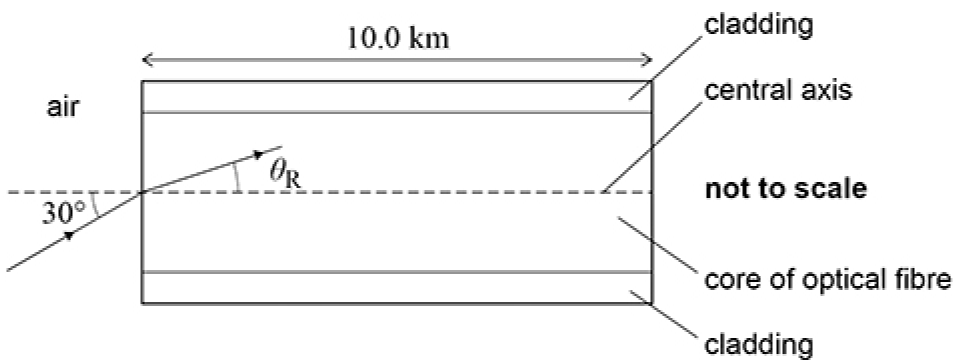
1. Optical fibres are used to carry pulses of light.

(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.

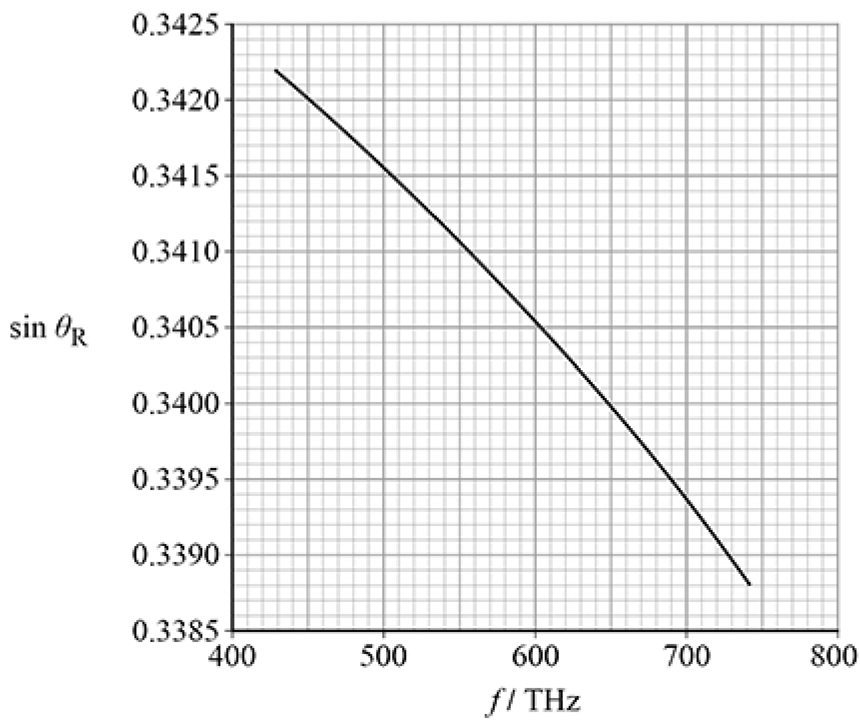
Figure 1



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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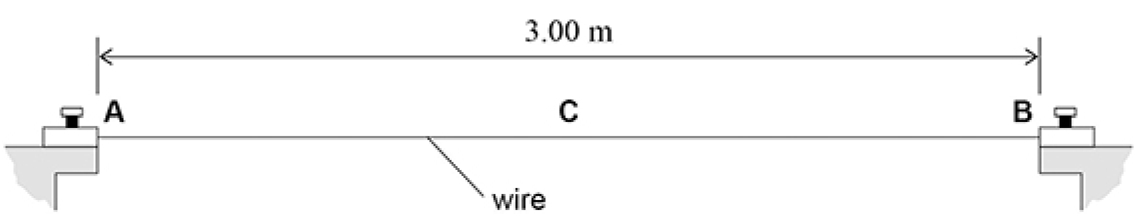
(1)
(Total 9 marks)

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**.

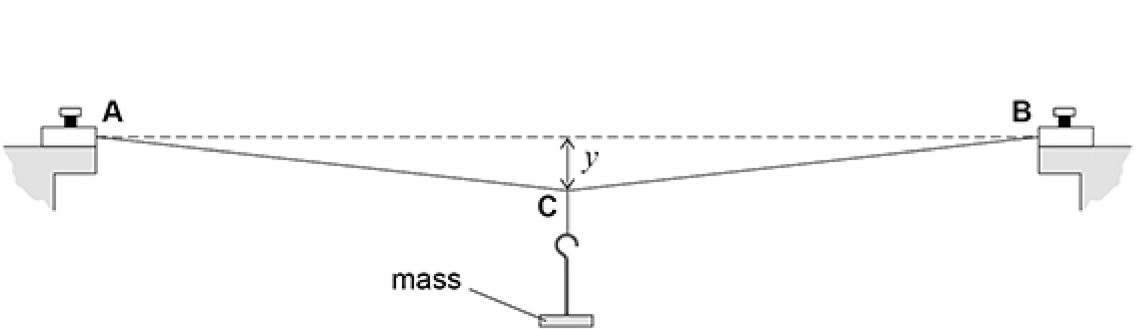
Figure 1



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

not to scale



(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

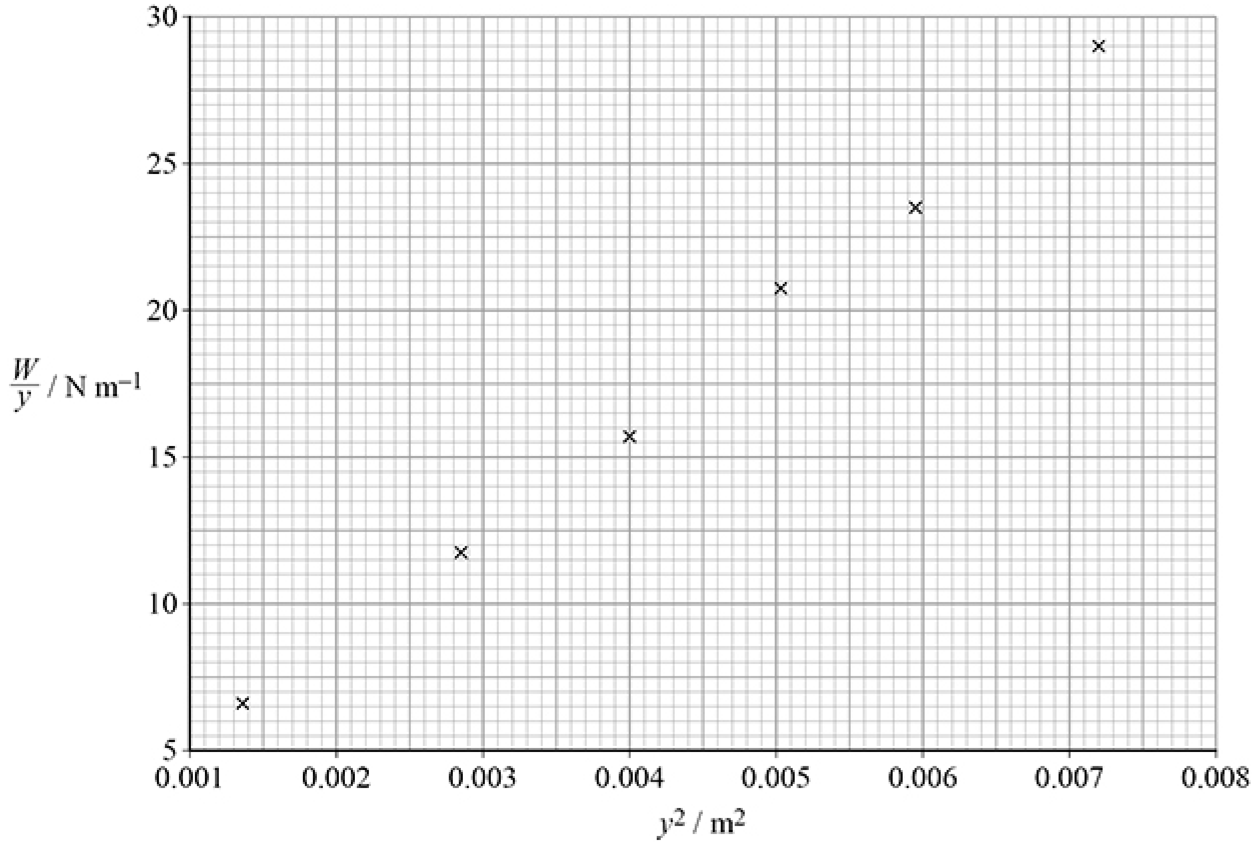
$A = 1.11 \times 10^{-7}\ \text{m}^2$

$x = 1.50$ 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.

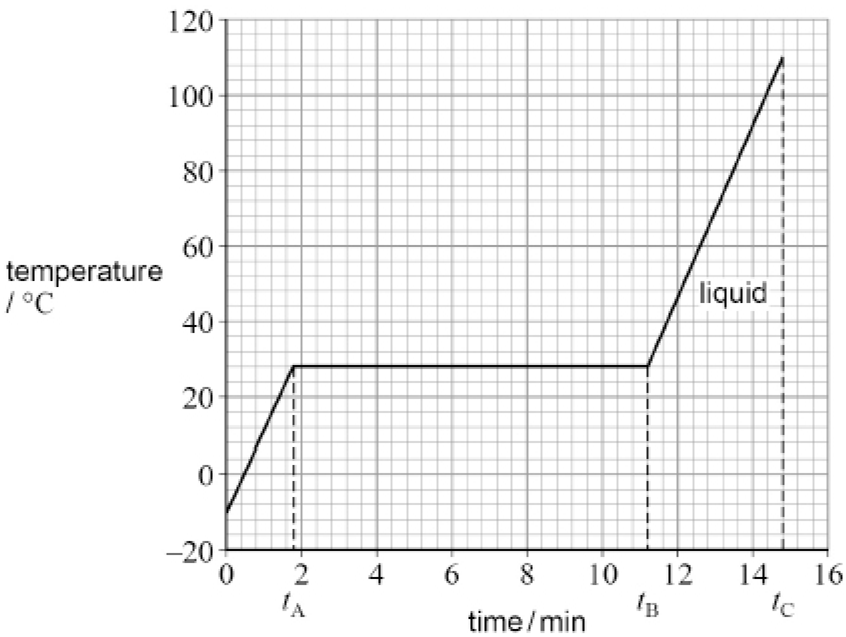
fundamental base units for k = _______________

(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.

(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.

(2)

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

(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**.

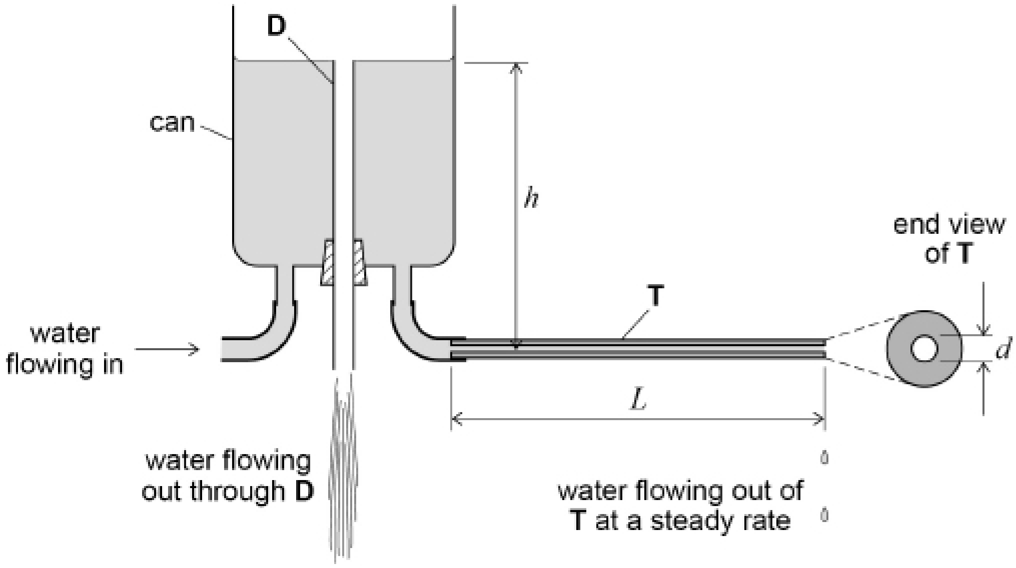
M = _______________

(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.

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(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} ☐

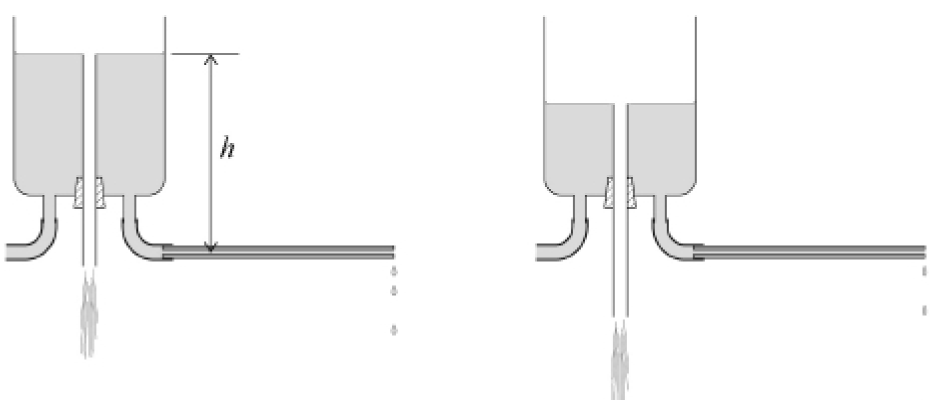
N m^{-2} s^{-1} ☐

(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 = ____________________

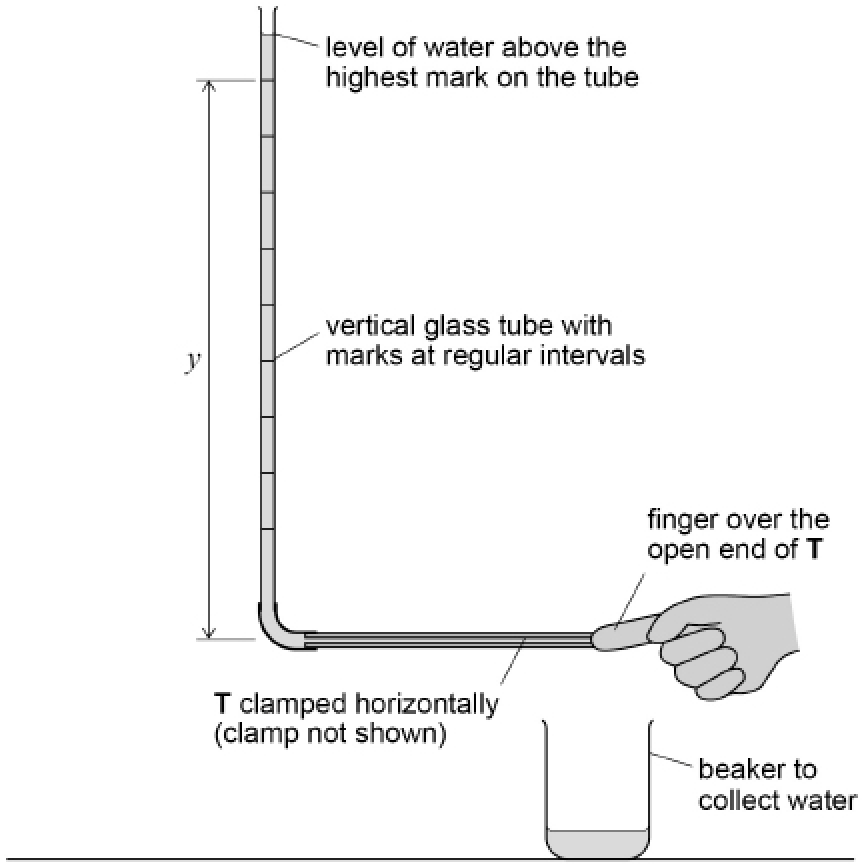
(2)

(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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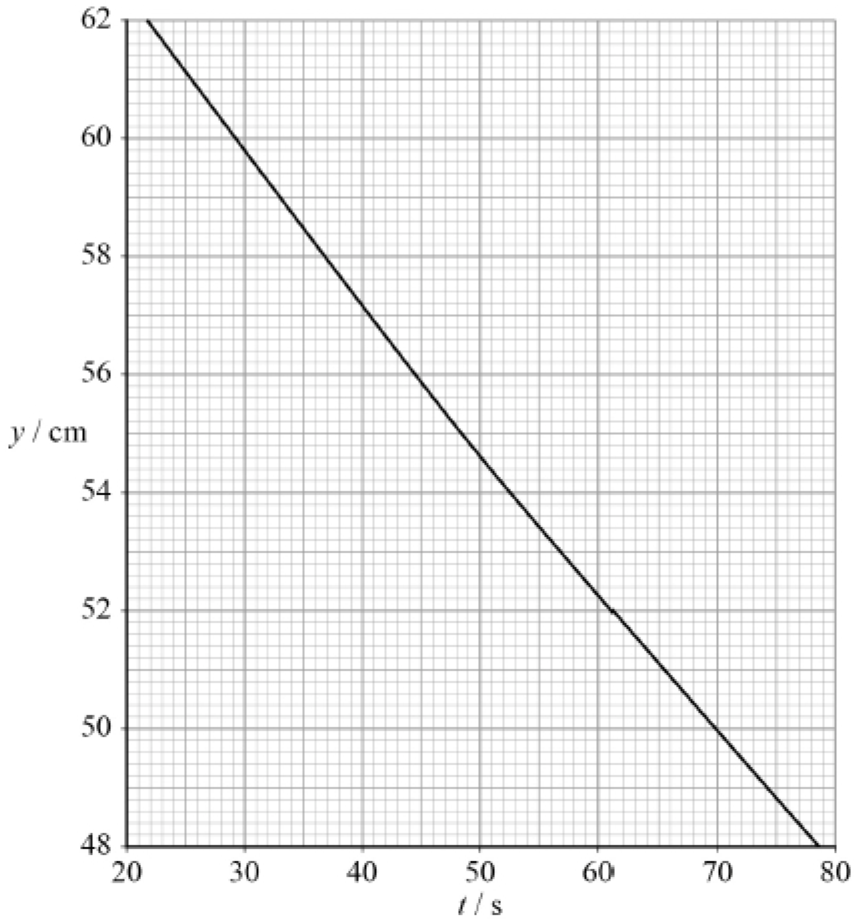
(1)

(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.

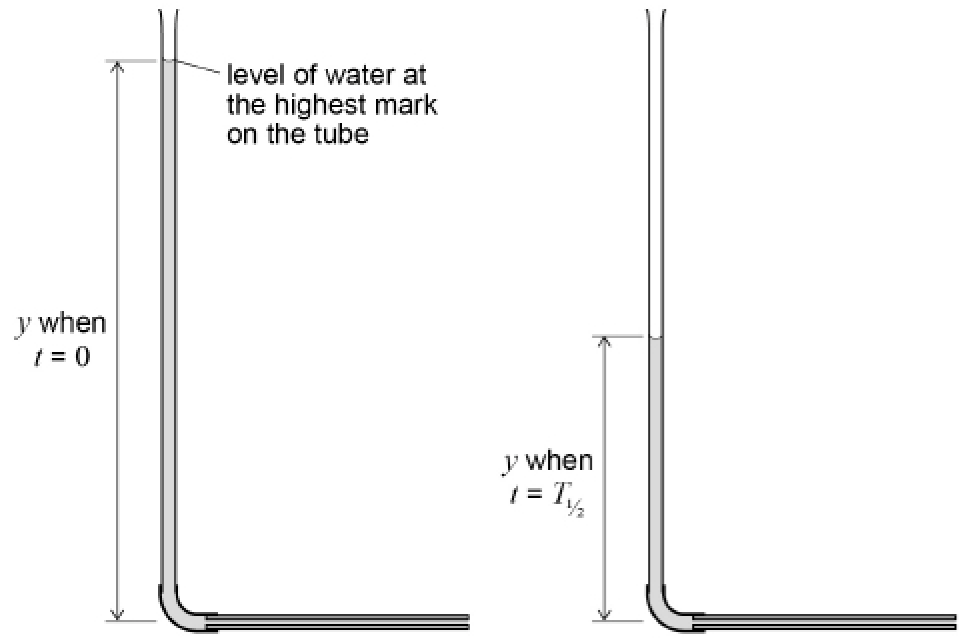
Show that λ, the decay constant for this process, is about 4.5×10^{-3} s^{-1}.

λ = ______________________ s^{-1}

(2)

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

Figure 5

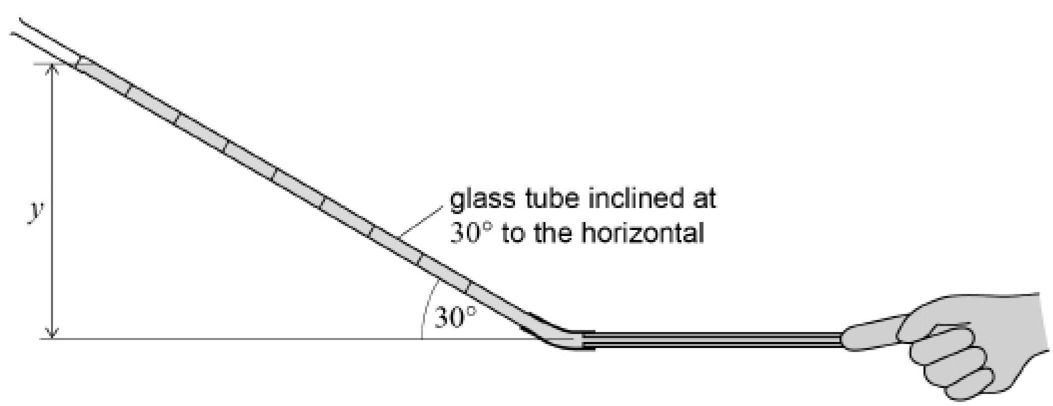


$T_{½}$ = ______________________ s

(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**.

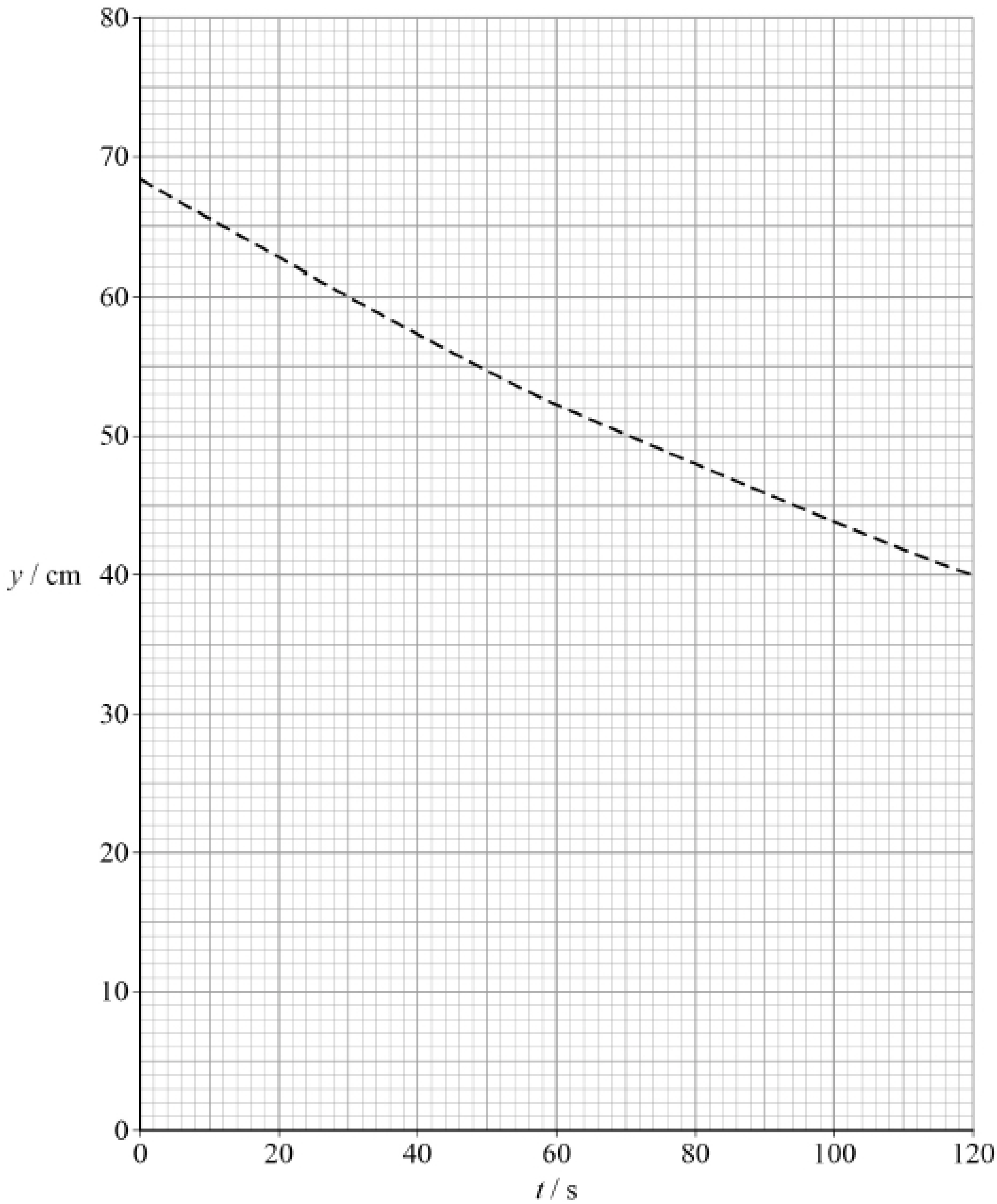
Figure 6



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. 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)

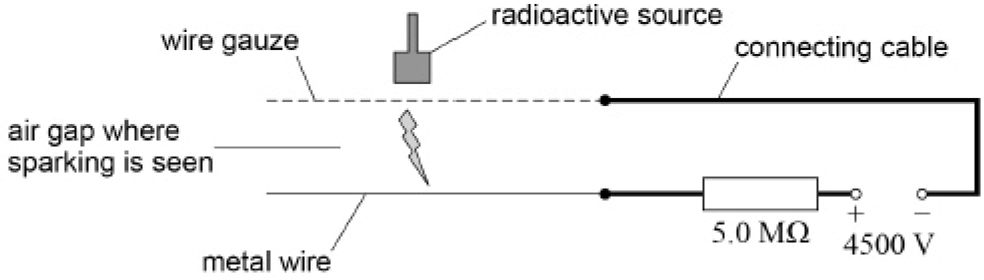
(c) An alpha particle transfers all its kinetic energy to air molecules and produces 5.1×10^{4} ions per centimetre over its range of 3.5 cm

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)

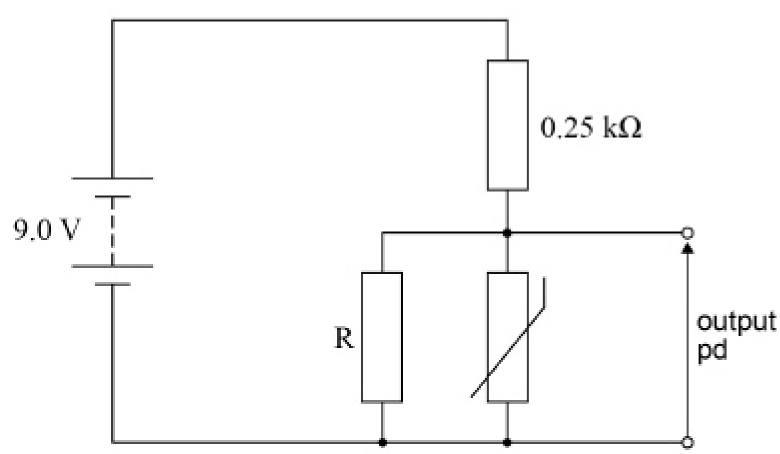
(e) The radioactive source was positioned 10 cm above the wire gauze before being moved slowly towards the wire gauze leading to the ionisation event in part **(d)**.

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.

(3)
(Total 12 marks)

6. The diagram shows a circuit designed by a student to monitor temperature changes.



The supply has negligible internal resistance and the thermistor has a resistance of 750 Ω at room temperature. The student wants the output potential difference (pd) at room temperature to be 5.0 V

(a) The 0.25 kΩ resistor is made of 50 turns of wire that is wound around a non-conducting cylinder of diameter 8.0 mm

Resistivity of the wire = 4.2×10^{-7} Ω m

Determine the area of cross-section of the wire that has been used for the resistor.

area of cross-section = ____________________ m^2

(3)

(b) The student selects a resistor rated at 0.36 W for the 0.25 kΩ resistor in the diagram.

Determine whether this resistor is suitable.

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(2)

(c) Determine the value of R that the student should select.

Give your answer to an appropriate number of significant figures.

value of R = ____________________ Ω

(5)

(d) State and explain the effect on the output pd of increasing the temperature of the thermistor.

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(2)

(Total 12 marks)

7. The diagram shows two railway trucks **A** and **B** travelling towards each other on the same railway line which is straight and horizontal.

The trucks are involved in an inelastic collision. They join when they collide and then move together.

The trucks move a distance of 15 m before coming to rest.

Truck **A** has a total mass of 16 000 kg and truck **B** has a total mass of 12 000 kg

Just before the collision, truck **A** was moving at a speed of 2.8 m s^{-1} and truck **B** was moving at a speed of 3.1 m s^{-1}

(a) State the quantity that is **not** conserved in an inelastic collision.

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(1)

(b) Show that the speed of the joined trucks immediately after the collision is about 0.3 m s^{-1}

(3)

(c) Calculate the impulse that acts on each truck during the collision.
Give an appropriate unit for your answer.

impulse = ____________________ unit ___________

(2)

(d) Explain, without doing a calculation, how the motion of the trucks immediately after the collision would be different for a collision that is perfectly elastic.

(2)

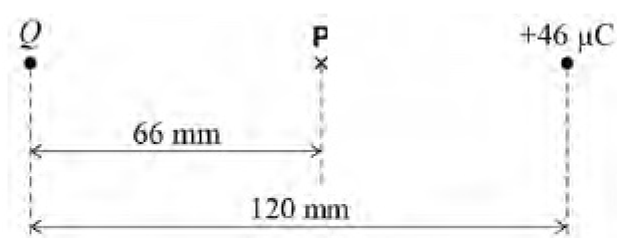
(Total 8 marks)

8. (a) Define the electric field strength at a point in an electric field.

(2)

(b) **Figure 1** shows a point charge of +46 μC placed 120 mm from a point charge Q.

Figure 1



Position **P** is on the line joining the charges at a distance 66 mm from charge Q.
The resultant electric field strength at position **P** is zero.

Calculate the charge Q.

Q = ____________________ C

(3)

(c) Explain, without calculation, whether net work must be done in moving a proton from infinity to position **P** in **Figure 1**.

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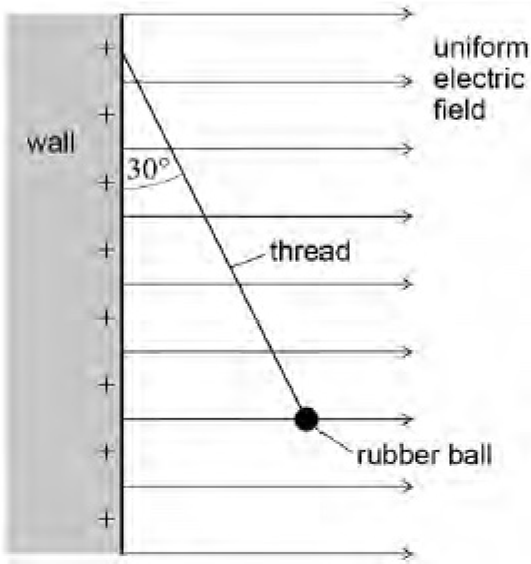
(2)

(d) A small rubber ball coated with a conducting paint carries a positive charge.
The ball is suspended in equilibrium from a vertical wall by an uncharged non-conducting thread of negligible mass. The wall is positively charged and produces a horizontal uniform electric field perpendicular to the wall along the whole of its length.
Figure 2 shows that the thread makes an angle of 30° to the wall.

Figure 2



The thread breaks.

Explain the motion of the ball.

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(2)
(Total 9 marks)

9. **Data analysis question**

Capillary action can cause a liquid to rise up a hollow tube. **Figure 1** shows water that has risen to a height h in a narrow glass tube because of capillary action.

Figure 1

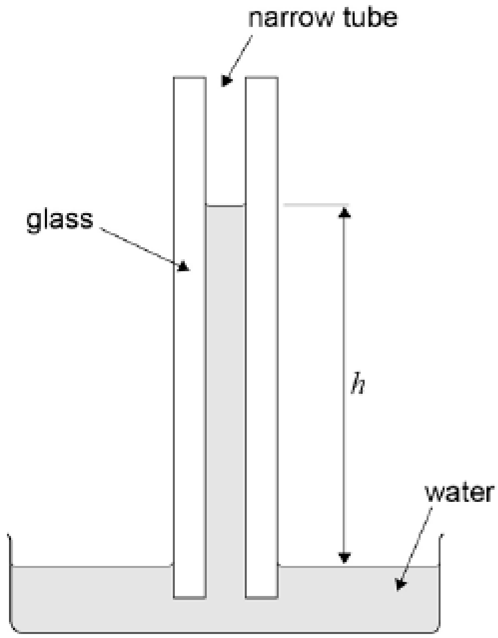
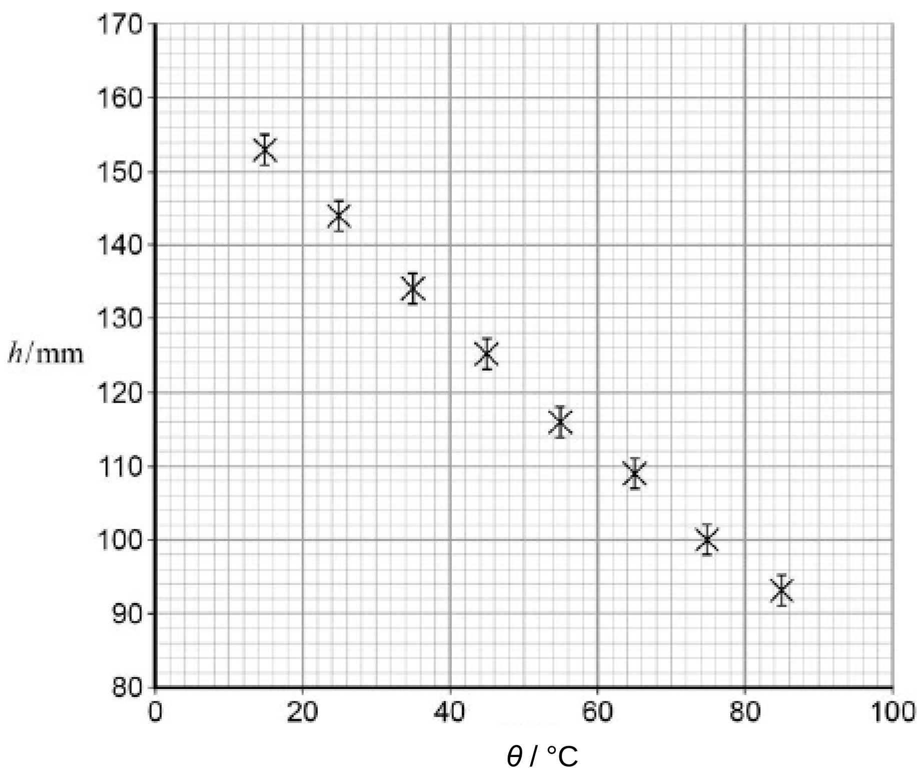


Figure 2 shows the variation of h with temperature θ for this particular tube.

Figure 2



The uncertainty in the measurement of h is shown by the error bars. Uncertainties in the measurements of temperature are negligible.

(a) Draw a best-fit straight line for these data **(Figure 2)**.

(1)

(b) It is suggested that the relationship between h and θ is

$$h = h_0 - (h_0 k)\theta$$

where h_0 and k are constants.
Determine h_0.

h_0 = = ____________________ mm

(1)

(c) Show that the value of h_0k is about 0.9 mm K^{-1}.

(3)

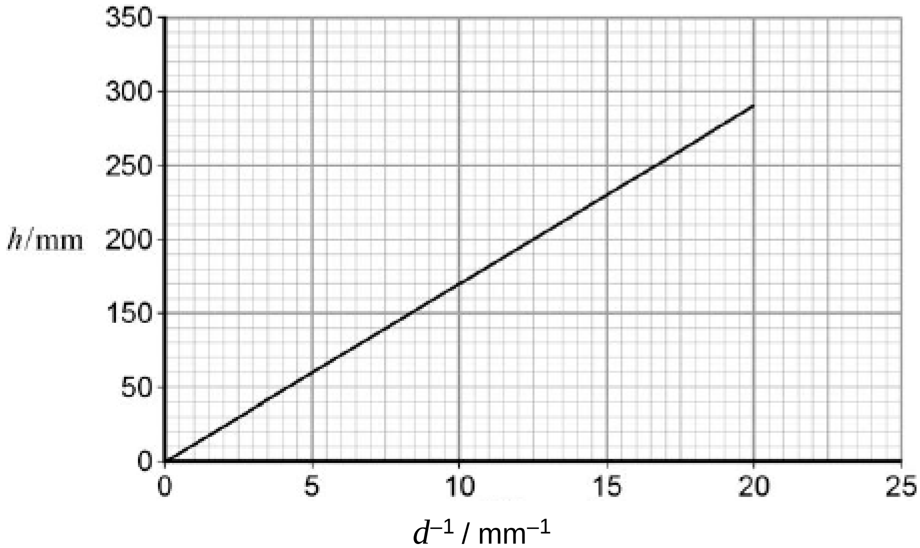
(d) Determine k. State a unit for your answer.

k = ____________________ unit = __________

(2)

(e) A similar experiment is carried out at constant temperature with tubes of varying internal diameter d. **Figure 3** shows the variation of h with $\frac{1}{d}$ at a constant temperature.

Figure 3



It is suggested that capillary action moves water from the roots of a tree to its leaves.

The gradient of **Figure 3** is 14.5 mm^2.

The distance from the roots to the top leaves of the tree is 8.0 m.

Calculate the internal diameter of the tubes required to move water from the roots to the top leaves by capillary action.

(2)

(f) Comment on the accuracy of your answer for the internal tube diameter in part (v).

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(1)

(Total 10 marks)

10. The term **ultrasound** refers to vibrations in a material that occur at frequencies too high to be detected by a human ear. When ultrasound waves move through a solid, both longitudinal and transverse vibrations may be involved. For the longitudinal vibrations in a solid, the speed c of the ultrasound wave is given by

$$c = \sqrt{\frac{E}{\rho}}$$

where E is the Young modulus of the material and ρ is the density. Values for c and ρ are given in the table below.

Substance	**c / m s^{-1}**	**ρ / kg m^{-3}**
glass	5100	2500
sea water	1400	1000

Ultrasound waves, like electromagnetic radiation, can travel through the surface between two materials. When all the energy is transmitted from one material to the other, the materials are said to be **acoustically matched**. This happens when ρc is the same for both materials.

(a) Calculate the magnitude of the Young modulus for glass.

Young modulus = ______________________

(1)

(b) State your answer to (a) in terms of SI fundamental units.

(1)

(c) The passage states that 'when ultrasound waves move through a solid both longitudinal and transverse vibrations may be involved'.

State the difference between longitudinal and transverse waves.

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(2)

(d) Show that when two materials are acoustically matched, the ratio of their Young moduli is equal to the ratio of their speeds of the ultrasound waves.

(2)

(e) The wave speed in a material X is twice that in material Y. X and Y are acoustically matched.

Determine the ratio of the densities of X and Y.

X = ______________________ Y = ______________________

(1)

(f) Ultrasound waves obey the same laws of reflection and refraction as electromagnetic waves.

Using data from **Table 1**, discuss the conditions for which total internal reflection can occur when ultrasound waves travel between glass and sea water.

(3)

(Total 10 marks)