# SL Paper 3

This question is about polarization.

Distinguish between polarized light and unpolarized light.

# Markscheme

light is said to be (plane) polarized if the electric field (vector) lies on one plane;

when light is unpolarized, the electric field (vector) lies on many planes/does not lie on a specific plane;

# Examiners report

(a) was either very well answered or lacking in reference to the electric field.

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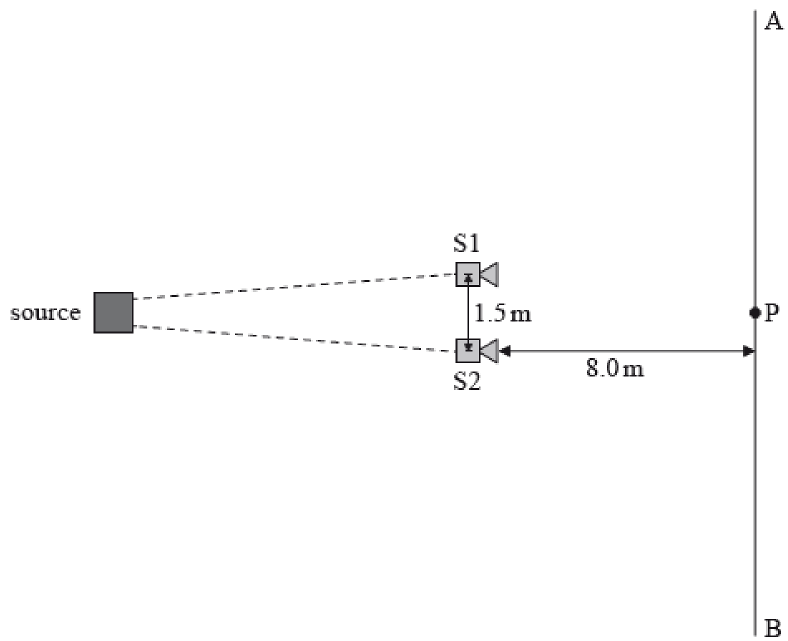
This question is about the interference of sound waves.

Two loudspeakers, S1 and S2, each emit a musical note of frequency 2.5 kHz with identical signal amplitude. Point P lies on the line AB and is equidistant from S1 and S2. The speakers are placed 1.5 m apart from each other and 8.0 m from line AB. The speed of sound is $330\ \mathrm{m\,s^{-1}}$.




A person walking in a straight line from A to B observes that the intensity of sound alternates between high and low.

a. With reference to interference, explain why the intensity of sound alternates along line AB. [3]

b. The sound has a maximum intensity at P. Calculate the distance along line AB to the next intensity maximum when S1 and S2 emit a musical note of frequency 2.5 kHz. [2]

c. S1 and S2 are moved so that they are now 3.0 m apart. They remain at the same distance from line AB. Discuss the changes, if any, in the rate at which the intensity of sound alternates when a person is walking along line AB at half the speed. [2]

# Markscheme

a. the waves are coherent so interference occurs;

high intensity sound corresponds to a position where sound constructively interferes/superposes / low/zero intensity sound corresponds to a position where sound destructively interferes/cancels;

high intensity is where the path difference is an integral number of wavelengths;

low/zero intensity of sound is where the path difference is $n+\frac{1}{2}$ wavelengths;

b. $\lambda=\frac{330}{2500}=0.132\text{ m};$

$x=\left(\frac{n\lambda D}{d}=\frac{1.0\times 0.132\times 8.0}{1.5}=\right)\ 0.70(4)\text{ m};$

c. distance doubles so fringe width is halved;

so fringes are encountered at the same rate, no change;

# Examiners report

a. Most described the interference in (a), without giving a cause, such as path difference.

b. Many answered (b) and (c) well.

c. Many answered (b) and (c) well.

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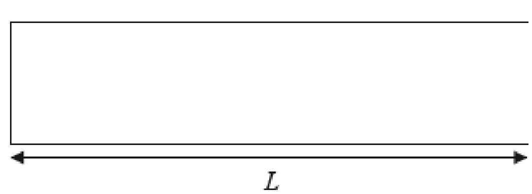
This question is about standing waves and organ pipes.

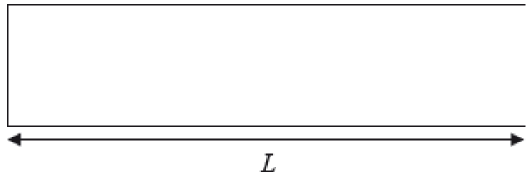
An organ pipe of length $L$ is closed at one end. On the diagrams, draw a representation of the displacement of the air in the pipe when the frequency of the note emitted by the pipe is the

a. State **one** way in which a standing wave differs from a travelling wave. [1]

b. (i) first harmonic frequency $f_1$. [2]




(ii) second harmonic frequency $f_2$.




c. Use your answer to (b) to deduce an expression for the ratio $\frac{f_1}{f_2}$. [3]

d. State, in terms of the boundary conditions of the standing waves that can be formed in the pipe, the reason why the ratio of the higher frequencies of the harmonics to that of the first harmonic must always be an integer number. [1]

# Markscheme

a. no energy propagated in a standing wave;

the amplitude of a standing wave is not constant;

points along a standing wave are either in phase or out of phase with each other / *OWTTE*;

b. (i) antinode at open end node at closed end;

(ii) antinode at open end and node at closed end and one more node along pipe;

*(judge by eye)*

c. for $\lambda_1 = 4L$ and for $\lambda_2 = \frac{4L}{3}$;

$f_1 = \frac{c}{4L}$ and $f_2 = \frac{3c}{4L}$;

$\frac{f_1}{f_2} = \frac{1}{3}$;

d. there must always be a node at the closed end and an antinode at the open end / there must always be an integer number of $\frac{\lambda}{4}$;

# Examiners report

a. Most candidates knew a difference between a standing and travelling wave.

b. Diagrams of the fundamental and second harmonic were often poor.

c. The manipulation of ratios defeated a lot of candidates.

d. Very few candidates recognised that there must always be either a node or antinode at each end of the pipes.

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This question is about lasers.

With reference to the light waves emitted by a laser, state what is meant by the terms

(i) monochromatic.

(ii) coherent.

# Markscheme

(i) (the waves) all have the same frequency/wavelength;

*Do not accept "one colour".*

(ii) (the waves) are all in phase with each other / the phase difference between the waves is constant;

# Examiners report

Most candidates knew what was meant by the terms monochromatic and coherent.

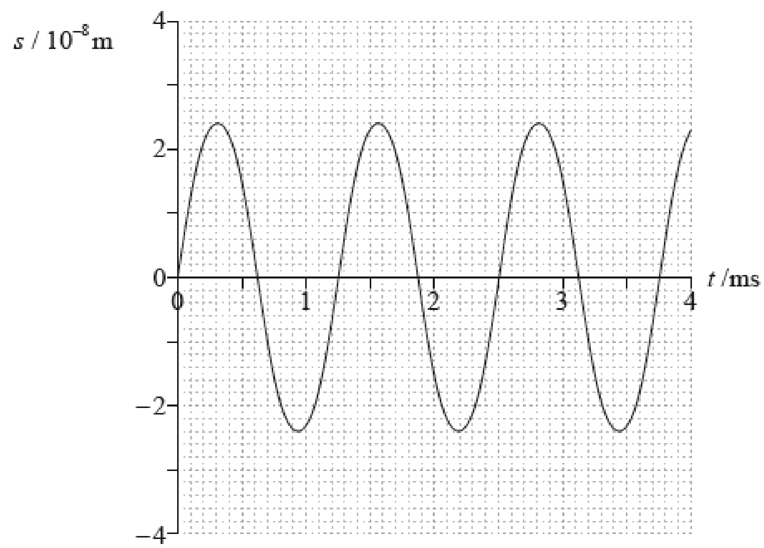
---

This question is about standing (stationary) waves.

The diagram shows a tube that is open at both ends.


Point A shows the position of one air molecule in the tube. A standing sound wave (not shown in the diagram) is set up in the tube.

The graph shows the variation of displacement $s$ with time $t$ for the molecule at point A.




a. Outline whether the standing wave is transverse **or** longitudinal. [1]

b. The standing wave in the tube corresponds to the fourth harmonic. The speed of sound in the tube is $340\ \mathrm{m\,s^{-1}}$. Using the graph, determine the length of the tube. [3]

c. The tube is now closed at one end and the first harmonic is sounded. Outline why the tube that is open at both ends produces a first harmonic with a wavelength shorter than the first harmonic of the tube that is closed at one end. [1]

# Markscheme

a. (longitudinal)

the standing wave is formed of (travelling) sound waves (which are longitudinal);

*Do not allow responses that focus only on travelling waves.*

b. the frequency is $f = \frac{1}{1.25 \times 10^{-3}}$ $(= 800\ \text{Hz})$;

and the wavelength is $\lambda = \frac{v}{f} = \frac{340}{800}$ $(= 0.425\ \text{m})$;

the fourth harmonic corresponds to 2 wavelengths in the tube, thus $L = 2\lambda = 0.85\ \text{m}$;

c. the length of the tube closed at one end corresponds to $\frac{\lambda}{4}$, while the length for the tube open at both ends corresponds to $\frac{\lambda}{2}$;

# Examiners report

a. (a) was very badly answered, with few appreciating that the standing wave is made from 2 (or more) travelling sound waves.

b. (b) was usually well attempted, with arithmetical errors or errors in the relationship between wavelength and pipe length giving any difficulty.

c. There was a mixed set of responses to (c), from those who clearly understood to those who could not give a mathematical reason.

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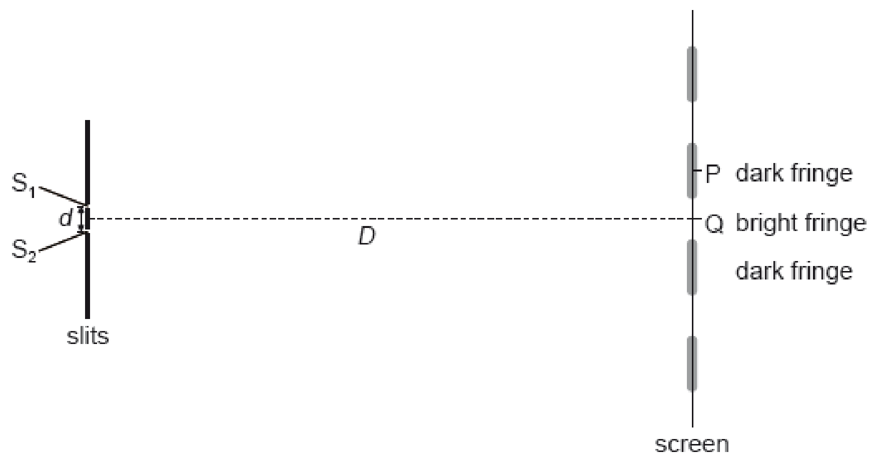
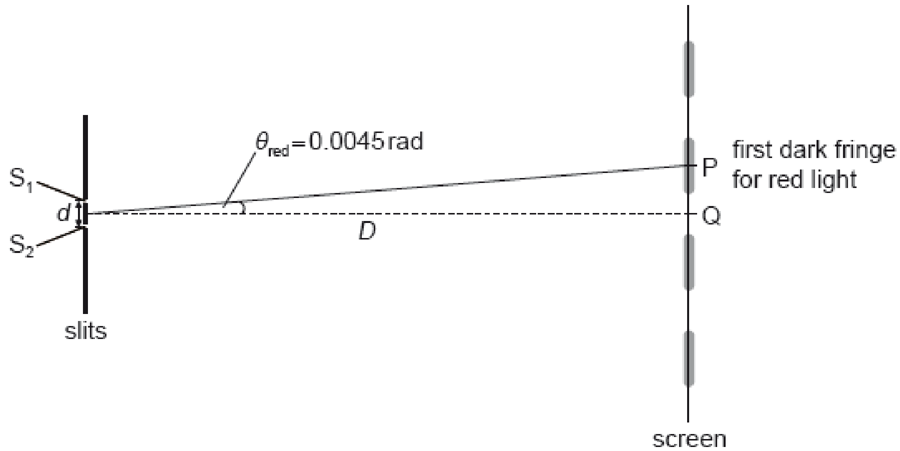
This question is about interference of light.

Coherent monochromatic light is incident on two narrow slits $S_1$ and $S_2$ a distance $d$ apart. A screen is placed a distance $D$ from the slits. An interference pattern of bright fringes and dark fringes appears on the screen. The central maximum is at Q.




When red light of wavelength 660 nm is used the first fringe at P subtends an angle 0.0045 rad from midpoint of $S_1$ and $S_2$.




a. State **one** way to ensure that the light incident on the slits is coherent. [1]

b. Light emerging from $S_1$ and $S_2$ reaches the screen. Explain why the screen appears dark at point P. [2]

c.i. Determine the change in angle when blue light of wavelength 440 nm is used. [2]

c.ii. Using the diagram below, draw the approximate position of the first bright fringe using blue light. The position of the first dark fringe with red light is labelled P. [1]

# Markscheme

a. single slit before the double slit / use a laser light / single source;

b. destructive interference;

path lengths from slits differ by half a wavelength;

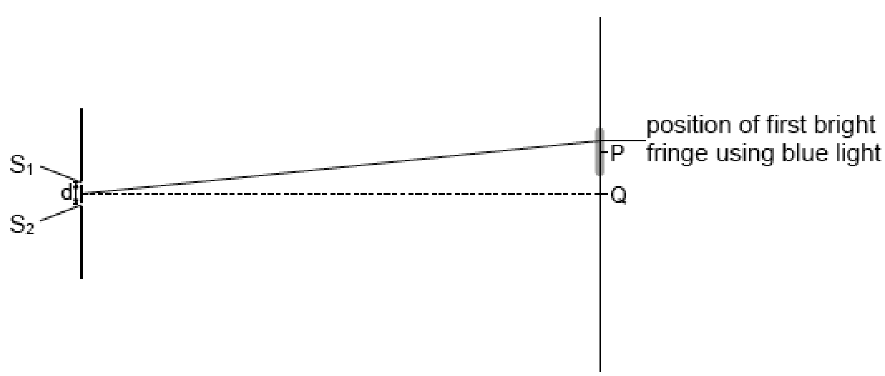
waves arrive antiphase / 180° out of phase / $\pi$ out of phase;

c.i. $\theta_{\text{blue}} = \left(\frac{\theta_{\text{red}}\lambda_{\text{blue}}}{\lambda_{\text{red}}} = \frac{0.0045 \times 440 \text{ nm}}{660 \text{ nm}} = \right) 0.0030 \text{ (rad)};$

$\Delta\theta_{\text{blue}} = (0.0045 - 0.0030 =) \; 0.0015 \text{ (rad)};$

c.ii. marking direction of shift on the diagram;

*Accept any point in the upper half of the dark fringe.*




# Examiners report

a. SL candidates could generally suggest a reasonable method to make sure the light was coherent, but rarely earned full marks in explaining why P was a dark fringe.

b. SL candidates could generally suggest a reasonable method to make sure the light was coherent, but rarely earned full marks in explaining why P was a dark fringe.

c.i. SL candidates could generally suggest a reasonable method to make sure the light was coherent, but rarely earned full marks in explaining why P was a dark fringe.

c.ii. SL candidates could generally suggest a reasonable method to make sure the light was coherent, but rarely earned full marks in explaining why P was a dark fringe.

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This question is about polarization.

State what is meant by polarized light.

# Markscheme

light in which the electric vector oscillates on one plane/direction;

# Examiners report

In part (a) the definition was often not specific enough, the idea that the electric field vector is oscillating rather than just light was often omitted.

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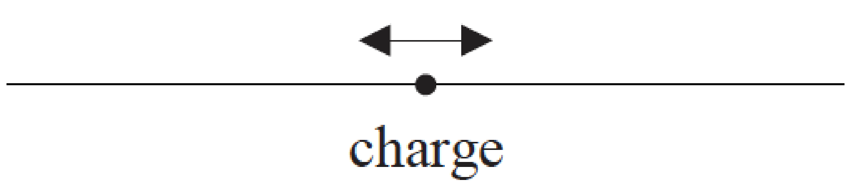
This question is about the nature and properties of electromagnetic waves.

a. Electromagnetic waves propagating in a medium suffer dispersion. Describe what is meant by dispersion. [2]

b. A charge moves backwards and forwards along a wire, as shown in the diagram below. [2]




Outline, with reference to the motion of the charge, why electromagnetic radiation is produced by the moving charge.

# Markscheme

a. waves of different wavelength/frequency;

travel at different velocities;

the index of refraction of the medium depends on the wavelength/frequency;

b. during simple harmonic motion the charge oscillates/accelerates;

(oscillating/accelerating) charges radiate/produce (varying) electric/magnetic fields / produce electromagnetic waves;

# Examiners report

a. Too many candidates showed that they do not know the terminology and vaguely described other phenomena instead of dispersion, quite often scattering. Breaking into component colours was sometimes mentioned by the candidates but this was not accepted as correct as the question was about electromagnetic waves, not only about light. A reasonable number of correct answers were seen with reference of both different speed and index of refraction.

b. In (b) only the stronger HL candidates clearly connected accelerated charge with the production of electromagnetic radiation. Most SL answers simply repeated the production of electromagnetic waves, missing the importance of the acceleration of the electron and not relating it to electric and magnetic fields.

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This question is about the nature of electromagnetic waves.

a. Outline what is meant by an electromagnetic wave. [2]

b. State **two** cases in which electrons may produce electromagnetic waves. [2]

# Markscheme

a. oscillating/vibrating electric and magnetic fields;

at right angles to each other;

at right angles to the direction of propagation/energy transfer of the wave/ velocity/transverse;

can travel through vacuum;

*Award **[2]** for a clearly drawn, correctly labelled diagram i.e. E and B fields at right angles to each other and at right angles to the direction of propagation.*

b. electrons that oscillate/accelerate/move on curved paths;

electrons making transitions between energy levels;

*Accept two specific instances of electrons being accelerated/decelerated e.g. electrons hitting metal target or electrons moving in magnetic fields.*

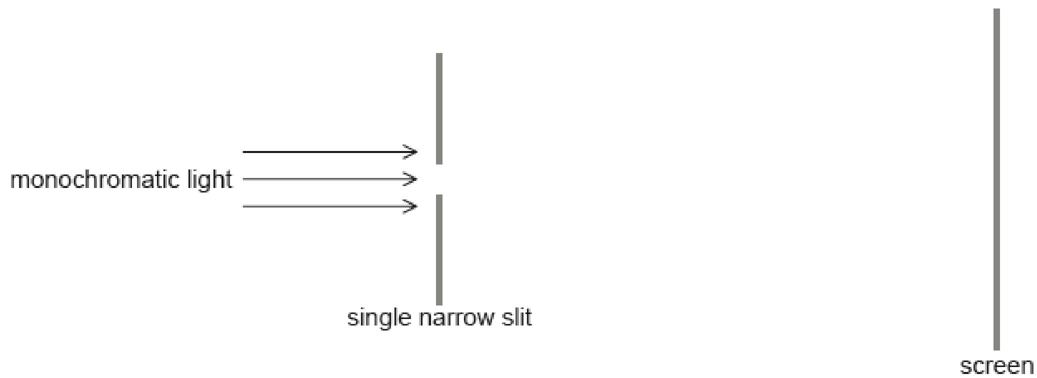
# Examiners report

a.

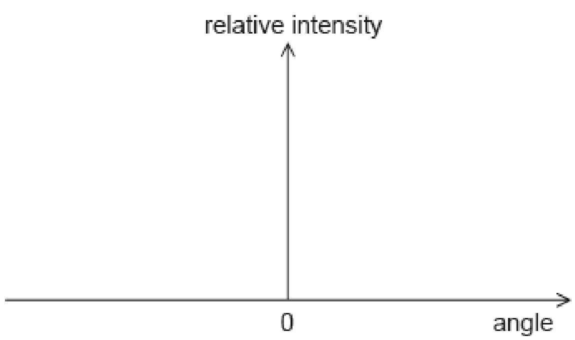
b.

This question is about diffraction and resolution.

Monochromatic light is incident normally on a single narrow slit and gives rise to a diffraction pattern on a screen.




a. Sketch, for the diffraction pattern produced, a graph showing the variation of the relative intensity of the light with the angle measured from the centre of the slit. [2]




b. The single narrow slit is replaced by a double narrow slit. Explain, with reference to your answer to (a), how the Rayleigh criterion applies to the diffraction patterns produced by the light emerging from the two slits. [3]

c. Two lamps emit light of wavelength 620 nm. The lights are observed through a circular aperture of diameter 1.5 mm from a distance of 850 m. Calculate the minimum distance between the lamps so that they are resolved. [2]

# Markscheme

a. large central peak and at least one subsidiary maximum on each side;

minima have intensity of zero and intensity of secondary maxima at most 25 % of central maximum; } *(judge by eye)*

b. explanation of resolving – seeing images as being from separate objects;

idea of diffraction patterns overlapping;

central maximum being at least as far from companion as the first minimum;

*Marking points may be seen on graph in (a).*

*Marking points may be seen from diffraction pattern showing resultant intensity from two sources with a slight dip in the centre.*

c. equating $1.22\frac{\lambda}{b}$ to $\frac{x}{D}$;

0.43 (m);

# Examiners report

a. The majority could correctly sketch the diffraction pattern and only a few showed non-zero intensity at the minima. The definition of Rayleigh's criterion was well known but candidates found it difficult to gain full marks explaining how the Rayleigh criterion applies to diffraction patterns, as asked. The calculation was well-attempted.

b. The majority could correctly sketch the diffraction pattern and only a few showed non-zero intensity at the minima. The definition of Rayleigh's criterion was well known but candidates found it difficult to gain full marks explaining how the Rayleigh criterion applies to diffraction patterns, as asked. The calculation was well-attempted.

c. The majority could correctly sketch the diffraction pattern and only a few showed non-zero intensity at the minima. The definition of Rayleigh's criterion was well known but candidates found it difficult to gain full marks explaining how the Rayleigh criterion applies to diffraction patterns, as asked. The calculation was well-attempted.

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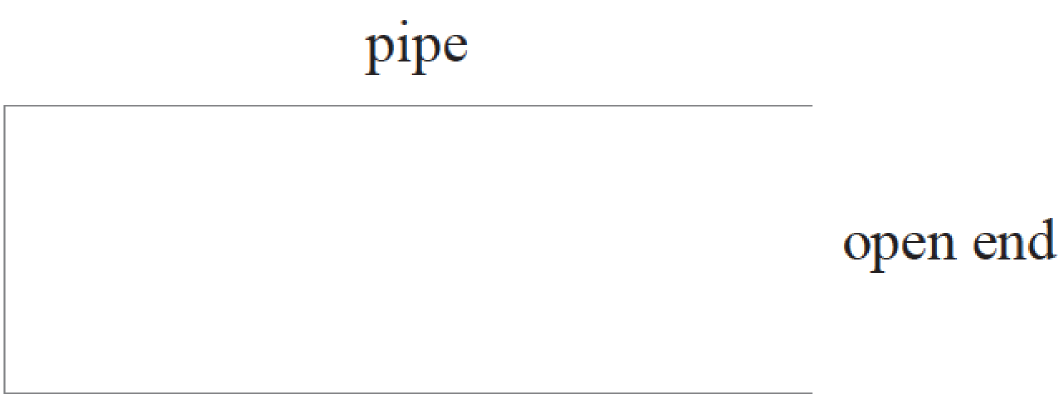
This question is about standing waves and the Doppler effect.

The horn of a train can be modeled as a pipe with one open end and one closed end. The speed of sound in air is 330ms$^{-1}$.




a. On leaving the station, the train blows its horn. Both the first harmonic and the next highest harmonic are produced by the horn. The difference in frequency between the harmonics emitted by the horn is measured as 820 Hz. [5]

(i) Deduce that the length of the horn is about 0.20 m.

(ii) Show that the frequency of the first harmonic is about 410 Hz.

b. (i) Describe what is meant by the Doppler effect. [4]

(ii) The train approaches a stationary observer at a constant velocity of 50ms$^{-1}$ and sounds its horn at the same frequency as in (a)(ii). Calculate the frequency of the sound as measured by the observer.

# Markscheme

a. (i) $f_1 = \frac{v}{4L}$, $f_2 = 3f_1 = \frac{3v}{4L}$;

$f_2 - f_1 = \frac{v}{2L} = 820\ (\mathrm{Hz})$;

$L = \frac{330}{2 \times 820}$;

($L$=0.20m)

(ii) $\lambda = 4L = 0.80\ (\mathrm{m})$;
$f = \left(\frac{330}{0.8}\right) = 413\mathrm{Hz}$;

*This is a question testing units for this option. Do not award second marking point for an incorrect or missing unit.*

b. (i) a change in the observed frequency/wavelength of a wave;

when there is relative motion of observer and source;

(ii) $f' \left(= f\frac{v}{v-u_s}\right) = 410 \times \frac{330}{330-50}$;
$f' = 480\ (\mathrm{Hz})$;
*Allow ECF from (a)(ii).*

# Examiners report

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

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This question is about sound waves.

A whistle on a steam train consists of a pipe that is open at one end and closed at the other. The sounding length of the whistle is 0.27 m and the steam pressure in the whistle is so great that the third harmonic of the pipe is sounding. The speed of sound in air is $340\ \mathrm{m\,s^{-1}}$.

a.i. Show that there must be a node at a distance of 0.18 m from the closed end of the pipe. [1]

a.ii. Calculate the frequency of the whistle sound. [2]

b. The train is moving directly away from a stationary observer at a speed of $22\ \mathrm{m\,s^{-1}}$ while the whistle is sounding. Calculate the frequency heard by the observer. [2]

# Markscheme

a.i. third harmonic means 1.5 loops; *(accept in form of a diagram)*

$\frac{2}{3} \times 0.27\ (= 0.18)$;

a.ii. length is $\frac{3}{4}$ of a wavelength so $\lambda = 0.36\ \mathrm{m}$;

$f = 940\ (\mathrm{Hz})$;

b. $f' = 940\left(\frac{340}{340+22}\right)$; *(allow ECF from (a)(ii))*

880 (Hz);

# Examiners report

a.i. Many candidates drew the 5th harmonic, not realising that the harmonic number is related to the multiple of the frequency which is only odd in "closed" pipes. This was not penalised in ECF.

a.ii. Many candidates drew the 5th harmonic, not realising that the harmonic number is related to the multiple of the frequency which is only odd in "closed" pipes. This was not penalised in ECF.

b. Many candidates drew the 5th harmonic, not realising that the harmonic number is related to the multiple of the frequency which is only odd in "closed" pipes. This was not penalised in ECF.

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This question is about properties of electromagnetic waves.

a. State **two** properties that are common to all electromagnetic waves. [2]

b. A single lens is used to form a magnified real image of an object. Explain, with reference to the dispersion of light, why the image has coloured edges. [3]

# Markscheme

a. transverse;

can be polarized;

all have same speed in a vacuum;

b. each colour/wavelength has different refractive index;

different focal lengths/amount of diffraction for each wavelength/colour;

so all coloured images do not overlap completely/not at same place;

# Examiners report

a. [N/A]

b. [N/A]

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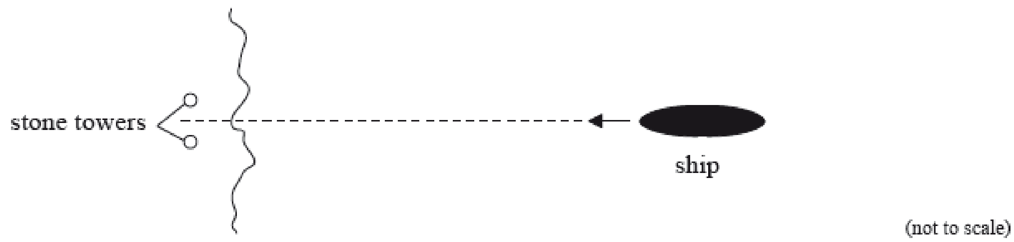
This question is about resolution and polarization.

A ship sails towards two stone towers built on land.




Emlyn, who is on the ship, views the towers. The pupils of Emlyn's eyes are each of diameter 2.0 mm. The average wavelength of the sunlight is 550 nm.

a. State the Rayleigh criterion. [2]

b. (i) Calculate the angular separation of the two towers when the images of the towers are just resolved by Emlyn. [3]

(ii) Emlyn can just resolve the images of the two towers when his distance from the towers is 11 km. Determine the distance between the two towers.

d. Emlyn puts on a pair of polarizing sunglasses. Explain how these sunglasses reduce the intensity of the light, reflected from the sea, that enters Emlyn's eyes. [2]

# Markscheme

a. for the images (of two sources) just to be resolved/distinguished/seen as separate;

central maximum of one diffraction pattern must coincide with first minimum of second / *OWTTE*;

*Accept a suitably drawn diagram for the second marking point.*

b. (i) $\theta = \left(\frac{1.22 \times 550 \times 10^{-9}}{2.0 \times 10^{-3}} =\right) 3.4 \times 10^{-4}\ (\text{rad})$ ***or*** 0.019°;

(ii) $d = 11 \times 10^3 \times 3.4 \times 10^{-4}$;

$= 3.7\ (\text{m})$;

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

d. reflected light is (partially) polarized parallel to sea surface/horizontally polarized;

sunglasses have a transmission axis at 90° to reflected light/vertical transmission axis;

# Examiners report

a. An improvement in the answers to (a) was noted.

b. In (b) very few omitted to use the factor of 1.22 and full marks were often scored for both calculations.

d. (d) was poorly answered with many being unable to make it clear that reflected light from the sea would be partially horizontally polarized. Some just referred to the darkness of the sunglasses' lens.

This question is about standing waves in a vibrating string.

A guitar string vibrates at 330 Hz in its fundamental mode.

a. Describe the formation of standing waves in a string fixed at both ends. [2]

b. The length of the string is 0.64 m. Calculate the velocity of the wave in the string. [2]

# Markscheme

a. wave travels down string and is reflected / *OWTTE;*

incident and reflected waves interfere/add/superpose to give a standing wave;

b. $\lambda = 2L = 1.28$ (m);

$v = \lambda f = 420$ ($ms^{-1}$);

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

# Examiners report

a. (a) and (b) were well done in general, though many forgot to multiply the length by 2 to obtain the wavelength in (b).

b. (a) and (b) were well done in general, though many forgot to multiply the length by 2 to obtain the wavelength in (b).

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This question is about dispersion.

State an approximate value for the wavelength of visible light.

# Markscheme

any value within the range 320 – 780 nm;

# Examiners report

[N/A]

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This question is about the electromagnetic spectrum.

Outline the nature of electromagnetic waves.

# Markscheme

a varying magnetic and electric field at right angles to each other;

vibration of $E$ and $B$ fields at right angles to the direction of propagation of the wave;

transverse wave;

same speed in a vacuum;

# Examiners report

[N/A]

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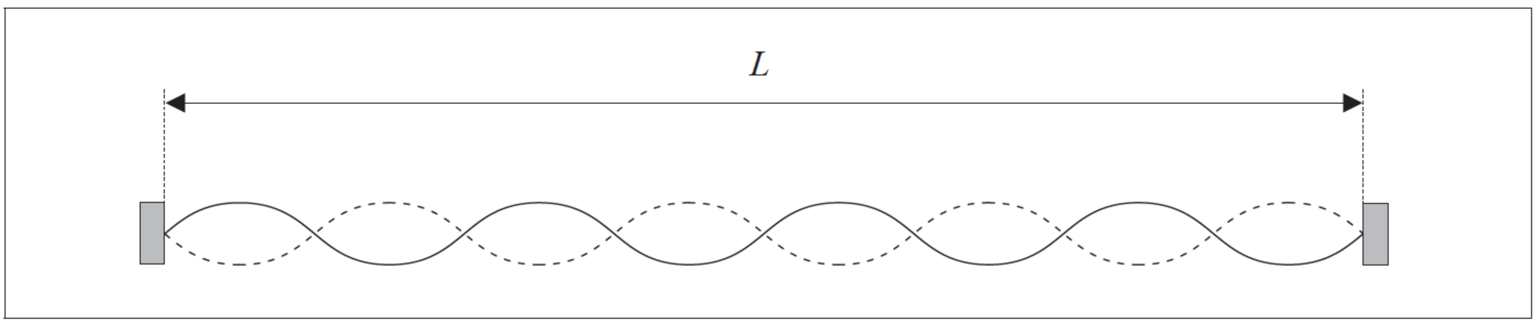
This question is about standing (stationary) waves.

The diagram represents a standing wave of wavelength $\lambda$ set up on a string of length $L$.




The string is fixed at both ends.

a. For this standing wave [3]

(i) state the relationship between $\lambda$ and $L$.

(ii) label, on the diagram, **two** antinodes where the string is vibrating in phase. Label the antinodes with the letter A.

b. The standing wave has wavelength $\lambda$ and frequency $f$. State and explain, with respect to a standing wave, what is represented by the product $f\lambda$. [3]

# Markscheme

a. (i) $L=4\lambda$ or $\lambda = \frac{L}{4}$;

(ii) two antinodes labelled;
with separation of integral number of wavelengths;

b. $f\lambda$ is the speed of the wave;

standing wave formed by interference of an incident and a reflected progressive wave;

speed is the speed of this progressive wave;

# Examiners report

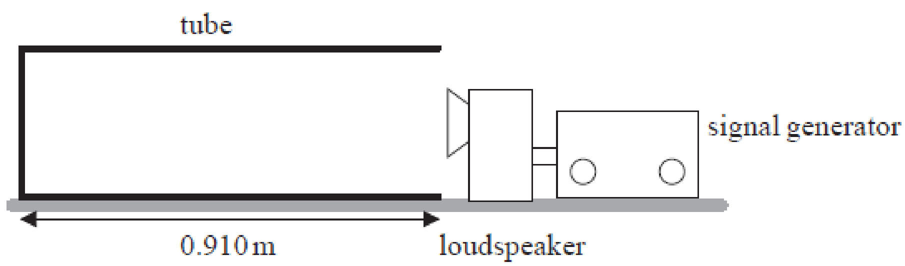
a. [N/A]
b. [N/A]

---

This question is about standing (stationary) waves.

a. State **one** way in which a standing wave differs from a travelling (progressive) wave. [1]

b. A loudspeaker connected to a signal generator is placed in front of the open end of a tube. [3]




The frequency of the sound is slowly increased from zero. At a frequency of 92.0 Hz the first large increase in the intensity of the sound is heard.

(i) On the diagram above, draw a representation of the wave in the tube for the frequency of 92.0 Hz.

(ii) The length of the tube is 0.910 m. Determine the speed of sound in the tube.

c. The frequency of sound is continuously increased above 92.0Hz. [2]

Calculate the frequency at which the next large increase in the intensity of the sound is heard.

# Markscheme

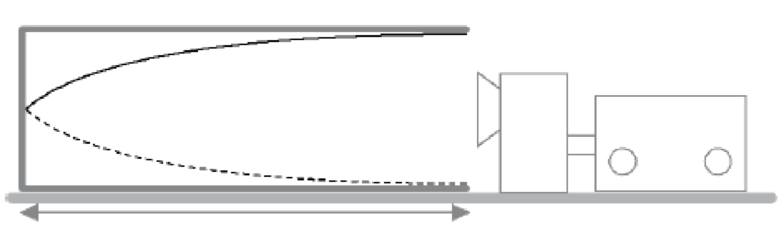
a. standing waves do not transfer energy;

standing waves do not have a constant amplitude;

points on a standing wave between consecutive nodes have a constant phase;

standing waves have permanent nodes/antinodes;

b. (i) correct diagram as shown; *(dotted line not essential for the mark)*



(ii) wavelength of sound is (4×0.910)=3.64m;
speed of sound 3.64×92=335ms$^{-1}$;

c. the next harmonic has wavelength $\frac{4\times 0.910}{3}=\frac{3.64}{3}\text{m}$;

and so frequency 3×92=276Hz ;

# Examiners report

a.

b.

c.

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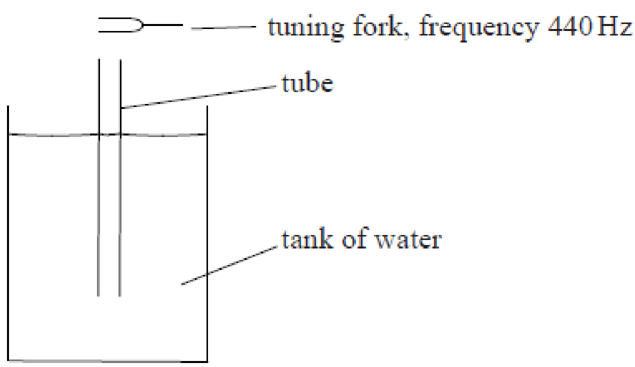
This question is about standing (stationary) waves.

a. Describe **two** ways that standing waves are different from travelling waves. [2]

b. An experiment is carried out to measure the speed of sound in air, using the apparatus shown below. [3]




A tube that is open at both ends is placed vertically in a tank of water, until the top of the tube is just at the surface of the water. A tuning fork of frequency 440 Hz is sounded above the tube. The tube is slowly raised out of the water until the loudness of the sound reaches a maximum for the first time, due to the formation of a standing wave.

(i) Explain the formation of a standing wave in the tube.

(ii) State the position in the tube that is always a node.

c. The tube is raised until the loudness of the sound reaches a maximum for a second time. Between the two positions of maximum loudness, the tube has been raised by 36.8 cm. The frequency of the sound is 440 Hz. Estimate the speed of sound in air. [2]

# Markscheme

a. energy is propagated by travelling waves / energy is not propagated by standing waves;

amplitude constant for travelling waves / amplitude varies with position for standing waves;

phase varies with position for travelling waves / phase constant for standing waves;

travelling waves do not have nodes and antinodes / standing waves do have nodes and antinodes;

travelling waves can have any wavelength/frequency / standing waves can only have certain wavelengths/frequencies (to fit boundary conditions);

b. (i) wave from tuning fork travels down tube and is reflected;

incident and reflected waves interfere/superpose/combine/add together to give a standing wave (that fits the boundary conditions);

(ii) the surface of the water (in/at the bottom of the tube);

c. $\frac{\lambda}{2} = 0.368 \Rightarrow \lambda = 0.736\text{m}$;

$v = f\lambda = 440 \times 0.736 = 320\text{ms}^{-1}$;

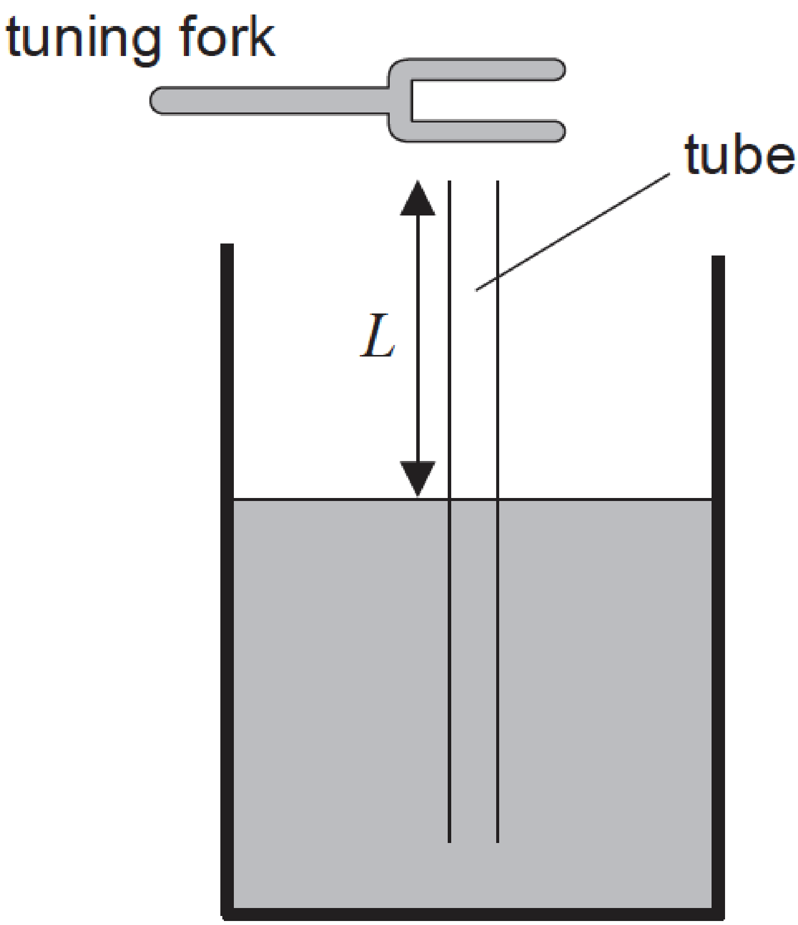
# Examiners report

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

---

This question is about standing (stationary) waves in a tube.

a. A thin tube is immersed in a container of water. A length L of the tube extends above the surface of water. [4]

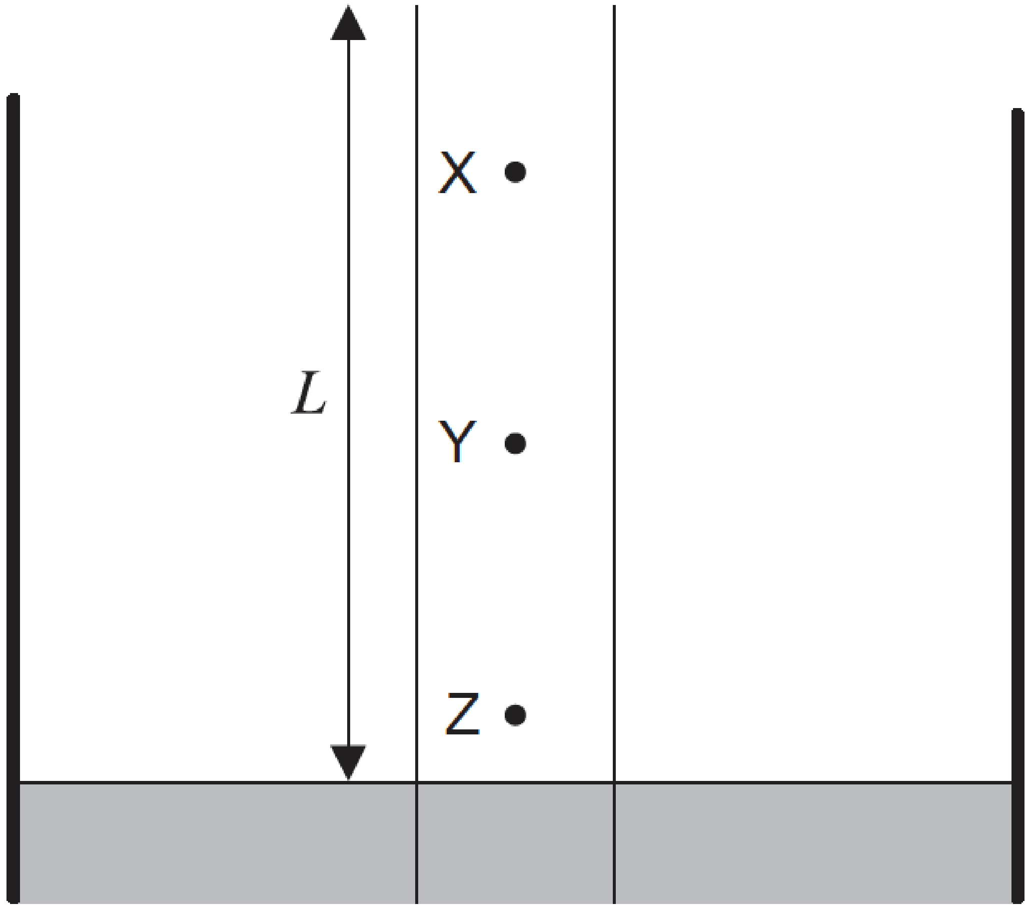



A tuning fork is sounded above the tube. For particular values of *L*, a standing wave is established in the tube.

(i) Explain how a standing wave is formed in this tube.

(ii) The frequency of the tuning fork is 256 Hz. The smallest length *L* for which a standing wave is established in the tube is 33.0 cm. Estimate the speed of sound in the tube.

b. The diagram shows an enlarged view of the tube shown in (a). X, Y and Z are three molecules of air in the tube. [2]




The length *L* is 33.0 cm.

(i) State the direction of oscillation of molecule Y.

(ii) Identify the molecule that has the greatest amplitude.

# Markscheme

a. (i) travelling waves move down the tube;

which then interfere with the reflected waves (from the closed end of the tube/surface of the water);

*Accept superposition as an alternative to interference.*

(ii) $\lambda = (4L = 4 \times 0.33 =)\,1.32\,(\text{m})\,;$
$v = (f\lambda = 256 \times 1.32 =)\,338\,(\text{ms}^{-1})$ ;

b. (i) vertical;

(ii) X;

# Examiners report

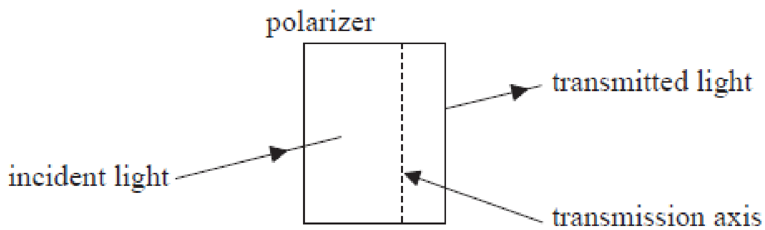
a. Part (a) was answered well by many, but the idea of superposition of incident and reflected waves was often expressed poorly. Candidates seemed to have memorised the definition of how a standing wave is formed but often struggled to see how it applied to this situation. Part (ii) was easy if the candidate knew that the wavelength was 4L. Many just used L or other multiples of L.

b. Part (b) was also an easy 2 marks as long as it was remembered that the waves were longitudinal.

This question is about polarization.

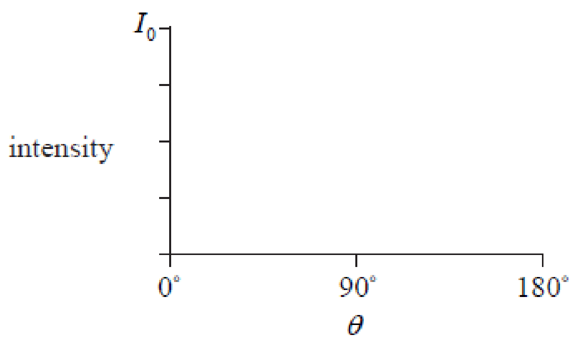
a. State what is meant by polarized light. [1]

b. Light of intensity $I_0$ is incident on a polarizer. The transmission axis of the polarizer is vertical. The polarizer is rotated by an angle $\theta$ about the direction of the incident light. The intensity of the transmitted light is measured for various angles $\theta$. [4]

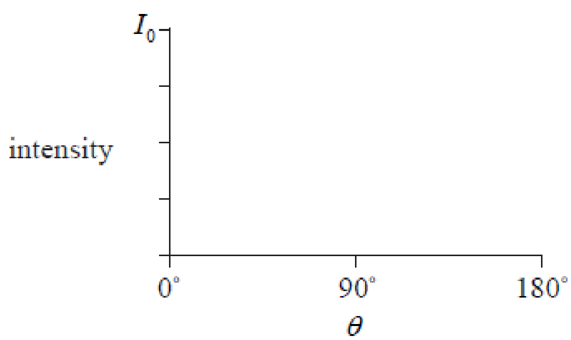



On the axes below, sketch graphs to show the variation of the transmitted intensity $I$ with $\theta$ when the incident light is

(i) horizontally polarized.




(ii) unpolarized.

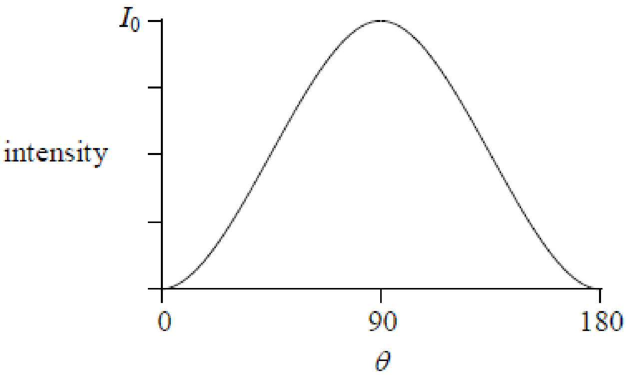



# Markscheme

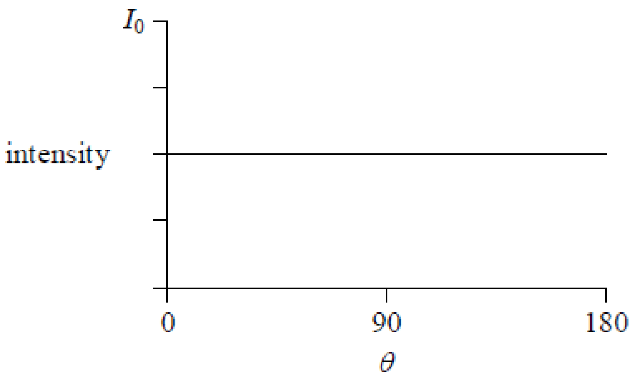
a. light in which the electric field oscillates in the same plane;

b. (i) zero at 0 and 180 degrees;

peak at 90 degrees;




(ii) horizontal straight-line;
through half the incident intensity;




# Examiners report

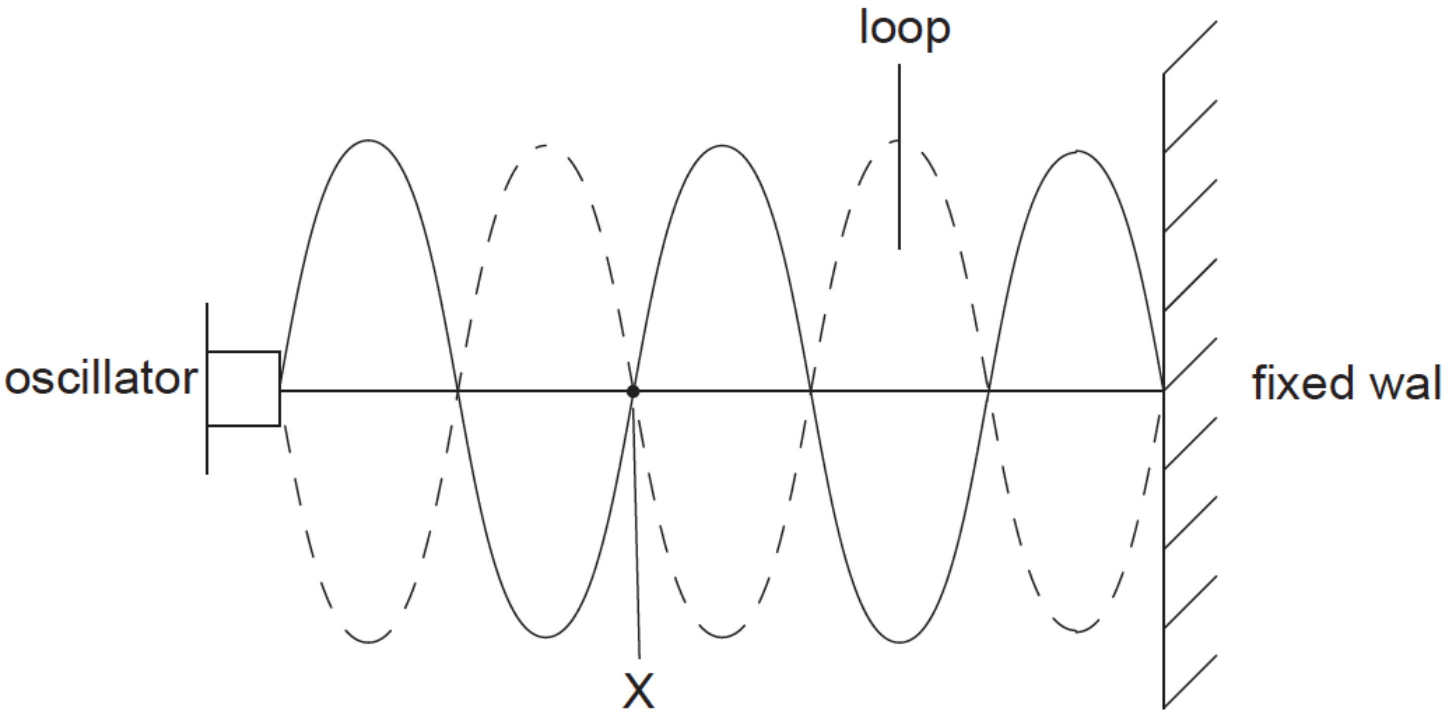
a.

b.

---

This question is about standing (stationary) waves.

The diagram shows an arrangement used to produce a standing (stationary) wave on a stretched string of length 2.4 m. A standing wave with five loops appears when the frequency of the oscillator is set to 150 Hz, as shown below.




a. State the name given to point X on the string. [1]

b. (i) Calculate the speed of the wave along the string. [3]

(ii) Calculate the frequency of the oscillator that would produce a standing wave with two loops on this string.

# Markscheme

a. node;

b. (i) wavelength $= \frac{2.4}{2.5} = (0.96\text{m})$;

$c = f\lambda = 144\ (\text{ms}^{-1})$;

(ii) 60 (Hz);

# Examiners report

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

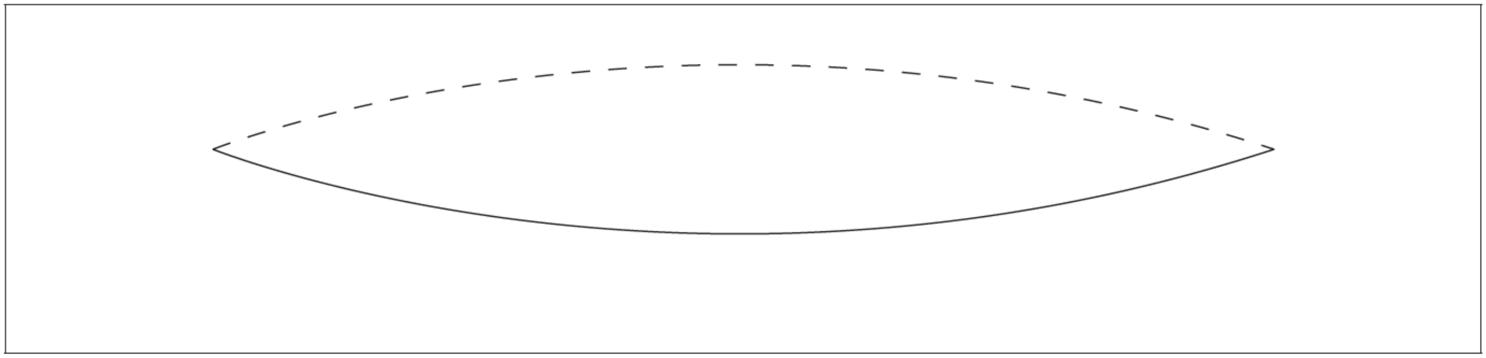
---

This question is about standing waves on strings.

a. A string is fixed at one end and the other free end is moved up and down. Explain how a standing wave can be formed on the string. [3]

b. The diagram shows a string vibrating in its first harmonic mode. Both ends [5]

of the string are fixed.



(i) Label an antinode on the diagram.

(ii) The length of the string is 0.85 m and its first harmonic frequency is 73 Hz. Calculate the speed of the waves on the string.

(iii) Sketch how the string will appear if it is vibrated at a frequency three times that of the first harmonic frequency.

(iv) State the speed of the wave when the string is vibrated at a frequency three times that of the first harmonic frequency.

# Markscheme

a. at certain fixed frequencies;

incident wave and reflected wave;

superpose (or interfere);

b. (i) antinode clearly labelled in centre;

(ii) wavelength=1.7 m;
speed=$1.2\times10^2$ $ms^{-1}$;

(iii)

(iv) $1.2\times10^2$ $ms^{-1}$;

# Examiners report

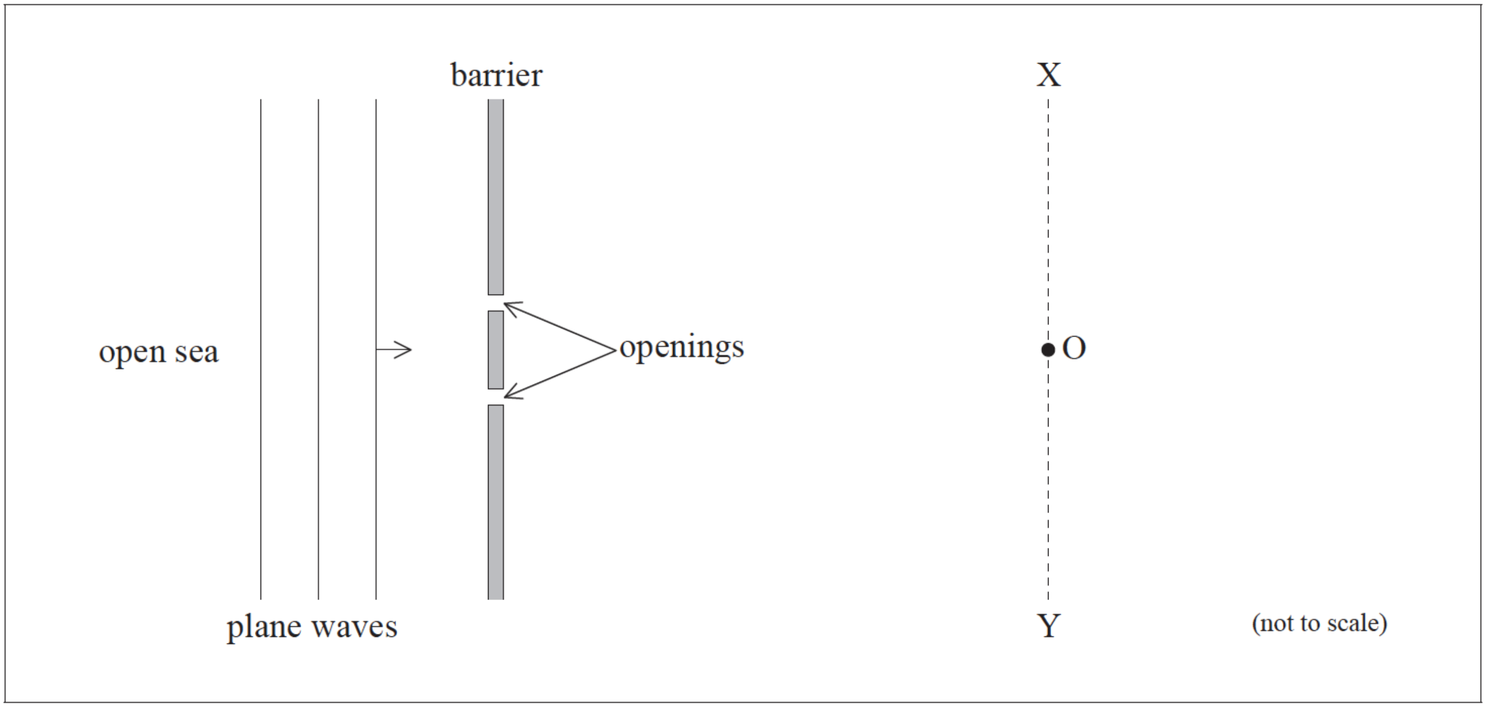
a. [N/A]
b. [N/A]

---

This question is about waves.

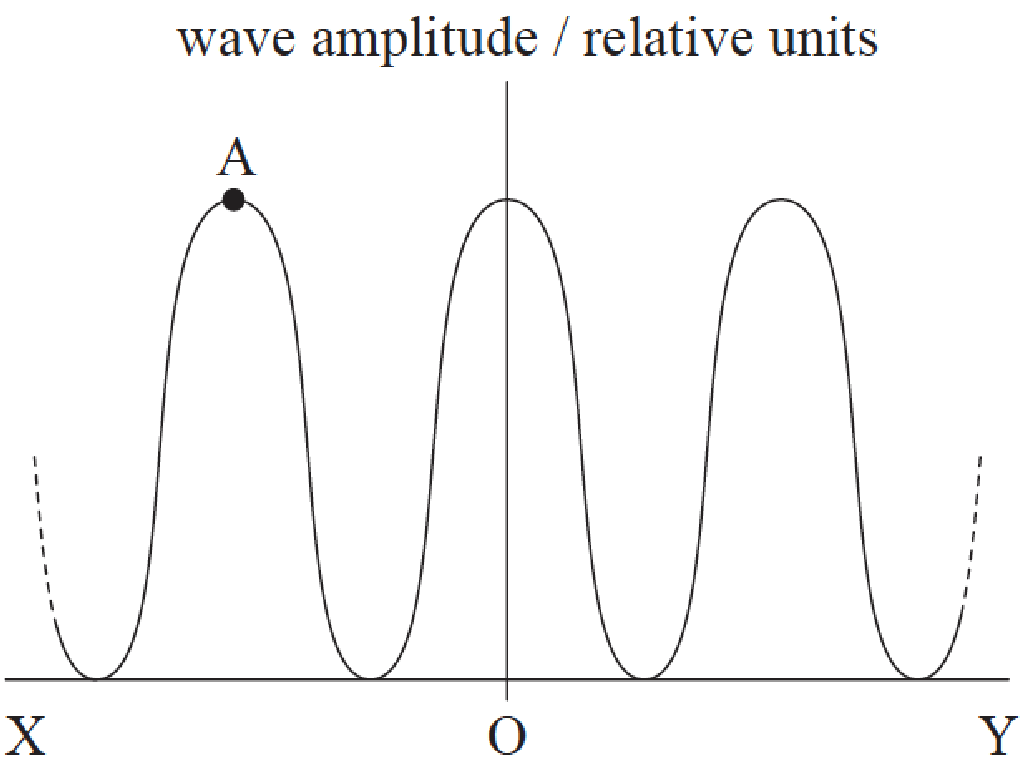
a. State the principle of superposition. [2]

b. The diagram shows a plan view of a harbour with a floating barrier that has two openings of equal width. [7]




Plane water waves from the open sea are incident on the barrier and the openings act as point sources of waves. The distance from the openings to XOY is much greater than the wavelength of the wave. O is equidistant from the openings.

The graph shows the variation of the magnitude of the wave amplitude that is observed along the line XOY.




(i) State why the two sets of waves emerging from the openings are coherent.

(ii) Explain how the disturbance at point A arises. You may draw on the diagram **of the harbour** to illustrate your answer.

(iii) The wavelength of the waves is doubled. State and explain the effect that this change will have on the graph.

c. The harbour in (b) is modified to have many narrower openings. The total width of the openings remains the same. Outline **two** ways in which the variation of wave amplitude along XY changes from that shown on the graph in (b). [2]

# Markscheme

a. net displacement of the medium;

equals the resultant/sum of individual displacements;

*Award **[1 max]** for reference to amplitude rather than displacement.*

*Award **[0]** for reference only to troughs and crests.*

b. (i) division of wavefront so constant phase;

(ii) interference/superposition occurs at A;
between waves from each opening;
waves arrive in phase / path difference is one wavelength;
producing a (1st order) maximum;
*Award **[3 max]** for clear points that appear on diagram.*

(iii) maxima occur when the path difference is an integral number of wavelengths;
because wavelength doubles, larger distances/angles required to achieve same path difference;
successive maxima fringes are twice as far/further apart;

***or***

quotes double slit/grating formula;
substitute $2\lambda$ into equation and states all other terms stay constant;
successive maxima fringes are twice as far/further apart;

c. *Assuming spacing of openings stays the same.*

same separation of maxima;

maxima increase in amplitude/intensity;

maxima narrower/sharper;

formation of secondary maxima;

*Award **[2 max]** for other reasonable responses if the response clearly states an assumption that the openings are closer or further apart than before.*

# Examiners report

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

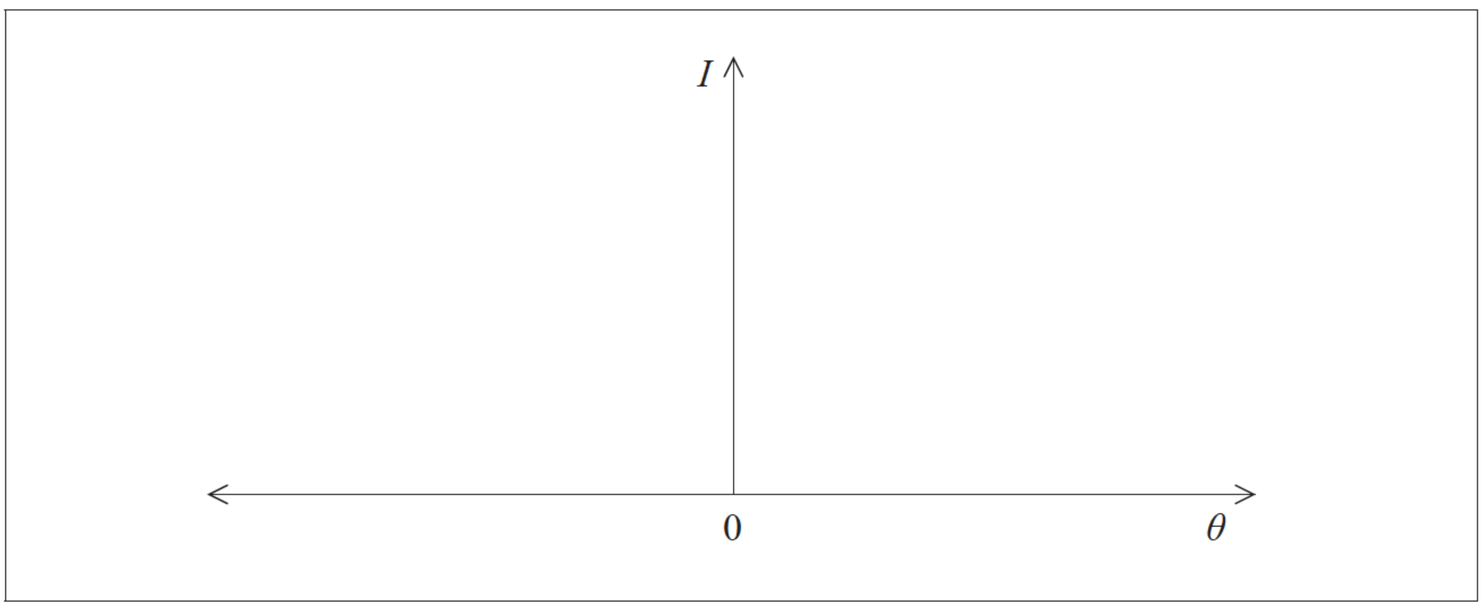
---

This question is about diffraction and polarization.

a. Light from a monochromatic point source $S_1$ is incident on a narrow, rectangular slit. [5]


After passing through the slit the light is incident on a screen. The distance between the slit and screen is very large compared with the width of the slit.

(i) On the axes below, sketch the variation with angle of diffraction *θ* of the relative intensity *I* of the light diffracted at the slit.




(ii) The wavelength of the light is 480 nm. The slit width is 0.1 mm and its distance from the screen is 1.2 m. Determine the width of the central diffraction maximum observed on the screen.

b. Judy looks at two point sources identical to the source $S_1$ in (a). The distance between the sources is 8.0 mm and Judy's eye is at a distance *d* from the sources. [3]

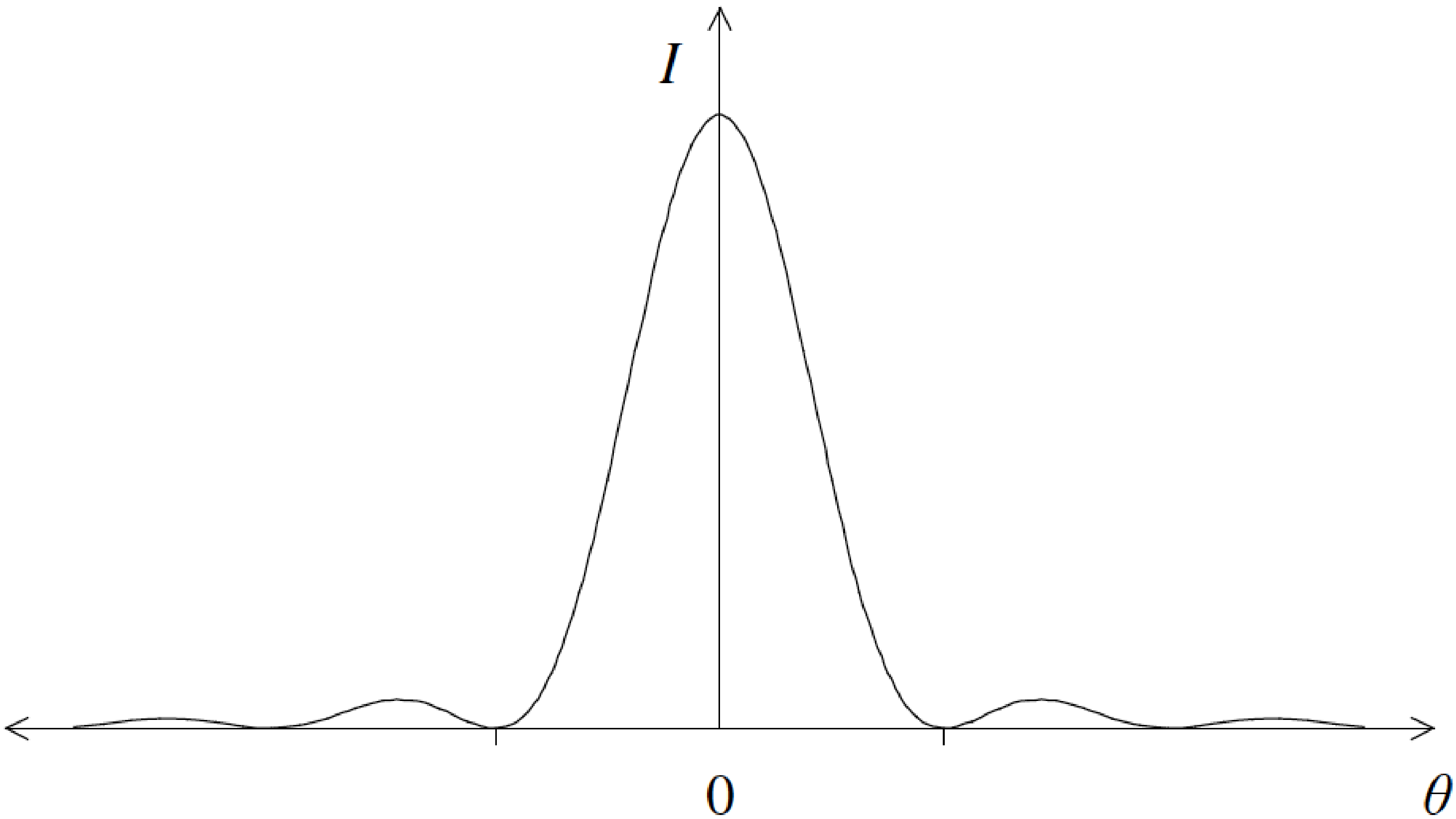
Estimate the value of *d* for which the images of the two sources formed on the retina of Judy's eye are just resolved.

c. The light from a point source is unpolarized. The light can be polarized by passing it through a polarizer. [3]

Explain, with reference to the electric (field) vector of unpolarized light and polarized light, the term polarizer.

# Markscheme

a. (i)




overall correct shape with central maxima at $\theta$=0; { *(only one secondary maximum required each side of θ=0)*
secondary maximum no greater than ¼ intensity of central maximum; { *(judge by eye)*

(ii) $\theta = \frac{\lambda}{b} = \frac{x}{D}$ (where *x* is the half width of central maximum);
$2x = 2\frac{D\lambda}{b}$;
$\left(\frac{2\times1.2\times4.8\times10^{-7}}{10^{-4}}\right) = 12\text{mm}$;

b. diameter of pupil =3.0 mm; *(accept answers in the range of 2.0 mm to 5.0 mm)*

$\theta = \left(1.22 \times \frac{\lambda}{b} = 1.22 \times \frac{4.8\times10^{-7}}{3.0\times10^{-3}} =\right) 1.95 \times 10^{-4}\,(\text{rad})$;

$d = \frac{8.0\times10^{-3}}{1.95\times10^{-4}} = 41\text{m}$; *(accept answer in the range of 20m to 70m)*

c. in unpolarized light the plane of vibration of the electric (field) vector is continually changing / *OWTTE*;

in polarized light the electric vector vibrates in one plane only;

a polarizer is made of material that absorbs/transmits either the horizontal or vertical component/only one component of the electric vector;

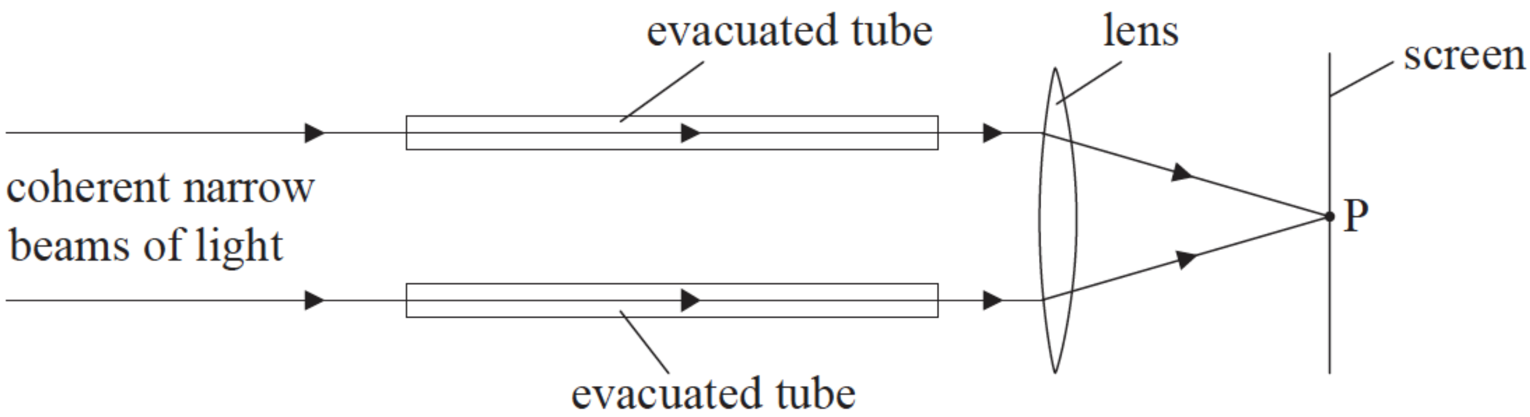
# Examiners report

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

---

This question is about interference of light.

Two coherent narrow beams of light pass through two identical evacuated tubes, as shown below.




The two coherent narrow beams are brought to a focus at point P on a screen.

a. State what is meant by coherence. [1]

b. State, with reference to the wavelength, the condition that must be satisfied for a bright fringe to be formed on the screen at point P. [1]

c. Air is allowed to enter gradually into one of the evacuated tubes. The brightness of the light at point P is seen to decrease and then increase again repeatedly. [2]

(i) State the effect on the wavelength of the light in the evacuated tube as the air is introduced.

(ii) Suggest why there is a variation in the brightness of the light at point P.

# Markscheme

a. constant phase difference;

b. path difference between beams=$n\lambda$, where $n$ is an integer/is one wavelength;

c. (i) wavelength decreases;

(ii) (effective/optical) path/phase difference changes;

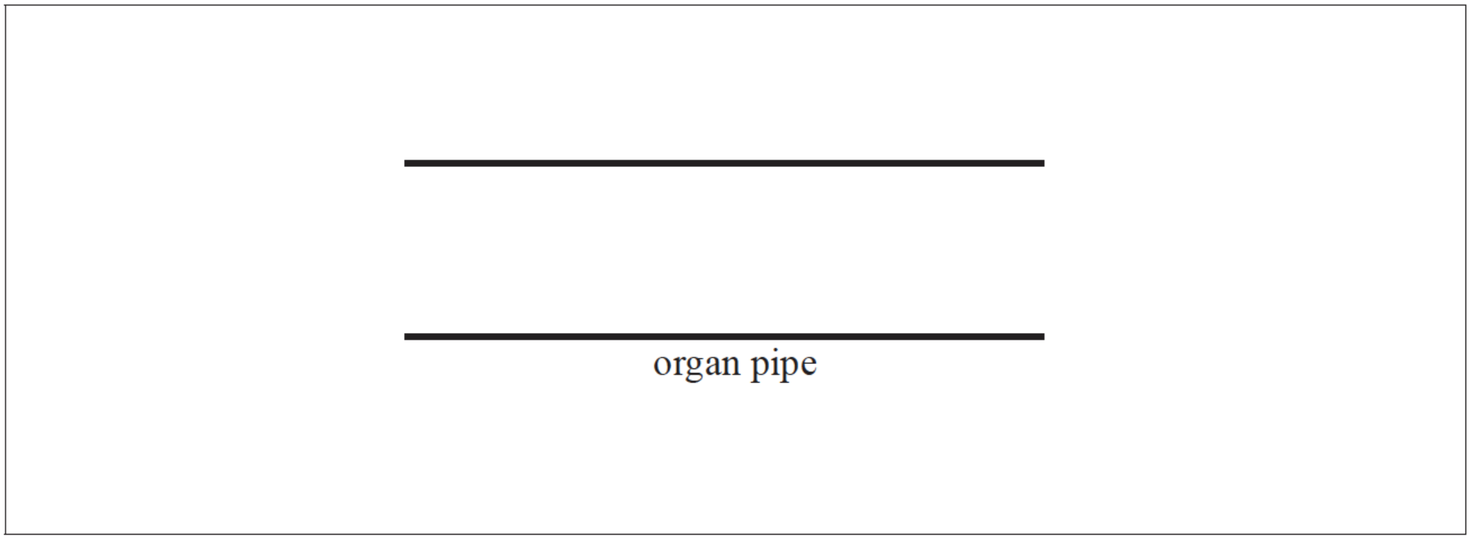
# Examiners report

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

---

This question is about standing waves in an organ pipe.

a. The diagram shows an organ pipe that is open at both ends. [3]




The pipe is emitting its lowest frequency note.

On the diagram above,

(i) sketch a representation of the standing wave set up in the pipe.

(ii) label with the letter P, the point or points within the pipe where the air pressure is a maximum.

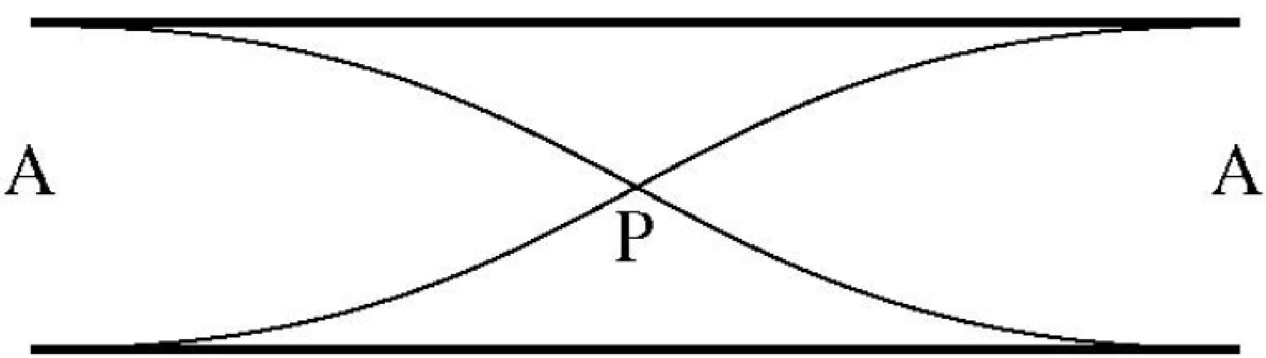
(iii) label with the letter A, the displacement antinodes.

b. The length of the pipe in (a) is 1.5 m. An organ pipe that is closed at one end has the same lowest frequency note as the pipe in (a). [3]

Show that the length of this pipe is 0.75 m.

# Markscheme

a.




(i) waveform showing node at centre and antinodes at end;

(ii) P as shown;

(iii) A as shown;

b. for open pipe $f = \frac{v}{2l}\left(= \frac{v}{3.0}\right)$;

for closed pipe $f = \frac{v}{4l} = \frac{v}{3.0}$;

so $l$ = 0.75m

# Examiners report

a. [N/A]

b. [N/A]

This question is about polarized light.

Describe what is meant by polarized light.

# Markscheme

the electric field vector oscillates in one plane/direction only;

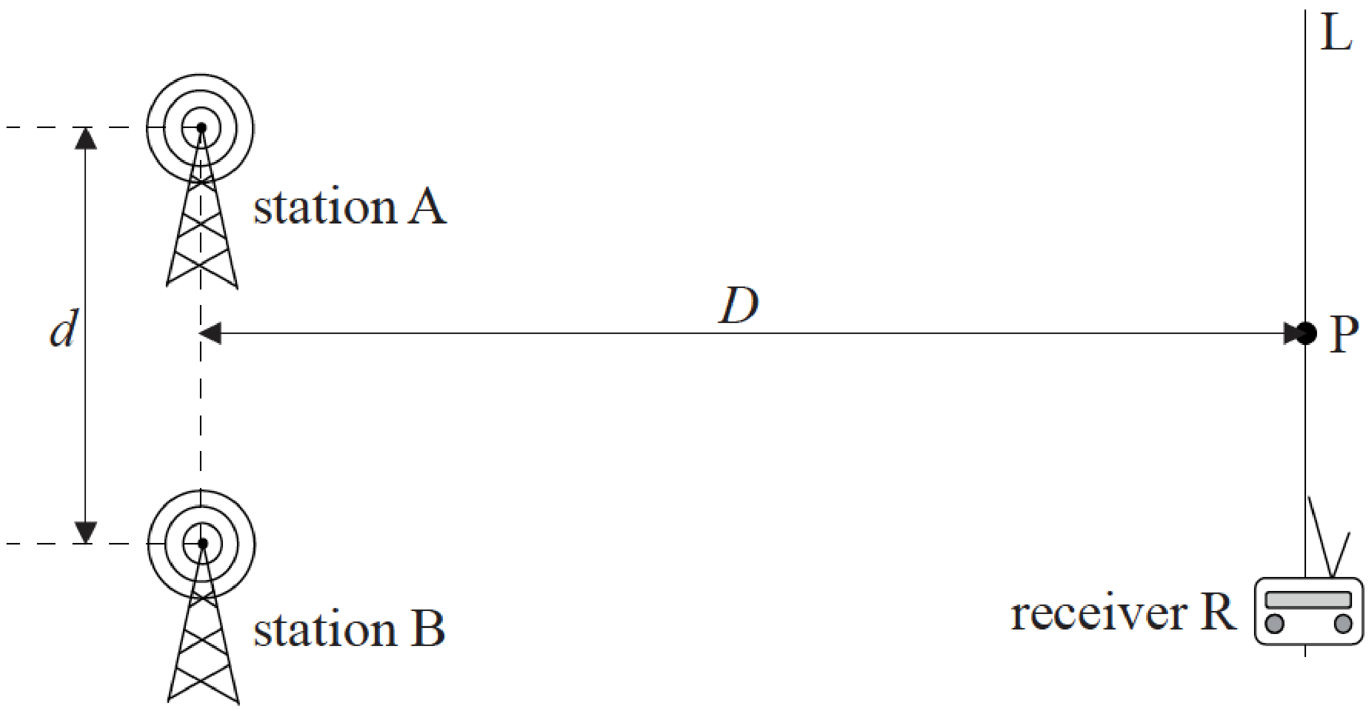
# Examiners report

[N/A]

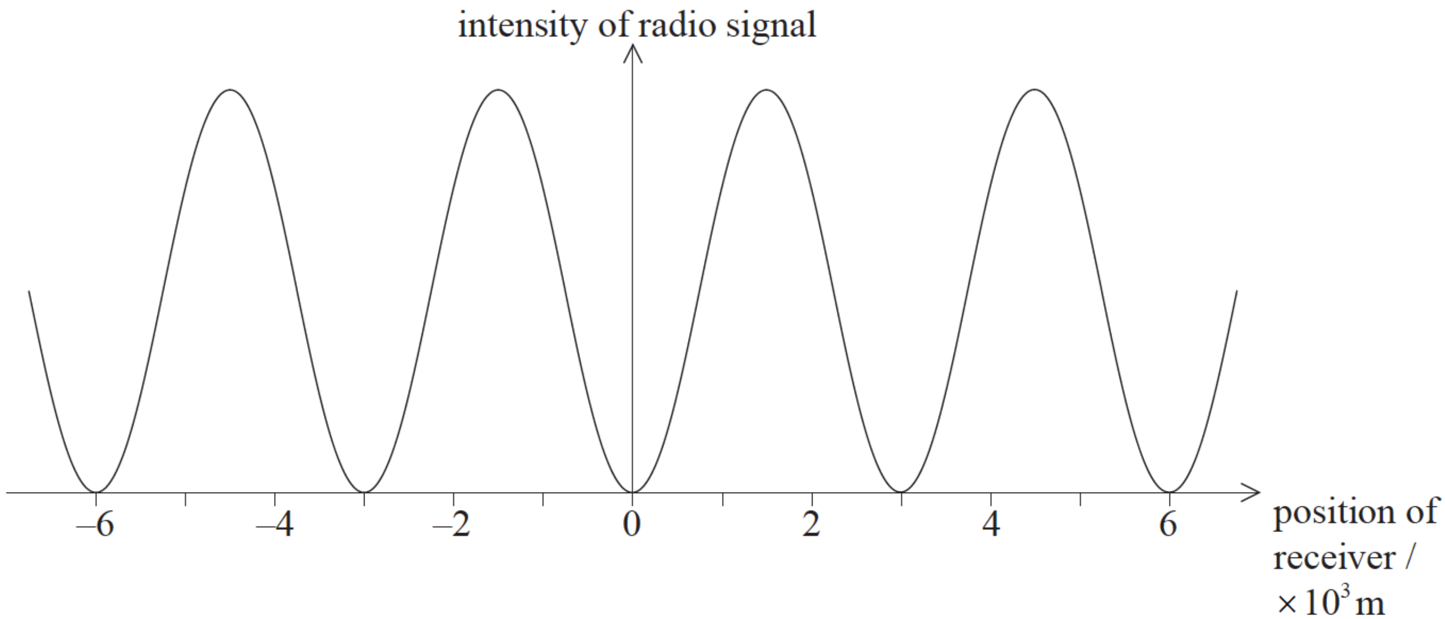
---

This question is about interference.

a. Two radio stations, A and B, broadcast two coherent signals. The separation *d* between A and B is much less than the distance *D* from the stations to the receiver R. Point P is at the same distance from A and B. [5]



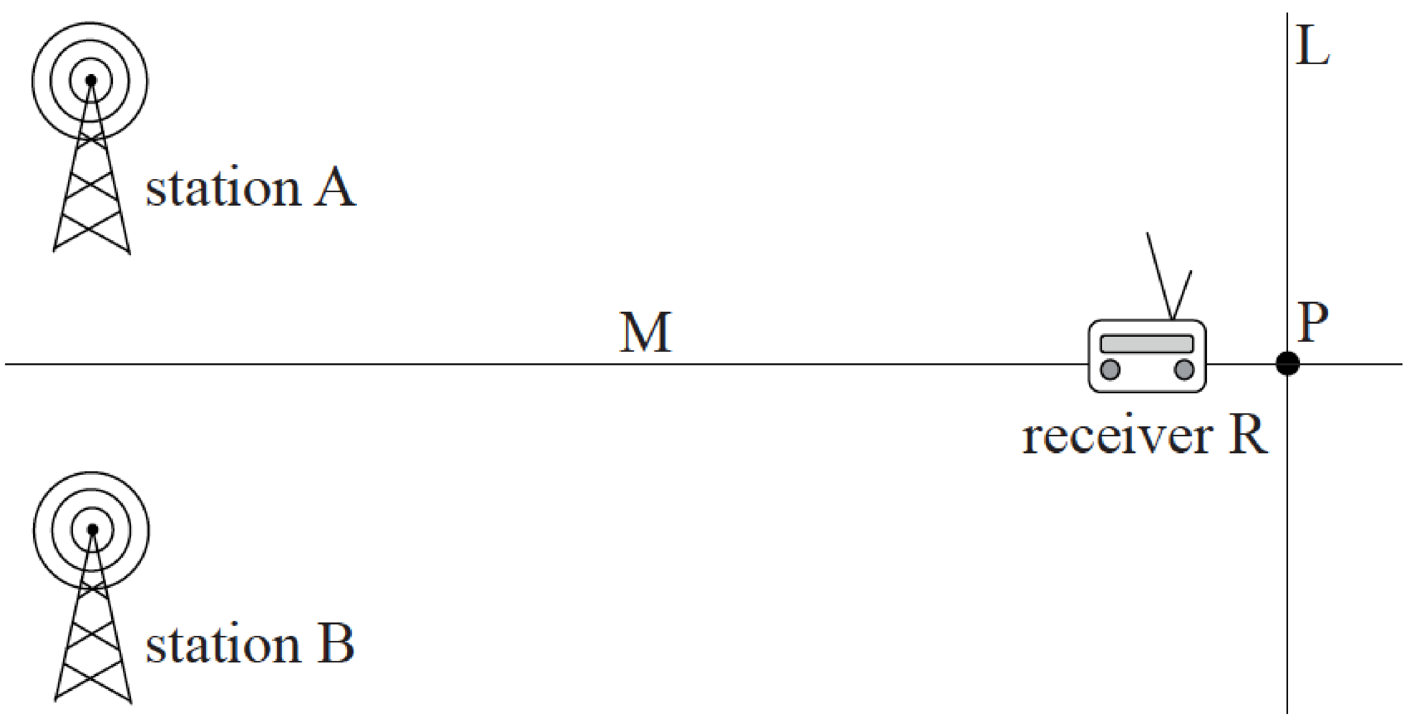

The graph shows how the intensity of the radio signal varies with position as the receiver is moved along line L. The position of the receiver is zero when the receiver is at P.




(i) Deduce that the two sources A and B are 180° out-of-phase.

(ii) The wavelength of the radio signal is 40m. Calculate the ratio $\frac{D}{d}$.

b. The receiver R then moves along a different line M which is at 90° to line L. [2]




Discuss the variation of the intensity of the radio signal with position as the receiver is moved along line M.

# Markscheme

a. (i) intensity at P is zero hence complete destructive interference occurs;

point P is at the same distance from A and B / path difference is zero;

destructive interference comes from a 180° phase difference in the signals;

(ii) separation between minima $s$=3(km);
$\frac{D}{d}\left(=\frac{s}{\lambda}=\frac{3000}{40}\right)=75;$

b. R is always equidistant to stations A and B / signals from A and B are always out of phase;

intensity is always zero;

# Examiners report

a. This question discriminated very well and a full range was seen in the quality of answers. Well prepared candidates showed a good understanding and ability to apply the concept of interference. Lesser prepared candidates were not able to analyse the intensity-position graph. In (a)(i), candidates repeated the question without additional information and did not gain marks in (a)(ii) because they did not have enough information.

b. (b) discriminated well between, as evidenced by candidates, those that analysed the situation and those that attempted to remember some information from problems with similar context. Well prepared HL candidates realized that point P has no special position on the line M. (b) was very poorly answered at SL. The explanation of why the intensity is always zero was generally unclear and did not signify thought.

---

This question is about polarized light.

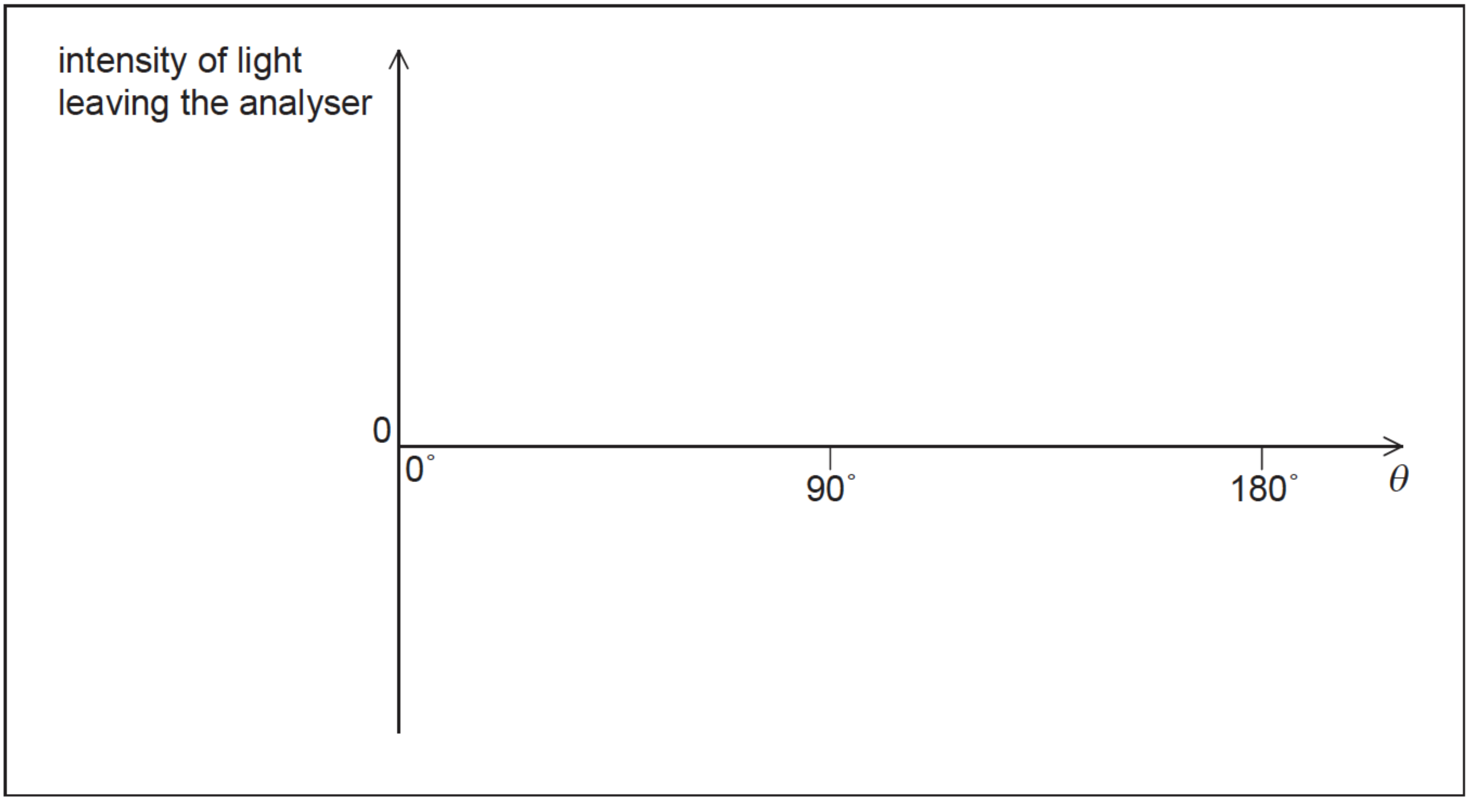
An analyser is used with polarized light.

a. Outline the function of an analyser in this context. [2]

b. Polarized light of intensity $I_0$ is incident on the analyser. [3]

(i) The transmission axis of the analyser is at an angle of 25° to the electric field of the polarized light. Calculate, in terms of $I_0$, the intensity of the light that leaves the analyser.

(ii) The angle $\theta$ between the transmission axis of the analyser and the electric field of the polarized light is varied. On the axes, sketch a graph to show the variation with $\theta$ of the intensity of the light leaving the analyser.



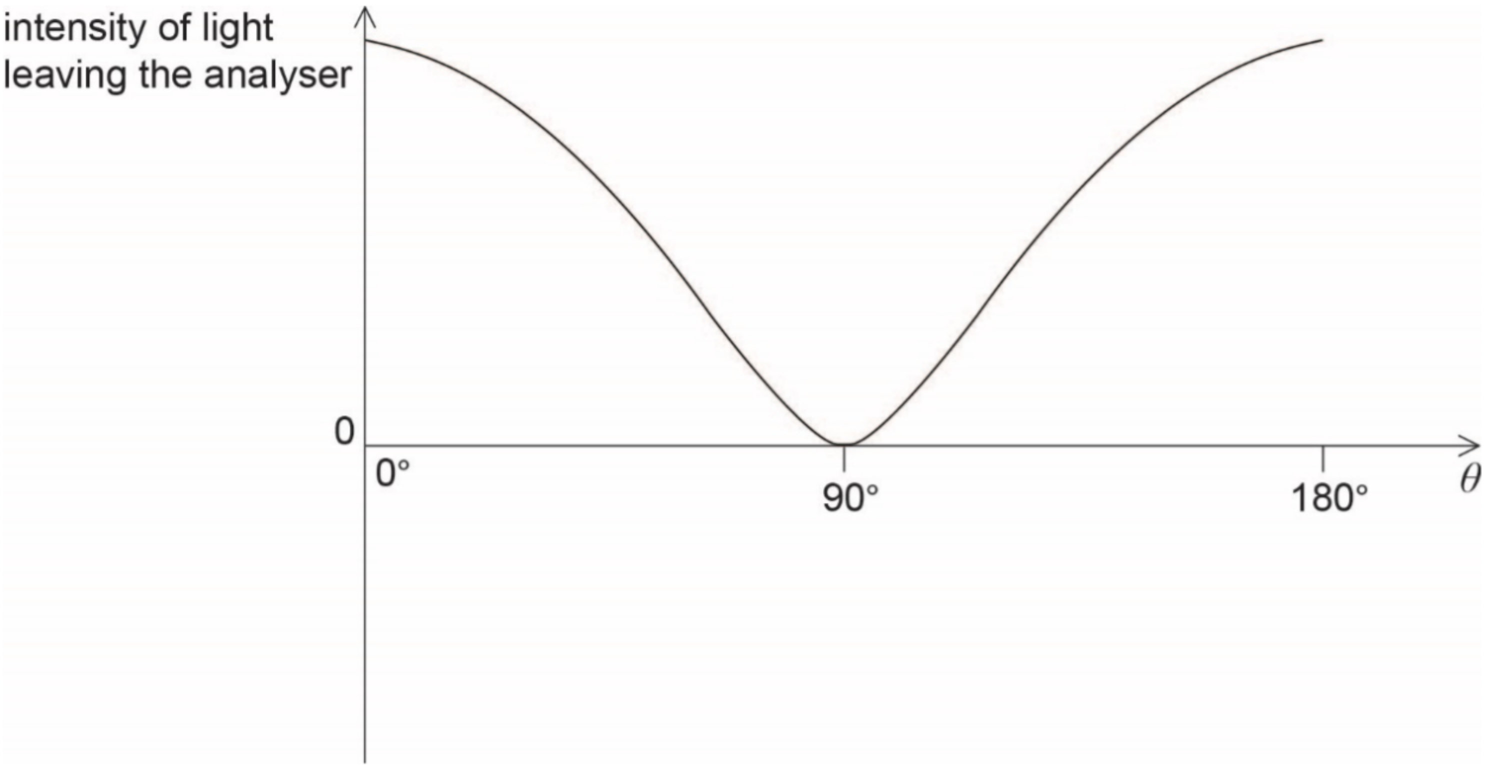

# Markscheme

a. by crossing the analyser with the polarized light;
the angle of polarization/electric field vector can be determined;

b. (i) ($I = I_0 \cos^2 25° =$) $0.82 I_0$;

(ii) $\cos^2$ shape; *(allow negative intensities for this mark)*

max at 0º and 180º, zero at 90º; *(allow non-cos² line for this mark)*



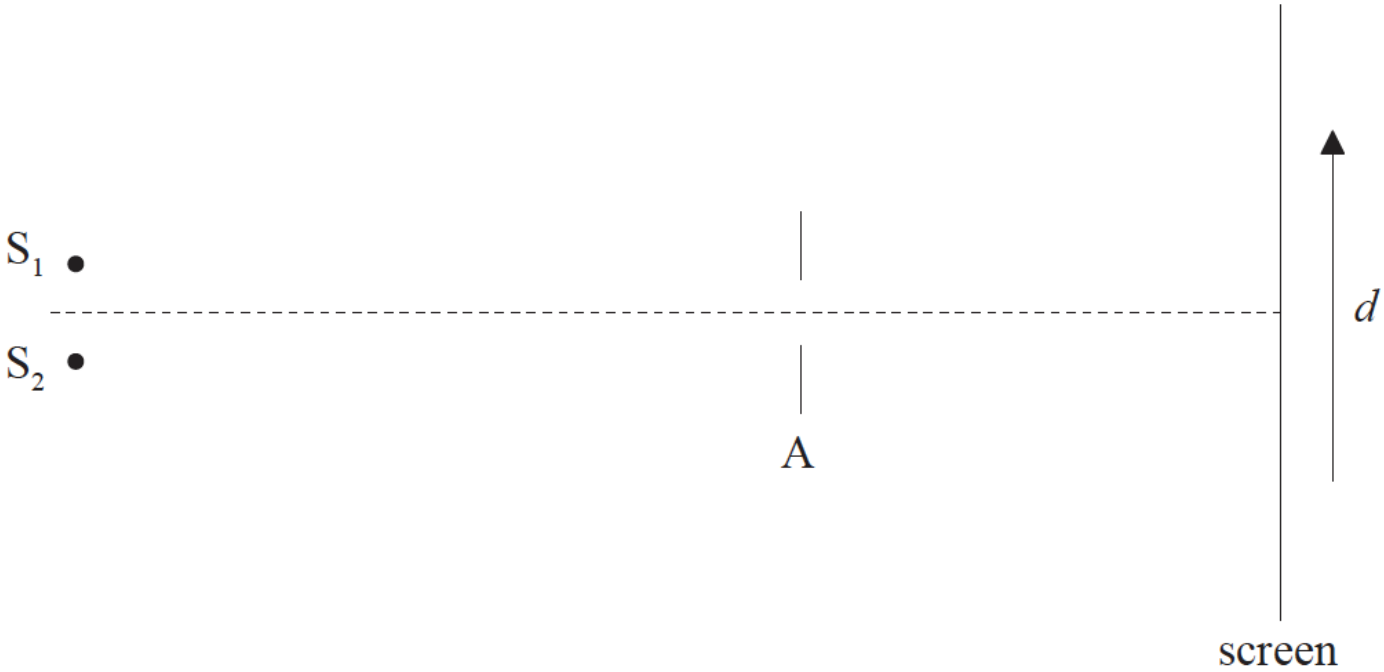

# Examiners report

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

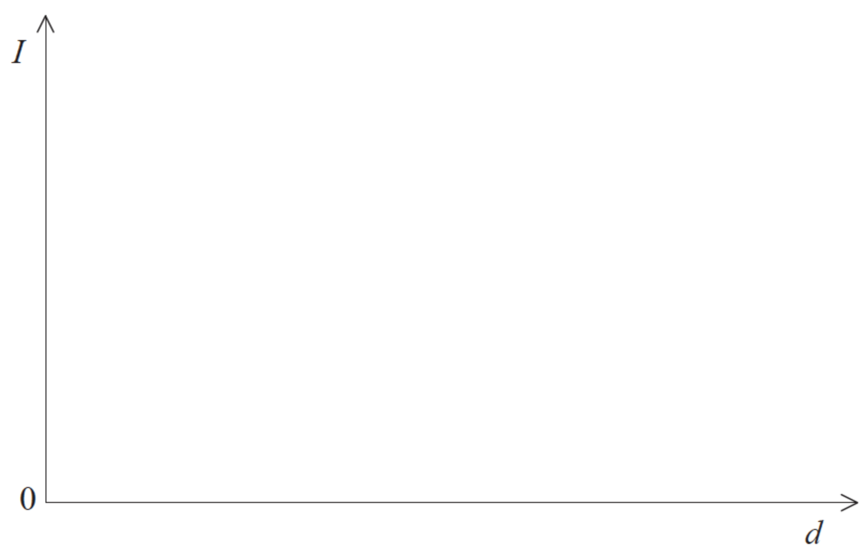
---

This question is about resolution.

a. Two point sources $S_1$ and $S_2$ emit monochromatic light of the same wavelength. The light is incident on a small aperture A and is then brought to focus on a screen. [3]




The images of the two sources on the screen are just resolved according to the Rayleigh criterion. Sketch, using the axes below, how the relative intensity *I* of light on the screen varies with distance along the screen *d*.




b. A car is travelling at night along a straight road. Diane is walking towards the car. She sees the headlights of the car as one single light. [3]

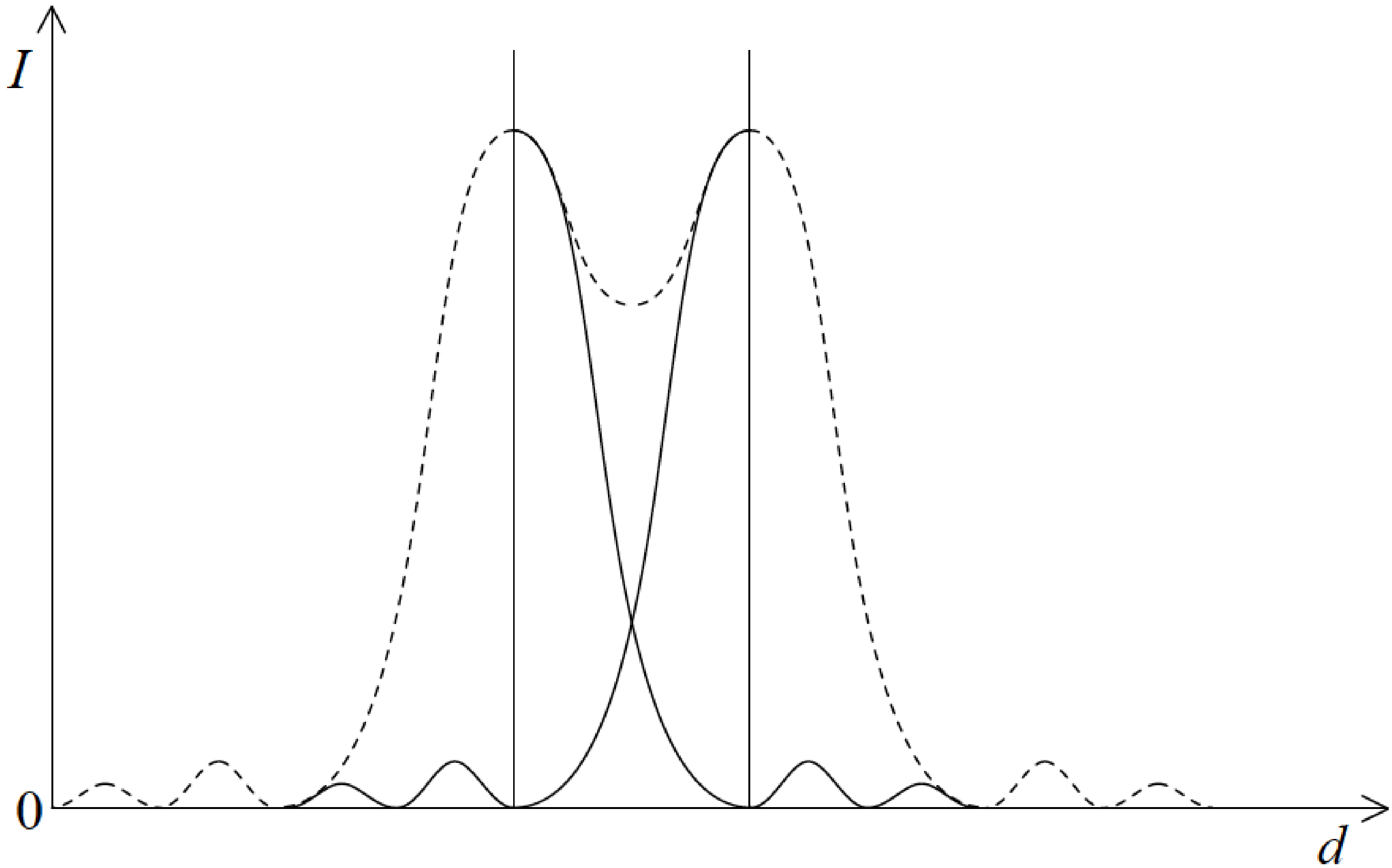
Estimate, using the data below, the separation *d* between Diane and the car at which, according to the Rayleigh criterion, Diane will just be able to see the headlights as two separate sources.

Distance between the headlights = 1.4 m
Average wavelength of light emitted by the headlights = 500 nm
Diameter of the pupils of Diane's eyes = 1.9 mm

c. The light from the car headlights in (b) is not polarized. State what is meant by polarized light. [1]

# Markscheme

a.




correct shape of two diffraction patterns showing central maximum and at least one secondary maximum each side of central maximum;
intensity of secondary maxima no greater than one third intensity of central maxima; } *(judge by eye)*
first minimum of one pattern coincident with central maximum of other pattern;

**or**

*Allow just the approximate dotted resultant intensity patterns:*
correct pattern of two symmetrical principal maxima;
with local minimum between them;
at least one secondary maximum on each side which are no more than $\frac{1}{3}$ of the intensity of the principal maxima;

b. angular separation for resolution=$1.22\frac{\lambda}{b} = 1.22 \times \frac{5.0\times10^{-7}}{1.9\times10^{-3}} = \left(3.21 \times 10^{-4}\right)(\text{rad})$;

$=\frac{1.4}{d}$;

$d$=4.4(km);

*Award* ***[2 max]*** *if 1.22 not used and answer is 5.3 km.*

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

c. light in which the electric/magnetic field (vector) vibrates only in one plane/direction;

# Examiners report

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