Section A

Answer **all** the questions.

1 A diffraction grating has 300 lines per mm.

(a) Calculate the separation between adjacent slits in the grating.

$$\frac{1\times10^{-3}}{300} =$$

separation = 3.3×10^{-6} m **[1]**

(b) Light from a helium-neon laser is incident at right angles to the grating. The wavelength of the light is 633 nm. Calculate the angle of the first-order maximum for this light.

$n\lambda = d\sin\theta \qquad n=1$

$\theta = \sin^{-1}(\lambda/d) = \sin^{-1}\left(\frac{633\times10^{-9}}{3.33\times10^{-6}}\right) =$

angle = 11 ° **[2]**

(c) Explain how many orders of maxima can be obtained from this grating with this light source.

Max value of $\theta = 90°$

and $\sin 90° = 1$

$\therefore\ n = d/\lambda = \frac{3.33\times10^{-6}}{633\times10^{-9}} = 5.3$

[2]

$\therefore$ max value of $n = 5$

2 A teacher sets up a demonstration represented in Fig.2. A ball-bearing is released from rest at the top of the curved track. After leaving the track it accelerates under gravity until striking the ground at horizontal distance *s* from the end of the track.

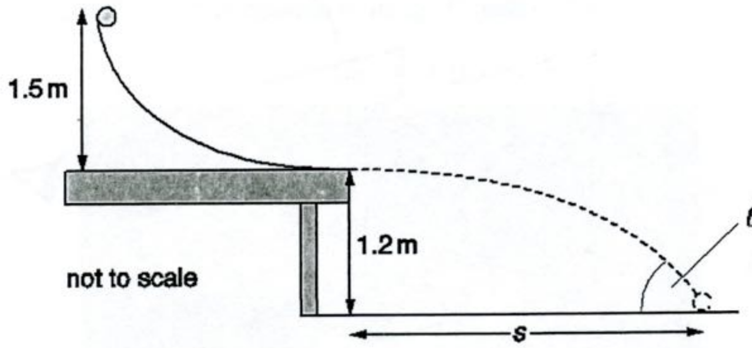


Fig. 2

(a) Show that the horizontal velocity of the ball-bearing as it leaves the track is about 5 m s^{-1}.
Assume that all the gravitational potential energy at the top of the track is transferred to translational kinetic energy at the bottom of the track.

$mgh = \frac{mv^2}{2} \quad \therefore \quad v = \sqrt{2gh} = \sqrt{2 \times 9.81 \times 1.5}$

$= 5.4 ms^{-1}$

[2]

(b) **(i)** Calculate the time the ball is in the air.

$u = 0 \quad \therefore \quad s = \frac{1}{2}at^2$

$\therefore \quad t = \sqrt{2s/a} = \sqrt{\frac{2 \times 1.2}{9.81}} =$

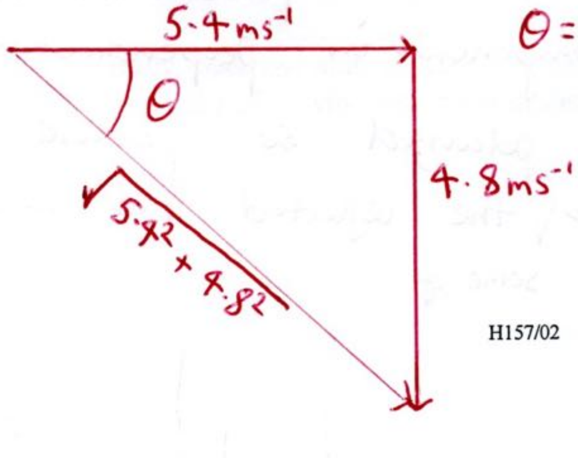
time = ...0.49.... s **[2]**

(ii) Use your answer to **(i)** to calculate the horizontal distance, *s*, the ball travels before hitting the ground.

$s = vt = 5.4 \times 0.49 =$

distance = ...2.6.... m **[1]**
(or 2.7)

(c) The vertical velocity of the ball when it strikes the ground is 4.8 m s^{-1}. By considering the horizontal and vertical components, calculate the velocity at which the ball strikes the ground.



$\theta = \tan^{-1}(4.8/5.4) = 41.6°$

magnitude of velocity = ...7.2.... m s^{-1}

angle to horizontal θ = ...42°.... °

[3]

3* Unpolarised light passes through two polarising filters as shown in Fig. 3.

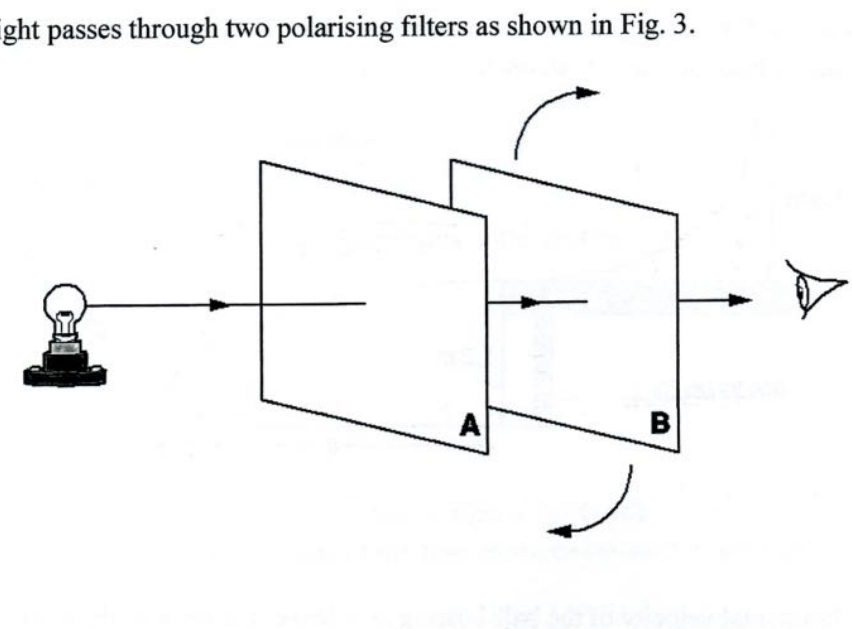


Fig. 3

The filters are initially oriented in the same direction, allowing light of maximum intensity to pass through to the observer.

Describe and explain how the intensity of light reaching the observer varies as filter **B** is rotated clockwise through 180° as indicated in the diagram. Use your reasoning to explain why skiers use polarising filters to cut down glare from sunlight reflected off snowy ground. You may include diagrams in your answer.

In unpolarized light electric field oscillates in random directions etc.

Polaroid only lets through components of the E-field in one plane through.

At 90° one polaroid absorbs all components in one plane and other absorbs all components in perpendicular plane. Reflected light is partially polarised so polaroid filters set at 90° will absorb some of the reflected light and cut down glare.

[6]

Section B

Answer **all** the questions

4 This question is about the Rosetta mission to image Comet 67P in 2014.

Fig. 4 shows an image of the comet at a distance of 285 km from the Rosetta spacecraft.

Fig. 4

Here are some data about the camera that captured the image:

Number of pixels on square light sensitive surface 2048 x 2048

Pixel size 13.5 μm x 13.5 μm

Focal length of lens system 0.717 m

Angular field of view 2.20°

Angular resolution 18.6 μrad per pixel

(a) (i) Each pixel is coded with 6 bits. Calculate the amount of data in an image.

$2048^2 \times 6 =$

number bits in an image = 2.5×10^7 **[1]**

(ii) Calculate the number of shades of grey available for each pixel in the image.

$2^6 =$

number of shades = 64 **[1]**

(iii) Typically, black and white imaging systems use 256 shades of grey for each pixel. Suggest and explain why using fewer shades of grey may be an advantage.

With fewer bits per pixel there is less data to transmit / store

[2]

(b) The camera captures an image that is 2.20° wide across 2048 pixels. Is the angular resolution given in the data accurate? Explain your reasoning.

1 μrad = 5.73 x 10^{-5} °

$\frac{2.2}{2048} = 1.07 \times 10^{-3}$ ° deg per pixel

$\frac{1.07 \times 10^{-3}}{5.73 \times 10^{-5}} = 18.7$ μrad pixel^{-1}

so correct to at least 2. sig. fig.

[2]

(c) (i) At a distance of 285 km from the comet, the image distance is equal to the focal length of the lens system.
Explain why this is the case.

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

When u is very large then $1/u \approx 0$ so $\frac{1}{v} = \frac{1}{f}$ ∴ $v = f$

[2]

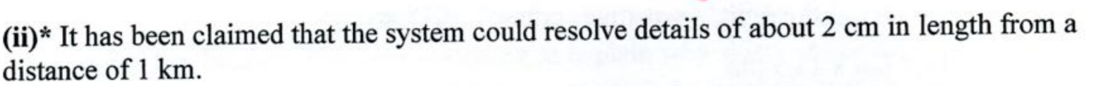
(ii)* It has been claimed that the system could resolve details of about 2 cm in length from a distance of 1 km.

Calculate the magnification of the system for an object distance of 1 km. Use this value, and suitable calculations using values from the data to discuss whether the claim that details down to 2 cm can be resolved by the camera at a distance of 1 km is true.

$m = \frac{v}{u} = \frac{0.717}{1000} = 7.2 \times 10^{-4}$

(u is still v. large so can assume $v \approx f$)

Angular resolution is 18.7×10^{-6} rad so at 1000 m



$\theta = \frac{arc}{rad}$ ∴ arc = θ rad

$s = 18.7 \times 10^{-6} \times 1000 = 0.019$ m

≈ 2 cm

✱

✱ AND / OR

$\frac{13.5\ \mu m}{7.2 \times 10^{-4}} = 0.019$ m ≈ 2 cm

pixel size ↑ ; magnification ↑ ; object size that = 1 pixel

[6]

5 This question is about the mechanical and electrical properties of steel and aluminium.

uncertainty.

(a) The following results were taken in a class experiment to determine the Young modulus of steel:

4% — diameter of steel wire = 0.24 +/- 0.01 mm
0.02% — original length of wire = 3.200 +/- 0.0005 m
0.04% — tensile force = 24.50 +/- 0.01 N
6% — extension of wire = 8.0 +/- 0.5 mm

$A = \pi r^2 = \pi \times (0.12 \times 10^{-3})^2 = 4.52 \times 10^{-8}\ m^2$

(i) Use the data to show that the Young modulus of steel is about $2 \times 10^{11}\ N\ m^{-2}$

$$E = \frac{Fl}{Ax} = \frac{24.5 \times 3.2}{4.52 \times 10^{-8} \times 8 \times 10^{-3}}$$

$$= 2.2 \times 10^{11}\ Pa$$

[3]

(ii) A student calculated that the maximum value of the Young modulus obtainable from the results is $2.5 \times 10^{11}\ N\ m^{-2}$. Explain how this value was reached and calculate the percentage uncertainty in the determined value of the Young modulus.

By using maximum possible values for F and l and minimum values for diameter and extension. (% uncertainties add up)

% uncertainty = 4% × 2 + 6% = 14% (as diameter is squared in calc)

OR

2.5 − 2.2

$\frac{0.3}{2.2} \times 100$

= 14%

[3]

(iii) Which measurement contributed the most to the percentage uncertainty of the value for the Young modulus? Explain your reasoning.

The diameter as radius² is used to calculate the cross-sectional area. So uncertainty in area = 8% which is largest uncertainty.

[3]

$G = \frac{\sigma A}{L}$ $G = \frac{I}{V} =$

(b) The **same wire** was used to determine the conductivity of steel. A current of 0.21A was recorded when the potential difference across the wire was 2.80 V.

Using the data from part (a) show that the conductivity of the steel is about 5×10^6 S m^{-1}.

$$\sigma = \frac{GL}{A} = \frac{IL}{VA} = \frac{0.21 \times 3.2}{2.8 \times 4.52 \times 10^{-8}}$$

$$= 5.3 \times 10^6 \text{ Sm}^{-1}$$

[2]

(c) Electricity transmission cables are used to transport electrical power over large distances with minimum energy losses. The cables are strung between points as indicated in Fig. 5.1. The weight of the suspended cable is about 6 kN.

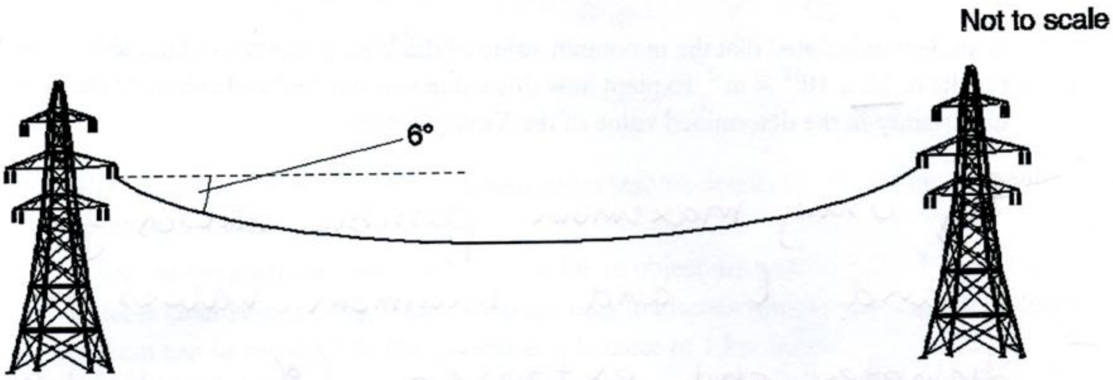
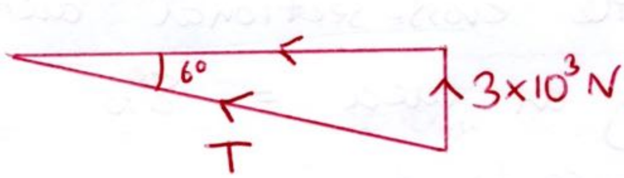


Fig. 5.1

Show that the tension at the top of a cable where it joins the pylon is about 30 kN.

Weight is shared by each pylon so vertical component of tension = 3kN



$\frac{3 \times 10^3}{T} = \sin 6°$ $\therefore T = \frac{3 \times 10^3}{\sin 6°}$ [2]

$= 28.7$ kN

(d)* Transmission cables are constructed from steel and lower- density aluminium strands as shown in Fig. 5.2. The radius of the cable is 25 mm.

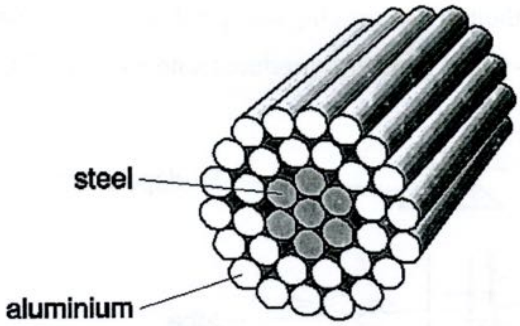


Fig. 5.2

Young Mod = steel / Al = $\frac{2.2\times10^{11}}{6.9\times10^{10}}$ = 3.2 times.

Steel won't stretch as much.

Here are data about aluminium:

Yield stress = 9.5×10^{7} N m^{-2} ; Young Modulus = 6.9×10^{10} N m^{-2}; conductivity = 3.5×10^{7} S m^{-1}

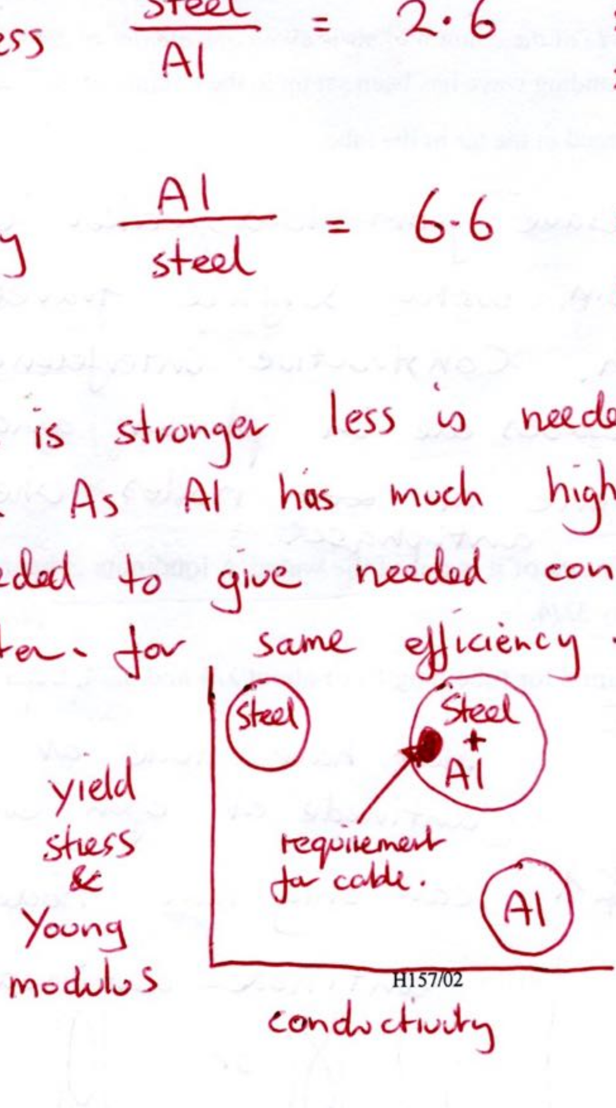
The yield stress of steel is 2.5×10^{8} N m^{-2}

Use data in the question to explain why two metals are used in cables rather than steel or aluminium alone. You may use calculations in your answer.

Yield stress $\frac{\text{steel}}{\text{Al}}$ = 2.6 so steel 2.6 times stronger.

Conductivity $\frac{\text{Al}}{\text{steel}}$ = 6.6 so Al 6.6 times more conductive.

As steel is stronger less is needed to hold weight of cable. As Al has much higher conductivity much less is needed to give needed conductivity making cable lighter for same efficiency.



[6]

Section C

Answer **all** the questions

6 This question is about a method of determining the speed of sound in air.

A loudspeaker attached to a signal generator produces a note of 440 Hz.

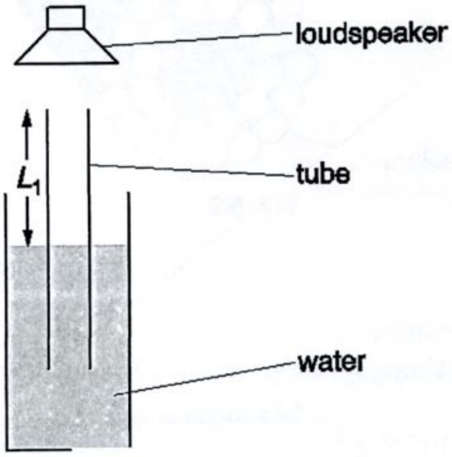


Fig. 6.1

A louder note is heard when the length L_1 of the column of air is about one quarter of the wavelength ($\lambda/4$) of the note from the speaker. A standing wave has been set up in the column of air in the tube.

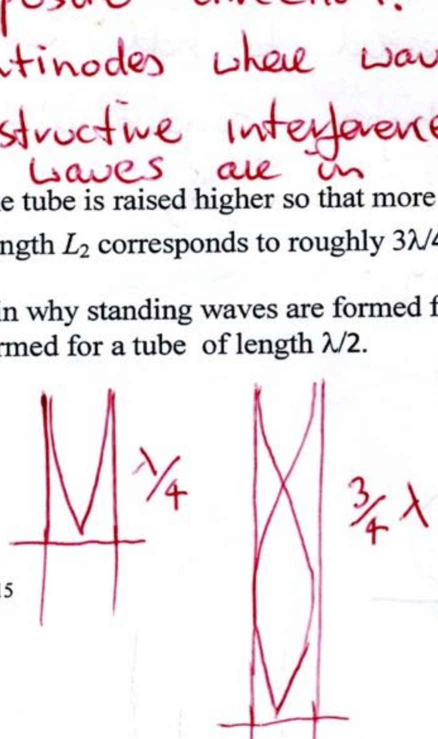
(a) Explain how a standing wave is formed in the air in the tube.

superposition of wave from loudspeaker with wave reflected from water surface travelling in opposite direction. Constructive interference at antinodes where waves are in phase and destructive interference at nodes where waves are in antiphase.

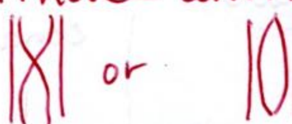
[3]

(b) The tube is raised higher so that more of it is out of the water. A loud note is heard at length L_2. The length L_2 corresponds to roughly $3\lambda/4$.

Explain why standing waves are formed for tube lengths of about $\lambda/4$ and $3\lambda/4$, but a standing wave is not formed for a tube of length $\lambda/2$.



Must have node at surface and antinode at open end. At $\lambda/2$ can only have node – node or antinode – antinode.



[2]

(c) The standing waves extend a distance *c* above the end of the tube. The precise relationships between the length of the tube and the wavelength, λ, are:

$\lambda/4 = L1 + c$ and $3\lambda/4 = L2 + c$

Show that $L_2 - L_1 = \frac{\lambda}{2}$

$L1 = \frac{\lambda}{4} - c \qquad L2 = \frac{3\lambda}{4} - c$

$L_2 - L_1 = \frac{3\lambda}{4} - \frac{\lambda}{4} - c + c = \frac{\lambda}{2}$

[1]

(d) The following results were recorded: $L_1 = 0.18$ m , $L_2 = 0.57$ m

(i) Calculate the wavelength of the 440 Hz note.

$\lambda = 2(L_2 - L_1) = 2 \times (0.57 - 0.18) =$

wavelength = 0.78 m **[1]**

(ii) Calculate the speed of sound in the air in the tube. Explain your choice of the number of significant figures in your answer.

$c = f\lambda = 440 \times 0.78 = 340$

speed of sound = 340 m s^{-1}

reasoning for choice of number of significant figures:

data used was to 2 sig. fig.

0.18m
0.57m
440 Hz (2 or 3)

[3]

(e) The frequency of the note is changed and the measurements are repeated. A graph of frequency versus wavelength^{-1} is plotted as shown in Fig. 6.2.

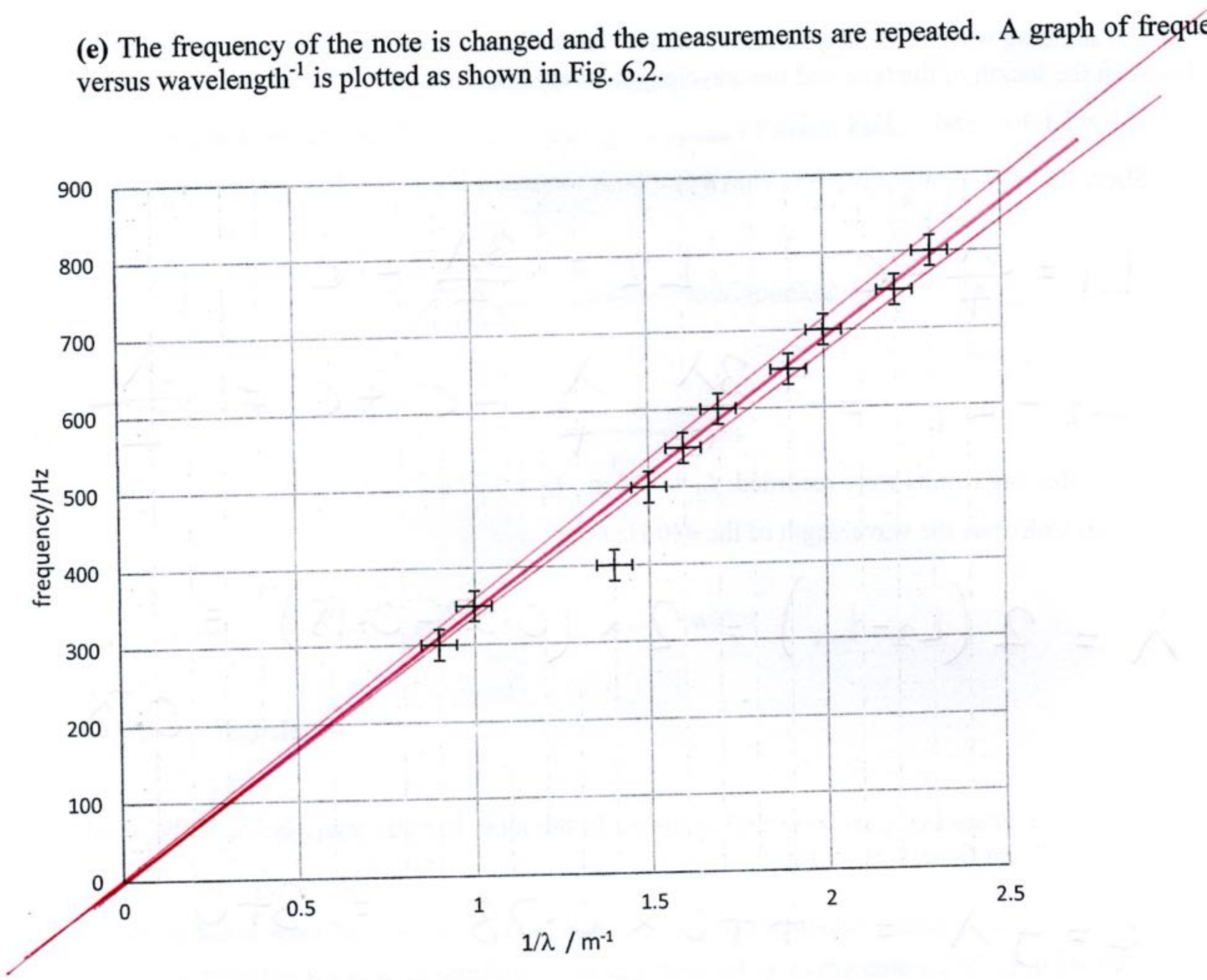


Fig. 6.2

(i) Draw the best fit line through the results. Use the gradient of the graph to find a value for the speed of sound in the air in the tube. Include an estimate of the uncertainty in your value and explain how you made this estimate.

gradient $= \frac{\Delta y}{\Delta x} = \frac{860}{2.5} = 344\ ms^{-1}$

Lines of worst fit. $\frac{900}{2.5} = 360$ & $\frac{830}{2.5} = 330$

range/2 = 15

speed of sound = ...344.... +/- ....15.... m s^{-1}

Reasoning for the estimate of uncertainty:

[5]

(ii) Explain why using the gradient of a best-fit line may give a more accurate value for the speed of sound than taking the average of repeated calculations for different frequencies.

The mean value would have included the 400 Hz measuement which is an anomaly. and this would have skewed the mean. The line of best fit can ignore the anomaly, which is easily spotted, and averages the rest of the data.

[3]

END OF QUESTION PAPER