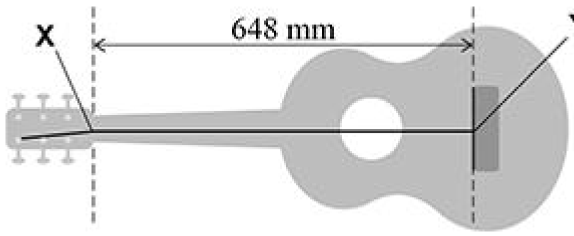
Q1.

Figure 1 shows a guitar with only one of its strings attached.
The string is fixed at **X** and **Y**.
The string is plucked and vibrates freely between **X** and **Y**.
The distance **XY** is 648 mm.

Figure 1



(a) The frequency of the first harmonic is 147 Hz.

Calculate the speed of the wave travelling in the string.

speed of wave = ____________________ $m\ s^{-1}$

(2)

(b) The tension in the string is 71 N.

Calculate the mass of the string between **X** and **Y**.

mass = ____________________ kg

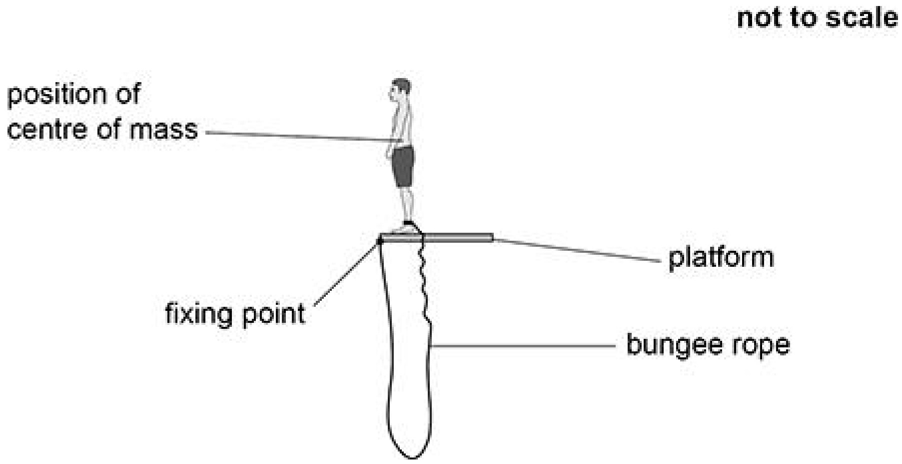
(3)

(Total 5 marks)

Q2.

Figure 1 shows a boy of mass m standing on a platform about to perform a bungee jump. He steps off the platform and falls vertically. The tension in the rope increases as it stretches. The boy decelerates to rest at the lowest point of the jump.
Assume that air resistance is negligible throughout this question.

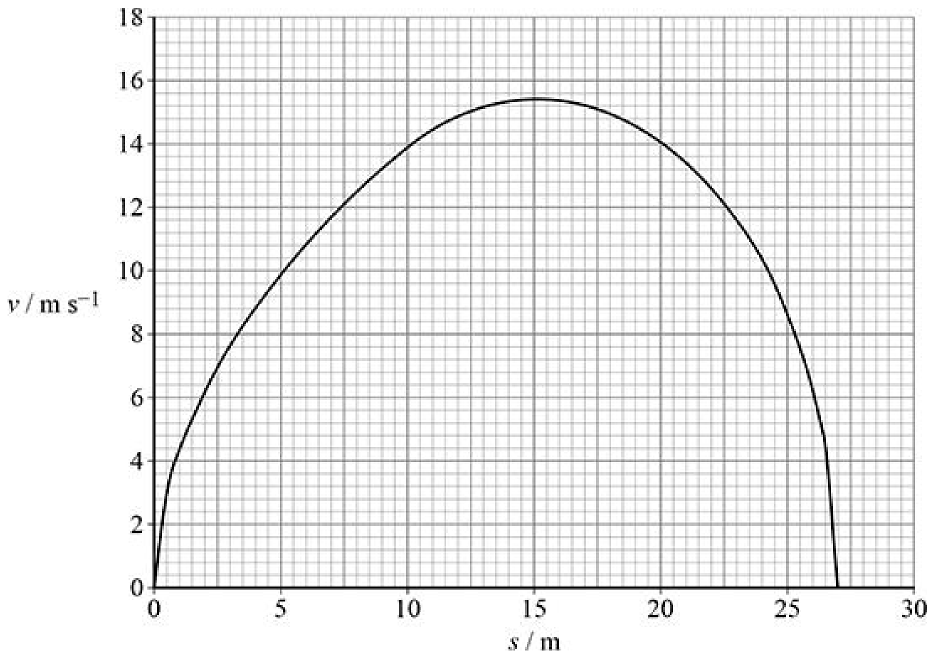
Figure 1



During the jump, s is the vertical displacement moved by the boy's centre of mass. The lowest point of the jump occurs when s is 27 m.

Figure 2 shows the variation of his velocity v with s during the jump.

Figure 2



(a) The boy experiences freefall when he steps off the platform.

During which part of the jump does the boy's acceleration begin to decrease?

Tick (✓) **one** box.

between s = 0 and s = 7.5 m	☐
between s = 7.5 m and s = 15 m	☐
between s = 15 m and s = 22.5 m	☐
between s = 22.5 m and s = 27 m	☐

(1)

(b) When the boy's centre of mass has moved through a distance s of 15.0 m the change in his gravitational potential energy is 9.56 kJ.

Calculate the mass m of the boy.

m = ____________________ kg

(2)

The bungee rope has a stiffness k of 110 $\mathrm{N\,m^{-1}}$ and obeys Hooke's law.

(c) The maximum kinetic energy of the boy is 7.71 kJ.

Calculate, by considering the energy transfers, the extension ΔL of the bungee rope when the kinetic energy of the boy is at a maximum.

ΔL = ____________________ m

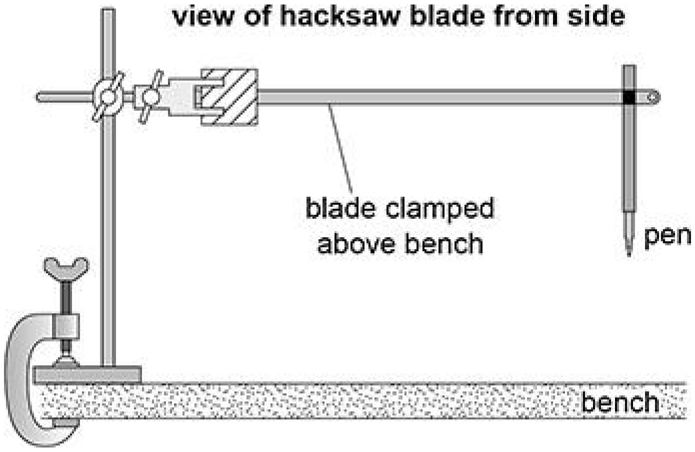
(3)

(Total 6 marks)

Q3.

A hacksaw blade is a thin flexible strip of metal.
Figure 1 shows a blade clamped between two blocks above a horizontal bench.
A pen is attached to the free end of the blade.

Figure 1



The free end of the blade is displaced and released.
The blade oscillates in a horizontal plane as shown in **Figure 2**.

Figure 2

The time for each oscillation is T.

(a) The table below shows repeated measurements of $60T$.

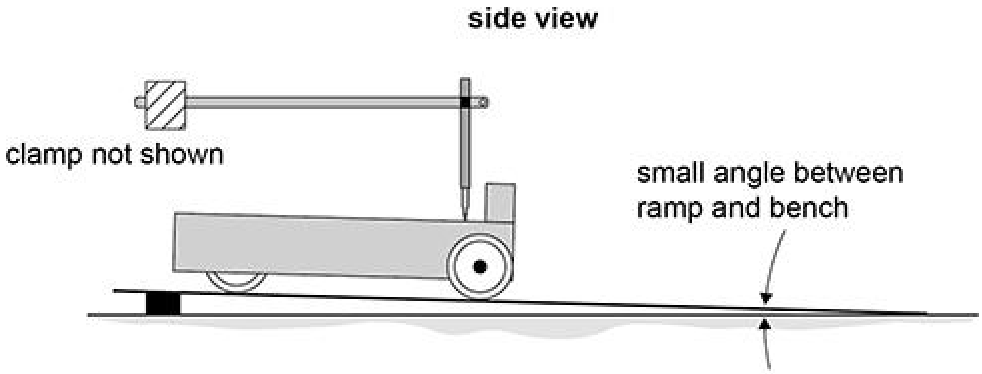
Measurements of $60T$ / s			
25.20	25.05	24.97	25.10

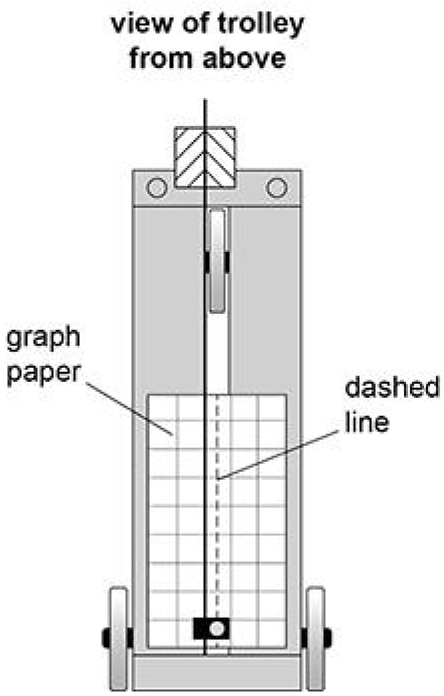
Show that T is about 0.42 s.

(1)

Figure 3 shows a trolley placed on a ramp that is inclined at a small angle to the bench.
A piece of graph paper is fixed to the upper surface of the trolley.
The blade and pen are positioned so that the tip of the pen rests on the graph paper.
The dashed line shows the rest position of the pen.

Figure 3





The free end of the blade is displaced as shown in **Figure 4a**.
The blade and the trolley are then both released at the same moment.
The blade oscillates horizontally.
The pen remains in contact with the graph paper as the trolley moves.
Figures 4b and **4c** show the trolley as it moves down the ramp with uniform acceleration.

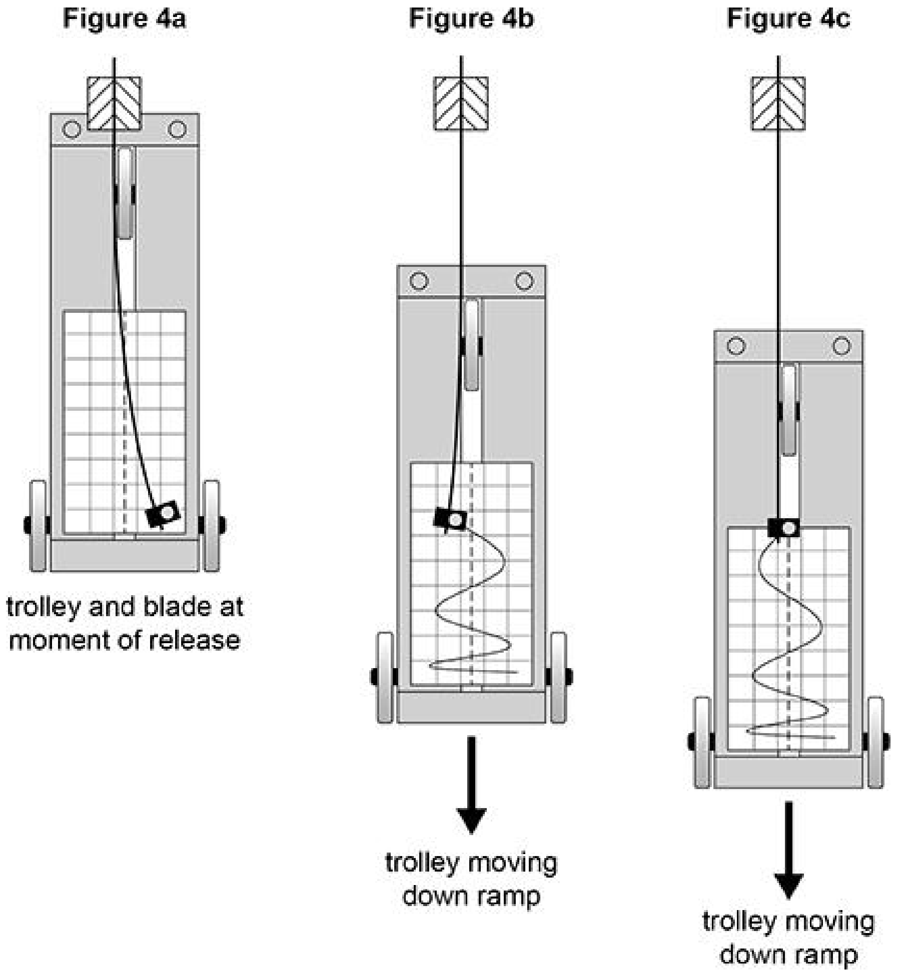
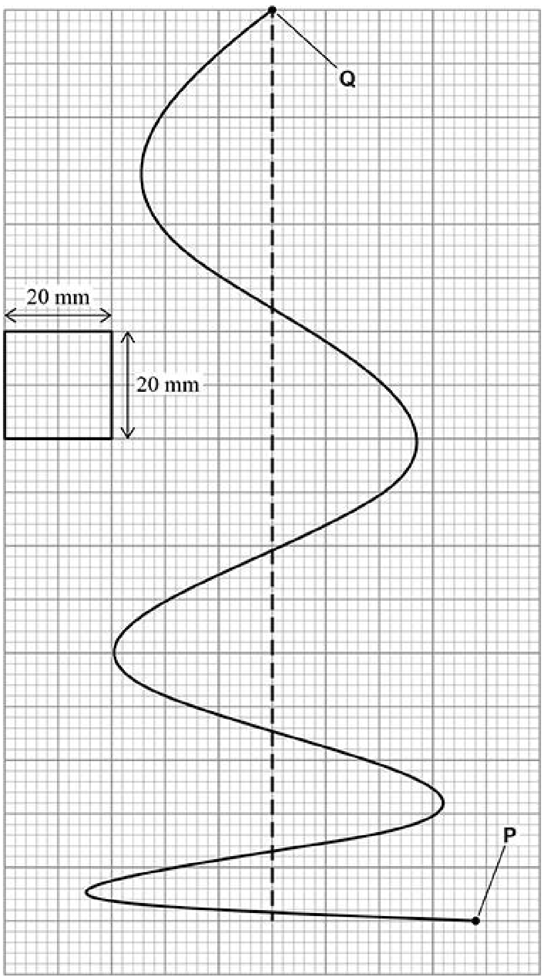


Figure 5 shows the graph paper.
Points **P** and **Q** mark the start and end of the continuous line drawn by the pen after the trolley is released.

Figure 5



T_{PQ} is the time for the pen to draw the line from **P** to **Q**.
s is the displacement of the trolley during T_{PQ}.

(b) Determine T_{PQ}.
Assume that the time for each full oscillation of the blade is 0.42 s.

T_{PQ} = ____________________ s

(2)

(c) Determine s.
The scale of the graph paper is shown on **Figure 5**.

s = ____________________ m

(1)

(d) Determine the acceleration a of the trolley.

a = ____________________ m s^{-2}

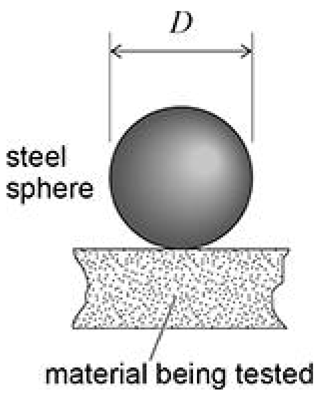
(2)

(Total 6 marks)

Q4.

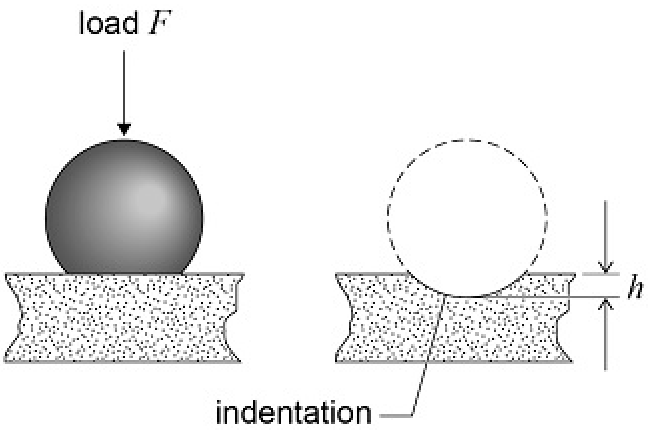
The Brinell test determines the hardness of the surface of a material.
Figure 1 shows a steel sphere on the surface of a material being tested.

Figure 1



In the test, a load F is applied to a steel sphere of diameter D and an indentation of depth h is produced in the material. **Figure 2** shows one test.

Figure 2



The Brinell hardness number B is given by

$$B = \frac{F}{\pi g D h}$$

where F is in N, g is in N kg^{-1} and D and h are in mm.
The unit of B is kg mm^{-2}.

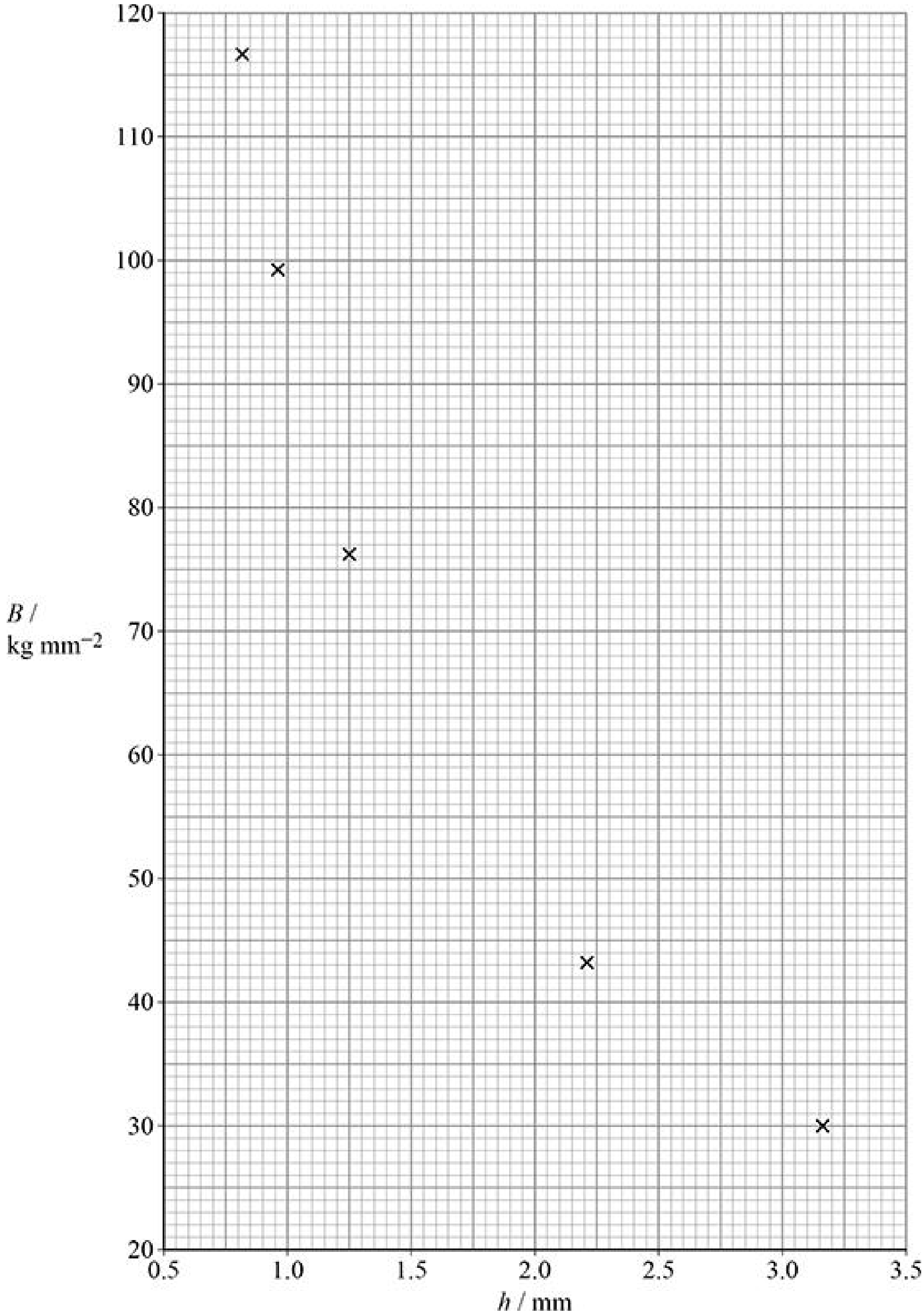
Using the same steel sphere, the value of h was measured for five materials.
B was calculated for each material.

For each material:

- F was the same
- D = 10.0 mm.

Figure 3 is a plot of B against h.

Figure 3



(a) Determine the value of F that was used to produce **Figure 3**.

F = ____________________ N

(1)

(b) Brass was not one of the five materials tested.
When brass was tested using these values of F and D, the value of h = 1.60 mm.

Determine, using **Figure 3**, B for brass.

B for brass = ____________________ kg mm^{-2}

(2)

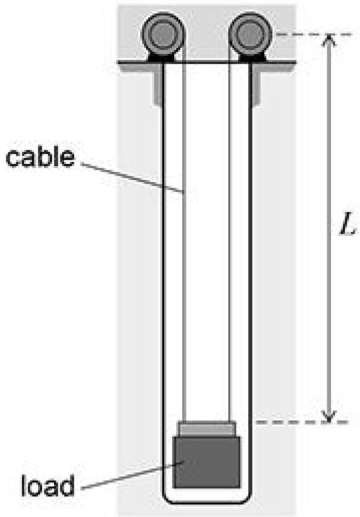
(Total 3 marks)

Q5.

Figure 1 shows an energy storage system. The system uses a load suspended from two long steel cables in a vertical tunnel. Energy is stored when the load is raised. Electricity is generated when the load falls.

Figure 1

not to scale



When the load is at its lowest point, each cable has a vertical length L.
The total mass of the two vertical cables is 3.7×10^4 kg.
Each cable has a cross-sectional area of 9.6×10^{-3} m^2.

(a) Calculate L.

density of steel = 7.4×10^3 kg m^{-3}

L = ____________________ m

(2)

(b) The load is accelerated from its lowest point. The mass of the load is 2.8×10^5 kg.

The maximum tension in each cable is 1.6×10^6 N during the acceleration.

Calculate the initial acceleration of the load.

initial acceleration = ____________________ m s^{-2}

(4)

(Total 6 marks)

Q6.

A room contains dry air at a temperature of 20.0 °C and a pressure of 105 kPa.

(a) Show that the amount of air in each cubic metre is about 40 mol.

(1)

(b) The density of the dry air is 1.25 $kg\ m^{-3}$.

Calculate c_{rms} for the air molecules.
Give your answer to an appropriate number of significant figures.

c_{rms} = ____________________ $m\ s^{-1}$

(3)

(c) Calculate, in K, the change of temperature that will double c_{rms} for the air molecules.

change of temperature = ____________________ K

(2)

(d) A room contains moist air at a temperature of 20 °C.
A dehumidifier cools and then condenses water vapour from the moist air.
The final temperature of the liquid water that collects in the dehumidifier is 10 °C.
Drier air leaves the dehumidifier at a temperature of 20 °C.

The table below compares the air flowing into and out from the dehumidifier.

	$\frac{\textbf{mass of water}}{\textbf{mass of air}}$
moist air flowing in	0.0057
drier air flowing out	0.0037

In one hour, a volume of 960 m^3 of air flows through the dehumidifier.
Assume that the density of the air remains constant at 1.25 $kg\ m^{-3}$.

Determine how much heat energy is removed in one hour from the water vapour by the dehumidifier.

specific heat capacity of water vapour = 1860 $J\ kg^{-1}\ K^{-1}$
specific latent heat of vaporisation of water = $2.3 \times 10^6\ J\ kg^{-1}$

heat energy removed = ____________________ J

(3)
(Total 9 marks)

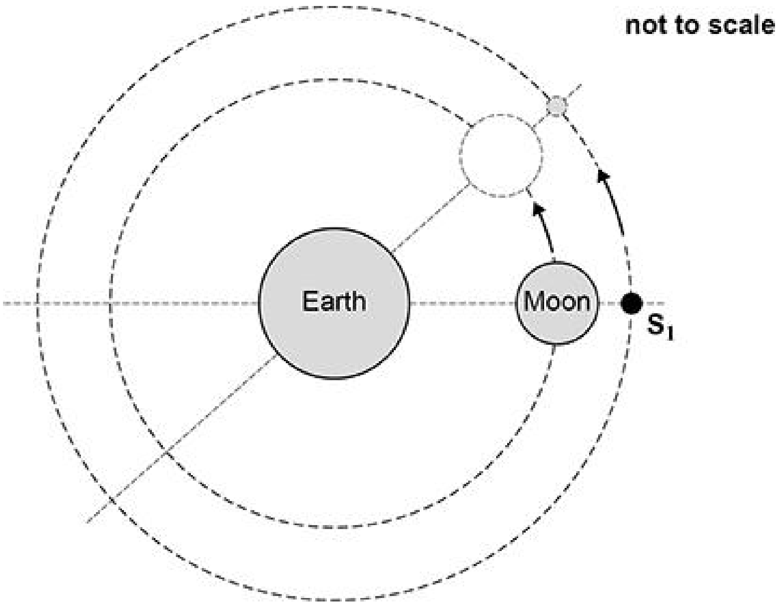
Q7.

A satellite **S_1** is placed in a circular orbit around the Earth so that observations of the far side of the Moon can be made continuously.

S_1 has the same angular speed as the Moon so that the centres of the Earth, the Moon and **S_1** are always in a straight line.

Figure 1 shows two positions of the Moon and **S_1** as they orbit the Earth.

Figure 1



(a) The resultant force on **S_1** is due to the gravitational forces from the Earth and the Moon.
The magnitude of the Earth's gravitational field strength at the orbital radius of **S_1** is 1.98×10^{-3} N kg^{-1}.
The magnitude of the Moon's gravitational field strength at the orbital radius of **S_1** is g_M.

Show that g_M is approximately 1.2×10^{-3} N kg^{-1}.

period of the Moon's orbit = 27.3 days
orbital radius of **S_1** = 4.489×10^5 km

(3)

(b) Calculate the distance from $\mathbf{S}_1$ to the centre of the Moon.

mass of the Moon = 7.35×10^{22} kg

distance = ____________________ m

(2)

(Total 5 marks)

Q8.

A student uses a refracting telescope in normal adjustment to make observations of Jupiter.
The telescope has an angular magnification of 75

(a) The eyepiece has a focal length of 22 mm.

Determine the distance between the eyepiece and the objective lens.

distance = ____________________ m

(2)

(b) When viewed through the telescope, the image of Jupiter subtends an angle of 1.7×10^{-2} rad.

Calculate, in km, the distance between the Earth and Jupiter.

mean radius of Jupiter = 7.0×10^{4} km

distance = ____________________ km

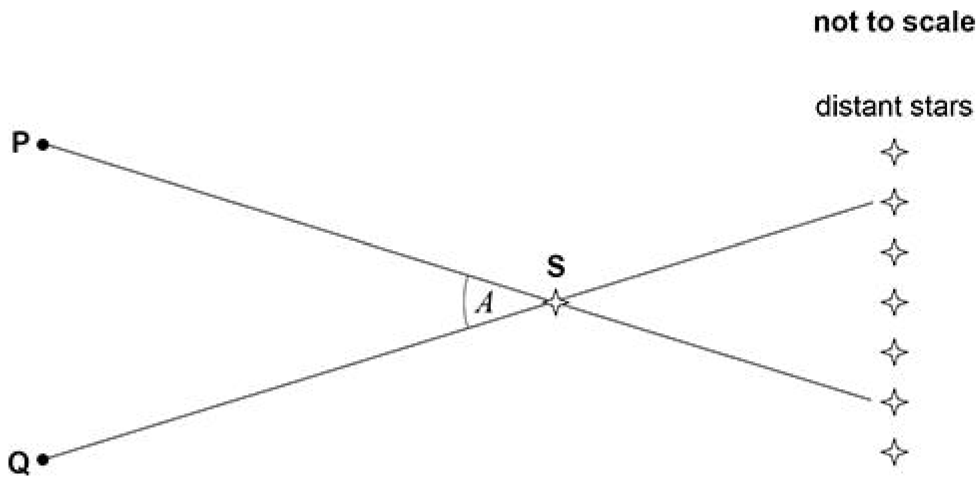
(2)

(Total 4 marks)

Q9.

The apparent change in position of a nearby star relative to distant stars is due to an effect known as parallax.

The figure below shows how parallax arises. As the Earth moves from point **P** to point **Q**, an observer on the Earth sees the position of a nearby star **S** change in relation to distant stars.



Angle A is the parallax angle. This angle can be used to determine the distance to a nearby star, provided that the relative motion between the star and the Sun is negligible between observations.

(a) The distance from the Sun to **S** is 79 ly.
The Earth takes 6 months to move from point **P** to point **Q**.

Calculate, in degrees, angle A.

A = ____________________ °

(2)

(b) Parallax is used to determine the distance to a different star. Observations of the star produce the following data:

distance determined using parallax = 0.40 pc
apparent magnitude = 13.5
absolute magnitude = 16.7

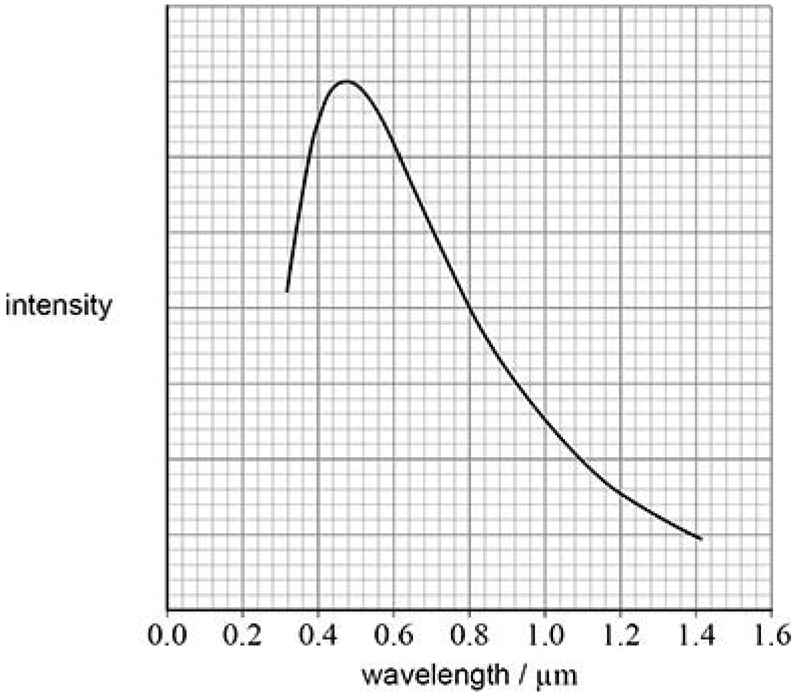
An astronomer suggests that the star moved significantly relative to the Sun between the two parallax observations.

Discuss whether this suggestion is valid.

(4)
(Total 6 marks)

Q10.

(a) The figure below shows the variation of intensity with wavelength for a star.



Show that above figure is consistent with a black-body temperature of about 6.0×10^3 K.

(2)

(b) The radius of the star is 9.6×10^6 m.

Calculate the power output of the star.

power output = ____________________ W

(2)

(Total 4 marks)

Q11.

The Earth is in the galaxy known as the Milky Way. The Andromeda Galaxy is one of the closest galaxies to the Milky Way.

(a) The Andromeda Galaxy approaches the Milky Way at a speed of 110 $km\ s^{-1}$.
The distance between the galaxies is 770 kpc.

Discuss whether these data can be used to estimate an age for the Universe.

___

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___

___

(2)

(b) There is a supermassive black hole at the centre of the Andromeda Galaxy. The mass of this black hole is 1.60×10^8 solar masses.

Calculate the radius of the event horizon of this black hole.
State an appropriate unit for your answer.

radius = ___

unit = ___

(3)

(Total 5 marks)

Q12.

The Lenoir engine was the first successful internal combustion engine.

Figure 1 shows the basic form of the Lenoir engine. The piston rod drives a crankshaft which is not shown. The fuel is a mixture of gas and air.

Figure 1

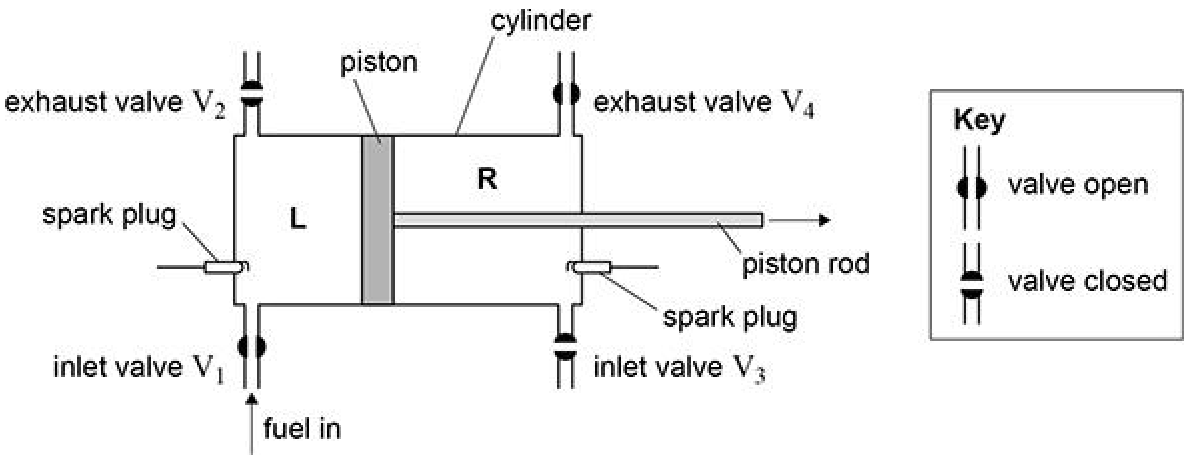
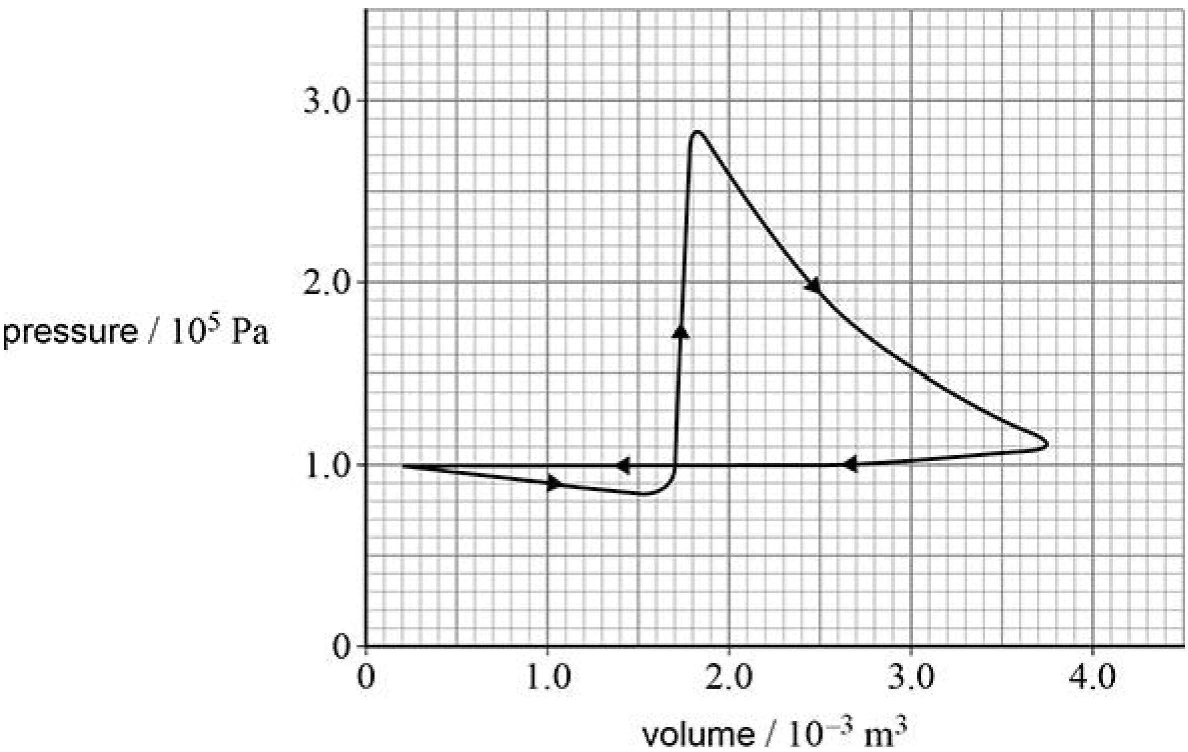


Figure 2 shows an indicator diagram for the space **L**, taken during a test on a Lenoir engine.

Figure 2



In one cycle the following changes occur in **L**.

- **Induction**. The piston starts at the left-hand end of the cylinder. It moves to the right and fuel passes through the open inlet valve V_1 into **L**. **Figure 1** shows the piston during this induction process, with V_1 open.
- **Ignition**. When the piston is nearly halfway along the cylinder, V_1 is closed. A spark ignites the fuel causing a sudden rise in pressure.
- **Expansion**. The hot gases expand and the piston moves to the end of the stroke.
- **Exhaust**. The exhaust valve V_2 opens. The piston moves to the left. The exhaust gases are expelled at atmospheric pressure.

The same processes are repeated in space **R** one half of a revolution of the crankshaft later than in **L**. So when the piston is moving to the left, induction, ignition and expansion occur in **R** at the same time as the exhaust process occurs in **L**.

(a) The indicator diagram is for a rotational speed of the crankshaft of 120 rev min^{-1}.

Determine, using **Figure 2**, the indicated power of the engine.
Assume that the indicator diagram for **R** is identical to the indicator diagram for **L**.

indicated power = ____________________ W

(5)

(b) The following data are taken during the test on the engine:

fuel consumption = 6.44×10^{-4} m^3 s^{-1}
calorific value of fuel = 18.0×10^6 J m^{-3}
torque at crankshaft = 39.0 N m
rotational speed = 120 rev min^{-1}

Calculate the input power and the output (brake) power of the engine.

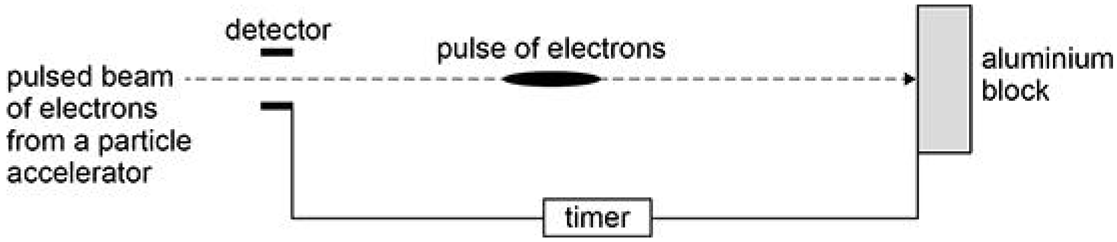
input power = ______________________ W

output power = ______________________ W

(2)
(Total 7 marks)

Q13.

The figure below shows a modern version of Bertozzi's experiment to measure the kinetic energy of high-speed electrons. A timer is used to measure the time taken for a pulse of electrons to travel from the detector to the aluminium block.



(a) A potential difference (pd) of 1.30 MV is used to accelerate the electrons.

Show that each electron gains approximately 2×10^{-13} J of kinetic energy.

(1)

(b) These electrons cause the temperature of the aluminium block to increase by 68.0 K.
The number of electrons that cause this increase in temperature is 4.50×10^{17}

Deduce whether this increase in temperature is consistent with an accelerating pd of 1.30 MV.

specific heat capacity of aluminium = 903 J kg^{-1} K^{-1}
mass of aluminium block = 1.50 kg

___

___

(2)

(c) The speed of the electrons between the detector and the block is 2.88×10^8 m s^{-1}.

Student **A** suggests that the non-relativistic equation for kinetic energy could be used.
Student **B** suggests that the relativistic equation for kinetic energy is required in this situation.

Evaluate the suggestions of student **A** and student **B**.
Support your answer with calculations.

___

___

___

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___

___

(4)

(d) The timer in above figure records a time of 29.8 ns.

What is the proper time interval for an electron travelling from the detector to the aluminium block?

Tick (✓) **one** box.

< 29.8 ns ☐

29.8 ns ☐

> 29.8 ns ☐

(1)
(Total 8 marks)

Q14.

Figure 1 shows a robotic helicopter that is used on Mars. The helicopter is powered by a battery. Before each flight, the battery is charged by a solar panel.

Figure 1

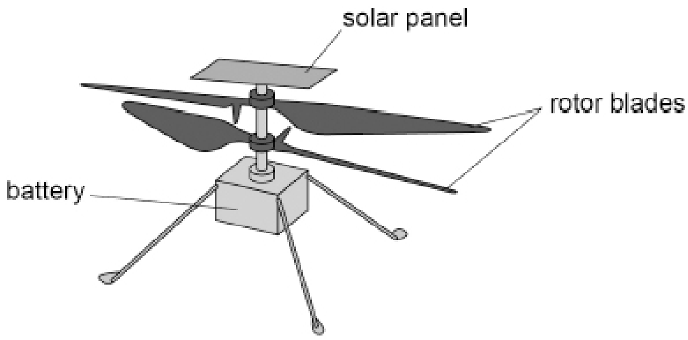
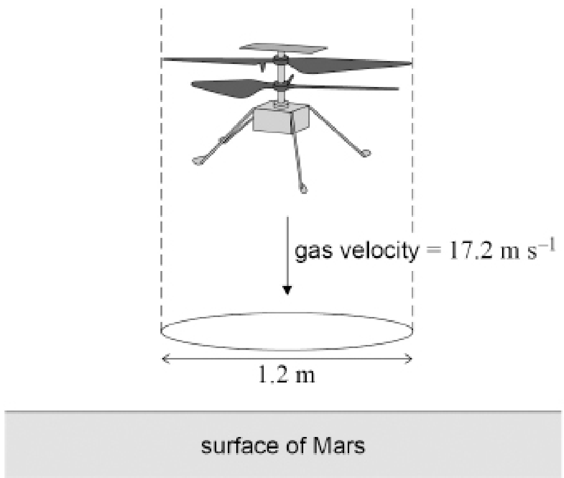


Figure 2 shows the helicopter hovering at a constant height above the surface of Mars. The rotor blades move a column of atmospheric gas vertically downwards at a velocity of 17.2 $m\ s^{-1}$. The diameter of this column is 1.2 m.

Figure 2



(a) The gas moved by the rotor blades has a density of 0.020 $kg\ m^{-3}$.

Show that the helicopter moves approximately 0.4 kg of gas every second.

(3)

The movement of the gas creates an upward force on the helicopter. This upward force enables the helicopter to hover at a constant height.

The gravitational field strength on Mars is 3.72 $N\ kg^{-1}$.

(b) Calculate the mass of the helicopter.

mass = ____________________ kg

(3)

(c) The battery stores 0.035 kW h of energy before a flight.
The flight lasts for 39 s.
The battery has a power output of 340 W during the flight.

Determine the percentage of the initial energy stored in the battery that is transferred during the flight.

percentage = ____________________ %

(2)

(d) The helicopter has a maximum flight time of a few minutes due to the limited amount of energy stored in the battery. The battery accounts for about 15% of the helicopter's mass.

A student suggests that adding another identical battery that doubles the energy available to the helicopter would double its flight time.

Deduce without calculation whether the student's suggestion is correct.

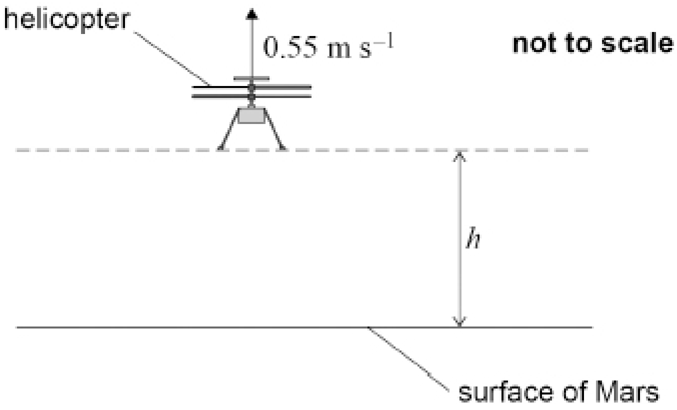
____

____

(3)

Figure 3 shows a simplified side view of the helicopter moving vertically upwards with a speed of 0.55 m s^{-1}.
At the instant shown, the helicopter is at a height h and the blades stop rotating.

Figure 3



The gravitational field strength on Mars is 3.72 N kg^{-1}.

The weight of the helicopter is the only force acting on it when the blades stop rotating. Drag forces on the helicopter are negligible as it rises to a maximum height and then falls back to the surface.

(e) Calculate the time taken for the helicopter to reach its maximum height from the instant the blades stop rotating.

time = ____________________ s

(2)

(f) When the helicopter makes contact with the surface it has a velocity of 2.2 m s^{-1}.

Calculate h.

h = ____________________ m

(2)

(Total 15 marks)

Q15.

Conductive putty can easily be formed into different shapes to investigate the effect of shape on electrical resistance.

(a) A student uses vernier callipers to measure the diameter d of a uniform cylinder made of the putty.

Suggest **one** problem with using callipers to make this measurement.

____

____

____

(1)

(b) The table below shows the calliper measurements made by a student.

d_1 / mm	d_2 / mm	d_3 / mm	d_4 / mm	d_5 / mm
34.5	34.2	32.9	33.4	34.0

Show that the percentage uncertainty in d is about 2.4%.
Assume that all the data are valid.

(2)

(c) The length of the cylinder is 71 ± 2 mm.

Determine the uncertainty, in mm^3, in the volume of the cylinder.

uncertainty = ____________________ mm^3

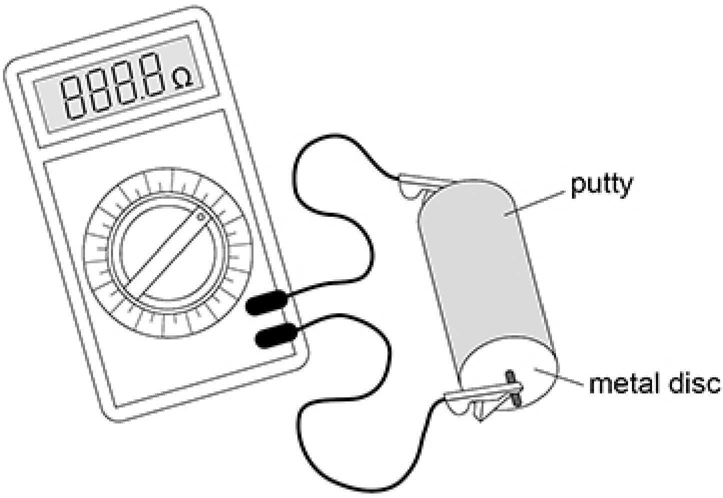
(4)

(d) A student is given some putty to form into cylinders.

To find the resistance of a cylinder, metal discs are placed in contact with the ends of the cylinder and connected to a resistance meter.

Figure 1 shows the apparatus.

Figure 1

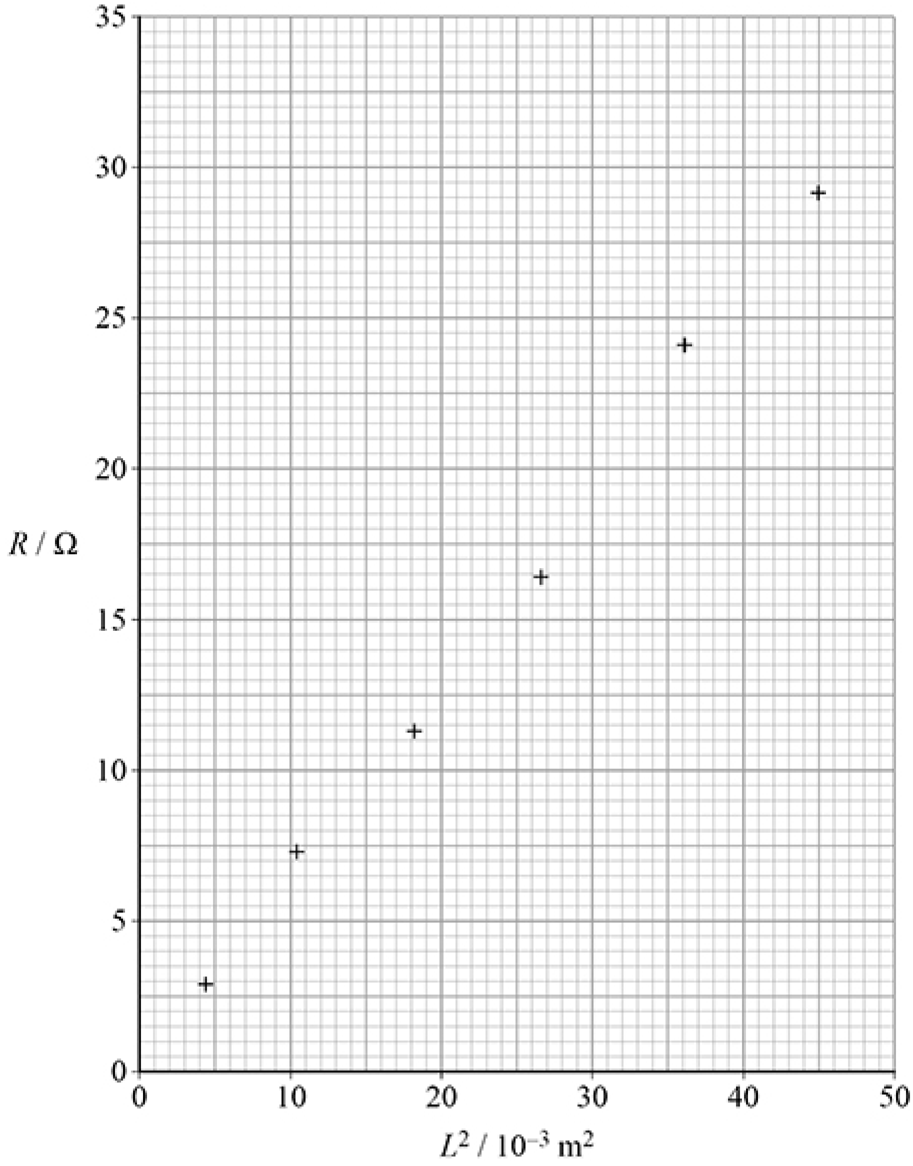


The student forms the putty into cylinders of different lengths, each of volume 5.83×10^{-5} m^3.
The length L and resistance R are measured for each cylinder.

It can be shown that $R = \dfrac{\rho L^2}{5.83 \times 10^{-5}}$ where ρ is the resistivity of the conductive putty.

The student plots the graph shown in **Figure 2**.

Figure 2



Determine ρ.
State an appropriate SI unit for your answer.

ρ = ________________ unit = ________________

(4)

(Total 11 marks)