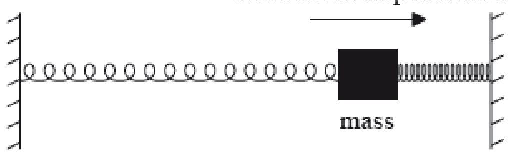
SL Paper 2

This question is in **two** parts. **Part 1** is about the oscillation of a mass. **Part 2** is about nuclear fission.

Part 1 Oscillation of a mass

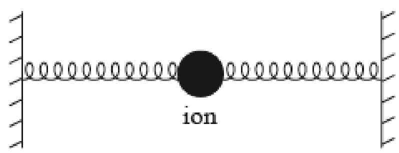
A mass of 0.80 kg rests on a frictionless surface and is connected to two identical springs both of which are fixed at their other ends. A force of 0.030 N is required to extend or compress each spring by 1.0 mm. When the mass is at rest in the centre of the arrangement, the springs are not extended.

The mass is displaced to the right by 60 mm and released.



(not to scale)

The motion of an ion in a crystal lattice can be modelled using the mass–spring arrangement. The inter-atomic forces may be modelled as forces due to springs as in the arrangement shown.



The frequency of vibration of a particular ion is 7×10^{12} Hz and the mass of the ion is 5×10^{-26} kg. The amplitude of vibration of the ion is 1×10^{-11} m.

Part 2 Nuclear fission

A reaction that takes place in the core of a particular nuclear reactor is as shown.

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{144}_{56}\text{Ba} + ^{89}_{36}\text{Kr} + 3^{1}_{0}\text{n}$$

In the nuclear reactor, 9.5×10^{19} fissions take place every second. Each fission gives rise to 200 MeV of energy that is available for conversion to electrical energy. The overall efficiency of the nuclear power station is 32%.

In addition to the U-235, the nuclear reactor contains a moderator and control rods. Explain the function of the

a.i. Determine the acceleration of the mass at the moment of release. [3]

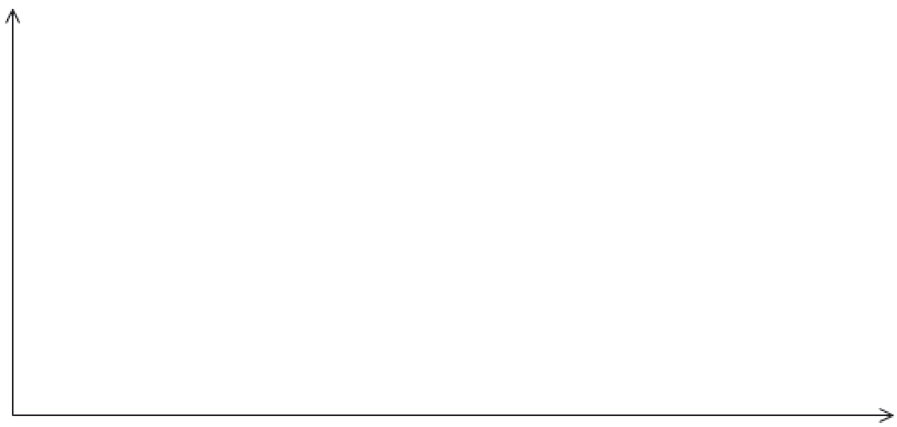
a.ii. Outline why the mass subsequently performs simple harmonic motion (SHM). [2]

a.iii. Calculate the period of oscillation of the mass. [2]

b.i. Estimate the maximum kinetic energy of the ion. [2]

b.ii. On the axes, draw a graph to show the variation with time of the kinetic energy of mass and the elastic potential energy stored in the springs. [3]

You should add appropriate values to the axes, showing the variation over one period.



c.i. Calculate the wavelength of an infrared wave with a frequency equal to that of the model in (b). [1]

d.i. Determine the mass of U-235 that undergoes fission in the reactor every day. [3]

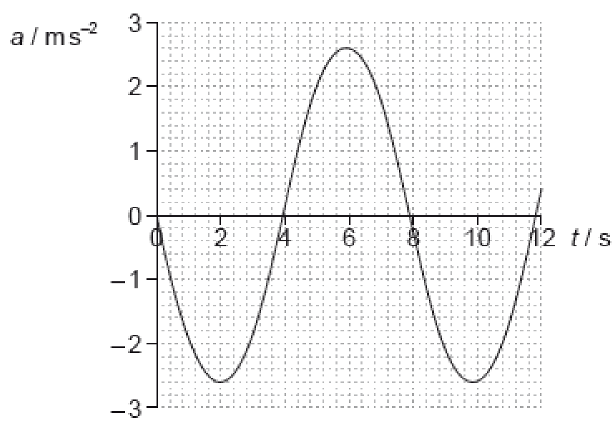
d.ii. Calculate the power output of the nuclear power station. [2]

e.i. moderator. [3]

e.ii. control rods. [2]

This question is about simple harmonic motion (SHM).

The graph shows the variation with time t of the acceleration a of an object X undergoing simple harmonic motion (SHM).



a. Define *simple harmonic motion (SHM)*. [2]

b. X has a mass of 0.28 kg. Calculate the maximum force acting on X. [1]

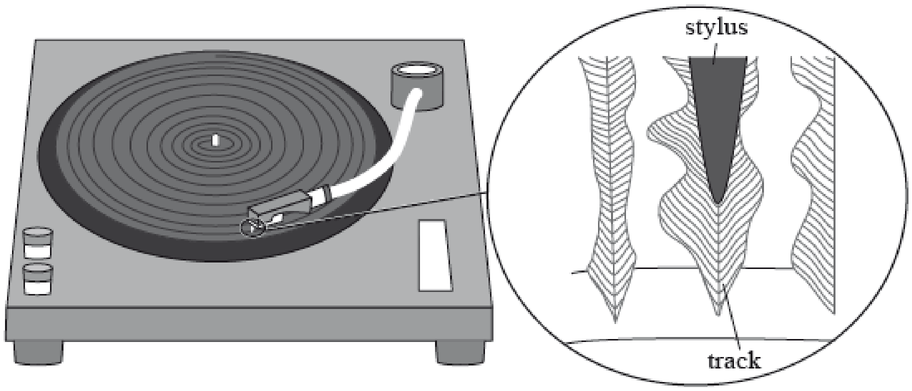
c. Determine the maximum displacement of X. Give your answer to an appropriate number of significant figures. [4]

d. A second object Y oscillates with the same frequency as X but with a phase difference of $\frac{\pi}{4}$. Sketch, using the graph opposite, how the acceleration of object Y varies with t. [2]

This question is in **two** parts. **Part 1** is about simple harmonic motion (SHM) and sound. **Part 2** is about electric and magnetic fields.

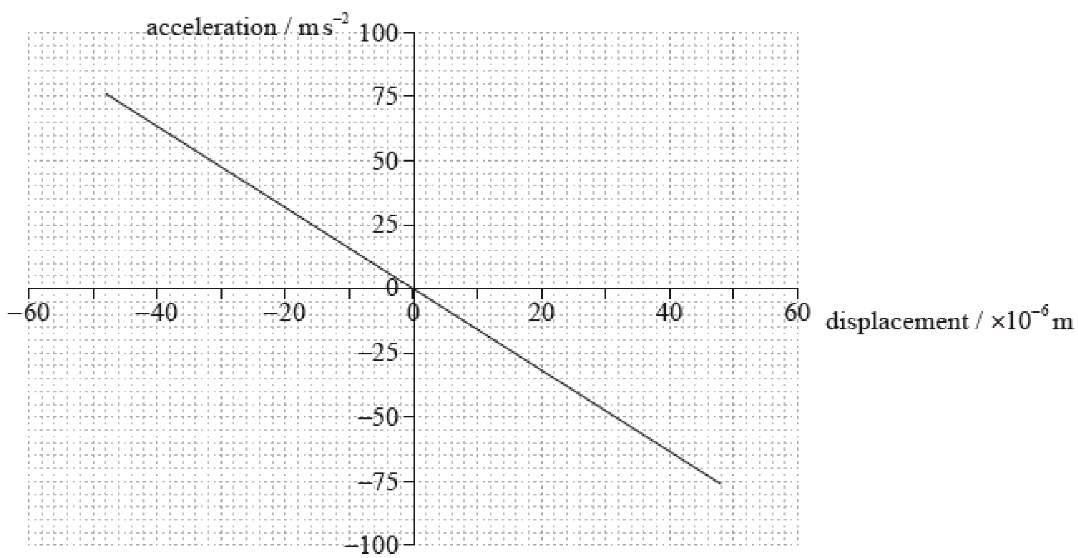
Part 1 Simple harmonic motion (SHM) and sound

The diagram shows a section of continuous track of a long-playing (LP) record. The stylus (needle) is placed in the track of the record.



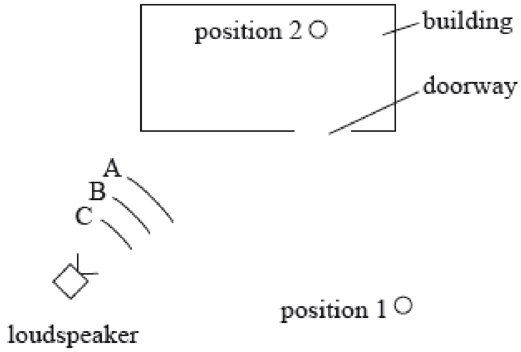
As the LP record rotates, the stylus moves because of changes in the width and position of the track. These movements are converted into sound waves by an electrical system and a loudspeaker.

A recording of a single-frequency musical note is played. The graph shows the variation in horizontal acceleration of the stylus with horizontal displacement.



Sound is emitted from a loudspeaker which is outside a building. The loudspeaker emits a sound wave that has the same frequency as the recorded note.

A person standing at position 1 outside the building and a person standing at position 2 inside the building both hear the sound emitted by the loudspeaker.



A, B and C are wavefronts emitted by the loudspeaker.

Part 2 Electric and magnetic fields

Electrical leads used in physics laboratories consist of a central conductor surrounded by an insulator.

a. Explain why the graph shows that the stylus undergoes simple harmonic motion. [4]

b. (i) Using the graph on page 14, show that the frequency of the note being played is about 200 Hz. [5]

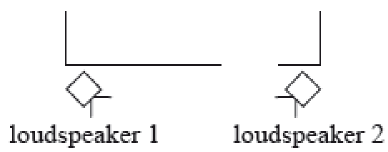
(ii) On the graph on page 14, identify, with the letter P, the position of the stylus at which the kinetic energy is at a maximum.

c. (i) Draw rays to show how the person at **position 1** is able to hear the sound emitted by the loudspeaker. [4]

(ii) The speed of sound in the air is $330\ \mathrm{m\,s^{-1}}$. Calculate the wavelength of the note.

(iii) The walls of the room are designed to absorb sound. Explain how the person at **position 2** is able to hear the sound emitted by the loudspeaker.

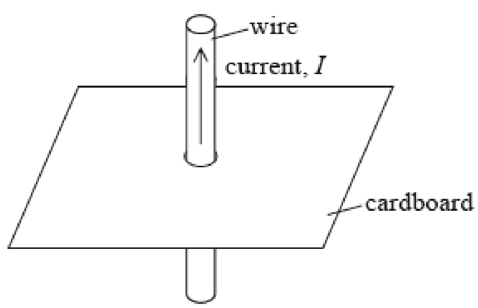
d. The arrangement in (c) is changed and another loudspeaker is added. Both loudspeakers emit the same recorded note in phase with each other. [3]



Outline why there are positions between the loudspeakers where the sound can only be heard faintly.

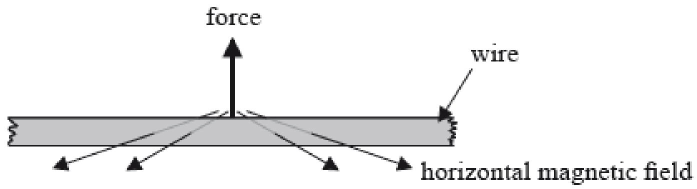
e. Distinguish between an insulator and a conductor. [2]

f. The diagram shows a current *I* in a vertical wire that passes through a hole in a horizontal piece of cardboard. [3]



On the cardboard, draw the magnetic field pattern due to the current.

g. (i) The diagram shows a length of copper wire that is horizontal in the magnetic field of the Earth. [4]



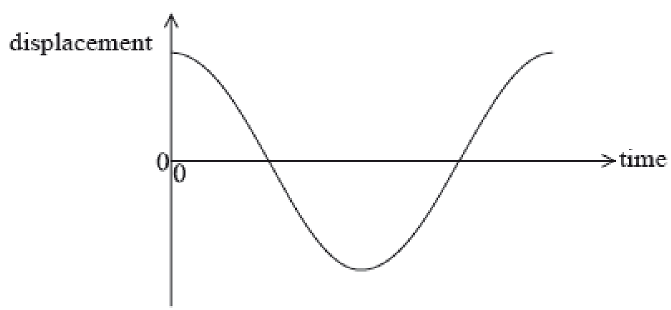
The wire carries an electric current and the force on the wire is as shown. Identify, with an arrow, the direction of electron flow in the wire.

(ii) The horizontal component of the magnetic field of the Earth at the position of the wire is $40\ \mu\mathrm{T}$. The mass per unit length of the wire is $1.41 \times 10^{-4}\ \mathrm{kg\,m^{-2}}$. The net force on the wire is zero. Determine the current in the wire.

This question is in **two** parts. **Part 1** is about a simple pendulum. **Part 2** is about the Rutherford model of the atom.

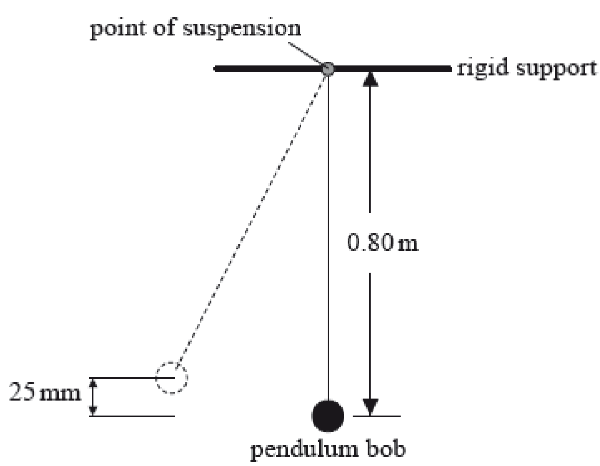
Part 1 Simple pendulum

A pendulum consists of a bob suspended by a light inextensible string from a rigid support. The pendulum bob is moved to one side and then released. The sketch graph shows how the displacement of the pendulum bob undergoing simple harmonic motion varies with time over one time period.

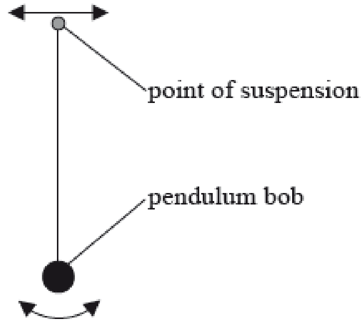


On the sketch graph above,

A pendulum bob is moved to one side until its centre is 25 mm above its rest position and then released.



The point of suspension of a pendulum bob is moved from side to side with a small amplitude and at a variable driving frequency f.



For each value of the driving frequency a steady constant amplitude A is reached. The oscillations of the pendulum bob are lightly damped.

Part 2 Rutherford model of the atom

The isotope gold-197 $\left({}^{197}_{79}Au\right)$ is stable but the isotope gold-199 $\left({}^{199}_{79}Au\right)$ is not.

Part 1.a. (i) label with the letter A a point at which the acceleration of the pendulum bob is a maximum. [2]

(ii) label with the letter V a point at which the speed of the pendulum bob is a maximum.

Part 1.b. Explain why the magnitude of the tension in the string at the midpoint of the oscillation is greater than the weight of the pendulum bob. [3]

Part 1.c. (i) Show that the speed of the pendulum bob at the midpoint of the oscillation is $0.70\ \mathrm{m\,s^{-1}}$. [5]

(ii) The mass of the pendulum bob is 0.057 kg. The centre of the pendulum bob is 0.80 m below the support. Calculate the magnitude of the tension in the string when the pendulum bob is vertically below the point of suspension.

Part 1.d. (i) On the axes below, sketch a graph to show the variation of A with f. [4]

(ii) Explain, with reference to the graph in (d)(i), what is meant by resonance.

Part 1.e. The pendulum bob is now immersed in water and the variable frequency driving force in (d) is again applied. Suggest the effect this immersion of the pendulum bob will have on the shape of your graph in (d)(i). [2]

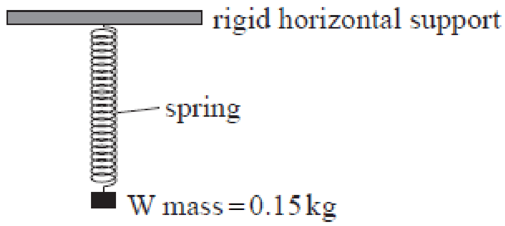
Part 2.a. Most alpha particles used to bombard a thin gold foil pass through the foil without a significant change in direction. A few alpha particles are deviated from their original direction through angles greater than 90°. Use these observations to describe the Rutherford atomic model. [5]

Part 2.b. (i) Outline, in terms of the forces acting between nucleons, why, for large stable nuclei such as gold-197, the number of neutrons exceeds the number of protons. [4]

(ii) A nucleus of ${}^{199}_{79}\mathrm{Au}$ decays to a nucleus of ${}^{199}_{80}\mathrm{Hg}$ with the emission of an electron and another particle. State the name of this other particle.

Part 2 Simple harmonic motion and waves

a. One end of a light spring is attached to a rigid horizontal support. [8]



An object W of mass 0.15 kg is suspended from the other end of the spring. The extension x of the spring is proportional to the force F causing the extension. The force per unit extension of the spring k is 18 Nm^{-1}.

A student pulls W down such that the extension of the spring increases by 0.040 m. The student releases W and as a result W performs simple harmonic motion (SHM).

(i) State what is meant by the expression “W performs SHM”.

(ii) Determine the maximum acceleration of W.

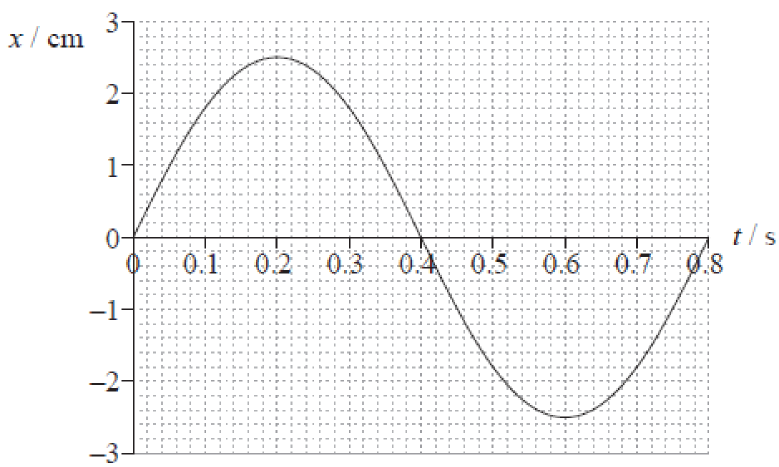
(iii) Determine the period of oscillation of the spring.

(iv) Determine the maximum kinetic energy of W.

c. A light spring is stretched horizontally and a longitudinal travelling wave is set up in the spring, travelling to the right. [6]

(i) Describe, in terms of the propagation of energy, what is meant by a longitudinal travelling wave.

(ii) The graph shows how the displacement x of one coil C of the spring varies with time t.



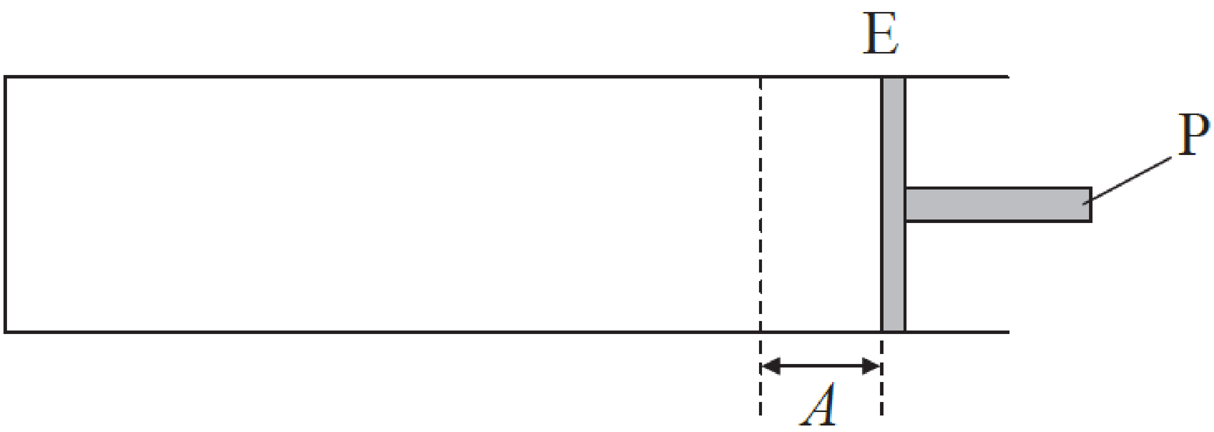
The speed of the wave is 3.0 cms^{-1}. Determine the wavelength of the wave.

(iii) Draw, on the graph in (c)(ii), the displacement of a coil of the spring that is 1.8 cm away from C in the direction of travel of the wave, explaining your answer.

This question is in **two** parts. **Part 1** is about simple harmonic motion (SHM) and waves. **Part 2** is about wind power and the greenhouse effect.

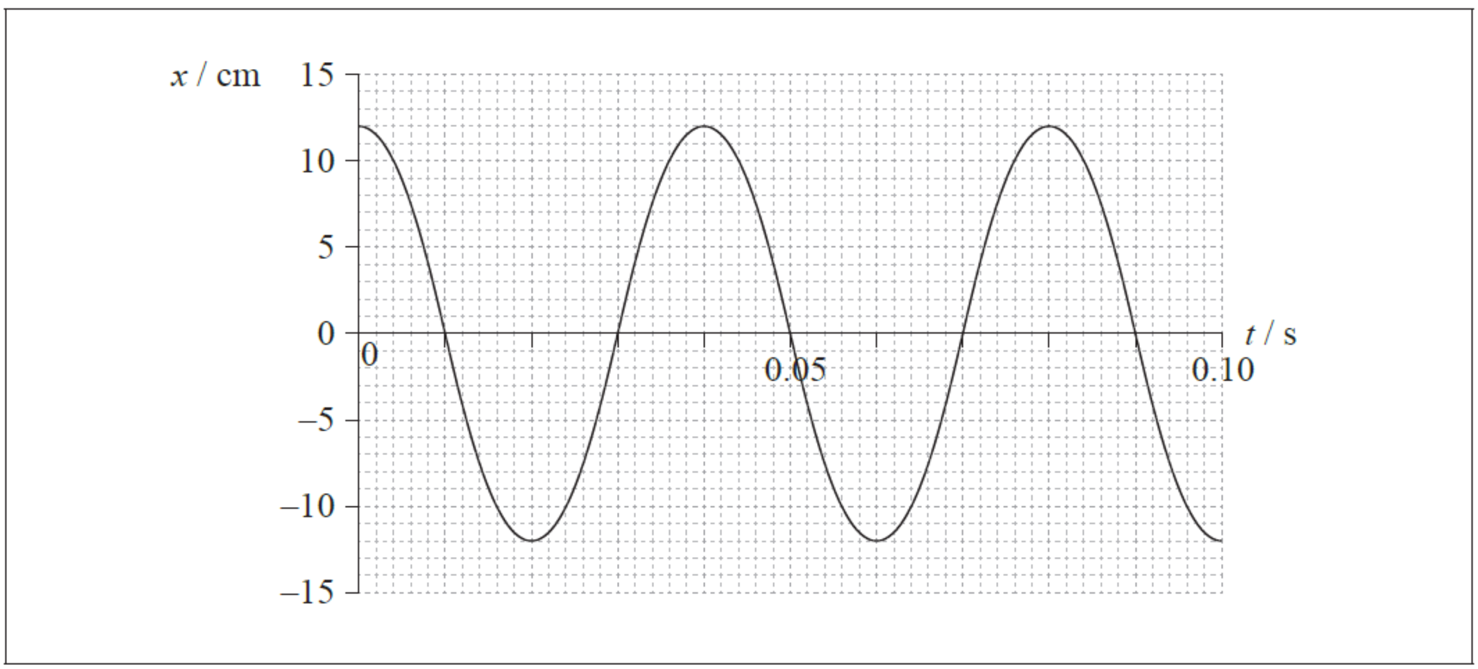
Part 1 Simple harmonic motion (SHM) and waves

a. A gas is contained in a horizontal cylinder by a freely moving piston P. Initially P is at rest at the equilibrium position E. [2]



The piston P is displaced a small distance *A* from E and released. As a result, P executes simple harmonic motion (SHM). Define *simple harmonic motion* as applied to P.

b. The graph shows how the displacement *x* of the piston P in (a) from equilibrium varies with time *t*. [7]



(i) State the value of the displacement *A* as defined in (a).

(ii) On the graph identify, using the letter M, a point where the magnitude of the acceleration of P is a maximum.

(iii) Determine, using data from the graph and your answer to (b)(i), the magnitude of the maximum acceleration of P.

(iv) The mass of P is 0.32 kg. Determine the kinetic energy of P at t=0.052 s.

c. The oscillations of P initially set up a longitudinal wave in the gas. [4]

(i) Describe, with reference to the transfer of energy, what is meant by a longitudinal wave.

(ii) The speed of the wave in the gas is 340 m s^{-1}. Calculate the wavelength of the wave in the gas.

Part 2 Gravitational fields

a. State Newton's universal law of gravitation. [3]

b. Deduce that the gravitational field strength g at the surface of a spherical planet of uniform density is given by [2]

$$g = \frac{GM}{R^2}$$

where M is the mass of the planet, R is its radius and G is the gravitational constant. You can assume that spherical objects of uniform density act as point masses.

c. The gravitational field strength at the surface of Mars g_M is related to the gravitational field strength at the surface of the Earth g_E by [2]

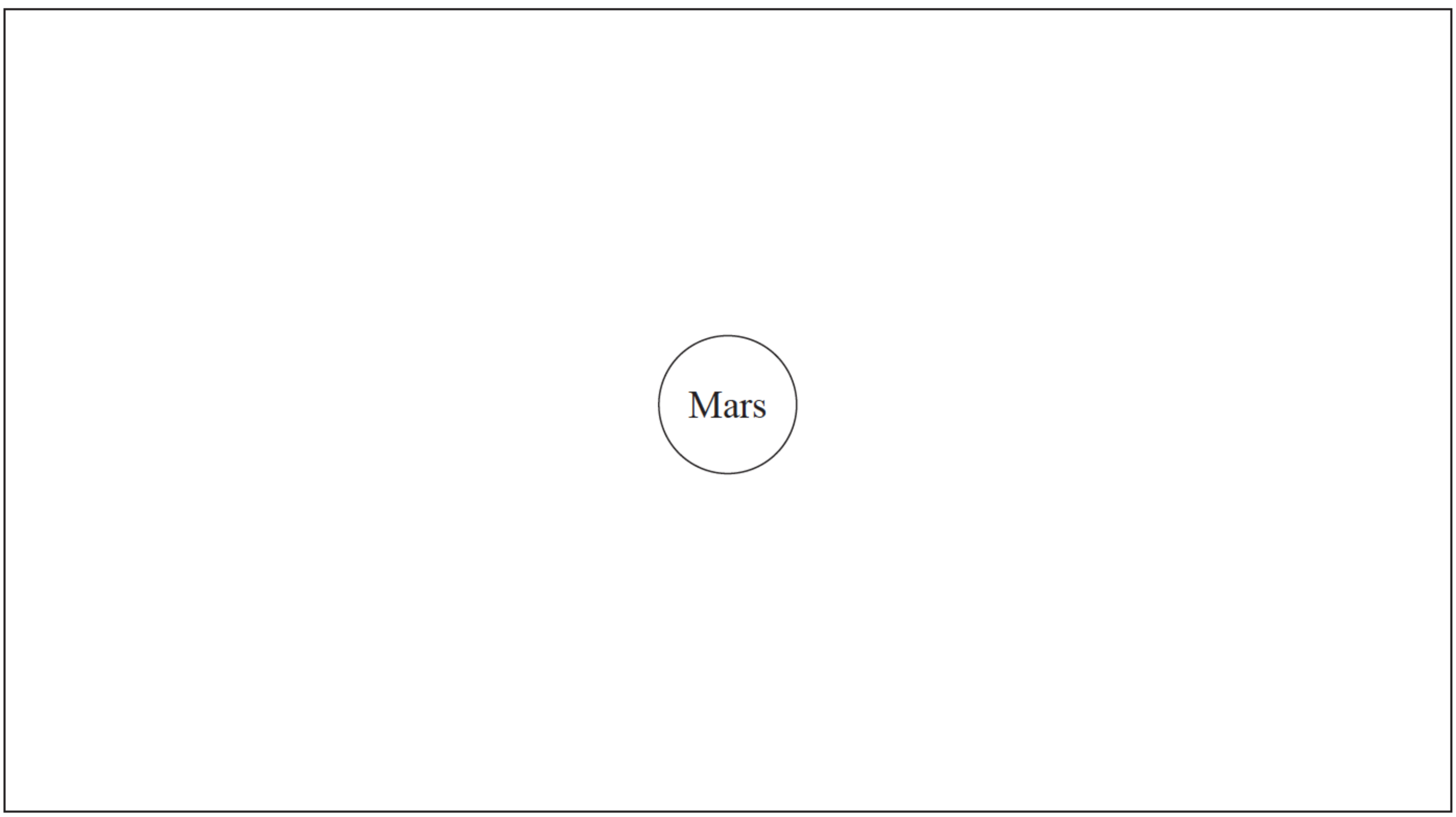
$$g_M = 0.38 \times g_E.$$

The radius of Mars R_M is related to the radius of the Earth R_E by

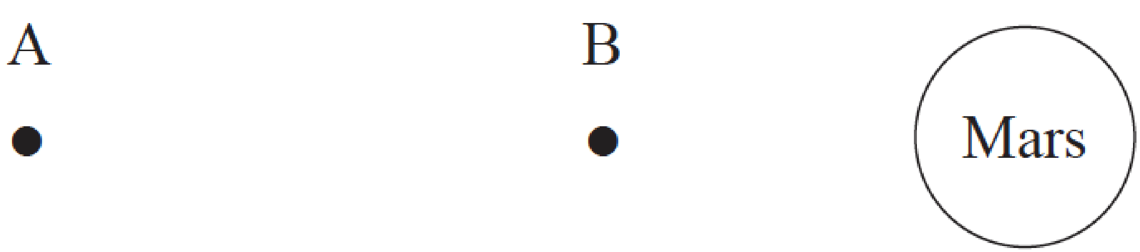
$$R_M = 0.53 \times R_E.$$

Determine the mass of Mars M_M in terms of the mass of the Earth M_E.

d. (i) On the diagram below, draw lines to represent the gravitational field around the planet Mars. [3]



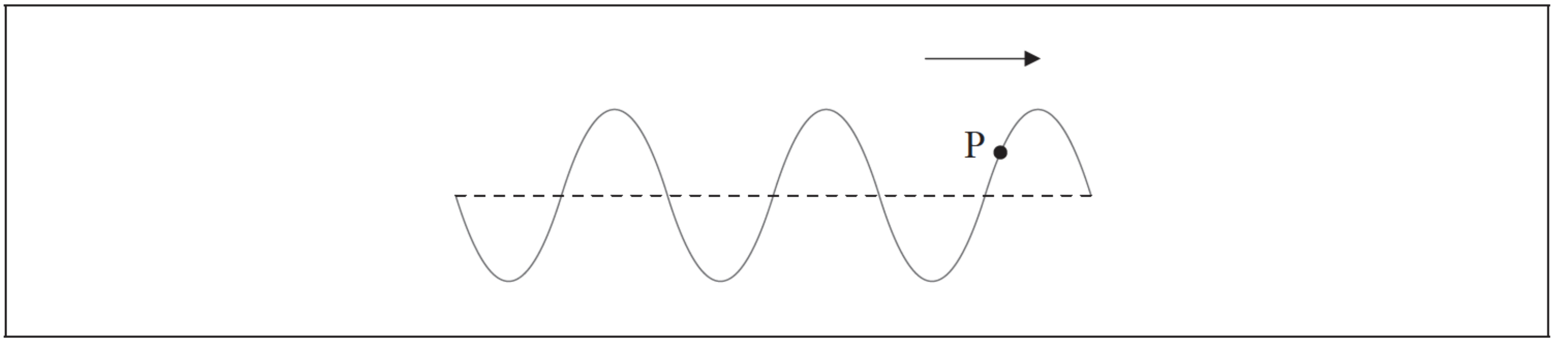
(ii) An object falls freely in a straight line from point A to point B in time t. The speed of the object at A is u and the speed at B is v. A student suggests using the equation $v=u+g_Mt$ to calculate v. Suggest **two** reasons why it is not appropriate to use this equation.



This question is in **two** parts. **Part 1** is about wave motion. **Part 2** is about renewable energy sources.

Part 1 Wave motion

The diagram shows a wave that is travelling to the right along a stretched string at a particular instant.



The dotted line shows the position of the stretched string when it is undisturbed. P is a small marker attached to the string.

a. On the diagram above, identify [2]

(i) with an arrow, the direction of movement of marker P at the instant in time shown.

(ii) the wavelength of the wave.

b. The wavelength of the wave is 25mm and its speed is 18mms^{-1}. [2]

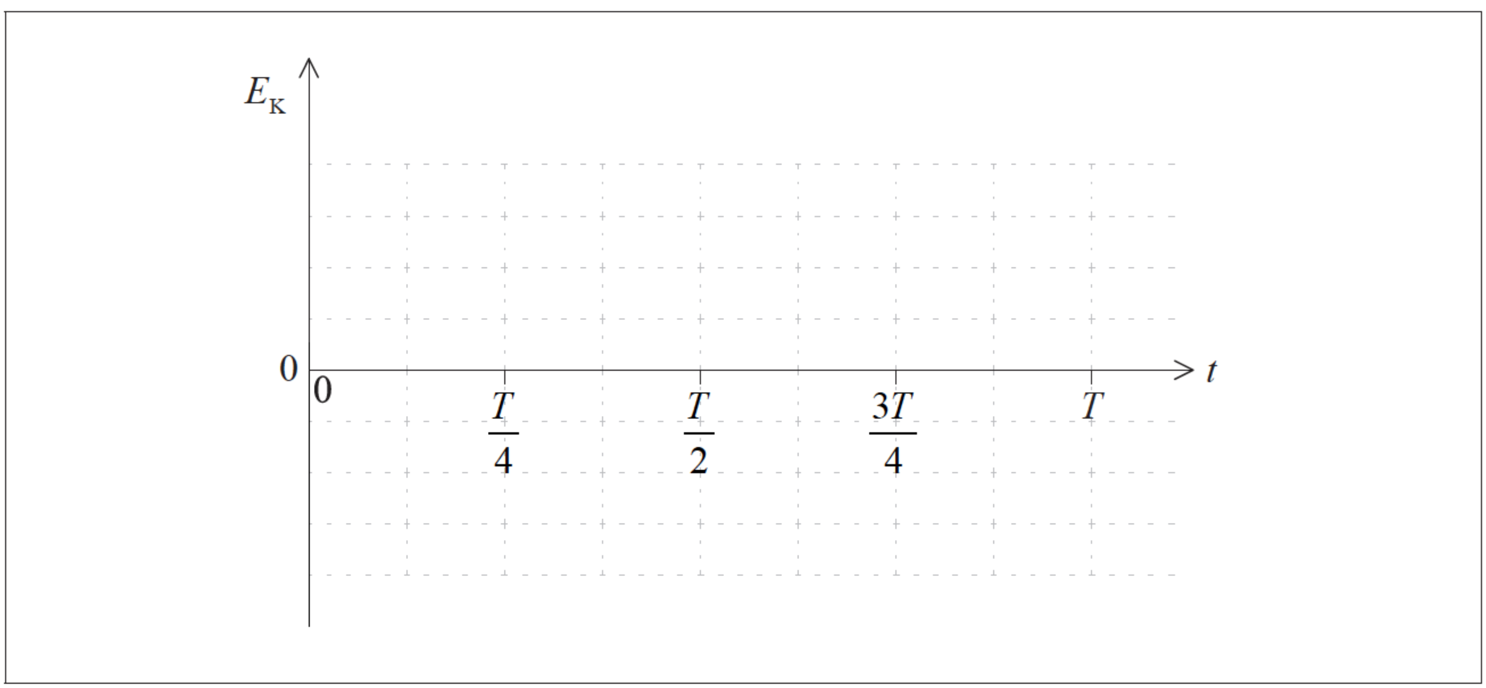
(i) Calculate the time period T of the oscillation of the wave.

(ii) On the diagram above, draw the displacement of the string at a time $\frac{T}{3}$ later than that shown in the diagram.

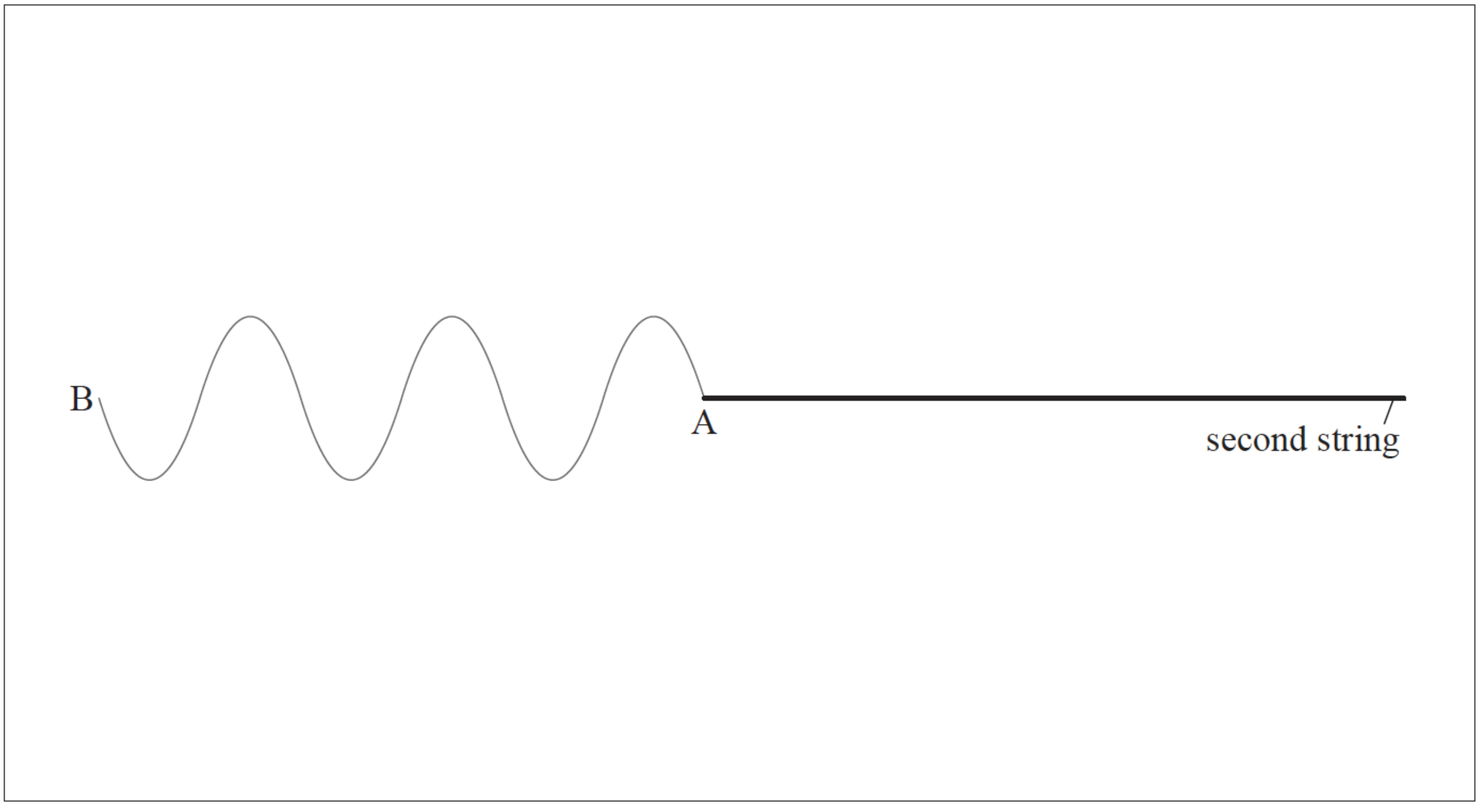
c. Marker P undergoes simple harmonic motion. The amplitude of the wave is 1.7×10^{-2}m and the mass of marker P is 3.5×10^{-3}kg. [5]

(i) Calculate the maximum kinetic energy of marker P.

(ii) Sketch a graph to show how the kinetic energy E_K of marker P varies with time t from t=0 to t=T, where T is the time period of the oscillation calculated in (b). Annotate the axes of the graph with numerical values.



d. The right-hand edge of the wave AB reaches a point where the string is securely attached to a second string in which the speed of waves is smaller than that of the first string. [5]



(i) On the diagram above, draw the shape of the second string after the complete wave AB is travelling in it.

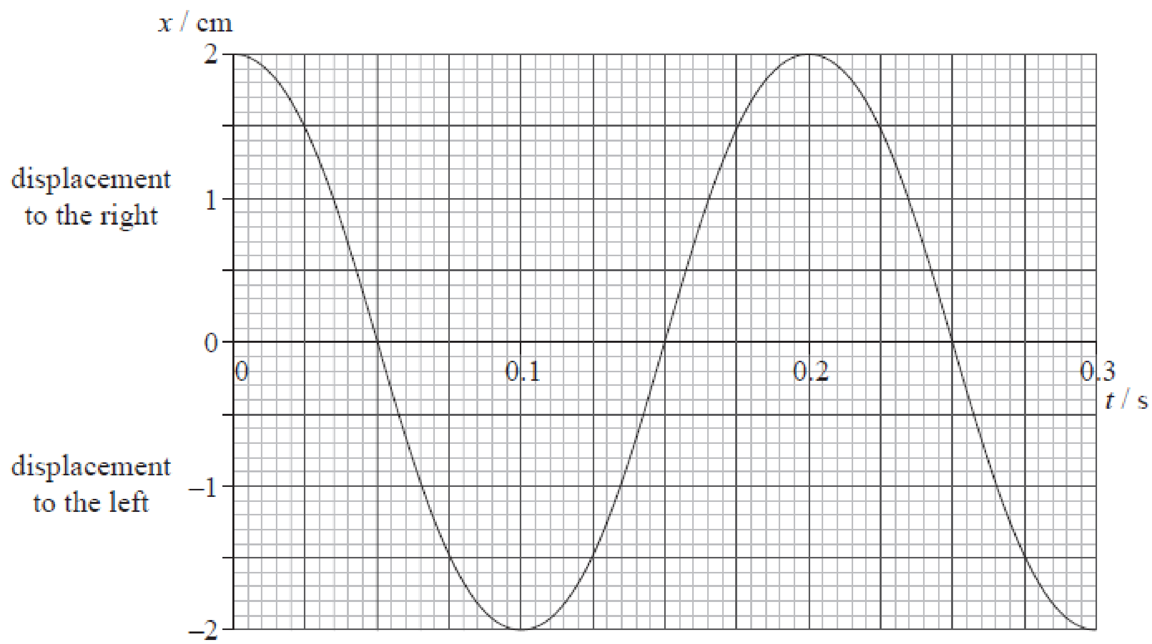
(ii) Explain the shape you have drawn in your answer to (d)(i).

Part 2 Simple harmonic oscillations

A longitudinal wave travels through a medium from left to right.

Graph 1 shows the variation with time *t* of the displacement *x* of a particle P in the medium.

Graph 1



a. For particle P, [6]

(i) state how graph 1 shows that its oscillations are not damped.

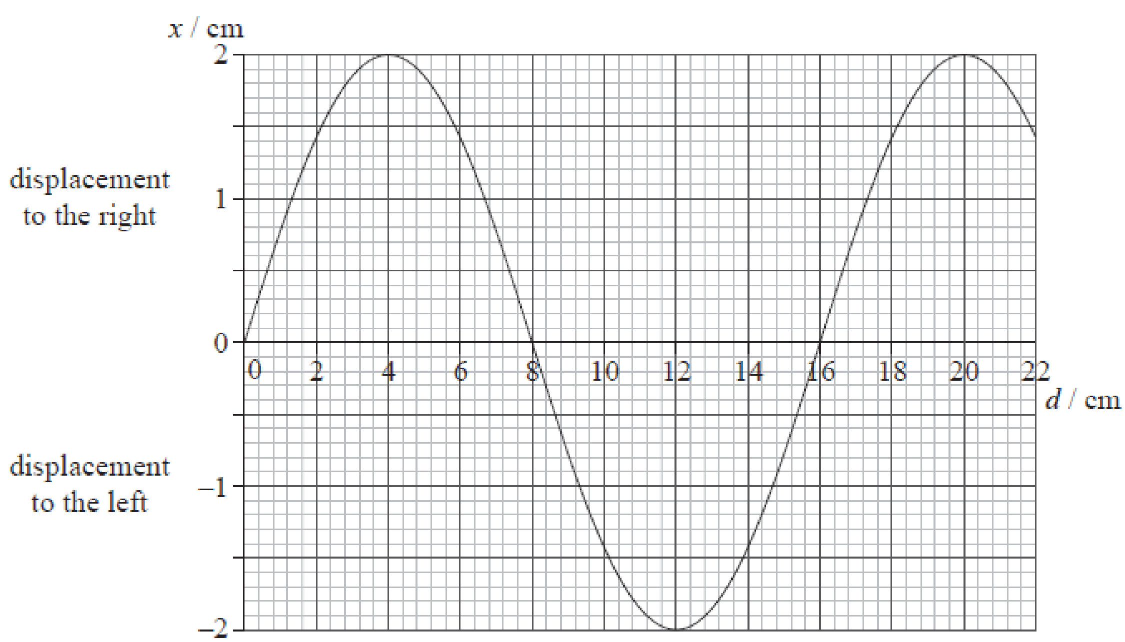
(ii) calculate the magnitude of its maximum acceleration.

(iii) calculate its speed at t=0.12 s.

(iv) state its direction of motion at t=0.12 s.

b. Graph 2 shows the variation with position d of the displacement x of particles in the medium at a particular instant of time. [4]

Graph 2

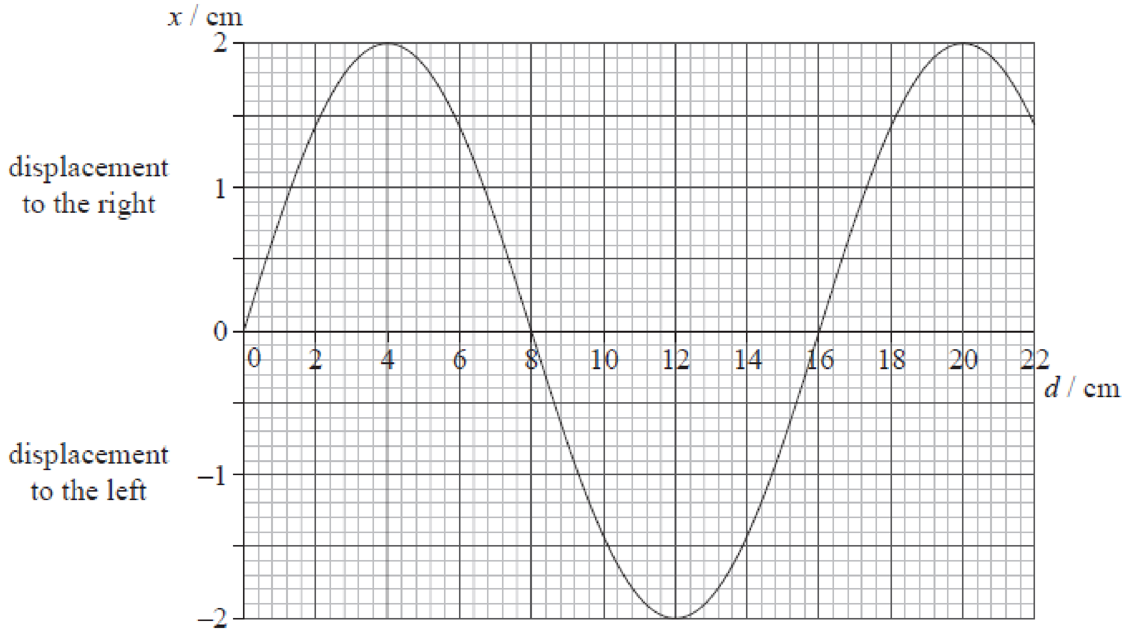


Determine for the longitudinal wave, using graph 1 and graph 2,

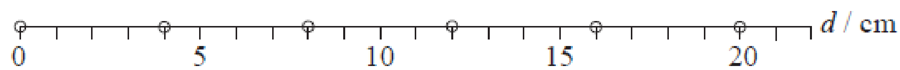
(i) the frequency.

(ii) the speed.

c. **Graph 2** – reproduced to assist with answering (c)(i). [4]



(c) The diagram shows the equilibrium positions of six particles in the medium.



(i) On the diagram above, draw crosses to indicate the positions of these six particles at the instant of time when the displacement is given by graph 2.

(ii) On the diagram above, label with the letter C a particle that is at the centre of a compression.

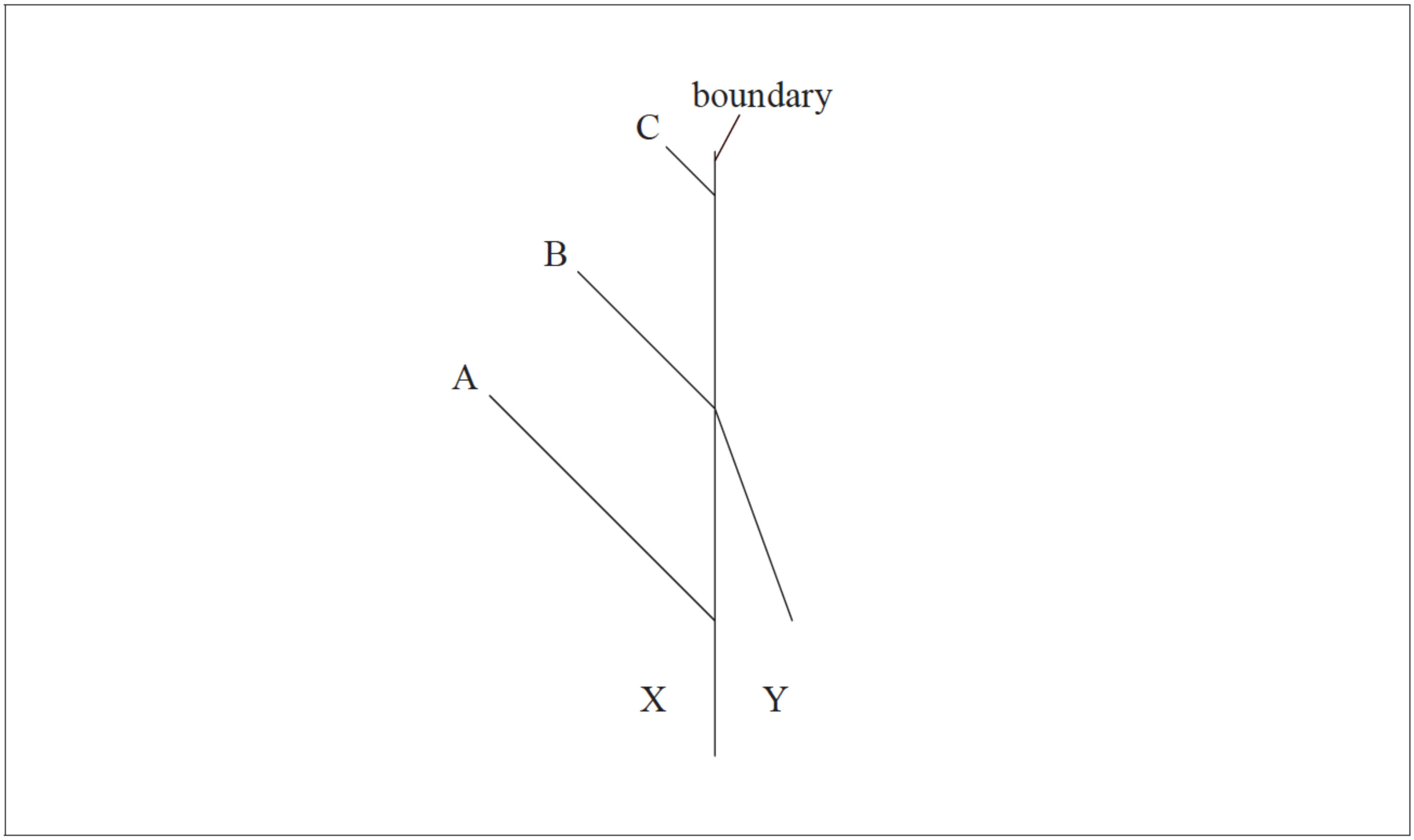
This question is in **two** parts. **Part 1** is about wave motion. **Part 2** is about the melting of the Pobeda ice island.

Part 1 Wave motion

a. State what is meant by the terms ray and wavefront and state the relationship between them. [3]

b. The diagram shows three wavefronts, A, B and C, of a wave at a particular instant in time incident on a boundary between media X and Y. [4]

Wavefront B is also shown in medium Y.

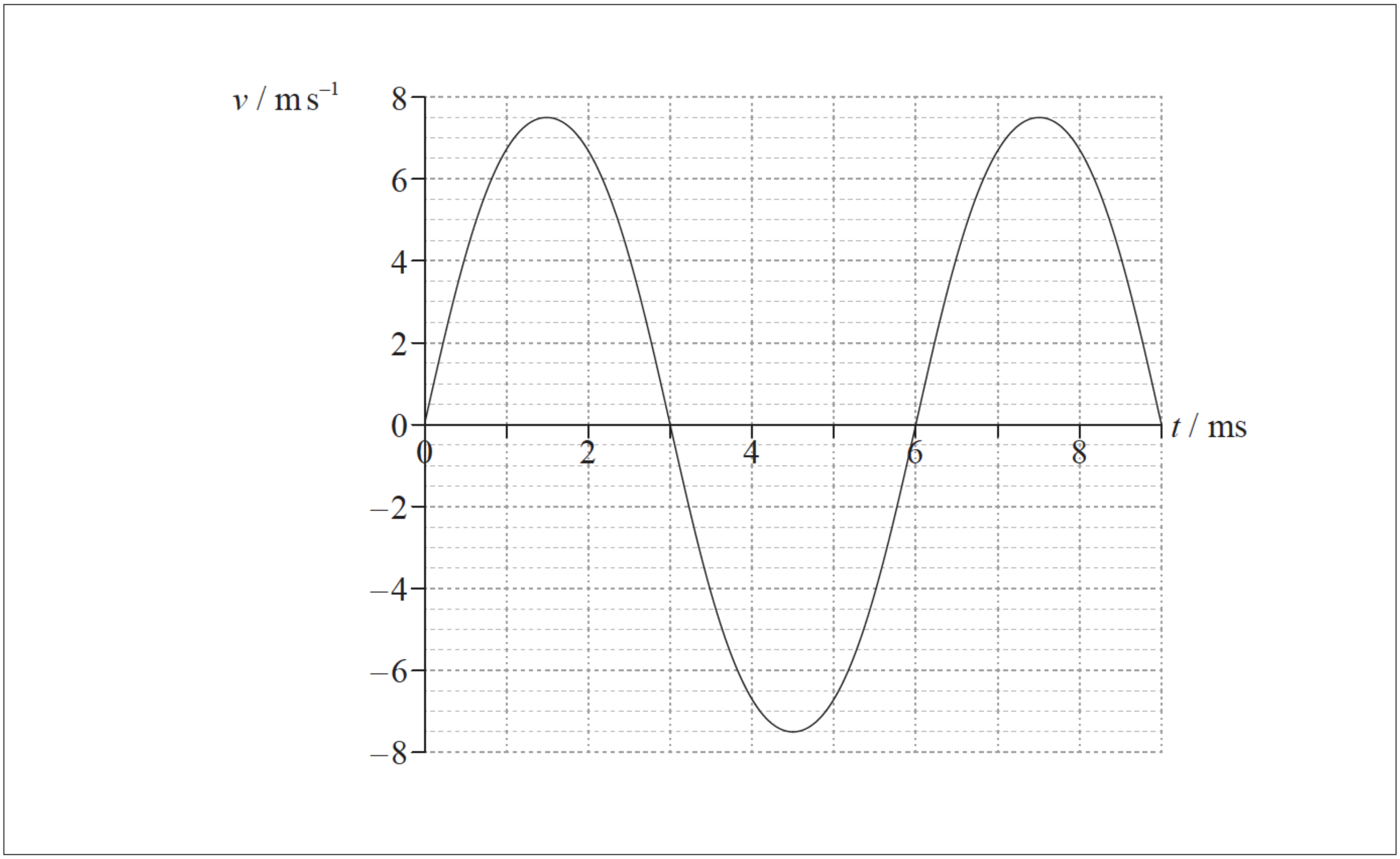


(i) Draw a line to show wavefront C in medium Y.

(ii) The refractive index of X is n_X and the refractive index of Y is n_Y. By making appropriate measurements, calculate $\frac{n_X}{n_Y}$.

c. Describe the difference between transverse waves and longitudinal waves. [2]

d. The graph below shows the variation of the velocity v with time t for one oscillating particle of a medium. [3]



(i) Calculate the frequency of oscillation of the particle.

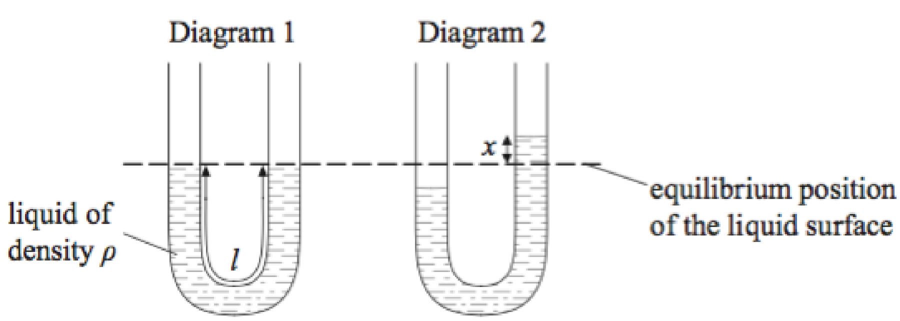
(ii) Identify on the graph, with the letter M, a time at which the displacement of the particle is a maximum.

This question is in **two** parts. **Part 1** is about simple harmonic motion (SHM) and a wave in a string. **Part 2** is about the unified atomic mass unit and a nuclear reaction.

Part 1 Simple harmonic motion and a wave in a string

a. By reference to simple harmonic motion, state what is meant by amplitude. [1]

b. A liquid is contained in a U-tube. [5]



The pressure on the liquid in one side of the tube is increased so that the liquid is displaced as shown in diagram 2. When the pressure is suddenly released the liquid oscillates. The damping of the oscillations is small.

(i) Describe what is meant by damping.

(ii) The displacement of the liquid surface from its equilibrium position is *x*. The acceleration *a* of the liquid in the tube is given by the expression

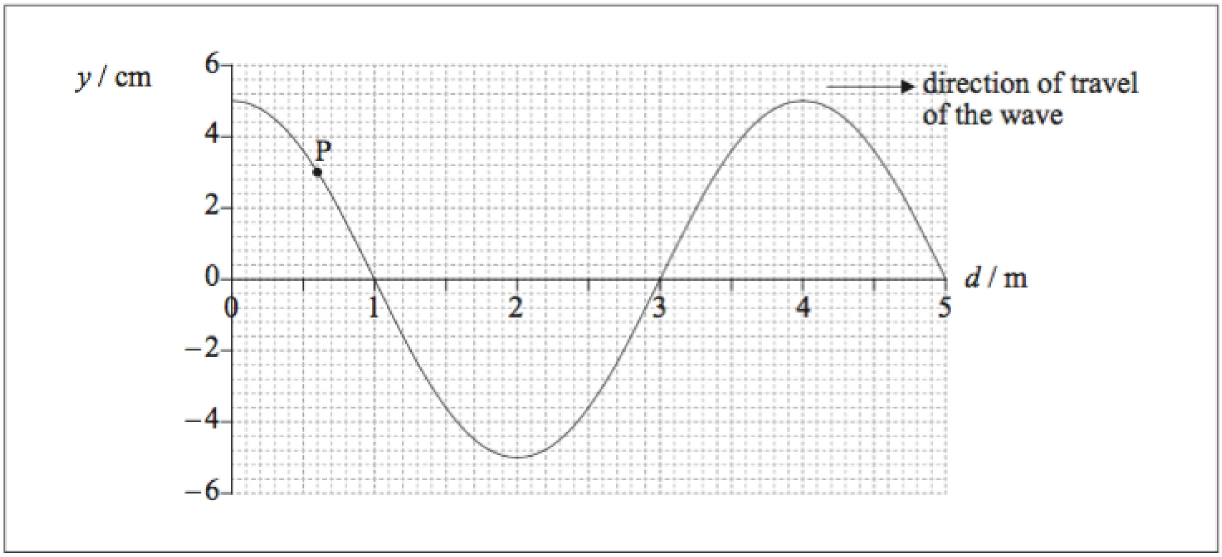
$$a = -\frac{2g}{l}x$$

where *g* is the acceleration of free fall and *l* is the total length of the liquid column. The total length of the liquid column in the tube is 0.32m. Determine the period of oscillation.

c. A wave is travelling along a string. The string can be modelled as a single line of particles and each particle executes simple harmonic motion. [9]

The period of oscillation of the particles is 0.80s.

The graph shows the displacement *y* of part of the string at time *t*=0. The distance along the string is *d*.



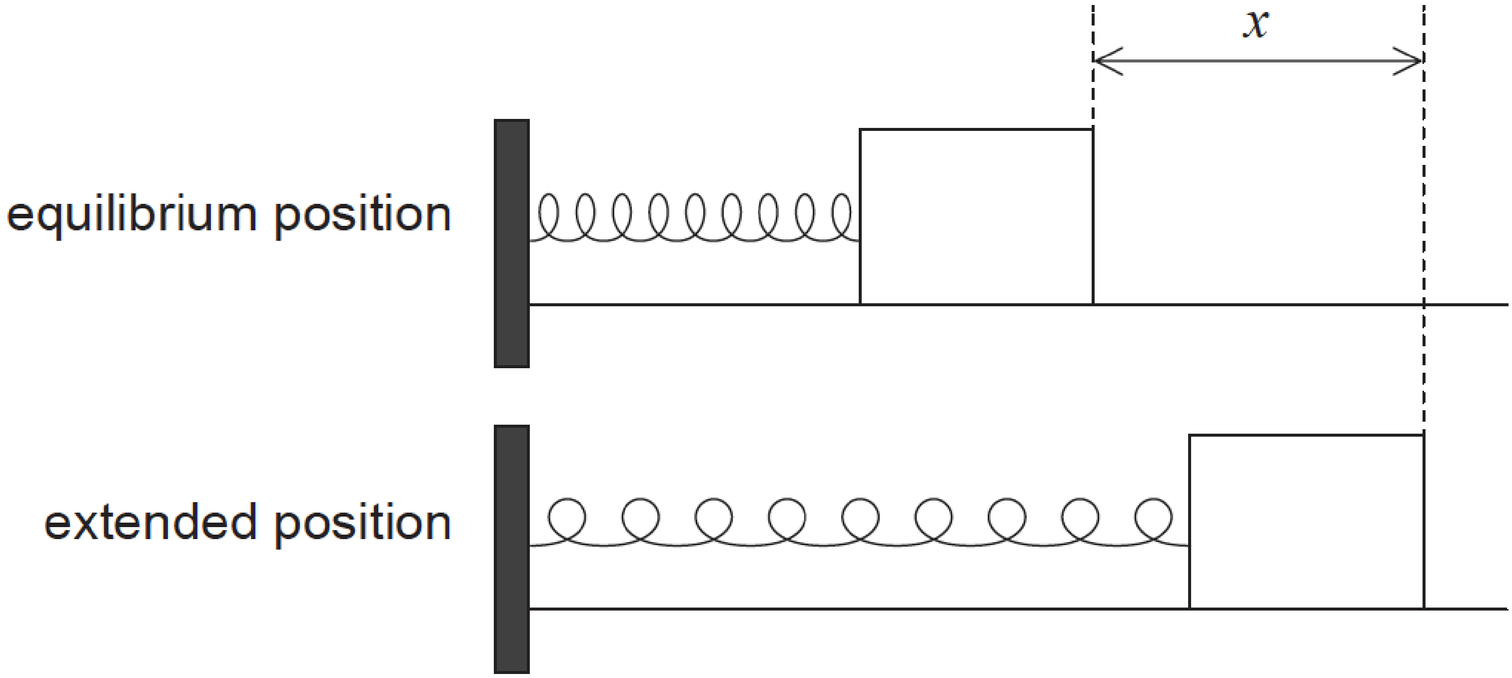
(i) On the graph, draw an arrow to show the direction of motion of particle P at the point marked on the string.
(ii) Determine the magnitude of the velocity of particle P.
(iii) Show that the speed of the wave is 5.0 ms^{-1}.

(iv) On the graph opposite, label with the letter X the position of particle P at *t*=0.40 s.

This question is in two parts. **Part 1** is about simple harmonic motion (SHM). **Part 2** is about current electricity.

Part 1 Simple harmonic motion (SHM)

An object is placed on a frictionless surface. The object is attached by a spring fixed at one end and oscillates at the end of the spring with simple harmonic motion (SHM).

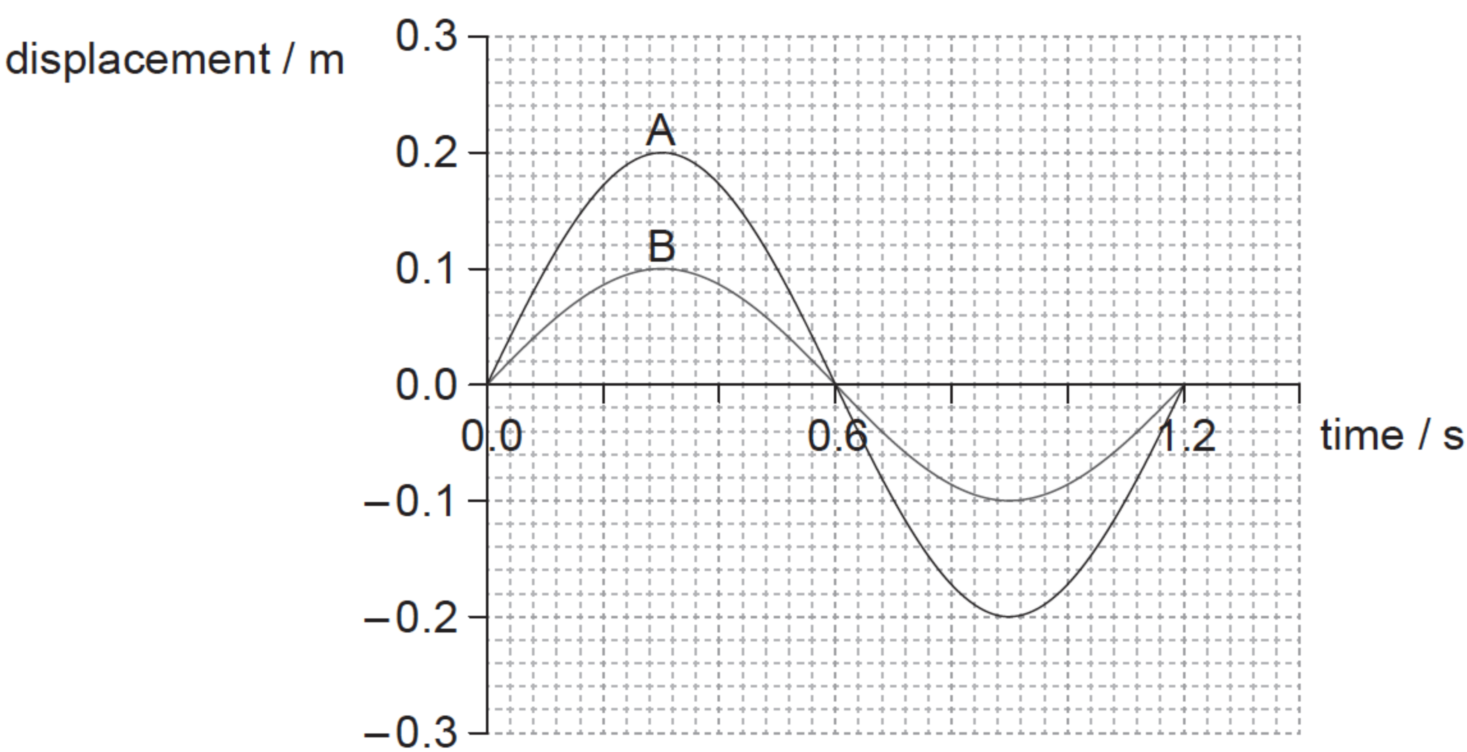


The tension F in the spring is given by $F = k\,x$ where x is the extension of the spring and k is a constant.

Part 2 Current electricity

a. Show that $\omega^2 = \frac{k}{m}$. [2]

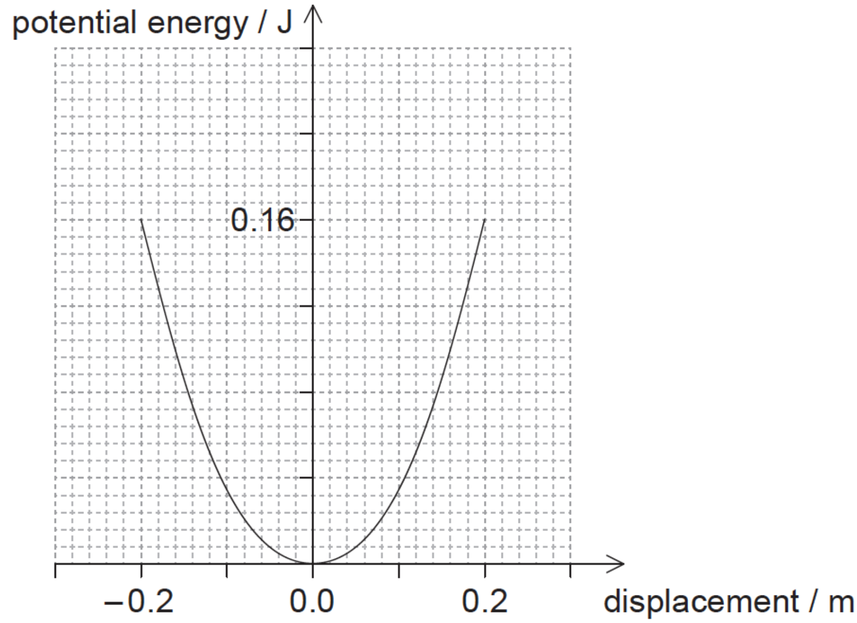
b. One cycle of the variation of displacement with time is shown for two separate mass–spring systems, A and B. [3]



(i) Calculate the frequency of the oscillation of A.

(ii) The springs used in A and B are identical. Show that the mass in A is equal to the mass in B.

c. The graph shows the variation of the potential energy of A with displacement. [5]



On the axes,

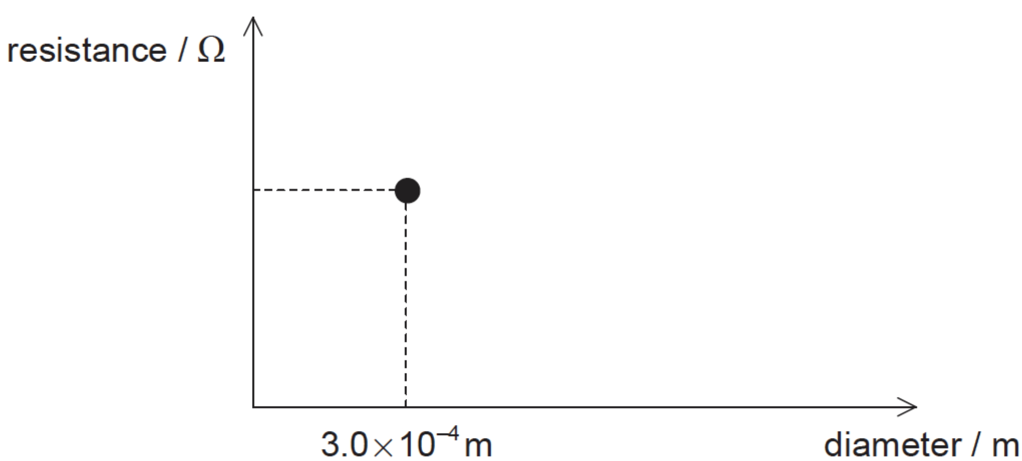
(i) draw a graph to show the variation of kinetic energy with displacement for the mass in A. Label this A.

(ii) sketch a graph to show the variation of kinetic energy with displacement for the mass in B. Label this B.

d. A 24 Ω resistor is made from a conducting wire. [4]

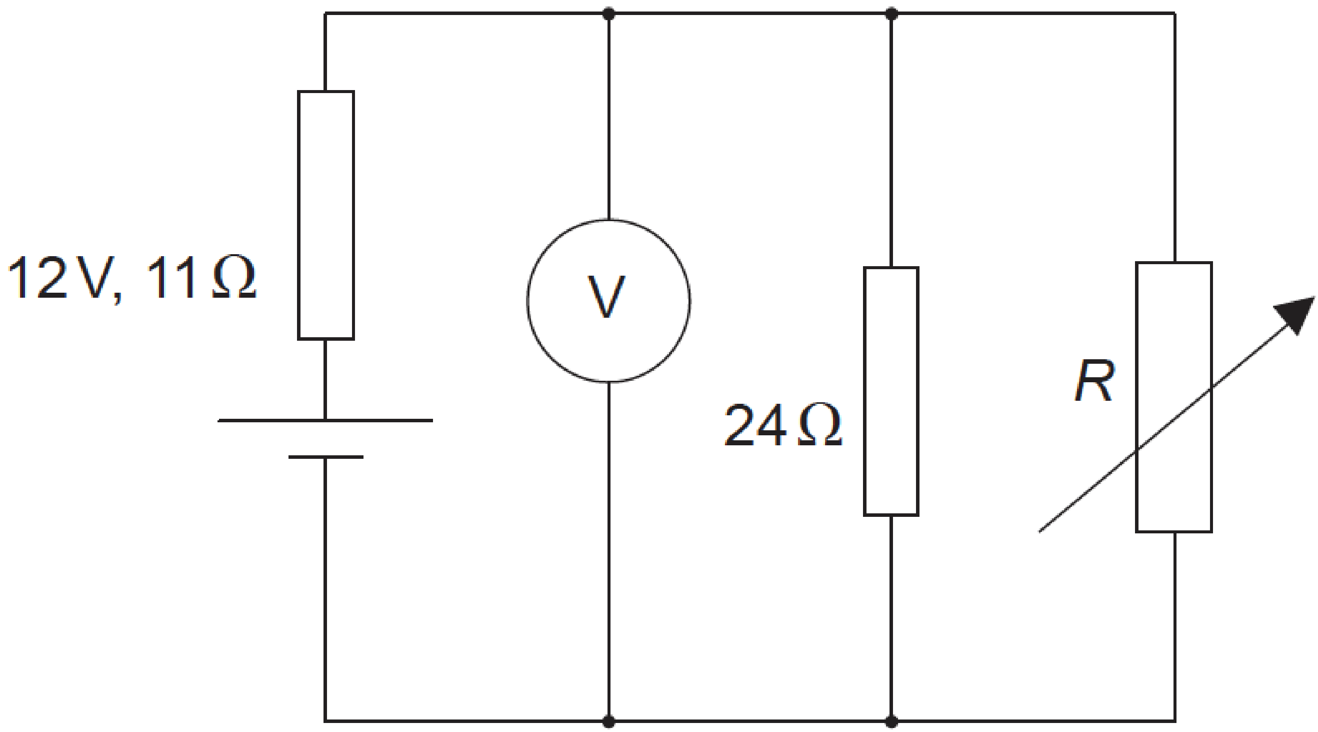
(i) The diameter of the wire is 0.30 mm and the wire has a resistivity of $1.7\times10^{-8}\,\Omega\text{m}$. Calculate the length of the wire.

(ii) On the axes, draw a graph to show how the resistance of the wire in (d)(i) varies with the diameter of the wire when the length is constant. The data point for the diameter of 0.30 mm has already been plotted for you.



e. The 24 Ω resistor is covered in an insulating material. Explain the reasons for the differences between the electrical properties of the insulating material and the electrical properties of the wire. [3]

f. An electric circuit consists of a supply connected to a 24Ω resistor in parallel with a variable resistor of resistance *R*. The supply has an emf of 12V and an internal resistance of 11Ω. [8]



Power supplies deliver maximum power to an external circuit when the resistance of the external circuit equals the internal resistance of the power supply.

(i) Determine the value of *R* for this circuit at which maximum power is delivered to the external circuit.

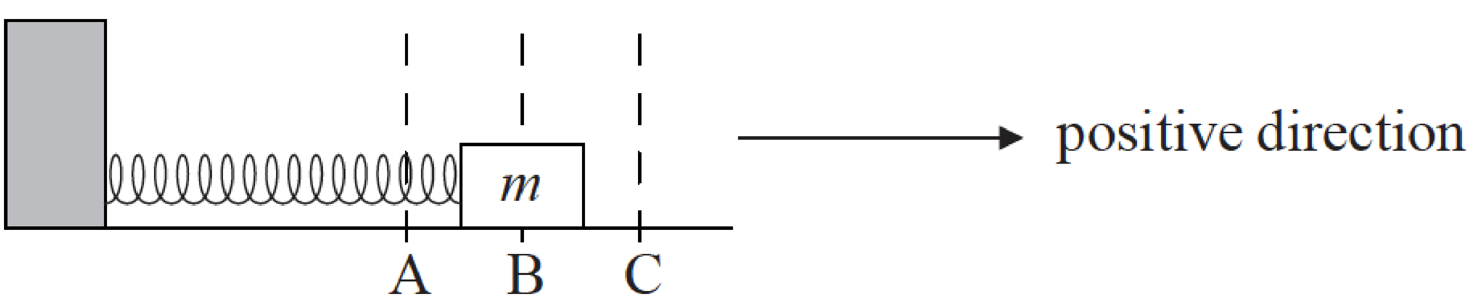
(ii) Calculate the reading on the voltmeter for the value of *R* you determined in (f)(i).

(iii) Calculate the total power dissipated in the circuit when the maximum power is being delivered to the external circuit.

This question is in **two** parts. **Part 1** is about simple harmonic motion and the superposition of waves. **Part 2** is about gravitational fields.

Part 1 Simple harmonic motion and the superposition of waves

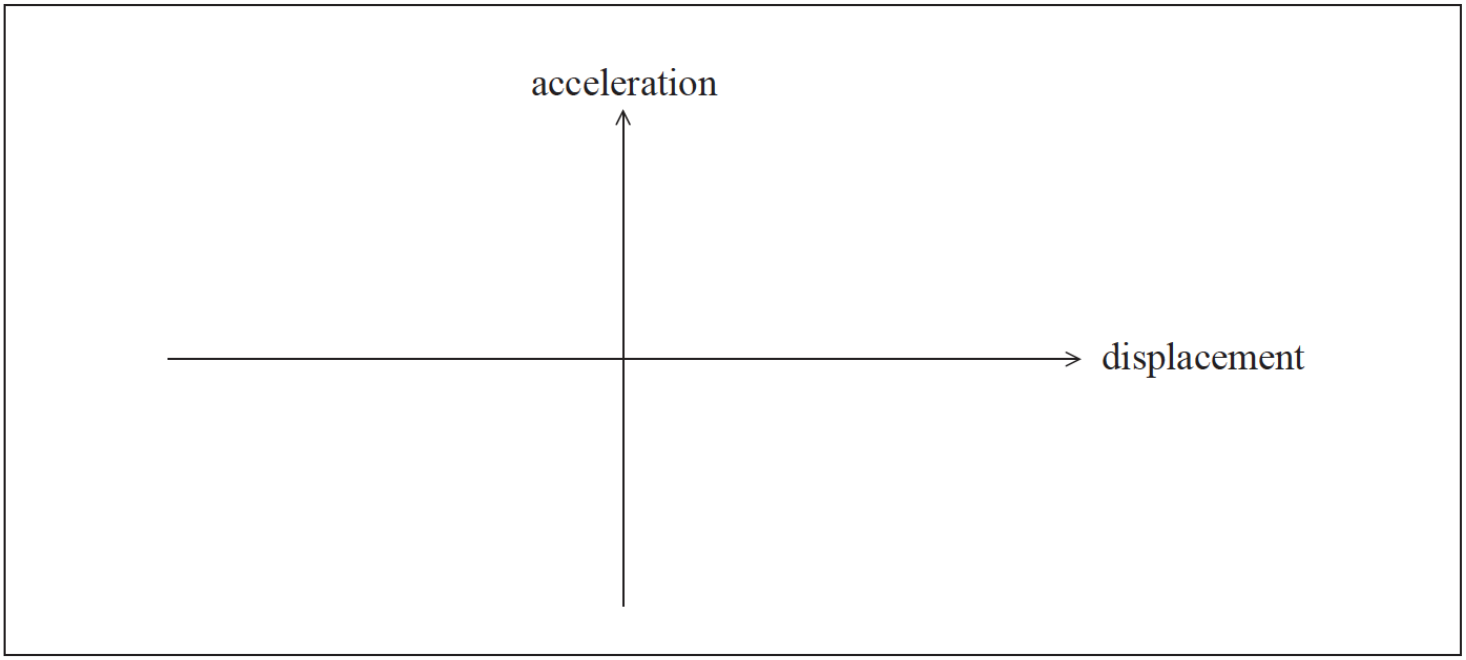
An object of mass *m* is placed on a frictionless surface and attached to a light horizontal spring. The other end of the spring is fixed.



The equilibrium position is at B. The direction B to C is taken to be positive. The object is released from position A and executes simple harmonic motion between positions A and C.

a. Define *simple harmonic motion*. [2]

b. (i) On the axes below, sketch a graph to show how the acceleration of the mass varies with displacement from the equilibrium position B. [3]



(ii) On your graph, label the points that correspond to the positions A, B and C.

c. (i) On the axes below, sketch a graph to show how the velocity of the mass varies with [3]

time from the moment of release from A until the mass returns to A for the first time.

(ii) On your graph, label the points that correspond to the positions A, B and C.

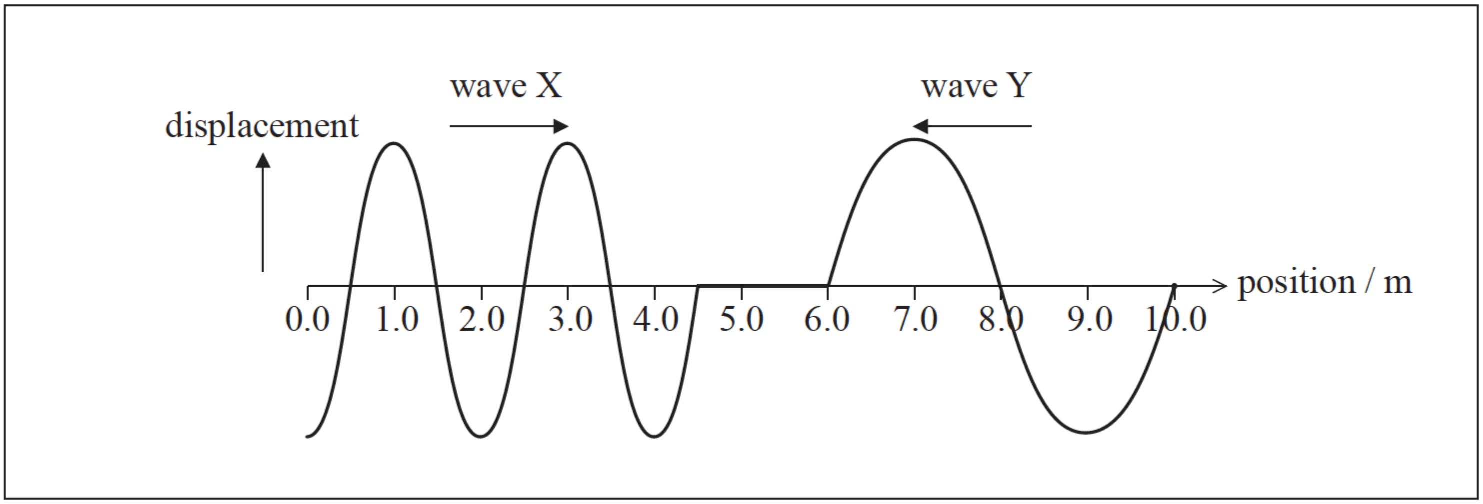
d. The period of oscillation is 0.20s and the distance from A to B is 0.040m. Determine the maximum speed of the mass. [3]

e. A long spring is stretched so that it has a length of 10.0 m. Both ends are made to oscillate with simple harmonic motion so that transverse [4]

waves of equal amplitude but different frequency are generated.

Wave X, travelling from left to right, has wavelength 2.0 m, and wave Y, travelling from right to left, has wavelength 4.0 m. Both waves move along the spring at speed 10.0 m s^{-1}.

The diagram below shows the waves at an instant in time.

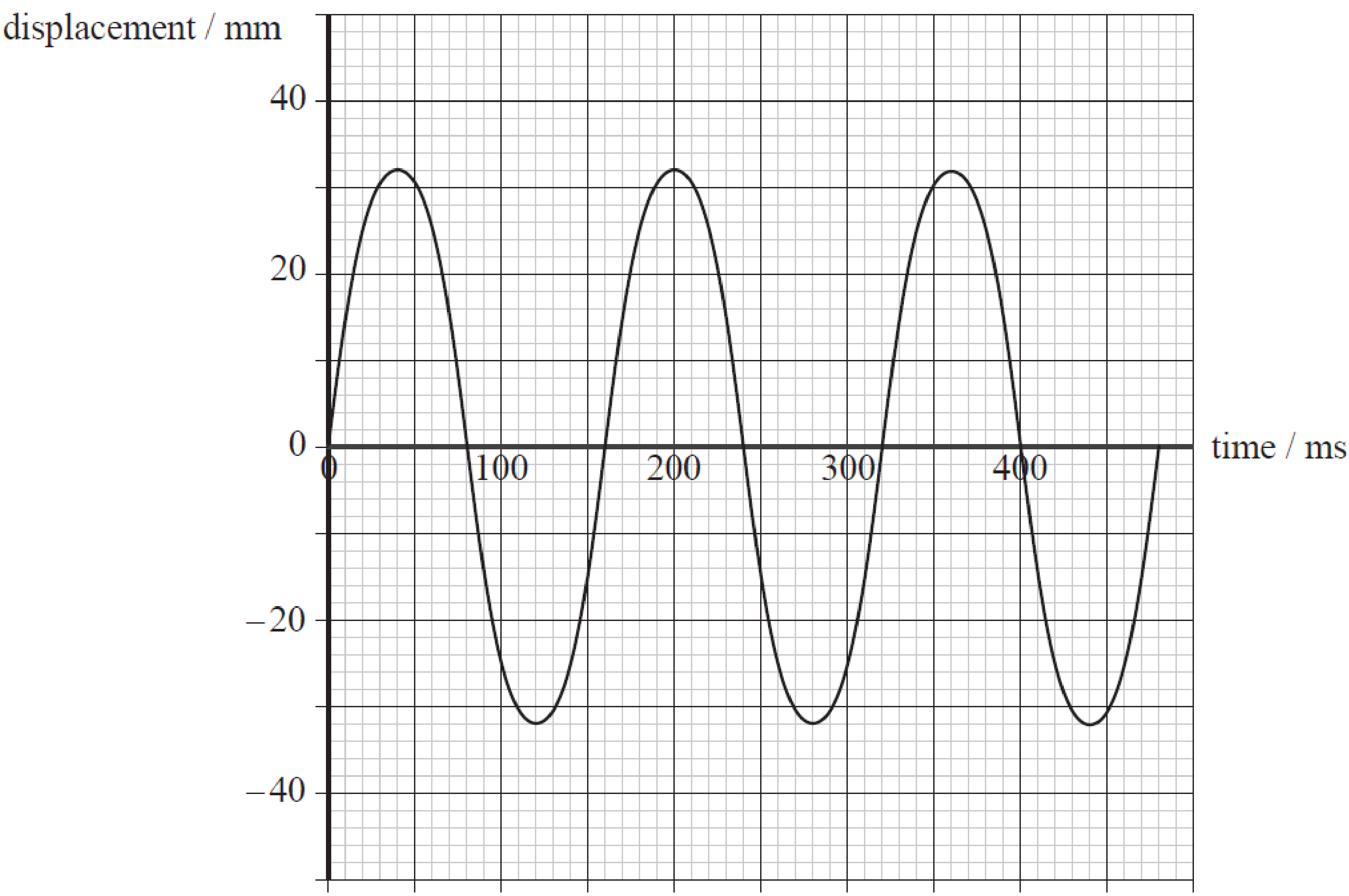


(i) State the principle of superposition as applied to waves.

(ii) By drawing on the diagram or otherwise, calculate the position at which the resultant wave will have maximum displacement 0.20 s later.

Simple harmonic motion and forced oscillations

The graph shows the variation with time of the displacement of an object undergoing simple harmonic motion.



a. (i) State the amplitude of the oscillation. [3]

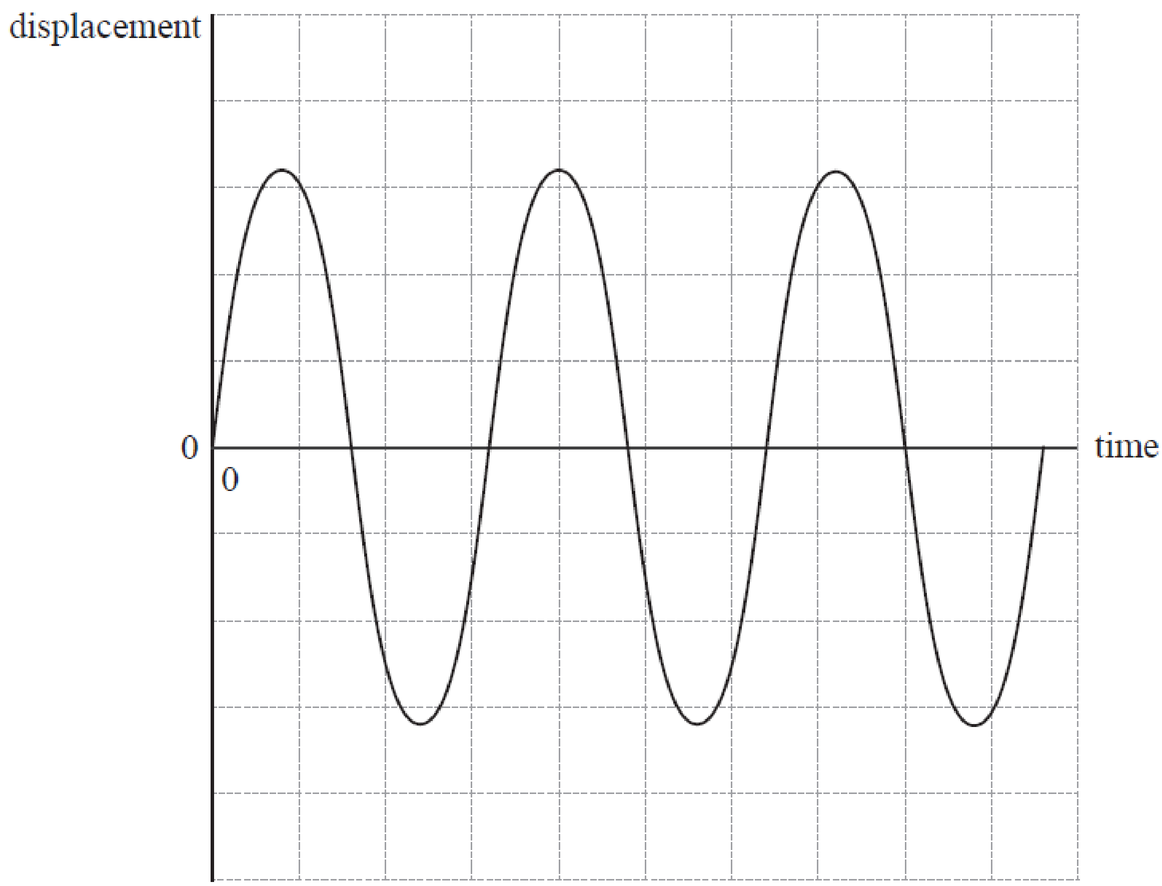
(ii) Calculate the frequency of the oscillation.

b. (i) Determine the maximum speed of the object. [4]

(ii) Determine the acceleration of the object at 140 ms.

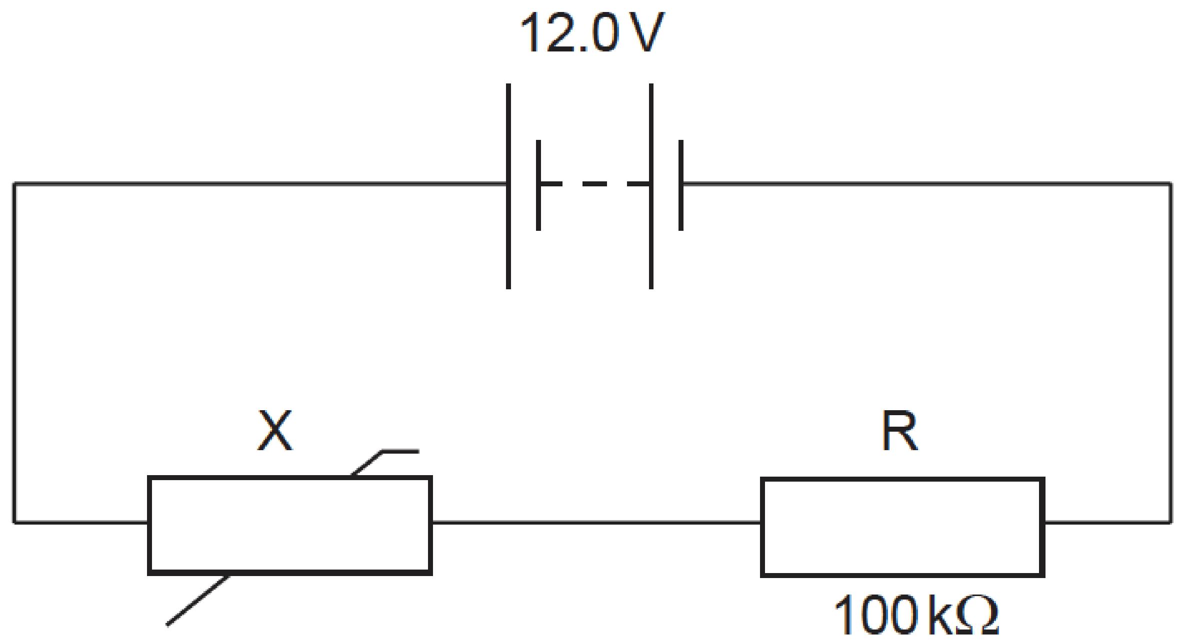
c. The graph below shows how the displacement of the object varies with time. Sketch on the same axes a line indicating how the kinetic energy of the object varies with time. [3]

You should ignore the actual values of the kinetic energy.



This question is in two parts. Part 1 is about a thermistor circuit. Part 2 is about vibrations and waves.

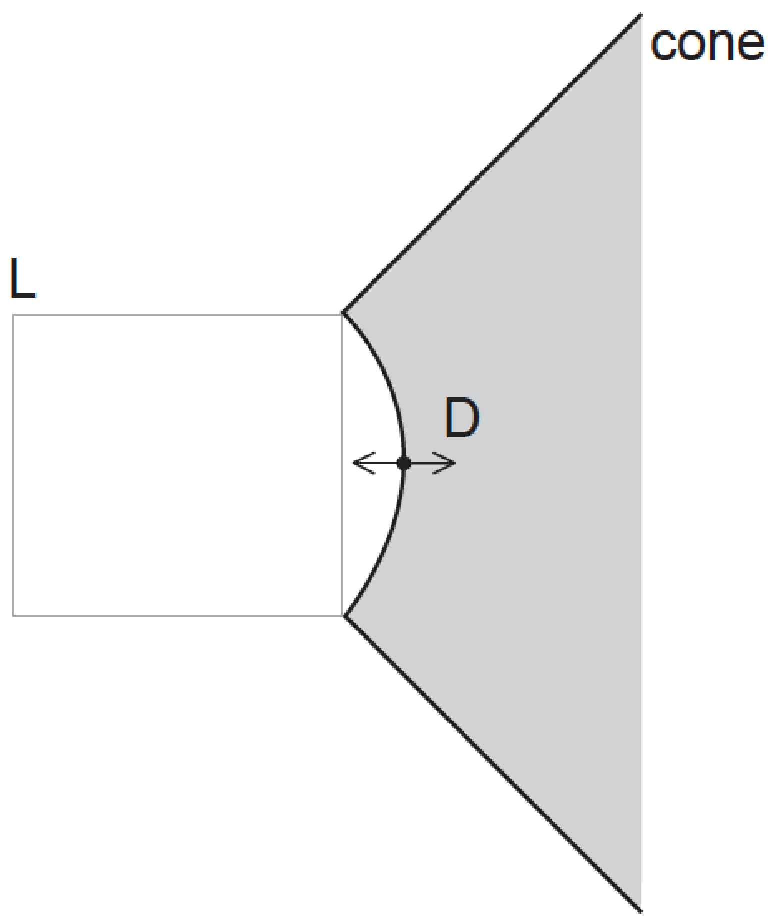
Part 1 Thermistor circuit
The circuit shows a negative temperature coefficient (NTC) thermistor X and a 100 kΩ fixed resistor R connected across a battery.



The battery has an electromotive force (emf) of 12.0 V and negligible internal resistance.

Part 2 Vibrations and waves

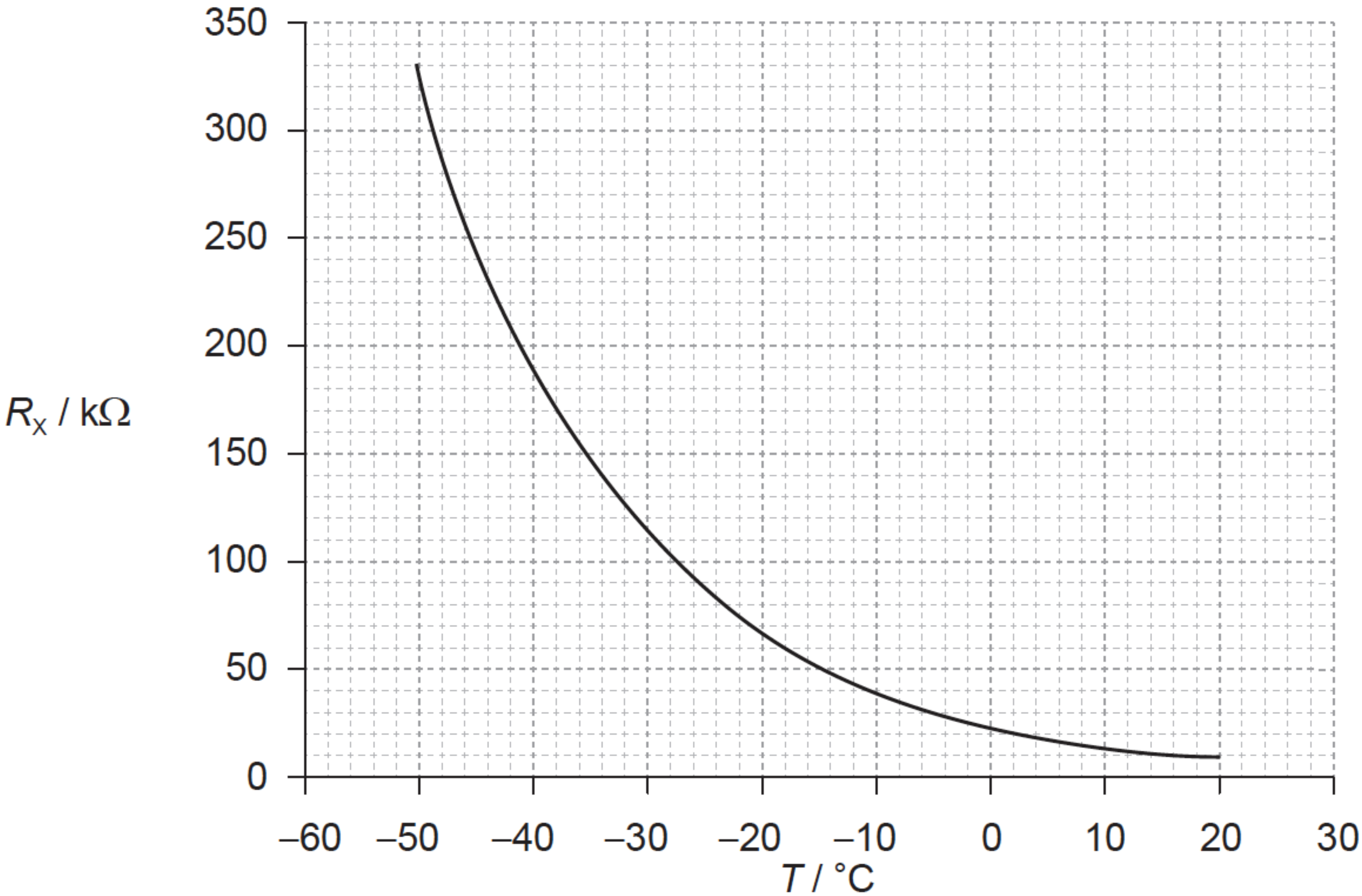
The cone and dust cap D of a loudspeaker L vibrates with a frequency of 1.25 kHz with simple harmonic motion (SHM).



a. (i) Define *electromotive force (emf)*. [2]

(ii) State how the emf of the battery can be measured.

b. The graph below shows the variation with temperature T of the resistance R_X of the thermistor. [7]



(i) Determine the temperature of X when the potential difference across R is 4.5V.

(ii) State the range of temperatures for which the change in the resistance of the thermistor is most sensitive to changes in temperature.

(iii) State and explain the effect of a decrease in temperature on the ratio

$$\frac{\text{voltageacrossX}}{\text{voltageacrossR}}$$

.

c. Define *simple harmonic motion (SHM)*. [2]

d. D has mass 6.5×10^{-3} kg and vibrates with amplitude 0.85 mm. [4]

(i) Calculate the maximum acceleration of D.

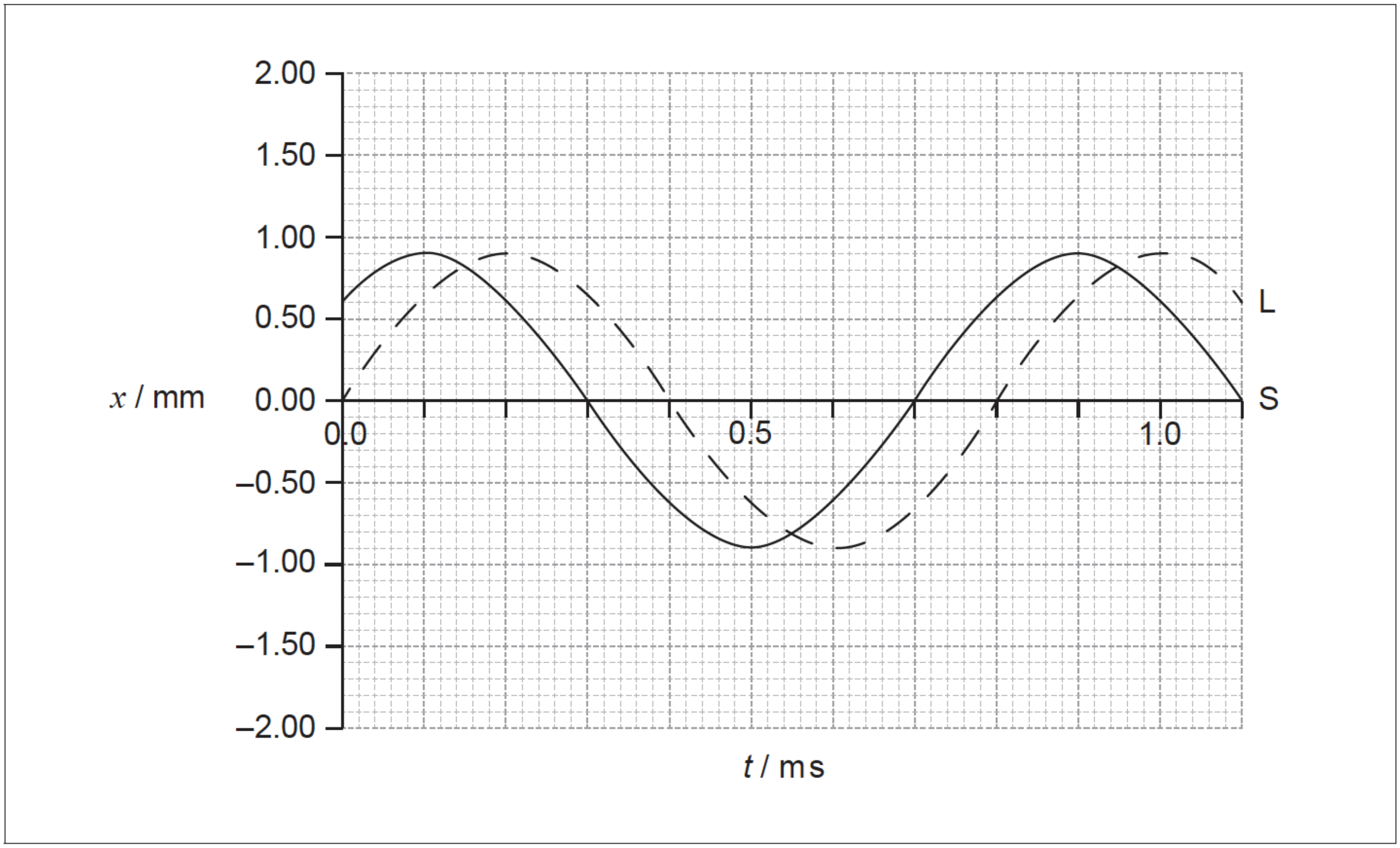
(ii) Determine the total energy of D.

e. The sound waves from the loudspeaker travel in air with speed 330 ms^{-1}. [2]

(i) Calculate the wavelength of the sound waves.

(ii) Describe the characteristics of sound waves in air.

f. A second loudspeaker S emits the same frequency as L but vibrates out of phase with L. The graph below shows the variation with time t of the displacement x of the waves emitted by S and L. [6]



(i) Deduce the relationship between the phase of L and the phase of S.

(ii) On the graph, sketch the variation with *t* of *x* for the wave formed by the superposition of the two waves.