1(a). A flute is a musical instrument made from a long tube that is open at both ends.

A stationary sound wave in the tube produces a musical note.

The lowest frequency note that a standard flute produces in air is 262 Hz.

The speed of sound in air at a temperature of 20°C is 340 m s^{-1}.

Show that a standard flute has an approximate length of 0.65 m.

[3]

(b). In an ideal gas, the speed *v* of sound is given by

$$v = \left(\frac{\gamma RT}{M}\right)^{1/2}$$

where

γ is a dimensionless constant that depends on the gas

R is the molar gas constant

T is the absolute temperature

M is the molar mass of the gas.

The table below shows values of γ and *M* for both air and helium.

Gas	**γ**	***M*/g mol^{-1}**
Air	1.40	29.0
Helium	1.67	4.00

i. The kinetic model of an ideal gas assumes that there are a large number of particles in rapid, random motion.

State **two** further assumptions for the kinetic model of an ideal gas.

1 ______________________________

____

2 ______________________________

______________________________ **[2]**

ii. A standard flute is placed inside a sealed chamber.

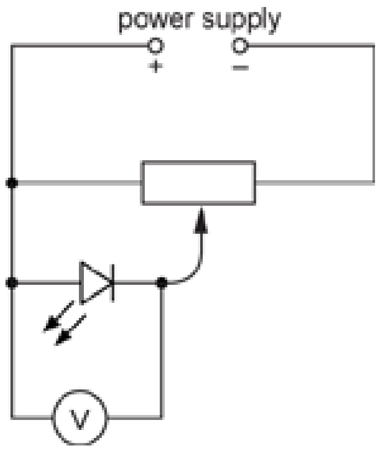
The chamber is filled with helium at a temperature of −10°C.

Calculate the lowest frequency that the flute could produce inside the chamber.

frequency = ... Hz **[4]**

2(a). A student carries out an investigation to determine the value of the Planck constant, *h*.

They use the circuit shown below



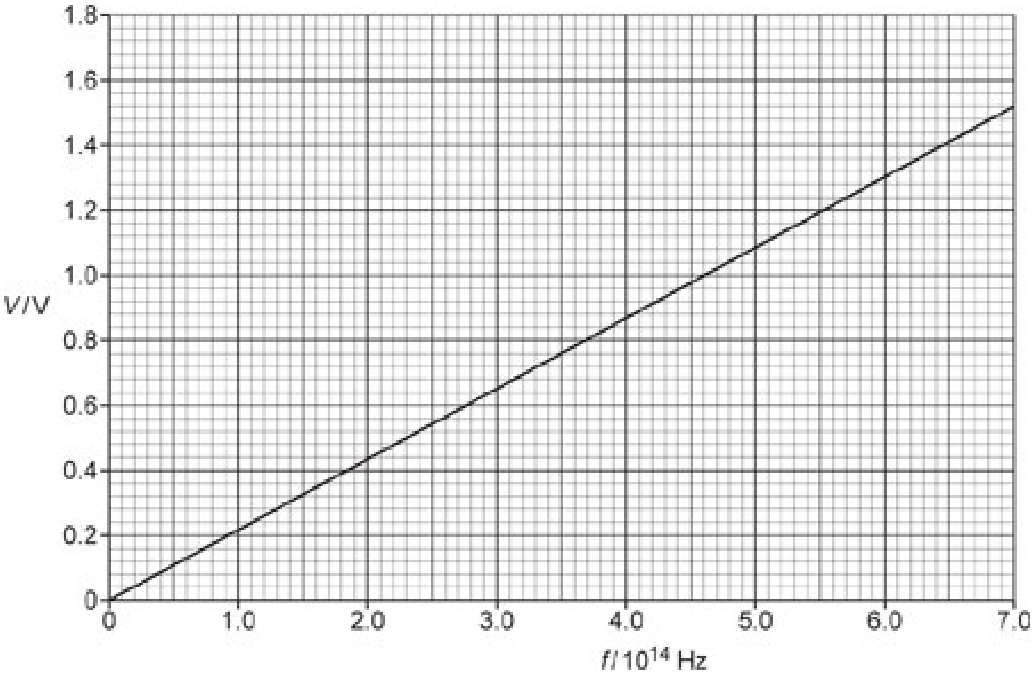
Initially the LED emits no light.

The student slowly increases the p.d. across the LED.

They record the p.d. *V* on the voltmeter when the LED just starts to emit light.

The measurement is repeated for LEDs that emit light with different frequencies *f*.

The student plots a graph of V against f, as shown below.



Calculate a value for the Planck constant using the graph.

Planck constant = ...J s**[3]**

(b). An accepted value for the Planck constant is 6.63×10^{-34} J s.

Calculate the percentage uncertainty in the student's results.

percentage uncertainty = ... %**[2]**

3. The light emitted by a laptop screen is polarised.

The laptop screen is viewed through a polarising filter.

Initially the brightness of the screen appears normal.

The filter is rotated gradually through an angle of 180°.

How does the brightness of the laptop screen appear after the filter has been rotated by 90˚, and then by 180˚?

	After a rotation of 90˚	After a rotation of 180˚
A	Dark	Dark
B	Dark	Normal
C	Normal	Dark
D	Normal	Normal

Your answer [1]

4. Electromagnetic waves pass through a gap of approximately 3 cm.

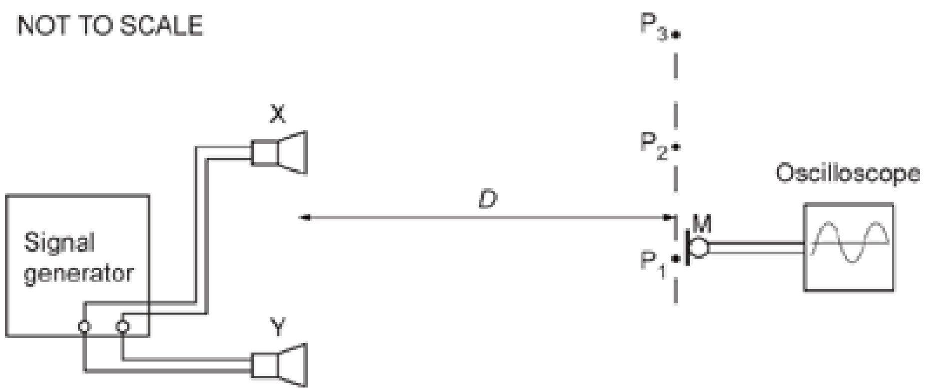
Which of the following will undergo a significant amount of diffraction?

A microwaves
B ultraviolet waves
C visible light waves
D X-rays

Your answer [1]

5(a). The diagram shows two identical loudspeakers X and Y connected to a signal generator. The loudspeakers emit sound waves of the same amplitude and frequency which are in phase.

A microphone M is moved along a line from P_1 to P_3 and the signal recorded on an oscilloscope.



As the microphone is moved along the line P_1 to P_3 the oscilloscope shows maximum signal at P_1, zero signal at P_2 and the next maximum signal at P_3.

The distance between the centres of X and Y is 70.0 cm, the distance *D* (as shown in the diagram) is 4.00 m and the distance from P_1 to P_2 is 1.25 m.

Use the two source interference formula to calculate the frequency of the sound waves. (Speed of sound = 340 m s^{-1})

frequency = ... Hz **[3]**

(b). Loudspeaker Y is replaced with a loudspeaker that produces sound waves of twice the original amplitude.

Describe how the signal observed on the oscilloscope varies as the microphone is moved along the line P_1 to P_3.

[2]

(c).

i. Explain what is meant by the term *intensity*.

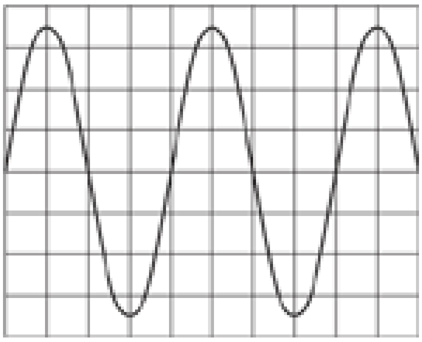
[1]

ii. Calculate the factor by which the intensity of the sound waves at P_1 in the previous question is larger than the intensity of the original sound waves at P_1.

factor = ... **[3]**

6. The image shows a display of an oscilloscope which is measuring an alternating voltage. The time base is set at 0.1s/division. The voltage scale (y-sensitivity) is set at 0.5V/division.

Which row of the table shows the correct amplitude and correct frequency?



	amplitude/V	frequency/Hz
A	1.75	0.4
B	1.75	2.5
C	3.50	0.4
D	3.50	2.5

Your answer ☐ **[1]**

7(a). The table shows the speed and wavelength of yellow light in air.

Quantity	Air	Glass
Speed of light / m s^{-1}	3.00×10^8	....
Wavelength / nm	588	....
Frequency / THz	....	....

The refractive index at the air glass boundary is 1.52.

i. Calculate the frequency, in THz, of yellow light in air.
Record your answer in the table.

[1]

ii. Complete the table for yellow light in glass.

[2]

(b). A student uses a ray box to investigate the refraction of yellow light in a rectangular glass block.

Fig. 5.1 shows the path the yellow light travels as it enters the block at point P and travels to point Q.

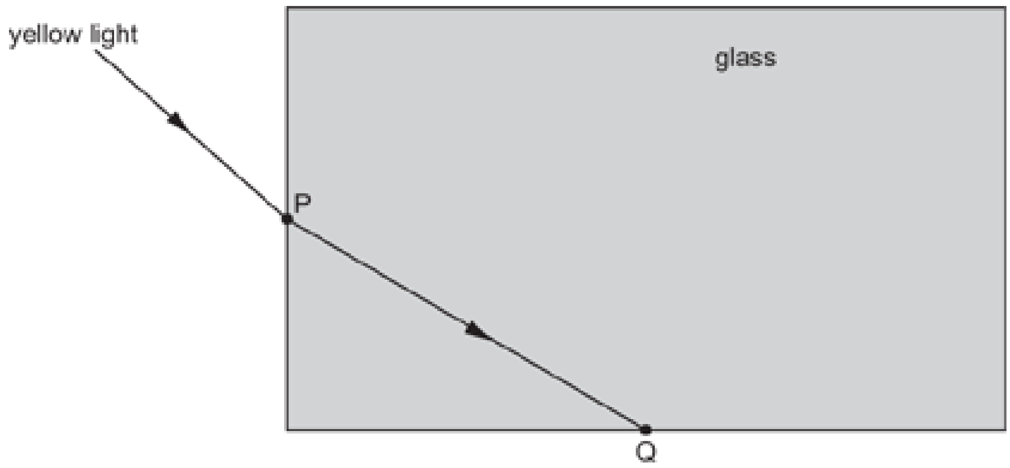


Fig. 5.1

i. **Draw on Fig. 5.1** the angle of incidence *i* and the angle of refraction *r* at point P.
Label the angles *i* and *r*.

[1]

ii. Describe how the student produces **Fig. 5.1** experimentally using a ray box.

[4]

iii. The angle of incidence *i* is 49.9°.

Show that the angle of refraction *r* is approximately 30°.

[1]

iv. Show that total internal reflection occurs at point Q.

[3]

v. **Draw on Fig. 5.1** the path of the light as it travels from point Q back into the air.

[1]

8(a). A stationary sound wave is set up in a closed resonance tube as shown in **Fig. 6.1.**

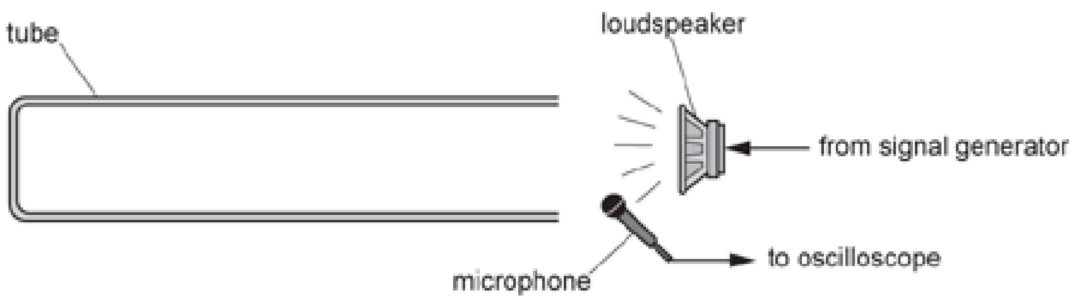


Fig. 6.1.

Sound is produced by a signal generator connected to a loudspeaker. The sound is detected by a microphone connected to an oscilloscope.

The time-base setting on the oscilloscope is 1 ms cm^{-1}.

The signal generator is adjusted until the fundamental mode of vibration is detected. **Fig. 6.2** shows the trace on the oscilloscope.

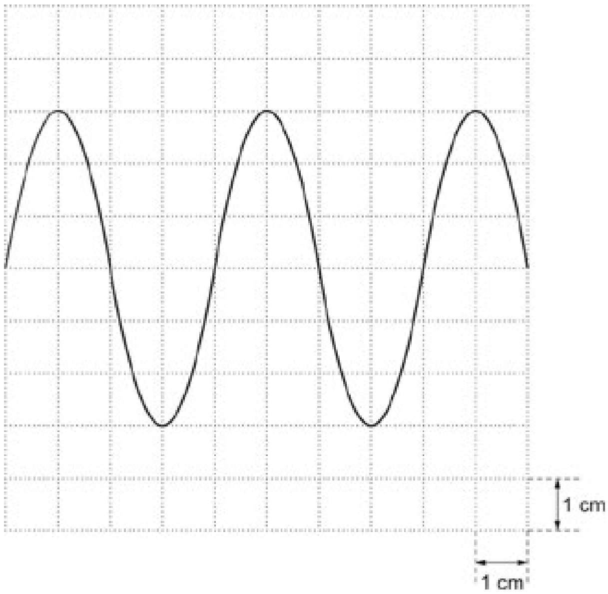


Fig. 6.2

Use **Fig. 6.2** to determine the frequency f_0 of the fundamental mode of vibration.

f_0 = ... Hz **[2]**

(b). Draw on Fig. 6.3 the stationary wave pattern for the fundamental mode of vibration.

Label on Fig. 6.3 the positions, if any, of any nodes **N** and any antinodes **A**.

Fig. 6.3

[2]

(c). The frequency of the signal generator is increased until the next harmonic is displayed on the oscilloscope.

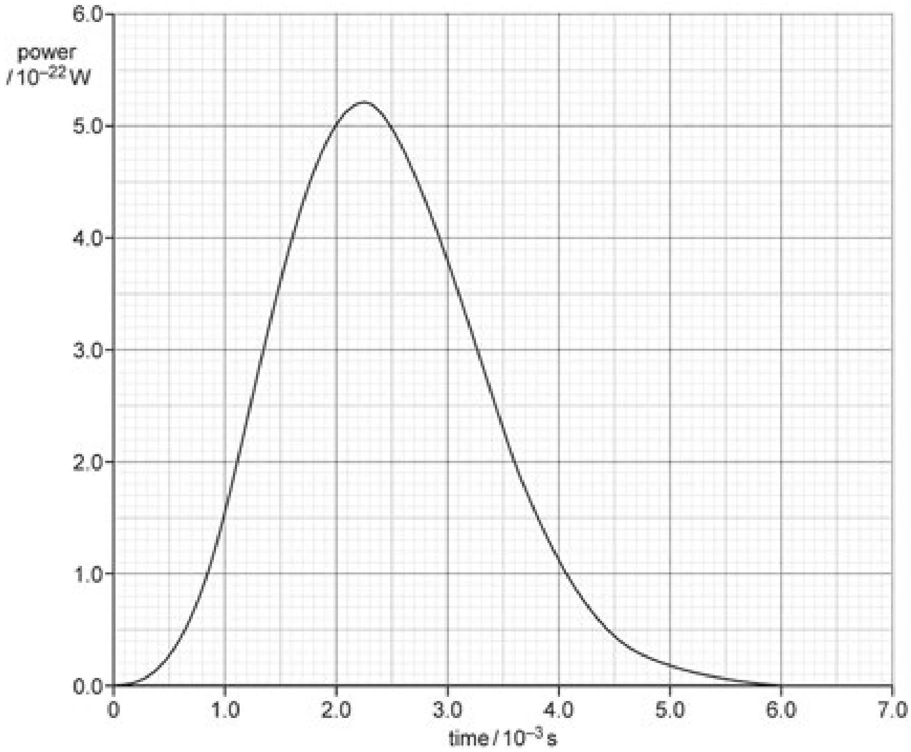
Calculate the frequency f_n of the next harmonic.

f_n = ... Hz **[1]**

9. A pulsar is a rapidly rotating neutron star that emits radio waves.

An astronomer uses a radio telescope to observe a pulsar.

The graph below shows the power that the telescope receives due to the radio waves from one full rotation of a pulsar.



i. By calculating the area between the curve and the horizontal axis, estimate the total energy received by the telescope in one full rotation of the pulsar.

total energy received = ... J **[2]**

ii. The surface area of the telescope is about 3000 m^2.

The distance to the pulsar is about 300 pc.

By assuming that the radiation from the pulsar is emitted equally in all directions, estimate the total energy emitted in one full rotation.

energy emitted = ...J **[3]**

10. A student carries out an experiment to determine the speed v of sound in air. The student forms stationary sound waves in a resonance tube with water at the bottom as shown in **Fig. 7.1**.

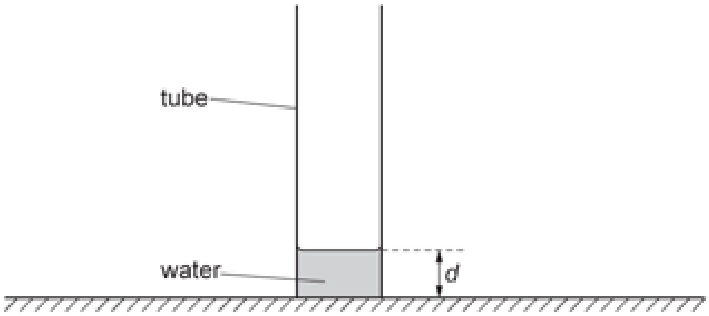


Fig. 7.1

The depth of the water is d.

Sound is produced by a signal generator connected to a loudspeaker. The sound is detected by a microphone connected to an oscilloscope.

The signal generator is adjusted. The frequency f of the fundamental mode of vibration of the sound in air is determined.

The experiment is repeated for different values of d.

The table shows the results. Values of $\frac{1}{f}$ have been included.

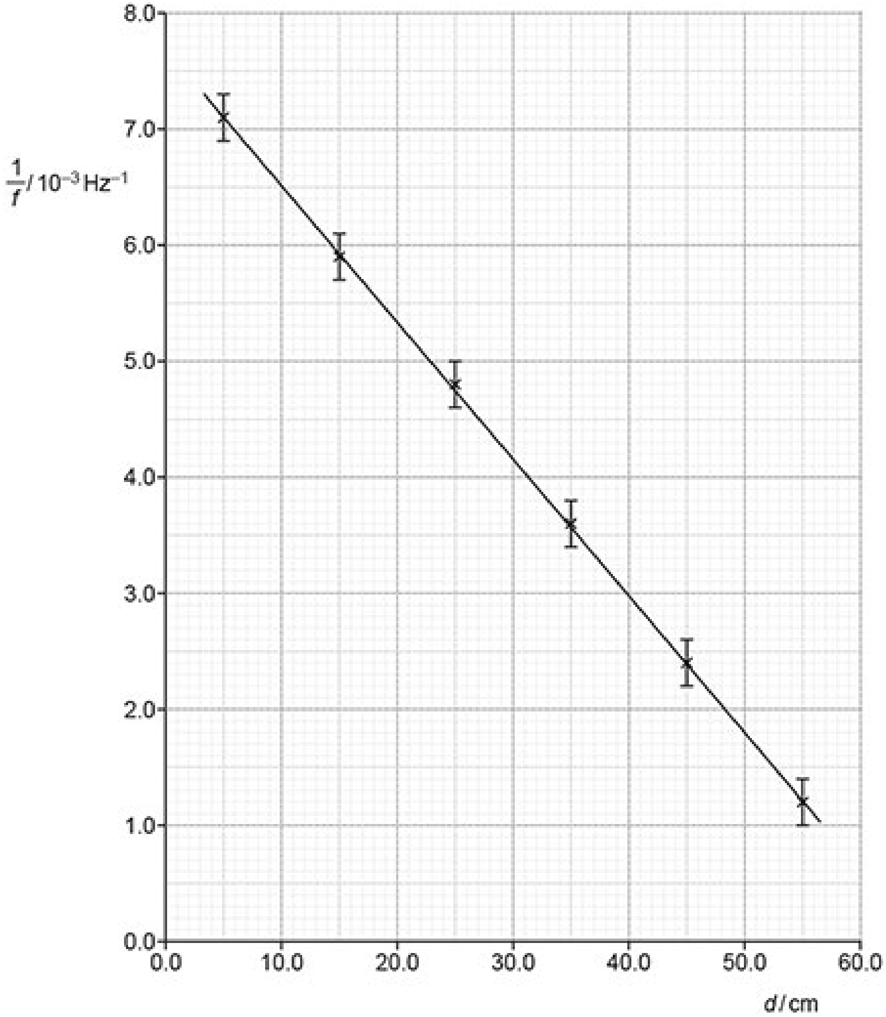
d / cm	f / Hz	$\frac{1}{f}$ / 10^{-3} Hz^{-1}
5.0	140	7.1 ± 0.2
15.0	170	5.9 ± 0.2
25.0	210	4.8 ± 0.2
35.0	280	3.6 ± 0.2
45.0	420	2.4 ± 0.2
55.0	840	1.2 ± 0.2

It is suggested that the relationship between f and d is

$$\frac{1}{f} = -\frac{4d}{v} + c$$

where v is the speed of sound in air and c is a constant.

A graph of $\frac{1}{f}$ / 10^{-3} Hz^{-1} on the *y*-axis against *d* / cm on the *x*-axis is plotted as shown below.



Explain how the apparatus is used to determine *f* **and** use the graph to determine *v*. Include the percentage uncertainty in your value of *v*.

[6]

11(a). Two spherical dippers, **D1** and **D2** oscillate on a ripple tank as shown in **Fig. 5.1**.

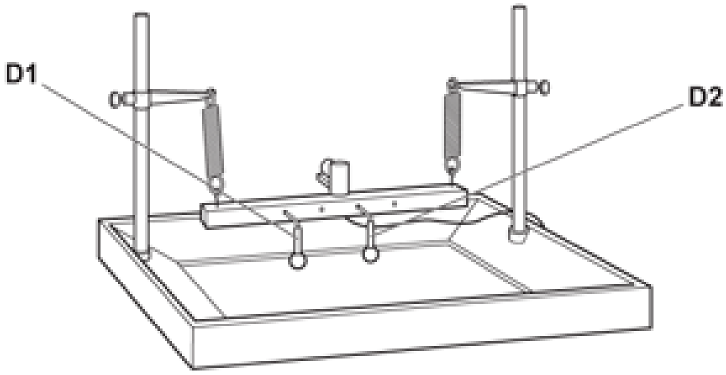


Fig. 5.1

Waves on the surface of the water are produced from each dipper. These waves are in phase with each other.

The water waves have a speed of 8.0 cm s^{-1} and a wavelength of 3.2 cm.

i. State and explain whether these waves are transverse or longitudinal waves.

[1]

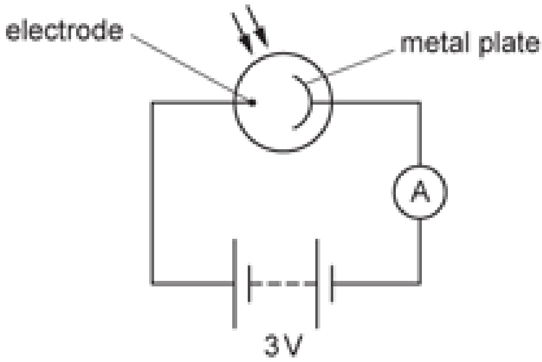
ii. State and explain whether these waves are plane polarised.

[1]

(b). Calculate the frequency *f* of the dippers.

f = ... Hz **[1]**

12. A light meter is used to measure the intensity of electromagnetic radiation. The meter consists of a metal plate and an electrode within an evacuated glass tube. It is connected to a circuit with an ammeter, a battery of e.m.f. 3.0 V and negligible internal resistance.



Electromagnetic radiation is incident on the metal plate. Electrons are released due to the photoelectric effect and are attracted to the electrode.

i. The reading on the ammeter is proportional to the intensity of the radiation. Use your knowledge of the photoelectric effect to explain why.

[3]

ii. When the light meter is irradiated with monochromatic radiation of frequency 8.2×10^{15} Hz, the number of electrons emitted every second is 3.1×10^{18} s^{-1}.

The surface area of the metal plate normal to the incident radiation is 4.9×10^{-3} m^2.

Determine the intensity of the radiation.

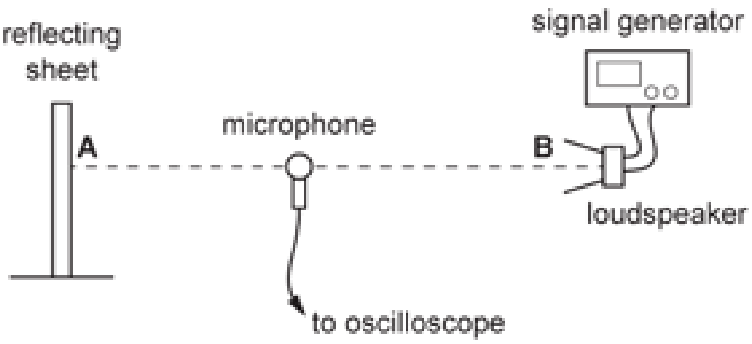
intensity = ...W m^{-2} **[4]**

13(a). Sound waves in air are longitudinal waves consisting of compressions and rarefactions.

Explain how the movement of air molecules creates compressions and rarefactions.

[3]

(b). A student investigates sound waves. They set up the following apparatus.



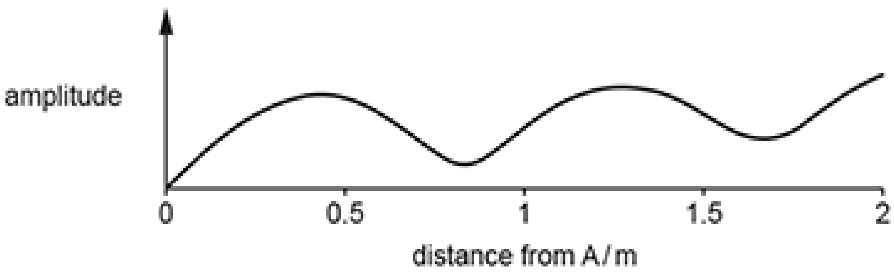
The sound wave emitted from the loudspeaker at **B** travels to the reflecting sheet at **A** and is reflected. A stationary wave is formed between the loudspeaker and the sheet.

The student moves a microphone along the line **AB**. The microphone is connected to an oscilloscope. The oscilloscope shows the relative amplitude of the stationary wave at each point along the line. The student observes a series of nodes and antinodes.

i. Explain how a stationary wave with nodes and antinodes is formed.

[3]

ii. The student measures the amplitude of the stationary wave at a range of distances from the reflecting sheet **A**. Their results are shown below.



The amplitudes at the nodes are observed to be:

- not exactly equal to zero
- closer to zero at distances closer to the reflecting sheet.

Explain these observations.

[3]

iii. The student measures the distance between two adjacent nodes as 0.84 m.

The frequency of the sound wave is 200 Hz.

Use these measurements to calculate a value for the speed of sound waves in air.

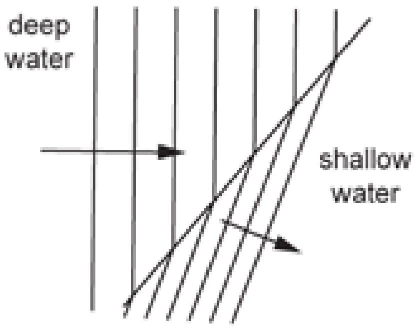
speed of sound waves = ... m s^{-1} **[2]**

iv. The student wants to reduce the uncertainty in their calculated value for the speed of sound waves in air.

Suggest a suitable improvement to the student's method.

[1]

14. A ripple tank can be used to demonstrate wave effects. When water waves in a ripple tank travel from deep to shallow water the wavelength decreases.



What happens to the speed and frequency of the waves as they move from deep to shallow water?

	speed	frequency
A	decrease	increase
B	decrease	constant
C	increase	increase
D	increase	constant

Your answer ☐ **[1]**

15. Unpolarised light is observed through a single polarising filter.

The intensity of the light transmitted by the filter is half the intensity of the incident light.

What happens to the intensity of the transmitted light when the filter is rotated through 90°?

A decreases
B decreases and then increases
C increases
D does not change

Your answer ☐ **[1]**

16(a). Radiographers commonly use molecules containing fluorine F-18 as tracers in positron emission tomography (PET) scanning.

Fluorine has a proton number of 9.

F-18 decays to oxygen (O) by β^+ decay.

Write the equation for the decay of a nucleus of F-18 using nuclear notation.

[2]

(b). The β^+ particle (positron) produced travels only a short distance in the patient before it meets an electron and is annihilated.

Calculate the wavelength λ of gamma photons produced.

λ = ...m **[3]**

(c). X-rays and gamma-rays are produced by different physical processes.

Briefly describe both processes.

[2]

(d). F-18 has a half-life of 109.7 minutes.

Explain the advantage that this has for the patient but the disadvantage that this has for the radiographers.

[3]

17. Fig.1 shows the pattern obtained in a Young double-slit experiment. The pattern is **not** to scale. Three regions of the pattern are labelled **A**, **B** and **D**. The central maximum is labelled **C**.

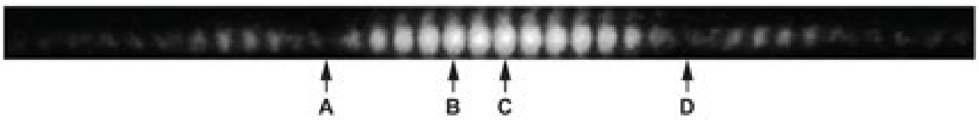


Fig. 1

Red light of wavelength 640 nm was used in the experiment. The distance between the centres of the two slits was 1.00×10^{-5} m. The distance from the double-slit to the screen was 4.0 m.

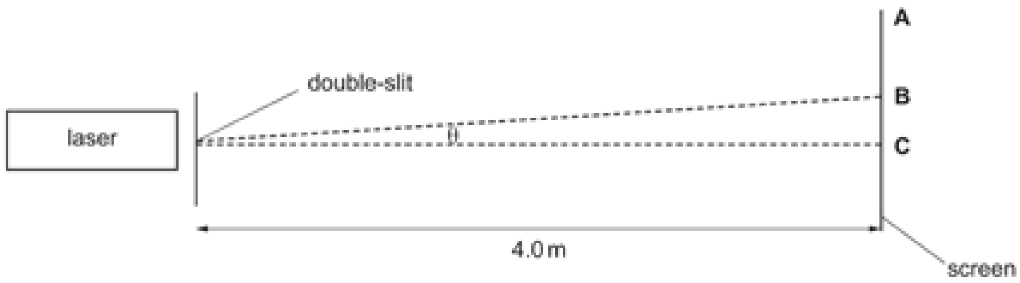


Fig. 2

Name the physical processes that cause the features labelled **A**, **D** and **B**, **C** in **Fig. 1**.

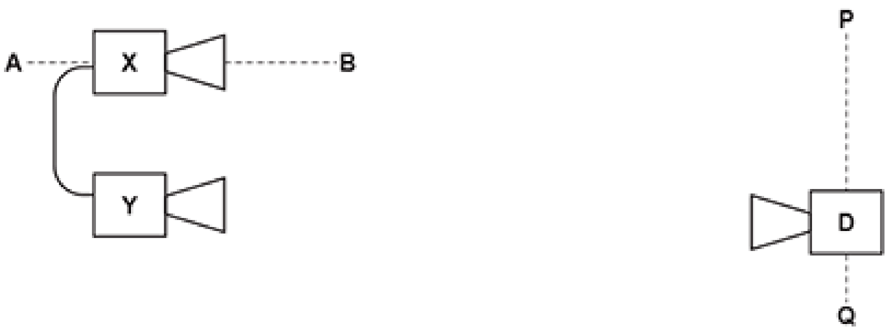
A and **D** --

B and **C** --

[2]

18. A student experiments with microwaves emitted from a transmitter. The frequency *f* of the microwaves from the transmitter can be adjusted.

The student connects two microwave transmitters **X** and **Y**, and places them in front of a microwave detector **D**, as shown in the diagram below.



The transmitters **X** and **Y** produce **coherent** vertically polarised microwaves with the same frequency *f*.

The detector **D** is sensitive to vertically polarised microwaves only.

When the detector **D** is moved along the line **PQ**, a pattern of maximum and minimum intensity is observed. Adjacent maxima are separated by a distance *x*.

i. *Explain:

- why this pattern of intensity occurs
- the expected relationship between the frequency *f* and the distance *x*
- how to verify this relationship experimentally.

[6]

ii. Transmitter **X** is rotated about the line **AB** and the experiment is repeated at different orientations until it has been rotated by 180°.

Describe and explain the observed patterns of maximum and minimum intensity.

[3]

19. A student investigates the oscillations of a uniform rod of length L which is pivoted at the top, as shown in **Fig. 2. 1**.

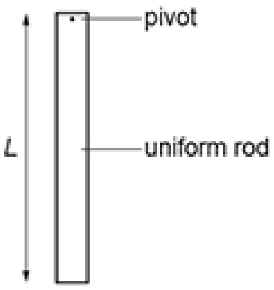


Fig. 2.1

The relationship between the frequency f of the oscillations of the rod and its length L is

$$f = \frac{1}{2\pi}\sqrt{\frac{3g}{2L}},$$

where g is the acceleration of free fall.

The student varies the length L of the rod and determines the period T for each length.

The student plots a graph of T^2 against L, shown in **Fig. 2.2**. A line of best fit has already been drawn.

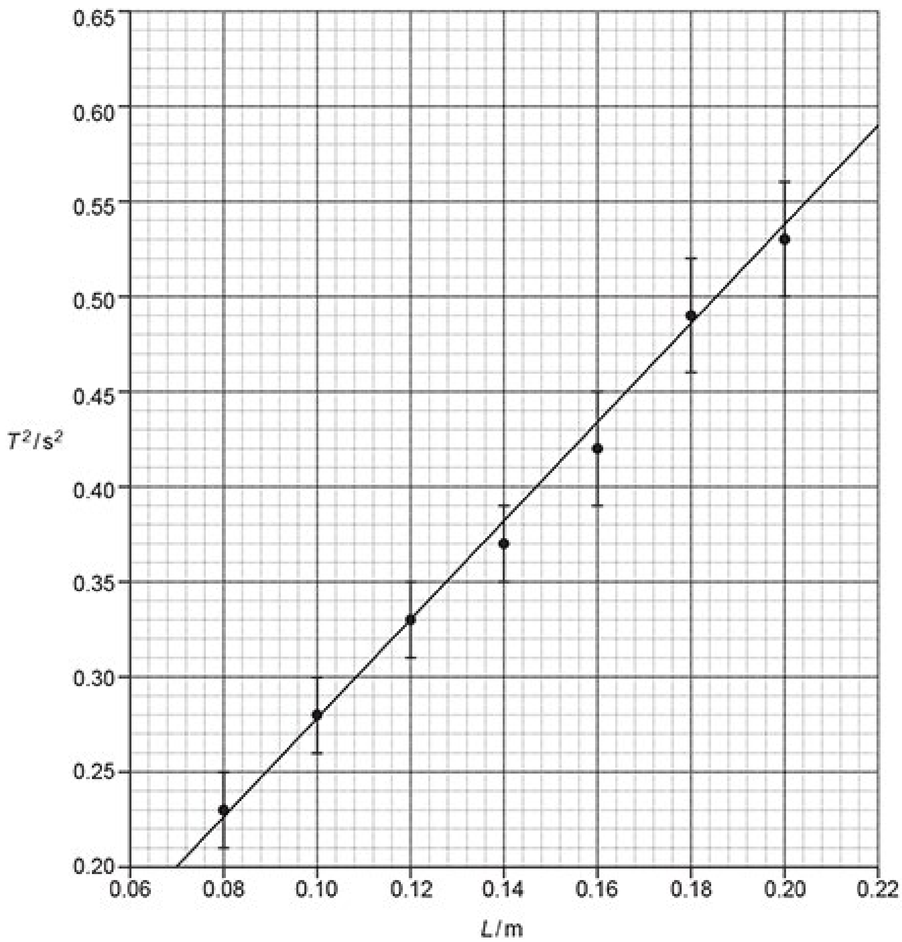


Fig. 2.2

i. Show that the gradient of the graph is given by the equation

gradient = $\frac{8\pi^2}{3g}$

[2]

ii. The gradient of the line of best fit on **Fig. 2.2** is 2.64 s^2 m^{-1}.

Use this value to determine *g*.

g = ... ms^{-2} **[2]**

iii. Draw a line of worst fit on **Fig. 2.2**.

[1]

iv. Use your line of worst fit to calculate the percentage uncertainty in *g*.

percentage uncertainty = ...% **[3]**

v. Use the true value of *g* (9.81 ms^{-2}) to evaluate the accuracy of the student's value of *g* from this experiment. Include a calculation in your answer.

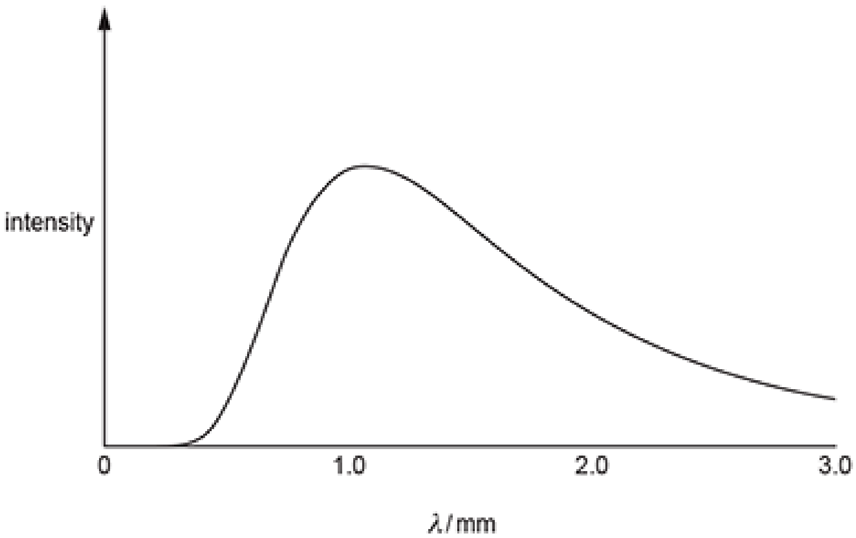
[2]

20. Astronomers can detect microwave background radiation coming from space in every direction.

The temperature of this microwave radiation is 2.7 K and its **total** intensity is about 3×10^{-6} W m^{-2}.

The figure below shows how the intensity of the microwave background radiation varies with its wavelength λ.

The **peak** intensity is at a wavelength of 1.1 mm.



This spectrum of microwave background radiation changes with temperature according to Wien's displacement law.

i. Suggest and explain how the spectrum might have looked in the distant past. You may draw on the figure to support your answer.

[2]

ii. Calculate the energy of a photon which has a wavelength of 1.1 mm.

energy = ... J **[2]**

iii. Estimate the number of photons of microwave background radiation incident per second on the back of your hand.

Assume that all emitted photons have the energy calculated in **(ii)**, and that the back of your hand has a surface area of 150 cm^2.

number of photons per second = ...s^{-1} **[2]**

iv. A scientist suggests that the microwave background radiation could be used as an energy source.

The scientist proposes using large tanks of water to absorb the microwave radiation.

Estimate the maximum rise in temperature that could be produced per second for a large cylindrical tank of depth 5.0 m. Assume that all microwave radiation incident on the top of the tank is absorbed.

density of water = 1000 kg m^{-3}
specific heat capacity of water = 4200 J kg^{-1} K^{-1}

maximum rise in temperature per second = ...°C s^{-1} **[3]**

21.

A parallel beam of X-rays is incident normally on a tissue as shown in **Fig. 24. 1**.

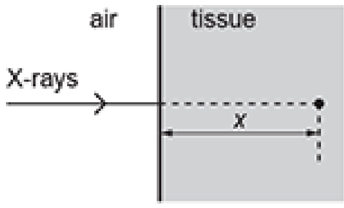


Fig. 24.1

The variation of the intensity *I* of the X-rays with depth *x* in the tissue is shown in **Fig. 24. 2**.

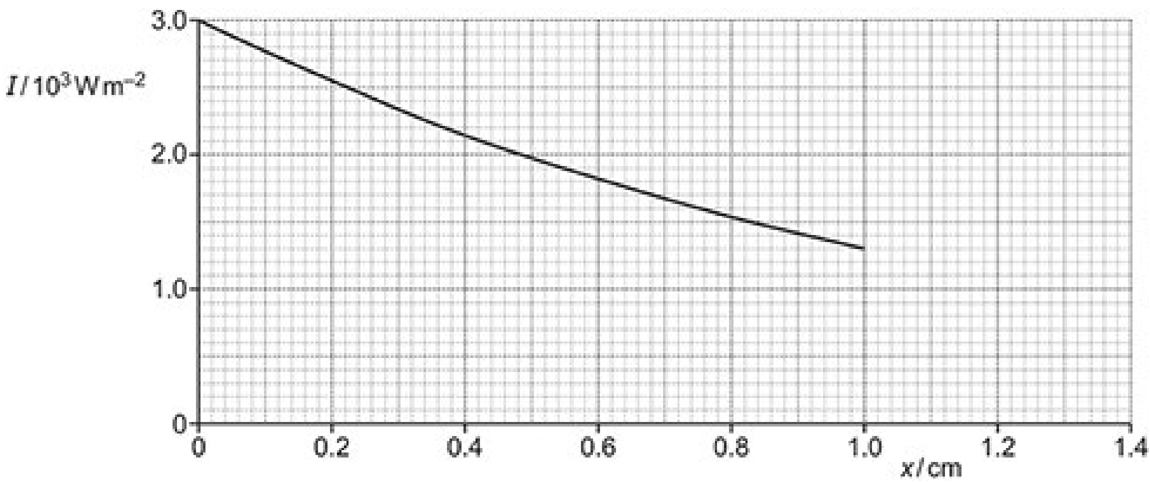


Fig. 24.2

The tissue has uniform structure between $x = 0$ and $x = 1.0$ cm.

i. Use the graph to determine the attenuation (absorption) coefficient μ in cm^{-1} of the tissue.

μ = ... cm^{-1} **[2]**

ii. Use the graph to determine the exposure time t for the total radiant energy incident per cm2 at a depth of 1.0 cm to be 2.6 J.

t = ... s **[3]**

iii. Beyond x = 1.0 cm, the tissue has a larger attenuation coefficient than the value calculated in **(i)**.

On **Fig. 24.2**, sketch the variation of I with x beyond x = 1.0 cm.

[2]

22.

A student is doing an experiment to determine the speed of sound in air by producing stationary waves inside a horizontal glass tube.

Fine powder is sprinkled inside the tube. A loudspeaker is placed close to the open end of the tube. The other end of the tube is closed. The loudspeaker is connected to a signal generator producing a frequency of 2.72 kHz. The powder inside the tube forms piles at certain locations inside the tube, see **Fig. 16. 2**.

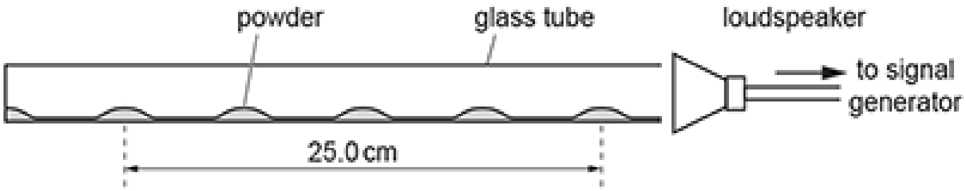


Fig. 16.2 (not to scale)

i. Suggest why the powder piles up at the nodes within the tube.

--**[1]**

ii. Use **Fig. 16. 2** to determine the speed of sound v.

v = ... ms^{-1} **[3]**

iii. Determine the fundamental (minimum) frequency f_0 of the stationary wave that can be formed within this tube.

f_0 = ... Hz **[2]**

23. A beam of sound of intensity I_0 is reflected off the surface of water.

The amplitude of the reflected sound is $\frac{1}{4}$ the amplitude of the incident sound.
What is the intensity of the reflected sound in terms of I_0?

A $\frac{I_0}{16}$

B $\frac{I_0}{8}$

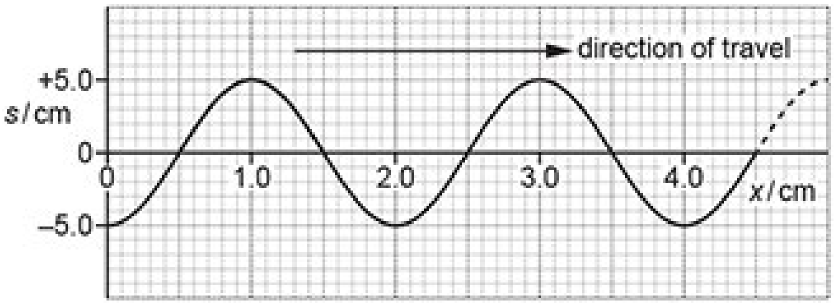
C $\frac{I_0}{4}$

D I_0

Your answer [ ] **[1]**

24.

A graph of displacement *s* against distance *x* for a **progressive** wave at time $t = 0$ is shown below.



Determine:

i. the phase difference ϕ in radians between the points on the wave at $x = 1.5$ cm and $x = 2.5$ cm

ϕ = ... rad **[1]**

ii. the displacement *s* at time $t = \frac{3}{4}T$ at $x = 1.5$ cm, where *T* is the period of the oscillations of the wave.

s = ... cm **[1]**

25.

A wire is fixed between two supports, as shown in **Fig. 24**.

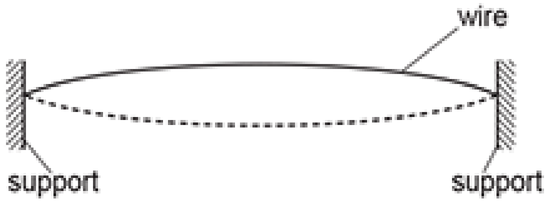


Fig. 24.

The wire is plucked in the middle. A stationary wave of fundamental frequency *f* is formed on the stretched wire.

The tension *T* in the stretched wire is given by the expression $T = 4f^2 mL$, where *f* is the frequency of the oscillating wire, *m* is the mass of the wire and *L* is the length of the wire.

A student is performing an experiment to determine the tension *T* in the wire. The measurements are shown in the table below.

Quantity	Measurement	Percentage uncertainty
f	58 Hz	2.5
m	9.7×10^{-4} kg	1.0
L	0.62m	0.5

i. Suggest how the student may have determined the fundamental frequency of the oscillating wire in the laboratory.

[2]

ii. Use the data in the table to determine

1 the wavelength of the progressive waves on the stretched wire

wavelength = ... m **[1]**

2 the speed of the progressive waves on the stretched wire

speed = ... m s^{-1} **[2]**

3 the **absolute** uncertainty in the tension *T*. Write your answer to 2 significant figures.

absolute uncertainty in *T* = ... N **[2]**

26. A laser emits a uniform beam of light.
What two quantities alone are required to calculate the intensity of the beam of light?

A amplitude, frequency
B cross-sectional area, power
C energy, time
D frequency, wavelength

Your answer ☐ **[1]**

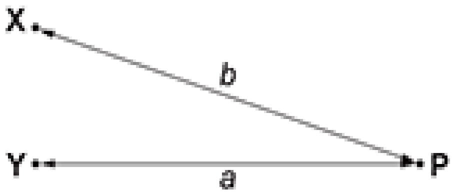
27. A student is experimenting with sound waves of wavelength 3.0 cm and electromagnetic waves also of wavelength 3.0 cm.

Which statement is correct about **both** of these waves?

A They can be polarised.
B They can form stationary waves.
C They have the same frequency.
D They have the same speed.

Your answer ☐ **[1]**

28. Two coherent waves are emitted from the sources **X** and **Y**.



The diagram is not to scale.
The waves at **X** and **Y** are in phase.
The waves have wavelength 4.0 cm.
The phase difference of the two waves meeting at point **P** is 270°.

Which row gives possible distances for *a* and *b*?

	a / cm	***b*** / cm
A	20.0	26.0
B	20.0	22.0
C	15.0	18.0
D	10.0	14.0

Your answer **[1]**

29(a). The table shows the refractive index of air, glass and oil for red light. It also shows the speed *v* of red light in air.

	air	**glass**	**oil**
refractive index *n*	1.00	1.52	1.46
speed of light *v* / ms^{-1}	3.00×10^8		

Complete the table by determining the missing values for *v* for glass and oil. Write your answers to 3 significant figures.

[1]

(b). Show that the critical angle for a ray of red light at the boundary between glass and air is less than 45°.

[2]

(c). Fig. 5.1 shows a glass block inside a beaker.

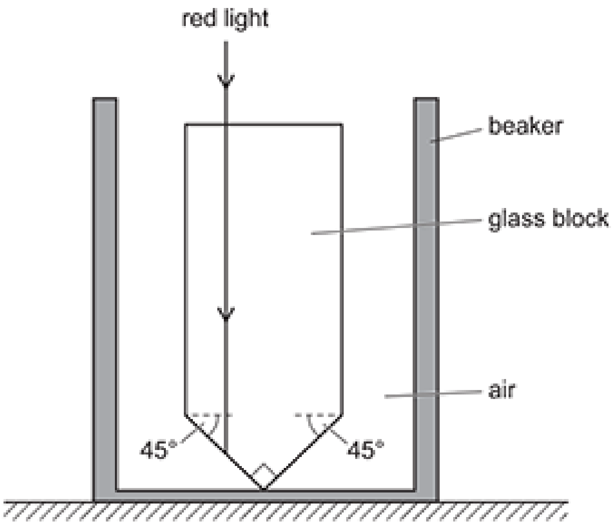


Fig. 5.1

The path of a ray of red light is shown entering the glass block.

Complete **Fig. 5.1** to show the path of the ray through the block until it leaves the block. **[2]**

(d). Oil is now added to the beaker as shown in **Fig. 5.2**.

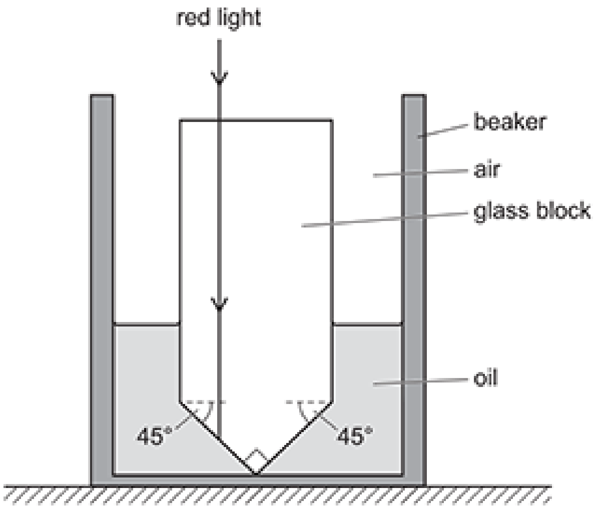


Fig. 5.2

The path of a ray of red light is shown entering the glass block.

i. Calculate the critical angle *C* for a ray of red light at the boundary between glass and oil.

C = ...° **[2]**

ii. Complete **Fig. 5.2** to show the path of the ray through the block until it leaves the block.

[1]

END OF QUESTION PAPER