Answer **all** the questions.

Section A

1 Here is a list of electrical units.

C S V Ω W

State which of these units is correct for each of the following combinations of quantities:

$\frac{\text{voltage}}{\text{current}}$ ....Ω........

$\frac{\text{energy}}{\text{time}}$ ....W........

current × time ....C........ [3]

2 A sample of plastic material is originally 10 cm long.
It is stretched to a strain of 3.

Calculate the **total length** of the sample at a strain of 3.
Make your method clear.

strain = $\frac{\text{extension}}{\text{length}}$

extension = strain × length
= 3 × 10 cm
= 30 cm

so total length = 10 cm + 30 cm

total length = ...40........ cm [2]

3 A bathroom ceramic tile needs to be difficult to break and difficult to scratch.

(a) Draw a straight line from each **requirement** to the necessary **property**.

requirement	property
difficult to break	brittle
difficult to scratch	hard
	stiff
	strong

[2]

(b) Tiles can be cut as follows:

- scratch a line across the glazed surface
- apply forces as shown in Fig. 3.1 to open the crack.

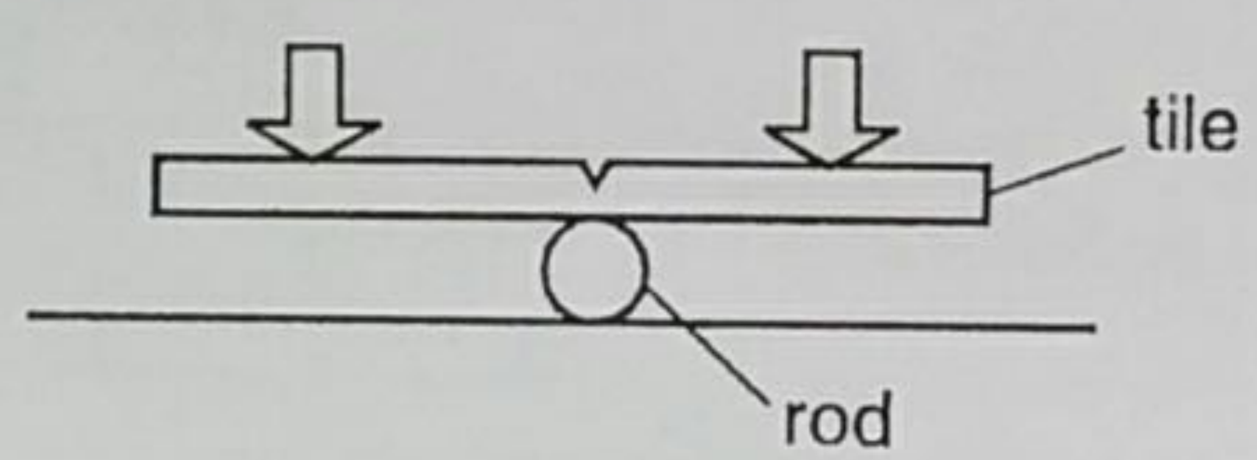


Fig. 3.1

Put (✓) in the boxes next to **two** statements below which, taken together, best explain how this method works.

The stress is uniform across the surface of the tile. ☐

The stress is concentrated at the tip of the crack. ☑

The stress builds up in the crack by plastic flow of the atomic structure. ☐

The stress at the scratch is reduced by plastic flow of the atomic structure. ☐

The stress cannot be relieved by slip within the random atomic structure. ☑

[2]

4 The speed of light in a sample of glass is $1.9 \times 10^8\,\mathrm{m\,s^{-1}}$.

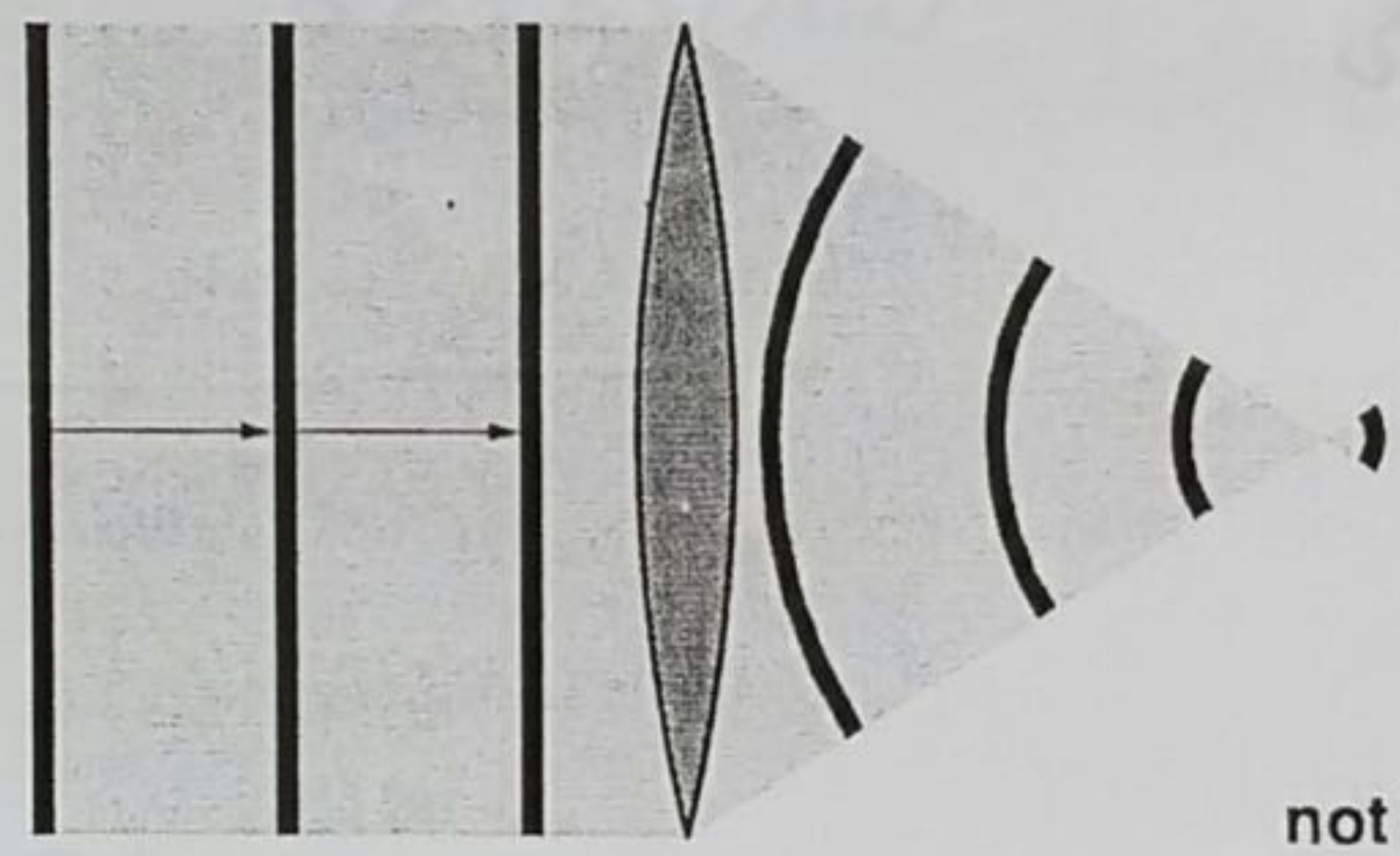
$c = 3.0 \times 10^8\,\mathrm{m\,s^{-1}}$

Calculate the refractive index of this glass.
Make your method clear.

$$n = \frac{c}{v} = \frac{3 \times 10^8}{1.9 \times 10^8} =$$

refractive index = 1.6 [2]

5 Fig. 5.1 shows the effect of a lens on wavefronts of a parallel beam of light.



not to scale

Fig. 5.1

(a) Describe the effect of the lens on the wavefronts.

Adds curvature

[1]

(b) Explain how the lens produces this effect.

Thicker in middle so waves slowed down for longer

[2]

6 Metals and long-chain polymer materials under stress can show plastic behaviour.

(a) Explain what is meant by *plastic behaviour*.

deforms and does not return to original shape

[1]

(b) Choosing **either** a metal **or** a long chain polymer, describe in terms of its internal structure how it can show plastic behaviour.

material chosen ......metal......

planes of atoms can slide past each other as dislocations move through the structure

polymer

[2]

polymer chains can uncoil and slide past each other.

7 Fig. 7.1 shows a graph of stress against strain for a stretched copper wire.

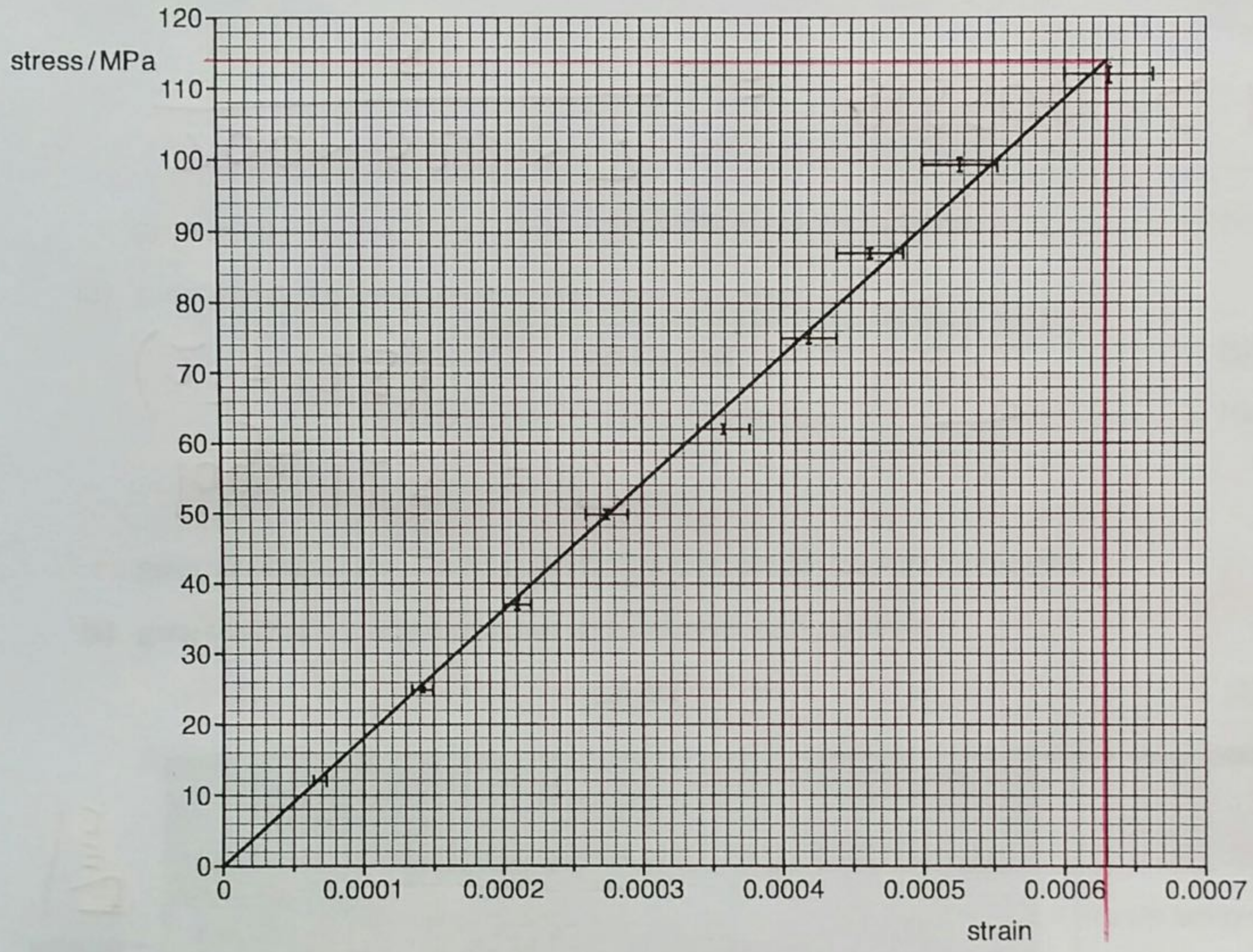


Fig. 7.1

(a) Use the data from the graph to calculate the Young modulus of copper.
Make your method clear.

$E = \frac{\text{stress}}{\text{strain}} = \frac{114 \text{ MPa}}{0.00063} = \text{gradient}$

$= 1.81 \times 10^{11}$ Pa

$= 0.18$ GPa

Young modulus = 1.8×10^{11} Pa **[2]**

(b) Explain how you would use the uncertainty bars in Fig. 7.1 to estimate the uncertainty in the measurement of the Young modulus.

You may draw on Fig. 7.1 to illustrate your answer.

Draw lines of worst fit & calculate max and min gradient of lines that still fit the graph (ie are within the error bars)

[2]

[Section A Total: 21]

Section B

8 Fig. 8.1 is a digital photograph of the identical space shuttles Atlantis (foreground) and Endeavour (background) at the NASA Space Centre in Florida. The length of each shuttle is shown by white marker lines.

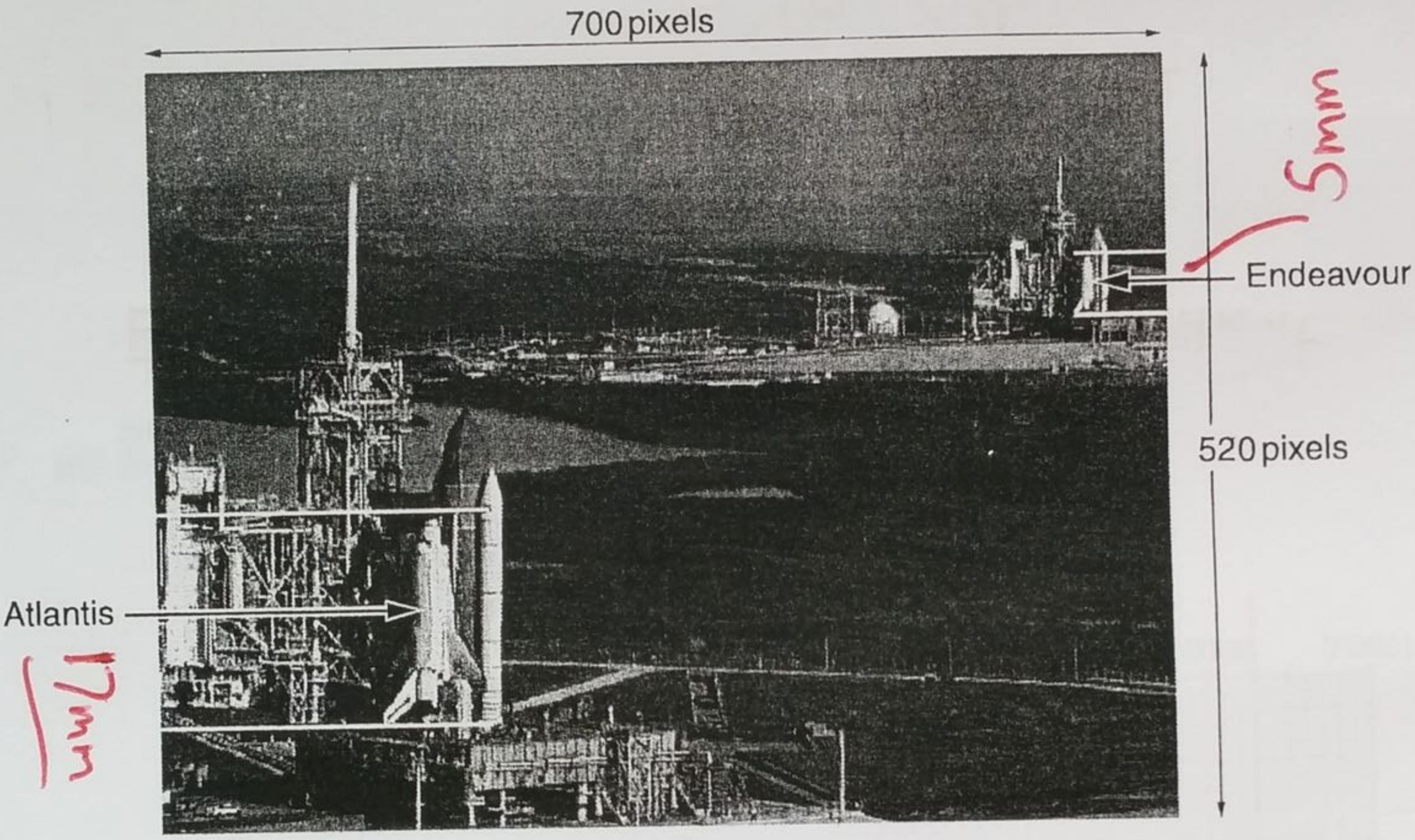


Fig. 8.1

(a) Each pixel of the image is recorded on a greyscale with 128 levels.

State and explain how many bits per pixel are needed for 128 alternative levels.

$\log_2 128 = 7$

$(2^7 = 128)$

bits per pixel = 7 [2]

(b) The image is 700 × 520 pixels.

Show that the amount of information in the image is less than 1 Mbyte.

$$\frac{700 \times 520 \times 7}{8} = 318500 < 10^6$$

[2]

(c) Use Fig. 8.1 to calculate the ratio:

$$\frac{\text{distance from camera to Endeavour}}{\text{distance from camera to Atlantis}}$$

In your answer, you should make the steps in your method clear.

1/size ratio = distance ratio

= 17/5 = 3.4

ratio = ... **[3]**

(d) The image resolution at the position of **Atlantis** is 0.24 m $pixel^{-1}$.

(i) Use this information to estimate the length of **Atlantis** indicated in Fig. 8.1.

Make your method clear.

side of image = 60mm

Fraction for Atlantis = 17/60

Pixels for Atlantis = 17/60 × 520 = 147

Size = 147 × 0.24

length = 35 m **[2]**

(ii) Estimate the resolution of the image at the position of **Endeavour**.

0.24 × 3.4 = 0.82

resolution at Endeavour = 0.82 m $pixel^{-1}$ **[1]**

[Total: 10]

9 This question is about digitising the analogue speech signal in a mobile telephone system. The range of frequencies from 300 to 3400 Hz of the analogue speech signal is converted into a digital signal.

(a) State the bandwidth of speech frequencies converted.

3400 - 300 =

bandwidth = 3100 Hz [1]

(b) (i) State the minimum sampling frequency for digitising the analogue signal. Explain why it has this value.

minimum sampling frequency = 6800 Hz

x2 max frequency in signal needed to avoid aliases & capture the highest frequency.

[2]

(ii) V_{noise} is the voltage range over which the noise varies. V_{total} is the voltage range over which the total transmitted signal including the noise varies.

For this system $\frac{V_{total}}{V_{noise}} \approx 250$.

Use this information to explain why there is no need to use more than 8 bits per sample for this system.

In your answer, you should make your explanation clear.

If $V_t/V_n \approx 250$ th is no need for more than 250 levels

$\log_2(250) = 7.96$ so 8 bits will capture all useful information. Any more than 8 just encodes the noise

[3]

(iii) Calculate the rate of transmission of information required for this system.

rate = sampling frequency × bits per sample

$= 6800 \times 8 = \underline{5.4 \times 10^4}$

rate of transmission = ... bit s^{-1} **[2]**

(c) In a different system a wider frequency range of the analogue signal from the original speech is used.

Explain one advantage and one disadvantage of using a wider frequency range.

advantage

higher quality sound so easier to understand

disadvantage

higher bandwidth needed so fewer calles can fit into digital signal

[2]

[Total: 10]

10 This question is about a copper conducting bar which must carry a large current from a generator to a transformer in a power station.

(a) The bar loses 2.0 kW of power P to the surroundings when it carries a current I of 8 000 A.

(i) Using $P = I^2 R$, show that the resistance R of the bar must be about $3 \times 10^{-5}\,\Omega$.

$$R = \frac{P}{I^2} = \frac{2 \times 10^3}{8000^2} = 3.1 \times 10^{-5}\,\Omega$$

[2]

(ii) Calculate the p.d. across the length of the bar.

$$V = IR = 8000 \times 3.1 \times 10^{-5}$$

p.d. = 0.25 V **[2]**

(b) (i) Using $G = \sigma A / L$, show that the uniform cross-sectional area A of a conductor of length L, of material of conductivity σ and resistance R is given by the equation

$$A = \frac{L}{\sigma R}.$$

$$G = \frac{\sigma A}{L} \therefore R = \frac{L}{\sigma A} \therefore A = \frac{L}{\sigma R}$$

$$R = \frac{1}{G}$$

[2]

(ii) The bar in **(a)** is 10 m long.
Calculate its cross-sectional area.

conductivity of copper = $5.9 \times 10^7\,\text{S m}^{-1}$

$$A = \frac{10\,\text{m}}{5.9 \times 10^7 \times 3.1 \times 10^{-5}}$$

cross-sectional area = 5.4×10^{-3} m^2 **[2]**

[Total: 8]

11 Fig. 11.1 shows how the emf $\mathcal{E}$ across a temperature sensor depends on temperature.

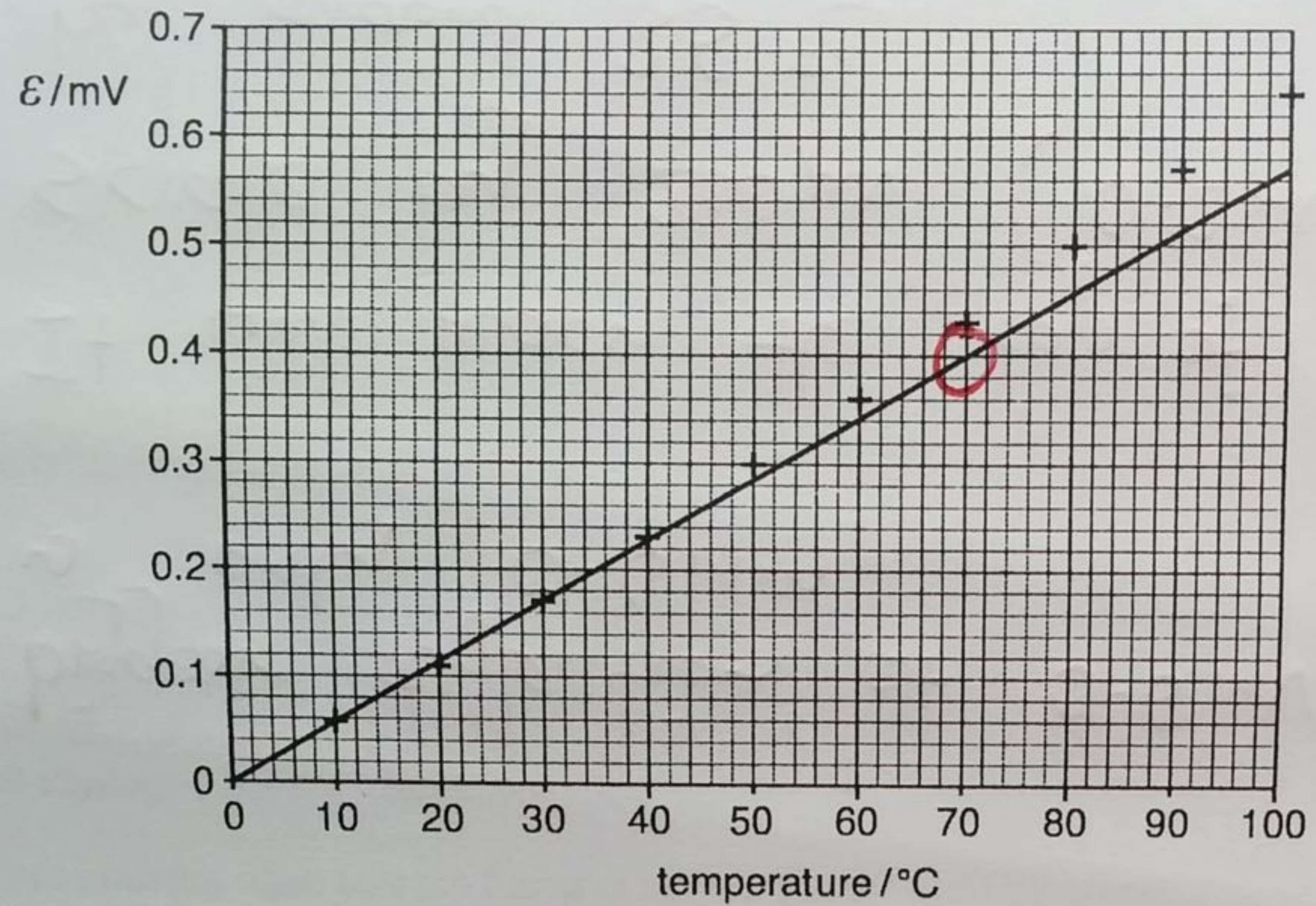


Fig. 11.1

(a) **(i)** A straight line that fits the data **up to 40 °C** has been added to the graph. Describe the relationship between the emf $\mathcal{E}$ and the temperature in the range 0 °C to 100 °C shown by **all** the data in Fig. 11.1.

Propational up to ~ 40°C then gradient increases (sensor becomes more sensitive)

[2]

(ii) Estimate the **sensitivity** of the temperature sensor in the range 0 °C to 40 °C. Make your method of estimating the sensitivity clear.

sensitivity = gradient $= \frac{\Delta y}{\Delta x} = \frac{0.4 \times 10^{-3}}{70}$

sensitivity = 5.7×10^{-6} V °C^{-1} [2]

(b) Fig. 11.2 shows the circuit diagram of the temperature sensor connected to an external resistance ***R***.

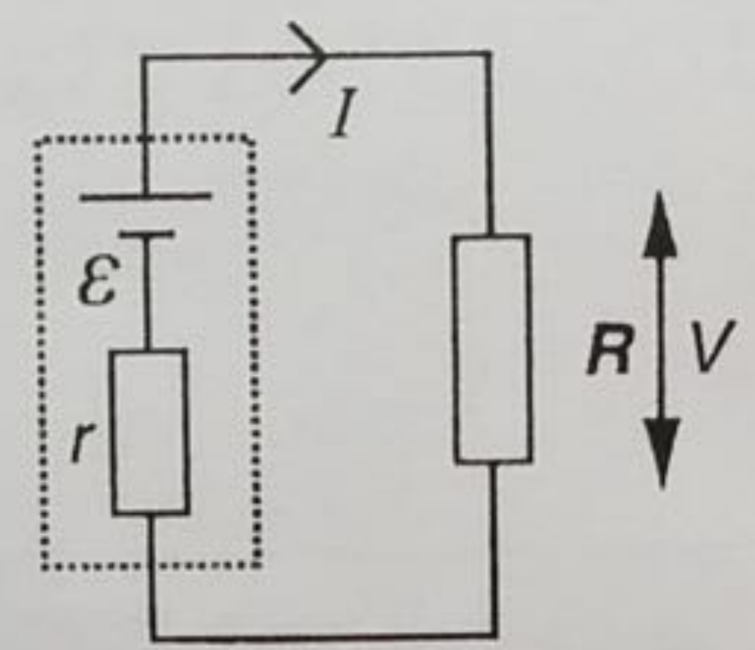


Fig. 11.2

The sensor behaves like a supply of variable emf $\mathcal{E}$ and constant internal resistance r.

(i) Explain why this circuit can be described as a potential divider circuit.

emf is shared across the two resistors which are in series

[1]

(ii) The p.d. V across the sensor, and the current I in the circuit are given by the equations:

$$V = \mathcal{E} - Ir \qquad \text{and} \qquad I = \frac{\mathcal{E}}{(R + r)}$$

Combine the equations to show that $V = \frac{\mathcal{E} R}{(R + r)}$.

$$V = \mathcal{E} - \frac{\mathcal{E} r}{R+r}$$

$$V = \frac{\mathcal{E}(R+r) - \mathcal{E} r}{R+r} = \frac{\mathcal{E}R + \mathcal{E}r - \mathcal{E}r}{R+r}$$

$$V = \frac{\mathcal{E}R}{R+r}$$

[2]

(iii) The resistor $\boldsymbol{R}$ is replaced by a meter to measure the p.d. across the sensor. This meter has a resistance R of 15 Ω.

Use the equation $V = \dfrac{\mathcal{E} R}{(R + r)}$ to show that the meter will display a voltage about 2% lower than the true emf $\mathcal{E}$.

internal resistance of sensor $r = 0.30\,\Omega$

$$V = \frac{\mathcal{E} \times 15}{15 + 0.3} = \mathcal{E} \times 0.98$$

98% is about 2% lower

[2]

(c) The meter used to measure the p.d. across the temperature sensor in **(b)(iii)** is the **moving coil galvanometer**, listed in the table below. Two other instruments which can be used to measure voltage are also shown.

instrument	full scale deflection (maximum reading)	sensitivity
moving coil galvanometer	300 mm	$10\,\mu V\,mm^{-1}$
cathode ray oscilloscope	100 mm	$1.0\,mV\,mm^{-1}$
digital voltmeter	200.0 μV	0.1 μV steps

Give **one** reason why each of these other instruments is **not** suitable.
Use data from the table **and** the graph of Fig. 11.1.

not the cathode ray oscilloscope because:

biggest deflection at 0.6 mV is only 0.6 mm

not the digital voltmeter because:

It will reach the top of its scale by 200 μV (0.2 mV) by around 35 °C

[2]

[Total: 11]

[Section B Total: 39]

END OF QUESTION PAPER