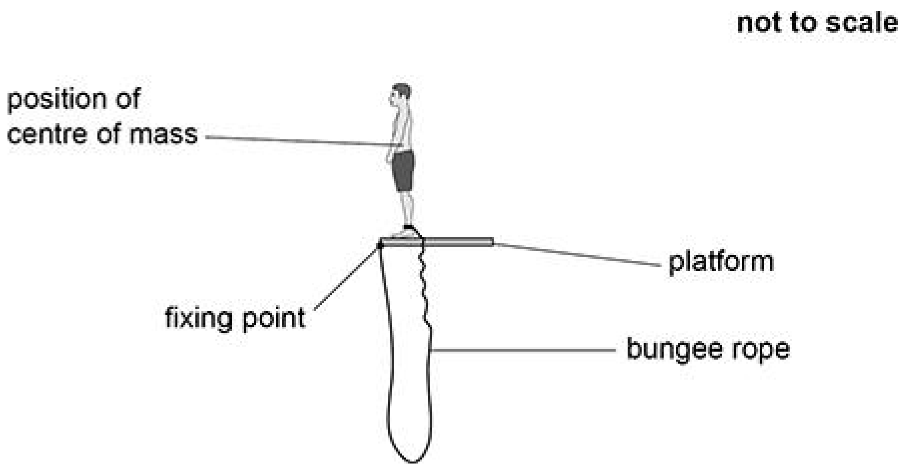
Q1.

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.

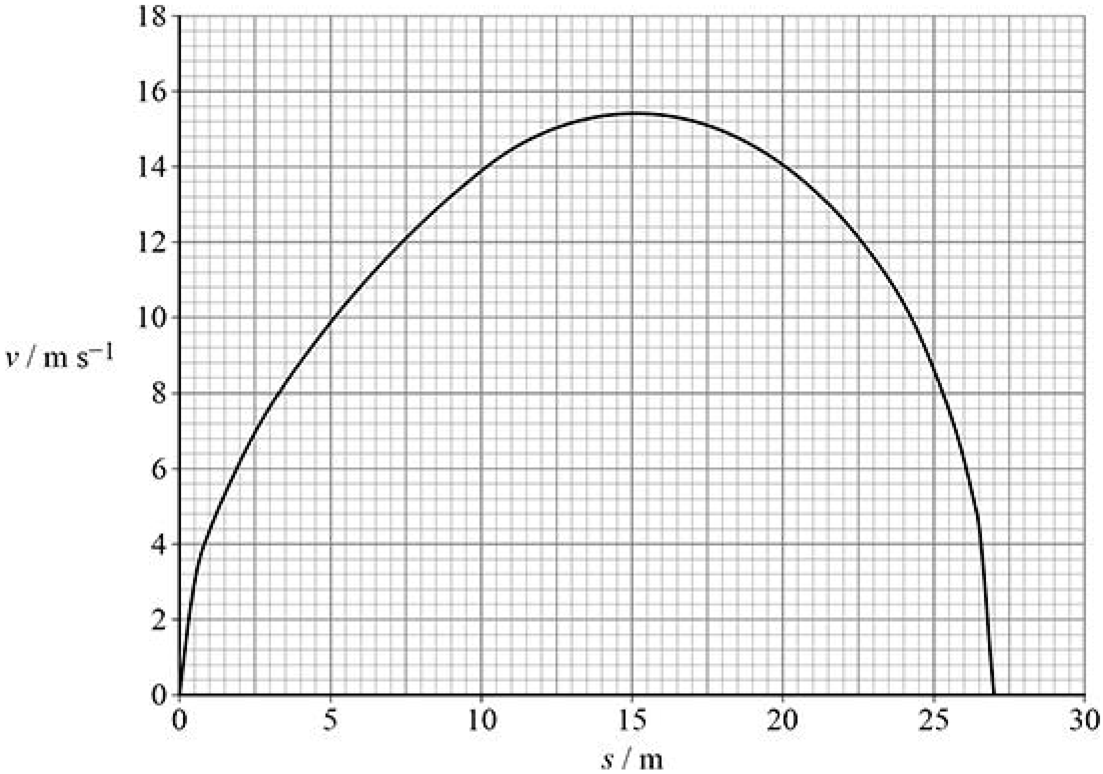
Figure 1



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 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)

(d) Deduce the tension in the rope when the kinetic energy of the boy is at a maximum.
Give a reason to support your answer.

tension = ______________________ N

reason ____

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(2)

The original rope is replaced with a second rope and the boy repeats the jump.

The table below contains information about the original rope and the second rope. Both ropes obey Hooke's law.

	Young modulus	**Cross-sectional area**	**Unstretched length**
original rope	E	A	L
second rope	1.2E	A	1.2L

The Young modulus is given by:

$$\text{Young modulus} = \frac{\text{stiffness} \times \text{unstretched length}}{\text{cross-sectional area}}$$

(e) Show that each rope has the same stiffness.

(1)

(f) Deduce whether the boy's maximum velocity is increased when using the second rope.

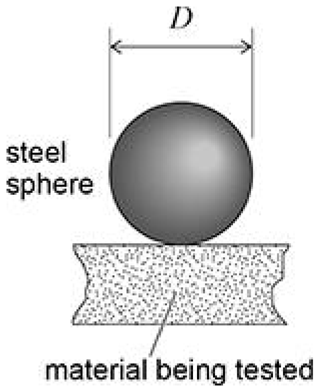
(3)

(Total 12 marks)

Q2.

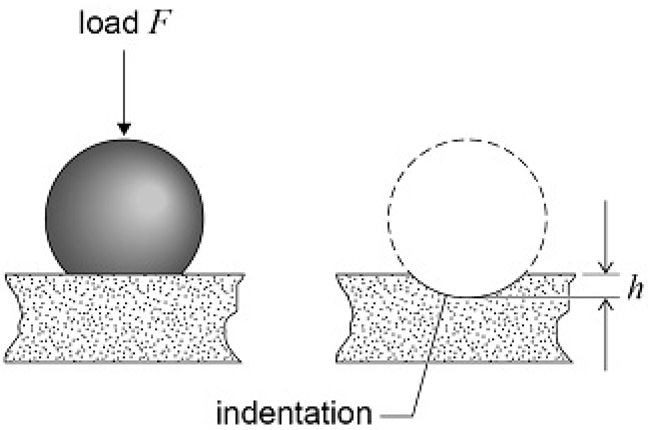
The Brinell test determines the hardness of the surface of a material.
Figure 1 shows a steel sphere on the surface of a material being tested.

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}.

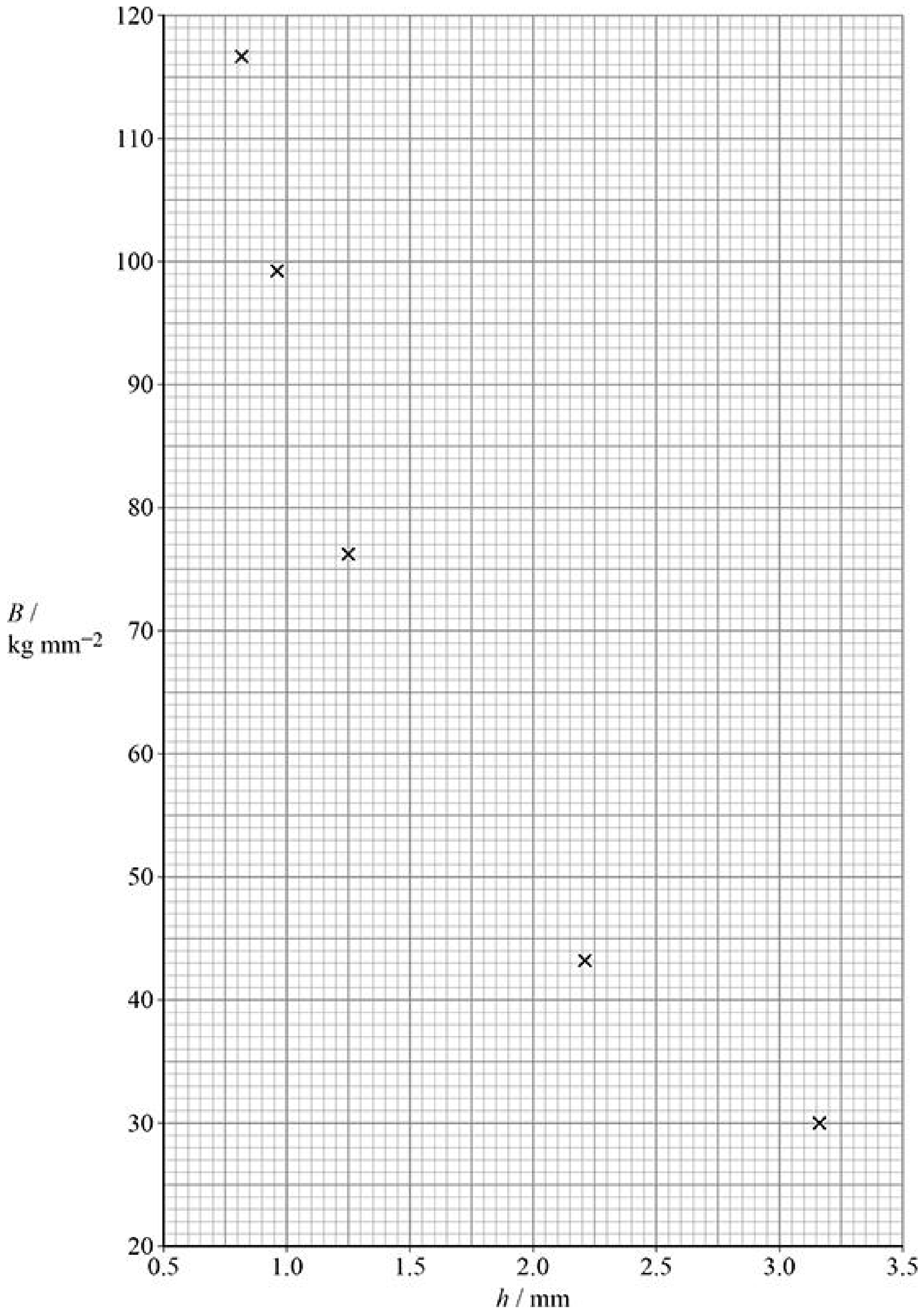
Using the same steel sphere, the value of h was measured for five materials.
B was calculated for each material.

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)

(c) B for lead is about 5 kg mm^{-2}.

Show that this result cannot be obtained with the steel sphere and the value of F used to produce **Figure 3**.
Go on to suggest how the test can be modified to determine B for lead.

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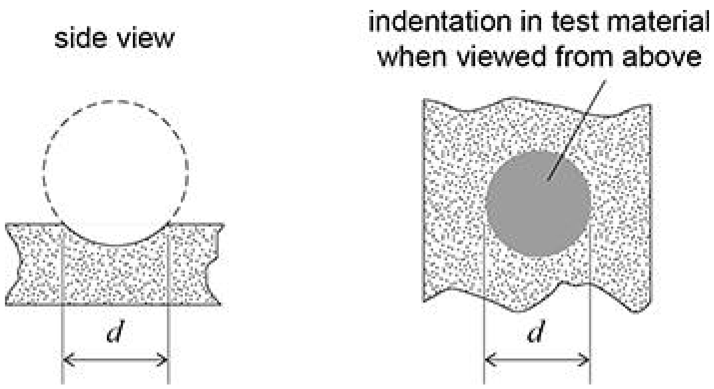
(2)

The Brinell hardness number can be determined by measuring the diameter d of the circular indentation rather than h.

Figure 4 shows d.

Figure 4



For the indentation created in brass, d = 7.33 mm.

(d) Suggest a suitable instrument that could have been used to measure this value of d.

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(1)

(e) For the indentation created in brass, h = 1.60 mm.

Explain **one** advantage of finding B by measuring d rather than h.

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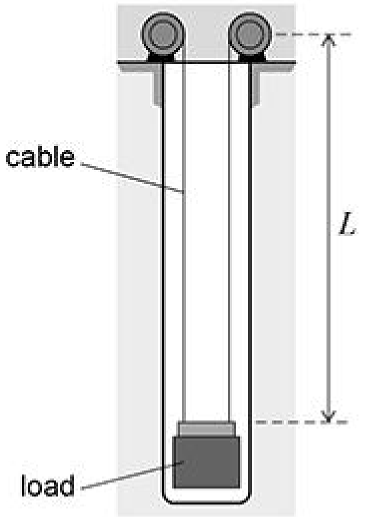
(2)
(Total 8 marks)

Q3.

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)

(c) For safety, the breaking stress of each steel cable must be at least three times the maximum stress produced during the initial acceleration.

breaking stress for steel = 890 MPa

Deduce whether this system operates safely.

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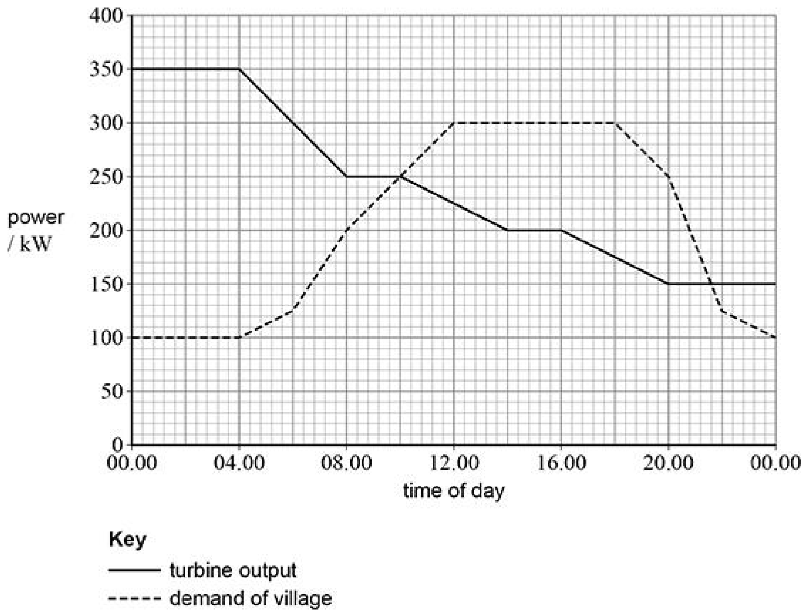
(2)

(d) A village combines the storage system with a wind turbine to provide energy.
Figure 2 shows how the output power of the wind turbine varies with time during one particular day.
The power demand of the village is also shown.

Figure 2



When the power demand is greater than the output power of the wind turbine, the load in the storage system descends and generates electricity to match the demand.
When the load has fully descended and the storage system is empty, electrical power is provided by the National Grid.
The efficiency of the energy transfer from the storage system to the village is 85%. The maximum energy stored by the storage system is 760 MJ.

Deduce whether the storage system and the wind turbine can together provide all the electrical energy needed by the village from 10.00 until 14.00.

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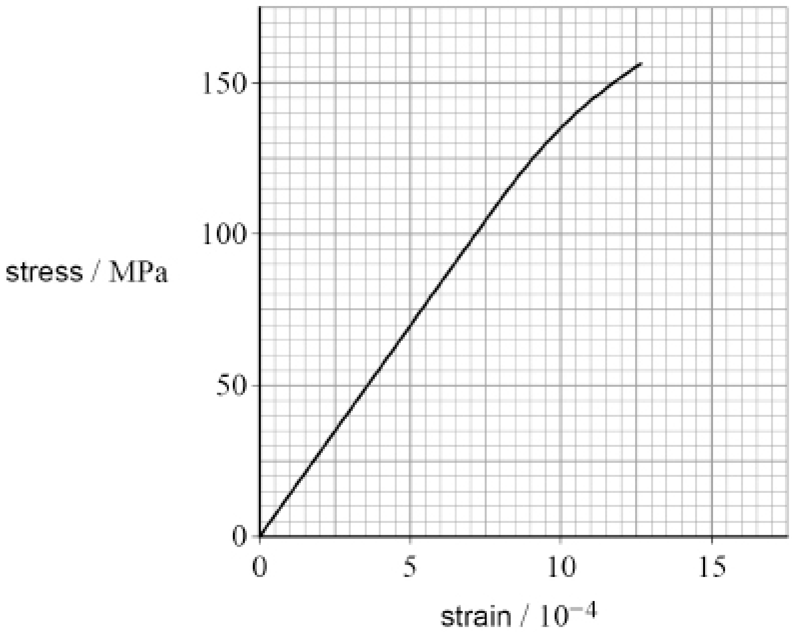
(4)
(Total 12 marks)

Q4.

Figure 1 shows the stress–strain graph for a metal in tension up to the point at which it fractures.

Figure 1



(a) Determine, using **Figure 1**, the Young modulus of the metal.

Young modulus = ____________________ Pa

(1)

(b) Explain how the graph shows that this metal is brittle.

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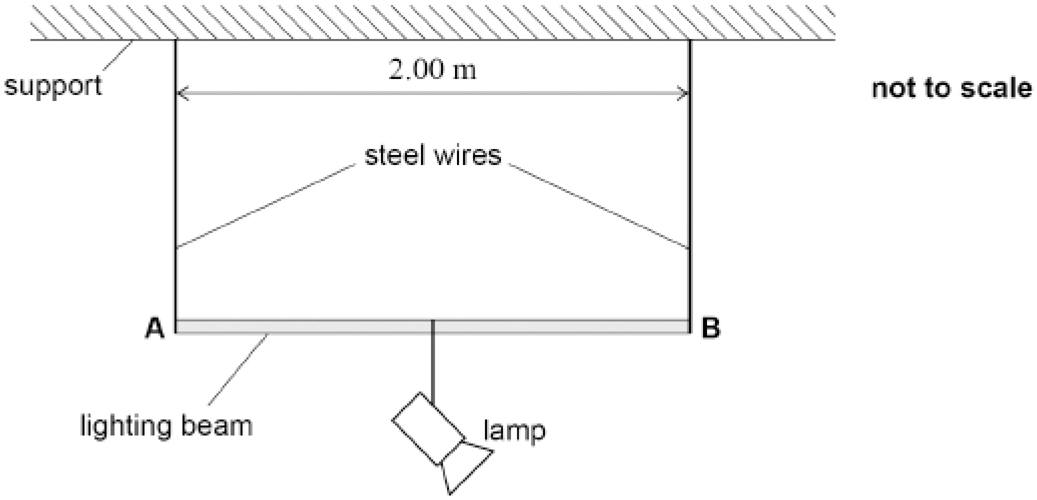
(1)

Figure 2 shows a uniform rigid lighting beam **AB** suspended from a fixed horizontal support by two identical vertical steel wires. A lamp is attached to the midpoint of **AB**.

Figure 2



The unloaded length of each steel wire was 1.20 m before it was attached to **AB**. **AB** is horizontal.

mass of **AB** = 4.4 kg
mass of lamp = 16.0 kg
distance between wires = 2.00 m
diameter of each wire = 0.800 mm
Young modulus of steel = 2.10×10^{11} Pa

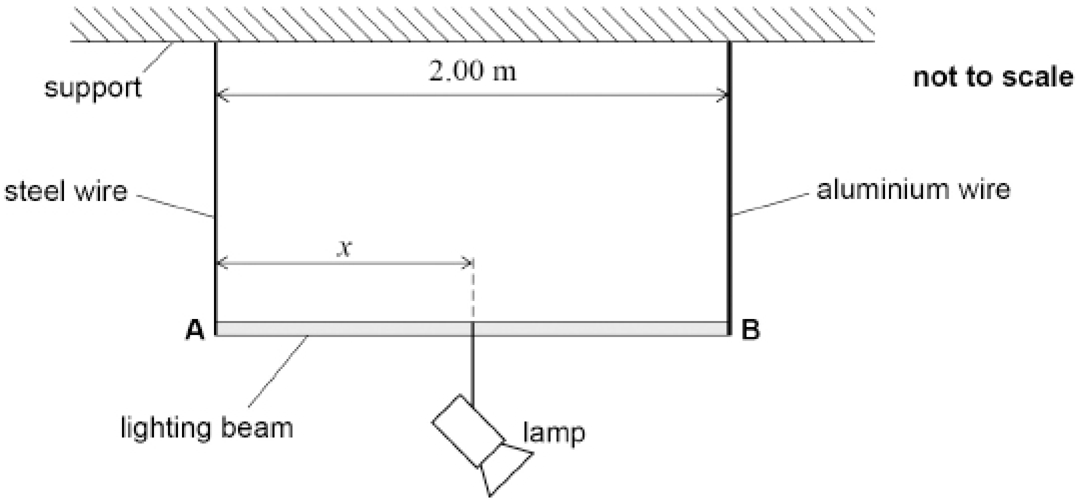
(c) Calculate the extension of each wire.

extension = ____________________ m
(3)

(d) The right-hand steel wire is removed and replaced with an aluminium wire of diameter 1.60 mm. The unloaded length of the aluminium wire is the same as that of the original steel wire.

When the lamp is at the midpoint of **AB**, one of the wires extends more than the other so that **AB** is not horizontal. To make **AB** horizontal the lamp has to be moved to a distance x from **A**. **Figure 3** shows the new arrangement.

Figure 3



The Young modulus of aluminium is 7.00×10^{10} Pa.

Deduce distance x.

x = ____________________ m

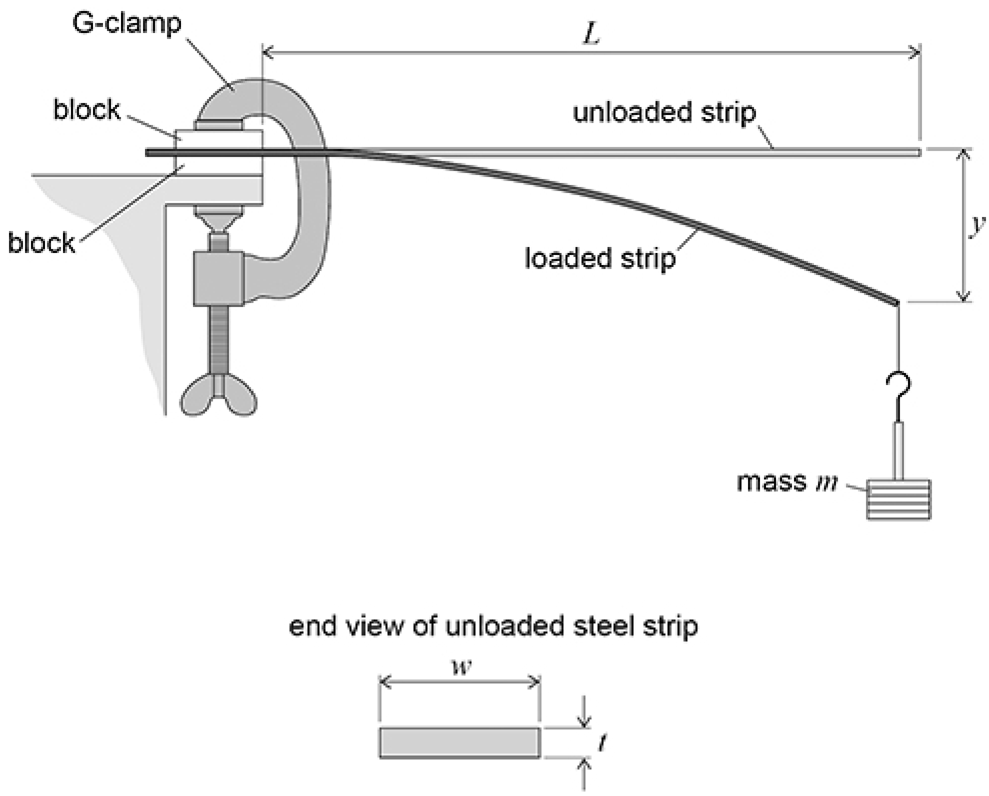
(5)

(Total 10 marks)

Q5.

Figure 1 shows a strip of steel of rectangular cross-section clamped at one end. The strip extends horizontally over the edge of a bench.

Figure 1



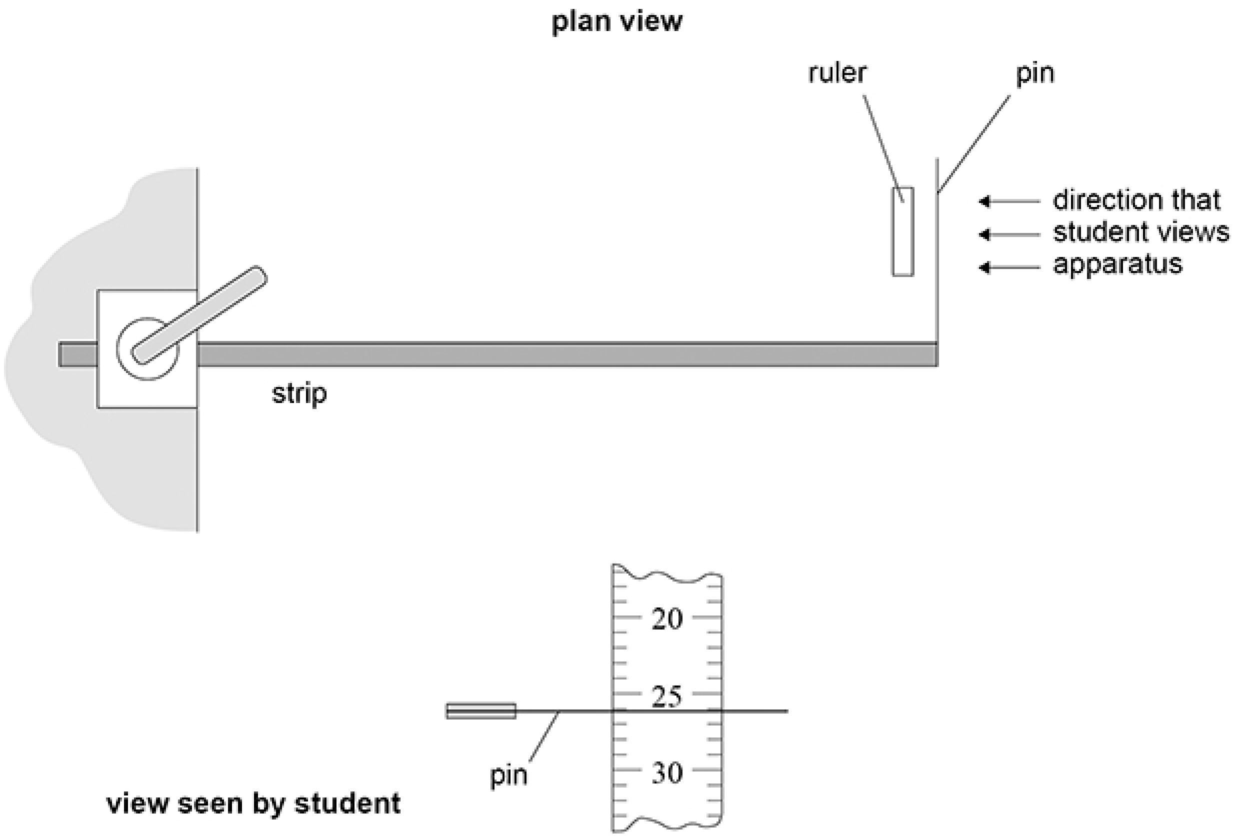
(a) A mass m is suspended from the free end of the strip.

This produces a vertical displacement y.

A student intends to measure y with the aid of a horizontal pin fixed to the free end of the steel strip.

She positions a clamped vertical ruler behind the pin, as shown in **Figure 2**.

Figure 2



Explain a procedure to avoid parallax error when judging the reading indicated by the position of the pin on the ruler.
You may add detail to **Figure 2** to illustrate your answer.

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(2)

(b) It can be shown that

$$y = \frac{4mgL^3}{Ewt^3}$$

where:

L is the distance between the free end of the **unloaded** strip and the blocks
w is the width of the strip and is approximately $1\ \text{cm}$
t is the thickness of the strip and is approximately $1\ \text{mm}$
E is the Young modulus of the steel.

A student is asked to determine E using the arrangement shown in **Figure 1** with the following restrictions:

- only one steel strip of approximate length $30\ \text{cm}$ is available
- m must be made using a $50\ \text{g}$ mass hanger and up to four additional $50\ \text{g}$ slotted masses
- the experimental procedure must involve only **one** independent variable
- a graphical method must be used to get the result for E.

Explain what the student must do to determine E.

(5)
(Total 7 marks)