



Oxford Cambridge and RSA

Monday 6 June 2022 – Morning

AS Level Physics B (Advancing Physics)

H157/02 Physics in depth

Time allowed: 1 hour 30 minutes



You must have:

- the Data, Formulae and Relationships Booklet

You can use:

- a scientific or graphical calculator
- a ruler (cm/mm)



Please write clearly in black ink. **Do not write in the barcodes.**

Centre number

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Candidate number

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First name(s)

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Last name

StemUp Model Solution

INSTRUCTIONS

- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answer should be supported with working. Marks might be given for a correct method, even if your answer is wrong.

INFORMATION

- The total mark for this paper is **70**.
- The marks for each question are shown in brackets [].
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **20** pages.

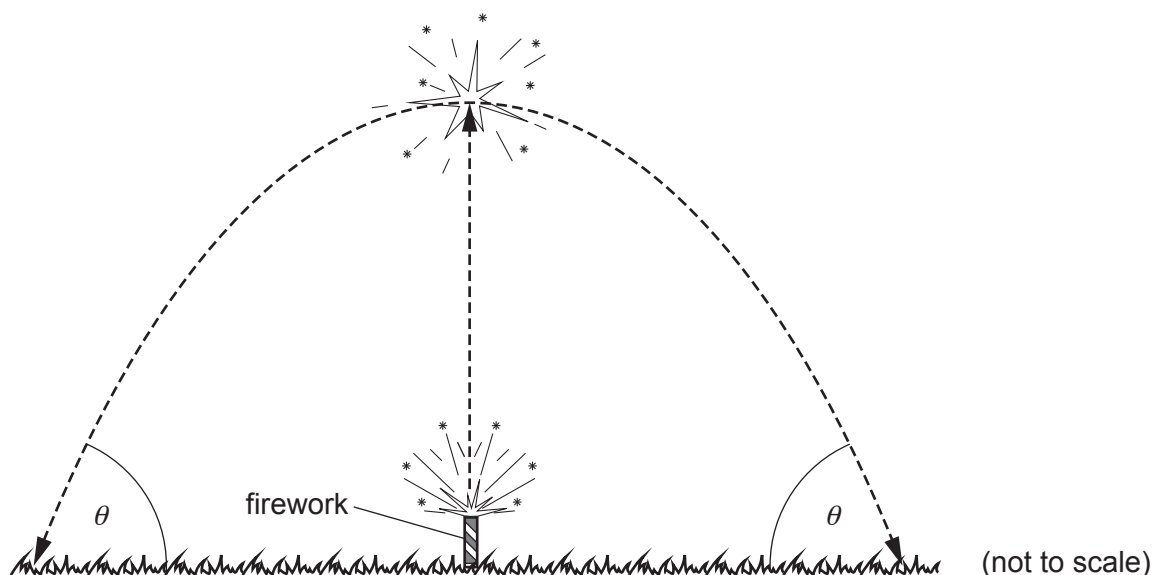
ADVICE

- Read each question carefully before you start your answer.

SECTION A

Answer **all** the questions.

- 1 A firework, mounted on the ground, ejects a packet vertically at an initial speed of 35 m s^{-1} . The packet explodes into many glowing fragments when it reaches its highest point.



- (a) Show that the height reached by the packet is approximately 60 m, assuming that air resistance is negligible and that the packet was fired from ground level.

$$v^2 = u^2 + 2as, \text{ with } v = 0 \text{ at the highest point and } a = -9.81 \text{ m s}^{-2}$$

$$0 = 35^2 + 2 \times (-9.81) \times h$$

$$h = 1225 / 19.62 = 62.4 \text{ m, which is approximately 60 m}$$

[2]

- (b) The glowing fragments travel initially horizontally at a speed of 15 m s^{-1} . Calculate the distance of one fragment from its launch site when it reaches the ground, assuming no air resistance.

$$\text{time to fall } 62.4 \text{ m from rest (no initial vertical velocity): } s = \frac{1}{2}gt^2$$

$$t = \sqrt{(2s / g)} = \sqrt{(2 \times 62.4 / 9.81)} = 3.57 \text{ s}$$

$$\text{horizontal velocity is constant, so distance} = u_h t = 15 \times 3.57$$

$$\text{distance} = 53.6 \text{ m}$$

distance = ..53.6..... m [2]

- (c) Calculate the angle θ with the horizontal at which the fragment hits the ground.

vertical velocity at the ground: $v_v = gt = 9.81 \times 3.57 = 35.0 \text{ m s}^{-1}$

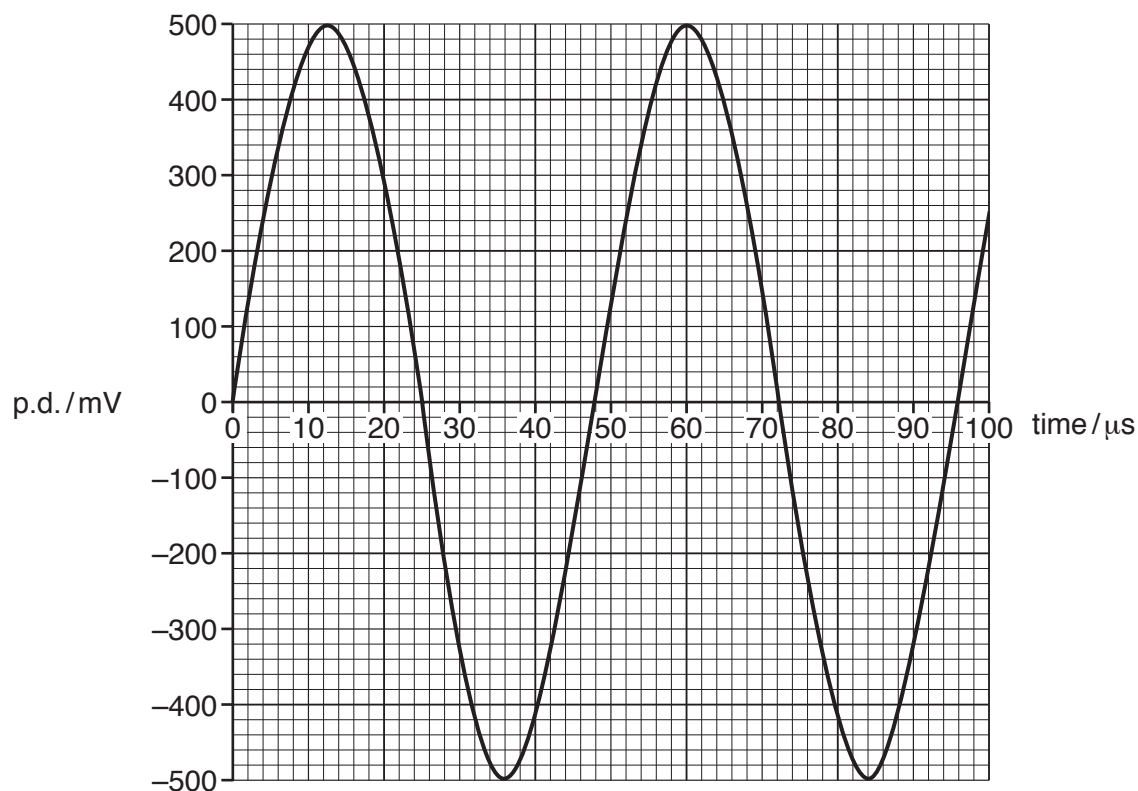
horizontal velocity is still 15 m s^{-1}

$\tan \theta = v_v / v_h = 35.0 / 15 = 2.33$

$\theta = \tan^{-1}(2.33) = 66.8^\circ$

angle = ..66.8.....° [2]

- 2 The signal below is a microphone recording of a pure sound wave of frequency f_{sound} .



The signal is to be transmitted by radio at a frequency $f_{\text{radio}} = 91.5 \text{ MHz}$.

- (a) Calculate the ratio $\frac{f_{\text{radio}}}{f_{\text{sound}}}$.

$$\text{two cycles take } 96 \text{ } \mu\text{s}, \text{ so } T = 48 \text{ } \mu\text{s}; f_{\text{sound}} = 1/T = 1/(48 \times 10^{-6}) = 20\,800 \text{ Hz}$$

$$f_{\text{radio}} / f_{\text{sound}} = 91.5 \times 10^6 / 20\,800 = 4390$$

$$\frac{f_{\text{radio}}}{f_{\text{sound}}} = 4.39 \times 10^3 \dots\dots\dots [2]$$

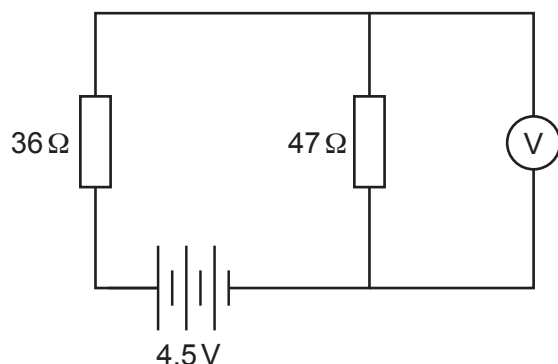
- (b) A more complex sound signal is a sum of musical notes with a frequency range 18 Hz to 24 kHz. It is to be encoded as a digital signal before transmission.

Calculate the lowest rate at which the sound signal should be sampled to avoid distortion.

$$\text{sampling rate} \geq 2 \times \text{highest frequency} = 2 \times 24 \text{ kHz}$$

$$\text{lowest sampling rate} = 4.8 \times 10^4 \dots\dots\dots \text{ samples s}^{-1} [1]$$

- 3 The voltmeter in the circuit below has a very high resistance.



- (a) Calculate the p.d. recorded by the voltmeter.

Assume that the internal resistance of the battery is negligible.

$$\text{potential divider: } V = 4.5 \times 47 / (36 + 47)$$

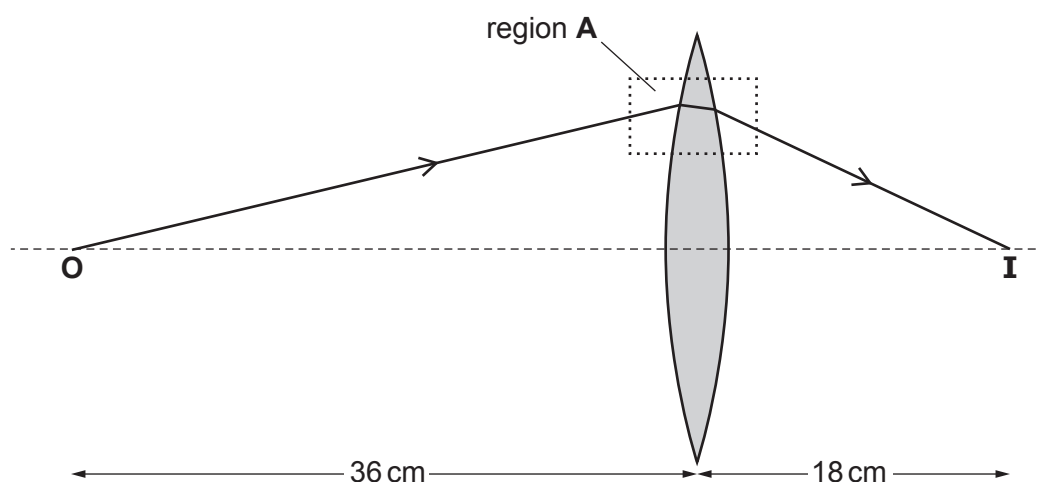
$$V = 4.5 \times 47 / 83 = 2.55 \text{ V}$$

p.d. = 2.55..... V [2]

- (b) Without calculation, state and explain how the voltmeter reading would differ from the answer to (a) if the battery internal resistance were not negligible.

The reading would be lower. The internal resistance is an extra resistance in series, so the total resistance is larger and the current I is smaller (there are lost volts across the internal resistance, $V = E - Ir$).
So $V = IR$ across the 47 Ω is smaller; the e.m.f. is shared between more resistances, so the 47 Ω takes a smaller fraction. [2]

- 4 A converging lens forms a real image **I** of a point object **O** as shown in the ray diagram. This ray is refracted in the region marked **A**.



- (a) Calculate the power P of the lens.

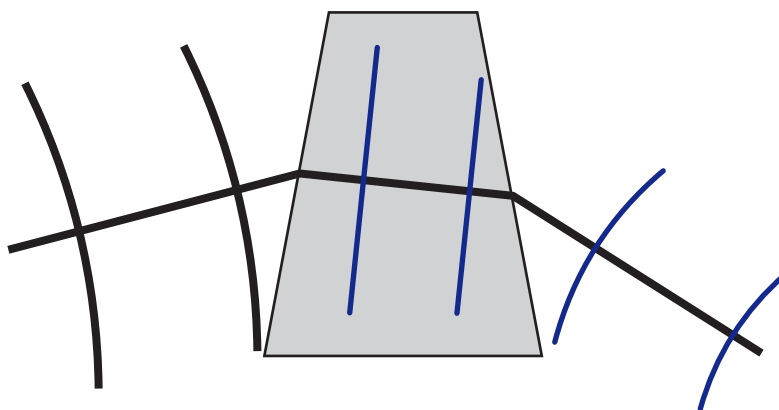
$$1/v = 1/u + 1/f \text{ and } P = 1/f, \text{ with } u = -0.36 \text{ m and } v = +0.18 \text{ m}$$

$$P = 1/v - 1/u = 1/0.18 - 1/(-0.36) = 5.56 + 2.78$$

$$P = 8.3 \text{ D}$$

$$P = \underline{8.3} \dots \dots \dots \text{ D [2]}$$

- (b) The diagram below shows the light ray in region **A**. Two wavefronts to the left of the lens are shown.



Draw wavefronts on this diagram to show how the shape and spacing of the wavefronts change as the light passes into the lens and back out on the right.

[3]

- 5 A cylindrical steel wire of diameter 1.2 mm and length 3.5 m hangs from a high ceiling.

(a) Calculate the stress in the wire if a load of mass 25 kg is attached to the bottom of the wire.

$$A = \pi r^2 = \pi \times (0.60 \times 10^{-3})^2 = 1.13 \times 10^{-6} \text{ m}^2$$

$$F = mg = 25 \times 9.81 = 245 \text{ N}$$

$$\sigma = F / A = 245 / 1.13 \times 10^{-6} = 2.17 \times 10^8 \text{ Pa}$$

$$\text{stress} = \underline{2.2 \times 10^8} \dots \text{Pa [2]}$$

(b) Calculate the elastic strain energy stored in the wire by the 25 kg load.
The Young modulus of elasticity of steel is $2.1 \times 10^{11} \text{ Pa}$.

$$\text{strain } \epsilon = \sigma / E = 2.2 \times 10^8 / 2.1 \times 10^{11} = 1.05 \times 10^{-3}$$

$$\text{extension } x = \epsilon L = 1.05 \times 10^{-3} \times 3.5 = 3.7 \times 10^{-3} \text{ m}$$

$$\text{energy stored} = \frac{1}{2}Fx = 0.5 \times 245 \times 3.7 \times 10^{-3}$$

$$\text{energy stored} = 0.45 \text{ J}$$

$$\text{energy stored} = \underline{0.45} \dots \text{J [2]}$$

(c) The yield stress of this steel is about 15% higher than the value calculated in (a). Explain why the 25 kg load, once attached to the end of the wire, should be lowered gently into its final position rather than allowing it to drop into place.

If dropped, the load accelerates and gains kinetic energy (and momentum) as it falls. The wire must decelerate it to rest, so this kinetic energy must also be transferred to elastic strain energy in the wire. The tension = weight + the force to decelerate the load, so the total stress exceeds that in (a) and could exceed the yield stress. [3]

SECTION B

Answer **all** the questions.

6 This question is about using remote sensors to make measurements on the planet Mars.

- (a) In February 2021, the rover *Perseverance* landed on the planet Mars. **Fig. 6.1** shows a simplified diagram of the last stage of this landing, using a 'sky crane.'

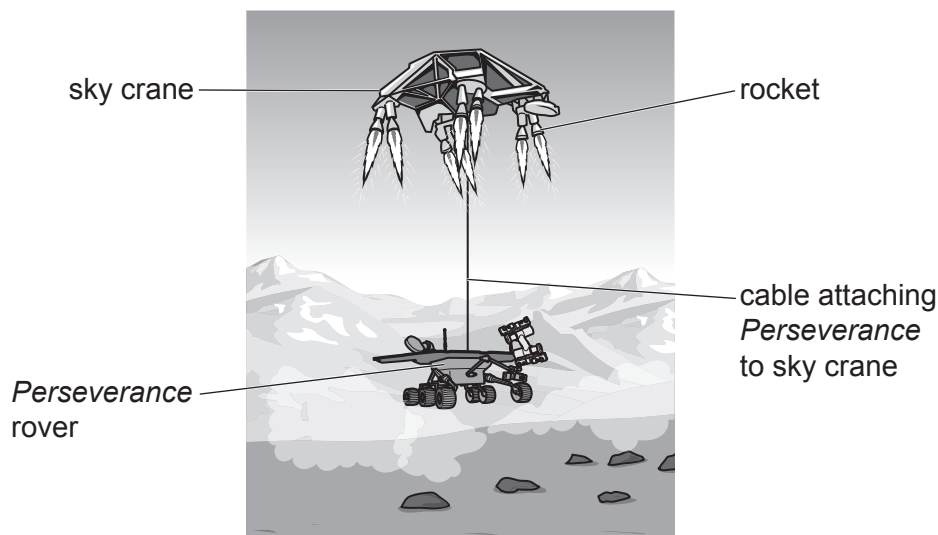


Fig. 6.1

The sky crane used its rockets to hover a fixed distance above the ground. It lowered the rover slowly at a steady speed until the rover reached the ground. Once the rover was securely on the ground, the supporting cable was cut and the sky crane flew off to crash some distance away.

The graph in **Fig. 6.2** shows how the upward force F produced by the rockets on the sky crane varied during the time it was hovering at a fixed height.

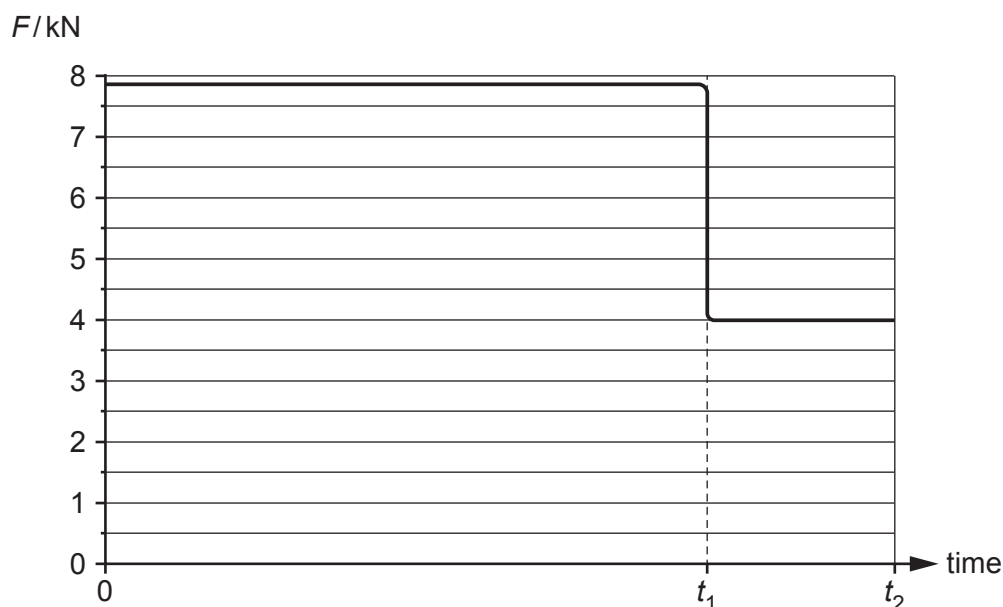


Fig. 6.2

- (i) Describe and explain the shape of the graph in **Fig. 6.2**.

The force is constant at about 7.8 kN from 0 to t_1 , then drops suddenly at t_1 to a lower constant value of 4.0 kN until t_2 .
 Hovering, the upward force balances the weight supported: the higher value is the weight of the sky crane + the weight of the rover (lowered at a steady speed).
 At t_1 the rover reaches the ground, so the lower value is the weight of the sky crane alone. [3]

- (ii) Use **Fig. 6.2** to calculate g , the acceleration due to gravity on the surface of Mars.

Mass of *Perseverance* rover = 1030 kg

$$\text{weight of rover } W = 7.8 \text{ kN} - 4.0 \text{ kN} = 3.8 \text{ kN}$$

$$g = W / m = 3800 / 1030$$

$$g = 3.7 \text{ N kg}^{-1}$$

$$g = 3.7 \text{ N kg}^{-1} \text{ [2]}$$

- (b) *Perseverance* has a pair of high-resolution cameras to aid navigation and to investigate the surroundings.

- (i) The CCD sensor in each camera consists of an array of square pixels. There are 1600×1200 square pixels in an area of $1.05 \times 10^{-4} \text{ m}^2$. Show that the length of an edge of one pixel is about $7 \mu\text{m}$.

$$\begin{aligned} \text{area of one pixel} &= 1.05 \times 10^{-4} / (1600 \times 1200) = 1.05 \times 10^{-4} / 1.92 \times 10^6 \\ &= 5.47 \times 10^{-11} \text{ m}^2 \end{aligned}$$

$$\text{edge length} = \sqrt{5.47 \times 10^{-11}} = 7.40 \times 10^{-6} \text{ m, about } 7 \mu\text{m}$$

[2]

- (ii) When the camera records an image of a distant object, the image distance v from the lens to the CCD sensor is 19.5 mm. Show that the camera can resolve two points less than 5 cm apart on an object 100 m from the camera.

$$\text{magnification } m = v / u = 19.5 \times 10^{-3} / 100 = 1.95 \times 10^{-4}$$

$$\text{smallest resolvable separation on the sensor} = \text{one pixel} = 7.40 \times 10^{-6} \text{ m}$$

$$\text{separation on object} = 7.40 \times 10^{-6} / 1.95 \times 10^{-4} = 0.038 \text{ m} = 3.8 \text{ cm}$$

$$3.8 \text{ cm} < 5 \text{ cm, so the camera can resolve points less than 5 cm apart}$$

[2]

- (iii) The full-colour images recorded by each camera are encoded at 11 bits pixel⁻¹. Suggest why more than 8 bits pixel⁻¹ are needed and calculate the number of images that can be stored in an 8 Gb (8×10^9 bit) memory unit.

Suggestion: Each pixel must encode its colour (red, green and blue intensities); 8 bits gives only $2^8 = 256$ levels, too few colours/shades.
 bits per image = $1600 \times 1200 \times 11 = 2.11 \times 10^7$ bits
 number = $8 \times 10^9 / 2.11 \times 10^7 = 378.8$, so 378 whole images

number of images = 378 [2]

- (iv)* As much of the data recorded by *Perseverance* on its 8 Gb memory unit as possible must be sent to Earth. Artificial Intelligence programs on the rover can check each image to select those which seem most useful.

Method A. *Perseverance* can transmit directly to Earth. This can be done for about 6 hours each Martian day, when Earth is 'visible' to the rover. Data can be sent in this way at a rate which varies between 500 bits per second and 3200 bits per second depending on the atmospheric conditions on Mars and how high Earth is above the Martian horizon.

Method B. There is a series of satellites in orbit around Mars. *Perseverance* can transmit to one of these satellites at a rate of 256 000 bits s⁻¹, and the satellite then transmits directly to Earth at a rate of 2 Mbit s⁻¹. This method of transferring data can be done for about 8 minutes each Martian day. 1 Martian day is about the same length as an Earth day.

Use the information above to decide whether method **A** or method **B**, or a combination of the two, should be used to transfer *Perseverance*'s data to Earth. Use calculations to justify your answer.

Method A: 6 h = 21 600 s per day. Worst case 500 × 21 600 = 1.1 × 10⁷ bits per day, so 8×10^9 bits takes $8 \times 10^9 / 1.08 \times 10^7 = 740$ days. Best case 3200 × 21 600 = 6.9 × 10⁷ bits per day, which takes 116 days. The rate varies, so plan for the worst case.
 Method B: the slow link is rover to satellite at 256 000 bit s⁻¹ (the 2 Mbit s⁻¹ satellite to Earth link is faster). 8 min = 480 s, so 256 000 × 480 = 1.23 × 10⁸ bits per day, and 8×10^9 bits takes 65 days.
 B sends more per day than even the best case of A, so B should be the main method, with A used for the hours when no satellite is in view: together $1.23 \times 10^8 + 1.1 \times 10^7 = 1.34 \times 10^8$ bits per day (worst case), so 60 days, faster than either alone. A should pick the best images to send first; key data can be sent twice in case of loss. [6]

7 This question is about refraction of light.

- (a) **Fig. 7.1(a)** shows plane wavefronts of monochromatic light travelling in a vacuum approaching a glass block and **Fig. 7.1(b)** shows the situation at a time $4T$ later, where T is the period of the wave.

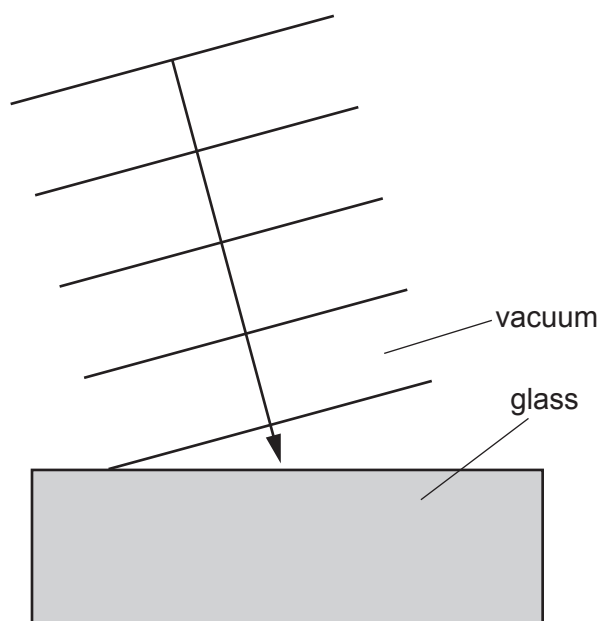


Fig. 7.1(a)

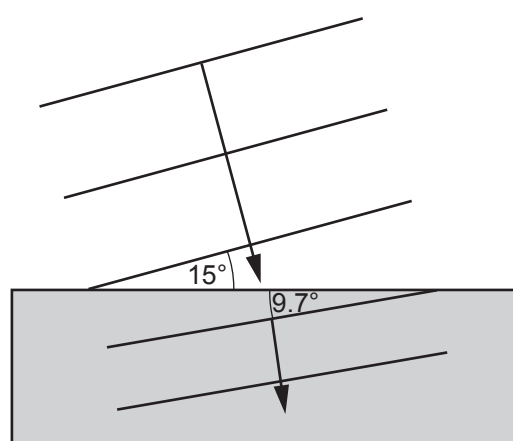


Fig. 7.1(b)

- (i) Calculate the wavelength λ in vacuum, given that the period $T = 1.53 \times 10^{-15} \text{ s}$.

$$f = 1/T = 1 / 1.53 \times 10^{-15} = 6.54 \times 10^{14} \text{ Hz}$$

$$\lambda = c / f = 3.00 \times 10^8 / 6.54 \times 10^{14} = 4.59 \times 10^{-7} \text{ m}$$

$$\lambda = \underline{4.59 \times 10^{-7}} \text{ m [2]}$$

- (ii) Show that the speed v of the light in glass is about $2 \times 10^8 \text{ m s}^{-1}$.

$$n = \sin i / \sin r = \sin 15^\circ / \sin 9.7^\circ = 0.259 / 0.168 = 1.536$$

$$n = c / v, \text{ so } v = c / n = 3.00 \times 10^8 / 1.536$$

$$v = 1.95 \times 10^8 \text{ m s}^{-1}, \text{ which is about } 2 \times 10^8 \text{ m s}^{-1}$$

[2]

- (iii) The refractive index n of glass is related to the wavelength λ of the light by the equation

$$n = A + \frac{B}{\lambda^2}$$

where A and B are constants for the glass used.

Without calculation, use this relationship to describe how longer-wavelength light will refract differently from **Fig. 7.1(b)**.

For longer wavelength λ , λ^2 is larger so B/λ^2 is smaller, so $n = A + B/\lambda^2$ is smaller.
 $n = \sin i / \sin r$ with the same i , so $\sin r$ is larger and the angle of refraction r is larger: longer-wavelength light is refracted (bent towards the normal) less than in Fig. 7.1(b).

[2]

- (b) A different model of light is that light consists not of waves but of particles, which Newton called 'corpuscles'.

Fig. 7.2 shows a corpuscle of light, travelling in a vacuum at a speed $3 \times 10^8 \text{ m s}^{-1}$, moving at an angle of 15° towards a glass block.

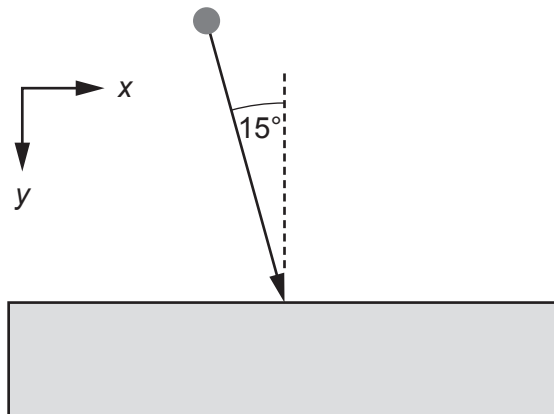


Fig. 7.2

- (i) Calculate the values of the velocity components of the corpuscle in the x- and y-directions just before it enters the glass block.

$$c_x = 3 \times 10^8 \times \sin 15^\circ, \quad c_y = 3 \times 10^8 \times \cos 15^\circ$$

component parallel to the vacuum-glass boundary, $c_x = 7.76 \times 10^7 \text{ m s}^{-1}$

component perpendicular to the vacuum-glass boundary, $c_y = 2.90 \times 10^8 \text{ m s}^{-1}$

[1]

- (ii) As the corpuscle enters the glass, due to an interaction with the vacuum-glass boundary it experiences a force into the glass perpendicular to the boundary, as shown in Fig. 7.3.

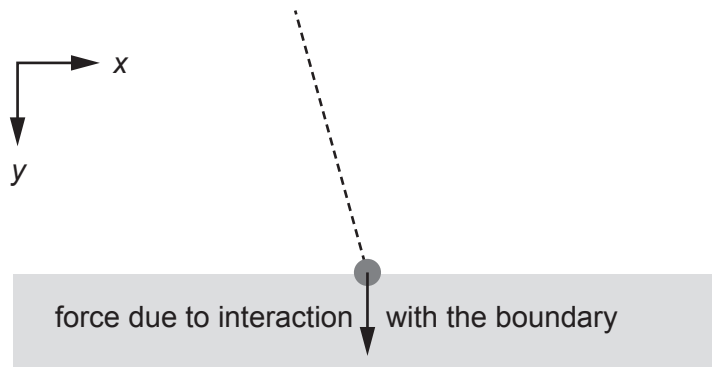


Fig. 7.3

Describe and explain the effect of this force has on the components c_x and c_y and of the magnitude and direction of the velocity of the corpuscle once it has passed the boundary. You should assume, as Newton did, that the corpuscle is not massless, and that it experiences zero force inside the glass.

c_x is unchanged, because the force is perpendicular to the boundary, so there is no component of force (no acceleration) in the x-direction.
 c_y increases, because the force acts in the +y direction (into the glass), so the corpuscle accelerates in the y-direction.
 The speed $c = \sqrt{c_x^2 + c_y^2}$ increases, as c_x is the same and c_y is larger, so it travels faster in glass. The velocity is closer to the y-direction: $r = \tan^{-1}(c_x/c_y)$ is smaller than 15° , so it bends towards the normal. [4]

- (c) Both the wave model and the corpuscle model can explain Snell's Law $n = \frac{\sin i}{\sin r}$ equally well, but other predictions of the two models disagree.

The French physicists Fizeau and Foucault compared the speed of light in air with the speed of light in water and found that light travels slower through water than through air. It was later shown that light travels slightly faster through vacuum than through air.

Explain what these experiments showed about the nature of light.

The wave model predicts that light travels slower in glass/water than in vacuum, but the corpuscle model predicts that it travels faster.
 Light was found to be slower in water, so the corpuscle theory is wrong; light behaves as a wave. [2]

SECTION C

- 8 Two students are doing experiments to measure the wavelength of microwaves.

Beth uses three sheets of aluminium to construct the double-slit arrangement shown in **Fig. 8.1** where $d = 8.0\text{ cm}$. She knows that the wavelength λ of the microwaves is in the range $1 - 5\text{ cm}$.

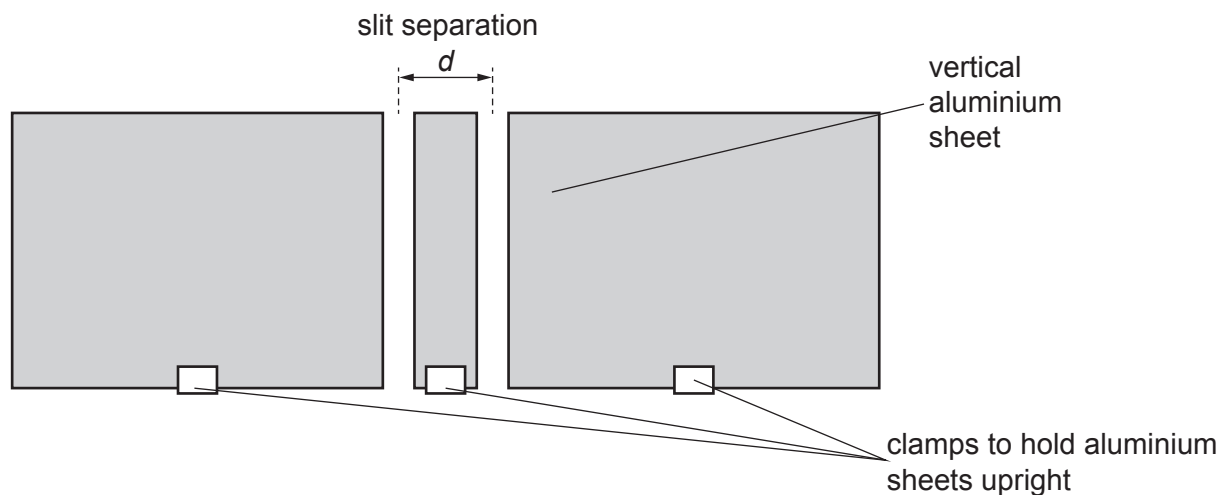


Fig. 8.1

A microwave emitter is placed facing the double-slit and a sensitive microwave sensor placed a distance L from the slits on the other side, as shown in **Fig. 8.2**. The microwave sensor is connected directly to a sensitive ammeter reading $0 - 100\text{ }\mu\text{A}$.

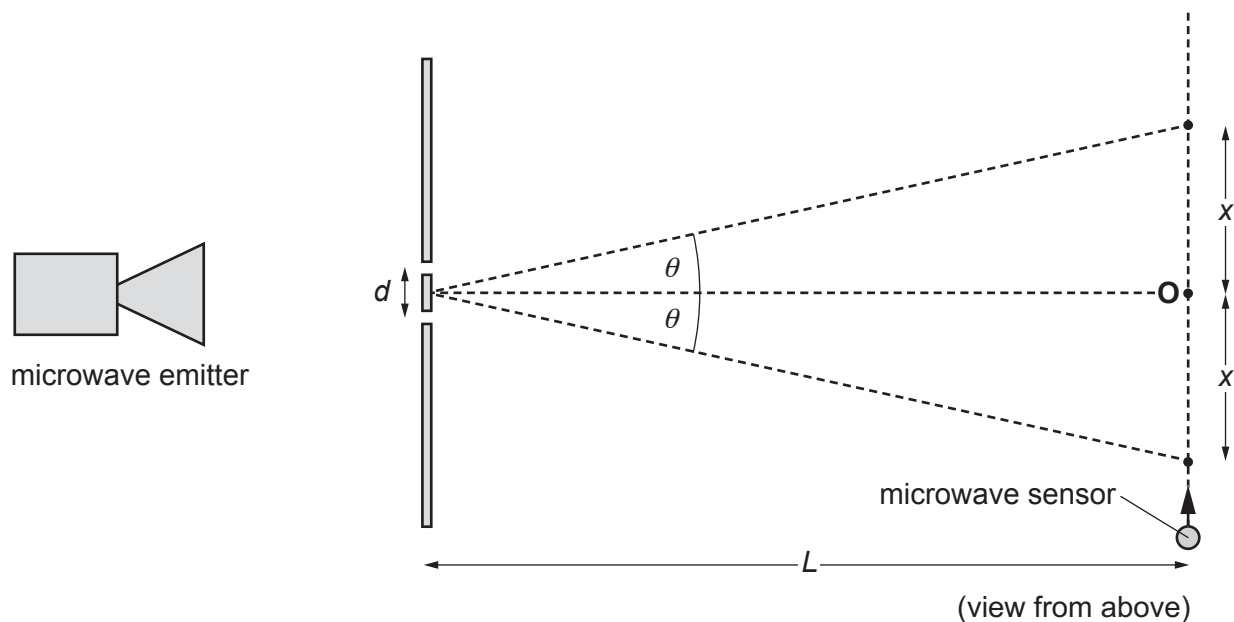


Fig. 8.2

The point O is directly opposite the centre of the double slits. The two points a distance x from O , and at an angle θ from the centre line, are the first-order intensity maxima of the double slit pattern.

- (a) Beth knows that, for small enough values of θ , the grating equation $\lambda = d \sin \theta$ can be written $\lambda = \frac{xd}{L}$ which can be rearranged to $x = \left(\frac{\lambda}{d}\right) L$.

She measured the distance $2x$ between the two first-order maxima for a range of values of L and estimated the uncertainty Δx by observing the range of values of $2x$ over which the ammeter reading seemed to stay at a maximum and then halving that value.

Fig. 8.3 shows the data from the experiment.

Complete the graph with suitable straight lines and use them to obtain the gradient $\frac{\lambda}{d}$ and its uncertainty. Use these values to calculate the wavelength of the microwaves and its uncertainty, given that $d = 8.0$ cm.

Express your answers to an appropriate number of significant figures.

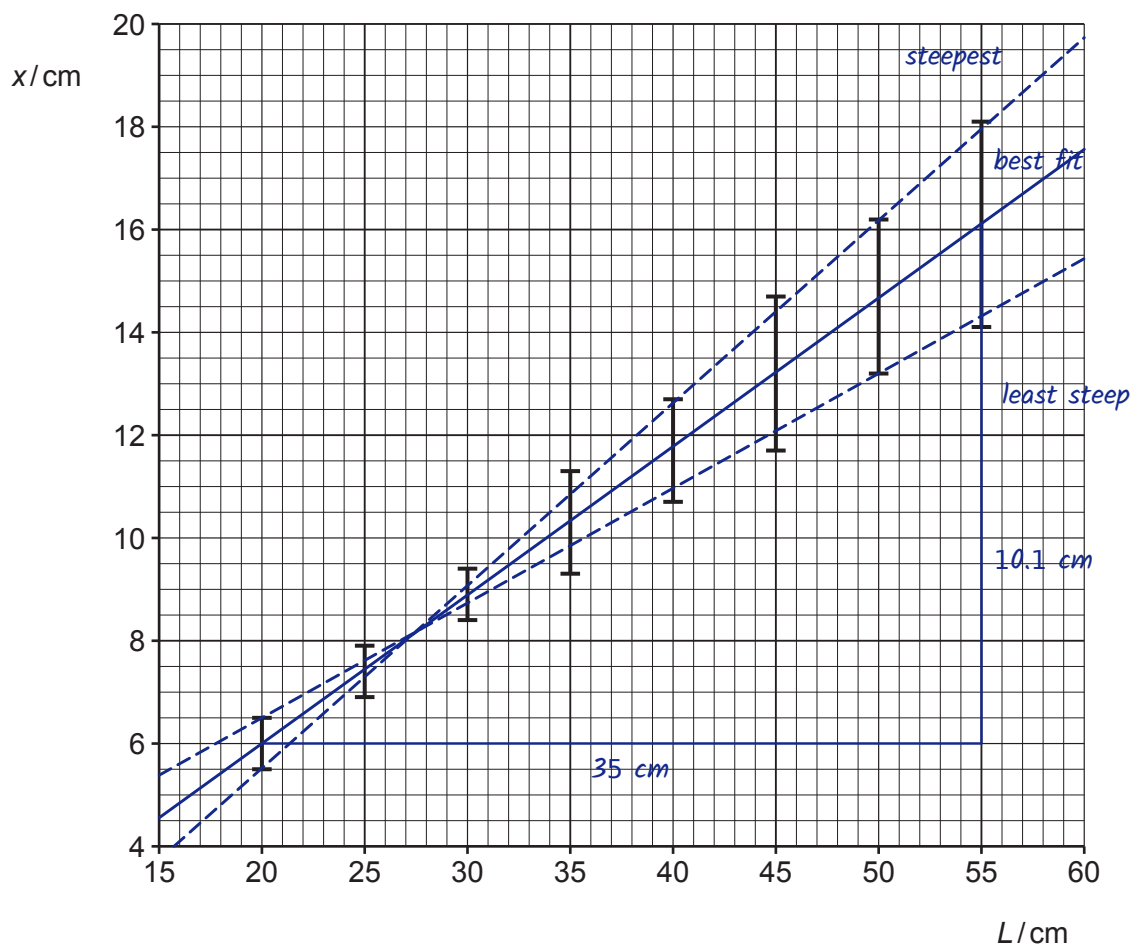


Fig. 8.3

$$\text{best fit gradient} = (16.1 - 6.0) / (55 - 20) = 10.1 / 35 = 0.29$$

$$\text{steepest} = (16.2 - 5.5) / 30 = 0.36, \text{ least steep} = (13.2 - 6.5) / 30 = 0.22$$

$$\text{uncertainty in gradient} = (0.36 - 0.22) / 2 = 0.07$$

$$\lambda = 0.29 \times 8.0 = 2.3 \text{ cm}$$

$$\text{gradient, } \frac{\lambda}{d} = \dots\dots\dots 0.29 \dots\dots\dots \pm \dots\dots\dots 0.07 \dots\dots\dots$$

$$\Delta \lambda = 0.07 \times 8.0 = 0.5 \text{ cm}$$

$$\lambda = \dots\dots\dots 2.3 \dots\dots\dots \pm \dots\dots\dots 0.5 \dots\dots\dots \text{ cm}$$

[5]

Turn over

- (b) Jack chooses a different method based on single-slit diffraction. He has read that the diffraction pattern produced by waves of wavelength λ passing through a slit of width b has its first subsidiary minimum at an angle θ from the straight-on direction, where $b \sin \theta = \lambda$.

Using the same microwave emitter and sensor, he sets up his experiment as in **Fig. 8.4**, where the slit width $b = 7.5 \text{ cm}$.

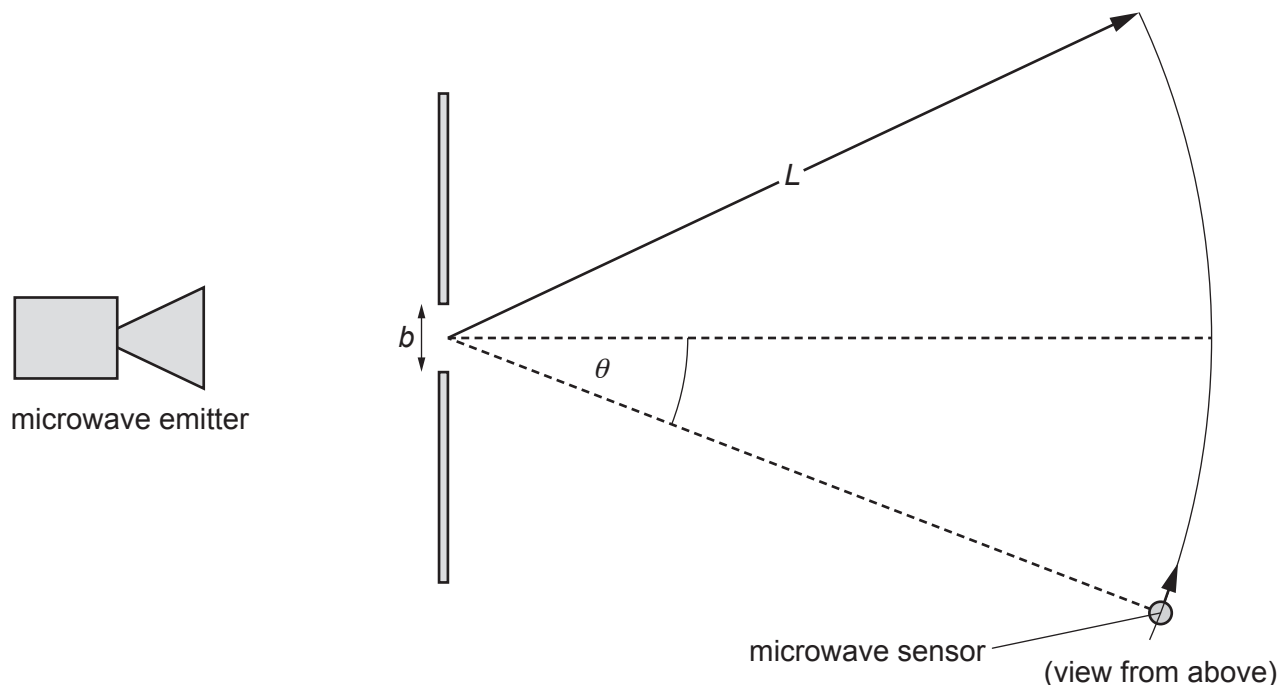


Fig. 8.4

He moves the microwave sensor gradually along the circular arc of radius L shown in **Fig. 8.4**, recording the ammeter reading at different values of angle θ , measured with a protractor of resolution $\pm 1^\circ$. The graph of **Fig. 8.5** shows his ammeter readings as a function of angle.

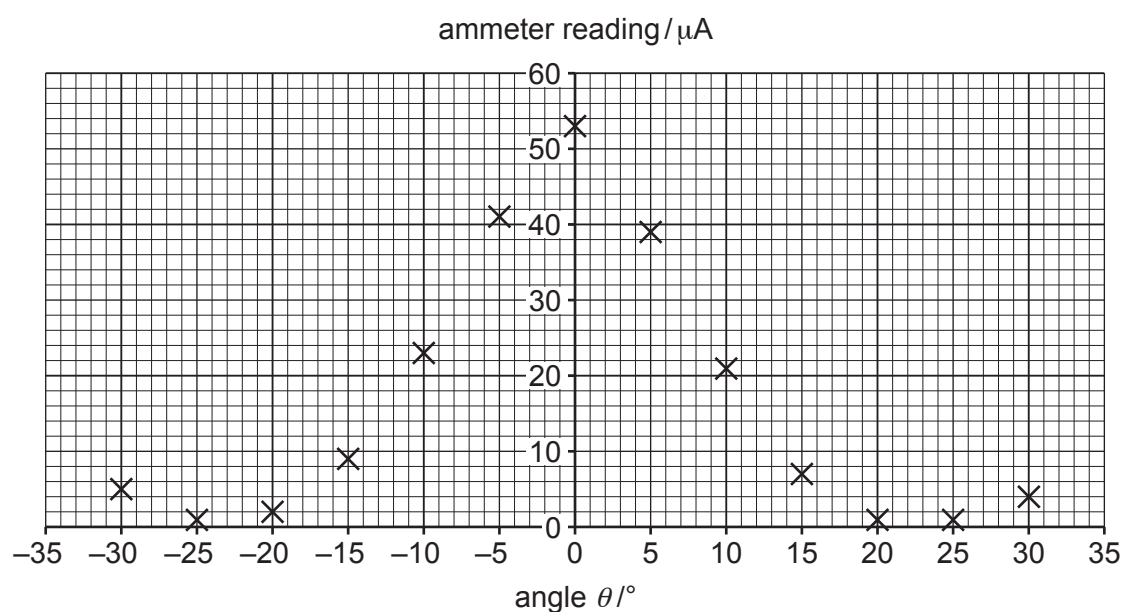


Fig. 8.5

Use **Fig. 8.5** to determine the wavelength λ of the microwaves, together with an estimate of the uncertainty. Show your working and express your answers to an appropriate number of significant figures.

The minima (first subsidiary minima) are where the reading is near zero:

at about -24° and $+22^\circ$ (-25° , $+20^\circ$ and $+25^\circ$ all read only about $1 \mu\text{A}$),

so $\theta = 23^\circ \pm 2^\circ$ (readings only every 5° , protractor $\pm 1^\circ$)

$$\lambda = b \sin \theta = 7.5 \times \sin 23^\circ = 2.93 \text{ cm}$$

$$\theta = 21^\circ: \lambda = 7.5 \sin 21^\circ = 2.69 \text{ cm}; \quad \theta = 25^\circ: \lambda = 7.5 \sin 25^\circ = 3.17 \text{ cm}$$

$$\text{so } \Delta\lambda \approx (3.17 - 2.69) / 2 = 0.2 \text{ cm}$$

$$\lambda = \dots\dots\dots 2.9 \dots\dots\dots \pm \dots\dots\dots 0.2 \dots\dots\dots \text{ cm [4]}$$

(c)* Evaluate the two experiments of parts (a) and (b).

Experiment (a) uses a graph of 8 points with uncertainty bars; the steepest and least steep lines give a sound estimate of the uncertainty, $\lambda = 2.3 \pm 0.5 \text{ cm}$, but this is large (about 20%). The small-angle approximation does not really apply: $\lambda/d \approx 0.3$, so $\theta \approx 17^\circ$ and $x/L = \tan \theta$ is not equal to $\sin \theta$. The range of L chosen (20 to 55 cm) is small and the uncertainty bars grow with L . Improve by using a wider range and larger L , or measuring θ directly and using $\lambda = d \sin \theta$.

Experiment (b) relies on measurements made for only one position, the angle of the minimum on each side, and readings were taken evenly every 5° , so the minimum is located only to a few degrees: $\lambda = 2.9 \pm 0.2 \text{ cm}$. He should concentrate readings near the minima (e.g. every 1° from 15° to 30° on both sides) rather than evenly spaced over the whole range, and average the two sides.

Comparison: the straight-line analysis in (a) uses many data points against just two measurements in (b), but (b) gives the smaller uncertainty. The results, $2.3 \pm 0.5 \text{ cm}$ and $2.9 \pm 0.2 \text{ cm}$, only just overlap (2.7 to 2.8 cm), so they do not agree well within their uncertainties, suggesting a systematic error such as the small-angle approximation in (a). Both lie in the expected 1 to 5 cm range. [6]

END OF QUESTION PAPER

[illegible]

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