



Rewarding Learning

ADVANCED SUBSIDIARY (AS)
General Certificate of Education
2025

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

WEDNESDAY 21 MAY, AFTERNOON

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 questions in black ink and use a dark HB pencil for drawings and graphs.

Do not write with a gel pen.

Answer **all ten** 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 or part question.

You may use a scientific calculator.

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



- 1 (a) Waves can be classified as transverse or longitudinal. What type of wave is a water wave?

Transverse

[1]

- (b) (i) A rectangular pool 15m wide, 25m long and 2m deep contains 675 m^3 of water. If the water is at a constant depth, calculate the depth of water in the pool.

$$V = \text{length} \times \text{width} \times \text{depth}$$

$$675 = 25 \times 15 \times h$$

$$h = 675 / 375 = 1.8 \text{ m}$$

Depth of water = 1.8 m [2]

- (ii) A wave is produced on the surface of the water which just reaches the top edge of the pool at its maximum displacement.

What name is given to the maximum displacement of the wave from its equilibrium position?

Amplitude

[1]



- (iii) When there is maximum displacement of the wave at each end of the 25 m length of the pool, there are four other crests visible in the water between the ends.

On the grid of **Fig. 1.1**, sketch a displacement–distance graph for **three** cycles of the wave. Label the axes with appropriate values.

Use the space above **Fig. 1.1** for any calculations needed.

$$\text{Amplitude} = 2.0 - 1.8 = 0.2 \text{ m}$$

Crests at both ends + 4 between = 6 crests, so 5 wavelengths in 25 m

$$\lambda = 25 / 5 = 5 \text{ m, so three cycles} = 15 \text{ m}$$

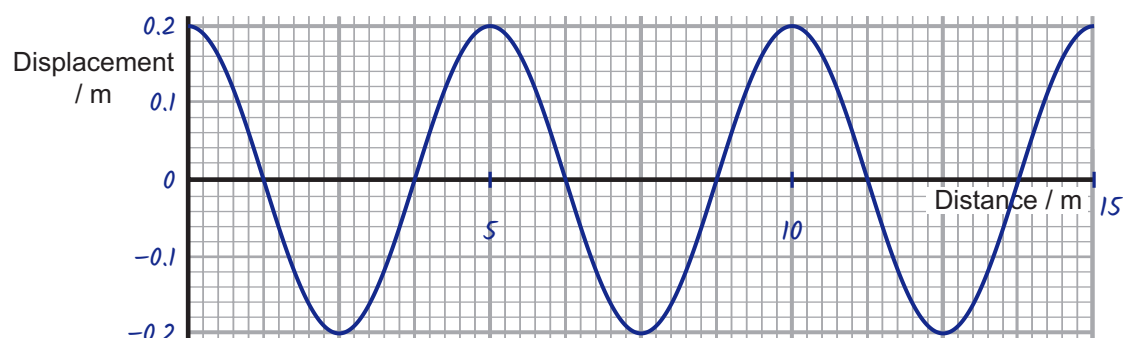


Fig. 1.1

[5]

- (c) The frequency of the wave is 4.5 Hz. Calculate the time it takes for a wavefront to travel the length of the pool.

$$v = f\lambda = 4.5 \times 5 = 22.5 \text{ m s}^{-1} (\approx 23 \text{ m s}^{-1})$$

$$t = d / v = 25 / 22.5$$

$$t = 1.1 \text{ s}$$

Time = 1.1 s

[4]

[Turn over]



2 (a) What is meant by refraction?

Refraction is the change in direction of a wave (caused by a change in speed) when the wave passes from one medium into another at an angle.

[2]

(b) A ray of light is directed along the normal at a glass block which has a triangular space in the middle of it, as shown in **Fig. 2.1**. Draw the path of the ray as it passes through and out of the other side of the block assuming total internal reflection does not take place. Include a normal at each boundary.

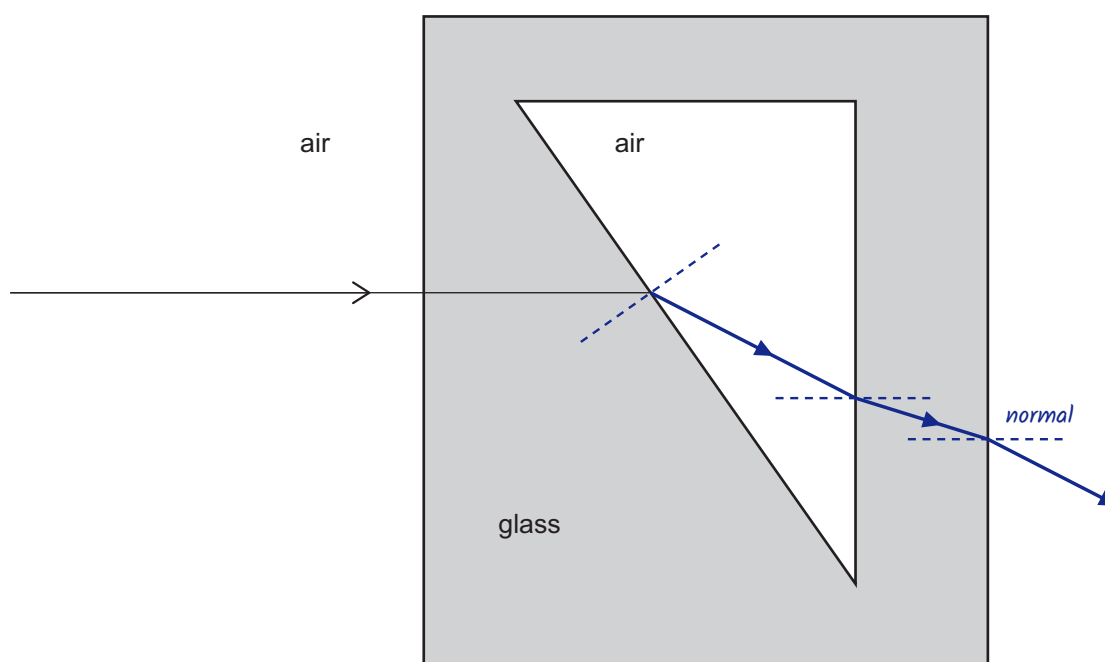


Fig. 2.1

[4]



- (c) The speed of light decreases by 35% when it enters the glass from the air.
Calculate the refractive index of the glass.

$$\text{speed in glass} = 0.65 \times 3.00 \times 10^8 = 1.95 \times 10^8 \text{ m s}^{-1}$$

$$n = c / v = 3.00 \times 10^8 / 1.95 \times 10^8$$

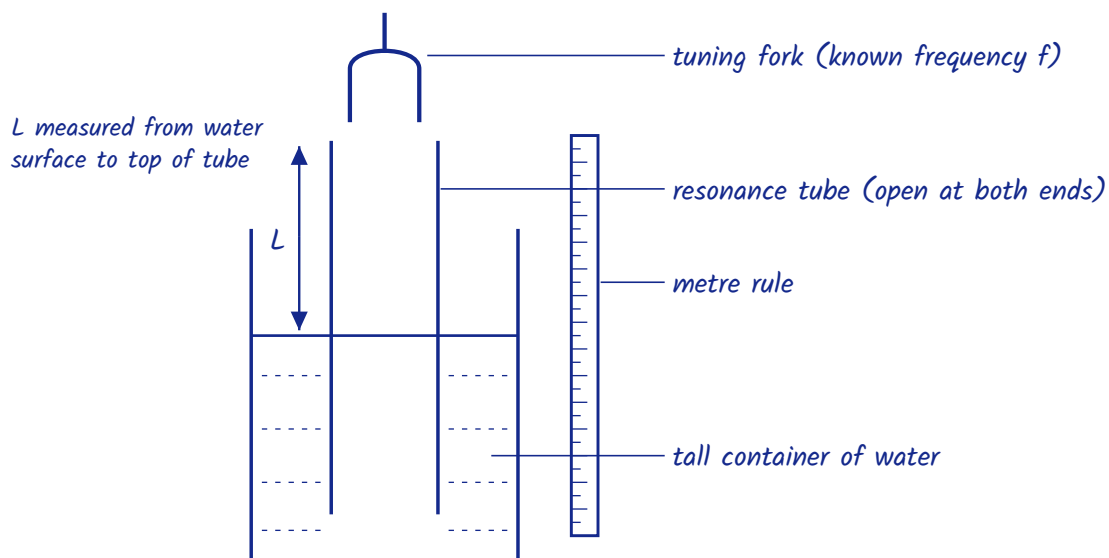
$$n = 1.54$$

Refractive index = 1.54 [3]



3 Describe a method to accurately determine the speed of sound in air using a resonance tube.

(a) Draw a labelled diagram of the apparatus required and how it is set up.



[3]

(b) Describe the method including the measurements taken.

Hold a struck tuning fork of known f just above the top of the tube.

From $L \approx 0$, slowly raise the tube and fork until the loudest sound is first heard (first resonance).

Measure L from the water surface to the top of the tube with the metre rule. Repeat for 5 different frequencies.

[4]



- (c) Describe how an accurate value for the speed of sound in air can be calculated from the results.

At the first resonance $L = \lambda/4$, so $v = f\lambda = 4fL$.

Plot f against $1/L$: a straight line through the origin with gradient $= v/4$,

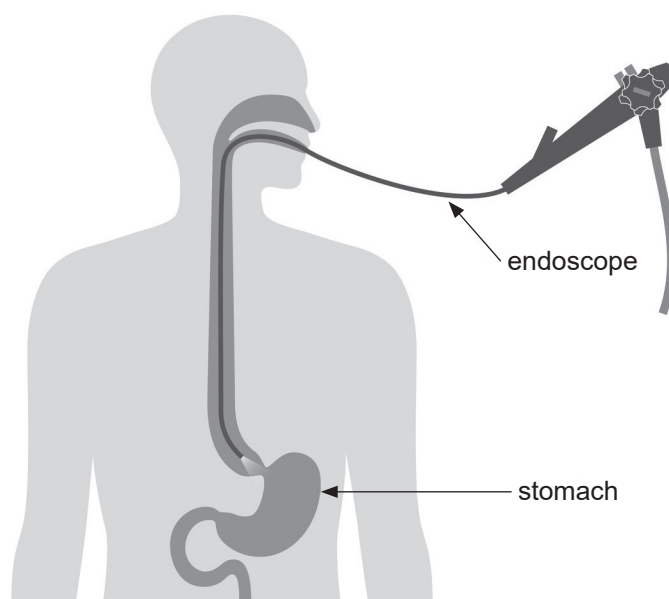
so $v = 4 \times \text{gradient}$ (or find $v = 4fL$ for each f and take the average).

[2]

[Turn over]



- 4 Fig. 4.1 shows an endoscope being used to **view inside** the stomach of a patient.



Source: © Getty images

Fig. 4.1

- (a) Describe the physical principles of optical fibres and how optical fibres are arranged when used in endoscopes.

An optical fibre has a glass core surrounded by glass cladding. The refractive index of the cladding is less than that of the core.

Light meeting the core to cladding boundary at more than the critical angle undergoes total internal reflection, so it travels along the fibre.

An endoscope has two bundles of fibres. The incoherent bundle carries light in to illuminate the stomach; its fibres do not need to be aligned.

The coherent bundle carries the image out; the fibre ends must be aligned in the same positions at both ends.

[6]



- (b) A type of glass has a refractive index of 1.46. Calculate the difference in the critical angle of light going from the glass towards air and the critical angle of light going from the same glass towards cladding of refractive index 1.43.

$$\sin C = 1/n$$

$$\text{glass to air: } \sin C = 1/1.46 = 0.685, C = 43.2^\circ$$

$$\text{glass to cladding: } \sin C = n_{\text{cladding}}/n_{\text{core}} = 1.43/1.46$$

$$\sin C = 0.979 \text{ (0.98)}, C = 78.4^\circ$$

$$\text{difference} = 78.4^\circ - 43.2^\circ = 35.2^\circ$$

Difference in critical angle = 35.2 ° [6]

[Turn over]



- 5 (a) Laser light is coherent and monochromatic. What is meant by each of these terms in the context of laser light?

Coherent:

The waves are in phase (constant phase relationship).

Monochromatic:

The light has a single wavelength (single frequency, one colour).

[2]



- (b) A laser emits light of wavelength 634 nm when an electron falls from an **energy level** of -20.66 eV to **energy level B** as shown in **Fig. 5.1**.

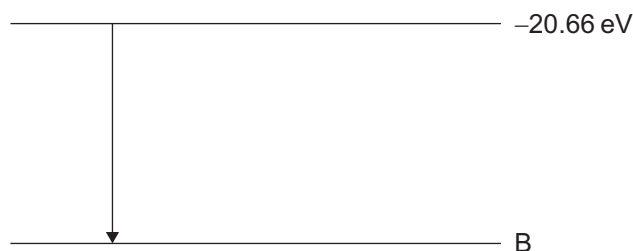


Fig. 5.1

- (i) Calculate the energy of energy level B, in eV.

$$E = hc / \lambda$$

$$E = (6.63 \times 10^{-34} \times 3.00 \times 10^8) / (634 \times 10^{-9})$$

$$E = 3.14 \times 10^{-19} \text{ J}$$

$$E = 3.14 \times 10^{-19} / 1.60 \times 10^{-19} = 1.96 \text{ eV}$$

$$\text{Level B is lower: } B = -20.66 - 1.96$$

$$B = -22.62 \text{ eV}$$

Energy = -22.62 eV [6]

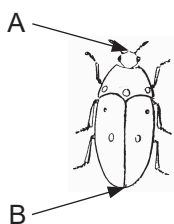
- (ii) Another laser emits electromagnetic radiation of wavelength 157 nm.
State what region of the electromagnetic spectrum this radiation belongs to.

Ultraviolet [1]

[Turn over]



- 6 A magnifying glass is used to view an insect. A full-scale diagram of the image that is seen when the insect is viewed through the magnifying glass is shown in **Fig. 6.1**.



Source: © Getty images

Fig. 6.1

- (a) (i) The actual length of the insect is 6 mm (measured between the points A and B as indicated on **Fig. 6.1**.) Calculate the magnification of the insect to one significant figure.

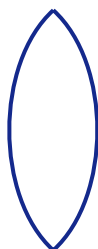
$$\text{image length } AB = 1.8 \text{ cm} = 18 \text{ mm}$$

$$M = \text{image length} / \text{object length} = 18 / 6$$

$$M = 3$$

Magnification = 3 [2]

- (ii) A converging lens is used in the magnifying glass. Sketch the shape of a converging lens.



converging (convex) lens

[1]



- (b) (i) Use the grid of **Fig. 6.2** to draw an accurate ray diagram showing how the lens magnifies the insect. The position of the lens has been drawn for you and the real, life-size insect is represented by the arrow.

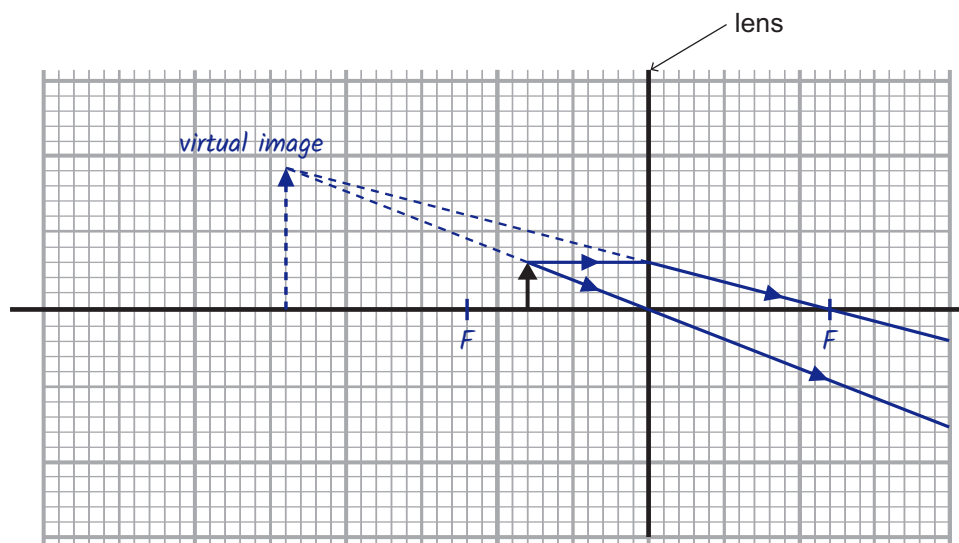


Fig. 6.2

[6]

- (ii) Measure the focal length f , of the lens directly from the full-scale ray diagram in **Fig. 6.2**.

$$f = \underline{2.4} \text{ cm [1]}$$

[Turn over]



- 7 In a double slit experiment, a source of electromagnetic radiation is directed at the double slits. The separation between the slits is 0.40 mm and a screen is placed 0.80 m away from the slits. Maxima and minima are detected at different positions along the screen as shown in **Fig. 7.1**.

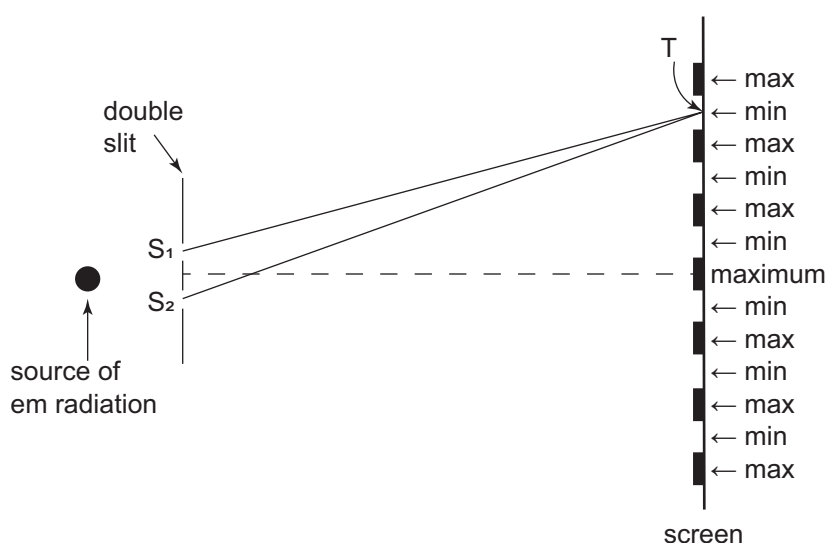


Fig. 7.1

- (a) The distance from the centre of one minimum to the centre of the maximum beside it is 1.2 cm.
- (i) Calculate the wavelength of the electromagnetic radiation.

$$\text{fringe spacing } y = 2 \times 1.2 \text{ cm} = 2.4 \text{ cm} = 0.024 \text{ m}$$

$$\lambda = ay / d \quad (a = 0.40 \text{ mm} = 0.40 \times 10^{-3} \text{ m}, d = 0.80 \text{ m})$$

$$\lambda = (0.40 \times 10^{-3} \times 0.024) / 0.80$$

$$\lambda = 1.2 \times 10^{-5} \text{ m}$$

$$\text{Wavelength} = 1.2 \times 10^{-5} \text{ m [4]}$$



- (ii) Calculate the path difference between S_1 T and S_2 T as shown in Fig. 7.1.

T is at a minimum, so path difference = $(n + \frac{1}{2})\lambda$

T is the third minimum: path difference = 2.5λ

$$= 2.5 \times 1.2 \times 10^{-5} = 3.0 \times 10^{-5} \text{ m}$$

$$\text{Path difference} = \underline{3.0 \times 10^{-5}} \text{ m [3]}$$

- (b) The double slit is replaced with a diffraction grating. The spacing between the lines of the diffraction grating is $5.18 \times 10^{-5} \text{ m}$.

- (i) How many lines per millimetre are on the diffraction grating?

$$\text{lines per metre} = 1 / 5.18 \times 10^{-5} = 1.93 \times 10^4 \text{ m}^{-1}$$

$$\text{lines per mm} = 1.93 \times 10^4 / 1000 = 19.3$$

$$\underline{19.3} \text{ lines mm}^{-1} \text{ [2]}$$

- (ii) Calculate the angle between central maximum and the third order maximum produced.

$$d \sin \theta = n\lambda$$

$$5.18 \times 10^{-5} \times \sin \theta = 3 \times 1.2 \times 10^{-5}$$

$$\sin \theta = 0.695$$

$$\theta = 44^\circ$$

$$\text{Angle} = \underline{44}^\circ \text{ [3]}$$

[Turn over]



- 8 **Fig. 8.1** represents a stationary wave on a stretched string at a frequency of 25 Hz. The diagram shows a time when each part of the string is at its **maximum displacement**.



Fig. 8.1

- (a) (i) On **Fig. 8.1**, draw an arrow at points A and B to indicate the direction in which they are about to move. [2]

- (ii) State the phase difference between points A and C. Give the unit of the phase difference.

Phase difference = 0

Unit = degrees (°) [2]



- (b) (i) The length of the stretched string is 0.66 m. Calculate the wavelength of the wave.

$$\text{string length} = 1.5 \lambda$$

$$0.66 = 1.5 \lambda$$

$$\lambda = 0.44 \text{ m}$$

$$\text{Wavelength} = \underline{0.44} \text{ m [2]}$$

- (ii) The frequency is increased. At what frequency will resonance next occur?

$$v = f\lambda = 25 \times 0.44 = 11 \text{ m s}^{-1}$$

$$\text{next resonance: 2 wavelengths on string, } \lambda = 0.66 / 2 = 0.33 \text{ m}$$

$$f = v / \lambda = 11 / 0.33 = 33.3 \text{ Hz}$$

$$\text{Frequency} = \underline{33.3} \text{ Hz [3]}$$

[Turn over]



- 9 An image intensifier is used in night vision goggles. Photons from very low intensity visible light are collected through a lens, and then strike a photocathode causing the photoelectric effect.

The electrons produced are accelerated by a potential difference of 23 kV to increase their energy and they then hit a fluorescent screen which produces an image.

A simplified diagram of an image intensifier is shown in **Fig. 9.1**.

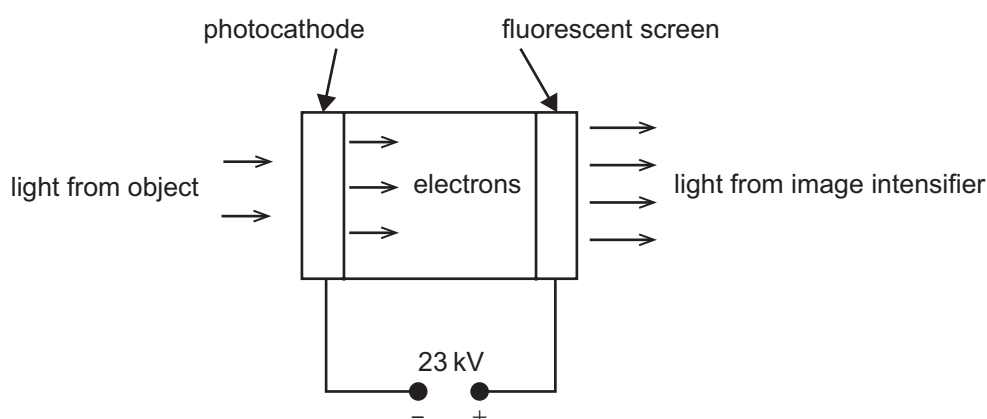


Fig. 9.1

- (a) What is meant by the photoelectric effect?

Electrons are released from a metal surface when electromagnetic radiation (photons) is incident on it, with photon energy greater than the work function.

[3]



- (b) (i) The work function of the photocathode is 2.30×10^{-19} J. Light of frequency 3.72×10^{14} Hz is incident on the photocathode.

Calculate the maximum velocity of the emitted electrons.

$$E = hf = 6.63 \times 10^{-34} \times 3.72 \times 10^{14} = 2.47 \times 10^{-19} \text{ J}$$

$$\frac{1}{2}mv_{\max}^2 = hf - \text{work function}$$

$$= 2.47 \times 10^{-19} - 2.30 \times 10^{-19} = 1.70 \times 10^{-20} \text{ J}$$

$$1.70 \times 10^{-20} = 0.5 \times 9.11 \times 10^{-31} \times v^2$$

$$v^2 = 3.73 \times 10^{10}$$

$$v = 1.93 \times 10^5 \text{ m s}^{-1}$$

Maximum velocity = 1.93×10^5 ms⁻¹ [6]

- (ii) Calculate the kinetic energy gained by an electron released from the photocathode by the time it reaches the fluorescent screen.

$$W = qV, \quad V = 23 \text{ kV} = 23\,000 \text{ V}$$

$$W = 1.60 \times 10^{-19} \times 23\,000$$

$$W = 3.68 \times 10^{-15} \text{ J}$$

Kinetic energy gained = 3.68×10^{-15} J [3]

[Turn over]



- 10 Fig. 10.1 shows two of the absorption lines in a spectrum of light from a distant galaxy and the same two lines from a light source on Earth.

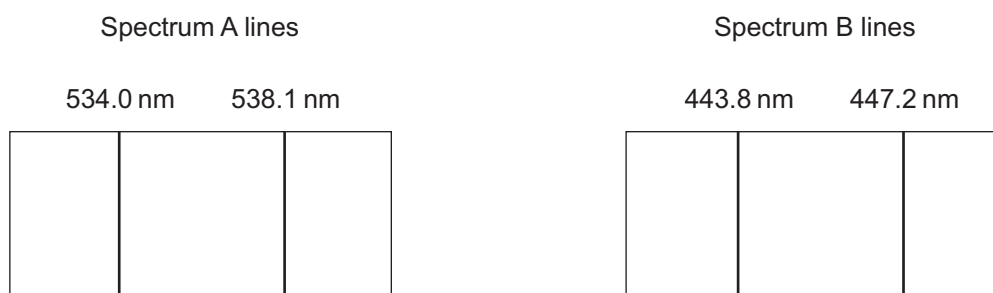


Fig. 10.1

- (a) Which spectrum, A or B, is of light from the distant galaxy?
Explain your answer.

Spectrum A. Its lines are at longer wavelengths than those of B, so the light is red shifted (the galaxy is moving away).

[2]

- (b) Use Fig. 10.1 to calculate a value for the velocity at which the galaxy is moving away from Earth.

$$\Delta\lambda = 534.0 - 443.8 = 90.2 \text{ nm}$$

$$z = \Delta\lambda / \lambda = 90.2 / 443.8 = 0.203$$

$$v = zc = 0.203 \times 3.00 \times 10^8$$

$$v = 6.1 \times 10^7 \text{ m s}^{-1}$$

Velocity = 6.1×10^7 ms⁻¹ [3]





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Question Number	Marks
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Examiner Number

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Rewarding Learning

ADVANCED SUBSIDIARY
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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

$$v = H_0 d$$

