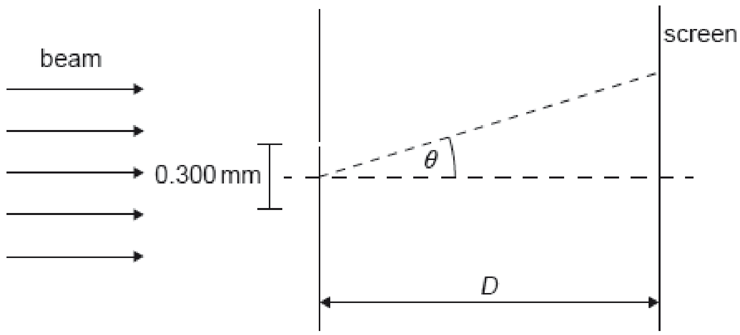
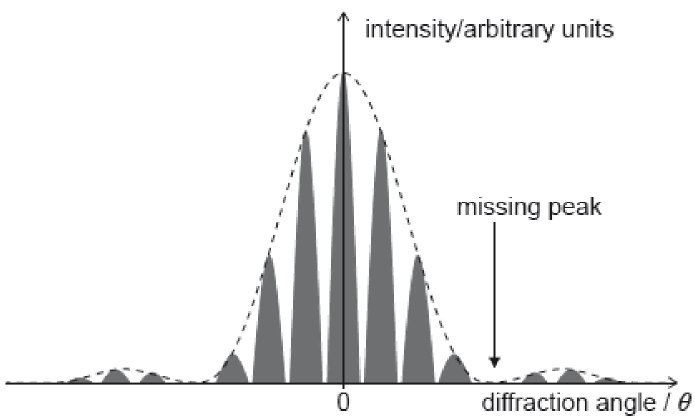
HL Paper 2

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]

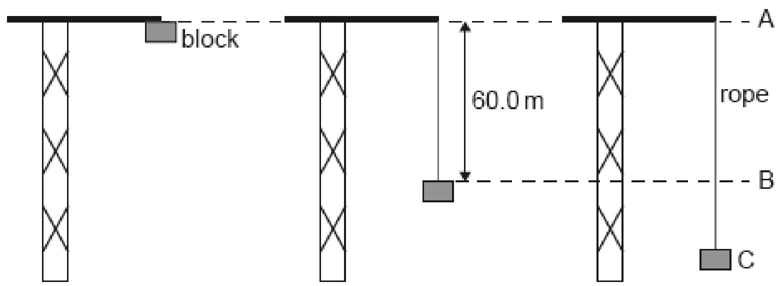
b.i. Calculate the angular separation between the central peak and the missing peak in the double-slit interference intensity pattern. State your answer to an appropriate number of significant figures. [3]

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.

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]

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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.

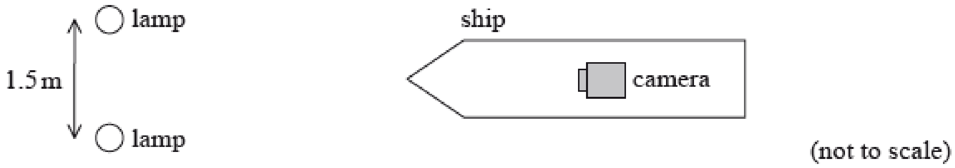
Diameter of circular radar receiver	= 9.3 m
Wavelength of radar	= 2.5 cm
Distance of two aircraft from the airport	= 31 km

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

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]

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.

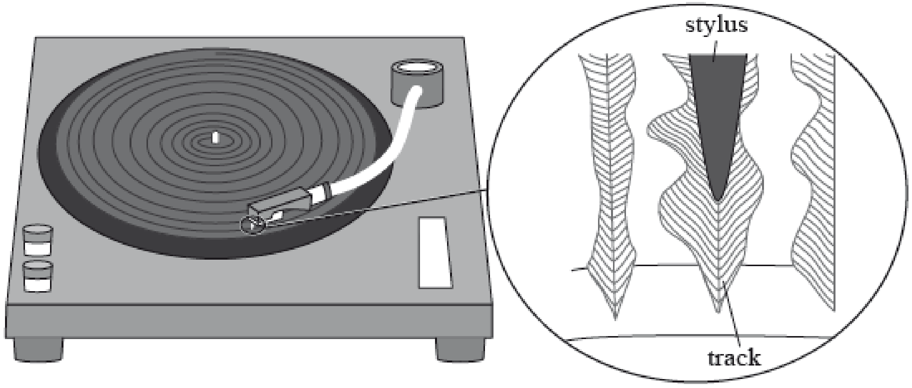
h. The star X has a companion star Y. The distance from Earth to the stars is 1.0×10^{18}m. The images of X and Y are just resolved according to the Rayleigh criterion by a telescope on Earth with a circular eyepiece lens of diameter 5.0×10^{-2}m. [5]

(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.

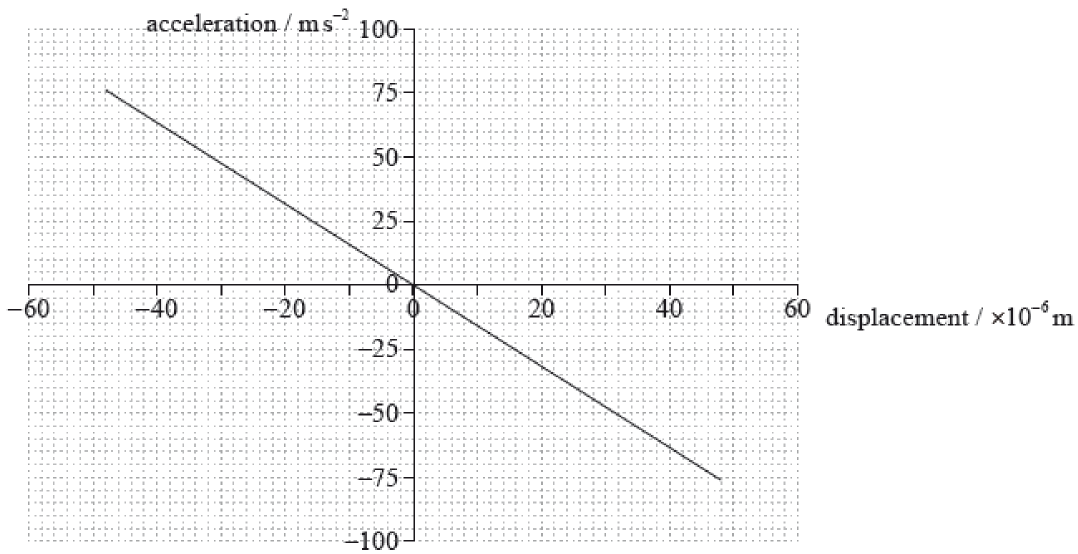
This question is about simple harmonic motion (SHM) and sound.

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.

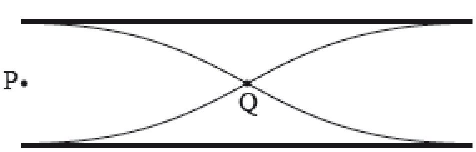
A recording of a single-frequency musical note is played. The graph shows the variation in horizontal acceleration of the stylus with horizontal displacement.



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

This question is about waves.

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

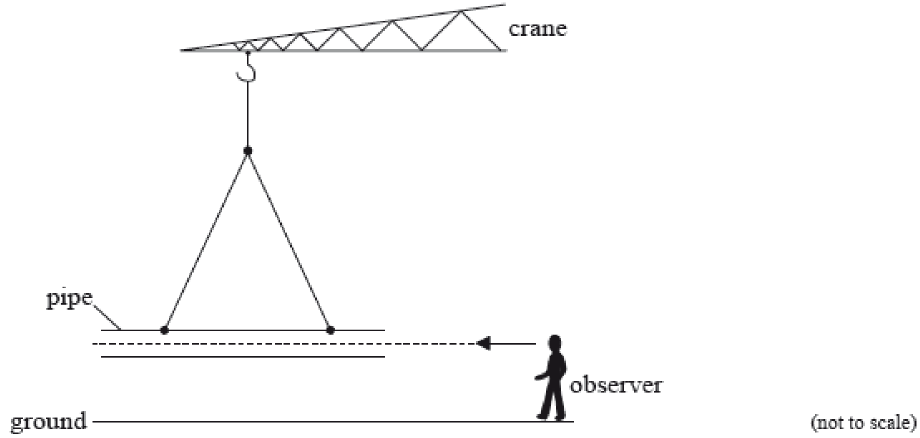


Two points in the pipe are labelled P and Q.

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]

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 .

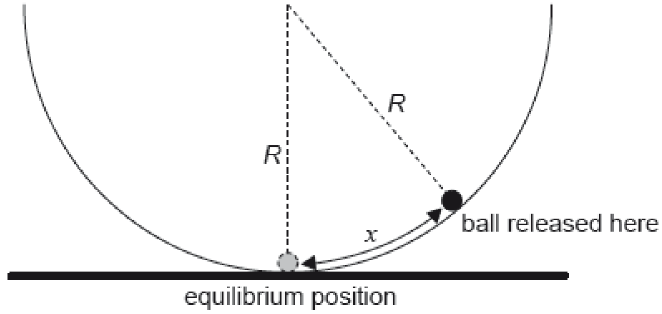
Effective distance of G_1 and G_2 from Earth = 2.2×10^{25} m
Separation $D = 4.0 \times 10^3$ m
Wavelength of radio waves received from G_1 and G_2= 0.14 m

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.

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

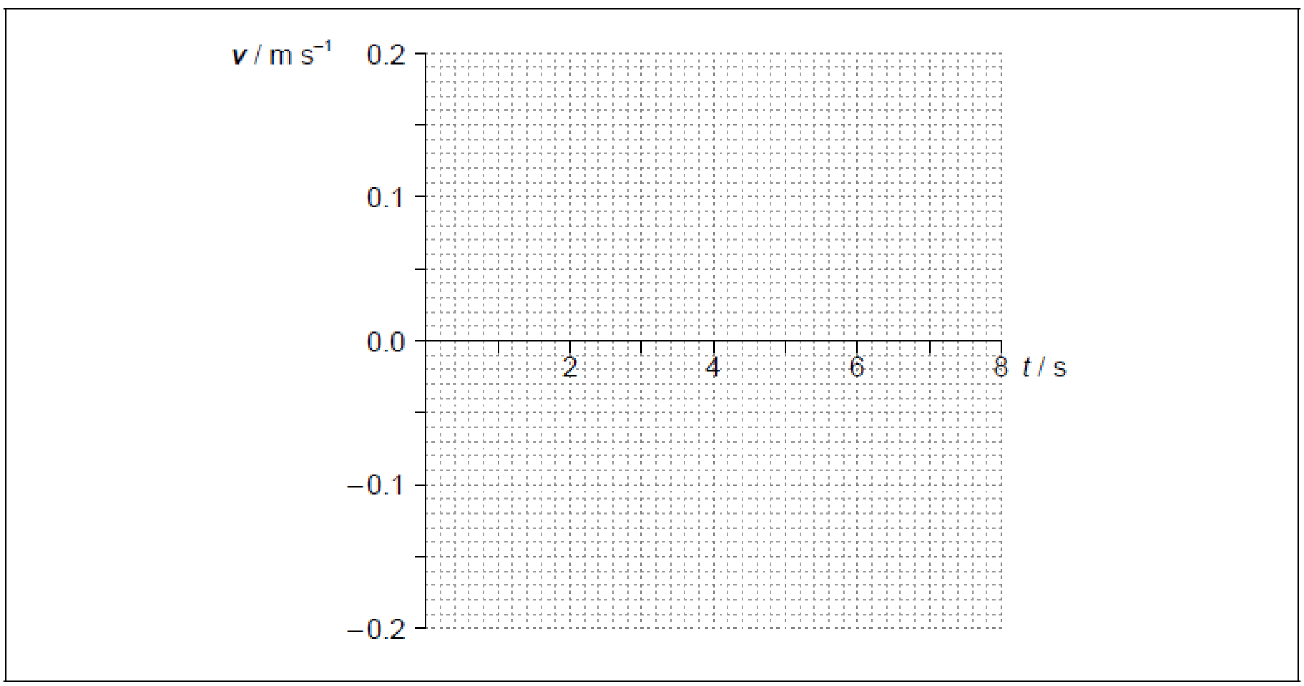
$$\frac{mgx}{R}$$

where R is the radius of the bowl.

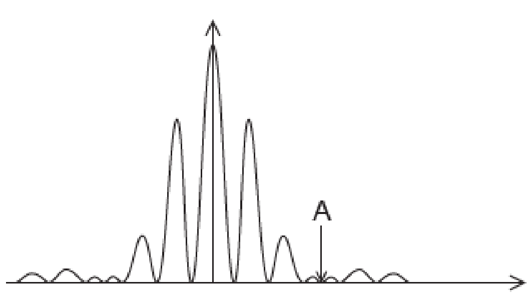
d.i. Outline why the ball will perform simple harmonic oscillations about the equilibrium position. [1]

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

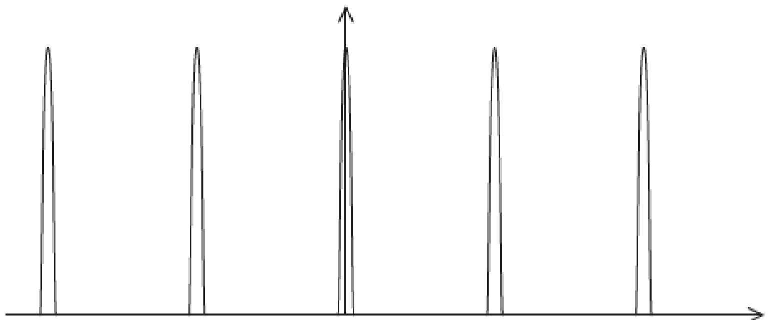
d.iii. The amplitude of oscillation is 0.12 m. On the axes, draw a graph to show the variation with time t of the velocity $\boldsymbol{v}$ of the ball during one period. [3]



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.

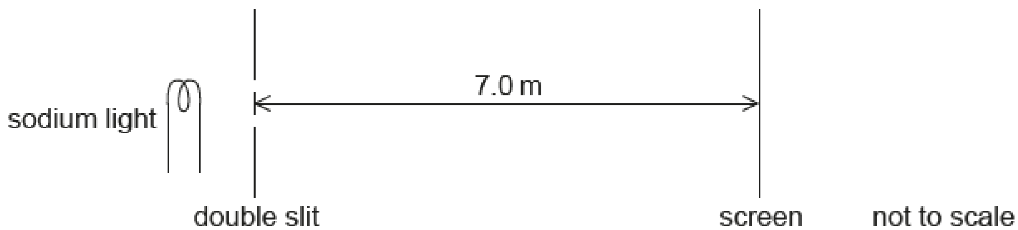


The double slit is replaced by a diffraction grating that has 600 lines per millimetre. The resulting pattern on the screen is shown.



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.

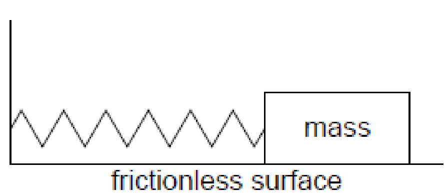
a.iii Calculate the separation of the two slits. [2]

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]

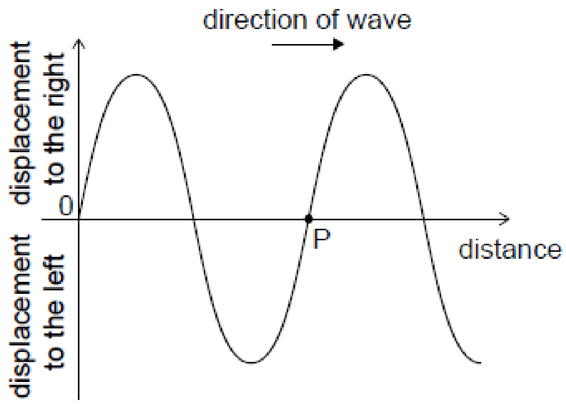
b.ii. The yellow light is made from two very similar wavelengths that produce two lines in the spectrum of sodium. The wavelengths are 588.995 nm and 589.592 nm. These two lines can just be resolved in the second-order spectrum of this diffraction grating. Determine the beam width of the light incident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

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]

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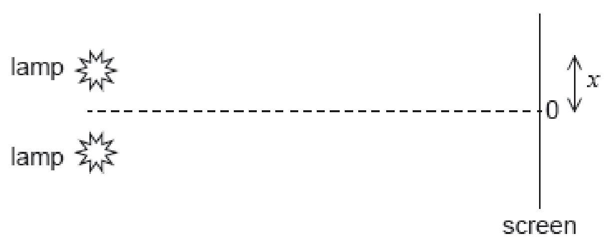
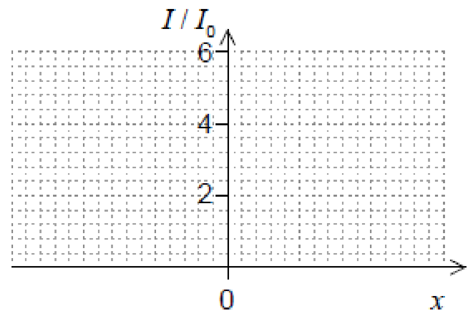
a. Monochromatic light from two identical lamps arrives on a screen. [1]

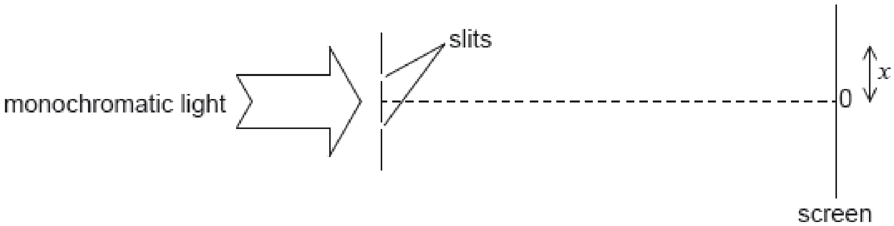


The intensity of light on the screen from each lamp separately is I_0.

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.



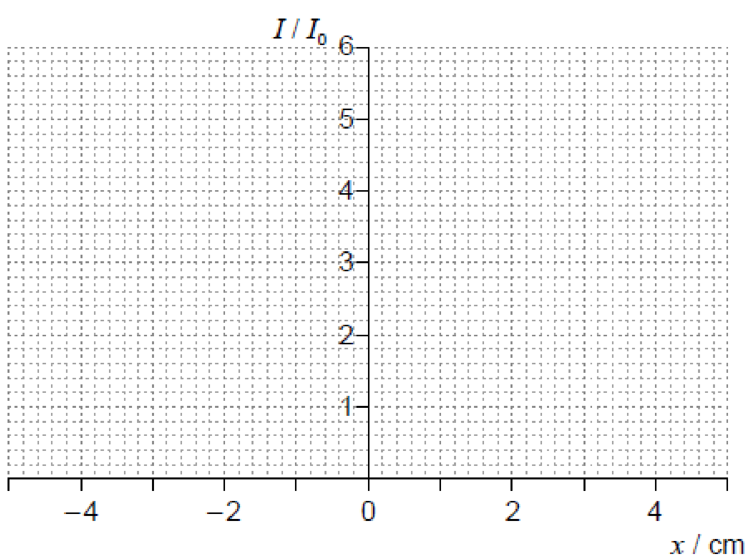
b. Monochromatic light from a single source is incident on two thin, parallel slits. [3]



The following data are available.

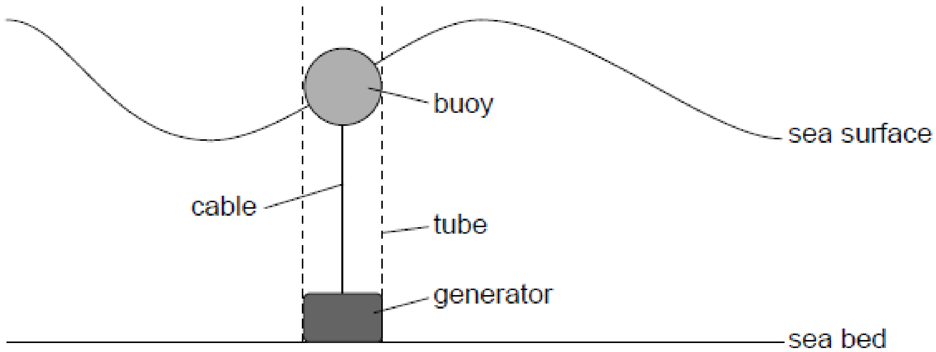
Slit separation	$= 0.12$ mm
Wavelength	$= 680$ nm
Distance to screen	$= 3.5$ m

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



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

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.



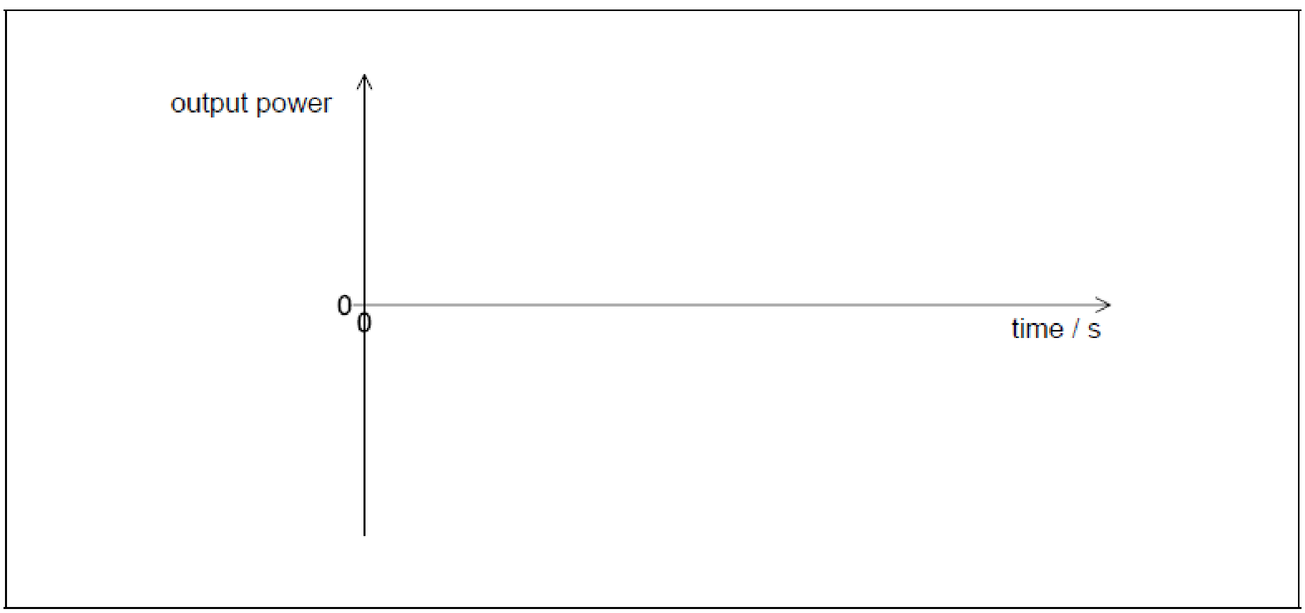
The motion of the buoy can be assumed to be simple harmonic.

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]

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2. ....
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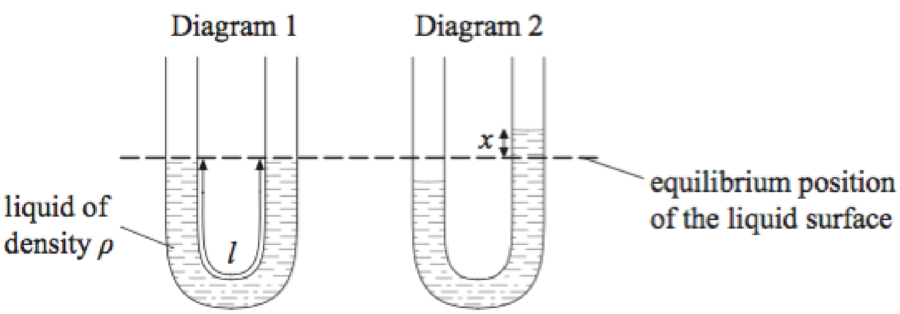
This question is about simple harmonic motion (SHM), wave motion and polarization.

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]

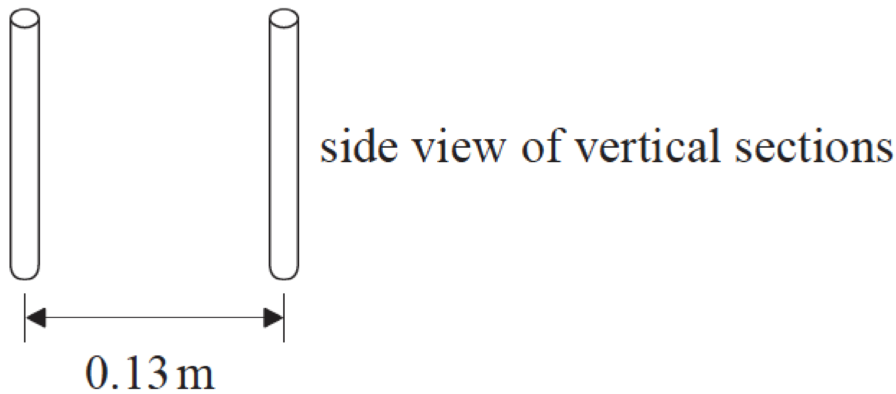
(i) Describe how the standing wave in the string gives rise to the first harmonic.
(ii) Outline how a travelling wave in a string can be used to describe the nature of polarized light.

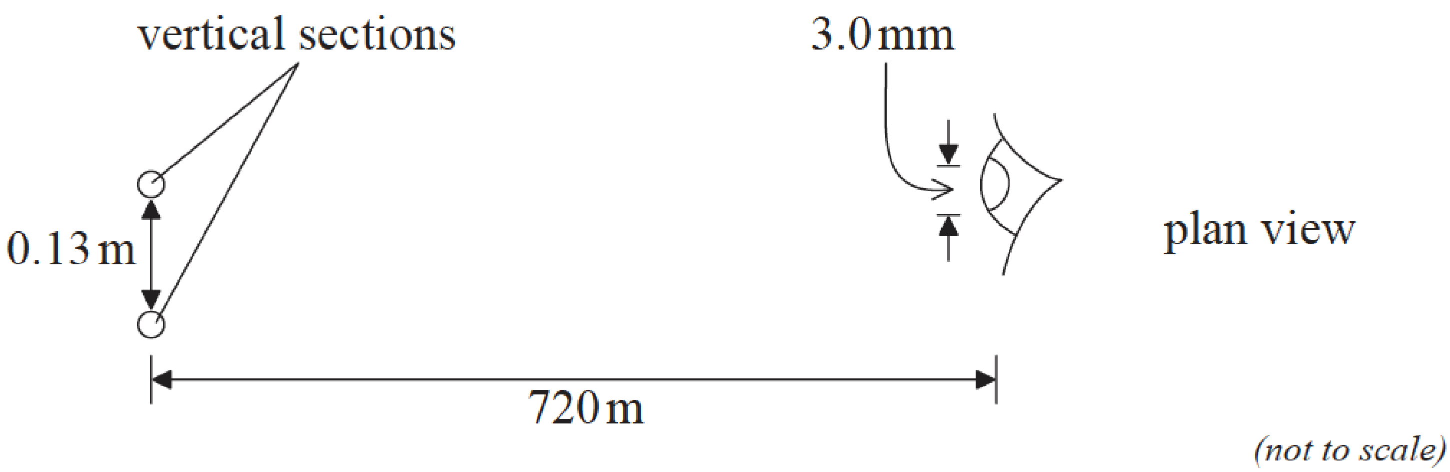
Part 2 Resolution

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]





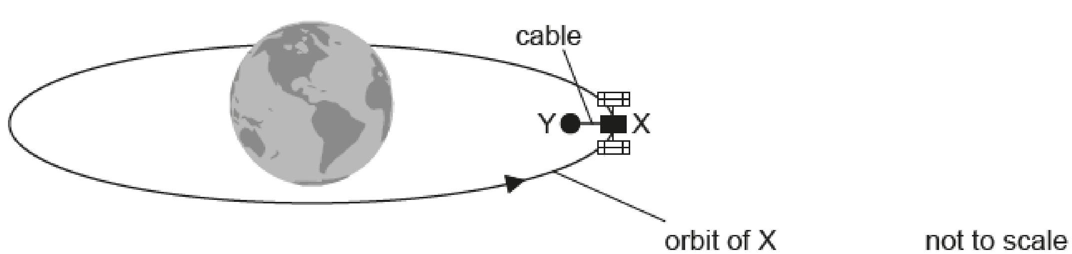
The vertical sections are separated by a horizontal distance of 0.13 m. An observer views them from a distance of 720 m. The wavelength of the emitted light is 510 nm and the diameter of the aperture of the observer's eye is 3.0 mm.

(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.

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]

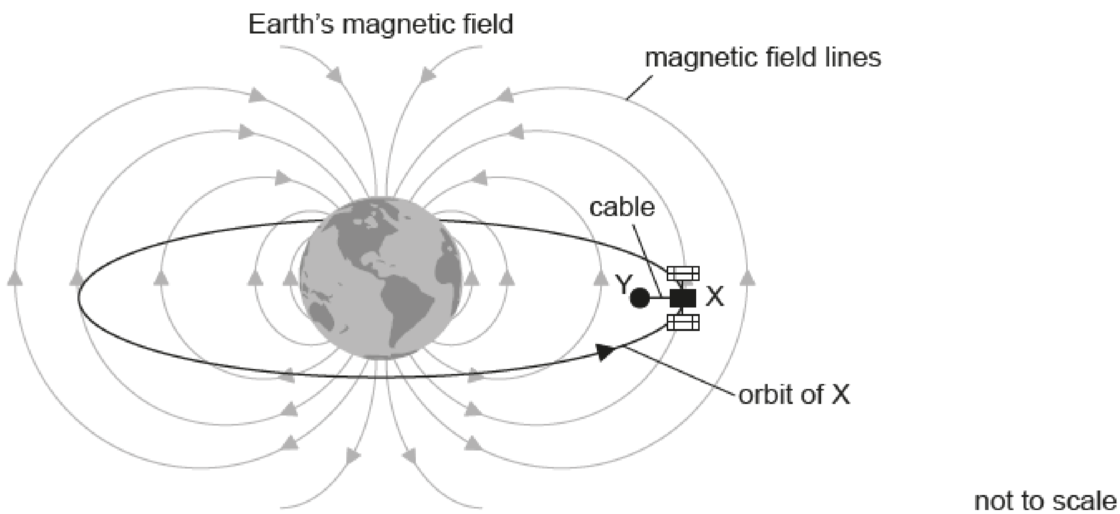
Mass of the Earth = 6.0×10^{24} kg

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]

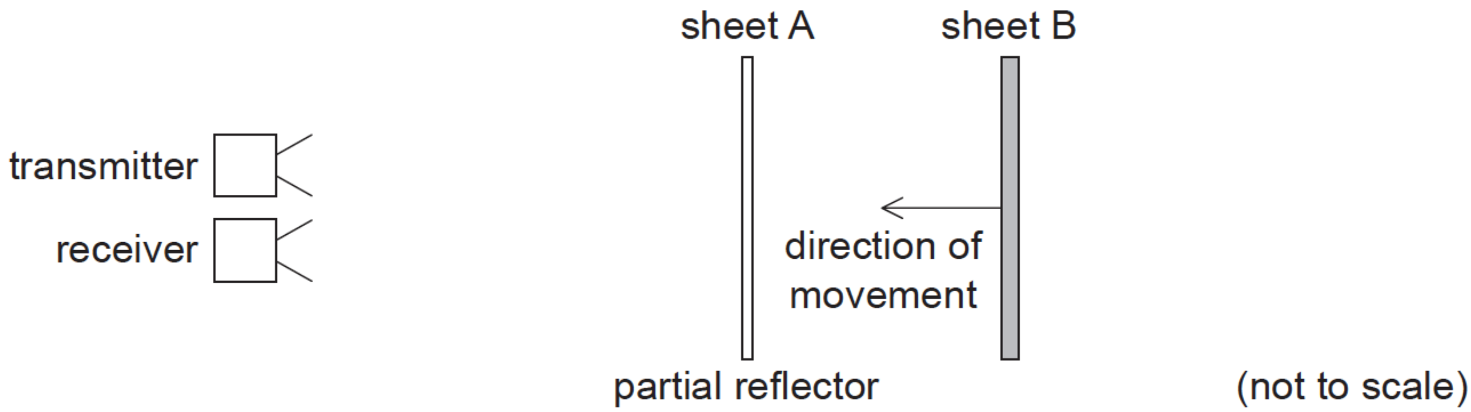
$$T = 2\pi\sqrt{\frac{m}{k}}$$

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]

This question is about the properties of waves.

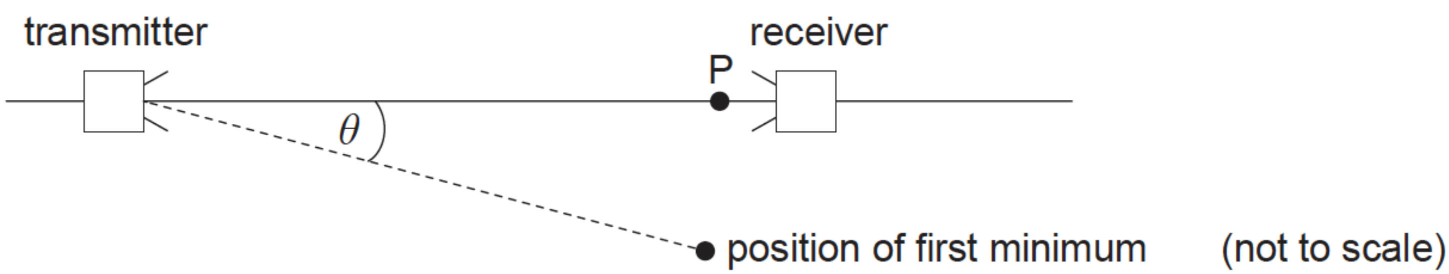
Microwaves from a microwave transmitter are reflected from two parallel sheets, A and B. Sheet A partially reflects microwave energy while allowing some to pass through. All of the microwave energy incident on sheet B is reflected.



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]

This question is about the Doppler effect.

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

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 $120\ ms^{-1}$.

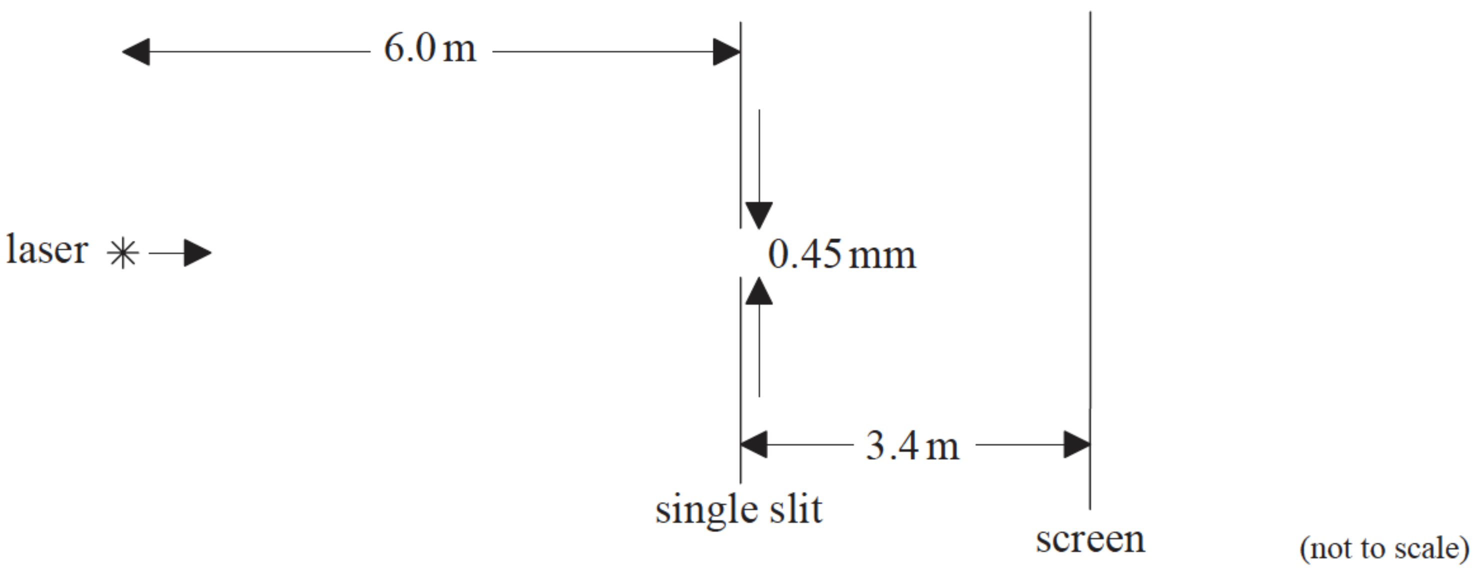
b. When both source and observer are stationary the wavelength is λ_0 and the wavespeed is v_0. [3]

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)		

This question is about diffraction and interference.

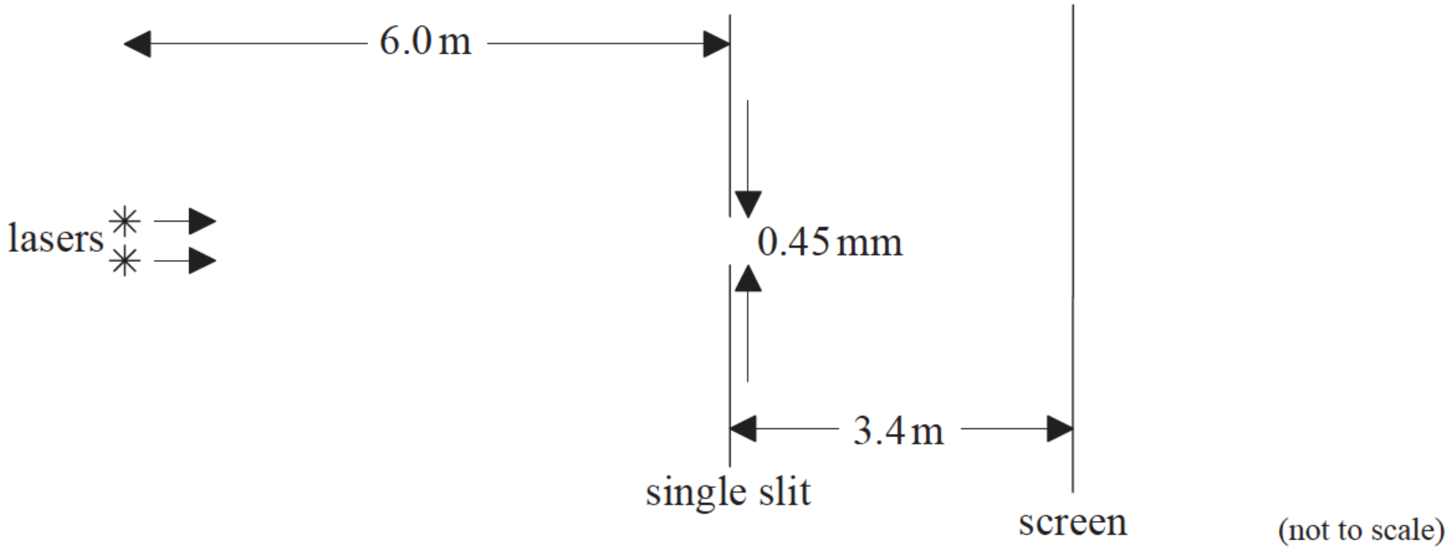
a. Light of wavelength 620 nm from a laser is incident on a single rectangular slit of width 0.45 mm. [2]



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]

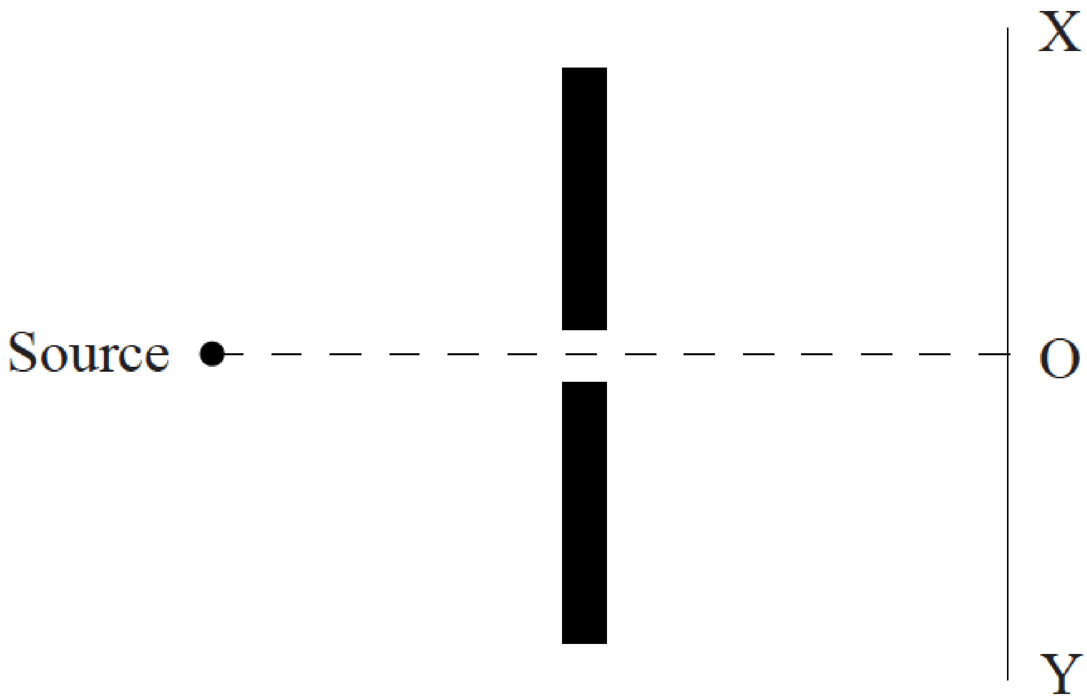
This question is about sound.

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]

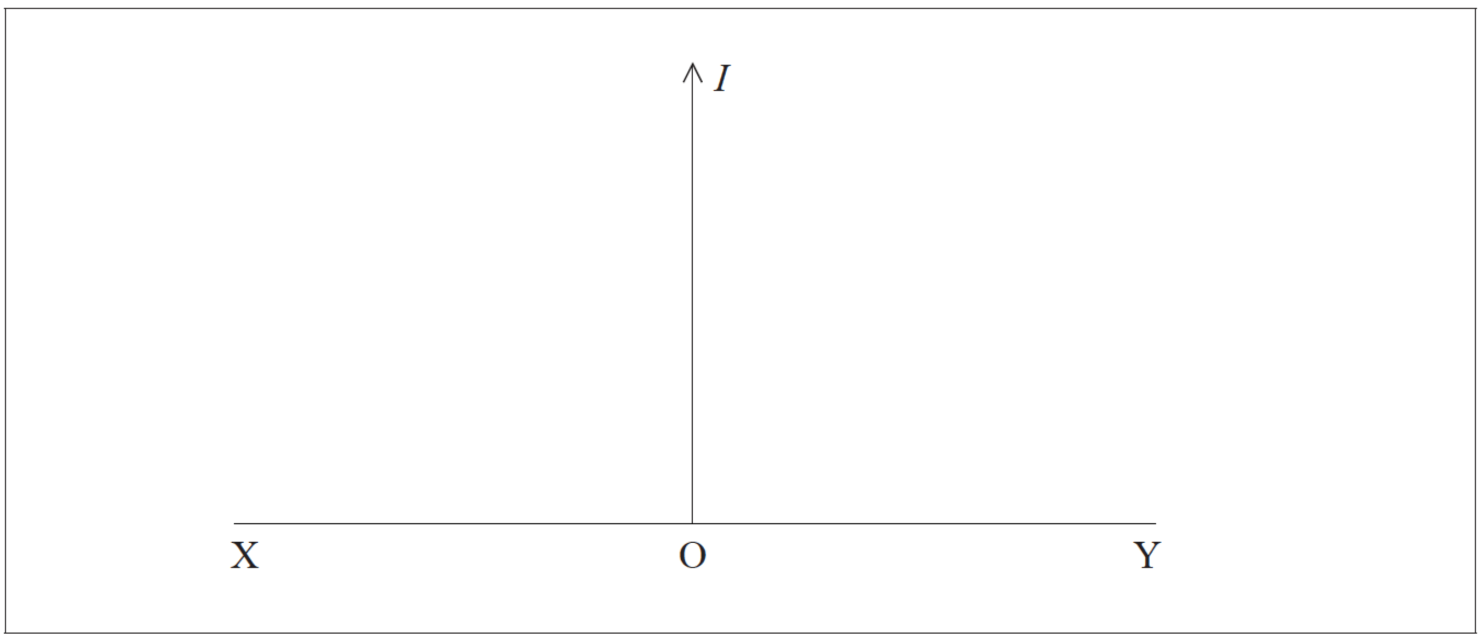
(ii) The frequency f is 275 Hz. The source is moving at speed 20.0 ms^{-1}. The speed of sound in air is 330 ms^{-1}. Calculate the observed frequency f' of the sound.

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.

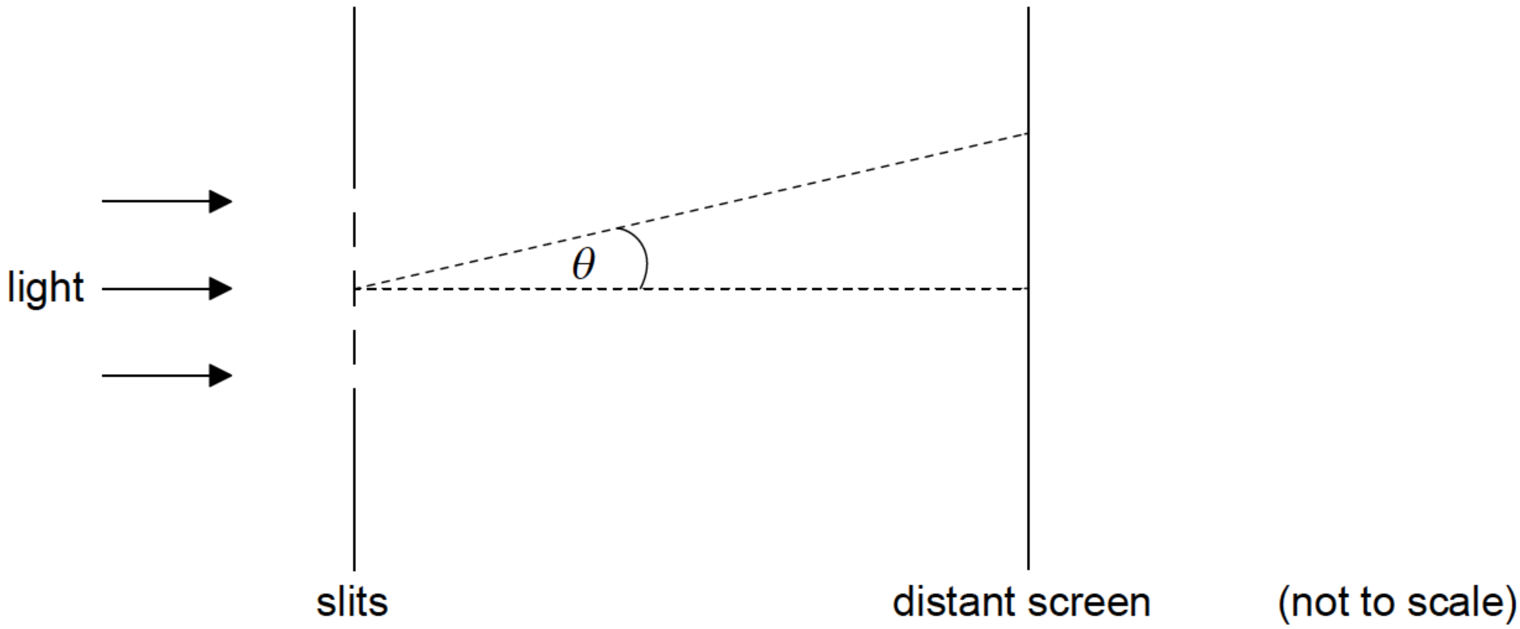


(ii) State the effect on the intensity pattern of increasing the wavelength of the sound.

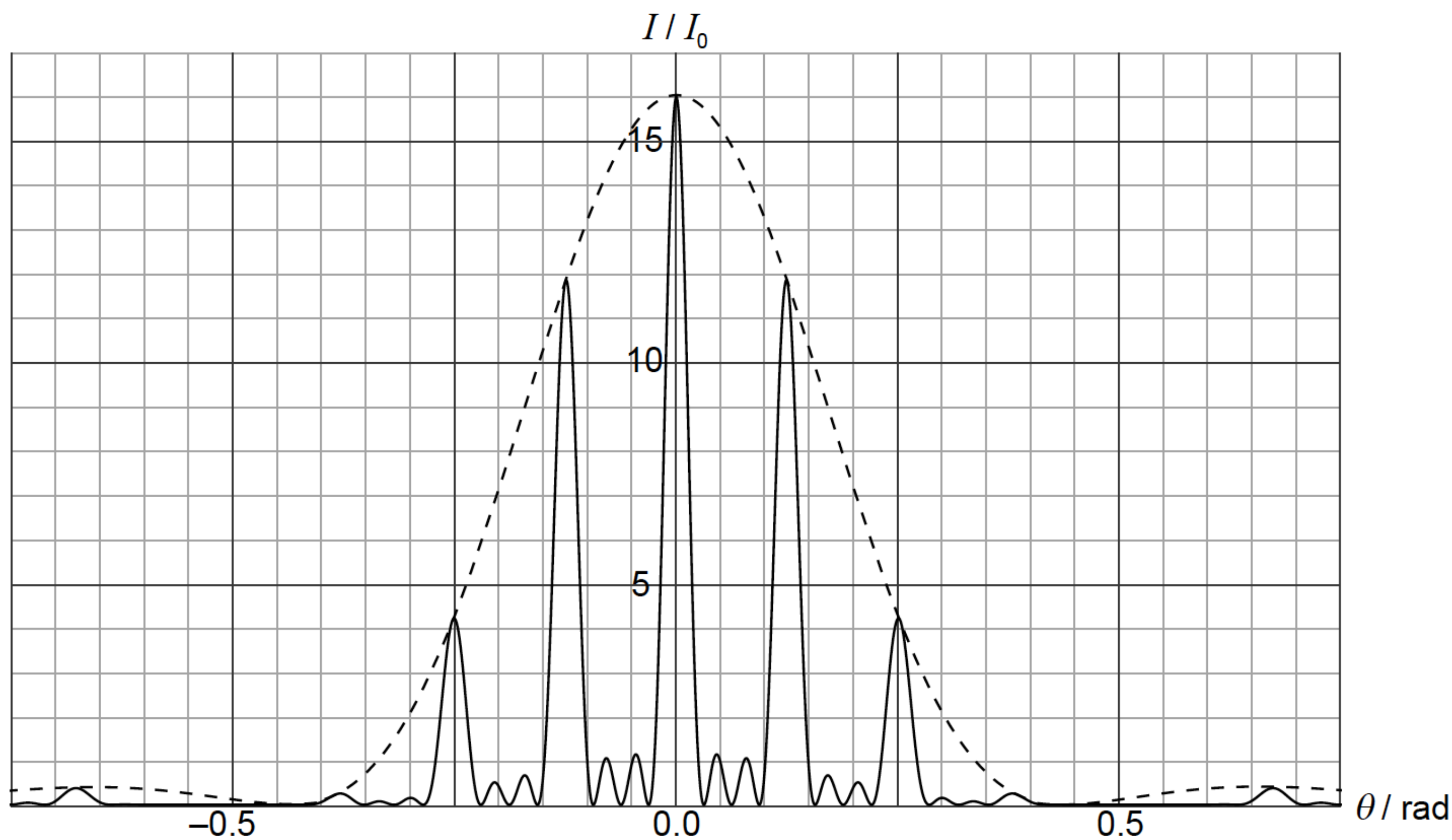
c. (i) Outline the difference between a polarized wave and an unpolarized wave. [3]

(ii) State why sound waves cannot be polarized.

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.

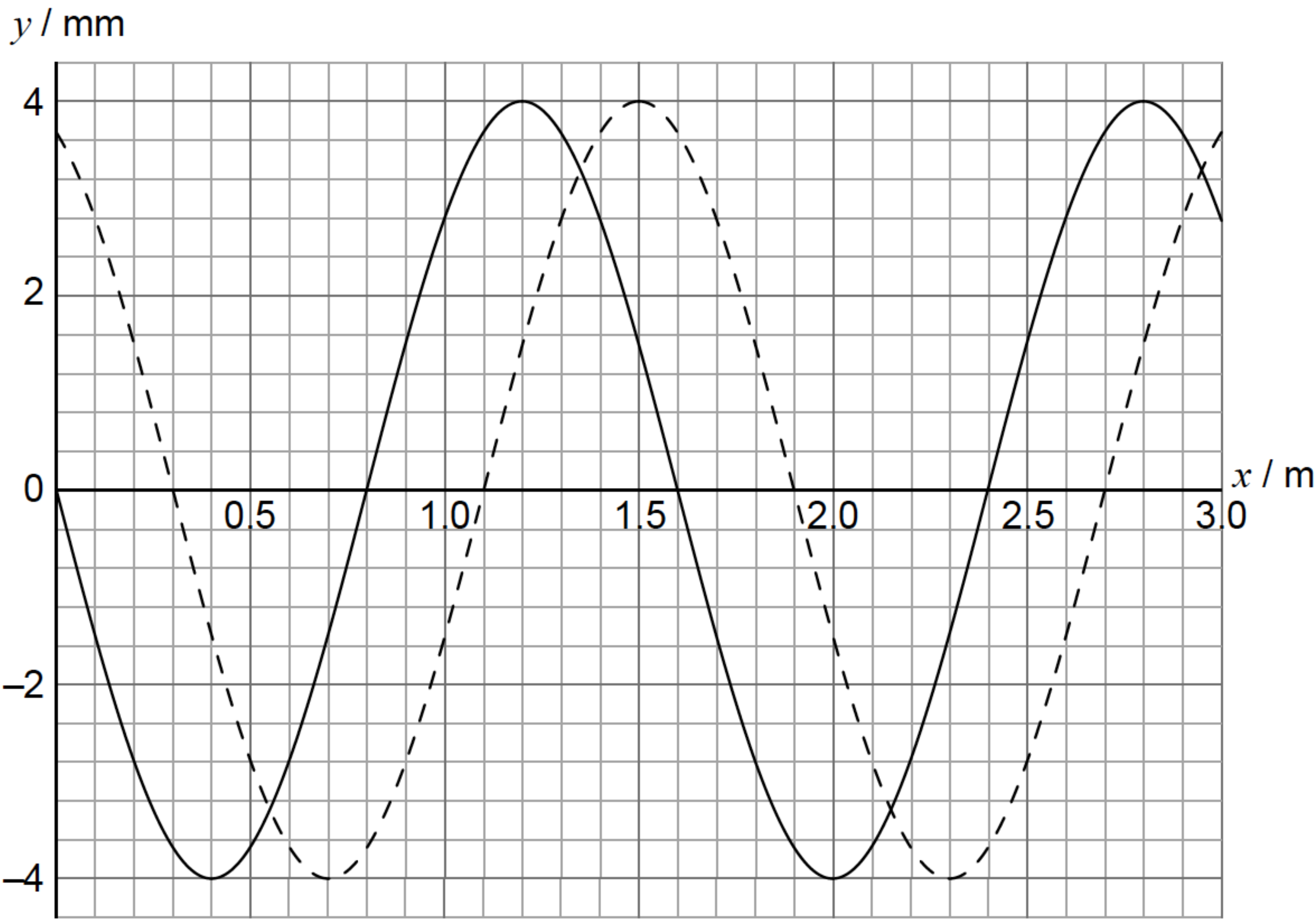
c. The arrangement is modified so that the number of slits becomes very large. Their separation and width stay the same. [4]

(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.

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

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.

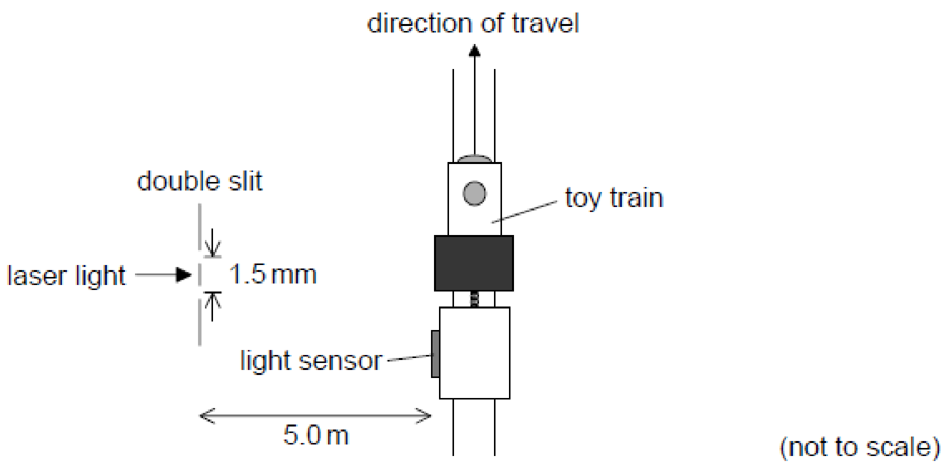
(ii) Show that the speed of this particle at t=0.882 ms is 4.9ms^{-1}.

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.

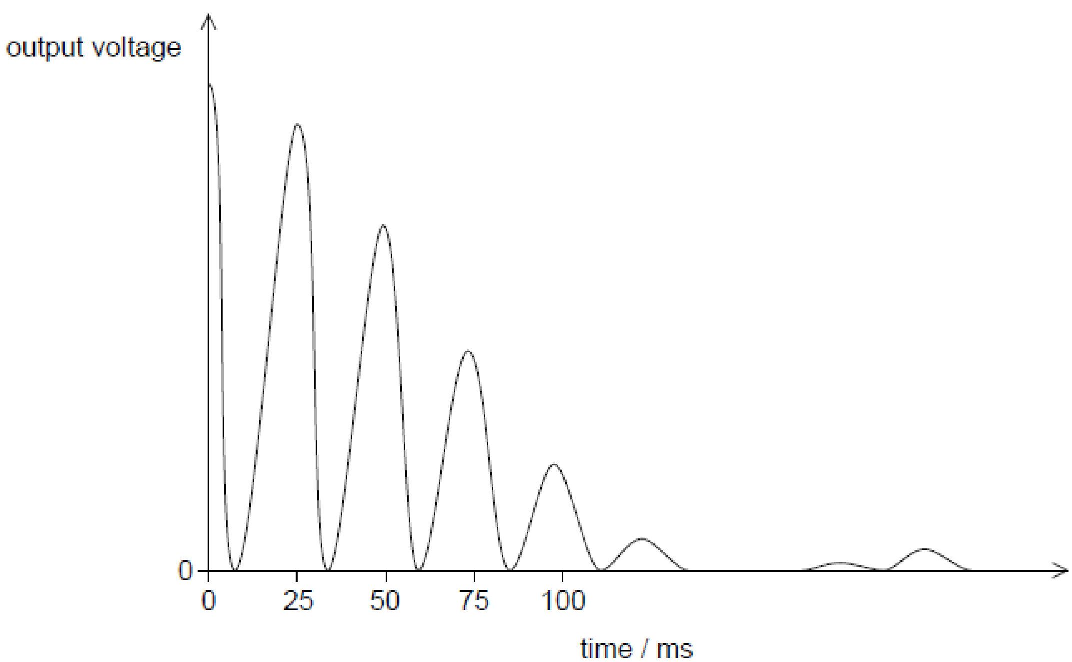
(ii) Demonstrate, using a calculation, that a standing wave will be established in this tube.

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

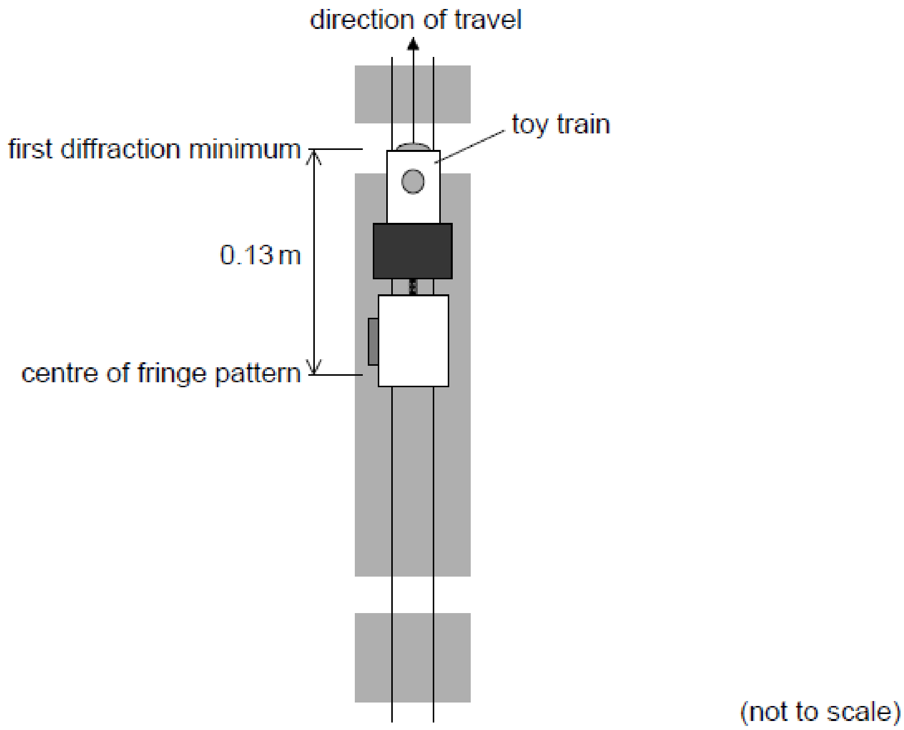


Light from a laser is incident on a double slit. The light from the slits is detected by a light sensor attached to the train.

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.



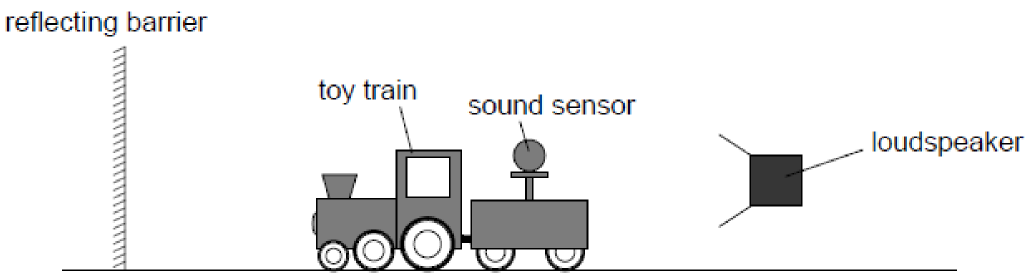
As the train continues to move, the first diffraction minimum is observed when the light sensor is at a distance of 0.13 m from the centre of the fringe pattern.



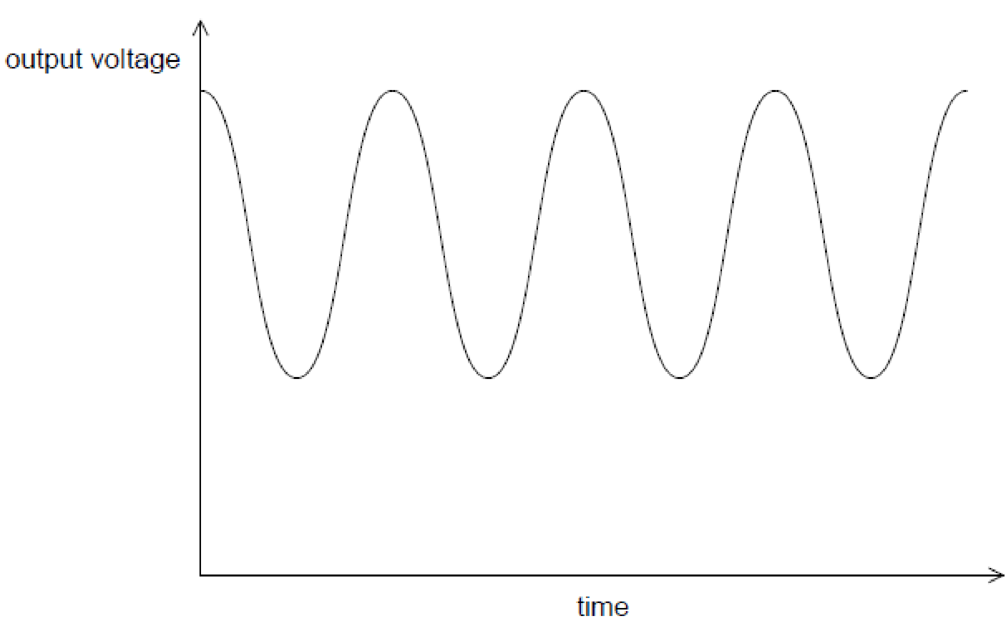
c.i. Determine the width of one of the slits. [2]

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.