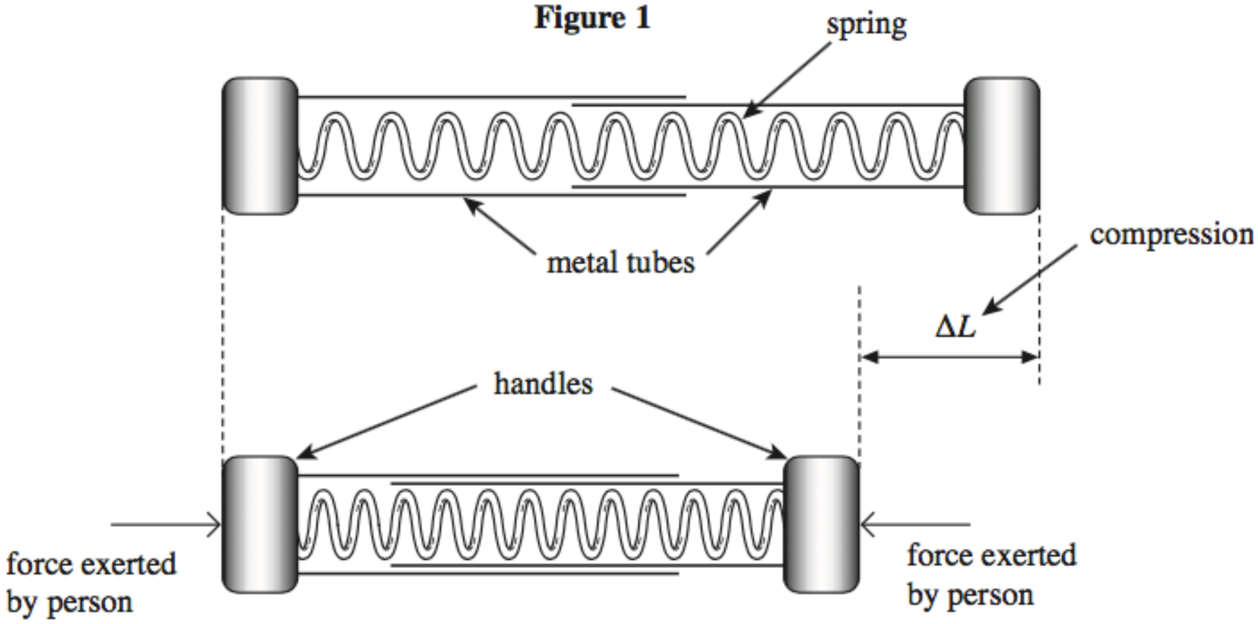
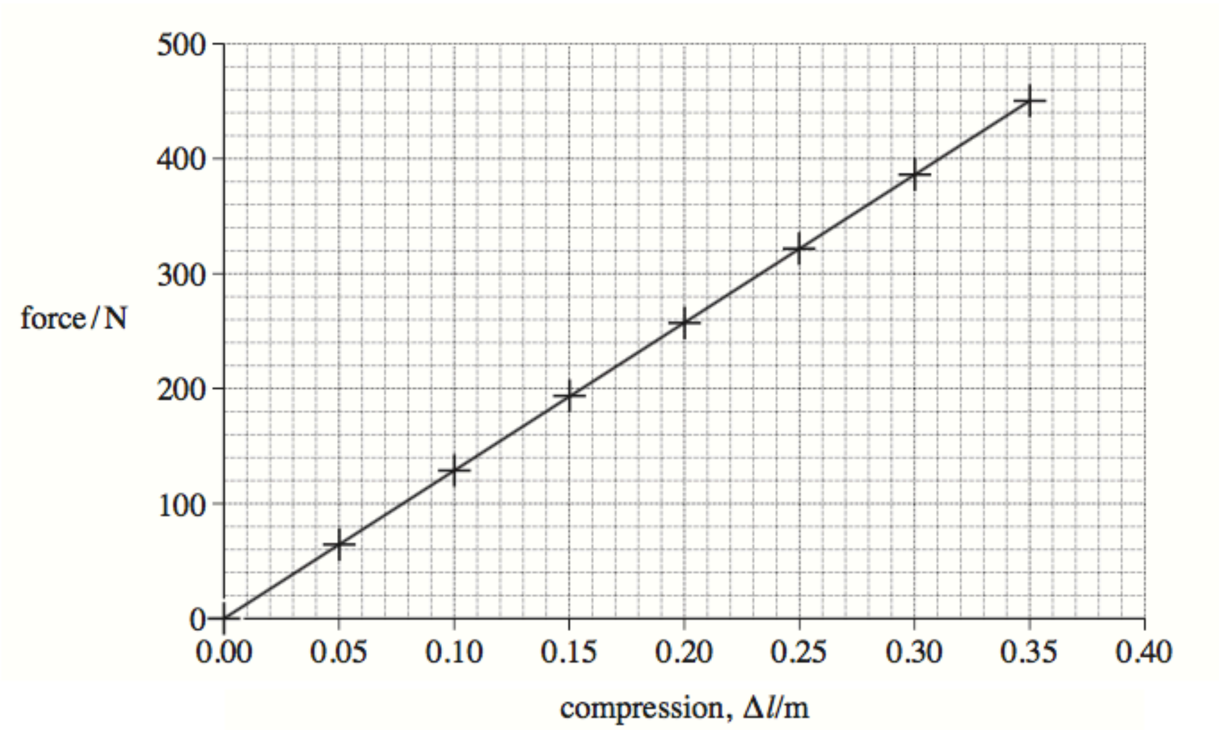
1)

A type of exercise device is used to provide resistive forces when a person applies compressive forces to its handles. The stiff spring inside the device compresses as shown in **Figure 1.**

Figure 1



(a) The force exerted by the spring over a range of compressions was measured. The results are plotted on the grid below.



(a) (i) State Hooke's law.

....

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(2 marks)

(a) (ii) State which two features of the graph confirm that the spring obeys Hooke's law over the range of values tested.

....

....

(2 marks)

(a) (iii) Use the graph to calculate the spring constant, stating an appropriate unit.

answer = ...

(3 marks)

(b) (i) The formula for the energy stored by the spring is

$$E = \frac{1}{2} F\Delta L$$

Explain how this formula can be derived from a graph of force against extension.

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(3 marks)

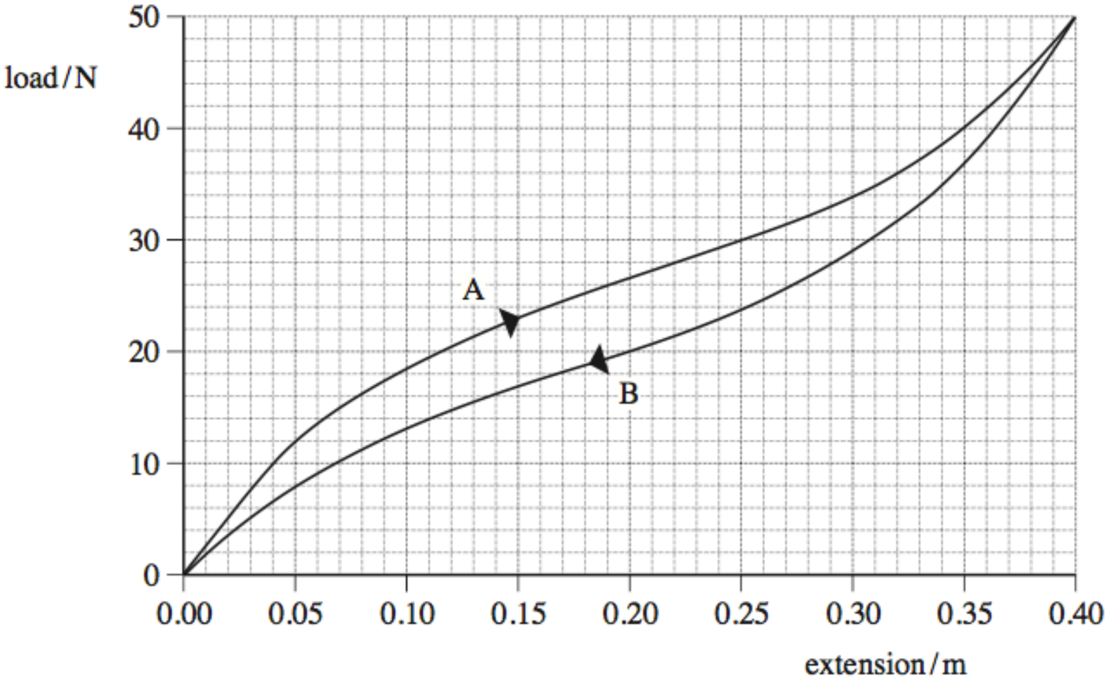
(b) (ii) The person causes a compression of 0.28 m in a time of 1.5 s. Use the graph in part (a) to calculate the average power developed.

answer = ...W
(3 marks)

2)

A rubber cord is used to provide mechanical resistance when performing fitness exercises. A scientist decided to test the properties of the cord to find out how effective it was for this purpose. The graph of load against extension is shown in **Figure 5** for a 0.50 m length of the cord.

Figure 5



Curve **A** shows loading and curve **B** shows unloading of the cord.

(a) State which feature of this graph confirms that the rubber cord is elastic.

....

(1 mark)

(b) Explaining your method, use the graph (curve **A**) to estimate the work done in producing an extension of 0.30 m.

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answer = ... J

(3 marks)

(c) Assuming that line **A** is linear up to an extension of 0.040 m, calculate the Young modulus of the rubber for small strains.

The cross-sectional area of the cord = $5.0 \times 10^{-6}\,m^2$
The unstretched length of the cord = 0.50 m

answer = ... Pa
(3 marks)

(d) The scientist compared this cord with a steel spring that reached the same extension for the same maximum load without exceeding its *limit of proportionality*.

(d) (i) On **Figure 5**, draw the load-extension line for this spring up to a load of 50 N and label it **C**.
(1 mark)

(d) (ii) With reference to the spring, explain what is meant by limit of proportionality.

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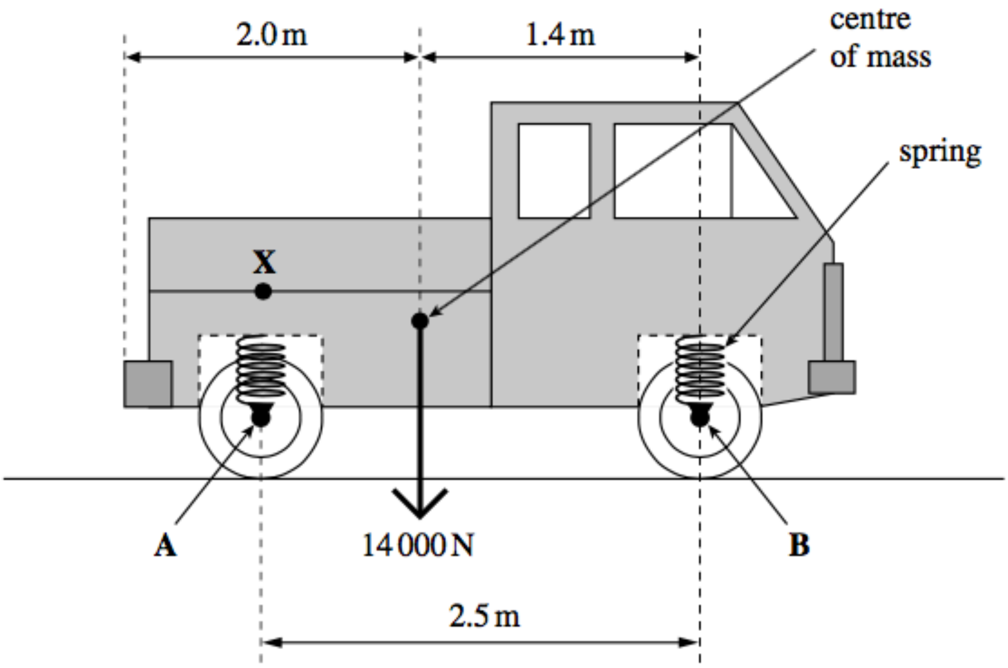
....
(1 mark)

3)

Heavy duty coil springs are used in vehicle suspensions. The pick-up truck shown in **Figure 2** has a weight of 14 000 N and length of 4.5 m. When carrying no load, the centre of mass is 2.0 m from the rear end. The part of the vehicle shown shaded in grey is supported by four identical springs, one near each wheel.

Figure 2



(a) (i) Define the moment of a force about a point.

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(2 marks)

(a) (ii) State and explain which pair of springs, front or rear, will be compressed the most.

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(2 marks)

(a) (iii) By taking moments about axle **B**, calculate the force exerted on the truck by each rear spring.

answer = ... N

(4 marks)

(b) The spring constant for each of these springs is 100 000 $N m^{-1}$.

Calculate the distance that each of these rear springs is compressed by this vehicle as shown in **Figure 2**.

answer = ... m

(2 marks)

(c) The springs must not be compressed by more than an additional 0.065 m. Calculate the maximum load that could be placed at point **X**, which is directly above the centre of the rear axle **A**, as shown in **Figure 2**.

answer = ... N

(2 marks)

4)

(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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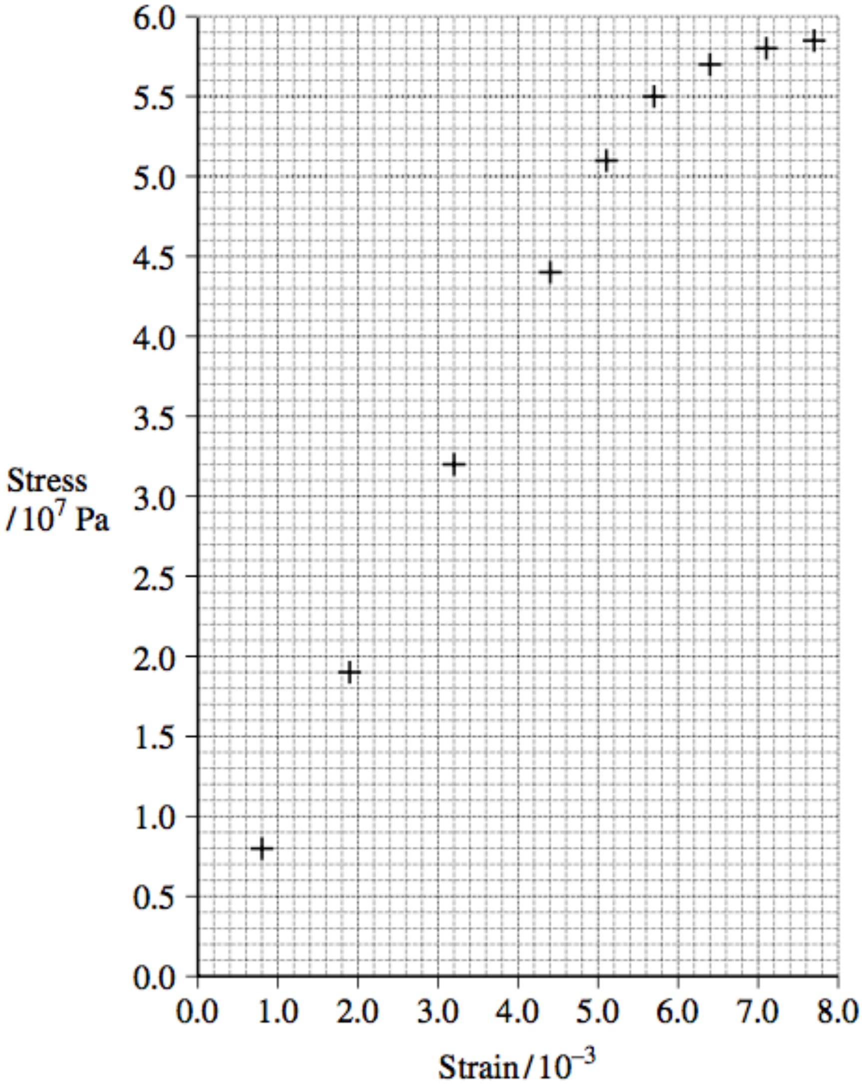
(6 marks)

(b) **Figure 7** is a plot of some results from an experiment in which a metal wire was stretched.

Figure 7



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

(1 mark)

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

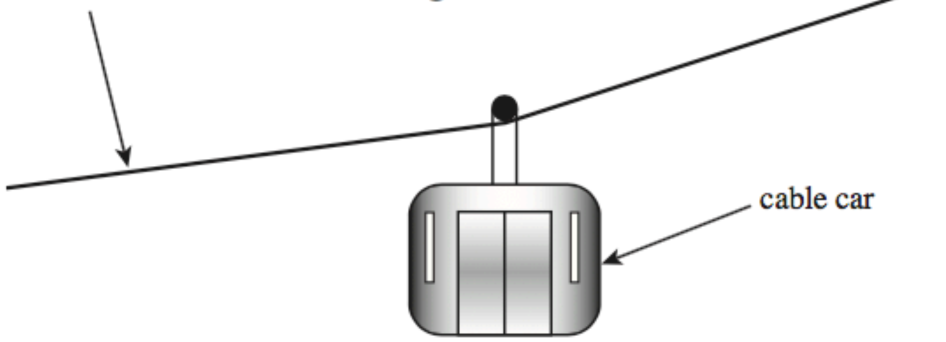
answer = ...
(4 marks)

(c) After reaching a strain of 7.7×10^{-3}, the wire is to be unloaded. On **Figure 7**, sketch the line you would expect to obtain for this.
(1 mark)

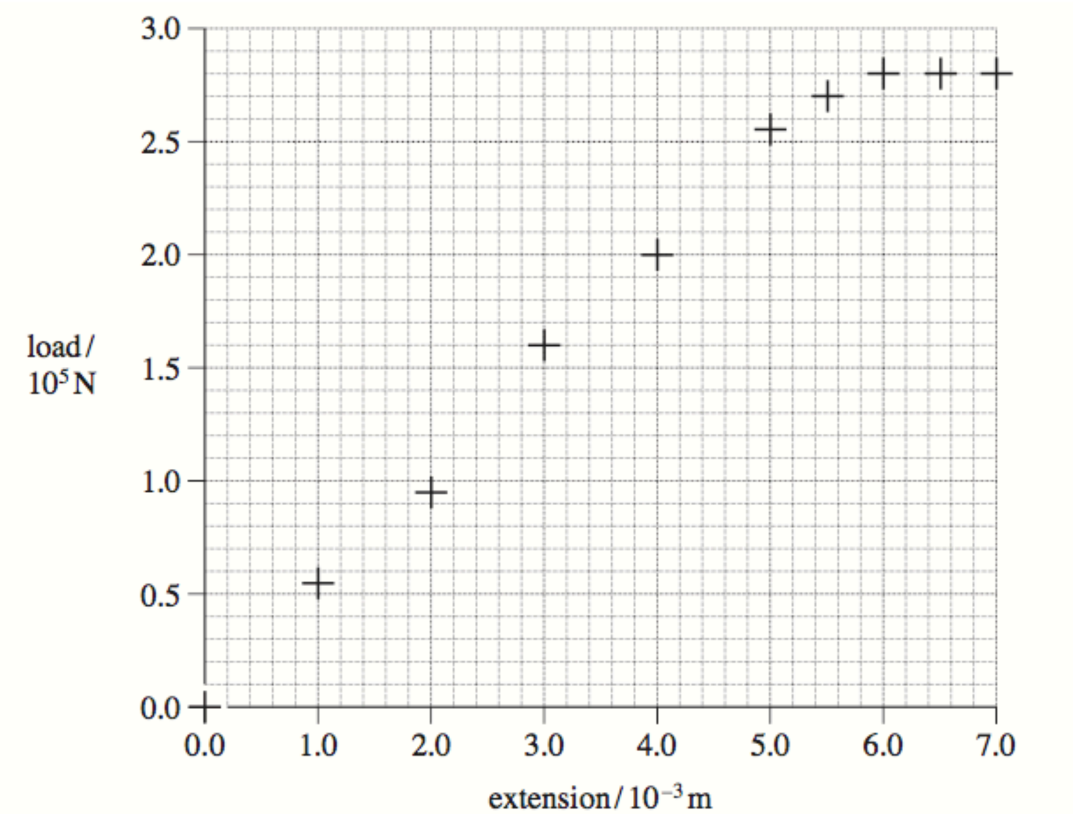
5)

A cable car system is used to transport people up a hill. **Figure 7** shows a stationary cable car suspended from a steel cable of cross-sectional area $2.5 \times 10^{-3}\,m^2$.

Figure 7



(a) The graph below is for a 10 m length of this steel cable.



(a) (i) Draw a line of best fit on the graph. *(2 marks)*

(a) (ii) Use the graph to calculate the initial gradient, *k*, for this sample of the cable.

answer = ... Nm^{-1}
(2 marks)

(b) The cable breaks when the extension of the sample reaches 7.0 mm. Calculate the breaking stress, stating an appropriate unit.

answer = ...

(3 marks)

(c) In a cable car system a 1000 m length of this cable is used. Calculate the extension of this cable when the tension is 150 kN.

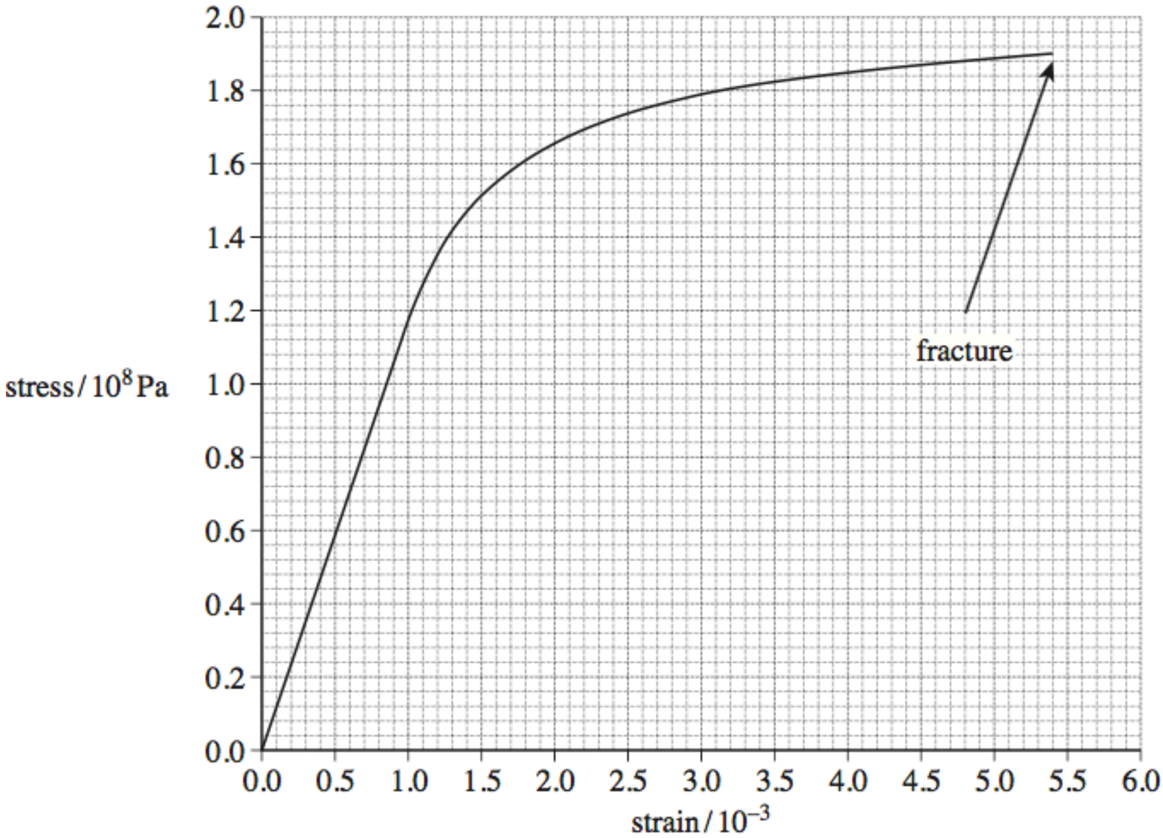
answer = ...m

(2 marks)

6)

Figure 4 shows a stress-strain graph for a copper wire.

Figure 4



(a) Define tensile strain.

....

....

(1 mark)

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

answer = ... Pa

(1 mark)

(c) Mark on **Figure 4** a point on the line where you consider plastic deformation may start. Label this point **A**.

(1 mark)

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

answer = ...

(3 marks)

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

(e) (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 marks)

(e) (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 marks)

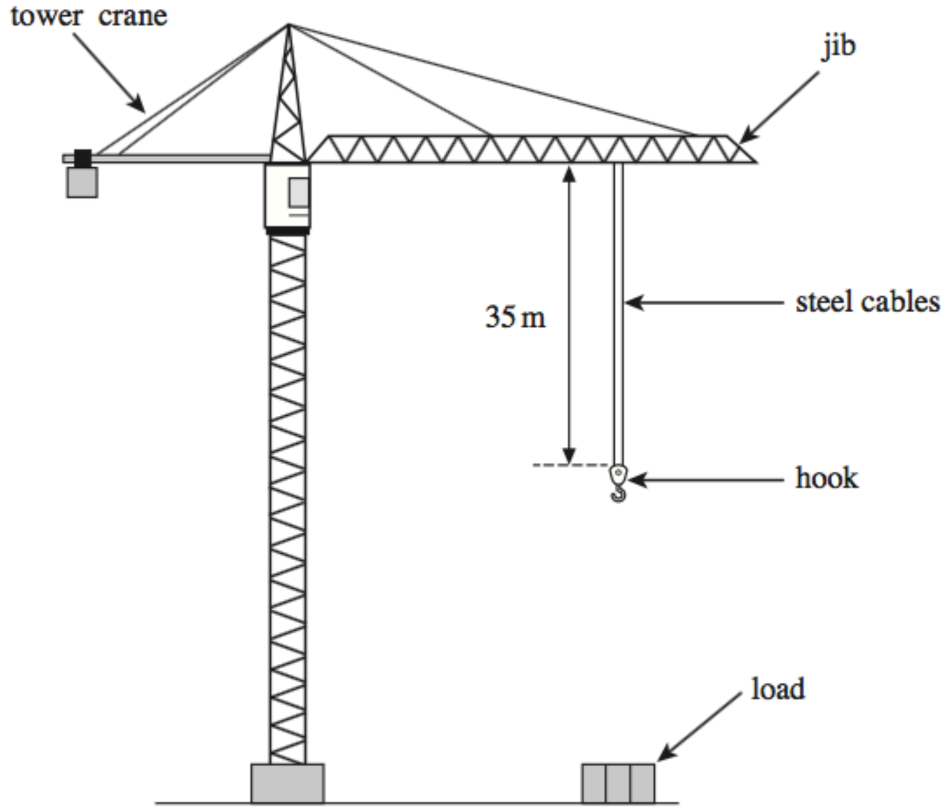
(f) A certain material has a Young modulus greater than copper and undergoes brittle fracture at a stress of 176 MPa.
On **Figure 4** draw a line showing the possible variation of stress with strain for this material.

(2 marks)

7)

Figure 3 shows a tower crane that has two identical steel cables. The length of each steel cable is 35 m from the jib to the hook.

Figure 3



(a) Each cable has a mass of 4.8 kg per metre. Calculate the weight of a 35 m length of **one** cable.

weight = ... N
(2 marks)

(b) The cables would break if the crane attempted to lift a load of 1.5×10^6 N or more. Calculate the breaking stress of **one** cable.

cross-sectional area of each cable = 6.2×10^{-4} m^2

breaking stress = ... Pa
(2 marks)

(c) When the crane supports a load **each** cable experiences a stress of 400 MPa. Each cable obeys Hooke's law. Ignore the weight of the cables.

Young modulus of steel = 2.1×10^{11} Pa

(c) (i) Calculate the weight of the load.

weight = ... N
(2 marks)

(c) (ii) The unstretched length of each cable is 35 m.

Calculate the extension of each cable when supporting the load.

extension = ... m
(3 marks)

(c) (iii) Calculate the combined stiffness constant, k, for the **two** cables.

stiffness constant = ... $N\,m^{-1}$
(2 marks)

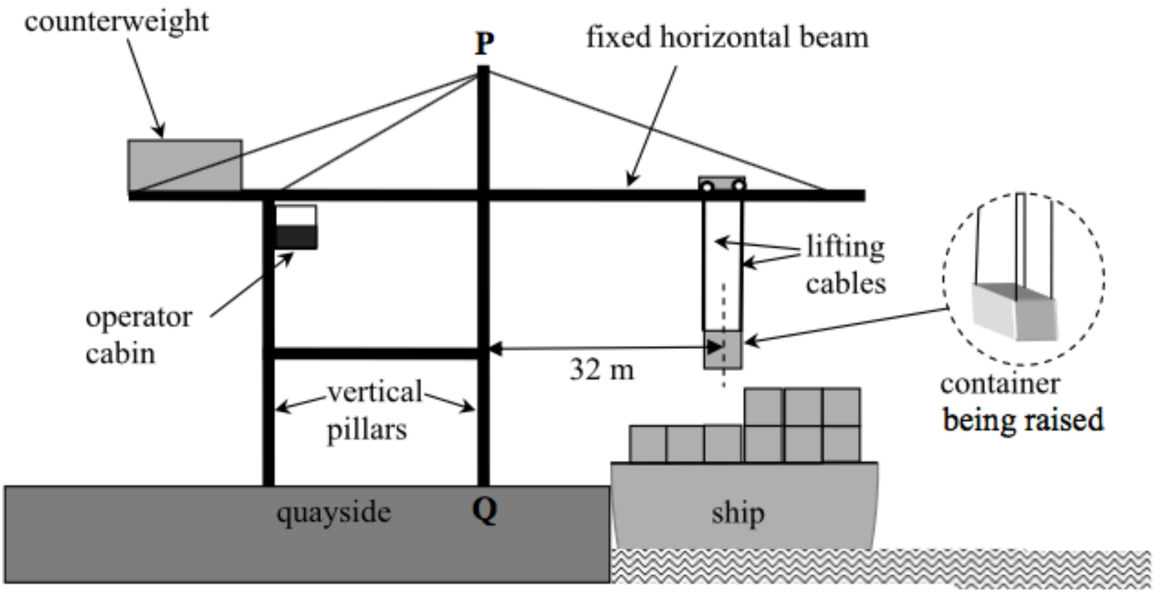
(c) (iv) Calculate the total energy stored in both stretched cables.

energy stored = ... J
(2 marks)

8)

Figure 2 shows a dockside crane that is used to lift a container of mass 22000 kg from a cargo ship onto the quayside. The container is lifted by four identical 'lifting' cables attached to the top corners of the container.

Figure 2



(a) When the container is being raised, its centre of mass is at a horizontal distance 32 m from the nearest vertical pillar **PQ** of the crane's supporting frame.

(a) (i) Assume the tension in each of the four lifting cables is the same. Calculate the tension in each cable when the container is lifted at constant velocity.

answer............................N
(2 marks)

(a) (ii) Calculate the moment of the container's weight about the point **Q** on the quayside, stating an appropriate unit.

answer............................
(3 marks)

(a) (iii) Describe and explain **one** feature of the crane that prevents it from toppling over when it is lifting a container.

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(2 marks)

(b) Each cable has an area of cross-section of $3.8 \times 10^{-4}\,\text{m}^2$.

(b) (i) Calculate the tensile stress in each cable, stating an appropriate unit.

answer.................................

(3 marks)

(b) (ii) Just before the container shown in **Figure 2** was raised from the ship, the length of each lifting cable was 25 m. Show that each cable extended by 17 mm when the container was raised from the ship.

Young modulus of steel = $2.1 \times 10^{11}\,\text{Pa}$

(2 marks)

9)

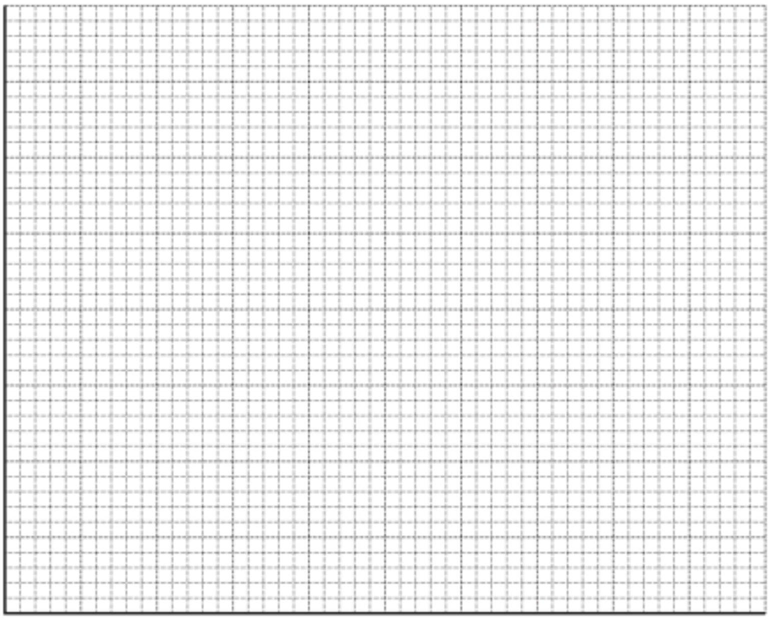
The table below shows the results of an experiment where a force was applied to a sample of metal.

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

(3 marks)

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

stress / 10^{8} Pa



strain / 10^{-3}

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

answer = ... Pa

(2 marks)

(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 1.0 mm. Calculate the minimum cross-sectional area required for the rod.

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

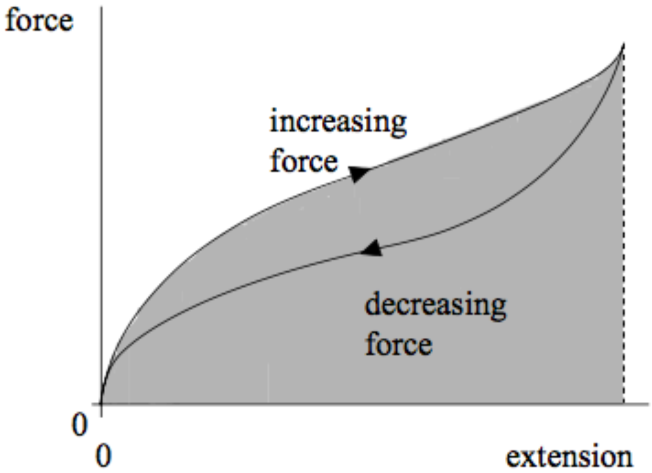
answer = ... m^2

(3 marks)

10)

A student investigated how the extension of a rubber cord varied with the force used to extend it. She measured the extension for successive increases of the force and then for successive decreases. **Figure 5** shows a graph of her results.

Figure 5



(a) (i) Give a reason why the graph shows the rubber cord does not obey Hooke's law.

....

....

(1 mark)

(a) (ii) Give a reason why the graph shows the rubber cord does not exhibit plastic behaviour.

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(1 mark)

(a) (iii) What physical quantity is represented by the area shaded on the graph between the loading curve and the extension axis?

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(1 mark)

(b) Describe, with the aid of a diagram, the procedure and the measurements you would make to carry out this investigation.

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

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(6 marks)

11)

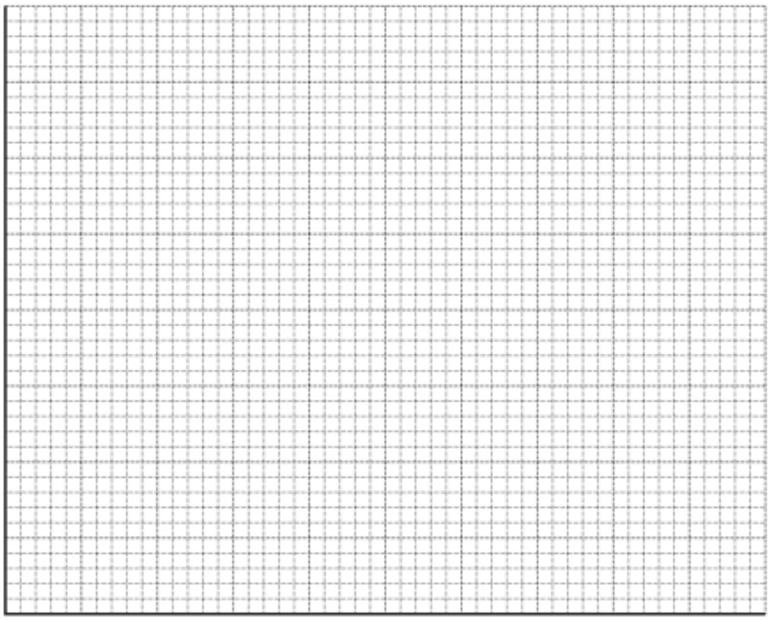
The table below shows the results of an experiment where a force was applied to a sample of metal.

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

(3 marks)

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

stress / 10^8 Pa



strain / 10^{-3}

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

answer = ... Pa

(2 marks)

(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 1.0 mm. Calculate the minimum cross-sectional area required for the rod.

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

answer = ... m^2
(3 marks)

12)

(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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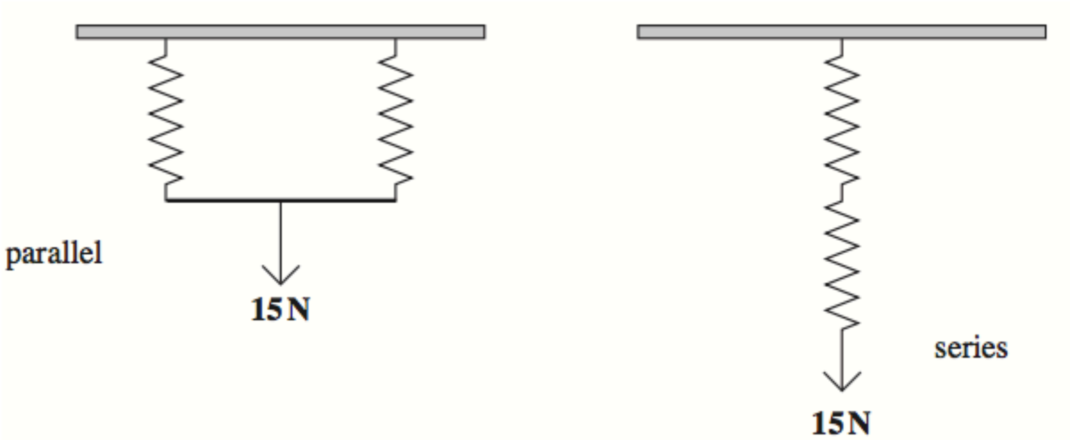
(6 marks)

(b) Two identical springs, each having a spring constant of $85\,\text{N m}^{-1}$, are shown arranged in parallel and series in **Figure 7**.

Figure 7



A load of 15 N is attached to each arrangement.

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

answer = ... m
(2 marks)

(b) (ii) Calculate the extension for the series arrangement.

answer = ... m
(2 marks)

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

answer = ... J
(2 marks)

(b) (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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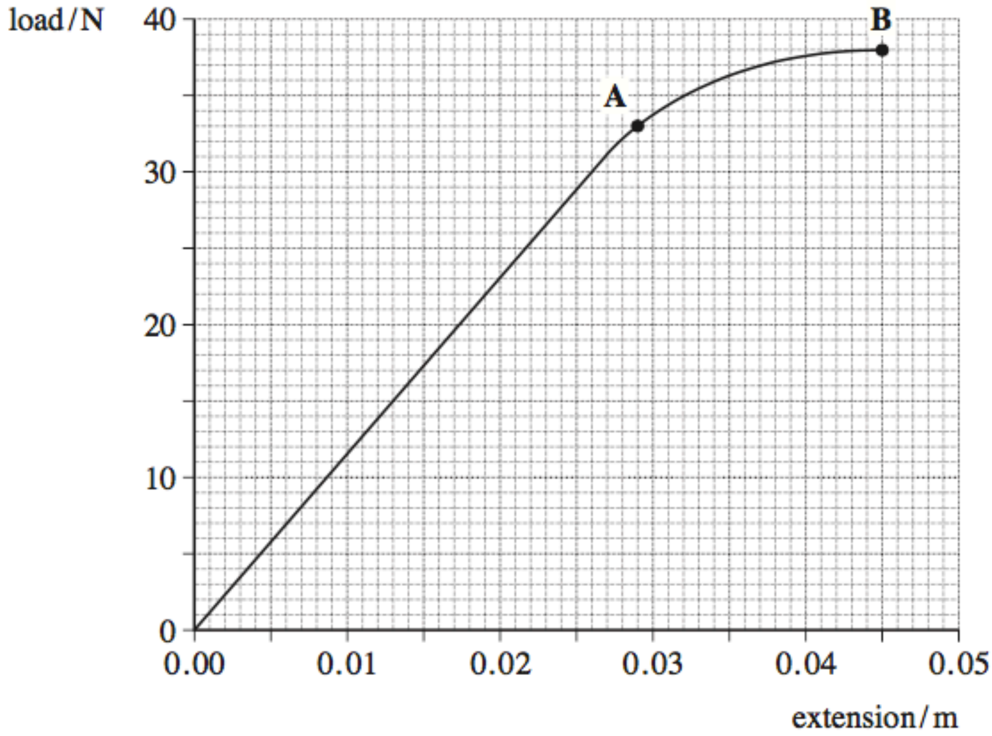
(3 marks)

13)

A manufacturer of springs tests the properties of a spring by measuring the load applied each time the extension is increased. The graph of load against extension is shown in **Figure 6**.

Figure 6



(a) State Hooke's law.

....

....

....

(2 marks)

(b) Calculate the spring constant, *k*, for the spring. State an appropriate unit.

spring constant .... unit ....

(3 marks)

(c) Use the graph to find the work done in extending the spring up to point **B**.

work done .... J

(3 marks)

(d) Beyond point **A** the spring undergoes *plastic deformation*.

Explain the meaning of the term plastic deformation.

....

....

(1 mark)

(e) When the spring reaches an extension of 0.045 m, the load on it is gradually reduced to zero. On the graph in **Figure 6**, sketch how the extension of the spring will vary with load as the load is reduced to zero.

(2 marks)

(f) Without further calculation, compare the total work done by the spring when the load is removed with the work that was done by the load in producing the extension of 0.045 m.

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(1 mark)

14)

(a) In order to compare the mechanical properties of two different types of metal alloy, an engineer decides to measure the Young modulus for each of them. She has a sample of each alloy in the form of a wire. Each wire is about 1.5 m in length but they have different diameters.

Describe an experimental method that she could use to obtain the data necessary to accurately determine the Young modulus of these metals. You may wish to illustrate your answer with a diagram.

The quality of your written communication will be assessed in your answer.

[6 marks]

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(b) In this experiment, wire **A** is found to have a higher Young modulus than wire **B** and it fractures before any permanent deformation takes place. Wire **B** stretches well beyond its elastic limit before fracturing.

(b) (i) From this evidence, state a mechanical property of the metal that wire **A** is made from.

[1 mark]

....

(b) (ii) On the axes below, sketch possible stress-strain graphs for wires **A** and **B**. Label the axes and label the lines **A** and **B**.

[3 marks]

Question 4 continues on the next page

(c) The engineer found that the Young modulus of alloy **A** was 2.80×10^{11} Pa. During the experiment, the 1.5 m wire underwent a 0.24% increase in length.

(c) (i) Calculate the stress on the wire for this extension.

[3 marks]

stress .... Pa

(c) (ii) For the same extension as in part (c)(i), calculate the load that must be applied to wire **A**. The diameter of the wire **A** is 1.40 mm.

[3 marks]

load .... N

15)

An aerospace engineer has built two differently designed wings. One wing is made from an aluminium alloy and the other is made from a carbon fibre composite.

The engineer tests a sample of each material by applying a varying stress.

(a) Tick (✓) **two** of the boxes in **Table 2** to indicate which are properties of the material from which the wing is made.

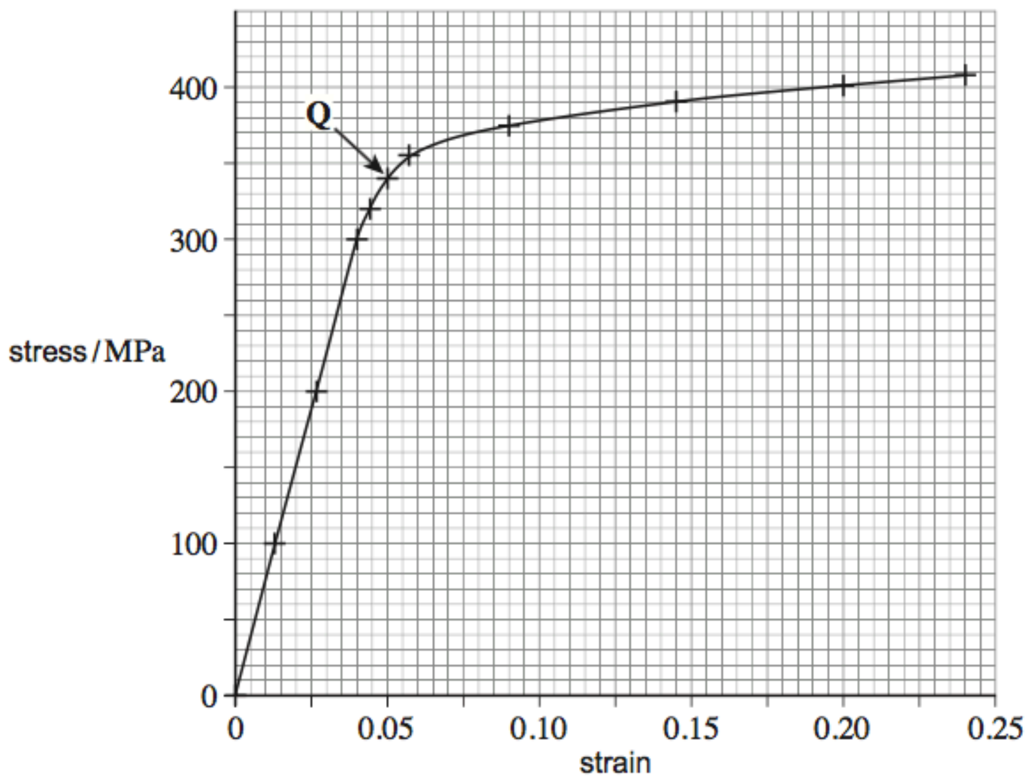
[1 mark]

Table 2

breaking stress	
stiffness constant, k	
tensile strain	
tensile stress	
Young modulus	

(b) **Figure 4** shows the stress–strain graph that the engineer obtains for the aluminium alloy.

Figure 4



(b) (i) The engineer has labelled a point **Q** on the graph in **Figure 4**. This is a point beyond which the behaviour of the material changes irreversibly. State the name for this point.

[1 mark]

....

(b) (ii) Use the graph to determine the Young modulus of the aluminium alloy.
Show your working.

[2 marks]

Young modulus = ... Pa

(c) The engineer who carried out the experiment to obtain the stress–strain graph decided to stretch another sample to a strain of 0.10. She then gradually reduced the stress to zero.

Show by drawing on **Figure 4** how you would expect the stress to vary with strain as the stress is reduced.

[2 marks]

(d) Calculate the volume of 25.0 kg of the aluminium alloy.

density of aluminium alloy = 2.78×10^3 kg m^{-3}.

[1 mark]

volume = ... m^3

(e) 1.28% of the aluminium alloy's volume is copper.
Calculate the mass of pure aluminium needed to make 25.0 kg of the aluminium alloy.

density of pure aluminium = 2.70×10^3 kg m^{-3}.

[2 marks]

mass of pure aluminium = ... kg

16)

(a) State Hooke's law.

....

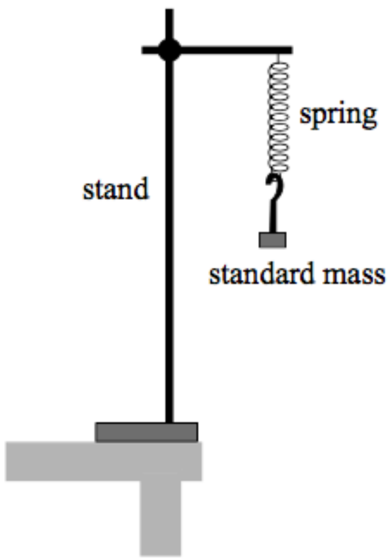
....

....

(2 marks)

(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 **Figure 2**.

Figure 2



(b) (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 marks)

(b) (ii) State and explain **one** modification you could make to the arrangement in **Figure 2** to make it more stable.

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(2 marks)