1. Steel can be classified as a strong material. This is because

A it is difficult to deform

B it has a large ultimate tensile stress value

C it has a large Young modulus value

D it breaks shortly after its proportional limit

(Total 1 mark)

2. Complete the gaps in the following paragraph by selecting appropriate words from the following list.

compressive density energy force mass stiff tensile tough

Increasingly, drinks containers are made out of polymers rather than glass. A container made from a polymer such as polythene has several advantages over a glass container. Polythene has low ...., and so the .... of the container is kept low. Polythene is also .... and so can absorb a large amount of .... before breaking. Glass is only strong under .... forces but polythene is also strong under .... forces.

(Total 3 marks)

3. A skydiver accelerates towards the ground at 9.81 m s–2 at the instant that he leaves the aeroplane.

(a) Explain why his acceleration will decrease as he continues to fall.

....

....

....

....

(2)

(b) The skydiver opens his parachute. Explain why he reaches a terminal velocity shortly afterwards.

....

....

....

....

(2)

(c) The velocity at which he then hits the ground is similar to that achieved when falling freely from a height of 3 m. Calculate this velocity.

Velocity = ...

(2)

(Total 6 marks)

4. A sign at a railway station advises passengers to keep back from the platform edge. This is because passing trains may cause turbulence.

Explain what is meant by turbulent flow, and suggest why it is dangerous for passengers to stand near the edge of the platform.

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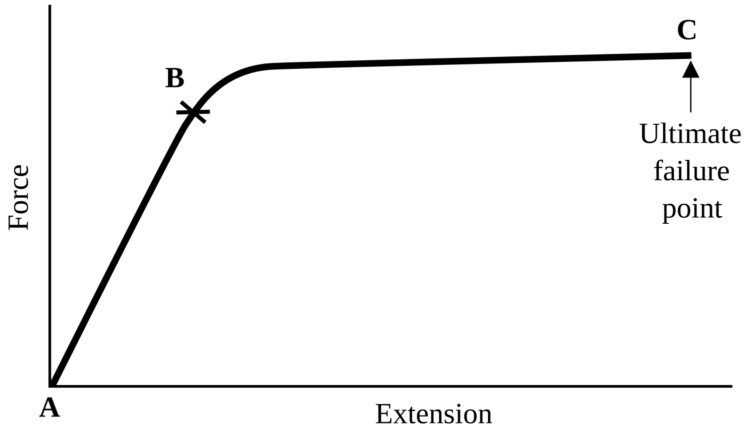
(Total 3 marks)

5. The graph shows how a sample of material behaves when extended by a force.



(a) What does point **B** represent?

....

(1)

(b) State the physical property represented by the gradient of the section **AB** of the graph.

....

(1)

(c) Explain the significance of the area underneath the line from **A** to **C**.

....

....

(2)
(Total 4 marks)

6. A raindrop has a radius of 0.70 mm. It is falling at terminal velocity through air.

(a) Show that the mass of the raindrop is approximately 1×10^{-6} kg.
Density of water = 1000 kg m^{-3}.

....

....

....

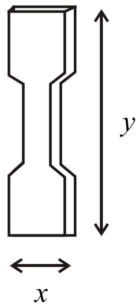
(2)

(b) Ignoring any upthrust on the raindrop, calculate its terminal velocity.
Viscosity of air = 8.90×10^{-4} kg m^{-1} s^{-1}.

Terminal velocity = ...

(2)
(Total 4 marks)

7. A tensile tester connected to a datalogger is used to investigate the effect of applying forces to a range of materials.



The sample has approximate dimensions x = 1 cm, y = 10 cm. It is fixed into the frame and force applied from a hydraulic system. The datalogger records the extension of the sample and the applied force.

(a) State any measurements, other than the force, that you would need to calculate the stress in the sample and name an appropriate instrument that you could use to make these measurements.

....

....

....

....

....

(2)

(b) Explain why access to a datalogger is useful when tensile testing is carried out.

....

....

....

....

....

(2)
(Total 4 marks)

8. (a) A chest expander is used to build up the chest muscles.

One type of expander consists of five identical springs as shown. A student disconnects one spring and finds that applying a force of 6 N to it causes an extension of 5 cm.

(i) Calculate the force required to stretch a single spring by 50 cm, stating the assumption you have made.

Assumption: ....

Force = ...

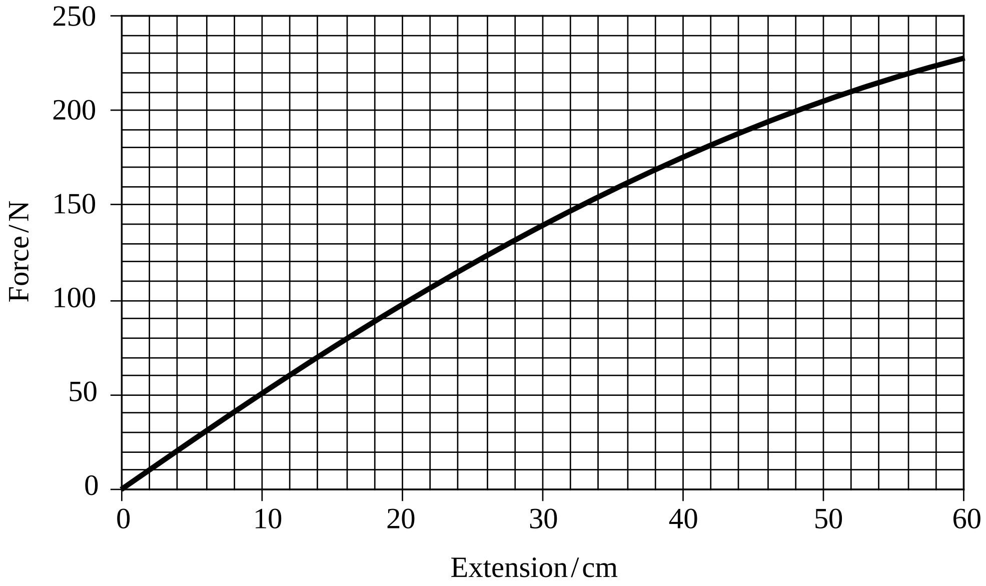
(3)

(ii) Calculate the work done when all five springs are stretched by 50 cm.

Work done = ...

(2)

(b) A different type of chest expander uses rubber cords instead of springs. The variation of restoring force with extension for this expander is shown.



(i) Use the graph to estimate the work done in extending the expander by 50 cm.

Work done = ...

(3)

(ii) When unloading the expander, it is found that at each extension the restoring force is always less than the loading force. Explain the significance of this, and describe what effect this would have on the rubber cords when performing a large number of repetitions with the expander.

....

....

....

....

....

....

(3)
(Total 11 marks)

9. (i) A wire fence is made of steel wire of diameter 2.5 mm.

Show that this wire has a cross-sectional area of approximately 5×10^{-6} m^2.

....

....

....

(2)

(ii) A force of 1500 N is applied to tension a single length of this wire.

Calculate the stress produced in the wire.

....

....

....

....

(2)

(iii) Hence calculate the extension, in mm, produced in a 33 m length of this wire when it is tensioned. The Young modulus of steel is 210 GPa.

....

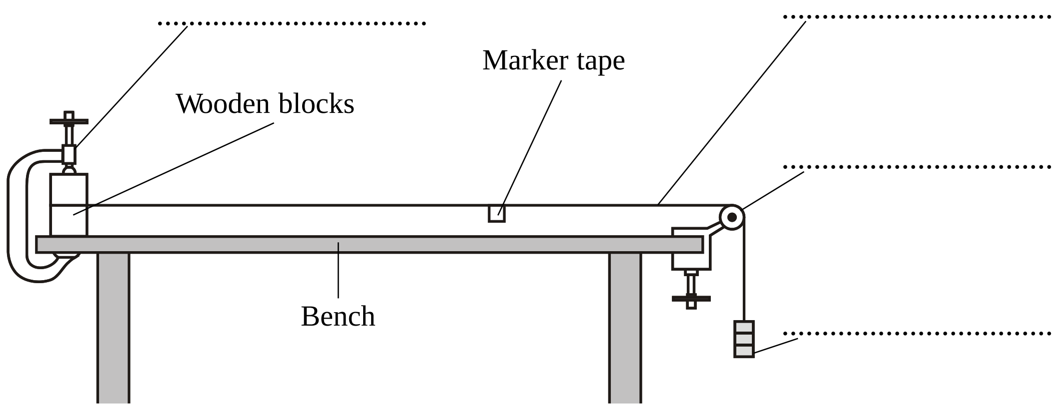
....

....

....

(4)
(Total 8 marks)

10. A student uses the following apparatus to determine the Young modulus of copper.



(i) The diagram above has four labels missing. Add these labels to the diagram.

(2)

(ii) On the diagram show accurately the length *l* of the copper wire that should be considered.

Suggest an appropriate length for *l*.

....

(2)

(iii) The student wishes to plot a stress-strain graph for the copper wire.

What two additional pieces of apparatus would be required to determine values for stress and strain?

1 ....

2 ....

(2)
(Total 6 marks)

11. The body armour worn by modern police officers falls into two categories: hard and soft.

(a) Hard body armour gives more protection but is heavier to wear and does not give any flexibility of movement.

(i) Circle the word which describes the type of behaviour hard body armour is likely to demonstrate.

Ductile Elastic Plastic Tough

State what is meant by the word you have circled.

....

....

....

(2)

(ii) Hard body armour is made of rigid ceramic plates. Ceramic materials are often described as being brittle. Why would this not be a desirable property for body armour?

....

(1)

(iii) Many ceramics are not brittle, including alumina, the ceramic material used in body armour. Alumina is also a very strong material. What is meant by a **strong** material?

....

(1)

(b) Soft body armour allows much greater flexibility of movement. Most soft body armour is made from Kevlar. A new fibre called Biosteel is now being developed, however, that is several times stronger than Kevlar.

The manufacturers claim that Biosteel can be up to 20 times stronger than an ordinary steel wire of the same thickness.

Material	Young Modulus	Breaking strain
Steel	2×10^{11} Pa	0.1%

(i) Calculate the maximum breaking stress that steel can withstand.

....

....

....

....

Maximum stress = ...

(2)

(ii) Hence show that the force needed to break a steel wire of diameter 1 mm is about 160 N.

....

....

....

....

(3)

(iii) If the manufacturers of Biosteel are correct, what maximum force would be needed to break a Biosteel fibre of the same dimensions as the steel wire?

....

Maximum force = ...

(1)

(iv) State one assumption you have made in your previous calculations.

....

....

(1)
(Total 11 marks)

(ii) When unloading the expander, it is found that at each extension the restoring force is always less than the loading force. Explain the significance of this, and describe what effect this would have on the rubber cords when performing a large number of repetitions with the expander.

....

....

....

....

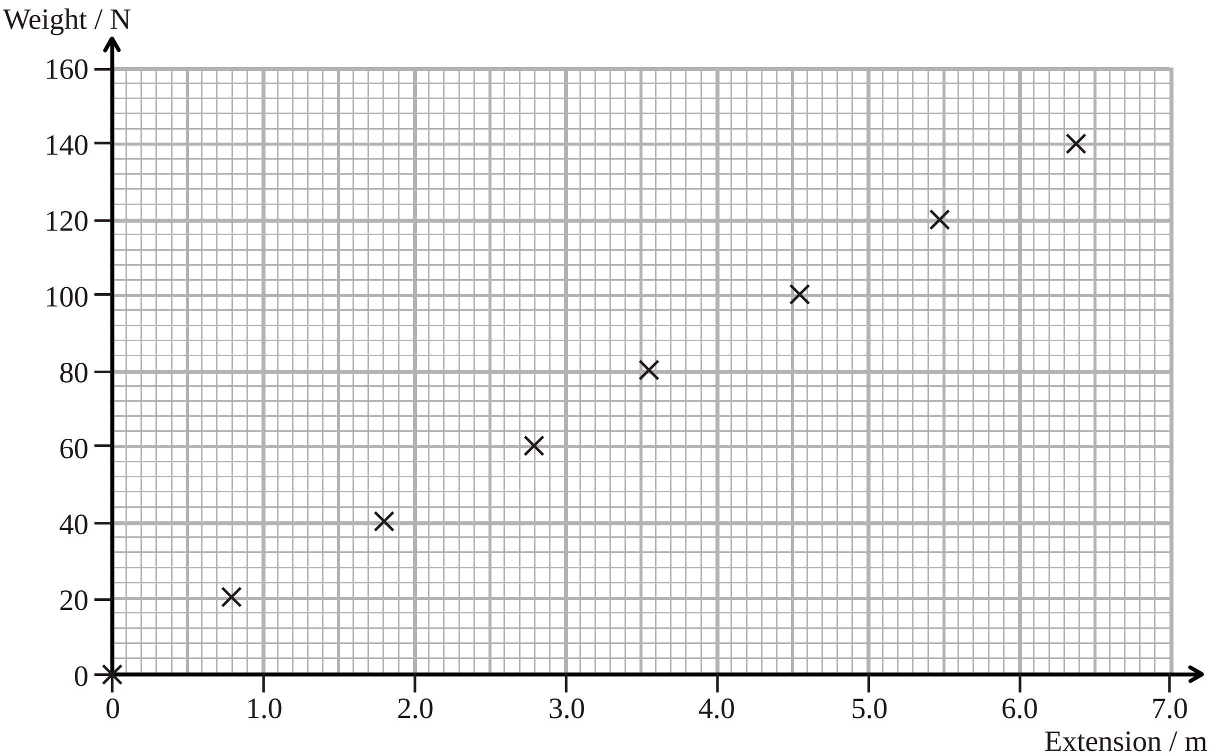
....

....

(3)
(Total 11 marks)

12. A child's trampoline consists of a plastic sheet tied to a frame by an elastic rope as shown below. When a child jumps on the trampoline, the rope stretches allowing the plastic sheet to move up and down.

Before the trampoline was constructed the rope was tested by hanging weights from one end and measuring the extension. The following graph shows the results obtained.



(a) Draw a line of best fit on the graph and then use the graph to calculate the stiffness of the rope.

....

....

....

Stiffness = ...

(3)

(b) Calculate the energy stored in the rope when a weight of 150 N is hung on the end.

....

....

....

Energy stored = ...

(2)

(c) In using the trampoline, a child weighing 150 N does not cause the rope to extend as much as shown on the graph. Suggest a reason for this.

....

....

(1)

(d) This trampoline could be adapted so that an adult could use it by replacing the elastic rope with one made of the same material but with different dimensions. Explain how the new dimensions would have to be different from those of the original rope.

....

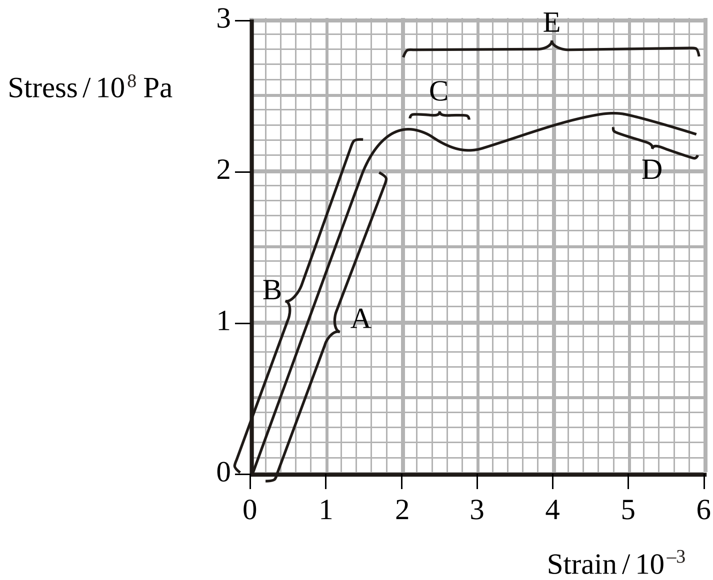
....

....

....

(2)
(Total 8 marks)

13. The graph shows the behaviour of a copper alloy when it is stressed.



(i) Complete the table by using the letters from the graph (A, B, C, D or E) to indicate the correct regions.

Necking	
Elastic deformation	
Plastic flow	

(3)

(ii) Calculate the Young modulus of the copper alloy.

....

....

....

....

....

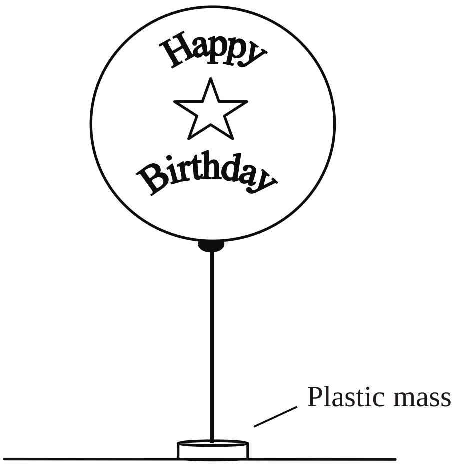
....

(4)

(iii) Add a second graph to the axes above to show the behaviour of a brittle material with a Young modulus lower than that of the copper alloy and which fractures at a strain of 2.6×10^{-3}.

(3)
(Total 10 marks)

14. A child's birthday balloon is filled with helium to make it rise. A ribbon is tied to it, holding a small plastic mass designed to prevent the balloon from floating away.



(a) Add labelled arrows to the diagram of the balloon to show the forces acting on the balloon.

(2)

(b) The balloon is approximately a sphere, of diameter 30 cm. Show that the upthrust on the balloon is about 0.2 N.

The density of the surrounding air $\rho = 1.30 \text{ kg m}^{-3}$

....

....

....

....

(3)

(c) The ribbon is cut and the balloon begins to rise slowly.

(i) Sketch a diagram to show the airflow around the balloon as it rises.

(1)

(ii) What is the name of this type of airflow?

....

(1)

(d) A student suggests that if the balloon reaches terminal velocity, its motion could be described by the relationship

$$mg + 6\pi r\eta v = \frac{4}{3}\pi r^3 \rho g$$

where η = viscosity of air, m = mass of the balloon, r = radius of the balloon and v = the terminal velocity reached.

(i) Write the above relationship as a word equation.

....

(1)

(ii) The balloon has a total weight of 0.17 N. Use the equation given above to calculate the corresponding value for the terminal velocity of the balloon.

Viscosity of air = 1.8×10^{-5} N s m^{-2}

....

....

....

....

Terminal velocity = ...

(3)

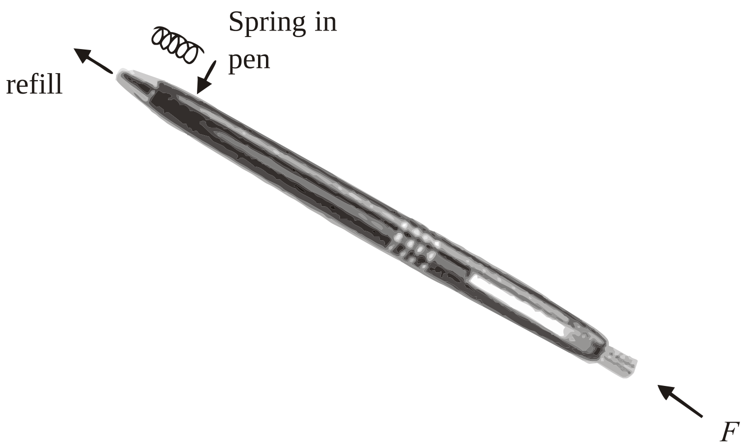
(iii) Suggest a reason why the balloon is not likely to reach this calculated velocity.

....

....

(1)
(Total 12 marks)

15. It is common for pens to have retractable ink refills. When a force *F* is applied to the button at the end of the pen, the tip of the refill is pushed out of the body of the pen. This compresses a spring in the end of the pen so that if the button is pressed again the refill is pushed back inside the pen.



(a) What sort of deformation must the spring undergo when compressed? Justify your answer.

....

....

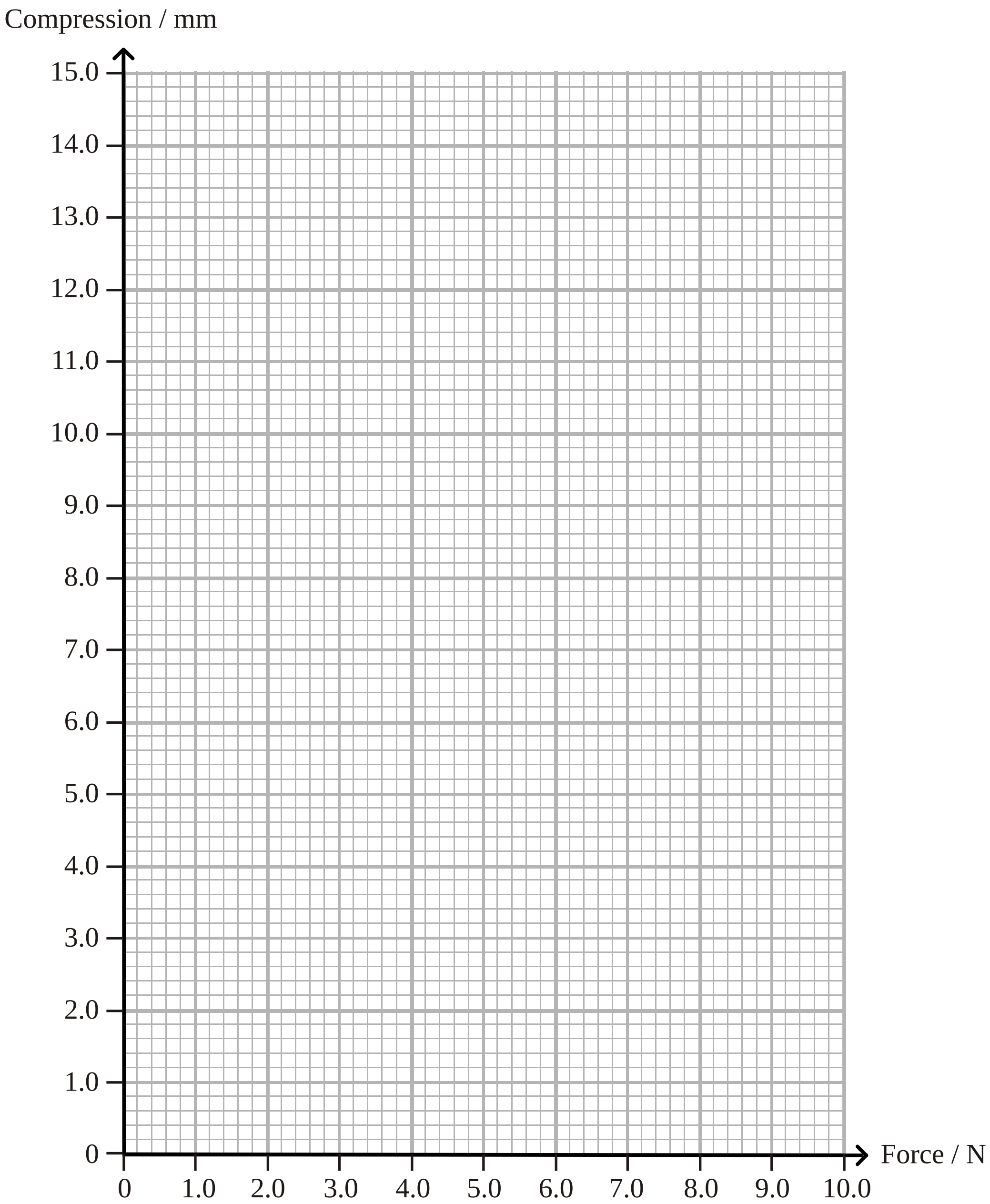
....

(2)

In an experiment, an increasing force was used to compress this spring. The table shows the compression for each value of force.

Force / N	Compression / mm
0.0	0.0
1.0	1.9
2.0	3.8
3.0	5.6
4.0	7.5
5.0	9.4
6.0	11.3
7.0	13.1
8.0	15.0

(b) On the grid below, plot a graph of compression against force for this spring. Add a line of best fit to your points.



(3)

(c) Calculate the stiffness of this spring.

....

....

Stiffness = ...

(2)

(d) In the pen, the spring is compressed by 6.0 mm. What force is needed for this compression?

....

Force = ...

(1)

(e) Calculate the elastic energy stored in the spring when its compression is 6.0 mm.

....

....

....

Elastic energy = ...

(3)

(f) The spring is replaced by another with double the length but identical in all other ways. How would the force needed to compress this new spring by 6.0 mm compare with the force needed for the original spring?

....

....

(1)
(Total 12 marks)

16. (a) Explain the difference between elastic and plastic behaviour in a metal. You should include reference to molecular behaviour in your answer.

....

....

....

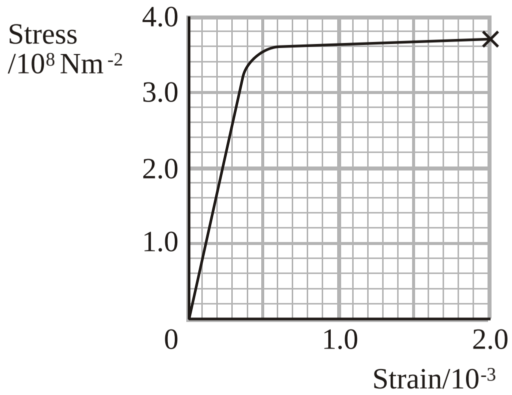
....

....

....

(3)

(b) The graph shows the behaviour of a metal when it is stressed until it breaks.



(i) State the ultimate tensile stress of this metal.

....

(1)

(ii) Calculate the Young modulus of the metal.

....

....

....

(3)

(iii) State whether the metal is tough or brittle. Justify your choice with reference to the graph.

....

....

....

....

(3)

(Total 10 marks)

17. (i) Define the terms stress and strain.

....

....

....

....

(1)

(ii) Hence show that the Young modulus E can be written as

$$E = \frac{Fl}{A\Delta l}$$

....

....

....

....

(2)

(iii) A tensile force of 150 N is applied to a 3.5 m length of copper wire. The resulting extension is 15 mm. Given that the Young modulus of the copper is 1.3×10^{11} Pa, show that the radius of the wire is approximately 0.3 mm.

....

....

....

....

....

(3)
(Total 6 marks)

18. Kevlar is a very useful and **strong** material. It can withstand temperatures of up to 300 °C and shows no loss of strength or signs of becoming **brittle** at temperatures as low as –196 °C. It undergoes **plastic deformation** when subjected to a sudden force and is used to make a variety of objects, from bullet-proof vests to bicycle tyres and canoes.

(a) Explain what is meant by the words in bold in the above passage.

strong ....

brittle ....

plastic deformation ....

....

(3)

One type of Kevlar, Kevlar 49, is used to make cloth.

The table gives details of some properties of a single fibre of Kevlar 49.

Diameter / mm	Breaking stress / 109 Pa
0.254	3.80

(b) Use information from the table to show that the maximum force which can be exerted on a single fibre of Kevlar 49 without breaking it is about 200 N.

....

....

....

(3)

(c) The material has a Young modulus of 1.31×10^{11} Pa. Calculate the extension of the Kevlar 49 fibre when a stress of 2.00×10^{9} Pa is applied to a 1.10 m length.

....

....

....

Extension =...

(3)

(d) Kevlar is a polymer. What is meant by the term polymer?

....

....

(2)
(Total 11 marks)

19. Volcanoes vary considerably in the strength of their eruptions. A major factor in determining the severity of the eruption is the viscosity of the magma material. Magma with a high viscosity acts as a plug in the volcano allowing very high pressures to build up. When the volcano finally erupts it is very explosive. Once magma is out of the volcano it is called lava.

(a) How would the flow of high viscosity lava differ from that of lava with a low viscosity?

....

(1)

(b) What would need to be measured to make a simple comparison between the viscosities of two lava flows?

....

....

(1)

(c) When the lava is exposed to the atmosphere it cools rapidly. What effect would you expect this cooling to have on the lava's viscosity?

....

(1)

(d) When lava is fast flowing, changes to its viscosity disrupt the flow, making it no longer laminar. Use labelled diagrams to show the difference between laminar and turbulent flow.

....

....

....

(3)

(e) Different types of lava have different viscosities. The least viscous type has a viscosity of about 1×10^3 Ns m^{-2} whereas a silica-rich lava has a viscosity of 1×10^8 Ns m^{-2}. What type of scale would be used to display these values on a graph?

....

(1)
(Total 7 marks)

20. Spider silk (or cobweb thread) has incredible properties. It is stronger than steel, extremely tough and can withstand great strain before it breaks. It can stop a relatively large insect, such as a bee, without breaking.

(i) Explain the meaning of the following words as used in the passage.

Tough ....

....

Strong ....

....

(3)

(ii) A bee flies into a cobweb thread of radius 2.0 μm. This causes a stress of 3.0×10^8 Pa in the thread. Calculate the force exerted by the bee.

....

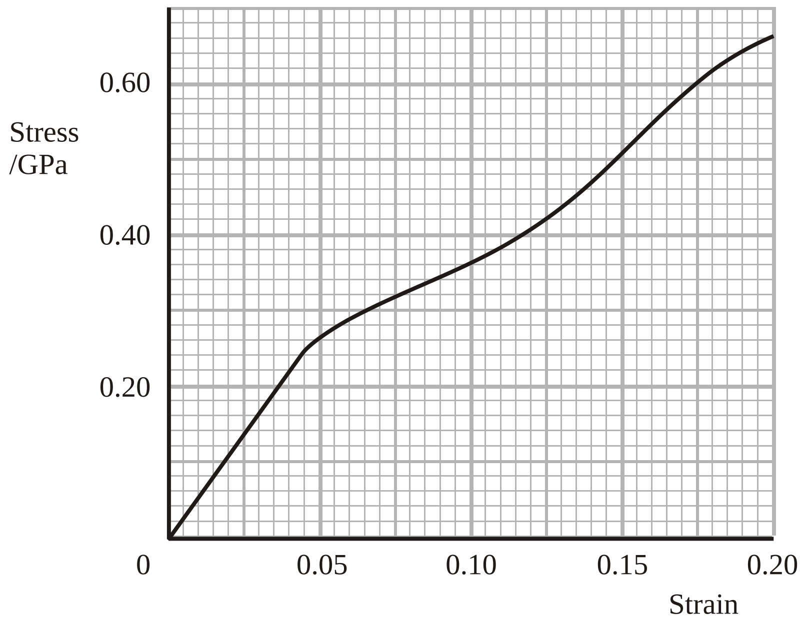
....

....

Force = ...

(3)

(iii) The graph below shows how the strain of spider silk varies as the stress applied to it varies.



Mark clearly on the graph the part of the line where the silk is most stiff.

(1)

(iv) Calculate the Young modulus of the silk when it is initially stressed.

....

....

....

Young modulus = ...

(3)

(Total 10 marks)

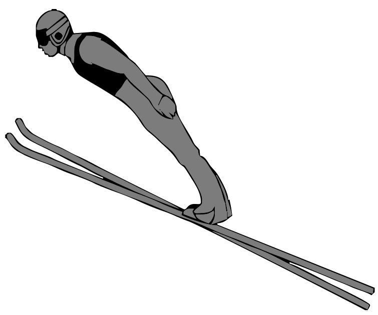
21. When going downhill, ski jumpers reach speeds of up to 30 m s–1 in order to jump great distances. As they move through the air, their body and ski position determines how far they jump.

(a) (i) Use one word to describe the type of airflow that the ski jumper is trying to achieve in mid-air.

....

(1)

(ii) The diagram shows a ski jumper in mid-air. Sketch the airflow pattern.



(2)

(iii) Suggest one way in which the ski jumper's equipment is designed to produce the maximum possible speed.

....

....

(1)

(b) Below is a list of material properties. Select one that is desirable and one that is undesirable for material from which the jumper's skis are made. Explain your choices.

Elastic Tough Plastic

(i) Desirable property: ....

Reason: ....

....

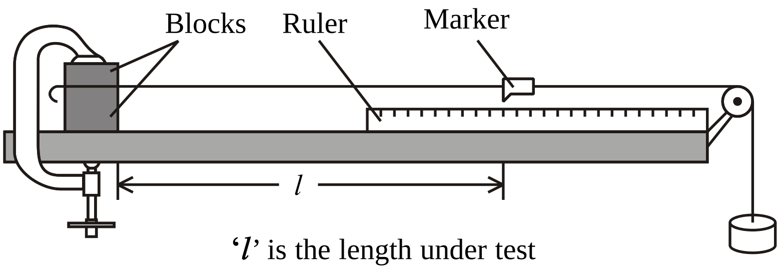
(ii) Undesirable property: ....

Reason: ....

....

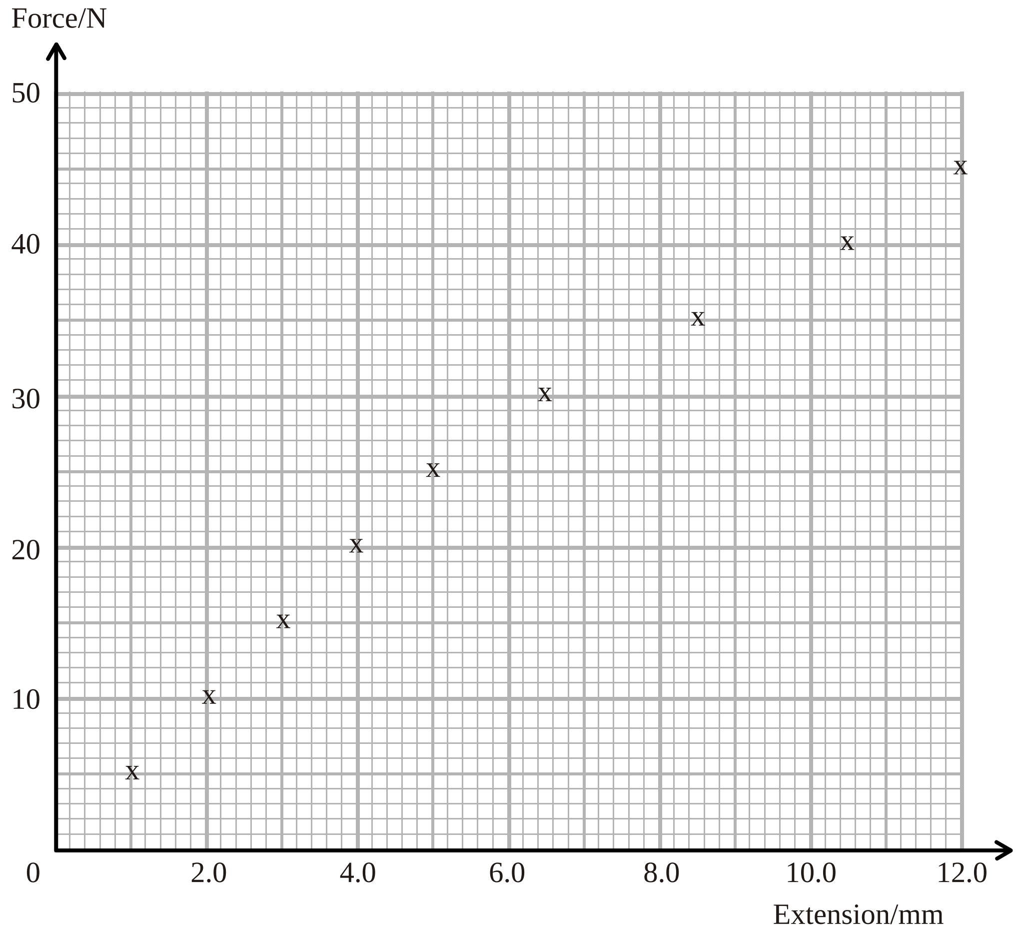
(4)
(Total 8 marks)

22. A student carries out an experiment to investigate the extension x of a clamped copper wire when he applies a varying force F to the free end.



'l' is the length under test

(a) The graph below shows his results.



(i) Add a line of best fit to the graph.

(1)

(ii) Add an X to the line to mark the limit of proportionality.

(1)

(b) (i) Calculate the energy stored in the copper wire due to a 20 N load.

....

....

....

....

Energy stored = ...

(3)

(ii) What property of the wire could be determined by calculating the gradient of this graph?

....

(1)

(c) Explain how the graph would be different if the student had used a thicker piece of copper wire.

....

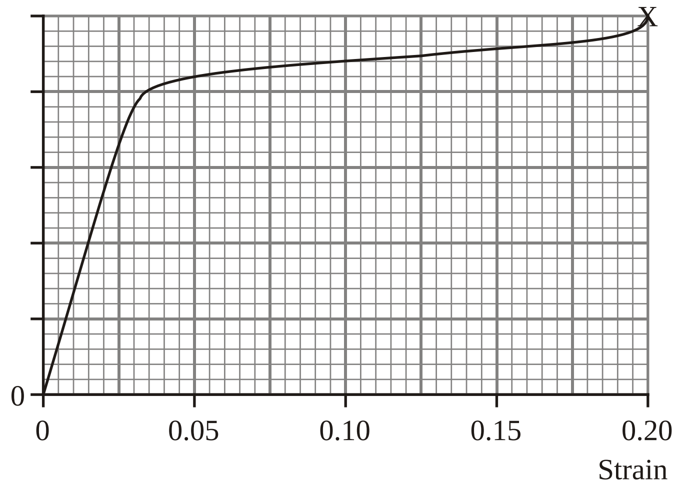
....

....

(2)

(Total 8 marks)

23. A copper wire is stretched in an experiment. The graph shows the behaviour of the copper until it breaks at point X.



(i) The area under the graph represents energy density. Add a suitable label and unit to the *y*-axis of this graph.

(2)

(ii) The Young modulus of copper is 130 GPa. By using an appropriate calculation add a suitable scale to the *y*-axis.

....

....

....

....

(3)

(iii) From the graph determine the ultimate tensile stress of the copper.

....

(1)

(iv) State what is meant by the term yield stress.

....

....

....

(1)

(v) Label the yield point with a Y on the graph.

(1)

(vi) A second material is less stiff than copper and follows Hooke's Law to a strain beyond 0.20. Add a second line to the graph to indicate its behaviour.

(2)

(vii) Use the graph to estimate the energy density of the copper when it is stretched until it breaks.

....

....

....

....

Energy density = ...

(3)

(viii) The volume of the copper wire is 3.8×10^{-7} m^3. Calculate the work done on this wire in the experiment.

....

....

....

Work done = ...

(2)

(Total 15 marks)

24. Training shoes (trainers) have changed a lot from the original rubber-soled canvas shoes of the 1930s. They now combine the most up-to-date research from the fields of physics and chemistry to cope with high levels of impact.

Complete the following table for the material properties listed.

Property	Desirable for trainers	Not desirable for trainers	Reason
Stiff		✓	Needs a large force to produce a small deformation
Plastic			
Tough			
Brittle			

(6)

Calculate the average compressive stress exerted on the soles of the trainers worn by an 80 kg athlete when the athlete is standing still.

Total area of both trainer soles in contact with the ground = 4.2×10^{-2} m^2.

....

....

....

....

Stress = ...

(2)

At certain positions during the athlete's running stride the stress is greater than when the athlete is standing still. Identify one such position and explain why the stress is greater.

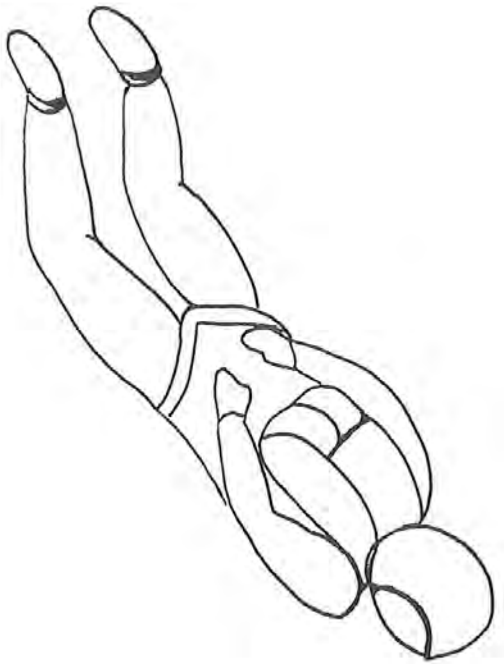
....

....

....

(2)
(Total 10 marks)

25. The diagram shows a sky diver.



Sketch the airflow around the sky diver on the diagram.

(1)

Add three **labelled** arrows to the diagram to identify the forces acting on the sky diver.

(2)

What is the relationship between these forces when the sky diver is falling with terminal velocity?

....

(1)

For some falling objects it is possible to use Stokes' law to help estimate the terminal velocity. State why this would not be appropriate for this sky diver.

....

....

(1)

Show that the upthrust force is about 4 N.

Volume of sky diver = 0.35 m^3.
Density of surrounding air = 1.2 kg m^{-3} (i.e. 1 m^3 of air has a mass of 1.20 kg).

....

....

....

....

....
(3)

Comment on the size of this force and its effect on the sky diver's terminal velocity.

....

....

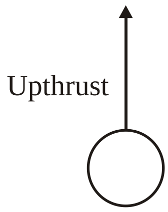
....
(2)

The sky diver slows her descent by opening her parachute. Give one word which describes the airflow after the parachute has opened.

....
(1)
(Total 11 marks)

26. After wine has been fermenting it contains many small particles. These particles are allowed to settle so that they can be separated from the liquid.

Add labelled arrows to this diagram showing the other two forces on a particle falling downwards within the wine.



(2)

The upthrust can be calculated using the expression $U = \frac{4}{3}\pi r^3 \rho_w g$ where ρ_w is the density of wine and r is the radius of the falling particle.

Explain how the above expression for upthrust is derived.

....

....

....

(2)

Write down the equation relating the three forces acting on the particle when it reaches terminal velocity.

....

(1)

Show that the terminal velocity v of a particle of density ρ_s is given by the following expression:

$$v = \frac{2r^2 g(\rho_s - \rho_w)}{9\eta}$$

where η is the viscosity of the wine.

....

....

....

....

(2)

Explain how you would expect the velocity of this particle to change if the temperature of the wine was increased.

....

....

....

(2)

Stokes's law is valid only provided the flow is laminar. Using a diagram, explain what is meant by the term **laminar flow.**

....

....

....

(2)
(Total 11 marks)

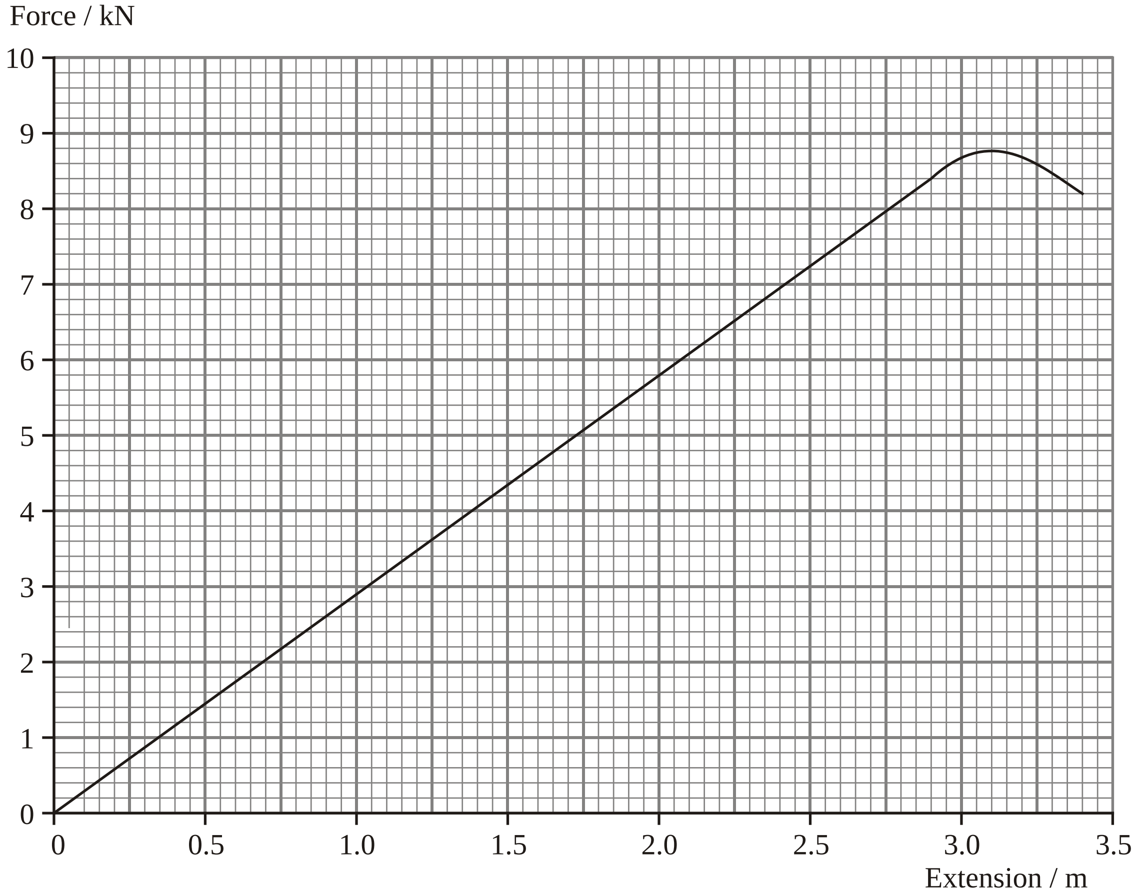
27. Climbing ropes are designed to be able to withstand large **impact** forces without breaking.

What material property describes such a rope?

....

(1)

The following graph shows the characteristics of a climbing rope when stretched up to its breaking point.



Mark the graph with two crosses labelled:

P at the limit of proportionality

E at a possible point for the elastic limit

(2)

Calculate the stiffness *k* of the rope.

....

....

Stiffness = ...

(2)

The original length of the rope is 50 m. Calculate the breaking strain of the rope.

....

....

Breaking strain = ...

(2)

A climber has a mass of 90 kg when wearing climbing equipment. Show that the energy stored when this person hangs from the rope is about 130 J.

....

....

....

....

(4)
(Total 11 marks)

28. (i) When calculating the energy density of a material, the area under a stress-strain graph is calculated. Show that the base units of energy density are kg m^{-1} s^{-2}.

....

....

....

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....

....

(3)

(ii) A sample deforms elastically obeying Hooke's law. A stress of 200 MPa produces a strain of 9.5×10^{-4}. Show that the energy density is approximately 100 kJ m^{-3}.

....

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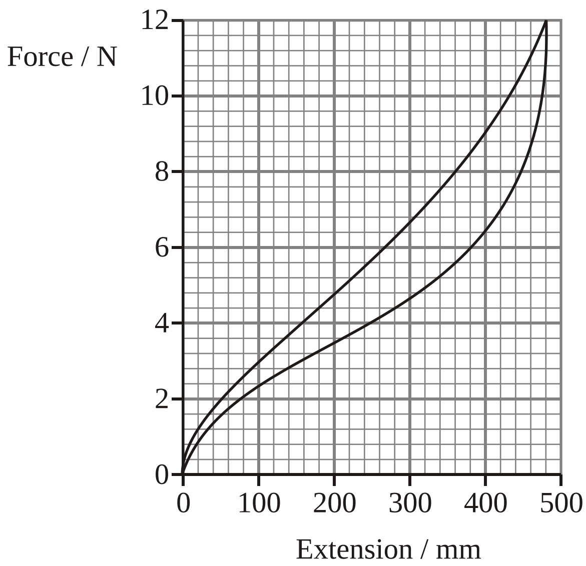
....

....

(3)

(Total 6 marks)

29. In an experiment to measure the extension of a rubber band the following graph was obtained. The line represents the extension during loading and unloading.



(i) Label the two lines to indicate which represents loading and which represents unloading.

(1)

(ii) What is the name for the characteristic behaviour shown by the shape of this graph?

....

(1)

(iii) If the rubber band has a cross-sectional area of 6.0×10^{-6} m^2 calculate the stress produced in the elastic band when it is fully loaded.

....

....

....

(2)

(iv) Estimate how much work is done on the rubber band as it is fully loaded.

....

....

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....

....

(4)

(v) Hence show that the energy dissipated during the loading and unloading process is approximately 1 J.

....

....

....

(2)

(vi) When the rubber band has a load placed on it a new reading is taken. Over the next minute this reading increases by a few millimetres. If a material deforms plastically in this way when stress is applied, what is the name of this mechanism?

....

(1)

(vii) State Hooke's law.

....

....

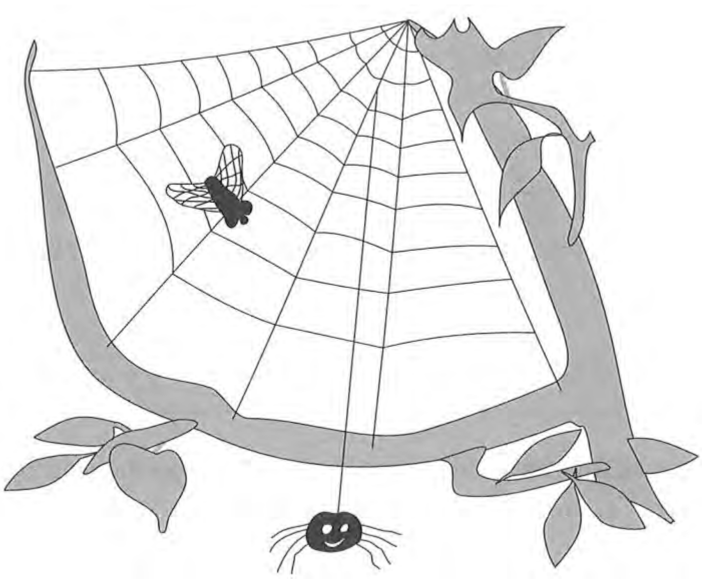
(1)

(viii) Draw a labelled diagram of the apparatus that could be used to produce a force-extension graph for a rubber band, for loads up to 12 N.

(4)

(Total 16 marks)

30.



A spider of mass 1.0×10^{-3} kg hangs from a silk thread of circular cross-section with a radius of 5×10^{-6} m. Show that the stress on the thread is about 1×10^{8} Pa.

....

....

....

....

(3)

Material	Young modulus	Breaking strain
Spider silk	6×10^{10} Pa	30%
Steel	2×10^{11} Pa	0.1%

Use the information given in the table to answer the following questions:

Steel is often used in the construction industry because of its strength. Calculate the maximum breaking stress that steel can withstand.

....

....

....

....

....

Maximum stress = ...

(3)

Hence determine the weight which would cause a steel rod with cross-sectional area 3×10^{-4} m^2 to break.

....

....

....

Weight = ...

(2)

Explain how this value would be different for the same sized rod made of spider silk.

....

....

....

(2)

State an assumption you have made about these two materials in order to make this comparison.

....

....

(1)
(Total 11 marks)

31. (a) Show that the energy stored in a stretched wire below the limit of proportionality can be written $\Delta W = ½\, k(\Delta x)^2$ where k is the Hooke's law constant.

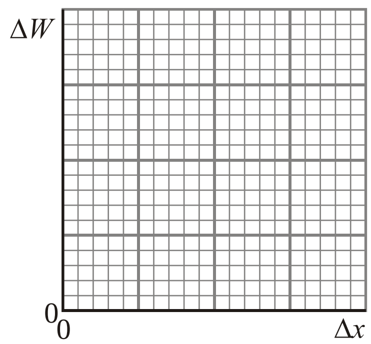
....

....

....

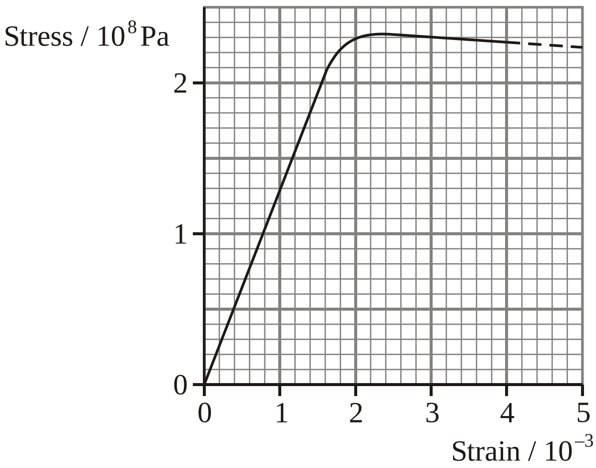
(2)

On the axes below sketch a graph showing how energy stored ΔW varies with extension Δx of a wire below its elastic limit.



(2)

(b) The graph shows the stress-strain relationship for copper.



Use the graph to determine the Young modulus of copper.

....

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....

....

(4)

A student is measuring the extension of a copper wire for a number of forces. Why should a long wire be used in this experiment?

....

....

(1)

The wire has a radius of 7.1×10^{-4} m. Calculate the stress produced when the wire is stretched by a force of 280 N.

....

....

....

(3)

Mark this point on the stress-strain graph. Label it P.

(1)

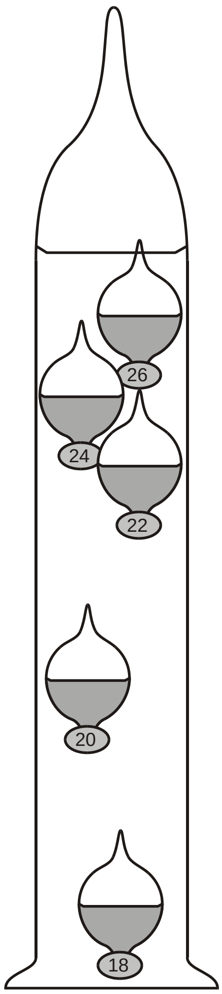
Is the behaviour of the wire at this stress likely to be elastic or plastic? Justify your answer.

....

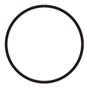
....

(1)
(Total 14 marks)

32. A Galilean thermometer consists of a column of liquid containing glass weights which can be regarded as spheres. The spheres drop one by one as the temperature rises.



The diagram below represents one of these spheres, falling through the liquid with **increasing** speed at a certain temperature. Add labelled arrows to the diagram to show the forces on this sphere.



(3)

How do these forces compare in size?

....

The radius of a sphere is 1.20×10^{-2} m. Calculate its volume.

....

....

Volume = ...

(1)

Calculate the mass of liquid displaced by this sphere when the density of the liquid is 1020 kg m^{-3}.

....

....

Mass = ...

(1)

Show that the upthrust on the sphere is about 0.07 N.

....

....

(2)

Another sphere is of the same radius but with a weight of 0.069 N. Explain where you would expect to find this sphere.

....

....

....

....

(2)

What two properties of the liquid would affect the sphere's terminal velocity?

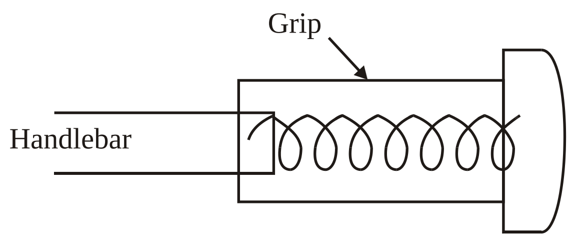
....

....

(2)

(Total 12 marks)

33. Children can seriously injure themselves when falling off bicycles if they land on upturned handlebars. A new design incorporates a spring inside the grip as shown below.



The grip needs to be tough.

(i) What does tough mean?

....

....

(ii) Suggest a suitable tough material.

....

(2)

The behaviour of the spring over the range of compression expected in a fall is elastic. What is meant by elastic?

....

.... **(1)**

The maximum compression of the spring is 9.0 cm. Its stiffness is 1250 N m^{-1}. The spring obeys Hooke's law. For maximum compression calculate

(i) the force in the spring,

....

....

....

Force = ...

(ii) the energy stored in the spring.

....

....

....

....

Energy = ... **(4)**

The mass of a child is 30 kg. Calculate the child's weight. Discuss how this new design could reduce the seriousness of an injury.

....

....

....

....

....

.... **(3)**

The Young modulus of the material of a wire can be related to the stiffness of the wire. A student suggests that if the cross-sectional area of the spring and the initial length of the spring were known, then the Young modulus of the spring material could be calculated using the data given in this question. Explain why this is incorrect.

....

....

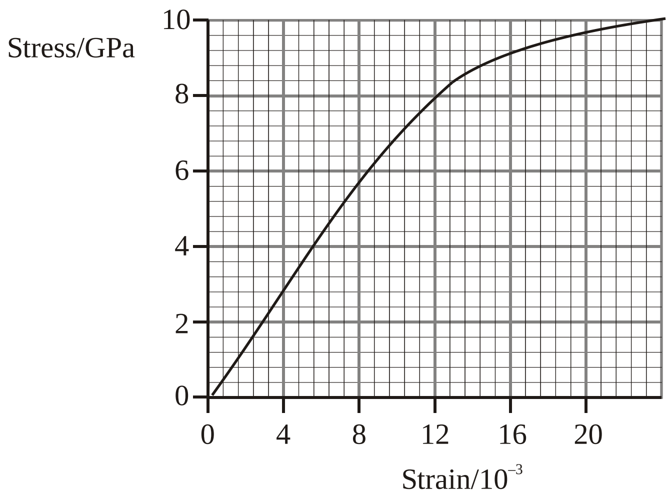
....

....

....

(2)
(Total 12 marks)

34. The graph shows the stress-strain relationship for a material from which car seat belts can be made.



What physical quantity does the area under this graph represent?

....

(1)

A car seat belt is 2 m long, 6 cm wide and 1.5 mm thick. Show that the volume of the seat belt is approximately 2×10^{-4} m^3.

....

....

(1)

A passenger of mass 55 kg wears the seat belt when travelling in a car at a speed of 24 m s^{-1}. Show that the kinetic energy of the passenger is about 16 kJ.

....

.... **(2)**

Calculate the energy per unit volume which must be absorbed by the seat belt as it restrains the passenger when the car stops suddenly. Assume that all the passenger's kinetic energy is absorbed by the seat belt.

....

.... **(1)**

Use the graph to show that a seat belt made from this material would be satisfactory for restraining the passenger in the situation described above. Assume the maximum strain in the belt is 20×10^{-3}.

....

....

....

.... **(2)**

In what way would the design of a seat belt, made from the same material, need to be changed to make it suitable for restraining the driver of a racing car when the car stops suddenly? Explain your answer.

....

....

.... **(2)**

(Total 9 marks)

35. State the energy conversions which take place when a rock-climber falls and is then stopped by a climbing rope.

....

.... **(2)**

From the list below circle three properties that would be most desirable in a climbing rope:

strength stiffness toughness elasticity brittleness

(2)

During a fall, a climber exerts a force of 6.0 kN on a rope. Use the rope data below to calculate the theoretical extension of the rope when this force is exerted assuming the elastic limit of the rope is not exceeded.

Effective Young modulus = 1.4×10^9 Pa
Length = 45 m
Diameter = 11 mm

....

....

....

....

....

.... **(4)**

Suggest one reason why a rope that has been involved in an extreme fall should be replaced as soon as possible.

....

.... **(1)**

(Total 9 marks)

36. Do not try this at home!

The website 'urban myths' claims that a man in California tied a number of balloons filled with helium to his chair in the garden, with a view to gently hovering above the neighbourhood.

The moment he cut the anchoring cord he shot upwards to a height of about 4000 m. Several hours later he was rescued by a helicopter after being spotted by an airline pilot.

If the combined mass of the man and the chair was 70 kg, calculate their weight.

....

....

Weight = ...

(1)

What is meant by the term **upthrust**?

....

....

....

(2)

Show that the upthrust in newtons from the balloons is about $13V$ where V is the total volume of the balloons in cubic metres.

The density of air is 1.29 kg m^{-3}.

....

....

....

....

(2)

Write down an expression, in terms of V, for the weight of the helium in the balloons. The density of helium is 0.18 kg m^{-3}.

....

(1)

Calculate the total volume of the balloons required just to lift the man and his chair from the ground. Assume the weight of the balloon fabric is negligible.

....

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(3)

Explain why any viscous drag force can be ignored in the previous calculation.

....

....

....

....

(2)
(Total 11 marks)

37. Iron is a relatively soft material but adding carbon makes it harder. Steel is made principally by mixing hot iron ore with carbon and then letting it cool. If there is too much carbon, the steel produced is brittle. By using electrons to examine steel at the atomic level, modern steelmakers have been able to create an extremely hard, tough new steel known as Ferrium C90.

State the meaning of the following terms:

(i) hard,

....

....

(ii) brittle,

....

....

(iii) tough.

....

....

....

(4)

Briefly explain how electrons can be used to examine the arrangement of atoms in materials.

....

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....

....

....

....

(3)
(Total 7 marks)

38. Energy density is the energy stored per unit volume. Show that the expression *Energy density* = ½ *stress* × *strain* is homogeneous with respect to units.

....

....

....

....

(Total 4 marks)

39. State Hooke’s law.

....

....

....

(2)

A brass wire of length 2.8 m and cross-sectional area 1.5×10^{-7} m^2 is stretched by a force of 34

N. The wire extends by 5.3 mm. Calculate the Young modulus of brass. Assume the stretched wire is still within the Hooke's law region.

....

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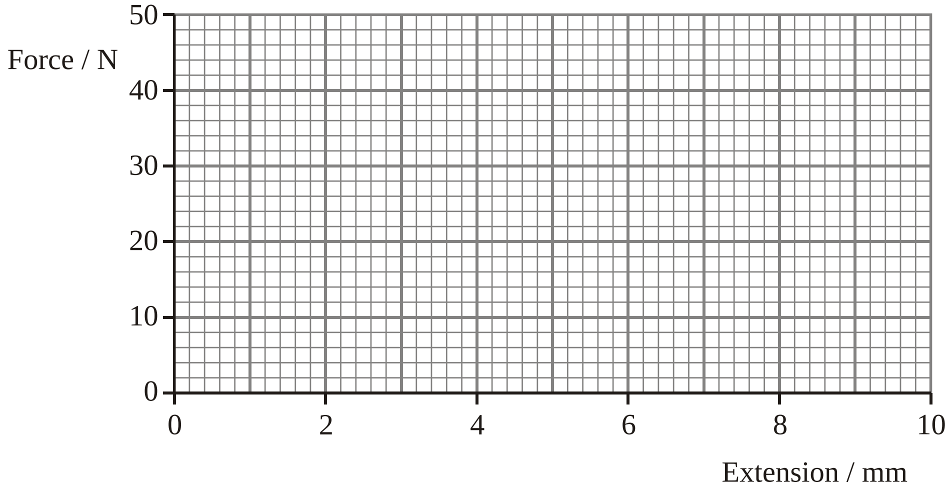
....

(4)

The wire obeys Hooke's law for forces up to 46 N.

On the axes below draw a force-extension graph for this brass wire in the Hooke's law region.



(2)

How could the graph be used to find the energy stored in the wire when it is stretched by a force of 24 N?

....

....

(1)

A second wire is made from the same brass and has the same length but a greater cross-sectional area.

This wire is also stretched by a force of 24 N.

Does the second wire store more energy, the same energy or less energy than the original wire? Justify your answer.

....

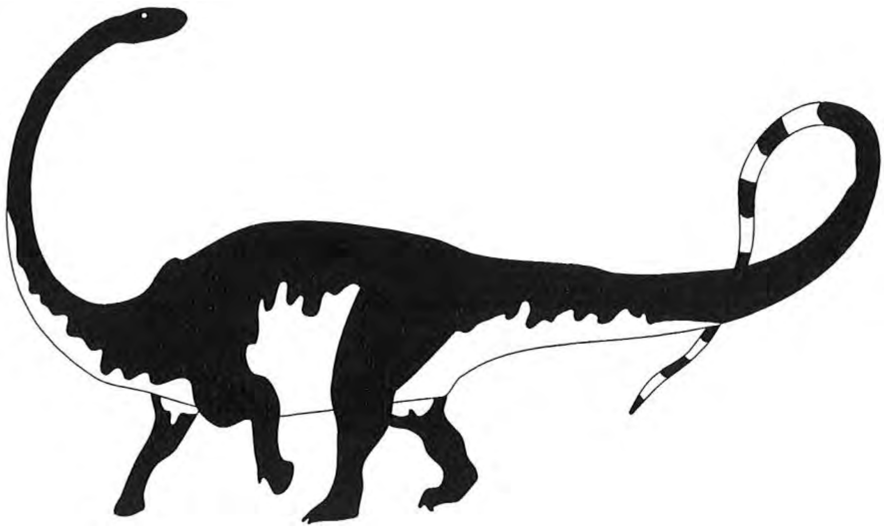
....

....

....

(3)
(Total 12 marks)

40. Fossil bones of the largest dinosaur, Argentinasaurus, have been discovered in ... Yes ... Argentina! This animal had a mass of about 10^5 kg which is equivalent to about 25 elephants. Its leg bones each had a diameter of 30 cm. It is thought that it looked like the picture below.



The compressive breaking stress of bone is 1.5×10^8 Pa. The Young modulus of bone is 1.0×10^{10} Pa.

With the aid of a suitable calculation decide whether an Argentinasaurus of weight 1.0×10^6 N was capable of supporting its own weight when standing still on all four legs.

....

....

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....

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....

(4)

The length of the leg bone was 4.0 m. Calculate the compression of a leg bone when the dinosaur was standing still.

....

....

....

....

....

....

Compression = ...

(3)

A student claims correctly that even if the dinosaur could support its weight when standing still it would break its leg bones if it tried to run. Explain the physics principles underlying this claim.

....

....

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....

....

....

....

(3)

Scientists have decided that the largest dinosaurs did not roam around on dry land but half-submerged themselves in swamps. Explain how this would reduce compressive forces in the leg bones.

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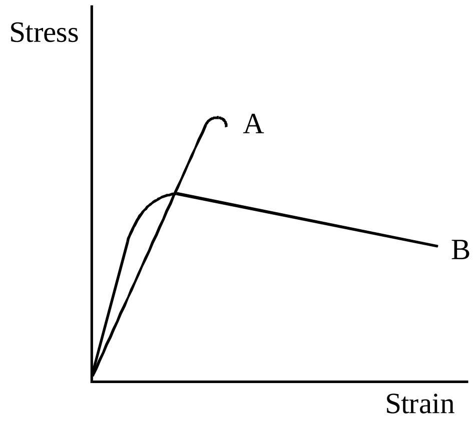
....

(3)
(Total 13 marks)

41. The stress-strain curves for two materials A and B up to their breaking points are shown below.



State, giving the reason for your choice in each case, which material is

(i) tougher ....

....

(ii) stiffer ....

....

(iii) more ductile ....

....

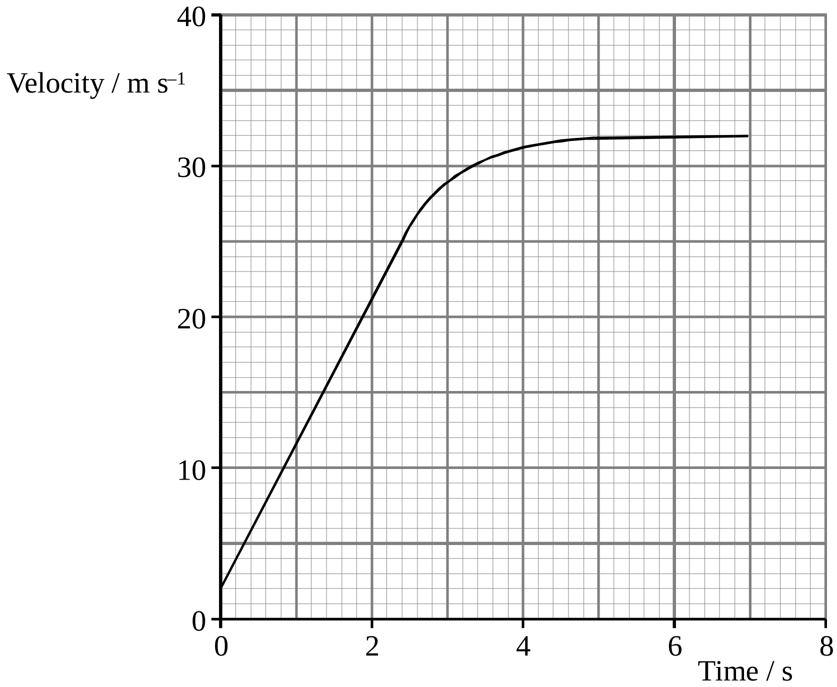
(3)

Add a third line to the graph above showing the behaviour of a material C which has the following properties:

C has a smaller Young modulus than A or B, is stronger than A or B and is brittle.

(3)
(Total 6 marks)

42. A student throws a ball downwards from a high bridge. Its velocity changes with time as shown in the graph.



Take measurements from the graph during the first 2 seconds of the fall to calculate the gradient of the straight line.

....

....

....

(2)

Hence deduce the equation which relates the velocity of the ball to time for the first 2 seconds of the fall.

....

....

....

(2)

The ball has a mass of 0.25 kg. Calculate its weight.

....

....
(1)

A student suggests that the ball reaches terminal velocity when the viscous drag, equals the weight of the ball. Use a suitable value from the graph and the data below to show that this statement is **not** valid.

Radius of ball = 0.040 m
Viscosity of air = 1.71×10^{-5} N s mg^{-2}

....

....

....

....

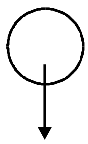
....

....

....

....
(3)

Another student suggests that there is an extra drag, force due to turbulence. Complete the diagram below to show turbulent flow around the falling ball.



(2)
(Total 10 marks)

43. The sap from a rubber tree may flow like thick treacle or thick oil. State **one** word which describes this flow behaviour.

....

(1)

The sap is treated to produce a lump of rubber. Choose **two** words from the list below and explain the meaning of each as it applies to rubber.

Elastic, brittle, hard, durable, stiff

(i) ....

....

....

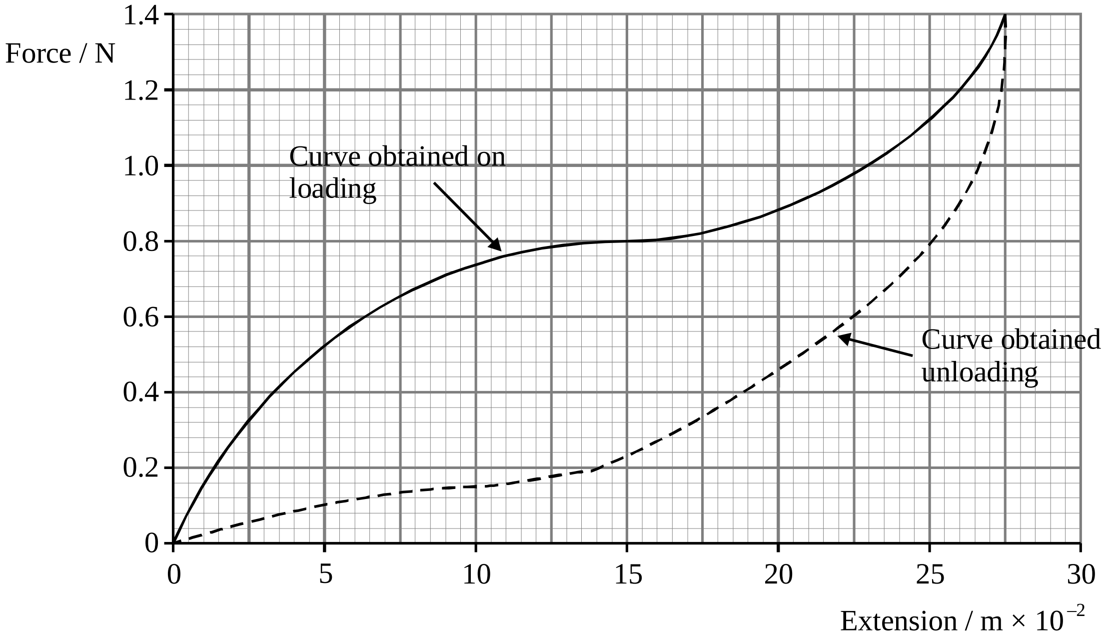
(ii) ....

....

....

(2)

The solid line on the following force-extension graph is obtained when a rubber band is stretched.



Use the graph to estimate the work done in stretching the rubber band to a tension of 1.0 N.

....

....

....

....

(4)

When the force is reduced gradually, the force-extension graph follows the dotted line.

What does the graph tell you about the work done by the rubber band when it returns to its original length?

....

....

(1)

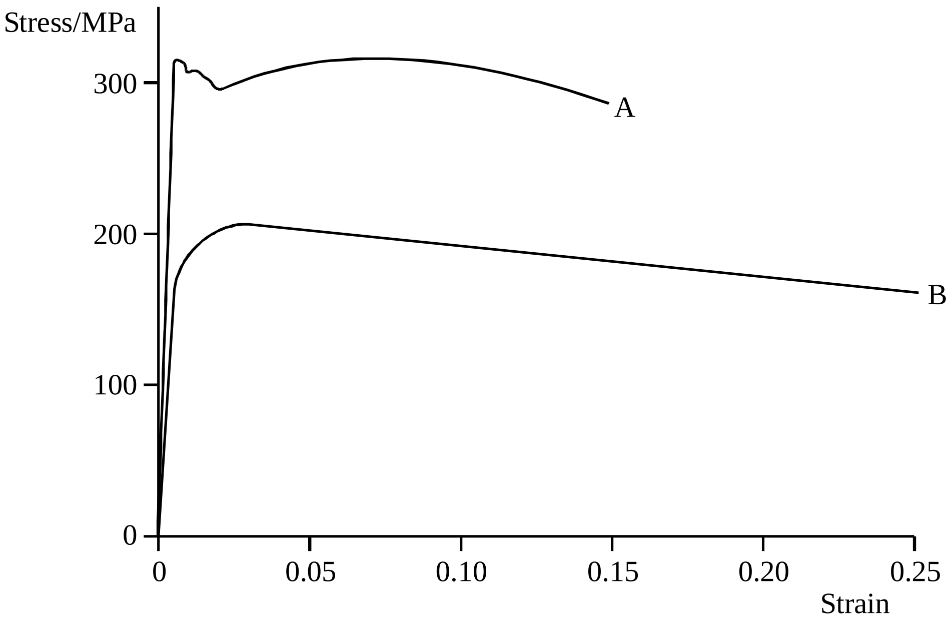
Rubber tyres are constantly being compressed and released as a car travels along a road. Explain why the tyres become quite hot.

....

....

(1)
(Total 9 marks)

44. Typical stress-strain curves for two metals, A and B, up to their breaking points are shown below.



Which metal is stiffer? Justify your answer.

....

.... **(1)**

Stating appropriate magnitudes where possible, explain which metal is

(i) stronger ....

....

....

(ii) more ductile ....

....

.... **(2)**

The two metals are mild steel and copper. Identify A and B.

A = ... B = ...

(1)

Estimate the work done per unit volume in stretching material A to its breaking point.

....

....

....

....

Work done per unit volume = ...

(3)

High carbon steel can be made harder and more brittle if it is quench hardened. State what is involved in this process.

....

....

....

(2)
(Total 9 marks)

45. Draw a labelled diagram of the apparatus you could use in a school laboratory to determine the Young modulus of copper in the form of a wire.

(3)

Suggest an appropriate length for the wire being tested.

....

How would you determine the cross-sectional area of the wire?

....

....

....

....

(3)

State the unit of *k*, the constant of proportionality in Hooke's law.

....

(1)

Show that for a wire of length *l* and cross-sectional area *A* the Young modulus $E = kl/A$.

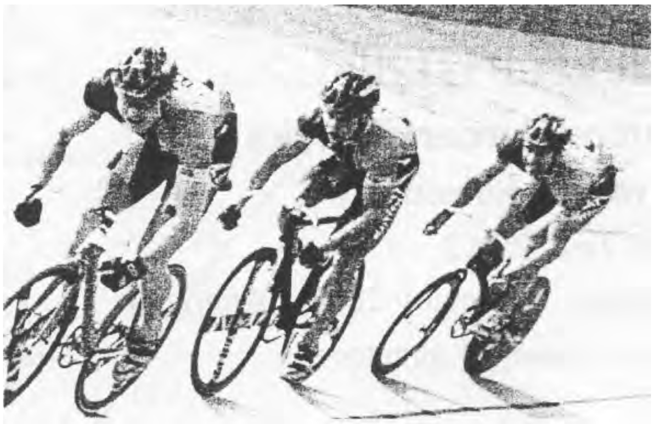
....

....

....

(3)
(Total 10 marks)

46. Speed cyclists need to reach very high speeds when competing.

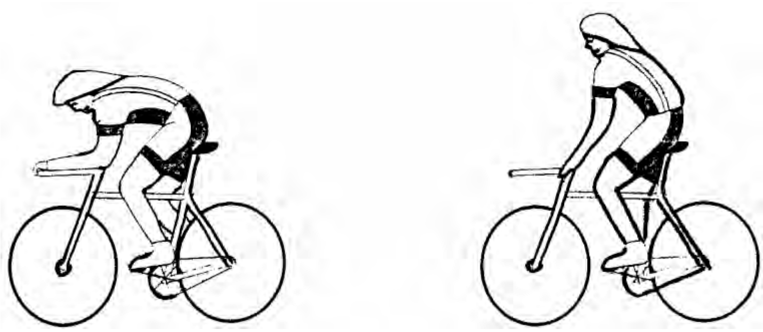


What word describes the preferred airflow around the body of a speed cyclist?

....

(1)

Draw the possible airflow above and behind the body of a speed cyclist



(i) in racing position (ii) when sitting upright.

(2)

What is the advantage to speed cyclists of travelling very close together as shown in the photograph?

....

....

(1)

Would **plastic** or **elastic** better describe the material of the bodysuit worn by a speed cyclist?

....

Explain your choice.

....

....

....

....

(2)

Would **brittle** or **tough** better describe the material of the helmet worn by a speed cyclist?

....

Explain your choice.

....

....

....

....

(2)

Explain why such a helmet is designed to deform in a crash.

....

....

(1)
(Total 9 marks)

47. A one-person spherical submarine called *Explorer* is used for underwater exploration.

EXPLORER SPHERICAL SUBMARINE

Diameter: 1.60 m
Mass of empty submarine: 2000 kg
Maximum mass of contents including water in buoyancy tanks: 110 kg

- BUOYANCY

  Buoyancy tanks can be flooded with sea water and emptied by compressed air.

- VIEWING

  Thick acrylic viewports provide visibility.
  Young modulus of acrylic is 3.0×10^9 Pa.

Use the information given above to answer the questions below.

Calculate the weight of the submarine when carrying maximum load.

....

....

Weight = ...

(1)

The submarine is at rest just above the seabed.

(i) State the magnitude of the upthrust on the submarine.

....

(ii) Give a reason for your answer.

....

....

(2)

The weight of the submarine is adjusted so that it rises with a constant velocity of 0.5 m s^{-1}.

(i) How would this change in weight of the submarine be achieved?

....

....

(ii) Calculate the viscous force on the submarine using Stokes' Law. Viscosity of water = 1.2×10^{-3} kg m^{-1} s^{-1}.

....

....

....

....

Viscous drag force = ...

(iii) The actual viscous drag force will be much greater. Suggest why.

....

(4)

At the operating depth, the pressure of water causes a stress on the viewports of 1.1×10^6 Pa.

Calculate the strain which would result from this stress.

....

....

....

(2)
(Total 9 marks)

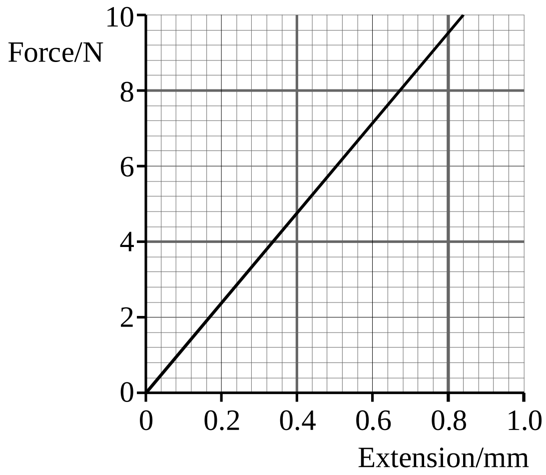
48. Calculate the stress in a steel wire of length 2.6 m and cross-sectional area 1.5×10^{-7} m^2 when it is subjected to a tensile force of 8.0 N.

....

....

(2)

Part of a force-extension graph for such a steel wire is shown below.



Use the graph to find the extension of the wire for an applied force of 8.0 N.

....

Show that the corresponding strain in the wire is approximately 3×10^{-4}.

....

....

Hence determine the Young modulus for steel.

....

....

....

Young modulus = ...

(4)

Calculate the work done in stretching the wire by 0.4 mm.

....

....

....

Work done = ...

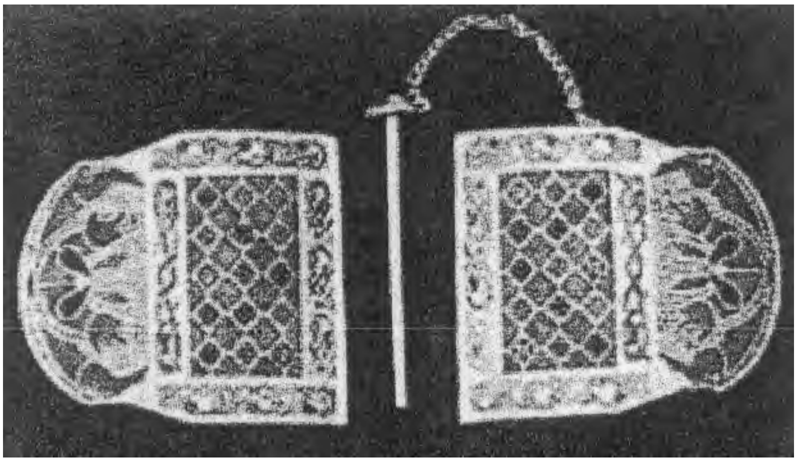
(3)

A second wire is made of the same steel. It has the same cross-sectional area but twice the length.

On the same axes draw the force-extension graph for this wire.

(2)
(Total 11 marks)

49. The picture shows an Anglo-Saxon gold shoulder clasp excavated in 1939 from the Sutton Hoo ship burial.



The decoration of the clasp is known as cloisonné. The clasp was made by:

- Hammering gold sheet to the desired shape
- Fixing thin gold wires to the surface to make “cloisons” (compartments)
- Filling these “cloisons” or compartments with an enamel paste
- Heating to bind the paste to the gold, forming a hard, shiny, attractive layer.

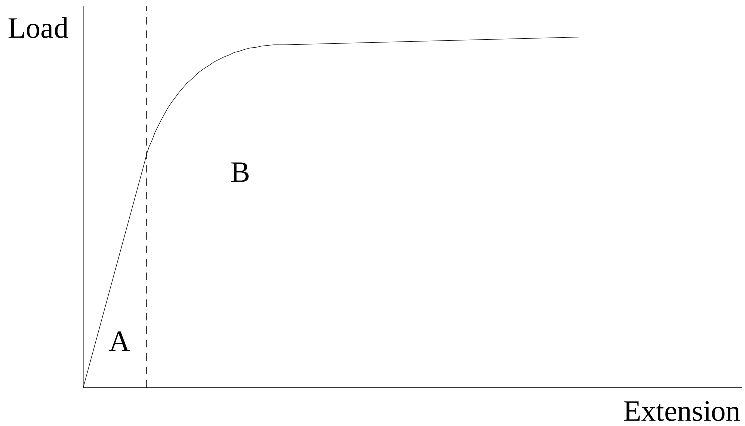
Gold was used to make this clasp because it has suitable properties. Fill in the gaps in the sentences to name the two properties described below.

Gold can be hammered to form the basic shape. It is ....

Gold can be made into thin wires. It is ....

(2)

When gold wire is stretched, its load-extension graph would have the typical shape shown below.



The graph can be divided into two regions, A and B. Name the property exhibited in region A.

....

(1)

Explain what is meant by the terms **hard** and **plastic behaviour**.

Hard

....

....

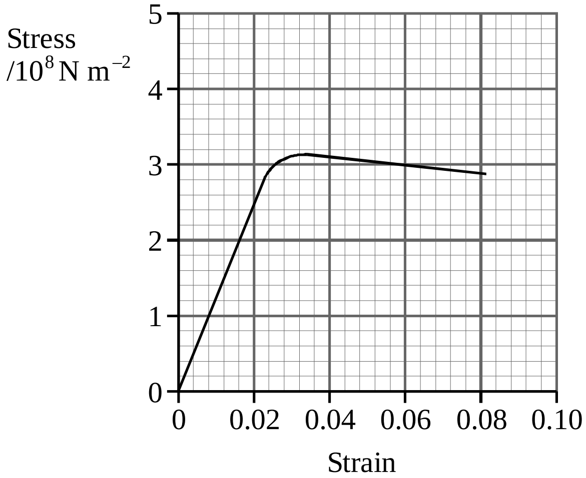
Plastic behaviour

....

....

(2)
(Total 5 marks)

50. Some properties of two materials A and B are given below, material A on the graph, material B in the table.



Material	Young modulus/10^{10} Pa	Ultimate tensile stress/10^8 N m^{-2}	Nature
A			Tough
B	3.0	3.6	Brittle

Use the graph to complete the table for material A.

(2)

Use the table to draw a graph on the grid above showing the behaviour of material B.

(3)

Show on the graph the region in which material A obeys Hooke's law.

(1)

Material A is in the form of a wire of cross-sectional area 8.8×10^{-7} m^2 and length 2.5 m. Calculate the energy stored in the wire when it experiences a strain of 0.020.

....

....

....

....

Energy = ...

(4)
(Total 10 marks)

51. Read the short passage below and answer the questions about it.

> Elastic materials under stress store strain energy. In a car with no springs there would be violent interchanges of gravitational potential energy and kinetic energy every time a wheel passed over a bump. The springs of the car enable changes of potential energy to be stored temporarily as strain energy, resulting in a smoother ride. Most ski runs are more bumpy than a normal road. The tendons in the legs of a fast moving skier must be able to store and give up again very large amounts of energy. Light aircraft which may have to land on rough ground often have their undercarriages sprung by means of rubber cords.
> [Adapted from *Structures* by J E Gordon]

Explain what is meant by the term strain energy.

....

....

....

(1)

Why is it important that the springs, tendons and rubber cords mentioned in the passage are not stressed beyond their elastic limits?

....

....

....

(1)

Useful data:

	Energy stored per unit mass/J kg^{-1}
Modern spring steel	130
Tendon in leg	2500
Rubber cord	8000

Show that a car of mass 1200 kg would need steel springs of total mass approximately equal to 3 kg to store energy when it encounters pot-holes of depth 3 cm.

....

....

....

....

....

....

(3)

The sum of the mass of leg tendons of a skier might be of the order of 0.4 kg. Estimate the size of 'bump' that a skier of mass 75 kg could theoretically negotiate.

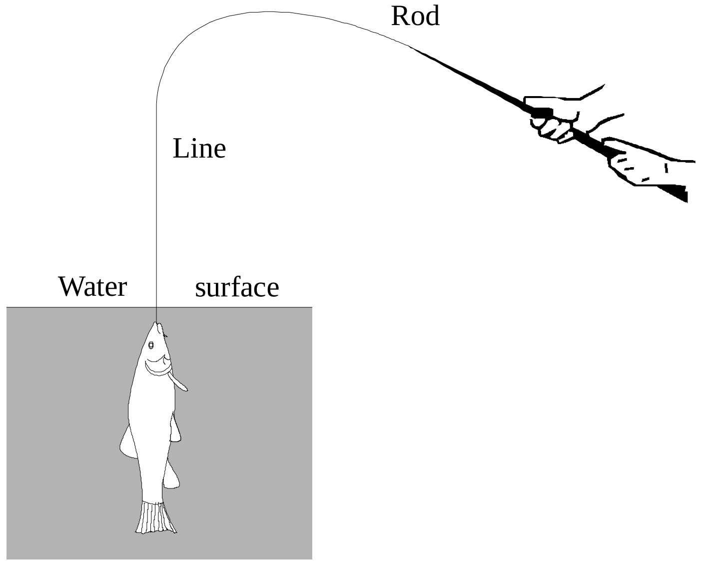
....

....

....

(2)
(Total 7 marks)

52. Nomlas is a new material intended for fishing rods.

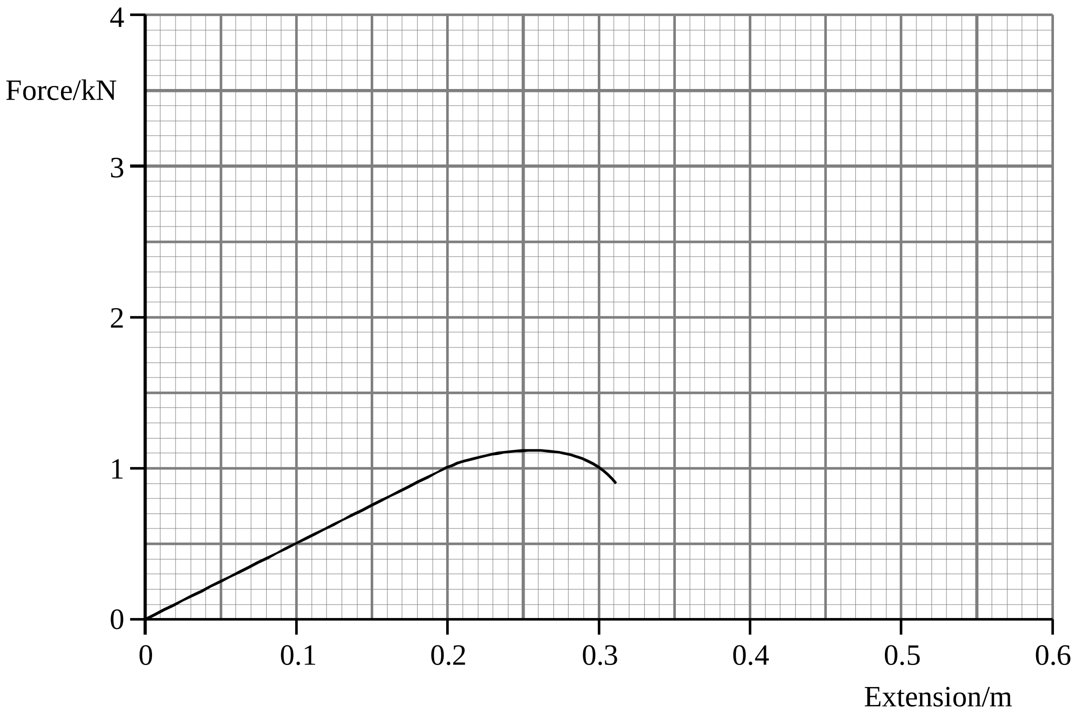


Complete the table below for the four other properties of materials listed.

Property	Desirable for rod	Not desirable for rod	Reason
Strong	✓		Needs a large force before it breaks
Elastic			
Brittle			
Hard			
Tough			

(Total 8 marks)

53. A nylon tow rope used for towing a car has the force-extension graph shown below.



Mark the graph with two crosses labelled:

P at the limit of proportionality,

Y at the yield point.

(2)

The 4.0 m long rope has an effective cross-sectional area of 3.0×10^{-5} m^2. Calculate the Young modulus of the nylon.

....

....

....

....

....

Young modulus = ...

(3)

On the graph grid, draw lines to show how force would vary with extension if the nylon rope had

(i) twice the length (label this graph L),

(ii) three times the cross-sectional area (label this graph A).

Explain your reasoning in each case.

(i) ....

....

(ii) ....

....

(4)

In use the original rope stretches by 0.20 m. Calculate the energy stored in the rope.

....

....

....

Energy stored = ...

(2)

Explain why a longer rope would be less likely to break when used for towing.

....

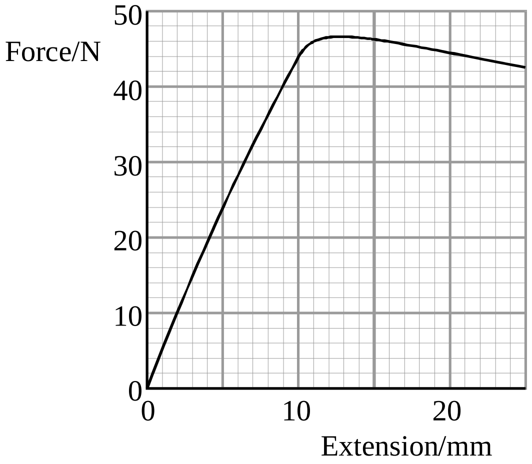
....

....

....

(1)
(Total 12 marks)

54. A force-extension graph for a brass wire of length 3.44 m and cross-sectional area 1.3×10^{-7} m^2 is shown below.

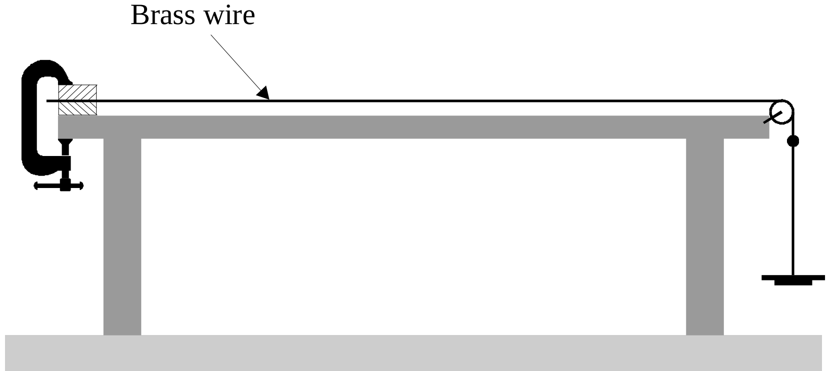


For what range of extensions is Hooke's law obeyed by this wire?

....

(1)

The diagram shows an arrangement for investigating this relationship between force and extension for the brass wire.



Add to the diagram suitable apparatus for measuring the extension of the wire as further masses are added to the slotted hanger.

Show on the diagram the length that would be measured in order to calculate the strain in the wire once the extension has been found.

(2)

Calculate the Young modulus for brass.

....

....

....

....

Young modulus =..

(3)

How much energy is stored in the wire when it has extended by 7.0 mm?

....

....

....

....

....

Energy stored =..

(2)

State one energy transformation that occurs as the wire extends.

....

....

(1)

Use the graph to calculate the tensile strength of brass.

....

....

....

Tensile strength =...

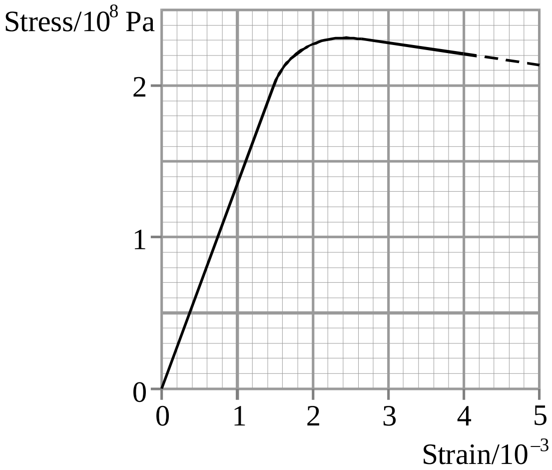
(3)
(Total 12 marks)

55. State Hooke's law.

....

.... **(2)**

The graph shows the stress-strain relationship for a copper wire under tension.



Use the graph to determine:

the ultimate tensile stress for copper ....

the Young modulus of copper ....

....

....

....

.... **(3)**

A copper wire of cross-sectional area 1.7×10^{-6} m^2 and length 3.0 m is stretched by a force of 250 N

Will the behaviour of the wire at this point be elastic or plastic? Justify your answer.

....

....

....

(2)

Show this point on the stress-strain graph above. Label it P.

(1)

Calculate the extension of the wire.

....

....

Extension = ...

(2)
(Total 10 marks)

56. Sketch a force-extension graph for natural rubber showing its behaviour for both increasing and decreasing force.

(2)

Use your graph to explain why a rubber band which is repeatedly stretched and relaxed becomes noticeably warmer.

....

....

....

....

(2)
(Total 4 marks)

57. Some people think that all raindrops fall at the same speed; others think that their speed depends on their size.

Calculate the speed of a raindrop after it has fallen freely from rest for 0.2 s.

....

....

Speed = …………………………

(1)

The raindrop falls for longer than 0.2 s. Explain why its acceleration does not remain uniform for the whole of its fall.

....

....

....

....

(2)

Show that the mass of a 0.5 mm diameter spherical raindrop is less than 1×10^{-7} kg.

1.0 m^3 of water has a mass of 1.0×10^3 kg

....

....

....

....

....

(2)

Calculate the raindrop's terminal velocity. Assume that the upthrust from the air is negligible.
Explain your working clearly.

Viscosity of air = 1.8×10^{-5} kg m^{-1} s^{-1}.

....

....

....

....

....

Terminal velocity = ...

(3)

Sketch a graph to show how the raindrop's velocity increases from rest to terminal velocity.
Add a scale to the velocity axis.

(3)

Explain how the terminal velocity would be different for a larger raindrop.

....

....

....

....

(1)
(Total 12 marks)

58. For many years surgeons have used metal implants to repair broken bones and joints. It is important to understand how the properties of the implant materials compare with bone so that comfortable and long-lasting repairs can be made.

One important property of the implant material is its stiffness. How is stiffness calculated?

....

....

(1)

Explain the difference between *stiffness* and the *Young modulus*.

....

....

....

(2)

The picture shows an X-ray of a hip joint after surgery to replace the weakened joint with an implant

A woman needs a hip replacement operation. Calculate the stress in the bone just below her hip when she is standing still.

Assume that the mass supported by this hip is 30 kg and that the bone just below her hip is of circular cross-section with radius = 2.0×10^{-2} m.

....

....

....

....

....

(3)

A manufacturer of hip replacements is considering using a new polymer of Young modulus 2×10^9 Pa. Explain whether this is a suitable material for hip replacements.

The Young modulus of bone is 1×10^{10} Pa.

....

....

....

....

(2)
(Total 8 marks)

59. This question is about the design of a car seat belt. The seat belt has to restrain a passenger when the car is involved in an accident.

Use definitions of stress and strain to show that *stress* × *strain* has the same units as *energy stored per unit volume of seat belt.*

……………………………………………………………………………………………

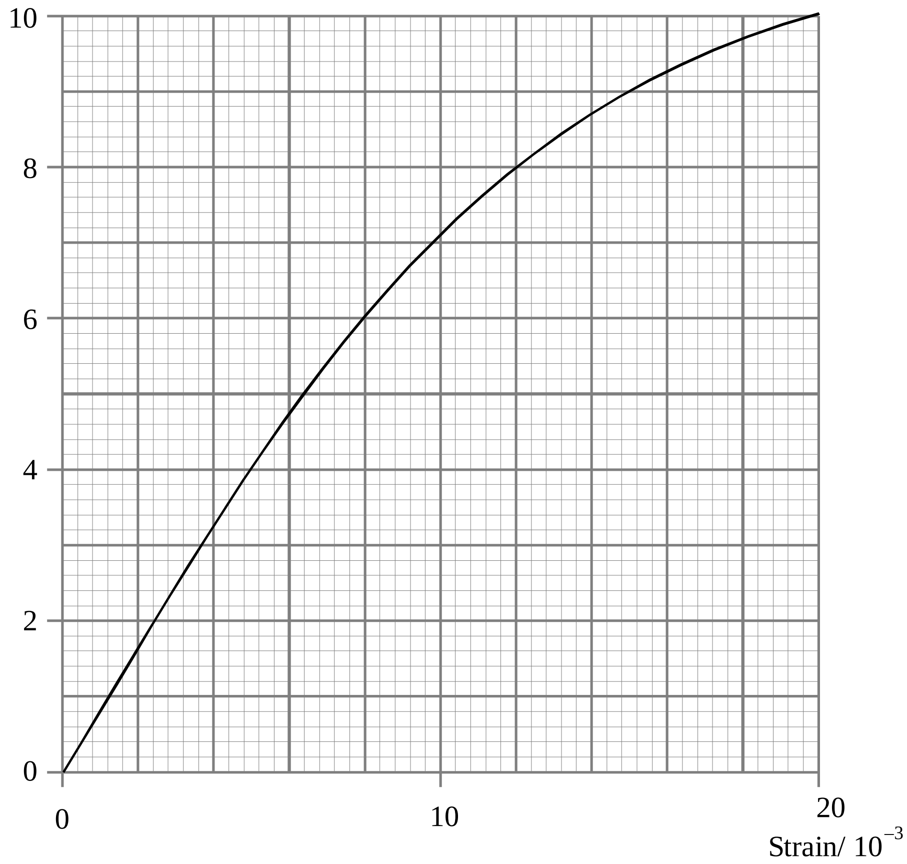
……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

(3)

The graph shows how stress varies with strain for the seat belt material.



Use the graph to show that the energy stored per unit volume of seat belt material when the strain is 20×10^{-3} is about 1×10^8 Jm^{-3}.

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

(3)

The car is travelling at 20 m s^{-1} carrying a 60 kg passenger who is wearing a seat belt.

(i) Show that the kinetic energy of the passenger is 12 000 J.

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

(1)

(ii) Calculate the volume of seat belt material which would be required to stop the passenger when the car stops suddenly.

Assume that the maximum strain in the seat belt is 20×10^{-3}.

………………………………..……………………………………………………

………………………………..……………………………………………………

………………………………..……………………………………………………

………………………………..……………………………………………………

Volume = ………………………..

(2)

(iii) Use your answer to part (ii) to suggest a suitable width and thickness of seat belt for this situation, assuming its length is 2.0 m.

………………………………..……………………………………………………

………………………………..……………………………………………………

………………………………..……………………………………………………

………………………………..……………………………………………………

(2)
(Total 11 marks)

60. The process of turbulence was described in verse by the British meteorologist, Lewis F. Richardson:

Big whorls have little whorls,
Which feed on their velocity,
And little whorls have lesser whorls,
And so on to viscosity.

Suggest what the author means by the word *whorl.*

…………………………………………………………………………………………

(1)

Draw diagrams in the boxes below to show laminar and turbulent flow.

Describe these flow patterns.

Laminar flow

Description:

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

(2)

Turbulent flow

Description:

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

(2)

Turbulence can be used to reduce the rate of flow of a fluid.

Explain this statement in terms of energy transfers.

....

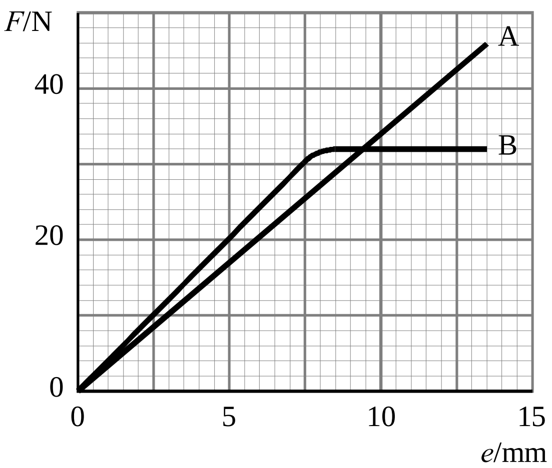
....

....

....

(2)
(Total 7 marks)

61. Two wires A and B are of the same length and cross-section but are made from different materials. The graph shows how the wires extend when subjected to a tensile force.



State how the graph is used to determine which material is

stronger ....

....

brittle ....

....

(4)

Which wire requires the most work to stretch it by 11 mm? Show how you obtained your answer.

....

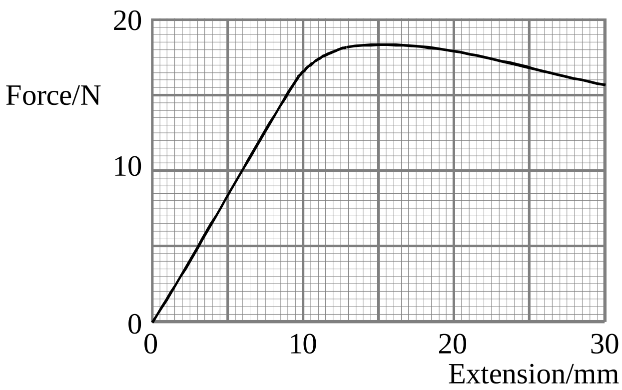
....

....

....

(2)
(Total 6 marks)

62. A force-extension graph for a long thin copper wire is drawn below.



Show clearly on the graph the region where the copper wire obeys Hooke’s law.

What additional information would be needed in order to calculate the Young modulus for copper from this graph?

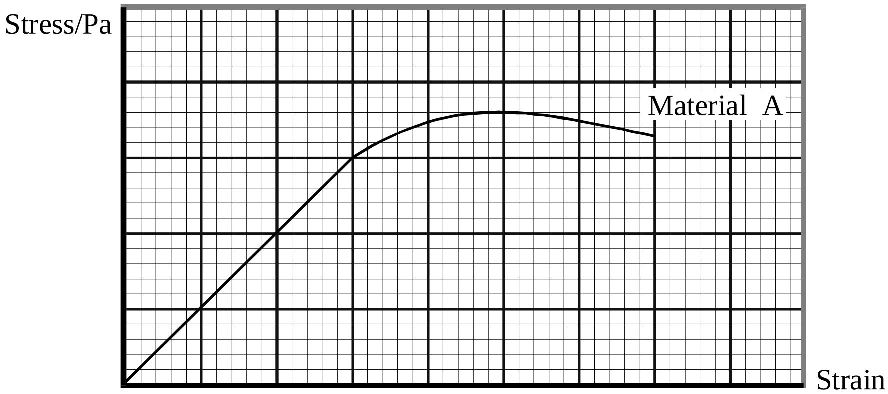
....

Estimate the energy stored in the wire when it has been extended by 20 mm.

Energy stored = ……………………………...

(Total 5 marks)

63. The graph below shows the behaviour of a material A subjected to a tensile stress.



How would you obtain the Young modulus of material A from the graph?

....

....

....

(2)

What is the unit of the Young modulus?

....

(1)

On the same graph, draw a second line to show the behaviour of a material B which has a *greater* Young modulus and is brittle.

Draw a third line to show the behaviour of a material C which has a *lower* value of Young modulus and whose behaviour becomes plastic at a lower strain.

(3)
(Total 6 marks)