1(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.

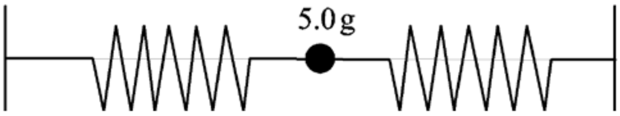


Fig. 21.1

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

--- [2]

(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.

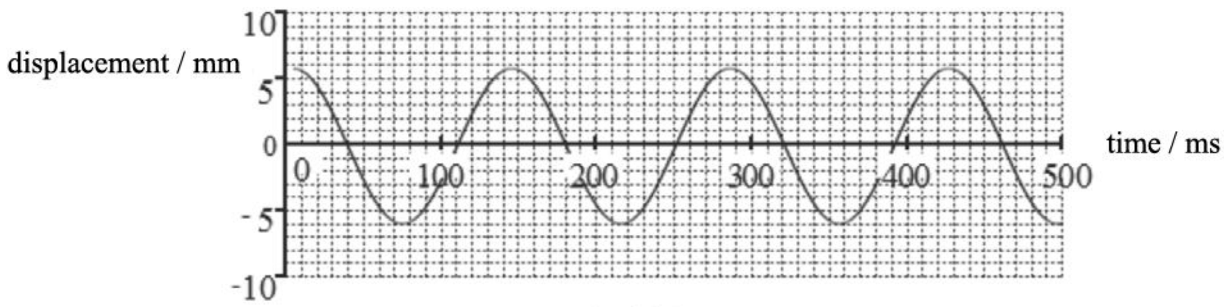


Fig. 21.2

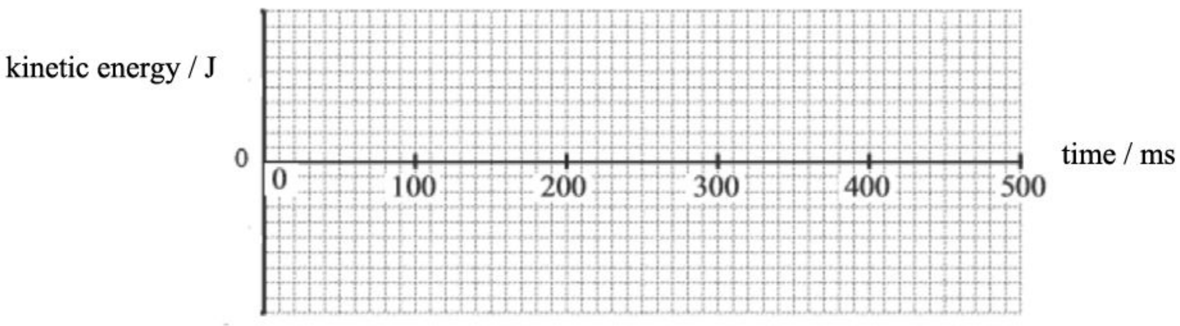


Fig. 21.3

(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]**

(d) 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]**

2 The motion of an oscillator is simple harmonic.

Which statement is correct about the period of the oscillator?

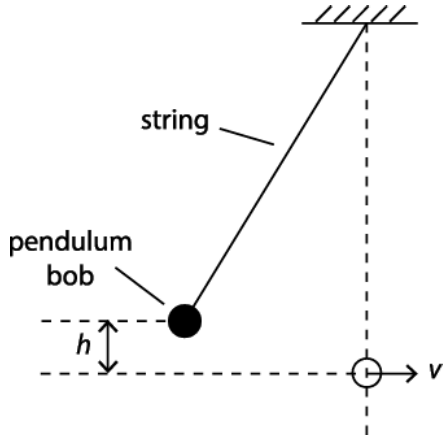
The period …

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]

3(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.*

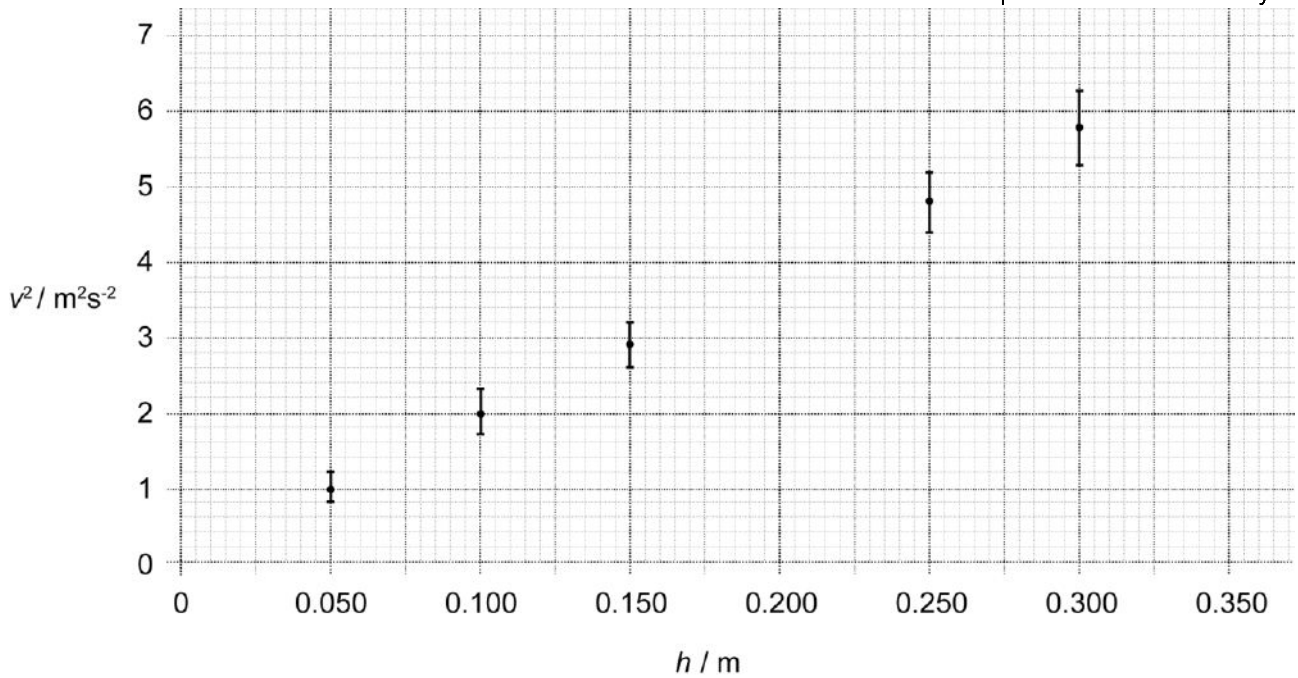


Fig. 24

(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]

4(a) Fig. 3.1 shows a metal plate attached to the end of a spiral spring. The end **A** of the spring is fixed to a rigid clamp. The plate is pulled down by a small amount and released. The plate performs simple harmonic motion in a vertical plane at a natural frequency of 8 Hz and the spring remains in tension at all times.

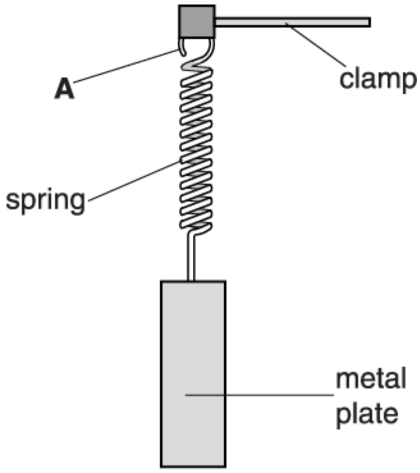


Fig. 3.1

(i) On Fig. 3.2 sketch an acceleration a against displacement *x* graph for the motion of the metal plate. You are not required to give values on the axes.

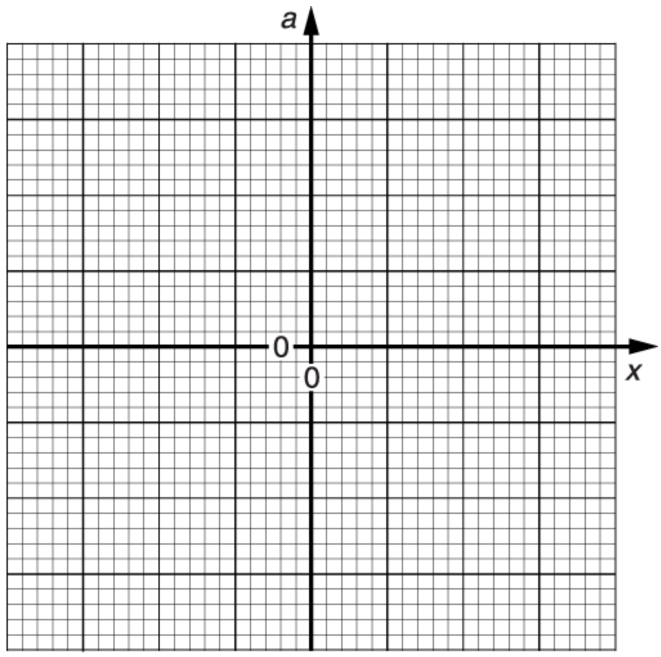


Fig. 3.2

[2]

(ii) Explain how your graph could be used to determine the frequency of oscillation of the metal plate.

[2]

(b) Fig. 3.3 shows the variation of the vertical velocity *v* of the plate with time *t* at a frequency of 8 Hz.

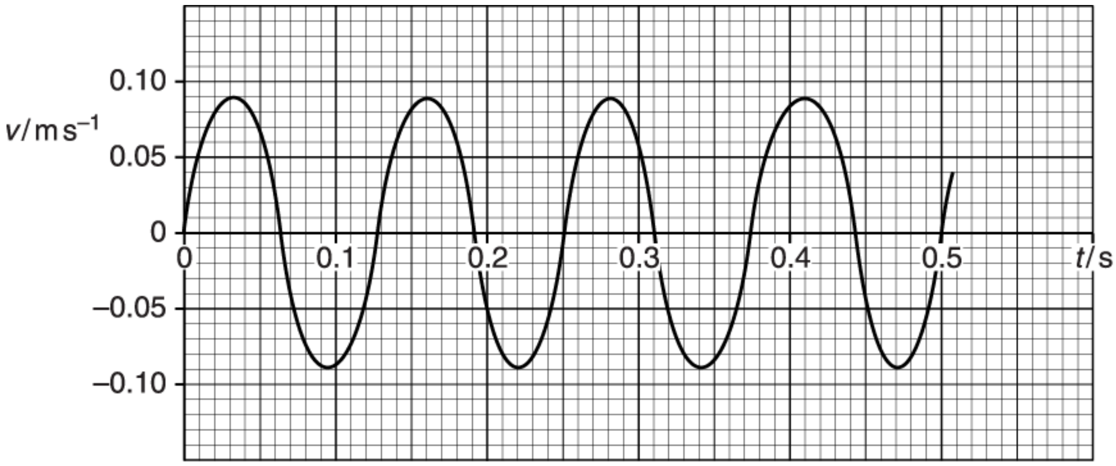


Fig. 3.3

(i) the amplitude of the motion

amplitude = ______________________________ m **[2]**

(ii) the maximum vertical acceleration of the plate.

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

(c) The metal plate is now immersed in light oil which provides a constant frictional force to the plate. On Fig. 3.4 draw carefully the graph you would expect to obtain for the variation of the vertical velocity *v* with time *t*. As a guide a copy of the graph in Fig. 3.3 is drawn for you.

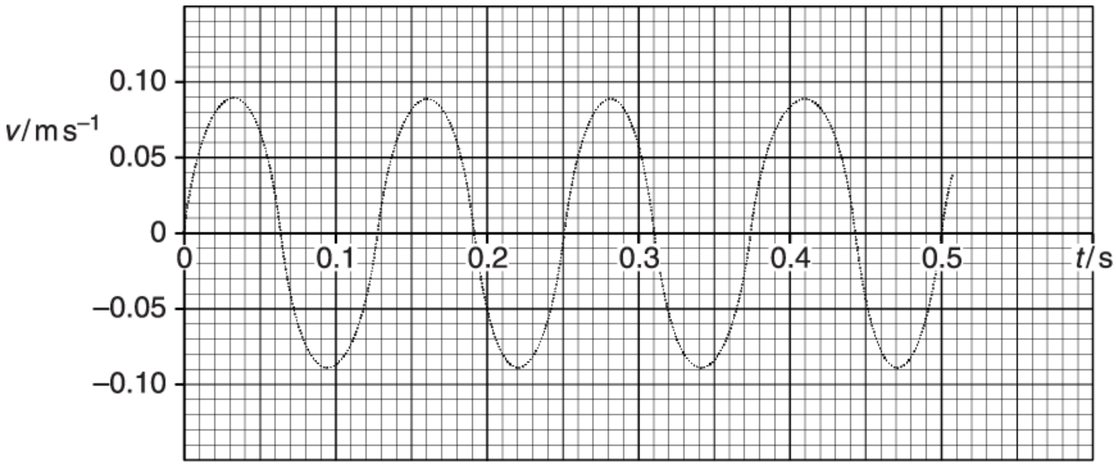


Fig. 3.4

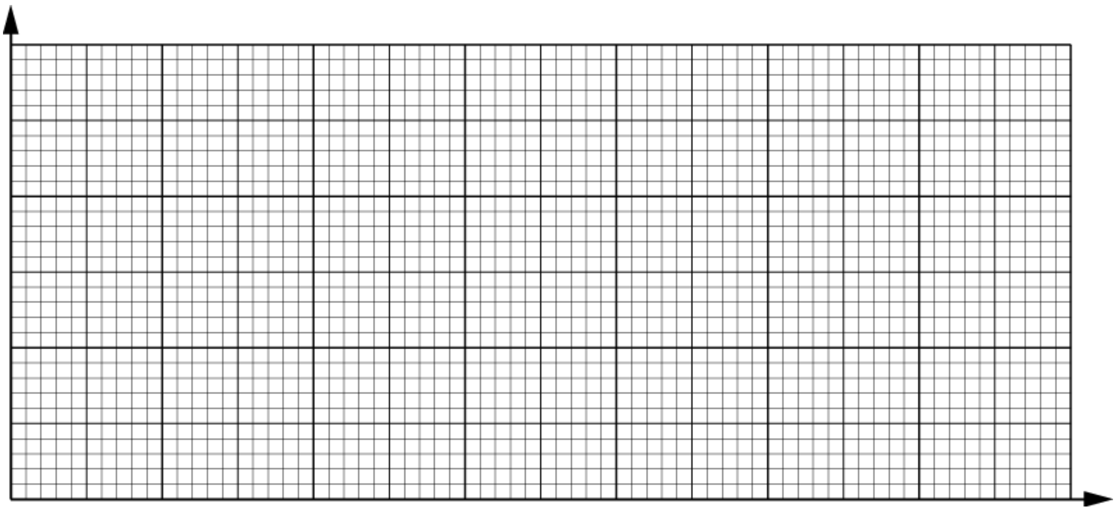
[2]

(d) The plate is now removed from the oil and the point **A** on the spring connected to an oscillator that vibrates vertically with constant amplitude. The frequency of the oscillator is increased slowly from 0 Hz to 12 Hz.

Describe and explain the motion of the metal plate during this procedure.

Sketch a labelled graph to help with your explanation.

In your answer, you should use appropriate technical terms spelled correctly.



[3]

5(a) Fig. 3.1 shows a simple pendulum consisting of a steel sphere suspended by a light string from a rigid support.
The sphere is displaced 50 mm from its vertical equilibrium position and released at time $t = 0$.

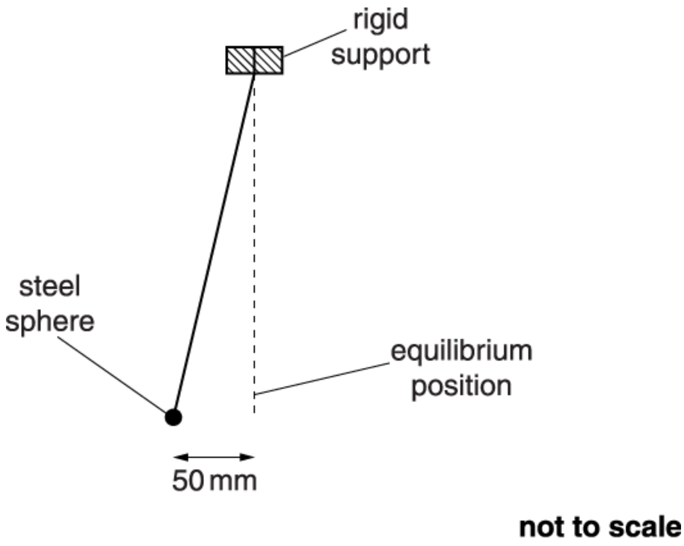


Fig. 3.1

Fig. 3.2 shows the graph of displacement x of the sphere against time t.

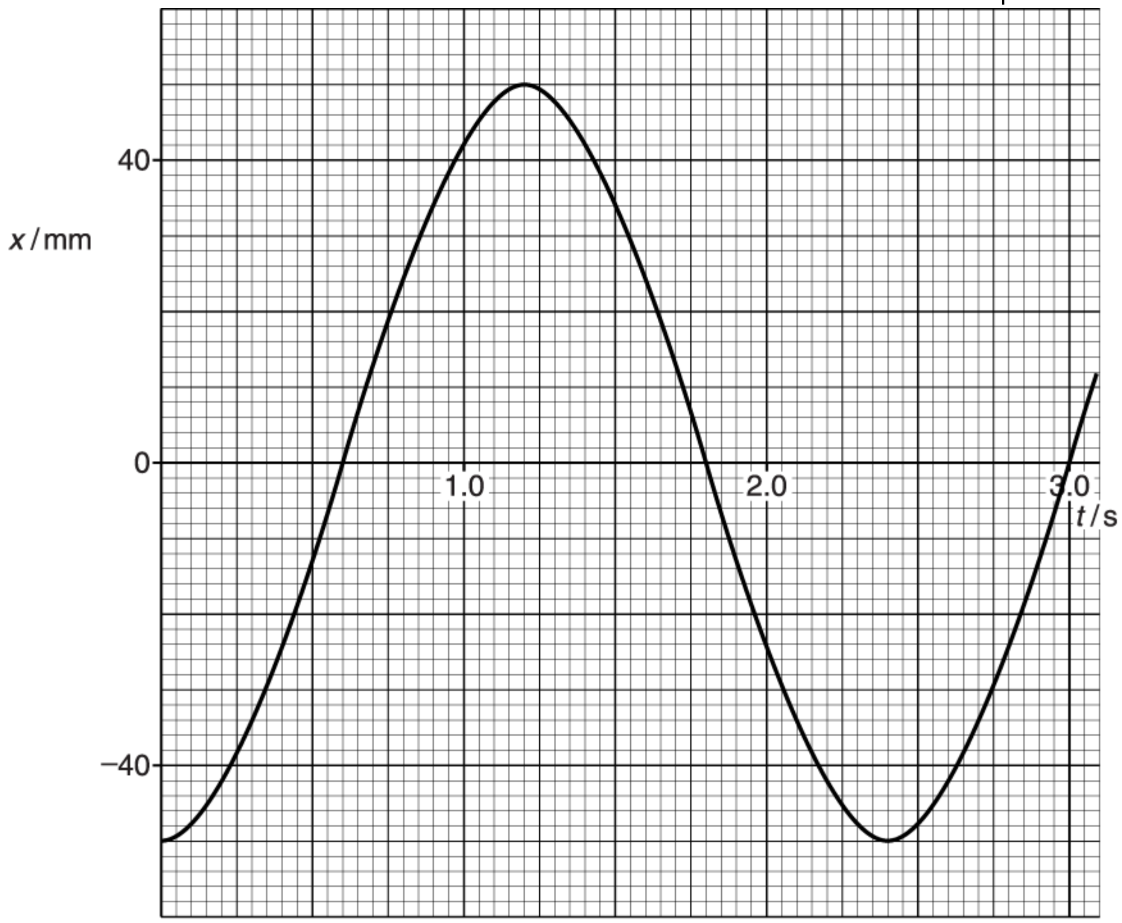


Fig. 3.2

(i) Use Fig. 3.2 to determine the frequency of oscillation of the pendulum.

frequency = ______________________________ Hz **[1]**

(ii) Use Fig. 3.2, or otherwise, to determine the maximum speed of the sphere.
Show your method clearly.

speed = ______________________________ $m\ s^{-1}$ **[2]**

(b) The sphere is now released from rest with a displacement x = 25 mm.
State with a reason, the change if any in

(i) the frequency of the oscillations

____

____

____ **[1]**

(ii) the maximum kinetic energy of the sphere.

____

____

____

____ **[2]**

(c) In turbulent air the wingtip of an aircraft can vibrate vertically. To investigate this effect, the acceleration and the vertical displacement of the wingtip are measured. Fig. 3.3 shows how the acceleration of the wingtip varies with displacement.

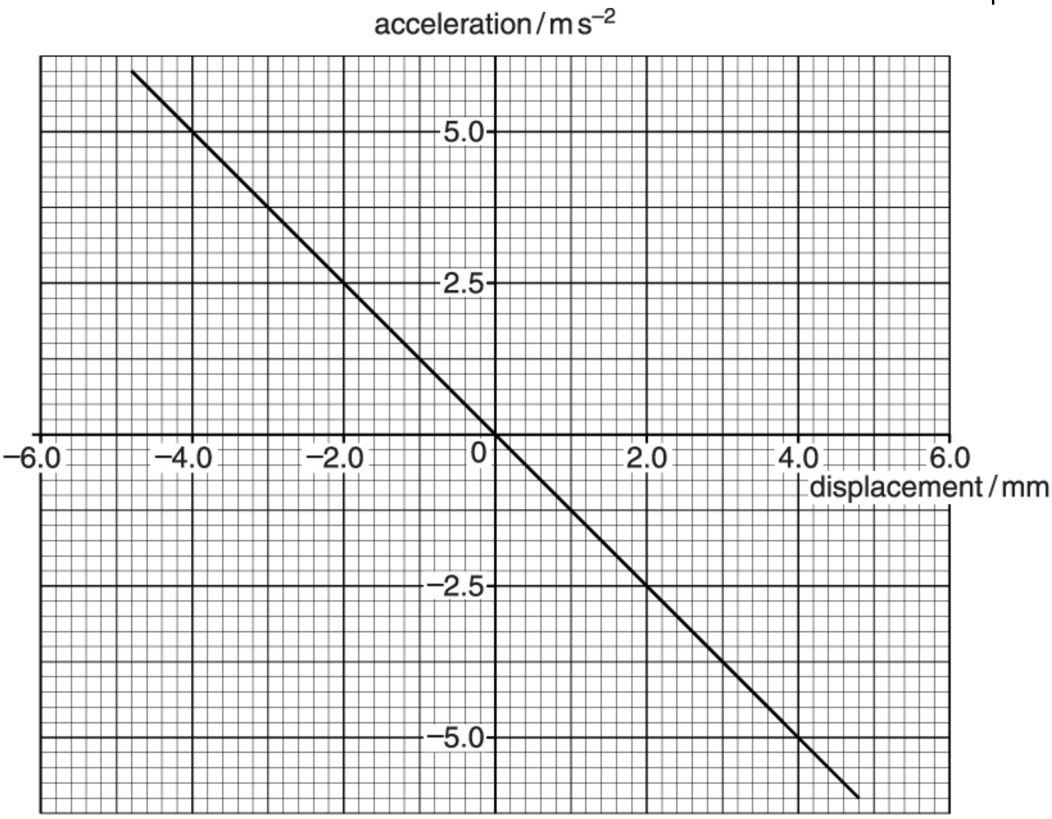


Fig. 3.3

(i) Explain how Fig. 3.3 suggests that the wingtip undergoes simple harmonic motion under the test conditions.

____

____

____

____ **[2]**

(ii) Use Fig. 3.3 to determine the frequency of the vibration.

frequency = ______________________________ Hz **[2]**

6 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.

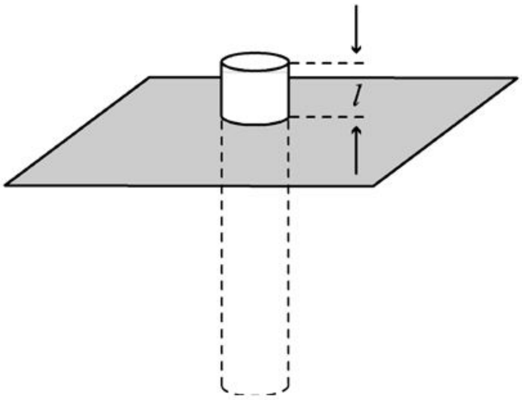


Fig. 4.1

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.

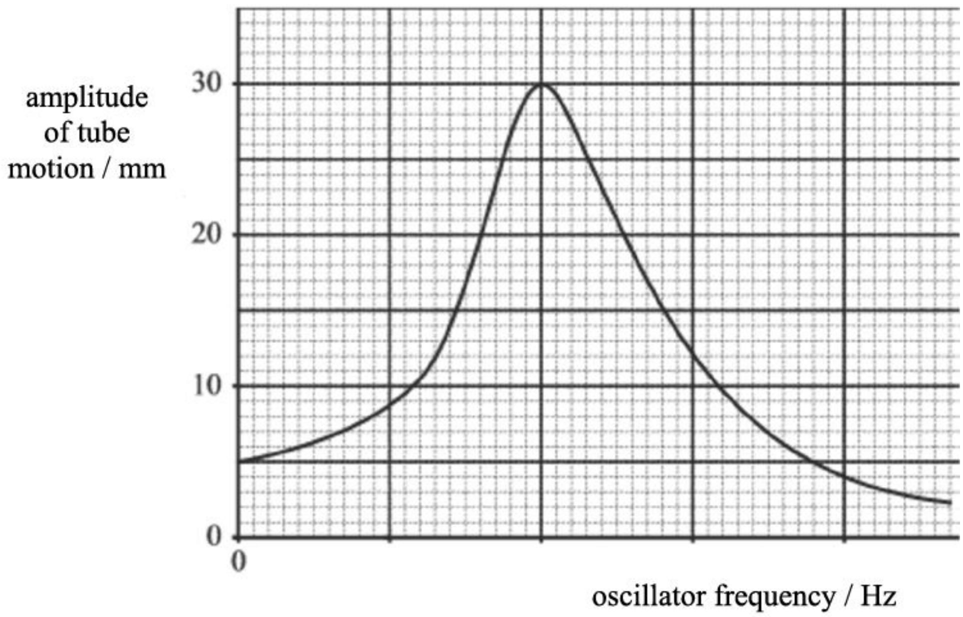


Fig. 4.2

(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]

7(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.

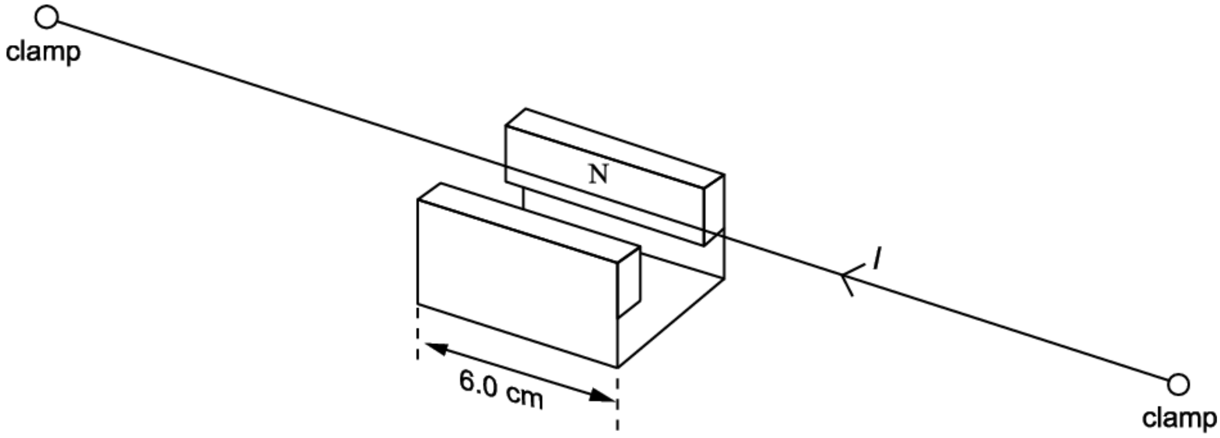


Fig. 5.1

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.

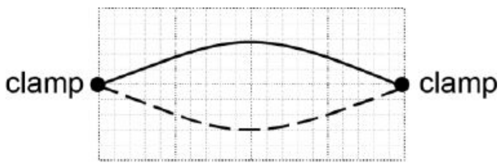


Fig. 5.2

(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

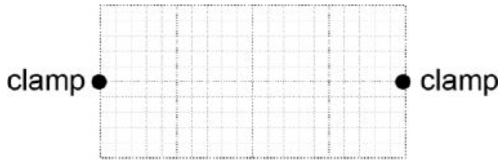


Fig. 5.3

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]**

8(a) Fig. 3.1 shows a displacement against time graph of an object undergoing simple harmonic motion. Seven points, **A** to **G**, have been labelled on the graph.

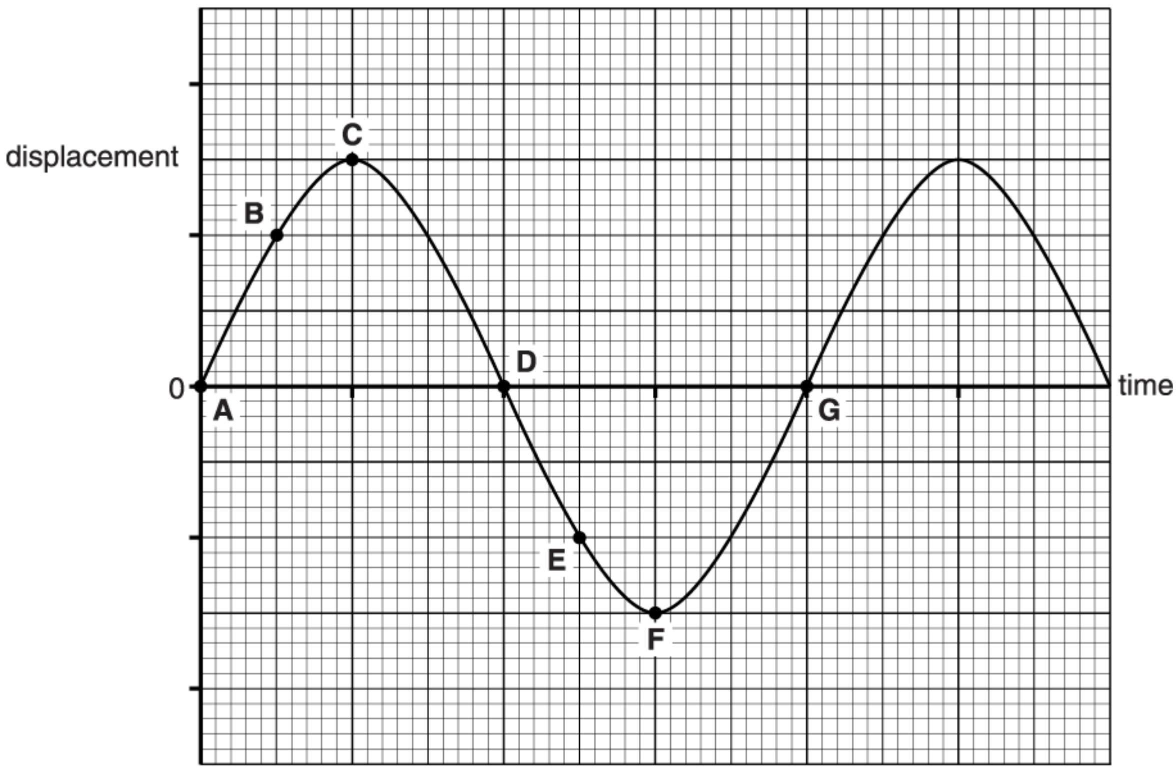


Fig. 3.1

(i) Write down two points that indicate when the object is at its amplitude position.

____ **[1]**

(ii) Write down a point which lags behind **D** by half a period.

____ **[1]**

(iii) Determine the phase difference, in radians, between points **B** and **F**.

phase difference = ______________________________ rad **[1]**

(b) Fig. 3.2 shows an airtrack glider of mass 0.45 kg held in equilibrium by two identical stretched springs. The glider is pulled 5.0 cm to the left. When released, it oscillates without friction. The springs are always in tension.

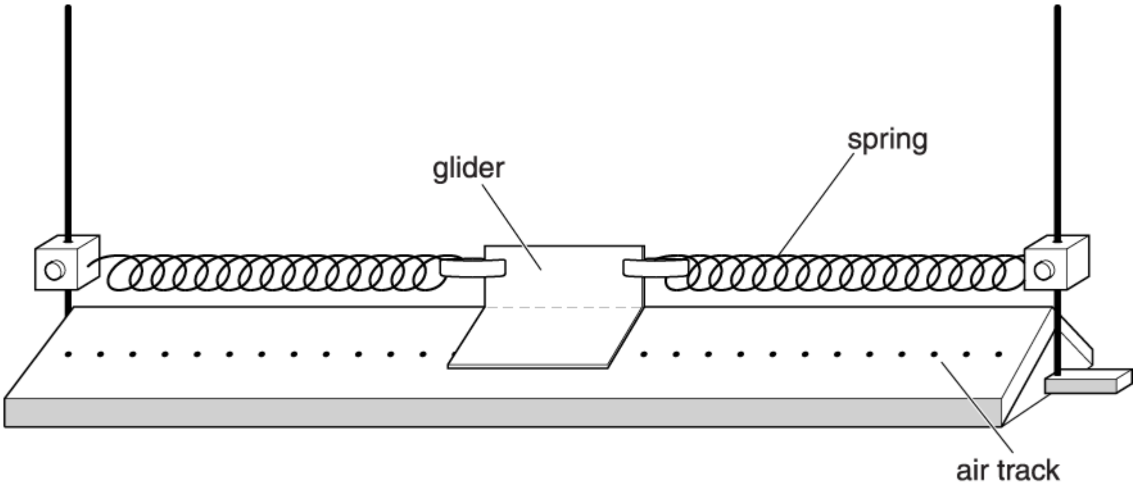


Fig. 3.2

The variation of elastic potential energy stored in the springs with displacement, *x*, of the glider is shown in Fig. 3.3.

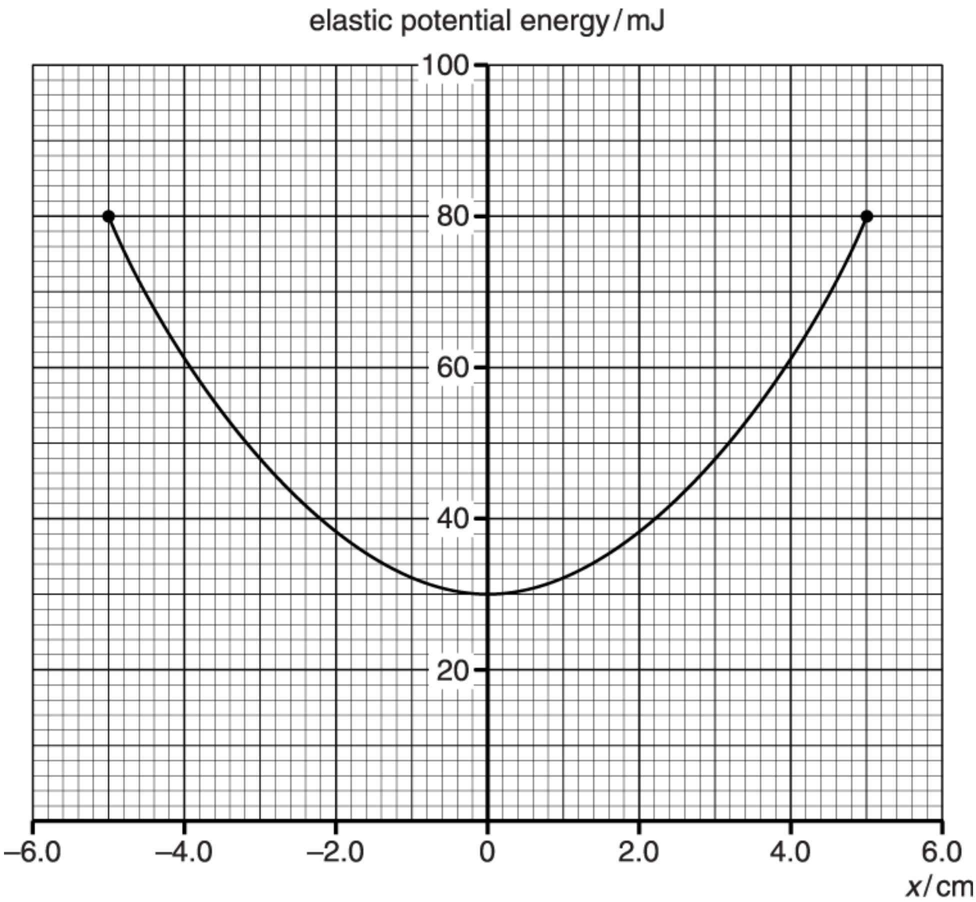


Fig. 3.3

(i) Draw on Fig. 3.3 a graph to show the variation of kinetic energy with displacement of the glider.

[2]

(ii) Calculate the maximum speed of the glider.

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

(iii) Determine the period of the oscillations.

period = ____________________________ s **[2]**

9 Which quantity has the unit hertz (Hz)?

A frequency
B acceleration
C phase difference
D angular frequency

Your answer ☐

[1]

10 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]

11(a) 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]

(b) 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*.

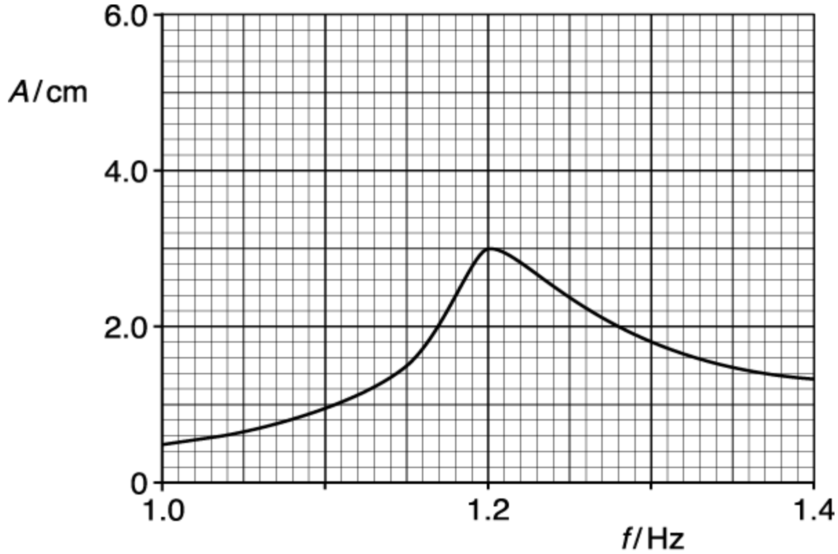


Fig. 21.1

(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]

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

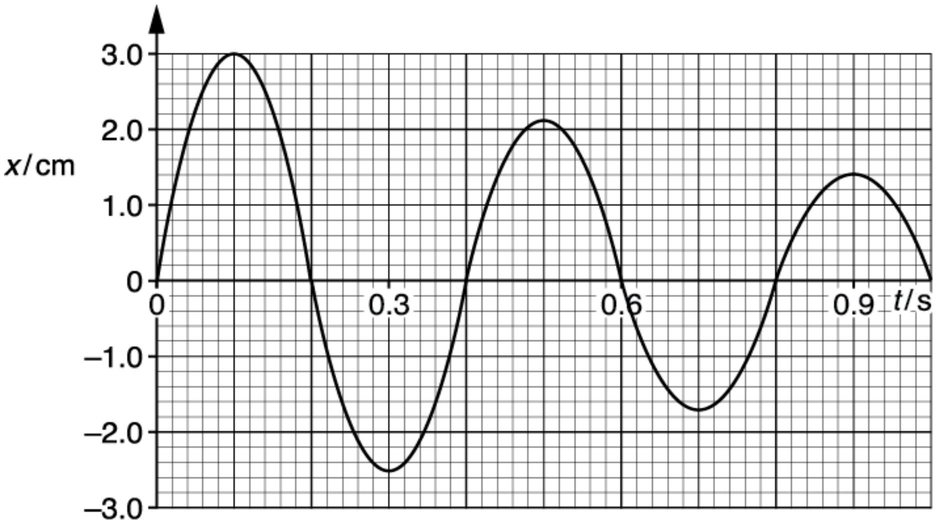


Fig. 21.2

(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]

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.

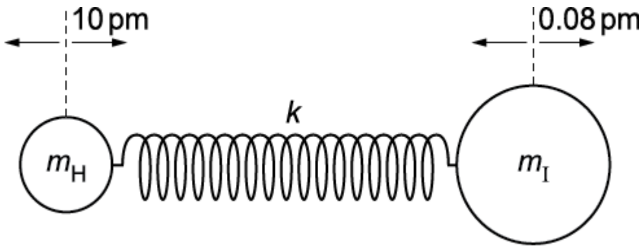


Fig. 3.2

(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.

____

____

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____

____

____

____ **[4]**

13(a) 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]

(b) 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]

(c) Another student conducts a similar 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]

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**.

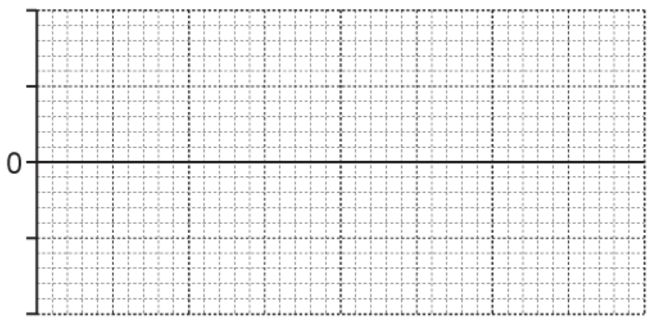


Fig. 5.2

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]**

15 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]**

16 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

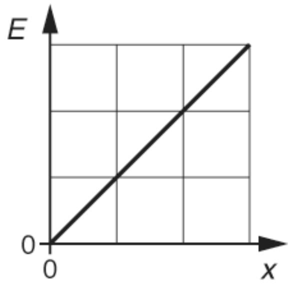
D 1, 2 and 3

Your answer [1]

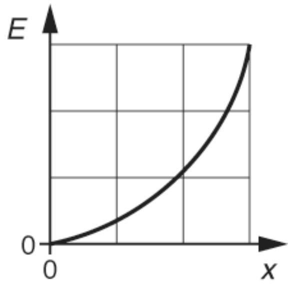
17 An object oscillates with simple harmonic motion.

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

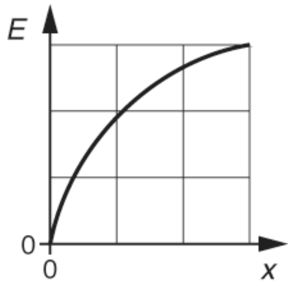
A



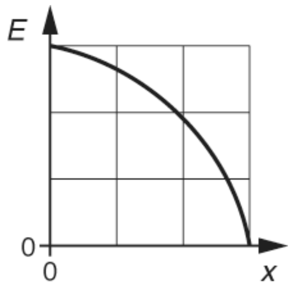
B



C



D



Your answer [1]

18(a) 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.

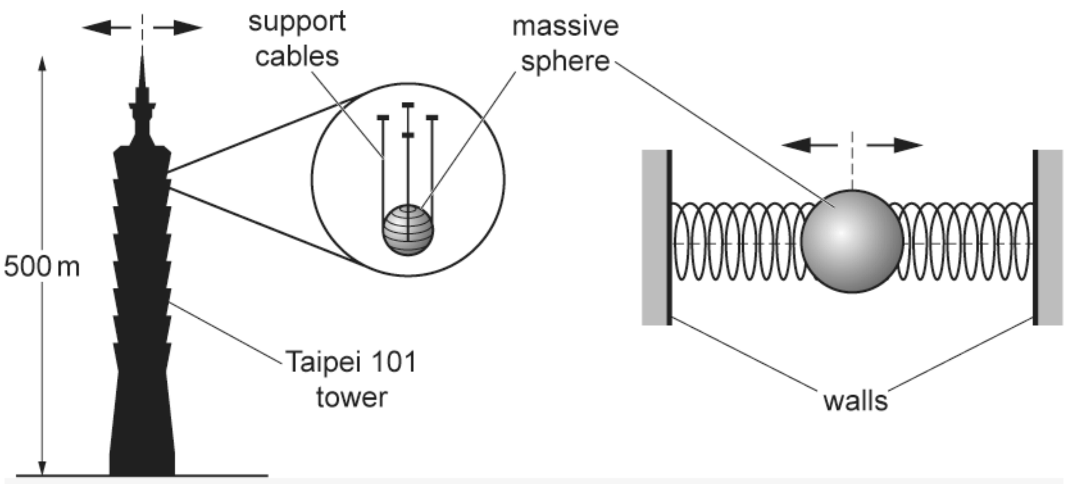


Fig. 2.1 Fig. 2.2

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]**

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

--- [2]

(c) 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]**

19 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]

20(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 $t = 0$.

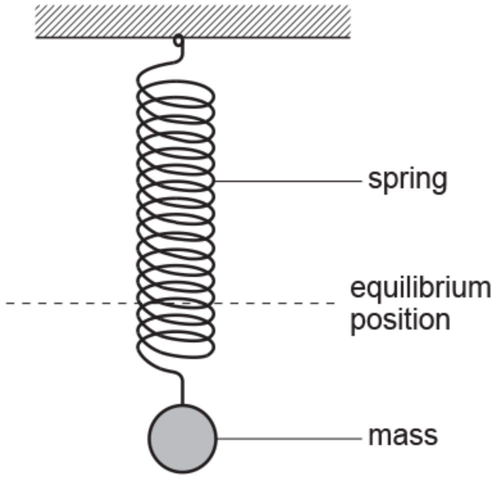


Fig. 18.1

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) 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]

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

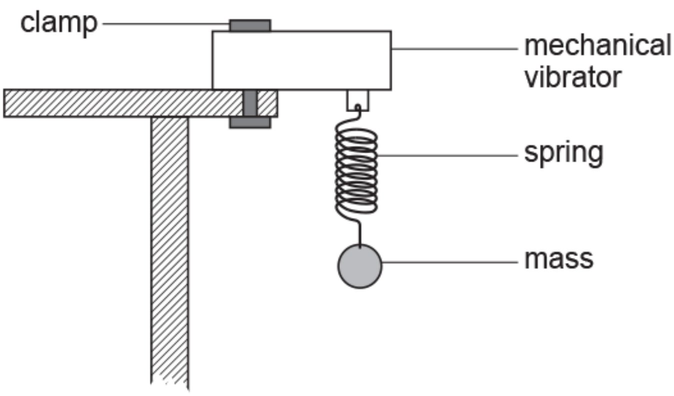


Fig. 18.2

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**.

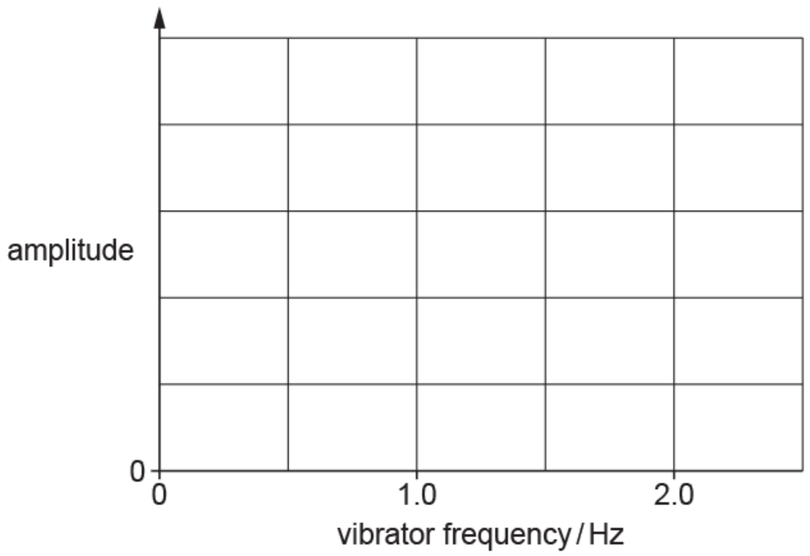


Fig. 18.3

[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.

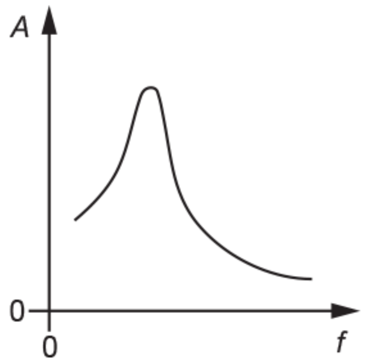
---

[2]

---

21 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.

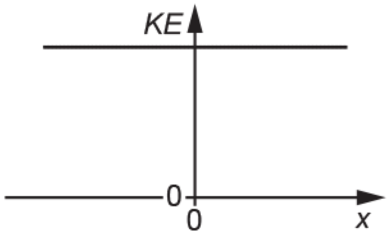
A Only 1
B Only 2
C Only 3
D 1, 2 and 3

Your answer [1]

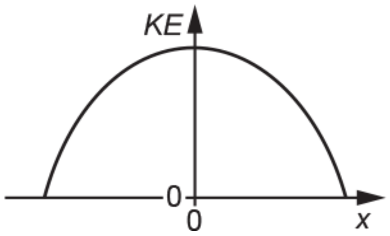
22 An oscillator is executing simple harmonic motion.

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

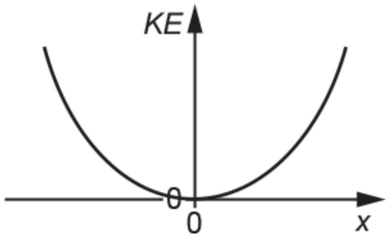
A



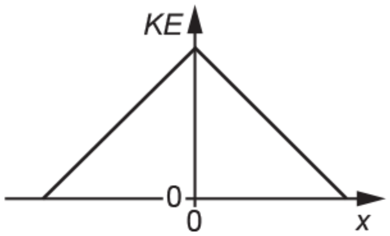
B



C

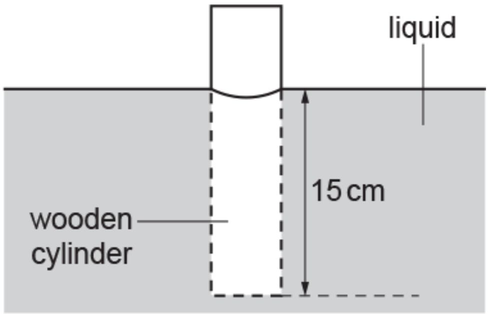


D



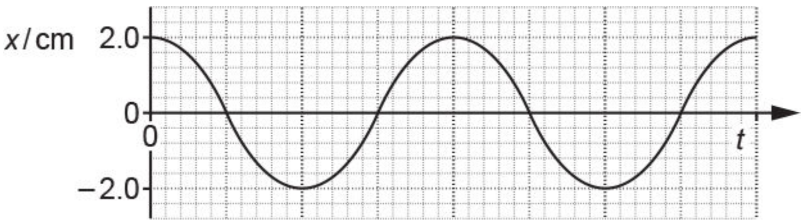
Your answer [1]

23 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]

24 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.

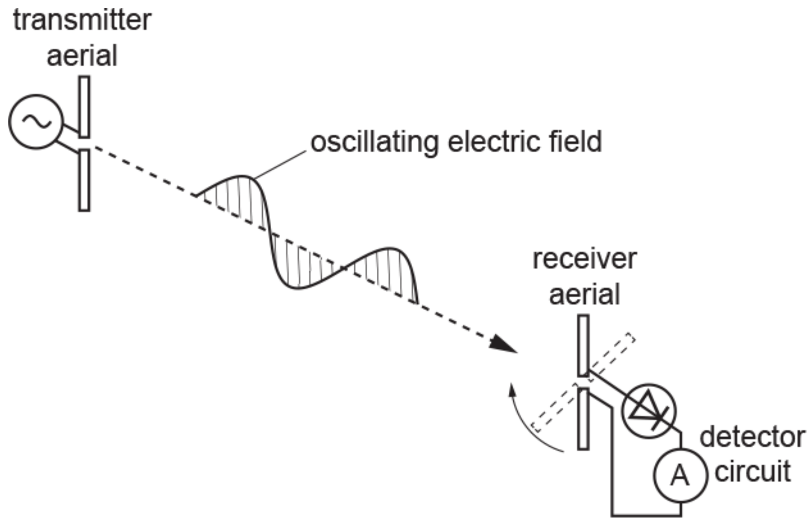


Fig. 5.1

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]**

25 Scientists are planning to launch a rocket from the surface of the Earth into an orbit at a distance of 18000 km above the centre of the Earth. The radius of the Earth is 6400 km and it has mass 6.0×10^{24} kg.

What is the minimum work done to move the 150 kg mass of the rocket into this orbit?

A -13×10^5 J
B -6.0×10^5 J
C $+6.0 \times 10^5$ J
D $+13 \times 10^5$ J

Your answer ☐

[1]

26(a) Explain how Newton's law of gravitation is applied between two non-spherical asteroids.

____

____

____ [1]

(b) A satellite moves in a circular orbit of radius 15 300 km from the centre of the Earth.

(i) State one of the main benefits satellites have on our lives.

____

____ [1]

(ii) Calculate the gravitational field strength g at the radius of 15 300 km.

g = ______________ N kg^{-1} **[2]**

(iii) Calculate the period of the orbiting satellite.

period = ______________ s **[3]**

(c) Determine the average density of the Earth. The radius of the Earth is 6400 km.

average density = _______________ kg m^{-3} **[3]**

27 A satellite of mass 3000 kg moves from a parking orbit of radius 6800 km to a geostationary orbit of radius 42 000 km. The mass of the Earth is 6.0×10^{24} kg.

What is the magnitude of the change in gravitational potential?

A $8.4\ J\ kg^{-1}$
B $2.5 \times 10^{4}\ J\ kg^{-1}$
C $4.9 \times 10^{7}\ J\ kg^{-1}$
D $1.5 \times 10^{11}\ J\ kg^{-1}$

Your answer ☐

[1]

28(a) Observations of the planets led to Kepler's three empirical laws:

1 The orbit of a planet is an ellipse with the Sun at one focus.
2 A line joining a planet and the Sun sweeps out equal areas during equal time intervals.
3 The square of the orbital period T is proportional to the cube of the average orbital radius r.

With the help of a labelled diagram, illustrate Kepler's second law for the planets in our Solar System.

[2]

(b) Fig. 22 shows the elliptical orbit of a planet around the Sun.

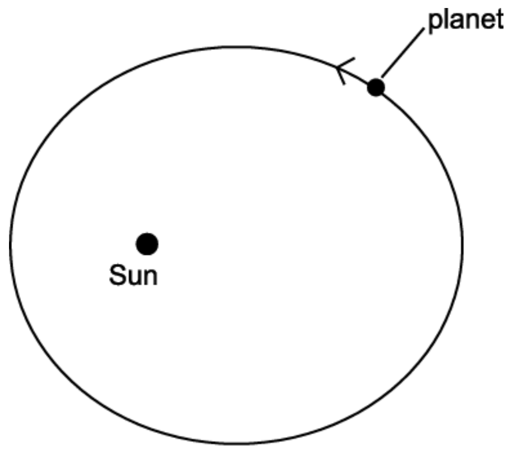


Fig. 22

Draw the gravitational force acting on the planet at the position shown in Fig. 22.

[1]

(c) Three exoplanets orbit the star KIC 11442793. Measurements of average orbital radius *r* and period *T* for the exoplanets are shown in the table.

r / AU	*T* / days
0.0881	8.719
0.520	124.9
0.996	331.6

It is suggested that the relationship between *T* and *r* is given by Kepler's third law:

$$T^2 \propto r^3$$

Propose and carry out a test to check if the relationship is true for the three exoplanets.

Test proposed:

Working:

Conclusion:

-- [3]

29 Hubble's law can be used to estimate the age of the universe. Fig. 23 shows some of Hubble's early measurements of nearby galaxies plotted on a *v* against *d* graph, where *v* is the recessional speed of a galaxy and *d* is its distance from us. Measurements of distant galaxies taken over the last 85 years have refined the value of H_0 to be 68 km s^1 Mpc^{-1}.

(i) Suggest why measurements for our nearest galaxies can deviate from the current Hubble's law trend line.

____

____ **[1]**

(ii) Suggest why measurements for galaxies at the largest distances deviate from the Hubble's law trend line.

____

____ **[1]**

30(a) The apparatus shown in **Fig. 20.1** is used to investigate the variation of the product *PV* with temperature in the range 20 °C to 100 °C. The pressure exerted by the air is *P* and the volume of air inside the flask is *V*.

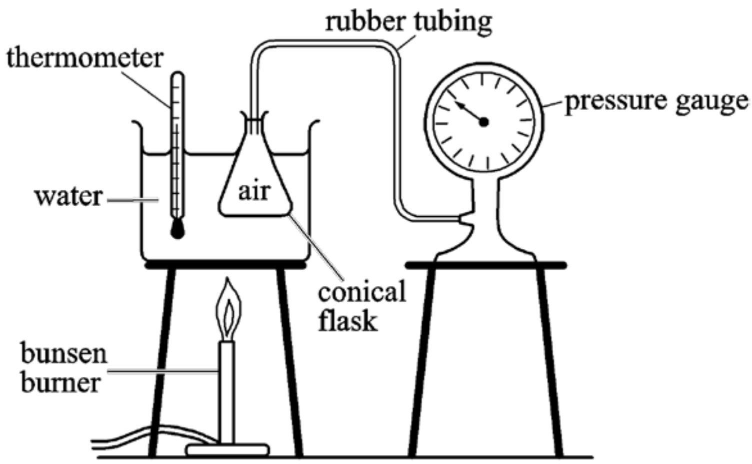


Fig. 20.1

Describe how this apparatus can be set up and used to ensure accurate results.

--- [4]

(b) An investigation similar to that shown in **Fig. 20.1** gives measurements of the pressure *P*, volume *V* and temperature θ in degrees Celsius of a fixed mass of gas.

The results are used to plot the graph of *PV* against θ shown in **Fig. 20.2**.

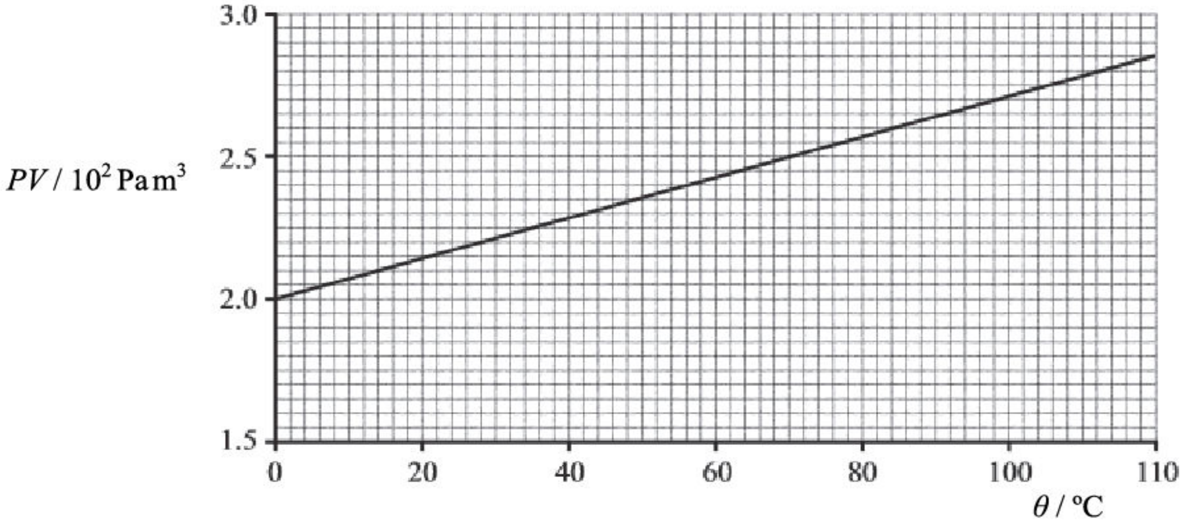


Fig. 20.2

(i) Explain, in terms of the motion of particles, why the graph does **not** go through the origin.

____

____

____ **[2]**

(ii) The mass of a gas particle is 4.7×10^{-26} kg. Use the graph in **Fig 20.2** to calculate

1 the mass of the gas

mass = ______________ kg

2 the internal energy of the gas at a temperature of 100 °C.

internal energy = ______________ J **[4]**

31(a) Write a word equation which states Newton's law of gravitation.

--- **[1]**

(b) A planet of mass m moves in a circular orbit of radius *r* about a star of mass *M*. The planet has an orbital period *T*.

Use your knowledge of circular motion and Newton's law of gravitation to derive Kepler's third law.

[4]

(c) The star HD10180 in the constellation Hydrus is notable for its large planetary system. The period T and the mean orbital radius r for HD10180's planets have been deduced from recent observations. Fig. 4.1 has been constructed using these data.

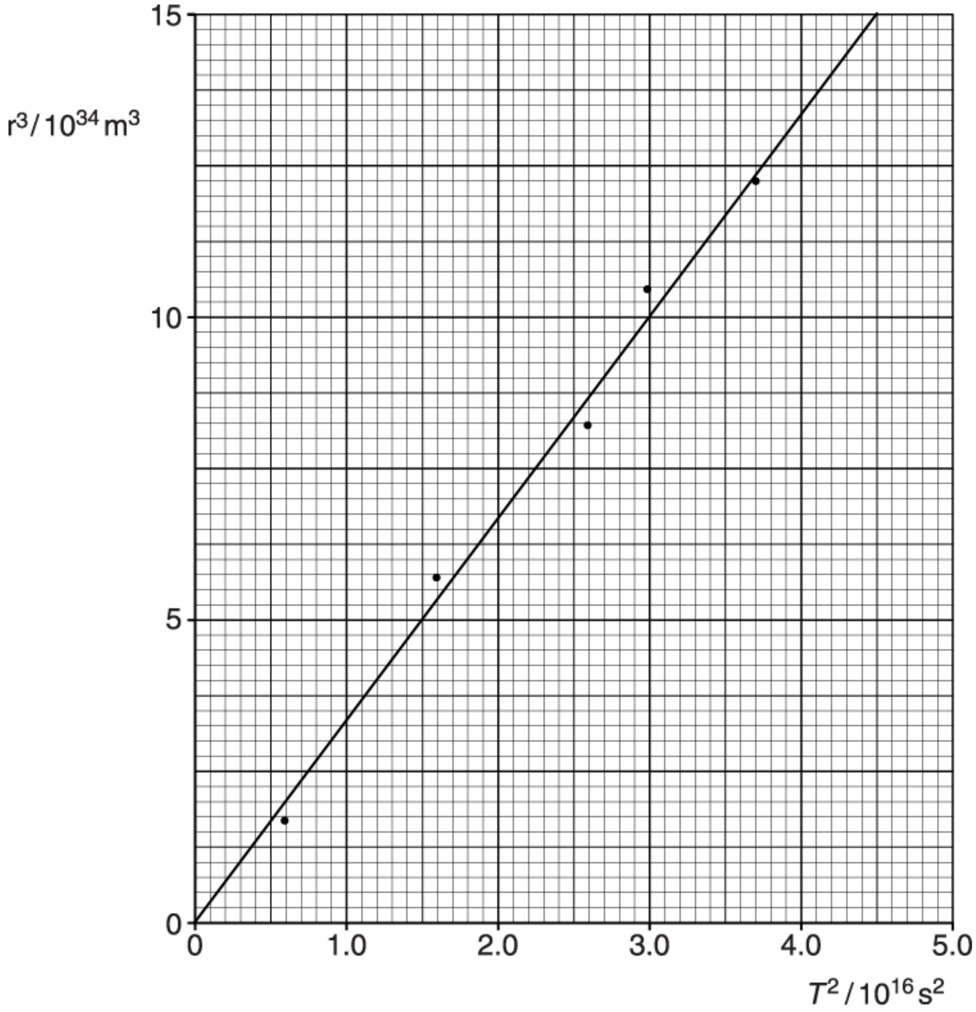


Fig. 4.1

(i) State what features of Fig. 4.1 support the view that Kepler's third law may be applied to this system.

--- **[1]**

(ii) Use Fig. 4.1 to determine the mass of the star HD10180.

mass = ____________________________ kg **[3]**

32 Fig. 1.4 shows a stationary positively charged particle.

Fig. 1.4

This particle creates both electric and gravitational fields in the space around it. Explain why the **ratio** of the electric field strength *E* to the gravitational field strength *g* at any point around this charge is independent of its distance from the particle.

____

____

____

____ **[1]**

33 Sirius A and B are binary stars in our galaxy at a distance of 8.6 ly from the Sun. Sirius B is a white dwarf of diameter 12 km and mass 2.0×10^{30} kg.

The mass of the Sun is the same as Sirius B. The Sun has a diameter of 1.4×10^{9} m.

Calculate the ratio

$$\frac{\text{gravitational field strength on the surface of Sirius B}}{\text{gravitational field strength on the surface of the Sun}}.$$

ratio = ______________________________ **[2]**

34 State **one** difference and **one** similarity between the electric field of a point charge and the gravitational field of a point mass.

difference ____

____

similarity ____

____ **[2]**

35(a) State what is meant by the term *geostationary orbit*.

____

____

____ **[1]**

(b) In a science fiction movie, a spaceship approaches a planet called Benzar.
Benzar has a period of rotation of 1.2×10^5 s.
The captain of the spaceship orders the crew to "enter a stationary orbit over the South Pole of Benzar".

(i) Use your knowledge of physics to explain why it is impossible to follow these orders.

____

____

____

____

____ **[2]**

(ii) Benzar has mass 8.9×10^{25} kg.
Calculate the radius of the possible stationary orbit for a spaceship circling Benzar.

radius = ______________________________ m **[3]**

36 Describe the similarities and the differences between the gravitational field of a point mass and the electric field of a point charge.

[3]

37(a) Explain what is meant by the statement:

The gravitational potential at the Earth's surface is -62.7×10^6 *J kg*$^{-1}$.

____

____

____

____

____ **[3]**

(b) The International Space Station (ISS) circles the Earth at a height of 4.0×10^5 m.

Its mass is 4.2×10^5 kg.

The radius of the Earth is 6.4×10^6 m.

(i) Show that the speed of the ISS in orbit is about 8 km s^{-1}.

[3]

(ii) Calculate the total energy of the ISS.

total energy = ____________________ J **[2]**

(c) * A supply rocket, with its engines shut down, is trying to dock with the ISS. Initially it is moving in the same circular orbit above the Earth and at the same speed as the ISS. The two craft are separated by a distance of a few kilometres. The rocket is behind the ISS. It can move closer to the ISS using the following procedure.

The rocket engines are fired in reverse for a few seconds to slow the rocket down. This action causes the rocket to fall into an orbit nearer to the Earth.

After an appropriate time, the rocket engines are fired forwards for a few seconds to move the rocket back into the original orbit closer to the ISS.

Use your knowledge of gravitational forces and uniform motion in a circular orbit to explain the physics of this procedure.

[6]

38(a) This question is about Mars and its two moons, Phobos and Deimos.

Calculate

(i) the mass of Mars

gravitational field strength on the surface of Mars is 3.7 N kg^{-1} radius of Mars is 3.4×10^3 km

mass = ______________________________ kg **[2]**

(ii) the gravitational field strength at a height of 3.4×10^3 km **above** the surface of Mars.

gravitational field strength = ______________________________ N kg^{-1} **[1]**

(b)

(i) State Kepler's third law.

____

____ **[1]**

(ii) Phobos completes a circular orbit of mean radius 9.4×10^3 km in 7.7 hours. Deimos completes its orbit in 30 hours.

Calculate the mean radius of the orbit of Deimos.

mean radius = ______________________________ km **[2]**

(c) Recent observations of Phobos indicate that it is slowly spiralling towards the surface of Mars. State and explain how you would expect this to affect the speed of Phobos.

____

____

____ **[1]**

39(a) A binary star consists of two stars that orbit about their common centre of mass **C**, as shown in Fig. 5.1.

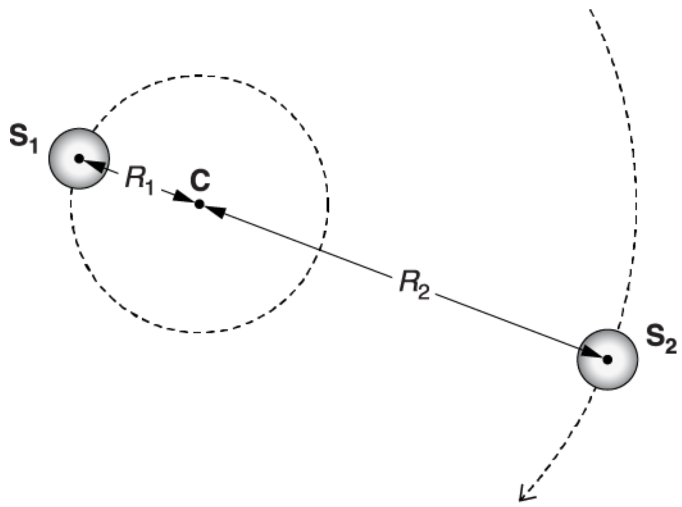


Fig. 5.1

The star S_1 has mass M_1 and orbits in a circle of radius R_1. Star S_2 has mass M_2 and a circular orbit of radius R_2. Both stars have the same orbital period T about **C**.

Using the terms G, M_1, M_2, R_1, R_2 and T write an expression for

(i) the gravitational force F experienced by each star

[1]

(ii) the centripetal force F_1 acting on the star S_1

[1]

(b) Use **(a)(ii)** to show that the ratio of the masses of the stars is given by the expression

$$\frac{M_1}{M_2} = \frac{R_2}{R_1}$$

[2]

(c) The ratio of the masses, M_1/M_2, is equal to 3.0 and the separation between the stars is 4.8×10^{12} m.

Calculate the radii R_1 and R_2.

R_1 = ______________________________ m

R_2 = ______________________________ m **[3]**

(d) The orbital period T of each star is 4.0 years.

Calculate the orbital speed of S_1.

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

(e) Calculate the mass of S_2.

mass = ______________________________ kg **[3]**

40 Planets **X** and **Y** each have a single moon.

Planet **X** has twice the mass of planet **Y**. The orbital radius of the moon around planet **X** is three times the orbital radius of the moon around planet **Y**.

The gravitational potential of the planet **X** is V_X at the position of its moon. The gravitational potential of the planet **Y** is V_Y at the position of its moon.

What is the value of the ratio $\frac{V_X}{V_Y}$?

A 0.22
B 0.67
C 1.50
D 6.00

Your answer

[1]

41 A satellite is in a circular orbit around the Earth. The vertical **height** of the satellite above the surface of the Earth is 3200 km. The radius of the Earth is 6400 km.

What is the ratio

$$\frac{\text{weight of satellite in orbit}}{\text{weight of satellite on the Earth's surface}}?$$

A 0.25
B 0.44
C 0.50
D 0.67

Your answer

[1]

42 A group of students have gathered data on four stars from the Internet. The information is shown in the table below.

Star	T / K	λ_{max} /µm
Antares	3.1×10^{3}	9.4×10^{-1}
Zeta	3.0×10^{4}	9.7×10^{-2}
Vega	9.3×10^{3}	3.1×10^{-1}
OTS-44	2.3×10^{3}	1.3×10^{0}

The surface temperature of the star in kelvin is T and λ_{max} is the wavelength of the emitted electromagnetic radiation at which the intensity is maximum.

A sensor of cross-sectional area 4.0×10^{-4} m^2 mounted on a satellite orbiting the Earth is used to gather the electromagnetic radiation from the star Antares.
Antares is 550 light years from the Earth. The radiant power entering the sensor from Antares is 2.6×10^{-11} W.

(i) Calculate the luminosity L of Antares.

L = ______________________________ W **[3]**

(ii) Use your answer in **(i)** and the data in the table to calculate the radius r of Antares.

r = ______________________________ m **[2]**

(iii) The mean density of Antares is 4.4×10^{-5} kg m^{-3}.

Calculate the gravitational field strength g at the surface of Antares.

g = ______________________________ N kg^{-1} **[2]**

43 This question is about helium in the atmosphere of the Earth.

Experiment shows that most of the Earth's atmosphere is contained within a very thin shell around the surface of the Earth. Less than 0.0001% of this is helium.

The height of the atmosphere is negligible compared with the radius *R* of the Earth.

(i) Show that the minimum speed v_E required for an atom or molecule to escape from the top of the Earth's atmosphere is given by the expression

$$v_E = \sqrt{2gR}\,.$$

[3]

(ii) The radius *R* of the Earth is 6.4×10^6 m. Calculate this escape speed v_E.

v_E = ____________________________ m s^{-1} **[1]**

(iii) Calculate the temperature *T* in kelvin required at the top of the Earth's atmosphere for the root mean square speed $c_{r.m.s.}$ of the helium atoms there to equal this escape speed.

Molar mass of helium = 0.004 kg mol^{-1}

T = ____________________________ K **[3]**

(iv) Fig. 1 shows the distribution of the speeds of the atoms of an ideal gas.

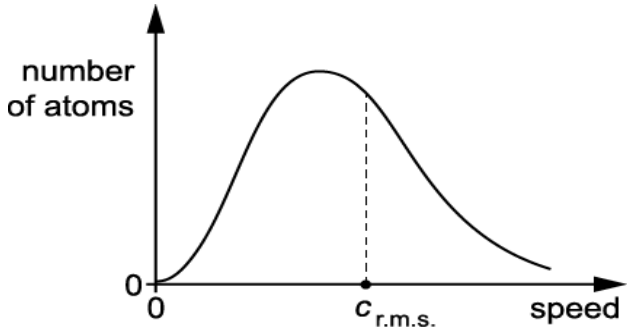


Fig. 1

Use your knowledge of the kinetic theory of gases to describe the shape of this distribution and explain why some helium is able escape from the Earth.

____

____

____

____

____

____

____

____ **[4]**

(v) Over a very long period of time all of the helium should have escaped from the Earth. Suggest why there is still a small amount of helium, about 0.0001%, in the Earth's atmosphere.

____

____

____ **[2]**

44 Which of the following is a correct unit for gravitational field strength?

A $J\ kg^{-1}$

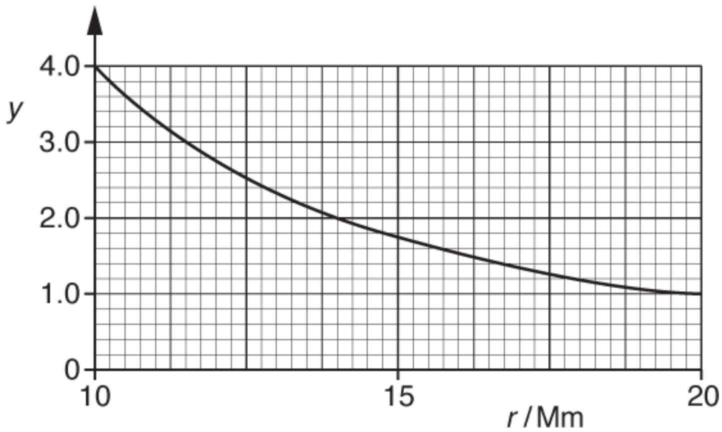
B $N\ kg^{-1}$

C $N\ m^2\ kg^{-2}$

D $kg\ m\ s^{-1}$

Your answer [1]

45 A graph of *y* against distance *r* from the centre of a planet is shown below.



The graph shows that *y* is inversely proportional to r^2.

Which quantity is best represented on the *y*-axis of the graph?

A Period of a satellite orbiting the planet.

B Gravitational potential of the planet.

C Gravitational field strength of the planet.

D Kinetic energy of a satellite orbiting the planet.

Your answer [1]

46(a)

Write an expression for the gravitational potential V_g at the surface of a planet of mass M and radius r.

[1]

(b) The table below shows some data for Mercury and Pluto.

	Mass / kg	Radius / m	Mean distance from Sun / m
Mercury	3.30×10^{23}	2.44×10^{6}	57.9×10^{9}
Pluto	0.131×10^{23}	1.19×10^{6}	5910×10^{9}

(i) Show that the escape velocity v of a gas molecule on the surface of Pluto is given by the equation

$$v = \sqrt{\frac{2GM}{r}}$$

where M is the mass of Pluto and r is its radius.

[2]

(i) Calculate the escape velocity v of gas molecules on the surface of Pluto.

v = ____________________ m s^{-1} **[1]**

(ii) Explain why Mercury has no atmosphere whilst Pluto still has a thin atmosphere. Use data from the table to support your explanation.

--- **[3]**

47 Earth has a mass of 6.0×10^{24} kg and a radius of 6400 km.
A satellite of mass 320 kg is lifted from the Earth's surface to an orbit 1200 km above its surface.

What is the change in the gravitational potential energy of the satellite?

A 9.1×10^{2} J
B 9.9×10^{6} J
C 3.2×10^{9} J
D 3.8×10^{9} J

Your answer ☐ **[1]**

Phobos is one of the two moons orbiting Mars. Fig. 17.1 shows Phobos and Mars.

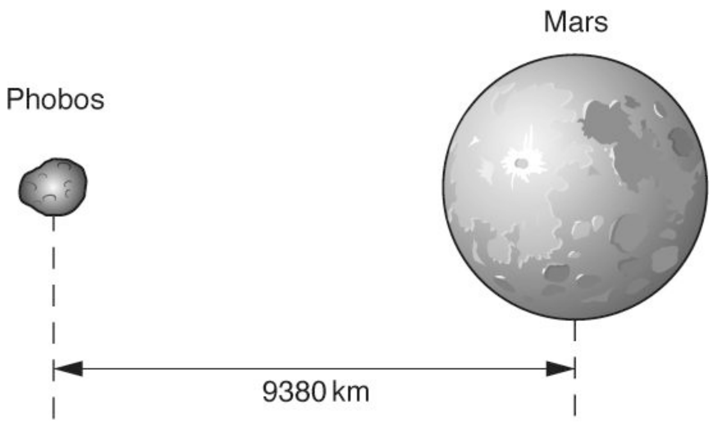


Fig. 17.1

The orbit of Phobos may be assumed to be a circle. The centre of Phobos is at a distance 9380 km from the centre of Mars and it has an orbital speed 2.14×10^3 m s^{-1}.

(i) On Fig. 17.1, draw an arrow to show the direction of the force which keeps Phobos in its orbit. **[1]**

(ii) Calculate the orbital period *T* of Phobos.

T = ____________________________________ s **[2]**

(iii) Calculate the mass *M* of Mars.

M = ____________________________________ kg **[3]**

49(a) A binary star is a pair of stars which move in circular orbits around their common centre of mass.

In this question consider the stars to be point masses situated at their centres.

Fig. 3.1 shows a binary star where the mass of each star is *m*. The stars move in the same circular orbit.

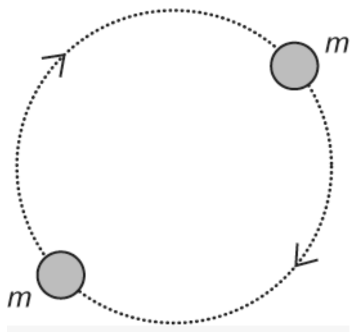


Fig. 3.1

(i) Explain why the stars of equal mass must always be diametrically opposite as they travel in the circular orbit.

--- [2]

(ii) The centres of the two stars are separated by a distance of $2R$ equal to 3.6×10^{10} m, where R is the radius of the orbit. The stars have an orbital period T of 20.5 days. The mass of each star is given by the equation

$$m = \frac{16\pi^2 R^3}{GT^2}$$

where G is the gravitational constant.

Calculate the mass m of each star in terms of the mass $M_{\odot}$ of the Sun.

1 day = 86400 s
$M_{\odot} = 2.0 \times 10^{30}$ kg

m = ………………………………… $M_{\odot}$ **[3]**

(iii) The stars are viewed from Earth in the plane of rotation.
The stars are observed using light that has wavelength of 656 nm in the laboratory. The observed light from the stars is Doppler shifted.

Calculate the maximum change in the observed wavelength $\Delta\lambda$ of this light from the orbiting stars. Give your answer in nm.

$\Delta\lambda$ = ………………………………… nm **[2]**

(b) Fig. 3.2 shows a binary star where the masses of the stars are 4*m* and *m*.

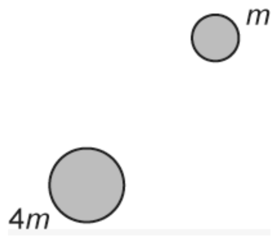


Fig. 3.2

(i) The centre of mass of the binary star lies at the surface of the star of mass 4*m*. Draw on **Fig. 3.2** two circles to represent the orbits of **both** stars. **[1]**

(ii) Explain why the smaller mass star travels faster in its orbit than the larger mass star.

--- **[2]**

50(a)

An isotope of polonium-213 ($^{213}_{84}Po$) first decays into an isotope of lead-209 ($^{209}_{82}Pb$) and this lead isotope then decays into the stable isotope of bismuth (Bi).

Fig. 24 shows two arrows on a neutron number *N* against proton number *Z* chart to illustrate these two decays.

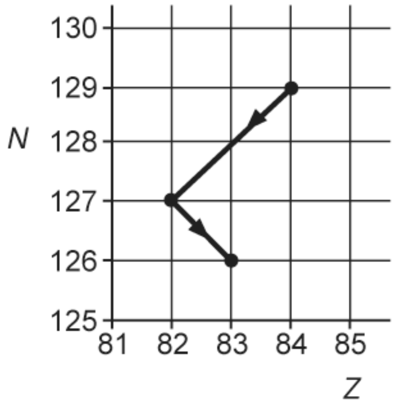


Fig. 24

Complete the nuclear decay equations for

(i) the polonium isotope

$$^{213}_{84}Po \longrightarrow {}^{209}_{82}Pb + \text{..................}$$ **[1]**

(ii) the lead isotope.

$$^{209}_{82}Pb \longrightarrow {}^{\dots\dots}_{83}Bi + {}^{0}_{-1}e + \text{..................}$$ **[2]**

(b) A pure sample of polonium-213 is being produced in a research laboratory.

The half-life of ${}^{213}_{84}Po$ is very small compared with the half-life of ${}^{209}_{82}Pb$.

After a very short time, the ionising radiation detected from the sample is mainly from the beta-minus decay of the lead-209 nuclei.

(i) Briefly describe and explain an experiment that can be carried out to confirm the beta-minus radiation emitted from the lead nuclei.

-- [2]

(ii) The activity of the sample of ${}^{209}_{82}Pb$ after 7.0 hours is 12 kBq.

The half-life of ${}^{209}_{82}Pb$ is 3.3 hours.

Calculate the initial number of lead-209 nuclei in this sample.

number of nuclei = ------------------------------ [4]

51 The Earth is surrounded by a gravitational field.

Which of the following statements is/are correct about the gravitational field lines near the surface of the Earth.

1 They are parallel.
2 They show the direction of the force on a small mass.
3 They are equally spaced.

A Only 1

B Only 1 and 2

C Only 2 and 3

D 1, 2 and 3

Your answer [ ] **[1]**

52 A student has collected some data on the Solar System.

The student plots a graph, but only two data points are shown below.

The distance from the centre of the Sun is *r*.

Which quantity *y* is represented on the vertical axis?

A Speed of a planet.

B Period of a planet.

C Gravitational potential of the Sun.

D Gravitational field strength of the Sun.

Your answer **[1]**

53 Kepler's third law can be applied to a satellite in a geostationary orbit around the Earth.

(i) Complete the equation for Kepler's third law below.
You do not need to define any of the terms.

$$\text{.......................} = \frac{4\pi^2}{GM} \text{ ....}$$ [1]

(ii) The mass of Earth is 6.0×10^{24} kg.
Calculate the radius of the circular path of a satellite in a geostationary orbit around the Earth.

radius = ... m **[2]**

54 The galaxies in the Universe may be assumed to be distributed uniformly through space.

In this model, the separation between two neighbouring galaxies is 1.4×10^{23} m and each galaxy occupies a cube of space of volume 2.7×10^{69} m3 as shown in Fig. 24.2.

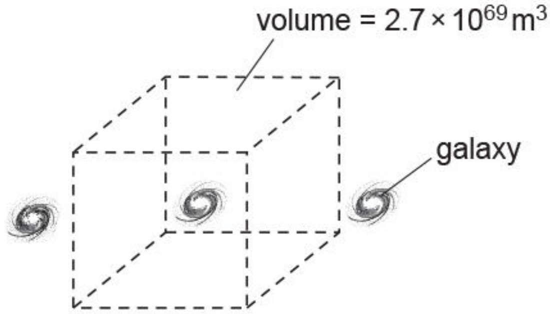


Fig. 24.2

There are on average 10^{11} stars in each galaxy and the mass of an average star is about 2.0×10^{30} kg.

(i) Estimate the gravitational force between two neighbouring galaxies.

force = ... N **[2]**

(ii) Show that the mean density of the Universe is about 7×10^{-29} kg m^{-3}.

[1]

(iii) Suggest why the actual mean density of the Universe is different from the value calculated in (ii).

[1]

55 The gravitational force between two point-mass objects **X** and **Y** is F_1.

The mass of **X** increases and the distance between **X** and **Y** is halved.

Which statement about the new gravitational force F_2 between these two objects is correct?

A $0 < F_2 < 0.25F_1$

B $F_2 > 4F_1$

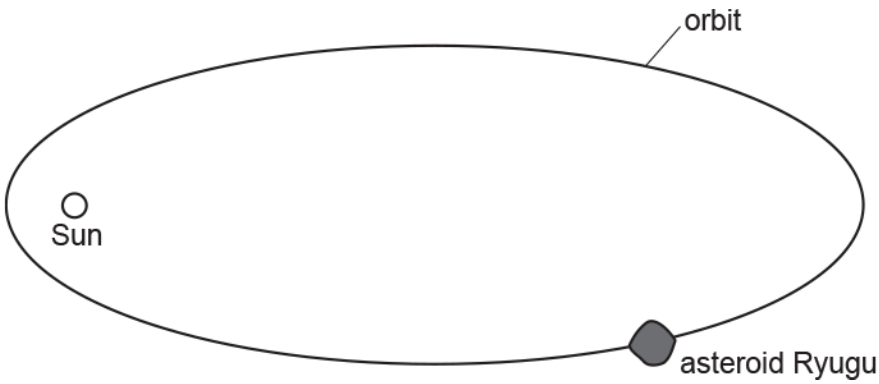
C $F_2 = F_1$

D $2F_1 < F_2 < 4F_1$

Your answer [1]

56(a) In June 2018, the spacecraft Hayabusa2 arrived at an asteroid called Ryugu.

The asteroid orbits the Sun in an elliptical orbit as shown below.



The diagram is **not** drawn to scale.

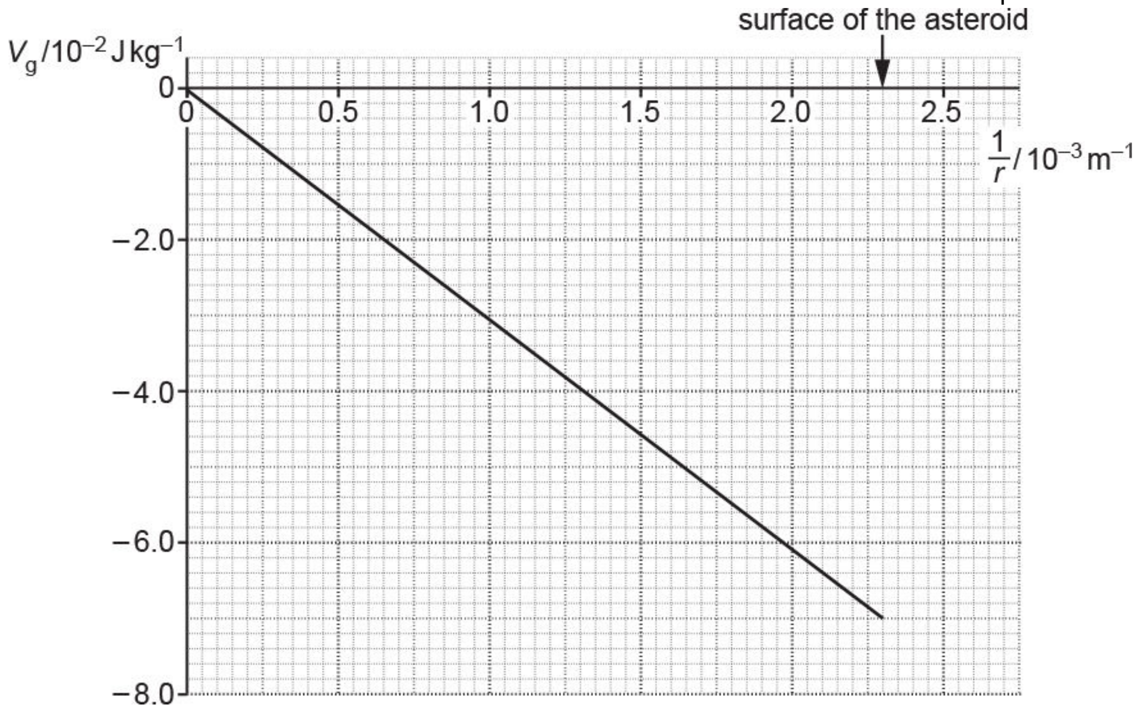
(i) Indicate with a letter **X** on the orbit where the asteroid would be moving at maximum speed. **[1]**

1 Use Kepler's **second law** to explain your answer to **(a)(i)** .

---

[2]

(b) The gravitational potential at a distance *r* from the centre of the asteroid Ryugu is *V*g. The graph of *V*g against $\frac{1}{r}$ for the asteroid is shown below.



(i) Define **gravitational potential** .

---

[1]

(ii) Show that the magnitude of the gradient of the graph is equal to *GM*, where *M* is the mass of the asteroid and *G* is the gravitational constant.

[1]

(iii) Use the gradient of the graph to show that the mass *M* of the asteroid is about 4.6×10^{11} kg.

M = ... kg **[2]**

(c) In October 2018, the probe Mobile Asteroid Surface Scout (MASCOT) was released from **rest** from the Hayabusa2 spacecraft from a distance of 600 m from the centre of the asteroid.

Assume that the spacecraft was stationary relative to the asteroid when MASCOT was dropped.

Use information from **(b)** to calculate the speed of the impact *v* when MASCOT landed on the surface of the asteroid.

v = ... m s^{-1} **[3]**

END OF QUESTION PAPER

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
1	a		Resultant force from springs is proportional to displacement from centre **or** acceleration (of mass) is proportional to displacement from centre. Directed to centre or fixed point.	B1 B1	
	b		Graph correct shape and always positive and suitable scale on kinetic energy axis. Maxima occur at zero displacement times.	B1 B1	
	c	i i	Period from graph = 500/3.5 = 143 ms Acceleration = $\omega^2 A = (2\pi/0.143)^2 \times 0.006$ = 12 (ms^{-2})	C1 A1	
		ii ii	KE = $0.5 \times 0.005 \times (2\pi / 0.143 \times 0.006)^2$ KE = 1.7×10^{-4} (J)	C1 A1	
	d		**Accept any sensible and successful method.** **Stroboscope:** Any two from • Use of stroboscope of known frequency or period • Photograph to capture several positions on one picture • Measure displacement from centre using a scale put behind the mass. **or** **Motion sensor:** Any two from • Motion sensor connected to data logger which sends information on displacement and time to computer. • Sensor placed close to moving mass to eliminate reflections from other objects. • Small reflector attached to mass.	B1 × 2	Video camera with freeze frame facility, where time between frames is known. Apply marking points as for the stroboscope.

Question			Answer/Indicative content	Marks	Guidance
			Safeguards to ensure accuracy **Stroboscope:** Any two from • Use frequency such that positions of mass are close together on photograph. • distance scale close to oscillating mass or camera set back from mass to reduce parallax. • Camera should be directed at equilibrium point or at 90° to oscillation. **or** **Motion sensor:** Any two from • Any attached reflector should not cause damping. • Motion sensor directed along line of oscillation or motion sensor signal blocked by supports so must be as near to line of oscillation as possible. • Use thin supports to reduce reflections.	B1 × 2	
			Total	12	
2			A	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
3	a		3.6 ± 0.4 ($m^2\ s^{-2}$)	B1	
	b	i	Data point and error bar correctly plotted	B1	**Allow** ecf from previous part.
		ii	* **Level 3 (5–6 marks)** Detailed analysis of the graph clearly linked to the principle of conservation of energy, including determination of the value of *g* and the related uncertainty in the answer. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Analysis of the graph linked to kinetic energy and / or potential energy, with an attempt to find the value of *g*. Mention of where one would find uncertainties in the answer but without analysis. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Line of best fit drawn and gradient attempted. Mention of energy and / or where uncertainties may occur. *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.	B1 × 6	**Explanation** 1 Principle of conservation of energy used to derive relationship. 2 $mgh = ½ mv^2$ or $v^2 = 2gh$ 3 A graph of v^2 against *h* will be a straight line (through the origin). 4 Gradient of line = 2*g*. **Determination** 1 Line of best fit drawn through all data points. 2 Gradient in the range 17 to 21 ($m^2\ s^{-2}$). 3 *g* determined correctly from the gradient. **Uncertainty** 1 Worst line of fit drawn. 2 Correct attempt to determine the uncertainty.
			Total	**8**	

Question			Answer/Indicative content	Marks	Guidance
4	a	i	Straight line through the origin	M1	
		i	Negative gradient and symmetrical about (0,0) by eye.	A1	**Examiner's Comments** Most candidates did well and secured two marks for drawing a straight line through the origin with negative gradient. Most of these graphs were carefully drawn and were consequently easy to mark. A wide variety of incorrect graphs were drawn ensuring that the question differentiated across the entire spectrum of abilities.
		ii	Linking gradient to $[2\pi f]^2$.	C1	**Allow:** use of a single data point used in $a = (-)[2\pi f]^2 x$
		ii	$\text{Frequency} = \frac{\sqrt{\text{gradient}}}{2\pi}$	A1	**Note** frequency must be the subject of this equation Almost half of the candidates gave good answers correctly related to their acceleration against displacement graph plotted in (i). Since the graph was drawn through the origin, examiners allowed use of a point taken from the straight line as an alternative to the expected gradient. A significant number clearly knew how to get the frequency but failed to score the second mark by stating '*transpose the equation to get frequency*' rather than quoting a formula with frequency as the subject. A small number also lost this mark as a result of imprecisely drawing their square root sign so that the division by 2? was incorrectly shown.
	b	i	$A = \frac{v_{max}}{2\pi f} = \frac{0.09}{2\pi \times 8.0}$	C1	**Allow:** values for T in range 0.125 to 0.13s
		i	$A = 1.8 \times 10^{-3}$ (m)	A1	

Question			Answer/Indicative content	Marks	Guidance
		i			**Examiner's Comments** Most candidates recognised the need to use $v_{max} = 2\pi f A$ to obtain the amplitude. On the whole the calculation was carefully done and the answer correctly rounded to at least two significant figures. A surprisingly large number of candidates misread the *v* scale as 0.9 at maximum and lost one mark. It was pleasing to note that few candidates attempted to answer this question using 'suvat' equations.
		ii	$a_{max} = (2\pi f)^2 A$		Possible ecf from b(i)
		ii	$a_{max} = (2\pi \times 8.0)^2 \times 1.8 \times 10^{-3}$ $a_{max} = 4.5\ (\text{ms}^{-2})$	C1 A1	**Allow:** Tangent drawn on graph at any $v = 0$ point (C1) calculation of gradient (A1)
		ii			**Examiner's Comments** Given the application of error carried forward from (i) most candidates scored full marks; choosing the $amax = (2\pi\ f)^2\ A$ approach. A small number of candidates used a graphical method most of which showed a clear tangent at one of the $v = 0$ points. The scale of the graph did not allow for great accuracy using this method and marks were awarded for obtaining an answer in a fairly wide range. A minority of candidates unwisely used two points positioned on the curve to determine the gradient usually resulting in a substantial error.
	c		Curve with same frequency / period	B1	**Allow**: ½ small square error on $v = 0$ points

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			max velocities decreasing at **three** successive **positive** peaks	B1	**Examiner's Comments** The examiners recognised that it was difficult to accurately draw the required curve and focused their attention on two features: • The points at which the curve crossed the time axis • The height of the positive peaks. A wide range of curves were seen; many of them were carefully drawn and easily meeting the two criteria. A common error seen was a graph of correct frequency but with constant maximum velocity. The question succeeded in discriminating across the entire spectrum.
	d		Axes labelled and graph showing correct bell shaped curve (amplitude increases then decreases) Maximum / largest amplitude or energy at f=8 Hz / natural frequency When driving / oscillator's frequency is equal to natural frequency / 8 Hz **resonance** occurs (AW).	B1 B1 B1	**Allow** this mark if curves are drawn asymptotically (to 8 Hz) May be scored on diagram or in text  **'resonance'** / **'resonant'** to be spelled correctly for this mark to be scored. **Examiner's Comments** The majority of candidates did well in this question and scored two or more marks. A significant minority did not realise that the question was about resonance and wrote, sometimes at length, about frequencies, phase and even wavelength. None of these answers could be awarded any marks. Those drawing resonance curves generally produced reasonable diagrams with good labelling which was appreciated by the Examiners.
			Total	13	

Question			Answer/Indicative content	Marks	Guidance
5	a	i	T = 2.4 (s) f = 1/T = 1/2.4 = 0.42 (Hz)	A1	No marks for T = 3 (s) leading to f = 0.33 (Hz).
		ii	$v_{max} = 2\pi fA$		**Allow:** Tangent drawn on graph at any × = 0 point (C1) calculation of gradient to give value in range 0.12 to 0.14 (m s^{-1}) (A1)
		ii	$v_{max} = 2\pi \times \frac{1}{2.4} \times 50 \times 10^{-3}$	C1	Mark is for substitution. Possible ecf from a(i).
		ii	v_{max} =0.13 (m s^{-1})	A1	Answer to 3 sf = 0.131 (m s^{-1}). Expect v_{max} = 0.10 (m s^{-1}) if answer in (i) f = 0.33 Hz (T=3). **Examiner's Comments** Almost all candidates were able to score full marks in this question. Only a minority making errors in reading the scales given on the graph.
	b	i	frequency is the same / not changed since (in SHM) it is independent of amplitude / (starting) displacement (AW)	B1	**Allow:** …since length of pendulum is unchanged
		ii	(maximum velocity) is reduced because amplitude / (starting) displacement is reduced (AW)	B1	**Allow:** (Max) KE is smaller since amplitude / (starting) displacement is smaller
		ii	(Max) KE is reduced to one quarter / 4 times smaller	B1	**Allow:** (Max) KE is smaller because GPE is smaller **Examiner's Comments** This was another question requiring a reason from candidates and all too often this was not given at all or was only partially stated by the observation that the periodic time had not changed.
	c	i	Straight line through origin means acceleration ∝ displacement	B1	**Allow:** Straight line through origin means a ∞ x

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		i	Negative gradient means acceleration and displacement are in opposite directions / acceleration directed is towards the midpoint / equilibrium point (AW)	B1	**Allow:** 1 mark for straight line through origin and negative gradient means $a \propto -x$ (hence SHM) **Examiner's Comments** This question also discriminated well, largely as a result of candidates not reading the question carefully. The vast majority knew the conditions for SHM and stated them accurately but failed to relate them in any way to the features of the graph. Full credit was only given if both requirements were clearly linked to the separate features of the graph. A significant number of candidates were under the impression that any straight line graph indicated direct proportionality and made no mention of the fact that the graph passed through the origin.
		ii	(Magnitude) Gradient = ω^2 = 5 / 0.004 = $(2\pi f)^2$	C1	C1 mark is for substitution of gradient for ω^2 or $(2\pi f)^2$
		ii	f = 5.6 (Hz)	A1	Answer to 3 sf = 5.63 (Hz) **Allow:** 1 mark for f = 0.178 (Hz) not converting mm to m **Examiner's Comments** Most candidates scored full marks in this calculation. The most commonly seen error was the omission of the millimetre to metre conversion in the determining the gradient. Only a small minority made errors in handling the square root which was encouraging.
			Total	10	

Question			Answer/Indicative content	Marks	Guidance
6		i	5 (mm).	A1	
		ii	1.0 mark on scale at peak of curve.	B1	minimum requirement for mark: 0 to 3 Hz marked at 1 Hz intervals along axis.
		iii	approx. same (or slightly lower) resonance frequency.	B1	
		iii	smaller amplitude/broader peak *but curves must not cross* and passes through (0, 5 mm).	B1	
			Total	4	
7	a	i	$a = (–)\ 4\pi^2 f^2 x = 4 \times 9.87 \times 4900 \times 0.004$	C1	**allow** 774 (m s^{-2})
		i	a = 770 (m s^{-2})	A1	
		ii	**1** sketch showing one wavelength and 140 (Hz)	B1	both sketch and value required for 1 mark
		ii	**2** driving force is around nodal point / AW;	B1	**max** 3 of the 4 marking points
		ii	points either side of nodal point try to move in opposite directions when force in one direction / AW;	B1	
		ii	move magnet to antinodal point; ¼ of distance between clamps	B1	**not** increase current
	b	i	*f α* √T so f = 70/√2 = 49 or 50 Hz	B1	
		ii	**1** μ increases / goes up by 0.4%	B1	**allow** +0.4% NOT 0.4%
		ii	**2** 0.2%,	B1	**or** half of answer to **(ii)1**
		ii	f is lower because μ is bigger and μ is on the bottom of the formula	B1	**or** greater inertia present with same restoring force / other physical argument
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
8	a	i	C and F	B1	**Examiner's Comments** Most candidates secured the first mark by identifying correctly the two points at the amplitude position.
		ii	G	B1	**Examiner's Comments** It was disappointing to see that only a small minority were able to distinguish the lagging point from the leading point. As a result this became a very discriminating question.
		iii	$5\pi/4$ (= 1.25 π) or 3.93 (rad)	B1	
	b	i	Correct shape graph (by eye)	B1	
		i	Through the points (–5,0) (0,50) and (5,0)	B1	**Note :** Max KE = 80 – 30 = 50 (mJ) **Examiner's Comments** Most candidates gave a correctly shaped curved graph but only a minority were able to correctly locate the maximum point at 50 mJ.
		ii	$\frac{1}{2}(0.45)v_{max}^2 = 50 \times 10^{-3}$ $v_{max} = 0.47$ (m s^{-1})	A1	**Allow** ECF if max value on y axis from b(i) is used. If max KE = 80 mJ then v_{max} = 0.596 = 0.60 (m s^{-1}) **Examiner's Comments** Given the application of 'error carried forward' the majority were able to score full marks here. The most common error seen was the failure to correctly interpret the milli prefix in the energy units.
		iii	$v_{max} = \frac{2\pi A}{T}$		
		iii	$T = \frac{2\pi(5.0\times10^{-2})}{0.47}$	C1	**Allow** C1 mark for correct frequency =1.5 (Hz) ECF from b(ii)

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	T = 0.67 (s)	A1	Using v_{max} = 0.60 leads to T = 0.52 (s) and using v_{max} = 0.596 leads to T = 0.53 (s) **Examiner's Comments** Many recognised the need to use v_{max} = $2\pi f A$ to obtain the frequency and subsequently the period. On the whole the calculation was carefully done and the answer correctly rounded to at least two significant figures. It was pleasing to note that few candidates attempted to answer this question using 'suvat' equations.
			Total	8	
9			A	1	
			Total	1	
10			B	1	
			Total	1	

Question			Answer/Indicative content	Marks	Guidance
11	a		Force the mass to oscillate with a periodic force. (AW)	B1	
			The mass oscillates at maximum amplitude when the forcing frequency is equal to the natural frequency of the spring–mass system. (AW)	B1	
	b	i	$\omega = 2\pi \times 1.2$	C1	
		i	($a_{max} = \omega^2 A$); $a_{max} = [2\pi \times 1.2]^2 \times 3.0 \times 10^{-2}$	C1	
		i	maximum acceleration = 1.7 (m s^{-2})	A1	
		ii	Correct curve with peak of greater amplitude.	B1	
		ii	Peak slightly right of first curve.	B1	**Allow** graph peaking at 1.2 (Hz)
	c	i	Using the graph to determine at least two ratios of the amplitudes.	M1	For example: 2.5/3.0 and 2.1/2.5
		i	Correct statement matching the ratios.	A1	For example: 'The statement is correct because 2.5/3.0 ≈ 2.1/2.5 ≈ constant. '
		ii	At time $t = 0$	M1	
		ii	Oscillator has maximum speed and hence the greatest friction. (AW)	A1	
			Total	11	
12		i	$a = 4\pi^2 f^2 \times$	C1	condition for SHM
		i	so $k = (m4\pi^2 f^2) = 1.7 \times 10^{-27} \times 4 \times 9.87 \times 43.7 \times 10^{26}$	B1	substitution
		i	k = 292 (N m^{-1})	A1	**ecf** if incorrect mass used
		ii	(N2 gives) $F_H = m_H a_H$ and $F_I = m_I a_I$	B1	**allow** total momentum = 0 at all times
		ii	(N3 gives) $F_H = F_I$ *can be implicit*	B1	SHM gives $v = 2\pi f x_{max}$
		ii	SHM gives a α (–)x	B1	so $m_H X_H = m_I x_I$
		ii	hence $x_H/x_I = a_H/a_I = m_I/m_H = 127$	B1	**accept** $127 = x_H/x_I \approx 10/0.08 = 125$
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
13	a	i	$\omega^2 = g/L$ $\omega = \frac{2\pi}{T}$ Correct substitution $\frac{4\pi^2}{T^2} = \frac{g}{L}$ and rearranging to give correct expression	M1 M1 A1	**Note:** Both M1 marks are required to score this A1 mark **Examiner's Comments** Most students had considerable success in deriving the required expression.
		ii	Transfer of **energy** to air / retort stand (because of air resistance / friction) No effect on T (as T is independent of amplitude in SHM for small amplitude oscillations of pendulum)	B1 B1	**Allow** 'loss of energy from pendulum (due to friction)' **Allow** 'work done' for 'energy' **Allow** 'isochronous' **Examiner's Comments** A pleasingly large proportion of students remembered that specification point 5.3.1 (f) states that the period of a simple harmonic oscillator is independent of its amplitude. A similarly large proportion referred to damping or action of the drag force but fell slightly short of the idea that the effect of that force is to reduce the energy stored in the pendulum.

Question			Answer/Indicative content	Marks	Guidance
	b		**Level 3 (5–6 marks)** Clear description including steps to obtain high quality data **and** analysis *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Clear description **and** some analysis *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description **and** analysis **Or** limited description *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.	B1 × 6	**Indicative scientific points may include:** **Experiment** **Description** • Pendulum string clamped / fixed (can be shown on diagram) • Use a stopwatch to determine time period *T* • Time multiple oscillations to determine *T* • Use a ruler to measure *L* • Vary length *L* and determine *T* **Quality of Data** • Method used to ensure small oscillations • Small angles i.e. <10 degrees • Idea of fiducial mark • Start / stop timing at the centre of the oscillation • Measure from the fixed point to the centre of the bob **Analysis** • Correct plotting of graph, e.g. T^2 against *L* or *T* against $\sqrt{L}$ or lg *T* against lgL • Analysis of data table showing T^2/L = constant

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					• Expect a straight line through the origin • Correct gradient of the line e.g. $4\pi^2/g$ Use only L1, L2 and L3 in RM Assessor. **Examiner's Comments** While a small number of candidates described the incorrect experiment (such as masses on a spring or circular motion) most candidates made excellent attempts to describe the experiment and the ensuing analysis. References to even the most basic equipment are essential, such as measuring lengths with a ruler and periods of time with a stopwatch or other suitable timer. Candidates that did neither could not score higher than Level 1. Level 3 responses included ideas about achieving high quality data, such as use of a fiducial mark, starting the oscillation count (and hence the timer) at the midpoint where the pendulum bob is fastest, stating a suitable small angle of ten degrees or less and how to achieve that consistently with a protractor and by measuring the length of the string from the suspension point to the centre of the bob. By far the preferred method of analysis leading to verification of the relationship was plotting a graph of T^2 against L and expecting the trend to be not only straight but also through the origin with a gradient of ($4\pi^2/g$). An acceptable alternative was to suggest calculating several values of (T^2/L) and demonstrating that ratio to be constant and equal to ($4\pi^2/g$). Note that writing 'Plot a graph of T^2/L' is not an acceptable short hand for 'plot T^2 on the y-axis and L on the x-axis.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c	i	Correct substitution of T= 2(.0 s) into $T^2 = \frac{4\pi^2}{g}L$ length = 0.99 (m)	C1 A1	**Note:** 1 (m) here cannot score this A1 mark **Examiner's Comments** A large majority of candidates successfully showed that the pendulum length should be 0.99m for a 'tick' length of 1.0 seconds. Candidates that attempted the reverse argument, by assuming a length of 1 m and then calculating the corresponding length, were usually unable to show the period of the resulting pendulum was 2.01s. Candidates that showed how to arrive at this period gained full credit.
		ii	Lower g / gravitational field strength / acceleration (of free fall) on Moon. T is longer (on Moon) **and** justified by $T^2 = \frac{4\pi^2}{g}L$ or $T^2 \propto 1/g$ or $\frac{4\pi^2}{g}$ is larger	B1 B1	**Accept** 'g is a sixth of g on Earth' AW **Not** gravity (is less) **Examiner's Comments** Many candidates suggested that g is less on the Moon than it is on the Earth, gaining one mark of credit. Most candidates suggested that would mean the period of the pendulum would be larger, but did so without justification from the formula in the question or contradicted themselves by stating that would make the pendulum 'run faster'.
			Total	15	

Mark Scheme

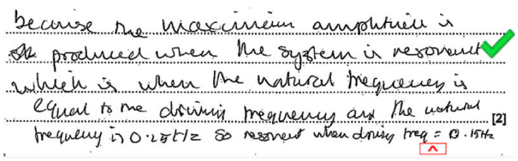
Question			Answer/Indicative content	Marks	Guidance
14		i	sin **or** cos wave with 1.5 wavelengths (between **C** and **R**) y-axis showing scale, i.e. (amplitude) 2.(0) × 10^{-6} (m) correct scale on x-axis showing λ = 0.2 (m) **X** and **Y** labelled at adjacent intercepts on x-axis	**B1** **B1** **B1** **B1**	 unit must be present, e.g 10^{-6} m **NOT** if axis labelled time **Examiner's Comments** Most candidates correctly labelled the scale on the displacement axis of the sinusoidal graph that they drew. The points where the air particles were moving the fastest were also well known. Fewer labelled *distance* on the x-axis, many incorrectly writing *time.* Only the better candidates marked the correct scale on this axis and very few indicated that there were 1.5 wavelengths between the points **C** and **R.**

Question			Answer/Indicative content	Marks	Guidance
		ii	1 $v = A\omega$ **or** $2\pi fA$ $v = (2 \times 10^{-6} \times 2 \times 3.14 \times 1.7 \times 10^{3} =)$ 2.1×10^{-2} (m s^{-1}.) 2 $½Mv^2 = 3/2\ RT$ and $T = 290$ $v = \sqrt{(3 \times 8.31 \times 290 / 0.029)}$ $v = 5(.0) \times 10^{2}$ (m s^{-1}.)	C1 A1 C1 A1	**or** $½mv^2 = 3/2\ kT$ so $v^2 = 3\ (k / m)\ 290$ **N.B. remember to record a mark out of 4 here** **Examiner's Comments** Answers were generally well structured into two sections, one for each experiment. A few candidates thought they could measure the wavelength on the oscilloscope screen. In experiment (a) most understood that the phase difference between the two oscillations at the microphone changed as one speaker was moved away. Explanations often muddled *path* and *phase* difference or referred to *nodes* and *antinodes* detected by the microphone. Some candidates misinterpreted the experiment moving the microphone to detect interference fringes, allowing the double slits formula to be used to find the wavelength. Others thought that Doppler shift was applicable. For experiment (b) many candidates used *maxima* and *minima* in place of *antinodes* and *nodes* although most recognised this to be a *standing* wave situation. Quite a few candidates ignored the instruction about reducing the uncertainty. The best candidates suggested reducing the frequency to reduce the percentage uncertainty in the wavelength measurement.
			Total	8	

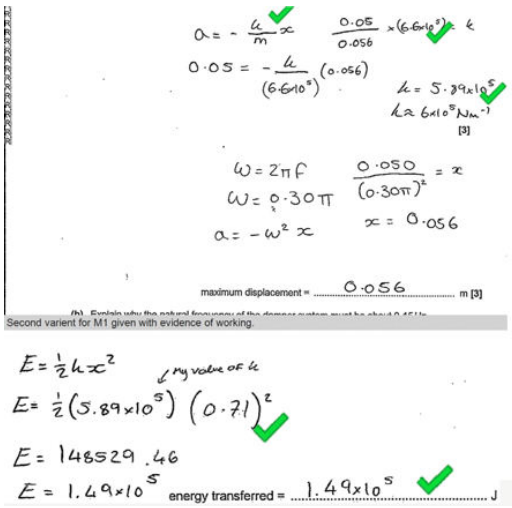
Question			Answer/Indicative content	Marks	Guidance
15			A	1	Examiner's Comments About three quarters of all candidates recognised that since = $-\omega^2 2$, the angular frequency of this motion was 5. Also, since $\omega = 2\pi f$, the frequency must be equal to $5/(2\pi)$.
			Total	1	
16			B	1	Examiner's Comments The damping force is always opposite in direction to velocity. If the displacement is zero, then the speed is greatest and hence the damping force is also greatest in magnitude. The damping force is not always opposite in direction to acceleration, although the displacement must be, according to the definition of SHM.
			Total	1	
17			B	1	Examiner's Comments In SHM, when x = 0, the object is moving at its fastest and so has maximum KE. This in turn means that the PE must be minimum, eliminating option D. The speed of the object slightly away from the point where x=0 does not increase rapidly nor linearly. This only leaves option B.
			Total	1	

Question			Answer/Indicative content	Marks	Guidance
18	a		ω = ($2\pi f$ =) $2\pi \times 0.15$ or 0.3π (= 0.942 rad s^{-1}) a_{max} = ($-\omega^2 A$ =) $4\pi^2 f^2 A = 0.050$ $A = 0.05/(2\pi \times 0.15)^2$ $A = 5.6 \times 10^{-2}$ (m)	C1 C1 A1	ω mark can be implicit in calculation ω^2 = 0.88 or 0.89 using 0.942 or 0.94 **allow** 0.057 (m); **N.B.** answer is 0.053 if use ω instead of ω^2 mark as a TE **max** 2/3 Examiner's Comments The words *simple harmonic motion* in the text pointed almost all candidates to use the correct formula. The angular frequency was calculated correctly. Two common errors were to forget to square the value or to give the final answer to only one significant figure rather than a minimum of two.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		Maximum energy is transferred between tower (driver) and sphere when sphere (driven) is at/close to the natural frequency <u>of the tower</u> **or** in this forced oscillation/resonance situation	B1 B1	**allow** causes maximum damping <u>of the tower</u> **or** maximum amplitude <u>of the sphere</u>/AW **allow** AW e.g. sphere must be driven close to/at the natural/resonance frequency <u>of the tower</u> <u>**Examiner's Comments**</u> The answers gave a clear indication as to how well the candidates understood a resonance situation. Many omitted to explain which of the three oscillating elements were acting as drivers and which were driven. The candidate who wrote the answer (exemplar 3) shown here has some understanding of the situation but has failed to communicate it clearly to the reader. **Exemplar 3**  because the maximum amplitude is produced when the system is resonant which is when the natural frequency is equal to the driving frequency as the natural frequency is 0.28Hz so resonant when driving freq = 0.15Hz [2] The ball was often quoted as just acting against the tower to reduce the amplitude rather than using the clue at the end of the initial paragraph about the energy drawn from the tower being absorbed by the dampers. Hence the requirement for the ball to be given a large amplitude or absorb the maximum amount of energy.
	c	i	$\omega^2 = k/m$ **or** $(2\pi f)^2 = k/m$ **or** $kA = ma_{max}$ $k = (m4\pi^2f^2) = 6.6 \times 10^5 \times (2\pi \times 0.15)^2$ **or** $(k = ma_{max}/A) = 6.6 \times 10^5 \times 0.05/0.056$ $k = 5.9 \times 10^5$ (N m^{-1})	C1 M1 A1	 **allow** ω or ω^2 = 0.88 or 0.89 quoted from **(a)** **ecf** value of A from **(a)** as this is a 'show that' question some definite evidence of working must be shown. **not** $k = 6 \times 10^5$ **allow** answer to 2 or more SF.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$E = ½kA^2 = = 0.5 × 5.9 × 10^5 × 0.71^2$ $E = 1.5 × 10^5$ (J)	C1 A1	**allow** value from (c)**(i)** or 6; **or** a = (k/m)A , F = ma, E = ½F*A* **accept** 1.48 to 1.51 or value from **ecf** **special case:** give 1/2 for $E = 3(.0) × 10^5$ (J) where **it is clear that** 2k has been used as the spring constant __Examiner's Comments__ The exercise in this section completed successfully by most candidates was to perform standard calculations stating correct formulae and showing clear working to determine the required quantities. The example (exemplar 4) shown here is of a typical neat script. The most common error was to forget to square quantities in part (ii) or to use the amplitude calculated part (a) rather than the figure given in the stem of this part. **Exemplar 4** 
			Total	10	

Mark Scheme

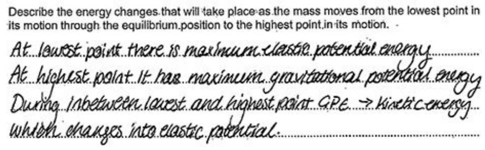
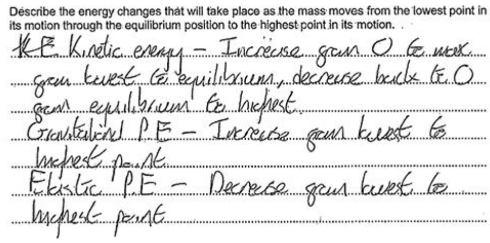
Question			Answer/Indicative content	Marks	Guidance
19			D	1	Examiner's Comments The correct formula here is $v_{max} = A\omega$. This means that to find the angular frequency, ω, you must divide the maximum speed by the amplitude. The amplitude is given in centimetres so that needs to be converted to metres. This gives 24/0.056 = 429 rad s^{-1}, giving the answer D.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
20	a	i	$a = -\omega^2 x$ seen Suitable linking $a = -\omega^2 x$ and either $\omega = 2\pi f$ or $\omega = 2\pi/T$ with substitution f = 1.41 (Hz)	B1 M1 A1	e.g. $4\pi^2 f^2$ = 78.3 or f = sqrt(3.6/4π^2 x 4.6 x 10^{-2}) or f=8.85/2π or T=0.71... **Allow** f = 1.408... (Hz)
		ii	$A = \frac{x}{\cos \omega t}$ or $A = \frac{4.6\times10^{-2}}{\cos(2\times\pi\times1.4\times6.5)}$ (Any subject) A = 0.057 (m)	M1 A1	**Not**: sine for cosine. **Note** A = 0.090(4)(m) if 1.41 used **Note** A = 0.0796 (m) if 1.408 used **Allow** 1 mark for cosine used with calculator in degrees <u>**Examiner's Comments**</u> As the mass is pulled down before release, the mass is away from the equilibrium position. This means that the sine relationship between displacement and time cannot be correct. Many candidates got this idea correct. The relationship *x = A cos(ωt)* requires that the value of *ω*t is expressed in radians. This meant that to calculate the amplitude correctly, the calculator has to be in radians mode, rather than degrees mode.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		EPE decreases (from bottom to top) GPE increases (from bottom to top) KE starts at zero, finishes at zero and max at equilibrium point. Air gains thermal energy / Total energy (of mass and spring) decreases over time	B1 B1 B1 B1	**Not** EPE becomes 0 (or negative) **Allow** for the first two marking points: description that refers to total potential energy starts at maximum, is minimum at equilibrium point and max again at top, provided total potential energy is stated to be the sum of EPE and GPE **Allow** as alternative for first three marks: EPE to KE and GPE in bottom half EPE and KE to GPE in top half EPE at start to GPE at top <u>Examiner's Comments</u> The best way to answer this question is to plan out what happens to each of the relevant energy types. Exemplar 4 starts off well yet is insufficient. Exemplar 5 is far clearer. In this case the relevant energy types are elastic potential, gravitational potential and kinetic energy. Candidates often carefully recalled the details of energy changes for a horizontal mass-spring system, which was incorrect. Earlier in the question, the candidates were told that the spring is always under tension. This means that the elastic potential energy cannot be zero or indeed negative. At the bottom and the top of the motion, the kinetic energy of the system is zero, as the objects have zero velocity. At the equilibrium position, the kinetic energy of the system is maximum. Responses that included merely 'potential energy' were too vague, unless it was clear that the potential energy of this system is the sum of both the gravitational and

Question			Answer/Indicative content	Marks	Guidance
					elastic potential energies. Exemplar 4  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. At lowest point there is maximum elastic potential energy At highest point it has maximum gravitational potential energy During inbetween lowest and highest point GPE → kinetic energy which changes into elastic potential. The first 2 statements in this response are true yet not enough. The third statement is untrue, as it implies that GPE is decreasing (and so contradicts the second statement) and also states that the elastic potential energy is increasing. Zero marks. Exemplar 5  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. KE Kinetic energy – Increase from 0 to max from lowest to equilibrium, decrease back to 0 from equilibrium to highest. Gravitational PE – Increase from lowest to highest point Elastic PE – Decrease from lowest to highest point This response is separated out into the 3 main energy types. The changes for each of the types is correct. The only thing they haven't mentioned is that the total energy of the system will decrease because of the damping effect of the air. 3 marks.

Question			Answer/Indicative content	Marks	Guidance
	c	i	(Smooth) curve showing amplitude increases and then decreases maximum at 1.4 Hz by eye	B1 B1	**Not:** more than 1 peak **Allow:** asymptote instead of peak Examiner's Comments The correct shape for Question 18(c)(i) is a standard resonance curve. The natural frequency of this system is 1.4 Hz, as stated in Question 18(a). This means that the peak of the curve should come at 1.4 Hz. The curve for Question 18(c) needed to be of lower amplitude throughout the frequency range (not including at 0 Hz). Some candidates put the peak of curve D at the same frequency as curve K and others put the peak of curve D slightly to the left. Both were given the mark.
		ii	Curve similar shape yet lower at all non-zero f points with peak shifted slightly to left (of 1.4 Hz)	B1	**Allow:** curve without shifted peak i.e. peak at 1.4 Hz ECF their K curve Examiner's Comments The correct shape for Question 18(c)(i) is a standard resonance curve. The natural frequency of this system is 1.4 Hz, as stated in Question 18(a). This means that the peak of the curve should come at 1.4 Hz. The curve for Question 18(c) needed to be of lower amplitude throughout the frequency range (not including at 0 Hz). Some candidates put the peak of curve D at the same frequency as curve K and others put the peak of curve D slightly to the left. Both were given the mark.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	Bridge close to resonance if frequency of driver is close to natural frequency of bridge (Close to resonance) giving larger amplitude which causes damage or other named consequence	B1 B1	**Allow:** footfall/people walking/wind for driver **Allow:** resonance (occurs) when frequency of driving force is at natural frequency of bridge **Allow**: Maximum for larger **Examiner's Comments** Many candidates linked the possibility of a driving force, such as footsteps or the wind, giving a driver frequency at or near the natural frequency of a bridge and that this phenomenon is known as resonance. The second mark was for a link of the resonance idea of maximum amplitude to a consequence, such as a bridge shaking itself apart or being too unstable for use.
			Total	14	
21			C	1	
			Total	1	
22			B	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
23		i	$x = A\cos(\omega t)$ **or** $x = A\cos(2\pi ft)$ $x = 2.0\cos(2\pi \times 1.4 \times 0.60)$ displacement = 1.1 (cm)	C1 C1 A1	**Note** : Treat use of sine as **TE** **Note** answer is 1.07 (cm) to 3SF **Note** answer if calculator left in degrees of 1.99cm scores 2 marks.
		ii	$(v_{max} =)\ 2\pi \times 1.4 \times 0.02$ maximum speed = 0.18 (m s^{-1})	C1 A1	
		iii	**1** Larger (amplitude) **2** Same (period)	B1 B1	
			Total	7	
24			$a_{max} = -\omega^2 A$ or $a_{max} = -(2\pi f)^2 A$ $\omega = 2 \times \pi \times 5.0 \times 10^8 = 3.1(4) \times 10^9$ (rad s^{-1}) or $10^9\pi$ $a_{max}\ (= \pi^2 \times 10^{18} \times 4.0 \times 10^{-6}) = 3.9 \times 10^{13}$ (m s^{-2})	C1 C1 A1	**Allow** without the minus sign **ECF** from **(a)** **Not** $4.0 \times 10^{12}\pi^2$ <u>Examiner's Comments</u> The words 'simple harmonic motion' in the text prompted almost all candidates to use the correct formula here.
			Total	3	
25			C	1	
			Total	1	

Question			Answer/Indicative content	Marks	Guidance
26	a		Force is proportional to the product of the mass of each asteroid. **and** the force is inversely proportional to the distance squared between the centres of mass of the asteroids.	B1	
	b	i	Any sensible suggestion, e.g. Satellites used for global communication, instant access to news, weather forecasting etc.	B1	
		ii	$g = (6400/15300)^2 \times 9.81$	C1	
		ii	$g = 1.72$ ($N\ kg^{-1}$)	A1	
		iii	Acceleration towards centre = $1.72\ ms^{-2}$ or centripetal force = mass of satellite × 1.72 N	C1	ecf (b)(i)
		iii	$T^2 = 4 \times \pi^2 \times 1.53 \times 10^7 / 1.72$	C1	
		iii	$T = 1.87 \times 10^4$ (s)	A1	Allow 1.9
	c		Use of $M = gr^2 / G$ (accept any subject)	C1	Calculation using g = 1.72 at radius of 15300 km Possible ecf from **(b)(i)**
			Density = $3g / 4\pi rG = 3 \times 9.81/4\pi \times 6.4 \times 10^6 \times 6.67 \times 10^{-11}$	C1	Density = $\dfrac{3 \times 1.72 \times (1.53 \times 10^7)^2}{4\pi \times (6.4 \times 10^6)^3 \times 6.67 \times 10^{-11}}$
			$= 5.49 \times 10^3$ ($kg\ m^{-3}$)	A1	$= 5.50 \times 10^3\ kg\ m^{-3}$
			Total	**10**	
27			C	1	
			Total	**1**	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
28	a		Labelled diagram showing a line joining a planet and the Sun	B1	
			Comparing swept areas at different parts of orbit	B1	
	b		Arrow acting along line from planet towards sun	B1	Any arrow length
	c		Appropriate test proposed, e.g. T^2 / r^3 = constant k	B1	
			Test carried out on **all** three pairs of data	M1	k = (1.112, 1.109, 1.113) × 10^{-5} respectively
			Conclusion consistent with test result	B1	
			Total	6	
29		i	(Stronger) gravitational attraction between nearby galaxies affects motion / clustering of galaxies	B1	
		ii	Expansion rate may not have been constant / non-linear expansion / effect of dark energy causing accelerating rate of expansion	B1	
			Total	2	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
30	a		Ensure largest possible proportion of flask is immersed. Make volume of tubing small compared to volume of flask. Remove heat source and stir water to ensure water at uniform temperature throughout. Allow time for heat energy to conduct through glass to air before reading temperature.	B1 × 4	
	b	i	Pressure is caused by collisions of particles with sides.	B1	
		i	Velocity of particles (and volume of gas) are not zero at 0 °C.	B1	
		ii	**1:** Gradient of graph $0.75 \times 10^2 / 100 = 0.75$		
		ii	Number of moles of gas = gradient / R = $0.75 / 8.31 = 0.09$	C1	Alternative method Internal energy = $3/2 \times p \times V$
		ii		A1	
		ii	Mass of gas = $0.09 \times 6.02 \times 10^{23} \times 4.7 \times 10^{-27} = 2.5 \times 10^{-4}$ (kg)		At θ = 100°C $pV = 2.73 \times 10^2$
		ii	**2:** Internal energy = $3/2 \times NkT$		Internal energy = $1.5 \times 2.73 \times 10^2 = 410$ (J)
		ii	$= 1.5 \times 0.09 \times 6.02 \times 10^{23} \times 1.38 \times 10^{-23} \times (100 + 273)$	C1	
		ii	= 410 (J)	A1	
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
31	a		(gravitational) force ∝ [mass 1] [mass 2] / [separation (of masses)]²	B1	**Allow:** equation in symbols if symbols are defined **Allow:** equality **Not** radius **Examiner's Comments** Most candidates did well and secured the mark for an accurate statement or word equation. The common errors seen were a definition of gravitational field strength, omission of square and taking the sum of masses.
	b		Use of $F = \frac{GMm}{R^2}$ AND $F = \frac{mv^2}{R}$	B1	**Ignore** signs **Allow:** equation with cancelling shown
			$v = \frac{2\pi R}{T}$	B1	
			$\frac{GM}{R^2} = \frac{1}{R}\left(\frac{(2\pi R)}{T}\right)^2$	B1	This mark is for some evidence of substitution and manipulation
			$R^3 = \frac{GM}{4\pi^2}T^2$ *OR* $R^3 \propto T^2$	A1	**Allow:** subject must be either R^3 or T^2 **Allow:** Max 1 mark for bald statement of $R^3 = \frac{GM}{4\pi^2}T^2$ without proof **Examiner's Comments** Candidates were well prepared in this area and answered this question well; many scoring full marks. In general the derivation was clearly set out and the logic was easy to follow. In a few scripts candidates omitted a square but managed to correct this at a later stage. The small minority who were unable to complete the derivation, wisely looked up the formula in the Data, Formulae and Relationship Booklet and quoted this accurately thus earning a single mark for recognition.

Question			Answer/Indicative content	Marks	Guidance
	c	i	Graph is a straight line / has constant gradient and passes through the origin	B1	**Examiner's Comments** Just over half of the candidates gave a full correct answer to this question on Kepler's law. The most common error was a failure to mention that the graph passed through the origin. This feature is critical to the conclusion that r^3 is proportional to T^2.
		ii	$\text{gradient of graph} = \frac{GM}{4\pi^2} = \frac{15\times10^{34}}{4.5\times10^{16}} = \left(3.3\times10^{18}\right)$	C1	**Allow:** ± half small square on reading off points on line **Note** 2 possible POT error in this equation would give max 1 out 3 with FT.
		ii	$M = \frac{4\pi^2 \times 3.3\times10^{18}}{6.67\times10^{-11}}$	C1	**Allow:** use of a point read from straight line substituted into Kepler's equation **Allow:** FT from their gradient value.
		ii	$M = 1.97 \times 10^{30}$ (kg)	A1	2.0×10^n where $n \neq 30$ scores **max** 2 out of 3 marks **Examiner's Comments** Candidates generally coped very well with this slightly less familiar setting to Kepler's law and scored highly on the question across a wide range of the ability spectrum. This clearly reflects a thorough preparation in Centres for this important topic. A small number of candidates lost marks through poor transposition of formulae which is still fairly common in questions generally. There was a slight increase in the number of errors seen involving powers of ten, usually as a result of misreading the scales on the graph. Candidates are advised to pay particular attention to the scales on graphs.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
32			Both *E* and *g* vary with 1/distance^2. (Hence the ratio is independent of the distance.)	B1	**Allow**: $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ <u>and</u> $g = \frac{GM}{r^2}$ **or** $E \propto \frac{1}{r^2}$ <u>and</u> $g \propto \frac{1}{r^2}$ **Allow** 'both are inverse square laws'. Examiner's Comments This was a good discriminator with many candidates giving excellent answers in terms of the inverse square law with distance for both electric and gravitational field strengths. Some candidates even went as far as to derive an expression for the ratio and showed how the r^2 terms cancel out. A small number of candidates gave incorrect reasoning for why there was no dependence on the distance, this is shown below. *g = F/m* and *E = F/Q*. Therefore *g/E = Q/m* which has no distance.
			Total	1	

Question			Answer/Indicative content	Marks	Guidance
33			$g \propto 1/r^2$	C1	
			ratio $\left(\frac{1.4\times10^9}{12\times10^3}\right)^2$ or ratio = $\left(\frac{0.7\times10^9}{6\times10^3}\right)^2$		
			ratio = 1.4×10^{10}	A1	**Note** : The answer to 3 sf is 1.36×10^{10}. **Allow** 1 mark for 7.3×10^{-11} - inverse of the ratio. **Examiner's Comments** Candidates answered this question well. A variety of methods were used to get this correct answer. Some candidates calculated the surface field strengths for the Sun and Sirius B and then divided these to calculate the ratio. Candidates at the top-end opted for a simpler route. Since $g \propto 1/r^2$, the ratio was $\left(\frac{0.7\times10^9}{6\times10^3}\right)^2 = 1.4\times10^{10}$
			Total	2	

Question			Answer/Indicative content	Marks	Guidance
34			Difference: Any one from • gravitational field / force is attractive (AW) • electric field / force can be either attractive or repulsive (AW)	B1	**Allow**: Gravitational force is in the direction of the field / towards the mass **Note**: For the second bullet point, must have reference to both attractive and repulsive or 'towards charge' and 'away from charge' **Allow**: (Both) obey the inverse-square law (with distance) or (Both) have $F \alpha 1/r^2$ or $g \alpha 1/r^2$ and $E \alpha 1/r^2$
			Similarity: Any one from: • Force / field (strength) inversely proportional to distance squared • Radial fields	B1	**Allow**: 'radius or separation' for 'distance' **Examiner's Comments** The majority of the candidates gained two marks. Most candidates were aware that gravitational force or field was always attractive and that electric force or field can either be attractive or repulsive depending on the charge creating the electric field. Most candidates wrote the similarity as either *'both obey inverse square law'* or *'both create radial fields'*.
			Total	2	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
35	a		Spaceship is (always vertically) above the same point on (the surface of the Earth / planet) (AW)	B1	**Allow:** Spaceship must orbit the equator with a period of 24 h / 1 day **and** must have the same direction of rotation as Earth / planet (AW) **Not :** same point in sky **Examiner's Comments** The majority scored the mark in this question but unfortunately a significant minority did not make any reference to the direction of rotation in relation to the Earth and so could not be given the mark.
	b	i	Centre of spaceship's orbit must coincide with the centre of mass of Benzar **OR** orbit must be equatorial (AW)	B1	S Pole is on axis of rotation (radius of orbit is zero)
		i	Velocity of spaceship must be parallel to the velocity of a point on the surface of Benzar. **OR** Spaceship must orbit in the same direction as Benzar rotates (AW)	B1	Spacecraft must be stationary / not orbiting planet / spinning on its axis OR Spacecraft will only pass over S Pole once in each orbit **Examiner's Comments** Many candidates found difficulty in expressing their thoughts in this question and as a consequence marks were generally lower than expected.
		ii	$R^3 = \frac{GT^2M}{4\pi^2}$	C1	Must have R or R^3 as subject
		ii	$R^3 = \frac{6.67\times10^{-11}\times(1.2\times10^5)^2\times8.9\times10^{25}}{4\pi^2}$	C1	Mark is for substitution
		ii	$R = 1.3 \times 10^8$ (m)	A1	Answer to 3 sf is 1.29×10^8 (m) **Examiner's Comments** Well answered, on the whole; although a significant number unfortunately forgot to square the period before taking the cube root.
			Total	6	

Question			Answer/Indicative content	Marks	Guidance
36			Similarity The field strength or force ∝ 1 / separation^2 or both produce a radial field.	B1	
			Differences Gravitational field is linked to mass and electric field is linked to charge.	B1	
			Gravitational field is always attractive whereas electric field can be either attractive or repulsive.	B1	
			Total	3	

Question			Answer/Indicative content	Marks	Guidance
37	a		Grav. potential V_g at a point is defined as the work done to bring 1 kg from infinity to that point in space;	B1	
			(G) force is attractive so the work done is negative (as separation is decreasing);	B1	**or** work is required to move away from the
			V_g is given the value zero at infinity so is negative nearer the Earth.	B1	Earth / AW
	b	i	$F = GMm/r^2 = mv^2/r$	C1	where $r = 6.8 \times 10^6$ m
		i	$v = (GM/r)^{1/2} = (g/r)^{1/2}R$ (as $g = GM/R^2$)	C1	**N.B.** some working must be shown as a
		i	$v = 7.7$ (km s^{-1}).	A1	*show that* Q
		ii	total energy = $½mv^2 – GMm/r = –GMm/2r$	M1	**no ecf from (i); allow** numerical values
		ii	$E = –gR^2m/2r = –1.2(4) \times 10^{13}$ (J)	A1	with no algebra if clear **no mark for** correct value without the minus sign

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		**Level 3 (5–6 marks)** a structured combination of at least 6 statements taken from A, B and C or A and D a combination of at least 5 statements; script of a lower quality **N.B.** bonus given for any of E at any level *The ideas are well structured providing significant clarity in* *the communication of the science.* **Level 2 (3–4 marks)** a good combination of at least 4 statements taken from A and B or A and C or B and C or A and D a combination of at least 3 statements taken from two sections which are relevant together. *There is partial structuring of the ideas with communication of the science generally clear.* **Level 1 (1–2 marks)** at least 2 statements from A, B, C or D which are relevant together some attempt which is related to the question *The ideas are poorly structured and impede the communication of the science.* **Level 0 (0 marks)** Insufficient or relevant science.	B1	**A initial scenario** • for circular orbit a centripetal force (of magnitude mv^2 / r) is required or AW in terms of accelerations • this is provided by the gravitational force GMm/r^2 **or** G force just pulls radially inwards sufficiently to maintain orbit • the speed in orbit $v = (GM/r)^{1/2}$ **B reverse thrust** • G force causes rocket to spiral towards Earth when rocket slowed; • rocket speeds up in process • v in orbit is larger when radius r is smaller; condition for faster lower orbit can be achieved **or** T smaller because either v is larger or r / circumference is smaller or both or $2\pi r/v$ is smaller **C forward thrust** • when rocket speeds up with engines fired forwards G force insufficient to hold orbit so spirals to larger orbit • slowing as it does so **D energy approach** • some p.e. goes to k.e. when rocket is slowed as it moves towards Earth • so v increases • vice versa when rocket is accelerated **E further comments** • extra corrections needed to obtain circular orbit after manoeuvre (not mentioned in passage) • any other relevant statement not included above

Question			Answer/Indicative content	Marks	Guidance
			Total	14	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
38	a	i	$M = \frac{gR^2}{G}$		
		i	$M = \frac{3.7 \times (3.4 \times 10^6)^2}{6.67 \times 10^{-11}}$ [any subject]	C1	If square is omitted from 3.4×10^6 score is 0/2.
		i	$M = 6.4 \times 10^{23}$ (kg)	A1	**Allow** 1 mark for $M = 6.4 \times 10^{17}$ (Mars radius km not converted to m) **Examiner's Comments** Most candidates did well and secured both marks although a significant minority did not convert the given radius to metre. This was one of the questions where the square was omitted from the radius resulting in an unrealistically low mass for Mars.
		ii	$g_h = \frac{g_s R^2}{(R+h)^2} = \frac{3.7 \times (3.4 \times 10^6)^2}{(6.8 \times 10^6)^2}$ $g_h = 0.93$ (N kg^{-1}	A1	**Allow**: $h = R$ so $g_h = ¼\ g_s$ **Allow** use of $g_h = \frac{GM}{(R+h)^2}$ **Allow** ECF from (i) **Examiner's Comments** Candidates were well prepared in this area and answered this question well using consistent, if not SI, units. Most found it easier to use $g = \frac{GM}{(R+h)^2}$ together with their answer from (i) rather than a ratio method.
	b	i	$T^2 \propto R^3$ with T = period **and** R = orbital radius	B1	**Allow** separation / distance between bodies Do **not** allow bald radius for R **Examiner's Comments** Although Kepler's law was well known, many lost the mark by failing to identify carefully the terms used in the law.
		ii	$\left(\frac{R_D}{R_P}\right)^3 = \left(\frac{T_D}{T_P}\right)^2$		

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$R_D = 9.4 \times 10^3 \times \left(\frac{30}{7.7}\right)^{2/3}$ [any subject]	C1	C1 mark is for correct substitution **Allow** use of $R^3 = \frac{GMT^2}{4\pi^2}$ with possible ECF from (i)
		ii	$R_D = 2.3 \times 10^4$ (km)	A1	[Note M=6.4 × 10^{17} leads to 2.3 × 10^2 km] **Examiner's Comments** Apart from a few cases where either the square or cube was omitted, candidates coped very well with this question. This clearly reflects a thorough preparation in Centres for this important topic. A small number of candidates lost marks through inconsistent units. An even smaller number approached the problem by the ratio method which would have eliminated much of the arithmetical work.
	c		Speed will increase	M0	
			Because a decrease in orbital radius results in a decrease in period (by Kepler's law) / Correct reference to centripetal force = gravitational force or v^2 =Gm/R	A1	**Allow** GPE decreases so KE increases **Examiner's Comments** This discriminating question caused many candidates difficulties and even those who realised that the speed would increase were unable to convince Examiners with their reasoning. The expected energy method was rarely seen, unfortunately, as it is by far the easiest method to explain.
			Total	**7**	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
39	a	i	$F = \frac{GM_1M_2}{(R_1 + R_2)^2}$	B1	Ignore sign **Examiner's Comments** Question 5 was specifically aimed at the high level candidates whilst giving some hints to enable others to score a proportion of the marks. Many were able to use the diagram to correctly identify the separation of the stars and so score the mark for the gravitational force
		ii	$F_1 = \frac{4\pi^2 M_1 R_1}{T^2}$	B1	Allow $F_1 = \left(\frac{2\pi}{T}\right)^2 M_1R_1$ **Examiner's Comments** Most candidates were aware that $F=mv^2/r$ was to be used with appropriate modification of the terms. Unfortunately many omitted the square when substituting for v and almost as many failed to square the period as well as the $2\pi R_1$ when undertaking the required simplification.
	b		Centripetal forces on both star are same magnitude / $F_1 = F_2$ / answer to a(ii) equated to similar expression for **S**$_2$ Correct working starting from correct a(ii) forces $\frac{M_1}{M_2} = \frac{R_2}{R_1}$	M1 A1 A0	Eg $\frac{4\pi^2 M_1 R_1}{T^2} = \frac{4\pi^2 M_2 R_2}{T^2}$ **Examiner's Comments** This question was deliberately written in 'show' format to enable all candidates to attempt part (c) on an equal footing. The proof depends on the fact that the forces on the stars are of equal magnitude and although many used this idea it was rarely stated explicitly nor linked to Newton's third law. The mark scheme was designed to enable these candidates to score marks as well as those forced to start from an incorrect formula derived in a(ii).
	c		$\frac{R_2}{R_1} = 3$ $\therefore$ $R_2 = 3R_1$ *and* $R_1 + R_2 = 4.8 \times 10^{12}$	C1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			$R_1 = \frac{1}{4} \times 4.8 \times 10^{12} = 1.2 \times 10^{12}$ (m) $R_2 = \frac{3}{4} \times 4.8 \times 10^{12} = 3.6 \times 10^{12}$ (m)	A1 A1	Allow 2 marks if $R_1 = 3.6 \times 10^{12}$ (m) And $R_2 = 1.2 \times 10^{12}$ (m) **Examiner's Comments** This part of the demanding question gave little trouble to the majority. The number of candidates giving 'reversed' answers was very small which was pleasing.
	d		$v_1 = \frac{2\pi R_1}{T} = \frac{2\pi \times 1.2 \times 10^{12}}{4 \times 3.16 \times 10^7}$ $v_1 = 6.0 \times 10^4$ (m s^{-1})	C1 A1	Possible ECF Mark is for substitution Max 1 mark if *T* is not converted to seconds (leads to speed = 1.9×10^{12}) **Examiner's Comments** Most candidates were able to score one if not two marks particularly given the application of error carried forward.
	e		$\frac{M_1 v_1^2}{R_1} = \left(\frac{4\pi^2 R_1 M_1}{T^2}\right) = \frac{GM_1 M_2}{(R_1 + R_2)^2}$ $M_2 = \frac{(6.0 \times 10^4)^2 \times (4.8 \times 10^{12})^2}{6.67 \times 10^{-11} \times 1.2 \times 10^{12}}$	C1 C1	**Allow ECF** from (c) and (d) **only** if method is correct **Allow** this C1 mark if M_1 has been cancelled

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			$M_2 = 1.0\times10^{33}$ (kg)	A1	**Special case** Use of $T^2 \propto R^3$ will lead to 1.73×10^{33} (kg) this scores 1 mark. Do not allow any ECF if this method is used. **Examiner's Comments** As expected only the very able candidates were able to apply the hints given in the earlier parts of the question and so obtain the correct mass for the second star. Many attempted to apply the simplified form of Kepler's law to the problem despite the similarity in the masses of the two Stars. The Examiners decided to award a compensatory mark to those using this approach, who obtained an answer consistent with the given data. Almost as many equated the centripetal force to the force obtained from Newton's law but unfortunately did not use the correct separation of the stars despite the hint in a(i). They too were awarded a compensatory mark if they obtained a consistent answer.
			Total	12	
40			B	1	
			Total	1	
41			B	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
42		i	distance = 550 × 9.5 × 10^{15} (m)	C1	
		i	$L = \frac{4\pi\times(550\times9.5\times10^{15})^2}{4.0\times10^{-4}} \times 2.6\times10^{-11}$	C1	
		i	L = 2.2 × 10^{31} (W)	A1	
		ii	($r = \sqrt{\frac{L}{4\pi\sigma T^4}}$) ; $r = \sqrt{\frac{2.2\times10^{31}}{4\pi\times5.67\times10^{-8}\times(3.1\times10^3)^4}}$	C1	**Possible** ECF from **(i)** **Allow** any subject
		ii	r = 5.8 × 10^{11} (m)	A1	
		iii	mass = 4.4 × 10^{-5} × 4/3π × (5.8 × 10^{11})^3 $g = \frac{6.67\times10^{-11}\times4.4\times10^{-5}\times{}^4/_3\pi\times(5.8\times10^{11})^3}{(5.8\times10^{11})^2}$	C1	**Possible** ECF from **(ii)**
		iii	g = 7.1 × 10^{-3} (N kg^{-1})	A1	
			Total	**7**	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
43		i	$-mV_g = ½mv^2$ or $½mv^2 + mV_g = 0$	B1	
		i	$V_g = -GM/R = -gR$	B1	
		i	$v = \sqrt{(2gR)}$	B1	Working must be shown
		ii	$v = \sqrt{(2 \times 9.81 \times 6.4 \times 10^6)} = 11 \times 10^3$ m s^{-1}	B1	allow 11(.2) km s^{-1}
		iii	$½mc^2 = 3/2\ kT$ where $m = (M/N_A) = 6.6 \times 10^{-27}$ kg	B1	**ecf (ii); allow** m = 4u or $4 \times 1.67 \times 10^{-27}$
		iii	$T = 6.6 \times 10^{-27} \times 121 \times 10^6 / 3 \times 1.38 \times 10^{-23}$	C1	
		iii	$T = 1.9 \times 10^4$ (K)	A1	**allow** 2 or 2.0
		iv	1 random motion and elastic collisions of particles	B1	**max** 4 out of 5 marking points where answer is a logical progression
		iv	2 lead to distribution of kinetic energies/velocities among particles	B1 B1	
		iv	3 a very few will have very high velocities at top end of distribution 4 a long way from mean /r.m.s. velocity at 300 K 5 hence some able to escape	B1	
		v	helium nucleus is an α-particle	B1	**max** 2 out of 3 marking points
		v	so helium is generated by radioactive decay helium is found in (natural gas) deposits underground	B1	
			Total	**13**	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
44			B	1	Examiner's Comments Virtually all questions showed a positive discrimination, except for question **10.** The questions themselves require careful inspection, as crucial information that could lead to the exclusion of many options can be obtained reducing the need for calculation and guessing. Underlining or circling key points may help candidates to converge towards the correct responses. Candidates should ensure that all letters are clearly formed. If there is a need to amend an answer crossing through the incorrect answer and writing the correct answer adjacent to the box will help avoid any potential for misunderstanding by the examiner. This question proved particularly straightforward and accessible to nearly all candidates.
			Total	1	
45			C	1	Examiner's Comments This question proved particularly straightforward and accessible to nearly all candidates.
			Total	1	

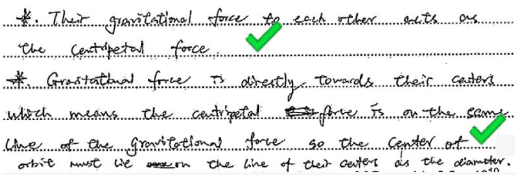
Question			Answer/Indicative content	Marks	Guidance
46	a		$V_{(g)} = -\frac{GM}{r}$	B1	**Examiner's Comments** The expression for gravitational potential was listed on the Data, Formulae and Relationships in the module 5 section and was hence reproduced well by the candidates. The minus sign was required.
	b	i	KE = $\frac{1}{2}mv^2$ **and** GPE = GMm / r $\frac{1}{2}mv^2 = GMm / r$ then a valid step to $v = \sqrt{(2GM / r)}$	C1 A1	Allow m = 1 (kg) if clearly defined **Examiner's Comments** Examiners were delighted that candidates proved the relationship for escape velocity very clearly indeed with the higher ability candidates correctly suggesting that 'KE + GPE = 0' was the condition for escape, although 'KE lost = GPE gained' would have been a clear way of reconciling any minus sign confusion. A minority of candidates tried, unsuccessfully, to invoke the expression for circular motion inappropriately.
		ii	($v^2 = 2 \times 6.67 \times 10^{-11} \times 0.131 \times 10^{23} / 1.19 \times 10^6$) v = 1200 (m s^{-1})	A1	Answer to 3.s.f. is 1210 **Examiner's Comments** Approximately four-fifths of all candidates calculated the escape velocity on Pluto correctly. Those that did not score the mark for this item did so because of improper calculator use or, more rarely, because they selected the wrong data from the question.

Question			Answer/Indicative content	Marks	Guidance
		iii	Mercury has a higher escape velocity than Pluto (ORA)	B1	**Allow** a supporting calculation (speed is about 4.2 km s^{-1})
			Mercury is closer to sun **and** Mercury is hott<u>er</u> (ORA)	M1	
			Molecules on Mercury (are more likely to) have **speed** higher than the escape velocity	A1	**Allow** 'required speed' for 'escape velocity' **Allow** 'fast enough to escape' **Examiner's Comments** Candidates found this last item very challenging indeed, with only exceptional candidates gaining two or three marks. Many candidates suggested that the reason for Mercury's lack of atmosphere was the superior gravitational pull of the Sun, which is wholly incorrect. Others suggested that the solar wind or 'radiation' had burnt off the atmosphere. Rather fewer candidates correctly related Mercury's smaller mean distance to the Sun and its higher temperature or reasoned that Mercury's escape velocity was higher than Pluto's. Only a small minority of candidates recognised that even though Mercury has a higher escape velocity, its higher temperature gave the atmosphere's molecules a higher average speed which would have exceeded Mercury's escape velocity.
			Total	7	
47			C	1	<u>Examiner's Comments</u> This question requires the candidate to calculate the gravitational potential energy when r = 6.4×10^3 m and again when r = 7.6×10^3 m. The difference of those two energies gives answer C. About two thirds of all candidates got this correct.
			Total	1	

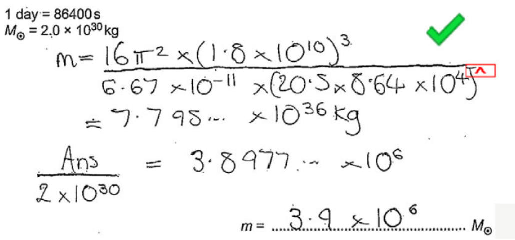
Question			Answer/Indicative content	Marks	Guidance
48		i	Horizontal arrow pointing to the right.	B1	Judgement by eye **Examiner's Comments** The examiners were quite lenient in this series in terms of the precise direction of the arrow, which should point towards the centre of Mars.
		ii	$2.14 \times 10^3 = \frac{2 \times \pi \times 9380 \times 10^3}{T}$ $T = 2.75 \times 10^4$ (s)	C1 A1	**Allow** 2SF answer **Note:** 2.75… × 10^n scores 1 mark. **Examiner's Comments** Around four fifths of candidates got this right. Those that did not either poorly converted the radius from km or used the area rather than the circumference of the orbit.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	$\frac{GMm}{r^2} = \frac{mv^2}{r}$ or $v^2 = \frac{GM}{r}$ $(2.14 \times 10^3)^2 = 6.67 \times 10^{-11} \times M/9380 \times 10^3$ $M = 6.44 \times 10^{23}$ (kg)	C1 C1 A1	**Allow** ecf of answer for T from (a)(ii) **Allow** 2 SF answer **Note:** Use of 2.8×10^4 seconds gives 6.3×10^{23} (kg) for 3 marks. **Alternative Method for C1C1** • $M = 4\pi^2R^3/(T^2G)$ (Databook formula re–arranged with M as subject) • $M = 4\pi^2(9380 \times 10^3)^3/((2.75 \times 10^4)^2 \times 6.67 \times 10^{-11})$ (i.e. M as subject) **Note:** In alternative method, PoT error forgetting km–>m conversion gives 6.46×10^{14} (kg) for 2 marks. <u>Examiner's Comments</u> Many candidates successfully used the equation for Kepler's Third Law, which is encouraging. A quicker route was to find the Phobos's acceleration (from v^2/r) and equating that to the gravitational field strength at Phobos from Mars (GM_{mars}/r^2) and then rearranging to find the mass of Mars.
			Total	6	

Question			Answer/Indicative content	Marks	Guidance
49	a	i	(For circular orbit) centripetal force provided by gravitational force (of attraction) (Gravitational / centripetal) force is along line joining stars which must therefore be diameter of circle (AW)	M1 A1	**Examiner's Comments** Only a minority of candidates related the gravitational force between the stars to the centripetal force required for circular motion to occur. This candidate has written the perfect answer (exemplar 5). There were two popular insufficient answers; that if the stars were not diametrically opposite they would collide and that the centre of mass of the system had to be at the centre of the orbit. **Exemplar 5**  *. Their gravitational force to each other acts as the centripetal force. *. Gravitational force is directly towards their centers which means the centripetal force is on the same line of the gravitational force so the center of orbit must be on the line of their centers as the diameter.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$T = 20.5 \times 86400$ (= 1.77×10^6 s) **and** $R = 1.8 \times 10^{10}$ (m)	C1	values of T **and** R scores first mark; **both** incorrect 0/3
			$m = 16 \times \pi^2 \times (1.8 \times 10^{10})^3/G \times (20.5 \times 86400)^2$	C1	correct substitution allowing π^2 and G $m = 16 \times 9.87 \times 1.8^3 \times 10^{30}/6.67 \times 10^{-11} \times 1.8^2 \times 10^{12}$
			giving $m = 4.4 \times 10^{30}$ so $m = 2.2\ M_\odot$	A1	using 2R gives $35.2 \times 10^{30} = 17.6\ M_\odot$ or using T = 1 day gives $1850 \times 10^{30} = 930\ M_\odot$ **award** 2/3 **<u>Examiner's Comments</u>** This question tested the candidates' ability to interpret and substitute data into an elaborate formula and then evaluate it. The most common error was to write the formula with the correct substitutions but then to omit the square symbol against T. Candidates should be encouraged to consider whether their answers are reasonable before moving on to the next question. In the calculation (exemplar 6) shown here, is it possible that these stars could be four million times the mass of the Sun? The correct answer of 2.2 Sun masses seems very plausible and should give candidates confidence. **Exemplar 6** 

Question			Answer/Indicative content	Marks	Guidance
		iii	$v = 2\pi R/T = 2 \times 3.14 \times 1.8 \times 10^{10} / 1.8 \times 10^{6}$ (giving $v = 6.3$ or 6.4×10^{4}) $\Delta\lambda = (v/c)\lambda = (6.3/3) \times 10^{-4} \times 656 = 0.14$ (nm)	C1 A1	**do not** penalise repeated error for R or T **ecf** for incorrect v, gives $\Delta\lambda = v \times 2.2 \times 10^{-6}$ $\Delta\lambda = 0.28$ for 2R; $\Delta\lambda = 2.9$ for 1 day and $\Delta\lambda = 5.7$ for both incorrect <u>Examiner's Comments</u> Most of the higher performing candidates completed this problem successfully. Two common errors among the remainder were to equate the formula for central force gravitational potential energy *(GMm/r)* to kinetic energy to find a value for the speed of the stars and to rewrite incorrectly metres in powers of 10 in nanometres.
	b	i	Two circles with centres at CoM with radii in ratio 4 :1 CoM at surface of larger star on line joining stars	B1	**allow** diameter of m orbit through CoM as 44 ± 10 % for example; full reasonable circles required; ignore arrows;
		ii	Same period/(angular) frequency of stars but longer path for smaller star/AW **or** $v = 2\pi R/T$ **or** $v \alpha R$ **or** stars stay at opposite ends of line through CoM	B1 B1	any arguments using $F = mv^2/r$ score zero <u>Examiner's Comments</u> Candidates should be encouraged to draw diagrams such as part (i) as accurately as they can. Some had drawing instruments and drew accurate circles. Many drew shapes which were very far from circular, making it difficult in some examples to judge whether the candidate knew the correct path. A secondary purpose of this part was to reinforce the idea that the stars remain diametrically opposite as in part (a) (i). Many did not respond to this trigger having Kepler's laws or centripetal force requirements central in their minds. The rest stated clearly that the orbital period for the two stars had to be the same and consequently were credited both marks.
			Total	10	

Question			Answer/Indicative content	Marks	Guidance
50	a	i	alpha-particle / ${}^{4}_{2}\text{He}$ / ${}^{4}_{2}\alpha$	B1	
		ii	nucleon number for Bi = 209 antineutrino / ${}^{(0)}_{(0)}\bar{\upsilon}_{(e)}$	B1 B1	**Note**: Do not allow incorrect subscript and superscript
	b	i	Aluminium (sheet placed between source and detector) The count (rate) reduces **or** Magnetic / electric field used Electrons identified from correct deflection / motion in field	M1 A1 M1 A1	**Allow** count (rate) drop to background / zero **Allow** 2 marks for 'the range in air is a few m' <u>Examiner's Comments</u> This turned out to be a low-scoring question from candidates across the ability spectrum. Only a quarter of the candidates gained 2 marks for identifying aluminium as the absorber for the beta-minus radiation (electrons) and providing adequate description in terms of reduction in the count-rate. A small number of candidates opted for charged parallel plates and identified the electrons curving towards the positive plate. There were some baffling descriptions involving pointing the source at *'wires and measuring the current'*. Fluorescent screens and cloud chambers were not allowed as acceptable answers because both can be used to detect the presence of gamma-photons and alpha-particles.

Question			Answer/Indicative content	Marks	Guidance
		ii			**Allow** credit for alternative methods
			(λ =) ln2/3.3 (h^{-1}) **or** (λ =) 0.21 (h^{-1})	C1	
			(A_0 =) $12 \times 10^3/e^{-(0.21 \times 7.0)}$ **or** (A_0 =) 5.219×10^4 (Bq)	C1	**Note** this is the same as $12 \times 10^3 \div (0.5)^{7.0/3.3}$
			(N_0 =) $5.219 \times 10^4/5.835 \times 10^{-5}$	C1	
			number of nuclei = 8.9×10^8	A1	**Note** 9.0×10^8 can score full marks if numbers are rounded
			Or		
			(λ =) ln2/[3.3 × 3600] (s^{-1}) **or** (λ =) 5.835×10^{-5} (s^{-1})	C1	
			(N =) $1.2 \times 10^4/5.835 \times 10^{-5}$ **or** 2.057×10^8	C1	Possible ECF for incorrect conversion of time
			(N_0 =) $2.057 \times 10^8/e^{-(0.21 \times 7.0)}$	C1	Note this is the same as 2.057 × 108 ÷ $(0.5)^{7.0/3.3}$
			number of nuclei = 8.9×10^8	A1	<u>Examiner's Comments</u> The question was multi-stepped calculation, requiring knowledge of radioactive decay equations, half-time and activity. The final stage of the calculation was dependent on the equation $A = \lambda N$ and working consistently in Bq for the activity and in s^{-1} for the decay constant. The number of nuclei N could not be calculated with the activity in Bq and the decay constant in either h^{-1} or min^{-1}. About half of the candidates scored full marks. Those working with inconsistent units invariably ended up with the incorrect value 2.5×10^5 nuclei, but this still earned them 2 marks for the preceding steps.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
51			D	1	Examiner's Comments Near to the surface of the Earth, the gravitational field is approximately uniform. This means that they are parallel and equally spaced. Gravitational field lines in general show the direction of the force on a small mass. This makes all 3 statements are correct, giving the answer D.
			Total	1	
52			B	1	Examiner's Comments Answering this question needs knowledge of Kepler's Third Law and the formulae for gravitational potential and gravitational field strength, all of which are given in the data, formulae and relationships booklet. This relationship cannot be gravitational potential or gravitational field strength, as quantity y increases with distance from the Sun. By equating the gravitational force on a planet with the centripetal force, it can be shown also that (orbital speed)^2 and orbital radius are inversely proportional. This graph does not show an inversely proportional relationship. The formula sheet says that the square of a planet's period is directly proportional to the cube of the planet's orbital radius. In other words, the relationship shows that as orbital radius increases, so does the period, but not directly proportionally. This is the relationship shown on the graph, giving answer B.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
53		i	$T^2 = \frac{4\pi^2}{GM} r^3$	B1	
		ii	$86400^2 = (4\pi^2/6.0 \times 10^{24} \times 6.67 \times 10^{-11})\ r^3$ (Any subject) radius = 4.23×10^7 (m)	C1 A1	<u>Examiner's Comments</u> The radius of the orbit of a geostationary satellite was found with ease by the majority of candidates by using the formula in the data book or by looking at their response for part 23(b)(i). There were a few ways of generating an arithmetical error, such as using the square root instead of the cube root for the final step, getting the wrong power for the time or by using a time equal to one year instead of one day.
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
54		i	$F = GMm/r^2$ $F = G$ x $(2.0 \times 10^{41})^2 / (1.4 \times 10^{23})^2$ force = 1.4×10^{26} (N)	C1 A1	**Note** the mark is for substitution, value of G is not required **Ignore**: minus sign **Allow** 1 mark for 1.4×10^4 N ;use of mass of star instead of mass of galaxy. <u>Examiner's Comments</u> While some lower level responses included an attempt to find the gravitational field strength rather than the force most selected the correct formula. After selecting the correct relationship, most candidates could then correctly find the force, provided that they remembered to multiply the masses and square the distance of separation.
		ii	density = $10^{11} \times 2.0 \times 10^{30}/2.7 \times 10^{69}$ density = 7.4×10^{-29} (kg m^{-3})	M1 A0	
		iii	Any reasonable answers questioning model such as observed average distance may be different, average mass may be wrong etc.	B1	**e.g.** black holes, dark energy/matter, expanding universe <u>Examiner's Comments</u> This was a question about challenging the model of the universe. The model takes into account an average mass and average distance of separation, so answers that referred to a variation in masses or distances between galaxies did not score. Higher level responses included that the universe was expanding, so that the distances involved were always changing, or that dark matter was not included in the calculations. There was no indication that candidates were constrained by time in this paper.
			Total	**4**	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
55			B	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
56	a	i	X at closest point on orbit to the Sun	B1	**Allow** X on the orbit to the left of the Sun
		ii	(When the asteroid orbits the sun a) line segment joining the asteroid to the Sun sweeps out equal areas in equal time (intervals) Longer distance (in orbit for the same time)	B1 B1	**Allow** this mark on diagram (no labelling required) **Allow** 'equal area swept in same time'
	b	i	Work done per unit mass to move an object from infinity (to that point)	B1	**Not** ' work done on 1 kg'
		ii	Manipulation of $V_{(g)} = (–)\ GM/r$	B1	
		iii	gradient = (–)30.4 or equivalent working candidate's gradient or expression = $6.67 \times 10^{-11} \times M$ and M calculated correctly from that gradient $M = 4.6 \times 10^{11}$ (kg)	C1 C1 A0	**Allow** ± 2 Possible ECF from incorrect gradient **Allow** any subject
	c		**Method 1:** Evidence of 2.3×10^{-3} and 600^{-1} or $(2.3 \times 10^{-3})^{-1}$ and 600 $\frac{1}{2} v^2 = 6.67 \times 10^{-11} \times 4.6 \times 10^{11} \times (2.3 \times 10^{-3} - 600^{-1})$ $v = 0.20$ (m s^{-1}) **Method 2:** Evidence of 7.0×10^{-2} and 5.1×10^{-2} from graph $\frac{1}{2} v^2$ (= $\Delta V_{(g)}$) = $7.0 \times 10^{-2} - 5.1 \times 10^{-2}$ $v = 0.19$ (m s^{-1})	C1 C1 A1 (C1) (C1) (A1)	Possible ECF from **(b)(iii)** for either value of *GM* or *M* **Allow** $\frac{1}{2} v^2 = 30 \times (2.3 \times 10^{-3} - 600^{-1})$ **Note** answer can be 0.19 or 0.20 or 0.2 m s^{-1} **Note** answer can be 0.19 or 0.20 or 0.2 m s^{-1} **Allow** correct use of one piece of data arriving at a value for v for 1 mark max
			Total	**10**	