



Rewarding Learning

ADVANCED SUBSIDIARY (AS)
General Certificate of Education
2022

Centre Number

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Candidate Number

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Physics

StemUp Model Solution

Assessment Unit AS 2

assessing

Module 2: Waves, Photons
and Astronomy



SPH21

[SPH21]

MONDAY 6 JUNE, MORNING

TIME

1 hour 45 minutes.

INSTRUCTIONS TO CANDIDATES

Write your Centre Number and Candidate Number in the spaces provided at the top of this page.

You must answer the questions in the spaces provided.

Do not write outside the boxed area on each page or on blank pages.

Complete in black ink only. **Do not write with a gel pen.**

Answer **all eleven** questions.

INFORMATION FOR CANDIDATES

The total mark for this paper is 100.

Figures in brackets printed down the right-hand side of pages indicate the marks awarded to each question.

Your attention is drawn to the Data and Formulae Sheet which is inside this question paper.

You may use an electronic calculator.



- 1 (a) A surface water wave is classified as a transverse wave. Explain what is meant by a transverse wave.

A wave in which the particles (of the medium) oscillate perpendicular to the direction of travel of the wave (direction of energy transfer).

[2]

- (b) Transverse waves can be polarised. Explain what is meant by a polarised wave.

A wave in which the oscillations are confined to one plane only (containing the direction of travel).

[1]

- (c) A surface water wave of wavelength 2.24 m is moving at a speed of 56.0 m s^{-1} . The amplitude of the wave is 15.0 cm.

- (i) Calculate the frequency of the wave.

$$v = f\lambda, \text{ so } f = v / \lambda$$

$$f = 56.0 / 2.24$$

$$f = 25 \text{ Hz}$$

Frequency = 25 Hz

[3]



- (ii) On **Fig. 1.1**, sketch a graph showing two full cycles of the wave. Include values on both axes. Show any working out clearly.

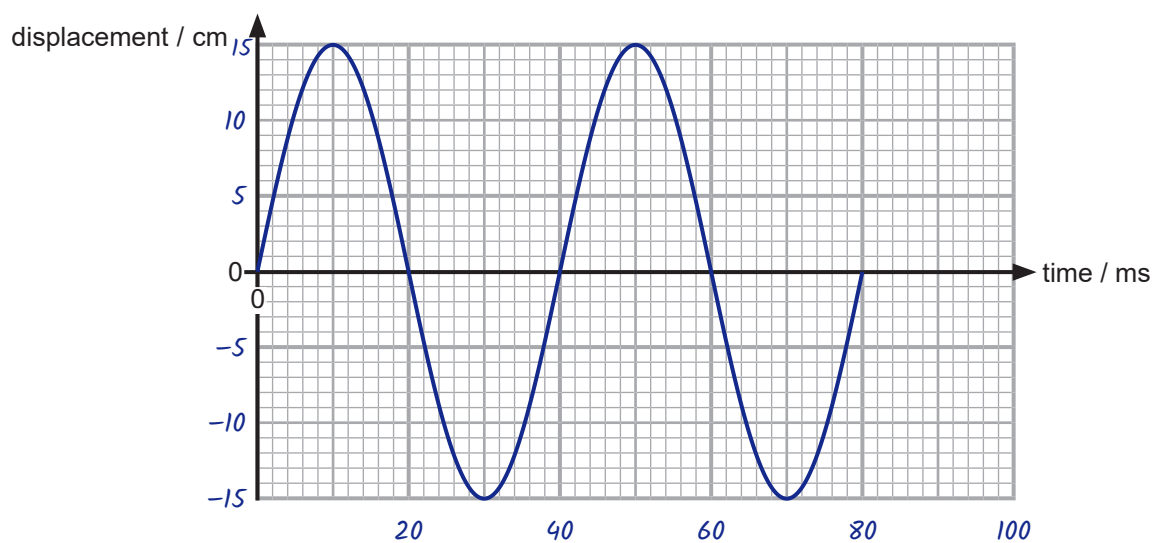


Fig. 1.1

[5]

$$T = 1 / f = 1 / 25 = 0.040 \text{ s} = 40 \text{ ms}$$

$$\text{Two cycles take } 2 \times 40 = 80 \text{ ms}$$

Amplitude = 15.0 cm, so peaks at +15 cm and -15 cm

[Turn over]



- 2 The spiral galaxy NGC 2403 is estimated to be at a distance of 8 million light years from the Earth. One light year is the distance travelled by light in one year.

(a) Show that the NGC 2403 galaxy is approximately 7.6×10^{22} m from the Earth.

$$1 \text{ year} = 365.25 \times 24 \times 3600 = 3.16 \times 10^7 \text{ s}$$

$$1 \text{ ly} = 3.00 \times 10^8 \times 3.16 \times 10^7 = 9.47 \times 10^{15} \text{ m}$$

$$d = 8 \times 10^6 \times 9.47 \times 10^{15} = 7.57 \times 10^{22} \text{ m}$$

$$d \approx 7.6 \times 10^{22} \text{ m}$$

[3]

(b) (i) Calculate the recession speed of the NGC 2403 galaxy.

$$v = H_0 d$$

$$v = 2.4 \times 10^{-18} \times 7.6 \times 10^{22}$$

$$v = 1.82 \times 10^5 \text{ m s}^{-1}$$

$$\text{Recession speed} = \underline{1.82 \times 10^5} \text{ m s}^{-1}$$

[2]

(ii) Calculate the redshift parameter z for the NGC 2403 galaxy.

$$z = v / c$$

$$z = 1.82 \times 10^5 / 3.00 \times 10^8$$

$$z = 6.1 \times 10^{-4}$$

$$z = \underline{6.1 \times 10^{-4}}$$

[2]



(c) One of the lines of the emission spectrum of hydrogen has wavelength 656 nm.

- (i) Calculate the wavelength redshift $\Delta\lambda$ of this spectral line when emitted from the NGC 2403 galaxy and observed on Earth.

$$z = \Delta\lambda / \lambda, \text{ so } \Delta\lambda = z\lambda$$

$$\Delta\lambda = 6.1 \times 10^{-4} \times 656 \text{ nm}$$

$$\Delta\lambda = 0.40 \text{ nm}$$

$$\Delta\lambda = \underline{0.40} \text{ nm} \quad [2]$$

- (ii) How does your answer to (c)(i) compare to the $\Delta\lambda$ value for the 656 nm spectral line emitted from a galaxy 1000 times more distant than the NGC 2403 galaxy?

My answer is 1000 times smaller ($\Delta\lambda$ is proportional to v , which is proportional to distance). [1]



3 Sodium metal has a work function of 2.00 eV.

(a) Explain what is meant by the 'work function' of sodium.

*The minimum energy required for an electron to escape (be released)
from the surface of the sodium metal.*

[2]

(b) Calculate the threshold frequency of sodium.

$$\phi = hf_0$$

$$\phi = 2.00 \times 1.60 \times 10^{-19} = 3.20 \times 10^{-19} \text{ J}$$

$$f_0 = \phi / h = 3.20 \times 10^{-19} / 6.63 \times 10^{-34}$$

$$f_0 = 4.83 \times 10^{14} \text{ Hz}$$

$$\text{Frequency} = 4.83 \times 10^{14} \text{ Hz}$$

[3]

(c) (i) Use Einstein's photoelectric equation to calculate the maximum velocity of electrons emitted from the surface of sodium when it is illuminated by light of wavelength 330 nm.

$$\lambda = 330 \text{ nm} = 330 \times 10^{-9} \text{ m}$$

$$hf = hc / \lambda = 6.63 \times 10^{-34} \times 3.00 \times 10^8 / 330 \times 10^{-9} = 6.03 \times 10^{-19} \text{ J}$$

$$\frac{1}{2}mv_{\text{max}}^2 = hf - hf_0 = 6.03 \times 10^{-19} - 3.20 \times 10^{-19} = 2.83 \times 10^{-19} \text{ J}$$

$$v_{\text{max}}^2 = 2 \times 2.83 \times 10^{-19} / 9.11 \times 10^{-31} = 6.21 \times 10^{11}$$

$$v_{\text{max}} = 7.88 \times 10^5 \text{ m s}^{-1}$$

$$\text{Maximum velocity} = 7.88 \times 10^5 \text{ m s}^{-1}$$

[6]



- (ii) The intensity of the incident light of wavelength 330 nm is increased. What effect, if any, will this have on the maximum velocity of the emitted electrons?

No effect: the maximum velocity stays the same (more electrons are emitted per second, but each photon has the same energy).

[1]

- (iii) State what would be observed if light of frequency 4.55×10^{14} Hz and of the original intensity is incident on the surface of sodium. Explain your reasoning.

No electrons would be emitted.

4.55×10^{14} Hz is below the threshold frequency (4.83×10^{14} Hz),

so photon energy < work function.

[2]

[Turn over



- 4 **Fig. 4.1** shows the emission line spectrum for excited hydrogen gas. Explain how the spectrum is produced in terms of energy levels within the atom of hydrogen. Numerical values are not required in your answer.

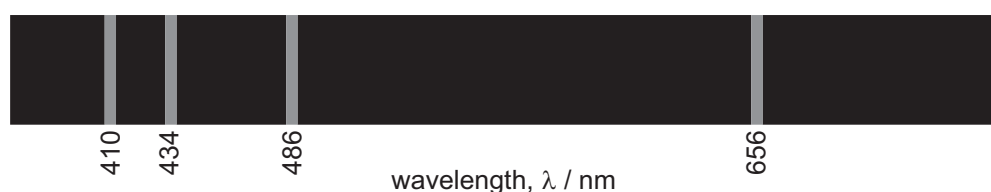


Fig. 4.1

Electrons in the hydrogen atom can only exist in certain discrete energy levels.

When the gas is excited, electrons are raised to higher energy levels. They then fall (make a transition) back to a lower energy level.

As an electron drops, it emits a photon (a discrete bundle or quantum of energy).

The energy of the photon equals the difference in energy between the two levels: $hf = E_1 - E_2$.

As only certain energy differences are possible, the light is observed as lines of specific wavelengths (e.g. 656 nm).

[5]



- 5 (a) A converging lens is used to produce a real, magnified image of an object. Draw a ray diagram on **Fig. 5.1** to locate the position of the object **O** when the focused image **I** is formed as shown. The points labelled **F** are the principal foci of the lens.

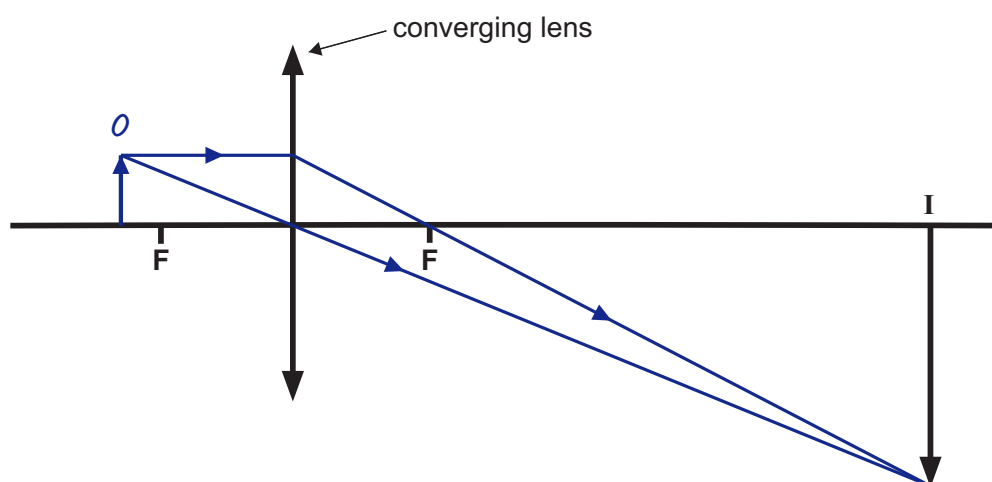


Fig. 5.1

[4]

- (b) A projector is used to produce a real, magnified image of a square microscope slide on a screen placed at a distance of 3.5 m from the lens. The length of one side of the slide is 4.0 cm and the focused image on the screen is a square of side 88 cm.

Calculate the focal length of the lens being used in the projector.

$$m = \text{image size} / \text{object size} = 88 / 4.0 = 22$$

$$m = v / u, \text{ so } u = v / 22 = 3.5 / 22 = 0.159 \text{ m}$$

$$1/f = 1/u + 1/v = 1/0.159 + 1/3.5$$

$$1/f = 6.29 + 0.286 = 6.57 \text{ m}^{-1}$$

$$f = 0.152 \text{ m}$$

Focal length = 0.15 m

[4]

[Turn over]



6 Lasers produce light which is monochromatic and coherent. In relation to laser action, explain the terms below.

(a) Metastable state

An excited energy level in which electrons can remain for a much longer time than in other excited levels.

[2]

(b) Population inversion

When a greater number of electrons are in a higher (excited, metastable) energy level than in the lower level (ground state).

[2]

(c) Coherent light

All the photons (waves) are in phase (constant phase difference).

[1]

(d) Monochromatic light

Light of a single frequency (one wavelength, one colour).

[1]





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- 7 An electron diffraction tube, as shown in **Fig. 7.1**, is used to demonstrate the wave–particle duality of electrons.

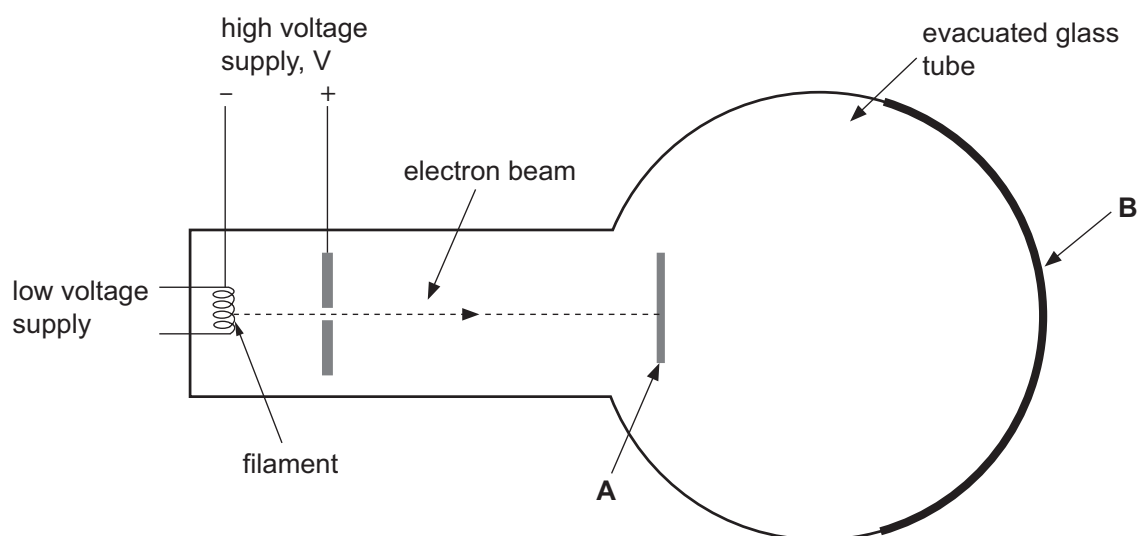


Fig. 7.1

- (a) (i) Name the piece of apparatus labelled **A**.

Thin graphite (carbon) film target

[1]

- (ii) Name the piece of apparatus labelled **B** and describe what is observed at **B**.

B is a fluorescent screen.

A pattern of bright concentric rings (circles) is observed on the screen, around a central bright spot.

[3]



- (iii) Explain how the diffraction apparatus in **Fig. 7.1** demonstrates both the wave nature and the particle nature of electrons.

Particle nature: the electrons are accelerated by the p.d. (electron gun), behaving as charged particles in an electric field.

Wave nature: the electrons are diffracted by the graphite, giving an interference (superposition) pattern of rings.

[2]

- (b) (i) In an electron diffraction tube, a high voltage supply accelerates the electrons to a velocity of $1.39 \times 10^7 \text{ m s}^{-1}$. Determine the de Broglie wavelength of these electrons.

$$p = mv = 9.11 \times 10^{-31} \times 1.39 \times 10^7$$

$$p = 1.27 \times 10^{-23} \text{ kg m s}^{-1}$$

$$\lambda = h / p = 6.63 \times 10^{-34} / 1.27 \times 10^{-23}$$

$$\lambda = 5.24 \times 10^{-11} \text{ m}$$

Wavelength = 5.24×10^{-11} m

[4]

- (ii) What region of the electromagnetic spectrum would a photon of the wavelength calculated in (b)(i) belong to?

Gamma rays

[1]

[Turn over]



- 8 A diffraction grating may be used to experimentally determine the wavelength of visible laser light, using the arrangement shown in **Fig. 8.1**.

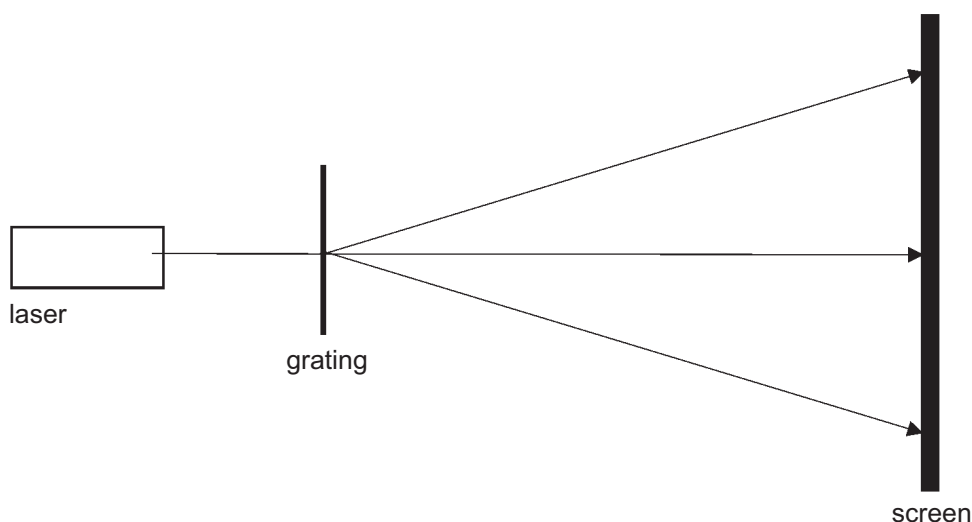


Fig. 8.1

The diffraction equation is given by **Equation 8.1**.

$$d \sin \theta = n \lambda \quad \text{Equation 8.1}$$

- (a) Define the terms used in **Equation 8.1**.

n : the order of the maximum (fringe); $n = 0$ is the central, straight-through beam

d : the slit spacing of the grating (distance between adjacent lines)

θ : the angle between the zero order (central) beam and the n th order beam

[3]



- (b) In one such experiment, the laser emits light of wavelength $660 \times 10^{-9} \text{ m}$, the grating has 200 lines per mm and a sheet of white paper of width 296 mm is being used as the screen. Use the diffraction grating formula to calculate a minimum grating to screen distance in order for both the first order fringes to be observed on the edges of the paper.

$$d = 1 / (200 \times 10^3) = 5.00 \times 10^{-6} \text{ m}$$

$$d \sin \theta = n\lambda \text{ with } n = 1: \sin \theta = 660 \times 10^{-9} / 5.00 \times 10^{-6} = 0.132$$

$$\theta = 7.59^\circ$$

$$\text{Each first order fringe at the edge: } y = 296 / 2 = 148 \text{ mm} = 0.148 \text{ m}$$

$$\tan \theta = 0.148 / D$$

$$D = 0.148 / \tan 7.59^\circ = 0.148 / 0.133$$

$$D = 1.1 \text{ m}$$

Minimum distance from grating to screen = 1.1 m [6]



- 9 A child wears spectacle lenses of focal length $+0.56\text{ m}$ in order to correct the near point to a normal distance of 25 cm from their eye.

(a) (i) What defect of vision is being corrected by a lens of focal length $+0.56\text{ m}$?

Long sightedness (hypermetropia)

[1]

(ii) What could cause the defect you have named in (i)?

The eyeball is too short (or the eye lens is too thin / weak,
cornea not curved enough).

[1]

(iii) What is meant by the near point?

The closest point to the eye at which an object can be clearly
focused (seen distinctly).

[1]

- (b) With the correcting lens in place, complete a ray diagram on **Fig. 9.1** to illustrate the path of two rays from an object placed 25 cm from the eye of the child. Draw the correct shape of the correcting lens on the dotted line shown and two rays passing through the correcting lens and the eye lens to the retina.

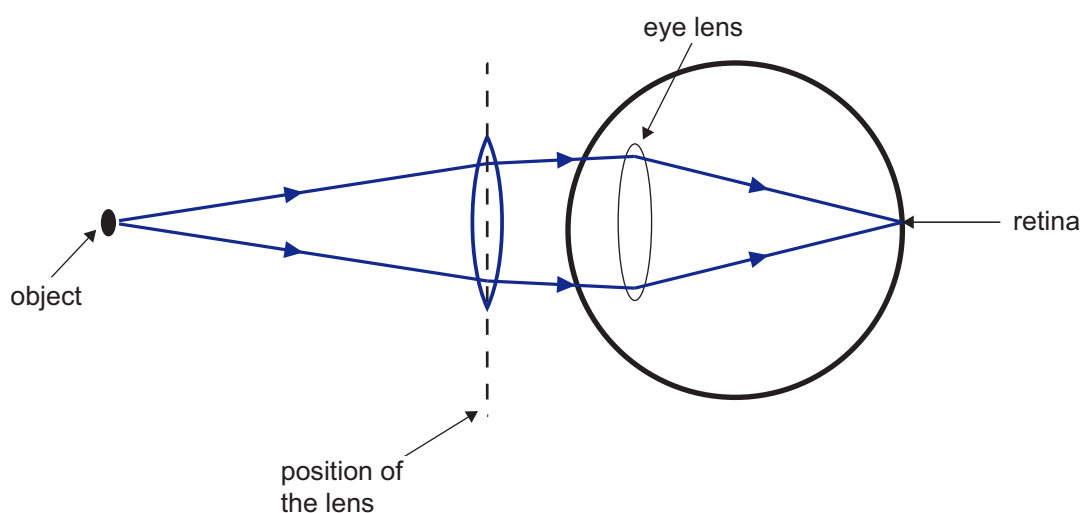


Fig. 9.1

[4]





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10 (a) State the principle of superposition.

When two (or more) waves meet at a point, the resultant displacement is equal to the (vector) sum of the individual displacements of each wave at that point.

[2]

(b) Interference effects can be demonstrated using sound waves.

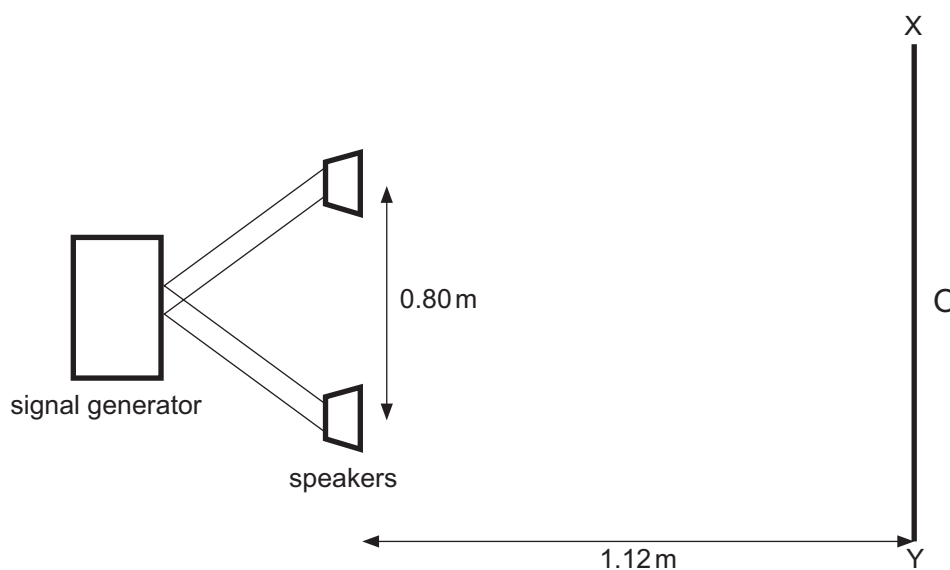


Fig. 10.1

Two loudspeakers connected to the same signal generator are placed 0.80 m apart as in **Fig. 10.1**. Students walking along the line XY at a distance of 1.12 m from the speakers can hear variations in the loudness of the sound.

Student A reports hearing loud sounds at 42 cm intervals and Student B at 44 cm intervals. Both agree that the loudest sound can be heard at point O, equidistant from both speakers.



- (i) Explain why a loud sound is heard at point O.

O is equidistant from both speakers, so the path difference is zero

and the waves arrive in phase.

They interfere constructively, giving maximum amplitude (a loud sound).

[2]

- (ii) By averaging the results of the two students, estimate the frequency of the sound being generated. The speed of sound in air is 334 m s^{-1} . Give your answer to two significant figures.

$$y = (42 + 44) / 2 = 43 \text{ cm} = 0.43 \text{ m}$$

$$\lambda = ay / d = 0.80 \times 0.43 / 1.12$$

$$\lambda = 0.307 \text{ m}$$

$$f = v / \lambda = 334 / 0.307$$

$$f = 1087 \text{ Hz}$$

$$f = 1100 \text{ Hz (2 s.f.)}$$

Frequency = 1100 Hz

[6]

[Turn over]



11 Diamond has a refractive index of 2.42.

(a) Show that the critical angle for diamond is 24° .

$$\sin C = 1 / n = 1 / 2.42 = 0.413$$

$$C = 24.4^\circ \approx 24^\circ$$

[2]

(b) Pieces of diamond are cut so as to 'sparkle'. This is partly due to the phenomenon of total internal reflection of light within the stone. A ray of white light incident at 90° to the surface of a cut diamond is shown in **Fig. 11.1**.

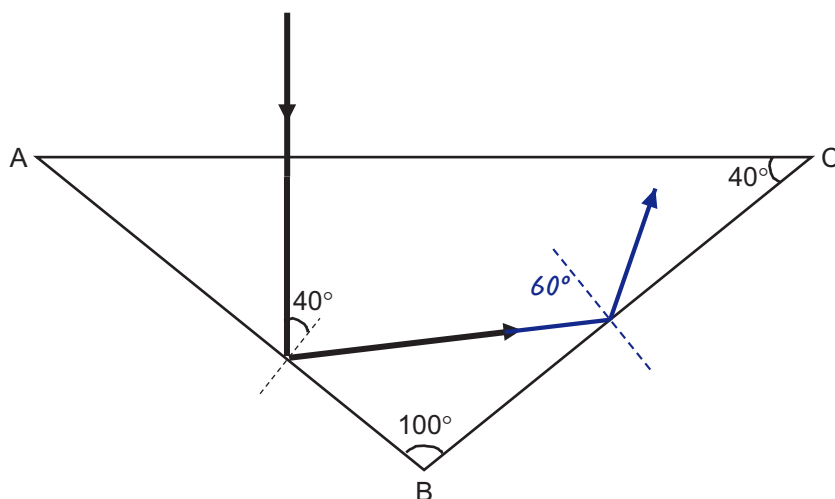


Fig. 11.1

(i) Explain why the ray has taken the path shown after striking boundary AB.

The angle of incidence at AB (40°) is greater than the critical angle (24°) and the light is going from a more dense to a less dense medium, so total internal reflection occurs.

[2]



- (ii) Continue the path of the ray on **Fig. 11.1** to show the path it follows before and just after striking boundary BC. Draw the normal line and include a value for the angle of incidence at the boundary BC. [3]

- (iii) Diamonds which are 'shallow cut', such as the one in **Fig. 11.2**, would not sparkle in the same manner. Explain why this is the case. You may illustrate your answer by continuing the path of the ray after striking boundary EF on **Fig. 11.2**.

The angle of incidence at the lower face is only 20° , smaller than the critical angle (24°), so the ray refracts out into the air instead of being totally internally reflected. [2]

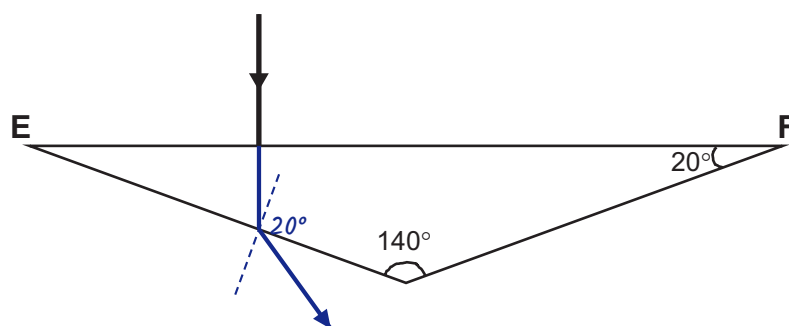


Fig. 11.2

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Rewarding Learning

ADVANCED SUBSIDIARY
General Certificate of Education

Physics

Assessment Units AS 1 and AS 2

[SPH11/SPH21]

DATA AND FORMULAE SHEET

Data and Formulae Sheet for AS 1 and AS 2

Values of constants

speed of light in a vacuum	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
the Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
mass of electron	$m_e = 9.11 \times 10^{-31} \text{ kg}$
mass of proton	$m_p = 1.67 \times 10^{-27} \text{ kg}$
acceleration of free fall on the Earth's surface	$g = 9.81 \text{ m s}^{-2}$
electron volt	$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$
the Hubble constant	$H_0 \approx 2.4 \times 10^{-18} \text{ s}^{-1}$

Useful formulae

The following equations may be useful in answering some of the questions in the examination:

Mechanics

conservation of energy	$\frac{1}{2} mv^2 - \frac{1}{2} mu^2 = Fs$ for a constant force
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Waves

two-source interference	$\lambda = \frac{ay}{d}$
diffraction grating	$d \sin \theta = n\lambda$

Light

lens equation

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

Electricity

terminal potential difference

$$V = E - Ir \text{ (e.m.f., } E; \text{ Internal Resistance, } r)$$

potential divider

$$V_{\text{out}} = \frac{R_1 V_{\text{in}}}{R_1 + R_2}$$

Particles and photons

Einstein's equation

$$\frac{1}{2} m v_{\text{max}}^2 = hf - hf_0$$

de Broglie equation

$$\lambda = \frac{h}{p}$$

Astronomy

red shift

$$z = \frac{\Delta\lambda}{\lambda}$$

recession speed

$$z = \frac{v}{c}$$

Hubble's law

$$v = H_0 d$$

