Mechanical Properties of Materials Past Paper Questions

Taken from 2860 apart from final question

Hooke's law	$F = kx$
elastic strain energy	$\frac{1}{2}kx^2$
Young modulus	$E = \frac{\text{stress}}{\text{strain}}$, $\text{stress} = \frac{\text{tension}}{\text{cross-sectional area}}$, $\text{strain} = \frac{\text{extension}}{\text{original length}}$

Jan 2005

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**.

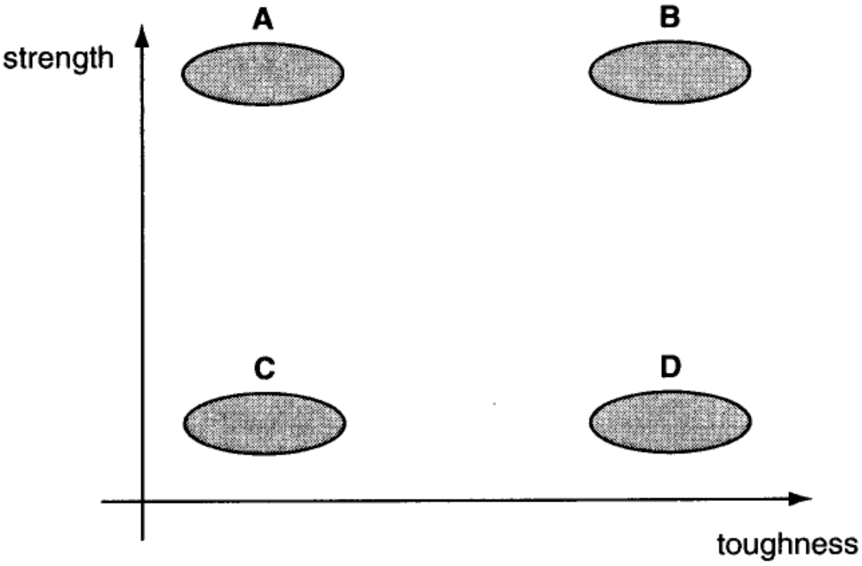


Fig. 1.1

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

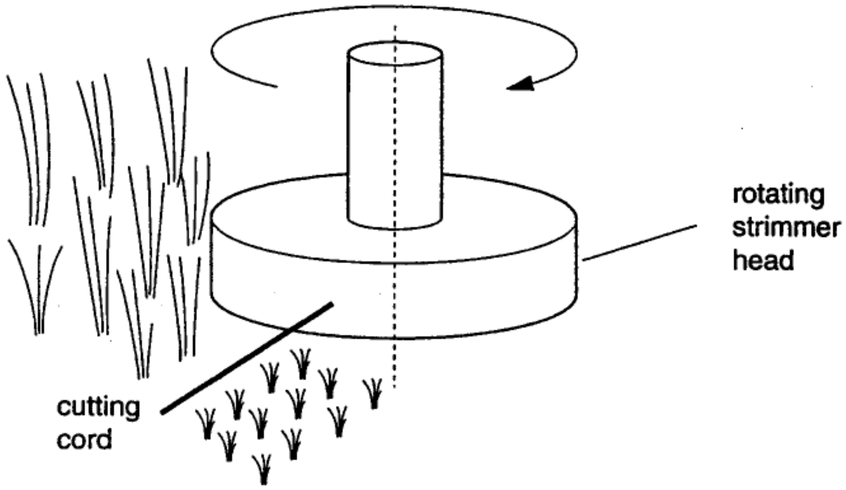
a material suitable for car bodies e.g. steel ....

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

a brittle metal e.g. cast iron under tension .... [3]

Jan 2001

11 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 / kg m^{-3}	Young modulus / GPa	toughness / 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).

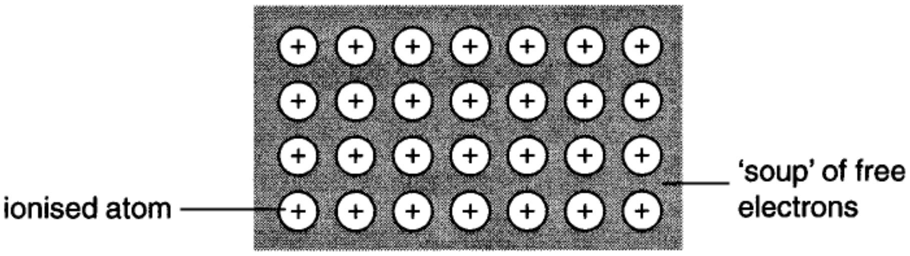
maximum strain =................................ [2]

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

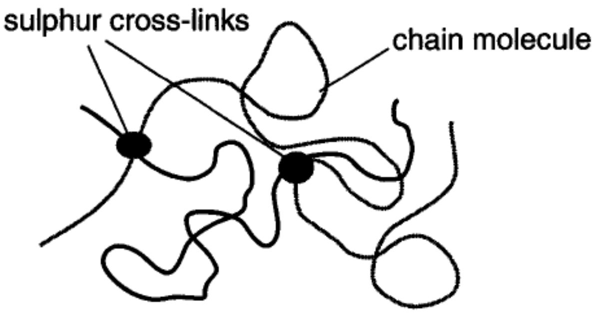
Choose from the list the type of material that best matches each microstructure.

(a)



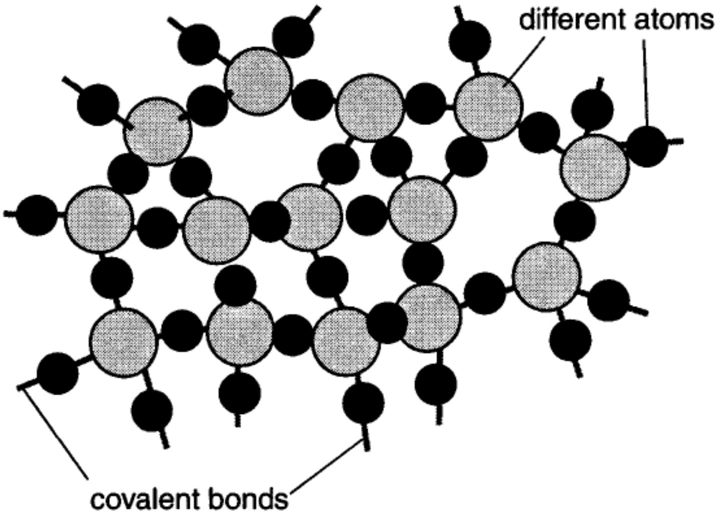
material ....

(b)



material ....

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



material ....

[3]

June 2004

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 μm
Young modulus	5.0×10^9 Pa
breaking stress	3.0×10^8 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 2.5×10^8 Pa.

[1]

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

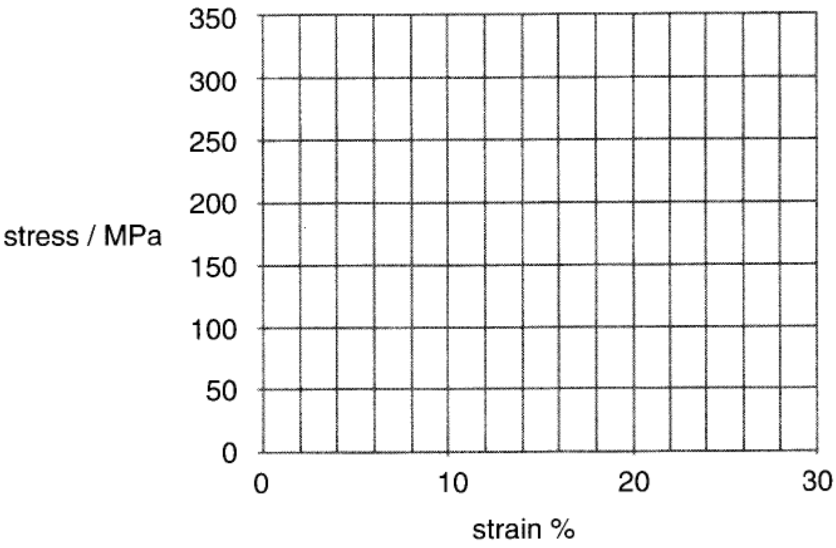


Fig. 11.1 [2]

(c) (i) Show that the cross-sectional area of a typical hair is about 2×10^{-9} 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.

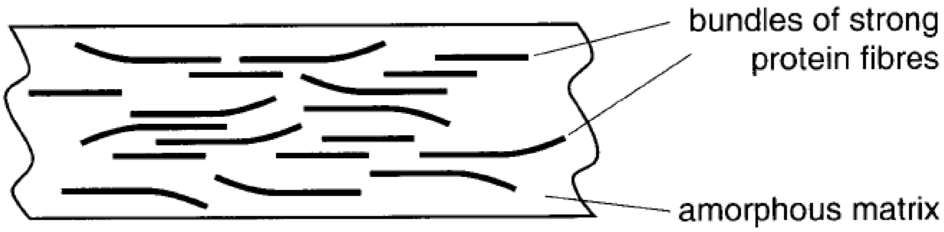


Fig. 11.2

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).

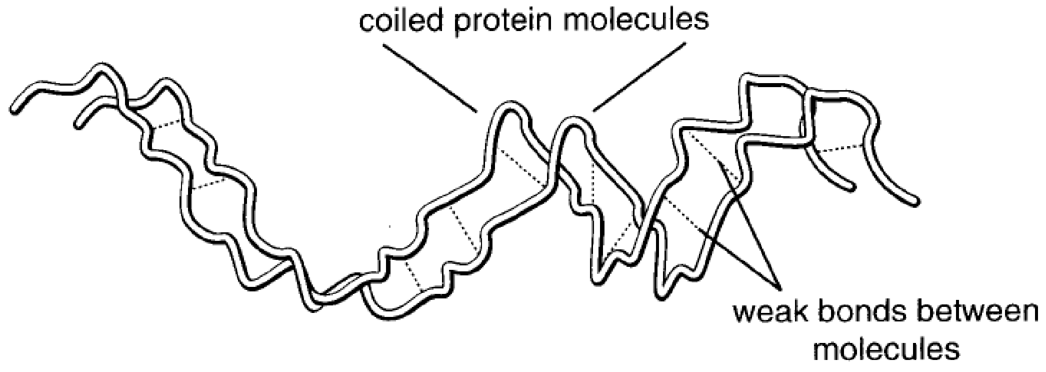


Fig. 11.3

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]

7 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 = ... 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 = ... 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]

June 2005

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.

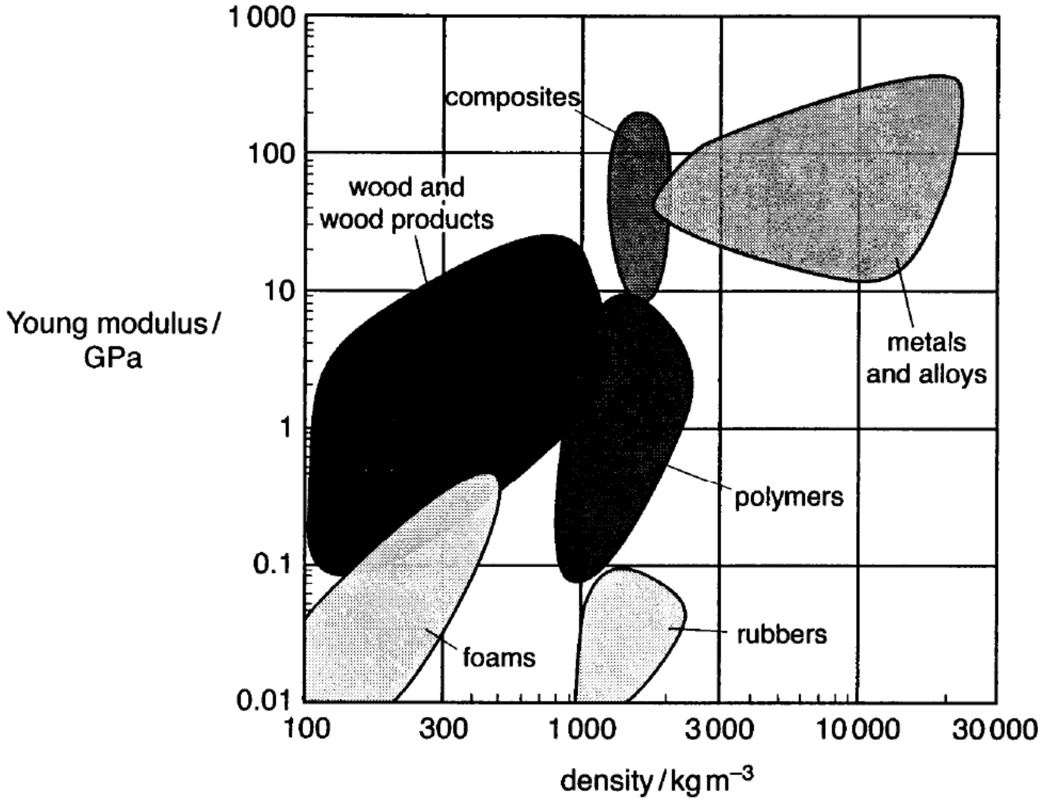


Fig. 3.1

(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]

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

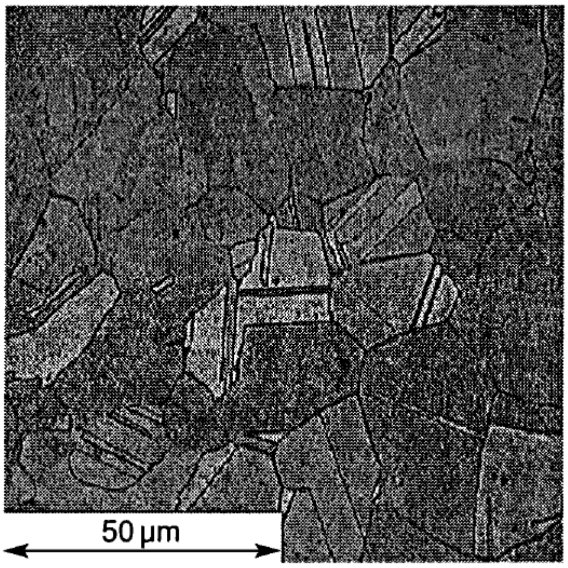


Fig. 6.1

The polycrystalline grain structure of the brass can be seen.

Explain the meaning of the term *polycrystalline*.

[2]

June 2007

1 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]

June 2005

10 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.

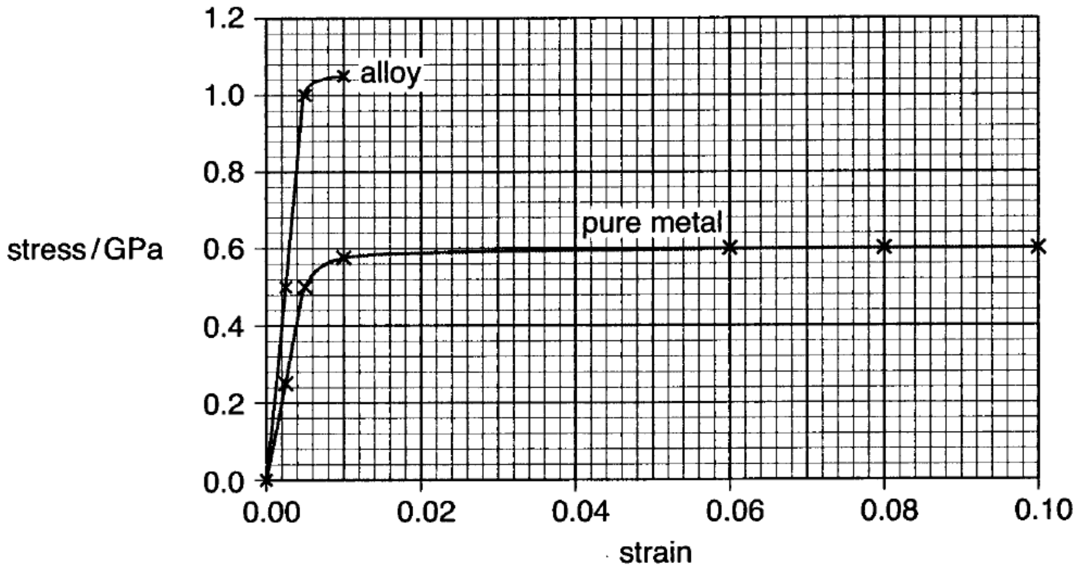


Fig. 10.1

(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

[3]

(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.

pure metal

Fig. 10.2

alloy

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]

June 2006

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

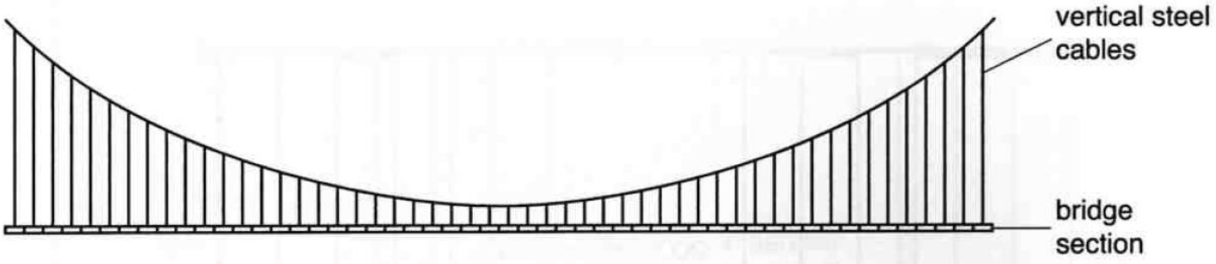


Fig. 9.1

(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.

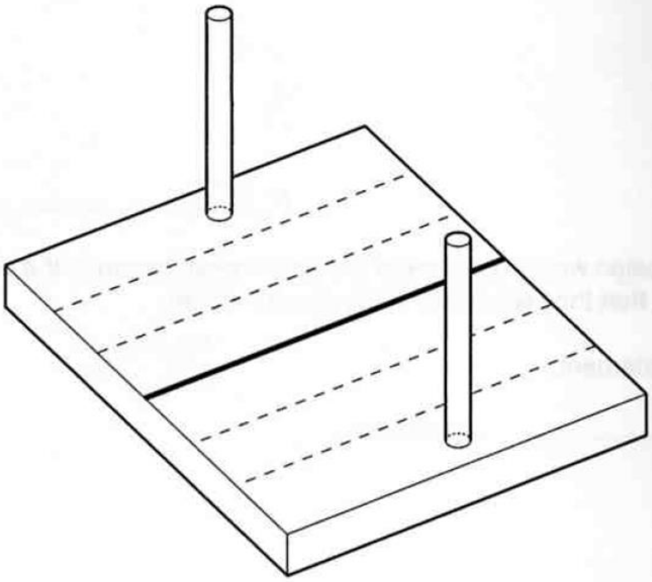


Fig. 9.2

(i) Each bridge section weighs 1.8 MN.
This weight causes a stress in each cable of 1.3×10^8 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 150 m in length.

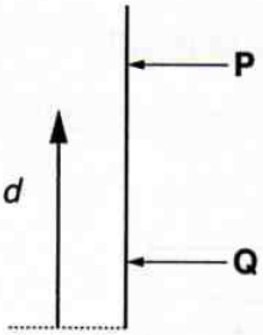
Calculate the extension of these cables when the bridge section is attached.

The Young modulus for steel = 2.1×10^{11} Pa.

extension = ... m [3]

(c) **(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**.

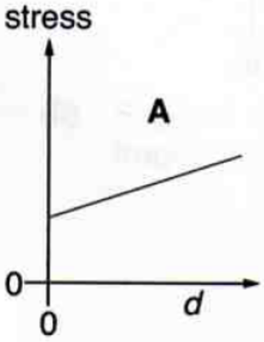


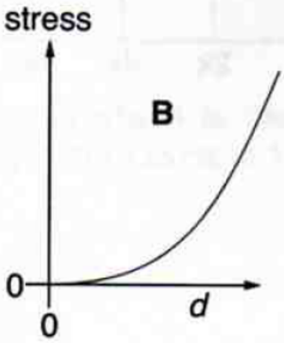
[1]

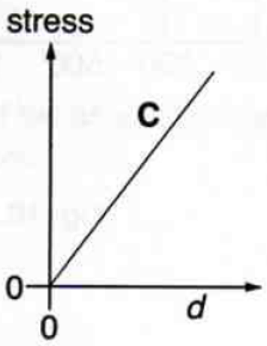
Fig. 9.3

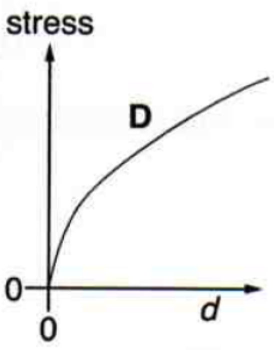
(ii) Here are four graphs, **A, B, C, D.**

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]

Jan 2007

4 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.

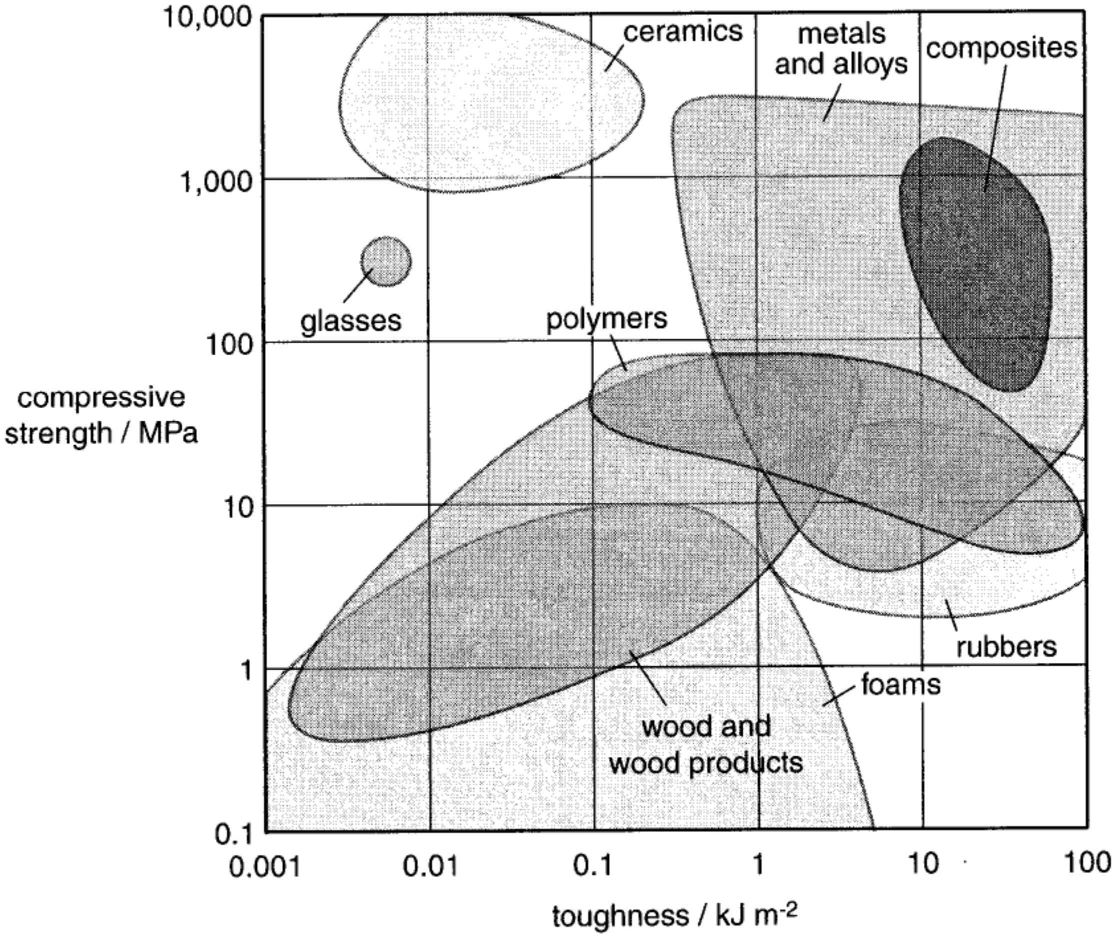


Fig. 4.1

(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]

8 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.

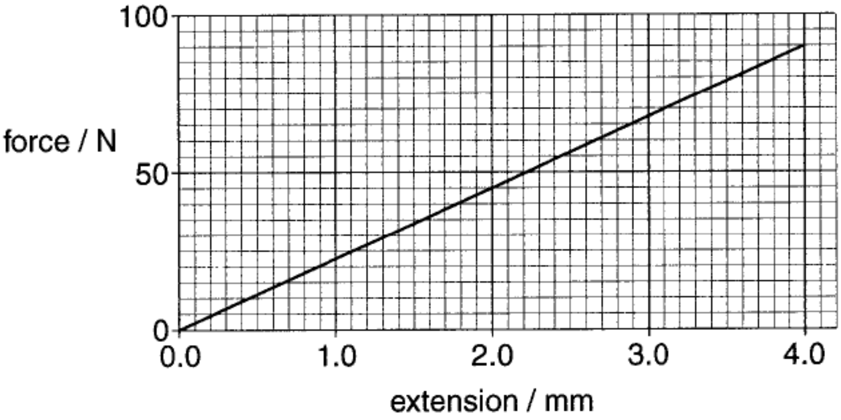


Fig. 8.1

(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 2.5×10^{-7} 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]

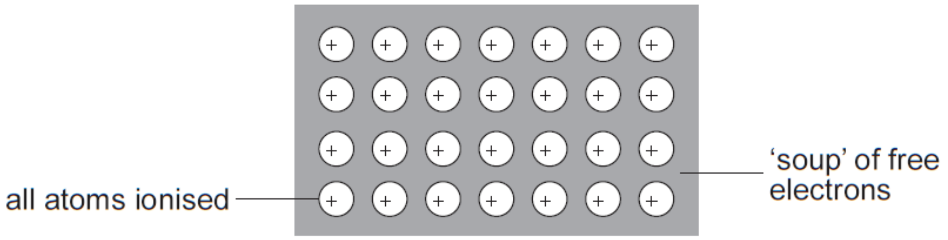
strain = ...[2]

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

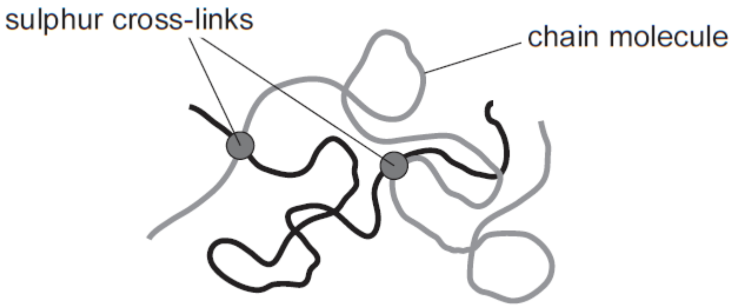
Young modulus = ... unit ....[2]

Jan 2008

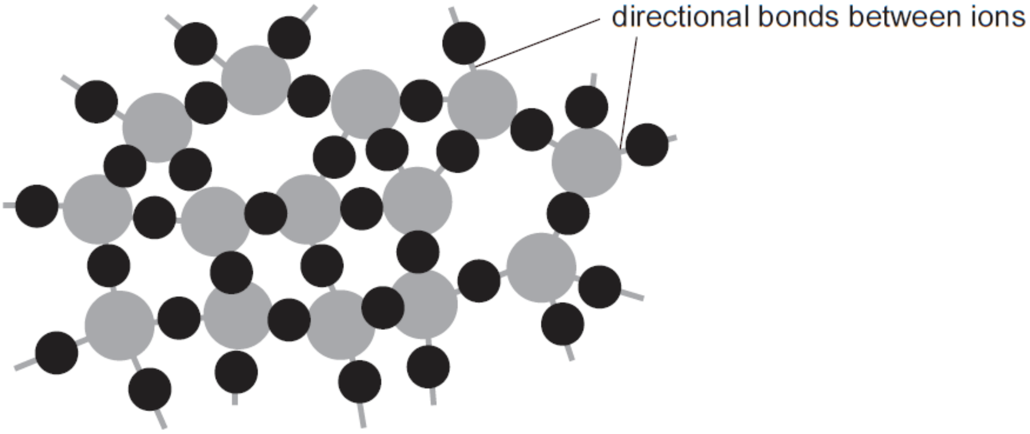
5 Here are four diagrams **A**, **B**, **C**, **D** of the microstructures of different classes of materials.



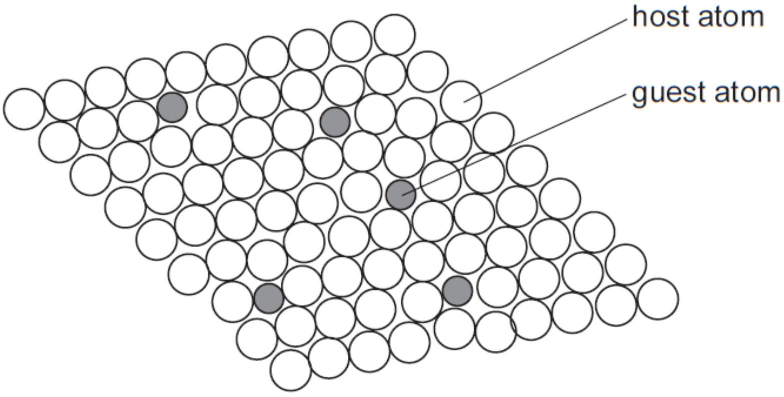
A



B



C



D

State which diagram **A**, **B**, **C** or **D** best represents the internal structure of:

a pure metal .... an alloy................ a glass .... [3]

10 Fig. 10.1 shows a stress-strain graph for a sample of metal which has been loaded and then unloaded.

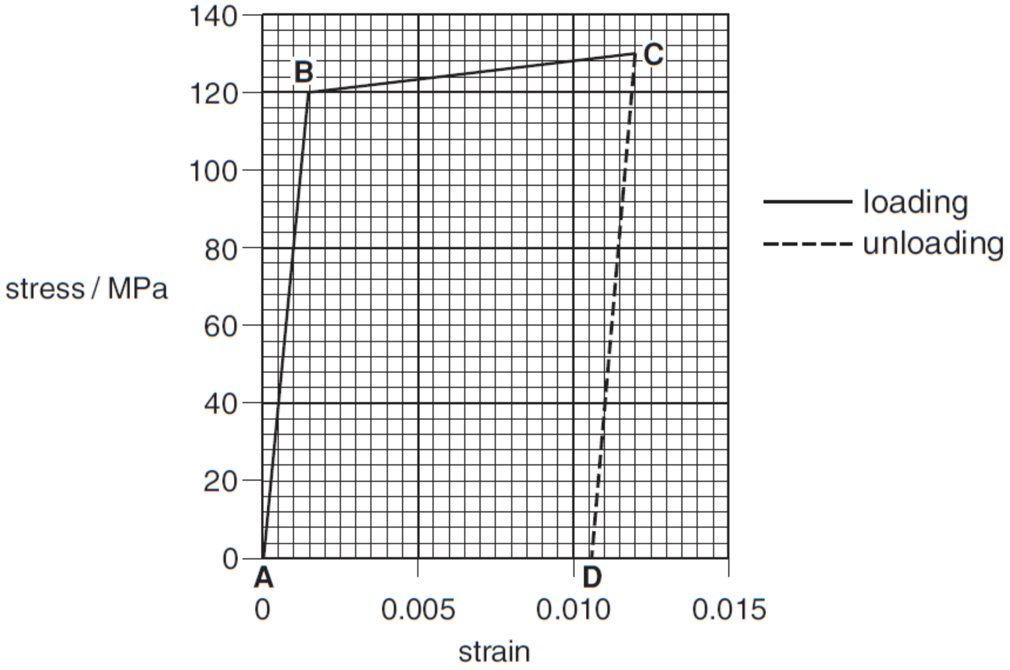


Fig. 10.1

(a) The graph Fig. 10.1 can be divided into three sections **AB**, **BC** and **CD**.

(i) Name the section(s) that show **elastic** behaviour ....

(ii) Name the section(s) that show **plastic** behaviour ....

[3]

(b) State from the graph Fig. 10.1

(i) the yield stress of the metal

yield stress = ... MPa [1]

(ii) the permanent strain of the metal after the load is removed.

strain = ... [1]

(c) Calculate the Young modulus of the metal in MPa using data from Fig. 10.1.

Make your method clear.

Young modulus = ... MPa [3]

(d) Explain the difference between elastic and plastic behaviour in a metal in terms of the arrangement and movement of the atoms in a metal.

Labelled diagrams may help to illustrate your answer.

[3]

7 Two samples of similar size and shape of different polymers are stretched to test their stiffness. Figs. 7.1 and 7.2 show diagrams of their internal structure.

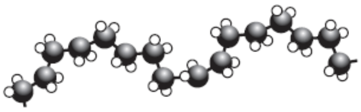


Fig. 7.1 Polythene

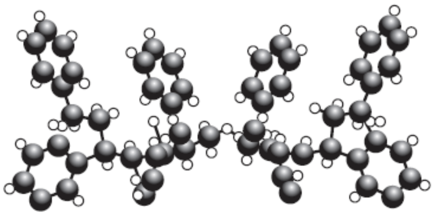


Fig. 7.2 polystyrene

Fig. 7.1 shows Polythene. It has long chain molecules which can be folded up. The bonds in the chain can rotate freely.

Fig. 7.2 shows polystyrene. It has long chain molecules which have bulky side rings. The rings make it difficult for the bonds in the chain to rotate freely.

(a) State **one** difference you would expect to find in the mechanical properties of the samples of the two polymers.

[1]

(b) Suggest a reason for this difference using the information given about the two different polymers.

[1]

8 This question is about the properties of mild steel bars.

A sample of mild steel is tested in the laboratory. Fig. 8.1 shows the stress versus strain graph obtained when a bar is stretched in a tensile testing machine.

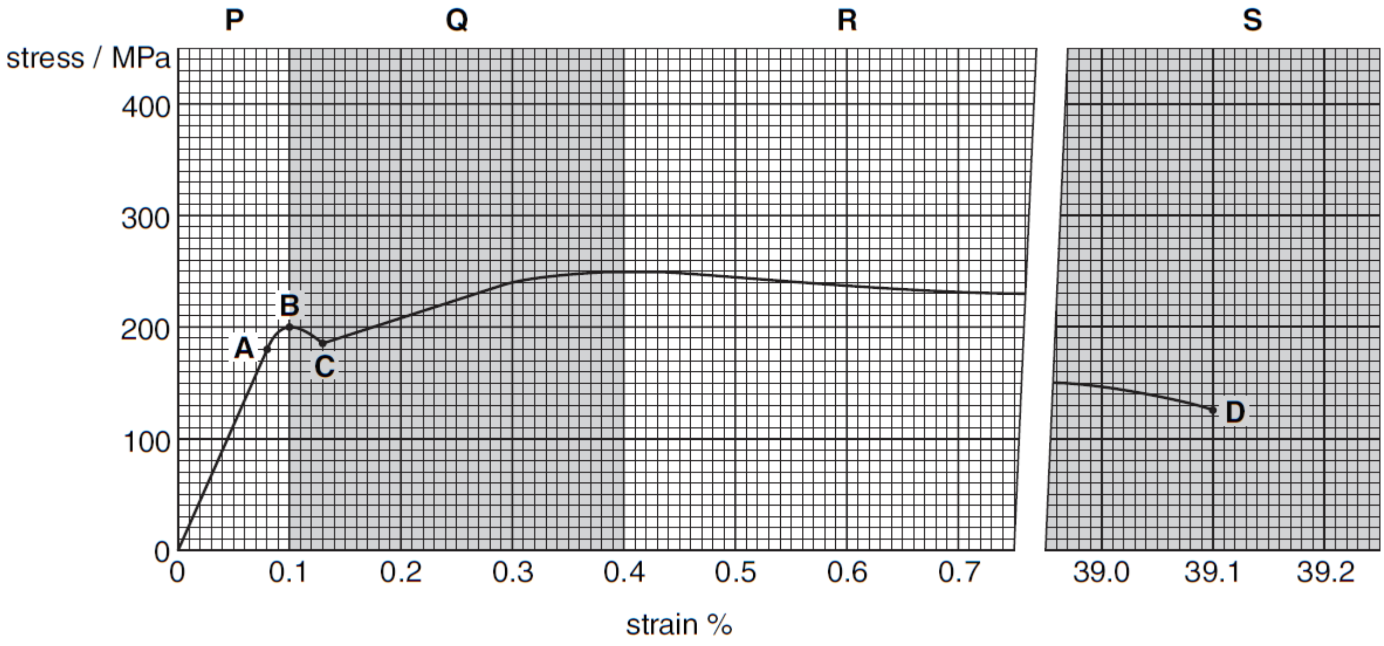


Fig. 8.1

(a) State which of the points on the graph **A**, **B**, **C** or **D** correspond to

(i) the breaking point ....

(ii) the limit of proportionality ....

and which of the shaded regions **P**, **Q**, **R** or **S** corresponds to

(iii) the region where the Young modulus can be defined. .... **[3]**

(b) Use the graph to obtain an estimate for the Young modulus of mild steel.
Make your method clear.

Young modulus = ... Pa **[2]**

(c) The test is repeated using another bar of the **same material** but the tensile test is stopped when the bar reaches point **C** on the graph, and the tensile force is removed.

(i) Draw on the axes of Fig. 8.1 a line that helps you to estimate the permanent strain of the mild steel bar after the stress is removed.

[1]

(ii) State your estimate for the permanent strain.

permanent strain = ... **[1]**

(d) Alloys are often made from a pure metal with a small fraction of impurity atoms of a different size added to them.

Suggest and explain **one** improvement in mechanical properties that an alloy can have compared to the pure metal from which it is made.

[2]

June 2009

1 Here is a list of units for mechanical quantities.

N **$\mathrm{N\,m^{-2}}$** **$\mathrm{kg\,m^{-3}}$** **$\mathrm{J\,m^{-2}}$**

Select the correct unit for:

density ....

stress ....

Young modulus .... **[3]**

3 Fig. 3.1 shows a plot of fracture stress against Young modulus for different materials. Four areas have been shaded and labelled **A**, **B**, **C** and **D**.

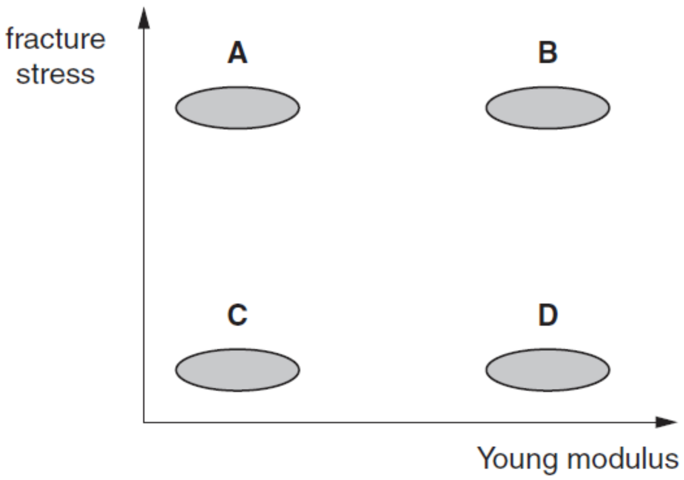


Fig. 3.1

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

a material suitable for a girder in a building e.g. steel ....

a weak material that is hard to bend e.g. cracker biscuit ....

a material that is **not** stiff and breaks at low stress e.g. putty ....

[3]

9 In an experiment a series of weights are suspended from a rubber band and then removed again one by one. Fig. 9.1 shows the stress against strain relationship for the rubber as it is loaded and then unloaded.

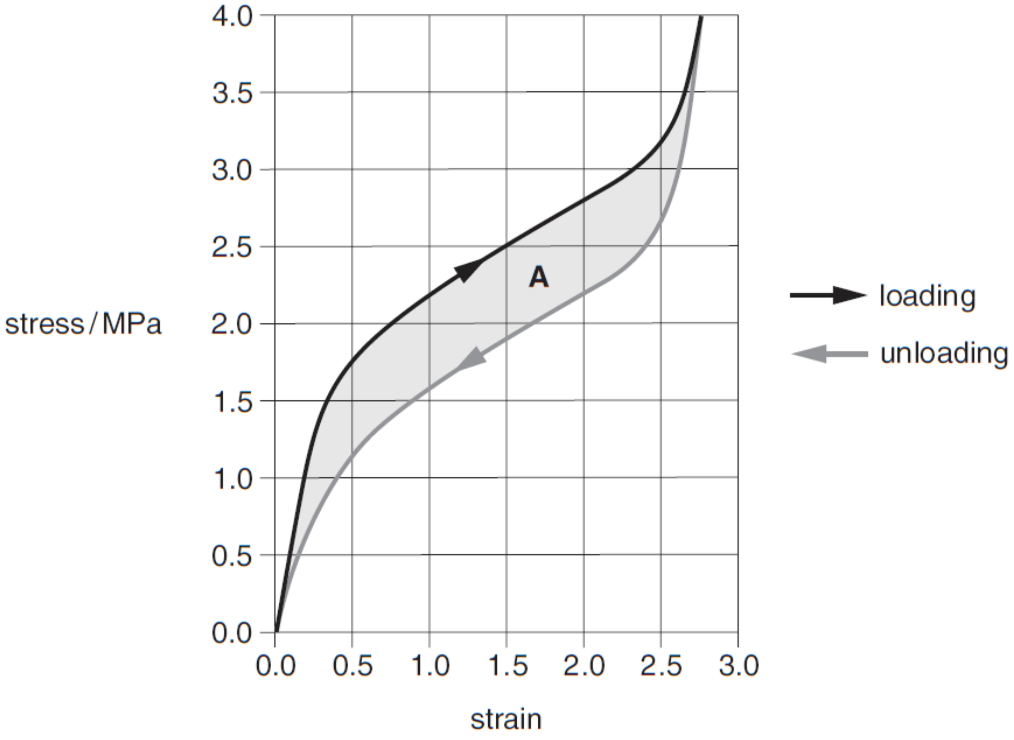


Fig. 9.1

(a) **(i)** State the feature of the stress against strain graph that shows that the Young modulus of rubber is not constant.

[1]

(ii) Use the graph to show that, for a small strain, the Young modulus of rubber is between 10^6 Pa and 10^7 Pa. Make your method clear.

[2]

(b) Use Fig. 9.1 to describe how the stiffness of rubber changes during loading and unloading.

[2]

(c) The area under a stress against strain graph represents the energy per unit volume.

(i) Use the defining equations for stress and strain to show that the quantity (stress × strain) is equivalent to energy per unit volume.

stress =

strain =

(stress × strain) =

[2]

(ii) Suggest the physical quantity that the shaded area **A** inside the loading-unloading loop in Fig. 9.1 represents.

[1]

(iii) Estimate the value of this quantity for the rubber, making your method clear.

energy / volume = ... J m^{-3} **[2]**

8 This question is about elastomers, polymers which can extend a great amount under stress and return to their original size.

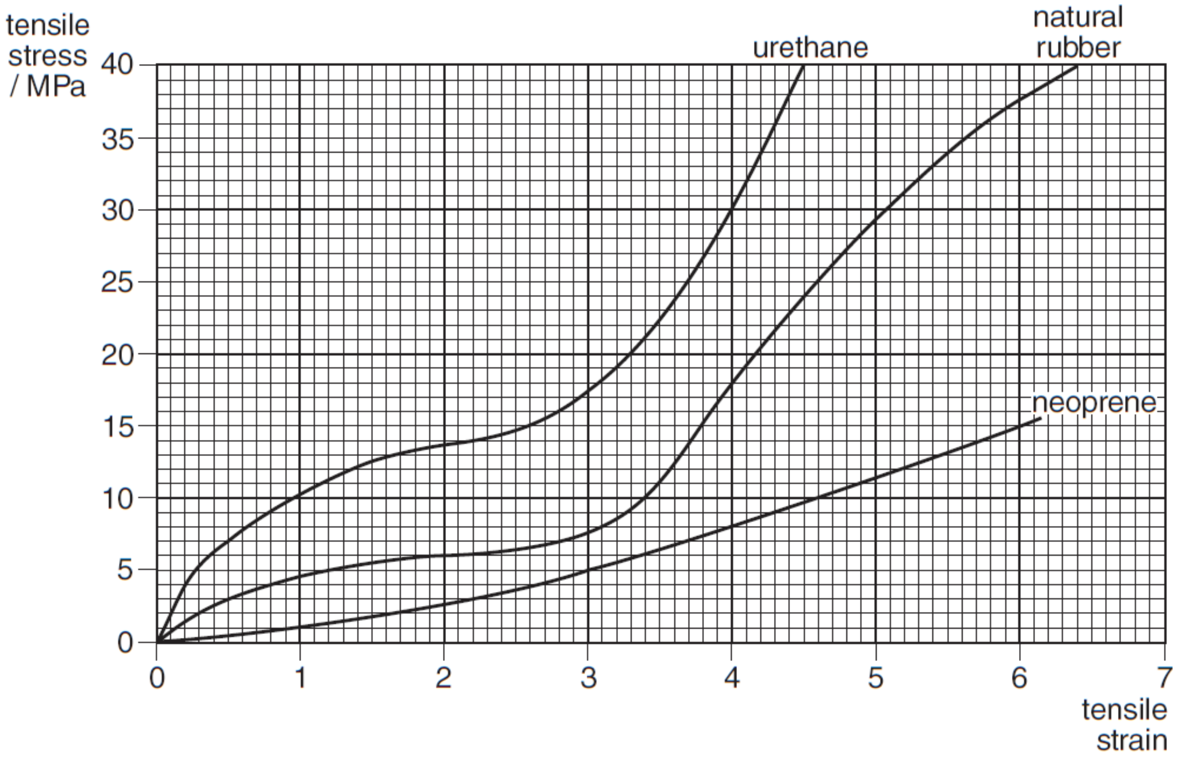


Fig. 8.1

(a) Fig. 8.1 shows the stress-strain curves for three elastomers: urethane, natural rubber and neoprene.

Imagine you were to pull a strip of **natural rubber** until it was six times its original length, and then repeat this with a similar strip of **neoprene**. Use the graph to describe what you would feel when you stretched the natural rubber and neoprene.

[3]

(b) (i) Use data from the graph to find a value of the Young modulus for **urethane** at a tensile strain of 4.0. Give your answer to an appropriate number of significant figures.

Young modulus E = ... Pa **[3]**

(ii) Consider the Young modulus of **urethane** at a strain of 3.0. Explain whether it is larger or smaller than the value calculated in **(b)(i)**.

[1]

(c) A natural rubber cord, initially 20 cm long, has a 30 N load attached to it, and it stretches to a length of 1.0 m.

(i) Calculate the strain in the rubber cord.

strain = ... **[1]**

(ii) Use the graph of Fig. 8.1 to find the area of cross-section of this **natural rubber** cord while it is stretched by the 30 N load.

area of cross-section = ... m^2 **[3]**