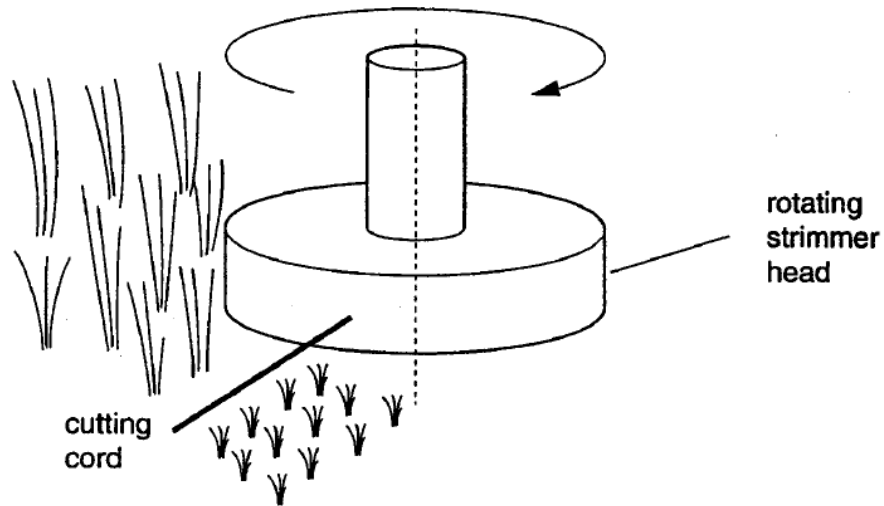






t test : Materials 1

- 1 This question is about choosing a material, to be used as the cutting cord of a motorised lawn cutter (strimmer). This is illustrated in Fig. 11.1.



The strimmer head is rotated at high speed and the taut plastic cord slices the grass.

**Fig. 11.1**

- (a) Suggest one reason why the material of the cord needs to be tough.

[1]

The table, Fig. 11.2, shows mechanical properties for three different polymers.

Polymer	density / $\text{kg m}^{-3}$	Young modulus / GPa	toughness / $\text{J m}^{-2}$	yield stress / MPa	hardness / MPa
Nylon 6	1200	1.8	2600	48	130
Polypropylene	900	1.3	2800	26	77
Polystyrene	1100	2.6	370	35	110

**Fig. 11.2**



(b) (i) Explain the terms: toughness, yield stress and hardness.

Toughness:

Yield stress:

Hardness:

[3]

(ii) Which of the three materials in Fig. 11.2 would be the best choice for the strimming cord?

[1]

(iii) Give three reasons for your choice of material.

[3]

(iv) Rapid rotation of the strimmer sets up tensile stress in the cord. The tensile stress is kept below half the yield stress.  
Calculate the maximum strain on the cord.  
Use data for the material you selected in (b)(i).

maximum strain = ..... [2]

10 A lift operates in a building 80 m tall. The cage of the lift weighs 4 000 N and is designed to carry a maximum additional load of 6 400 N. It is supported by a steel cable.

(a) (i) What is the maximum total tensile load acting on the cable?

tension in cable = ..... N [1]

(ii) The steel cable that supports the lift has a tensile strength of 600 MPa. The Young modulus for steel is 200 GPa. Calculate the strain at the yield point.

breaking strain = ..... [3]

(iii) Sketch the shape of the stress/strain graph for steel on Fig. 10. Mark on your graph the point where the steel yields.

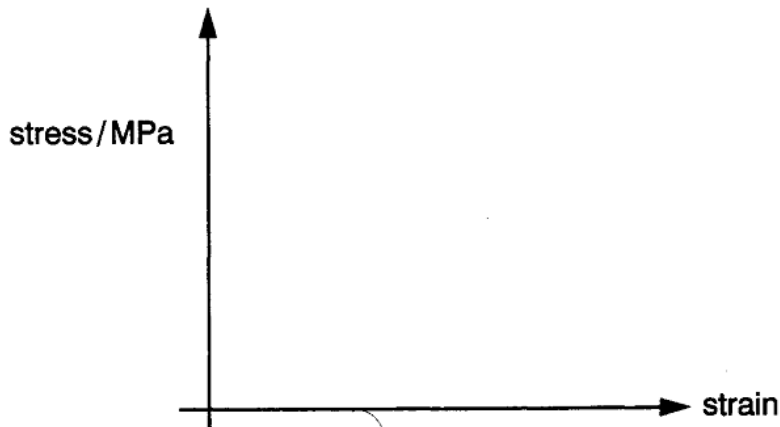


Fig. 10

[3]

(b) In choosing the thickness of the cable needed, the maximum static tensile stress should be  $\frac{1}{4}$  of the tensile strength. How much extension will this cause in the 80 m cable?

extension = ..... m [4]

t test : Materials 3

2 The material chosen for a hip joint replacement needs to be strong.

(a) State **one** other **mechanical** property that is important for this use of the material, and explain its meaning.

mechanical property: .....

meaning of property: .....[2]

(b) Explain the importance of the property to this use of the material.

[1]

The graph in Fig. 3.1 shows how the stress in a rubber cord varies with strain, up to the breaking stress of 30 MPa.

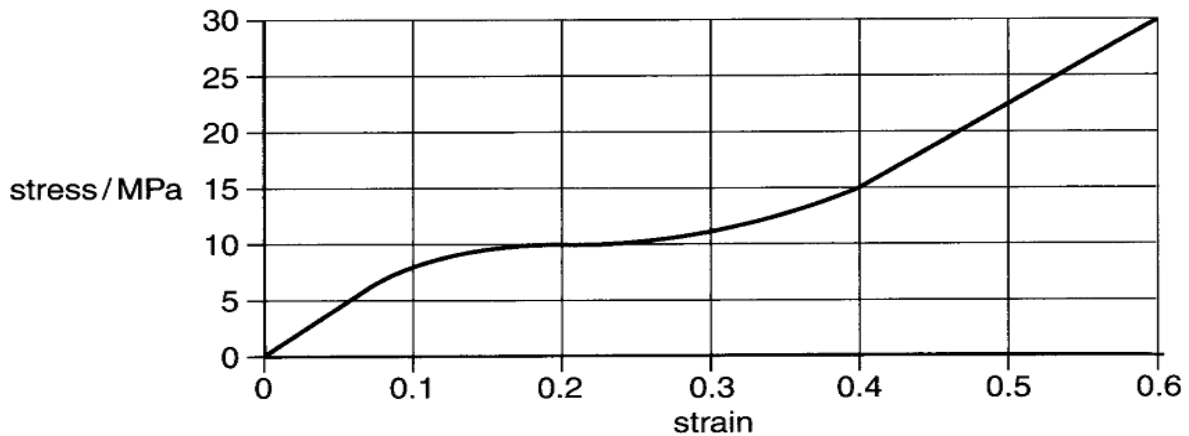


Fig. 3.1

The rubber cord is cooled to well below room temperature. It is found that it becomes much stiffer, finally breaking at the same stress, but at half the original breaking strain.

Sketch this variation for the cooled rubber cord on the graph of Fig. 3.1. [3]

Here is a list of five units for physical quantities:

- $\text{Nm}^{-2}$       D      J       $\Omega\text{m}$        $\text{Sm}^{-1}$

From the list:

(a) Write down the unit for the power of a lens. ....[1]

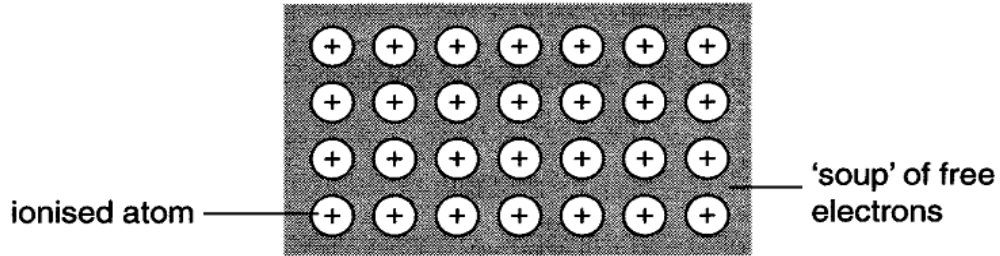
(b) Write down the unit for electrical conductivity. ....[1]

3 The diagrams below illustrate the microstructure of three different types of material. Here is a list of different types of material.

glass                  ionic crystal                  metal                  rubber

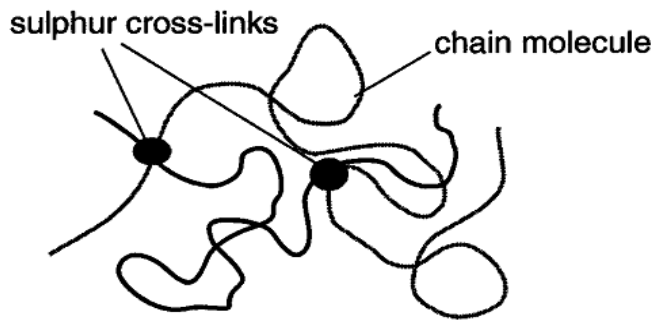
Choose from the list the type of material that best matches each microstructure.

(a)



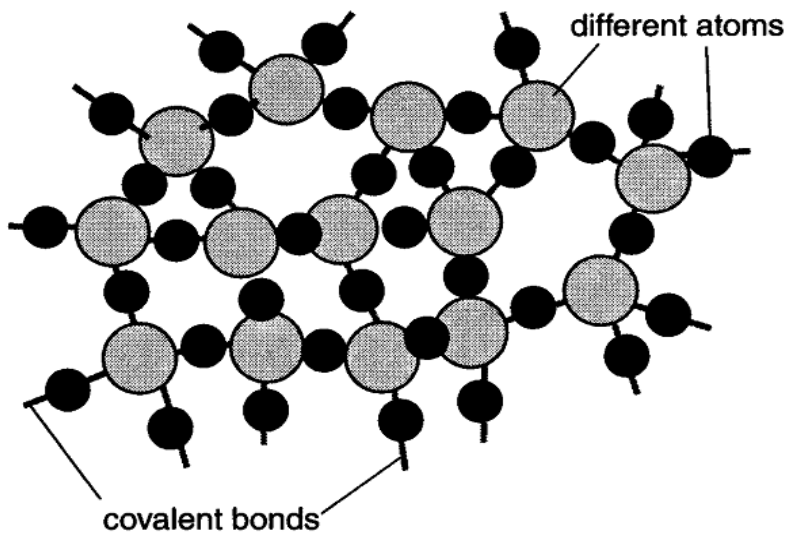
material .....

(b)



material .....

(c) Covalent bonds share electrons between neighbouring atoms. These bonds are directional: they lock atoms in place like scaffolding.

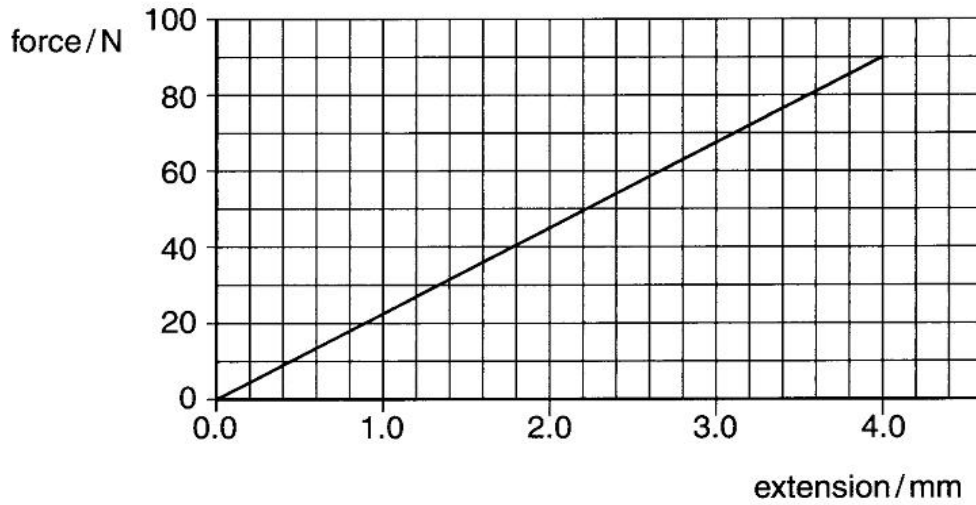


material .....



**11** This question is about steel wires in tension.

Guitar strings can be made from tensile steel wire. A sample of steel wire is tested in the laboratory. Fig. 11.1 shows the force-extension graph obtained when the wire is stretched.



**Fig. 11.1**

**(a)** Describe how the extension varies as the force is increased.

[1]

**(b)** The area under the force against extension graph equals the energy stored in the stretched wire.

**(i)** Calculate the energy stored when the force in the wire is 90 N.

energy = ..... unit .....

[3]

- (ii) This sample of steel wire had an original length of 2.0 m and cross-sectional area of  $2.5 \times 10^{-7} \text{ m}^2$ .

Use these facts and information from the graph, to calculate the Young modulus of the steel.

Young modulus = .....  $\text{N m}^{-2}$   
[5]

- (c) The test is repeated using another sample of the same wire, but of only **half** the original length.

- (i) **Sketch on the axes of Fig. 11.1** the force-extension graph you would expect for this wire, as the force is increased to 90 N.  
[1]

- (ii) How does the Young modulus for this wire compare with that of the sample used in the first test?  
Explain your reasoning.

[2]

10 This question is about two methods of estimating the size of a molecule.

(a) This is the first method.

The field of view of an STM (scanning tunnelling microscope) is 20 nm wide. It is possible to resolve 14 molecules across it, as shown in Fig. 10.1.



Fig. 10.1

Estimate the size of a molecule using this information.

molecular size = ..... m [2]

(b) Another method is to allow one drop of oil to spread out on a water surface.

(i) The oil drop has a diameter of 0.50 mm.

Show that the volume of oil in the drop is about  $0.07 \text{ mm}^3$ .

$$\text{volume of sphere} = \frac{4}{3} \pi r^3$$

[2]

(ii) When the oil spreads out on the water surface, it forms a circular patch.

This is assumed to be one molecule thick. Therefore the thickness of the patch gives an estimate of the size of the molecule.

The diameter of the patch can be measured because the oil has moved aside powder scattered on the water surface as illustrated in Fig. 10.2.

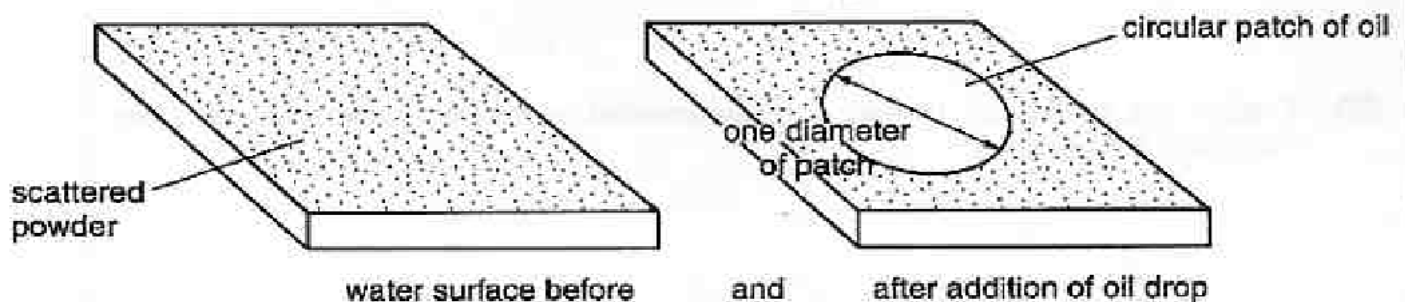


Fig. 10.2

The diameter of the patch is measured in four different directions.  
The results are given below.

diameter / mm	300	280	280	260
---------------	-----	-----	-----	-----

Calculate the mean diameter of the patch from these measurements.

mean diameter = ..... mm [1]

- (iii) Use the mean radius of the circular patch to show that its surface area is about  $6.2 \times 10^4 \text{ mm}^2$ .

area of circle  $A = \pi R^2$

[2]

- (iv) The method assumes that the oil drop and the circular patch have the same **volume**.

For a patch of area  $A$  and thickness  $h$  the volume =  $A h$

Calculate the thickness of the patch using the data from parts (b)(i) and (b)(iii).

This is your estimate of molecular size.

estimate of molecular size = ..... unit ..... [3]

[Total: 10]

**10** This question is about materials that have been used to build railway tracks.

Railway tracks must withstand the effects of metal train wheels running along them. The first metal tracks, which were made of cast iron, were **hard** but also **brittle** and often broke. These were replaced by wrought iron, which is **stronger** and **tougher**.

(a) State what is meant by the following words from the passage.

**brittle**

**hard**

**strong**

**tough**

- (b) More recently, steel has replaced wrought iron as the material for railway tracks. The table gives data for wrought iron and steel.

material	toughness / $\text{J m}^{-2}$	strength / $\text{MN m}^{-2}$
wrought iron	4000	350
steel	16000	430

- (i) Look at the data in the table.

State the **main** reason why steel replaced wrought iron as the preferred material for railway tracks.

[1]

- (ii) Suggest why toughness is measured in units  $\text{J m}^{-2}$ .

[2]

- (c) Fig. 10.1 shows how stress varies with strain for the three materials, cast iron, wrought iron and steel.

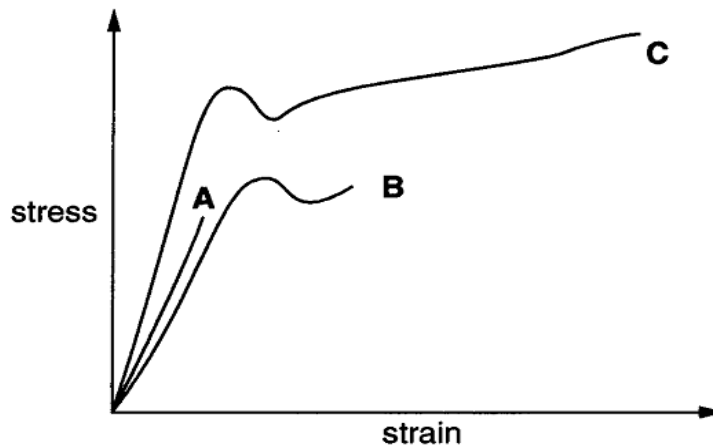


Fig. 10.1

- (i) State which graph, **A**, **B** or **C**, best represents wrought iron ..... [1]

- (ii) Explain your choice of graph.

[1]

[Total: 9]

t test : Materials 7

- 1 A particular material breaks after plastic deformation. It requires a large energy to create new surface area, but does **not** fracture by crack propagation.

Here is a list of four different mechanical properties.

stiff      strong      tough      hard

Write down the **one** word from the list that best describes this material.

..... [1]

Fig. 1.1 shows a plot of strength against toughness for different materials. Four areas have been shaded and labelled **A**, **B**, **C** and **D**.

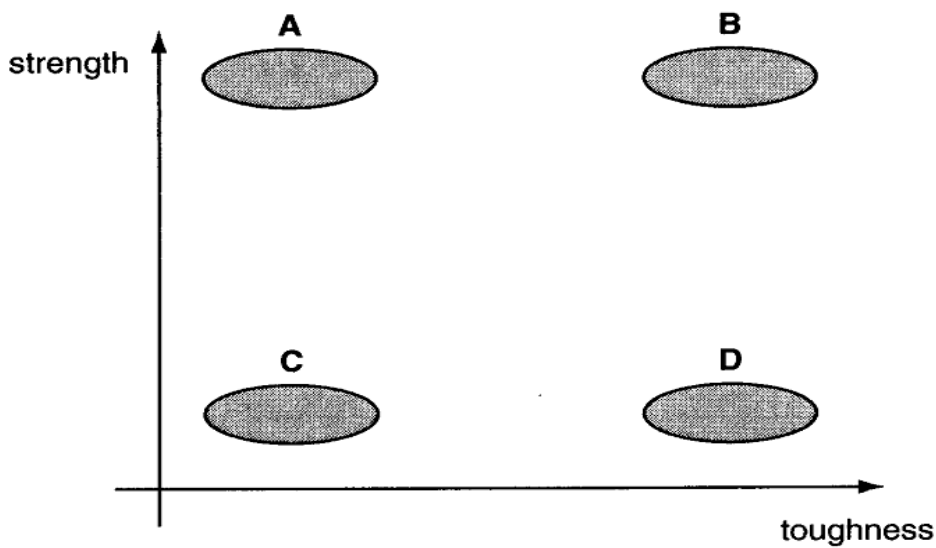


Fig. 1.1

Select the area of the graph, **A**, **B**, **C** or **D**, that best fits each of the following materials.

a material suitable for car bodies e.g. steel .....

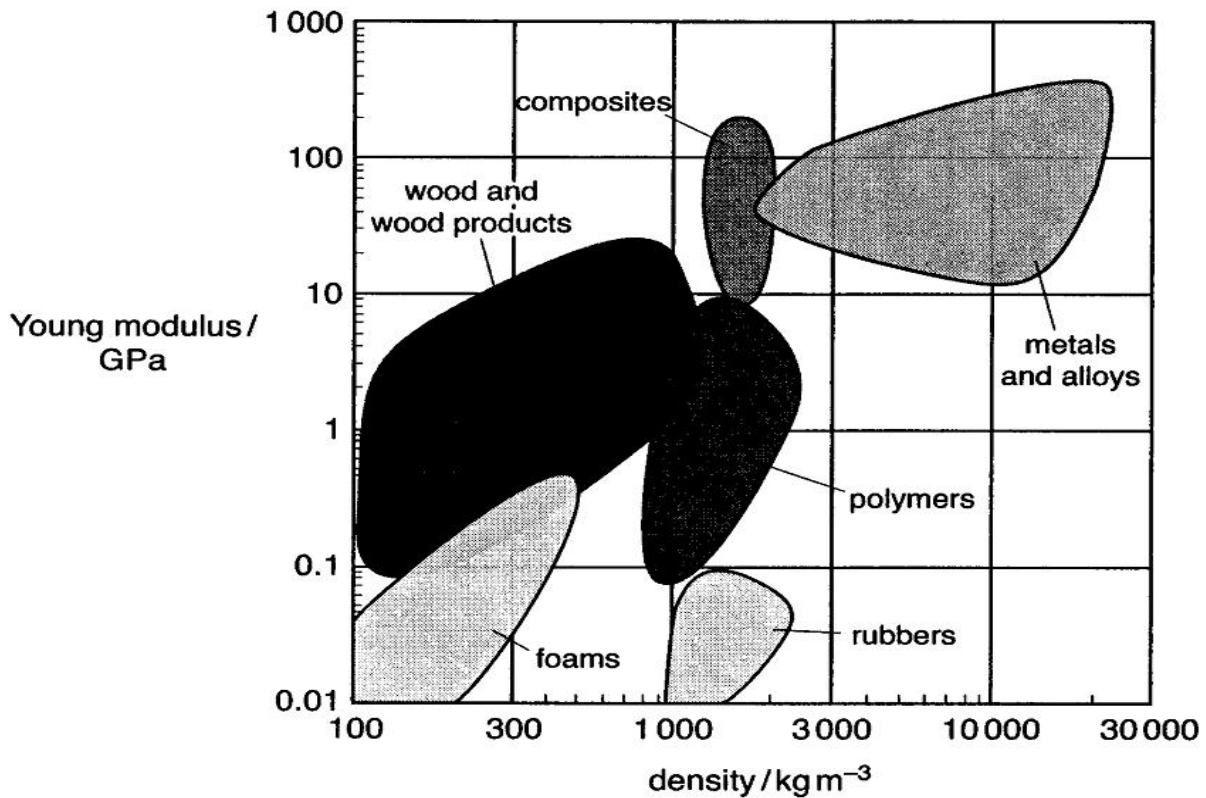
a weak material that is easy to snap e.g. biscuit .....

a brittle metal e.g. cast iron under tension .....

[3]

This question is about selecting materials for sports equipment.

Fig. 3.1 shows, on a plot of the Young modulus against density, ranges of values for different classes of material.



**Fig. 3.1**

(a) Foams are used for filling landing mats for high jumpers.

Explain this choice of material using information from Fig. 3.1.

[2]

(b) Some sports rackets are now made of a composite material rather than of metal.

Suggest and explain a reason for this change using information from Fig. 3.1.

[2]



Read the paragraph below about the properties of spider silk.

Spider silk is a very strong material. It also requires a large energy to create new surface area or to break it. It is twice as strong as stainless steel, having a breaking stress of  $2.0 \times 10^9 \text{ N m}^{-2}$ . Yet, it can be stretched by more than one third of its original length and recover without permanent distortion.

(a) Here is a list of words describing mechanical properties of materials

**elastic      hard      plastic      tough**

Choose **two words from this list** that best state the mechanical properties of spider silk as described in the paragraph.

..... and ..... [2]

(b) A 'spiderwoman' weighs 550 N.

Calculate the **minimum** cross-sectional area of spider silk needed to support her weight.

cross-sectional area = .....  $\text{m}^2$  [2]

(c) (i) Explain the meaning of *elastic limit* for a material.

[1]

(ii) At the elastic limit of spider silk, the strain is 0.35 and the stress is  $1.6 \times 10^9 \text{ N m}^{-2}$ .

Estimate the Young modulus for spider silk.

Young modulus = .....  $\text{N m}^{-2}$  [2]

**(d)** Spider silk consists of long chain polymer molecules.

Spider silk can 'be stretched by more than one third of its original length and recover without permanent distortion'.

**(i)** Sketch and label diagrams of a possible molecular structure for spider silk before and during stretching.

diagram of molecules before the silk is stretched

diagram of molecules while the silk is stretched

**(ii)** Describe how your proposed structure does enable spider silk to be stretched as described above.

[3]

[Total: 10]

**11** This question is about the mechanical properties of human hair.

A single hair recovers almost completely elastically when strains of up to 25% are removed.

The table gives typical data for human hair.

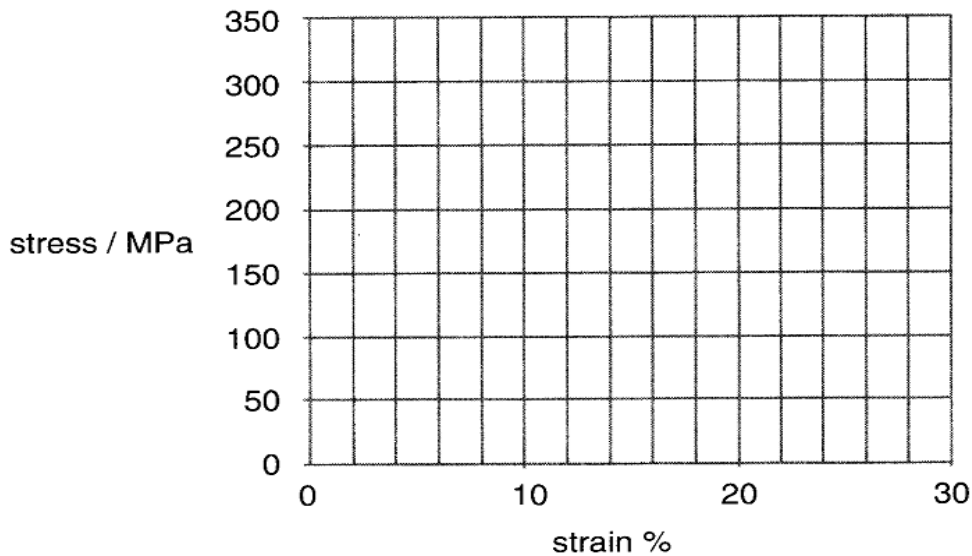
diameter	50 $\mu\text{m}$
Young modulus	$5.0 \times 10^9 \text{ Pa}$
breaking stress	$3.0 \times 10^8 \text{ Pa}$
breaking strain	25%

**(a)** Up to 5% strain, the stress is directly proportional to the strain. At greater than 5% strain the relationship becomes non-linear.

Show that the stress at 5% strain is  $2.5 \times 10^8 \text{ Pa}$ .

[1]

**(b)** Sketch the stress against strain graph for hair, up to its breaking point, on the axes of Fig. 11.1.



**Fig. 11.1**

[2]

**(c) (i)** Show that the cross-sectional area of a typical hair is about  $2 \times 10^{-9} \text{ m}^2$ .

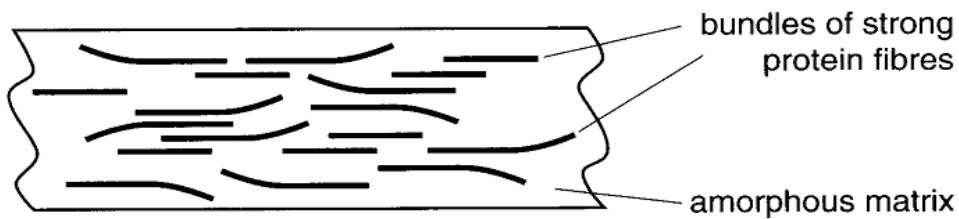
[1]

**(ii)** Calculate the force that breaks such a hair.

force = ..... N [2]

(d) Hair is a composite material. Its microscopic structure influences its mechanical behaviour.

- (i) Hairs are made of bundles of strong protein fibres, embedded in an amorphous protein matrix (Fig. 11.2). Strong sulphur bonds glue the bundles of fibres to the amorphous matrix.

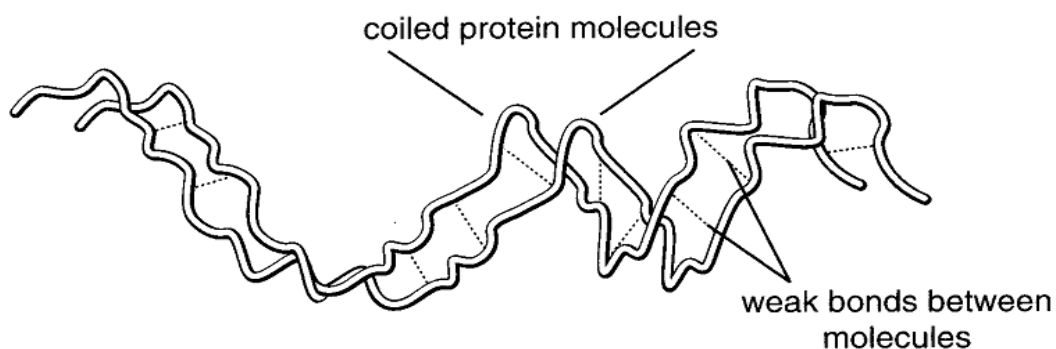


**Fig. 11.2**

Suggest and explain one mechanical property that hair is likely to have as a result of this composite microstructure.

[2]

- (ii) The protein fibres are made of long coiled protein molecules (Fig. 11.3).



**Fig. 11.3**

Bundles of protein fibres consist of several protein molecules coiling around each other. Weak bonds hold the protein molecules to their neighbours, giving the fibres large flexibility.

Suggest how hair can recover almost completely elastically up to strains of 25% as a result of this microstructure.

[2]

[Total: 10]

Fig. 6.1 shows the microstructure on the surface of a brass specimen.

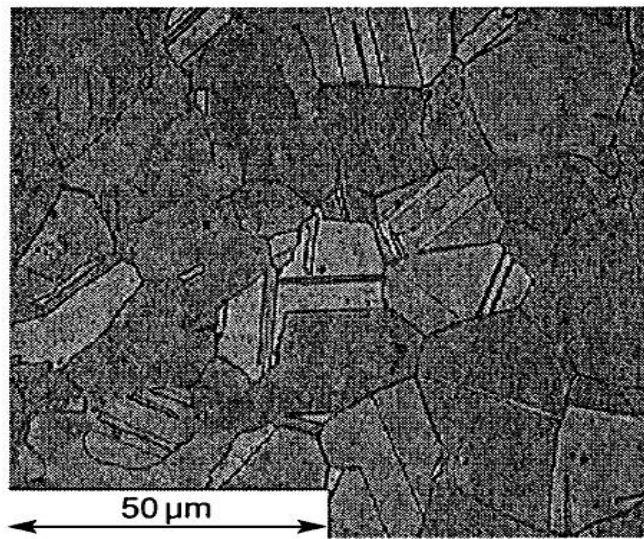


Fig. 6.1

The polycrystalline grain structure of the brass can be seen.

Explain the meaning of the term *polycrystalline*.

[2]

A wine glass can support large compressive stress, but may shatter, by crack propagation, if dropped a small distance onto a hard surface.

Here is a list of some mechanical properties of materials.

- brittle      elastic      plastic      strong      tough**

Write down the two properties of glass from the list that best fit the statement about the wine glass.

..... and ..... [2]

Here is a list of units.

- $\text{kg m}^{-3}$        $\text{Jm}^{-2}$        $\text{Nm}$        $\text{Nm}^{-2}$

Choose the correct unit for

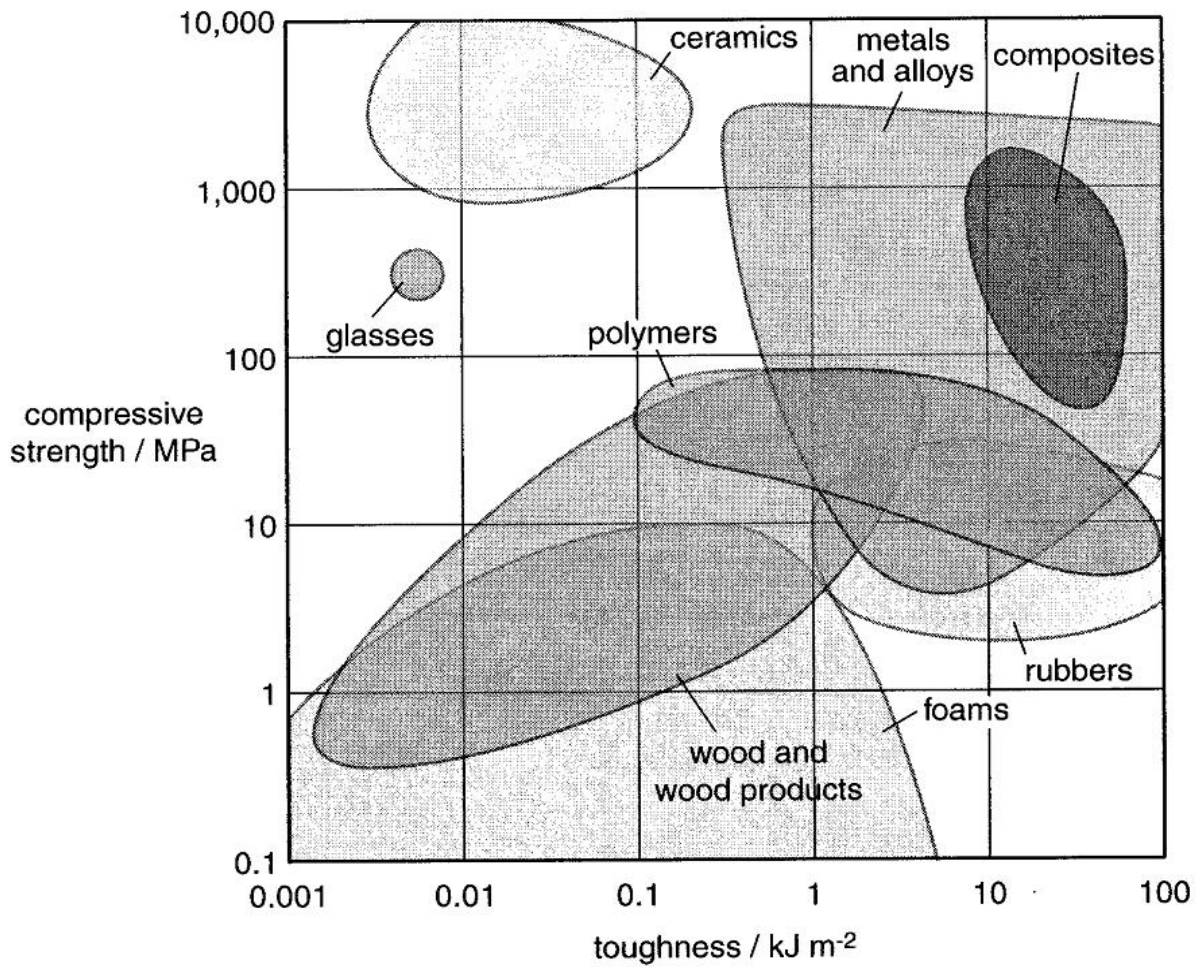
(a) Young modulus .....

(b) density. ....

[2]

This question is about some properties of materials.

Fig. 4.1 shows, on a plot of the compressive strength against toughness, ranges of values for different classes of material.



**Fig. 4.1**

(a) State the class of materials shown in Fig. 4.1 that has the greatest average strength in compression.

[1]

(b) State what is meant by the compressive strength of a material.

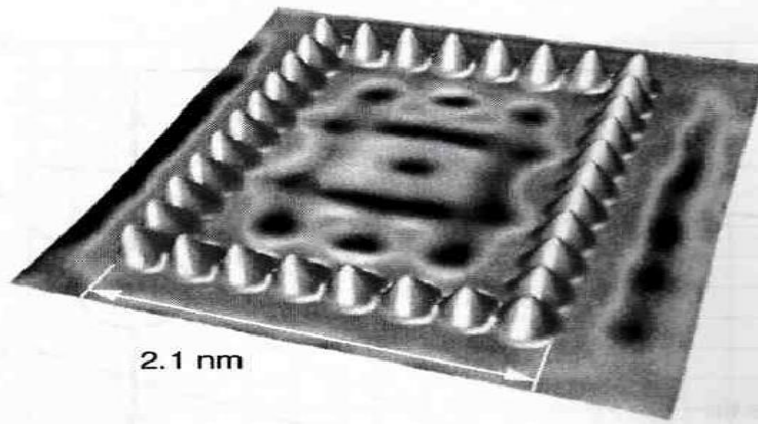
[1]

(c) The head of a hammer needs to be strong.

Explain whether the class of material you named in (a) might be suitable for constructing the head of a hammer.

[1]

Fig. 5.1 shows an STM image of 34 iron atoms arranged in a rectangle on a copper surface.



**Fig. 5.1**

The length of the front row of iron atoms is 2.1 nm.

Calculate the diameter of an iron atom.  
Give your answer to 2 significant figures.  
Show your working clearly.

diameter of iron atom = .....m [2]

Here is a list of mechanical properties of materials.

**brittleness      plasticity      stiffness      strength**

- (a) For each of the descriptions below write down the word from the list that is being described:
- a measure of the stress a material can take before yielding .....
  - a measure of a material's resistance to stretching or bending .....
  - the tendency of a material to break by crack propagation .....

[3]

- (b) State the meaning of the remaining property that you have not chosen above.

[1]

This question is about the behaviour of a metal alloy.

Fig. 10.1 shows the stress against strain graphs to breaking point for samples of a pure metal and one of its alloys.

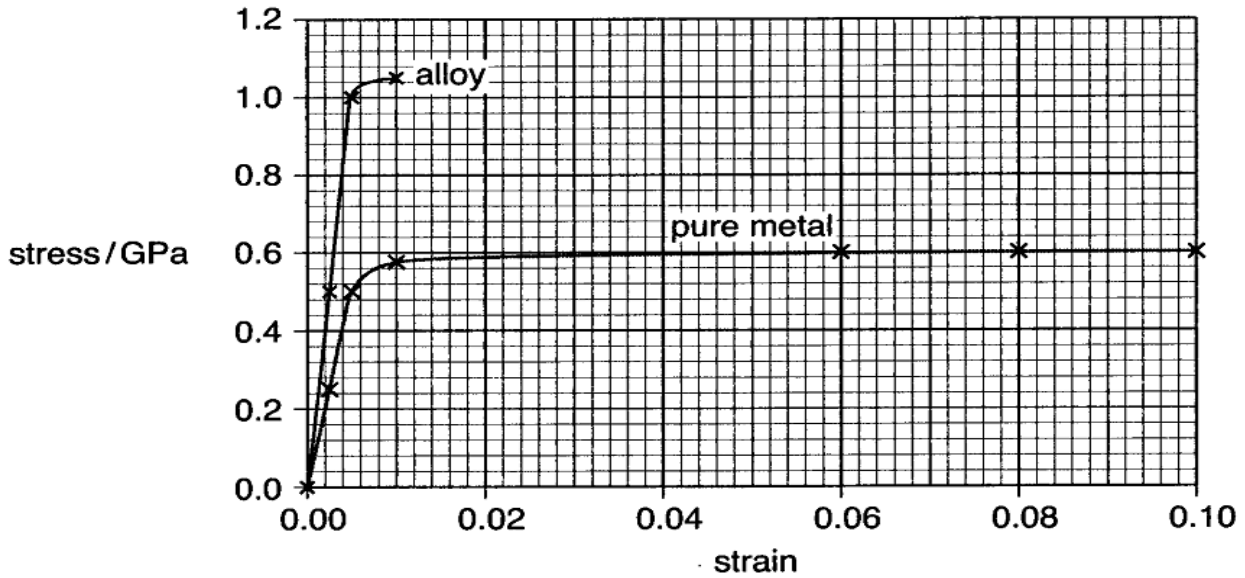


Fig. 10.1

- (a) (i) Use data from Fig. 10.1 to calculate the Young modulus of the pure metal. Make your method clear.

Young modulus = .....GPa [3]

- (ii) Explain how the graphs show that the alloy is stiffer and stronger but less ductile than the pure metal.

stiffer

stronger

less ductile



(b) Girders to support the floors in buildings are made from this alloy rather than the pure metal.

Suggest why the properties of this alloy make it more suitable than the pure metal for girders.

[1]

(c) The microstructure of the pure metal is shown in Fig. 10.2.

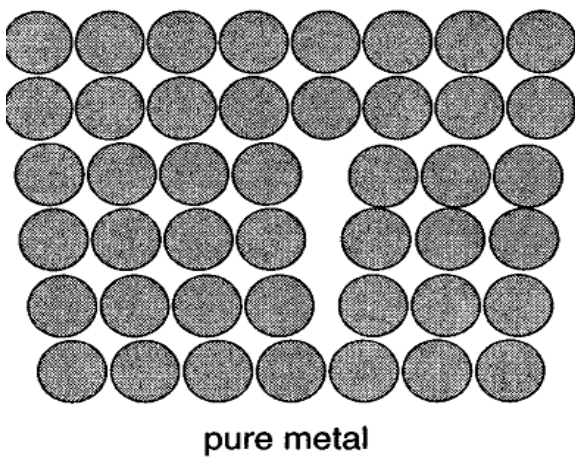


Fig. 10.2

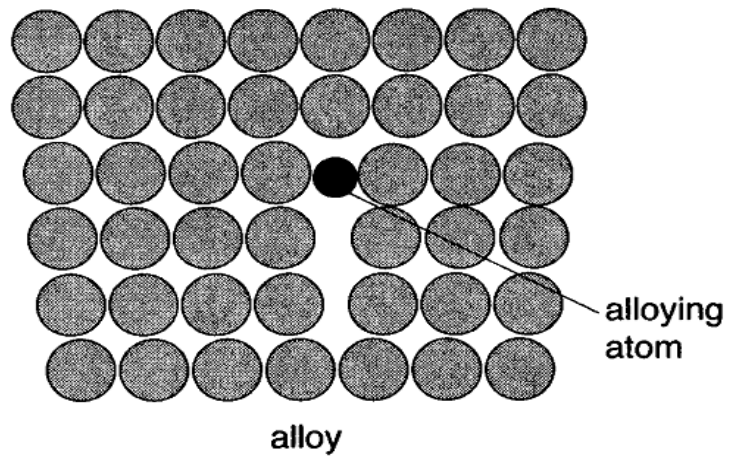


Fig. 10.3

The alloy microstructure is shown in Fig. 10.3.

The alloying metal atoms randomly replace a few of the host metal atoms in the structure. The alloying atoms are smaller than the host atoms.

Use the information above about the microstructures, to suggest and explain why the alloy is less ductile than the pure metal.

[3]

[Total: 10]

t test 12 : Materials

This question is about the height  $h$  of a column of solid material that can support its own weight without yielding under compression.

(a) Fig. 10.1 shows a vertical column of a solid material.

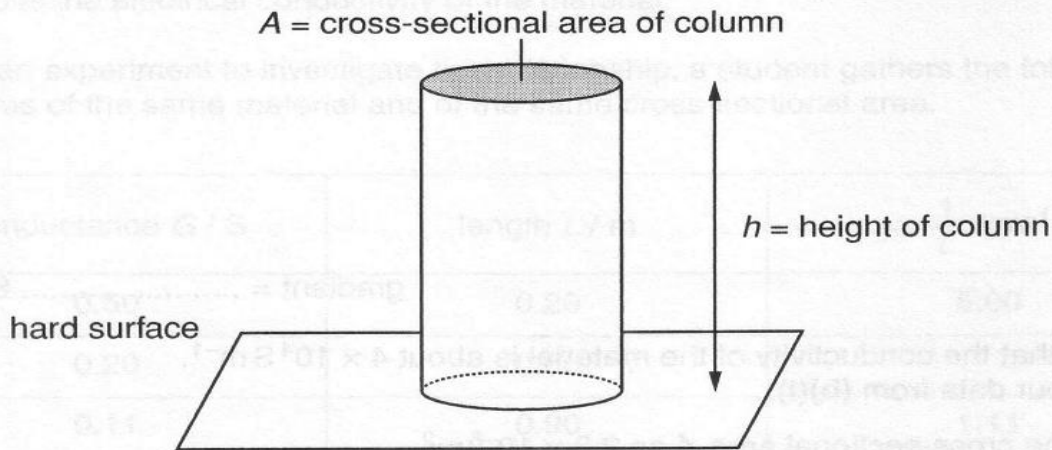


Fig. 10.1

(i) The stress at the base of the column =  $h \rho g$

where  $\rho$  = density of material and  $g$  = gravitational field strength.

Derive this expression, by completing the following algebraic reasoning. Fill the boxes, using the symbols given above.

volume of column =  $A \times h$

mass of column =

weight of column =

stress at base of column =  $\frac{\text{weight}}{\text{area}}$  =

=  $h \rho g$  [3]

(ii) Explain why the failure of a tall column of solid material is most likely to occur at its base.

[1]

(iii) Explain why columns of the same material fail at the **same value** of  $h$  regardless of their cross-sectional area.

[1]

(b) (i) The compressive stress at which rock yields is about  $2.4 \times 10^8 \text{ N m}^{-2}$ .

Show that the maximum height  $h$  of a column of rock that could support its own weight on Earth is about 9 km.

$$\text{density of surface rock on Earth} = 2700 \text{ kg m}^{-3}$$

$$\text{gravitational field strength on Earth} = 9.8 \text{ N kg}^{-1}$$

[2]

(ii) Everest is the highest mountain on Earth. It is about 8.8 km high. On the planet Mars the highest point is the volcano Olympus Mons, shown in Fig. 10.2, which is about 22 km high.

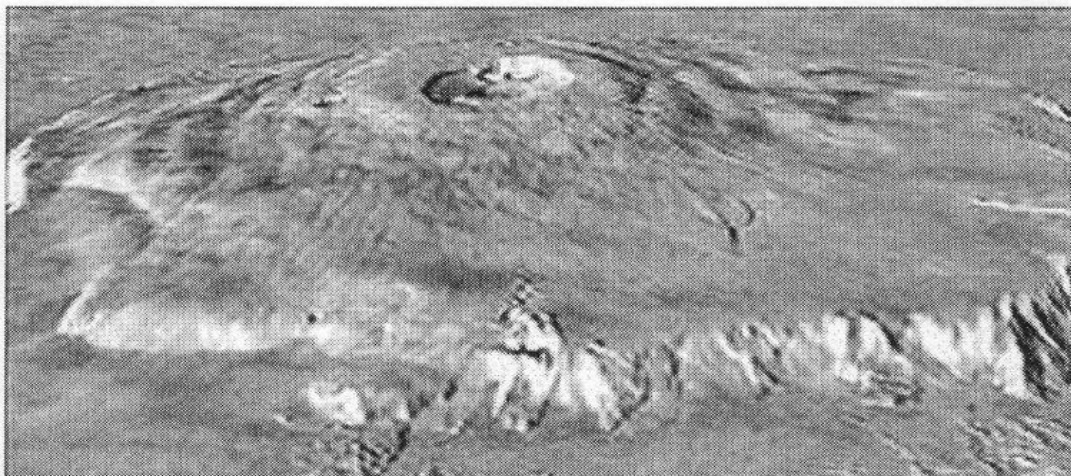


Fig. 10.2

Suggest explanations why no mountain higher than Everest exists on Earth and why Olympus Mons can be so much higher.

[3]

[Total: 10]

9 Fig. 9.1 shows a diagram of part of a suspension bridge.

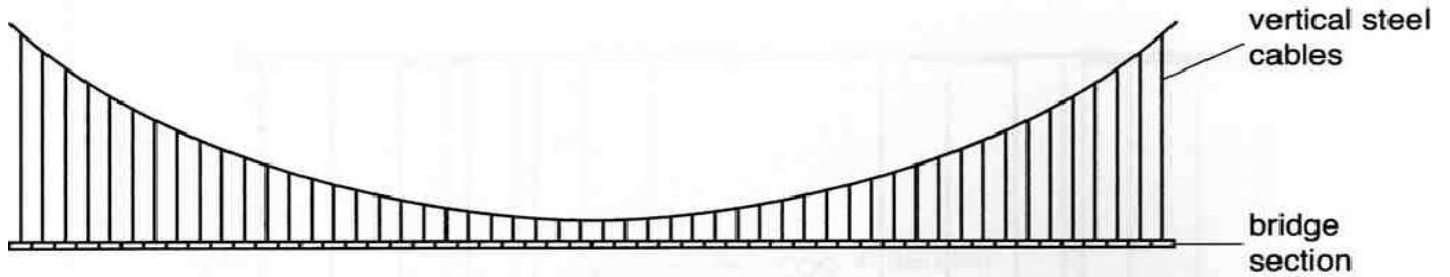


Fig. 9.1

(a) (i) Bridge sections are hung from uniform vertical steel cables.

State **one** mechanical property of steel that makes it a suitable material for these vertical cables.

.....[1]

(ii) Explain why this property is important.

[1]

(b) Two vertical cables support each bridge section as shown in Fig. 9.2.

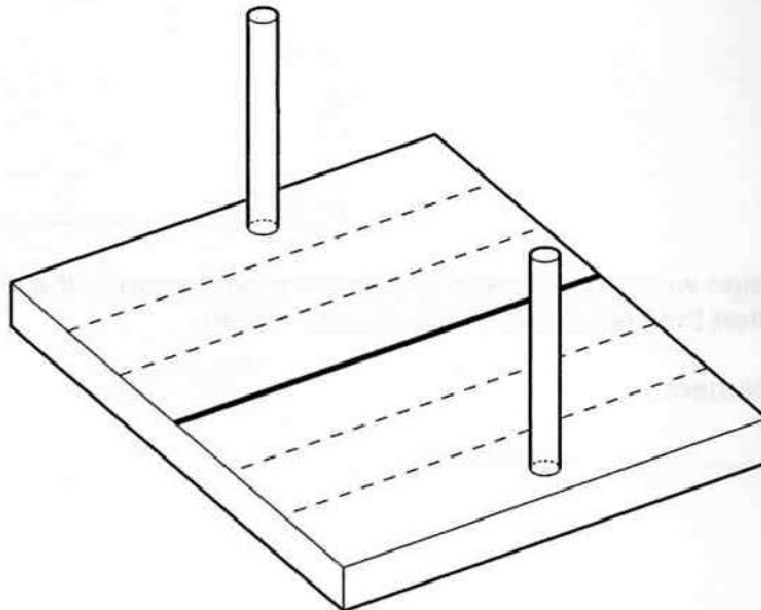


Fig. 9.2

(i) Each bridge section weighs 1.8 MN.  
This weight causes a stress in each cable of  $1.3 \times 10^8$  Pa.

Show that the cross-sectional area of **each** cable is about  $7 \times 10^{-3} \text{m}^2$ .

[3]

(ii) The longest vertical cables of the bridge are 150m in length.

Calculate the extension of these cables when the bridge section is attached.

The Young modulus for steel =  $2.1 \times 10^{11}$  Pa.

extension = ..... m [3]

(i) Fig. 9.3 shows one freely hanging uniform vertical cable **before the bridge section is added**.

Suggest why the stress in the cable at **P** is greater than the stress at **Q**.

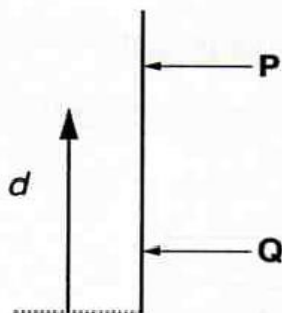
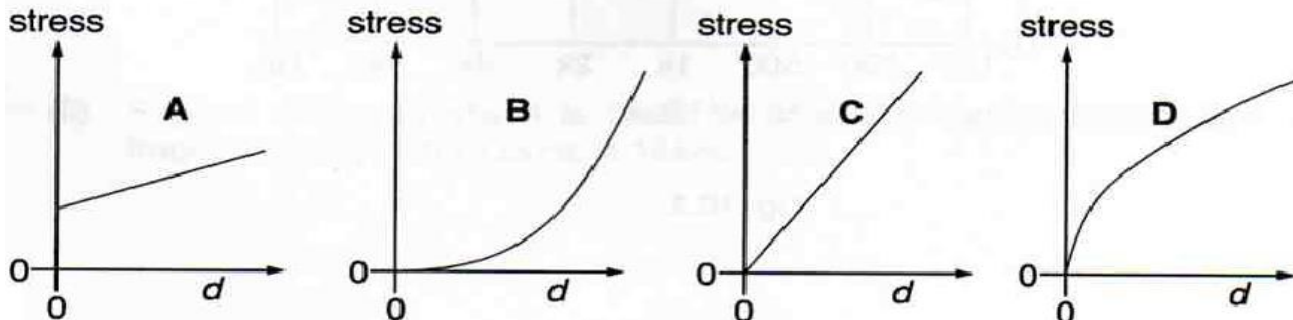


Fig. 9.3

[1]

(ii) Here are four graphs, **A, B, C, D**.

Select the graph which best represents how the stress in the vertical cable (y-axis) varies with distance  $d$  from the **bottom** of the cable (x-axis) **before the bridge section is added**.

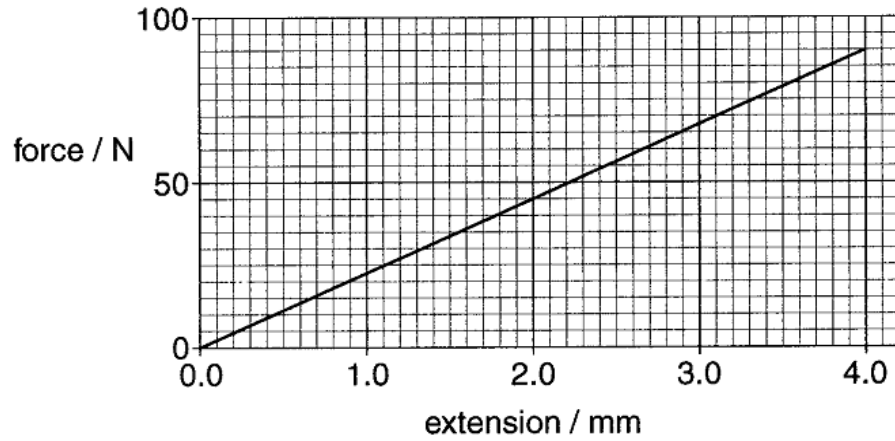


answer ..... [1]

[Total: 10]

This question is about steel wires in tension.

A sample of steel wire is tested in the laboratory. Fig. 8.1 shows the force-extension graph obtained when the wire is stretched elastically.



**Fig. 8.1**

- (a) (i) Describe how the extension varies as the force is increased.

[1]

- (ii) The test is repeated using another sample of the same wire, but of only **half** the original length.

**Draw** on the axes of Fig. 8.1 the force-extension graph for this wire, as the force is increased to 90 N.

[1]

- (iii) Explain why both wires have the **same** value for the Young modulus.

[1]

- (b) (i)** The original steel wire has an unstretched length of 2.0 m and a cross-sectional area of  $2.5 \times 10^{-7} \text{ m}^2$ .

Use these facts and information from the graph to calculate the stress and strain in the wire at a force of 90 N.

stress = ..... Pa [2]

strain = ..... [2]

- (ii)** Calculate the Young modulus of the steel.  
State the unit.

Young modulus = ..... unit ..... [2]

[Total: 9]

