in Fig. 2.1. The tower has a massive sphere suspended across five floors near the top of the building to dampen down movement of the tower in high winds and earthquakes. The sphere is connected to pistons (not shown) which drive oil through small holes providing damping. The vibration energy of the sphere is converted to thermal energy.

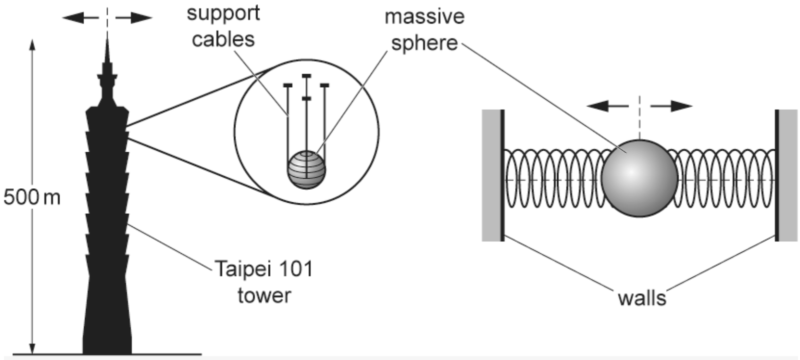


Fig. 2.1 **Fig. 2.2**

Fig. 2.2 models the damper system as the sphere held between two springs. The movement of the walls of the tower forces the sphere to oscillate in **simple harmonic motion**.

In the strongest wind, the natural frequency of the oscillations of the tower is 0.15 Hz and the maximum acceleration of the sphere is 0.050 m s^{-2}.

Explain why the natural frequency of the damper system must be about 0.15 Hz.

---

[2]

13(a). A stabilising mechanism for electrical equipment on board a high-speed train is modelled using a 5.0 g mass and two springs, as shown in **Fig. 21.1**. For testing purposes, the springs are horizontal and attached to two fixed supports in a laboratory.

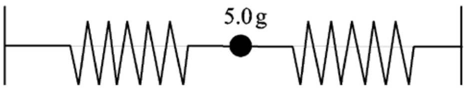


Fig. 21.1

Explain why the mass oscillates with simple harmonic motion when displaced horizontally.

---

[2]

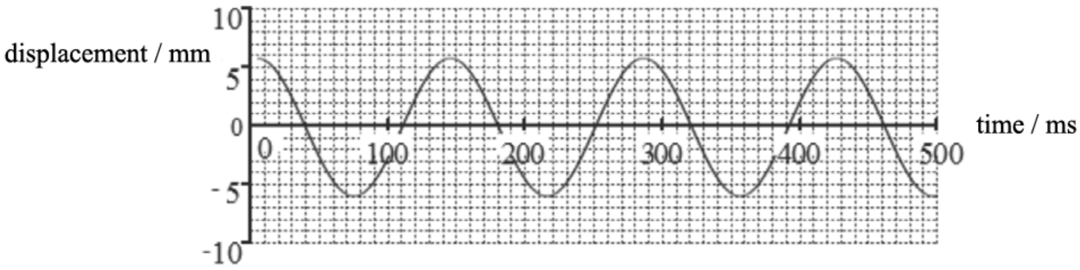


Fig. 21.2

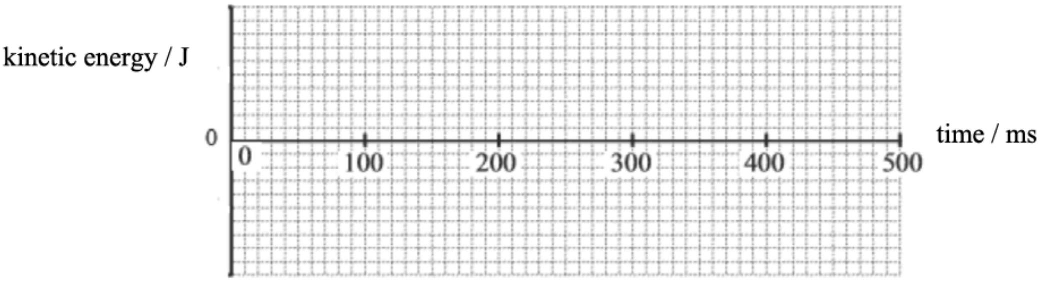


Fig. 21.3

(b). On **Fig. 21.3** sketch a graph showing the variation of kinetic energy with time. Add a scale to the kinetic energy axis.

[2]

(c). Fig. 21.2 shows the graph of displacement against time for the oscillating mass.

i. Determine the maximum acceleration of the mass during the oscillations.

maximum acceleration = ... ms^{-2} **[2]**

ii. Calculate the maximum kinetic energy of the mass during the oscillations.

maximum kinetic energy = ... J **[2]**

14. A mass is hung from the bottom end of a flexible spring.
Describe and explain how the mass can be made to show resonance.

-- **[2]**

15. The 500 m tall Taipei 101 tower is shown in Fig. 2.1. The tower has a massive sphere suspended across five floors near the top of the building to dampen down movement of the tower in high winds and earthquakes. The sphere is connected to pistons (not shown) which drive oil through small holes providing damping. The vibration energy of the sphere is converted to thermal energy.

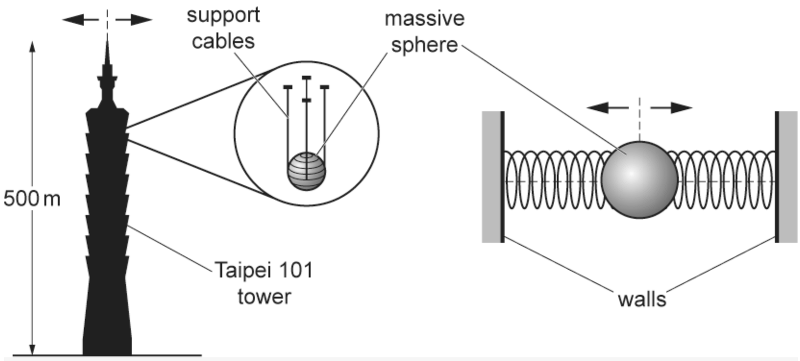


Fig. 2.1 **Fig. 2.2**

Fig. 2.2 models the damper system as the sphere held between two springs. The movement of the walls of the tower forces the sphere to oscillate in **simple harmonic motion**.

In the strongest wind, the natural frequency of the oscillations of the tower is 0.15 Hz and the maximum acceleration of the sphere is 0.050 m s^{-2}.

Calculate the maximum displacement of the sphere in the strongest wind.

maximum displacement = -- m **[3]**

16. This question is about investigations involving an electromagnetic wave.

A vertical transmitter aerial emits a **vertically polarised** electromagnetic wave which travels towards a vertical receiver aerial. The wavelength of the wave is 0.60 m.

Fig. 5.1 shows a short section of the oscillating electric field of the electromagnetic wave.

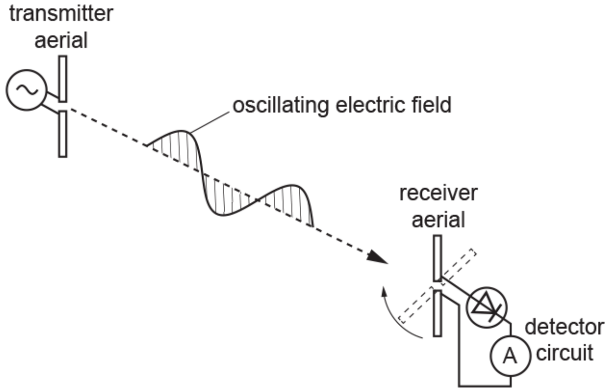


Fig. 5.1

The electromagnetic wave is caused by electrons oscillating in the transmitter aerial. Each electron oscillates with simple harmonic motion.

Calculate the maximum acceleration a_{max} of an electron which oscillates with an amplitude of 4.0×10^{-6} m.

a_{max} = ... m s^{-2} **[3]**

17. This question is about a simple pendulum made from a length of string attached to a mass (bob). For oscillations of small amplitude, the acceleration *a* of the pendulum bob is related to its displacement *x* by the expression

$$a = -\left(\frac{g}{L}\right)x$$

where *g* is the acceleration of free fall and *L* is the length of the pendulum.
The pendulum bob oscillates with simple harmonic motion.

A student conducts an experiment in the laboratory to investigate the small amplitude oscillations of a pendulum of a mechanical clock. Each 'tick' of the clock corresponds to **half** a period.

i. Show that the length of the pendulum required for a tick of 1.0 s is about 1 m.

[2]

ii. If the pendulum clock were to be used on the Moon, explain whether this clock would run on time compared with an identical clock on the Earth.

[2]

18. Fig. 21.2 shows the displacement *x* against time *t* graph of an oscillator damped in air.

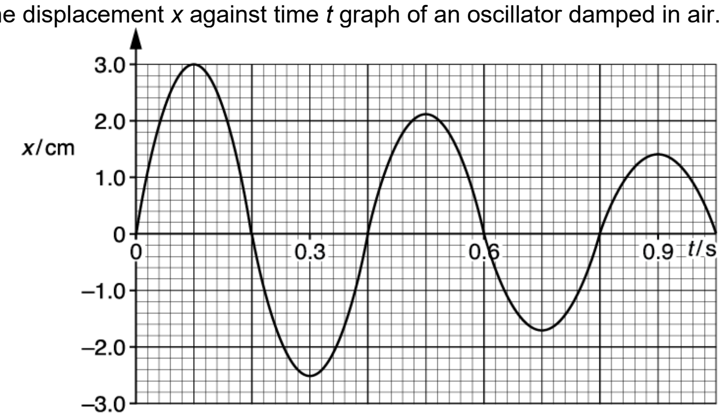


Fig. 21.2

i. According to a student, the amplitude of the oscillator decays by the same fraction every half oscillation. Analyse Fig. 21.2 to assess whether or not the student is correct.

[2]

ii. State and explain at which time the oscillator dissipates **maximum** energy.

[2]

19. A mass hanging from a vertical spring is pulled down.
It is then released from rest at time $t = 0$.
The mass oscillates vertically in a **vacuum** with simple harmonic motion about the equilibrium position. The spring is in tension at all times.

Fig. 18.1 shows the position of the mass at $t = 0$.

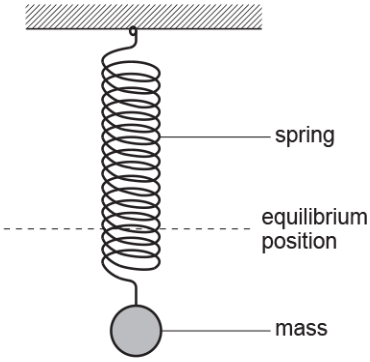


Fig. 18.1

At time $t = 6.5$ s the magnitude of the acceleration a of the mass is 3.6 m s^{-2} and its displacement x is 4.6×10^{-2} m.

The mass-spring system shown in Fig. 18.1 is now made to oscillate in **air**.

Different types of energy are involved in the oscillations of this mass-spring system.

Describe the energy changes that will take place as the mass moves from the lowest point in its motion through the equilibrium position to the highest point in its motion.

----

[4]

20. A stabilising mechanism for electrical equipment on board a high-speed train is modelled using a 5.0 g mass and two springs, as shown in **Fig. 21.1**. For testing purposes, the springs are horizontal and attached to two fixed supports in a laboratory.

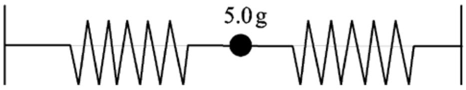


Fig. 21.1

Plan how you can obtain experimentally the displacement against time graph for the oscillating mass in the laboratory. Include any steps taken to ensure the graph is an accurate representation of the motion.

----

[4]

21. Civil engineers are designing a floating platform to be used at sea. **Fig. 4.1** shows a model for one section of this platform, a sealed metal tube of uniform cross-sectional area, loaded with small pieces of lead, floating upright in equilibrium in water.

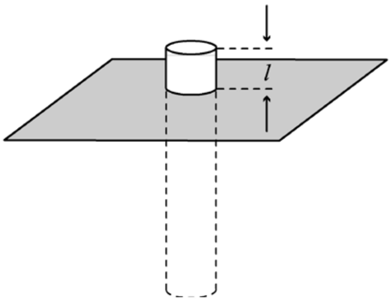


Fig. 4.1

When the tube is pushed down a small amount into the water and released it moves vertically up and down with simple harmonic motion. The period of these oscillations which quickly die away is about one second.

The oscillations of the tube can be maintained over a range of low frequencies by using a flexible link to a simple harmonic oscillator.

Fig. 4.2 shows a graph of amplitude of vertical oscillations of the tube against frequency obtained from this experiment.

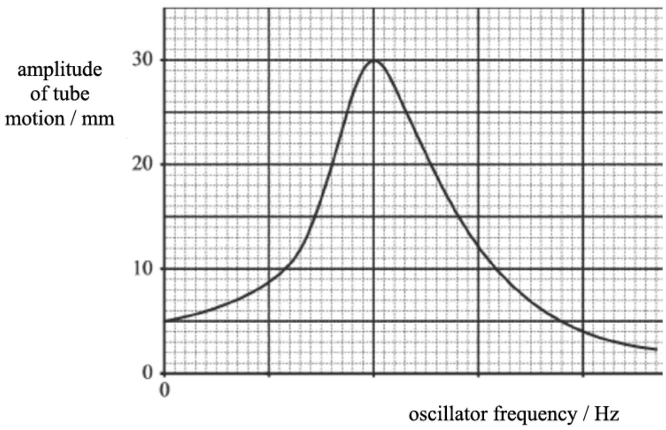


Fig. 4.2

i. Use information from **Fig. 4.2** to state the amplitude of the motion of the oscillator.

amplitude = ... mm **[1]**

ii. Add a suitable scale to the frequency axis of **Fig. 4.2**.

[1]

iii. The experiment is repeated in a much more viscous liquid such as motor oil.
On **Fig. 4.2** sketch the graph that you would predict from this experiment.

[2]

22. The 500 m tall Taipei 101 tower is shown in Fig. 2.1. The tower has a massive sphere suspended across five floors near the top of the building to dampen down movement of the tower in high winds and earthquakes. The sphere is connected to pistons (not shown) which drive oil through small holes providing damping. The vibration energy of the sphere is converted to thermal energy.

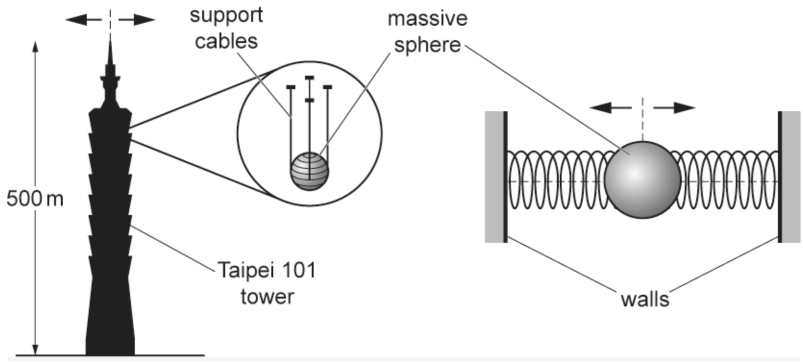


Fig. 2.1 **Fig. 2.2**

Fig. 2.2 models the damper system as the sphere held between two springs. The movement of the walls of the tower forces the sphere to oscillate in **simple harmonic motion**.

In the strongest wind, the natural frequency of the oscillations of the tower is 0.15 Hz and the maximum acceleration of the sphere is 0.050 m s^{-2}.

The acceleration a of the sphere is given by the equation

$$a = -\left(\frac{k}{m}\right)x$$

where k is the force constant of the spring combination, x is the displacement of the sphere and m is the mass of the sphere.

The mass of the sphere is 6.6×10^5 kg. The natural frequency of the oscillations of the sphere is 0.15 Hz.

i. Show that the force constant k of the spring combination is about 6×10^5 N m^{-1}.

[3]

ii. The S-wave of an earthquake causes a sudden movement of the building displacing the sphere 0.71 m from its equilibrium position relative to the building.

Use your answer in **(i)** to calculate the energy transferred to the springs of the damper system.

energy transferred = ______________________ J **[2]**

23 (a). A mass hanging from a vertical spring is pulled down.
It is then released from rest at time $t = 0$.
The mass oscillates vertically in a **vacuum** with simple harmonic motion about the equilibrium position. The spring is in tension at all times.

Fig. 18.1 shows the position of the mass at $t = 0$.

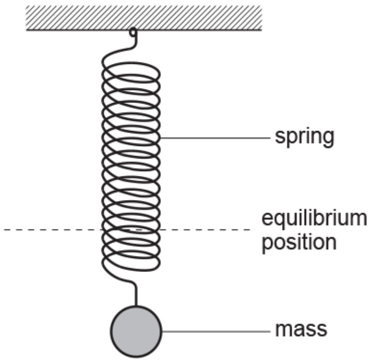


Fig. 18.1

At time $t = 6.5$ s the magnitude of the acceleration a of the mass is 3.6 m s^{-2} and its displacement x is 4.6×10^{-2} m.

i. Use the defining equation for simple harmonic motion to show that the natural frequency f_0 of the mass-spring system is about 1.4 Hz.

[3]

ii. Calculate the amplitude A of the oscillations.

A = ... m **[2]**

(b). Fig. 18.2 shows the mass and spring now attached to a mechanical vibrator, which can oscillate with variable frequency.

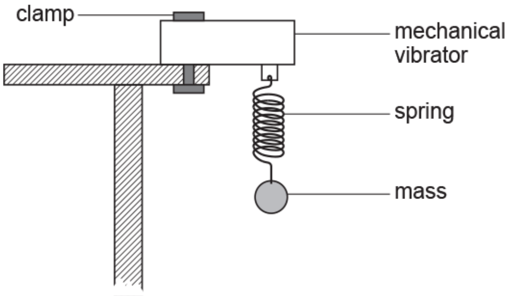


Fig. 18.2

The mass oscillates in air.

i. The vibrator frequency is varied from 0 Hz to 2.5 Hz.
On Fig. 18.3, sketch a graph to show the variation with vibrator frequency of the amplitude of the mass. Label your graph **K**.

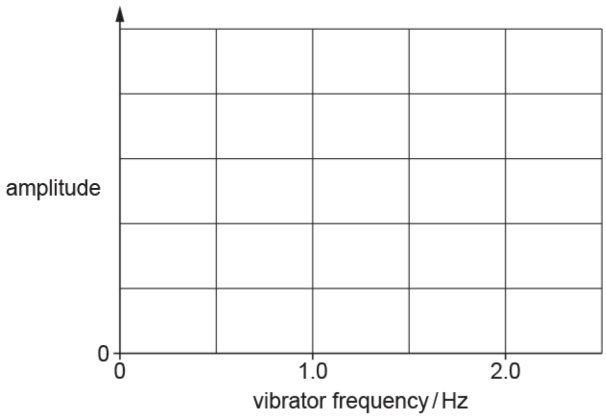


Fig. 18.3

[2]

ii. A light disc is now attached to the mass to increase the damping.
The vibrator frequency is again varied from 0 Hz to 2.5 Hz.
Sketch a second graph on Fig. 18.3 to show the new variation of the amplitude.
Label this graph **D**.

[1]

iii. Explain why the phenomenon demonstrated in this experiment can cause problems for engineers when designing suspended footbridges.

---

[2]

24. This question is about a simple pendulum made from a length of string attached to a mass (bob). For oscillations of small amplitude, the acceleration *a* of the pendulum bob is related to its displacement *x* by the expression

$$a = -\left(\frac{g}{L}\right)x$$

where *g* is the acceleration of free fall and *L* is the length of the pendulum.
The pendulum bob oscillates with simple harmonic motion.

i. Show that the period *T* of the oscillations is given by the expression

$$T^2 = \frac{4\pi^2}{g}L.$$

[3]

ii. A student notices that the amplitude of each oscillation decreases over time.
Explain this observation and state what effect this may have on *T*.

----

[2]

25. A mechanical oscillator is forced to oscillate in a viscous fluid.

The graph in Fig. 21.1 shows the variation of amplitude A of the oscillator with driving (forced) frequency f.

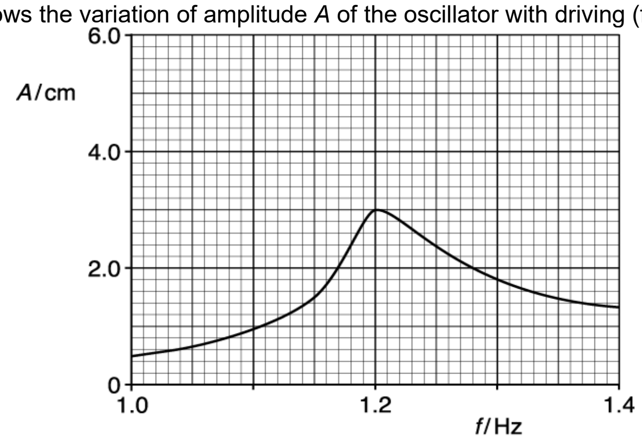


Fig. 21.1

i. Use Fig. 21.1 to determine the **maximum** acceleration of the oscillator at resonance.

maximum acceleration = ... m s^{-2} **[3]**

ii. The oscillator is now removed from the viscous fluid. It is now forced to oscillate in air.
On Fig. 21.1 sketch the new shape of the amplitude against frequency graph.

[2]

26. This question is about a simple pendulum made from a length of string attached to a mass (bob). For oscillations of small amplitude, the acceleration a of the pendulum bob is related to its displacement x by the expression

$$a = -\left(\frac{g}{L}\right)x$$

where g is the acceleration of free fall and L is the length of the pendulum.
The pendulum bob oscillates with simple harmonic motion.

Describe with the aid of a labelled diagram how an experiment can be conducted and how the data can be analysed to test the validity of the equation $T^2 = \frac{4\pi^2}{g}L$ for oscillations of small amplitude.

----

[6]

27 (a). Fig. 5.1 shows a horizontal copper wire placed between the opposite poles of a permanent magnet. The wire is held in tension *T* by the clamps at each end. The length of the wire in the magnetic field of flux density 0.032 tesla is 6.0 cm.

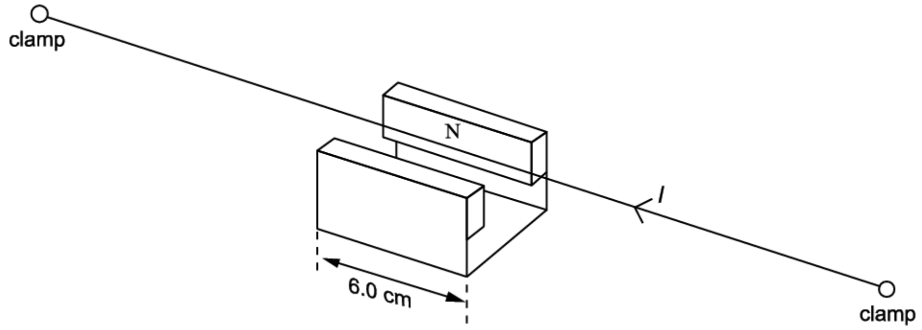


Fig. 5.1

The direct current is changed to an alternating current of constant amplitude and variable frequency, causing the wire to oscillate. The frequency of the current is increased until the fundamental natural frequency of the wire is found as shown in Fig. 5.2. This is 70 Hz.

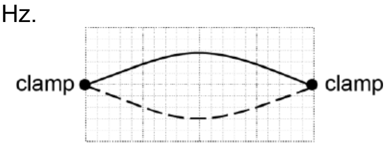


Fig. 5.2

i. In the situation shown in Fig. 5.2 the amplitude of the oscillation of the centre point of the wire is 4.0 mm. Calculate the maximum acceleration of the wire at this point.

maximum acceleration = ... m s^{-2} **[2]**

ii. The frequency is increased until another stationary wave pattern occurs. The amplitude of this stationary wave is much smaller.

1. Sketch this pattern on Fig. 5.3 and state the frequency

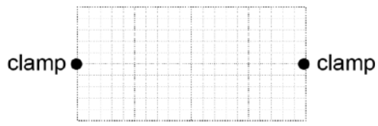


Fig. 5.3

frequency = ... Hz **[1]**

2. Explain why the amplitude is so small. Suggest how the experiment can be modified to increase the amplitude.

---

[3]

(b). The speed *v* of a transverse wave along the wire is given by $v = \sqrt{\frac{T}{\mu}}$ where *T* is the tension and μ is the mass per unit length of the wire.

i. Assume that both the length and mass per unit length remain constant when the tension in the wire is halved.
Calculate the frequency of the new fundamental mode of vibration of the wire.

frequency = ... Hz **[1]**

ii. In practice the mass per unit length changes because the wire contracts when the tension is reduced.
For the situation in which the tension is halved the strain reduction is found to be 0.4%.

1. Calculate the percentage change in *μ.* State both the size and sign of the change.

percentage change in *μ* = ... % **[1]**

2. Write down the percentage error this causes in your answer to **(i)**. State, giving your reasoning, whether the actual frequency would be higher or lower than your value.

---

[2]

28. Fig. 3.1 shows a simple representation of a hydrogen iodide molecule. It consists of two ions ${}^{1}_{1}H^{+}$ and ${}^{127}_{53}I^{-}$, held together by electric forces.

Fig. 3.1

Fig. 3.2 shows a simple mechanical model of the molecule consisting of two unequal masses connected by a spring of force constant k and negligible mass. The ions oscillate in simple harmonic motion when disturbed.

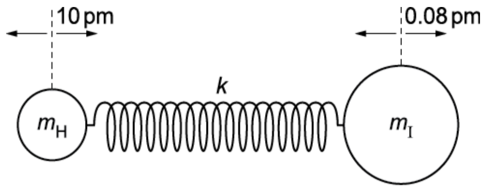


Fig. 3.2

i. The approximate acceleration a of the hydrogen ion, mass m_H, is given by the equation

$$a = -\left(\frac{k}{m_H}\right)x$$

where k is the force constant of the spring and x is the displacement of the ion.
The ions oscillate with a frequency of 6.6×10^{13} Hz. The mass m_H is 1.7×10^{-27} kg.
Show that the value of k is about 300 N m^{-1}.

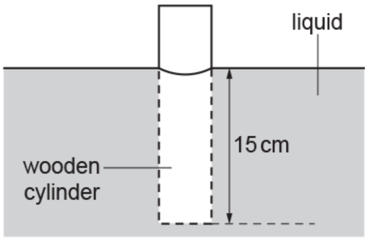
[3]

ii. Use Newton's laws of motion and a requirement for simple harmonic motion to explain why the amplitude of oscillation of the iodine ion, mass m_I, is about 0.08 pm when the amplitude of oscillation of the hydrogen ion is about 10 pm.

----

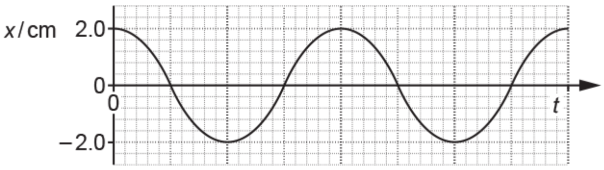
[4]

29. A long wooden cylinder is placed into a liquid and it floats as shown.



The length of the cylinder below the liquid level is 15 cm.

The cylinder is pushed down into the liquid and then allowed to oscillate freely. The graph of displacement *x* against time *t* is shown below.



The cylinder oscillates with simple harmonic motion with frequency of 1.4 Hz.

i. Calculate the displacement, in cm, at time t = 0.60 s.

displacement = ... cm **[3]**

ii. Calculate the maximum speed of the oscillating cylinder.

maximum speed = ... m s^{-1} **[2]**

iii. The cylinder is now pushed down further into the liquid before being released. As before, the cylinder oscillates with simple harmonic motion.

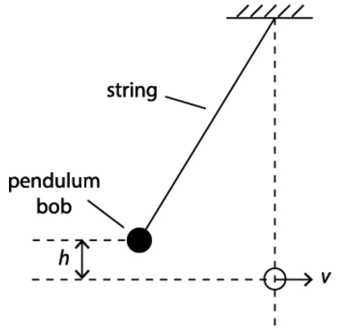
State the effect this has on

1 the amplitude

2 the period.

[2]

30 (a). A group of students are conducting an experiment in the laboratory to determine the acceleration of free *g* using a simple pendulum as shown below.



The pendulum bob is released from **rest** from a height *h.* The speed of the pendulum bob as it passes through the vertical position is *v.* The speed *v* is measured using a light-gate and a computer.
The results from the students are shown in a table.

h / m	v / m s^{-1}	v^2 / m^2 s^{-2}
0.052	1.0 ± 0.1	1.0 ± 0.2
0.100	1.4 ± 0.1	2.0 ± 0.3
0.151	1.7 ± 0.1	2.9 ± 0.3
0.204	1.9 ± 0.1	
0.250	2.2 ± 0.1	4.8 ± 0.4
0.302	2.4 ± 0.1	5.8 ± 0.5

Complete the missing value of v^2 in the table.

[1]

(b). Fig. 24 shows the graph of v^2 against *h.*

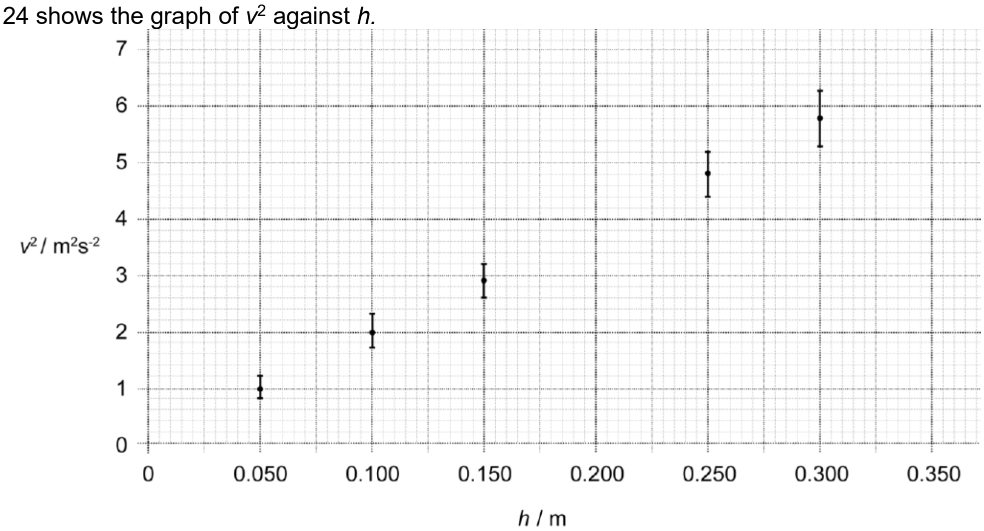


Fig. 24

i. Plot the missing data point and error bar on Fig. 24.

[1]

ii. * Explain how Fig. 24 can be used to determine the acceleration of free fall *g.*
Find the value of *g* and include the uncertainty in your answer.

[6]

31. A loudspeaker mounted on a bench is emitting sound of frequency 1.7 kHz to a microphone. Fig. 5.1 shows an illustration of the bulk movement of the air at one instant of time.

Fig. 5.1

The maximum displacement of the air particles from their mean positions is 2.0×10^{-6} m.

The speed of sound in air at 17 °C is 340 m s^{-1}.

i. On Fig. 5.2, sketch the sinusoidal variation of the displacement of the air with distance between **C** and **R**.

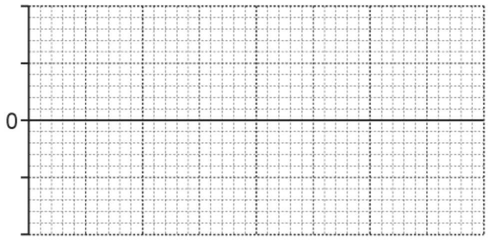


Fig. 5.2

1. Label the axes and include sensible scales.
2. On Fig. 5.2, mark one point where air particles are moving at maximum speed. Label it **X**.
3. On Fig. 5.2, mark one point where air particles are moving at maximum speed but travelling in the opposite direction to the air particles in **2**. Label it **Y**.

[4]

ii. Calculate
1. the maximum speed v_{max} of the oscillating particles in the sound wave

v_{max} = ... m s^{-1} **[2]**

2. the root mean square speed c of the air molecules in the room.
The molar mass of air is 2.9×10^{-2} kg mol^{-1}.

c = ... m s^{-1} **[2]**

END OF QUESTION PAPER