Answer **all** the questions.

SECTION A

1 Here is a list of electrical units.

As **AV** **AV^{-1}** **JC^{-1}** **VA^{-1}**

From the list select the unit that could be used to measure:

power ....AV........ $P = IV$

charge ....As........ $Q = It$

conductance ....AV^{-1}........ $G = I/V$

[3]

2 The refractive index of a transparent material is 1.7.

Calculate the speed of light in this material.

Give your final answer to an appropriate number of significant figures. = 2

speed of light in vacuum = $3.0 \times 10^8\,m\,s^{-1}$

$n = \frac{C_{vac}}{C_{mat}}$ $\therefore$ $C_{mat} = 3\times10^8/1.7 = 1.76\times10^8\,ms^{-1}$

speed of light in material = ...1.8×10^6........ $m\,s^{-1}$ **[2]**

3 Fig. 3.1 shows a potential divider circuit.

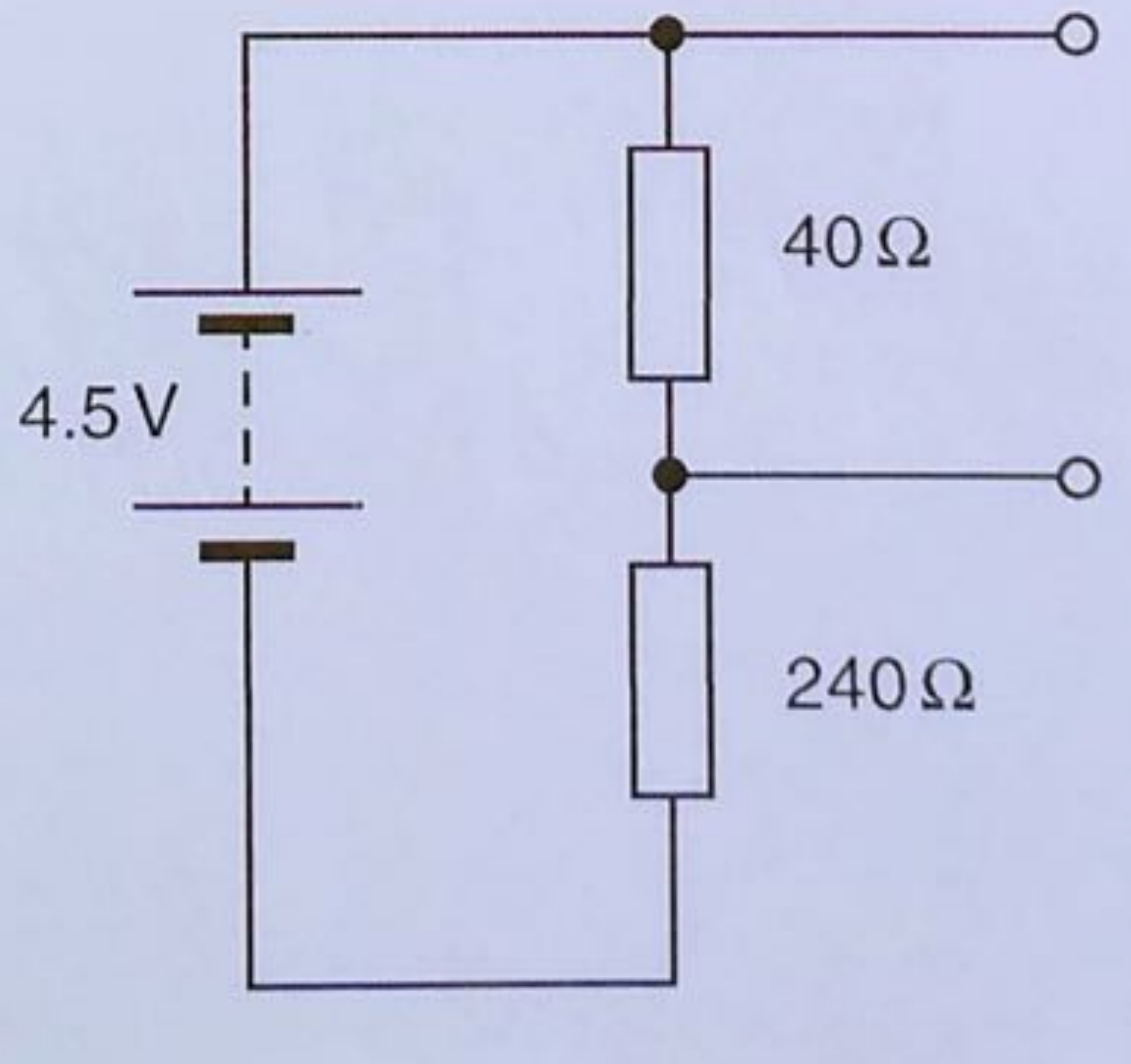


Fig. 3.1

Calculate the potential difference (p.d.) across the 40 Ω resistance.

$V_{out} = \frac{R_{OUT}}{R_{TOT}} \times V_{IN} = \frac{40}{280} \times 4.5 =$

p.d. = ...0.64........ V **[2]**

4 Fig. 4.1 shows how the frequency of one chirrup of bird song varies with time.

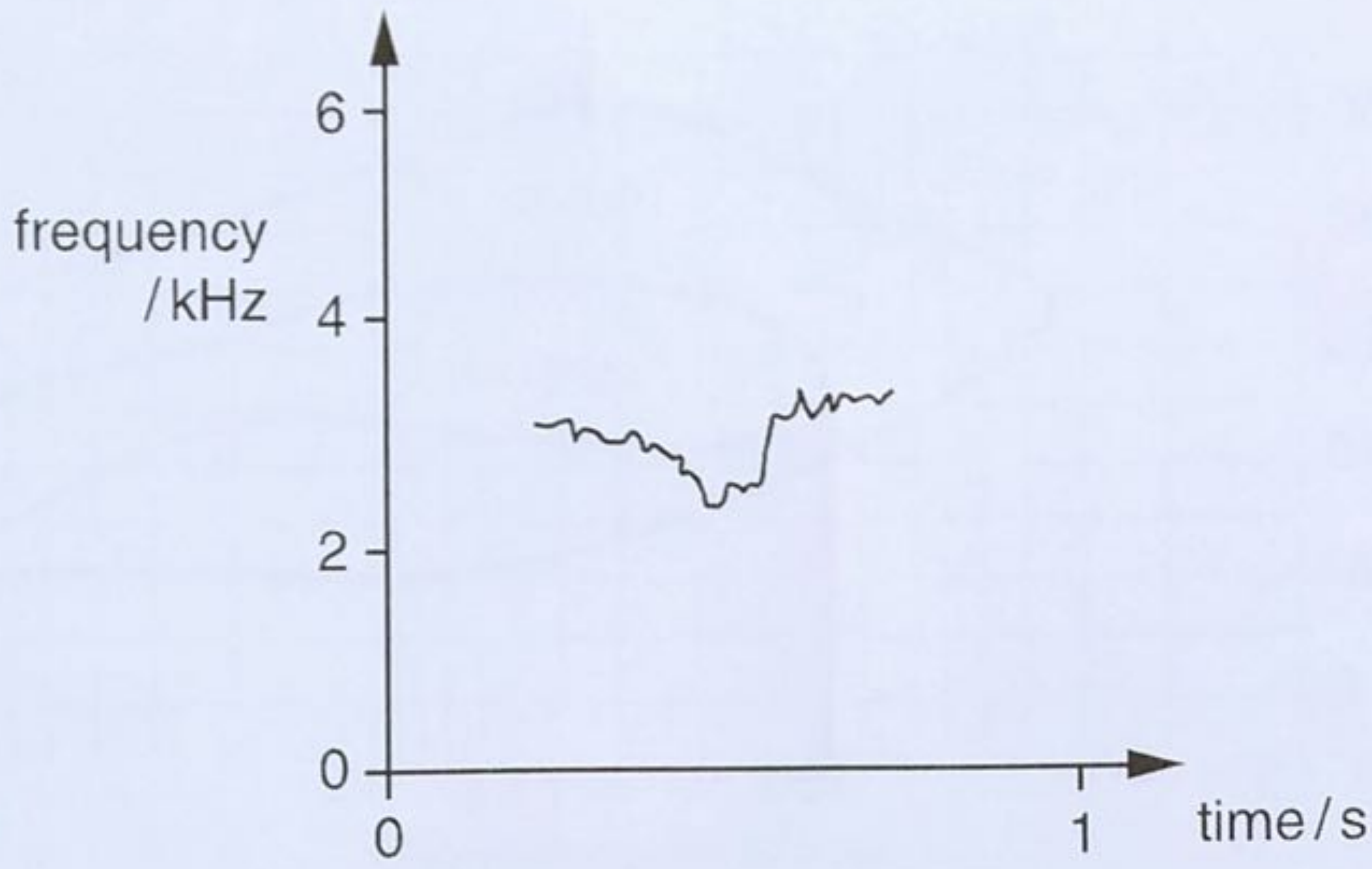


Fig. 4.1

(a) Describe **two** aspects of the frequency variation of the chirrup shown in Fig. 4.1.

1 Mean frequency ≈ 3 kHz

Lasts ≈ 0.5 s

2 etc

[1]

(b) Estimate the total number of oscillations represented by the frequency variation in Fig. 4.1.

Make your method clear.

osc = mean frequency × time

$= 3 \times 10^3 \times 0.5 =$

number of oscillations = 1500 **[2]**

5 Fig. 5.1 compares the frequency range of human speech with that of orchestral music.

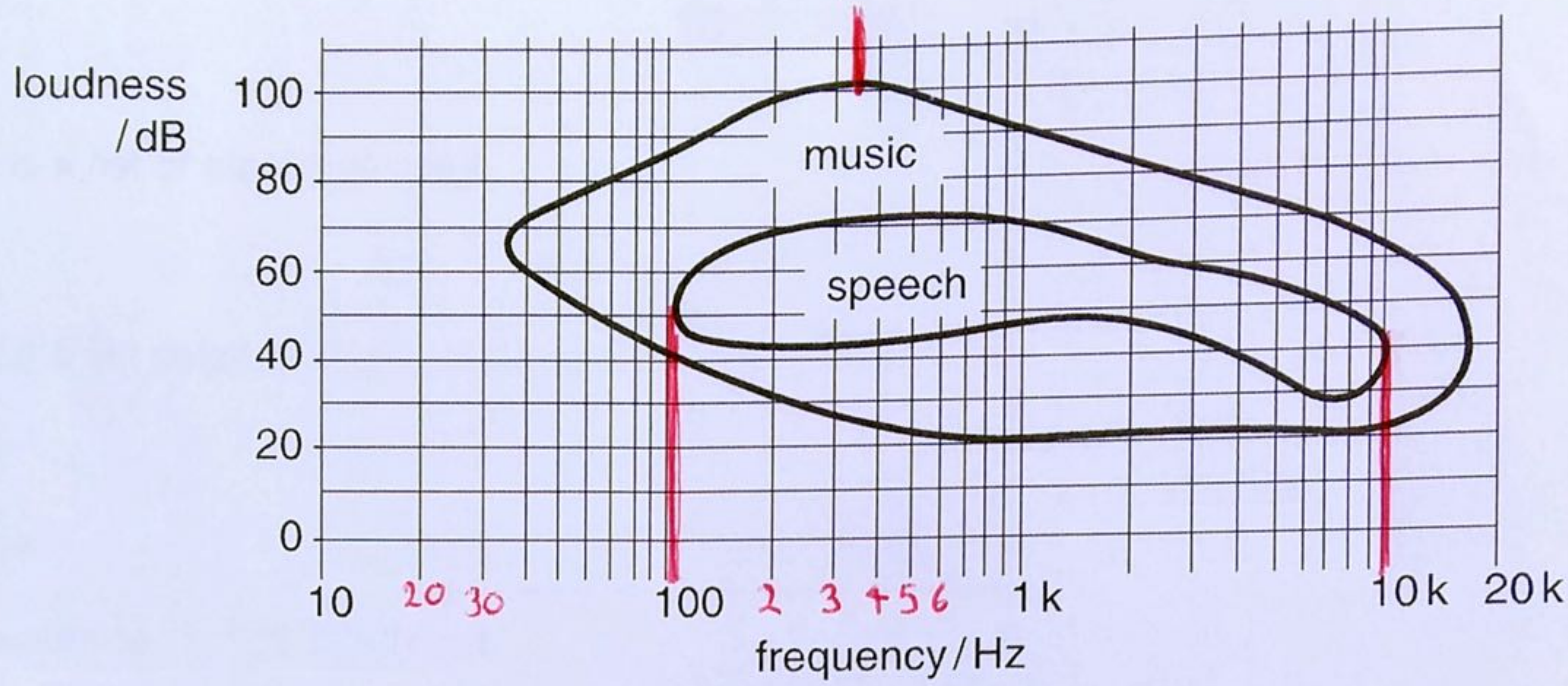


Fig. 5.1

(a) State how you recognise that the frequency scale is logarithmic.

Equal steps on the f scale represent equal multiples (or an increase of a constant factor)

[1]

(b) State the frequency *f* of the loudest sound in orchestral music.

(Half way on a $\log_{10}$ scale is $10^{1.5}$ %)

f = 330 Hz **[1]**

(c) Calculate the bandwidth for human speech.

Not on new spec but easy

$10 \times 10^3 - 100 =$

bandwidth = 9900 Hz **[1]**

6 A long-sighted person has a near point at 1.25 m from the eye. This is the smallest object distance from their eye for comfortable vision.

(a) Calculate the curvature of waves arriving at the eye from a distance of 1.25 m.

$$C = \frac{1}{u} = \frac{1}{-1.25} = -0.80\,D$$

curvature = – 0.80 D **[1]**

(b) A person with a near point at 1.25 m needs spectacles to read a book at a distance of 0.25 m from their eye.

Calculate the power of the spectacle lens needed for this.

Make your method clear.

Curvature from 0.25 m = $1/-0.25 = -4\,D$

$\therefore$ Extra curvature to get from -4 to -0.8

$= -0.8 - (-4) = +3.2\,D$

power of lens = 3.2 D **[2]**

7 Fig. 7.1 shows how the voltage of a lithium-ion rechargeable battery varies with time as it discharges into a constant load of 5.0 Ω.

Graphs for temperatures of 50 °C and –20 °C are given.

2.75V for 8min
1.5V for 2min

mean = $\frac{2.75 \times 8 + 1.5 \times 2}{10}$

= 2.5V

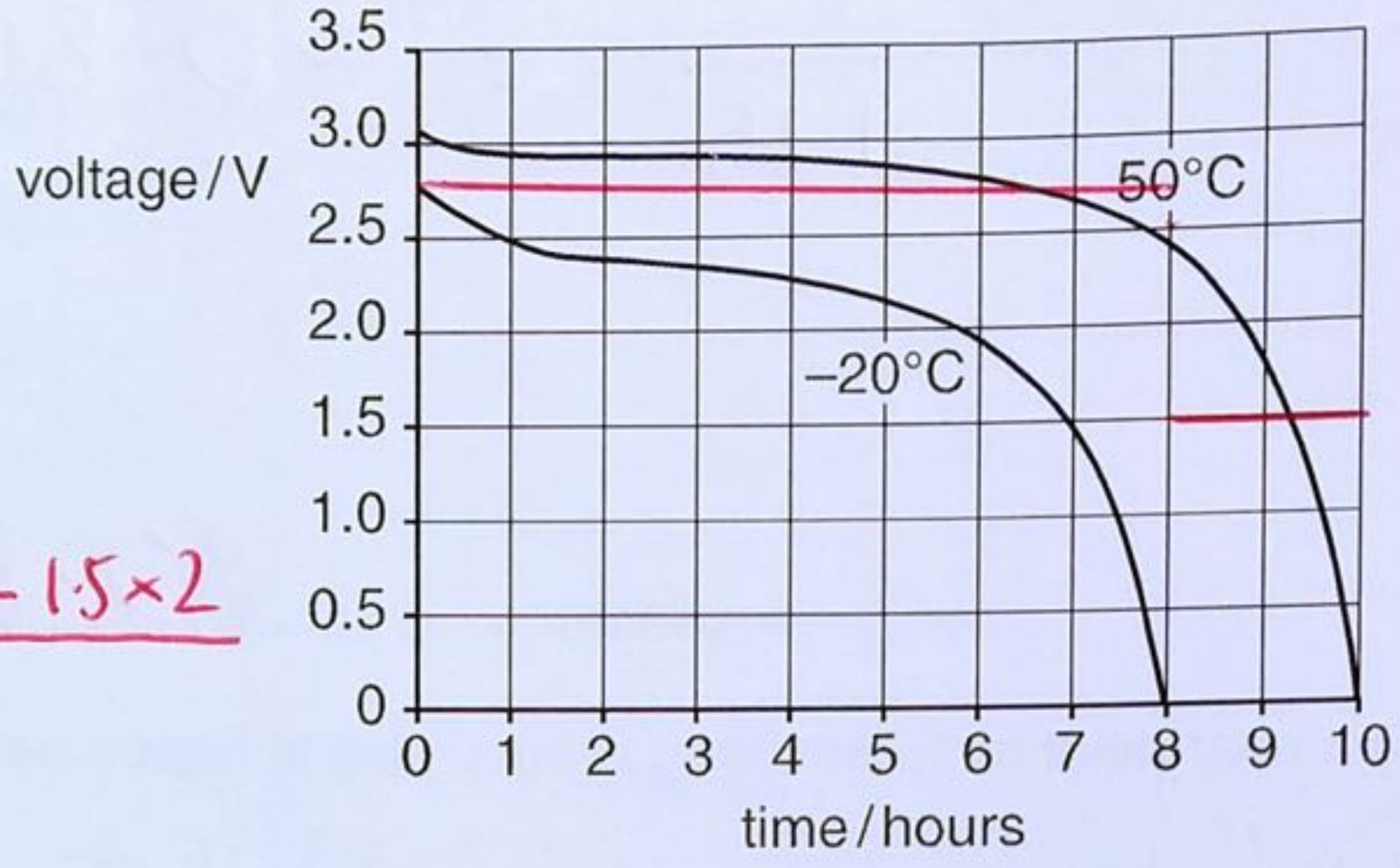


Fig. 7.1

(a) State **two** effects of changing temperature on the voltage variation.

1 At the lower temperature V is always lower.

2 At the lower temp V falls to 0V sooner.

[2]

(b) 1 Use data from Fig. 7.1 to estimate the average current delivered by the battery when operating at 50 °C. The load is constant at 5.0 Ω.

At 50°C mean V ≈ 2.5V & $I = V/R = 2.5/5$ =

average current = ...0.50...... A **[1]**

0.48 to 0.56 allowed

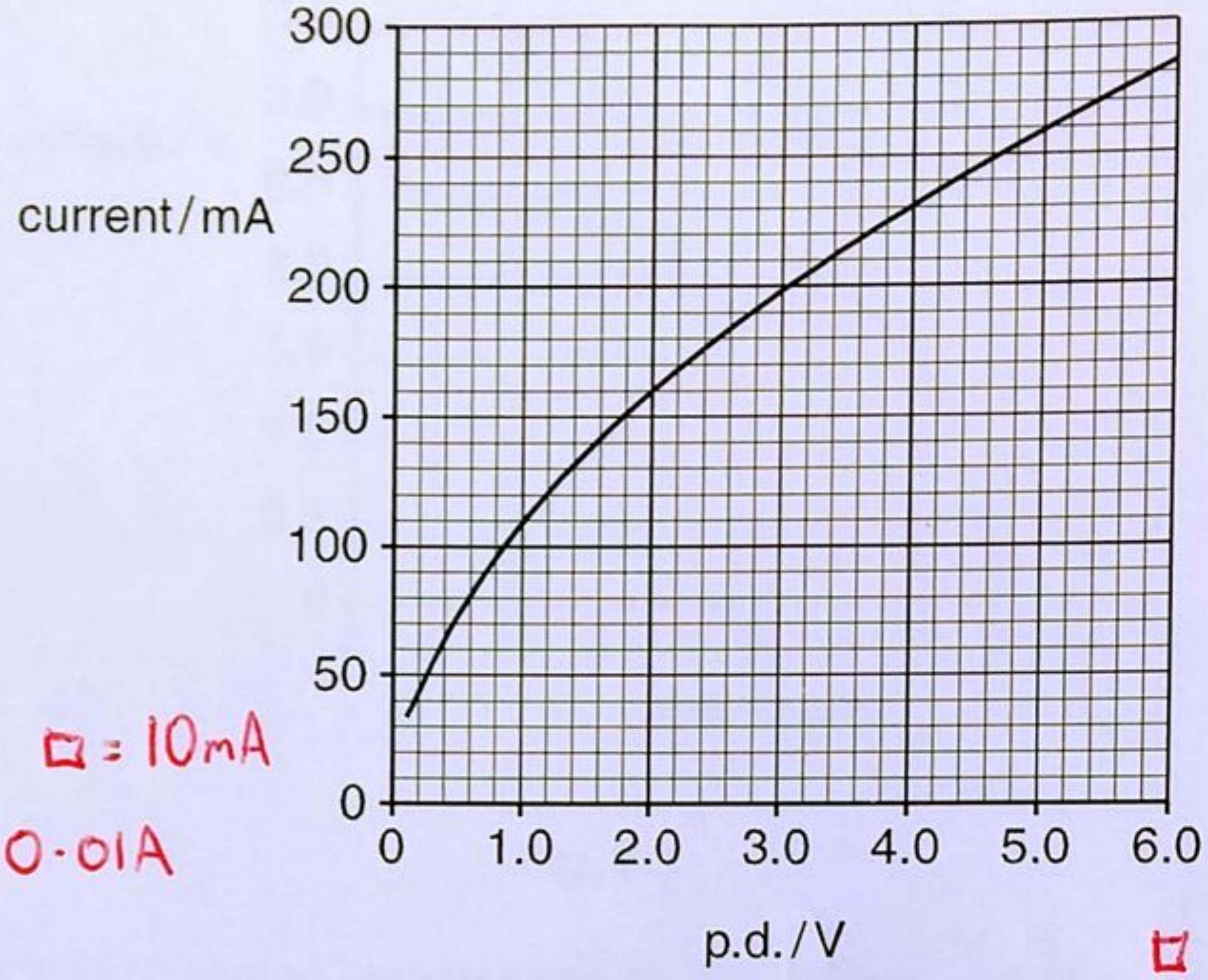
2 Estimate the charge delivered by the battery in one complete discharge when operating at 50 °C. Make your method clear.

$Q = It = 0.50 \times 10 \times 60 \times 60 =$

charge delivered = ...1.8×10^4...... C **[2]**

17 – 22 kC **[Section A Total: 21]**

8 Fig. 8.1 shows the graph of current against p.d. for a 6.0 V tungsten filament lamp.



□ = 10mA

= 0.01A

□ = 0.2V

Fig. 8.1

(a) State how data from the graph indicates that the filament is **not** obeying Ohm's law.

Not a straight line

[1]

(b) **(i)** Complete the table of Fig. 8.2 which shows data for the smallest and largest p.d. readings displayed in the graph.

$R = V/I$ $\quad P = IV$

p.d./V	current/mA	resistance/Ω	power/W
0.11	35	3.14	0.0039
6.00	285	21.1	1.7

284 ± 1

Fig. 8.2

[3]

(ii) State and explain why the filament in the lamp is not obeying Ohm's law.

You do not need to discuss the metal microstructure.

Resistivity increases with temperature

or Conductivity decreases " "

or resistance / conductance

[2]

(iii) The filament is made of tungsten wire of cross-sectional area $3.2 \times 10^{-10}\,\text{m}^2$.

resistivity of tungsten at 20 °C, $\rho_{20} = 5.6 \times 10^{-8}\,\Omega\,\text{m}$

Calculate the length of wire needed to make the filament.

State any assumption made.

$$R = \frac{\rho L}{A} \quad \therefore \quad L = \frac{RA}{\rho} = \frac{3.14 \times 3.2 \times 10^{-10}}{5.6 \times 10^{-8}} = 0.0179\,\text{m}$$

at 0.11V / 35mA temp remains ≈ 20°C

length = 0.018 m **[3]**

(iv) The tungsten of the filament heats to about 3000 °C when working at 6.0 V.

Estimate the value of $\frac{\rho_{3000}}{\rho_{20}}$.

Assume that changes in filament dimensions during warming are not significant.

Make your reasoning clear. $R \propto \rho$ so $\frac{\rho_{3000}}{\rho_{20}} = \frac{R_{3000}}{R_{20}}$

$$= \frac{21.1}{3.14} = 6.72$$

$\frac{\rho_{3000}}{\rho_{20}} =$ 6.7 **[2]**

(c) ① Explain in terms of microstructure why metals are good conductors of electricity. ② Suggest why the resistivity of tungsten might alter with temperature.

Make your explanation clear and use technical terms spelled correctly in your answer.

① Metals have high charge carrier density due to delocalised electrons which carry charge.

② Metal ions vibrate more as Temp increases which scatter electrons so resisting their flow.

[3]

Turn over

9 Fig. 9.1 shows the stress against strain graphs for four **metal alloys A**, **B**, **C** and **D** to their breaking points.

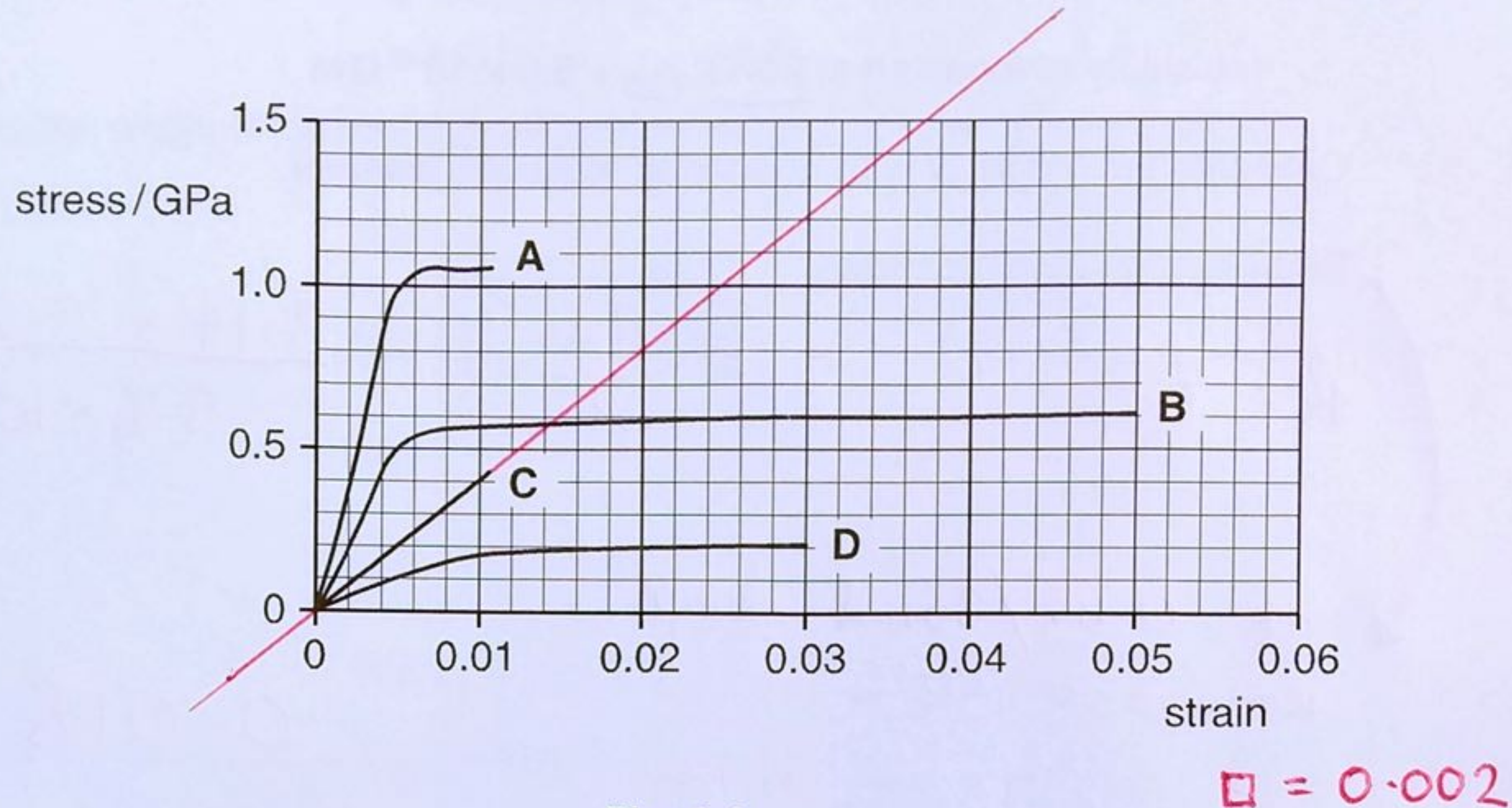


Fig. 9.1

(a) State which metal alloy

(i) has the lowest Young modulus .....D..... $E = \frac{\text{stress}}{\text{strain}}$ = gradient

(ii) has the highest tensile strength .....A..... Highest breaking stress

(iii) has the greatest plastic region .....B..... (Largest strain)

[3]

(b) **(i)** Calculate the Young modulus for alloy **C**.

$$E = \frac{\text{stress}}{\text{strain}} = \text{gradient} = \frac{1.5\times10^9}{0.037} = 4.05\times10^{10}$$

Young modulus = ... 4.1×10^{10} ..... Pa **[2]**

(3.9 – 4.1)

(ii) A cable made of alloy **C** of length 420 m is stretched until its strain is 0.0075.

Calculate the extension of this cable.

$$\text{strain} = \frac{\text{extension}}{\text{length}} \quad \therefore \quad \text{ext} = \text{strain} \times \text{length}$$
$$= 0.0075 \times 420 = 3.15$$

extension = ... 3.2 ..... m **[2]**

(c) Many objects are made of metal alloys. Two examples are **(i)** the cables for a lift and **(ii)** the section of a car which crumples during a collision.

State with reasons which alloy **A**, **B**, **C** or **D** you would choose for each application. Explain how its microstructure could lead to the desirable mechanical behaviour as shown on Fig. 9.1.

Use technical terms spelled correctly in your answer.

(i) the cables for a lift: alloy ....A....

It is strongest (has highest tensile strength) because alloying atoms pin dislocations in place preventing slip.

[3]

(ii) the section of a car which crumples during a collision: alloy ....B....

It has a large plastic region indicating it is tough. The large area under the graph represents the energy the material absorbs. It can do this because dislocations can move through the structure as atoms slide over each other.

[3]

10 Fig. 10.1 shows an image made with atoms using a scanning tunnelling microscope. The image is less than 100 atoms wide.

500 × 300 pixels

Image removed due to third party copyright restrictions

Each atom = 2mm diameter

Fig. 10.1

(a) The greyscale of the image has 16 alternative intensity levels.

(i) Show that 4 bits are needed for 16 levels.

$N = 2^b$ & $2^4 = 16$

[1]

(ii) Calculate the maximum number of bytes needed to store the image of Fig. 10.1.

$$\frac{500 \times 300 \times 4}{8} = 75000 \text{ bytes}$$

maximum number = ...75000.......... bytes **[2]**

(iii) The image from Fig. 10.1 is one frame from the movie, “A boy with his atom”. The movie lasts for 90 s at a rate of 5 images per second.

Calculate the maximum number of bytes needed to store the movie.

$75000 \times 90 \times 5 = 33.75 \times 10^6$ bytes

maximum number = ...34 Mbytes.......... bytes **[1]**

(b) The diameter of the atoms used to make the movie is 270 pm.

Take measurements from Fig. 10.1 to calculate the magnification of the atoms in this image.

$= \quad 2 \times 10^{-3} / 270 \times 10^{-12} \quad =$

magnification = 7.4×10^{6} **[1]**

(c) Use Fig. 10.1 to estimate the resolution of the image. Make your method clear.

??

Assume atom is 2×2 pixels

$\therefore$ resolution $= 270 \times 10^{-12} / 2 \quad =$

resolution = 1.3×10^{-10} m pixel^{-1} **[2]**

(d) A scanning tunnelling microscope (STM) positions a sharp tip at a height h above a flat surface as shown in Fig. 10.2a. When a p.d. is applied, there is a tiny 'tunnelling' current between the tip and the surface. The current varies rapidly with changes in h, as shown in Fig. 10.2b, so that small changes in h can be measured.

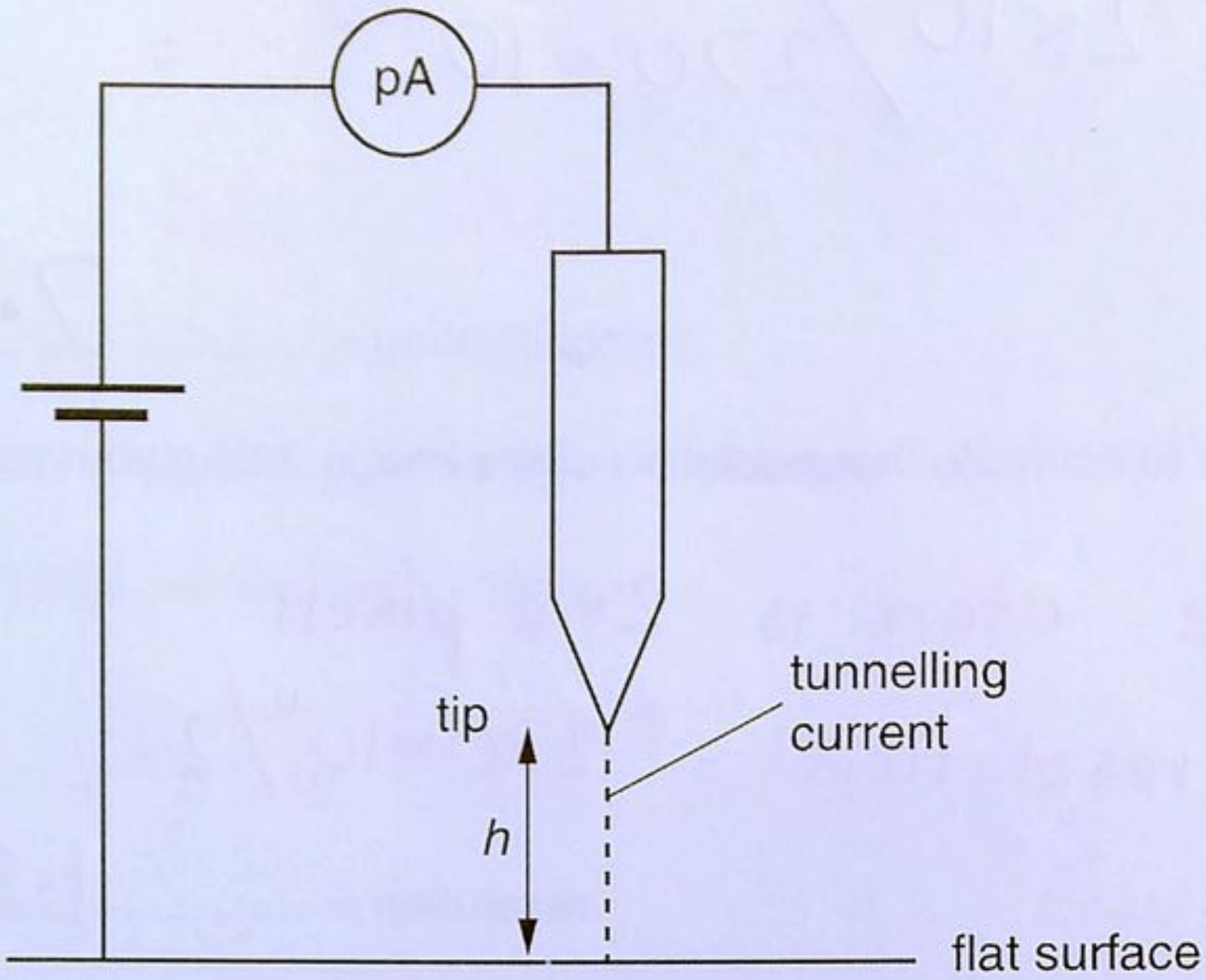


Fig. 10.2a

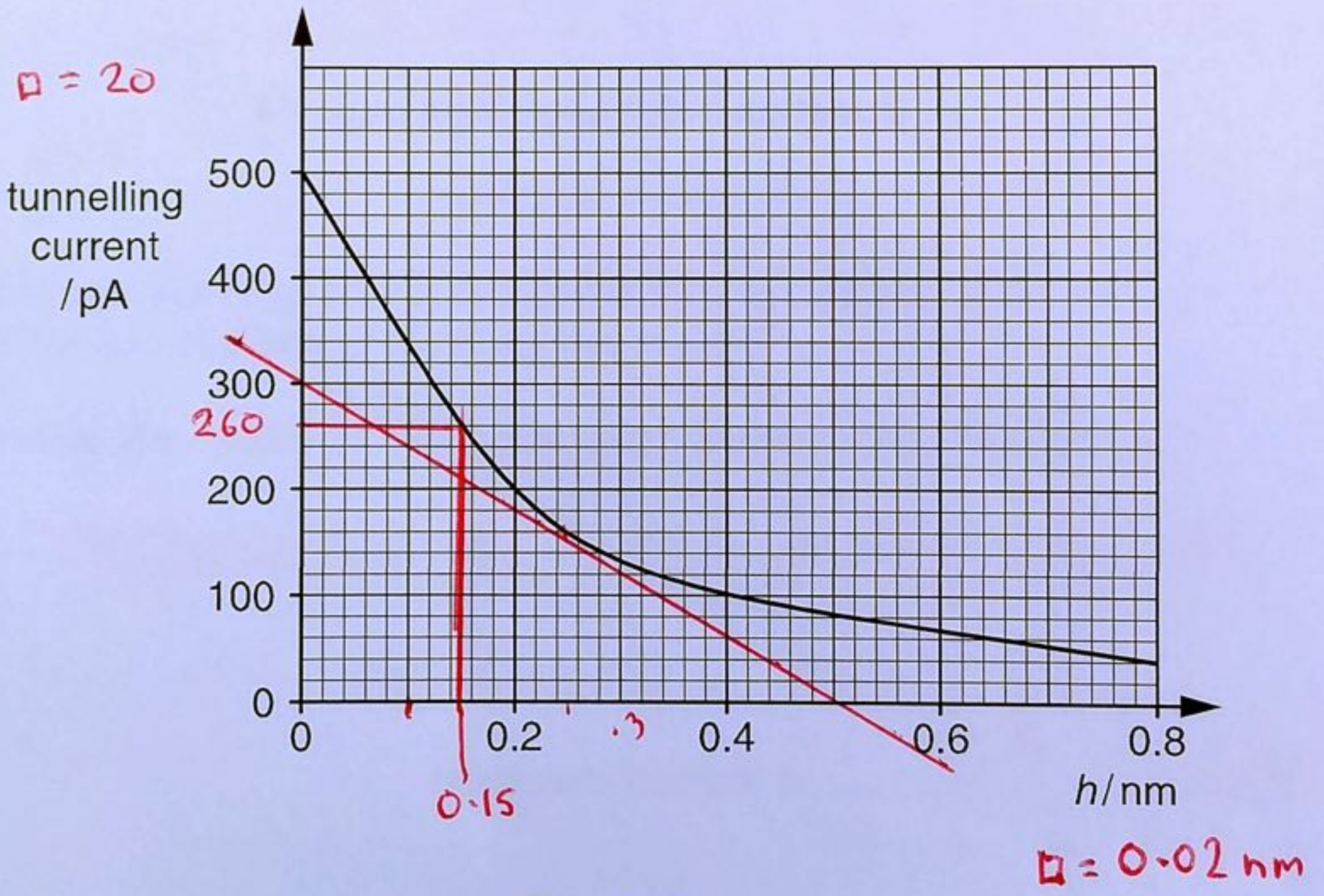


Fig. 10.2b

(i) The sensitivity of the STM is defined as the gradient of the graph. Calculate the sensitivity at height h of 0.25 nm which is about one atomic diameter.

gradient = 300 pA / 0·5 nm =

sensitivity = ...600...... pA nm^{-1} **[2]**

∴ gradient

(600–750)

(ii) Fig. 10.3 shows three atoms, of diameter 0.25 nm, on a surface. The tip of the STM is scanned across the surface at a constant height h of 0.40 nm above the surface.

0.40 − 0.25
= 0.15 nm

∴ I =

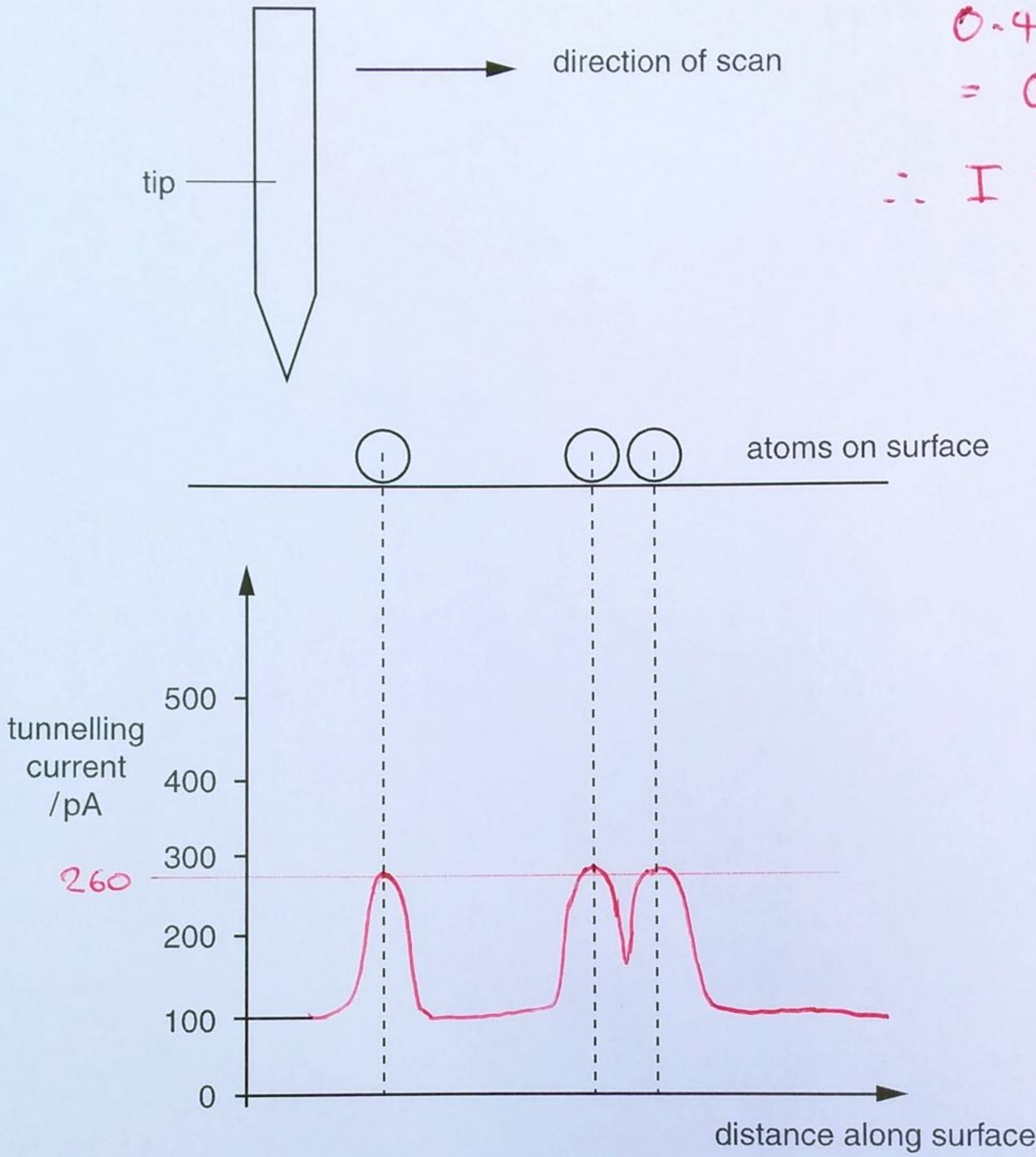


Fig. 10.3

On the axes shown on Fig. 10.3, use the data from 10.2b to draw the graph of tunnelling current against distance along the surface. The graph has been started for you. **[2]**

(iii) Suggest how the graph you have drawn in Fig. 10.3 shows how the image in Fig. 10.1 was produced.

The pixel value depends on the current.

[1]