



Rewarding Learning

ADVANCED SUBSIDIARY (AS)
General Certificate of Education
2018

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

FRIDAY 18 MAY, 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 nine** 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 student observes the spectrum emitted by a mercury vapour lamp and notices that each line has a different colour, as represented by **Fig. 1.1**.



Fig. 1.1

- (a) Explain the origin of the different colours observed.

Electrons can only exist in fixed (discrete) energy levels. A falling electron emits a photon of energy $\Delta E = hf$; each transition has a different ΔE , so a different frequency and colour.

[2]



(b) Fig. 1.2 shows some of the energy levels for a hydrogen atom.

Energy level	Energy/eV
F	0
E	-0.24
D	-0.82
C	-1.49
B	-3.38
A	-13.60

Fig. 1.2

- (i) State the magnitude of the energy level value of the ground state of the hydrogen atom shown in Fig. 1.2.

Energy level value = 13.6 eV [1]

[Turn over]



- (ii) Write down the expression for the wavelength λ of the radiation emitted during a transition between two energy levels. The two energy levels are separated by an energy difference ΔE . Identify any other symbols used.

$$\Delta E = hf \text{ and } c = f\lambda, \text{ so } \Delta E = hc/\lambda$$

$$\lambda = hc / \Delta E$$

where h = the Planck constant and

c = the speed of light in a vacuum

[3]

- (iii) Calculate the wavelength of the photons emitted when electrons fall from level **D** to **B** in **Fig. 1.2**.

$$\Delta E = -0.82 - (-3.38) = 2.56 \text{ eV}$$

$$\Delta E = 2.56 \times 1.60 \times 10^{-19} = 4.10 \times 10^{-19} \text{ J}$$

$$\lambda = hc / \Delta E = (6.63 \times 10^{-34} \times 3.00 \times 10^8) / 4.10 \times 10^{-19}$$

$$\lambda = 4.86 \times 10^{-7} \text{ m}$$

Wavelength = 4.86 × 10⁻⁷ m

[3]

- (iv) Are the photons emitted during the transition from energy level **D** to energy level **B** visible? Explain your answer.

Yes: $\lambda = 486 \text{ nm}$, which lies within the visible spectrum (400
to 700 nm).

[1]



- (c) Explain how a laser works. In your explanation, use and describe the terms **population inversion**, **metastable state** and **stimulated emission**.

Energy is supplied (pumping) to excite electrons to higher energy

levels. They drop into a metastable state, an excited level in which

electrons stay for a relatively long time.

This produces a population inversion: more electrons are in the excited

(metastable) state than in the lower (ground) state.

Stimulated emission: a photon with energy exactly equal to the energy

gap passes an excited electron and stimulates it to fall to the lower

level, emitting a second photon of the same energy (frequency), phase

and direction.

These photons stimulate further emissions, so the light is amplified;

mirrors at each end reflect the light back and forth and some leaves

through the partially silvered mirror.

[4]

[Turn over



- 2 (a) Explain the meaning of the term **diffraction**.

*The spreading out of waves as they pass through a gap (opening)
or around an obstacle.*

[1]

- (b) **Fig. 2.1** shows diagrams of wavefronts as they approach two different sized apertures. Carefully complete the diagrams to show how aperture size affects the diffraction pattern observed for water waves.

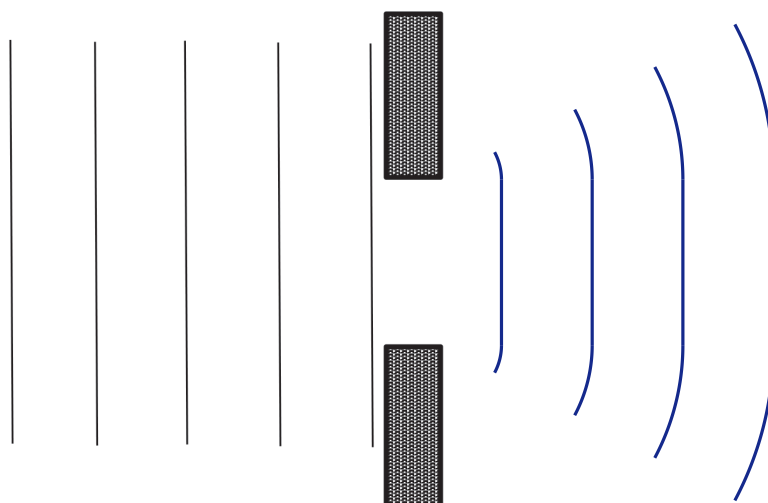


Fig. 2.1a

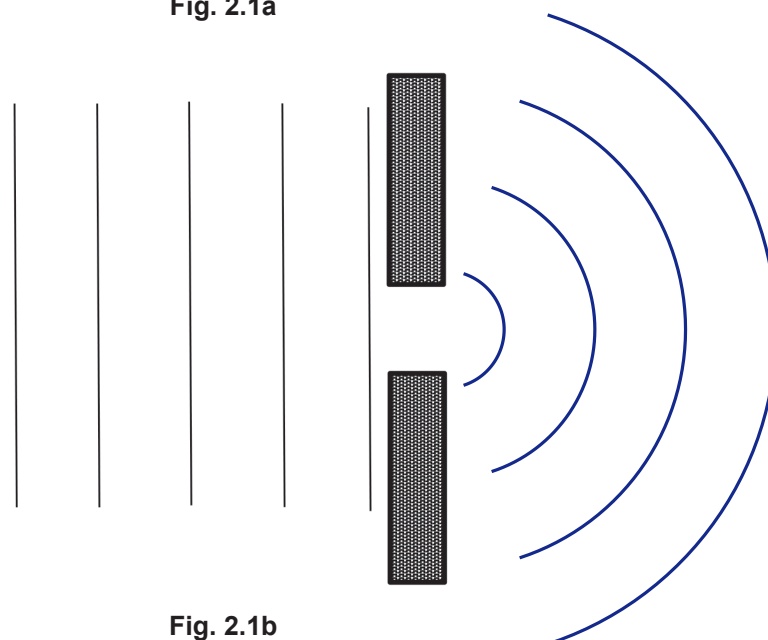


Fig. 2.1b

[3]





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[Turn over



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- (c) Light from a laser is incident normally on a diffraction grating with 200 lines per millimetre. **Fig. 2.2** shows a schematic diagram of the apparatus and the observed pattern on the screen. The distance along the screen between both third order maxima was measured to be 60.6 cm. The distance between the diffraction grating and the screen was 84.2 cm.

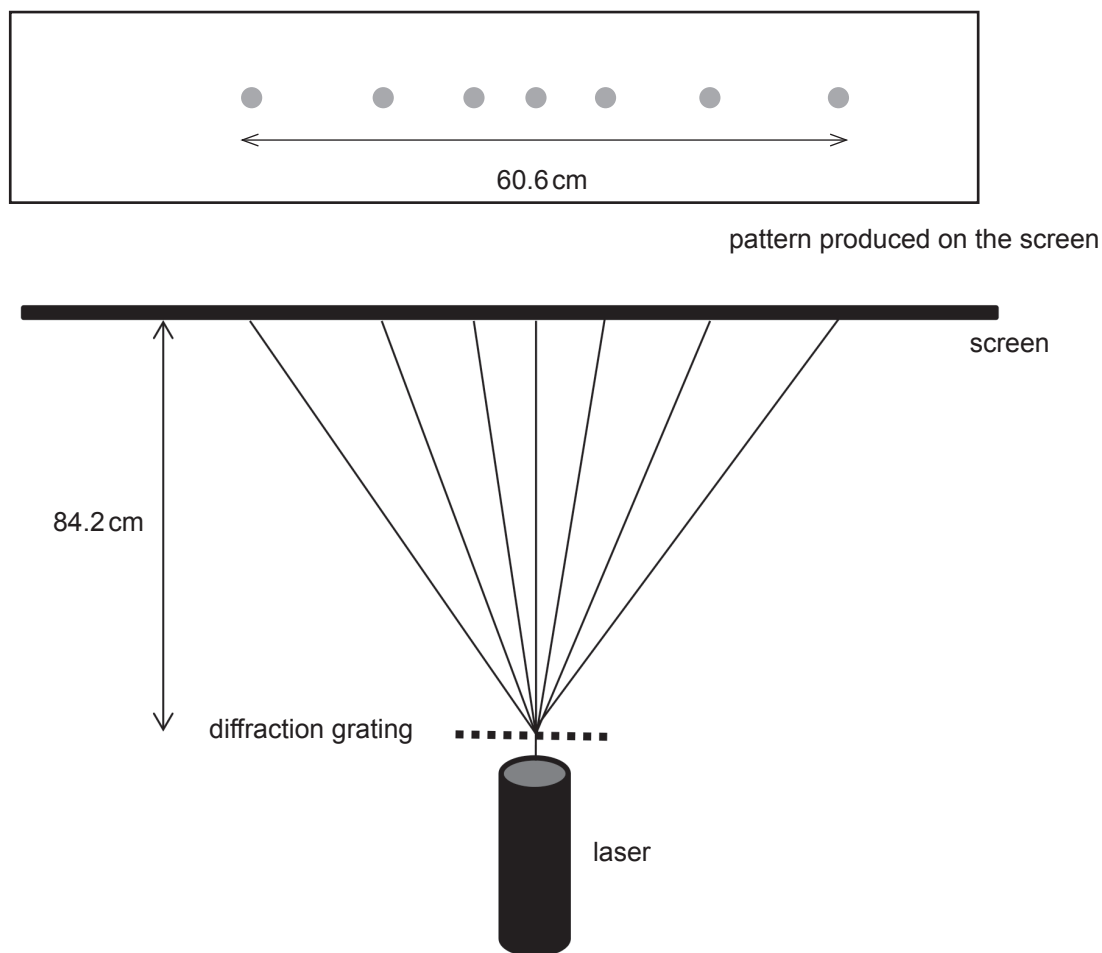


Fig. 2.2



- (i) Use this information to show that the angle of diffraction for the third order maximum was 20° .

$$\text{Distance from centre to 3rd order maximum} = 60.6 / 2 = 30.3 \text{ cm}$$

$$\tan \theta = 30.3 / 84.2 = 0.360$$

$$\theta = 19.8^\circ \approx 20^\circ$$

[2]

- (ii) Calculate the wavelength of the laser light used in this experiment, in nanometres.

$$d = 1 / (200 \times 10^3) = 5.0 \times 10^{-6} \text{ m}$$

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

$$3\lambda = 5.0 \times 10^{-6} \times \sin 19.8^\circ$$

$$\lambda = 5.65 \times 10^{-7} \text{ m}$$

$$\lambda = 565 \text{ nm}$$

Wavelength of light = 565 nm

[4]

[Turn over]



- 3 Electrons, of mass m and charge e are emitted at a hot cathode. They are accelerated to a speed v by applying a potential difference V between the hot cathode and anode. The arrangement is shown in Fig. 3.1.

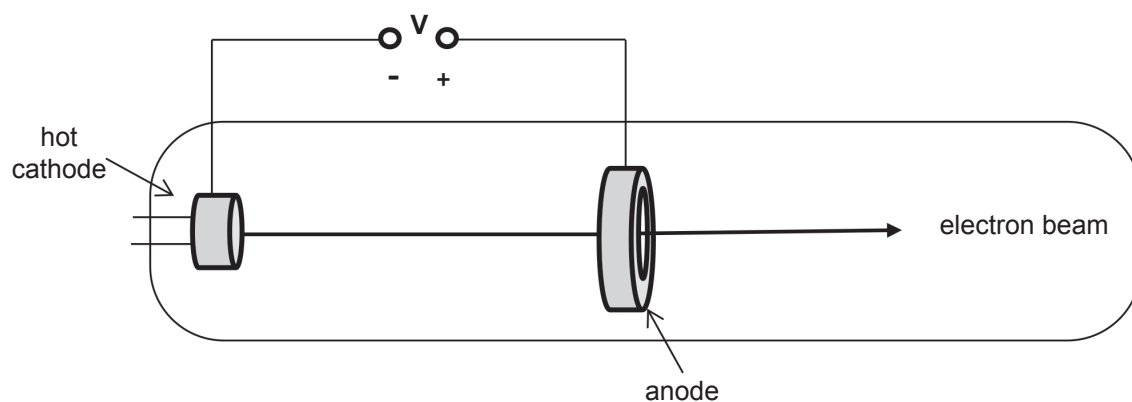


Fig. 3.1

- (a) The speed of the electrons can be given by the expression $v = K\sqrt{V}$ where K is a constant. Find an expression for K in terms of e and m .

$$eV = \frac{1}{2}mv^2$$

$$v^2 = 2eV / m$$

$$v = \sqrt{(2e/m)} \times \sqrt{V}$$

$$K = \underline{\sqrt{(2e/m)}}$$

[3]



(b) The moving electrons each have a kinetic energy of $1.55 \times 10^{-15} \text{ J}$.

(i) Calculate the momentum of these moving electrons.

$$E_k = \frac{1}{2}mv^2, \text{ so } 1.55 \times 10^{-15} = \frac{1}{2} \times 9.11 \times 10^{-31} \times v^2$$

$$v^2 = 3.40 \times 10^{15}, \quad v = 5.83 \times 10^7 \text{ m s}^{-1}$$

$$p = mv = 9.11 \times 10^{-31} \times 5.83 \times 10^7$$

$$p = 5.31 \times 10^{-23} \text{ kg m s}^{-1}$$

Momentum = 5.31×10^{-23} kg m s⁻¹ [3]

(ii) Calculate the de Broglie wavelength of these moving electrons.

$$\lambda = h / p = 6.63 \times 10^{-34} / 5.31 \times 10^{-23}$$

$$\lambda = 1.25 \times 10^{-11} \text{ m}$$

de Broglie wavelength = 1.25×10^{-11} m [2]

[Turn over]



- (c) In an electron diffraction tube, fast moving electrons pass through a very thin metal foil target before striking a fluorescent screen. The arrangement is shown in Fig. 3.2.

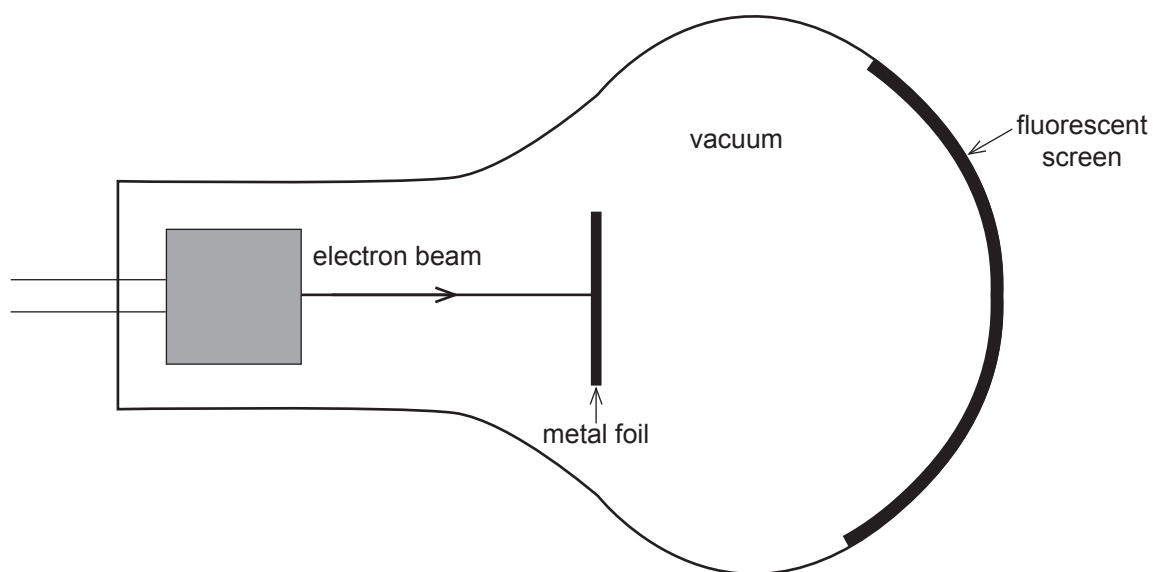
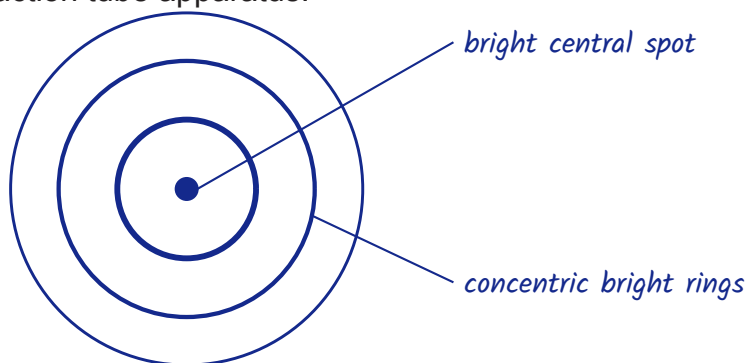


Fig. 3.2

- (i) Sketch, in the space below, the diffraction pattern obtained using the electron diffraction tube apparatus.



[1]

- (ii) State how the pattern changes when the accelerating voltage is increased.

The rings get smaller (diameter decreases) as the electrons' wavelength decreases.

[1]





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- 4 **Fig. 4.1** shows a loudspeaker placed over the open end of a cylinder of length 1.20 m. The loudspeaker is connected to a signal generator which can be used to vary the frequency.

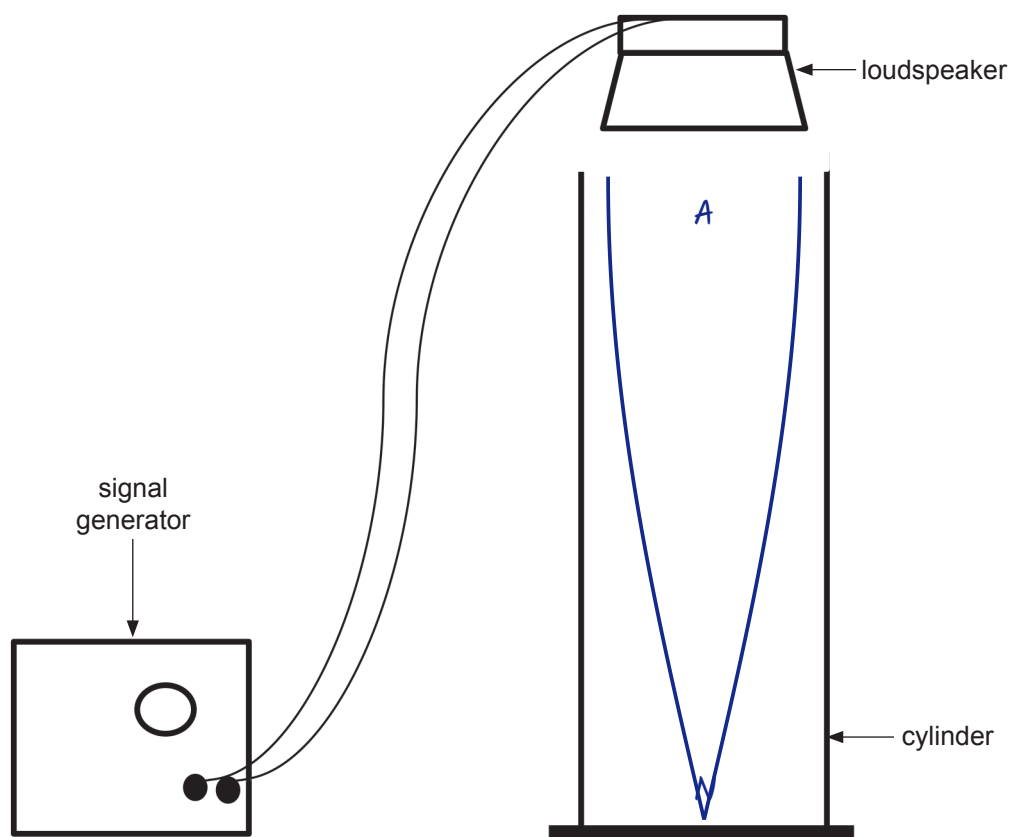


Fig. 4.1

- (a) (i) Describe how you would use this apparatus to obtain the **first** mode of vibration of a standing wave in the air column.

Start at a low frequency and slowly increase the frequency of the signal generator until the first (lowest frequency) loud sound, resonance, is heard.

[2]

- (ii) On **Fig. 4.1** sketch the standing wave pattern formed in the tube in this mode of vibration. Mark the positions of all nodes N and antinodes A. [2]



- (b) (i) At the first mode of vibration, the frequency reading on the signal generator was 70.0 Hz. What is the value of the speed of sound that can be obtained from this result?

$$\lambda/4 = 1.20 \text{ m, so } \lambda = 4 \times 1.20 = 4.80 \text{ m}$$

$$v = f\lambda = 70.0 \times 4.80$$

Speed of sound = 336 ms⁻¹ [2]

- (ii) Determine the values of frequency, f_1 and f_2 , at which the next two modes of vibration occur.

Closed tube: only odd harmonics, 3×70.0 and 5×70.0

$f_1 =$ 210 Hz $f_2 =$ 350 Hz [2]

- (c) Water is now added to the cylinder until it is one quarter full. The signal generator is switched on and it is noticed that the first mode of vibration is no longer at 70.0 Hz. Calculate by how much the reading on the signal generator must be changed to observe the first mode of vibration again.

$$\text{New air column length} = 1.20 - 0.30 = 0.90 \text{ m}$$

$$\text{New } \lambda = 4 \times 0.90 = 3.60 \text{ m}$$

$$f = v / \lambda = 336 / 3.60 = 93.3 \text{ Hz}$$

$$\text{Change} = 93.3 - 70.0 = 23 \text{ Hz (increase)}$$

Change in frequency = 23 (increase) Hz [4]

[Turn over]



5 An observer sitting on a platform at a train station listens to the sound produced by a train moving through the station at a constant speed.

(a) Discuss the changes in the observed sound. Include in your discussion:

- the frequency of the sound as the train moves towards, and away from, the observer;
- the Doppler equations to describe the frequency or wavelength of the sound as the train moves towards, and away from, the observer.

Include an explanation of any symbols used.

As the train approaches, the observed frequency is higher (higher pitch) than the frequency emitted; as it moves away, the observed frequency is lower than that emitted. It is highest when moving towards and lowest when moving away.

Moving towards the observer: $\lambda = (v_{\text{sound}} - v_{\text{train}}) / f$, so $f' = f$

$v_{\text{sound}} / (v_{\text{sound}} - v_{\text{train}})$.

Moving away from the observer: $\lambda = (v_{\text{sound}} + v_{\text{train}}) / f$, so $f' = f$

$v_{\text{sound}} / (v_{\text{sound}} + v_{\text{train}})$.

f = frequency emitted by the train, f' = observed frequency, λ = observed wavelength, v_{sound} = speed of sound, v_{train} = speed of the train.

[3]



- (b) (i) When astronomers observe distant galaxies, they notice the light is red shifted. What is red shift and how do astronomers explain the red shift observed in light from **distant** galaxies?

Red shift is an increase in the observed wavelength of light

(towards the red end). Galaxies are receding from us due to the

expansion of space (the universe).

[2]

- (ii) The shift in the wavelength of light from a distant galaxy is $2.2 \times 10^{-9} \text{ m}$. The wavelength of the light observed is $550 \times 10^{-9} \text{ m}$. Calculate the recession speed of this galaxy in kilometres per second.

$$z = \Delta\lambda / \lambda = 2.2 \times 10^{-9} / 550 \times 10^{-9} = 4.0 \times 10^{-3}$$

$$z = v / c, \text{ so } v = zc = 4.0 \times 10^{-3} \times 3.00 \times 10^8$$

$$v = 1.2 \times 10^6 \text{ m s}^{-1} = 1200 \text{ km s}^{-1}$$

Recession speed = 1200 km s⁻¹

[3]

- (c) Calculate a value for the estimated age of the universe in years.

$$\text{Age } T \approx 1 / H_0 = 1 / 2.4 \times 10^{-18}$$

$$T = 4.2 \times 10^{17} \text{ s}$$

$$T = 4.2 \times 10^{17} / (365 \times 24 \times 3600) = 1.3 \times 10^{10} \text{ years}$$

Estimated age of the universe = 1.3×10^{10} years

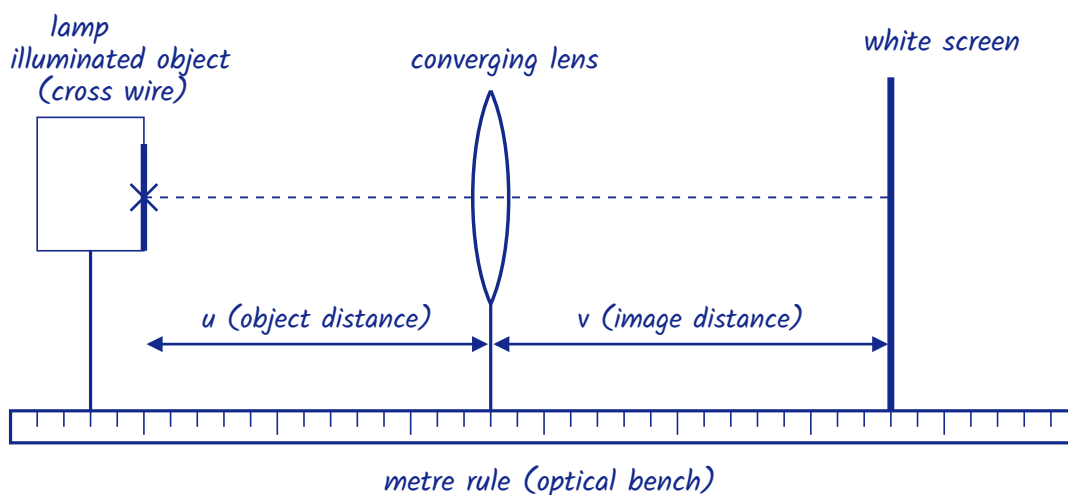
[3]

[Turn over]



- 6 Describe an experiment to obtain the results needed to draw a graph from which an accurate value for the focal length of a converging lens can be determined.

(a) In the space below, draw a labelled sketch of the apparatus you would use. Clearly identify on the diagram the measurements to be taken.



[3]

(b) Outline how you would use the equipment to collect data for this experiment.

Set the object at distance u , move the screen until a sharp

(focused) image forms and measure u and v with the metre rule.

Repeat for at least 6 different object distances ($u > f$).

[2]



- (c) On **Fig. 6.1**, label both axes and sketch a line graph which can be used to determine an accurate value for the focal length of the lens.

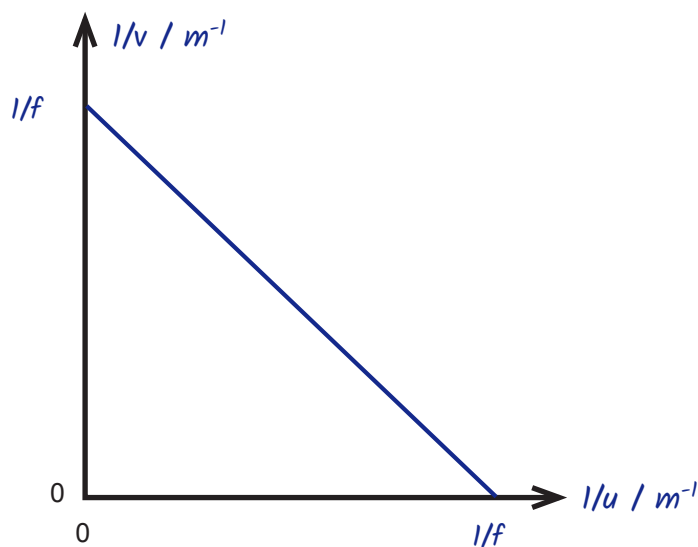


Fig. 6.1

[2]

- (d) Describe how an accurate value of the focal length of the lens can be determined from the graph you have sketched in **Fig. 6.1**.

Each intercept equals $1/f$: take the inverse of both intercepts and average them to give f .

[1]

[Turn over]



- 7 A diverging lens can be used to produce an image of a real object.

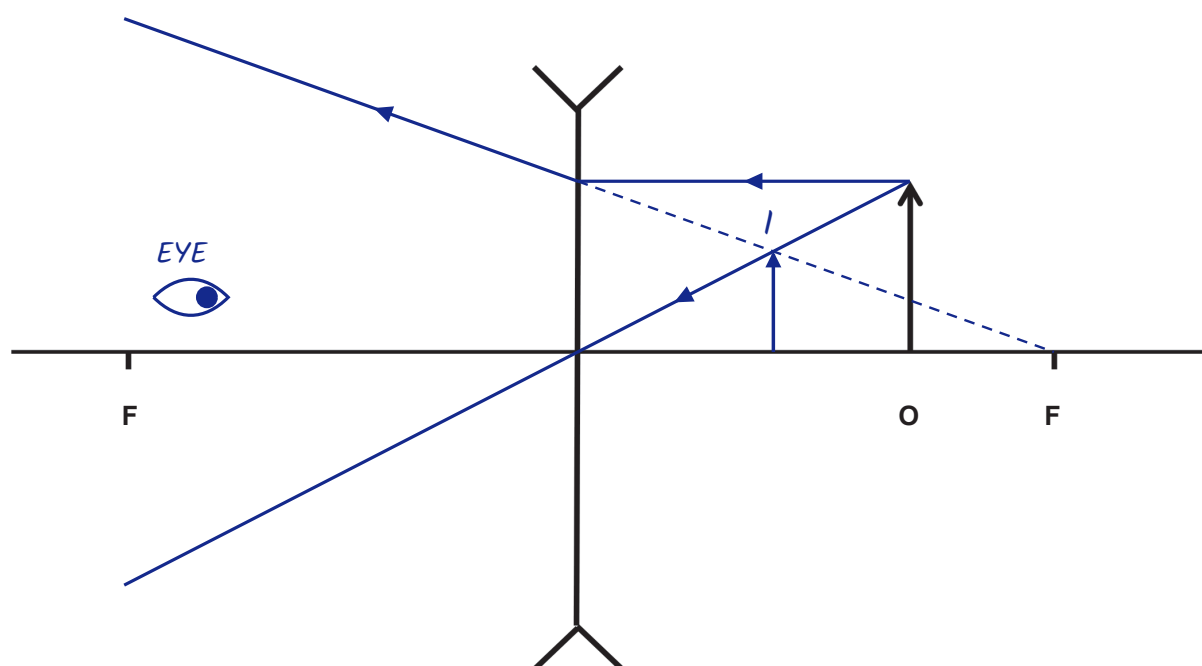


Fig. 7.1

- (a) (i) Draw the ray diagram for the diverging lens in **Fig. 7.1** to locate the image of object **O**. Label the image **I**. Show where the eye should be positioned to view the image. [4]
- (ii) Describe the image by placing ticks in the appropriate boxes in **Table 7.1**.

Table 7.1

Real		Virtual	✓
Magnified		Diminished	✓
Inverted		Upright	✓

[1]



- (b) (i) An object is placed in front of a diverging lens of focal length 15.0 cm. The height of the object is 14.0 cm and the linear magnification of the image is 0.42. Calculate the distance of the object from the lens and the height of the image formed.

Diverging lens, so $f = -15.0$ cm; image virtual, so $v = -0.42u$

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

$$-1/15.0 = 1/u - 1/(0.42u)$$

$$-1/15.0 = (0.42 - 1) / 0.42u = -0.58 / 0.42u$$

$$0.42u = 0.58 \times 15.0 = 8.7, \text{ so } u = 20.7 \text{ cm}$$

$$m = i / o, \text{ so } i = 0.42 \times 14.0 = 5.9 \text{ cm}$$

Object distance from the lens = 20.7 cm

Image height = 5.9 cm [6]

- (ii) How far is the image from the object?

$$v = 0.42 \times 20.7 = 8.7 \text{ cm, on the same side of the lens as the object}$$

$$\text{Distance} = u - v = 20.7 - 8.7 = 12.0 \text{ cm}$$

Distance from image to object = 12.0 cm [2]

[Turn over]



- 8 (a) (i) Waves may be categorised as either transverse or longitudinal. Describe, in terms of particle movement, how to distinguish between these two categories.

Longitudinal: particles vibrate parallel to the direction of travel of the wave (energy transfer).

Transverse: particles vibrate perpendicular to it.

[2]

- (ii) Explain what is meant by polarisation. State which category of waves can be polarised.

Polarisation: the vibrations are confined to only one plane

(containing the direction of travel). Only transverse waves can be polarised.

[2]

- (b) A student writes the equation for the period T of a wave as shown in **Equation 8.1**.

$$T = \frac{\lambda}{v} \quad \text{Equation 8.1}$$

where λ is the wavelength and v is the wave speed. Show that **Equation 8.1** is valid.

$$v = f\lambda \quad \text{and} \quad f = 1/T$$

$$\text{so } \lambda / v = \lambda / (f\lambda) = 1/f$$

$$\text{and } 1/f = T, \text{ so } T = \lambda / v \quad (\text{equivalent to } v = f\lambda)$$

[2]



(c) Fig. 8.1 shows a graph of displacement against time for a wave.

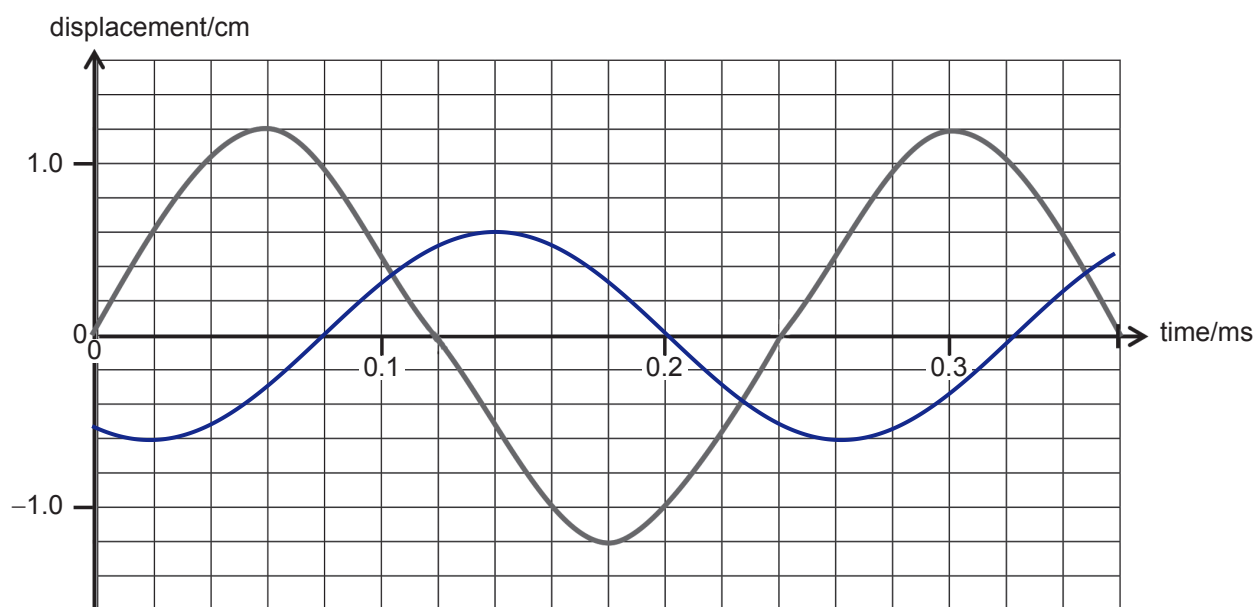


Fig. 8.1

(i) Calculate the frequency of the wave shown in Fig. 8.1.

$$T = 0.24 \text{ ms} = 0.24 \times 10^{-3} \text{ s}$$

$$f = 1/T = 1 / 0.24 \times 10^{-3}$$

Frequency = 4167 Hz [2]

(ii) On Fig. 8.1, sketch a wave which has half the amplitude and a phase difference of 120° from the original wave. [3]

[Turn over]



- 9 **Fig. 9.1** shows a section through part of a typical optical fibre. The core is a glass fibre that allows light to travel through. The cladding is also made from a transparent material. In practical uses, the fibres themselves are as thin as a human hair, and many of them are bundled together to make a fibre optic cable.

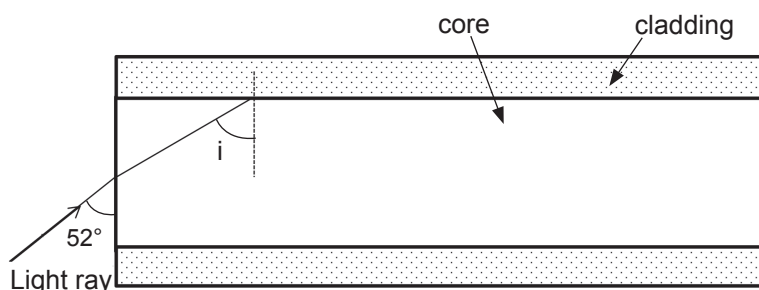


Fig. 9.1

- (a) (i) Tick a box in **Table 9.1** to show which of the following statements describes the relationship between the refractive index of the cladding and the refractive index of the core.

Table 9.1

The refractive index of the cladding is larger than the refractive index of the core	
The refractive index of the cladding is the same as the refractive index of the core	
The refractive index of the cladding is smaller than the refractive index of the core	✓

[1]

- (ii) The angle between the end of the glass fibre and the incident ray is 52° as shown in **Fig. 9.1**. The refractive index of the core is 1.52. Use these values to calculate the angle of incidence i at the boundary between the core and cladding.

$$\text{Angle of incidence at end face} = 90 - 52 = 38^\circ$$

$$n = \sin i / \sin r: 1.52 = \sin 38^\circ / \sin r, r = 23.9^\circ$$

$$i = 90 - 23.9 = 66.1^\circ$$

$$\text{Angle of incidence} = \underline{66.1}^\circ$$

[3]



- (b) (i) The shortest time for a ray of light to travel through an optical fibre is when there is axial transmission. This is when the ray of light enters the optical fibre along the normal.
Calculate the shortest time taken for a ray of light to travel through 3 km of this optical fibre.

$$n = c_1 / c_2, \text{ so } v = 3.00 \times 10^8 / 1.52 = 1.97 \times 10^8 \text{ m s}^{-1}$$

$$t = \text{distance} / \text{speed} = 3000 / 1.97 \times 10^8$$

$$t = 1.52 \times 10^{-5} \text{ s}$$

Shortest time = 1.52 × 10⁻⁵ s [4]

- (ii) Calculate the percentage increase in time for a ray travelling through the optical fibre at an angle of incidence at the core/cladding boundary of 70° compared to the shortest time for the light to travel through the optical fibre.

$$\sin 70^\circ = \text{axial path} / \text{actual path}$$

$$\text{actual path} = \text{axial path} / \sin 70^\circ = 1.064 \times \text{axial path}$$

$$\text{extra distance} = 0.064 \times \text{axial path}$$

$$\text{time} \propto \text{distance (same speed)}, \text{ so time is 6.4\% longer}$$

Percentage increase in time = 6.4 % [3]



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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

for use from 2017 onwards

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
------------------------	--

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

$$v = H_0 d$$

