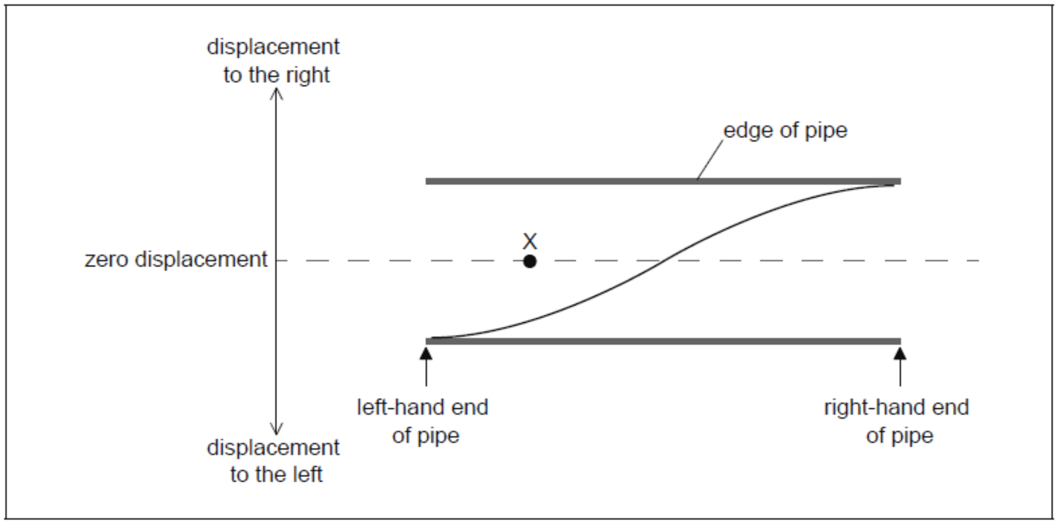
R2019_49 *[265 marks]*

A pipe is open at both ends. A first-harmonic standing wave is set up in the pipe. The diagram shows the variation of displacement of air molecules in the pipe with distance along the pipe at time $t = 0$. The frequency of the first harmonic is f.



1a. An air molecule is situated at point X in the pipe at $t = 0$. Describe the motion of this air molecule during one complete cycle of the standing wave beginning from $t = 0$. *[2 marks]*

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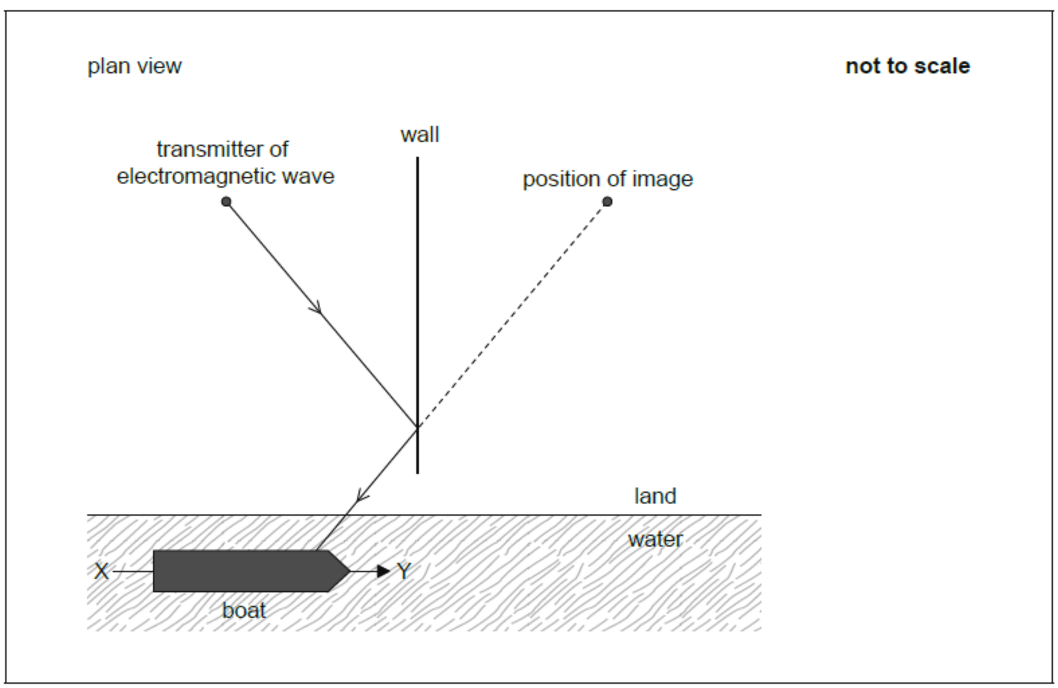
1b. The speed of sound c for longitudinal waves in air is given by *[3 marks]*

$$c = \sqrt{\frac{K}{\rho}}$$

where ρ is the density of the air and K is a constant.

A student measures f to be 120 Hz when the length of the pipe is 1.4 m. The density of the air in the pipe is 1.3 kg m^{-3}. Determine, in kg m^{-1} s^{-2}, the value of K for air.

A transmitter of electromagnetic waves is next to a long straight vertical wall that acts as a plane mirror to the waves. An observer on a boat detects the waves both directly and as an image from the other side of the wall. The diagram shows one ray from the transmitter reflected at the wall and the position of the image.



1c. Demonstrate, using a second ray, that the image appears to come from the position indicated. *[1 mark]*

1d. Outline why the observer detects a series of increases and decreases in the intensity of the received signal as the boat moves along the line XY. *[2 marks]*

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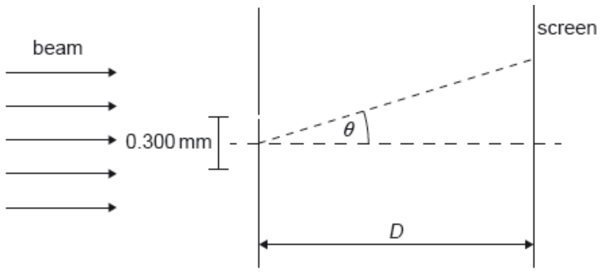
A beam of coherent monochromatic light from a distant galaxy is used in an optics experiment on Earth.

The beam is incident normally on a double slit. The distance between the slits is 0.300 mm. A screen is at a distance *D* from the slits. The diffraction angle θ is labelled.



2a. A series of dark and bright fringes appears on the screen. Explain how a dark fringe is formed. *[3 marks]*

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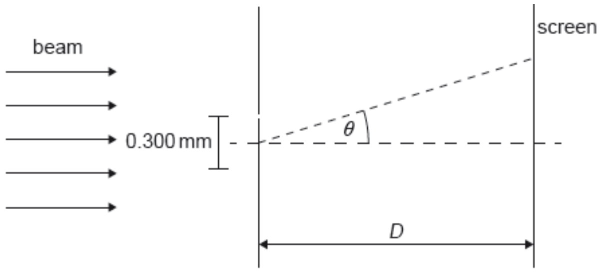
A beam of coherent monochromatic light from a distant galaxy is used in an optics experiment on Earth.

The beam is incident normally on a double slit. The distance between the slits is 0.300 mm. A screen is at a distance D from the slits. The diffraction angle θ is labelled.



2b. Outline why the beam has to be coherent in order for the fringes to be visible. *[1 mark]*

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2c. The wavelength of the beam as observed on Earth is 633.0 nm. The separation between a dark and a bright fringe on the screen is 4.50 mm. Calculate D. *[2 marks]*

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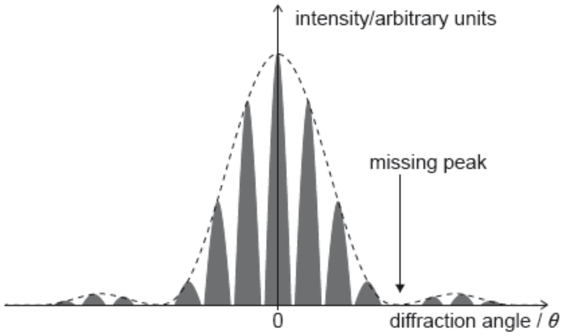
The graph of variation of intensity with diffraction angle for this experiment is shown.



2d. Calculate the angular separation between the central peak and the missing peak in the double-slit interference intensity pattern. State your answer to an appropriate number of significant figures. *[3 marks]*

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2e. Deduce, in mm, the width of one slit. *[2 marks]*

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2f. The wavelength of the light in the beam when emitted by the galaxy was 621.4 nm. *[2 marks]*

Explain, without further calculation, what can be deduced about the relative motion of the galaxy and the Earth.

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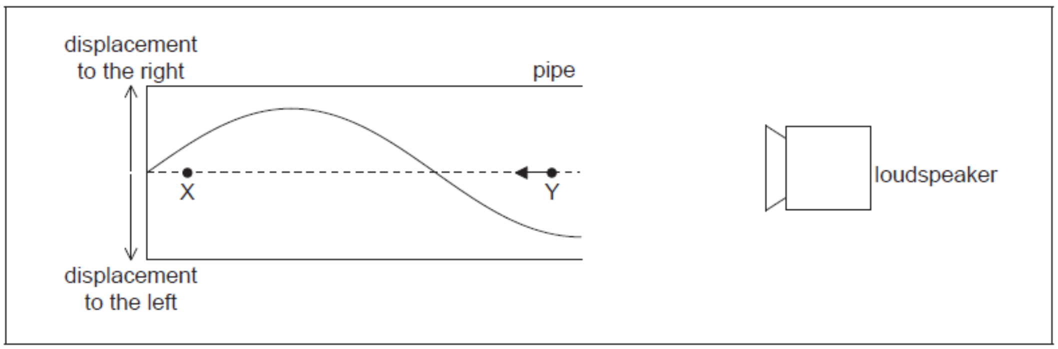
A loudspeaker emits sound towards the open end of a pipe. The other end is closed. A standing wave is formed in the pipe. The diagram represents the displacement of molecules of air in the pipe at an instant of time.



3a. Outline how the standing wave is formed. *[1 mark]*

X and Y represent the equilibrium positions of two air molecules in the pipe. The arrow represents the velocity of the molecule at Y.

3b. Draw an arrow on the diagram to represent the direction of motion of the molecule at X. *[1 mark]*

3c. Label a position N that is a node of the standing wave. *[1 mark]*

3d. The speed of sound is 340 m s^{-1} and the length of the pipe is 0.30 m. Calculate, in Hz, the frequency of the sound. *[2 marks]*

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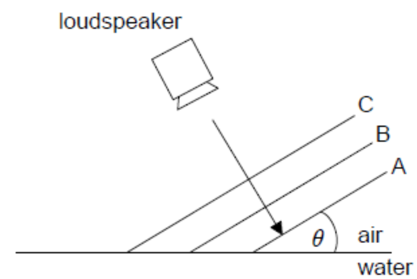
The loudspeaker in (a) now emits sound towards an air–water boundary. A, B and C are parallel wavefronts emitted by the loudspeaker. The parts of wavefronts A and B in water are not shown. Wavefront C has not yet entered the water.



3e. The speed of sound in air is 340 m s^{-1} and in water it is 1500 m s^{-1}. *[2 marks]*

The wavefronts make an angle θ with the surface of the water. Determine the maximum angle, θ_{max}, at which the sound can enter water. Give your answer to the correct number of significant figures.

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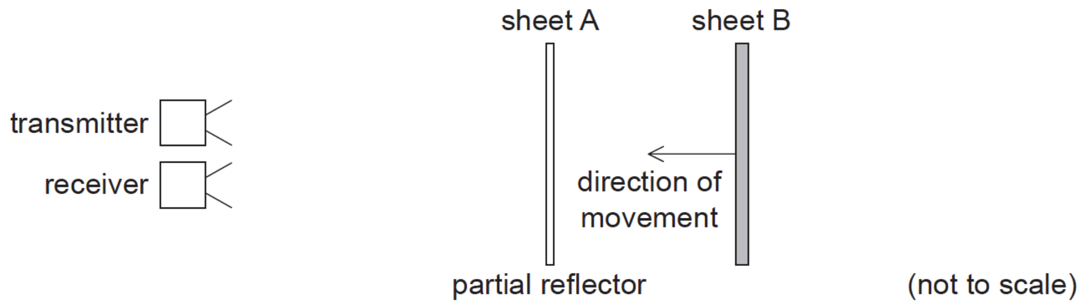
3f. Draw lines on the diagram to complete wavefronts A and B in water for $\theta < \theta_{max}$. *[2 marks]*

This question is about the properties of waves.

Microwaves from a microwave transmitter are reflected from two parallel sheets, A and B. Sheet A partially reflects microwave energy while allowing some to pass through. All of the microwave energy incident on sheet B is reflected.



Sheet A is fixed and sheet B is moved towards it. While sheet B is moving, the intensity of the signal detected at the receiver goes through a series of maximum and minimum values.

4a. Outline why a minimum in the intensity occurs for certain positions of sheet B. *[3 marks]*

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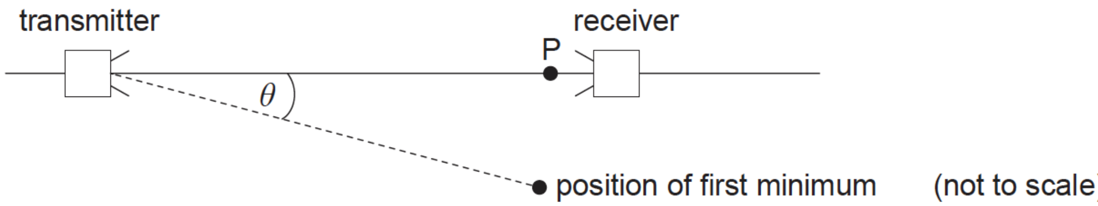
4b. The apparatus is arranged to demonstrate diffraction effects. *[3 marks]*



The microwaves emerge from the transmitter through an aperture that acts as a single slit.

(i) Outline what is meant by diffraction.

(ii) A maximum signal strength is observed at P. When the receiver is moved through an angle θ, a first minimum is observed. The width of the aperture of the transmitter is 60 mm. Estimate the value of θ.

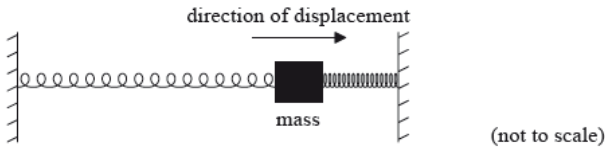
4c. Microwaves can be used to demonstrate polarization effects. Outline why an ultrasound receiver and transmitter **cannot** be used to demonstrate polarization. *[2 marks]*

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.



5a. Determine the acceleration of the mass at the moment of release. *[3 marks]*

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5b. Outline why the mass subsequently performs simple harmonic motion (SHM). *[2 marks]*

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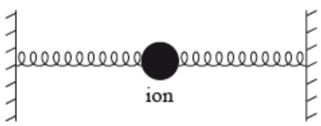
5c. Calculate the period of oscillation of the mass. *[2 marks]*

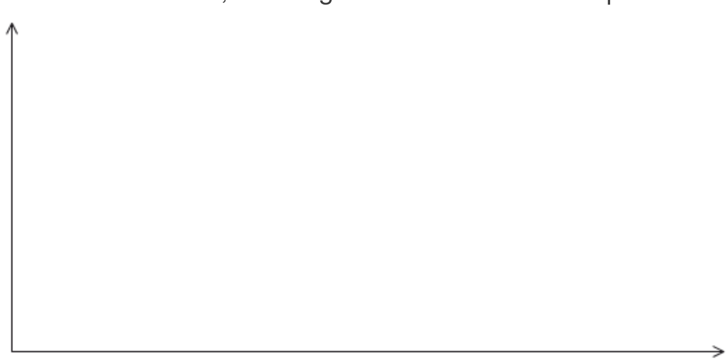
The motion of an ion in a crystal lattice can be modelled using the mass–spring arrangement. The inter-atomic forces may be modelled as forces due to springs as in the arrangement shown.



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.

5d. Estimate the maximum kinetic energy of the ion. *[2 marks]*

5e. 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. You should add appropriate values to the axes, showing the variation over one period. *[3 marks]*



5f. Calculate the wavelength of an infrared wave with a frequency equal to that of the model in (b). *[1 mark]*

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Part 2 Nuclear fission

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

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

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%.

5g. Determine the mass of U-235 that undergoes fission in the reactor every day. *[3 marks]*

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5h. Calculate the power output of the nuclear power station. *[2 marks]*

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

5i. moderator. *[3 marks]*

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5j. control rods. *[2 marks]*

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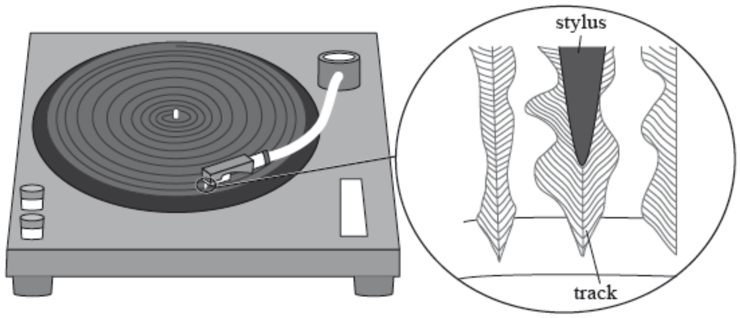
This question is in **two** parts. **Part 1** is about simple harmonic motion (SHM) and sound. **Part 2** is about electric and magnetic fields.

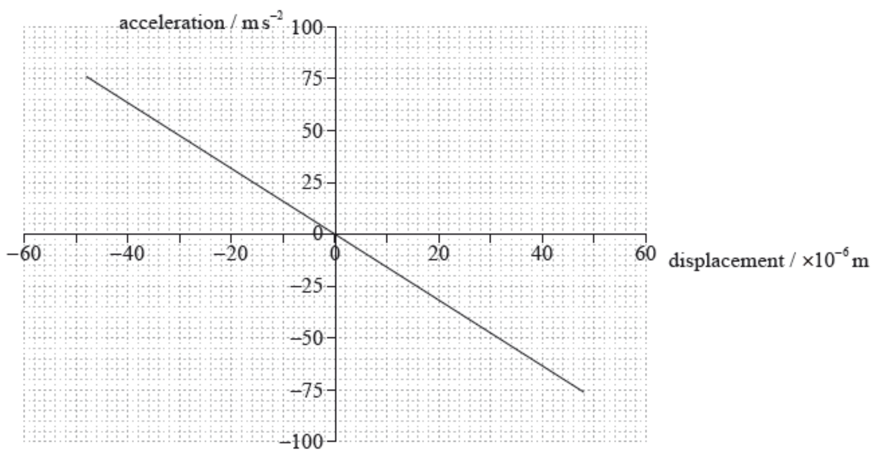
Part 1 Simple harmonic motion (SHM) and sound

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.



6a. Explain why the graph shows that the stylus undergoes simple harmonic motion. *[4 marks]*

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6b. (i) Using the graph on page 14, show that the frequency of the note being played is about 200 Hz. *[5 marks]*

(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.

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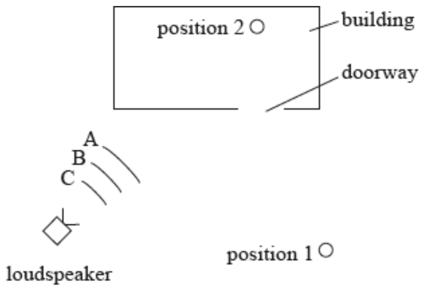
Sound is emitted from a loudspeaker which is outside a building. The loudspeaker emits a sound wave that has the same frequency as the recorded note.

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.

6c. (i) Draw rays to show how the person at **position 1** is able to hear the sound emitted by the loudspeaker. *[4 marks]*

(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.

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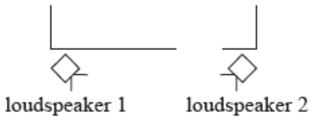
6d. The arrangement in (c) is changed and another loudspeaker is added. Both loudspeakers emit the same recorded note in phase with each other. *[3 marks]*



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

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Part 2 Electric and magnetic fields

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

6e. Distinguish between an insulator and a conductor. *[2 marks]*

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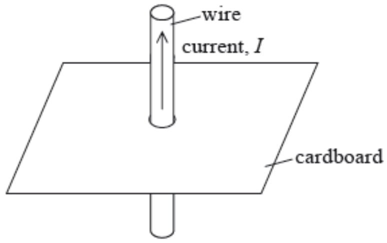
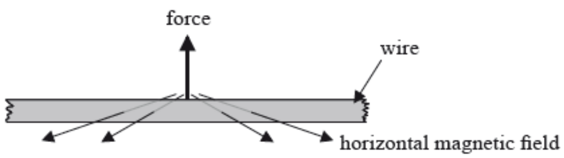
6f. The diagram shows a current I in a vertical wire that passes through a hole in a horizontal piece of cardboard. *[3 marks]*



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

6g. (i) The diagram shows a length of copper wire that is horizontal in the magnetic field of the Earth. *[4 marks]*



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.

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This question is about sound.

A source emits sound of frequency f. The source is moving towards a stationary observer at constant speed. The observer measures the frequency of the sound to be f'.

7a. (i) Explain, using a diagram, why f' is greater than f. *[5 marks]*

(ii) The frequency f is 275 Hz. The source is moving at speed 20.0 ms^{-1}. The speed of sound in air is 330 ms^{-1}. Calculate the observed frequency f' of the sound.

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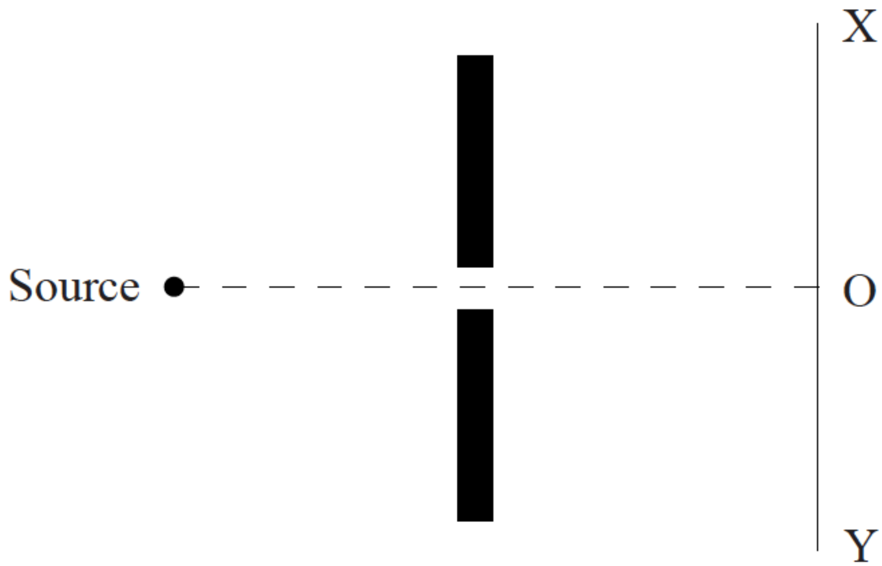
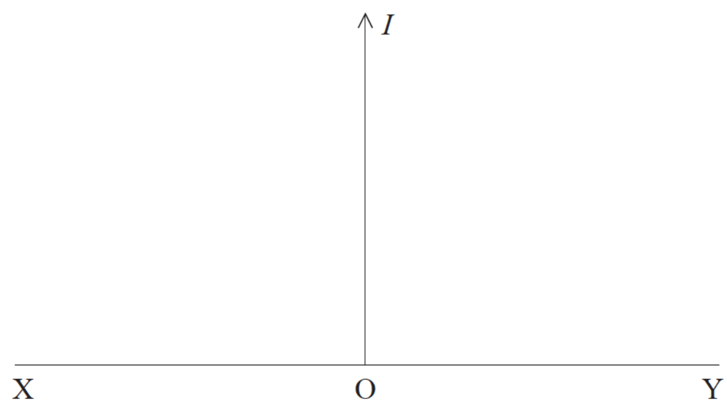
7b. A source of sound is placed in front of a barrier that has an opening of width comparable to the wavelength of the sound. *[4 marks]*



A sound detector is moved along the line XY. The centre of XY is marked O.

(i) On the axes below, sketch a graph to show how the intensity *I* of the sound varies as the detector moves from X to Y.



(ii) State the effect on the intensity pattern of increasing the wavelength of the sound.

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7c. (i) Outline the difference between a polarized wave and an unpolarized wave. *[3 marks]*

(ii) State why sound waves cannot be polarized.

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This question is about the superposition of waves.

8a. State what is meant by the principle of superposition of waves. *[1 mark]*

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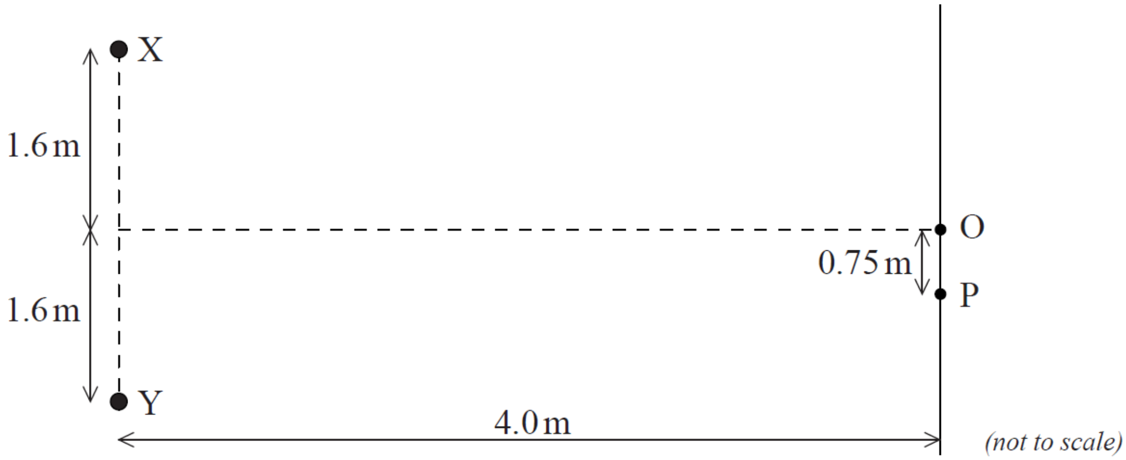
8b. The diagram shows two point sources of sound, X and Y. Each source emits waves of wavelength 1.1 m and amplitude *A*. Over the distances shown, any decrease in amplitude can be neglected. The two sources vibrate in phase. *[5 marks]*



Points O and P are on a line 4.0 m from the line connecting X and Y. O is opposite the midpoint of XY and P is 0.75 m from O.

(i) Explain why the intensity of the sound at O is 4 A^2.

(ii) Deduce that no sound is detected at P.

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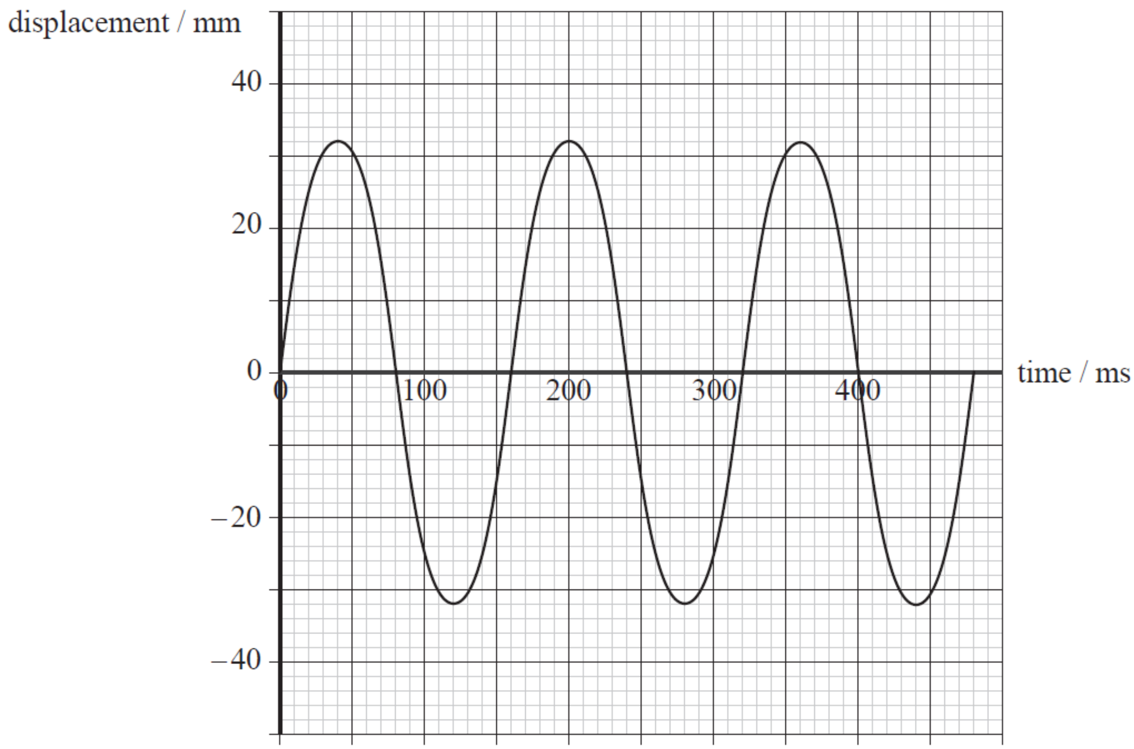
Simple harmonic motion and forced oscillations

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



9a. (i) State the amplitude of the oscillation. *[3 marks]*

(ii) Calculate the frequency of the oscillation.

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9b. (i) Determine the maximum speed of the object. *[4 marks]*

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

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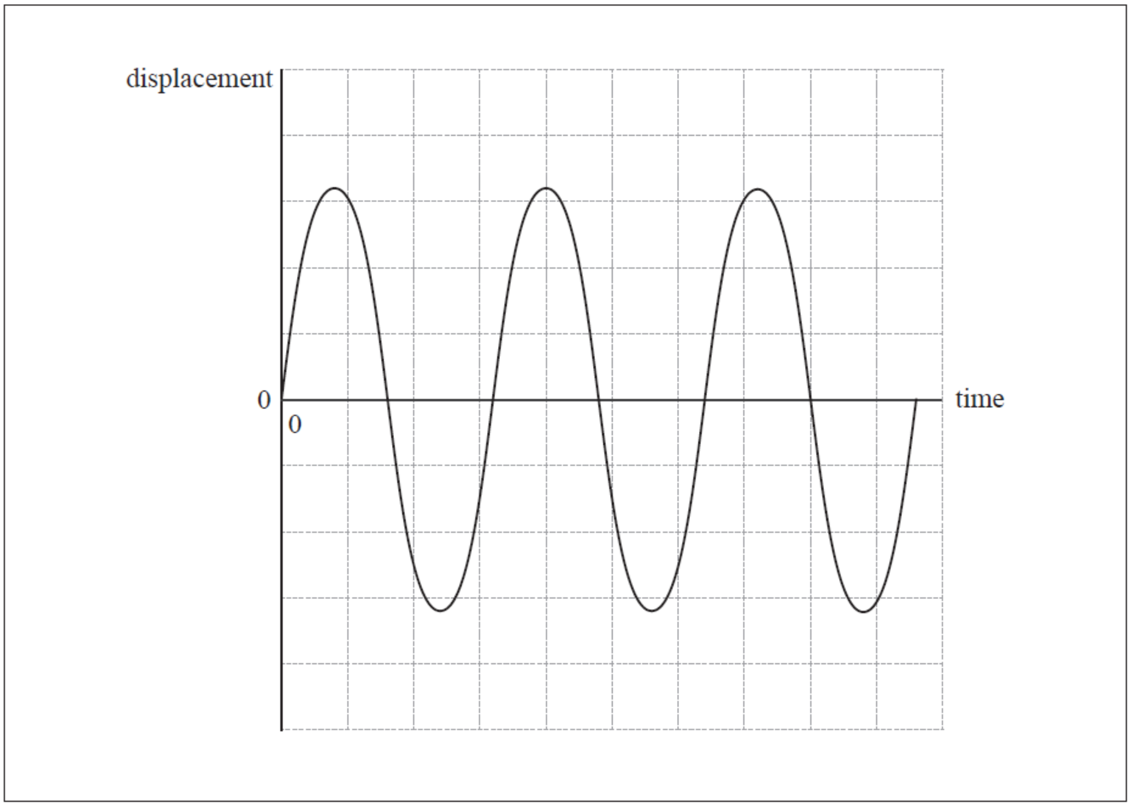
9c. The graph below shows how the displacement of the object varies with time. Sketch on the same axes a line indicating how the kinetic energy of the object varies with time. *[3 marks]*

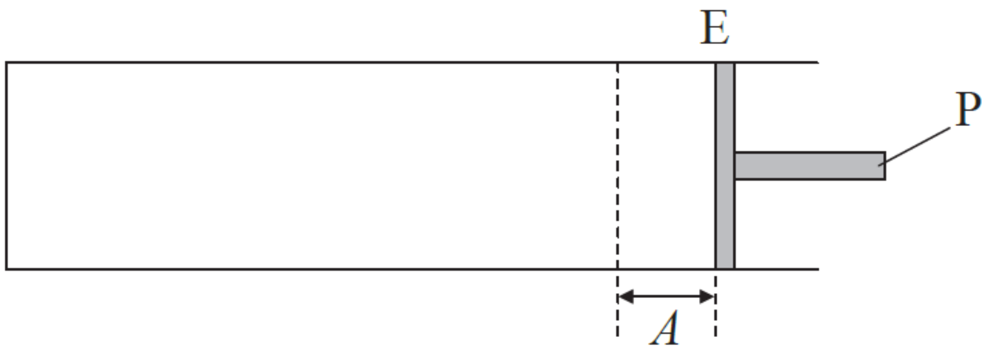
You should ignore the actual values of the kinetic energy.



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

10a. 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 marks]*



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.

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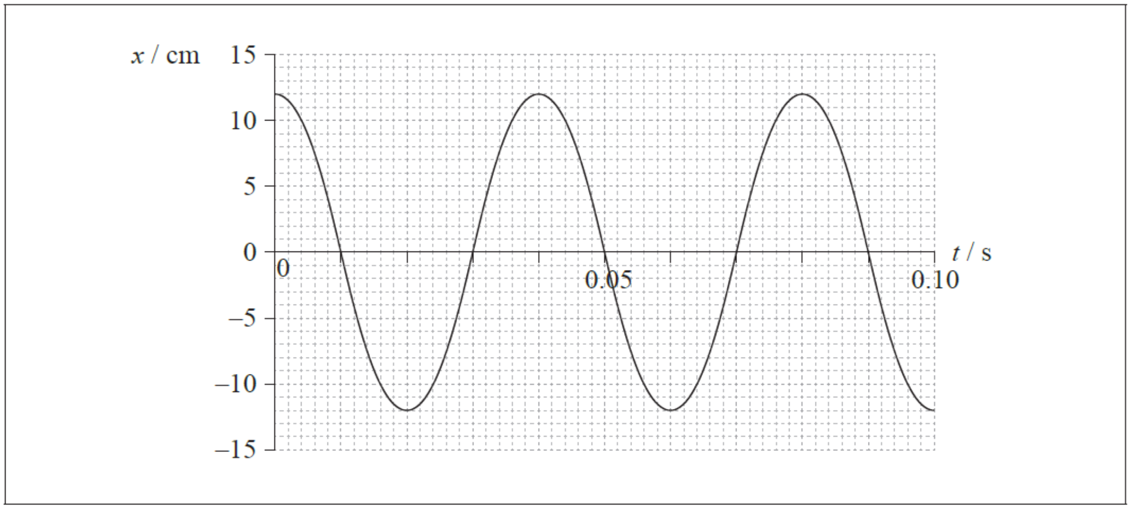
10b. The graph shows how the displacement x of the piston P in (a) from equilibrium varies with time t. *[7 marks]*



(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.

10c. The oscillations of P initially set up a longitudinal wave in the gas. *[4 marks]*

(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.

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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

11a. State what is meant by the terms ray and wavefront and state the relationship between them. *[3 marks]*

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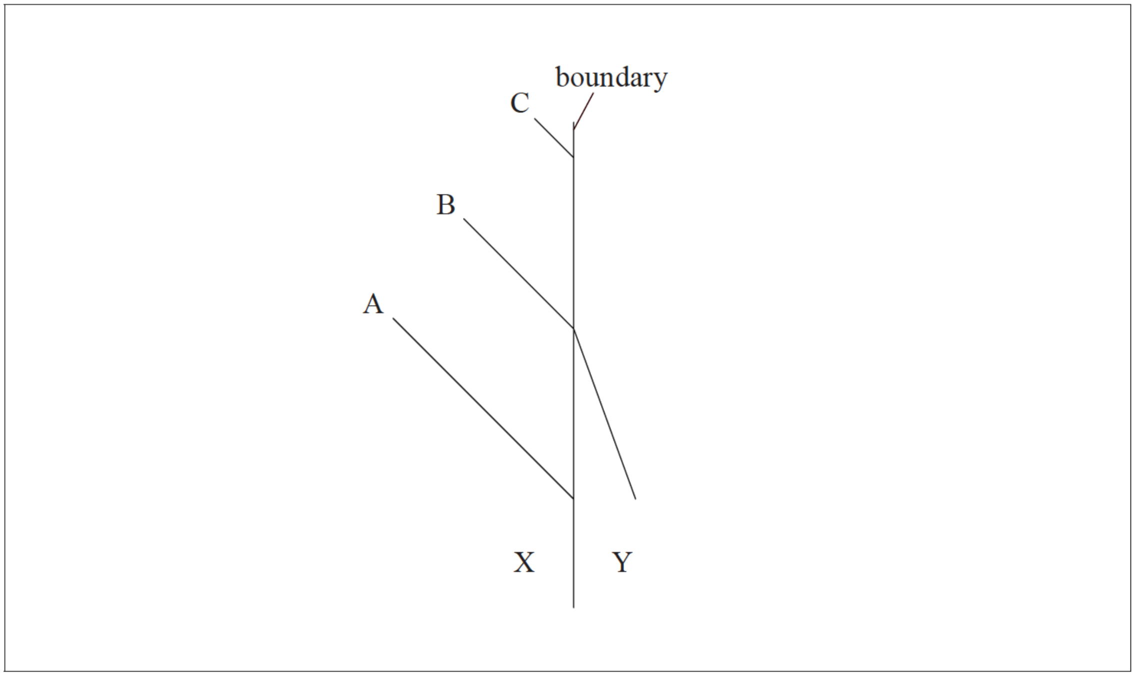
11b. The diagram shows three wavefronts, A, B and C, of a wave at a particular instant in time incident on a boundary between media X and Y. Wavefront B is also shown in medium Y. *[4 marks]*



(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 $\frac{n_X}{n_Y}$.

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11c. Describe the difference between transverse waves and longitudinal waves. *[2 marks]*

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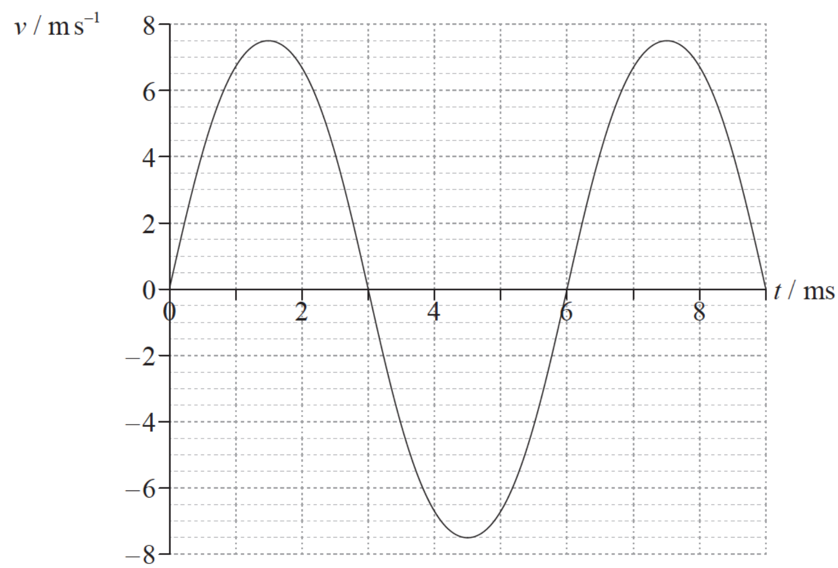
11d. The graph below shows the variation of the velocity v with time t for one oscillating particle of a medium. *[3 marks]*



(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.

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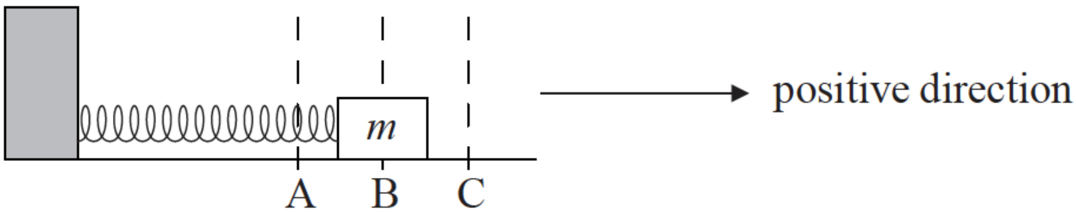
This question is in **two** parts. **Part 1** is about simple harmonic motion and the superposition of waves. **Part 2** is about gravitational fields.

Part 1 Simple harmonic motion and the superposition of waves

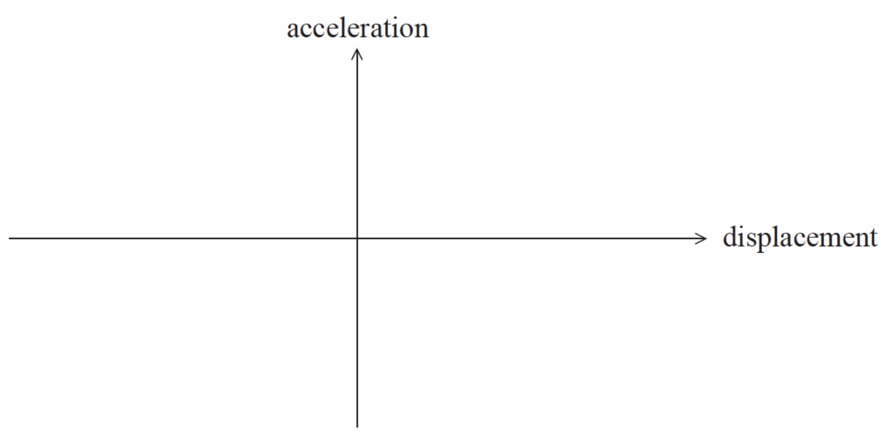
An object of mass *m* is placed on a frictionless surface and attached to a light horizontal spring. The other end of the spring is fixed.



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.

12a. Define *simple harmonic motion*. *[2 marks]*

12b. (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 marks]*



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

12c. (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 marks]*

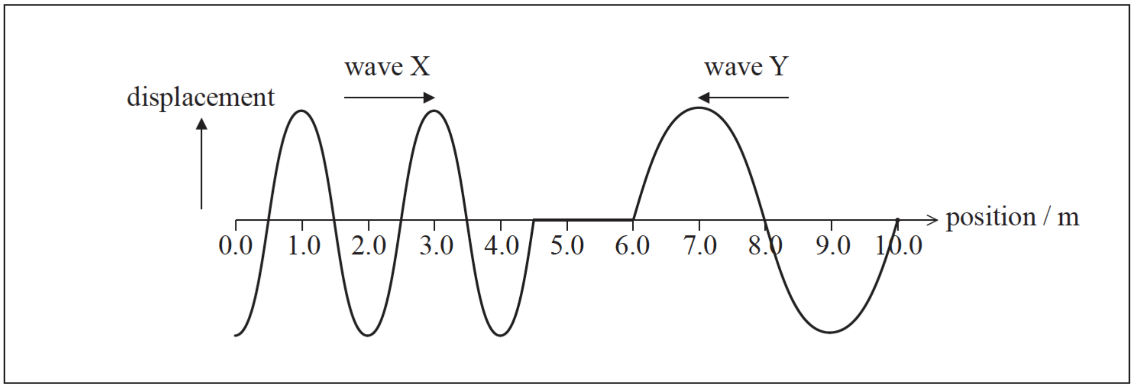
(ii) On your graph, label the points that correspond to the positions A, B and C.

12d. 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 marks]*

12e. 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 marks]*

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.

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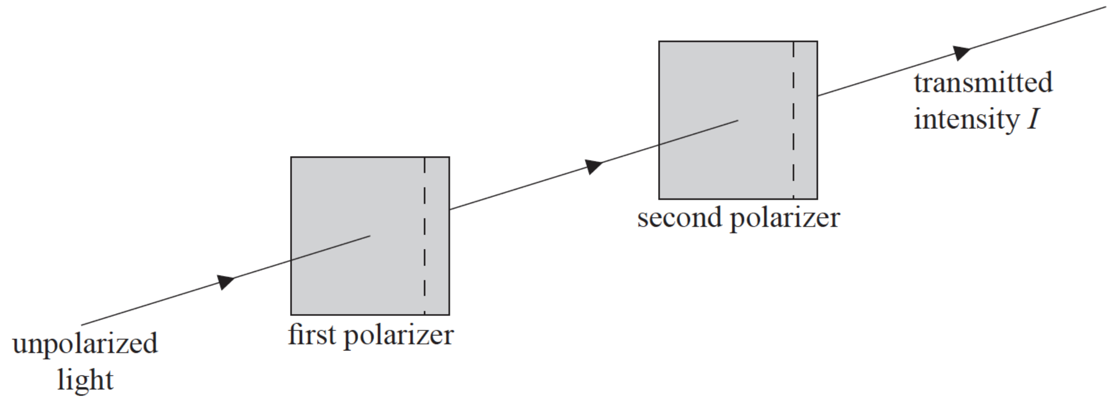
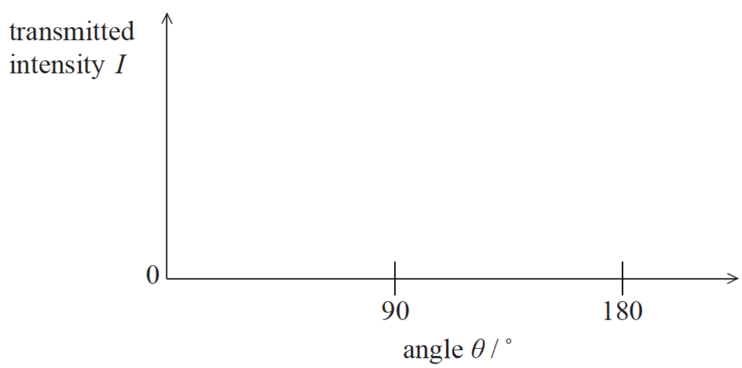
This question is about polarization.

Unpolarized light is directed towards two polarizers. The dashed lines represent the transmission axes of the polarizers. The angle θ between the transmission axes of the polarizers is initially 0º.



13. On the axes below, sketch a graph to show how the intensity I of the light emerging from the second polarizer varies with θ. *[2 marks]*



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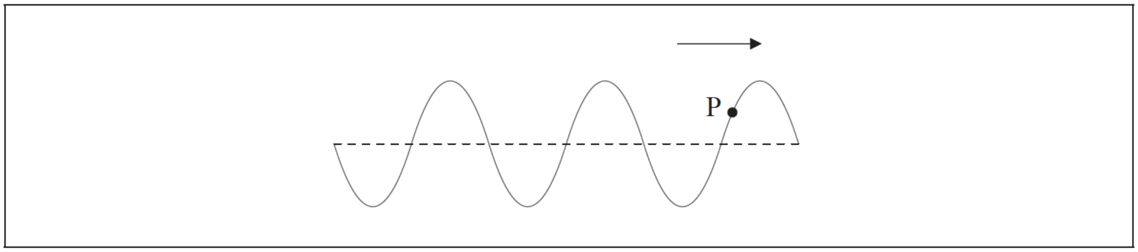
This question is in **two** parts. **Part 1** is about wave motion. **Part 2** is about renewable energy sources.

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.

14a. On the diagram above, identify *[2 marks]*

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

(ii) the wavelength of the wave.

14b. The wavelength of the wave is 25mm and its speed is 18mms $^{-1}$. *[2 marks]*

(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.

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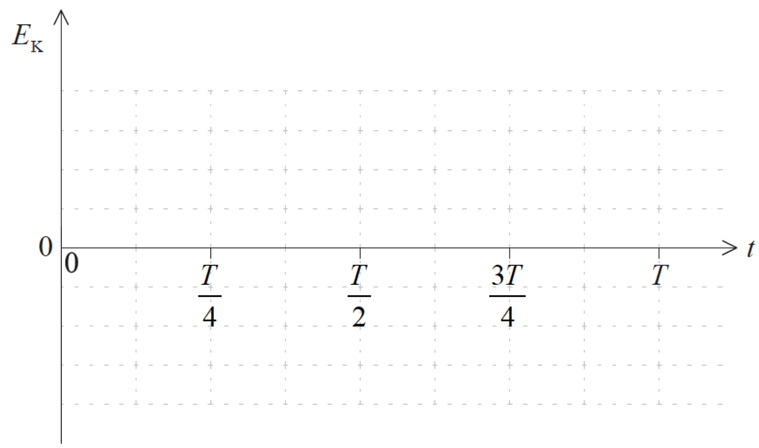
14c. Marker P undergoes simple harmonic motion. The amplitude of the wave is 1.7×10^{-2} m *[5 marks]* and the mass of marker P is 3.5×10^{-3} kg.

(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.



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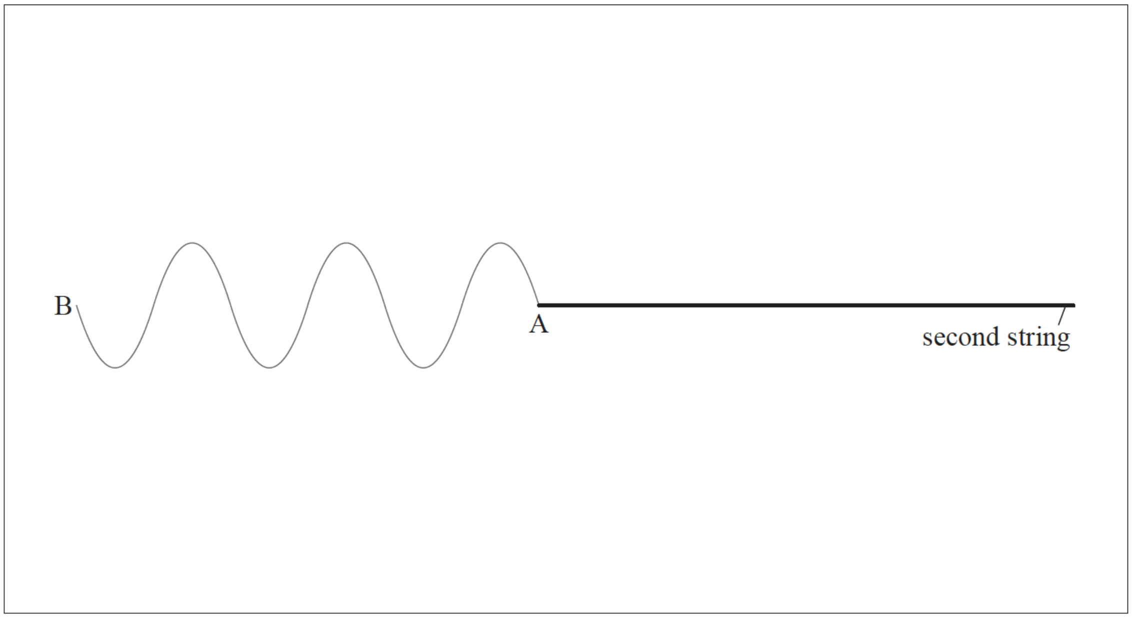
14d. The right-hand edge of the wave AB reaches a point where the string is securely attached to a second string in which the speed of waves is smaller than that of the first string. *[5 marks]*



(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).

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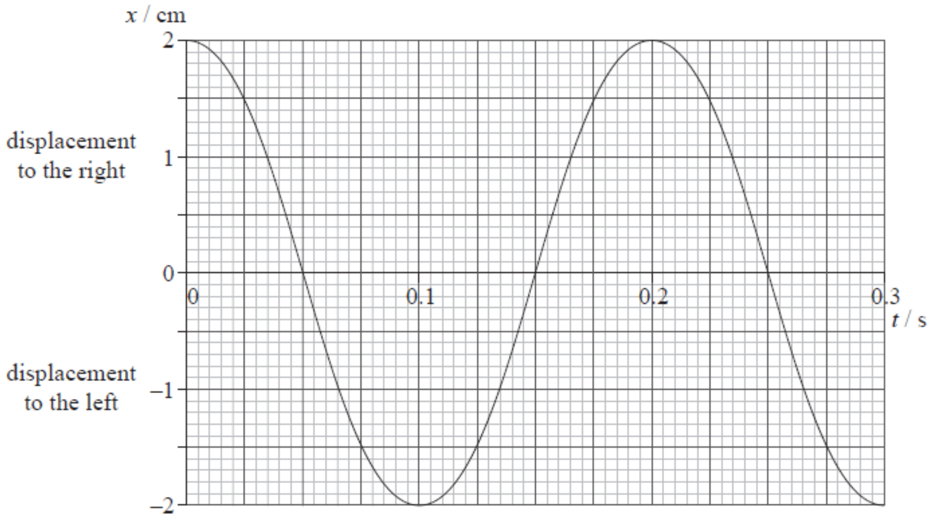
Part 2 Simple harmonic oscillations

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



15a. For particle P, *[6 marks]*

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

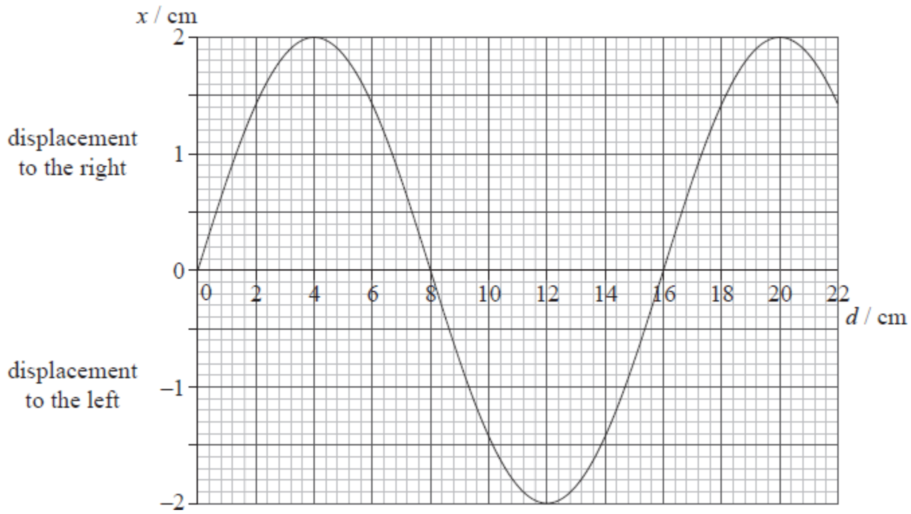
(ii) calculate the magnitude of its maximum acceleration.

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

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

15b. Graph 2 shows the variation with position d of the displacement x of particles in the medium at a particular instant of time. *[4 marks]*

Graph 2



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

(i) the frequency.

(ii) the speed.

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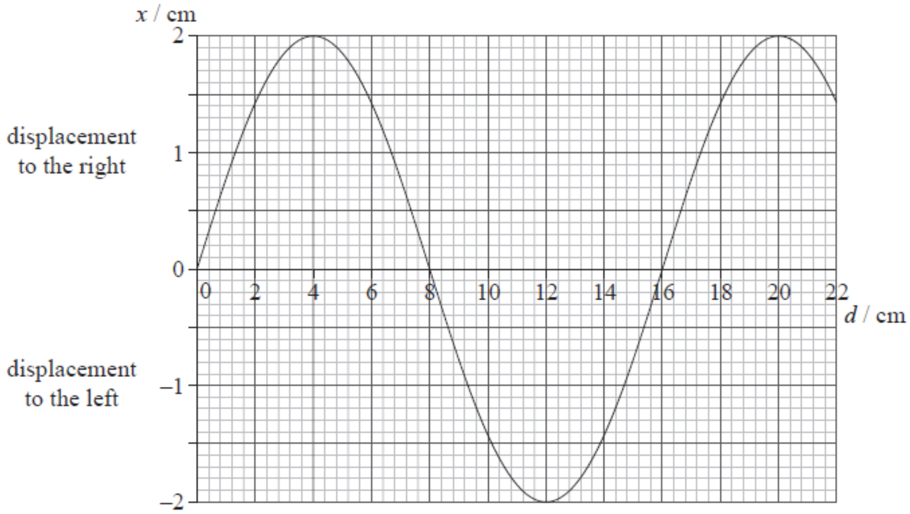
15c. **Graph 2** – reproduced to assist with answering (c)(i). *[4 marks]*



(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 about polarization.

16a. State what is meant by polarized light. *[1 mark]*

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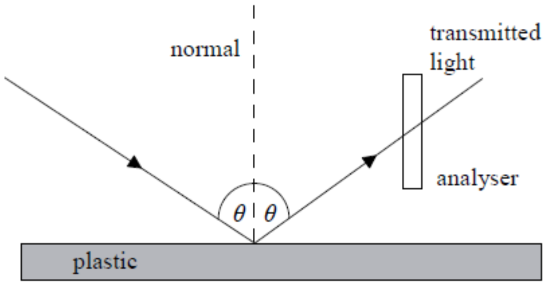
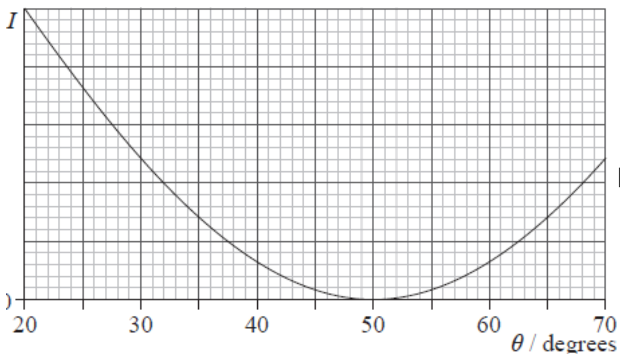
16b. Unpolarized light is incident on the surface of a plastic. The angle of incidence is θ . The reflected light is viewed through an analyser whose transmission axis is vertical. *[2 marks]*



The variation with θ of the intensity I of the transmitted light is shown in the graph.



Explain why there is an angle of incidence, for which the intensity of the transmitted light is zero.

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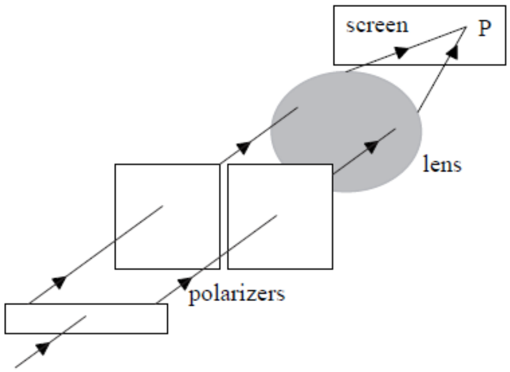
16c. Unpolarized light from a source is split, so that there is a path difference of half a wavelength between the two beams. *[4 marks]*



A lens brings the light to focus at point P on a screen. The lens does not introduce any additional path difference.

State and explain whether any light would be observed at P, in the case in which the polarizers have their transmission axes

(i) parallel.

(ii) at right angles to each other.

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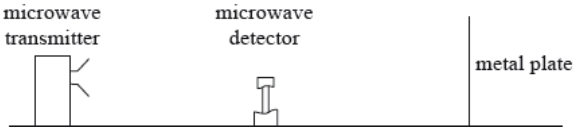
This question is in **two** parts. **Part 1** is about a lightning discharge. **Part 2** is about microwave radiation.

Part 2 Microwave radiation

A microwave transmitter emits radiation of a single wavelength towards a metal plate along a line normal to the plate. The radiation is reflected back towards the transmitter.



A microwave detector is moved along a line normal to the microwave transmitter and the metal plate. The detector records a sequence of equally spaced maxima and minima of intensity.

17a. Explain how these maxima and minima are formed. *[4 marks]*

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The microwave detector is moved through 130 mm from one point of minimum intensity to another point of minimum intensity. On the way it passes through nine points of maximum intensity. Calculate the

17b. (i) wavelength of the microwaves. *[4 marks]*

(ii) frequency of the microwaves.

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17c. Describe and explain how it could be demonstrated that the microwaves are polarized. *[3 marks]*

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This question is in **two** parts. **Part 1** is about solar radiation and the greenhouse effect. **Part 2** is about a mass on a spring.

Part 1 Solar radiation and the greenhouse effect

The following data are available.

Quantity	Symbol	Value
Radius of Sun	R	7.0×10^{8} m
Surface temperature of Sun	T	5.8×10^{3} K
Distance from Sun to Earth	d	1.5×10^{11} m
Stefan-Boltzmann constant	σ	$5.7 \times 10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$

18a. State the Stefan-Boltzmann law for a black body. *[2 marks]*

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18b. Deduce that the solar power incident per unit area at distance *d* from the Sun is given by *[2 marks]*

$$\frac{\sigma R^2 T^4}{d^2}$$

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18c. Calculate, using the data given, the solar power incident per unit area at distance *d* from the Sun. *[2 marks]*

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18d. State **two** reasons why the solar power incident per unit area at a point on the surface of the Earth is likely to be different from your answer in (c). *[2 marks]*

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18e. The average power absorbed per unit area at the Earth's surface is 240Wm $^{-2}$. By treating the Earth's surface as a black body, show that the average surface temperature of the Earth is approximately 250K. *[2 marks]*

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18f. Explain why the actual surface temperature of the Earth is greater than the value in (e). *[3 marks]*

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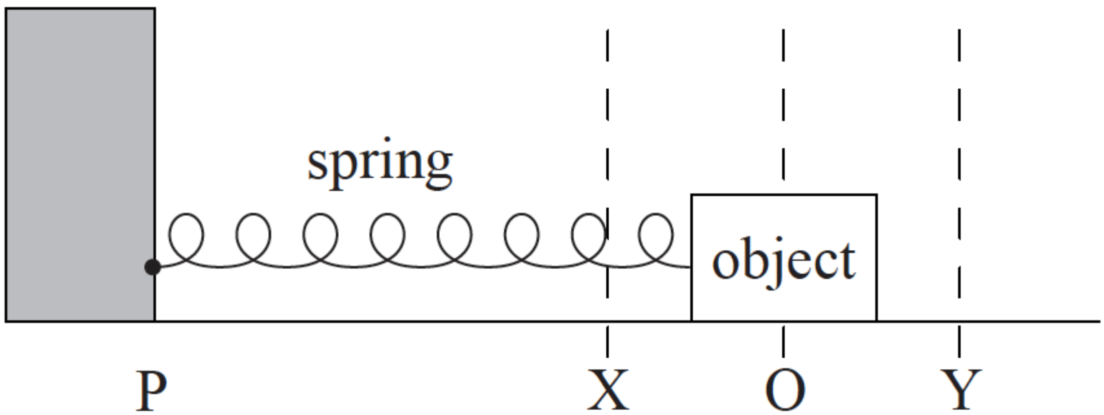
Part 2 A mass on a spring

An object is placed on a frictionless surface and attached to a light horizontal spring.



The other end of the spring is attached to a stationary point P. Air resistance is negligible. The equilibrium position is at O. The object is moved to position Y and released.

18g. Outline the conditions necessary for the object to execute simple harmonic motion. *[2 marks]*

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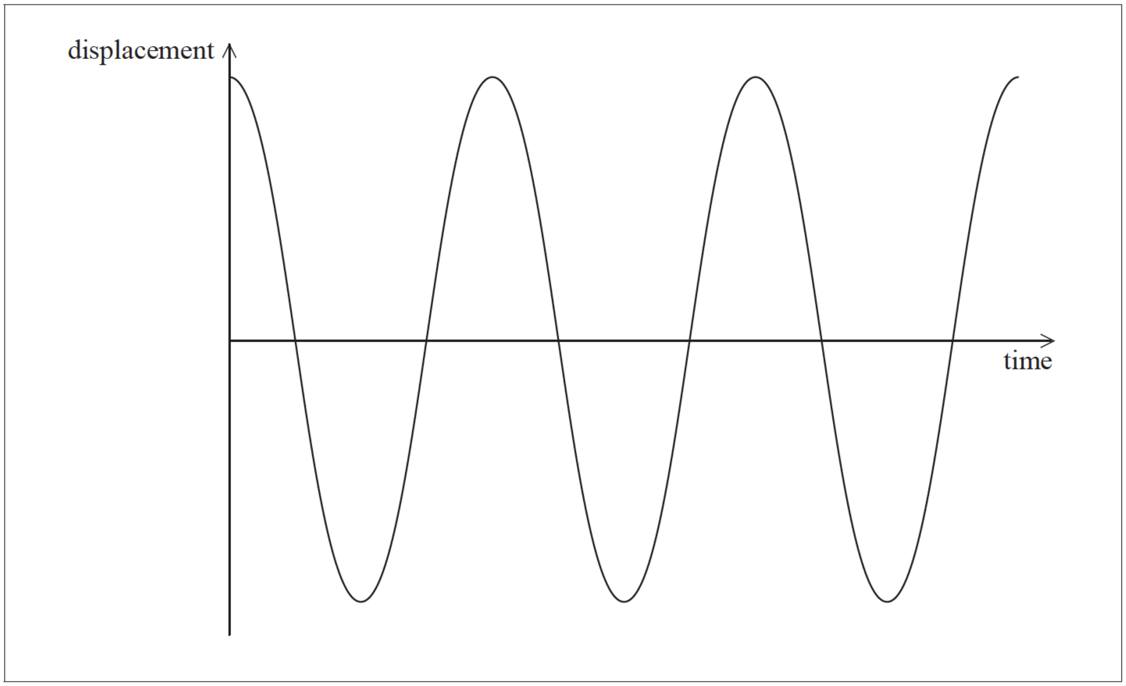
18h. The sketch graph below shows how the displacement of the object from point O varies with time over three time periods. *[4 marks]*



(i) Label with the letter A a point at which the magnitude of the acceleration of the object is a maximum.

(ii) Label with the letter V a point at which the speed of the object is a maximum.

(iii) Sketch on the same axes a graph of how the displacement varies with time if a **small** frictional force acts on the object.

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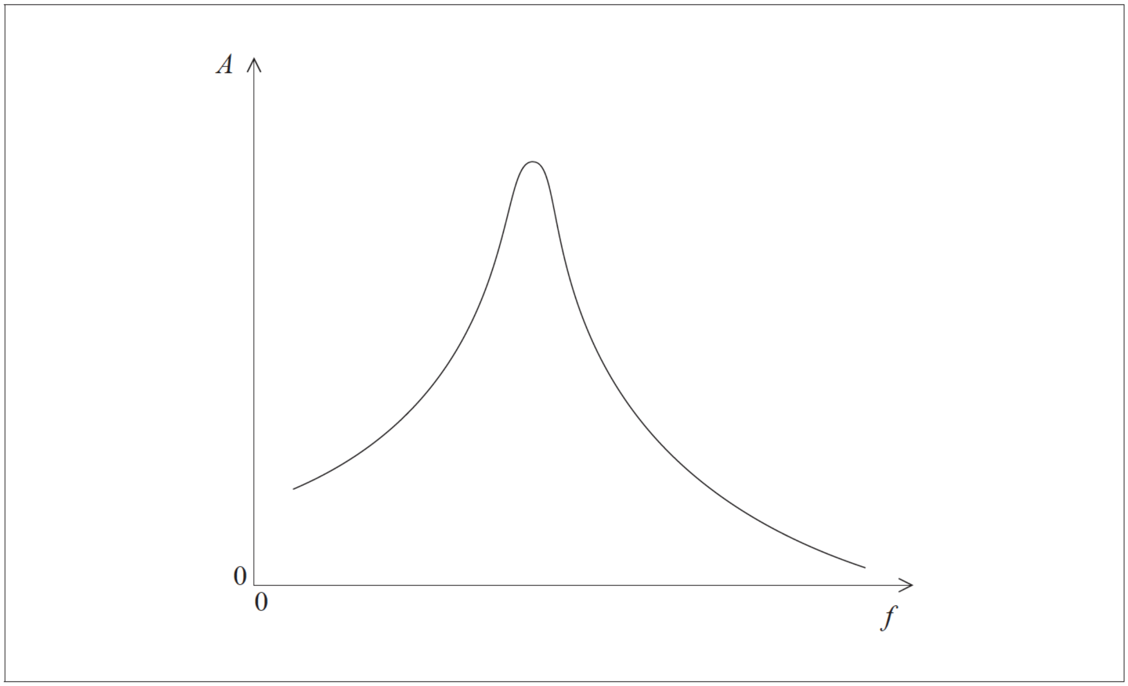
18i. Point P now begins to move from side to side with a small amplitude and at a variable driving frequency *f*. The frictional force is still small. *[4 marks]*

At each value of *f*, the object eventually reaches a constant amplitude *A*.

The graph shows the variation with *f* of *A*.



(i) With reference to resonance and resonant frequency, comment on the shape of the graph.

(ii) On the same axes, draw a graph to show the variation with *f* of *A* when the frictional force acting on the object is increased.

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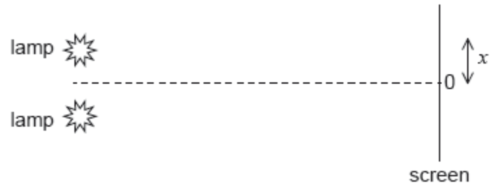
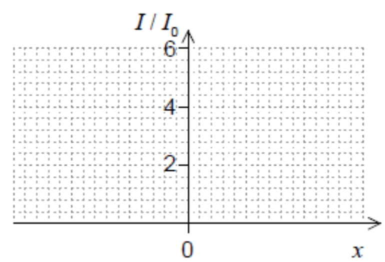
19a. Monochromatic light from two identical lamps arrives on a screen. *[1 mark]*

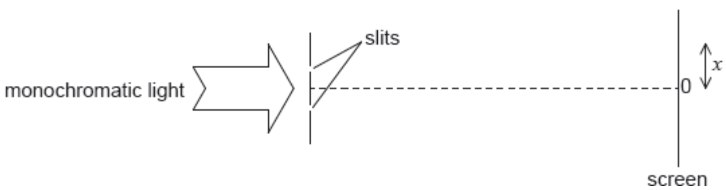


The intensity of light on the screen from each lamp separately is I_0.

On the axes, sketch a graph to show the variation with distance x on the screen of the intensity I of light on the screen.



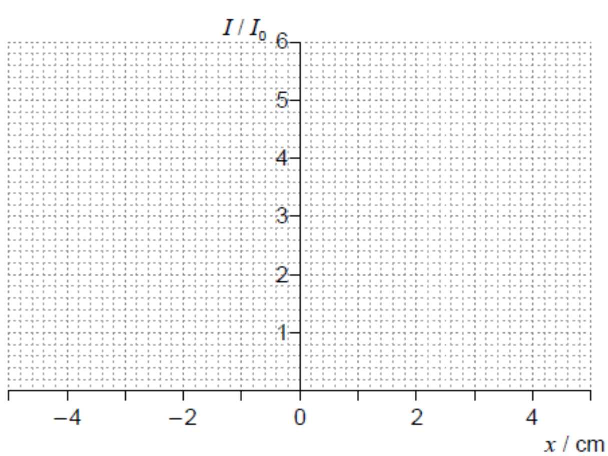
19b. Monochromatic light from a single source is incident on two thin, parallel slits. *[3 marks]*



The following data are available.

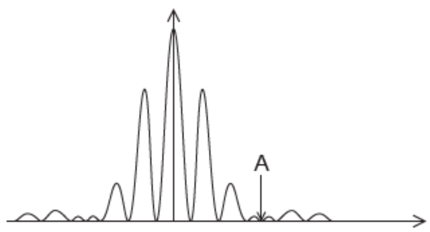
Slit separation	$= 0.12$ mm
Wavelength	$= 680$ nm
Distance to screen	$= 3.5$ m

The intensity I of light at the screen from each slit separately is I_0. Sketch, on the axes, a graph to show the variation with distance x on the screen of the intensity of light on the screen for this arrangement.



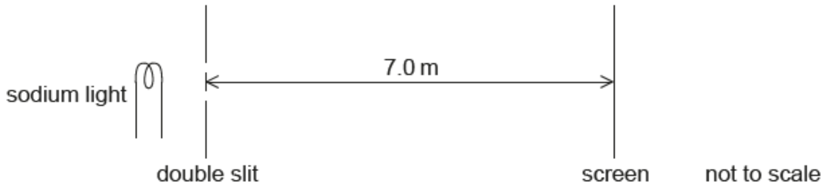
19c. The slit separation is increased. Outline **one** change observed on the screen. *[1 mark]*

Yellow light from a sodium lamp of wavelength 590 nm is incident at normal incidence on a double slit. The resulting interference pattern is observed on a screen. The intensity of the pattern on the screen is shown.



20a. Explain why zero intensity is observed at position A. *[2 marks]*

20b. The distance from the centre of the pattern to A is 4.1 x 10^{-2} m. The distance from the screen to the slits is 7.0 m. *[2 marks]*



Calculate the width of each slit.

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20c. Calculate the separation of the two slits. *[2 marks]*

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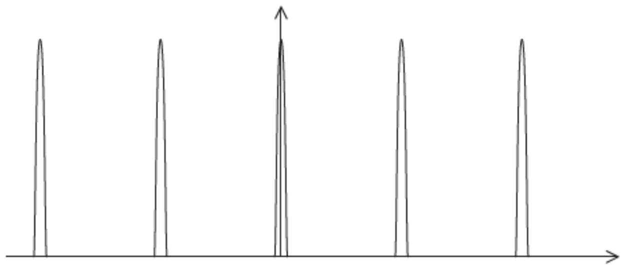
The double slit is replaced by a diffraction grating that has 600 lines per millimetre. The resulting pattern on the screen is shown.



20d. State and explain the differences between the pattern on the screen due to the grating and the pattern due to the double slit. *[3 marks]*

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20e. The yellow light is made from two very similar wavelengths that produce two lines in the spectrum of sodium. The wavelengths are 588.995 nm and 589.592 nm. These two lines can just be resolved in the second-order spectrum of this diffraction grating. Determine the beam width of the light incident on the diffraction grating. *[3 marks]*

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21a. Outline the conditions necessary for simple harmonic motion (SHM) to occur. *[2 marks]*

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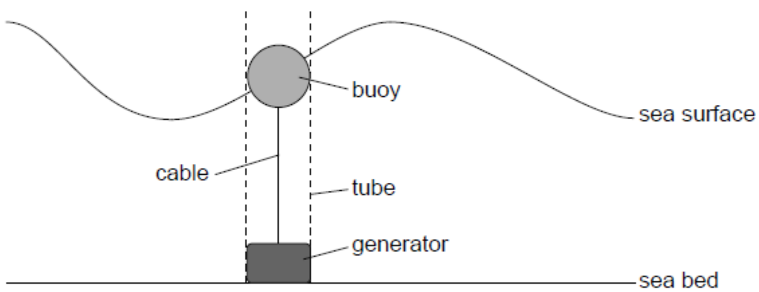
A buoy, floating in a vertical tube, generates energy from the movement of water waves on the surface of the sea. When the buoy moves up, a cable turns a generator on the sea bed producing power. When the buoy moves down, the cable is wound in by a mechanism in the generator and no power is produced.



The motion of the buoy can be assumed to be simple harmonic.

21b. A wave of amplitude 4.3 m and wavelength 35 m, moves with a speed of 3.4 m s $^{-1}$. Calculate the maximum vertical speed of the buoy. *[3 marks]*

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21c. Sketch a graph to show the variation with time of the generator output power. Label the time axis with a suitable scale. *[2 marks]*

Water can be used in other ways to generate energy.

21d. Outline, with reference to energy changes, the operation of a pumped storage hydroelectric system. *[2 marks]*

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21e. The water in a particular pumped storage hydroelectric system falls a vertical distance of 270 m to the turbines. Calculate the speed at which water arrives at the turbines. Assume that there is no energy loss in the system. *[2 marks]*

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21f. The hydroelectric system has four 250 MW generators. Determine the maximum time for which the hydroelectric system can maintain full output when a mass of 1.5×10^{10} kg of water passes through the turbines. *[2 marks]*

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21g. Not all the stored energy can be retrieved because of energy losses in the system. Explain **two** such losses. *[2 marks]*

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22a. Police use radar to detect speeding cars. A police officer stands at the side of the road and points a radar device at an approaching car. The device emits microwaves which reflect off the car and return to the device. A change in frequency between the emitted and received microwaves is measured at the radar device. *[6 marks]*

The frequency change Δf is given by

$$\Delta f = \frac{2fv}{c}$$

where f is the transmitter frequency, v is the speed of the car and c is the wave speed.

The following data are available.

Transmitter frequency f = 40 GHz Δf = 9.5 kHz Maximum speed allowed = 28 m s^{-1}

(i) Explain the reason for the frequency change.

(ii) Suggest why there is a factor of 2 in the frequency-change equation.

(iii) Determine whether the speed of the car is below the maximum speed allowed.

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22b. Airports use radar to track the position of aircraft. The waves are reflected from the aircraft and detected by a large circular receiver. The receiver must be able to resolve the radar images of two aircraft flying close to each other. *[2 marks]*

The following data are available.

Diameter of circular radar receiver = 9.3 m Wavelength of radar = 2.5 cm Distance of two aircraft from the airport = 31 km

Calculate the minimum distance between the two aircraft when their images can just be resolved.

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