Access Tuition

A-Level Physics

Measurements and Their Errors

Question Paper

Time available: 99 minutes
Marks available: 72 marks

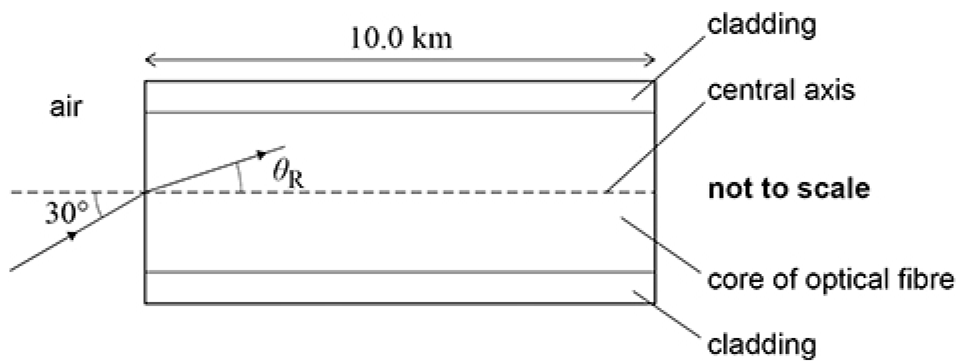
1. Optical fibres are used to carry pulses of light.

(a) Explain what is meant by modal dispersion in an optical fibre.

(2)

Figure 1 shows a ray of light incident on the central axis of an optical fibre at an angle of incidence of 30°. The optical fibre is straight and horizontal and has a length of 10.0 km.

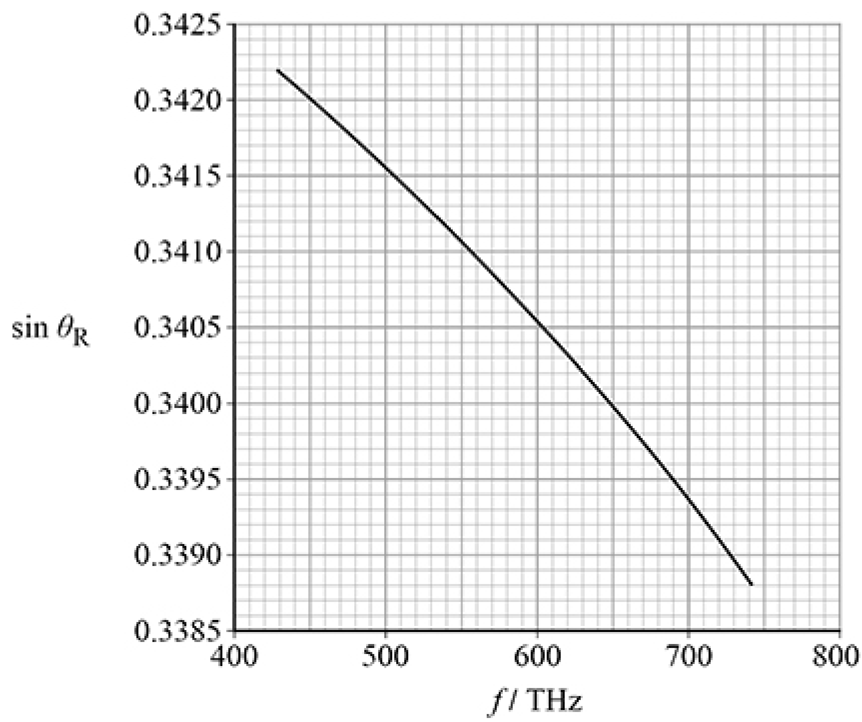
Figure 1



For light incident on the core at a given angle of incidence, the angle of refraction θ_R varies with the frequency f of the light.

Figure 2 shows how sin θ_R varies with f when the angle of incidence is 30°.

Figure 2



The transit time is the time between a pulse of light entering and leaving the optical fibre.
A single pulse of blue light is incident on the air−core boundary at an angle of incidence of 30°.

The transit time of this pulse along the 10 km length of the optical fibre is 5.225×10^{-5} s.

(b) Show that the horizontal component of the velocity of the pulse is approximately 1.9×10^8 $m\ s^{-1}$.

(1)

(c) The frequency of the blue light in the pulse is 720 THz.

Calculate the speed of the blue light in the core of the optical fibre.

speed = ________________ $m\ s^{-1}$

(3)

(d) Two pulses of monochromatic light are incident normally on the air−core boundary. They then travel along the central axis of the core.
One pulse consists of blue light; the other consists of red light.

Explain, with reference to refractive index, why the pulse of red light has a shorter transit time than the pulse of blue light.

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(2)

(e) Another two pulses, identical to the pulses in part (d), are incident on the central axis of the optical fibre and travel along its length.
However, the pulse of red light and pulse of blue light are now incident on the air−core boundary at an angle of incidence of 30°.

Suggest **one** reason why the difference in their transit times may **not** be the same as in part (d).

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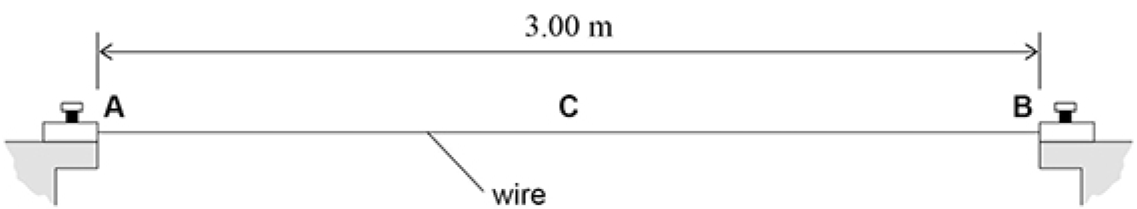
(1)
(Total 9 marks)

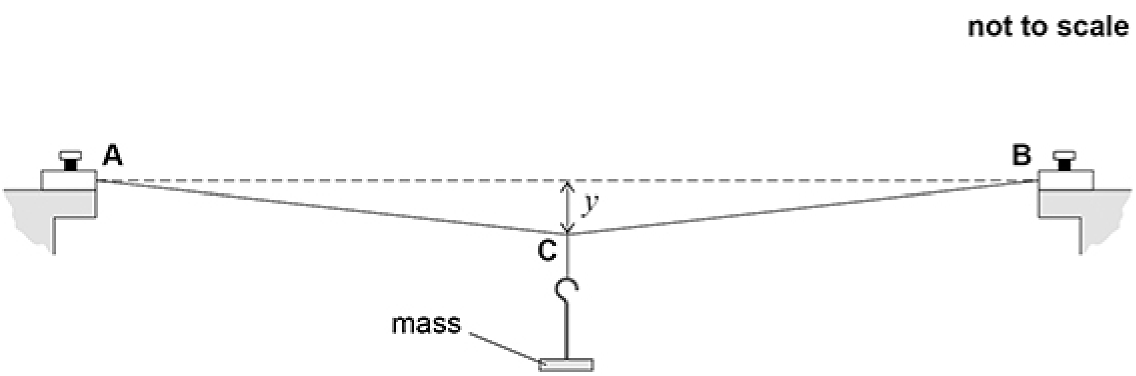
2. A student does an experiment to determine the Young modulus of a metal.
Figure 1 shows a wire made from the metal clamped at points **A** and **B** so that the wire is horizontal. The horizontal distance between **A** and **B** = 3.00 m.
C is the mid-point on the wire between **A** and **B**.

Figure 1



A mass of weight W is suspended at **C** to extend the wire. **Figure 2** shows that **C** moves vertically downwards by a distance y.

Figure 2



(a) When W is 1.0 N, y is 6.34 cm.

Show that the wire extends by approximately 3 mm.

(1)

(b) Calculate the tension in the wire when W is 1.0 N.

tension = _______________ N

(2)

It can be shown that

$$\frac{W}{y} = \frac{EAy^2}{x^3} + k$$

where E = Young modulus of the metal

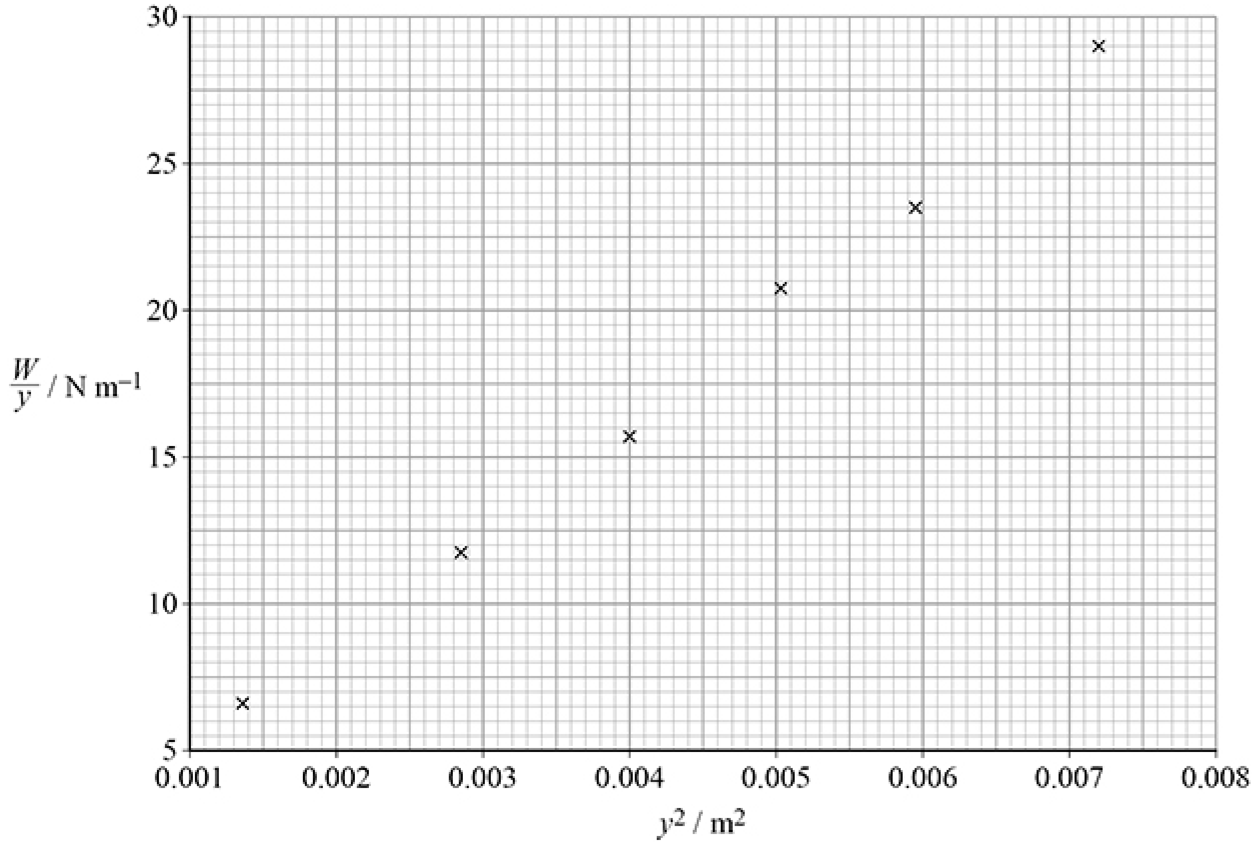
$A = 1.11 \times 10^{-7}$ m^2

x = 1.50 m

k = a constant.

A student measures y for different values of W and plots the graph shown in **Figure 3**.

Figure 3



(c) Determine E using **Figure 3**.

E = _______________ Pa

(4)

(d) Deduce the fundamental base units for k.

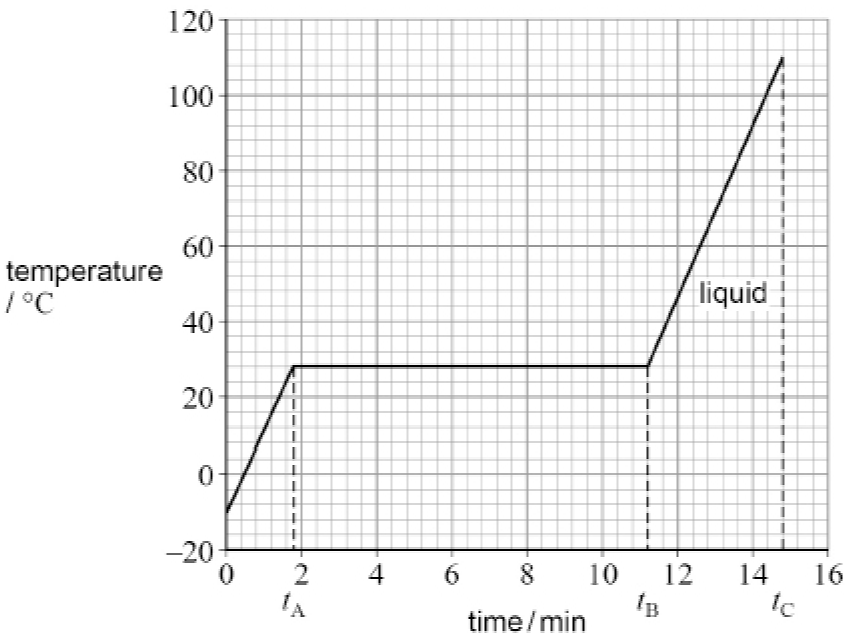
fundamental base units for k = _______________

(1)

(Total 8 marks)

3. A perfectly insulated flask contains a sample of metal **M** at a temperature of –10 °C.

The figure shows how the temperature of the sample changes when energy is transferred to it at a constant rate of 35 W.



(a) State the melting temperature of **M**.

temperature = _______________ °C

(1)

(b) Explain how the energy transferred to the sample changes the arrangement of the atoms during the time interval t_A to t_B.

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(1)

(c) State what happens to the potential energy of the atoms and to the kinetic energy of the atoms during the time interval t_A to t_B.

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(2)

(d) Describe how the motion of the atoms changes during the time interval t_B to t_C.

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(1)

(e) The sample has a mass of 0.25 kg.

Determine the specific heat capacity of **M** when in the liquid state. State an appropriate SI unit for your answer.

specific heat capacity = _______________ unit = __________

(3)

(f) The table shows the specific latent heats of fusion l for elements that are liquid at similar temperatures to **M**.

Element	Caesium	Gallium	Mercury	Rubidium
l / **kJ kg^{-1}**	16	80	11	26

M is known to be one of the elements in the table above.

Identify **M**.

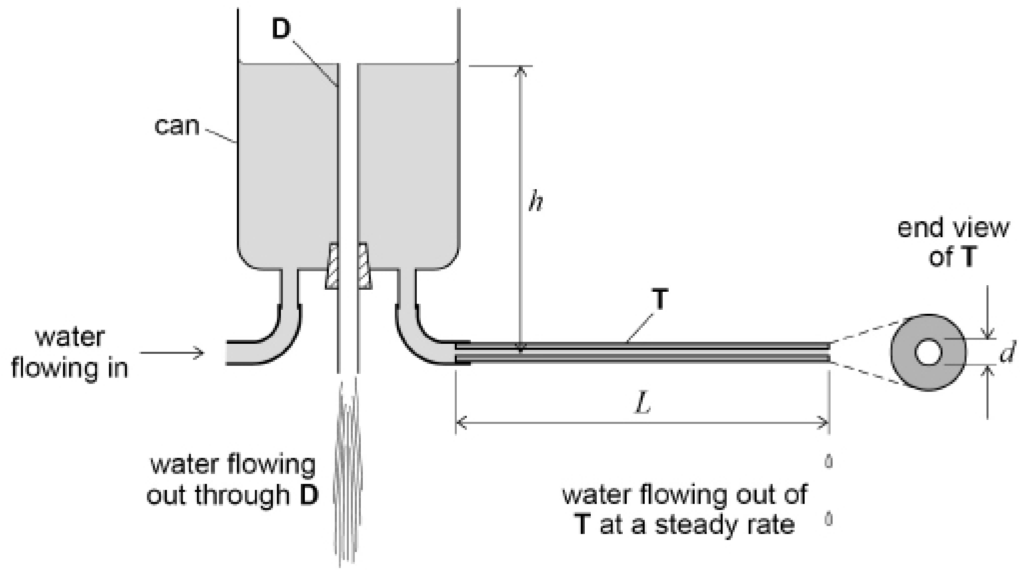
M = _______________

(2)

(Total 10 marks)

4. **Figure 1** shows apparatus used to investigate the rate at which water flows through a horizontal cylindrical tube **T** of internal diameter d and length L.

Figure 1



The apparatus ensures that the water level in the can is at a constant height h above the centre of **T**.

Water flows out of **T** at a steady rate.

(a) The volume flow rate through **T** is Q, where Q is in $m^3\ s^{-1}$.
A student wants to measure Q as water flows through **T**.

Outline a procedure the student should follow to measure Q.
Include in your answer

- the measuring instruments used
- how uncertainty in the measurements can be reduced.

(4)

(b) It can be shown that

$$Q = \frac{\pi \rho g h d^4}{128 L \eta}$$

where ρ is the density of water
g is the gravitational field strength
η is a property of the water called the coefficient of viscosity.

What is the SI unit for η?

Tick (✓) **one** box.

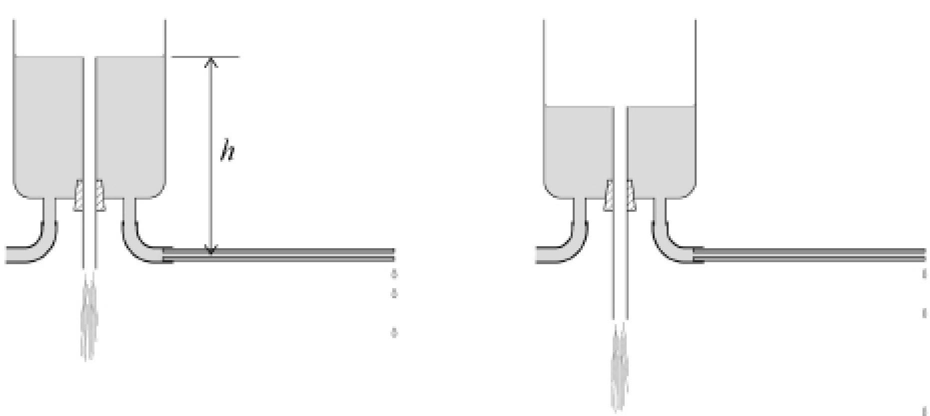
$N\ m^{-1}\ s$	☐
$N\ m^{-2}\ s$	☐
$N\ m^{-1}\ s^{-1}$	☐
$N\ m^{-2}\ s^{-1}$	☐

(1)

(c) An experiment is carried out to determine η by a graphical method.

The rate at which water flows out of **T** is varied by adjusting the height of the drain tube as shown in **Figure 2**.

Figure 2



During the experiment the temperature is kept constant.

Q is found for different values of h and a graph of these data is plotted, with Q on the vertical axis.

The percentage uncertainty in the gradient of the graph is 6.4%.

The dimensions of tube **T** are measured and the uncertainties in these data are calculated.

The percentage uncertainty

- in d is 2.9%
- in L is 1.8%.

The percentage uncertainties in ρ and g are negligible.

Deduce the percentage uncertainty in the result for η.

percentage uncertainty in η = ____________________

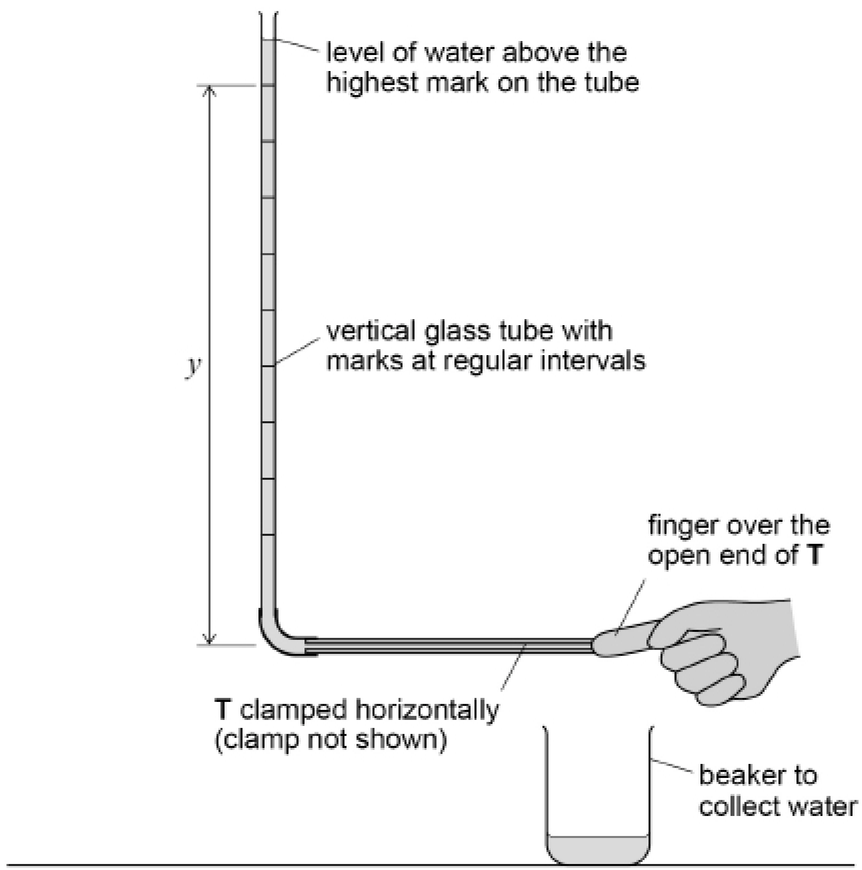
(2)

(d) In a different experiment, the horizontal tube **T** is connected to a vertical glass tube.
Marks have been made at regular intervals on the glass tube.

The student measures and records the vertical distance y between each of the marks and the centre of **T**.

She seals the open end of **T** and fills the glass tube with water, as shown in **Figure 3**.

Figure 3



T is opened and water flows into a beaker.
When the water level falls to the highest mark on the tube, she starts a stopwatch.
She records the time t for the water to reach each of the other marks.

Explain how the student could check that the glass tube was vertical.
You may wish to add detail to **Figure 3** to illustrate your answer.

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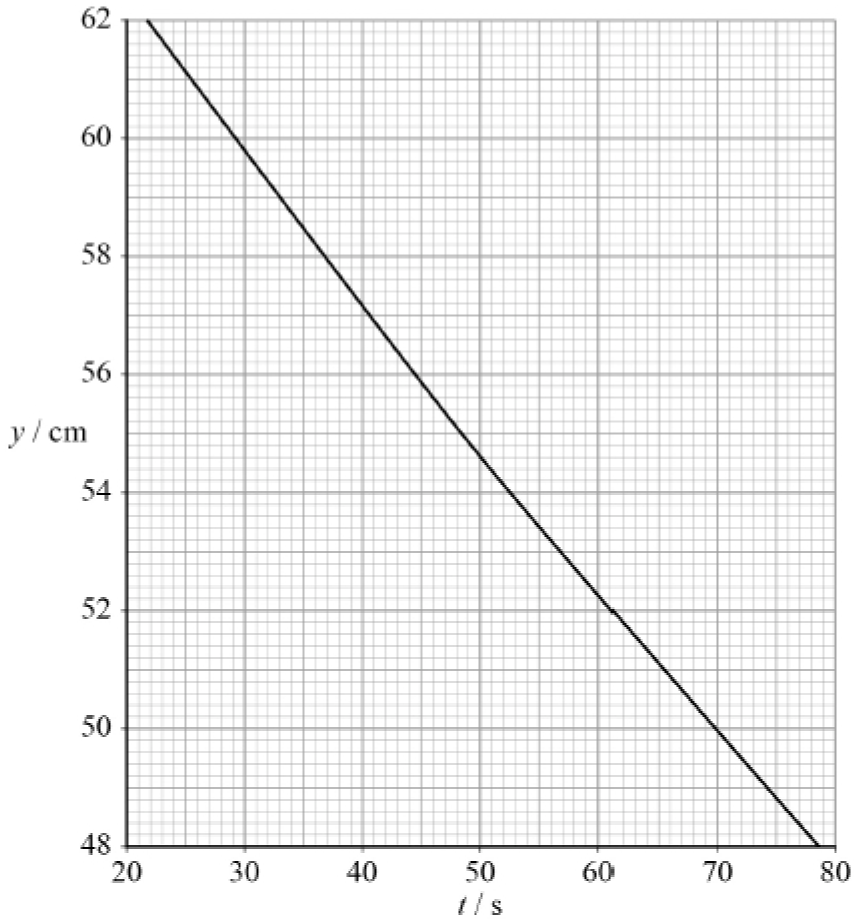
(1)

(e) **Figure 4** shows part of the graph drawn from the student's data.

Figure 4



It can be shown that y decreases exponentially with t.

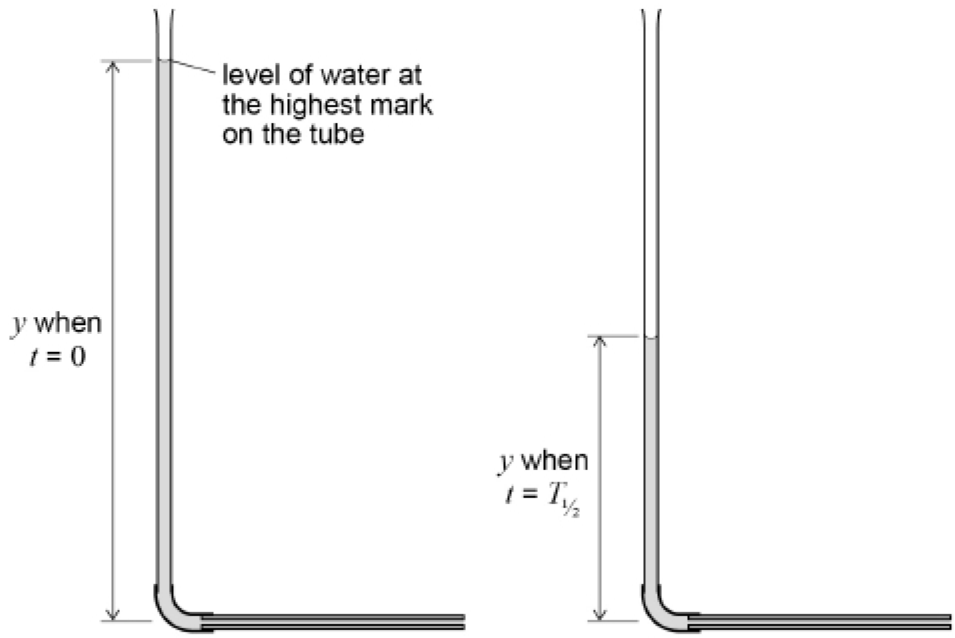
Show that λ, the decay constant for this process, is about 4.5×10^{-3} s^{-1}.

λ = ____________________ s^{-1}

(2)

(f) $T_{½}$ is the time for y to decrease by 50%, as shown in **Figure 5**.

Figure 5

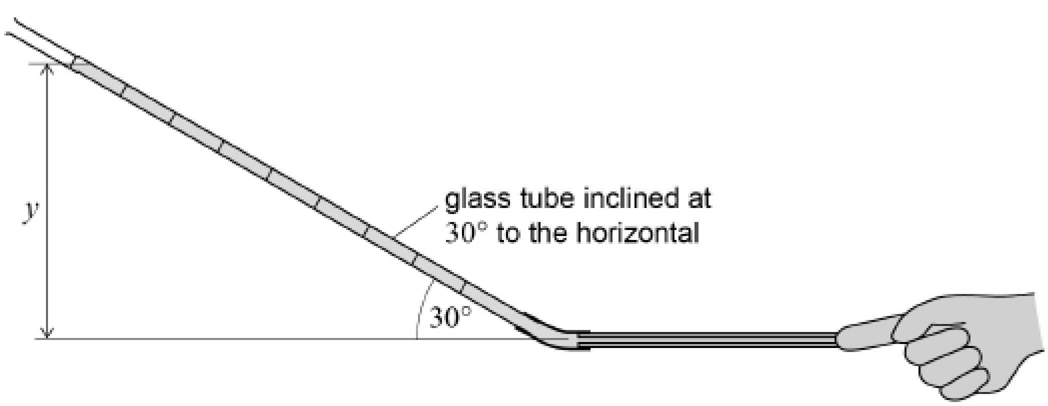


$T_{½}$ = ______________________ s

(1)

(g) The apparatus is adjusted so that the glass tube is inclined at 30° to the horizontal tube **T**, as shown in **Figure 6**.

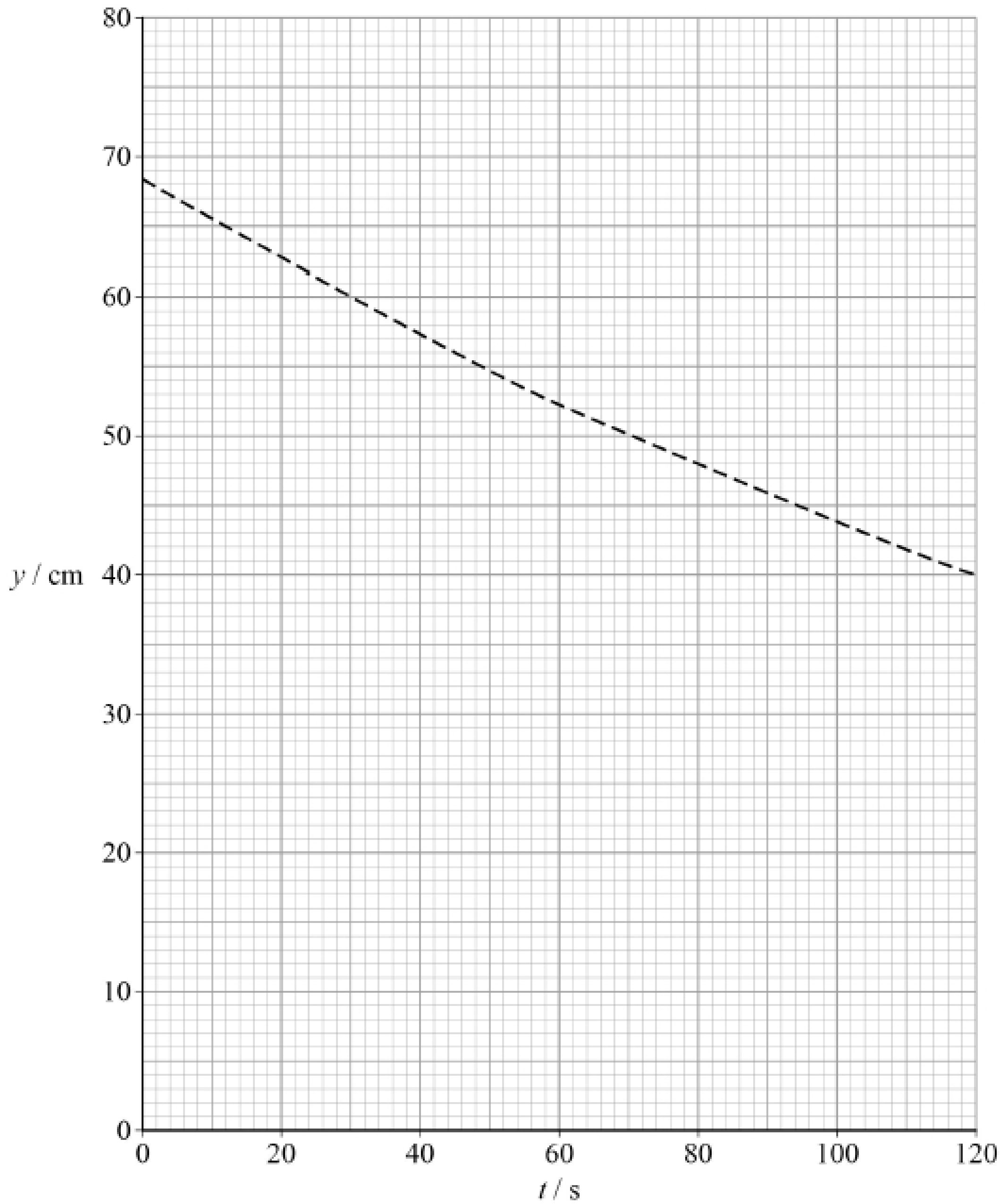
Figure 6



The student measures and records the new values of y, the mean vertical distance between each of the marks and the centre of **T**.
She then carries out the experiment as before, recording new values of t corresponding to each new value of y.

Draw a line on **Figure 7** to show the graph produced using the modified apparatus.
The dashed line is the original graph when the glass tube was vertical as shown in **Figure 3**.

Figure 7

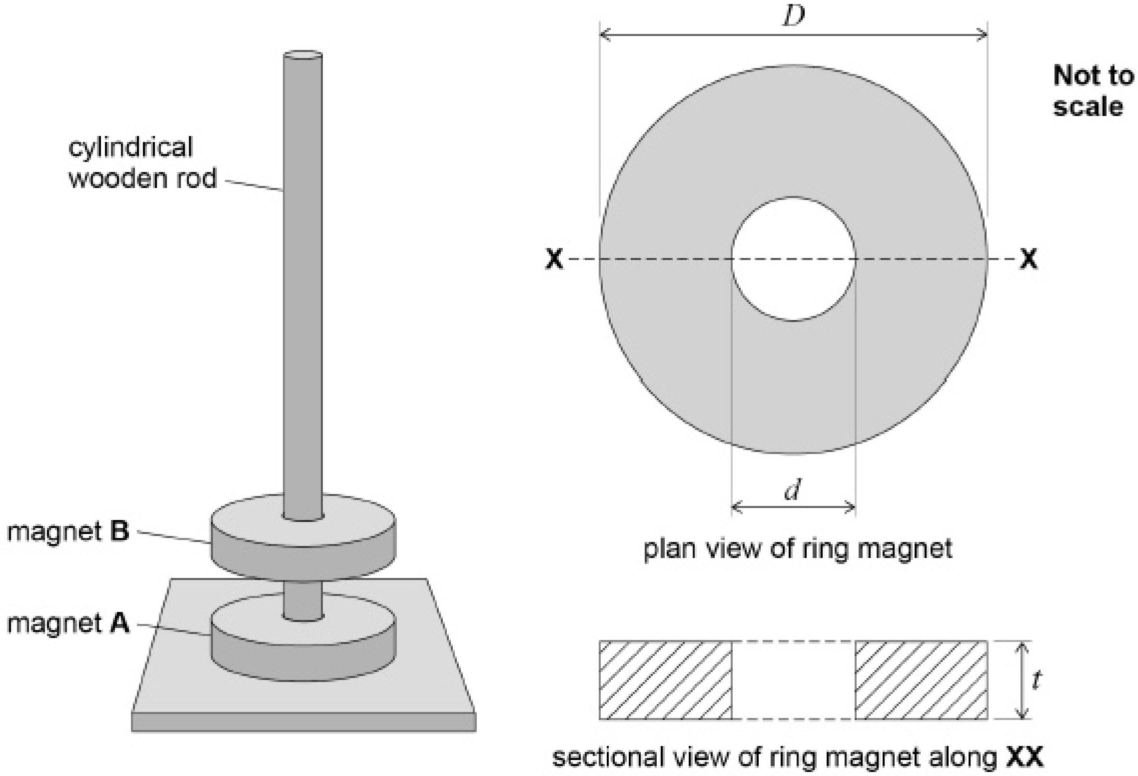


(2)
(Total 13 marks)

5. Identical ring magnets **A** and **B** are arranged on a cylindrical wooden rod. The magnets' magnetic poles are on their largest faces. When placed with like poles in opposition, the magnets repel one another as shown in **Figure 1**.

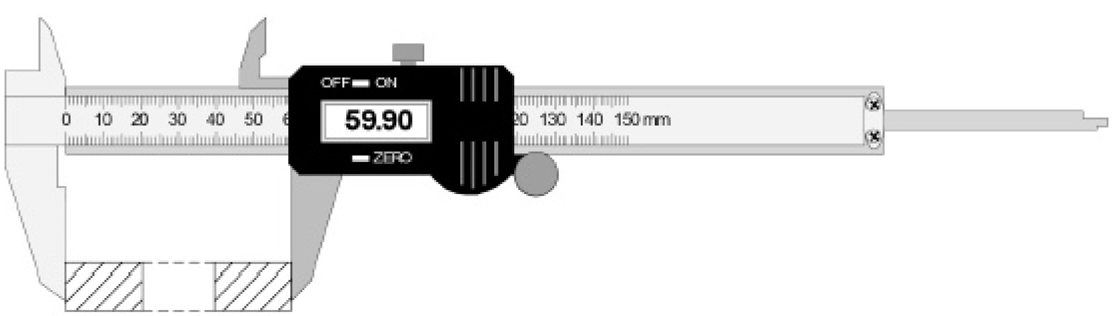
The plan and sectional views in **Figure 1** identify the dimensions of these magnets. Each magnet has a circular cross-section and the central hole is circular.

Figure 1



(a) A student uses digital vernier calipers to find the external diameter D of magnet **B**, as shown in **Figure 2**.

Figure 2



State precautions the student should take to reduce the effect of systematic and random errors when making this measurement.

Precaution to reduce effect of systematic error:

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Precaution to reduce effect of random error:

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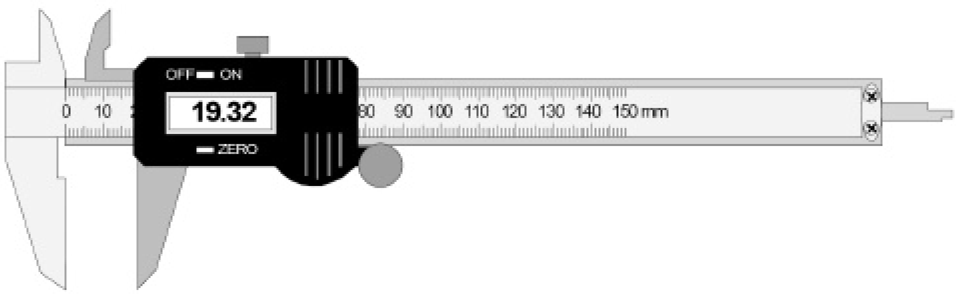
(2)

(b) **Figure 3** shows the reading on the calipers as the internal diameter d is measured.

Draw the sectional view of magnet **B** on **Figure 3** to indicate how d is measured.

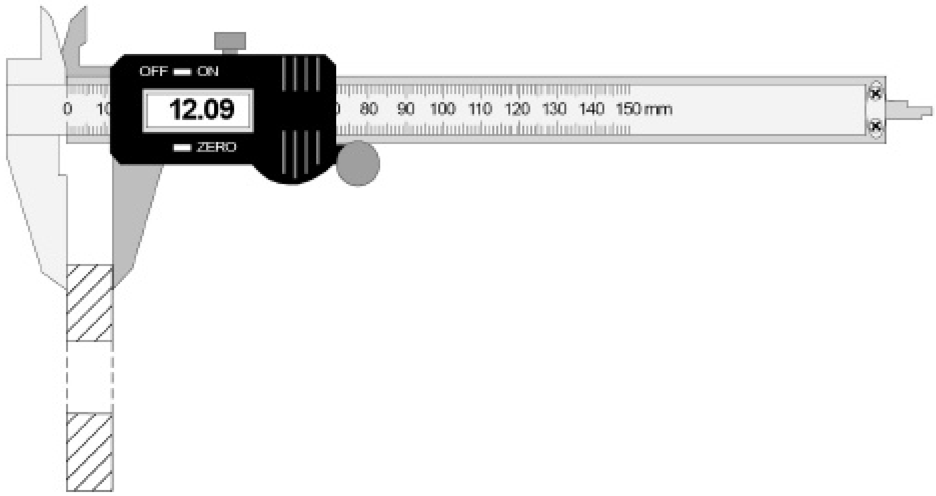
Figure 3



(1)

(c) **Figure 4** shows the reading on the calipers when the thickness t of magnet **B** is measured.

Figure 4



The readings that correspond to the dimensions of magnet **B** are shown in **Figures 2**, **3** and **4**.

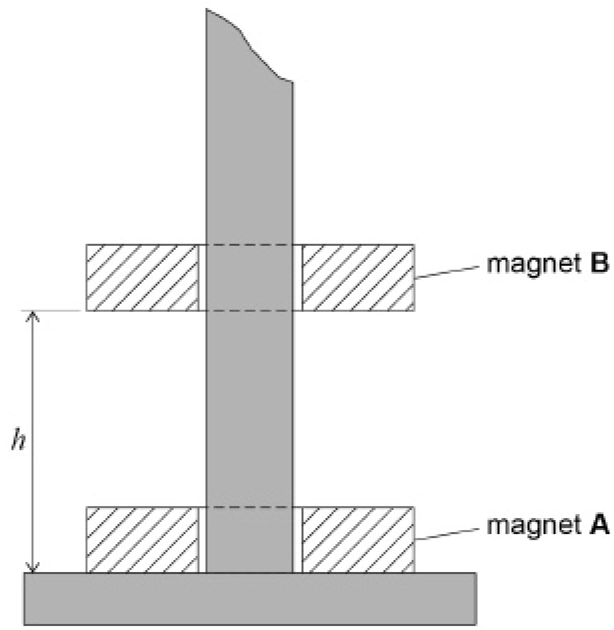
Calculate the volume of magnet **B**.

volume = ____________________ m^3

(3)

(d) The student measures the mass m_B of magnet **B** and then positions the magnet so it is in equilibrium above magnet **A** as shown in **Figure 5**.
The student measures the distance h.

Figure 5



The student adds modelling clay to magnet **B** to reduce h by 50%
She measures the mass m_C of this clay.

She concludes that the force F exerted on magnet **B** by magnet **A** is given by $F = \frac{k}{h^3}$

where k is a constant.

Describe an experiment to test the student's conclusion that $F = \frac{k}{h^3}$

Your answer should include:

- the procedure that could be used
- how the data produced could be analysed by a graphical method
- how the value of the constant k could be determined.

(5)

(Total 11 marks)

6. A radioactive source emits alpha particles each with 8.1×10^{-13} J of kinetic energy.

(a) Show that the velocity of an alpha particle with kinetic energy 8.1×10^{-13} J is approximately 2×10^{7} m s^{-1}

specific charge of an alpha particle = 4.81×10^{7} C kg^{-1}

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(2)

(b) The alpha particles travel through air in straight lines with a range of 3.5 cm

Calculate the average force exerted on an alpha particle as it is stopped by the air.

average force = ____________________ N

(2)

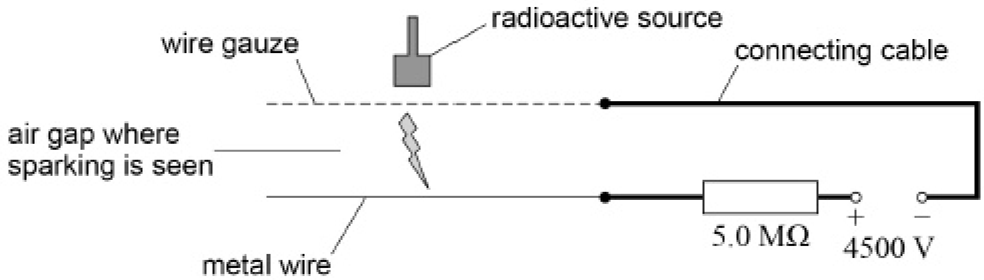
(c) An alpha particle transfers all its kinetic energy to air molecules and produces 5.1×10^{4} ions per centimetre over its range of 3.5 cm

Calculate the average ionisation energy, in eV, of a molecule of air.

ionisation energy = ____________________ eV

(3)

(d) A spark counter consists of a wire gauze separated from a metal wire by a small air gap. A power supply with an output of 4500 V is connected in series with a 5.0 MΩ resistor and the spark counter as shown in the diagram. When the radioactive source is moved close to the wire gauze, sparking is seen in the air gap.



Sparks are produced when alpha particles produce ionisation in the air gap.

One ionisation event produces a current of 0.85 mA for a time of 1.2 ns

Calculate the number of charge carriers that pass a point in the connecting cable during this ionisation event.

number of charge carriers = ____________________

(2)

(e) The radioactive source was positioned 10 cm above the wire gauze before being moved slowly towards the wire gauze leading to the ionisation event in part **(d)**.

Discuss how the potential difference across the air gap varied as the radioactive source was moved over this distance.

Assume the power supply has negligible internal resistance.

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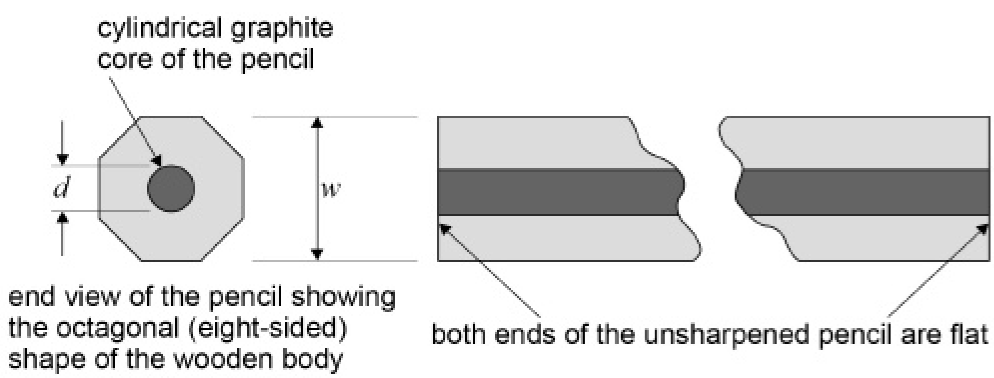
(3)
(Total 12 marks)

7. A pencil, unsharpened at both ends, has a cylindrical graphite core of uniform diameter d surrounded by an octagonal (eight-sided) wooden body.

Figure 1 shows an end view and a cross-sectional slice along the length of the pencil.

Figure 1



(a) A student used a micrometer to measure the width w at several points along the length of the pencil.

Explain why the student used this procedure to determine a value for w.

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(1)

(b) The student's results are shown in the table.

w_1 / mm	w_2 / mm	w_3 / mm	w_4 / mm	w_5 / mm
7.23	7.10	7.06	7.20	7.16

Determine the percentage uncertainty in the result the student obtains for w.

percentage uncertainty = ______________________________ %

(2)

(c) The cross-sectional area A of the end of the pencil is given by

$$A = 0.83\, w^2$$

The volume of the cylindrical core is known to be 9.0% of the volume of the unsharpened pencil.
The cylindrical core of the graphite has a diameter d.

Determine d.

d = ____________________________ mm

(2)

(d) A student investigates the rate at which a similar pencil wears away through use.

The student measures the length of the pencil using a sliding vernier scale placed alongside a fixed scale. The fixed scale has a precision of 1 mm.

Figure 2 shows the vernier scale in the zero position.

Figure 3 shows the pencil (which is now sharpened) placed next to the fixed scale.

The position of the vernier scale is adjusted so that the length of the pencil can be read.

Read and record the length of the pencil shown in **Figure 3**.

length of pencil = ____________________________ mm

(1)

(e) The pencil is then removed from the scale and is used to draw 20 lines on a sheet of paper. Each line has a length 25 cm.

The pencil is then replaced next to the fixed scale and the vernier scale adjusted so the new length of the pencil can be read, as shown in **Figure 4**.

Read and record the new length of the pencil shown in **Figure 4**.

new length of pencil = ____________________________ mm

(1)

(f) $L_{1/2}$ is the length of the line that could be drawn which would cause the original length of the pencil to be halved.

Calculate $L_{1/2}$.

Ignore any decrease in length as a result of sharpening the pencil.

$L_{1/2}$ = ______________________________ m

(2)

Figure 2

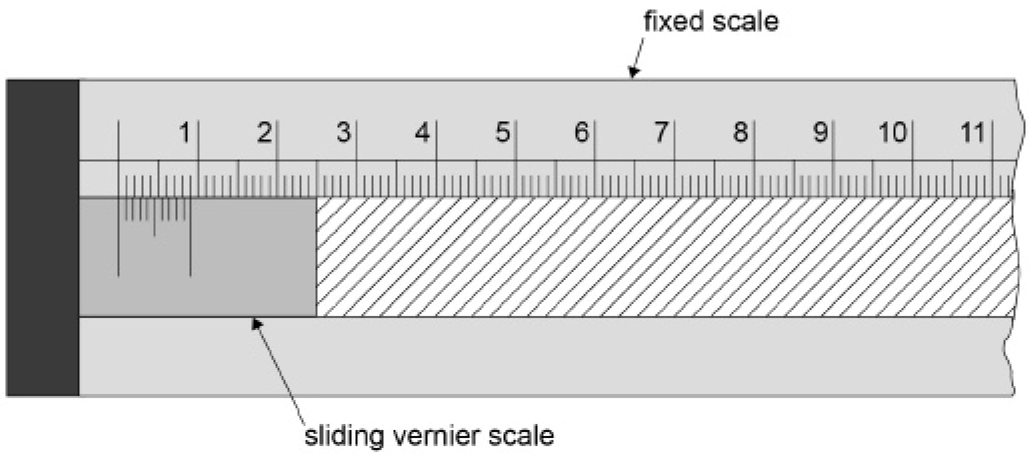


Figure 3

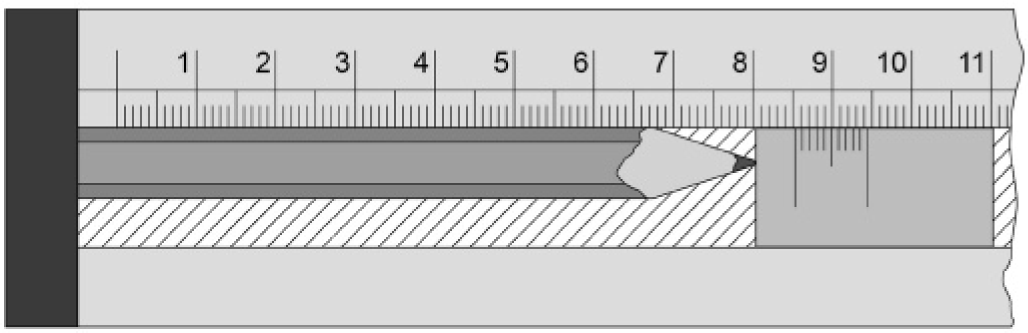
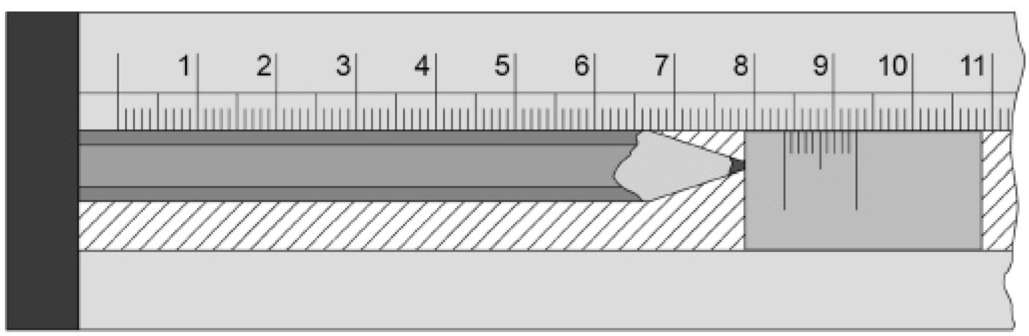


Figure 4



(Total 9 marks)