Deformation of Solids

Questions compiled by Leong Yee Pak

10.1 Stress, strain
10.2 Elastic and plastic behaviour

Stress, strain
Section A

*1 June 02 P1 Q22

22 Which of the following correctly defines the terms *stress*, *strain* and *Young modulus*?

	stress	strain	Young modulus
A	(force) x (area)	(extension) x (original length)	(stress) / (strain)
B	(force) x (area)	(extension) / (original length)	(stress) x (strain)
C	(force) / (area)	(extension) / (original length)	(stress) / (strain)
D	(force) / (area)	(extension) x (original length)	(stress) x (strain)

**2 June 02 P1 Q23

23 A wire is stretched by 8 mm when a load of 60 N is applied.

What will be the extension of a wire of the same material having four times the cross-sectional area and twice the original length, when the same load is applied?

A 2 mm B 4 mm C 8 mm D 16 mm

*3 June 03 P1 Q21

21 What is the ultimate tensile stress of a material?

A the stress at which the material becomes ductile

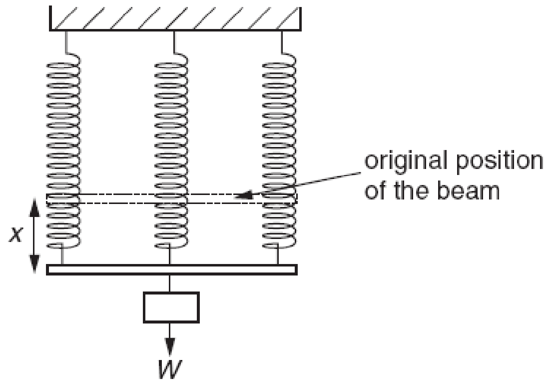
B the stress at which the material breaks

C the stress at which the material deforms plastically

D the stress at which the material reaches its elastic limit

**4 June 03 P1 Q22

22 A beam, the weight of which may be neglected, is supported by three identical springs. When a weight W is hung from the middle of the beam, the extension of each spring is x.



The middle spring and the weight are removed.

What is the extension when a weight of $2W$ is hung from the middle of the beam?

A $\frac{3x}{2}$ **B** $\frac{4x}{3}$ **C** $2x$ **D** $3x$

***5 Nov 03 P1 Q21**

21 What is the Young modulus of a metal?

A extension / force

B force / extension

C strain / stress

D stress / strain

****6 June 04 P1 Q23**

23 Nylon breaks when the stress within it reaches 1×10^9 Pa.

Which range includes the heaviest load that could be lifted by a nylon thread of diameter 1 mm?

A 2 N to 20 N

B 20 N to 200 N

C 200 N to 2000 N

D 2000 N to 20 000 N

***7 Nov 04 P1 Q21**

21 Which two substances are normally both crystalline?

A copper and diamond

B copper and glass

C diamond and glass

D diamond and rubber

****8 Nov 04 P1 Q22**

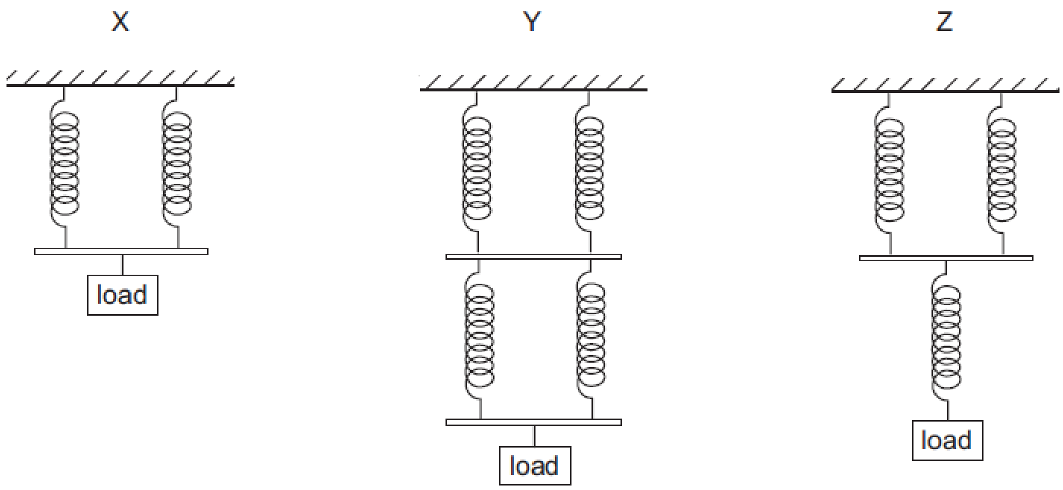
22 The table shows a load applied to four wires and the cross-sectional area of each.

Which of the wires is subjected to the greatest stress?

	load / N	cross-sectional area / mm^2
A	1500	0.25
B	2000	1.0
C	3000	0.56
D	5000	2.3

***9 June 05 P1 Q20**

20 A number of similar springs, each having the same spring constant, are joined in three arrangements X, Y and Z. The same load is applied to each.



What is the order of increasing extension for these arrangements?

	smallest	→	largest
A	X	Y	Z
B	Z	X	Y
C	Z	Y	X
D	Y	X	Z

10 June 05 P1 Q22

22 Two steel wires P and Q have lengths l and $2l$ respectively, and cross-sectional areas A and $\frac{A}{2}$ respectively. Both wires obey Hooke's law.

What is the ratio $\frac{\text{tension in P}}{\text{tension in Q}}$ when both wires are stretched to the same extension?

A $\frac{1}{4}$ B $\frac{1}{2}$ C $\frac{2}{1}$ D $\frac{4}{1}$

****11 Nov 05 P1 Q21**

21 A wire stretches 8 mm under a load of 60 N.

A second wire of the same material, with half the diameter and a quarter of the original length of the first wire, is stretched by the same load.

Assuming that Hooke's law is obeyed, what is the extension of this wire?

A 1 mm **B** 4 mm **C** 8 mm **D** 16 mm

***12 June 06 P1 Q21**

21 In describing the behaviour of a spring, the spring constant is used.

Different loads are used to extend the spring by different amounts.

To find the spring constant, which quantities are required?

A the elastic limit and the loads

B the elastic limit, extensions and the length of the spring

C the loads and the extensions of the spring

D the loads and the length of the spring

***13 Nov 06 P1 Q22**

22 What is represented by the gradient of a graph of force (vertical axis) against extension (horizontal axis)?

A elastic limit

B spring constant

C stress

D the Young modulus

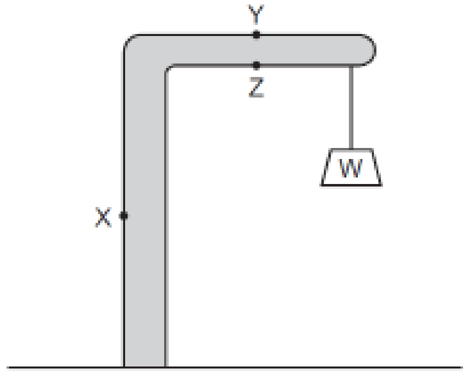
***14 Nov 06 Q23**

23 What is the unit of the Young modulus?

A N m^{-1} **B** N m **C** N m^{-2} **D** N m^{2}

****15 June 07 P1 Q20**

20 A simple crane consists of a rigid vertical pillar supporting a horizontal beam.



A weight W is lifted by a rope at the end of the beam.

What are the forces at points X, Y and Z due to the weight W?

	force at X	force at Y	force at Z
A	tension	compression	tension
B	tension	tension	compression
C	compression	tension	compression
D	compression	compression	compression

**16 June 08 P1 Q24

24 The Young modulus of steel is determined using a length of steel wire and is found to have the value E.

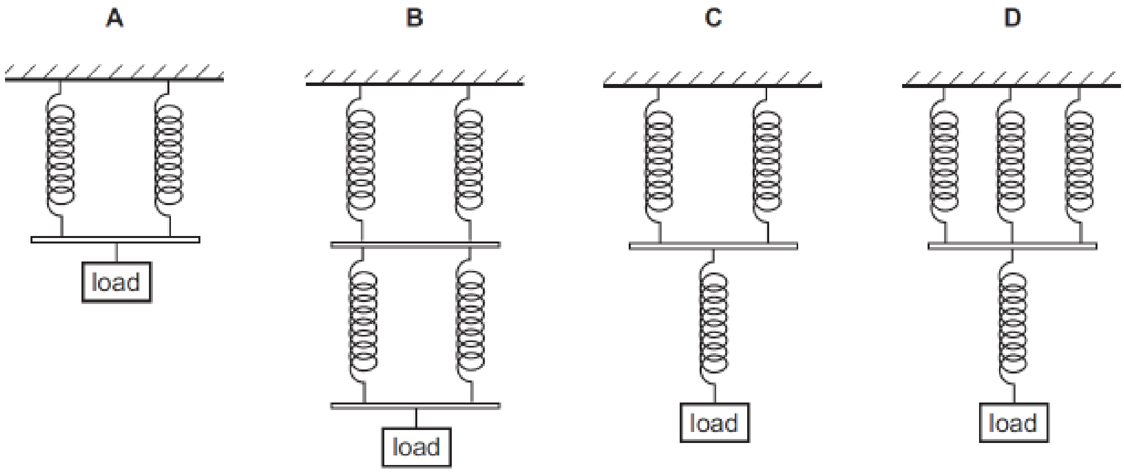
Another experiment is carried out using a wire of the same steel, but of twice the length and half the diameter.
What value is obtained for the Young modulus in the second experiment?

A $\frac{1}{4}E$ **B** $\frac{1}{2}E$ **C** E **D** $2E$

**17 Nov 08 P1 Q20

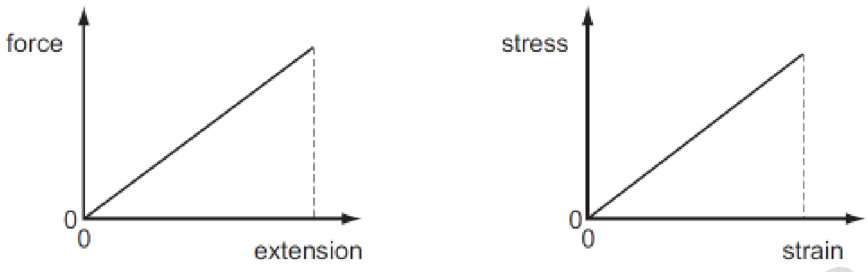
21 A number of similar springs, each having the same spring constant, are joined in four arrangements. The same load is applied to each.

Which arrangement gives the greatest extension?



***18 Nov 08 P1 Q22**

22 The graphs show how force varies with extension and stress varies with strain for the loading of a metal wire.



The Young modulus for this wire is equal to

A the gradient of the force-extension graph.

B the area between the force-extension graph and the extension axis.

C the gradient of the stress-strain graph.

D the area between the stress-strain graph and the strain axis.

****19 June 09 P1 Q20**

20 Two steel wires P and Q have lengths l and $2l$ respectively, and cross-sectional areas A and $\frac{A}{2}$ respectively. Both wires obey Hooke's law.

What is the ratio $\frac{\text{tension in P}}{\text{tension in Q}}$ when both wires are stretched to the same extension?

A $\frac{1}{4}$ **B** $\frac{1}{2}$ **C** $\frac{2}{1}$ **D** $\frac{4}{1}$

Stress and Strain
Section B

1 June 03 P2 Q3

3 **(a)** Fig. 3.1 shows the variation with tensile force of the extension of a copper wire.

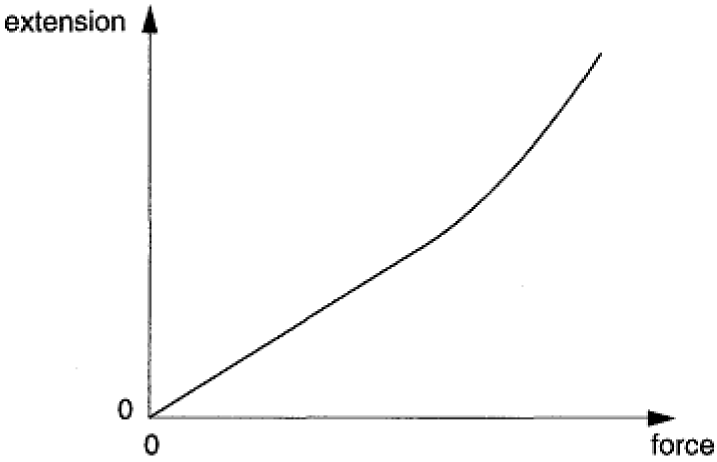


Fig. 3.1

(i) State whether copper is a ductile, brittle or polymeric material.

....

(ii) **1.** On Fig. 3.1, mark with the letter L the point on the line beyond which Hooke's law does not apply.

2. State how the spring constant for the wire may be obtained from Fig. 3.1.

....

....

[3]

(b) A copper wire is fixed at one end and passes over a pulley. A mass hangs from the free end of the wire, as shown in Fig. 3.2.

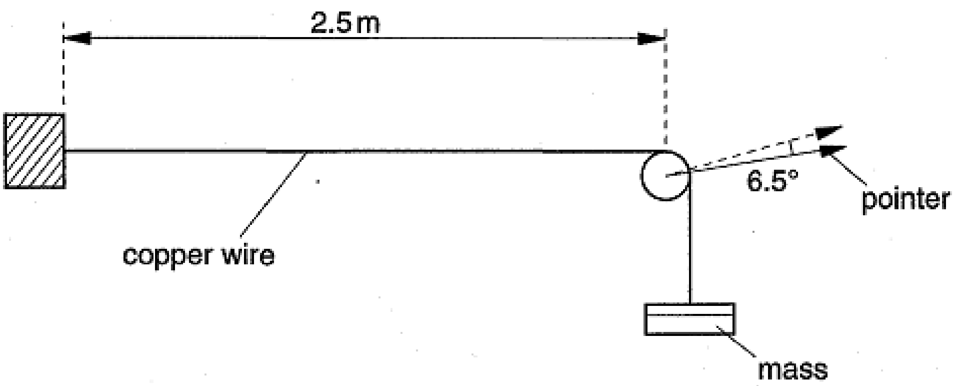


Fig. 3.2

The length of wire between the fixed end and the pulley is 2.5 m. When the mass on the wire is increased by 6.0 kg, a pointer attached to the pulley rotates through an angle of 6.5°. The pulley, of diameter 3.0 cm, is rough so that the wire does not slide over it.

(i) For this increase in mass,

1. show that the wire extends by 0.17 cm,

2. calculate the increase in strain of the wire.

increase in strain = ...

(ii) The area of cross-section of the wire is $7.9 \times 10^{-7}\,m^2$. Calculate the increase in stress produced by the increase in load.

increase in stress = ... Pa [3]

(iii) Use your answers to **(i) 2** and **(ii)** to determine the Young modulus of copper.

Young modulus = ... Pa [2]

(iv) Suggest how you could check that the elastic limit of the wire is not exceeded when the extra load is added.

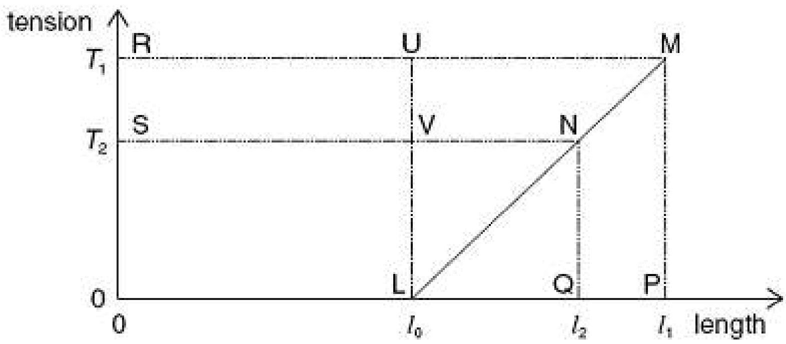
....

.... [1]

Elastic and plastic behaviour

****1 June 02 P1 Q24**

24 The tension in a spring of natural length l_0 is first increased from zero to T_1, causing the length to increase to l_1. The tension is then reduced to T_2, causing the length to decrease to l_2 (as shown).

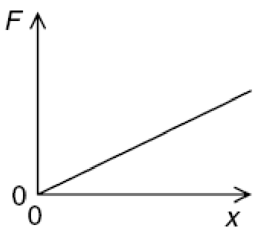


Which area of the graph represents the work done by the spring during this reduction in length?

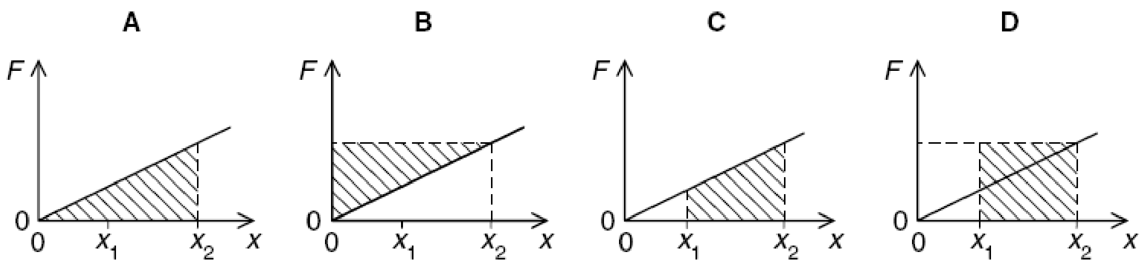
A MLP **B** MNQP **C** MNSR **D** MPLU

***2 Nov 02 P1 Q23**

23 The variation of the extension x of a spring with applied force F is shown.



Which shaded area represents the work done when the extension is increased from x_1 to x_2?



****3 Nov 02 P1 Q24**

24 Two springs P and Q both obey Hooke's law. They have spring constants $2k$ and k respectively.

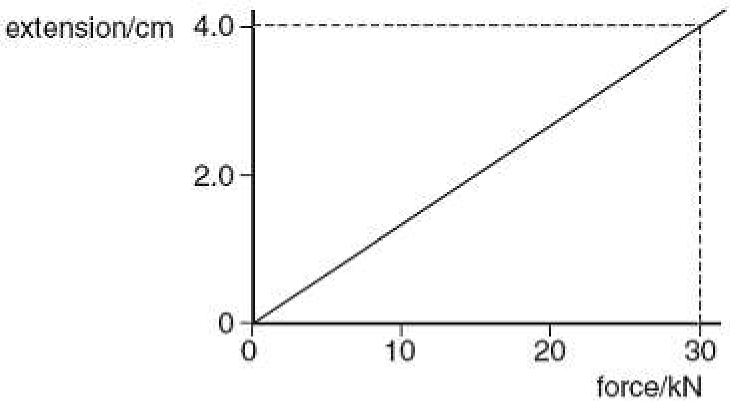
The springs are stretched, separately, by a force that is gradually increased from zero up to a certain maximum value, the same for each spring. The work done in stretching spring P is W_P, and the work done in stretching spring Q is W_Q.

How is W_P related to W_Q?

A $W_P = \frac{1}{4}W_Q$ **B** $W_P = \frac{1}{2}W_Q$ **C** $W_P = 2W_Q$ **D** $W_P = 4W_Q$

****4 Nov 03 P1 Q22**

22 The graph shows how the extension of a spring varies with the force used to stretch i

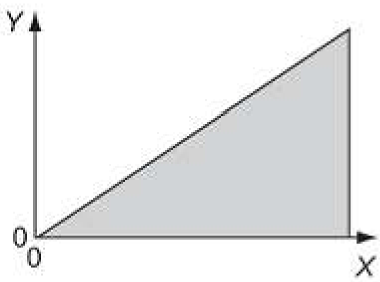


What is the strain energy stored in the spring when the extension is 4.0 cm?

A 60 J **B** 120 J **C** 600 J **D** 1200 J

****5 June 04 P1 Q22**

22 The graph shown was plotted in an experiment on a metal wire.



The shaded area represents the total strain energy stored in stretching the wire.

How should the axes be labelled?

	Y	*X*
A	force	extension
B	mass	extension
C	strain	energy
D	stress	strain

****6 Nov 04 P1 Q22**

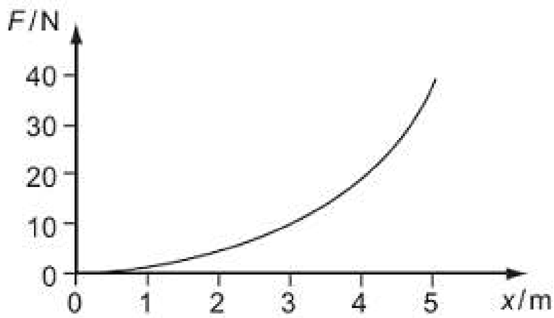
22 The table shows a load applied to four wires and the cross-sectional area of each.

Which of the wires is subjected to the greatest stress?

	load / N	cross-sectional area / mm^2
A	1500	0.25
B	2000	1.0
C	3000	0.56
D	5000	2.3

****7 Nov 04 P1 Q23**

23 The force *F* required to extend a sample of rubber by a distance *x* is found to vary as shown.



The energy stored in the rubber for an extension of 5 m is

A less than 100 J.

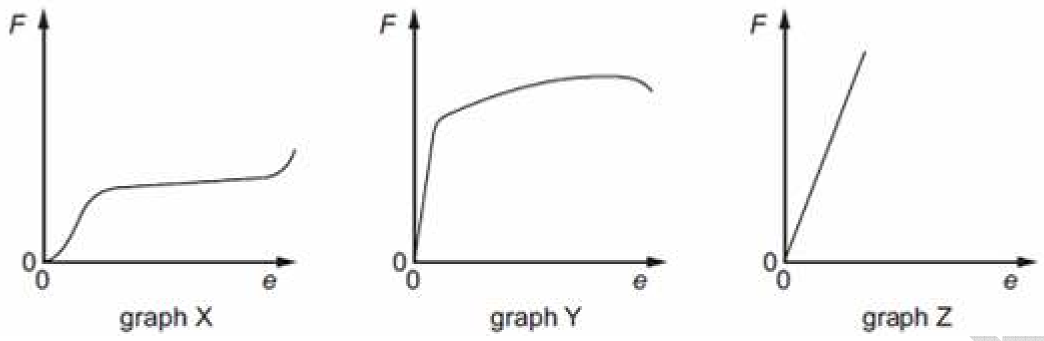
B 100 J.

C between 100 J and 200 J.

D more than 200 J.

****8 June 05 P1 Q21**

21 Cylindrical samples of steel, glass and rubber are each subjected to a gradually increasing tensile force F. The extensions e are measured and graphs are plotted as shown below.



Which row correctly relates the graphs to the materials?

	steel	glass	rubber
A	X	Y	Z
B	X	Z	Y
C	Y	X	Z
D	Y	Z	X

***9 Nov 05 P1 Q19**

19 When white sugar granules are heated, they melt. When the melt is cooled quickly, a brittle solid form of toffee is produced.

How does the structure of the sugar change?

A amorphous to polymeric

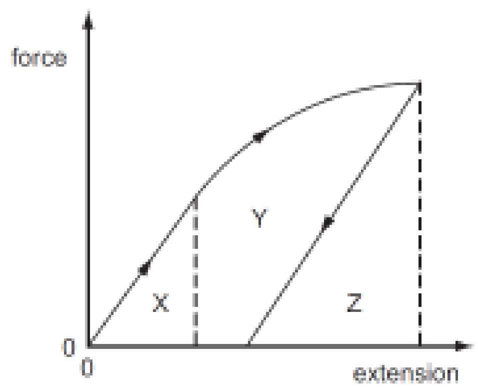
B crystalline to amorphous

C crystalline to polymeric

D polymeric to amorphous

****10 Nov 05 P1 Q20**

20 A ductile material is stretched by a tensile force to a point beyond its elastic limit. The tensile force is then reduced to zero. The graph of force against extension is shown below.

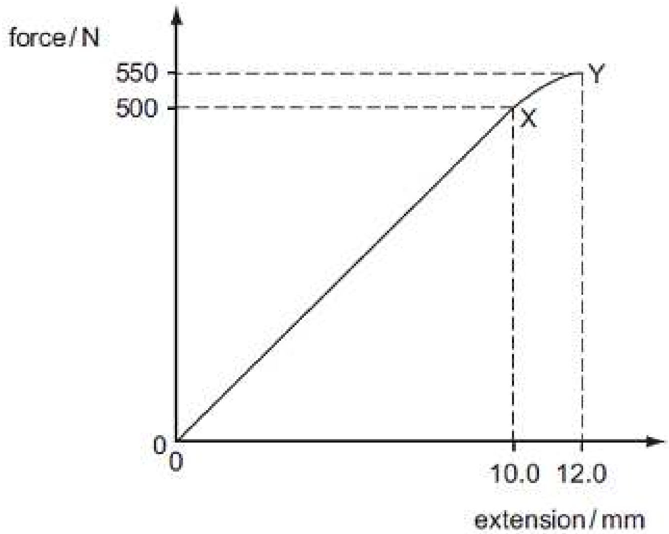


Which area represents the net work done on the sample?

A X **B** X + Y **C** Y + Z **D** Z

**** 11 June 06 P1 Q22**

22 The graph shows the behaviour of a sample of a metal when it is stretched until it starts to undergo plastic deformation.



What is the total work done in stretching the sample from zero extension to 12.0 mm?
Simplify the calculation by treating the region XY as a straight line.

A 3.30 J **B** 3.55 J **C** 3.60 J **D** 6.60 J

***12 June 07 P1 Q17**

17 A piece of copper is drawn into a continuous wire.
What behaviour is the copper exhibiting?

A brittle only

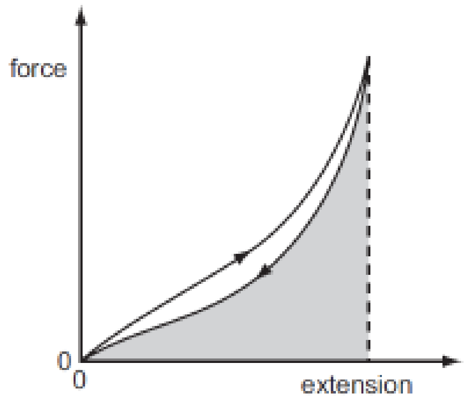
B elastic only

C plastic only

D both brittle and elastic

***13 June 07 P1 Q18**

18 The force-extension graph of a particular sample of rubber as a load is applied and then removed is shown.



What does the shaded area represent?

A the energy transformed into heat during the complete cycle

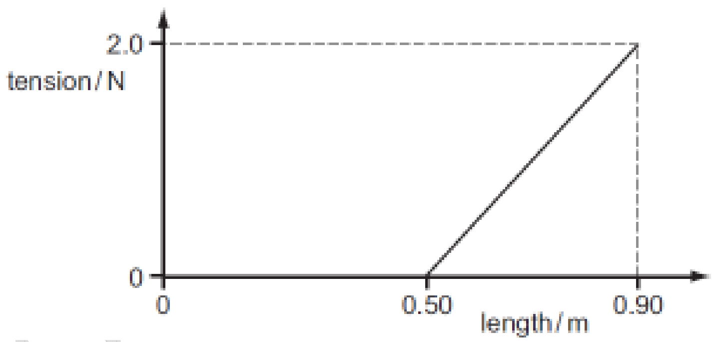
B the recoverable elastic potential energy stored at maximum extension

C the work done on the sample while loading

D the work done on the sample while unloading

****14 June 07 P1 Q19**

19 A spring of unextended length 0.50 m is stretched by a force of 2.0 N to a new length of 0.90 m. The variation of its length with tension is as shown.



How much strain energy is stored in the spring?

A 0.40 J **B** 0.80 J **C** 0.90 J **D** 1.8 J

***15 Nov 07 P1 Q19**

19 What is plastic deformation?

A Plastic deformation occurs when strain is not proportional to stress but when the load is removed the material returns to its original length.

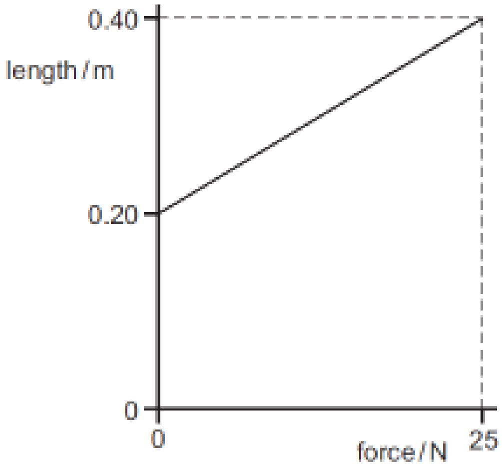
B Plastic deformation occurs if, when the load is removed, the material contracts but a permanent stretching has occurred.

C Plastic deformation occurs until the extension is no longer proportional to the load.

D Plastic deformation occurs when the material extends so that strain is directly proportional to stress.

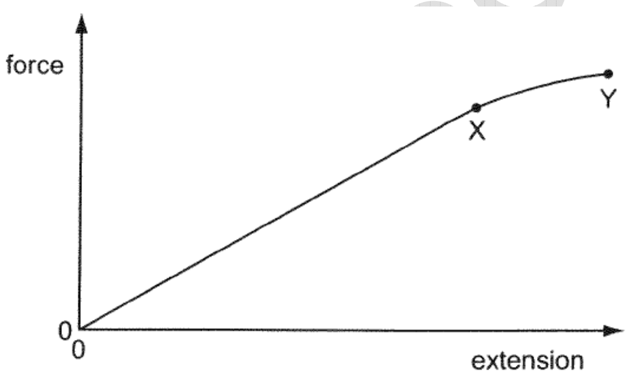
****16 Nov 07 P1 Q20**

20 The graph shows how the length of a particular rubber cord varies as force is applied.



****17 June 08 P1 Q22**

22 A sample of metal is subjected to a force which increases to a maximum value and then decreases back to zero. A force-extension graph for the sample is shown.



When the sample contracts it follows the same force-extension curve as when it was being stretched.

What is the behaviour of the metal between X and Y?

A both elastic and plastic

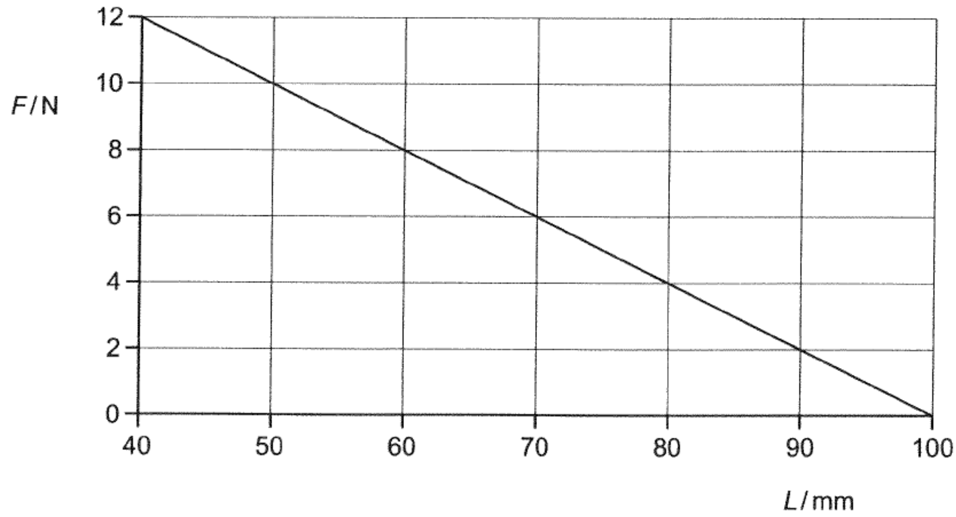
B elastic but not plastic

C plastic but not elastic

D not elastic and not plastic

****18 June 08 P1 Q23**

23 A spring of original length 100 mm is compressed by a force. The graph shows the variation of the length *L* of the spring with the compressing force *F*.



What is the energy stored in the spring when the length is 70 mm?

A 0.090 J **B** 0.21 J **C** 0.27 J **D** 0.63 J

*19 Nov 08 P1 Q19

19 Which properties best describe modelling clay?

A brittle and ductile

B ductile and elastic

C elastic and plastic

D plastic and ductile

*20 Nov 08 P1 Q23

23 For a wire, Hooke's law is obeyed for a tension F and extension x. The Young modulus for the material of the wire is E.

Which expression represents the elastic strain energy stored in the wire?

A $\frac{1}{2}Ex$ **B** Ex **C** $\frac{1}{2}Fx$ **D** Fx

**21 June 09 P1 Q19

19 Four materials are formed into rods of the same dimensions.

At room temperature, which can sustain the largest plastic deformation?

A the ductile material aluminium

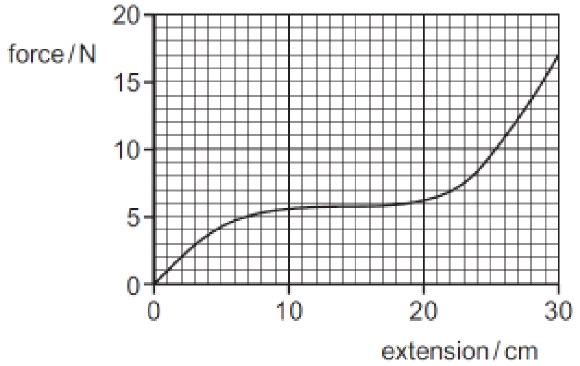
B the brittle material carbon

C the brittle material glass

D the ductile material steel

****22 June 09 P1 Q21**

21 A rubber band is stretched by hanging weights on it and the force-extension graph is plotted from the results.



What is the best estimate of the strain energy stored in the rubber band when it is extended 30 cm?

A 2.0 J **B** 2.6 J **C** 5.1 J **D** 200 J

Deformation of Solids
Section B

1 June 05 P2 Q4

4 A glass fibre of length 0.24 m and area of cross-section $7.9 \times 10^{-7}\ m^2$ is tested until it breaks. The variation with load F of the extension x of the fibre is shown in Fig. 4.1.

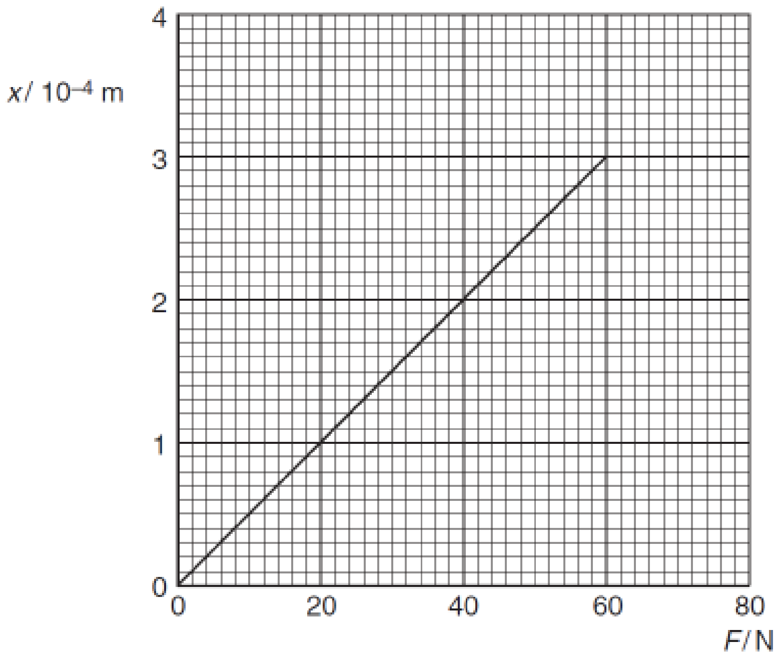


Fig. 4.1

(a) State whether glass is ductile, brittle or polymeric.

....[1]

(b) Use Fig. 4.1 to determine, for this sample of glass,

(i) the ultimate tensile stress,

ultimate tensile stress = ... Pa [2]

(ii) the Young modulus,

Young modulus = ... Pa [3]

(iii) the maximum strain energy stored in the fibre before it breaks.

maximum strain energy = ... J [2]

(c) A hard ball and a soft ball, with equal masses and volumes, are thrown at a glass window. The balls hit the window at the same speed. Suggest why the hard ball is more likely than the soft ball to break the glass window.

....

....

....

....[3]

2 June 06 Q5

5 Fig. 5.1 shows the variation with force F of the extension x of a spring as the force is increased to F_3 and then decreased to zero.

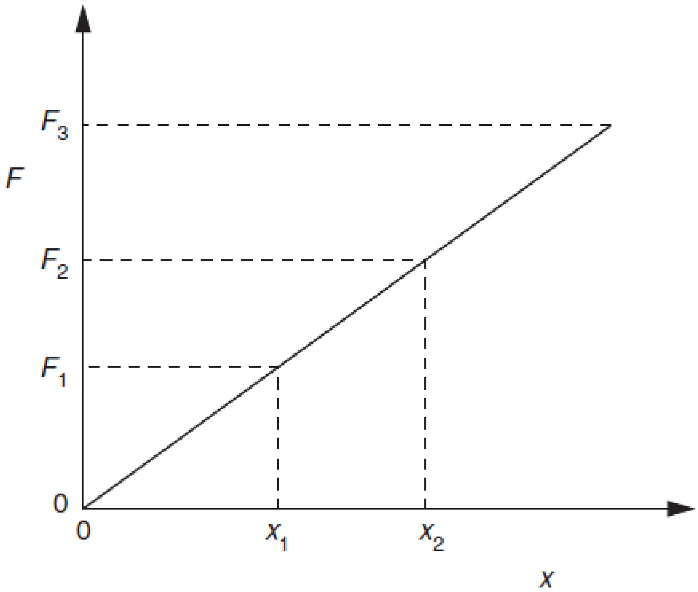


Fig. 5.1

(a) State, with a reason, whether the spring is undergoing an elastic change.

....

.... [1]

(b) The extension of the spring is increased from x_1 to x_2.

Show that the work W done in extending the spring is given by

$$W = \tfrac{1}{2}k(x_2^2 - x_1^2),$$

where k is the spring constant.

(c) A trolley of mass 850 g is held between two fixed points by means of identical springs, as shown in Fig. 5.2.

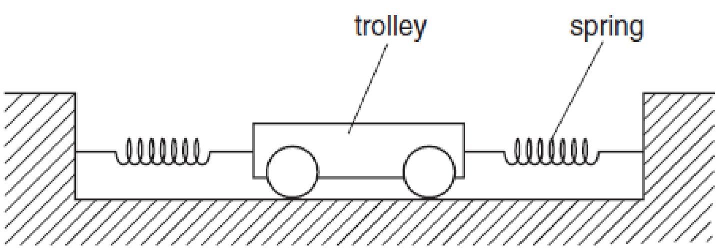


Fig. 5.2

When the trolley is in equilibrium, the springs are each extended by 4.5 cm. Each spring has a spring constant 16 N cm^{-1}.

The trolley is moved a distance of 1.5 cm along the direction of the springs. This causes the extension of one spring to be increased and the extension of the other spring to be decreased. The trolley is then released. The trolley accelerates and reaches its maximum speed at the equilibrium position.

Assuming that the springs obey Hooke's law, use the expression in **(b)** to determine the maximum speed of the trolley.

speed = ... m s^{-1} [4]

3 Nov 07 P2 Q4

4 A sample of material in the form of a cylindrical rod has length *L* and uniform area of cross-section *A*. The rod undergoes an increasing tensile stress until it breaks.
Fig. 4.1 shows the variation with stress of the strain in the rod.

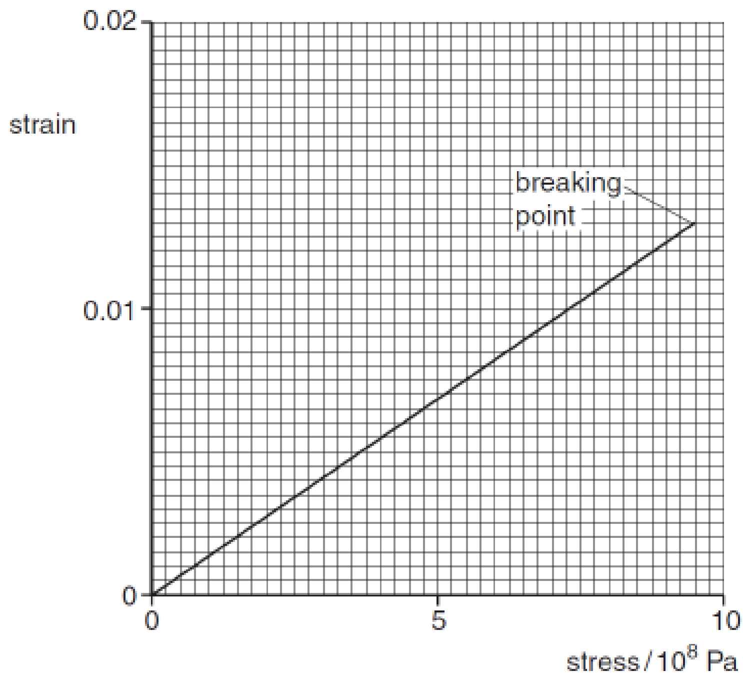


Fig. 4.1

(a) State whether the material of the rod is ductile, brittle or polymeric.

.... [1]

(b) Determine the Young modulus of the material of the rod.

Young modulus = ... Pa [2]

(c) A second cylindrical rod of the same material has a spherical bubble in it, as illustrated in Fig. 4.2.

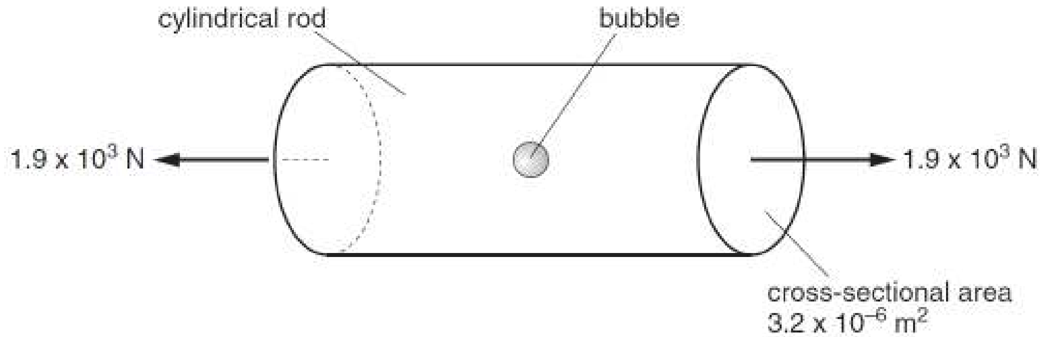


Fig. 4.2

The rod has an area of cross-section of $3.2 \times 10^{-6}\,m^2$ and is stretched by forces of magnitude $1.9 \times 10^3\,N$.
By reference to Fig. 4.1, calculate the maximum area of cross-section of the bubble such that the rod does not break.

area = ... m^2 [3]

(d) A straight rod of the same material is bent as shown in Fig. 4.3.

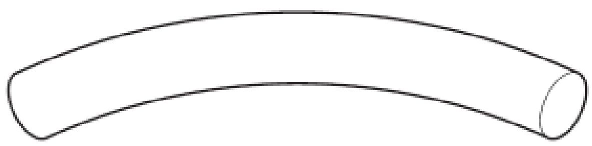


Fig. 4.3

Suggest why a thin rod can bend more than a thick rod without breaking.

....

....

.... [2]

4 June 08 P2 Q2

2 A spring is placed on a flat surface and different weights are placed on it, as shown in Fig. 2.1.

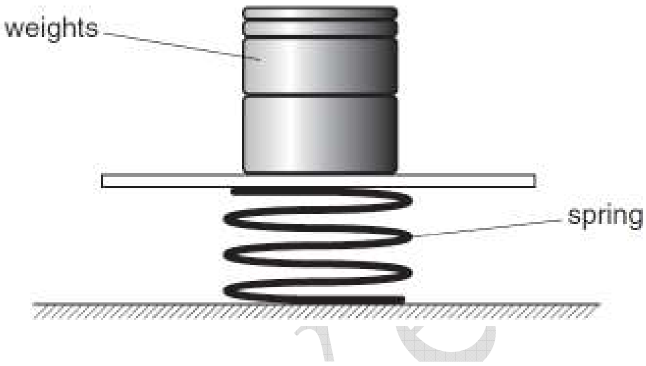


Fig. 2.1

The variation with weight of the compression of the spring is shown in Fig. 2.2.

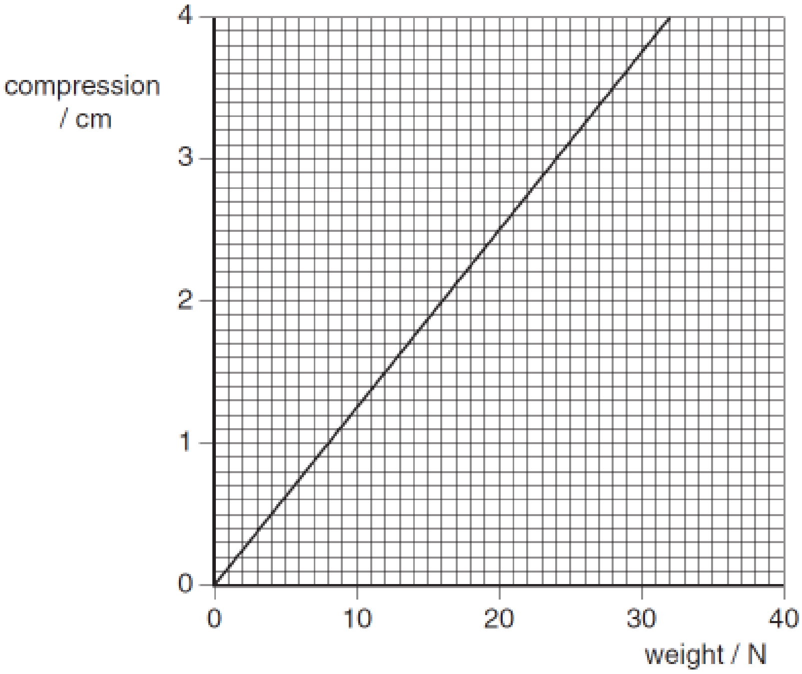


Fig. 2.2

The elastic limit of the spring has not been exceeded.

(a) **(i)** Determine the spring constant *k* of the spring.

k = ... $N\,m^{-1}$ [2]

(ii) Deduce that the strain energy stored in the spring is 0.49 J for a compression of 3.5 cm.

[2]

(b) Two trolleys, of masses 800 g and 2400 g, are free to move on a horizontal table. The spring in **(a)** is placed between the trolleys and the trolleys are tied together using thread so that the compression of the spring is 3.5 cm, as shown in Fig. 2.3.

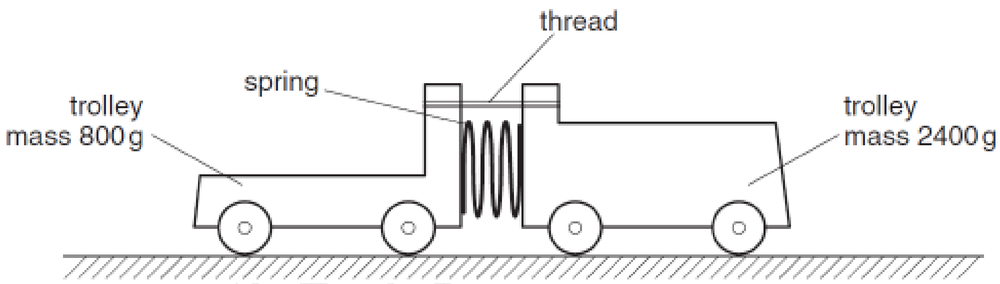


Fig. 2.3

Initially, the trolleys are not moving.
The thread is then cut and the trolleys move apart.

(i) Deduce that the ratio

$$\frac{\text{speed of trolley of mass 800 g}}{\text{speed of trolley of mass 2400 g}}$$

is equal to 3.0.

[2]

(ii) Use the answers in **(a)(ii)** and **(b)(i)** to calculate the speed of the trolley of mass 800 g.

speed = ... $m\,s^{-1}$ [3]

5 June 08 P2 Q4

4 **(a)** **(i)** Define the terms

1. tensile stress,

....

....[1]

2. tensile strain,

....

....[1]

3. the Young modulus.

....

....[1]

(ii) Suggest why the Young modulus is not used to describe the deformation of a liquid or a gas.

....

....[1]

(b) The change ΔV in the volume V of some water when the pressure on the water increases by Δp is given by the expression

$$\Delta p = 2.2 \times 10^9 \frac{\Delta V}{V},$$

where Δp is measured in pascal.
In many applications, water is assumed to be incompressible.
By reference to the expression, justify this assumption.

....

....

....[2]

(c) Normal atmospheric pressure is 1.01×10^5 Pa.

Divers in water of density $1.08 \times 10^3\,\text{kg}\,\text{m}^{-3}$ frequently use an approximation that every 10 m increase in depth of water is equivalent to one atmosphere increase in pressure. Determine the percentage error in this approximation.

error = ... % [3]

6 June 09 P2 Q4

4 A spring having spring constant *k* hangs vertically from a fixed point. A load of weight *L*, when hung from the spring, causes an extension *e*. The elastic limit of the spring is not exceeded.

(a) State

(i) what is meant by an *elastic deformation*,

....

....

.... [2]

(ii) the relation between *k*, *L* and *e*.

.... [1]

(b) Some identical springs, each with spring constant *k*, are arranged as shown in Fig. 4.1.

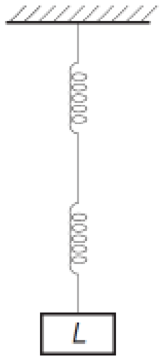
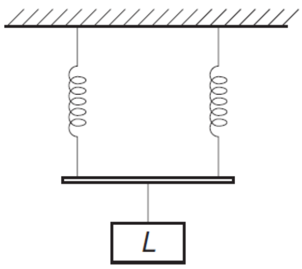
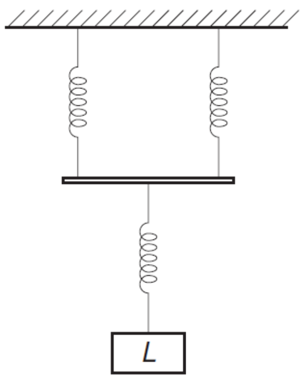
arrangement	total extension	spring constant of arrangement
	....	....
	....	....
	....	....

Fig. 4.1

The load on each of the arrangements is *L*.

For each arrangement in Fig. 4.1, complete the table by determining

(i) the total extension in terms of *e*,

(ii) the spring constant in terms of *k*.

[5]