Materials

Density, Hooke's law, Young modulus

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174 minutes

174 marks

Q1. A uniform wooden beam of mass 35.0 kg and length 5.52 m is supported by two identical vertical steel cables **A** and **B** attached at either end, as shown in **Figure 1**.

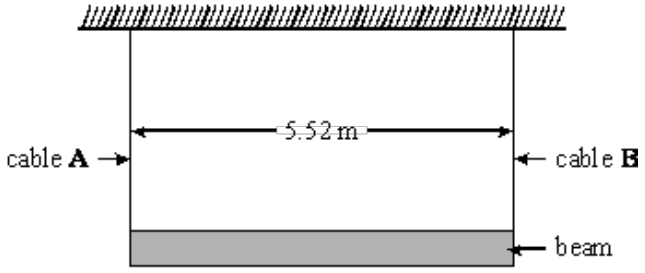

Figure 1

(a) Calculate

(i) the weight of the beam,

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(ii) the tension in each cable.

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(2)

(b) Each unstretched cable has a diameter of 8.26 mm and a length 2.50 m. Calculate the extension of each cable when supporting the beam.

The Young modulus for steel = 2.10×10^{11} Pa

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(4)

(c) An object of mass 20.0 kg is hung from the beam 1.00 m from cable **A**, as shown in **Figure 2**.

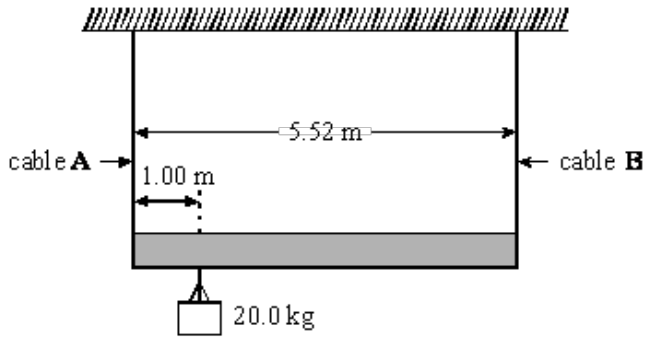

Figure 2

(i) Show that the new tension in cable **A** is 332 N.

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(ii) Calculate the new tension in cable **B**.

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(6)
(Total 12 marks)

Q2. A material in the form of a wire, 3.0 m long and cross-sectional area = 2.8×10^{-7} m^2 is suspended from a support so that it hangs vertically. Different masses may be suspended from its lower end. The table shows the extension of the wire when it is subjected to an increasing load and then a decreasing load.

load/N	0	24	52	70	82	88	94	101	71	50	16	0
extension/mm	0	2.2	4.6	6.4	7.4	8.2	9.6	13.0	10.2	8.0	4.8	3.2

(a) Plot a graph of load (on *y* axis) against extension (on *x* axis) both for increasing and decreasing loads.

(Allow one sheet of graph paper)

(4)

(b) Explain what the shape of the graph tells us about the behaviour of the material in the wire. You may be awarded marks for the quality of written communication in your answer.

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(4)

(c) Using the graph, determine a value of the Young modulus for the material of the wire.

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(3)

(d) State how the graph can be used to estimate the energy stored during the loading process.

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(1)

(Total 12 marks)

Q3. (a) Define the *density* of a material.

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(1)

(b) Brass, an alloy of copper and zinc, consists of 70% **by volume** of copper and 30% **by volume** of zinc.

density of copper $= 8.9 \times 10^{3}$ kg m^{-3}
density of zinc $= 7.1 \times 10^{3}$ kg m^{-3}

(i) Determine the mass of copper and the mass of zinc required to make a rod of brass of volume 0.80×10^{-3} m^{3}.

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(ii) Calculate the density of brass.

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(4)
(Total 5 marks)

Q4. (a) When a *tensile stress* is applied to a wire, a *tensile strain* is produced in the wire.
State the meaning of

tensile stress, ...

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tensile strain. .....

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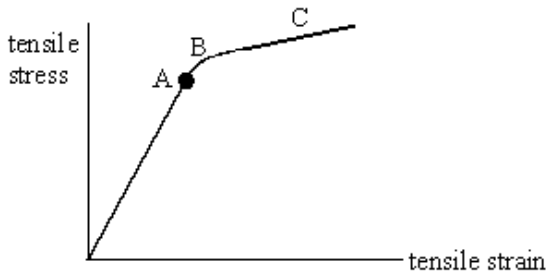
(2)

(b) A long thin line metallic wire is suspended from a fixed support and hangs vertically. Weights are added to increase the load on the free end of the wire until the wire breaks. The graph below shows how the tensile strain in the wire increases as the tensile stress increases.



With reference to the graph, describe the behaviour of the wire as the load on the free end is increased. To assist with your answer refer to the point A, and regions B and C.

You may be awarded marks for the quality of written communication in your answer.

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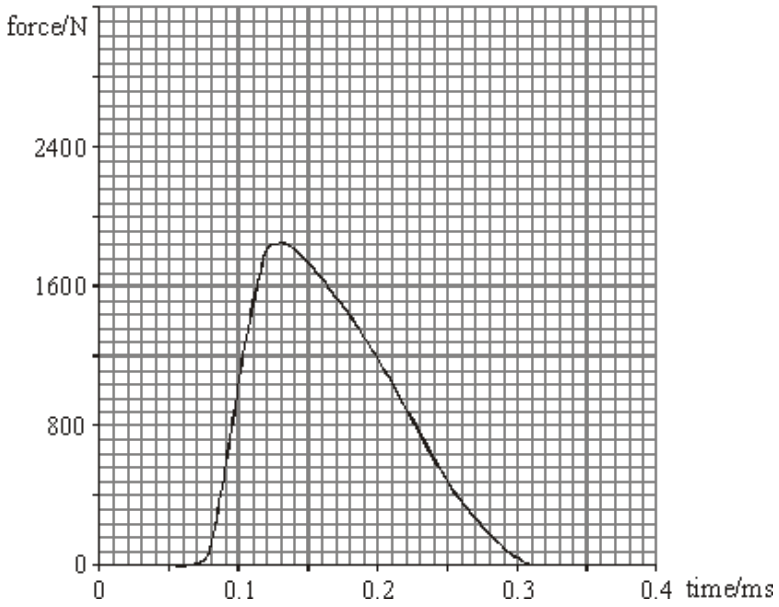
(5)
(Total 7 marks)

Q5. The diagram below shows how the impact force on the heel of a runner's foot varies with time during an impact when the runner is wearing cushioned sports shoes.



(a) Estimate the maximum stress on the cartilage pad in the knee joint as a result of this force acting on the cartilage pad over a contact area of 550 mm^2.

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(4)

(b) On the diagram above, sketch the graph of force against time you would expect to see if a sports shoe with less cushioning had been used.

(3)
(Total 7 marks)

Q6. (a) State *Hooke's law* for a material in the form of a wire.

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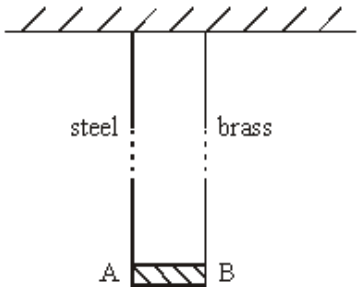
(2)

(b) A rigid bar AB of negligible mass, is suspended horizontally from two long, vertical wires as shown in the diagram. One wire is made of steel and the other of brass. The wires are fixed at their upper end to a rigid horizontal surface. Each wire is 2.5 m long but they have different cross-sectional areas.



When a mass of 16 kg is suspended from the centre of AB, the bar remains horizontal.

the Young modulus for steel = 2.0×10^{11} Pa
the Young modulus for brass = 1.0×10^{11} Pa

(i) What is the tension in each wire?

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(ii) If the cross-sectional area of the steel wire is 2.8×10^{-7} m^2, calculate the extension of the steel wire.

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(iii) Calculate the cross-sectional area of the brass wire.

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(iv) Calculate the energy stored in the steel wire.

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(7)

(c) The brass wire is replaced by a steel wire of the same dimensions as the brass wire. The same mass is suspended from the midpoint of AB.

(i) Which end of the bar is lower?

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(ii) Calculate the vertical distance between the ends of the bar.

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(2)
(Total 11 marks)

Q7. (a) When determining the Young modulus for the material of a wire, a *tensile stress* is applied to the wire and the *tensile strain* is measured.

(i) State the meaning of

tensile stress .....

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tensile strain .....

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(ii) Define the Young modulus .....

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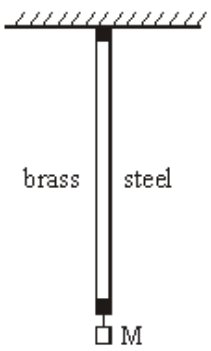
(3)

(b) The diagram below shows two wires, one made of steel and the other of brass, firmly clamped together at their ends. The wires have the same unstretched length and the same cross-sectional area.
One of the clamped ends is fixed to a horizontal support and a mass M is suspended from the other end, so that the wires hang vertically.



(i) Since the wires are clamped together the extension of each wire will be the same.
If E_S is the Young modulus for steel and E_B the Young modulus for brass, show that

$$\frac{E_S}{E_B} = \frac{F_S}{F_B},$$

where F_S and F_B are the respective forces in the steel and brass wire.

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(ii) The mass M produces a total force of 15 N. Show that the magnitude of the force $F_S = 10$ N.

the Young modulus for steel = 2.0×10^{11} Pa
the Young modulus for brass = 1.0×10^{11} Pa

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(iii) The cross-sectional area of each wire is 1.4×10^{-6} m^2 and the unstretched length is 1.5 m. Determine the extension produced in either wire.

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(6)

(Total 9 marks)

Q8. (a) State *Hooke's law* for a material in the form of a wire and state the conditions under which this law applies.

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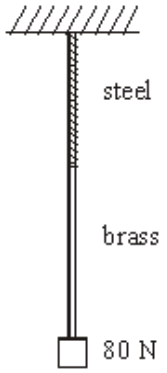
(2)

(b) A length of steel wire and a length of brass wire are joined together. This combination is suspended from a fixed support and a force of 80 N is applied at the bottom end, as shown in the figure below.



Each wire has a cross-sectional area of 2.4×10^{-6} m^2.

length of the steel wire = 0.80 m
length of the brass wire = 1.40 m
the Young modulus for steel = 2.0×10^{11} Pa
the Young modulus for brass = 1.0×10^{11} Pa

(i) Calculate the total extension produced when the force of 80 N is applied.

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(ii) Show that the mass of the combination wire = 4.4×10^{-2} kg.

density of steel = 7.9×10^3 kg m^{-3}
density of brass = 8.5×10^3 kg m^{-3}

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(7)

(c) A single brass wire has the same mass and the same cross-sectional area as the combination wire described in part (b). Calculate its length.

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(2)
(Total 11 marks)

Q9. (a) When a *tensile stress* is applied to a wire, a *tensile strain* is produced in the wire. State the meaning of

tensile stress, ….....

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tensile strain. .....

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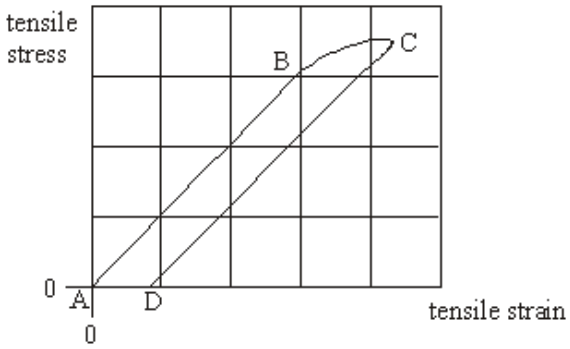
(2)

(b) A long, thin metal wire is suspended from a fixed support and hangs vertically. Masses are suspended from its lower end.

As the load on the lower end is increased from zero to a certain value, and then decreased again to zero, the variation of the resulting tensile strain with the applied tensile stress is shown in the graph.



(i) Describe the behaviour of the wire during this process. Refer to the points A, B, C and D in your answer.
You may be awarded marks for the quality of written communication in your answer.

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(ii) State, with a reason, whether the material of the wire is ductile or brittle.

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(iii) What does AD represent?

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(iv) State how the Young modulus for the material may be obtained from the graph.

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(v) State how the energy per unit volume stored in the wire during the loading process may be estimated from the graph.

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(9)

(c) The wire described in part (b) has an unstretched length of 3.0 m and cross-sectional area 2.8×10^{-7} m^2. At a certain stage between the points A and B on the graph, the wire supports a load of 75 N. Calculate the extension produced in the wire by this load.
the Young modulus for the material of the wire = 2.1×10^{11} Pa

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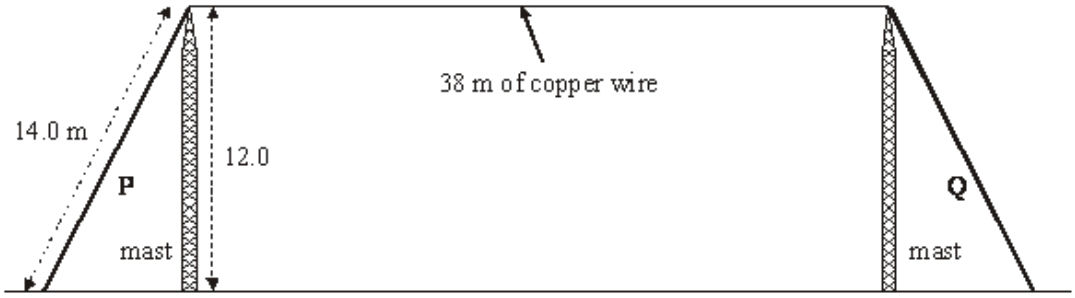
(2)
(Total 13 marks)

Q10. An aerial system consists of a horizontal copper wire of length 38 m supported between two masts, as shown in the figure below. The wire transmits electromagnetic waves when an alternating potential is applied to it at one end.



(a) The wavelength of the radiation transmitted from the wire is twice the length of the copper wire. Calculate the frequency of the transmitted radiation.

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(1)

(b) The ends of the copper wire are fixed to masts of height 12.0 m. The masts are held in a vertical position by cables, labelled **P** and **Q**, as shown in the figure above.

(i) **P** has a length of 14.0 m and the tension in it is 110 N. Calculate the tension in the copper wire.

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(ii) The copper wire has a diameter of 4.0 mm. Calculate the stress in the copper wire.

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(iii) Discuss whether the wire is in danger of breaking if it is stretched further due to movement of the top of the masts in strong winds.

breaking stress of copper = 3.0×10^8 Pa

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(7)
(Total 8 marks)

Q11. (a) (i) Describe the behaviour of a wire that obeys Hooke's law.

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(ii) Explain what is meant by the elastic limit of the wire.

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(iii) Define the Young modulus of a material and state the unit in which it is measured.

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(5)

(b) A student is required to carry out an experiment and draw a suitable graph in order to obtain a value for the Young modulus of a material in the form of a wire.
A long, uniform wire is suspended vertically and a weight, sufficient to make the wire taut, is fixed to the free end. The student increases the load gradually by adding known weights. As each weight is added, the extension of the wire is measured accurately.

(i) What other quantities must be measured before the value of the Young modulus can be obtained?

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(ii) Explain how the student may obtain a value of the Young modulus.

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(iii) How would a value for the elastic energy stored in the wire be found from the results?

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(6)
(Total 11 marks)

Q12. (a) (i) Describe the behaviour of a wire that obeys Hooke's law.

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(ii) Explain what is meant by the elastic limit of the wire.

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(iii) Define the Young modulus of a material and state the unit in which it is measured.

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(5)

(b) A student is required to carry out an experiment and draw a suitable graph in order to obtain a value for the Young modulus of a material in the form of a wire. A long, uniform wire is suspended vertically and a weight, sufficient to make the wire taut, is fixed to the free end. The student increases the load gradually by adding known weights. As each weight is added, the extension of the wire is measured accurately.

(i) What other quantities must be measured before the value of the Young modulus can be obtained?

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(ii) Explain how the student may obtain a value of the Young modulus.

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(iii) How would a value for the elastic energy stored in the wire be found from the results?

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(6)
(Total 11 marks)

Q13. (a) State Hooke's law.

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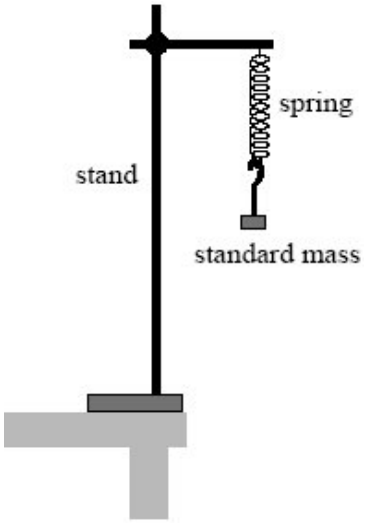
(2)

(b) A student is asked to measure the mass of a rock sample using a steel spring, standard masses and a metre rule. She measured the unstretched length of the spring and then set up the arrangement shown in the diagram below.



(i) Describe how you would use this arrangement to measure the mass of the rock sample. State the measurements you would make and explain how you would use the measurements to find the mass of the rock sample.
The quality of your written communication will be assessed in this question.

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(6)

(ii) State and explain **one** modification you could make to the arrangement in the diagram above to make it more stable.

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(2)
(Total 10 marks)

Q14. (a) Describe how to obtain, accurately by experiment, the data to determine the Young modulus of a metal wire.

A space is provided for a labelled diagram.

The quality of your written answer will be assessed in this question.

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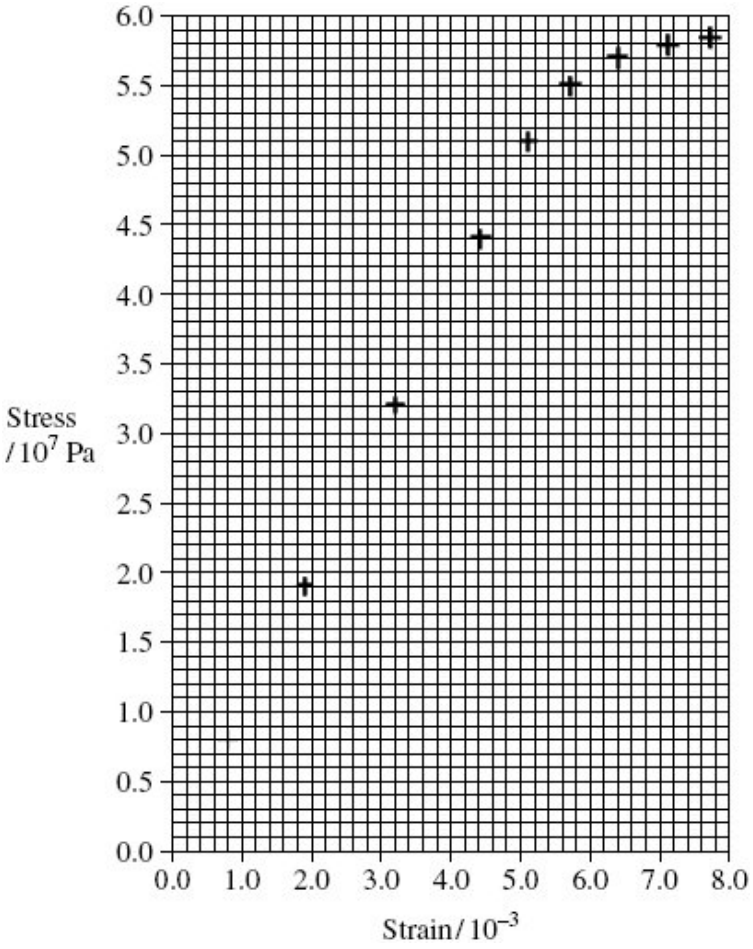
(6)

(b) The diagram below is a plot of some results from an experiment in which a metal wire was stretched.



(i) Draw a best-fit line using the data points.

(1)

(ii) Use your line to find the Young modulus of the metal, stating an appropriate unit.

answer = ...

(4)

(c) After reaching a strain of 7.7×10^{-3}, the wire is to be unloaded. On the diagram above, sketch the line you would expect to obtain for this.

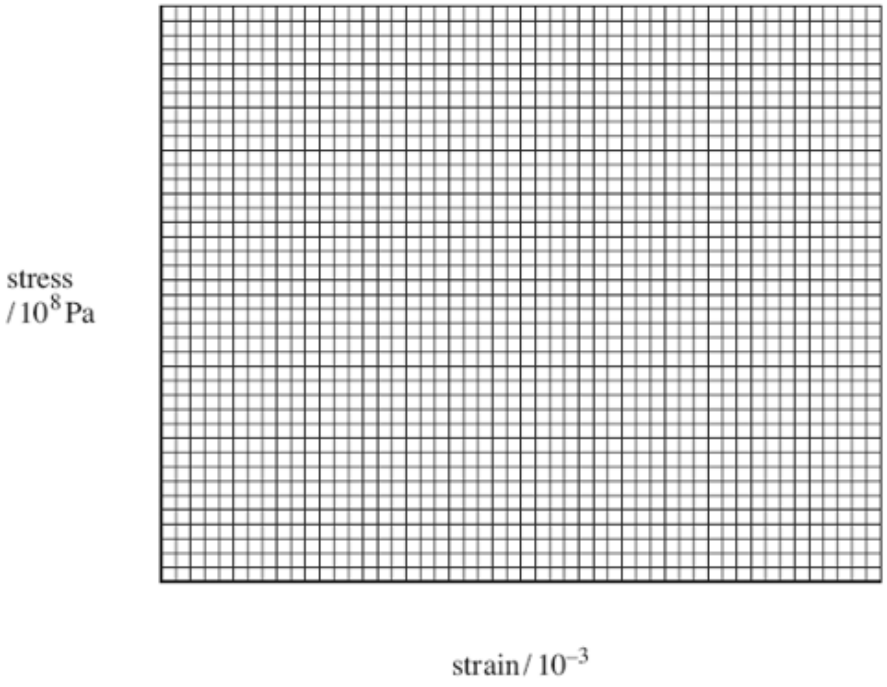
(1)

(Total 12 marks)

Q15. The table below shows the results of an experiment where a force was applied to a sample of metal.

(a) On the axes below, plot a graph of stress against strain using the data in the table.

Strain / 10^{-3}	0	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
Stress /10^{8} Pa	0	0.90	2.15	3.15	3.35	3.20	3.30	3.50	3.60	3.60	3.50



(3)

(b) Use your graph to find the Young modulus of the metal.

answer = ... Pa

(2)

(c) A 3.0 m length of steel rod is going to be used in the construction of a bridge. The tension in the rod will be 10 kN and the rod must extend by no more than 1.0mm. Calculate the minimum cross-sectional area required for the rod.

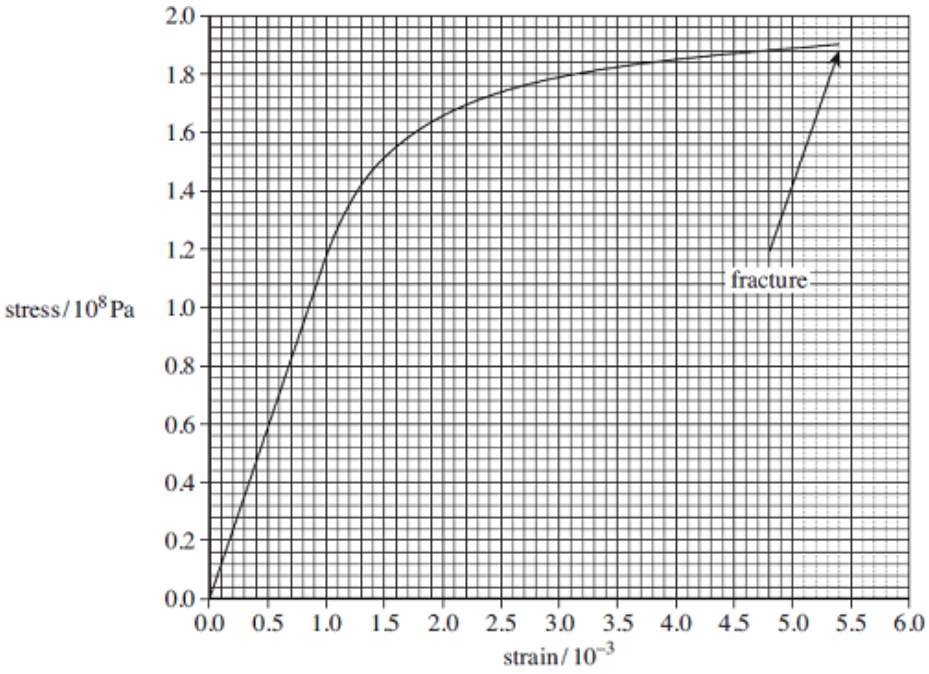
Young modulus of steel = 1.90×10^{11} Pa

answer = ... m^2

(3)

(Total 8 marks)

Q16. The figure below shows a stress-strain graph for a copper wire.



(a) Define tensile strain.

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(1)

(b) State the breaking stress of this copper wire.

answer = ... Pa

(1)

(c) Mark on the figure above a point on the line where you consider plastic deformation may start.
Label this point **A**.

(1)

(d) Use the graph to calculate the Young modulus of copper. State an appropriate unit for your answer.

answer = ...

(3)

(e) The area under the line in a stress-strain graph represents the work done per unit volume to stretch the wire.

(i) Use the graph to find the work done per unit volume in stretching the wire to a strain of 3.0×10^{-3}.

answer = ...J m^{-3}

(2)

(ii) Calculate the work done to stretch a 0.015 kg sample of this wire to a strain of 3.0×10^{-3}.

The density of copper = 8960 kg m^{-3}.

answer = ...J

(2)

(f) A certain material has a Young modulus greater than copper and undergoes brittle fracture at a stress of 176 MPa.

On the figure above draw a line showing the possible variation of stress with strain for this material.

(2)
(Total 12 marks)

Q17. (a) Describe an experiment to accurately determine the spring constant *k* of a spring that is thought to reach its limit of proportionality when the load is about 20 N.

Include details of the necessary measurements and calculations and describe how you would reduce uncertainty in your measurements. A space is provided for a labelled diagram should you wish to include one.

The quality of your written communication will be assessed in this question.

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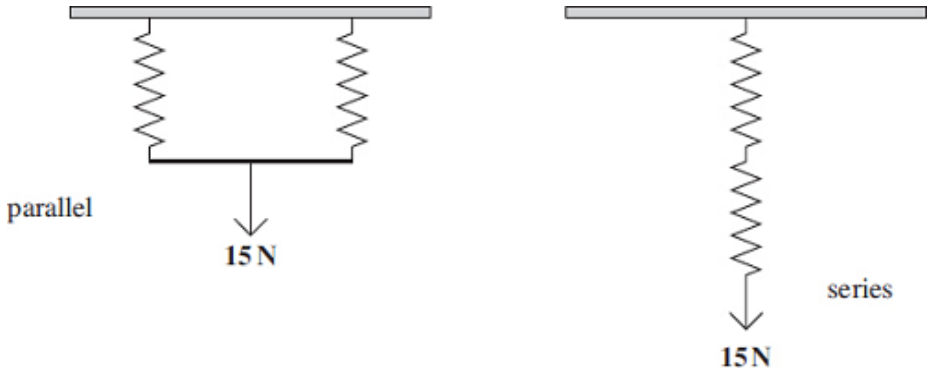
(6)

(b) Two identical springs, each having a spring constant of 85 Nm^{-1}, are shown arranged in parallel and series in the figure below.



A load of 15 N is attached to each arrangement.

(i) Calculate the extension for the parallel arrangement when the load is midway between the lower ends of the springs.

answer = ... m

(2)

(ii) Calculate the extension for the series arrangement.

answer = ... m

(2)

(iii) Calculate the energy stored in the parallel arrangement.

answer = ... J

(2)

(iv) Without further calculation, discuss whether the energy stored in the series arrangement is less, or greater, or the same as in the parallel arrangement.

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(3)
(Total 15 marks)