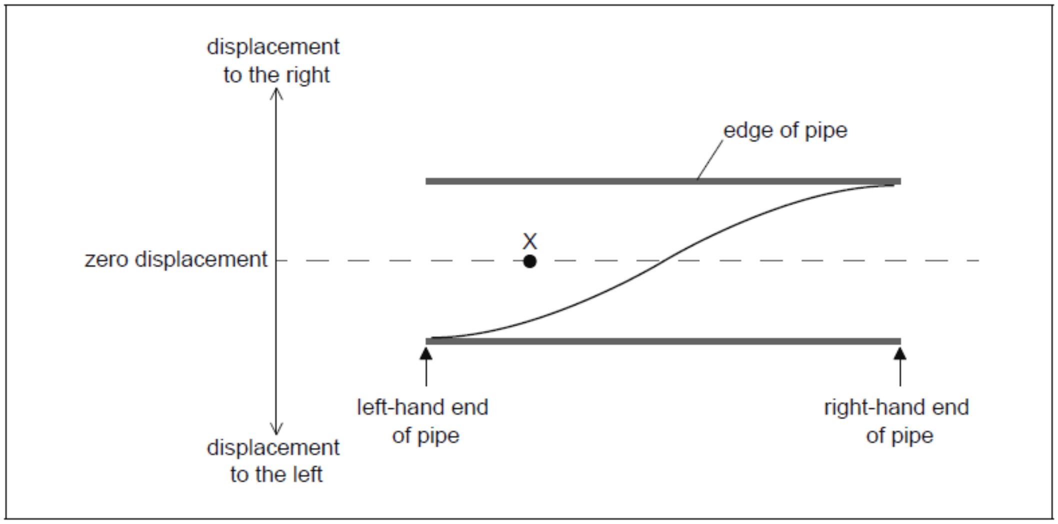
R2019_49 *[265 marks]*

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]*

Markscheme

«air molecule» moves to the right and then back to the left ✔

returns to X/original position ✔

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.

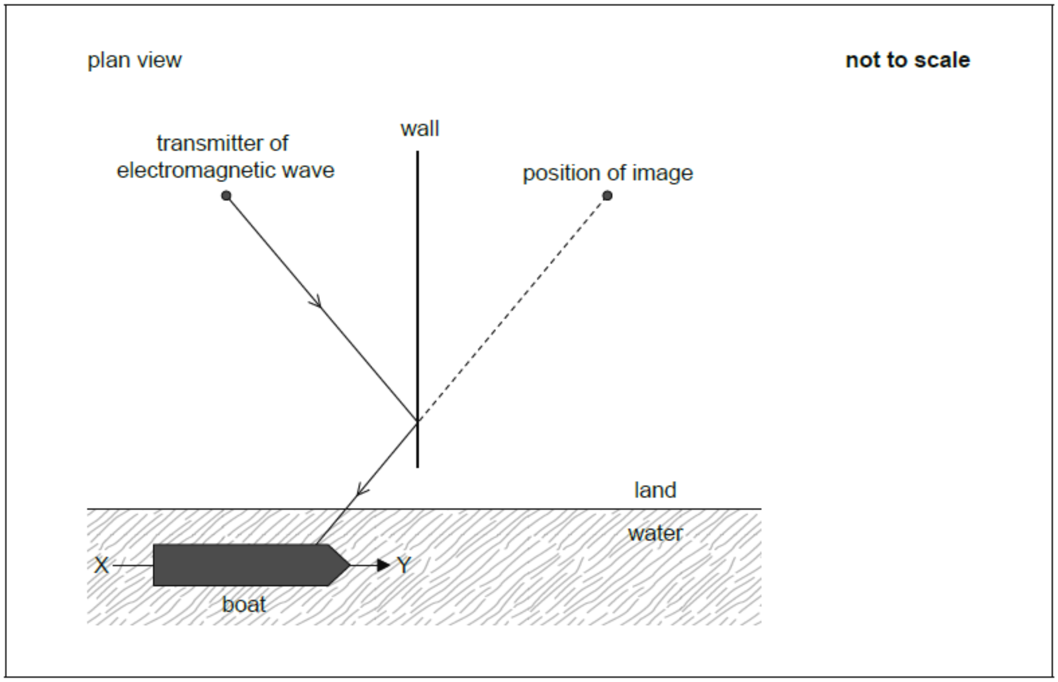
Markscheme

wavelength = 2 × 1.4 = «2.8 m» ✔

c = «$f\lambda$ =» 120 × 2.8 «= 340 m s^{-1}» ✔

K = «ρc^2 = 1.3 × 340^2 =» 1.5 × 10^5 ✔

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]*

Markscheme

construction showing formation of image ✔

Another straight line/ray from image through the wall with line/ray from intersection at wall back to transmitter. Reflected ray must intersect boat.

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]*

Markscheme

interference pattern is observed

OR

interference/superposition mentioned ✔

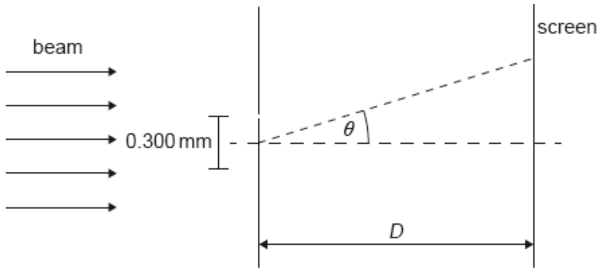
maximum when two waves occur in phase/path difference is $n\lambda$

OR

minimum when two waves occur 180° out of phase/path difference is $(n + \frac{1}{2})\lambda$ ✔

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]*

Markscheme

superposition of light from each slit / interference of light from both slits

with path/phase difference of any half-odd multiple of wavelength/any odd multiple of π (in words or symbols)

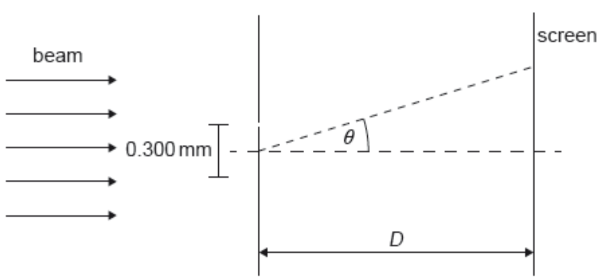
producing destructive interference

Ignore any reference to crests and troughs.

[3 marks]

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]*

Markscheme

light waves (from slits) must have constant phase difference / no phase difference / be in phase

OWTTE

[1 mark]

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]*

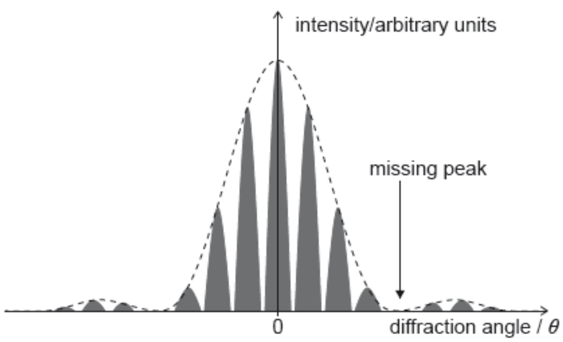
Markscheme

evidence of solving for D «$D = \frac{sd}{\lambda}$» ✔

«$\frac{4.50\times10^{-3}\times0.300\times10^{-3}}{633.0\times10^{-9}} \times 2$» = 4.27 «m» ✔

*Award **[1]** max for 2.13 m.*

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]*

Markscheme

sin $\theta = \frac{4 \times 633.0 \times 10^{-9}}{0.300 \times 10^{-3}}$

sin θ = 0.0084401…

final answer to three sig figs (*eg* 0.00844 or 8.44 × 10^{-3})

Allow ECF from (a)(iii).

*Award **[1]** for 0.121 rad (can award MP3 in addition for proper sig fig)*

Accept calculation in degrees leading to 0.481 degrees.

Award MP3 for any answer expressed to 3sf.

[3 marks]

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

Markscheme

use of diffraction formula «$b = \frac{\lambda}{\theta}$»

OR

$\frac{633.0 \times 10^{-9}}{0.00844}$

«=» 7.5«00» × 10^{-2} «mm»

Allow ECF from (b)(i).

[2 marks]

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.

Markscheme

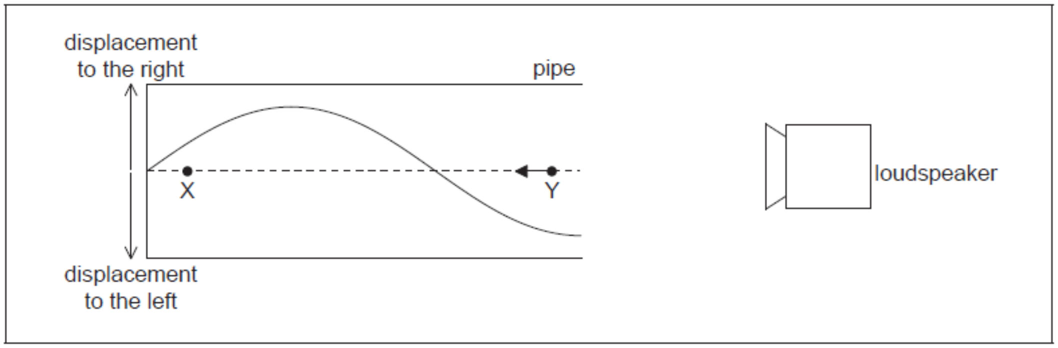
wavelength increases (so frequency decreases) / light is redshifted

galaxy is moving away from Earth

Allow ECF for MP2 (ie wavelength decreases so moving towards).

[2 marks]

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]*

Markscheme

the incident wave «from the speaker» and the reflected wave «from the closed end» superpose/combine/interfere

Allow superimpose/add up

Do not allow meet/interact

[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]*

Markscheme

Horizontal arrow from X to the right

MP2 is dependent on MP1

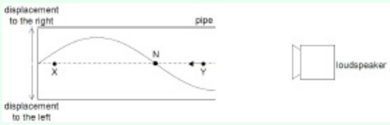
Ignore length of arrow

[1 mark]

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

Markscheme

P at a node



[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]*

Markscheme

wavelength is λ = «$\frac{4\times0.30}{3}$ =» 0.40 «m»

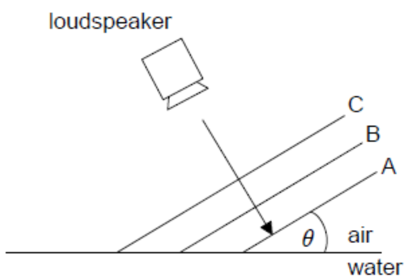
f = «$\frac{340}{0.40}$» 850 «Hz»

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

Allow ECF from MP1

[2 marks]

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.

Markscheme

$$\frac{\sin\theta_c}{340} = \frac{1}{1500}$$

θ_c = 13«°»

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

*Award **[2]** for a bald answer of 13.1*

Answer must be to 2/3 significant figures to award MP2

Allow 0.23 radians

[2 marks]

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

Markscheme

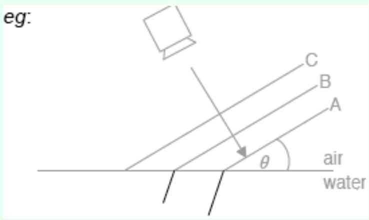
correct orientation

greater separation

Do not penalize the lengths of A and B in the water

Do not penalize a wavefront for C if it is consistent with A and B

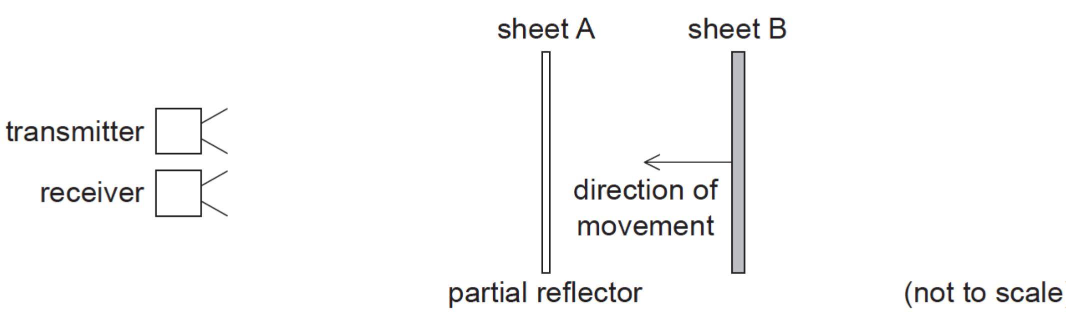
MP1 must be awarded for MP2 to be awarded



[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.

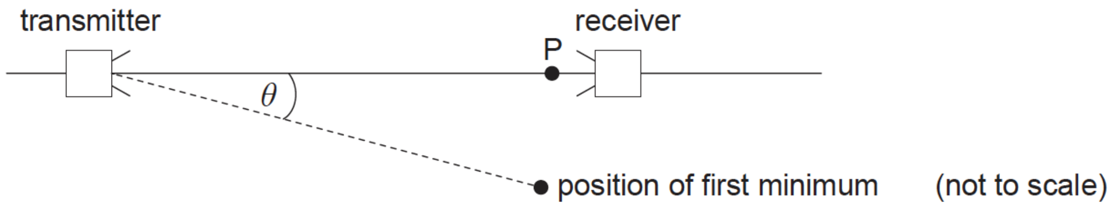
4a. Outline why a minimum in the intensity occurs for certain positions of sheet B. *[3 marks]*

Markscheme

mention of interference;
interference is between reflected waves from both reflectors;
minimum caused (by destructive interference) when crest meets trough/when path difference is $\frac{\lambda}{2}$ / (completely) out of phase / phase difference of π/180º / *OWTTE*;
minimum occurs when twice the distance between plates is $\left(n+\frac{1}{2}\right)\lambda$;

Ignore references to standing waves.

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.

Markscheme

(i) spreading out of a wave; *(do not allow "bending" even if context is obstacle)*
when it meets an aperture/gap/slit/obstacle;
Allow credit for answers appearing on clear labelled diagram for both marks.

(ii) $\left(\theta = \frac{32}{60} =\right) 0.533\,(\text{rad})$ ***or*** 30.6(º);
*Award **[0]** for calculation that uses 1.22 (0.65 rad).*
*Award **[0]** for 0.533º or 30.6 rad.*
At least one centre is using the abbreviation c for rad. Please allow this.

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

Markscheme

sound waves (in air) are longitudinal;
longitudinal waves cannot be polarized / only transverse waves can be polarized;

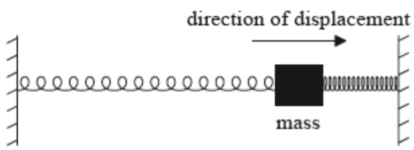
*Award **[0]** for any suggestion that ultrasound is an electromagnetic wave.*

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

Part 1 Oscillation of a mass

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

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



(not to scale)

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

Markscheme

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

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

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

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

Markscheme

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

and is proportional to displacement;

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

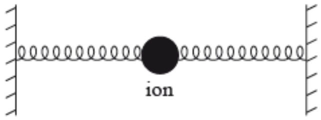
Markscheme

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

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

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

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]*

Markscheme

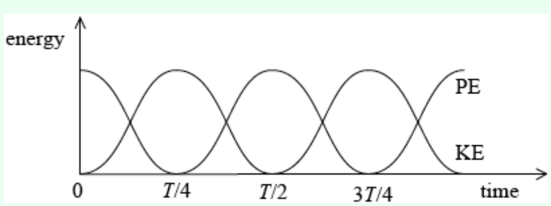
$\omega = 2\pi \times 7 \times 10^{12} (= 4.4 \times 10^{13} Hz)$;

5×10^{-21} J;

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

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]*

Markscheme



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;

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

Markscheme

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

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]*

Markscheme

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

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

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

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

Markscheme

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

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* $6.1 \times 10^{27} \text{ eVs}^{-1}$.

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

5i. moderator. *[3 marks]*

Markscheme

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);

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

Markscheme

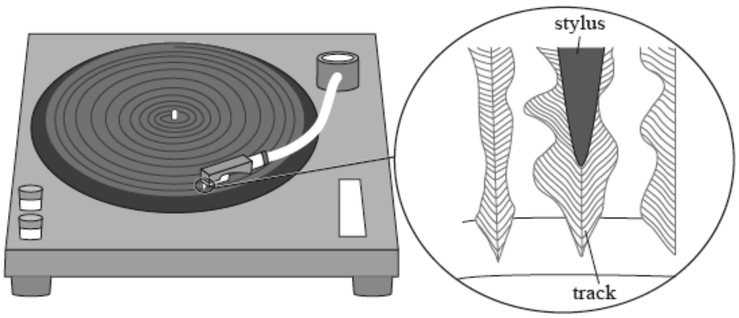
have high neutron capture cross-section/good at absorbing neutrons;

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

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

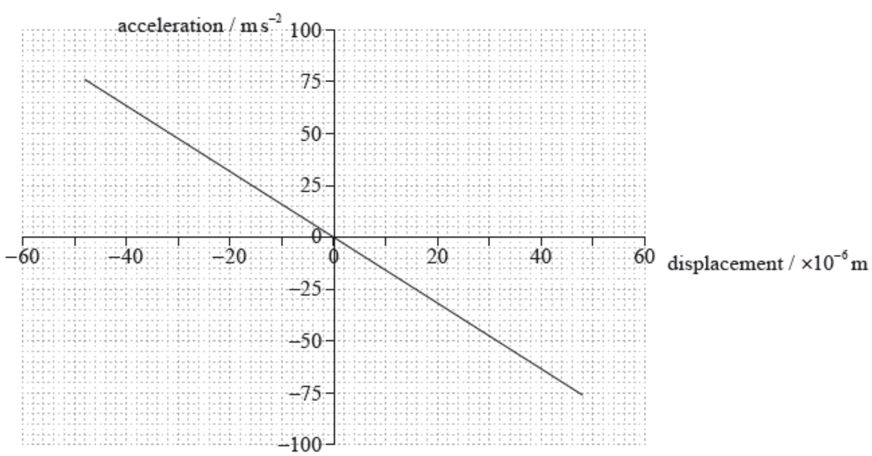
Part 1 Simple harmonic motion (SHM) and sound

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]*

Markscheme

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;

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.

Markscheme

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

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

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

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

or

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

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

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

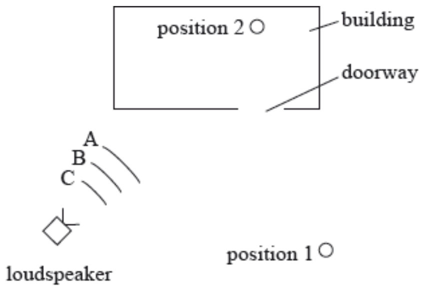
$f = 198\ (\text{Hz})$;

Allow substitution for fourth mark.

(ii) at origin;

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.

Markscheme

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

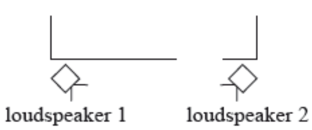
(ii) 1.65 (m); *(allow ECF from (b)) (accept rounding to 1.6 or 1.7)*

(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.

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.

Markscheme

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”);

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]*

Markscheme

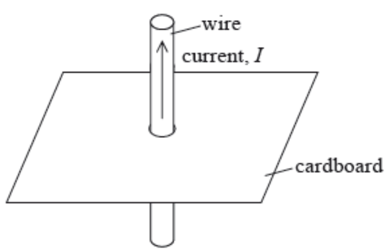
conductor has free electrons/charges that are free to move within/through it / insulator does not have free electrons/charges that are free to move within/ through it;

electrons act as charge carriers;

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.

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.

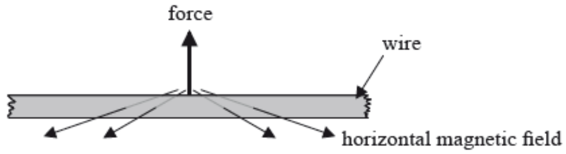
Markscheme

anti-clockwise arrows;

at least three circles centred on wire;

increasing in separation from centre;

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

Markscheme

(i) arrow to the right;

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

$I = \left(\frac{mg}{lB} =\right) \frac{1.41\times10^{-4}\times9.8}{40\times10^{-6}}$;

35 (A);

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

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

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.

Markscheme

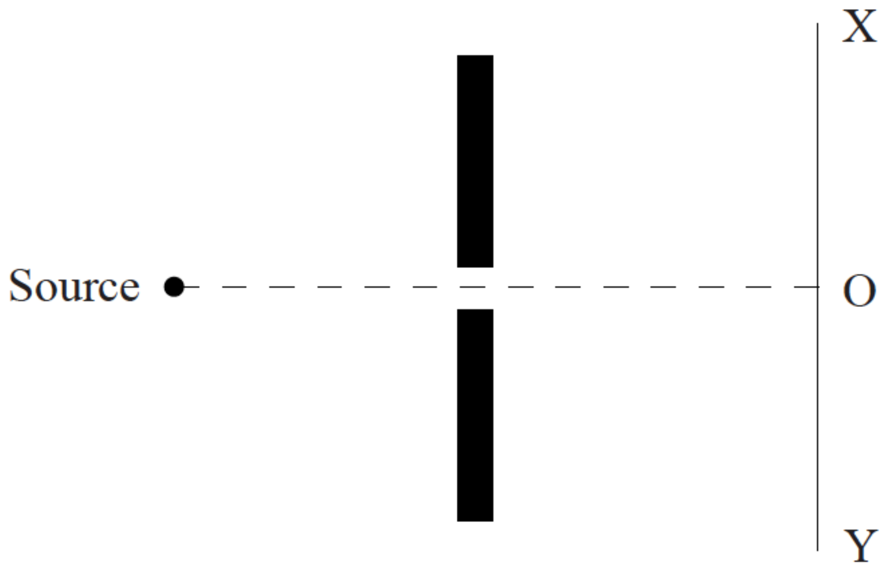
(i) diagram showing (circular) wavefronts around source, so that wavefronts are closer together on side of observer;
speed of sound waves for observer is the same (as for stationary case) but observed wavelength is smaller;

since $f' = \frac{v}{\lambda'}$, (observed frequency is larger);

(ii) $f'\left(= f\left[\frac{v}{v-u_s}\right]\right) = 275\left[\frac{330}{330-20}\right]$;
=293(Hz);

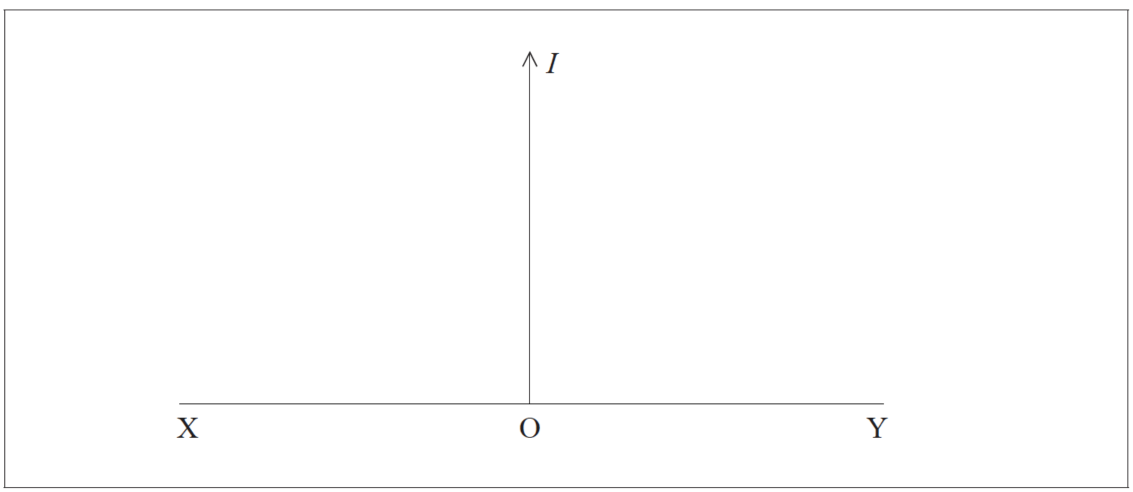
*Award **[0]** for use of moving observer formula.*
*Award **[1]** for use of v+u_s to give 259 (Hz).*
*Award **[2]** for a bald correct answer.*

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.

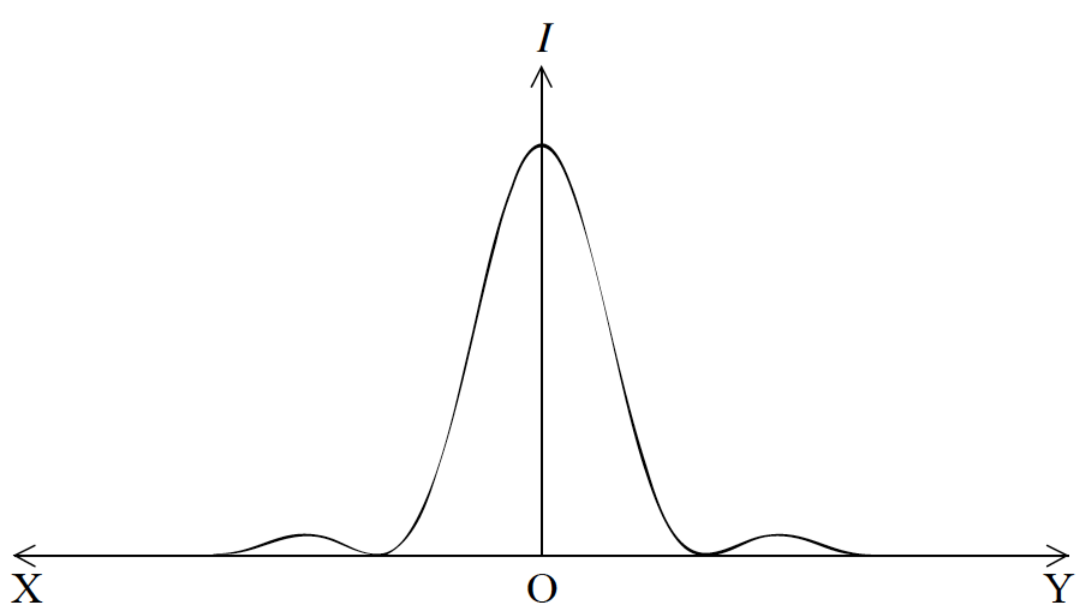


(ii) State the effect on the intensity pattern of increasing the wavelength of the sound.

Markscheme

(i) central symmetrical maximum;
at least one secondary maximum on each side, no more than one third the height of the central maximum; { *(judge by eye)*

minima drawn to zero, *ie* touching axis;
width of the secondary maximum half the width of the primary maximum; { *(judge by eye)*



(ii) greater distance between maxima/minima / pattern more spread out;

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

(ii) State why sound waves cannot be polarized.

Markscheme

(i) in a polarized wave, the oscillations/vibrations are in one direction/plane only;
in an unpolarized wave, the oscillations/vibrations are in all directions/ planes (perpendicular to the direction of energy transfer);
Must see mention of oscillations or vibrations in first or second marking point.

(ii) sound waves are longitudinal / the oscillations/vibrations are always parallel to direction of energy transfer;

This question is about the superposition of waves.

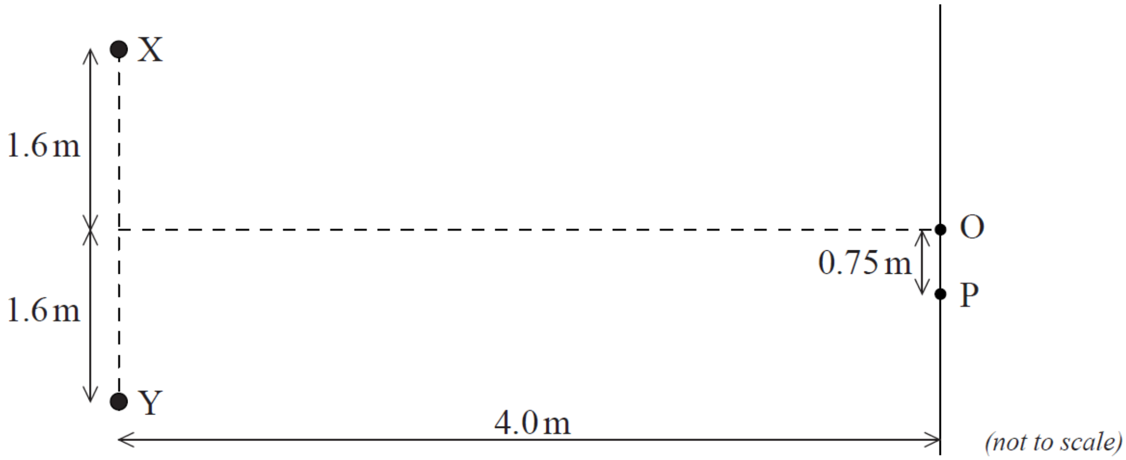
8a. State what is meant by the principle of superposition of waves. *[1 mark]*

Markscheme

(when two similar waves meet) the resultant displacement is the (vector) sum of the individual displacements;

*Allow **[0]** for description in terms of amplitude.*

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.

Markscheme

(i) (constructive interference gives) amplitude 2A; intensity is proportional to square of total amplitude (=4A^2);

(ii) attempted use of Pythagoras to measure path difference;

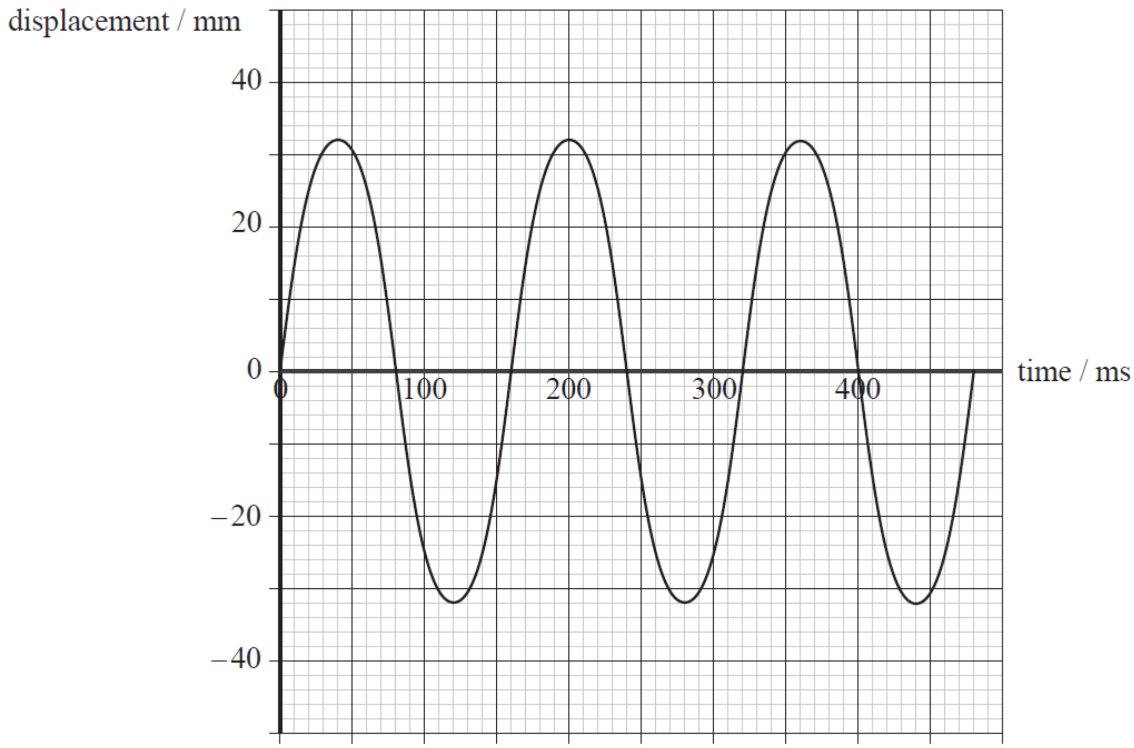
path difference =0.55 (m);

path difference = $\frac{\lambda}{2}$ (so out of phase / destructive interference);

Attempted use of Pythagoras may appear on diagram for (b)(i).

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.

Markscheme

(i) 32 (mm);

(ii) period = 160 (ms);

frequency = 6.2/6.3 (Hz);

Allow ECF for incorrect period.

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

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

Markscheme

(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;

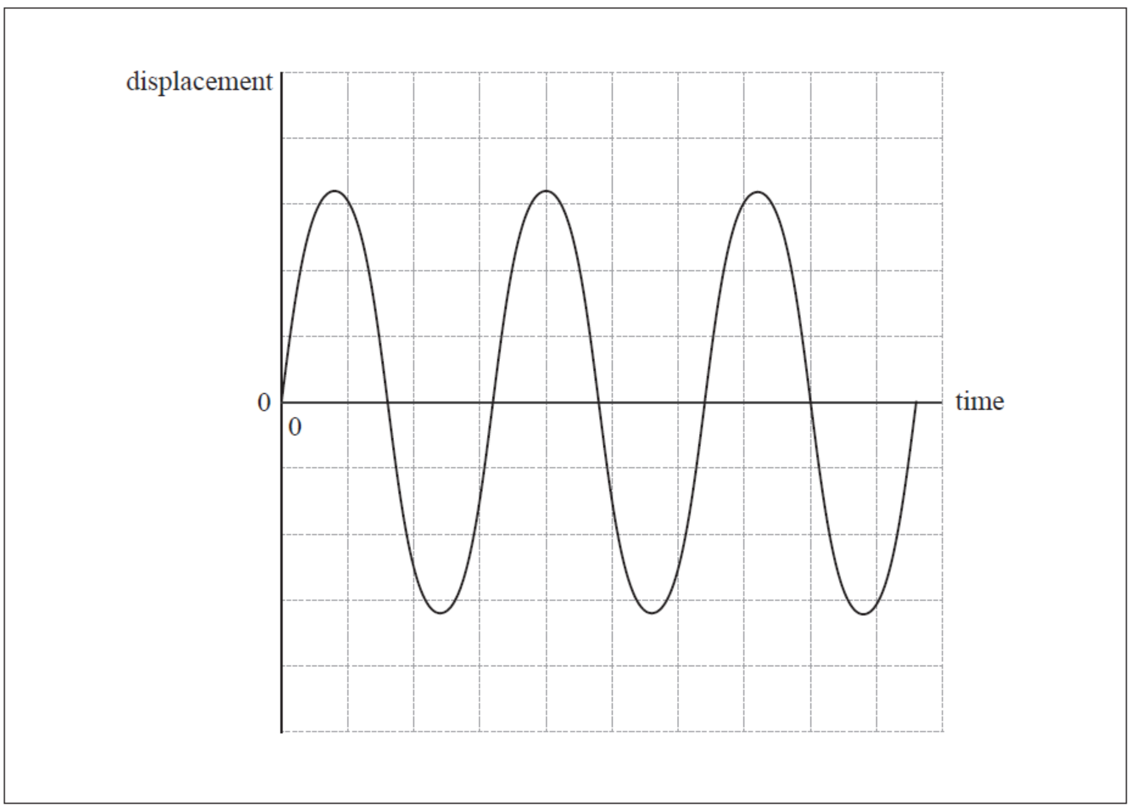
(ii) displacement = 23–26 (mm);

35–40 (ms^{-2});

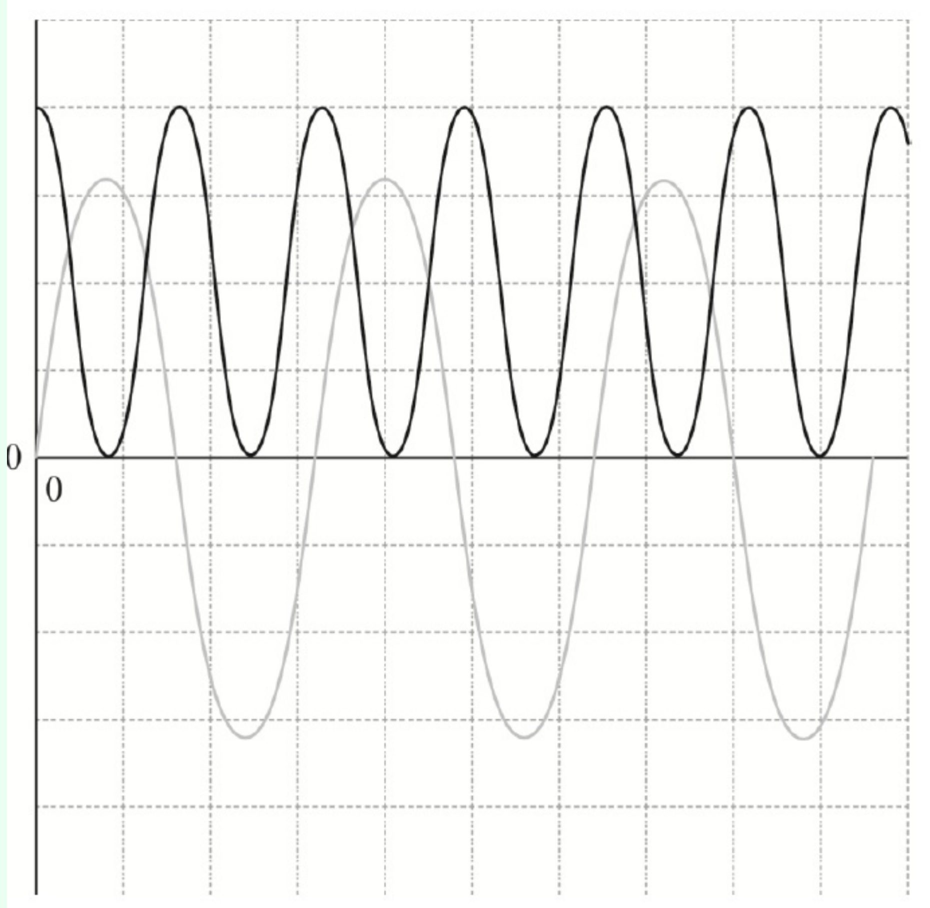
23 mm found by calculating displacement

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.



Markscheme



double frequency;

always positive and constant amplitude;

correct phase *ie* cosine squared;

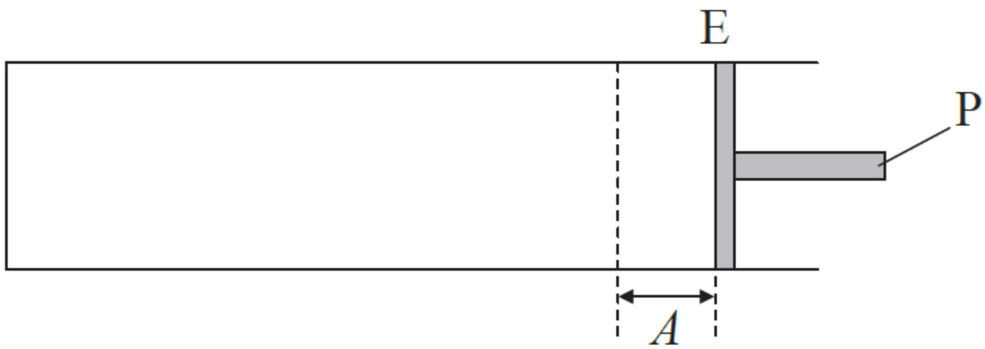
Ignore amplitude value.

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

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]*

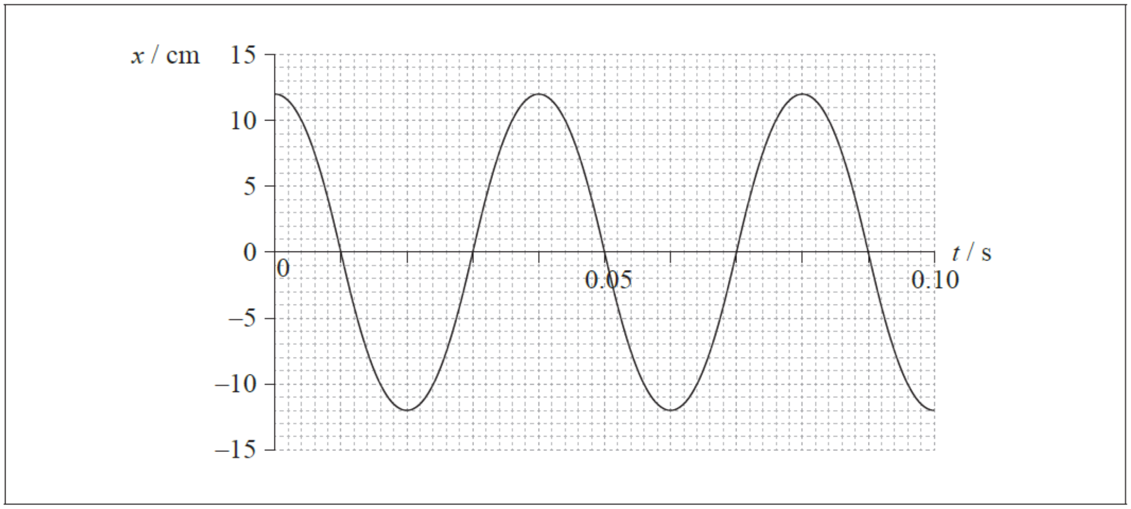


The piston P is displaced a small distance *A* from E and released. As a result, P executes simple harmonic motion (SHM).
Define *simple harmonic motion* as applied to P.

Markscheme

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]***.

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.

Markscheme

(i) 12(cm); (*accept* –12)

(ii) any maximum or minimum of the graph;

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

$\omega = \left(\frac{2\pi}{T} =\right) \frac{2\times3.14}{0.04} = 157\,(\text{rads}^{-1})$

maximum acceleration=$(A\omega^2=)0.12\times157^2=3.0\times10^3(\text{ms}^{-2})$; *(watch for ECF from wrong period)*

(iv) at t=0.052s x=(-)4(±1)cm;

$\text{KE} = \left(\frac{1}{2}m\omega^2\left[A^2 - x^2\right] =\right) 0.5 \times 0.32 \times 157^2\left[0.12^2 - 0.04^2\right] = 50\,(\pm7)\,(\text{J});$

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 ωt to obtain v.
*Award **[2]** for a bald correct answer.*

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.

Markscheme

(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;

(ii) $f = \left(\frac{1}{T} =\right) \frac{1}{0.04} = 25\,(\mathrm{Hz})$;
$\lambda = \left(\frac{v}{f} =\right) \frac{340}{25} = 14\,(\mathrm{m})$;

*Award **[1 max]** if frequency is not clearly stated.*
Allow ECF from calculations in (b)(iii).

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

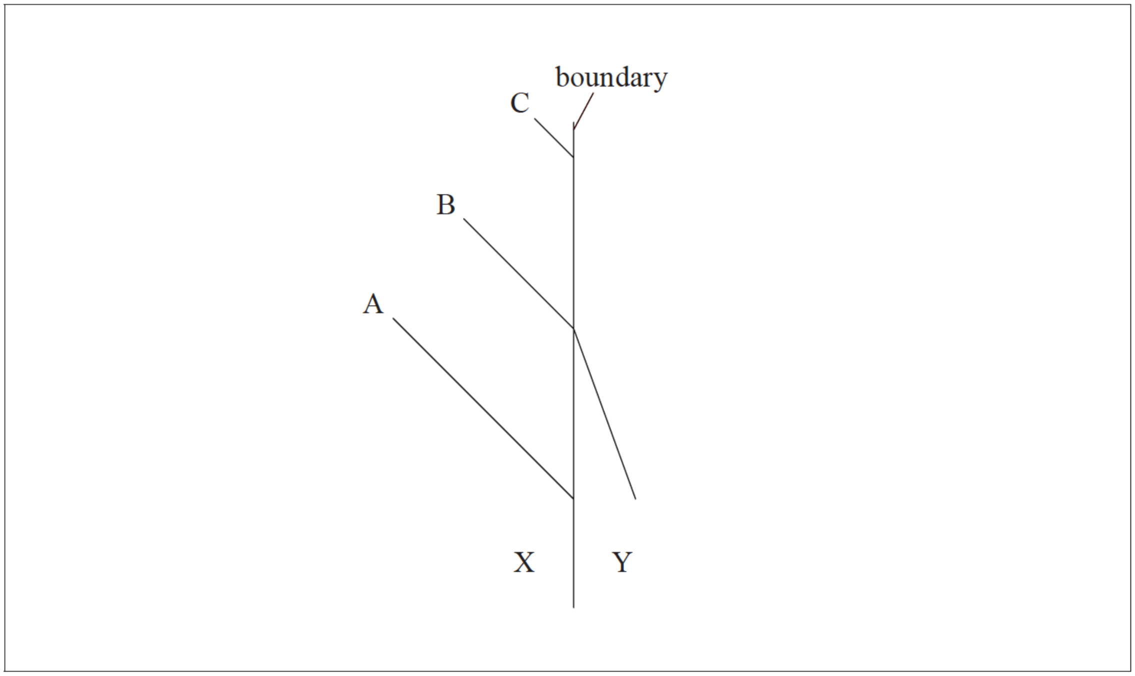
Part 1 Wave motion

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

Markscheme

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;

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.

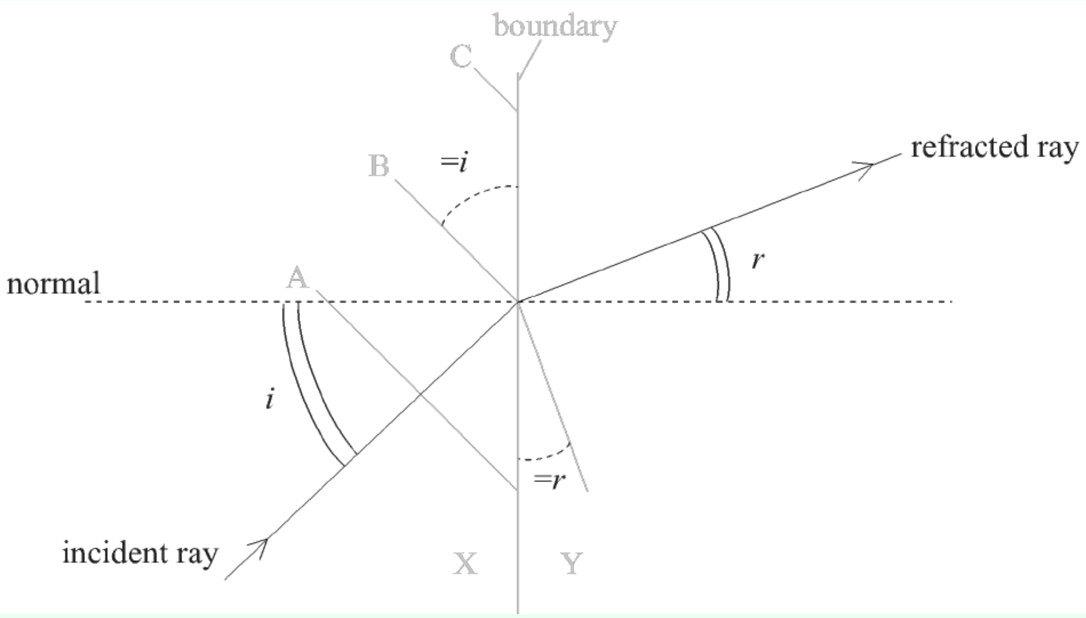
(ii) The refractive index of X is n_X and the refractive index of Y is n_Y. By making appropriate measurements, calculate $\frac{n_X}{n_Y}$.

Markscheme

(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



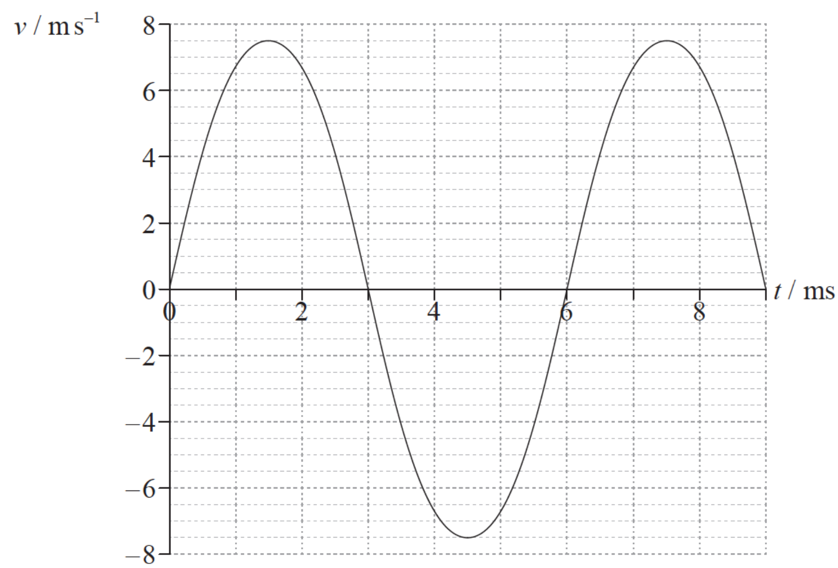
justification that angles needed for calculation are either pair of *i* and *r* as shown and angles measured correctly;
$\frac{n_X}{n_Y} = \frac{\sin r}{\sin i}$;
0.5:1;

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

Markscheme

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;

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.

Markscheme

(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;

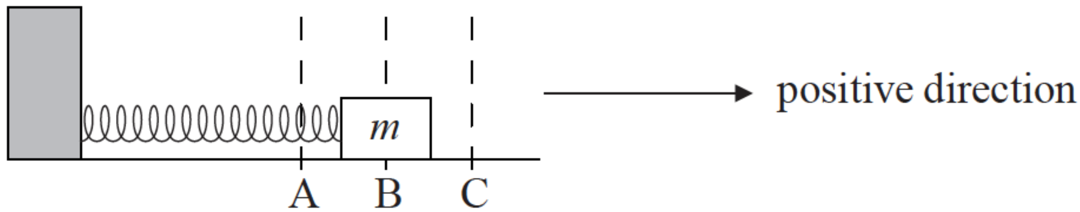
or

$\omega = (2\pi f =) 330\pi$;
$a = \left(\frac{v}{w} =\right) \frac{7.5}{330\pi}$;
7.2 mm;
Allow any valid algebraic method, eg $v = \omega\sqrt{(x_0{}^2 - x^2)}$.

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.



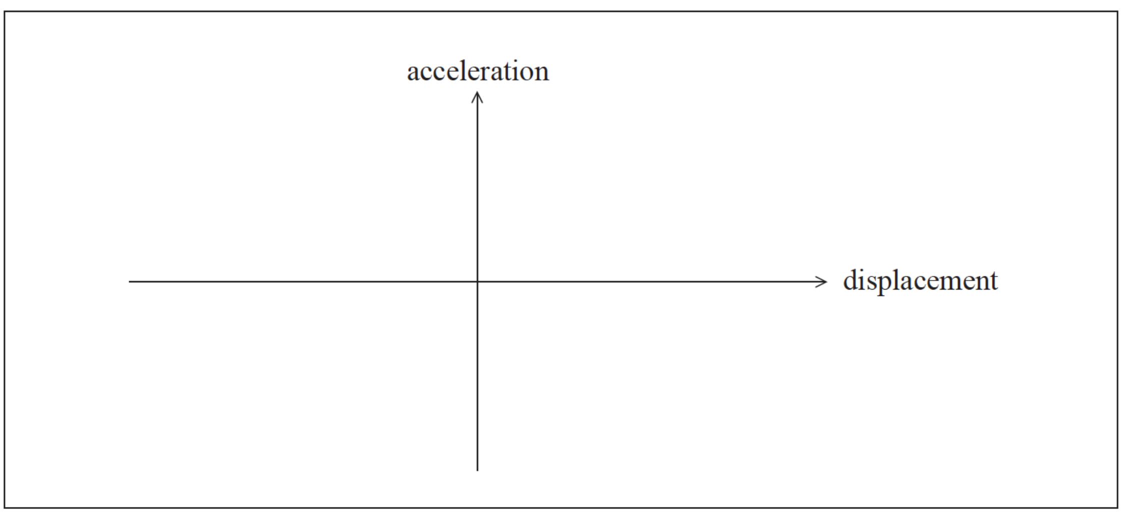
The equilibrium position is at B. The direction B to C is taken to be positive. The object is released from position A and executes simple harmonic motion between positions A and C.

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

Markscheme

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;

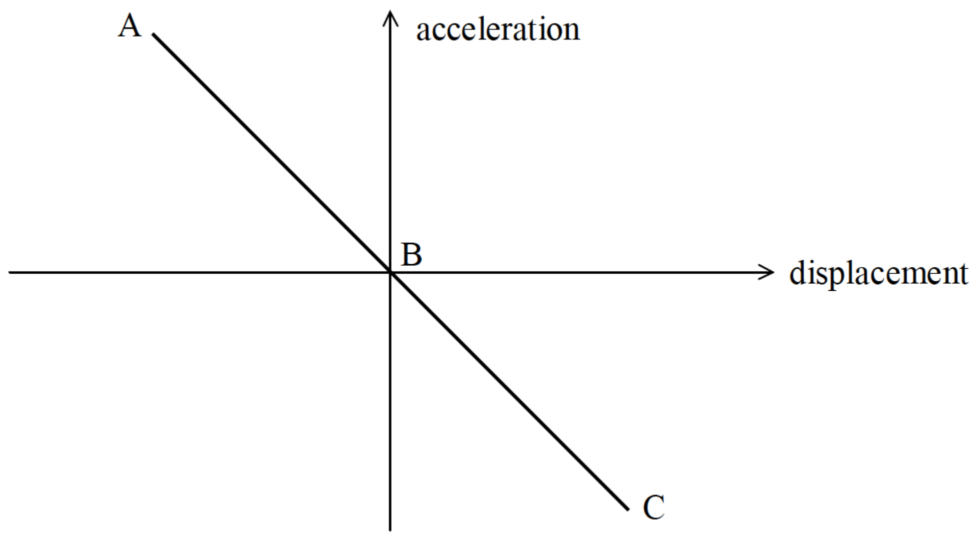
12b. (i) On the axes below, sketch a graph to show how the acceleration of the mass varies with displacement from the equilibrium position B. *[3 marks]*



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

Markscheme

(i) straight line through the origin;
with negative gradient;



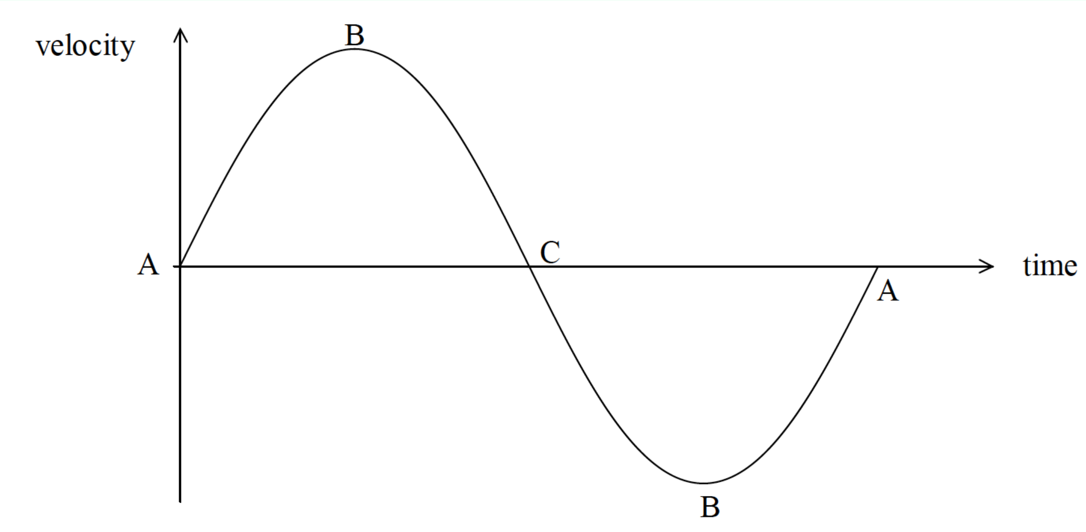
(ii) all three labels correct;

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.

Markscheme

(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.

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]*

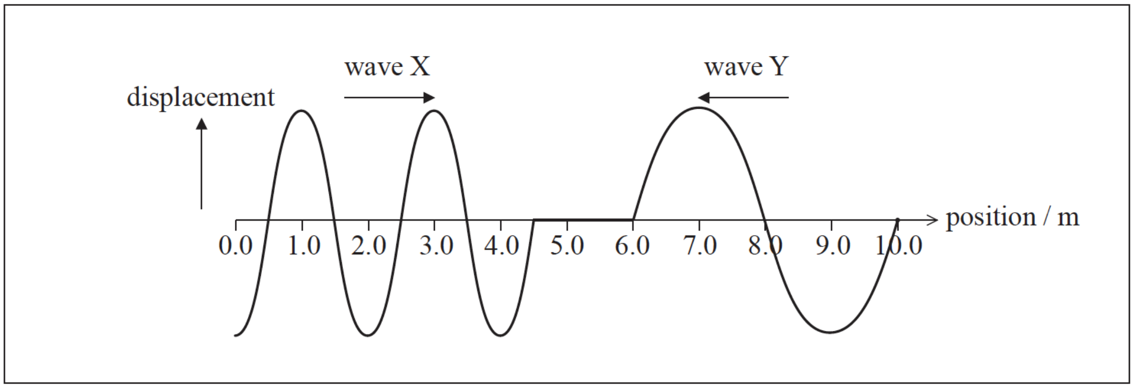
Markscheme

$\omega = \frac{2\pi}{T} = \frac{2\pi}{0.20} = 31.42 \approx 31\text{rads}^{-1}$;
$v_{\text{max}} = \omega x_0 = 31.42 \times 0.040$;
$v_{\text{max}} = 1.257 \approx 1.3\text{ms}^{-1}$;

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.



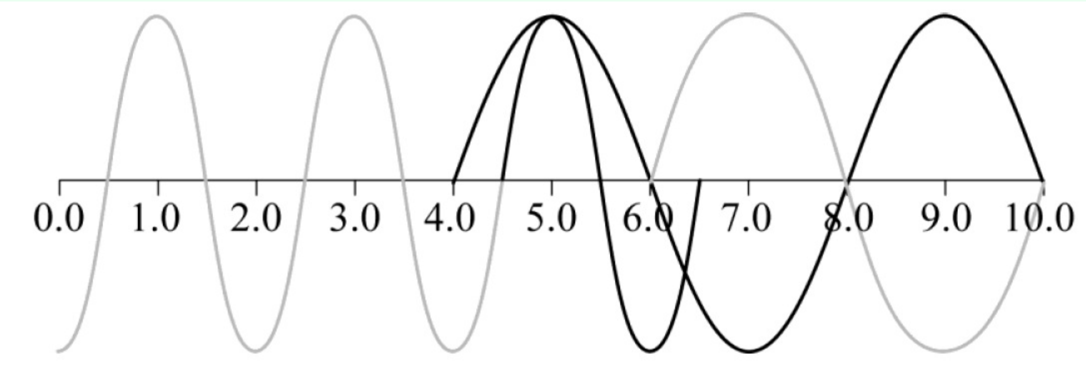
(i) State the principle of superposition as applied to waves.

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

Markscheme

(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;

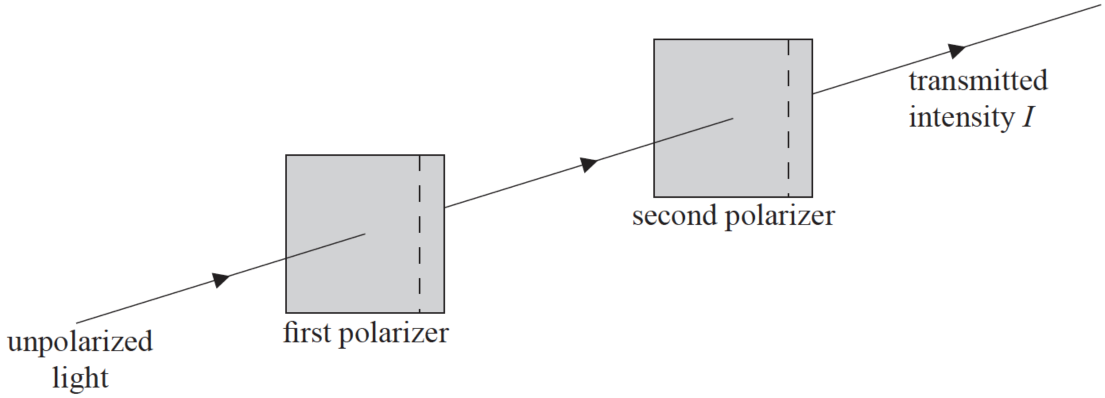
(ii) 0.20 s later, wave X will have crests at 5.0, 3.0 and 1.0 m, wave Y will have crests at 5.0 and 9.0 m / each wave will have moved forward by 2.0 m in 0.20 s / wave profiles for 0.20 s later drawn on diagram;



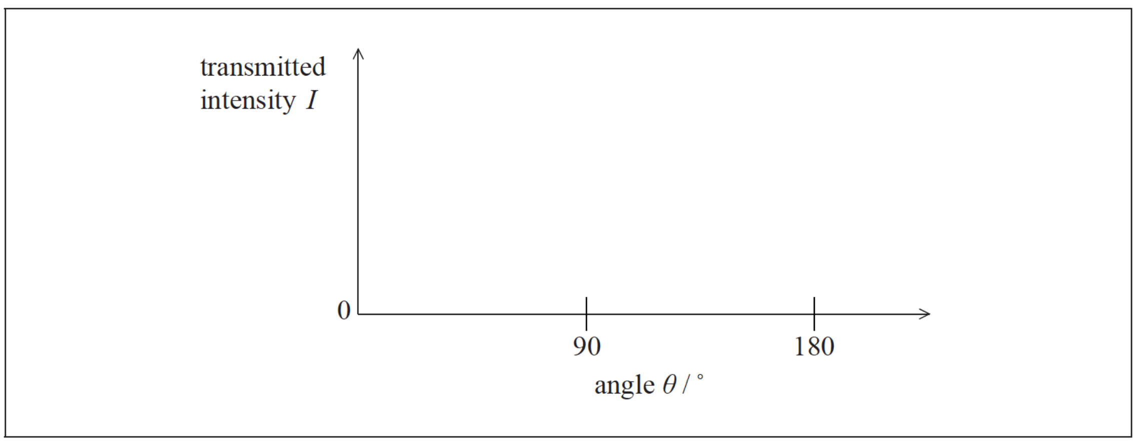
maximum displacement where two crests meet, *i.e.* at 5.0 m;

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.

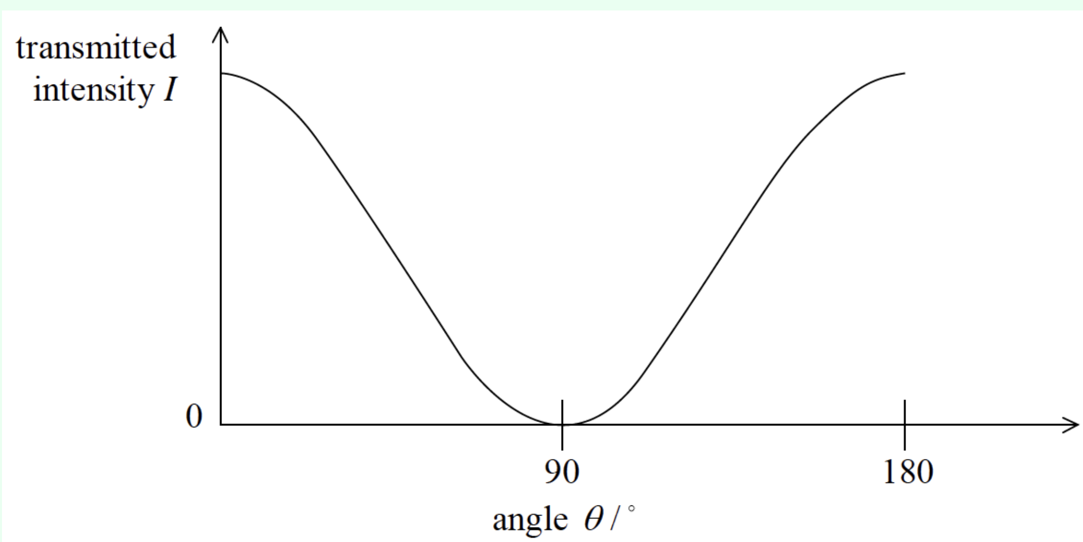


13. On the axes below, sketch a graph to show how the intensity *I* of the light emerging from the second polarizer varies with θ. *[2 marks]*



Markscheme

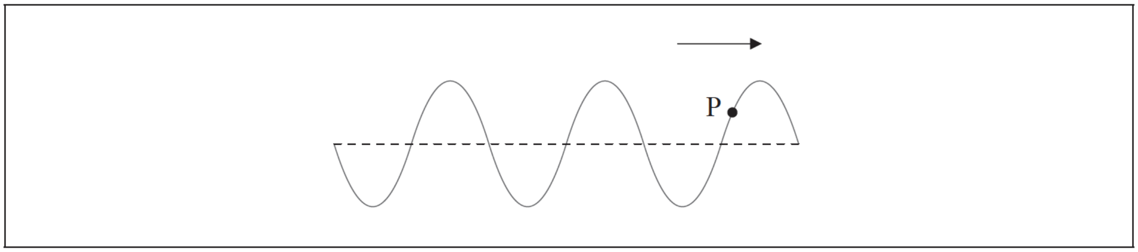
general $\cos^2$ shape;
zero intensity at 90˚ and maximum at both 0˚ and 180˚;



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.

Markscheme

(i) downward arrow at P;

(ii) clear single wavelength marked;

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.

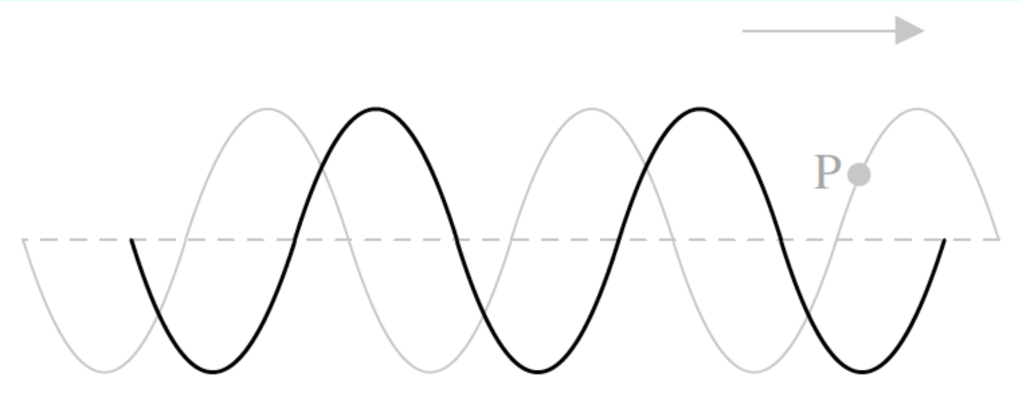
Markscheme

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

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

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

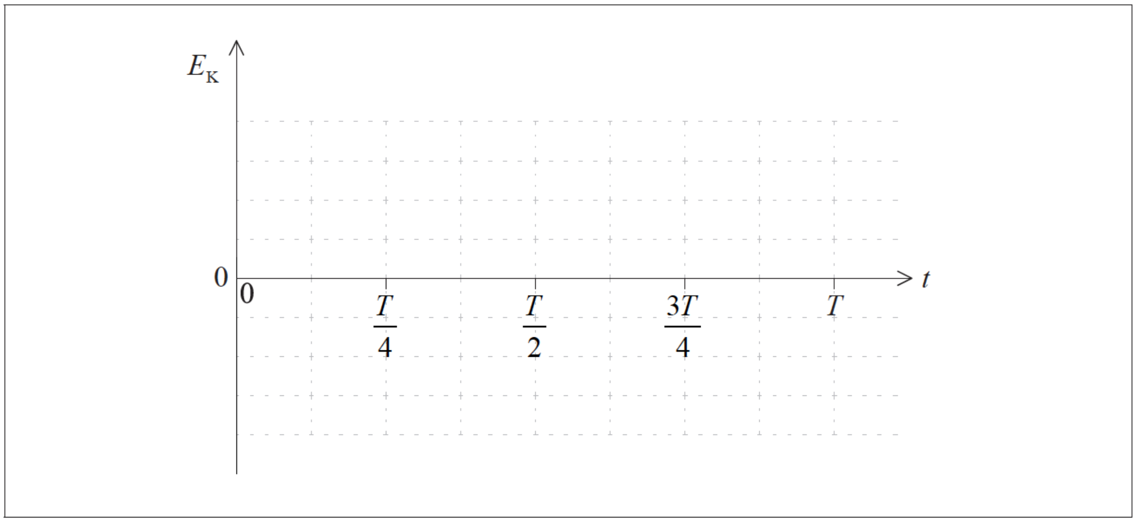
(ii) wave moved to right by one-third of a cycle by eye;



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.



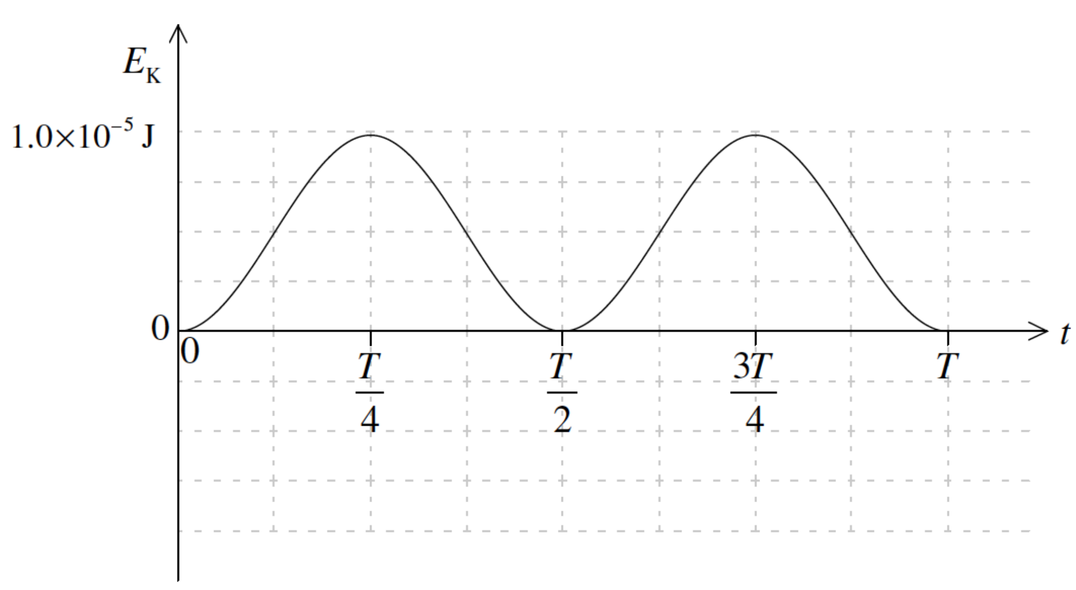
Markscheme

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

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

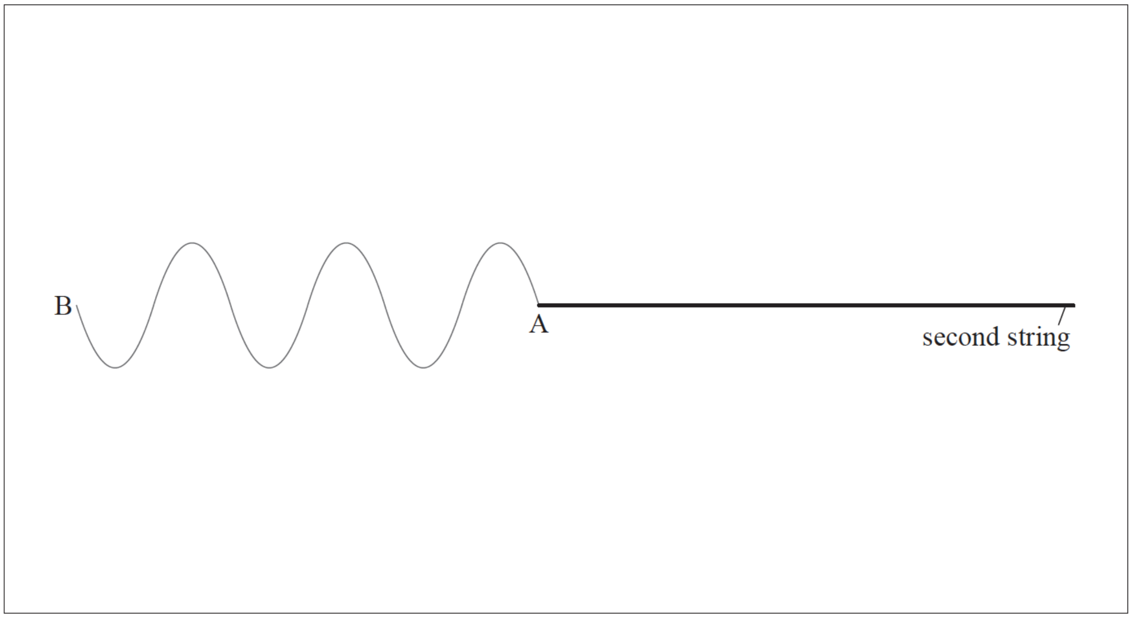
*Award **[2]** for a bald correct answer.*

(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 $\frac{T}{2}$;

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).

Markscheme

(i) reduced wavelength;
reduced amplitude;

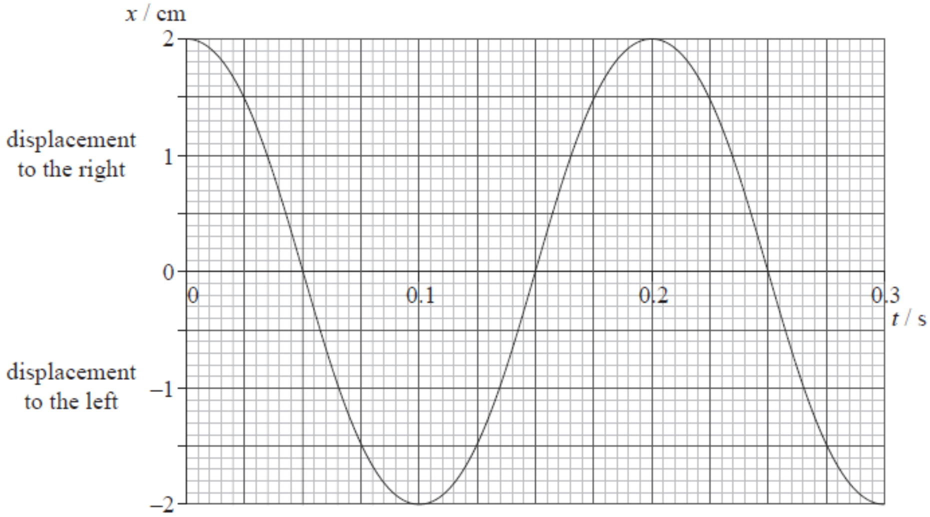
(ii) speed reduced and frequency constant;
therefore wavelength reduced;
some energy reflected at boundary / second string is denser/greater mass per unit length;
therefore amplitude reduced;

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.

Markscheme

(i) the amplitude is constant;

(ii) period is 0.20s;

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

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

(iii) displacement at *t* = 0.12cm is (–)1.62cm;

$$v\left(=\frac{2\pi}{T}\sqrt{x_0 - x^2}\right) = 31.4\sqrt{\left(2.0\times10^{-2}\right)^2 - \left(1.62\times10^{-2}\right)^2} = 0.37\text{ms}^{-1};$$

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

or

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

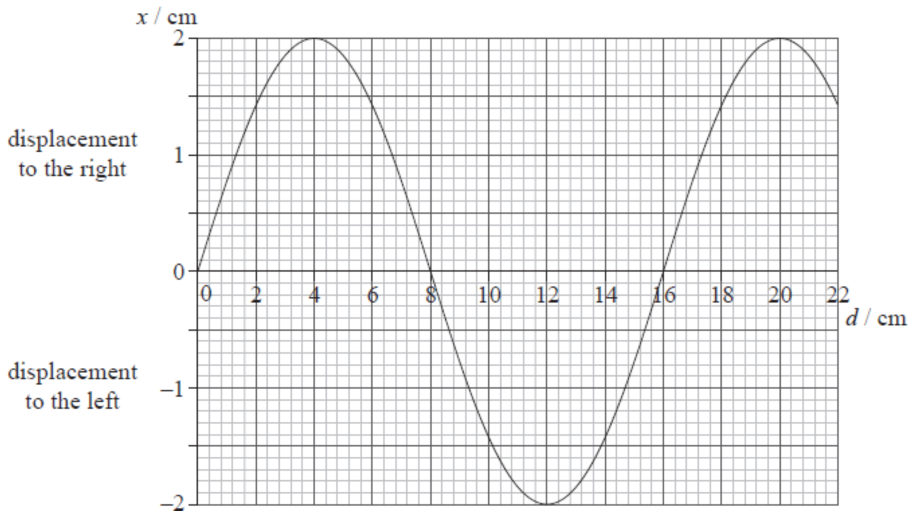
$$|v| = \left(\left|-v_0\sin\left[\frac{2\pi}{T}t\right]\right| \Rightarrow |v| = |-0.628\sin[31.4\times0.12]| = |0.37|\right) = 0.37\text{ms}^{-1};$$

or

drawing a tangent at 0.12s;
measurement of slope of tangent;
Accept answer in range 0.33ms^{-1} to 0.38ms^{-1} .

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.

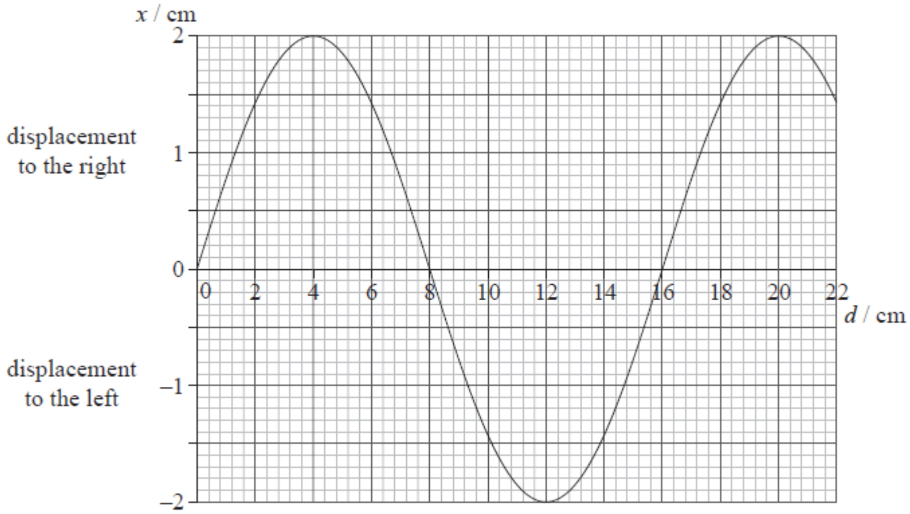
(ii) the speed.

Markscheme

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

(ii) wavelength is 16cm;
and so speed is $v(=f\lambda=5.0\times0.16)=0.80\text{ms}^{-1}$;

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



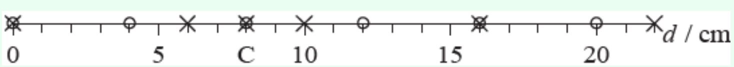
(c) The diagram shows the equilibrium positions of six particles in the medium.

(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.

Markscheme

(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;

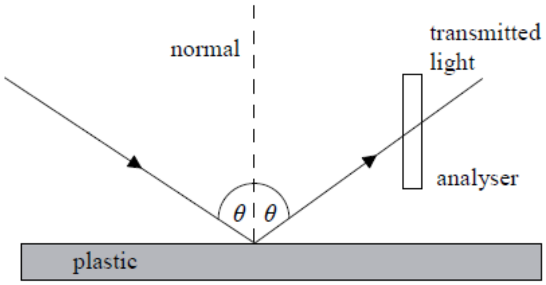
This question is about polarization.

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

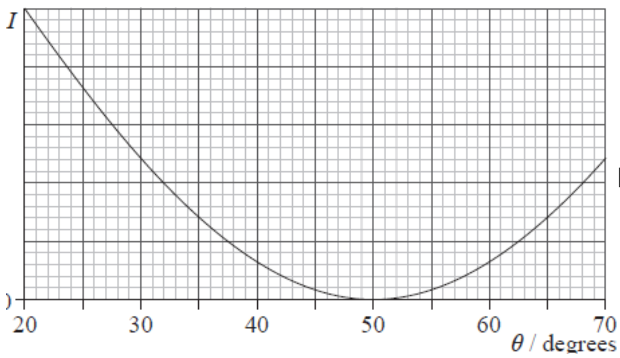
Markscheme

light for which the electric field is oscillating in (only) one plane;

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.

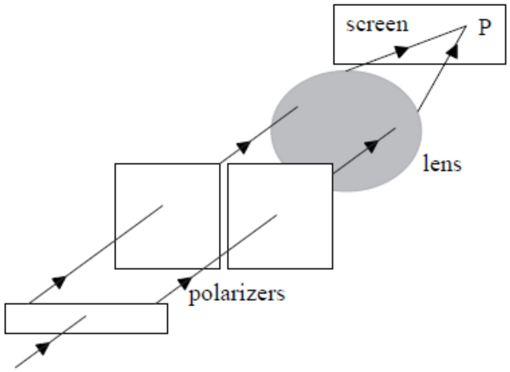
Markscheme

at a particular angle of incidence the reflected light is horizontally polarized;
and will be blocked by an analyser/polarizer with a vertical transmission axis;

or

at a particular angle of incidence when the reflected and refracted rays are at right angles the reflected light/rays will be horizontally polarized;
and will be blocked by an analyser/polarizer with a vertical transmission axis;

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.

Markscheme

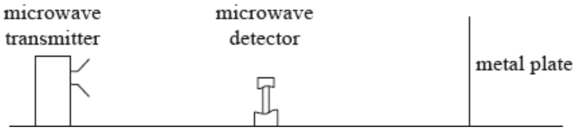
(i) mention of superposition/interference;
interference is destructive and so there will be no light at P;
*Award **[0]** for correct answer with no or wrong argument.*

(ii) there will be light at P;
the two sources cannot interfere because their planes of polarization are at right angles;
*Award **[0]** for correct answer with no or wrong argument. Award **[0]** if answer mentions no light at P irrespective of anything else said.*

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]*

Markscheme

standing wave formed;

by superposition/interference of (forward) wave and reflected wave;

maximum where interference is constructive / minimum where interference is destructive;

maxima where waves in phase;

minima where waves are completely/180°/π/half wavelength out of phase;

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.

Markscheme

(i) $130 \text{ mm} \equiv 9 \text{ half wavelengths};$

29 mm;

(ii) $f = \frac{c}{\lambda}$;

$= 10 \text{ GHz}$;

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

Markscheme

place a metal grid/analyser between source and detector;

electric field vector (of the microwaves) vibrates in only one direction/plane;

rotate the metal grid/detector;

until minimum signal is detected;

or

electric field vector vibrates in only one direction/plane;

rotate transmitter through an angle;

need to rotate receiver through same angle to restore signal in transmitter;

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	5.7×10^{-8} W m^{-2} K^{-4}

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

Markscheme

power/energy per second emitted proportional to surface area;
and proportional to fourth power of absolute temperature / temperature in K;
Accept equation with symbols defined.

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

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

Markscheme

solar power given by 4πR2σT 4 ;
spreads out over sphere of surface area 4πd 2 ;
Hence equation given.

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

Markscheme

$$\left(\frac{\sigma R^2 T^4}{d^2} =\right) \frac{5.7\times10^{-8}\times\left[7.0\times10^{8}\right]^2\times\left[5.8\times10^{3}\right]^4}{\left[1.5\times10^{11}\right]^2};$$

$=1.4\times10^{3}(\text{Wm}^{-2})$;
Award [2] for a bald correct answer.

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]*

Markscheme

some energy reflected;
some energy absorbed/scattered by atmosphere; depends on latitude;
depends on time of day;
depends on time of year;
depends on weather (*eg* cloud cover) at location; power output of Sun varies;
Earth-Sun distance varies;

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]*

Markscheme

power radiated = power absorbed;
$T = \sqrt[4]{\frac{240}{5.7 \times 10^{-8}}} = (250\text{K});$
Accept answers given as 260 (K).

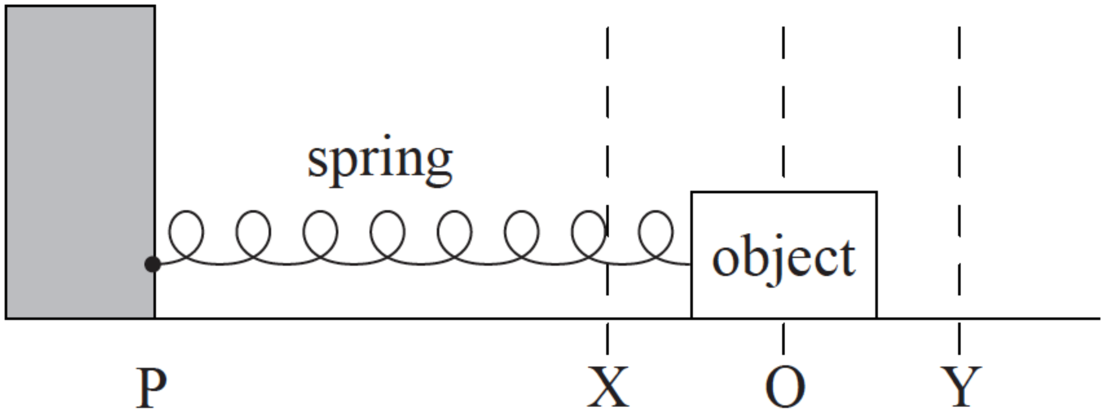
18f. Explain why the actual surface temperature of the Earth is greater than the value in (e). *[3 marks]*

Markscheme

radiation from Sun is re-emitted from Earth at longer wavelengths; greenhouse gases in the atmosphere absorb some of this energy; and radiate some of it back to the surface of the Earth;

Part 2 A mass on a spring

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



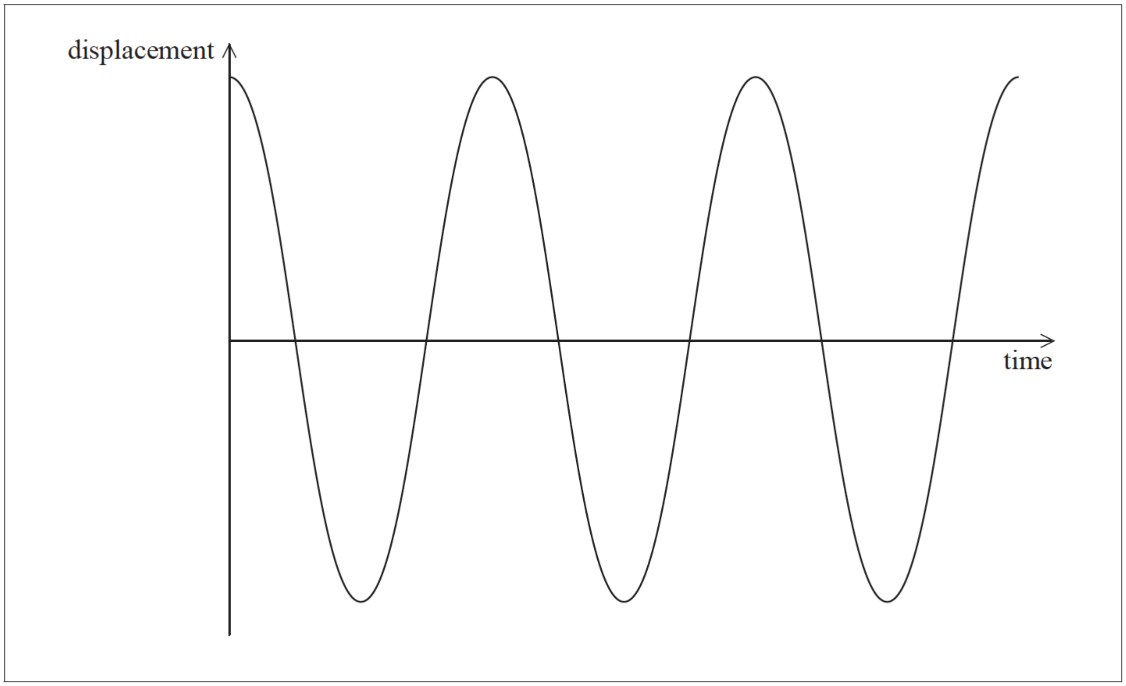
The other end of the spring is attached to a stationary point P. Air resistance is negligible. The equilibrium position is at O. The object is moved to position Y and released.

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

Markscheme

the force (of the spring on the object)/acceleration (of the object/point O) must be proportional to the displacement (from the equilibrium position/centre/point O);
and in the opposite direction to the displacement / always directed towards the equilibrium position/centre/point O;

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.

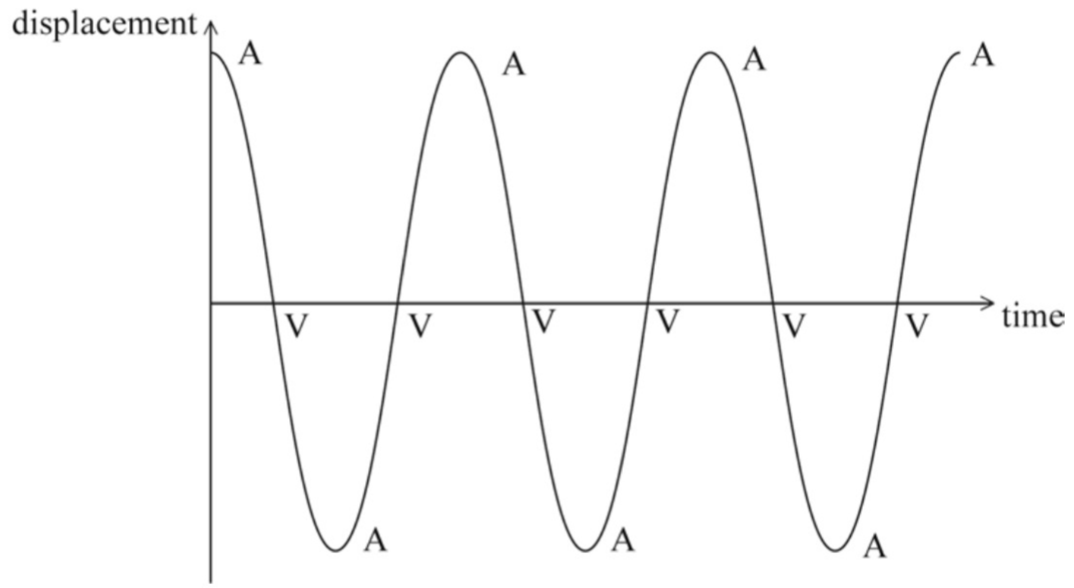
(ii) Label with the letter V a point at which the speed of the object is a maximum.

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

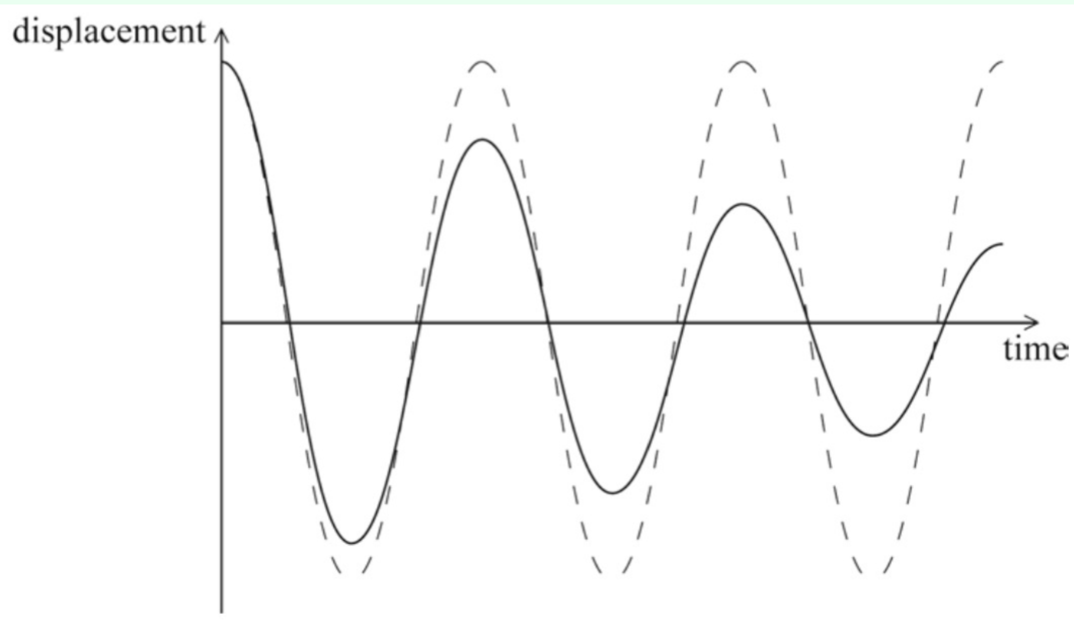
Markscheme

(i) one A correctly shown;

(ii) one V correctly shown;



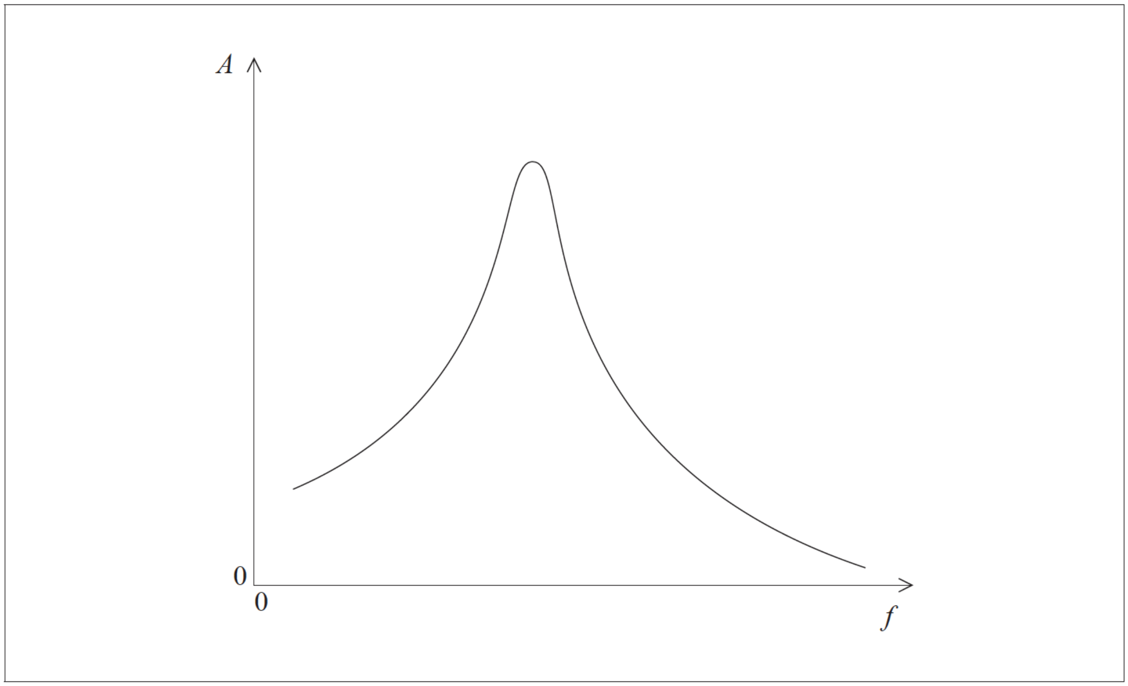
(iii) same period; *(judge by eye)*
amplitude decreasing with time;



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*.



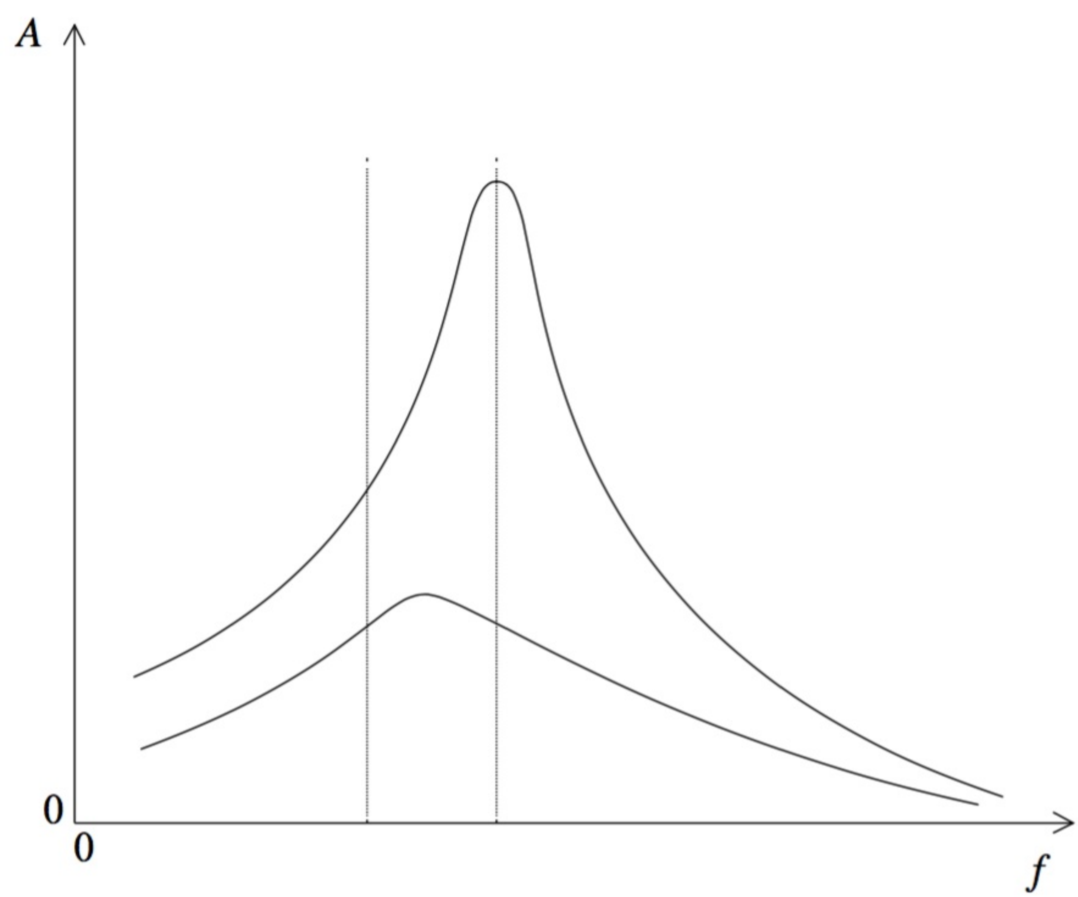
(i) With reference to resonance and resonant frequency, comment on the shape of the graph.

(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.

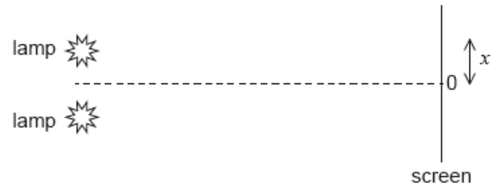
Markscheme

(i) resonance is where driving frequency equals/is close to natural/resonant frequency;
the natural/resonant frequency is at/near the maximum amplitude of the graph;

(ii) lower amplitude everywhere on graph, bit still positive;
maximum in same place/moved slightly *(that is, between the lines)* to left on graph;

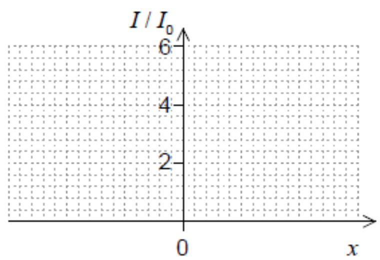


19a. Monochromatic light from two identical lamps arrives on a screen. *[1 mark]*



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

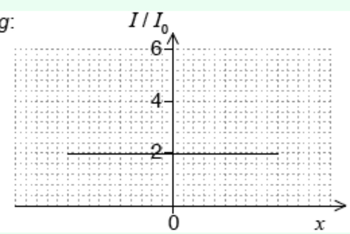
On the axes, sketch a graph to show the variation with distance x on the screen of the intensity I of light on the screen.



Markscheme

horizontal straight line through $I = 2$

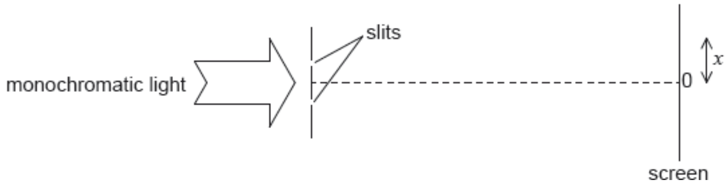
eg:



Accept a curve that falls from I = 2 as distance increases from centre but not if it falls to zero.

[1 mark]

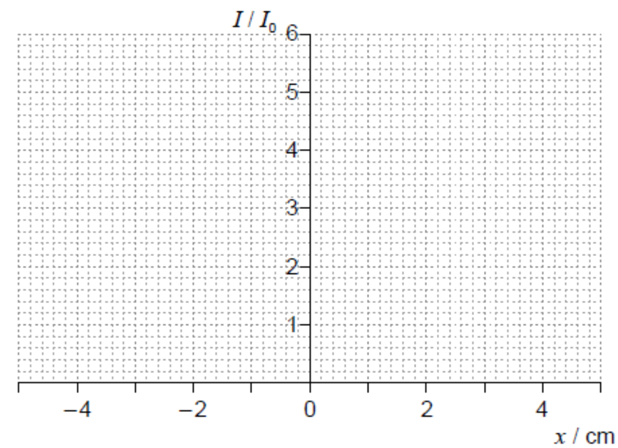
19b. Monochromatic light from a single source is incident on two thin, parallel slits. *[3 marks]*



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.



Markscheme

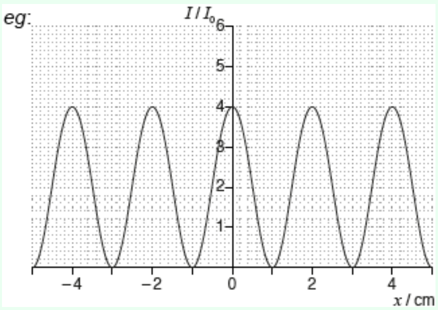
«standard two slit pattern»

general shape with a maximum at $x = 0$

maxima at $4 I_0$

maxima separated by « $\frac{D\lambda}{s}$ =» 2.0 cm

Accept single slit modulated pattern provided central maximum is at 4. ie height of peaks decrease as they go away from central maximum. Peaks must be of the same width



[3 marks]

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

Markscheme

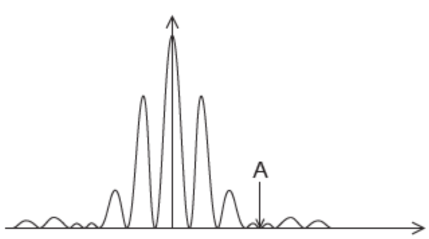
fringe width/separation decreases

OR

more maxima seen

[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]*

Markscheme

the diagram shows the combined effect of «single slit» diffraction and «double slit» interference

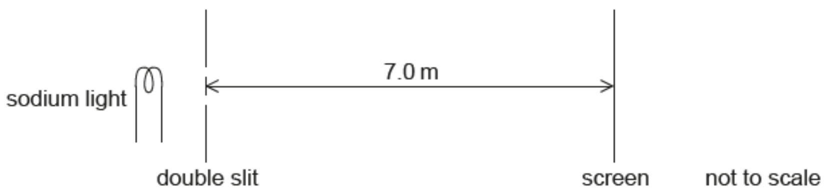
recognition that there is a minimum of the single slit pattern

OR

a missing maximum of the double slit pattern at A

waves «from the single slit» are in antiphase/cancel/have a path difference of ($n + \frac{1}{2}$)λ/destructive interference at A

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.

Markscheme

$\theta = \frac{4.1\times10^{-2}}{7.0}$ ***OR*** $b = \frac{\lambda}{\theta}$ «= $\frac{7.0\times5.9\times10^{-7}}{4.1\times10^{-2}}$ »

1.0 × 10^{-4} «m»

*Award **[0]** for use of double slit formula (which gives the correct answer so do not award BCA)*

Allow use of sin or tan for small angles

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

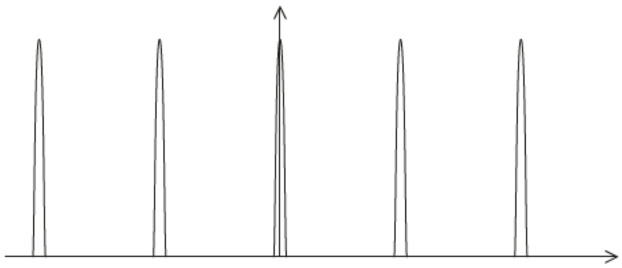
Markscheme

use of $s = \frac{\lambda D}{d}$ with 3 fringes « $\frac{590\times10^{-9}\times7.0}{4.1\times10^{-2}}$ »

3.0 x 10^{-4} «m»

Allow ECF.

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]*

Markscheme

fringes are further apart because the separation of slits is «much» less

intensity does not change «significantly» across the pattern ***or*** diffraction envelope is broader because slits are «much» narrower

the fringes are narrower/sharper because the region/area of constructive interference is smaller/there are more slits

intensity of peaks has increased because more light can pass through

*Award **[1 max]** for stating one or more differences with no explanation*

*Award **[2 max]** for stating one difference with its explanation*

*Award **[MP3]** for a second difference with its explanation*

Allow "peaks" for "fringes"

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]*

Markscheme

$\Delta\lambda$ = 589.592 – 588.995

OR

$\Delta\lambda$ = 0.597 «nm»

N = «$\frac{\lambda}{m\Delta\lambda}$ =» $\frac{589}{2\times0.597}$ «493»

beam width = «$\frac{493}{600}$ =» 8.2 x 10^{-4} «m» ***or*** 0.82 «mm»

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

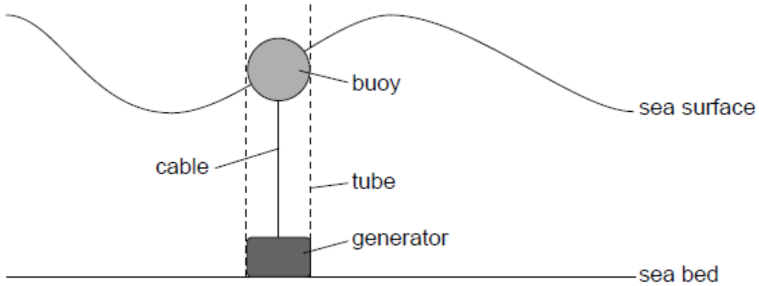
Markscheme

force/acceleration proportional to displacement «from equilibrium position»

and directed towards equilibrium position/point
OR
and directed in opposite direction to the displacement from equilibrium position/point

Do not award marks for stating the defining equation for SHM.
*Award **[1 max]** for a ω–=²x with a and x defined.*

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]*

Markscheme

frequency of buoy movement $= \frac{3.4}{35}$ ***or*** 0.097 «Hz»

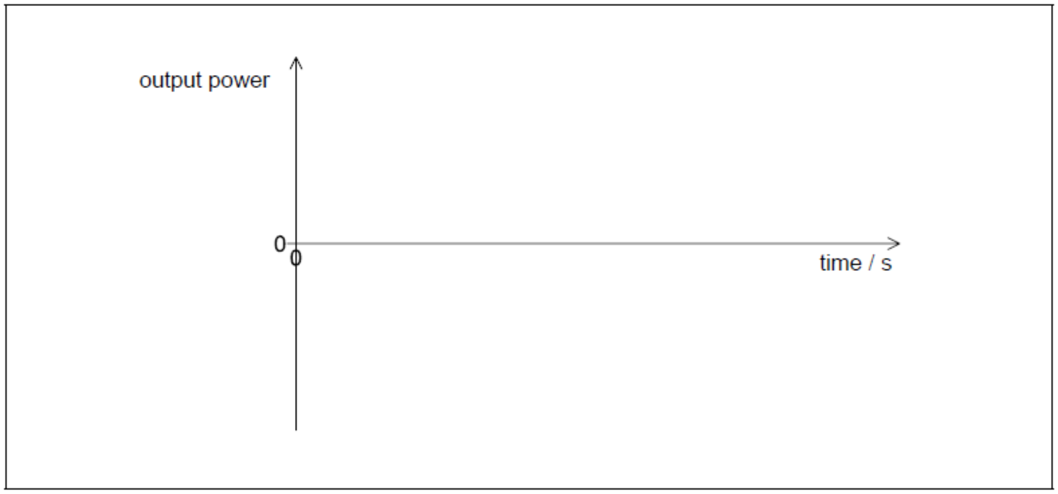
OR

time period of buoy $= \frac{35}{3.4}$ ***or*** 10.3 «s» ***or*** 10 «s»

v = «$\frac{2\pi x_0}{T}$ ***or*** $2\pi f x_0$» $= \frac{2\times\pi\times4.3}{10.3}$ ***or*** $2 \times \pi \times 0.097 \times 4.3$

2.6 «m s^{-1}»

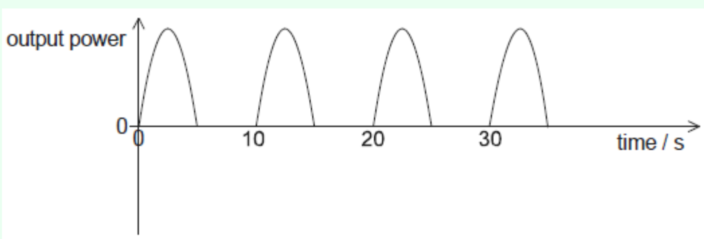
21c. Sketch a graph to show the variation with time of the generator output power. Label the time axis with a suitable scale. *[2 marks]*



Markscheme

peaks separated by gaps equal to width of each pulse «shape of peak roughly as shown»

one cycle taking 10 s shown on graph



Judge by eye.
Do not accept $\cos_2$ *or* $\sin_2$ *graph*
At least two peaks needed.
Do not allow square waves or asymmetrical shapes.
Allow ECF from (b)(i) value of period if calculated.

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]*

Markscheme

PE of water is converted to KE of moving water/turbine to electrical energy «in generator/turbine/dynamo»

idea of pumped storage, *ie:* pump water back during night/when energy cheap to buy/when energy not in demand/when there is a surplus of energy

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]*

Markscheme

specific energy available = «*gh* =» 9.81 x 270 «= 2650J kg^{-1}»

OR

$mgh = \frac{1}{2}mv^2$

OR

$v^2 = 2gh$

v = 73 «ms^{-1}»

Do not allow 72 as round from 72.8

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 x 10^{10} kg of water passes through the turbines. *[2 marks]*

Markscheme

total energy = «*mgh* = 1.5 x 10^{10} x 9.81 x 270=» 4.0 x 10^{13} «J»

OR

total energy = «$\frac{1}{2}mv^2 = \frac{1}{2} \times 1.5 \times 10^{10} \times$ (answer (c)(ii))^2 =» 4.0 x 10^{13} «J»

time = «$\frac{4.0 \times 10^{13}}{4 \times 2.5 \times 10^8}$» 11.1h ***or*** 4.0 x 10^4 s

Use of 3.97 x 10^{13} «J» gives 11 h.

*For MP2 the unit **must** be present.*

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

1. . . . .

. . . .

. . . .

2. . . . .

. . . .

. . . .

Markscheme

friction/resistive losses in pipe/fluid resistance/turbulence/turbine or generator «bearings»
OR
sound energy losses from turbine/water in pipe

thermal energy/heat losses in wires/components

water requires kinetic energy to leave system so not all can be transferred

Must see "seat of friction" to award the mark.

Do not allow "friction" bald.

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.

Markscheme

i

mention of Doppler effect

OR

«relative» motion between source and observer produces frequency/wavelength change

Accept answers which refer to a double frequency shift.

*Award **[0]** if there is any suggestion that the wave speed is changed in the process.*

the reflected waves come from an approaching "source"

OR

the incident waves strike an approaching "observer"

increased frequency received «by the device ***or*** by the car»

ii

the car is a moving "observer" and then a moving "source", so the Doppler effect occurs twice

OR

the reflected radar appears to come from a "virtual image" of the device travelling at 2 v towards the device

iii

ALTERNATIVE 1

*For both alternatives, allow ecf to conclusion if v **OR** Δf are incorrectly calculated.*

v = «$\frac{(3\times10^8)\times(9.5\times10^3)}{(40\times10^9)\times2} =$» 36 «$ms^{-1}$»

«36> 28» so car exceeded limit

There must be a sense of a conclusion even if numbers are not quoted.

ALTERNATIVE 2

reverse argument using speed limit.

$\Delta f =$ «$\frac{2\times40\times10^9\times28}{3\times10^8} =$» 7500 «Hz»

« 9500> 7500» so car exceeded limit

There must be a sense of a conclusion even if numbers are not quoted.

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.

Markscheme

$x = \frac{31 \times 10^3 \times 1.22 \times 2.5 \times 10^{-2}}{9.3}$

*Award **[2]** for a bald correct answer.*
*Award **[1 max]** for POT error.*

100 «m»
*Award **[1 max]** for 83m (omits 1.22).*

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