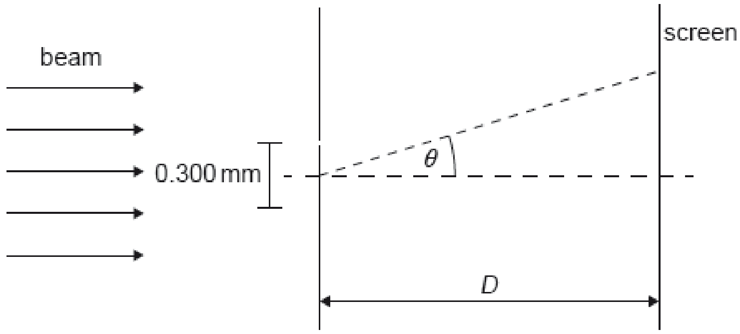
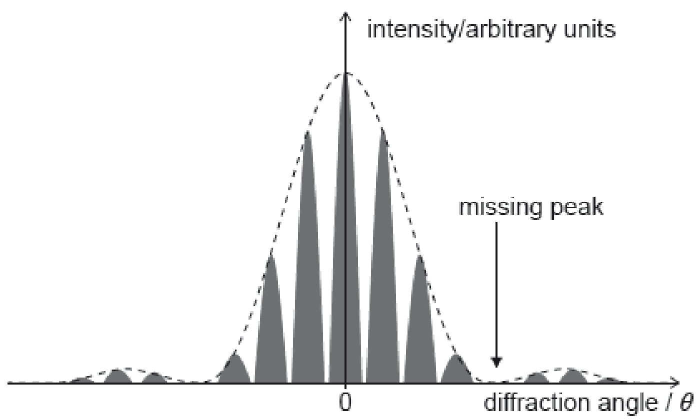
HL Paper 2

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 answer to an appropriate number of significant figures. [3]

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. $\sin\theta = \frac{4\times633.0\times10^{-9}}{0.300\times10^{-3}}$

$\sin\theta = 0.0084401\ldots$

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

$\frac{633.0\times10^{-9}}{0.00844}$

«=» 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

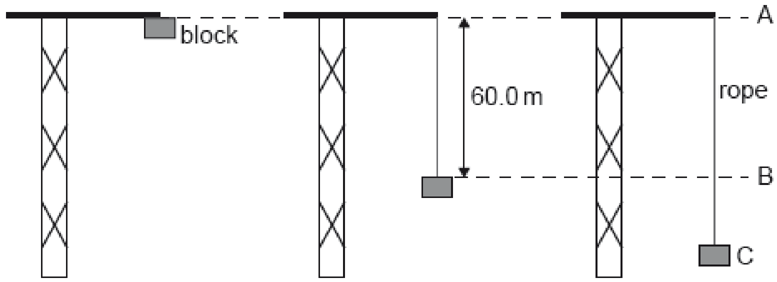
Allow ECF for MP2 (ie wavelength decreases so moving towards).

[2 marks]

Examiners report

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

An elastic climbing rope is tested by fixing one end of the rope to the top of a crane. The other end of the rope is connected to a block which is initially at position A. The block is released from rest. The mass of the rope is negligible.



The unextended length of the rope is 60.0 m. From position A to position B, the block falls freely.

In another test, the block hangs in equilibrium at the end of the same elastic rope. The elastic constant of the rope is 400 Nm^{-1}. The block is pulled 3.50 m vertically below the equilibrium position and is then released from rest.

e.i. Calculate the time taken for the block to return to the equilibrium position for the first time. [2]

e.ii. Calculate the speed of the block as it passes the equilibrium position. [2]

Markscheme

e.i. $T = 2\pi\sqrt{\frac{80.0}{400}} = 2.81$ «s»

time $= \frac{T}{4} = 0.702$ «s»

*Award **[0]** for kinematic solutions that assume a constant acceleration.*

[2 marks]

e.ii. ***ALTERNATIVE 1***

$\omega = \frac{2\pi}{2.81} = 2.24$ «rad s^{-1}»

$v = 2.24 \times 3.50 = 7.84$ «ms^{-1}»

ALTERNATIVE 2

$\frac{1}{2}kx^2 = \frac{1}{2}mv^2$ ***OR*** $\frac{1}{2}400 \times 3.5^2 = \frac{1}{2}80v^2$

$v = 7.84$ «ms^{-1}»

*Award **[0]** for kinematic solutions that assume a constant acceleration.*

Allow ECF for T from (e)(i).

[2 marks]

Examiners report

e.i. [N/A]

e.ii. [N/A]

a. 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]

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.

b. 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]

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

a. 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.

b. $x = \frac{31\times10^{3}\times1.22\times2.5\times10^{-2}}{9.3}$

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

Award ***[1 max]*** *for POT error.*

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

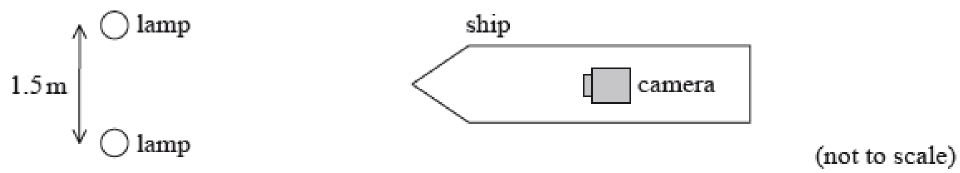
Examiners report

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

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

*Award **[2 max]** if distance is $1.79 \times 10^{4}\ m$ (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) horizontally 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.

Part 2 The Doppler effect and optical resolution

The Doppler effect can be used to deduce that a particular star X is moving towards Earth.

f. Describe what is meant by the Doppler effect. [2]

g. One of the lines in the spectrum of atomic hydrogen has a frequency of 4.6×10^{16}Hz as measured in the laboratory. The same line in the spectrum of star X is observed on Earth to be shifted by 1.3×10^{12}Hz. [4]

(i) State the direction of the observed frequency shift.

(ii) Determine the speed at which X is moving towards Earth stating any assumption that you have made.

h. The star X has a companion star Y. The distance from Earth to the stars is 1.0×10^{18}m. The images of X and Y are just resolved according to the Rayleigh criterion by a telescope on Earth with a circular eyepiece lens of diameter 5.0×10^{-2}m. [5]

(i) State what is meant by the statement “just resolved according to the Rayleigh criterion”.

(ii) The average wavelength of the light emitted by the stars is 4.8×10^{-7}m. Determine the separation of X and Y.

Markscheme

f. the observed change in frequency/wavelength of a wave;

emitted by a source moving away from or towards/relative to the observer;

g. (i) a blue-shift / towards the blue end of the spectrum / to a higher frequency / *OWTTE*;

(ii) $v = \left(\frac{c\Delta f}{f} =\right) \frac{3\times10^{8}\times1.3\times10^{12}}{4.6\times10^{16}}$;
$8.5\times10^{3}ms^{-1}$;
assume that the speed is very much less than speed of light;

h. (i) the two stars are (just) seen as separate images;

if the central maximum of the diffraction image of one star coincides with the first minimum of the diffraction image of the other star / *OWTTE*;

Accept an appropriate diagram for second marking point.

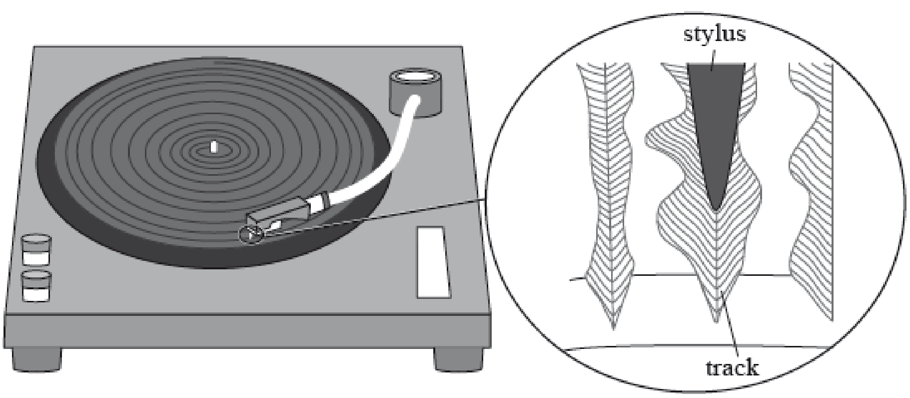
(ii) $\theta = \left(\frac{1.22\lambda}{b} =\right) \frac{1.22\times4.8\times10^{-7}}{5.0\times10^{-2}}$ ***or*** 1.17×10^{-5}rad;
$\theta = \frac{d}{1.0\times10^{18}}$;
(d=)1.2×10^{13}m;
*Award **[2 max]** if 1.22 is missing, giving an answer of 0.98×10^{13}.*

Examiners report

f. [N/A]
g. [N/A]
h. [N/A]

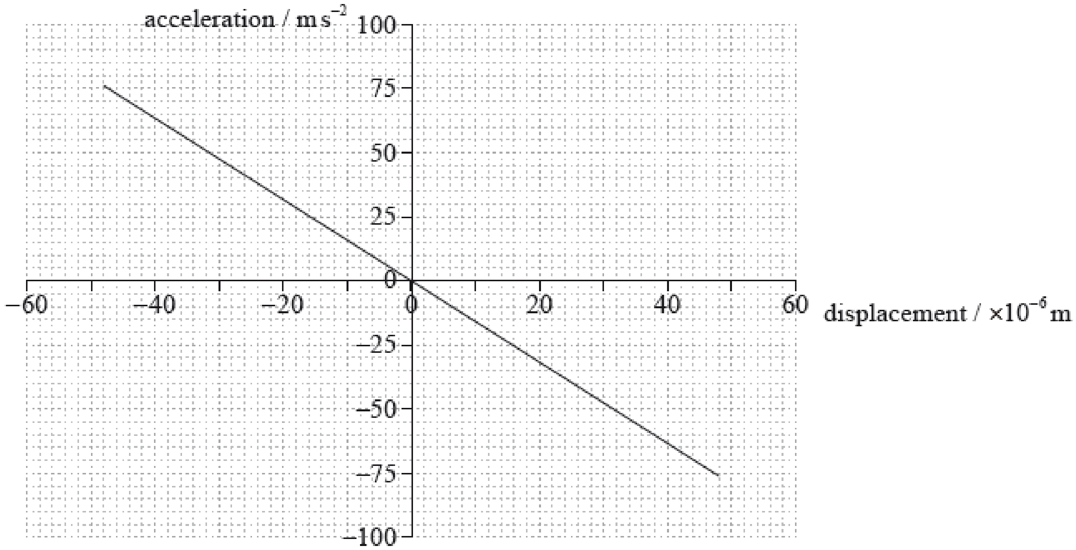
This question is about simple harmonic motion (SHM) and sound.

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.



The mass of the stylus is 5.5×10^{-4} kg. Determine the maximum kinetic energy of the stylus.

Markscheme

$x_0 = 4.8 \times 10^{-5}$ (m);

$E_k = \frac{1}{2}m\omega^2 x_0^2 = 9.9 \times 10^{-7}$ (J) ***or*** 1.0×10^{-6} (J);

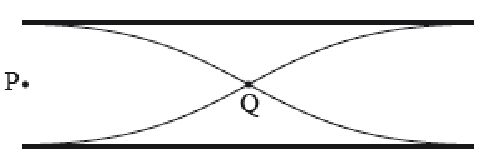
*Allow **[2]** for a bald correct answer.*

Examiners report

[N/A]

This question is about waves.

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

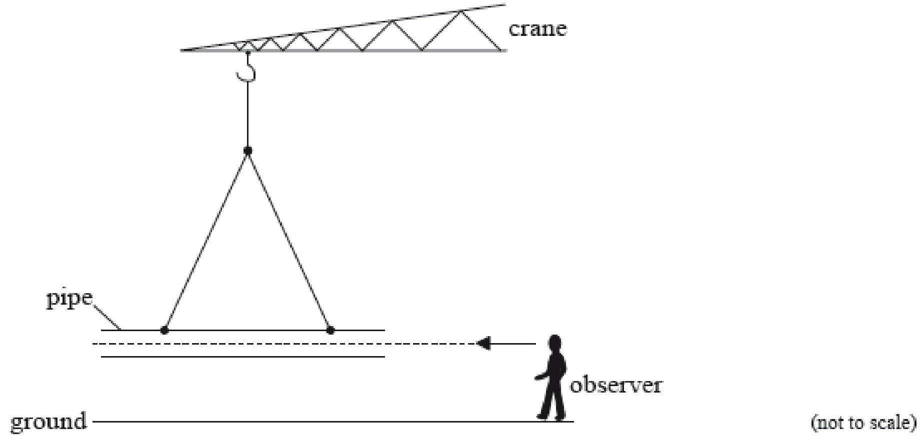


Two points in the pipe are labelled P and Q.

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. $\lambda = 4.2\ \mathrm{m}$;

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.

Part 2 Resolution and the Doppler effect

a. Radio telescopes can be used to locate distant galaxies. The ability of such telescopes to resolve the images of galaxies is increased by using two telescopes separated by a large distance *D*. The telescopes behave as a single radio telescope with a dish diameter equal to *D*. [5]

The images of two distant galaxies G_1 and G_2 are just resolved by the two telescopes.

(i) State the phenomenon that limits the ability of radio telescopes to resolve images.

(ii) State the Rayleigh criterion for the images of G_1 and G_2 to be just resolved.

(iii) Determine, using the following data, the separation *d* of G_1 and G_2 .

Effective distance of G_1 and G_2 from Earth = 2.2×10^{25} m
Separation $D = 4.0 \times 10^3$ m
Wavelength of radio waves received from G_1 and G_2= 0.14 m

b. Due to the Doppler effect, light from distant galaxies is often red-shifted. [5]

(i) Describe, with reference to the Doppler effect, what is meant by red-shift.

(ii) The frequency of a particular spectral line as measured in the laboratory is 4.57×10^{14} Hz. The same line in the spectrum of a distant galaxy has a frequency that is lower than the laboratory value by 6.40×10^{11} Hz. Determine the speed with which the galaxy is receding from Earth.

Markscheme

a. (i) diffraction;

(ii) the (central) maximum of the diffraction pattern of one image coincides with the first minimum of the diffraction pattern of the other image;
Allow mark for clear diagram.

(iii) angular separation of G_1 and $G_2 = \frac{d}{2.2\times10^{25}}$;
$\frac{d}{2.2\times10^{25}} = \left(1.22\frac{\lambda}{D} =\right) \frac{1.22\times0.14}{4.0\times10^{3}}$;
d□9.4□10^{20} m;

b. (i) if there is relative motion between source/galaxy and observer/Earth;

the observed frequency/wavelength will differ from the source frequency/wavelength;

the observed frequency will be lower / the observed wavelength will be greater if the direction of relative motion is away from the source;

(to award the mark it must be clear in which direction a red-shift occurs)

*Award **[3]** for a good description that mentions all of the above.*

*Award **[3]** for a clear annotated diagram that shows all of the above points.*

(ii) $\frac{\Delta f}{f} = \frac{v}{3\times10^8} = \left(\frac{6.40\times10^{11}}{4.57\times10^{14}} =\right) 1.40 \times 10^{-3}$;
$v = \left(3 \times 10^8 \times 1.40 \times 10^{-3} =\right) 4.20 \times 10^5 \text{ms}^{-1}$;

Examiners report

a. (i) Many recognized that the phenomenon at work is diffraction. Common incorrect responses included “Rayleigh criterion” and “interference”.

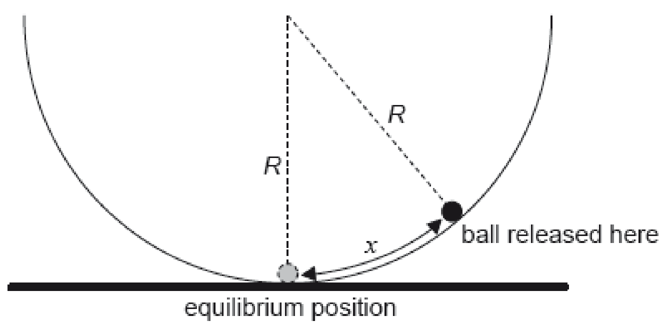
(ii) Candidates often failed to make clear that their answer referred to the diffraction patterns of G_1 and G_2, it was common to see candidates writing about the “first maximum of G_1” etc.

(iii) Many were able to negotiate this two-step calculation with ease.

b. (i) Descriptions of red shift in terms of the Doppler effect were well done with many high marks seen.

(ii) Candidates frequently became confused in this calculation as to the meaning of the symbols quoted in the Data Booklet. Examiners often saw answers of about 3 x 10^8 m s^{-1} (or greater) with no realization by the candidate that an answer of this magnitude is implausible.

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



The magnitude of the force on the ball towards the equilibrium position is given by

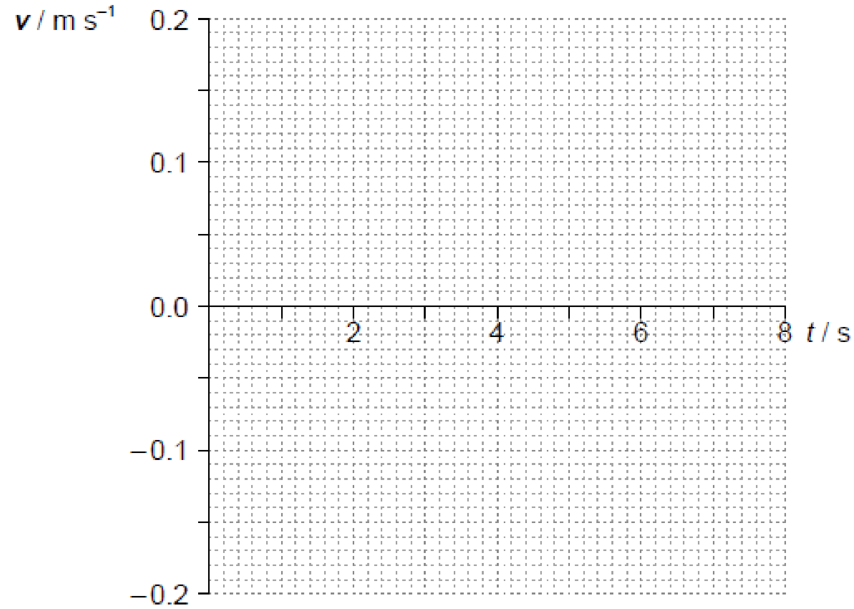
$$\frac{mgx}{R}$$

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 ω = «$\sqrt{\frac{g}{R}}$» = $\sqrt{\frac{9.81}{8.0}}$ «= 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]

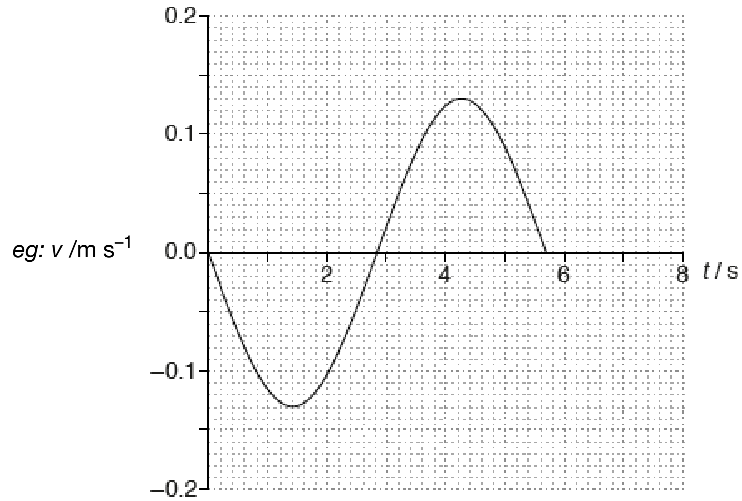
d.iii sine graph

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*

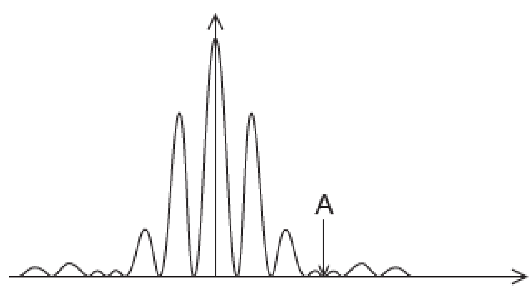


[3 marks]

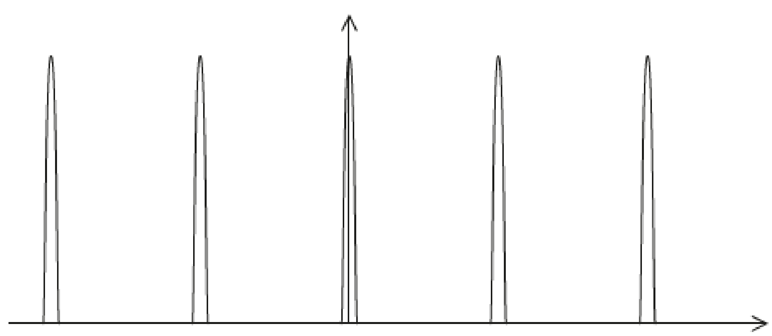
Examiners report

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

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.

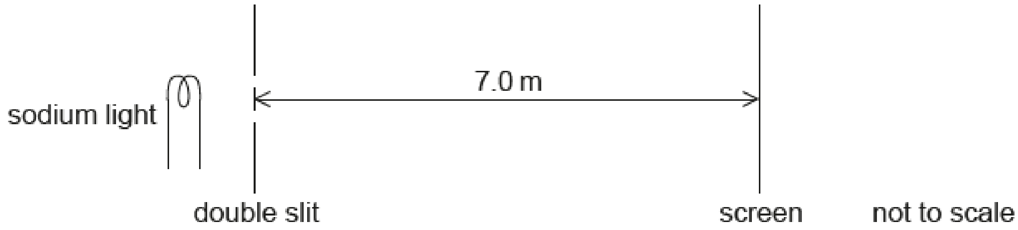


The double slit is replaced by a diffraction grating that has 600 lines per millimetre. The resulting pattern on the screen is shown.



a.i. Explain why zero intensity is observed at position A. [2]

a.ii. 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]



Calculate the width of each slit.

a.iii Calculate the separation of the two slits. [2]

b.i. State and explain the differences between the pattern on the screen due to the grating and the pattern due to the double slit. [3]

b.ii. 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]

Markscheme

a.i. 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 $(n + \frac{1}{2})\lambda$/destructive interference at A

a.ii $\theta = \frac{4.1\times10^{-2}}{7.0}$ ***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

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

3.0×10^{-4} «m»

Allow ECF.

b.i. 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”

b.ii $\Delta\lambda$ = 589.592 – 588.995

OR

$\Delta\lambda$ = 0.597 «nm»

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

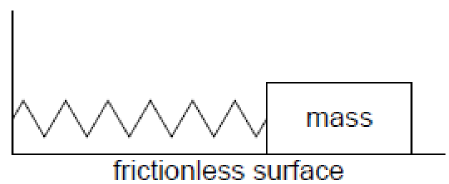
beam width = «$\frac{493}{600}$ =» 8.2 x 10^{-4} «m» ***or*** 0.82 «mm»

Examiners report

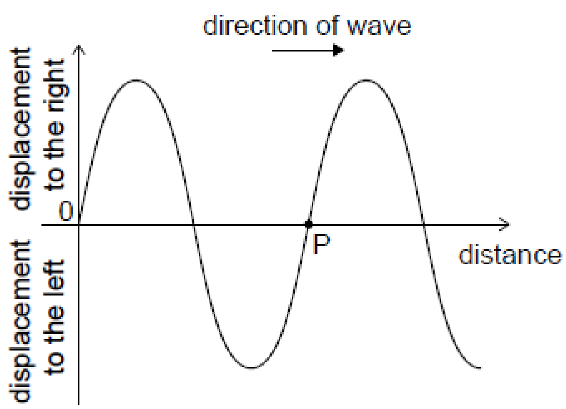
a.i. [N/A]
a.ii. [N/A]
a.iii. [N/A]
b.i. [N/A]
b.ii. [N/A]

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 the oscillation of the wooden block. [3]

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

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. ω = «$\frac{2\pi}{0.74}$» = 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.

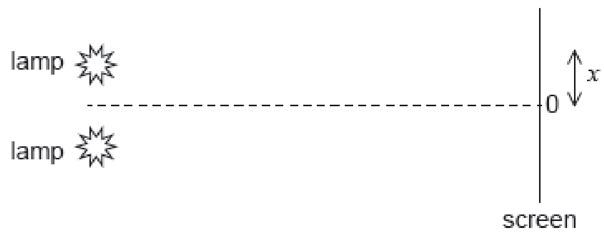
Allow ECF from MP1 if the movement of the coils imply a compression.

Examiners report

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

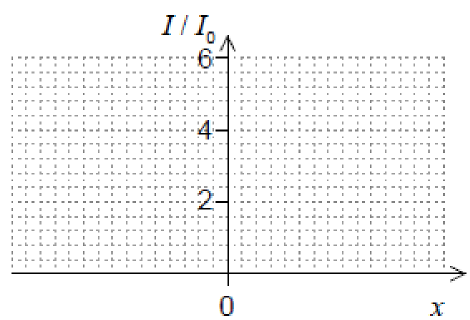
---

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

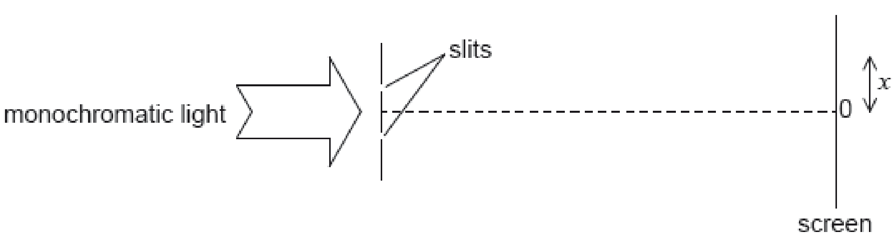


The intensity of light on the screen from each lamp separately is I_0.

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.



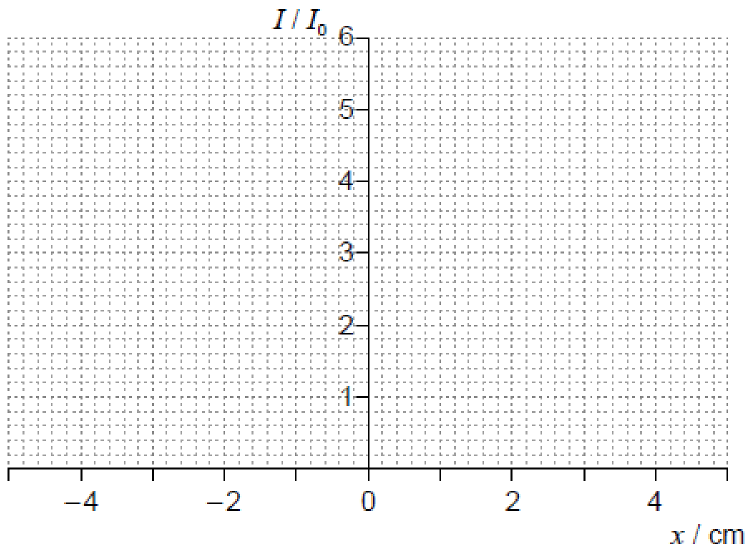
b. Monochromatic light from a single source is incident on two thin, parallel slits. [3]



The following data are available.

$$\begin{aligned} &\text{Slit separation} &&= 0.12 \text{ mm} \\ &\text{Wavelength} &&= 680 \text{ nm} \\ &\text{Distance to screen} &&= 3.5 \text{ m} \end{aligned}$$

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.

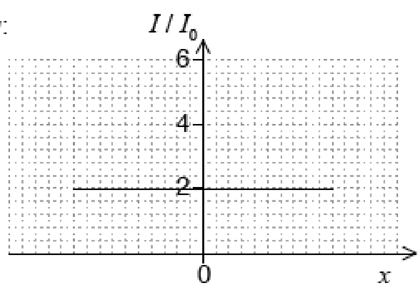


c. The slit separation is increased. Outline **one** change observed on the screen. [1]

Markscheme

a. 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]

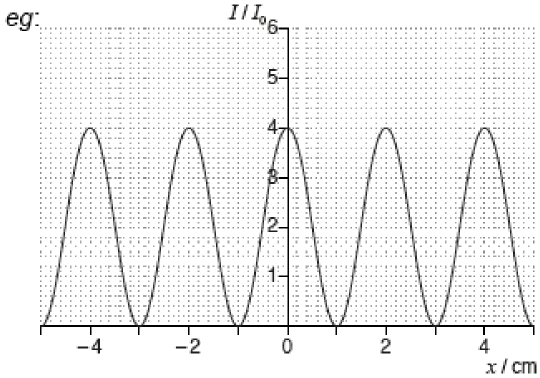
b. «standard two slit pattern»

general shape with a maximum at $x = 0$

maxima at $4I_0$

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 eg:



[3 marks]

c. fringe width/separation decreases

OR

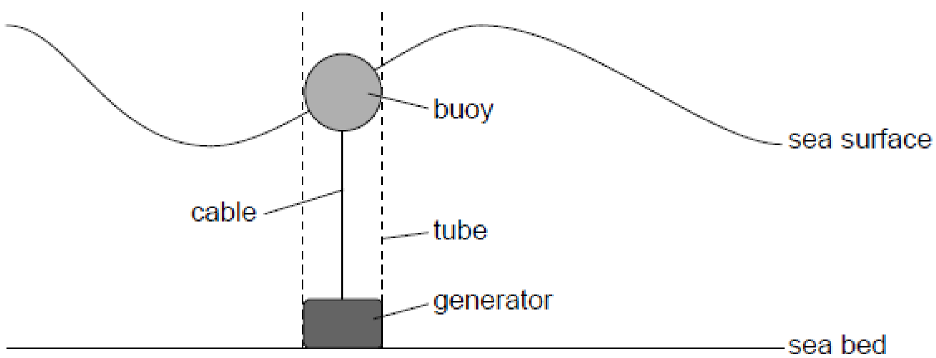
more maxima seen

[1 mark]

Examiners report

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

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.



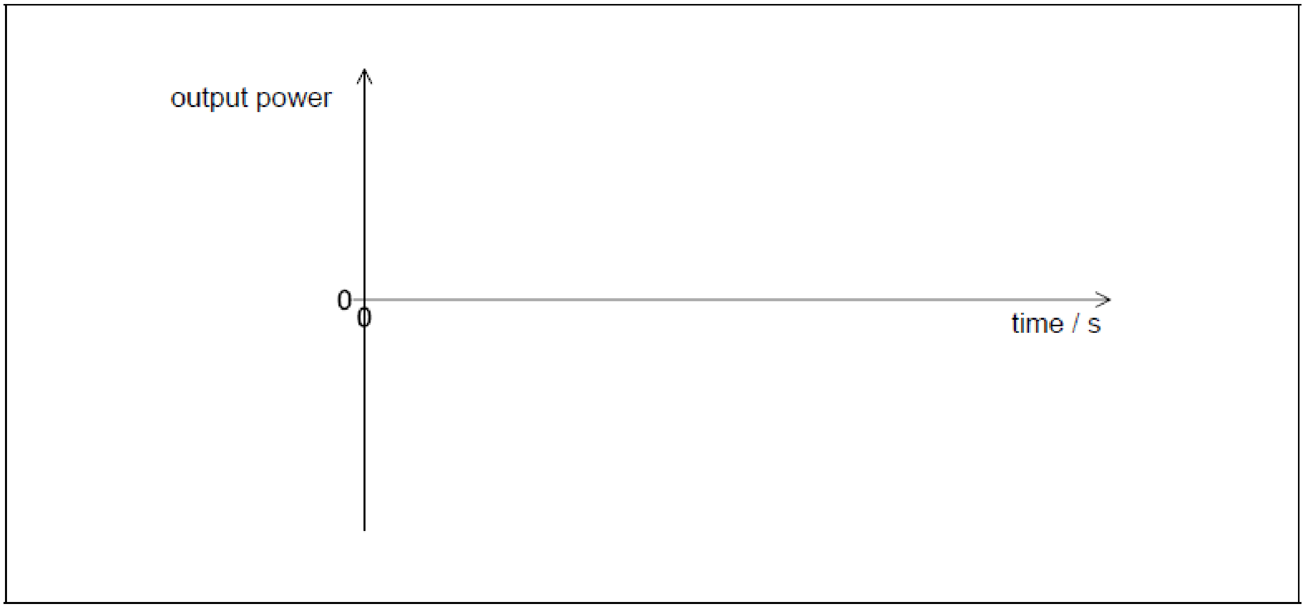
The motion of the buoy can be assumed to be simple harmonic.

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]



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 water arrives at the turbines. Assume that there is no energy loss in the system. [2]

c.iii. 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]

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

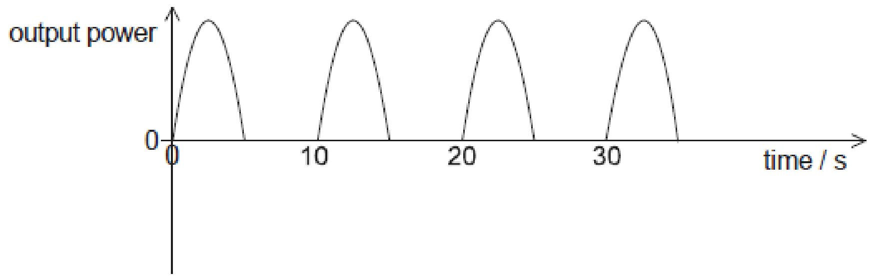
time period of buoy $= \frac{35}{3.4}$ ***or*** 10.3 «s» ***or*** 10 «s»

v = «$\frac{2\pi x_0}{T}$ ***or*** $2\pi f x_0$» $= \frac{2\times\pi\times4.3}{10.3}$ ***or*** $2\times\pi\times0.097\times4.3$

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 = «$\frac{1}{2}mv^2 = \frac{1}{2}\times1.5\times10^{10}\times$ (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.

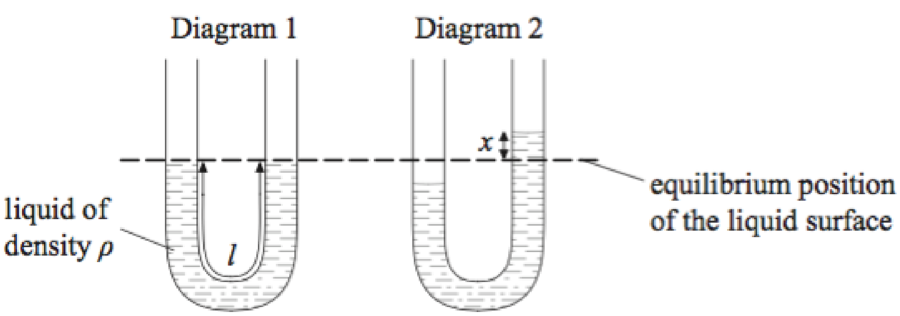
Do not allow “friction” bald.

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 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.

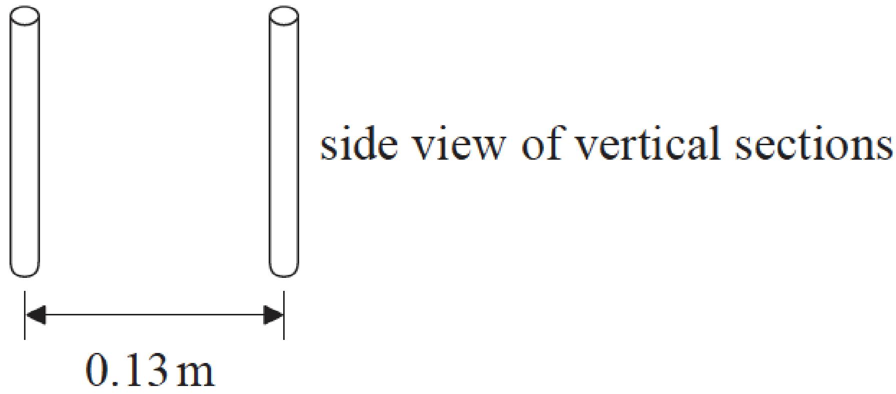
(ii) Candidates were vague as to the nature of polarized light (a clear description in terms of the field vectors was required), as to the description of the travelling wave on the string, and as to the way in which it could be used. Many will have seen the demonstration in the laboratory but could not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

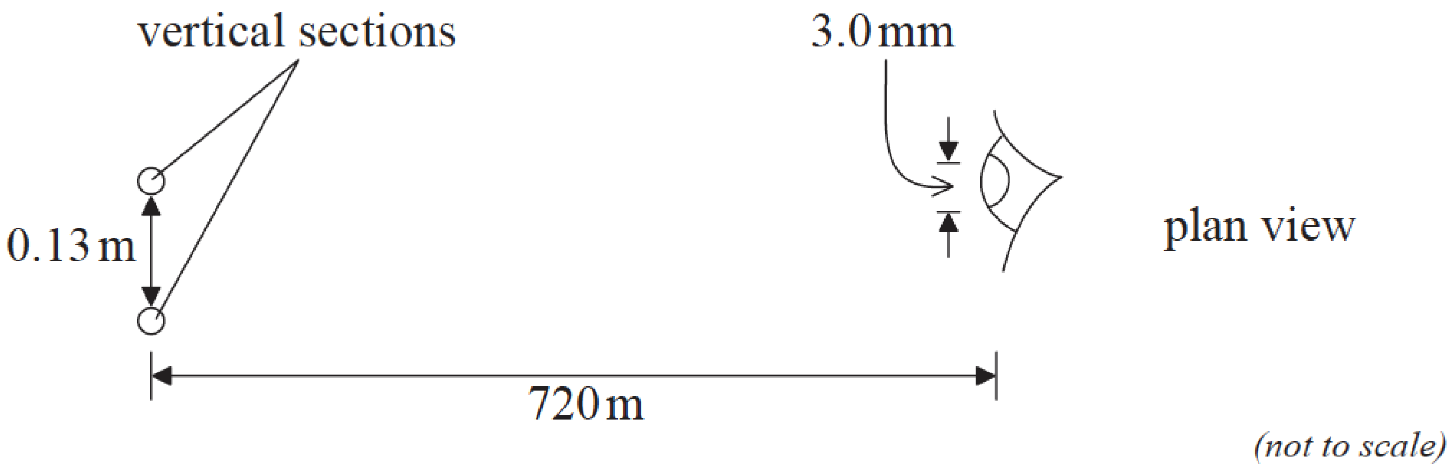
Part 2 Resolution

a. (i) State the wave phenomenon that limits the resolution of the eye. [3]

(ii) State the Rayleigh criterion for determining if the images of two objects are just resolved.

b. An advertising sign contains two straight vertical sections that emit light. [5]





The vertical sections are separated by a horizontal distance of 0.13 m. An observer views them from a distance of 720 m. The wavelength of the emitted light is 510 nm and the diameter of the aperture of the observer's eye is 3.0 mm.

(i) Determine if the images formed on the retina of the observer will be resolved.

(ii) One of the vertical sections is switched off. The observer looks at the illuminated vertical section. The diameter of the aperture of the observer's eye is now 2.5 mm.

Calculate the angular width of the central maximum of the diffraction pattern formed on the observer's retina.

Markscheme

a. (i) diffraction;

(ii) the first minimum of one diffraction pattern;
falls on central maximum of other diffraction pattern;

b. (i) $\theta = \left(1.22 \times \frac{5.1\times10^{-7}}{3.0\times10^{-3}} =\right) 2.1 \times 10^{-4}\,(\text{rad})$;

angular separation of sections$=\left(\frac{0.13}{720} =\right) 1.8 \times 10^{-4}\,(\text{rad})$/ required minimum

separation for resolution$= \left(2.1 \times 10^{-4} \times 720 =\right) 0.15\text{m}$;

they cannot be resolved;

Ignore omission of 1.22 (gives θ=1.7×10^{−4} and (ECF) are just resolved).

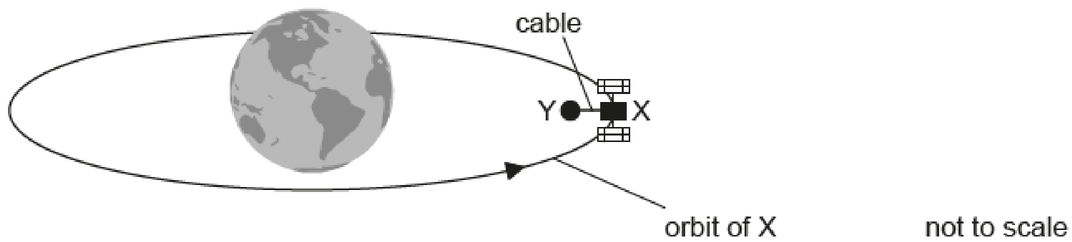
*Award **[0]** for a bald correct answer.*

(ii) $\theta = \left(1.22 \times \frac{510\times10^{-9}}{3.5\times10^{-3}} =\right) 1.78 \times 10^{-4}\,(\text{rad})$;
$3.6 \times 10^{-4}\,(\text{rad})$;
Ignore omission of 1.22 (gives 2.9×10^{-4} (rad)).

Examiners report

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

There is a proposal to power a space satellite X as it orbits the Earth. In this model, X is connected by an electronically-conducting cable to another smaller satellite Y.



Satellite Y orbits closer to the centre of Earth than satellite X. Outline why

The cable acts as a spring. Satellite Y has a mass *m* of 3.5×10^{2} kg. Under certain circumstances, satellite Y will perform simple harmonic motion (SHM) with a period *T* of 5.2 s.

a. Satellite X orbits 6600 km from the centre of the Earth. [2]

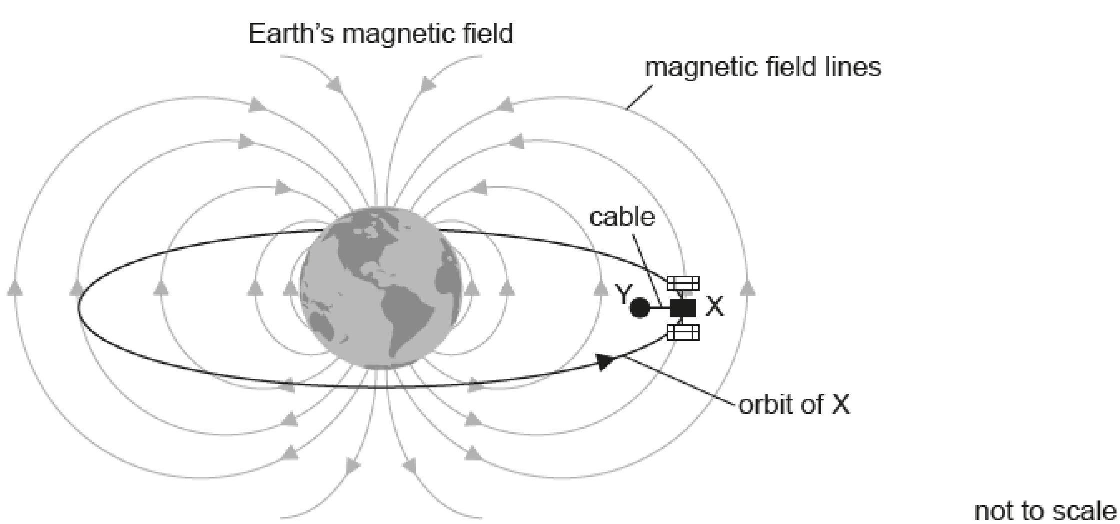
Mass of the Earth = 6.0×10^{24} kg

Show that the orbital speed of satellite X is about 8 km s^{-1}.

b.i. the orbital times for X and Y are different. [1]

b.ii. satellite Y requires a propulsion system. [2]

c. The cable between the satellites cuts the magnetic field lines of the Earth at right angles. [3]



Explain why satellite X becomes positively charged.

d. Satellite X must release ions into the space between the satellites. Explain why the current in the cable will become zero unless there is a method for transferring charge from X to Y. [3]

e. The magnetic field strength of the Earth is 31 μT at the orbital radius of the satellites. The cable is 15 km in length. Calculate the emf induced in the cable. [2]

f.i. Estimate the value of *k* in the following expression. [3]

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Give an appropriate unit for your answer. Ignore the mass of the cable and any oscillation of satellite X.

f.ii. Describe the energy changes in the satellite Y-cable system during one cycle of the oscillation. [2]

Markscheme

a. «$v = \sqrt{\frac{GM_E}{r}}$» = $\sqrt{\frac{6.67\times10^{-11}\times6.0\times10^{24}}{6600\times10^{3}}}$

7800 «m s^{-1}»

Full substitution required

Must see 2+ significant figures.

b.i. Y has smaller orbit/orbital speed is greater so time period is less

Allow answer from appropriate equation

Allow converse argument for X

b.ii. to stop Y from getting ahead

to remain stationary with respect to X

otherwise will add tension to cable/damage satellite/pull X out of its orbit

c. cable is a conductor and contains electrons

electrons/charges experience a force when moving in a magnetic field

use of a suitable hand rule to show that satellite Y becomes negative «so X becomes positive»

Alternative 2

cable is a conductor

so current will flow by induction flow when it moves through a B field

use of a suitable hand rule to show current to right so «X becomes positive»

Marks should be awarded from either one alternative or the other.

Do not allow discussion of positive charges moving towards X

d. electrons would build up at satellite Y/positive charge at X

preventing further charge flow

by electrostatic repulsion

unless a complete circuit exists

e. «$\varepsilon = Blv$ =» 31 x 10^{-6} x 7990 x 15000

3600 «V»

Allow 3700 «V» from v = 8000 m s^{-1}.

f.i. use of k = «$\frac{4\pi^2 m}{T^2}$ =» $\frac{4\times\pi^2\times 350}{5.2^2}$

510

N m^{-1} ***or*** kg s^{-2}

Allow MP1 and MP2 for a bald correct answer

Allow 500

Allow N/m etc.

f.ii. E_p in the cable/system transfers to E_k of Y

and back again twice in each cycle

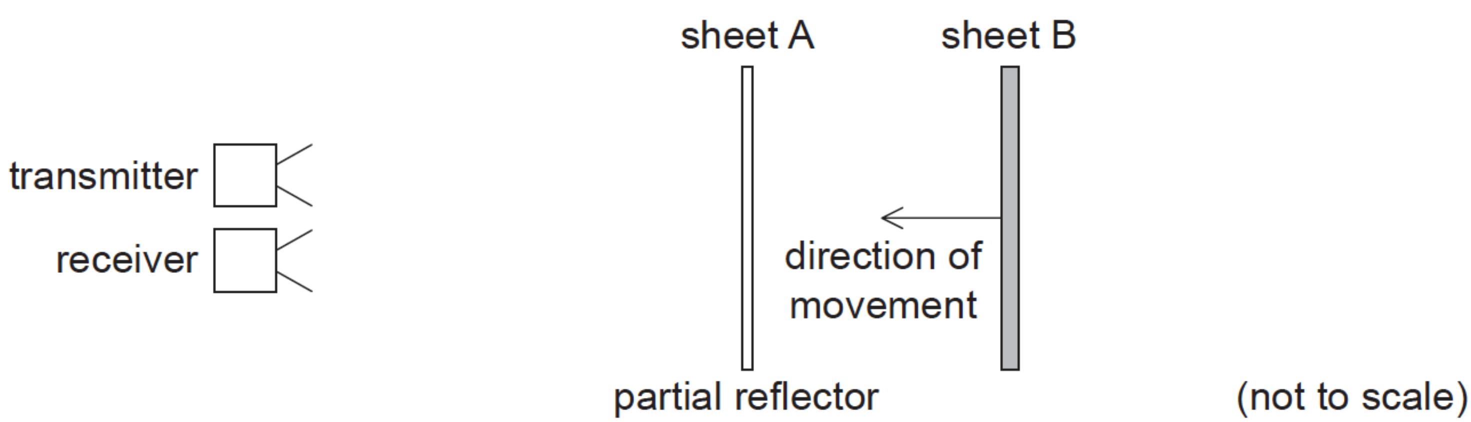
Exclusive use of gravitational potential energy negates MP1

Examiners report

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

This question is about the properties of waves.

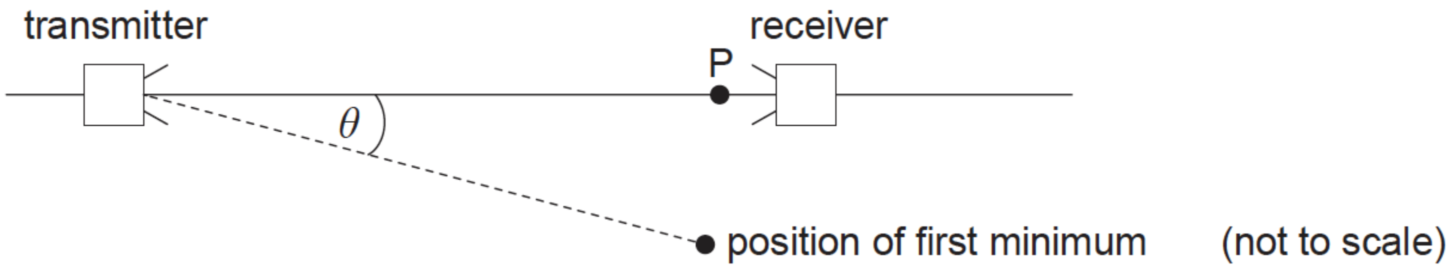
Microwaves from a microwave transmitter are reflected from two parallel sheets, A and B. Sheet A partially reflects microwave energy while allowing some to pass through. All of the microwave energy incident on sheet B is reflected.



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 demonstrate polarization. [2]

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 π/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 the Doppler effect.

A source emits sound of frequency 100Hz. The speed of sound in air is 330ms^{-1}.

a. Calculate the frequency measured by an observer when [4]

(i) the observer is stationary and the source is moving towards the observer at 120 ms^{-1}.

(ii) the source is stationary and the observer is moving towards the source at 120 ms^{-1}.

b. When both source and observer are stationary the wavelength is λ_0 and the wavespeed is v_0. [3]

In the table below, compare the values of measured wavelength and measured wavespeed, as measured by the observer, with respect to λ_0 and v_0. One of the values is given for you.

	Measured wavelength	**Measured wavespeed**
Moving source as in (a)(i)	less than λ_0	
Moving observer as in (a)(ii)		

Markscheme

a. (i) $f' = \left(f\left[\frac{v}{v-u_s}\right] =\right) 100 \times \left[\frac{330}{330-120}\right]$;

f'=157Hz;

(ii) $f' = \left(f\left[\frac{v+u_0}{v_s}\right] =\right) 100 \times \left[\frac{330+120}{330}\right]$;

f'=136Hz;

b.

	Measured wavelength	Measured wavespeed
Moving source	less than λ_0	equal to v_0;
Moving observer	equal to λ_0;	greater than v_0;

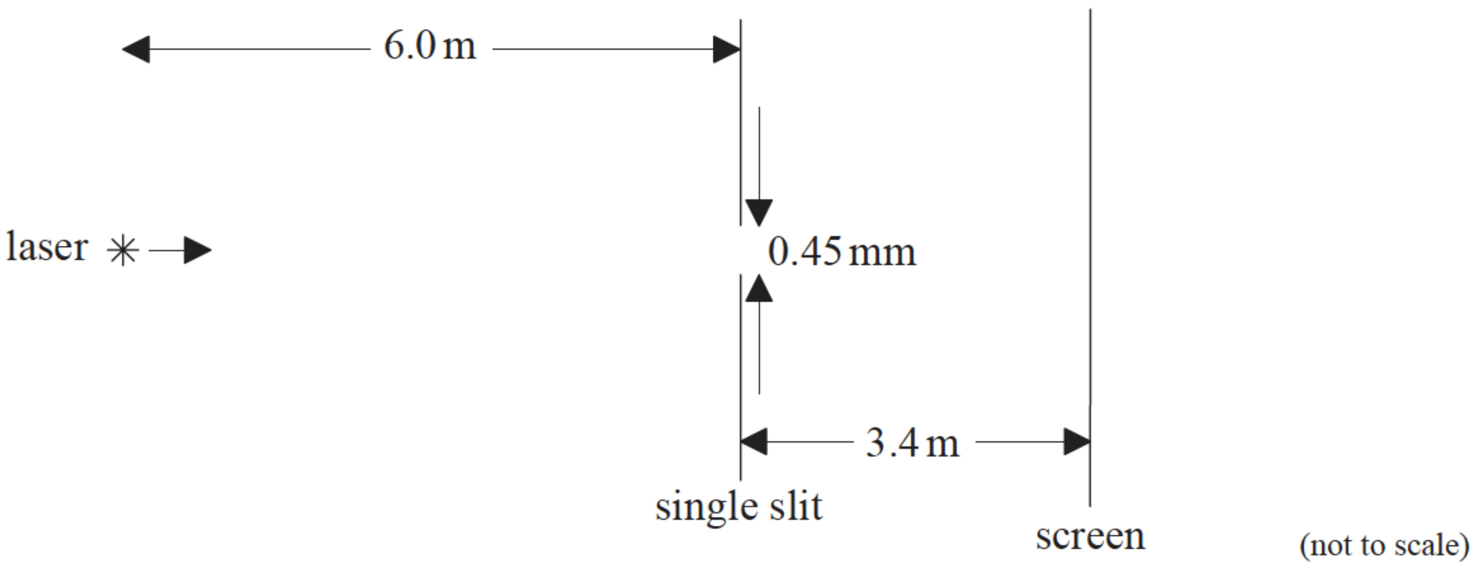
Examiners report

a. [N/A]

b. [N/A]

This question is about diffraction and interference.

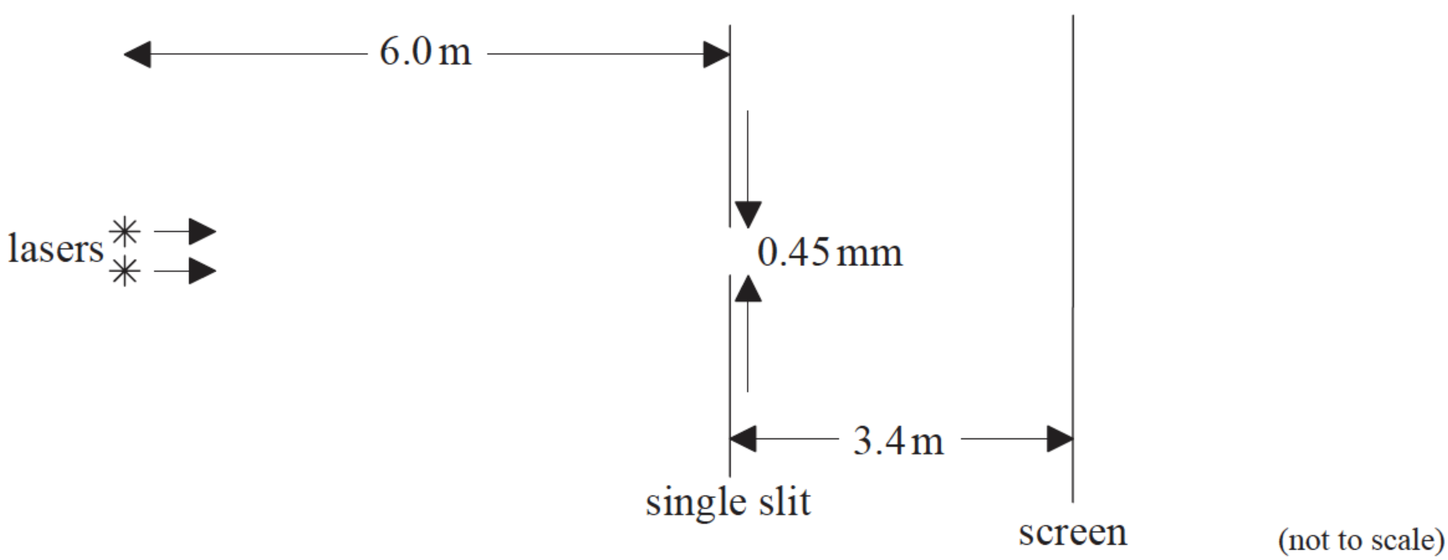
a. Light of wavelength 620 nm from a laser is incident on a single rectangular slit of width 0.45 mm. [2]



After passing through the slit, the light is incident on a screen that is a distance of 3.4 m from the slit. Calculate the distance between the centre and the first minimum of the diffraction pattern.

b. The laser in (a) is replaced by two identical lasers so that the light from both lasers illuminates the slit. The lasers are both 6.0 m from the slit. [3]

The two diffraction patterns on the screen are resolved according to the Rayleigh criterion.



(i) State what is meant by the Rayleigh criterion.

(ii) The minimum separation of the two laser beams is x. Determine x.

c. Compare the appearance of a single-slit diffraction pattern formed by laser light to that formed by a source of white light. [2]

Markscheme

a. $\theta = \frac{6.2\times10^{-7}}{4.5\times10^{-4}} \left(= 1.38 \times 10^{-3}\right)$;

distance ($=1.38\times10^{-3}\times3.4=4.68$)$\approx$4.7mm;

b. (i) in order to be (just) resolved the first minimum of diffraction pattern (of one image) coincides with the central maximum of the other (image) / *OWTTE*;

(ii) criterion specifies >4.7mm in this case / clear use of answer to (a) as distance;
$\left(\frac{4.7}{3.4} \times 6.0\right) = 8.3\text{mm};$
Award ***[1 max]*** *if factor of 1.22 used.*

c. *for white light:*

central maximum white, laser central maximum is monochromatic;

white light fringes/lines will be coloured;

blue diffracted least / *OWTTE*;

Examiners report

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

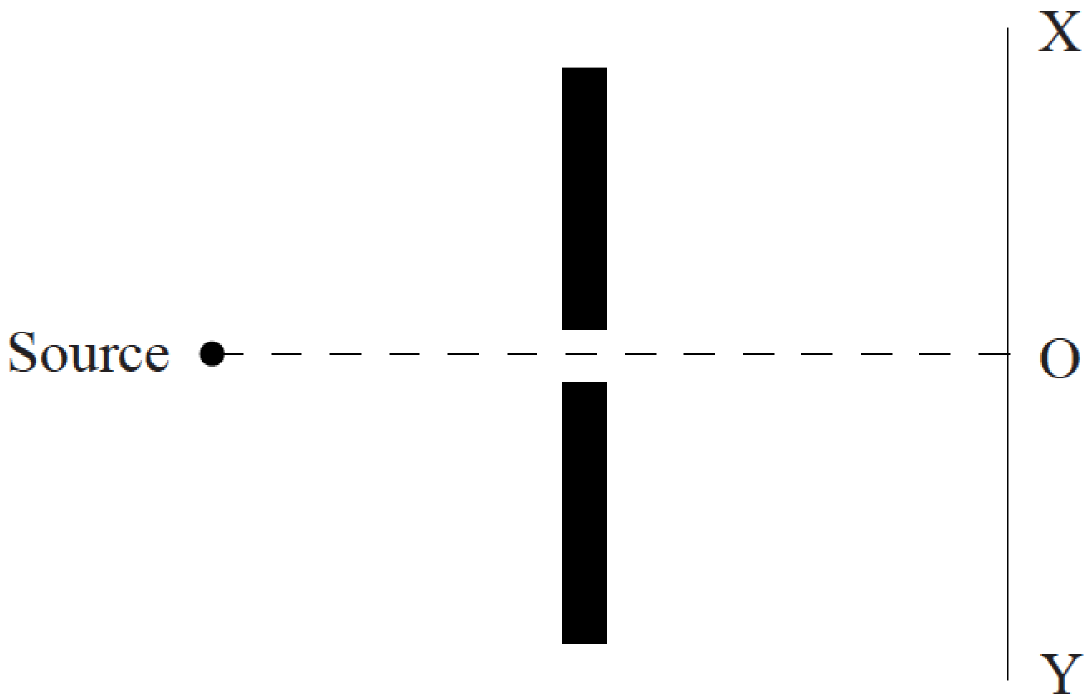
This question is about sound.

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'.

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

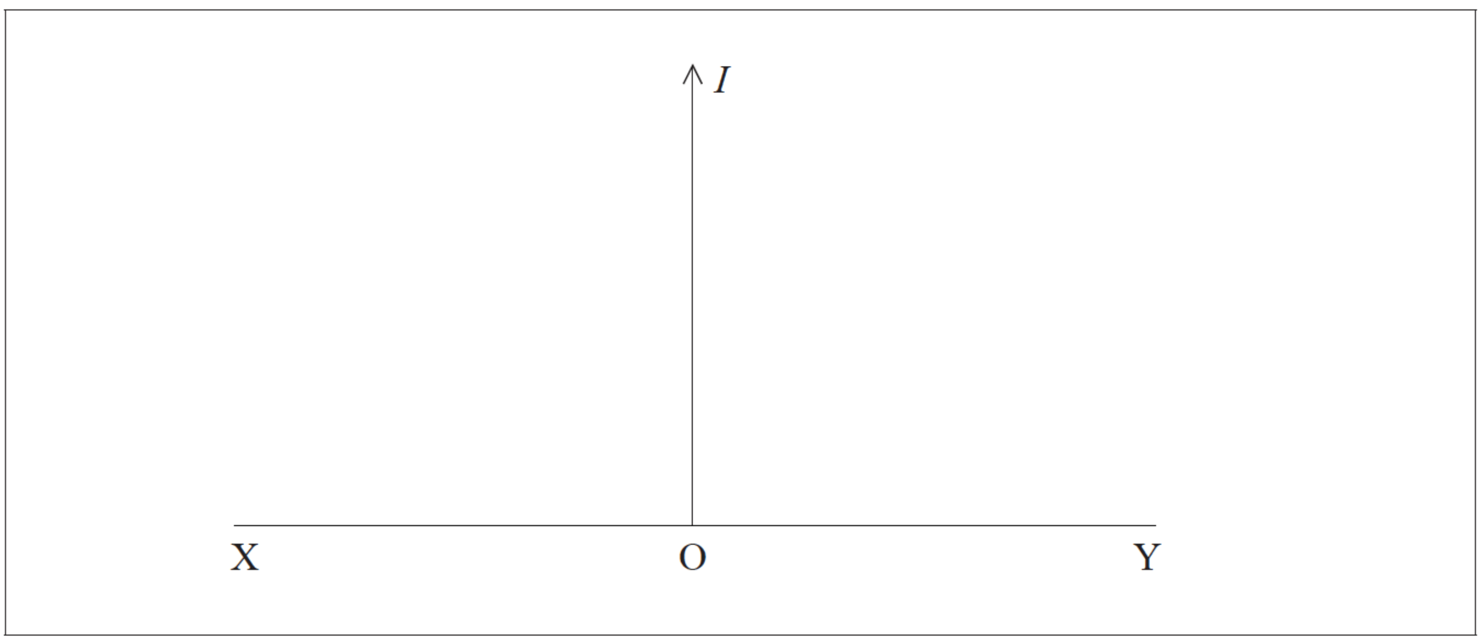
(ii) The frequency f is 275 Hz. The source is moving at speed 20.0 ms^{-1}. The speed of sound in air is 330 ms^{-1}. Calculate the observed frequency f' of the sound.

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

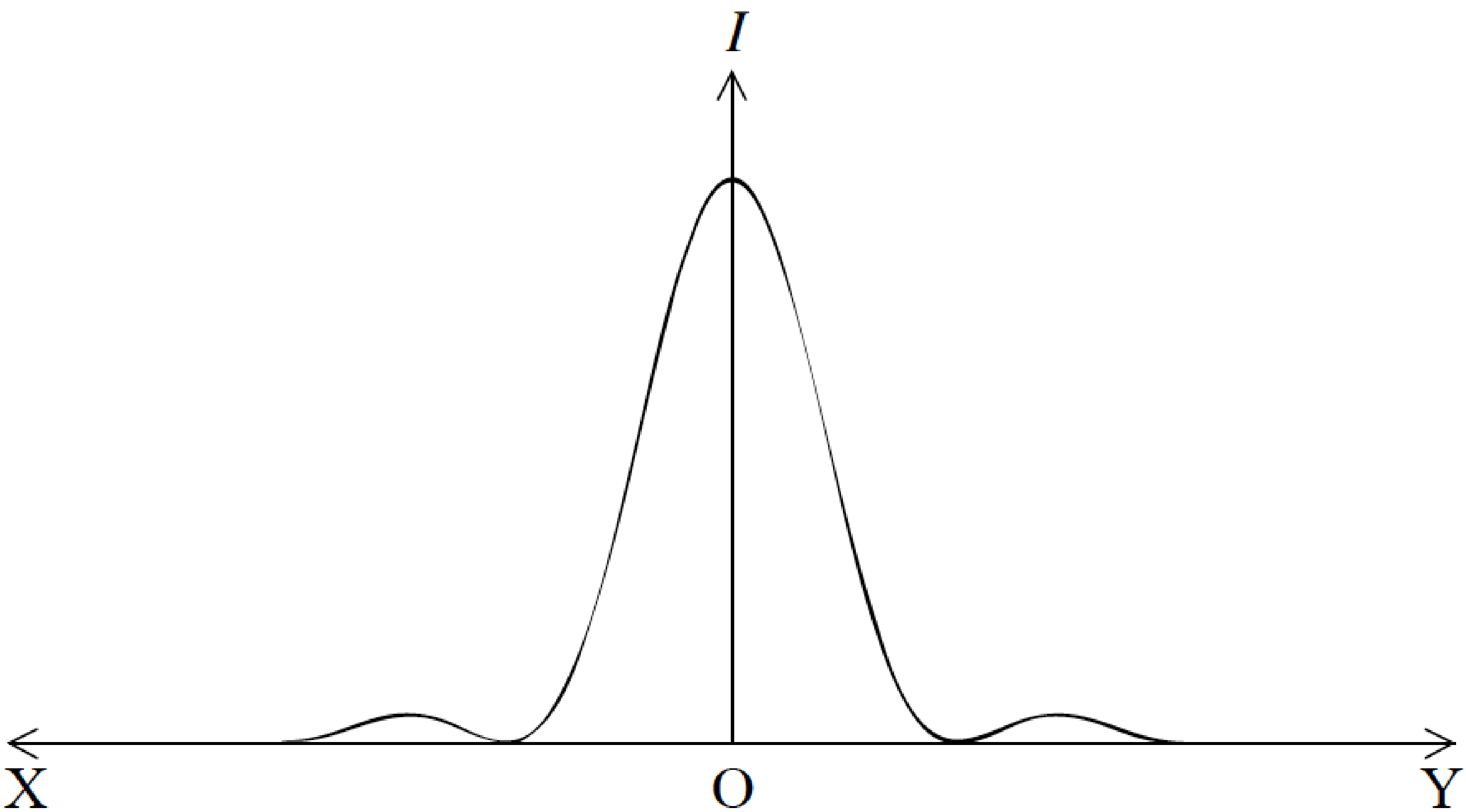
=293(Hz);

*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.

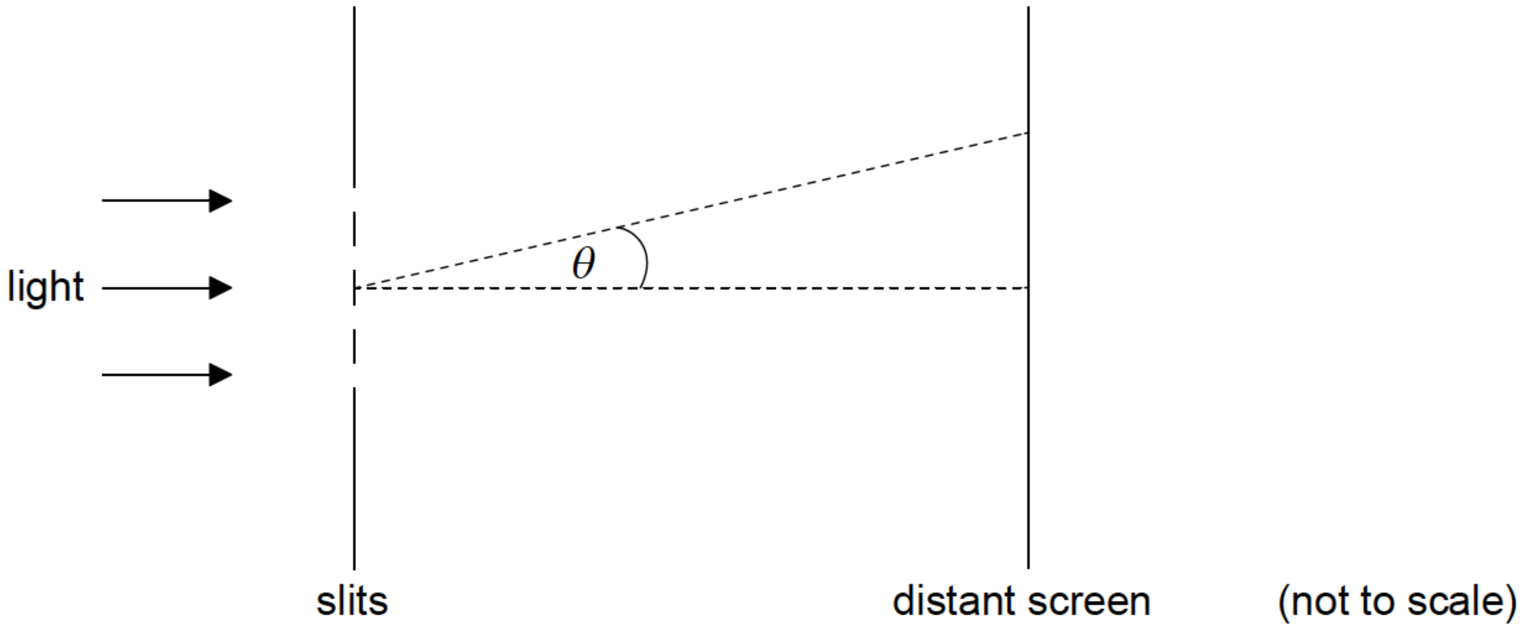
b. bi) Most candidates were able to score full marks on this question.

bii) Again this was answered successfully.

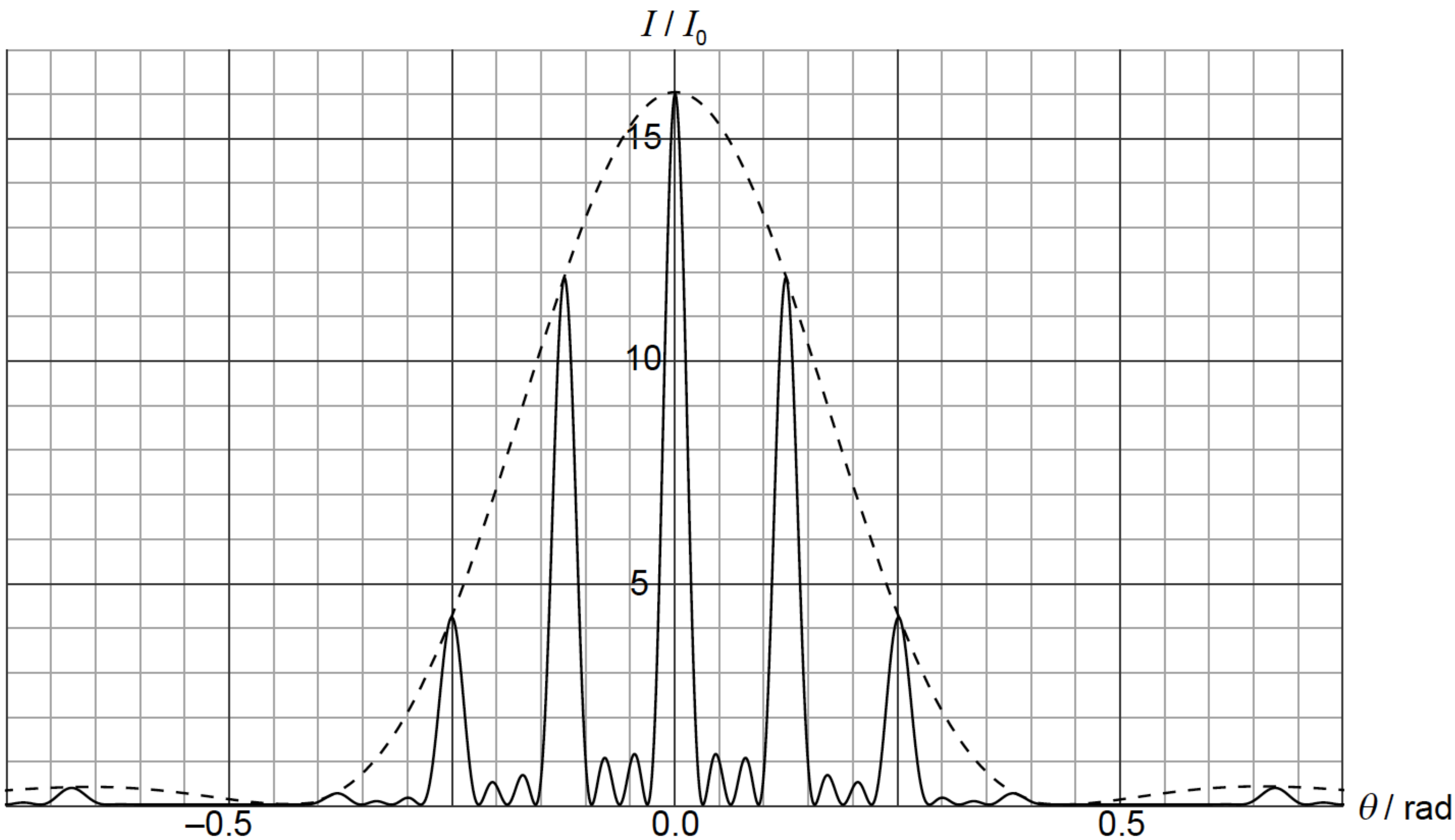
c. ci) Few candidates included the words oscillations or vibrations in their answers and consequently scored zero marks.

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

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



The graph shows the variation with diffraction angle θ of the intensity of light I at a distant screen.



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 θ=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

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

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.

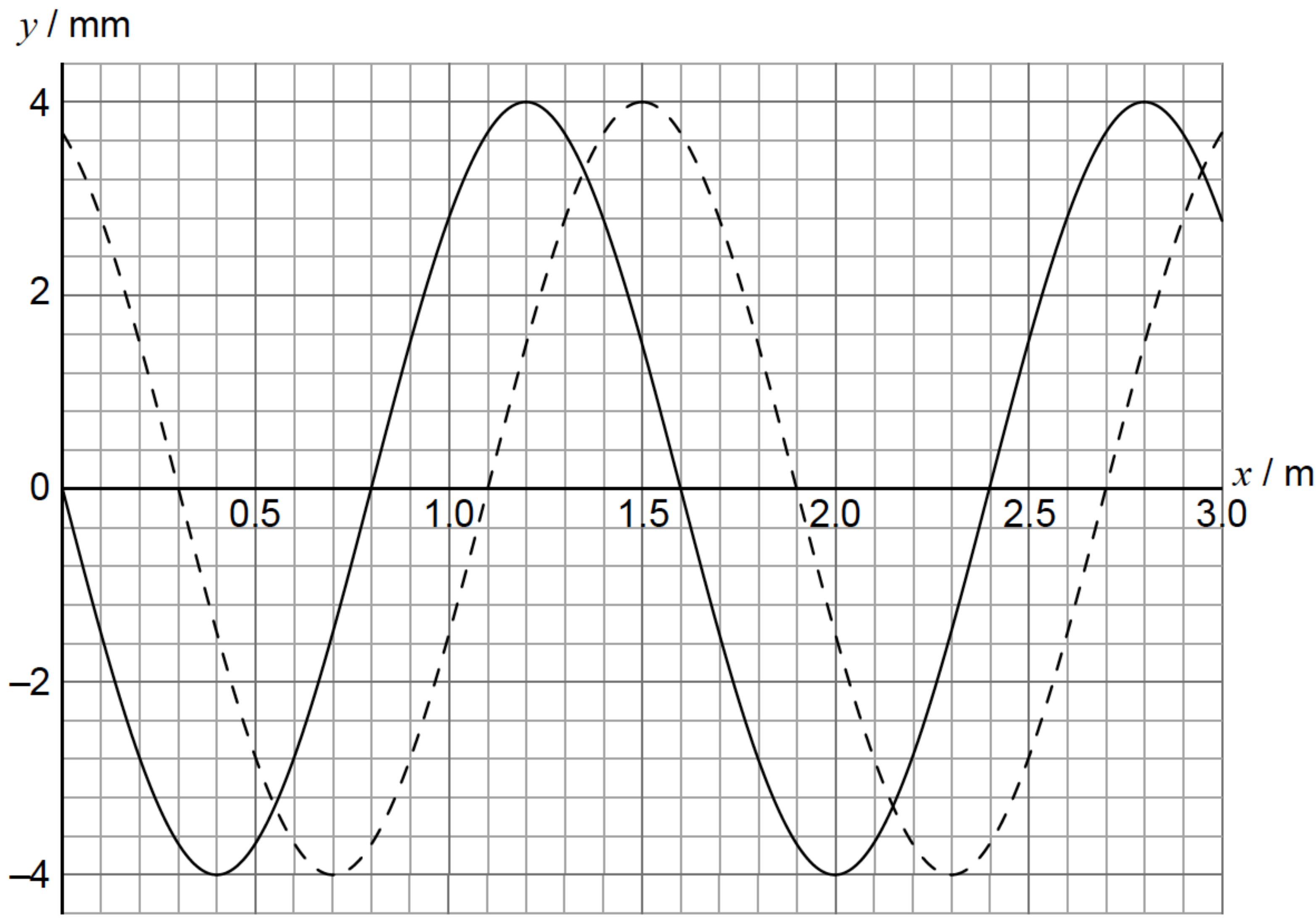
(ii)
$N = \ll \frac{\bar{\lambda}}{m\Delta\lambda} = \gg \frac{589.2935}{2 \times 0.5970}$
N=494 ***or*** 500

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 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 $\omega = 1.3 \times 10^3 \text{rads}^{-1}$.

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 4.9ms^{-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

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

ALTERNATIVE 2

evaluates $T = \frac{0.882 \times 10^{-3} \times 1.6}{0.3}$ «=4.7ms» to give *f* = 210 ***or*** 212 Hz

uses λ=1.6 m with $v=f\lambda$ to give 340ms^{-1}

(ii)

ALTERNATIVE 1

λ=1.60m

$\omega = \ll 2\pi f = \gg 2\pi \times \frac{340}{1.60} = 1.3 \times 10^3$ ***or*** 1.34×10^{3}rads^{-1}

ALTERNATIVE 2

«0.882 ms is $\frac{0.3}{1.6}$ of cycle so whole cycle is» $\frac{2\pi \times 3}{16 \times 0.882 \times 10^{-3}}$

1.35×10^{3}rads^{-1}

Allow ECF from (b)(i).

c. (i)

the displacement of the particle decreases ***OR*** «on the graph» displacement is going in a negative direction ***OR*** on the graph the particle goes down ***OR*** on the graph displacement moves towards equilibrium/0

to the left

Do not allow "moving downwards".

(ii)

y=–1.5mm

$v = 2\pi \times 212 \times \sqrt{(4.0 \times 10^{-3})^2 - (1.5 \times 10^{-3})^2}$

«*v*=4.939≈4.9ms^{-1}»

Allow ECF from (b)(ii).

Do not allow $\frac{4.3\text{mm}}{0.882\text{ms}} = 4.87\text{ms}^{-1}$.

d. (i)

the superposition/interference of two oppositely moving/reflected «identical travelling» waves

(ii)

the allowed wavelengths in the tube are $\lambda = \frac{4L}{n} = \frac{480}{n}$, *n* = 1, 3, 5,…

OR

diagram showing $\frac{3}{4}$ of a standing wavelength in the tube

$1.6 = \frac{4.80}{n} \Rightarrow n = 3$

OR

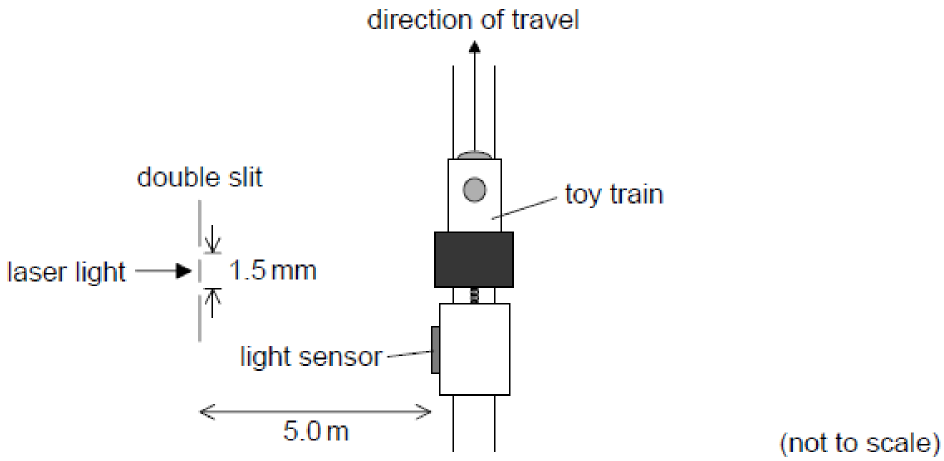
justification that $\frac{3}{4} \times 1.6 = 1.2\text{m}$

Allow diagram showing $\frac{3}{4}$ of a wavelength for MP1.

Examiners report

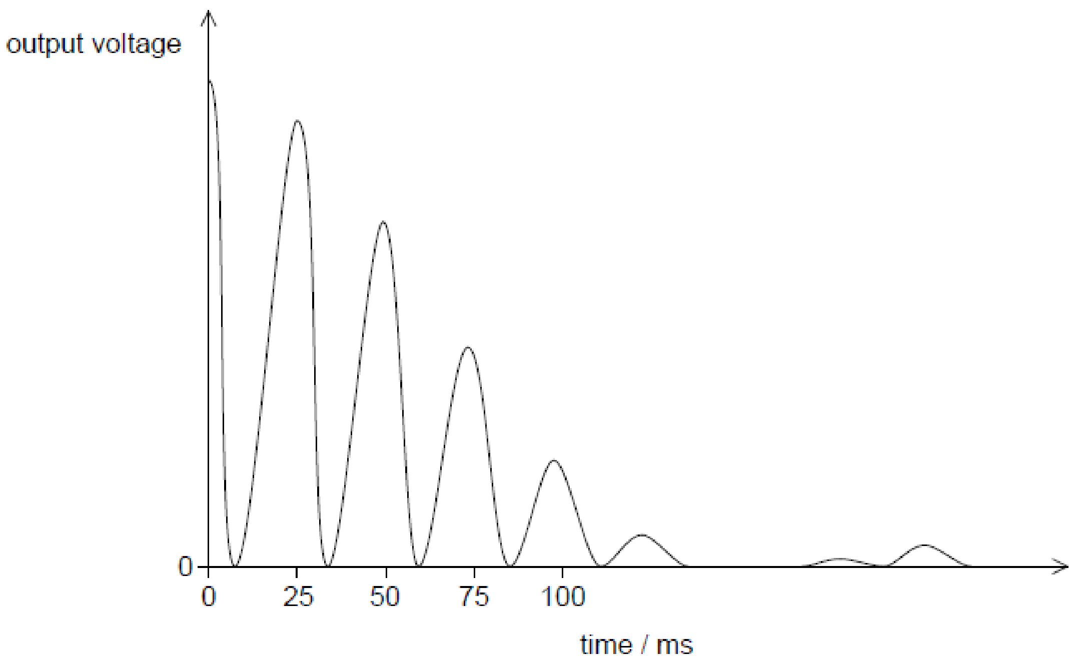
b. [N/A]
c. [N/A]
d. [N/A]

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

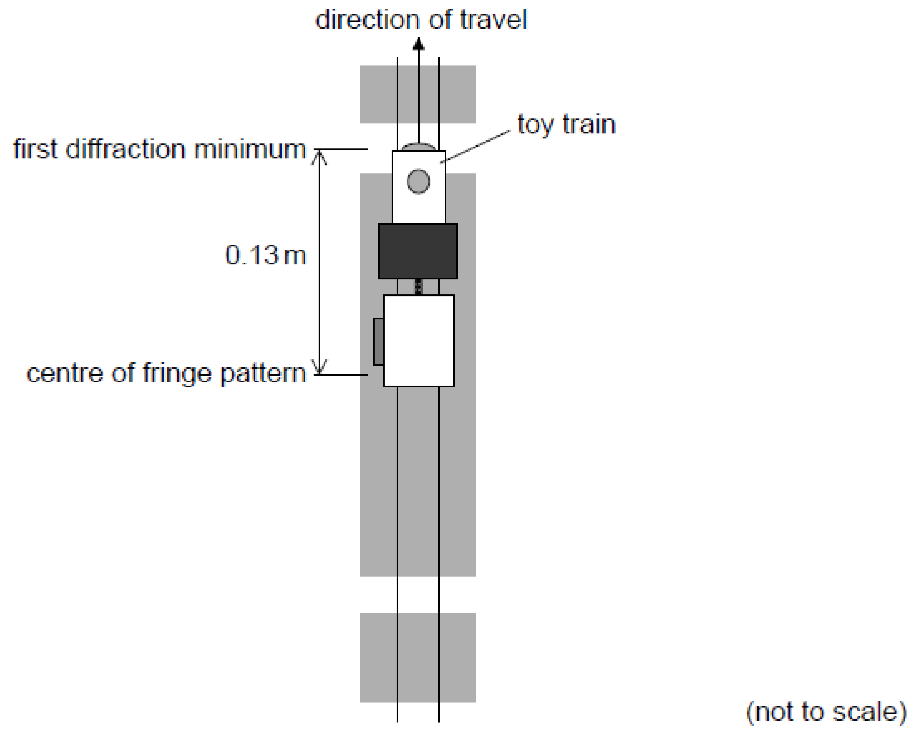


Light from a laser is incident on a double slit. The light from the slits is detected by a light sensor attached to the train.

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.



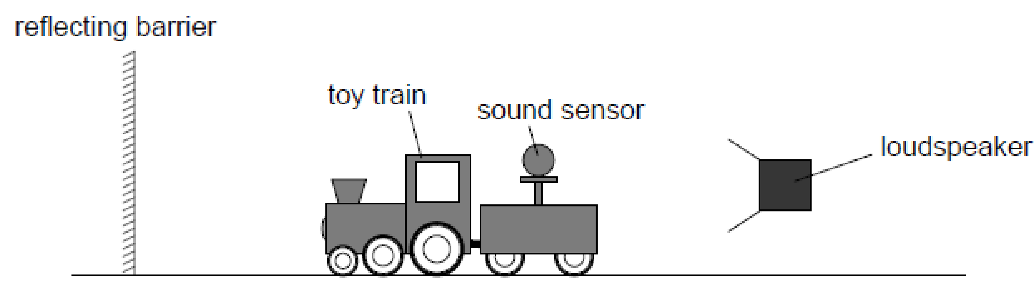
As the train continues to move, the first diffraction minimum is observed when the light sensor is at a distance of 0.13 m from the centre of the fringe pattern.



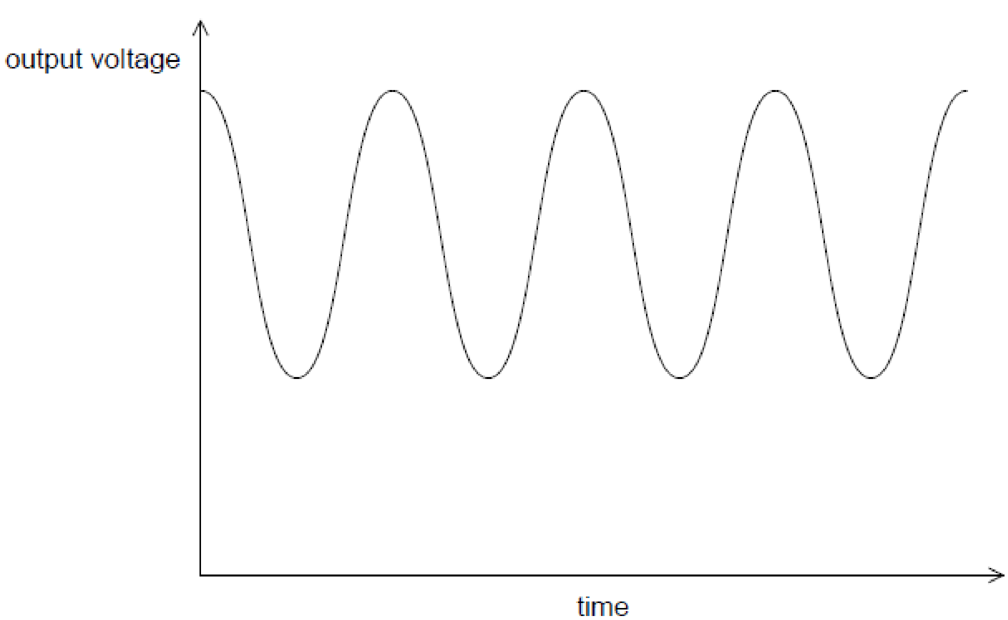
c.i. Determine the width of one of the slits. [2]

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 sound waves of constant amplitude and frequency towards a reflecting barrier. [2]



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



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]