

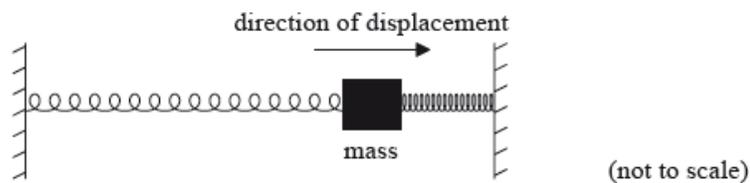
SL Paper 2

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

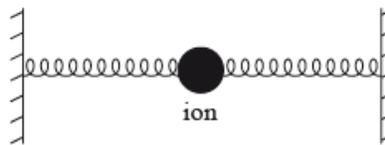
Part 1 Oscillation of a mass

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.



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.



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]

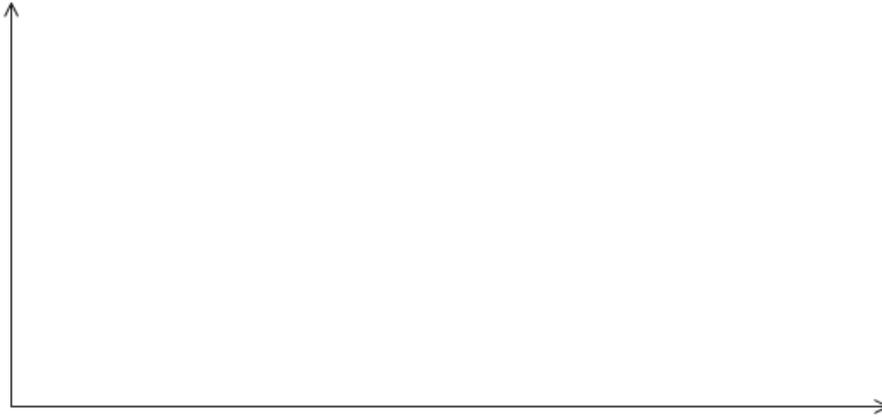
a.ii. Outline why the mass subsequently performs simple harmonic motion (SHM). [2]

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]

Markscheme

a.i. force of 1.8 N for each spring so total force is 3.6 N;

$$\text{acceleration} = \frac{3.6}{0.8} = 4.5 \text{ ms}^{-2}; \text{ (allow ECF from first marking point)}$$

to left/towards equilibrium position / negative sign seen in answer;

a.ii. force/acceleration is in opposite direction to displacement/towards equilibrium position;

and is proportional to displacement;

$$\text{a.iii. } \omega = \left(\sqrt{\frac{a}{x}} \right) = \sqrt{\frac{4.5}{60 \times 10^{-3}}} (= 8.66 \text{ rad s}^{-1});$$

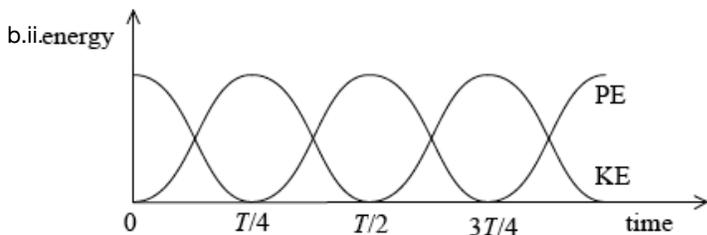
$$T = 0.73 \text{ s};$$

Watch out for ECF from (a)(i) eg award [2] for $T = 1.0 \text{ s}$ for $a = 2.25 \text{ m s}^{-2}$.

$$\text{b.i. } \omega = 2\pi \times 7 \times 10^{12} (= 4.4 \times 10^{13} \text{ Hz});$$

$$5 \times 10^{-21} \text{ J};$$

Allow answers in the range of 4.8 to $4.9 \times 10^{-21} \text{ J}$ if 2 sig figs or more are used.



KE and PE curves labelled – very roughly \cos^2 and \sin^2 shapes; } (allow reversal of curve labels)

KE and PE curves in anti-phase and of equal amplitude;

at least one period shown;

either E_{\max} marked correctly on energy axis, or T marked correctly on time axis;

c.i. 7.0×10^{12} Hz is equivalent to wavelength of 4.3×10^{-5} m;

d.i. number of fissions in one day = $9.5 \times 10^{19} \times 24 \times 3600$ ($= 8.2 \times 10^{24}$);

mass of uranium atom = $235 \times 1.661 \times 10^{-27}$ ($= 3.9 \times 10^{-25}$ kg);

mass of uranium in one day ($= 8.2 \times 10^{24} \times 3.9 \times 10^{-25}$) = 3.2 kg;

d.ii. energy per fission = $200 \times 10^6 \times 1.6 \times 10^{-19}$ ($= 3.2 \times 10^{-11}$ J);

power output = $(9.5 \times 10^{19} \times 3.2 \times 10^{-11} \times 0.32 =) 9.7 \times 10^8$ W;

Award [1] for an answer of 6.1×10^{27} eVs⁻¹.

e.i. neutrons have to be slowed down (before next fission);

because the probability of fission is (much) greater (with neutrons of thermal energy);

neutrons collide with/transfer energy to atoms/molecules (of the moderator);

e.ii. have high neutron capture cross-section/good at absorbing neutrons;

(remove neutrons from the reaction) thus controlling the rate of nuclear reaction;

Examiners report

a.i. This is a slightly different situation. Most candidates at SL did not use F and m to find acceleration. Very few added the force due to each spring and ECF was frequently applied.

a.ii. [N/A]

a.iii. [N/A]

b.i. [N/A]

b.ii. Care was needed in showing the constant and equal amplitudes. Many poor answers were seen.

c.i. [N/A]

d.i. [N/A]

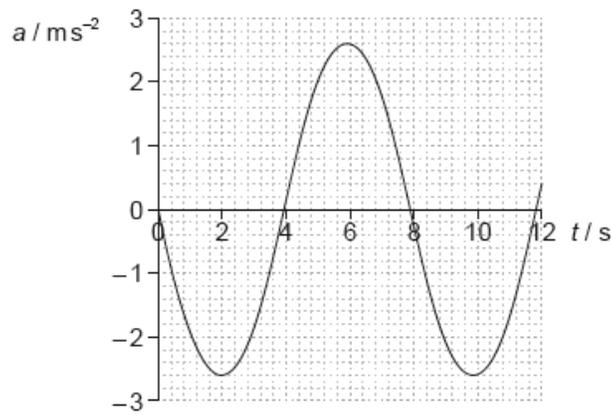
d.ii. [N/A]

e.i. Mostly good answers although it was rare to find a candidate who stated that the probability of further fusion is increased with thermal neutrons.

e.ii. Too many answers lacked precision referring only to the use of control rods in avoiding an explosion or meltdown.

This question is about simple harmonic motion (SHM).

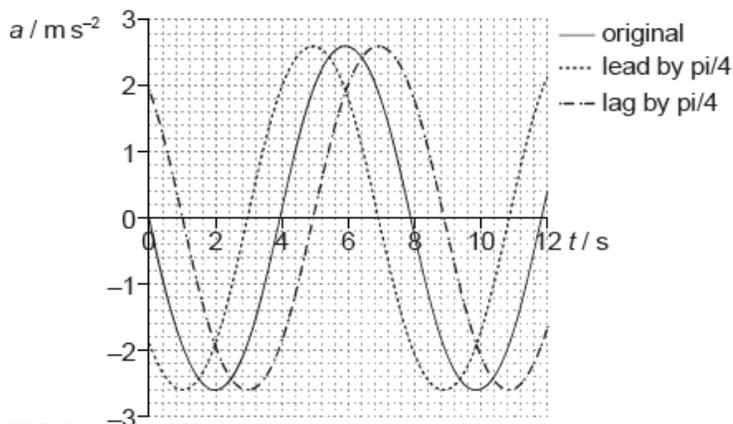
The graph shows the variation with time t of the acceleration a of an object X undergoing simple harmonic motion (SHM).



- 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]

Markscheme

- a. force/acceleration proportional to the displacement/distance from a (fixed/equilibrium) point/mean position;
 directed towards this (equilibrium) point / in opposite direction to displacement/ distance;
Allow algebra only if symbols are fully explained.
- b. 0.73 (N); (*allow answer in range of 0.71 to 0.75 (N)*)
- c. use of $a_0 = -\omega^2 x_0$;
 $T = 7.9$ (s) **or** $\omega = 0.795$ **or** $\frac{\pi}{4}$ (rad s^{-1}); (*allow answers in the range of $T = 7.8$ to 8.0 (s) **or** $\omega = 0.785$ to 0.805 (rad s^{-1})*)
 $x_0 = 4.1(1)$ (m); (*allow answers in the range of 4.0 to 4.25 (m)*)
 two significant figures in final answer whatever the value;
Award [4] for a bald correct answer.
- d. shape correct, constant amplitude for new curve, minimum of 10 s shown; } (*there must be some consistent lead or lag and no change in T*)
 lead/lag of 1 s (to within half a square by eye);



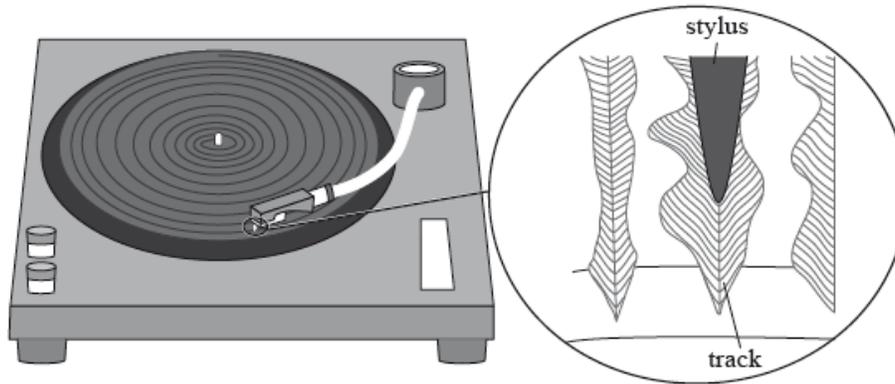
Examiners report

- A good definition of simple harmonic motion must focus on the proportionality between acceleration and displacement *from some fixed point* and on the directional relationship between acceleration and displacement. Many failed to emphasise the fixed-point aspect of the definition. Attempts made to define simple harmonic motion in algebraic terms normally omitted a clear statement of the symbols and the meaning of the negative sign.
- This was almost universally well done.
- Similarly, this was well done. Most appreciated the need to truncate the final answer to a sensible number of significant digits (two in this case).
- A large number of candidates could not translate a $\frac{\pi}{4}$ phase change into the correct time lead or lag. Most used the answer for $\frac{\pi}{2}$ and lost a mark in consequence. Most free-hand sketches of sine curves were acceptable.

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

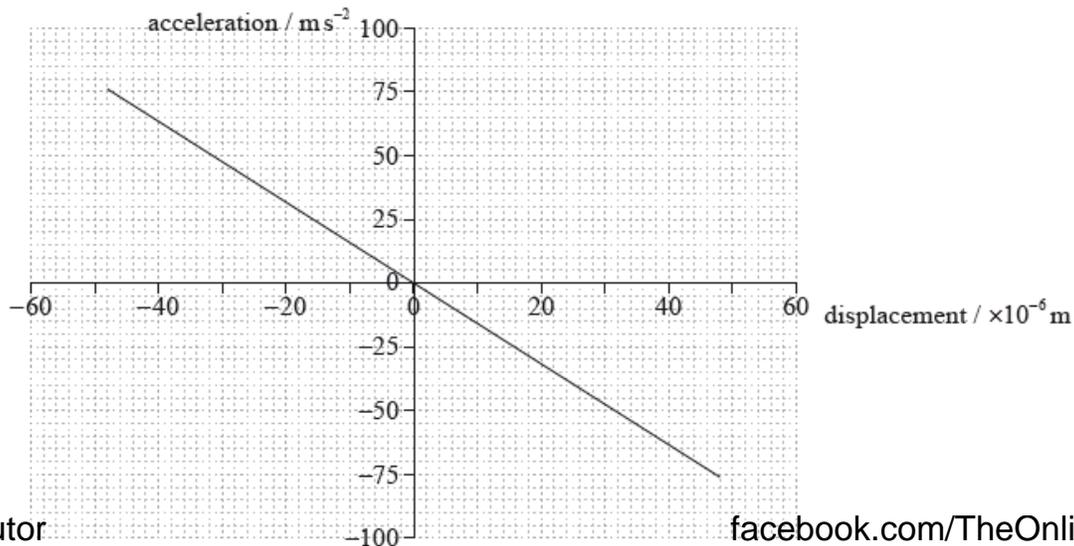
Part 1 Simple harmonic motion (SHM) and sound

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.



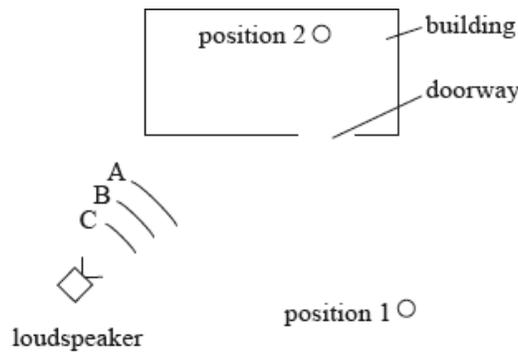
As the LP record rotates, the stylus moves because of changes in the width and position of the track. These movements are converted into sound waves by an electrical system and a loudspeaker.

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.

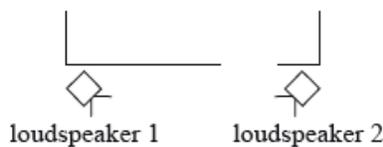


A, B and C are wavefronts emitted by the loudspeaker.

Part 2 Electric and magnetic fields

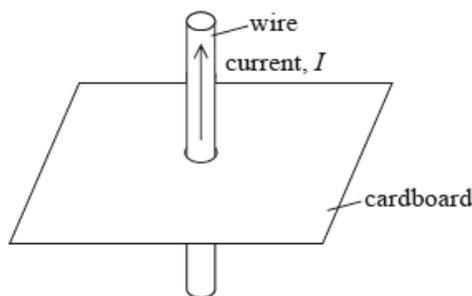
Electrical leads used in physics laboratories consist of a central conductor surrounded by an insulator.

- 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 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]



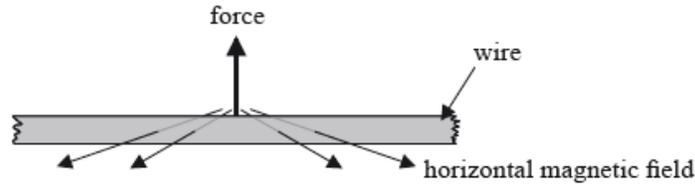
Outline why there are positions between the loudspeakers where the sound can only be heard faintly.

- 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.



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 $40 \mu\text{T}$. The mass per unit length of the wire is $1.41 \times 10^{-4} \text{ kg m}^{-2}$. The net force on the wire is zero. Determine the current in the wire.

Markscheme

a. acceleration is proportional to displacement;

force/acceleration is directed towards equilibrium (point)/rest position; } (do not accept "centre" or "fixed" point)

straight line through the origin shows the proportionality;

negative gradient shows acceleration directed towards equilibrium (point) / acceleration has opposite sign to displacement;

b. (i) gradient = $(-)\omega^2$;

$$\omega^2 = 1.56 \times 10^6 \text{ (s}^{-2}\text{)};$$

$$\omega = 1250 \text{ (rad s}^{-1}\text{)};$$

$$f = 198 \text{ (Hz)};$$

or

$$\omega^2 = (-)\frac{a}{x};$$

$$\omega = \sqrt{\frac{75}{48 \times 10^{-6}}};$$

$$f = \frac{1}{2\pi} \sqrt{\frac{75}{48 \times 10^{-6}}};$$

$$f = 198 \text{ (Hz)};$$

Allow substitution for fourth mark.

(ii) at origin;

c. (i) ray shown at 90° to wavefront A, plausible reflection and reflected ray goes in direction of position 1; } (judge by eye)

(ii) 1.65 (m); (allow ECF from (b)) (accept rounding to 1.6 or 1.7)

(iii) mention of diffraction;

diffraction means that sound spreads beyond the limit of geometrical shadow/can go around a corner / OWTTE;

Accept marking points in the form of a clearly drawn correctly labelled diagram.

d. interference/superposition mentioned;

when sounds arrive out of phase / path difference half integer number of wavelengths / OWTTE;

cancellation occurs / destructive (interference);

some (back) reflection from walls so cancellation may not be complete (hence "faint" not "zero");

e. conductor has free electrons/charges that are free to move within/through it / insulator does not have free electrons/charges that are free to move

within/ through it;

when a pd acts across a conductor a current exists when charge (carriers) move;

Do not allow “good/bad conductor/resistor” or reference to conductivity/resistivity.

f. anti-clockwise arrows;

at least three circles centred on wire;

increasing in separation from centre;

g. (i) arrow to the right;

$$(ii) \quad \frac{F}{l} = BI;$$

$$I = \left(\frac{mg}{lB} \right) = \frac{1.41 \times 10^{-4} \times 9.8}{40 \times 10^{-6}};$$

35 (A);

Award **[3]** for a bald correct answer.

Allow use of $g = 10 \text{ m s}^{-2}$ which also gives an answer of 35 (A).

Examiners report

a. It was rare to see all four marks awarded for statements of the requirements of harmonic oscillation and recognition of these in the straight-line graph. Candidates were generally happy to state that acceleration is directly proportional to displacement and that the straight line through the origin confirmed this. Correct statements with appropriate detail of the direction of the force/acceleration were rarer and the negative gradient was not often mentioned. Four marks were available and therefore candidates should have recognised that four points were required.

b. (i) This calculation was poorly done.

(ii) P – when it was marked on the graph at all – was either shown at the origin (correct) or one extreme (incorrect) of the graph in about equal numbers.

c. (i) Candidates are required to know the relationship between wavefronts and rays and it was surprising that many completed the diagram with wavefronts – and even these would not have gained much credit given the very poor draughtsmanship in evidence. Few candidates bothered to read the question. They failed to realise that all they were required to do was construct plausible incident and reflected rays that would enable the observer at point 1 to hear the sound.

(ii) There were many examples of correct evaluation of the wavelength of the sound but far too many were unable to complete this simple task. Inversions of the equation and mistakes in powers of ten and in rounding were common.

(iii) The usual phonetic spelling of “defraction” was observed. Examiners are unlikely to give a benefit of the doubt to what might have been a phonetic spelling or might equally have been confusion with “refraction” in this particular case. Many candidates were able to spot that the sound was being diffracted but an explanation of what diffraction is, in context, was much rarer.

d. [N/A]

e. Superficial answers were common. Candidates continue to ignore the mark allocations for questions and therefore the number of independent points they should mention in an answer. Here, most said that conductors contain free electrons (or the reverse for insulators) but did not go on to discuss the role of the free electrons in carrying charge or to relate the current to the existence of an electric field across the conductor. Far too many gave answers of the “conductors conduct well” variety that do not score marks.

f. There are three elements to a good drawing of the magnetic field around a long straight conductor: the concentric circularity of the lines, the direction of the lines related to the direction of charge flow, and the increasing separation between lines as the distance from the conductor increases. It was a rare candidate who was able to convince the examiner with all three points. In hindsight, the diagram could have been larger on the page. However, candidates could have taken more trouble over their sketches which were usually crude.

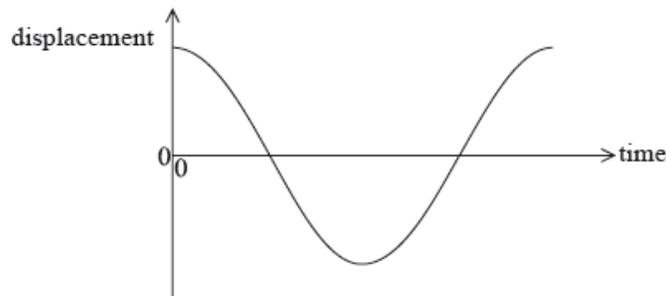
g. (i) Many forgot that the sign rules involve conventional current and lost the mark.

(ii) Few correct solutions were observed. This was a straightforward problem involving one re-arrangement of a standard equation and the incorporation of the weight of the conductor.

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

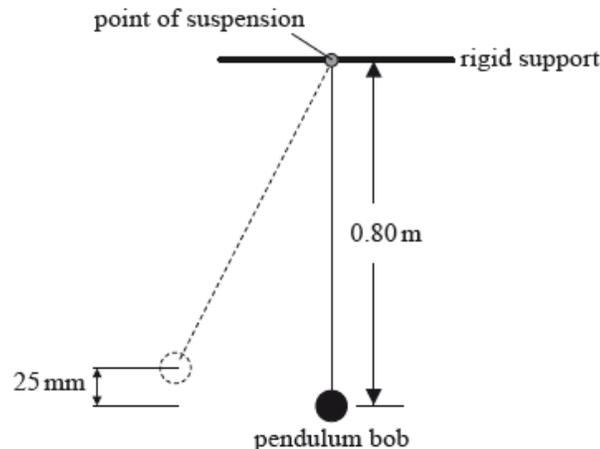
Part 1 Simple pendulum

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.

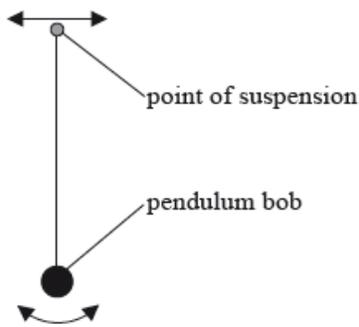


On the sketch graph above,

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

Part 1. a. 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. Show that the speed of the pendulum bob at the midpoint of the oscillation is 0.70 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. 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 2. 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]

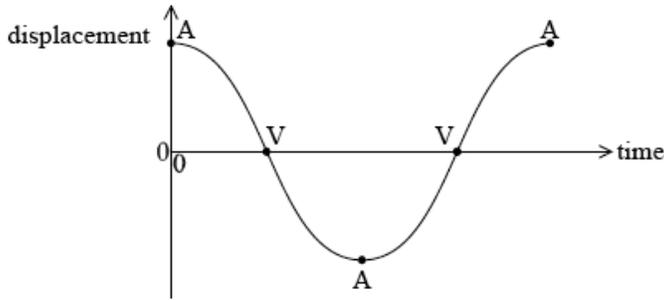
Part 2. b. Outline, in terms of the forces acting between nucleons, why, for large stable nuclei such as gold-197, the number of neutrons exceeds the number of protons. [4]

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

Markscheme

Part 1.a. one A correctly shown;

(ii) one V correctly shown;



Part 1.b. pendulum bob accelerates towards centre of circular path / OWTTE;

therefore force upwards;

that adds to tension produced by the weight;

Part 1.c. evidence shown of equating kinetic energy and gravitational potential energy;

$$v = \sqrt{(2 \times 9.8 \times 0.025)};$$

$$= 0.70 \text{ m s}^{-1}$$

Allow $g = 10 \text{ m s}^{-2}$ answer 0.71 m s^{-2} .

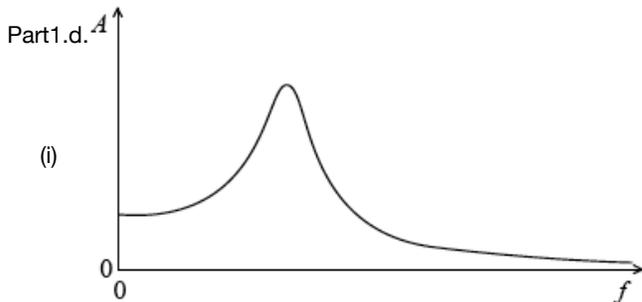
(ii) centripetal acceleration $\left(= \frac{v^2}{r} \right) \left[= \frac{0.7^2}{0.8} \right] = 0.61 \text{ (m s}^{-2}\text{)};$

net acceleration = $(9.81 + 0.61 =) 10.4 \text{ (m s}^{-2}\text{)}$ **or** $T - mg = m \times 0.61;$

tension = $(ma =) 0.59 \text{ N};$

Allow $g = 10 \text{ m s}^{-2}$ answer $0.60 \text{ N}.$

Award **[3]** for bald correct answer.



(i) one maximum shown and curve broadly similar to example above;

amplitude falls on each side by lower amount on low driving frequency side;

(ii) resonance is where driving frequency equals/close to natural frequency;

the frequency at the maximum amplitude of the graph;

Part 1.e. over amplitude everywhere on graph;

with a much broader resonance peak;

maximum moves to left on graph;

Award **[2]** for a sketch graph.

Part 1.f. most of the atom is empty space;

most of the mass/(protonic) charge of the atom is concentrated in the nucleus/nucleus is dense;

nucleus is positively charged;	{	<i>Thesepointscan beawardedto labelleddiagram.</i>
(most) alphas not close enough to nuclei to be deflected;		
(very few) alphas (are) close enough to nuclei to be deflected;		

To award the last two marking points for a diagram response the candidate must show that a non-deflected alpha is well away from a nucleus and a strongly deflected alpha is aimed very close or head-on.

Part 2.b.mention of Coulomb repulsion between protons;

mention of strong (nuclear) force (between nucleons);
overall balance must be correct (and more neutrons needed for this);

Award [0] for a statement that neutron is negative.

(ii) anti neutrino / $\bar{\nu}$;

Examiners report

Part 1.a. Identifications of points A and V were mixed. About half the candidates received both marks here.

Part 1.b. This was poorly done with many misapprehensions evident. The main problem was that candidates failed to associate the effect with the presence of a centripetal force and also unable to consider it in terms of the directions and additions of the various forces in the situation.

Part 1.c. This was well done by many. However a use of a *suvat* equation is not appropriate in this case as the acceleration is not uniform.

(ii) Candidates who kept a clear head were able to arrive at a correct answer even if they had failed in part (b)

Part 1.d. Graphs were poor in general with few gaining both marks and many candidates unable to make any progress. Graphs often showed a decreasing amplitude against time despite the frequency label on the *x*-axis.

(ii) Few understood the meaning of the term “resonance” sufficiently to be able to describe it in terms of the graph.

Part 1.e. Again, few candidates referred their answer to the graph. Some were able to gain credit for discussing changes in amplitude.

Part 2.a. Candidates who rely on a diagram rather than a written description must ensure that their sketches give all the required information unambiguously.

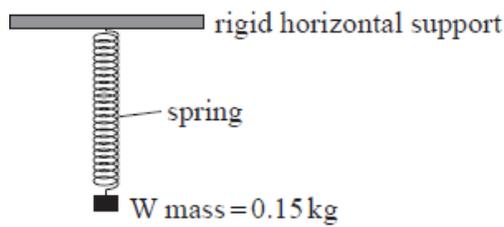
In this type of question it is also common to see candidates repeating part of the question itself back to the examiner; this will not gain credit. Candidates needed to distinguish between those alpha particles passing close to and those far away from a nucleus, and then to give the deduced properties of the nucleus from these observations. Descriptions were often illogical and repetitive.

Part 2.b. Most candidates could write with confidence about the repulsive nature of the proton-proton interaction and the attractive nature of the strong nuclear force. Few gave good accounts of the balance between these two forces or described the energy situation (a better way to answer). Weak candidates could not name the strong nuclear force adequately.

Part 2 Simple harmonic motion and waves

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

[8]



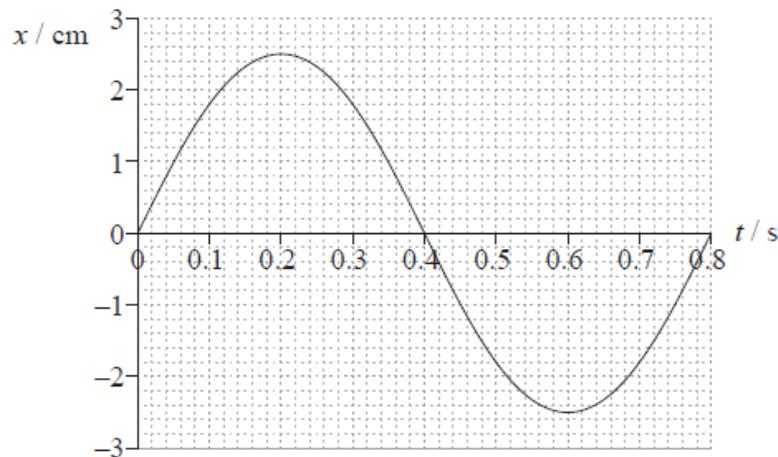
An object W of mass 0.15 kg is suspended from the other end of the spring. The extension x of the spring is proportional to the force F causing the extension. The force per unit extension of the spring k is 18 Nm^{-1} .

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).

- State what is meant by the expression “ W performs SHM”.
- Determine the maximum acceleration of W .
- Determine the period of oscillation of the spring.
- 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]

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

- 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.

Markscheme

a. (i) the acceleration of (force acting on) W is proportional to its displacement from equilibrium;

and directed towards equilibrium;

$$\text{(ii) } F = (18 \times 0.04) = 0.72\text{ N};$$

$$\text{acceleration} = \frac{0.72}{0.15} = 4.8\text{ ms}^{-2};$$

$$\text{(iii) } \omega = \sqrt{\frac{a}{x}};$$

$$= 10.95\text{ rads}^{-2};$$

$$T = \left(\frac{2\pi}{\omega}\right) = \frac{6.28}{10.95} = 0.57\text{ s};$$

$$\text{(iv) } = 1.4 \times 10^{-2}\text{ (J)};$$

- c. (i) the direction of oscillation of the particles of the medium;

(must see "particles")

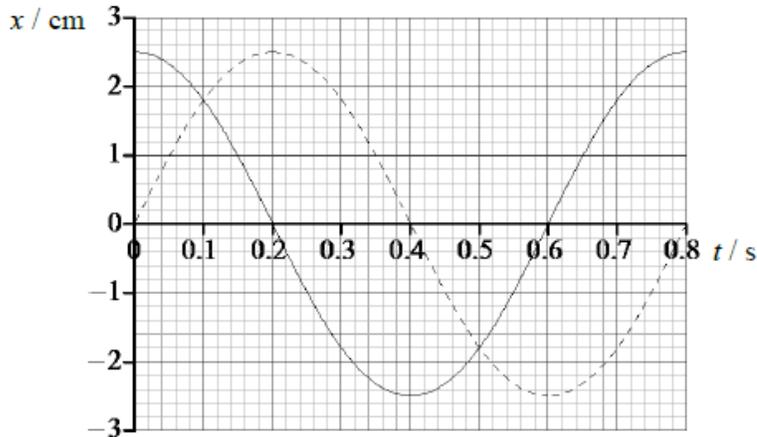
is in the direction of energy propagation;

Accept answer in terms of coils of spring in place of particles of medium.

(ii) frequency = $\left(\frac{1}{T} = \frac{1}{0.80} =\right) 1.25\text{Hz}$;

wavelength = $\frac{v}{f} = \frac{3.0}{1.25} = 2.4\text{cm or } 2.4 \times 10^{-2}\text{m}$;

- (iii)



graph: positive cosine; (line must cross axis at 0.2 and 0.6 as shown)

explanation: 1.8 cm is $\frac{3}{4}$ of a wavelength;

Examiners report

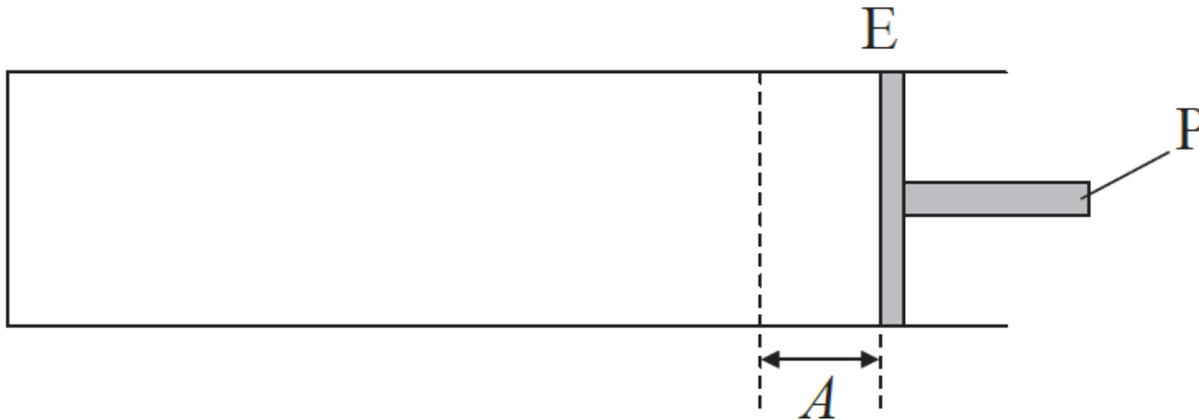
- a. There were a few G2 comments suggesting that this question was off-syllabus as it involved (the G2s claimed) the use of Hooke's law. In fact, k was defined as force per unit extension rather than as the spring constant and the whole question was accessible through knowledge based purely on SHM theory.
- (i) Many realized that for two marks they were required to state the relationship between acceleration and displacement and give the direction of acceleration.
- (ii) and (iii) The determination of the maximum acceleration and the period of oscillation were well done by many at HL. A number of routes were possible for part (iii) and all gained equal credit. Answers were patchier from SL candidates who struggled more than the HL with these tasks.
- (iv) **SL only** Performance was again patchy. Some of the candidates at SL do not seem at ease with the ideas and equations that lie behind SHM theory.
- c. (i) Examiners were disappointed to see that candidates could only rarely give a complete description of a longitudinal travelling wave. Descriptions were vague and rarely made the relative directions of energy propagation and particle displacement clear in an unambiguous way.
- (ii) Although many obtained the correct answer, the method used was often unexplained with no obvious link to the graph via a statement of frequency or period. Such non-clarity was penalized.
- (iii) Most candidates were unable to make progress with this question and it was frequently left blank. The problem required a recognition that a distance of 1.8 cm corresponded to a $\frac{3}{4}\lambda$ shift and hence a corresponding shift on the graph.

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.

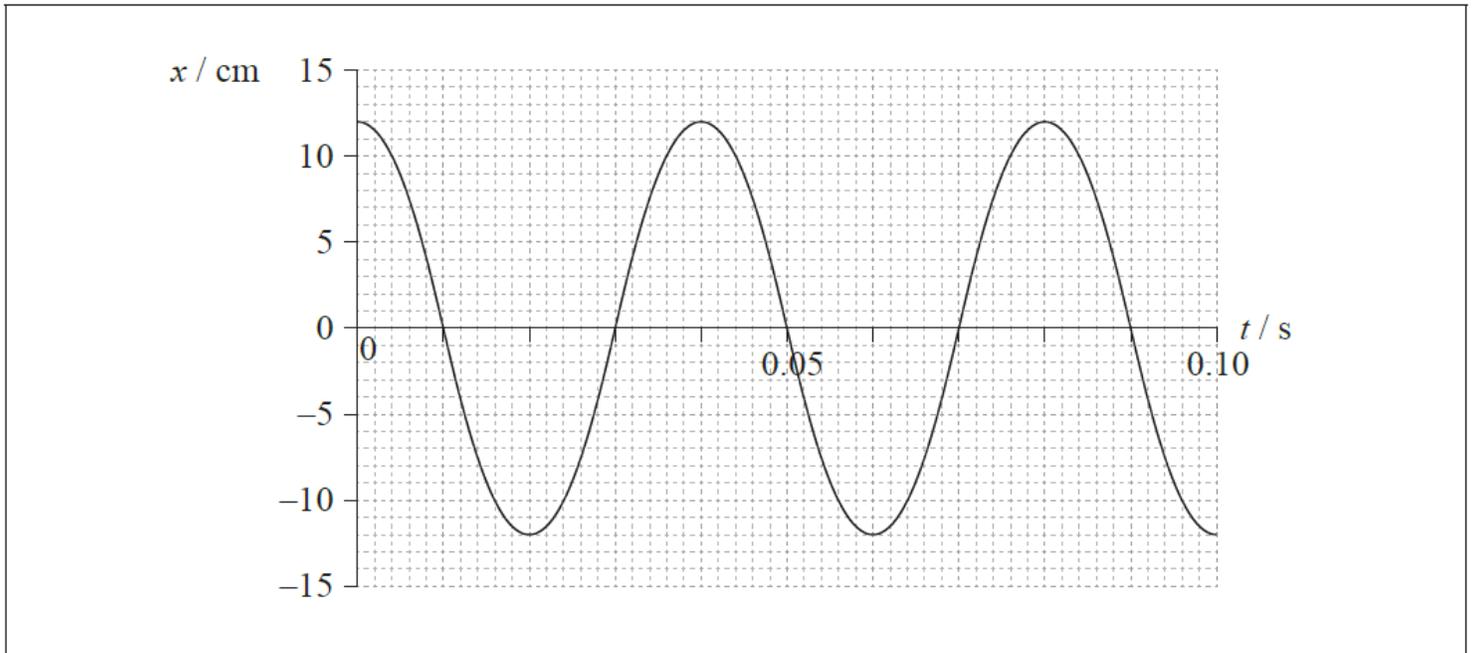
[2]



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.

Markscheme

- a. the acceleration of piston/P is proportional to its displacement from equilibrium;
and directed towards equilibrium;

There must be a clear indication what is accelerating otherwise award [1 max].

- b. (i) 12(cm); (accept -12)

(ii) any maximum or minimum of the graph;

(iii) period = 0.04 (s); (allow clear substitution of this value)

$$\omega = \left(\frac{2\pi}{T} = \right) \frac{2 \times 3.14}{0.04} = 157 \text{ (rads}^{-1}\text{)}$$

maximum acceleration = $(A\omega^2) = 0.12 \times 157^2 = 3.0 \times 10^3 \text{ (ms}^{-2}\text{)}$; (watch for ECF from wrong period)

(iv) at $t = 0.052 \text{ s}$, $x = (-)4(\pm 1) \text{ cm}$;

$$\text{KE} = \left(\frac{1}{2} m \omega^2 [A^2 - x^2] = \right) 0.5 \times 0.32 \times 157^2 [0.12^2 - 0.04^2] = 50 (\pm 7) \text{ (J)}$$

Watch for incorrect use of cm.

Allow ECF from calculations in (b)(iii).

Do not retrospectively credit a mark for ω to (b)(iii) if it was not gained there on original marking.

Allow use of $\sin \omega t$ to obtain v .

Award [2] for a bald correct answer.

- c. (i) the direction of the oscillations/vibrations/movements of the particles (in the medium/gas);

for a longitudinal wave are parallel to the direction of the propagation of the energy of the wave;

$$\text{(ii) } f = \left(\frac{1}{T} = \right) \frac{1}{0.04} = 25 \text{ (Hz)}$$

$$\lambda = \left(\frac{v}{f} = \right) \frac{340}{25} = 14 \text{ (m)}$$

Award [1 max] if frequency is not clearly stated.

Allow ECF from calculations in (b)(iii).

Examiners report

- a. Candidates were asked to define SHM as applied to the situation in the question. Many failed to do this and wrote in general terms about SHM.

- b. (i) This was well done.

(ii) Almost all candidates were able to identify a correct point for the maximum acceleration.

(iii) and (iv) Solutions for these were confused. Some attempted to use kinematic equations. Others mixed metres and centimetres in their answers. Other algebraic errors were present too (e.g. confusing $12^2 - 4^2$ for $(12 - 4)^2$). This is an area that candidates could practice more.

- c. (i) There were three marks for this question: for distinctions between longitudinal and transverse and for a clear description of the point of

comparison. The latter was the mark most frequently lost. Many candidates have the vague idea that something about transverse is perpendicular and that the same parameter is parallel for longitudinal, but what "that something" is was frequently confused.

(ii) Candidates are now taking more care over the clear declaration of the frequency leading to the wavelength.

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]

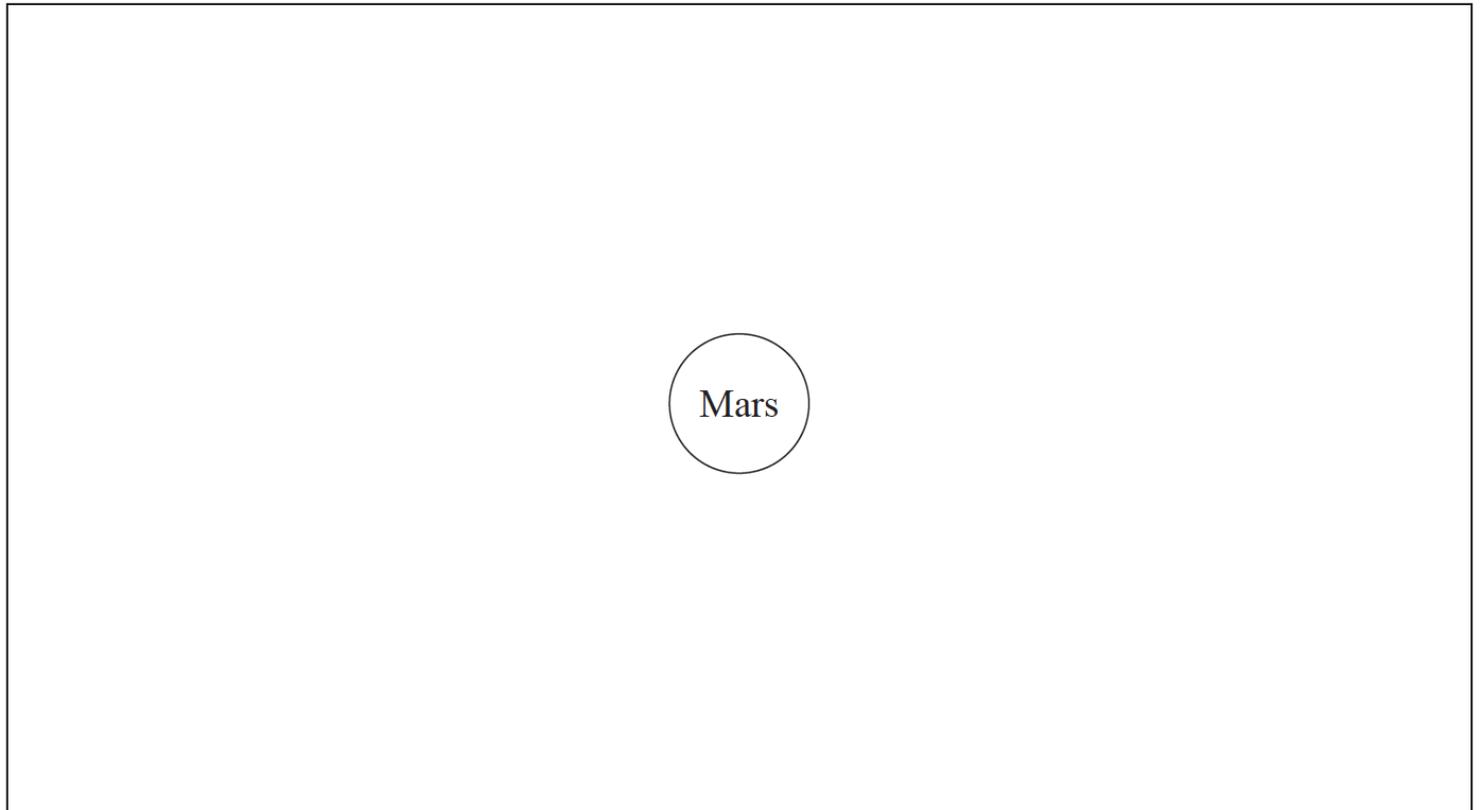
$$g_M = 0.38 \times g_E.$$

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]

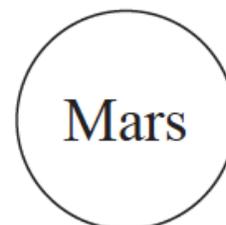


- (ii) An object falls freely in a straight line from point A to point B in time t . The speed of the object at A is u and the speed at B is v . A student suggests using the equation $v = u + g_M t$ to calculate v . Suggest **two** reasons why it is not appropriate to use this equation.

A



B



Markscheme

a. there is an attractive force;

between any two point/small masses;

proportional to the product of their masses;

and inversely proportional to the square of their separation;

Accept formula with all terms defined.

b. use of $g = \frac{F}{m}$ and $F = \frac{GmM}{R^2}$;

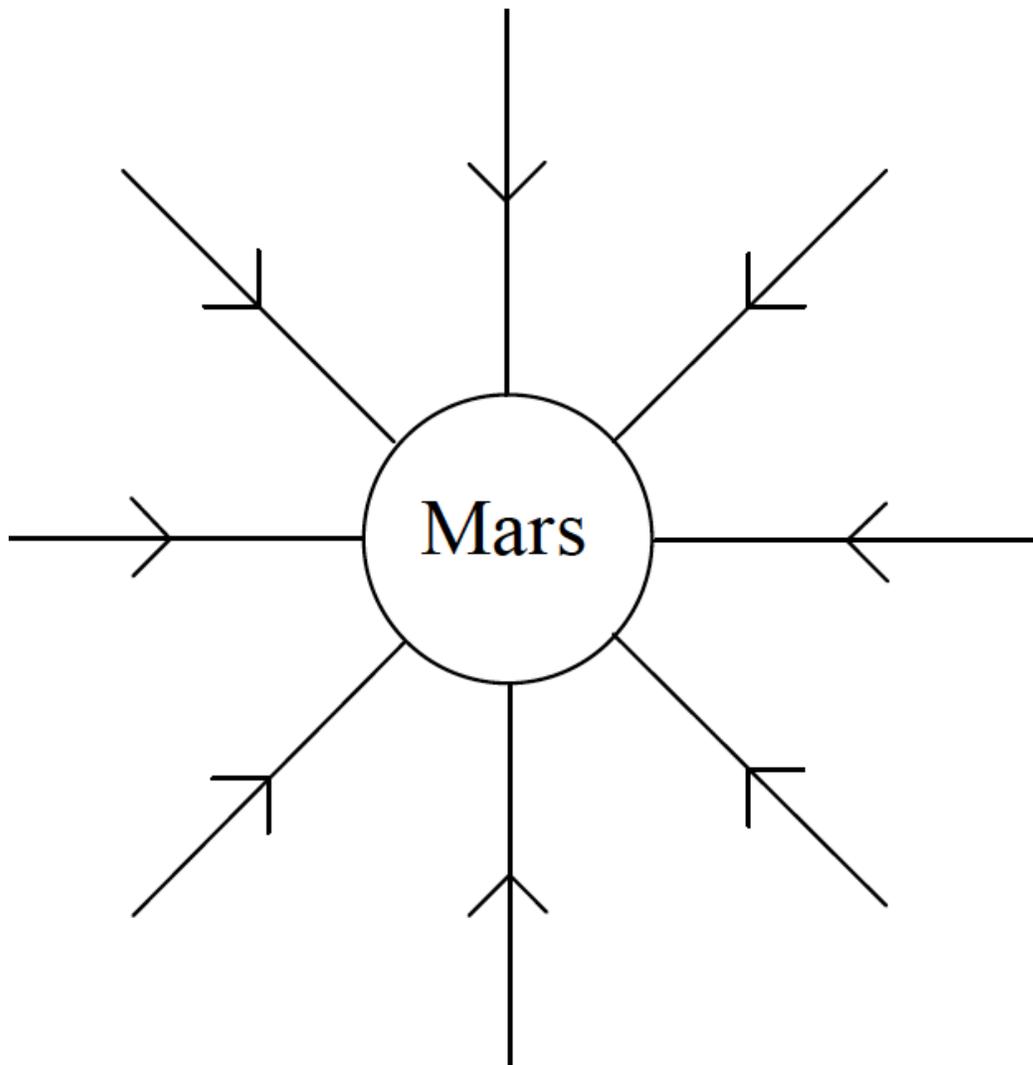
evidence of substitution/manipulation;

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

c. $\frac{g_M}{g_E} = \frac{\frac{M_M}{R_M^2}}{\frac{M_E}{R_E^2}} \Rightarrow \frac{M_M}{M_E} = \frac{g_M}{g_E} \times \left[\frac{R_M}{R_E} \right]^2$;

$M_M (= 0.38 \times 0.53^2 M_E) = 0.11 M_E$;

d. (i) radial field with arrows pointing inwards;



(ii) field between A and B is not equal to field at surface;
acceleration is not constant between these two points;

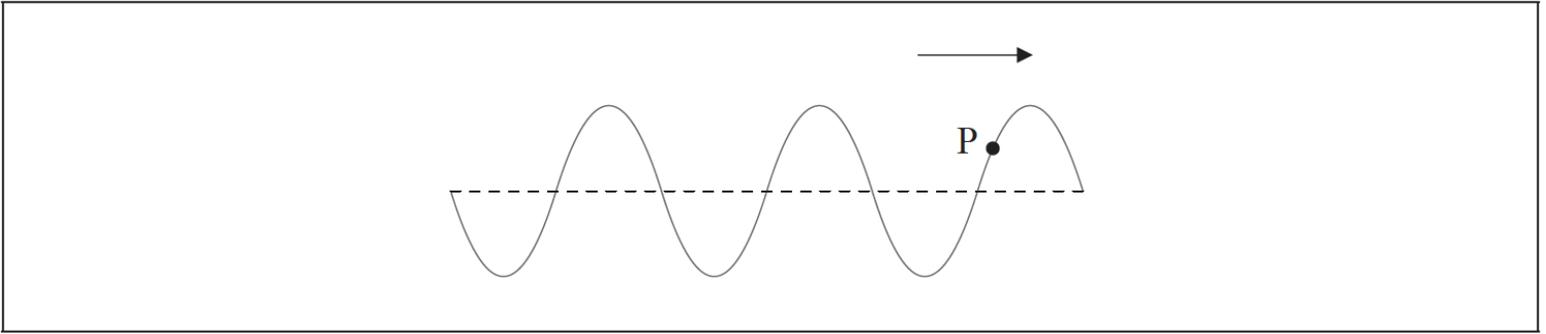
Examiners report

- a. [N/A]
- b. [N/A]
- c. [N/A]
- d. [N/A]

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

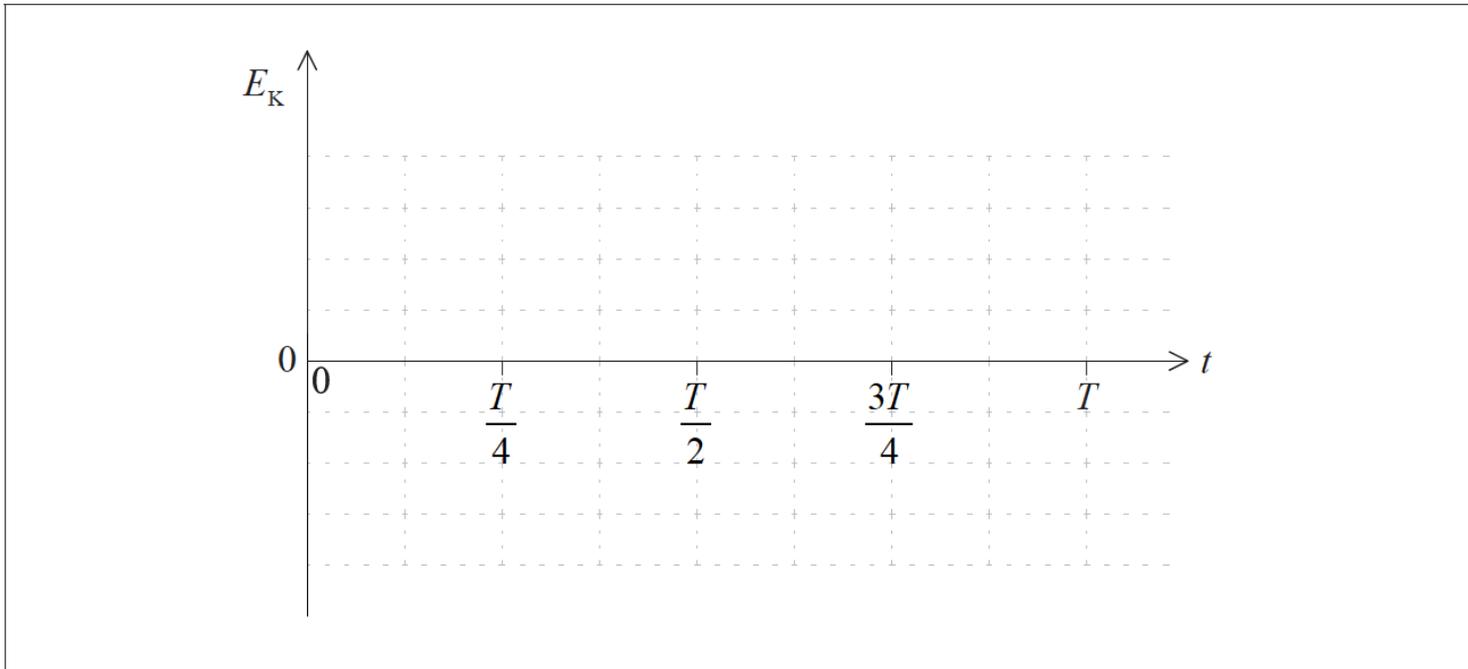
Part 1 Wave motion

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

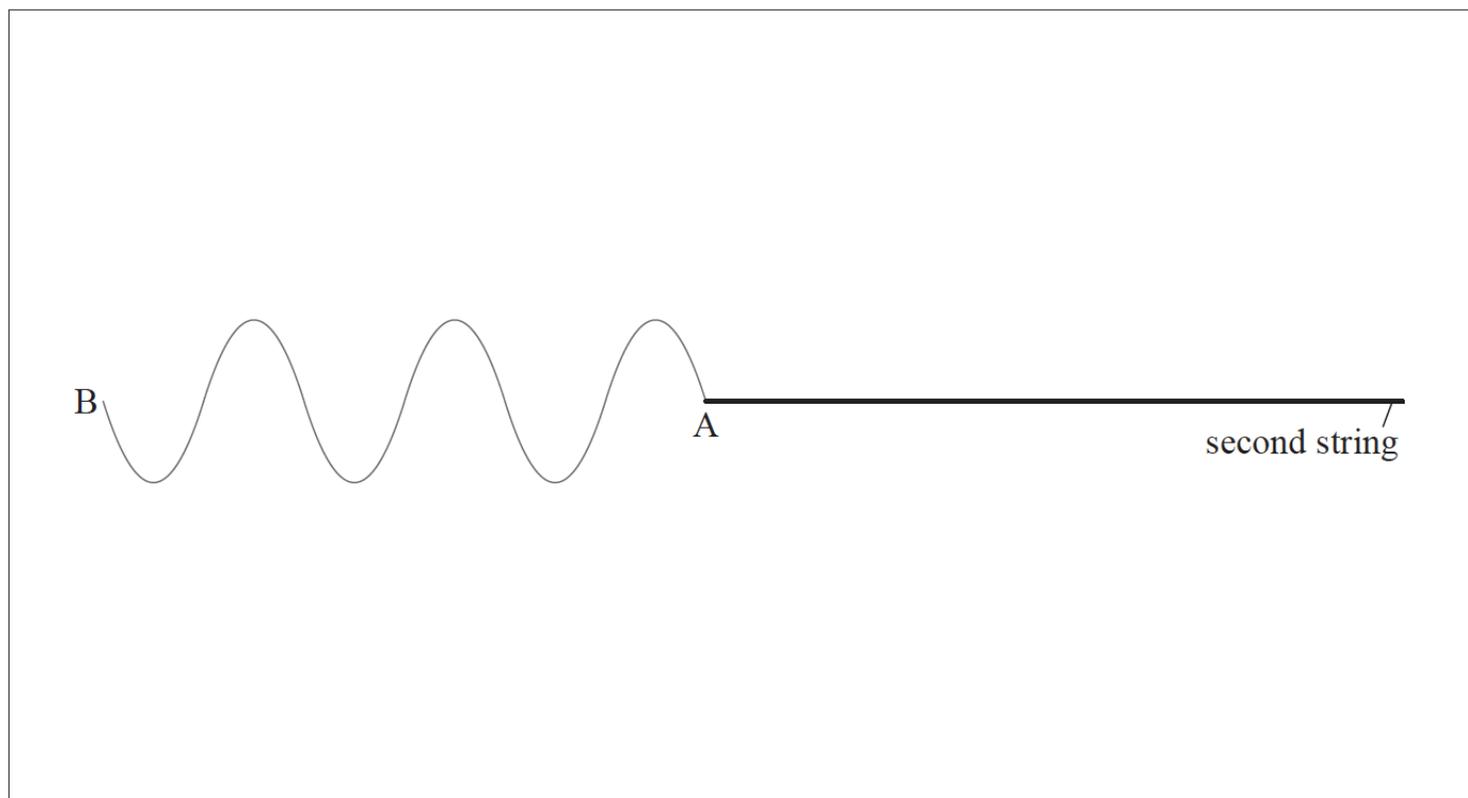


The dotted line shows the position of the stretched string when it is undisturbed. P is a small marker attached to the string.

- 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 $1.7 \times 10^{-2}\text{m}$ and the mass of marker P is $3.5 \times 10^{-3}\text{kg}$. [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]
- smaller than that of the first string.



- (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).

Markscheme

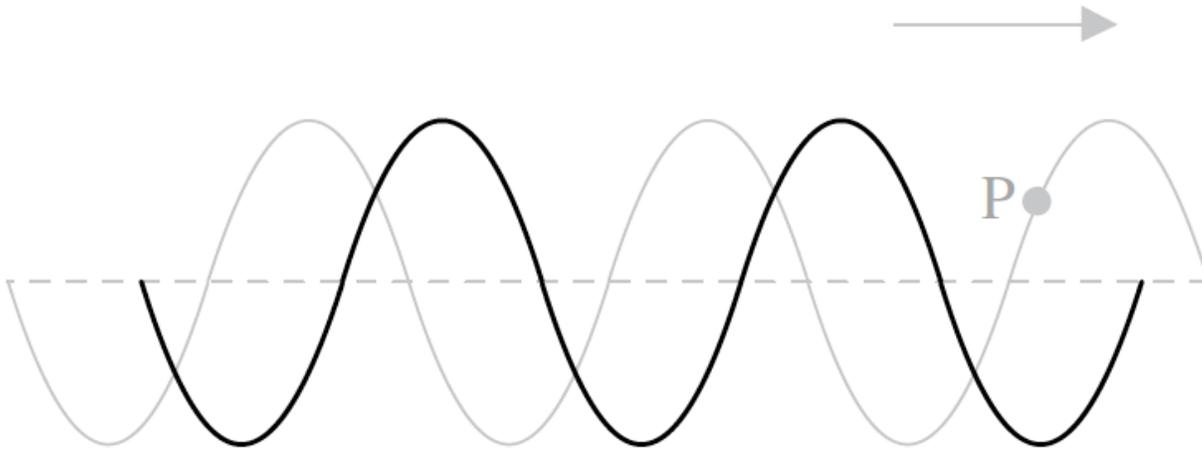
- a. (i) downward arrow at P;
- (ii) clear single wavelength marked;

b. (i) frequency = $\frac{18}{25}$ (Hz) = 0.72 (Hz);

period = $\left(\frac{1}{0.72}\right) = 1.4$ s;

Award [2] for a bald correct answer.

(ii) wave moved to right by one-third of a cycle by eye;

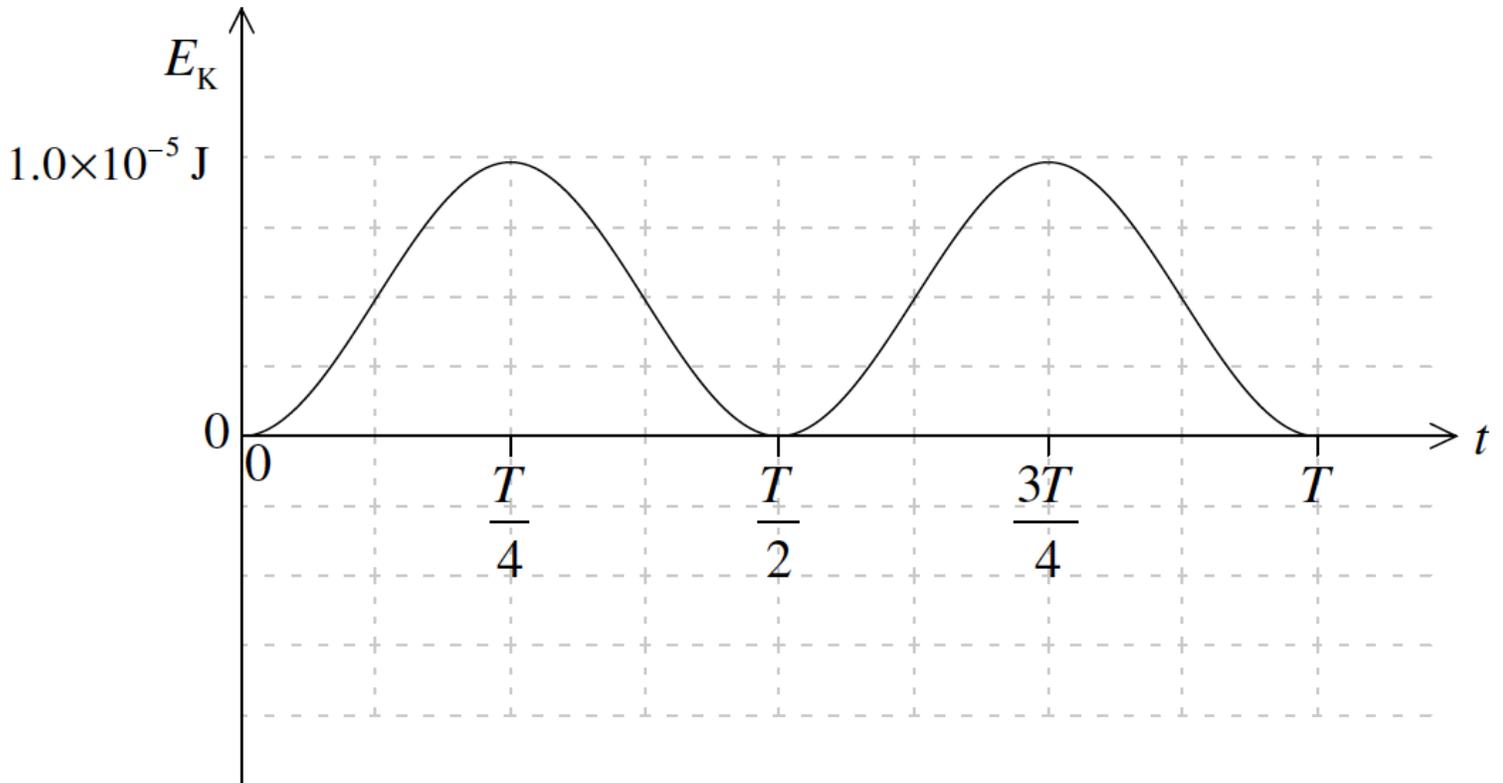


c. (i) $\omega = \frac{2\pi}{1.4}$;

$\left(\frac{1}{2} \times 3.5 \times 10^{-3} \times \left[\frac{4\pi^2}{1.4^2}\right] \times [1.7 \times 10^{-2}]^2\right) = 1.0 \times 10^{-5}$ J;

Award [2] for a bald correct answer.

(ii)



correct shape (\sin^2) ; (allow any phase for this graph)

varying between 0 and 1.0×10^{-5} J; { (allow ECF from (c)(i) but do not allow E to be negative)

one period takes $\frac{T}{2}$;

d. (i) reduced wavelength;

reduced amplitude;

(ii) speed reduced and frequency constant;

therefore wavelength reduced;

some energy reflected at boundary / second string is denser/greater mass per unit length;

therefore amplitude reduced;

Examiners report

a. [N/A]

b. [N/A]

c. [N/A]

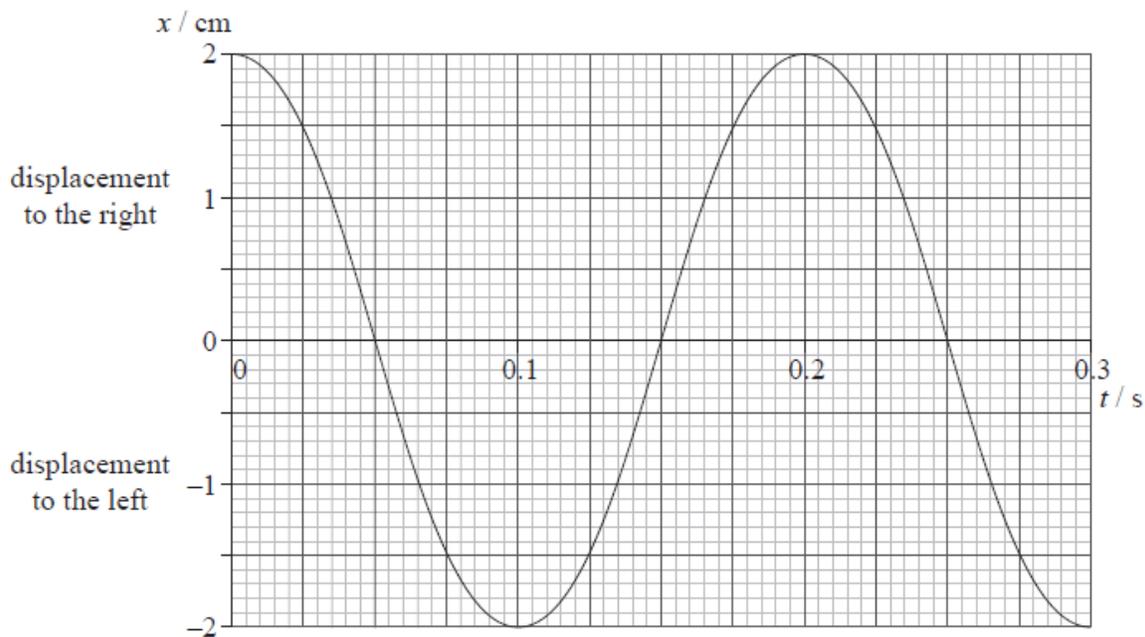
d. [N/A]

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.

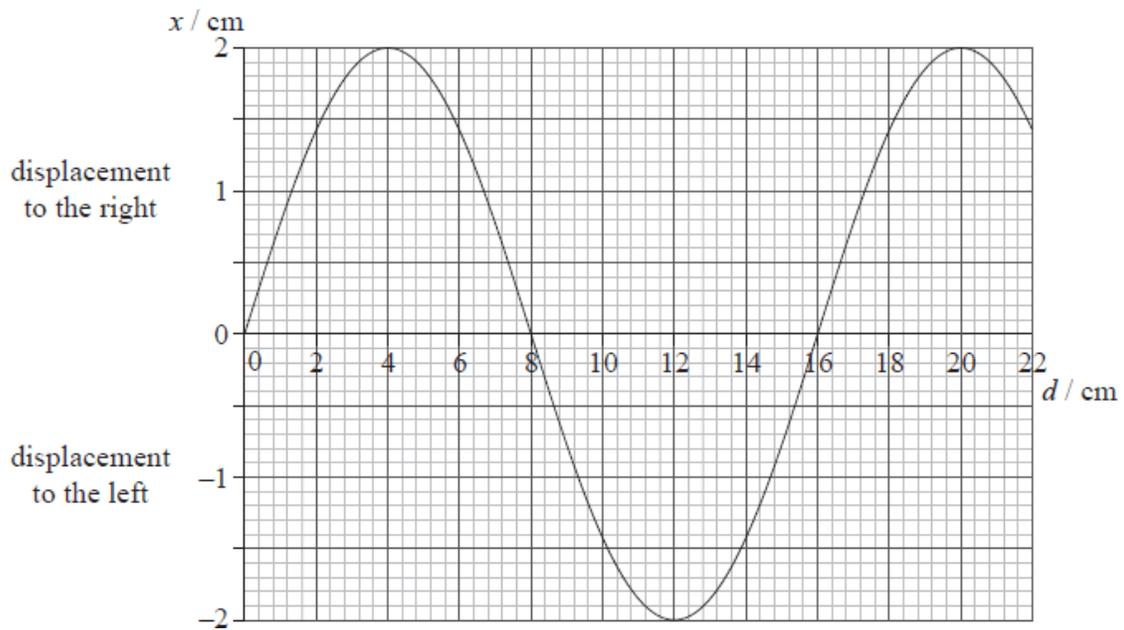
(iii) calculate its speed at $t=0.12$ s.

(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

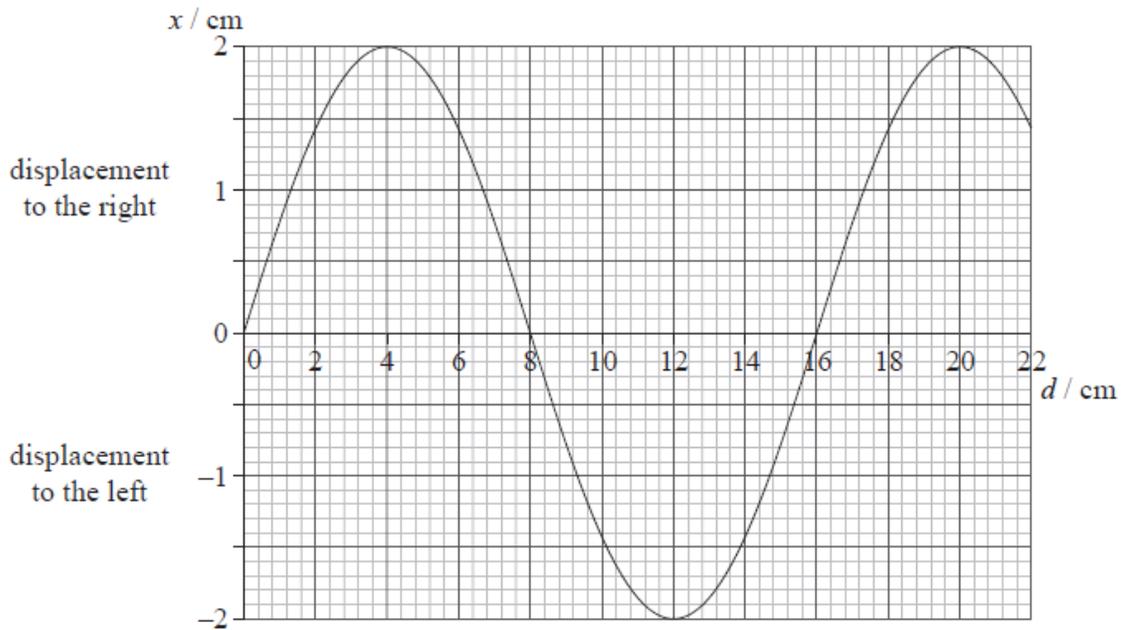


Determine for the longitudinal wave, using graph 1 and graph 2,

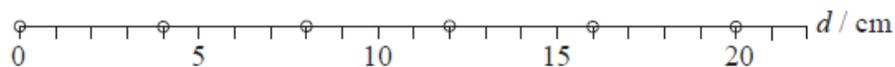
- (i) the frequency.
- (ii) the speed.

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.

Markscheme

a. (i) the amplitude is constant;

(ii) period is 0.20s;

$$a_{\max} = \left(\left[\frac{2\pi}{T} \right]^2 x_0 \right) = 31.4^2 \times 2.0 \times 10^{-2} = 19.7 \approx 20 \text{ms}^{-2}$$

Award [2] for correct bald answer and ignore any negative signs in answer.

(iii) displacement at $t = 0.12\text{cm}$ is (-1.62cm) ;

$$v \left(= \frac{2\pi}{T} \sqrt{x_0 - x^2} \right) = 31.4 \sqrt{(2.0 \times 10^{-2})^2 - (1.62 \times 10^{-2})^2} = 0.37 \text{ms}^{-1};$$

Accept displacement in range 1.60 to 1.70 cm for an answer in range 0.33ms^{-1} to 0.38ms^{-1} .

or

$$v_0 = \frac{2\pi}{T} x_0 = 0.628 \text{ms}^{-1};$$

$$|v| = \left(\left| -v_0 \sin \left[\frac{2\pi}{T} t \right] \right| \right) \Rightarrow |v| = \left| -0.628 \sin[31.4 \times 0.12] \right| = \left| 0.37 \right| = 0.37 \text{ms}^{-1};$$

or

drawing a tangent at 0.12s;

measurement of slope of tangent;

Accept answer in range 0.33ms^{-1} to 0.38ms^{-1} .

b. (i) use of $f = \frac{1}{T}$;

$$\text{and so } f \left(= \frac{1}{0.20} \right) = 5.0 \text{Hz};$$

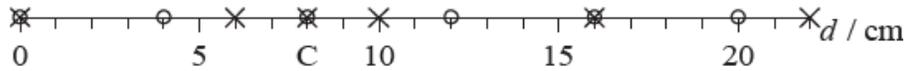
(ii) wavelength is 16cm;

and so speed is $v (= f\lambda = 5.0 \times 0.16) = 0.80 \text{ms}^{-1}$;

c. (i) points at 0, 8 and 16 cm stay in the same place;

points at 4 and 20 cm move 2 cm to the right;

point at 12 cm moves 2 cm to the left;



(ii) the point at 8 cm;

Examiners report

a. [N/A]

b. [N/A]

c. [N/A]

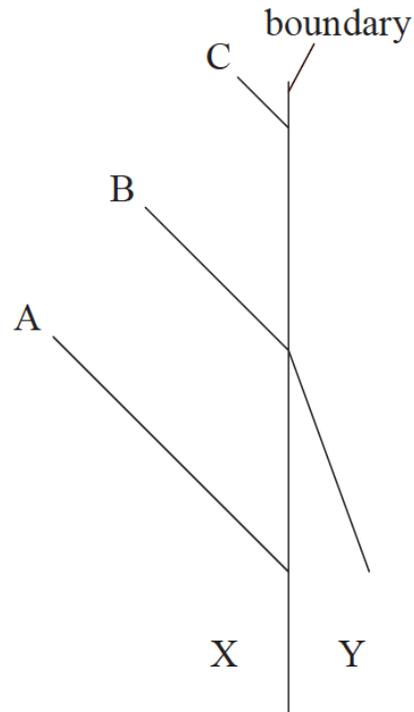
This question is in **two** parts. **Part 1** is about wave motion. **Part 2** is about the melting of the Pobeda ice island.

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.

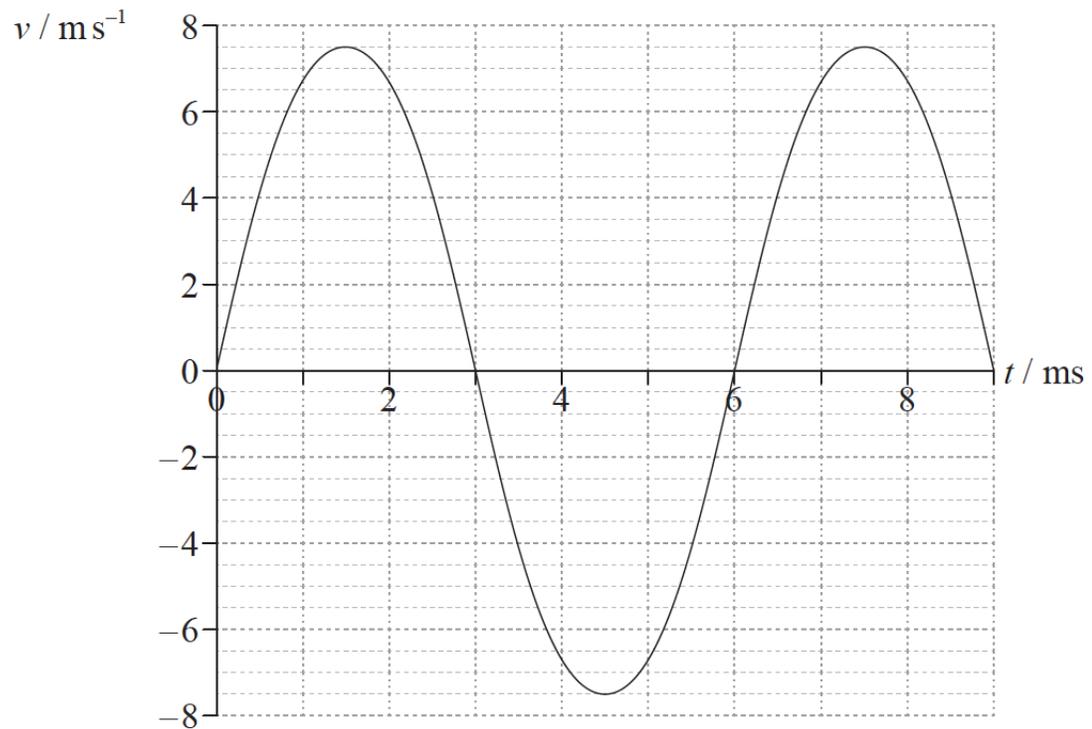
(ii) The refractive index of X is n_x and the refractive index of Y is n_y . By making appropriate measurements, calculate $\frac{n_x}{n_y}$.

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.

Markscheme

a. ray: direction of wave travel / energy propagation;

wavefront: line that joins points with same phase/of same crest/trough;

ray normal/at right angles/perpendicular to wavefront;

b. (i) line parallel to existing line in Y and continuous at boundary; *(both needed)*

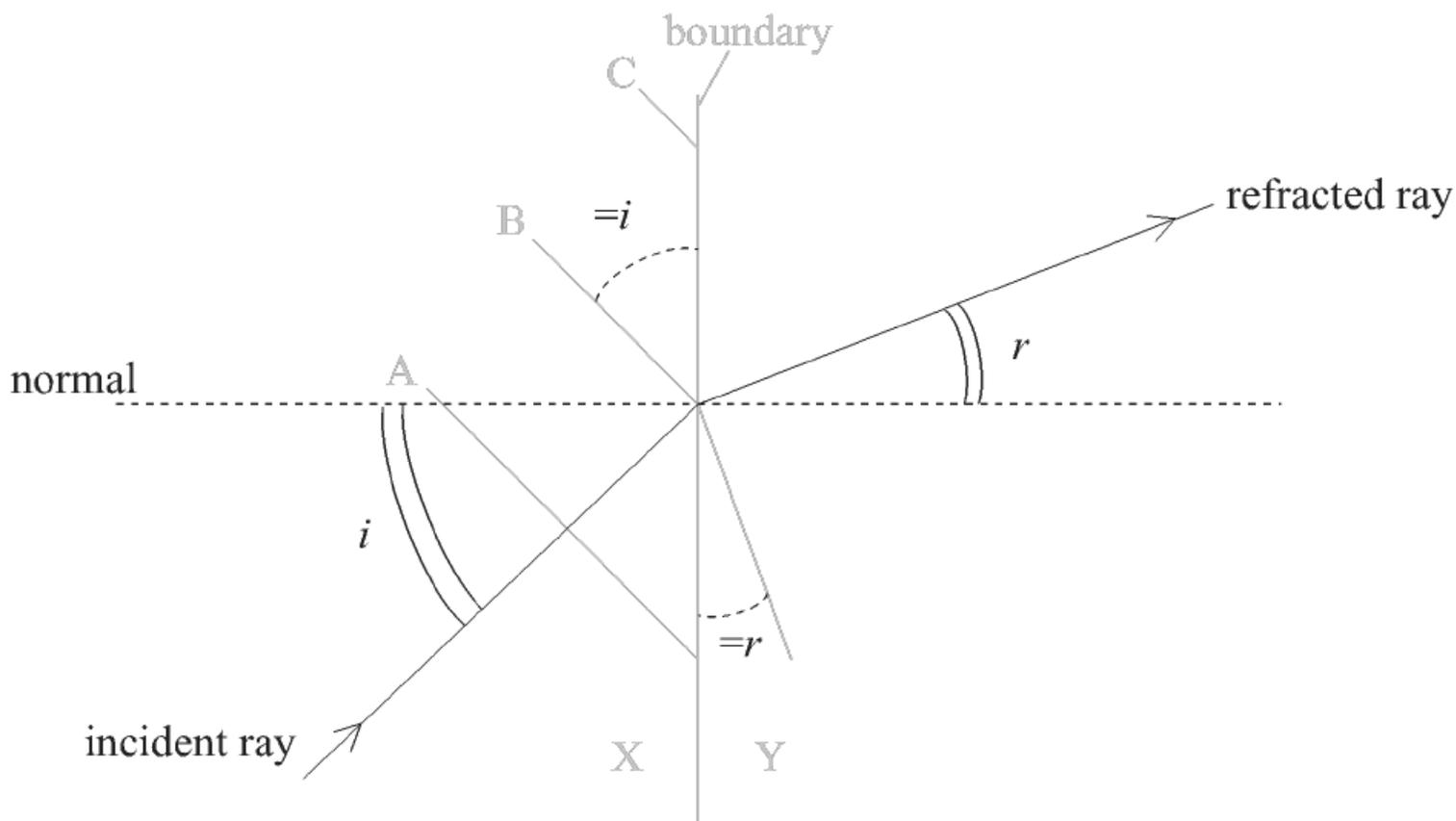
(ii) measures “wavelength” correctly in media X and Y; } *(by eye)*

(look for ratio of 0.5: 1 in responses)

$$\frac{n_X}{n_Y} = \frac{\lambda_Y}{\lambda_X};$$

0.5:1; *(accept answers in the range of 0.47 to 0.53)*

or



justification that angles needed for calculation are either pair of i and r as shown and angles measured correctly;

$$\frac{n_X}{n_Y} = \frac{\sin r}{\sin i};$$

0.5:1;

c. mention of perpendicular/right angle/90° angle for transverse and parallel for longitudinal;

clear comparison between direction of energy propagation and direction of vibration/oscillation of particles for both waves;

d. (i) time period=6.0ms;

167Hz;

(ii) M where line crosses x-axis;

(iii) counts rectangles (14±2) to first peak;

one rectangle equivalent to 0.5 mm;

7.2 mm;

or

$$\omega = (2\pi f =) 330\pi;$$

$$a = \left(\frac{v}{\omega} =\right) \frac{7.5}{330\pi};$$

7.2 mm;

Allow any valid algebraic method, eg $v = \omega \sqrt{(x_0^2 - x^2)}$.

Examiners report

a. [N/A]

b. [N/A]

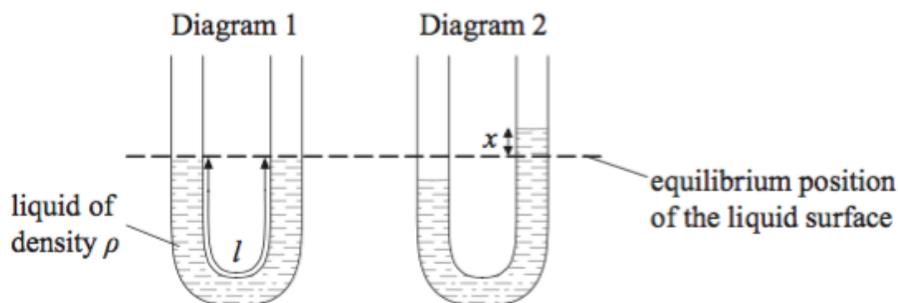
c. [N/A]

d. [N/A]

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

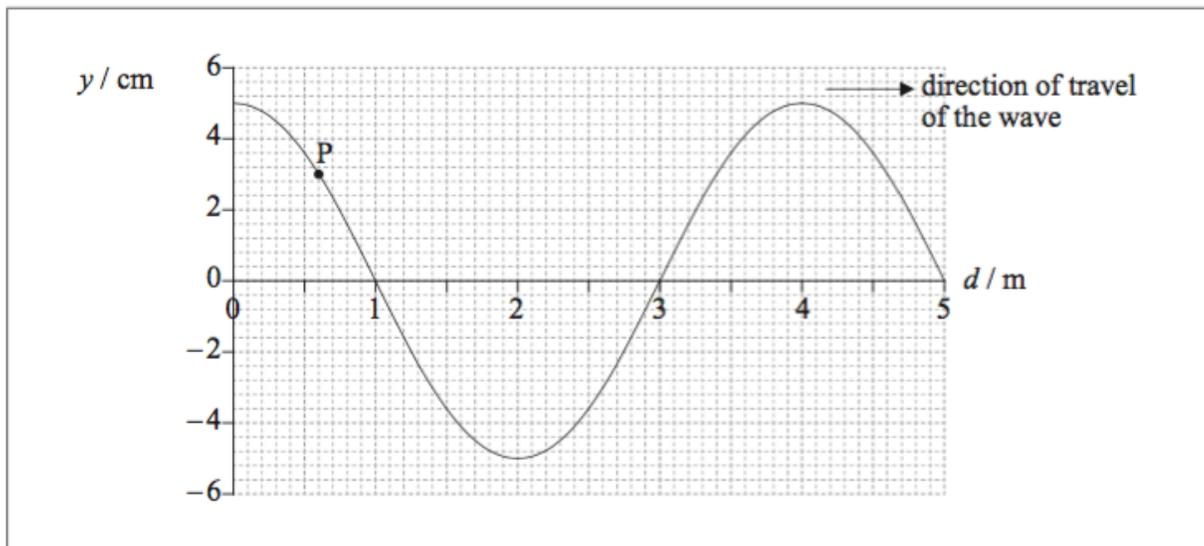
$$a = -\frac{2g}{l}x$$

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.

Markscheme

a. the maximum displacement of the system from equilibrium/from centre of motion / *OWTTE*;

b. (i) the amplitude of the oscillations/(total) energy decreases (with time); because a force always opposes direction of motion/there is a resistive force/ there is a friction force;

Do not allow bald "friction".

$$(ii) \omega = \sqrt{\frac{2g}{l}};$$

$$T = 2\pi\sqrt{\frac{0.32}{2 \times 9.81}};$$

$$=0.80\text{s};$$

c. (i) upwards;

(ii) $y_0 = 0.050\text{(m)}$ and $y = 0.030\text{(m)}$;

$$\omega = \left(\frac{2\pi}{0.80}\right) = 7.85 \text{ (rads}^{-1}\text{)};$$

$$v = 7.85\sqrt{[0.05]^2 - [0.03]^2};$$

$$=0.31\text{ms}^{-1}; \text{ (allow working in cm to give } 31 \text{ cms}^{-1}\text{)};$$

(iii) $\lambda=4.0\text{m}$;

$$\text{recognition that } f = \frac{1}{0.80} (= 1.25);$$

$$(f\lambda)v=1.25 \times 4.0;$$

$$(=5.0 \text{ ms}^{-1})$$

(iv) $y=-3.0 \text{ cm}$, $d=0.6 \text{ m}$;

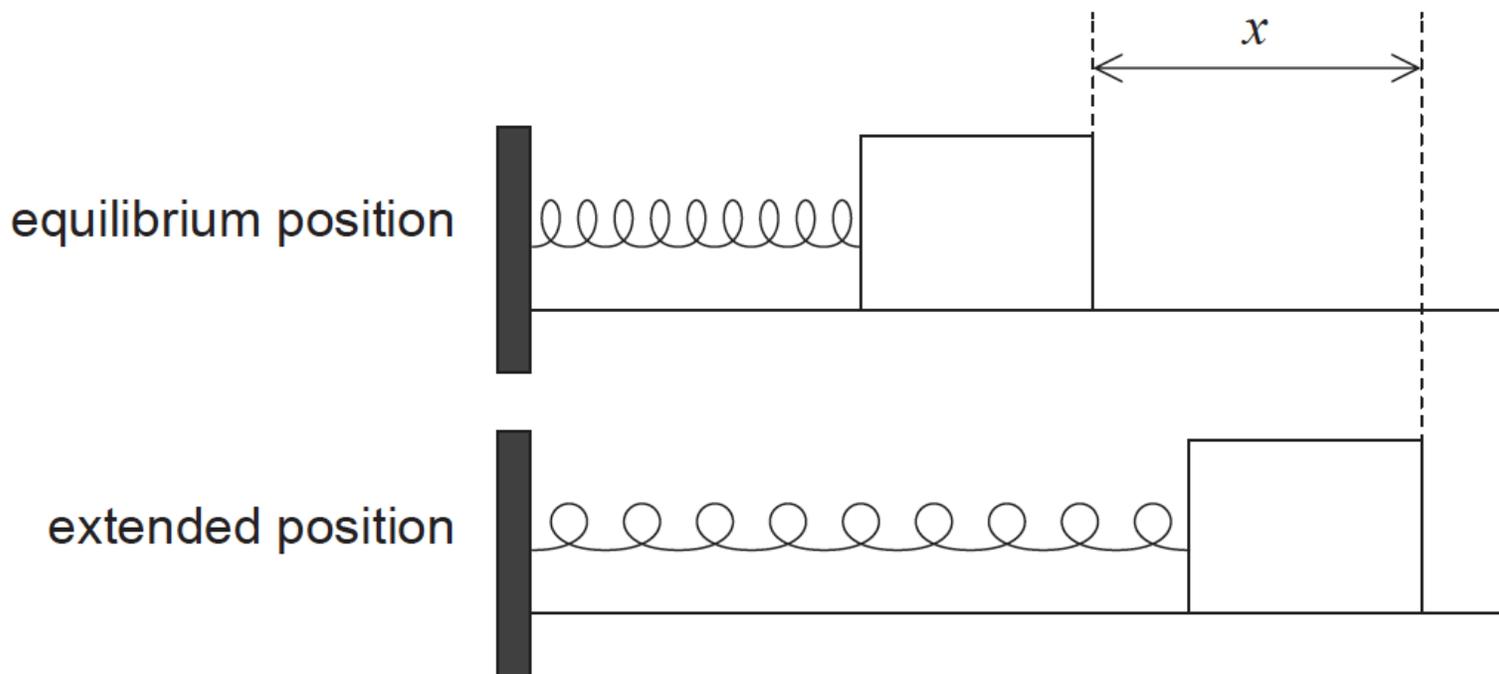
Examiners report

- a.
- b.
- c.

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).

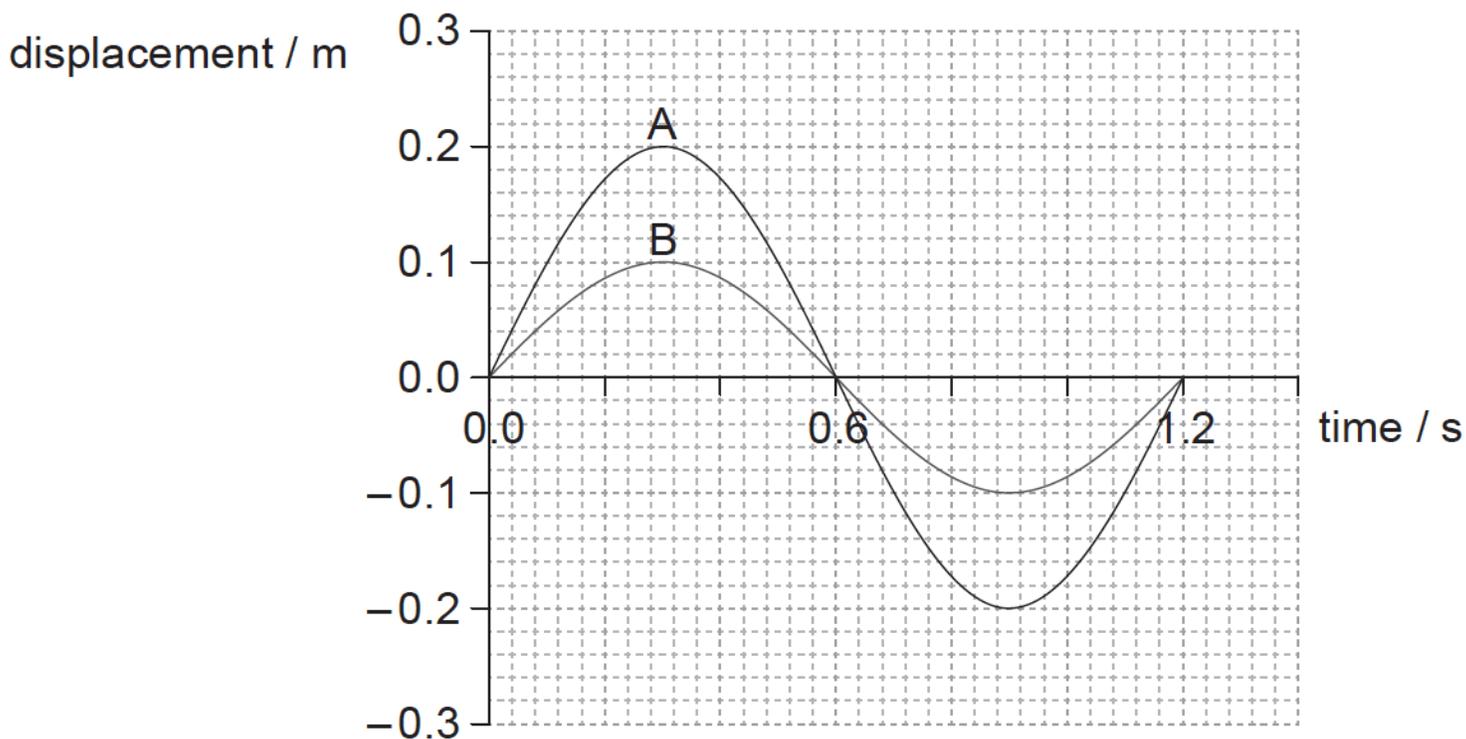


The tension F in the spring is given by $F = kx$ where x is the extension of the spring and k is a constant.

Part 2 Current electricity

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

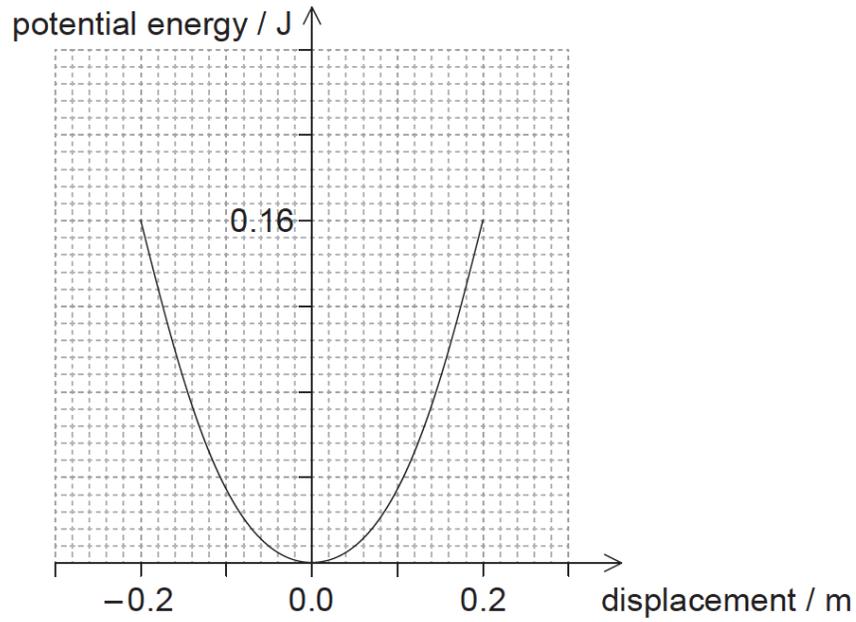
b. One cycle of the variation of displacement with time is shown for two separate mass–spring systems, A and B. [3]



(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]



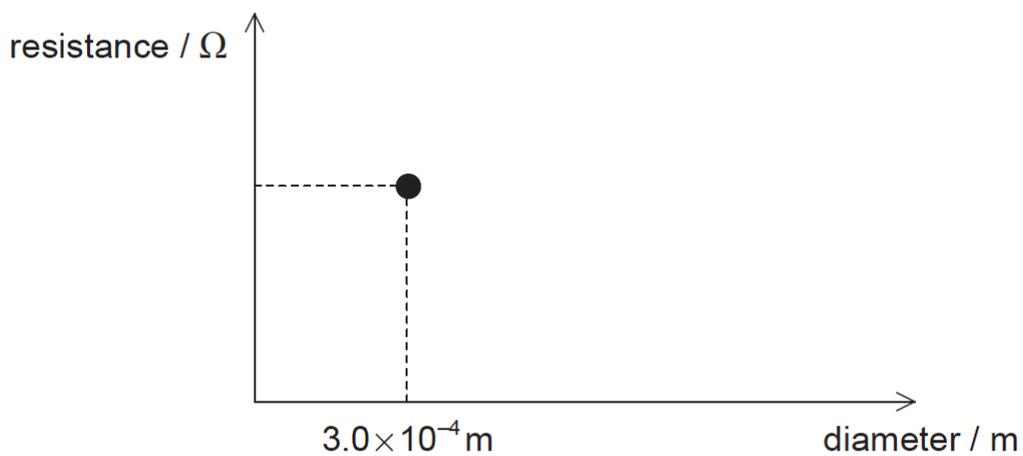
On the axes,

- (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 $24\ \Omega$ resistor is made from a conducting wire.

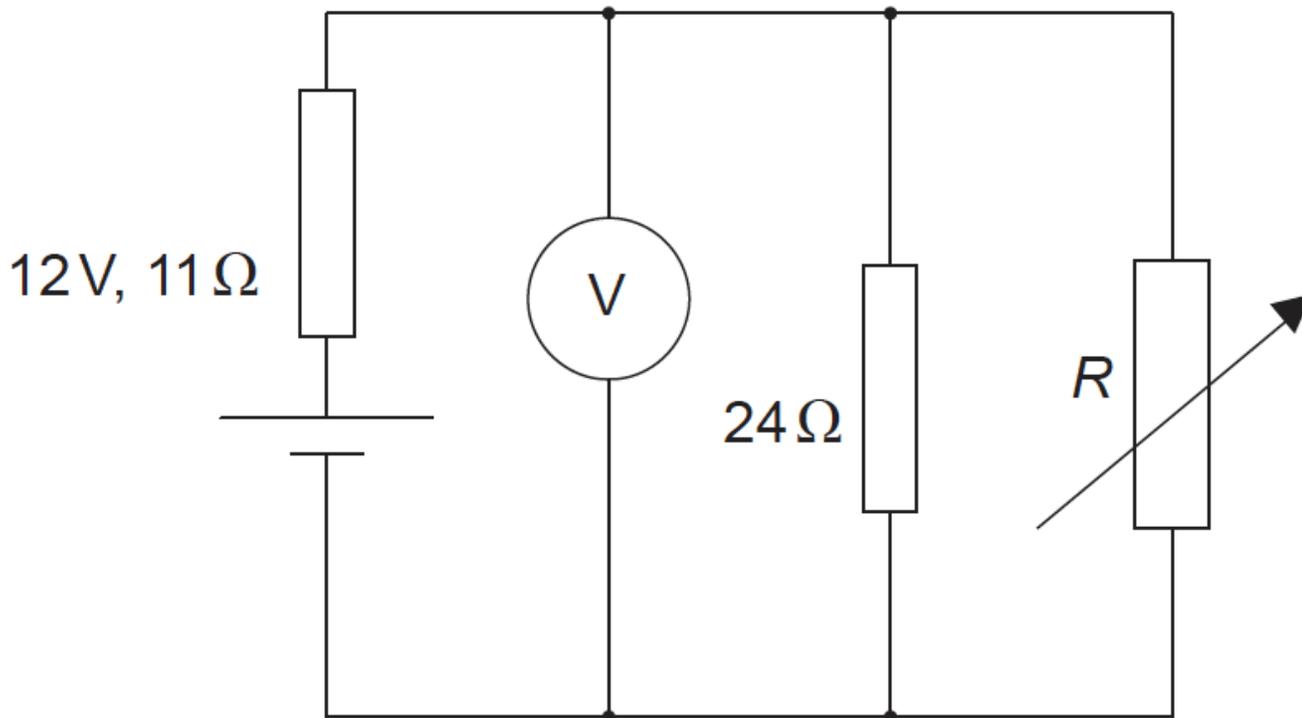
[4]

- (i) The diameter of the wire is $0.30\ \text{mm}$ and the wire has a resistivity of $1.7 \times 10^{-8}\ \Omega\text{m}$. 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 $0.30\ \text{mm}$ has already been plotted for you.



- e. The $24\ \Omega$ 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.

- Determine the value of R for this circuit at which maximum power is delivered to the external circuit.
- Calculate the reading on the voltmeter for the value of R you determined in (f)(i).
- Calculate the total power dissipated in the circuit when the maximum power is being delivered to the external circuit.

Markscheme

a. $ma = -kx$;

$$a = -\frac{k}{m}x; \text{ (condone lack of negative sign)}$$

$$\left(\omega^2 = \frac{k}{m}\right)$$

or

implied use of defining equation for simple harmonic motion $a = -\omega^2x$;

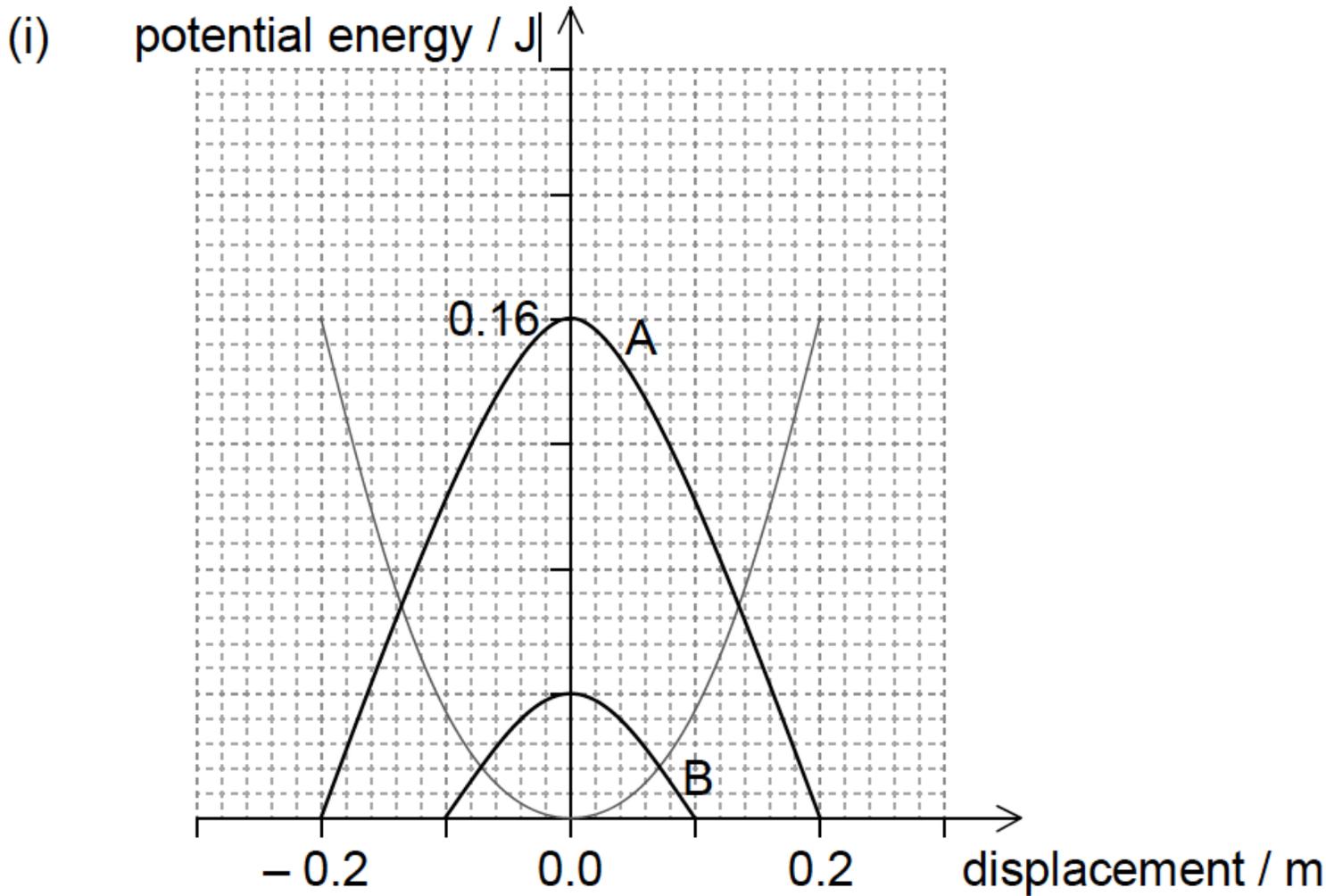
$$\left(\text{so } \omega^2 = \frac{k}{m}\right)$$

$$ma = -kx \text{ so } a = -\left(\frac{k}{m}\right)x;$$

b. (i) 0.833 (Hz) ;

- frequency/period is the same so ω is the same;
 k is the same (as springs are identical);
 (so m is the same)

c.



correct shape;
maximum at 0.16 J;

- (ii) end displacements correct $\pm 0.01\text{m}$;
maximum lower than 0.16J;
maximum equal to $0.04\text{J} \pm \text{half square}$;

d. (i) $l = \frac{\pi d^2 R}{4\rho}$ seen / correct substitution

into equation: $24 = \frac{l \times 1.7 \times 10^{-8}}{\pi \times (0.15 \times 10^{-3})^2}$; } (condone use of r for $\frac{d}{2}$ in first alternative)

99.7 (m);

Award **[2]** for bald correct answer.

Award **[1 max]** if area is incorrectly calculated, answer is 399 m if conversion to radius ignored, ie: allow ECF for second marking point if area is incorrect provided working clear.

- (ii) any line showing resistance decreasing with increasing diameter **and** touching point;
correct curved shape showing asymptotic behavior on at least one axis;

e. current/conduction is (related to) flow of charge;

conductors have many electrons free/unbound / electrons are the charge carriers / insulators have few free electrons;

pd/electric field accelerates/exerts force on electrons;

smaller current in insulators as fewer electrons available / larger current in conductors as more electrons available;

f. (i) use of total resistance = 11Ω ; (can be seen in second marking point)

$$\frac{1}{11} = \frac{1}{R} + \frac{1}{24};$$

$20.3(\Omega)$;

(ii) as current is same in resistor network and cell and resistance is same, half of emf must appear across resistor network;
 6.0 (V);

or

$$I = \frac{12}{(11+11)} = 0.545 \text{ (A)};$$

$$V=(0.545 \times 11=) 6.0 \text{ (V)};$$

Other calculations are acceptable.

Award **[2]** for a bald correct answer.

(iii) use of 22 (ohm) or $11+11$ (ohm) seen;

use of $\frac{V^2}{R}$ or equivalent;

6.54 (W);

Award **[3]** for bald correct answer.

Award **[2 max]** if cell internal resistance ignored, yields 3.27 V.

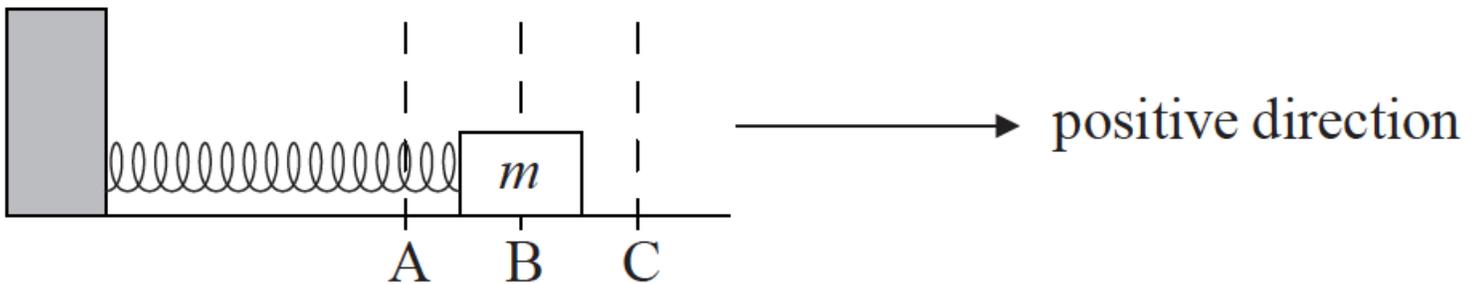
Examiners report

- a. [N/A]
- b. [N/A]
- c. [N/A]
- d. [N/A]
- e. [N/A]
- f. [N/A]

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

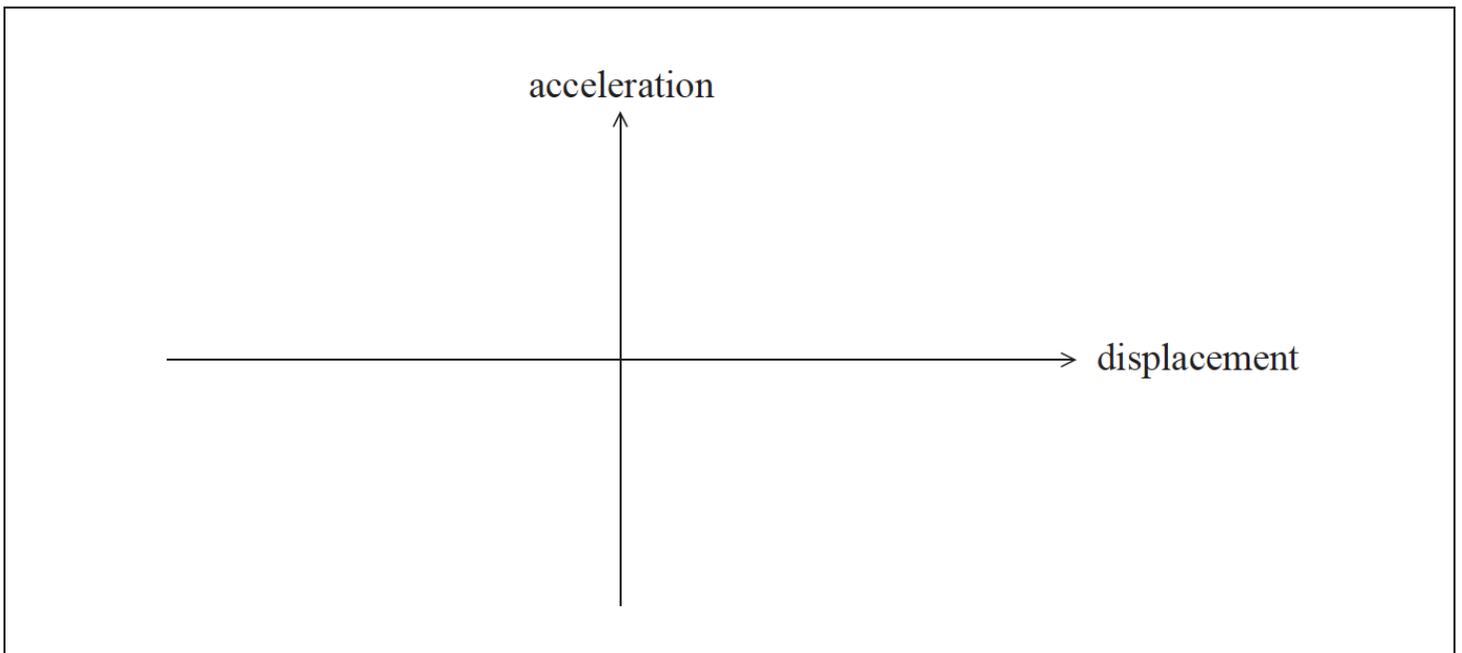
Part 1 Simple harmonic motion and the superposition of waves

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

[3]



(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.

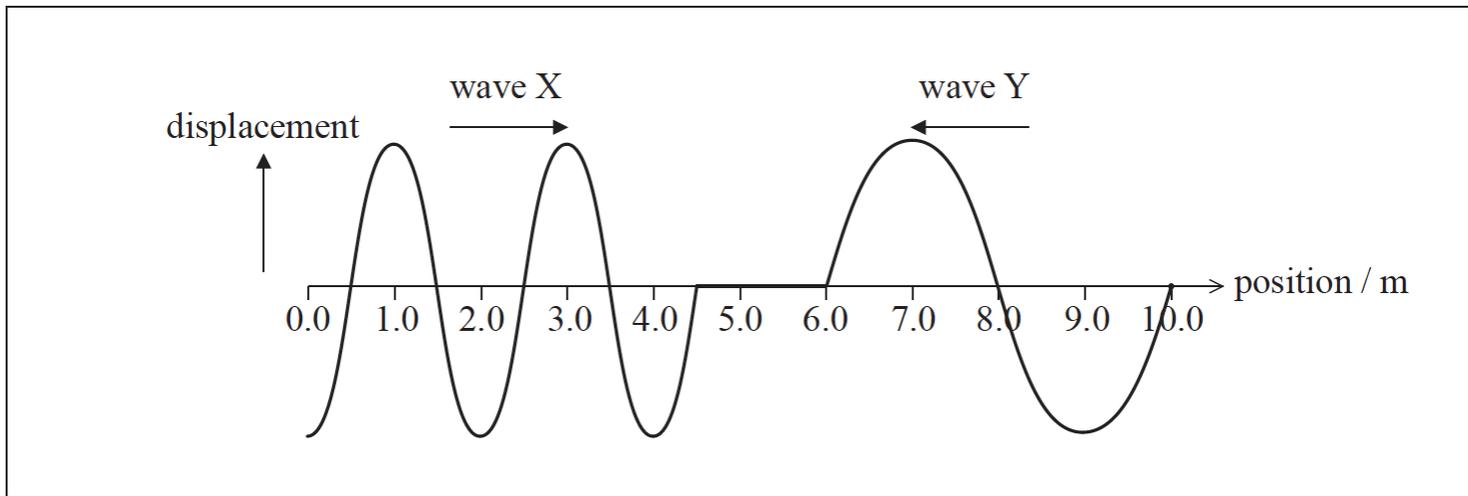
[3]

- 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 waves of equal amplitude but different frequency are generated.

[4]

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.

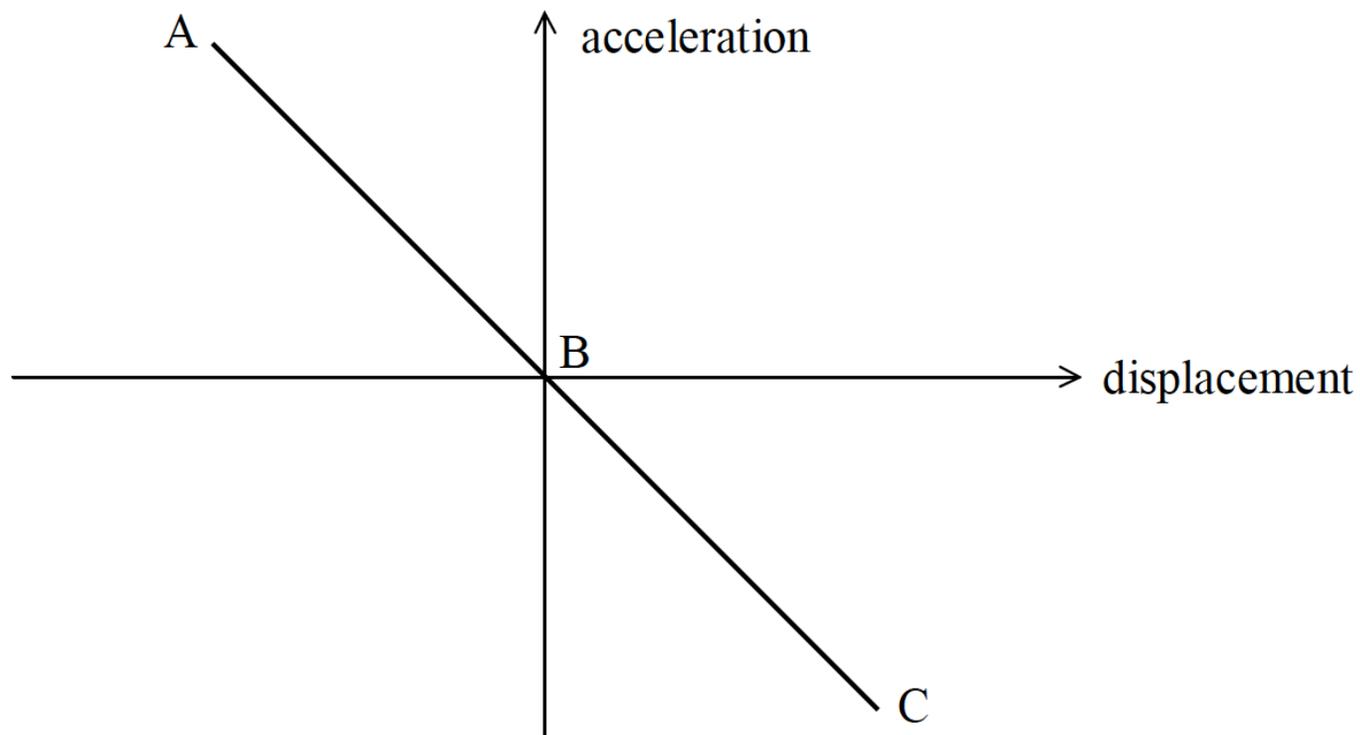
Markscheme

a. the force/acceleration is proportional to the displacement from the equilibrium position/centre;

the force/acceleration is directed towards the equilibrium position/centre / the force/acceleration is in the opposite direction to the displacement;

b. (i) straight line through the origin;

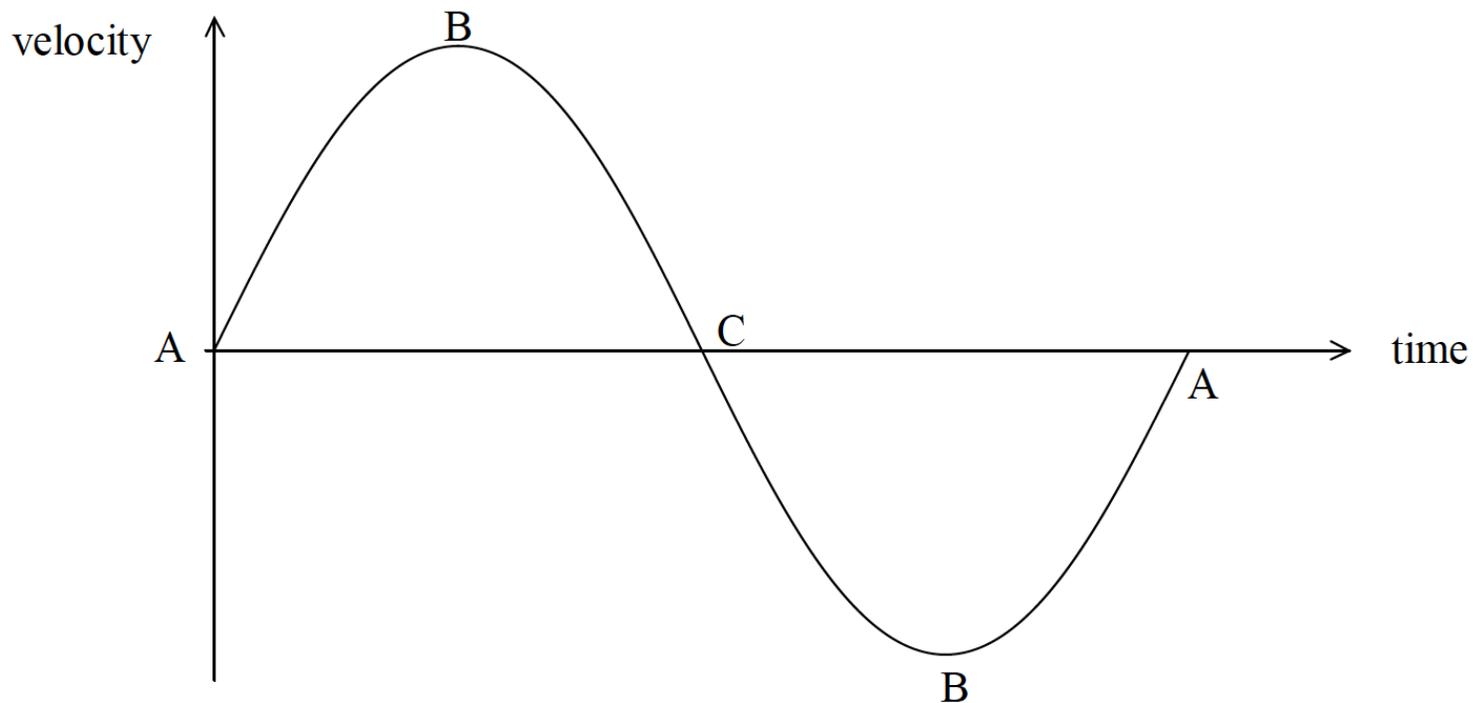
with negative gradient;



(ii) all three labels correct;

c. (i) positive sine graph;

drawn correctly for one period;



(ii) all three labels correct;

Accept either of the As and either of the Bs.

Accept either B if shown on the time axis in the correct position.

d. $\omega = \frac{2\pi}{T} = \frac{2\pi}{0.20} = 31.42 \approx 31\text{rads}^{-1}$;

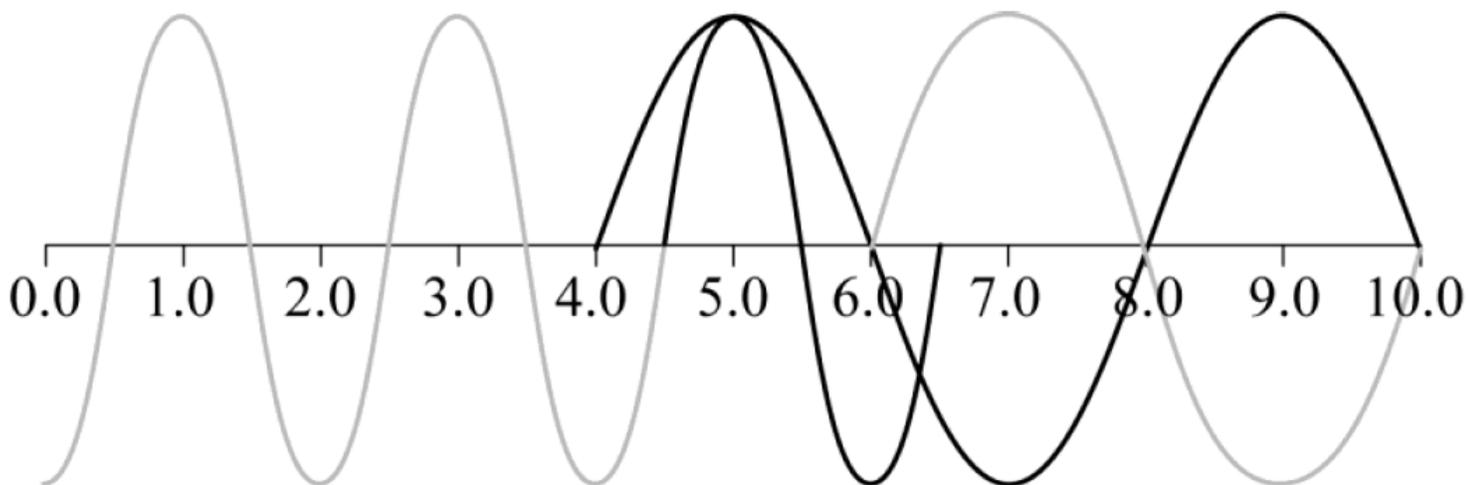
$v_{\text{max}} = \omega x_0 = 31.42 \times 0.040$;

$v_{\text{max}} = 1.257 \approx 1.3\text{ms}^{-1}$;

e. (i) if two or more waves overlap/meet/pass through the same point;

the resultant displacement at any point is found by adding the displacements produced by each individual wave;

(ii) 0.20 s later, wave X will have crests at 5.0, 3.0 and 1.0 m, wave Y will have crests at 5.0 and 9.0 m / each wave will have moved forward by 2.0 m in 0.20 s / wave profiles for 0.20 s later drawn on diagram;



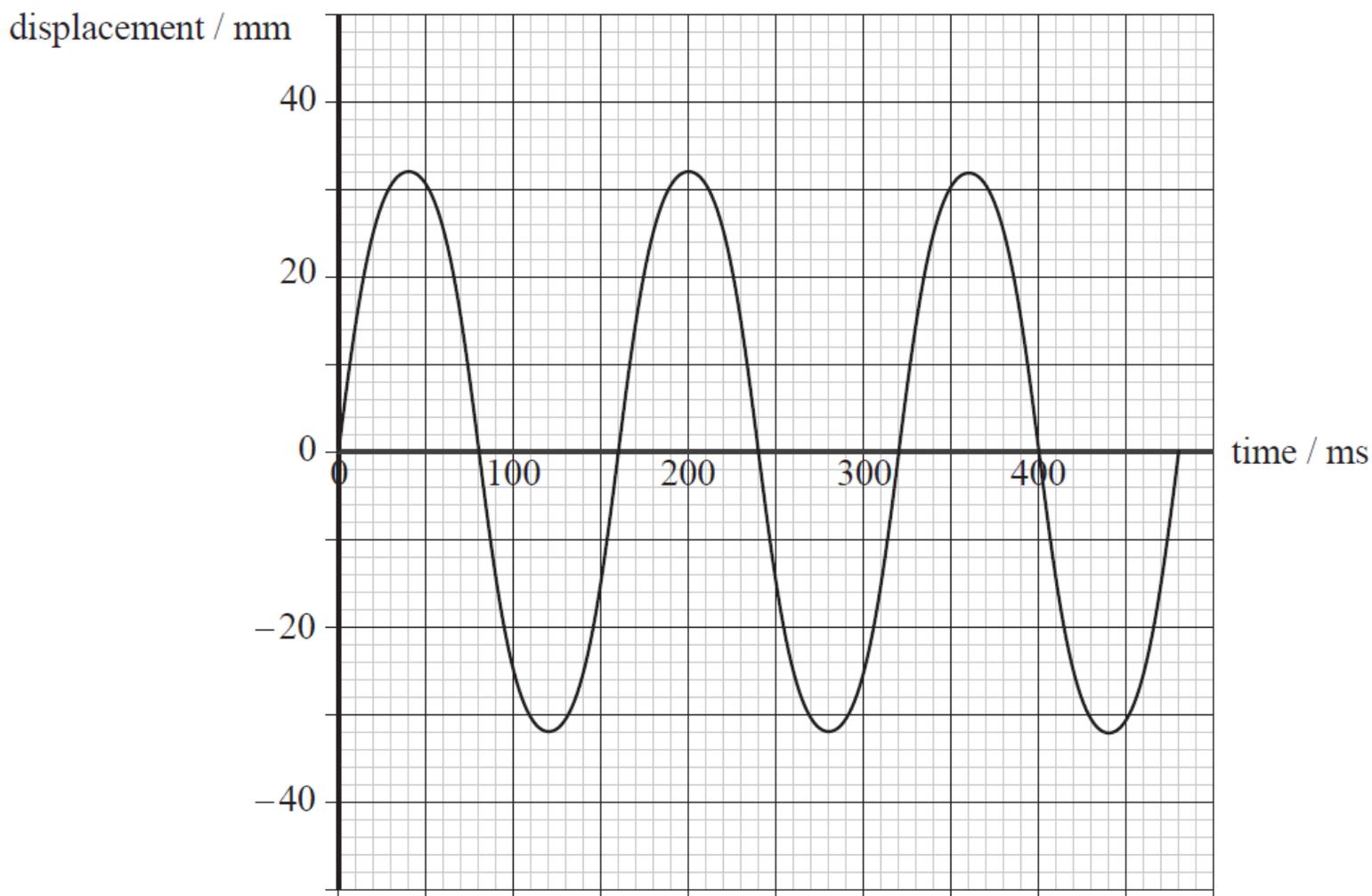
maximum displacement where two crests meet, i.e. at 5.0 m;

Examiners report

- a. [N/A]
- b. [N/A]
- c. [N/A]
- d. [N/A]
- e. [N/A]

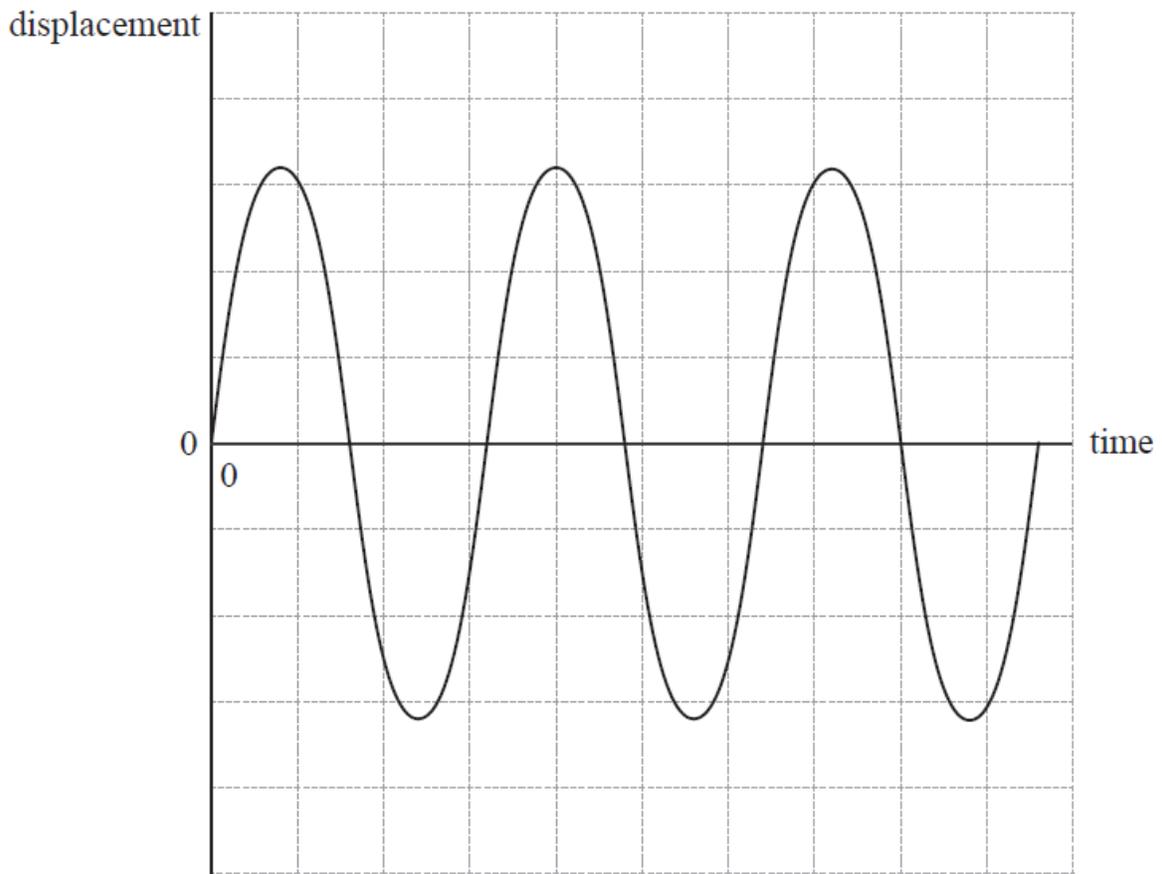
Simple harmonic motion and forced oscillations

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.



Markscheme

a. (i) 32 (mm);

(ii) period = 160 (ms);

frequency = $6.2/6.3$ (Hz);

Allow ECF for incorrect period.

b. (i) $\omega = 2\pi \times 6.25$;

$v = 39.3 \times 32 \times 10^{-3} = 1.3 (\text{ms}^{-1})$; *(allow ECF from (a))*

or

tangent drawn to graph at a point of zero displacement;

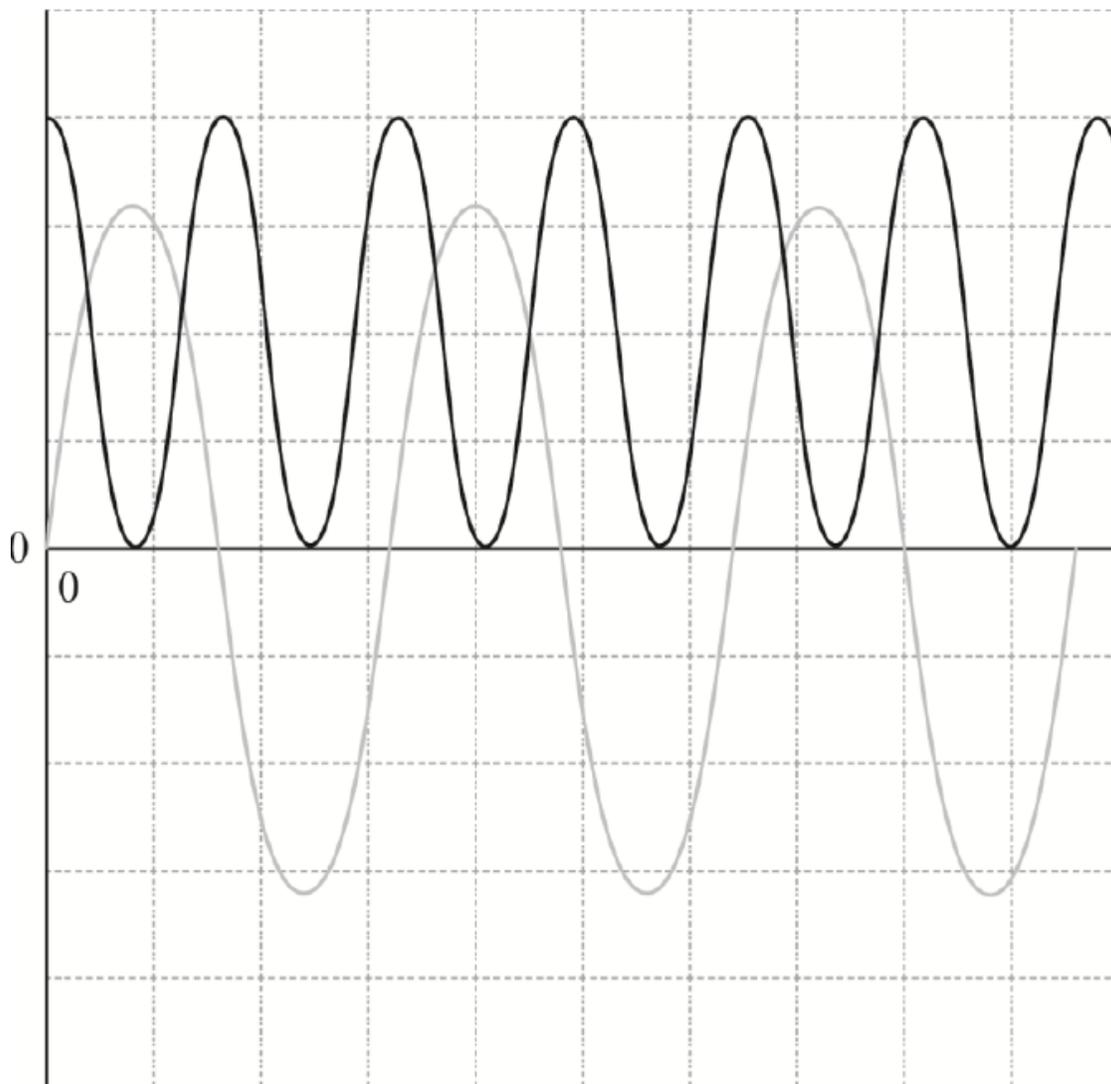
gradient calculated between 1.2 and 1.4;

(ii) displacement = 23–26 (mm);

35–40 (ms^{-2});

23 mm found by calculating displacement

c.



double frequency;

always positive and constant amplitude;

correct phase *ie* cosine squared;

Ignore amplitude value.

A minimum of one complete, original oscillation needed to award [3].

Examiners report

a. (i) Nearly all candidates correctly stated the amplitude as being 32 mm.

(ii) Most were able to measure the period and many then went on to calculate the frequency with the occasional hiccup with conversion of ms into kHz etc.

b. (i) A large proportion of candidates correctly determined the maximum speed of the object by correctly calculating the angular speed and multiplying it by the amplitude. Full marks were awarded to those calculating the gradient of the tangent to the displacement-time graph at zero displacement.

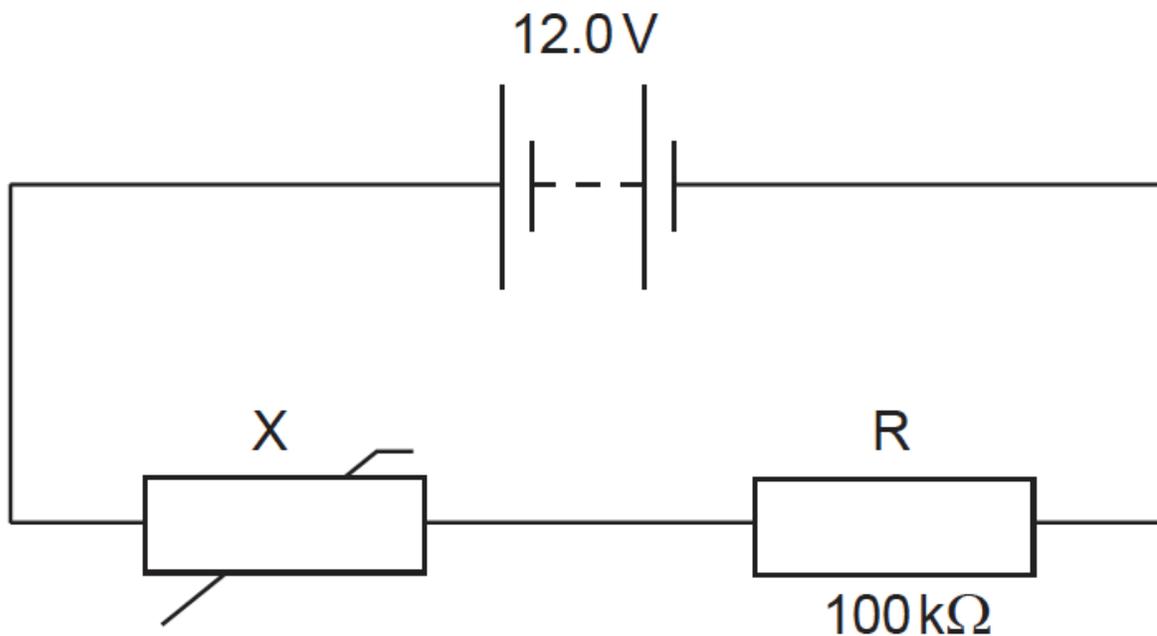
(ii) In the simplest route to the answer candidates were usually successful in measuring the displacement at 140 ms and then using the defining equation for SHM to calculate the acceleration. Other routes were allowed as alternatives but success was infrequent.

c. Given the relative difficulty of transposing the displacement into a velocity and then squaring it to find the shape of the kinetic energy function, this part was done very well. Most candidates recognised that the energy was always positive, of twice the frequency of the displacement graph and took a cosine squared shape. Sketches were of variable quality but often better than others on the paper.

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

Part 1 Thermistor circuit

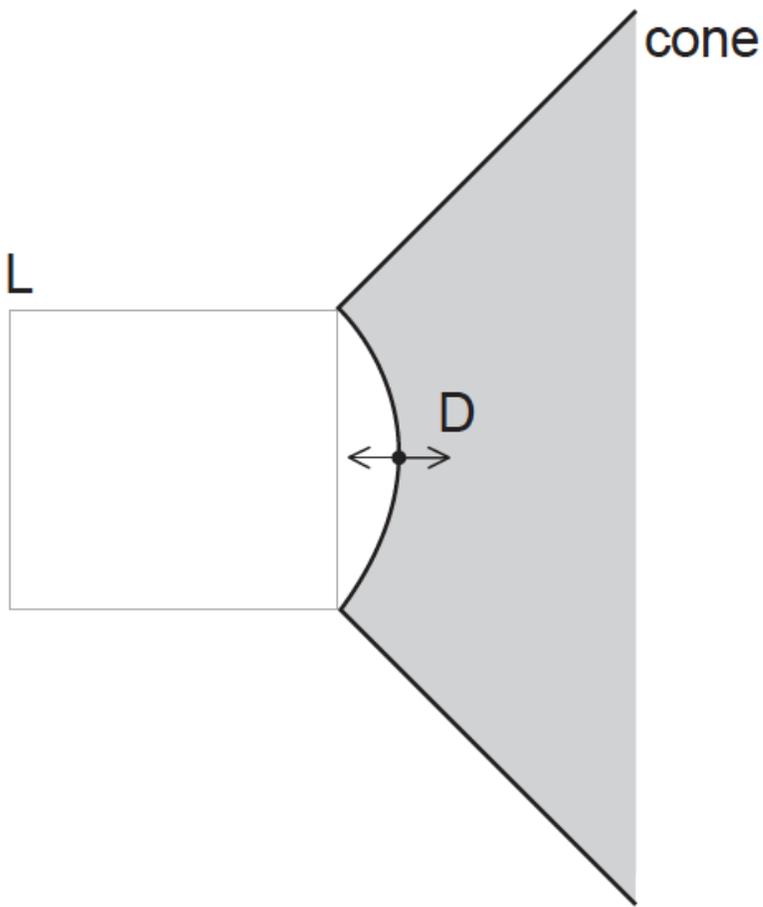
The circuit shows a negative temperature coefficient (NTC) thermistor X and a $100\text{ k}\Omega$ fixed resistor R connected across a battery.



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

Part 2 Vibrations and waves

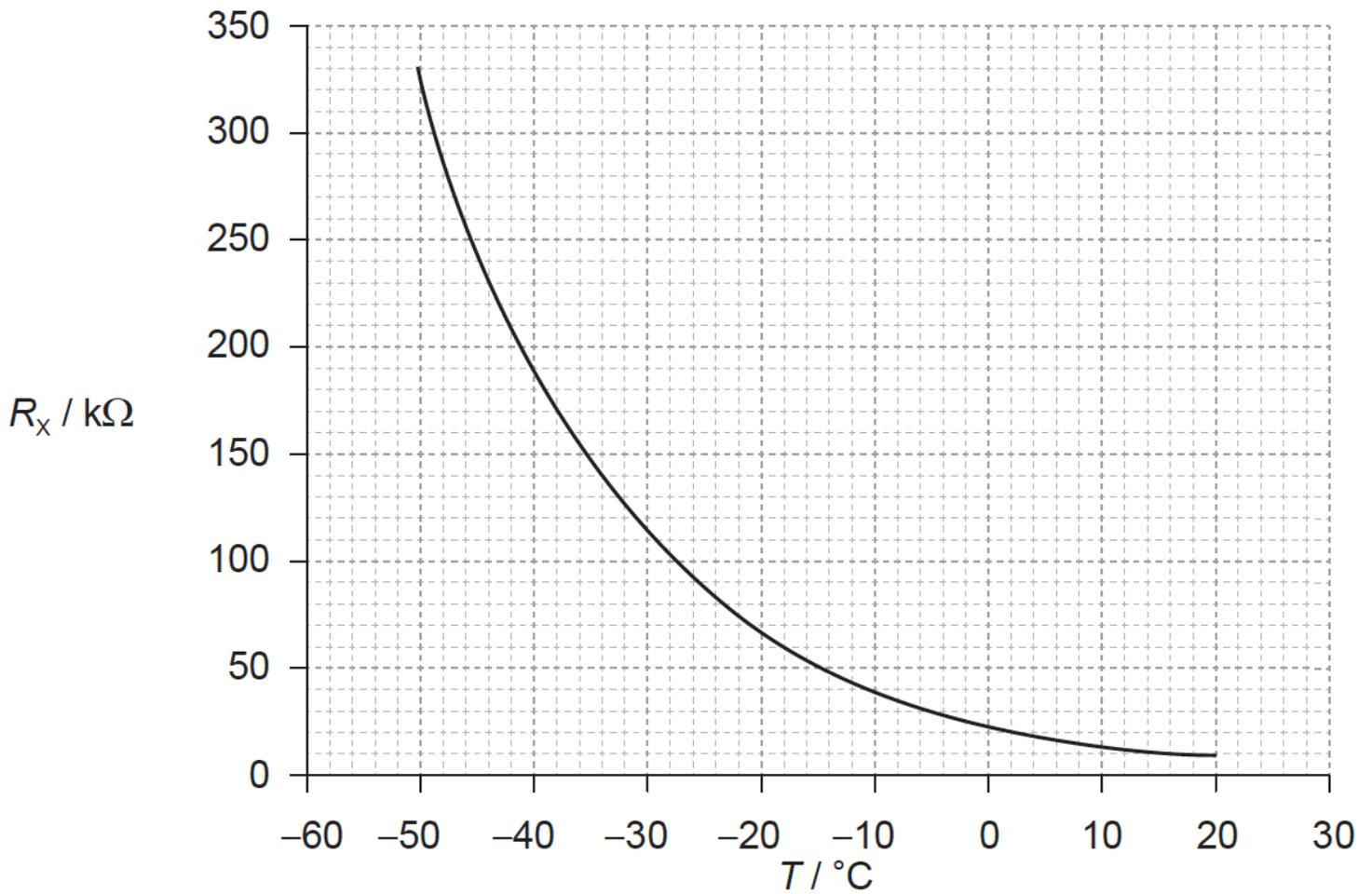
The cone and dust cap D of a loudspeaker L vibrates with a frequency of 1.25 kHz with simple harmonic motion (SHM).



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

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

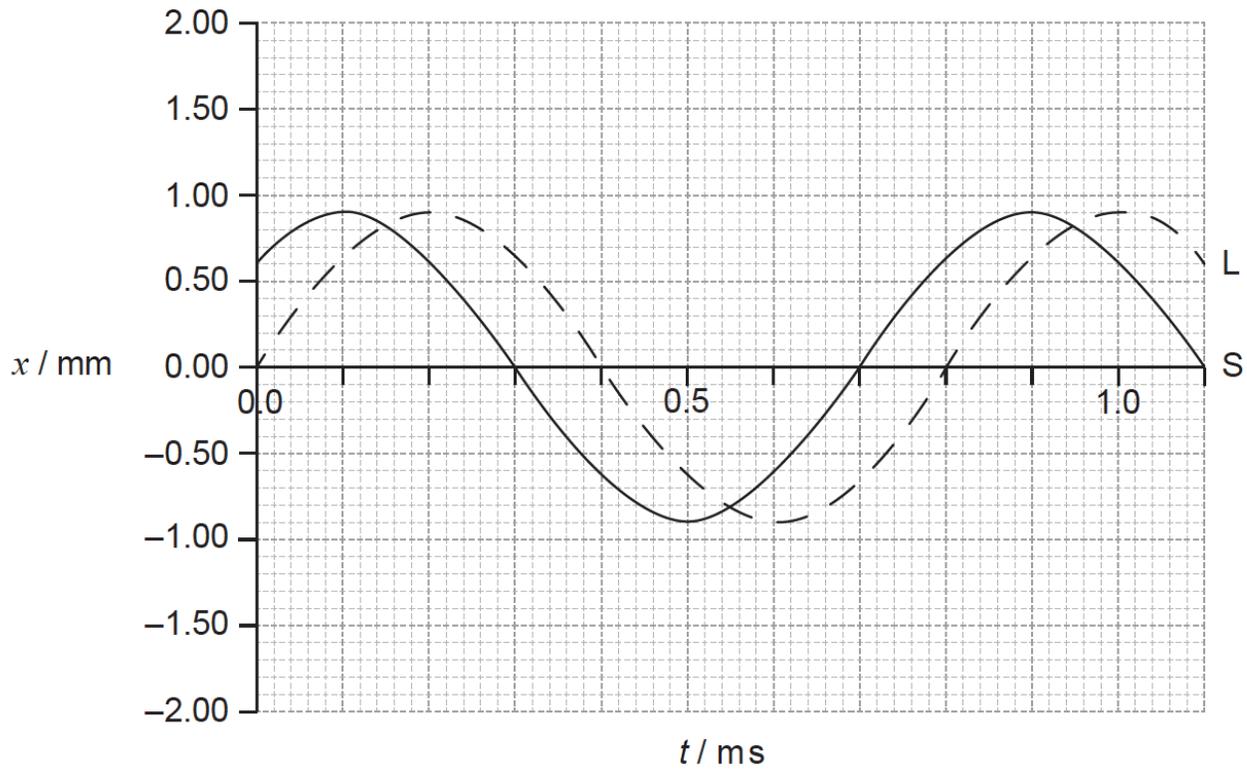
b. The graph below shows the variation with temperature T of the resistance R_x of the thermistor. [7]



- (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

$$\frac{\text{voltage across X}}{\text{voltage across R}}$$

- 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.

Markscheme

a. (i) the work done per unit charge in moving a quantity of charge completely around a circuit / the power delivered per unit current / work done per unit charge made available by a source;

(ii) place voltmeter across battery;

b. (i) $V_X = 7.5 \text{ V}$;

$$I \left(= \frac{4.5}{100 \times 10^3} \right) = 4.5 \times 10^{-5} \text{ A or } \frac{V_X}{V_R} = \frac{R_x}{R_R};$$

$$R_x \left(= \frac{7.5}{4.5 \times 10^{-5}} \right) = 1.67 \times 10^5 \Omega \text{ or } R_x \left(= \frac{7.5}{4.5} \times 100 \times 10^3 \right) = 1.67 \times 10^5 \Omega;$$

$T = -37 \text{ or } -38^\circ\text{C}$

(ii) -50 to (up to) -30°C / at low temperatures;

(iii) as the temperature decreases R_x increases;

same current through R and X so the ratio increases **or** V_X increases and V_R decreases so the ratio increases;

c. (periodic) motion in which acceleration/restoring force is proportional to the displacement from a fixed point;

directed towards the fixed point / in the opposite direction to the displacement;

d. (i) $\omega = (2\pi f = 2\pi \times 1250) 7854 \text{ rad s}^{-1}$;

$a_0 = (-\omega^2 x_0 = -7854^2 \times 0.85 \times 10^{-3} =) (-) 5.2 \times 10^4 \text{ ms}^{-2}$;

(ii) correct substitution into $E_T = \frac{1}{2} m \omega^2 x_0^2$ irrespective of powers of 10;

0.14 to 0.15 J;

e. (i) 0.264 m;

(ii) longitudinal;

progressive / propagate (through the air) / travels with constant speed (through the air);

series of compressions and rarefactions / high and low (air) pressure;

f. (i) S leads L / idea that the phase of L is the phase of S minus an angle;

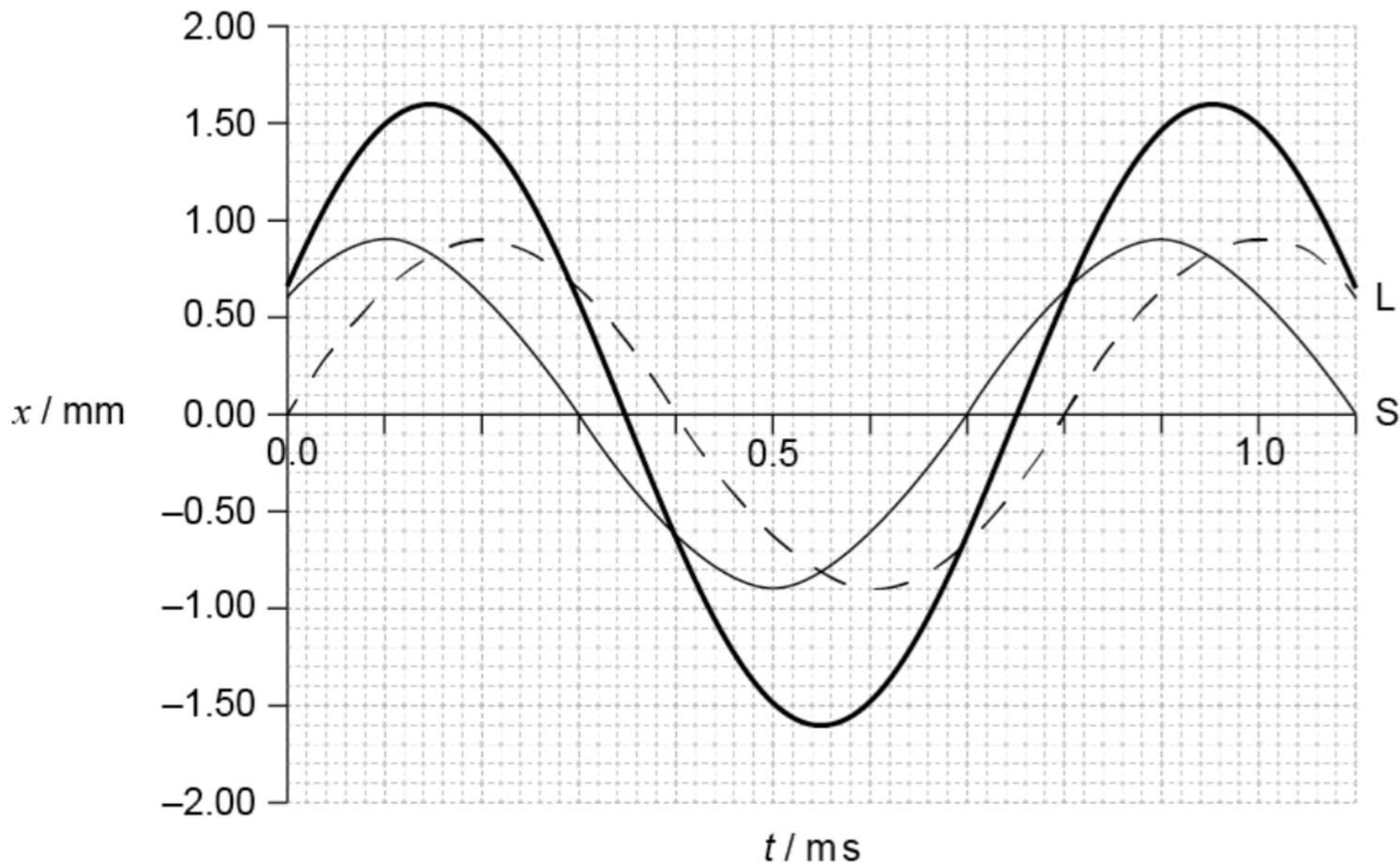
$\frac{1}{8}$ period / $1 \times 10^{-4} \text{ s}$ / 0.1 ms;

$\frac{\pi}{4}$ / 0.79 rad / 45 degrees;

(ii) agreement at all zero displacements;

maxima and minimum at correct times;

constant amplitude of 1.60 mm;



- a. [N/A]
 - b. [N/A]
 - c. [N/A]
 - d. [N/A]
 - e. [N/A]
 - f. [N/A]
-