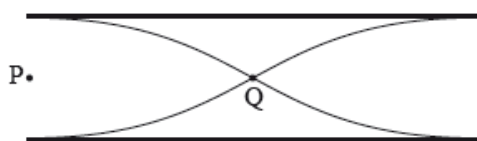# HL Paper 2

This question is about waves.

The diagram represents a standing (stationary) wave in air in a pipe which is open at both ends.

Two points in the pipe are labelled P and Q.

a. (i)   State the direction of oscillation of an air molecule at point P.   [3]

   (ii)   Compare the amplitude of oscillation of an air molecule at point P with that of an air molecule at point Q.

b. A hollow pipe open at both ends is suspended just above the ground on a construction site.   [2]
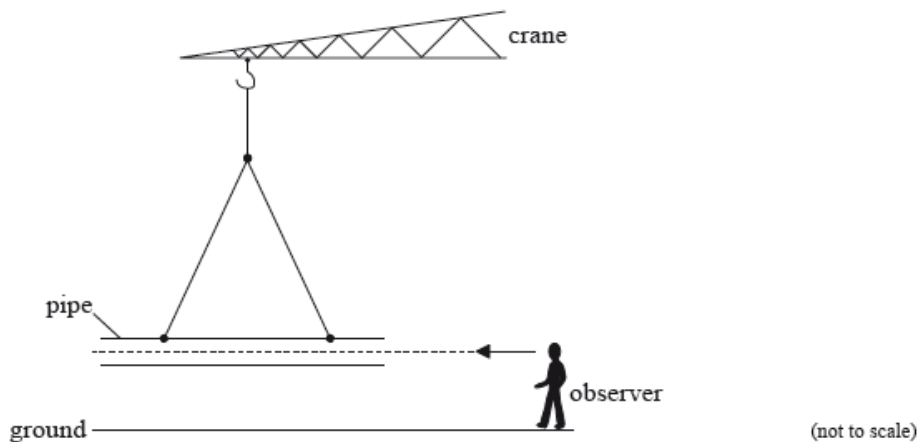
Wind blows across one end of the pipe. This causes a standing wave to form in the air of the pipe, producing the first harmonic. The pipe has a length of 2.1 m and the speed of sound in air is $330 \mathrm{~m~s}^{-1}$.

Estimate the frequency of the first harmonic standing wave.

c. The pipe is held stationary by the crane and an observer runs towards the pipe. Outline how the frequency of the sound measured by the observer is different from the frequency of the sound emitted by the pipe.   [3]

Markscheme

a. (i)   along axis of pipe / horizontal / left to right;

   Do not allow "right" or "left" alone. Allow correct answers that appear on the diagram.

   (ii)   P has greater/maximum amplitude;

   Q does not move/has zero amplitude;

b. $\lambda = 4.2$ m;

79 **or** 78.6 (Hz); *(do not allow 78 Hz)*

Award [2] for a bald correct answer.

c. wavefronts emitted by the pipe at regular time intervals;

observer crosses the wavefronts more often than if stationary;

so frequency is higher;

Award [0] for a bald correct answer.

or

observer moving towards the source measures the emitted wavelength;

but (relative) wave speed measured is higher than that emitted;

so frequency is higher;

Award [0] for a bald correct answer.

or

quotes Doppler equation correctly;

deduces higher frequency correctly;

Award [2 max] for this approach.

Examiners report

a. (i)   Most candidates were imprecise in their descriptions of the direction of motion of the air molecule. Very many think that the conventional

diagram for the standing sound wave in a gas shows that the molecules move between the drawn lines of the wave. Answers such as "vertical"

were common. Other inadequate responses featured "to the right" without the candidate realising that this implies that a molecule moves

continually to the right eventually leaving the tube.

(ii)   Descriptions of the amplitudes at P and Q were better but for a minority of candidates there was confusion between the meaning of node and
antinode.

b. Calculations were generally well done.

c. This question was an "outline" and required a more sophisticated approach than "it is caused by the Doppler effect". Examiners were looking for a

description of the causes of the change in wavelength as perceived by the moving observer. Explanations that quoted a Doppler equation (it had to

be the correct one) and deduced an increase in frequency were not awarded full marks as this is little more than copying by rote from the data

booklet.

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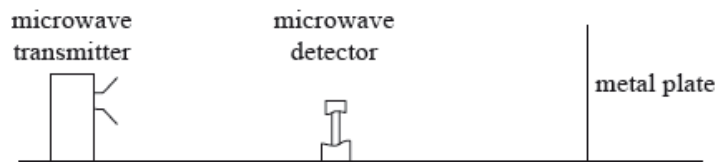
A microwave detector is moved along a line normal to the microwave transmitter and the metal plate. The detector records a sequence of equally spaced maxima and minima of intensity.

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

Part2.a. Explain how these maxima and minima are formed. [4]

Part2.b. (i) wavelength of the microwaves. [4]

(ii)   frequency of the microwaves.

Part2.c. Describe and explain how it could be demonstrated that the microwaves are polarized. [3]

Markscheme

Part2.a. 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;

Part2.b. (i) $130 \text{ mm} \equiv 9$ half wavelengths;

29 mm;

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

$= 10 \text{ GHz}$;

Part2.c. 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;

Examiners report

Part2.a. Few were able to give complete and convincing explanations of the formation of the standing wave. Common errors were to omit the consequence

of the reflection at the metal plate. Superposition was often poorly or even not described. Details of the phase relationships were also poor.

Part (i) and (ii) Candidates were very comfortable with these calculations although the number of wavelengths in (i) was often incorrect. Errors from (i) were carried forward to (ii) allowing many cases of full credit in this second part.

Part (c) Examiners saw very few good descriptions of the polarization demonstration. A number of techniques are available but it is clear that candidates have either not discussed these or find the concept difficult.

This question is about the motion of a ship and observing objects from it.

The sailors on the ship wear polarized sunglasses when observing the sea from the ship. Unpolarized light from the Sun is incident on the sea.

e. A security camera on the ship captures an image of two green lamps on the shore. The lamps emit light of wavelength 520 nm.   [3]
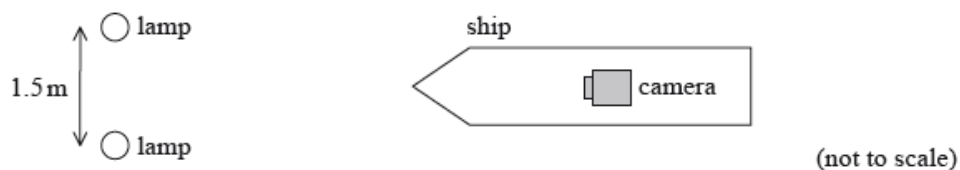
The camera has a circular aperture of diameter 6.2 mm. The lamps are separated by 1.5 m. Determine the maximum distance between the camera and the lamps at which the images of the lamps can be distinguished.

f.i. Describe the polarization of the sunlight that is reflected from the sea.   [2]

f.iii.Outline how polarized sunglasses help to reduce glare from the sea.   [3]

Markscheme

e. use of $\theta = \frac{1.22\lambda}{d}$;

$\left(\frac{1.22 \times 520 \times 10^{-9}}{6.2 \times 10^{-3}} \right) = 1.02 \times 10^{-4}$;

distance $= \left(\frac{1.5}{1.02 \times 10^{-4}} = \right) 1.47 \times 10^4$ m;

Award [2 max] if distance is 1.79×10^4 m (ignoring factor of 1.22) in second marking point.

f.i. partially/partly;

plane/horizontally polarized;

f.iii.the light from the sea is (predominantly) <u>horizontally</u> polarized;

the sunglasses are arranged to admit a particular/vertical plane of polarization;

hence polarized sunglasses absorb much of the reflected light/glare;

Examiners report

e. The Rayleigh criterion for a circular aperture was almost always used to find resolving power correctly. The third mark for finding distance was often lost as some candidates used tanθ (with their calculator in degree mode) or used 750m instead of 1500m in their calculation.

f.i. Two marks were obtained for stating that the reflected light from the sea was partially plane/horizontally polarised. Most candidates obtained only

one mark. Many obtained no mark as they simply stated that the light would be polarised – which is essentially rewording the question.

f.iii.This was a 3 mark question, so candidates needed to give a detailed response, including the respective planes of polarisation of reflected light and

the polaroid, in explaining the action of polarising sunglasses.

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.
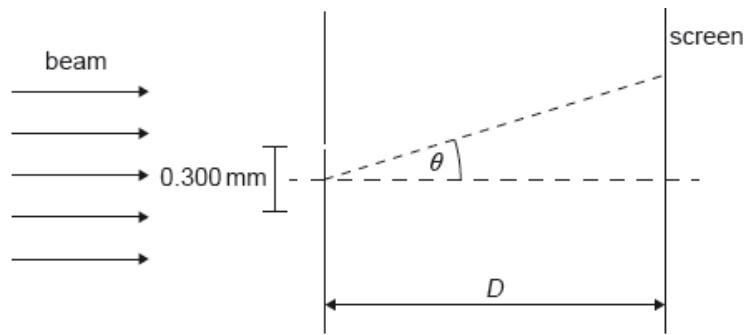
The graph of variation of intensity with diffraction angle for this experiment is shown.
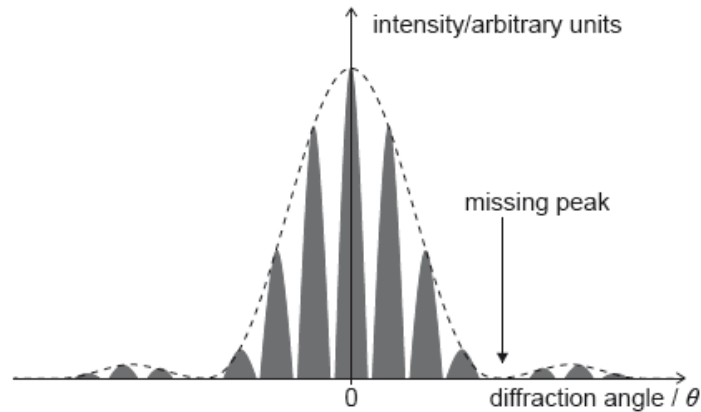
a.ii.Outline why the beam has to be coherent in order for the fringes to be visible. [1]

b.i.Calculate the angular separation between the central peak and the missing peak in the double-slit interference intensity pattern. State your [3]

answer to an appropriate number of significant figures.

b.ii.Deduce, in mm, the width of one slit. [2]

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

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

Markscheme

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

OWTTE

[1 mark]

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

$\sin \theta = 0.0084401\ldots$

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]

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

OR

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

«=» 7.5«00» $\times 10^{-2}$ «mm»

Allow ECF from (b)(i).

[2 marks]

c. wavelength increases (so frequency decreases) / light is redshifted

galaxy is moving away from Earth

Allow ECF for MP2 (ie wavelength decreases so moving towards).
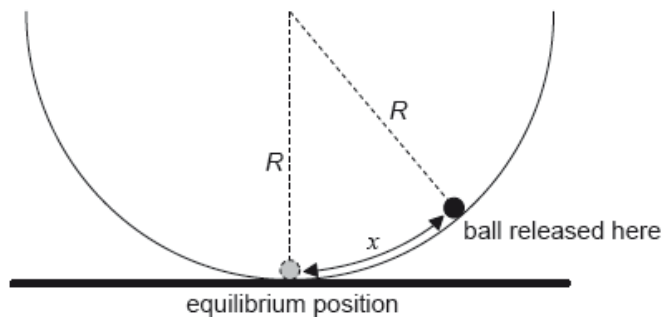
[2 marks]

Examiners report

a.ii.[N/A]
b.i.[N/A]
b.ii.[N/A]
c. [N/A]

The ball is now displaced through a small distance *x* from the bottom of the bowl and is then released from rest.

equilibrium position

The magnitude of the force on the ball towards the equilibrium position is given by
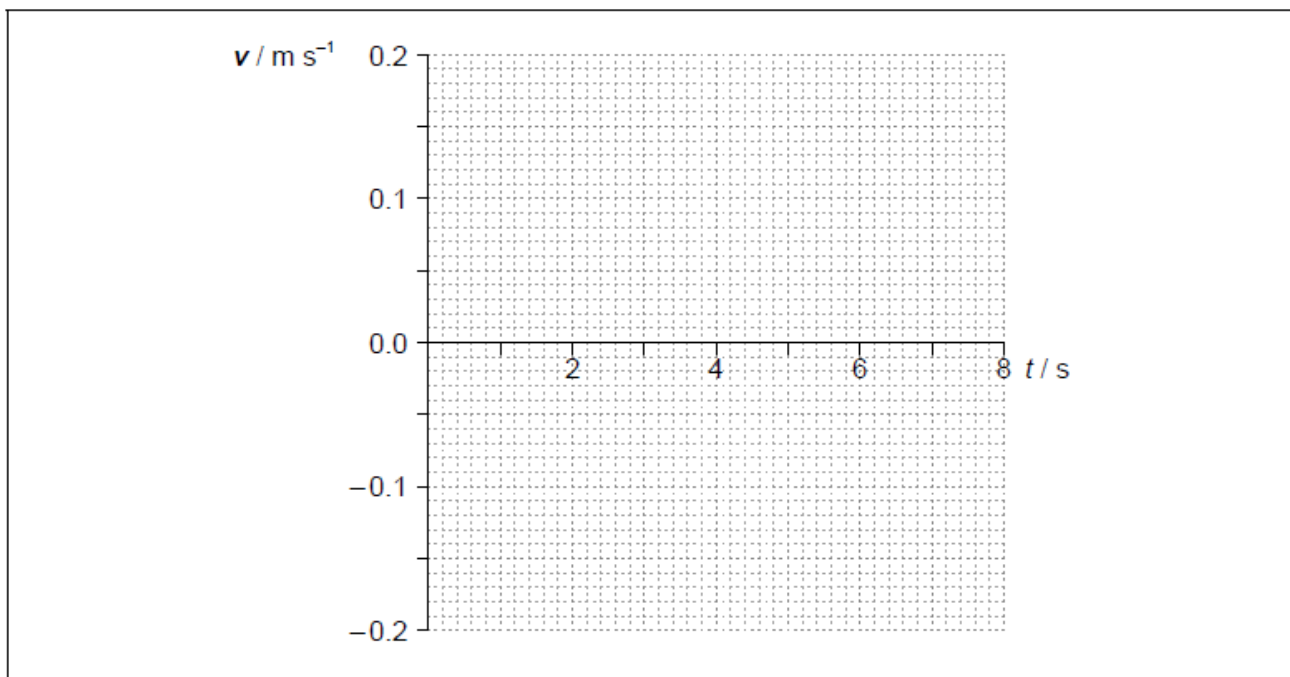
$$\frac{mgx}{R}$$

where R is the radius of the bowl.

d.i. Outline why the ball will perform simple harmonic oscillations about the equilibrium position. [1]

d.ii. Show that the period of oscillation of the ball is about 6 s. [2]

d.iii The amplitude of oscillation is 0.12 m. On the axes, draw a graph to show the variation with time t of the velocity v of the ball during one period. [3]

Markscheme

d.i. the «restoring» force/acceleration is proportional to displacement

Direction is not required

[1 mark]

d.ii $\omega = $ «$\sqrt{\frac{g}{R}}$» $= \sqrt{\frac{9.81}{8.0}}$ «$= 1.107$ s^{-1}»

$T = $ «$\frac{2\pi}{\omega}$» $= \frac{2\pi}{1.107}$ =» 5.7 «s»

Allow use of or g = 9.8 or 10

Award [0] for a substitution into $T = 2\pi\sqrt{\frac{I}{g}}$
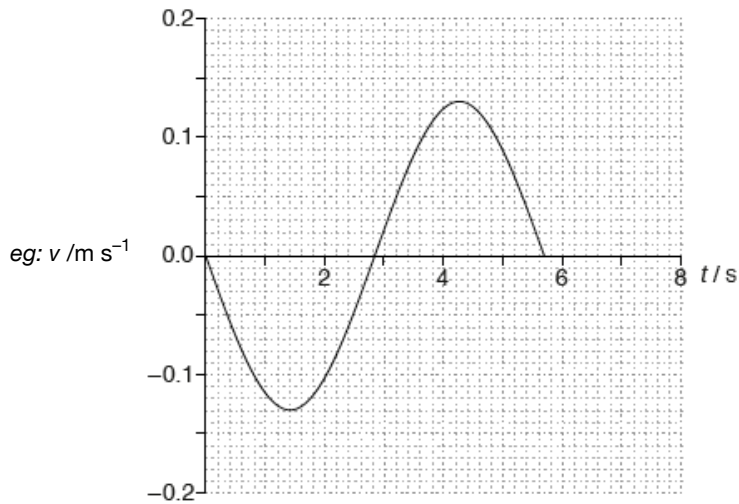
[2 marks]

d.iii.sine graph

correct amplitude «0.13 m s⁻¹»

correct period and only 1 period shown

Accept ± sine for shape of the graph. Accept 5.7 s or 6.0 s for the correct period.

Amplitude should be correct to $\pm\frac{1}{2}$ square for MP2
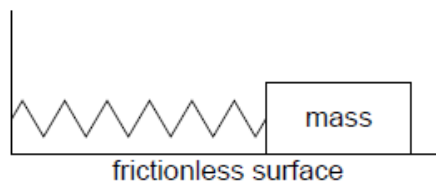

eg: v /m s⁻¹

[3 marks]

Examiners report

d.i. [N/A]
d.ii. [N/A]
d.iii. [N/A]

A student is investigating a method to measure the mass of a wooden block by timing the period of its oscillations on a spring.

A 0.52 kg mass performs simple harmonic motion with a period of 0.86 s when attached to the spring. A wooden block attached to the same spring oscillates with a period of 0.74 s.

With the block stationary a longitudinal wave is made to travel through the original spring from left to right. The diagram shows the variation with distance x of the displacement y of the coils of the spring at an instant of time.
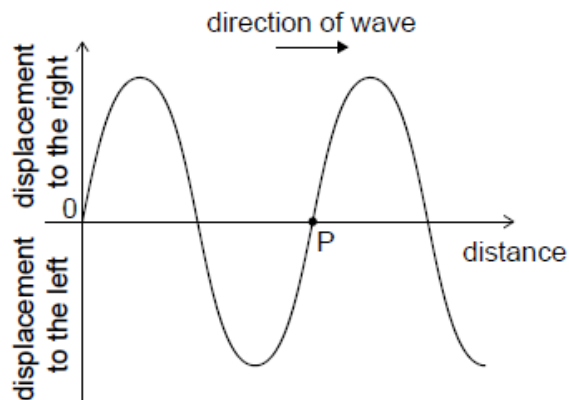
A point on the graph has been labelled that represents a point P on the spring.

a. Describe the conditions required for an object to perform simple harmonic motion (SHM). [2]

b. Calculate the mass of the wooden block. [2]

c. In carrying out the experiment the student displaced the block horizontally by 4.8 cm from the equilibrium position. Determine the total energy in [3] the oscillation of the wooden block.

d. A second identical spring is placed in parallel and the experiment in (b) is repeated. Suggest how this change affects the fractional uncertainty [3] in the mass of the block.

e.i. State the direction of motion of P on the spring. [1]

e.ii. Explain whether P is at the centre of a compression or the centre of a rarefaction. [2]

Markscheme

a. acceleration/restoring force is proportional to displacement

and in the opposite direction/directed towards equilibrium

b. **ALTERNATIVE 1**

$$\frac{T_1^2}{T_2^2} = \frac{m_1}{m_2}$$

mass = 0.38 / 0.39 «kg»

ALTERNATIVE 2

«use of $T = 2\pi\sqrt{\frac{m}{k}}$» k = 28 «Nm^{-1}»

«use of $T = 2\pi\sqrt{\frac{m}{k}}$» m = 0.38 / 0.39 «kg»

Allow ECF from MP1.

c. $\omega = «\frac{2\pi}{0.74}» = 8.5$ «rads^{-1}»

total energy $= \frac{1}{2} \times 0.39 \times 8.5^2 \times (4.8 \times 10^{-2})^2$

= 0.032 «J»

Allow ECF from (b) and incorrect ω.

Allow answer using k from part (b).

d. spring constant/k/stiffness would increase

   T would be smaller

   fractional uncertainty in *T* would be greater, so fractional uncertainty of mass of block would be greater

e.i. left

e.ii. coils to the right of P move right and the coils to the left move left

   hence P at centre of rarefaction

Do not allow a bald statement of rarefaction or answers that don't include reference to the movement of coils.

Allow ECF from MP1 if the movement of the coils imply a compression.
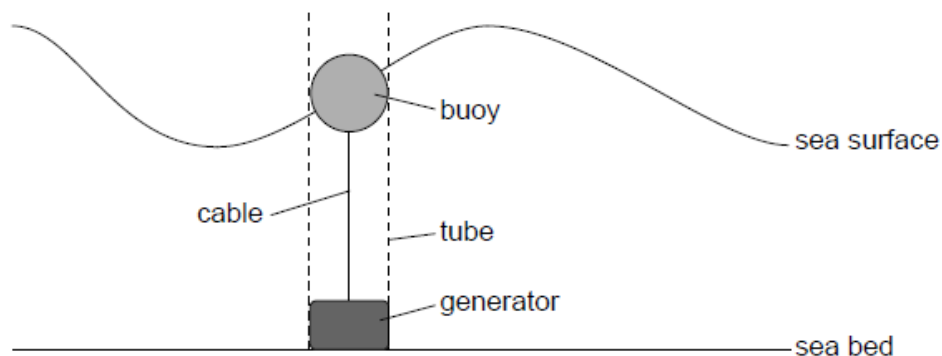
Examiners report

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.

Water can be used in other ways to generate energy.

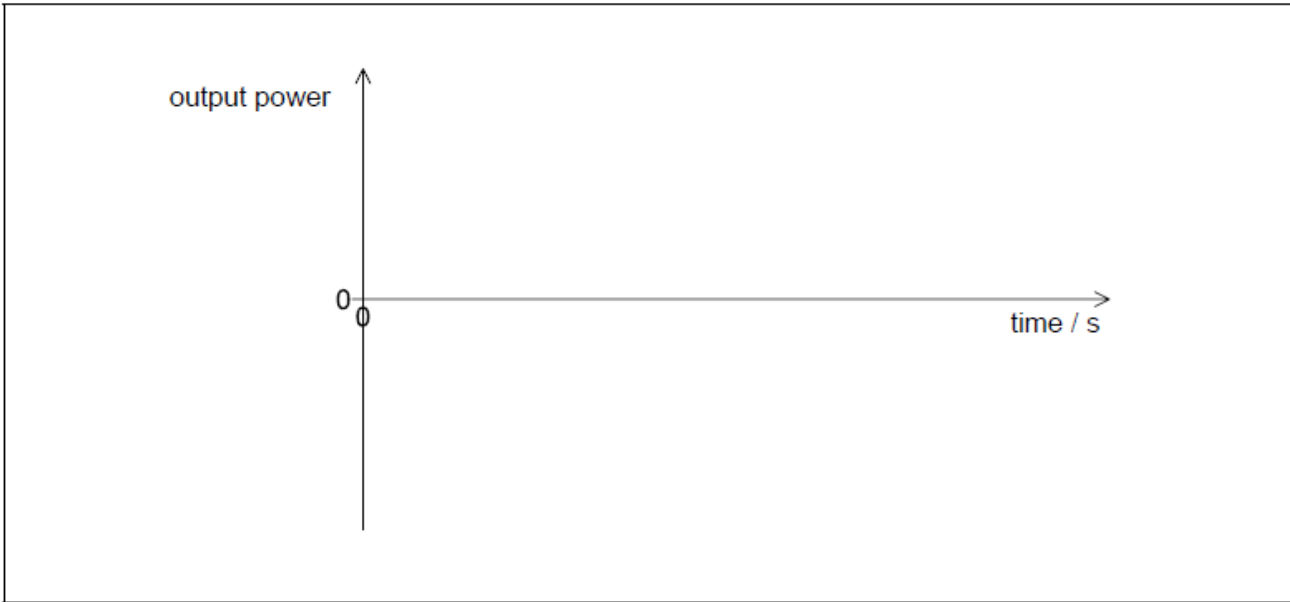a. Outline the conditions necessary for simple harmonic motion (SHM) to occur.   [2]

b.i. 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]

b.ii.Sketch a graph to show the variation with time of the generator output power. Label the time axis with a suitable scale.   [2]

output power

0
0   time / s

c.i. Outline, with reference to energy changes, the operation of a pumped storage hydroelectric system.   [2]

c.ii.The water in a particular pumped storage hydroelectric system falls a vertical distance of 270 m to the turbines. Calculate the speed at which   [2]

water arrives at the turbines. Assume that there is no energy loss in the system.

c.iii The hydroelectric system has four 250 MW generators. Determine the maximum time for which the hydroelectric system can maintain full output [2]

when a mass of 1.5 x 10^{10} kg of water passes through the turbines.

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

1. . . . .

. . . .

. . . .

2. . . . .

. . . .

. . . .

Markscheme

a. 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−=^{2}x with a and x defined.

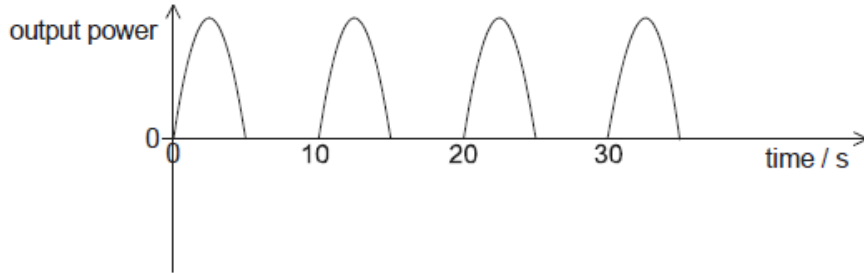b.i. frequency of buoy movement $= \frac{3.4}{35}$ *or* 0.097 «Hz»

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}»

b.ii. 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.

c.i. 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

c.ii. 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

c.iii. 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 $= «\frac{4.0\times10^{13}}{4\times2.5\times10^8}»$ 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.*

c.iv. 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.

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c.i. [N/A]
c.ii. [N/A]
c.iii. [N/A]
c.iv. [N/A]

This question is in **two** parts. **Part 1** is about simple harmonic motion (SHM) and waves. **Part 2** is about atomic and nuclear energy levels.

Part 1 Simple harmonic motion (SHM) and waves

Part 2 Atomic and nuclear energy levels

a. A particle P moves with simple harmonic motion. [3]

(i) State, with reference to the motion of P, what is meant by simple harmonic motion.

(ii) State the phase difference between the displacement and the velocity of P.

d. The diagram shows four spectral lines in the visible line emission spectrum of atomic hydrogen. [6]

410   434   485   656

wavelength λ / nm ⟶   (not to scale)

(i) Outline how such a spectrum may be obtained in the laboratory.

(ii) Explain how such spectra give evidence for the existence of discrete atomic energy levels.

e. The energies of the principal energy levels in atomic hydrogen measured in eV are given by the expression [4]

$E_n = -\frac{13.6}{n^2}$ where n=1, 2, 3 ....

The visible lines in the spectrum correspond to electron transitions that end at $n=2$.

(i) Calculate the energy of the level corresponding to $n=2$.

(ii) Show that the spectral line of wavelength $\lambda=485$nm is the result of an electron transition from $n=4$.

f.   The alpha particles and gamma rays produced in radioactive decay have discrete energy spectra. This suggests that nuclei also possess   [2]

discrete energy levels. However, beta particles produced in radioactive decay have continuous energy spectra. Describe how the existence of

the antineutrino accounts for the continuous nature of beta spectra.

Markscheme

a.   (i) the acceleration (of a particle/P) is (directly) proportional to displacement;

and is directed towards equilibrium/in the opposite direction to displacement;

Do not accept "directed towards the centre".

(ii) $\frac{\pi}{2}$/90°/quarter of a period;

d.   (i) light from a hydrogen discharge tube/hot hydrogen gas/ hydrogen tube with potential difference across it;

is passed onto a prism/diffraction grating;

and then is observed on a screen/through a telescope;

Accept good labelled diagram for explanation of any marking point.

(ii) each wavelength corresponds to the energy of the photon emitted;
when an electron makes a transition from a higher to lower energy level;
since only discrete wavelengths/finite number of wavelengths are present, then only discrete energy levels are present / *OWTTE*;

e.   (i) −3.40 eV;

Award [0] for omitted negative sign.

(ii) energy difference between levels$= \frac{hc}{\lambda e} = \frac{6.63\times10^{-34}\times3\times10^{8}}{4.85\times10^{-7}\times1.6\times10^{-19}}$;
$=2.55$eV;
$[3.40-2.55]=0.85=\frac{13.6}{n^2}$ to give n^2=16;
$n=4$;
Award [3] for reversed argument.

f.   the total emitted energy is shared between the electron and the antineutrino;

the energy/velocity can be shared/distributed in an infinite number of ways / *OWTTE*;
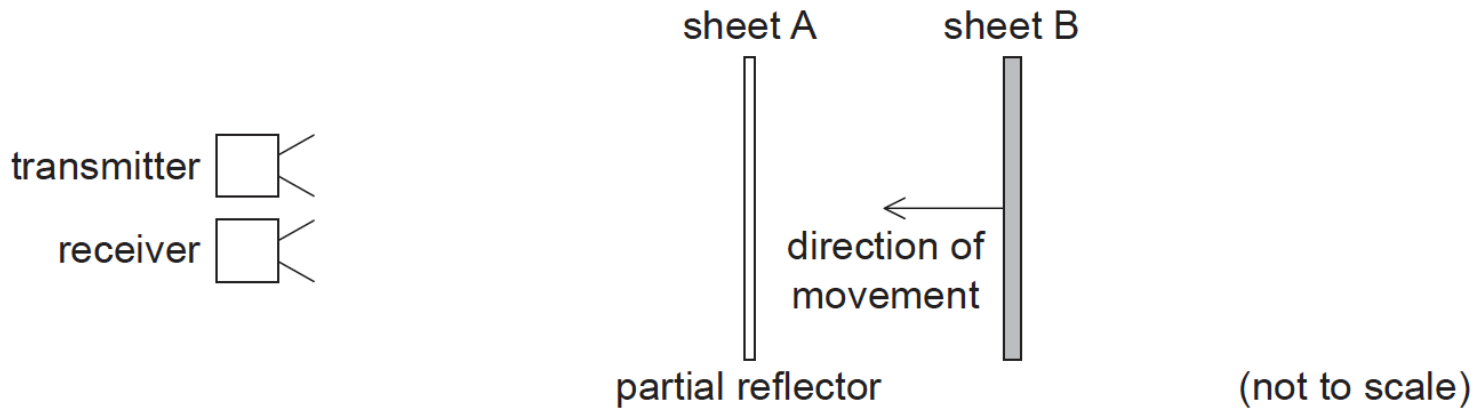
Examiners report

a.   [N/A]
d.   [N/A]
e.   [N/A]
f.   [N/A]

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.

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

c. The apparatus is arranged to demonstrate diffraction effects. [3]
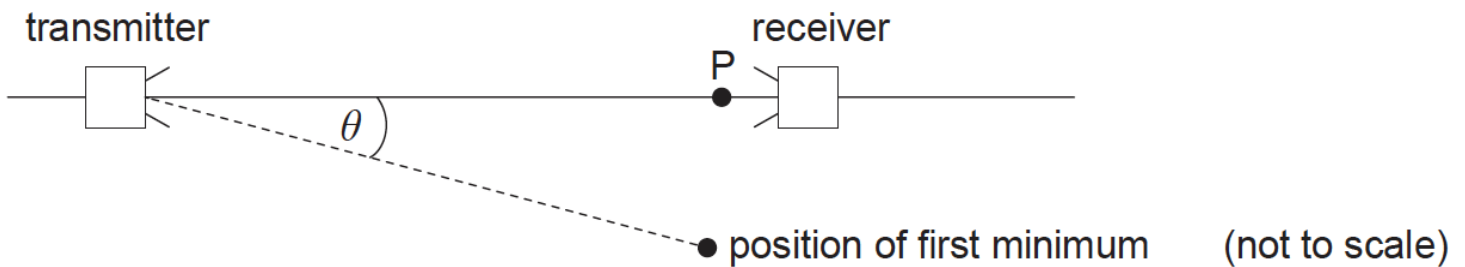
The microwaves emerge from the transmitter through an aperture that acts as a single slit.

(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.

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

demonstrate polarization.

Markscheme

a. 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 $\pi/180°$ / *OWTTE*;

minimum occurs when twice the distance between plates is $\left(n + \frac{1}{2}\right)\lambda$;

Ignore references to standing waves.

c. (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(°);

Award [0] for calculation that uses 1.22 (0.65 rad).

Award [0] for 0.533° or 30.6 rad.

At least one centre is using the abbreviation ^{c} for rad. Please allow this.

d. 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.

Examiners report

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

This question is about polarization.

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

b. 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 [2]

transmission axis is vertical.
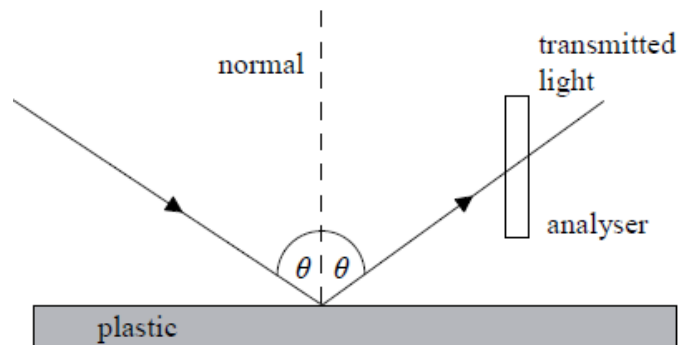
The variation with θ of the intensity *I* of the transmitted light is shown in the graph.
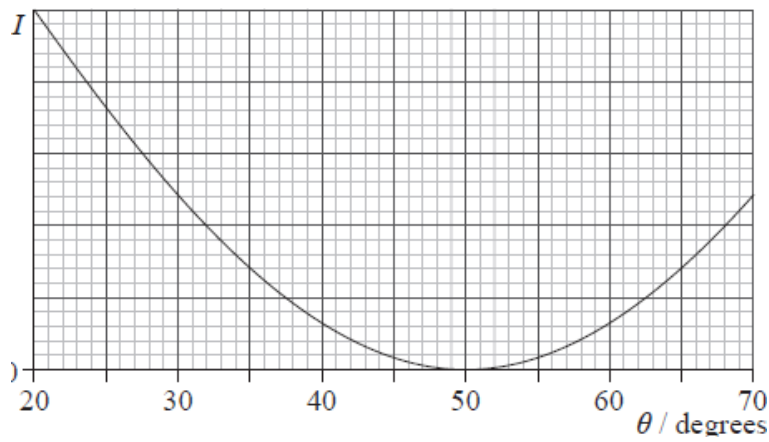
Explain why there is an angle of incidence, for which the intensity of the transmitted light is zero.

c. Unpolarized light from a source is split, so that there is a path difference of half a wavelength between the two beams.   [4]
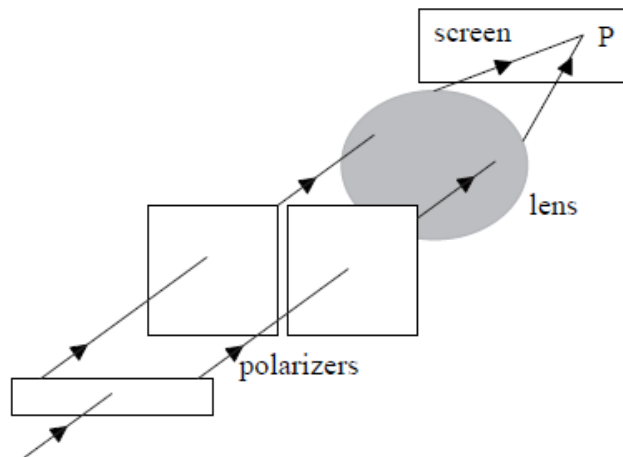
A lens brings the light to focus at point P on a screen. The lens does not introduce any additional path difference.

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

a. light for which the <u>electric field</u> is oscillating in (only) one plane;

b. 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;

c. (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.

Examiners report

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'.

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

(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.

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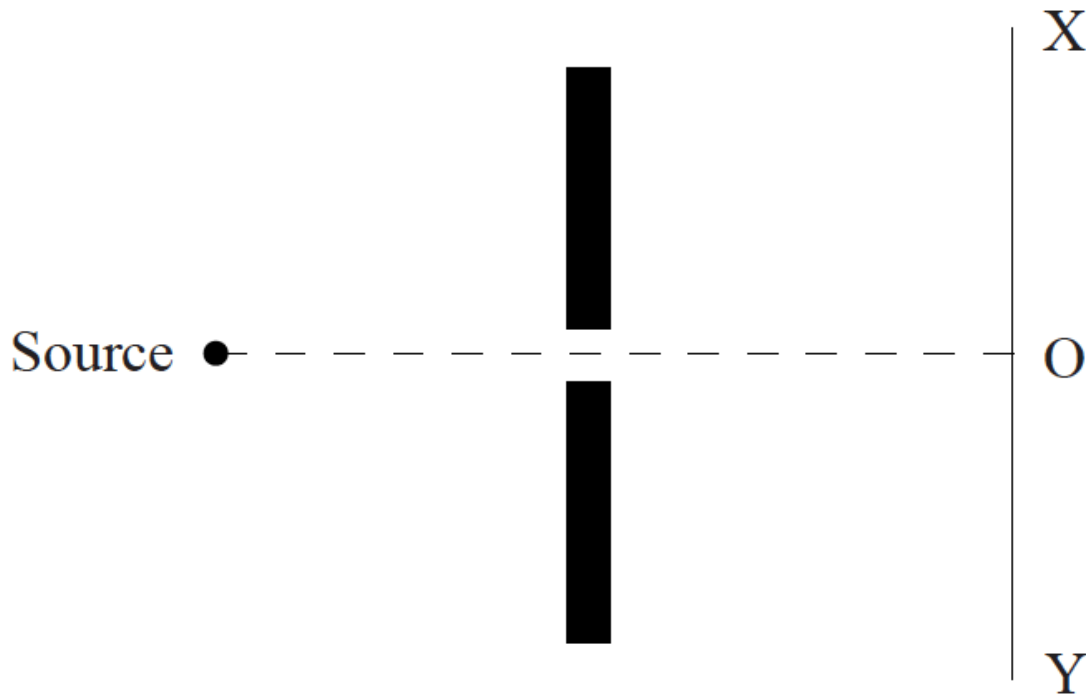
A sound detector is moved along the line XY. The centre of XY is marked O.

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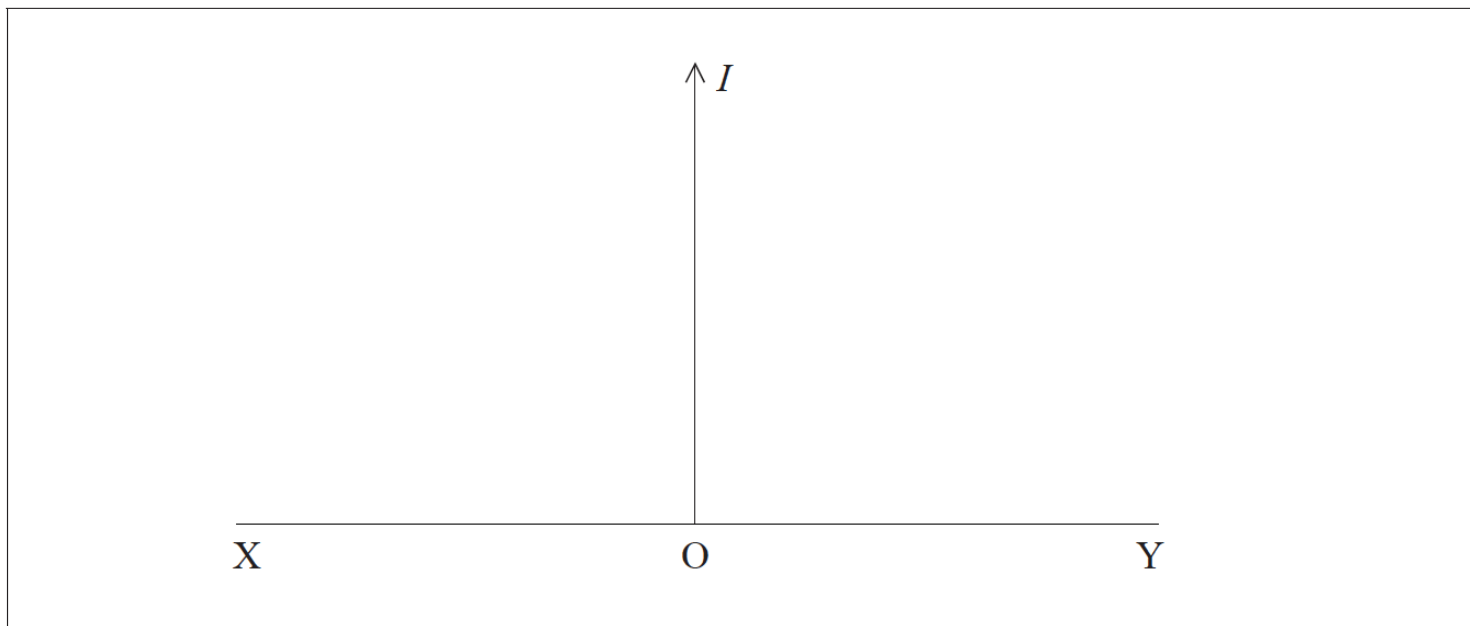
(ii) State the effect on the intensity pattern of increasing the wavelength of the sound.

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

(ii) State why sound waves cannot be polarized.

Markscheme

a. (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.

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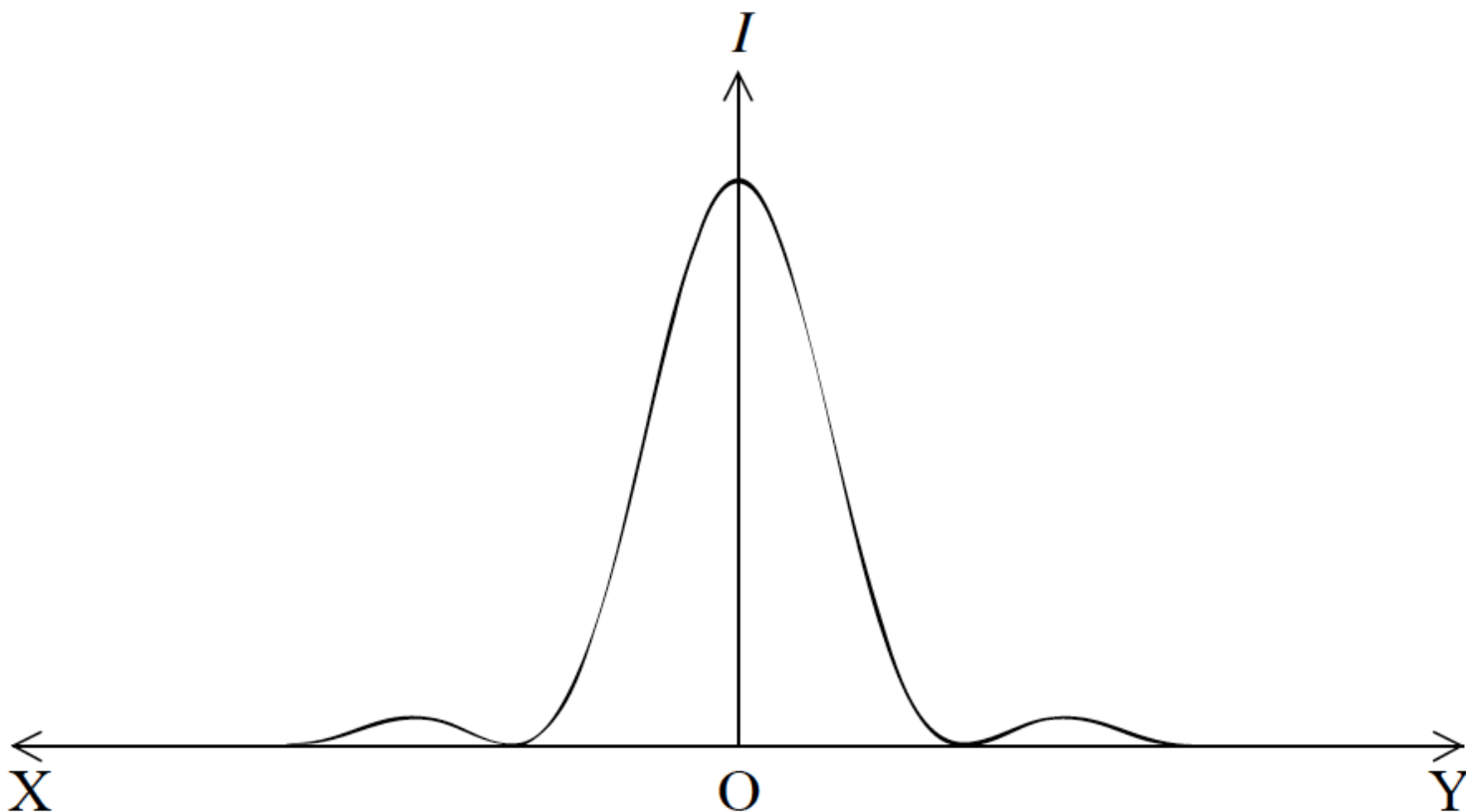
(ii) greater distance between maxima/minima / pattern more spread out;

c. (i) in a polarized wave, the <u>oscillations</u>/<u>vibrations</u> 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;

Examiners report

a. ai) Many candidates scored the first mark for the diagram showing the wavefronts closer on the side of the observer but most of the written explanations just

repeated this and didn't expand further.

aii) This question was very well answered with the majority of candidates choosing the appropriate formula and evaluating correctly.

b. bi) Most candidates were able to score full marks on this question.

bii) Again this was answered successfully.

c. ci) Few candidates included the words oscillations or vibrations in their answers and consequently scored zero marks.

cii) Many recognized that sound waves are longitudinal and that is why they cannot be polarized.

A longitudinal wave is travelling in a medium from left to right. The graph shows the variation with distance x of the displacement y of the particles in

the medium. The solid line and the dotted line show the displacement at $t=0$ and $t=0.882$ ms, respectively.
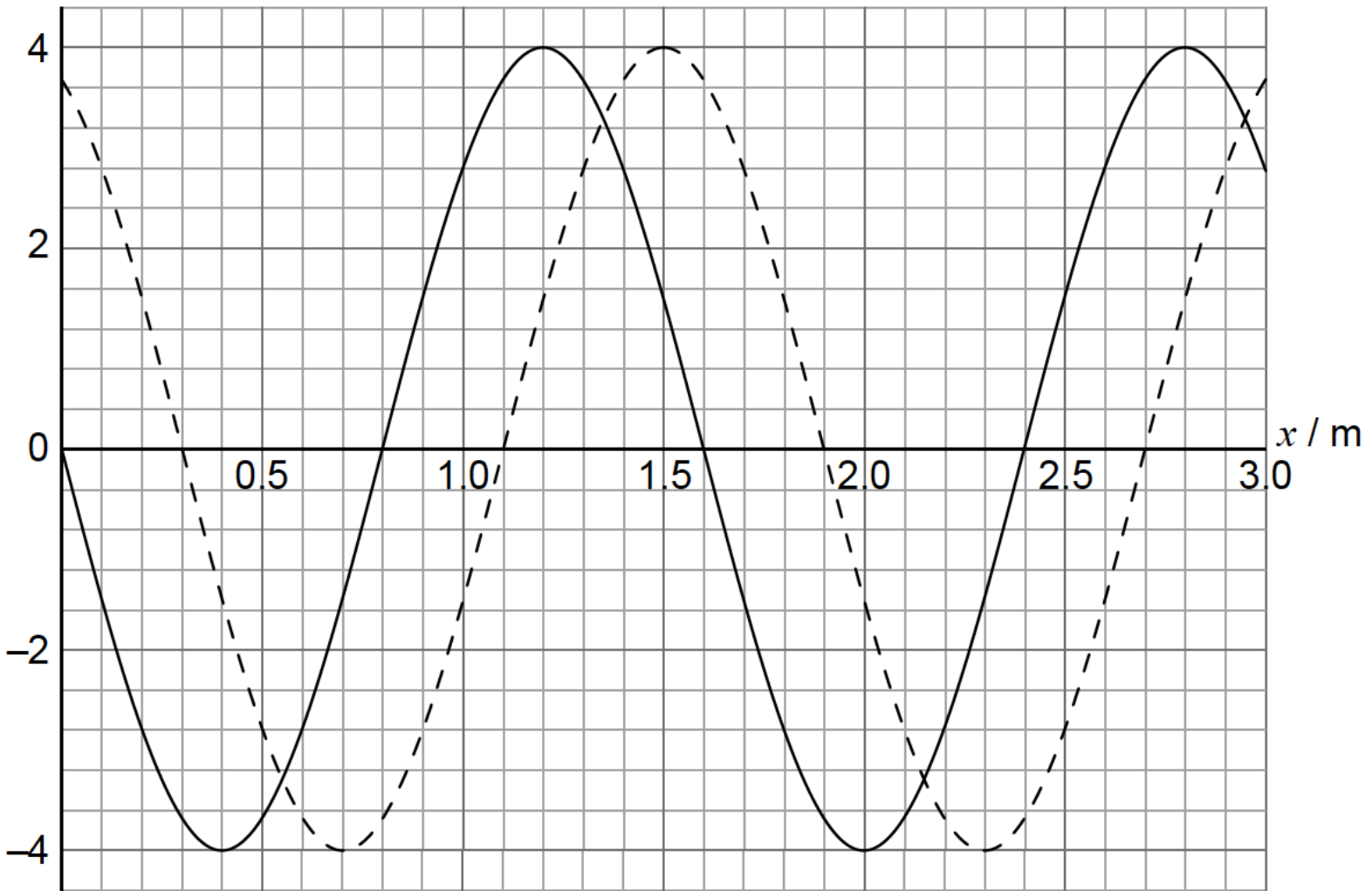
The period of the wave is greater than 0.882 ms. A displacement to the right of the equilibrium position is positive.

b. (i) Calculate the speed of this wave. [4]

(ii) Show that the angular frequency of oscillations of a particle in the medium is $\omega=1.3\times10^3\,\text{rads}^{-1}$.

c. One particle in the medium has its equilibrium position at $x=1.00$ m. [4]

(i) State and explain the direction of motion for this particle at $t=0$.

(ii) Show that the speed of this particle at $t=0.882$ ms is $4.9\,\text{ms}^{-1}$.

d. The travelling wave in (b) is directed at the open end of a tube of length 1.20 m. The other end of the tube is closed. [3]

(i) Describe how a standing wave is formed.

(ii) Demonstrate, using a calculation, that a standing wave will be established in this tube.

Markscheme

b. (i)

ALTERNATIVE 1

«distance travelled by wave =» 0.30 m

$v =\!\ll \frac{\text{distance}}{\text{time}} =\!\gg 340\text{ms}^{-1}$

Examiners report

Monochromatic light is incident normally on four thin, parallel, rectangular slits.

light

slits   distant screen   (not to scale)
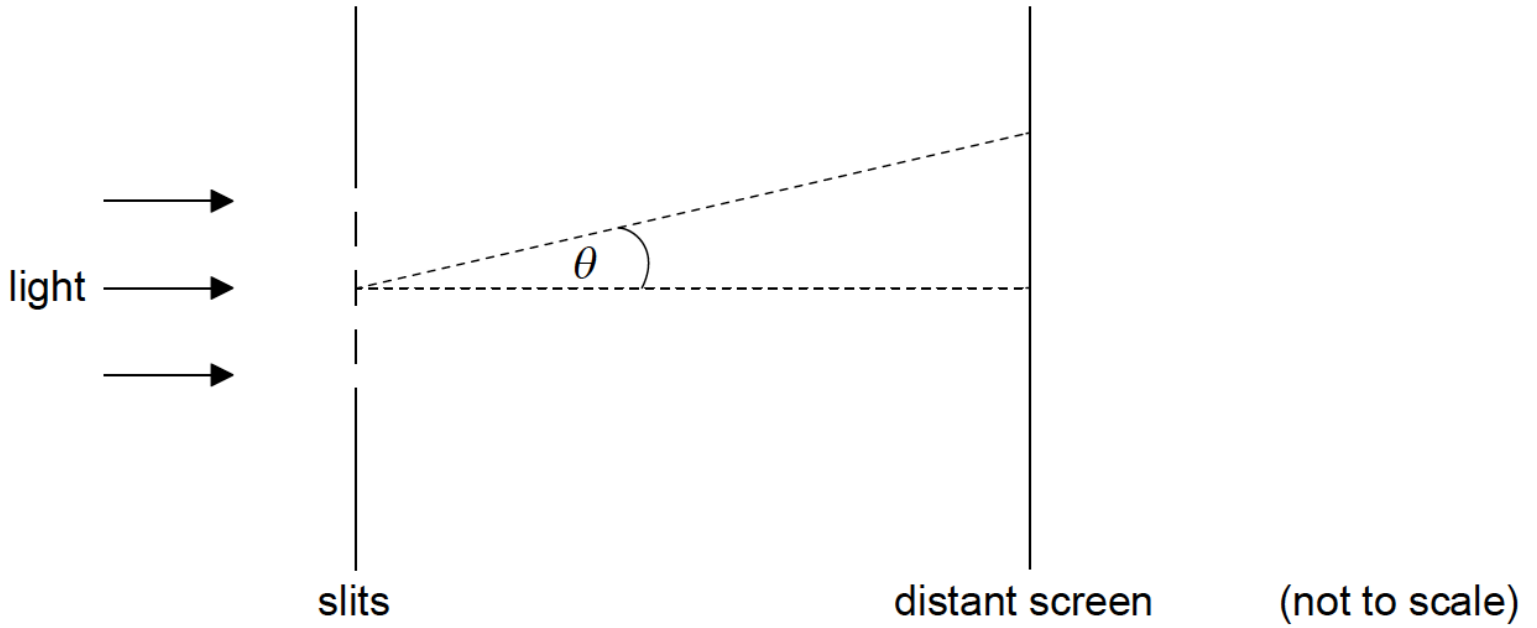
The graph shows the variation with diffraction angle θ of the intensity of light I at a distant screen.

I / I_0

15

10

5

−0.5   0.0   0.5 θ / rad
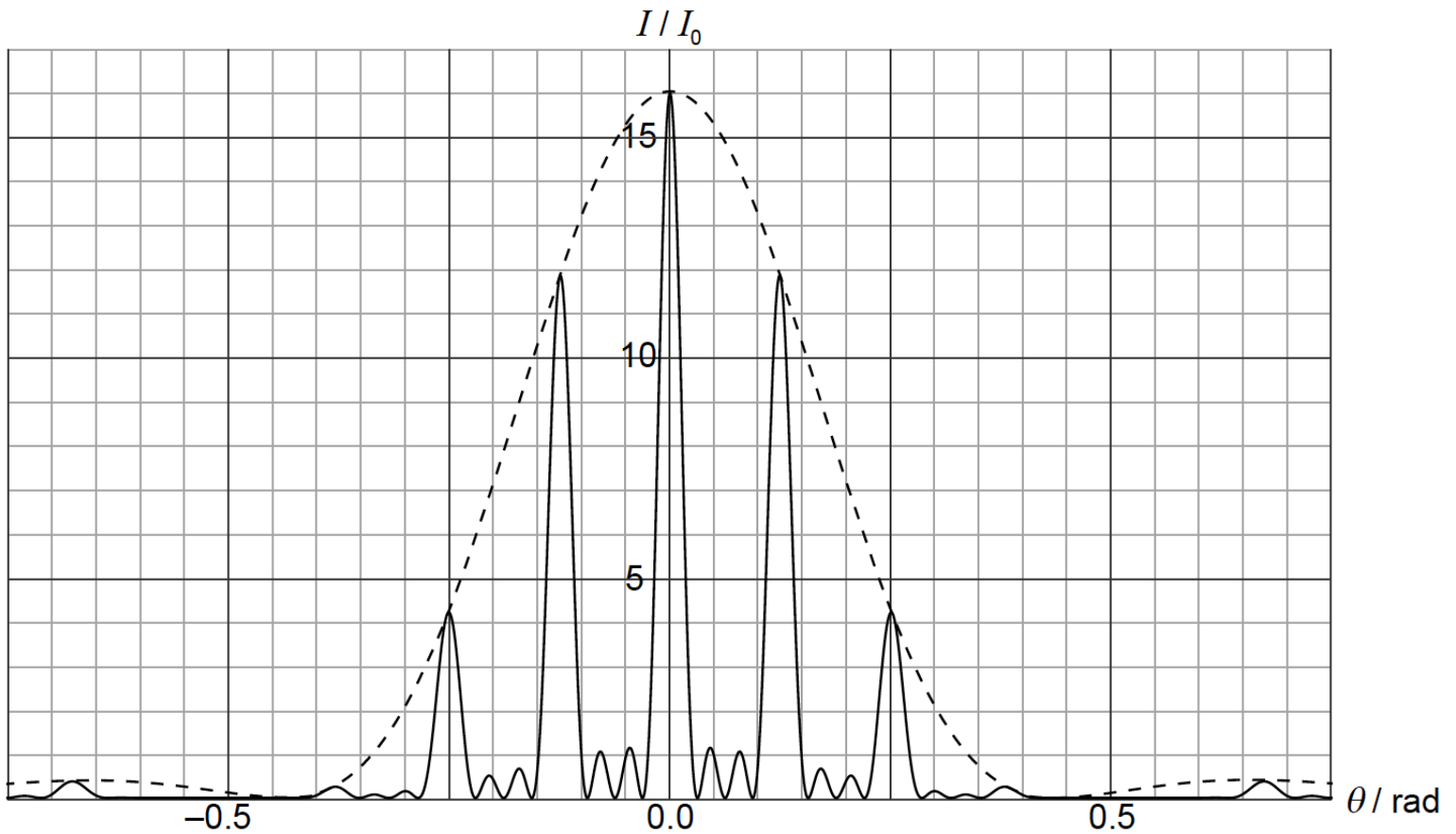
I_0 is the intensity of the light at the middle of the screen from **one** slit.

a. Explain why the intensity of light at $\theta=0$ is $16I_0$.   [3]

b. The width of each slit is 1.0μm. Use the graph to   [4]

(i) estimate the wavelength of light.

(ii) determine the separation of **two** consecutive slits.

c. The arrangement is modified so that the number of slits becomes very large. Their separation and width stay the same.   [4]

(i) State **two** changes to the graph on page 20 as a result of these modifications.

(ii) A diffraction grating is used to resolve two lines in the spectrum of sodium in the second order. The two lines have wavelengths 588.995nm and 589.592nm.

Determine the minimum number of slits in the grating that will enable the two lines to be resolved.

Markscheme

a. constructive interference

amplitude/amount of light from 4 slits is 4 × amplitude «from one slit»

intensity is proportional to amplitude^2 **OR** shows 4^2 = 16 in context of intensity

b. (i)

«diffraction minimum at» θ=0.43rad

$$\lambda = \ll b\theta = 1.0 \times 10^{-6} \times 0.43 = \gg 4.3 \times 10^{-7} \mathrm{m}$$

Accept θ in range 0.41 to 0.45 rad.
Allow λ=bsinθ but do not allow nλ=dsinθ.
Award [1 max] for solution using factor of 1.22.
Award [0] if use of $s = \frac{\lambda D}{d}$ seen.

(ii)
«first secondary maximum at» θ=0.125rad

$$d = \frac{1 \times \mathrm{valuefrom(b)(i)}}{\sin 0.125} = 3.4 \times 10^{-6} \mathrm{m}$$

Accept q in range 0.123 to 0.127 rad.
Sine must be seen to award MP2.
Allow ECF from (b)(i).
Allow use of 2nd or 3rd maxima (0.25 rad and 3.46 μm or 0.375 rad and 3.5 μm with appropriate n).

c. (i)

primary maxima/fringes become brighter/more intense

primary maxima become narrower/sharper

secondary maxima become unimportant/less intense/disappear

Insist on "secondary" for MP3.

(ii)
$$N = \ll \frac{\bar{\lambda}}{m\Delta\lambda} = \gg \frac{589.2935}{2 \times 0.5970}$$
N=494 **or** 500

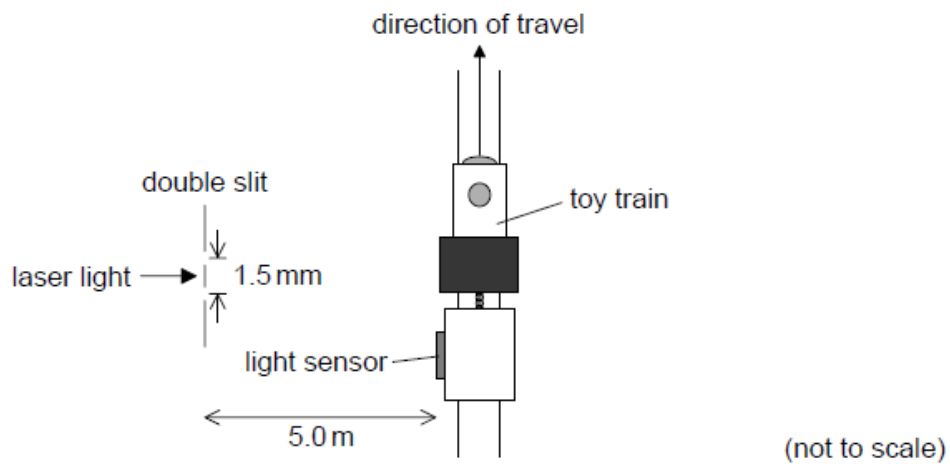*Allow use of 588.995 nm or 589.592 nm for $\bar{\lambda}$.*

Examiners report

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

A student investigates how light can be used to measure the speed of a toy train.

direction of travel

double slit

laser light → 1.5 mm

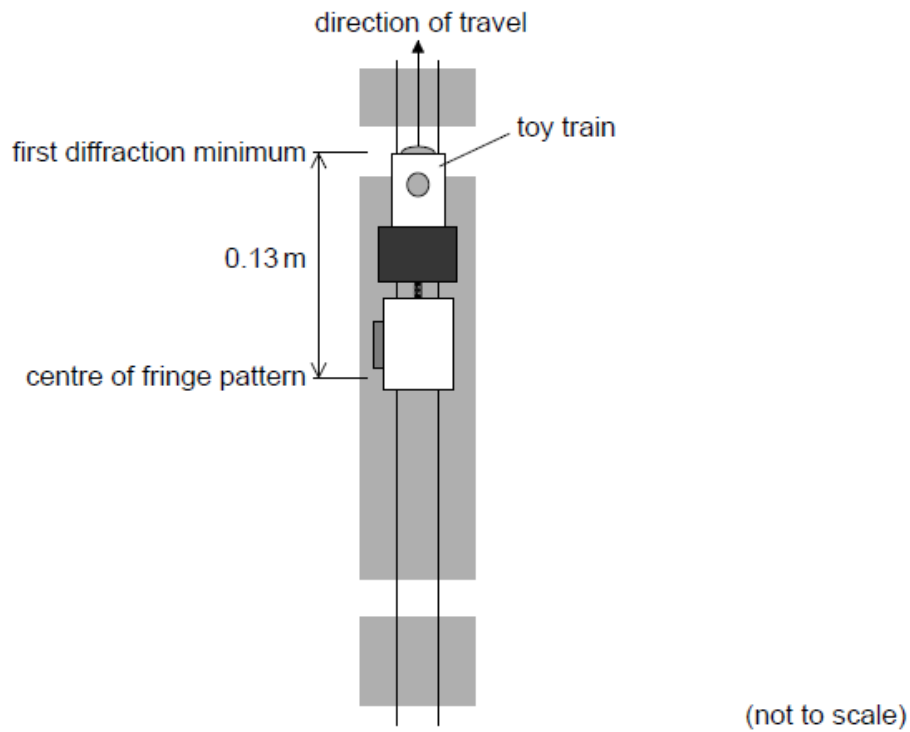light sensor

toy train

5.0 m

(not to scale)

Light from a laser is incident on a double slit. The light from the slits is detected by a light sensor attached to the train.

The graph shows the variation with time of the output voltage from the light sensor as the train moves parallel to the slits. The output voltage is proportional to the intensity of light incident on the sensor.

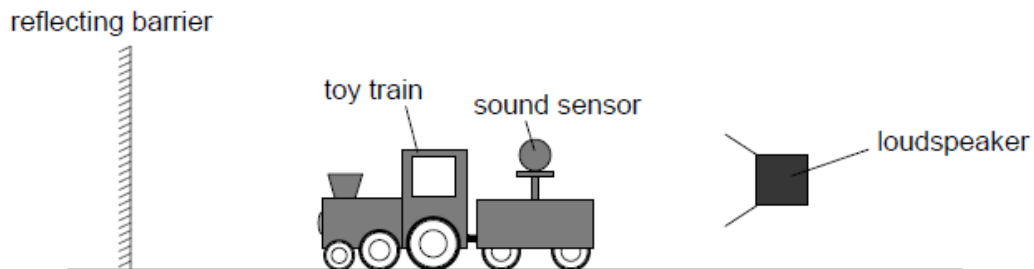output voltage

0

0   25   50   75   100

time / ms
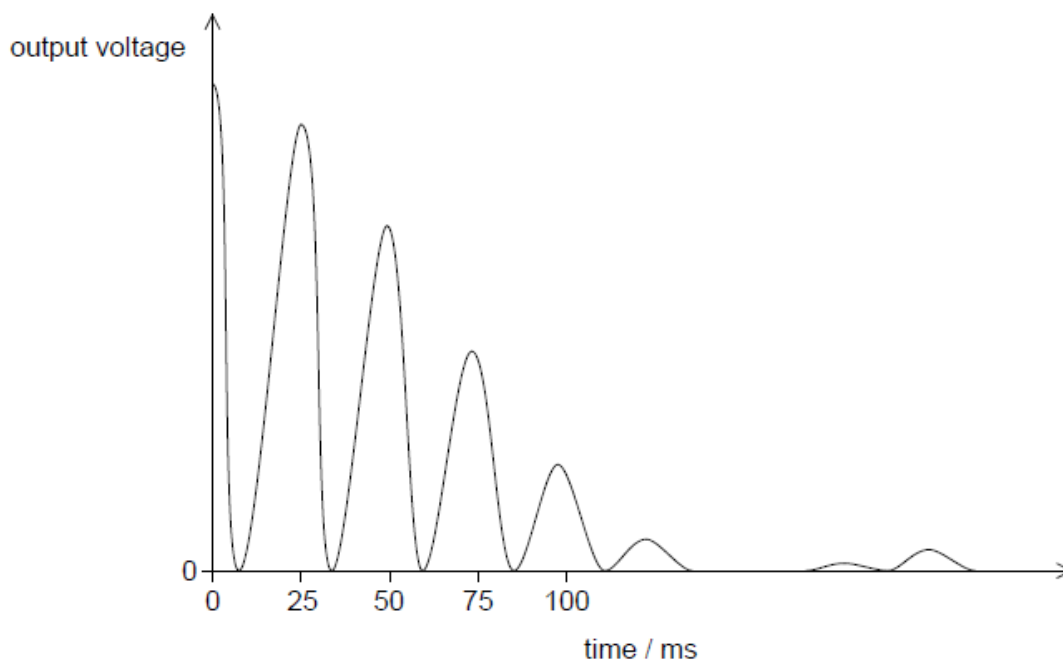
As the train continues to move, the first diffraction minimum is observed when the light sensor is at a distance of 0.13 m from the centre of the fringe pattern.

direction of travel

toy train

first diffraction minimum

0.13 m

centre of fringe pattern

(not to scale)

c.i. Determine the width of one of the slits. [2]

c.ii. Suggest the variation in the output voltage from the light sensor that will be observed as the train moves beyond the first diffraction minimum. [2]

d. In another experiment the student replaces the light sensor with a sound sensor. The train travels away from a loudspeaker that is emitting [2]

sound waves of constant amplitude and frequency towards a reflecting barrier.

reflecting barrier

toy train

sound sensor

loudspeaker

The graph shows the variation with time of the output voltage from the sounds sensor.

output voltage

time
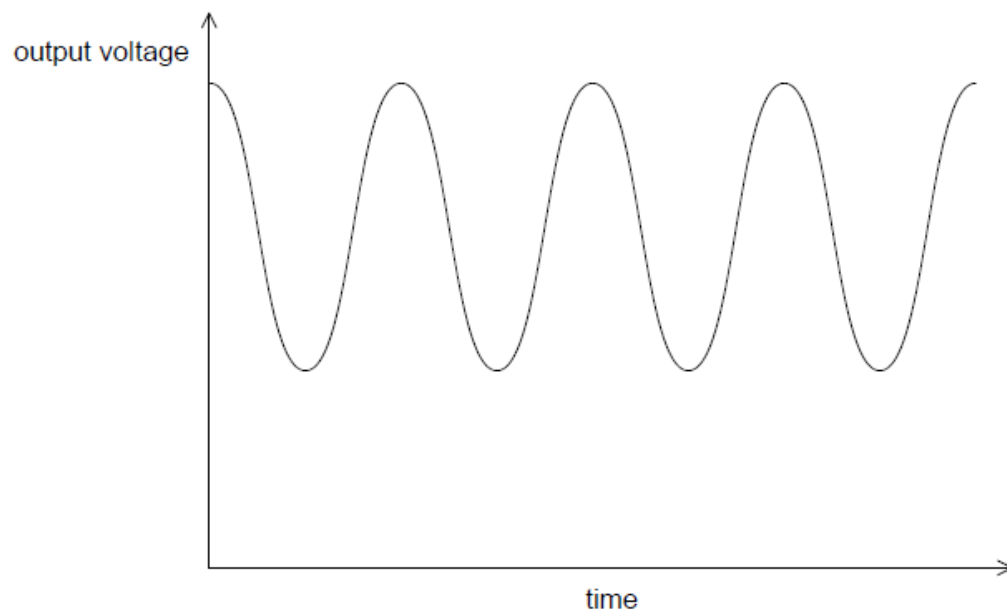
Explain how this effect arises.

Markscheme

c.i. angular width of diffraction minimum = $\frac{0.13}{5.0}$ «= 0.026 rad»

slit width = «$\frac{\lambda}{d} = \frac{6.3 \times 10^{-7}}{0.026}$ =» 2.4 x 10^{-5} «m»

*Award **[1 max]** for solution using 1.22 factor.*

c.ii. «beyond the first diffraction minimum» average voltage is smaller

«voltage minimum» spacing is «approximately» same

OR

rate of variation of voltage is unchanged

OWTTE

d. «reflection at barrier» leads to two waves travelling in opposite directions

mention of formation of standing wave

maximum corresponds to antinode/maximum displacement «of air molecules»
OR
complete cancellation at node position
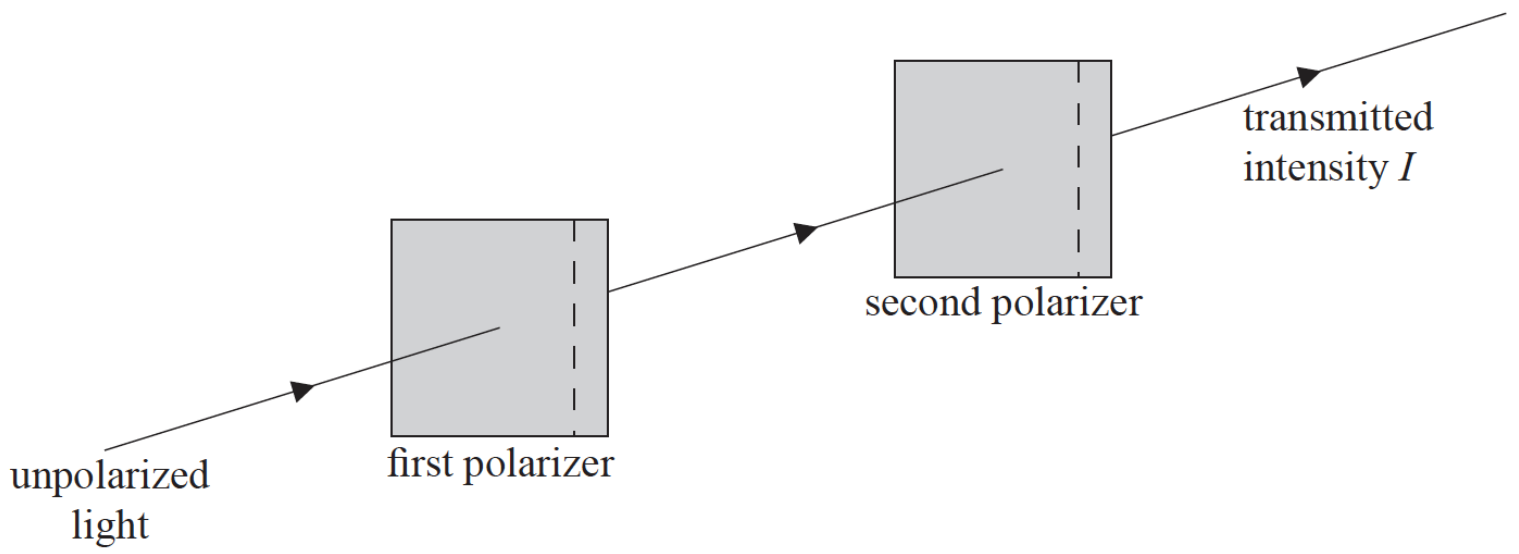
Examiners report

c.i. [N/A]
c.ii. [N/A]
d. [N/A]

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 0 °.
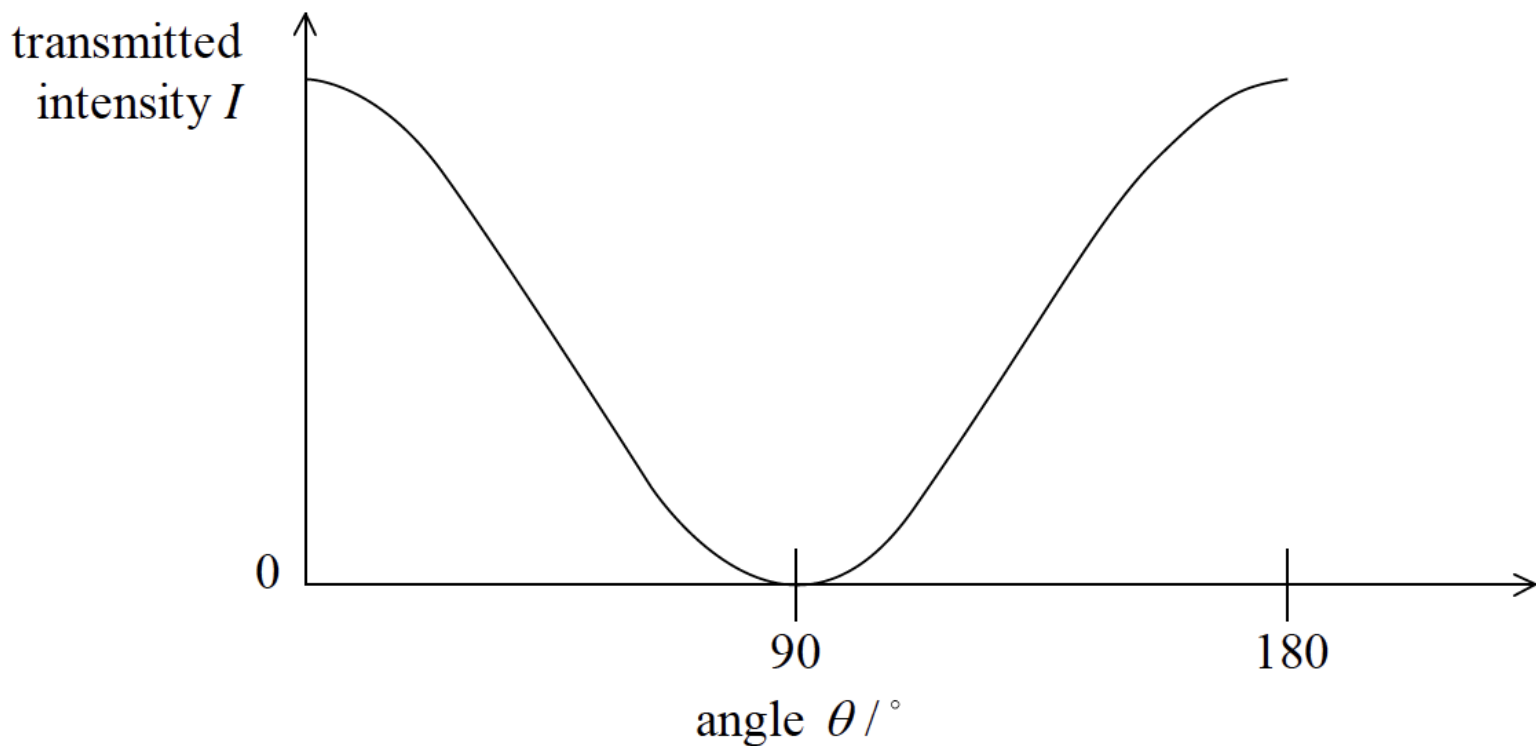
On the axes below, sketch a graph to show how the intensity *I* of the light emerging from the second polarizer varies with θ.
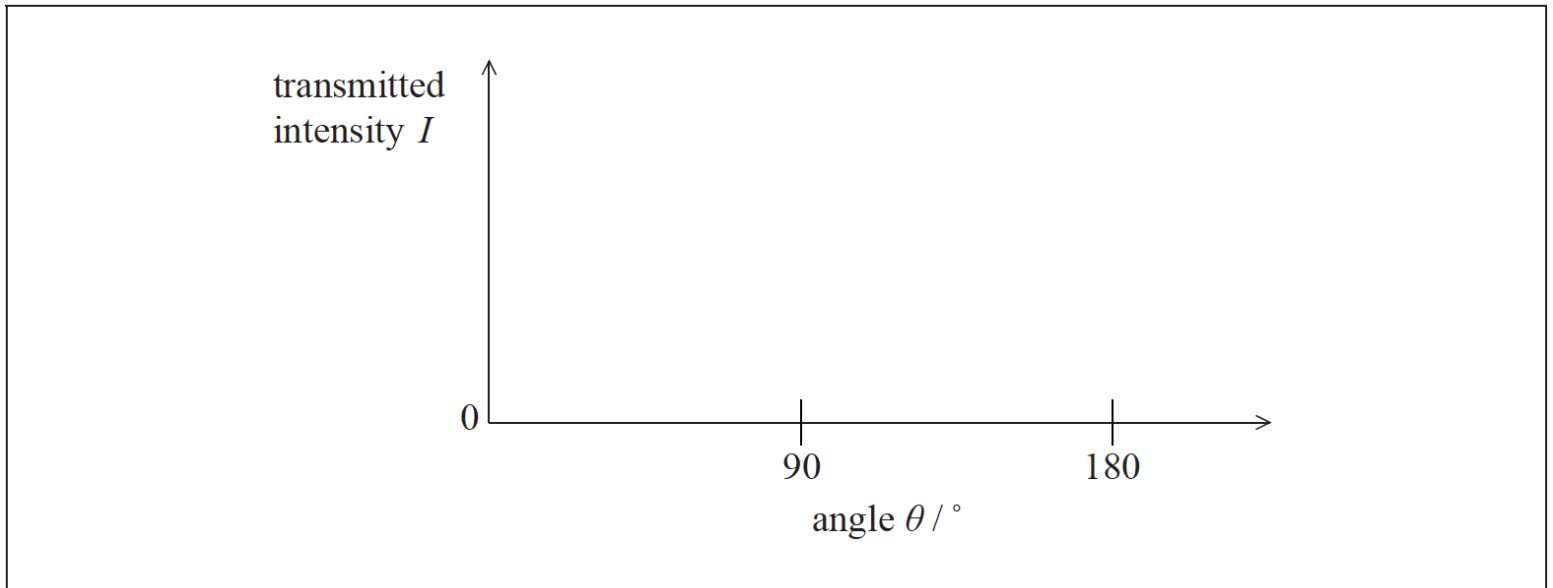
Markscheme

general cos² shape;

zero intensity at 90° and maximum at both 0° and 180°;
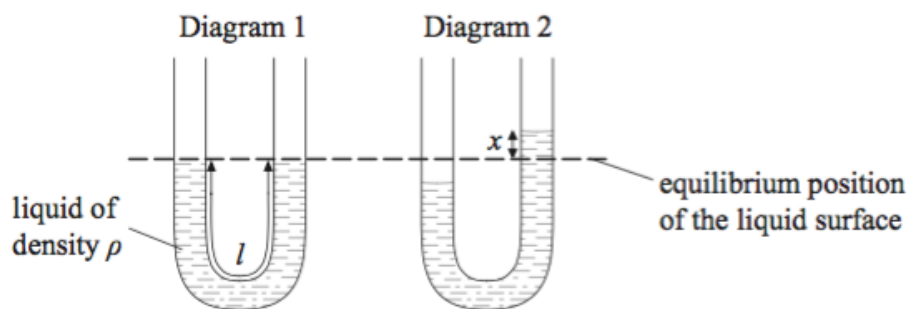
Examiners report

This question is about simple harmonic motion (SHM), wave motion and polarization.

b. A liquid is contained in a U-tube.   [7]

The pressure on the liquid in one side of the tube is increased so that the liquid is displaced as shown in diagram 2. When the pressure is

suddenly released the liquid oscillates. The damping of the oscillations is small.

(i) Describe what is meant by damping.

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

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

where g is the acceleration of free fall and l is the total length of the liquid column. Explain, with reference to the motion of the liquid, the significance of the minus sign.

(iii) The total length of the liquid column in the tube is 0.32m. Determine the period of oscillation.

d. The string in (c) is fixed at both ends and is made to vibrate in a vertical plane in its first harmonic. [6]

(i) Describe how the standing wave in the string gives rise to the first harmonic.
(ii) Outline how a travelling wave in a string can be used to describe the nature of polarized light.

Markscheme

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

Do not allow bald "friction".

(ii) the displacement and acceleration/force acting on (the surface); are in opposite directions;

(iii) $\omega = \sqrt{\frac{2g}{l}}$;
$T = 2\pi\sqrt{\frac{0.32}{2\times9.81}}$;
=0.80s;

d. (i) wave <u>reflects</u> at ends (of string);

interference/superposition occurs (between waves);

regions of maximum displacement/zero displacement form (that do not move);

one region of max displacement/antinode forms at centre with zero displacement/node at each end; {(*allow these marking points from clear diagram*)

(ii) the waves (in a string) are transverse and vibrate only in one plane;

light waves are transverse electromagnetic waves;

(and) for polarized light the electric field vector vibrates only in one plane;

Examiners report

b. Candidates had some uncertainty in discussing the negative sign in the SHM equation for the U-tube example. They were unclear about the terms in the equation and the relative direction of the vector quantities concerned.

d. (i) Although there were many suggestions that the wave is reflected at one end of the string and that this interferes in some way with the incident wave to produce the standing wave these were generally weak and incomplete. Some candidates focussed entirely on the shape of the standing wave (not really the question). It was rare to see 3 marks awarded; 2 was more common.

(ii) Candidates were vague as to the nature of polarized light (a clear description in terms of the field vectors was required), as to the description of the travelling wave on the string, and as to the way in which it could be used. Many will have seen the demonstration in the laboratory but could not describe it with clarity.