6. Deformation of Solids

6.1 Stress and strain

Paper 2

Question Paper

1 **(a)** Define strain.

.....

..... [1]

(b) A copper wire of length 4.0 m has a uniform cross-sectional area of $4.5 \times 10^{-7}\,m^2$.

A tensile force of 18 N is applied to the wire. This causes the wire to extend by 1.4 mm up to its limit of proportionality.

(i) Calculate the Young modulus of the wire.

Young modulus = ...Pa [3]

(ii) On Fig. 4.1, draw a line to show how the stress varies with the strain for the wire up to its limit of proportionality.

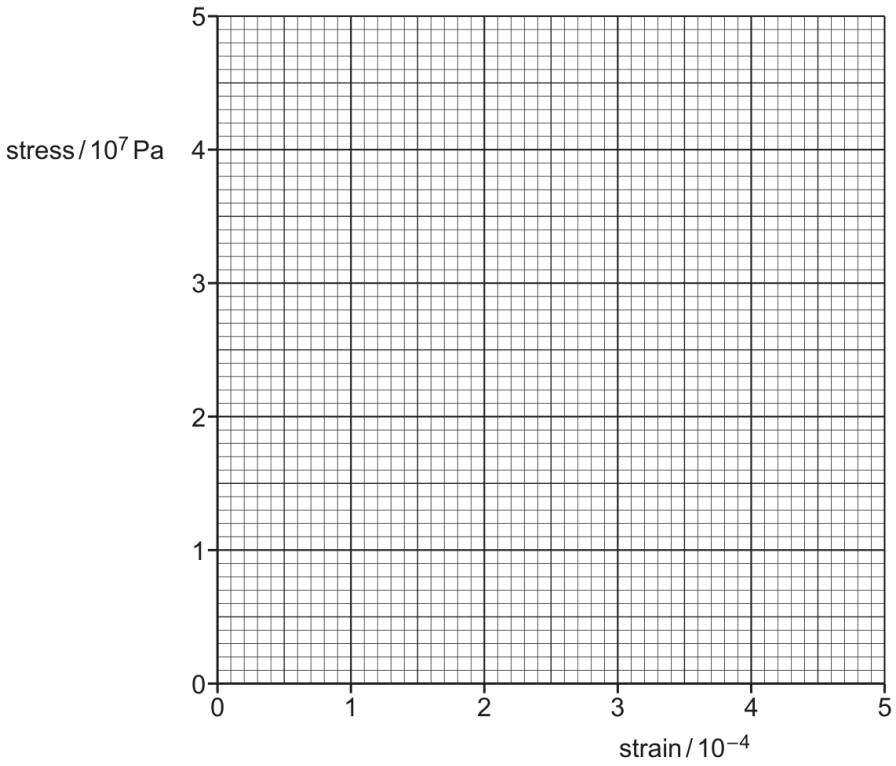


Fig. 4.1

[2]

(c) A second copper wire has the same length as the wire in **(b)** but a larger diameter. Both wires are subjected to a tensile force of 18 N.

By placing a tick (✓) in each row, complete Table 4.1 to compare the stress and strain of the two wires.

Table 4.1

	greater in second wire	less in second wire	the same in both wires
stress			
strain			

[2]

2 Lightning occurs when charge builds up in the atmosphere, creating a potential difference between the ground and the atmosphere.

During a lightning strike there is an average current of 3.3×10^4 A for a time of 2.6×10^{-5} s.

(d) A section of the lightning rod of length 0.12 m is removed for testing. A tensile stress of 1.9×10^6 Pa is applied, as shown in Fig. 3.2.

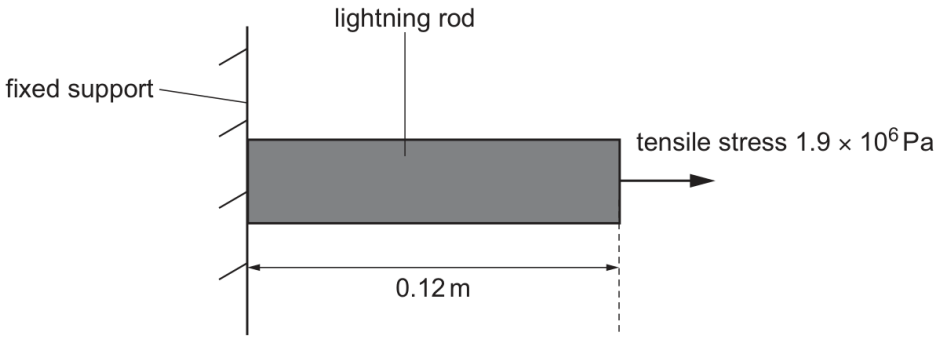


Fig. 3.2 (not to scale)

The section of the rod obeys Hooke's law. The Young modulus of copper is 1.3×10^{11} Pa.

Calculate the extension of the section.

extension = ... m [3]

3 **(a)** Define the Young modulus of a material.

.....

..... [1]

(b) A metal wire P that obeys Hooke's law is stretched within its limit of proportionality.

(i) On Fig. 4.1, sketch the variation of tensile force *F* in the wire with its extension *x*.



Fig. 4.1

[1]

(ii) State the name of the quantity represented by the gradient of the line in Fig. 4.1.

..... [1]

(c) Another wire Q is made from a metal that has twice the Young modulus of the metal of wire P in **(b)**. Wire Q has the same volume as wire P but has double the cross-sectional area of wire P.

The two wires are extended by equal tensile forces within their limits of proportionality.

State and explain how the extension of wire Q compares with the extension of wire P.

.....

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.....

.....

..... [3]

4 **(a)** The variation of stress with strain for a metal P is shown in Fig. 3.1.

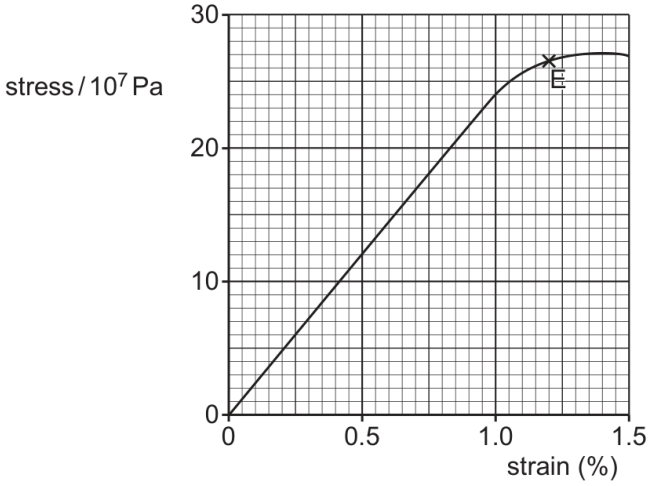


Fig. 3.1

Point E is the elastic limit of the metal.

(i) Use Fig. 3.1 to determine the Young modulus for P.

Young modulus = ... Pa [2]

(ii) On the line in Fig. 3.1, draw a cross (×) to show the limit of proportionality. Label this point Q. [1]

(c) A wire is used to hold a uniform shelf AB horizontally in equilibrium as shown in Fig. 3.2.

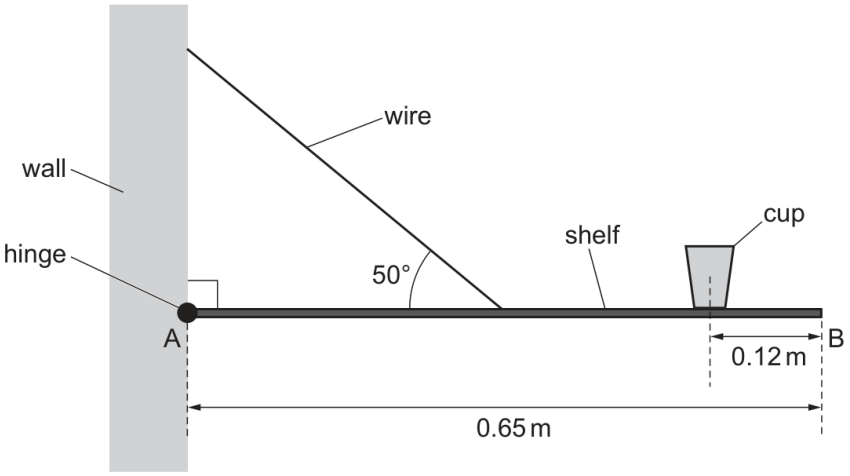


Fig. 3.2 (not to scale)

The wire is connected to the midpoint of shelf AB at an angle of 50° to the horizontal. The shelf is attached to a wall by a hinge at A. The length of shelf AB is 0.65 m and its weight is 33 N.
A cup of weight 1.5 N rests on the shelf with its centre of gravity at a horizontal distance of 0.12 m from B.

(ii) The stress in the wire is 1.5×10^7 Pa.

Determine the radius of the wire.

radius = ... m [2]

5 A spring is suspended from a fixed point at one end. The spring is extended by a vertical force applied to the other end. The variation of the applied force F with the length L of the spring is shown in Fig. 4.1.

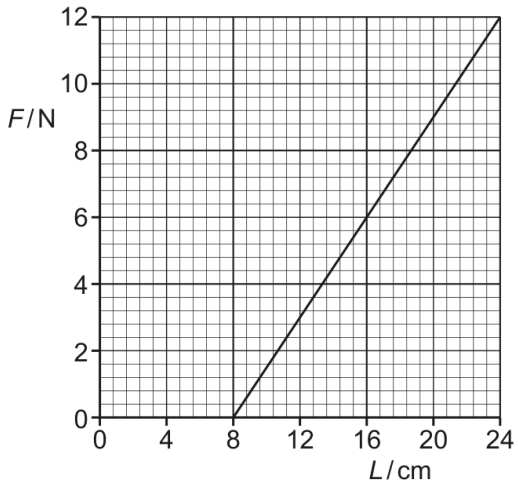


Fig. 4.1

For the spring:

(a) state the name of the law that gives the relationship between the force and the extension

..... [1]

(b) determine the spring constant, in $N\,m^{-1}$

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

6 A hot-air balloon floats just above the ground. The balloon is stationary and is held in place by a vertical rope, as shown in Fig. 2.1.

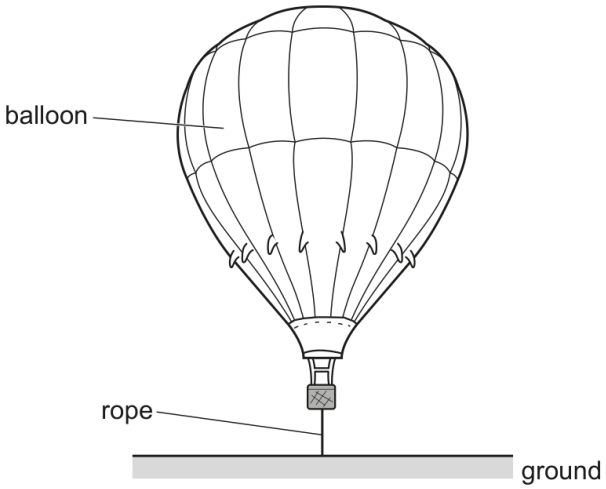


Fig. 2.1

The balloon has a weight W of 3.39×10^4 N. The tension T in the rope is 4.00×10^2 N.
Upthrust U acts on the balloon.
The density of the surrounding air is $1.23\,\text{kg}\,\text{m}^{-3}$.

(c) Before the balloon is released, the rope holding the balloon has a strain of 2.4×10^{-5}. The rope has an unstretched length of 2.5 m. The rope obeys Hooke's law.

(i) Show that the extension of the rope is 6.0×10^{-5} m.

[1]

(iii) The rope holding the balloon is replaced with a new one of the same original length and cross-sectional area. The tension is unchanged and the new rope also obeys Hooke's law.

The new rope is made from a material of a lower Young modulus.

State and explain the effect of the lower Young modulus on the elastic potential energy of the rope.

.....

.....

..... [2]

7 A spring is suspended from a fixed point at one end and a vertical force is applied to the other end, as shown in Fig. 4.1.

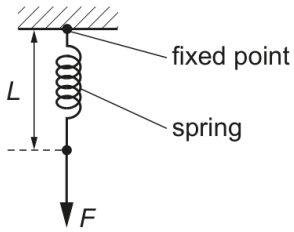


Fig. 4.1

The variation of the applied force *F* with the length *L* of the spring is shown in Fig. 4.2.

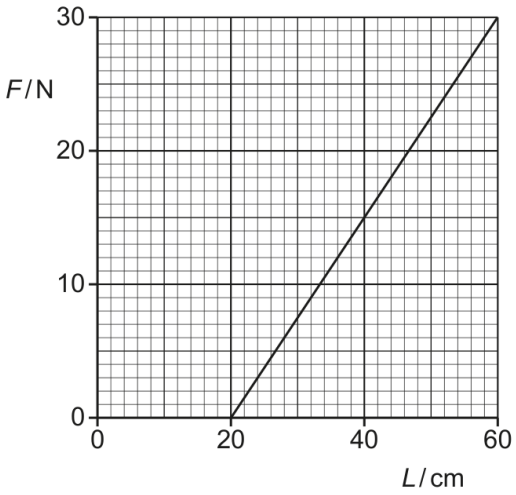


Fig. 4.2

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

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

8 A sphere is attached by a metal wire to the horizontal surface at the bottom of a river, as shown in Fig. 2.1.

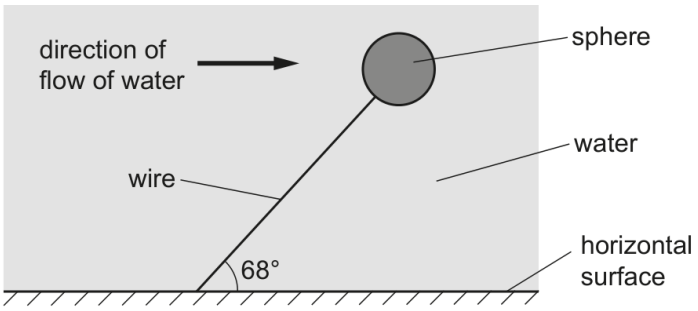


Fig. 2.1 (not to scale)

The sphere is fully submerged and in equilibrium, with the wire at an angle of 68° to the horizontal surface. The weight of the sphere is 32 N. The upthrust acting on the sphere is 280 N. The density of the water is 1.0×10^3 kg m^{-3}.

Assume that the force on the sphere due to the water flow is in a horizontal direction.

(d) The extension of the wire increases when the sphere changes position as described in **(c)**. The wire obeys Hooke's law.

(i) State a symbol equation that gives the relationship between the tension T in the wire and its extension x. Identify any other symbol that you use.

.....

..... [1]

9 A steel ball is projected horizontally from the top of a table, as shown in Fig. 2.1.

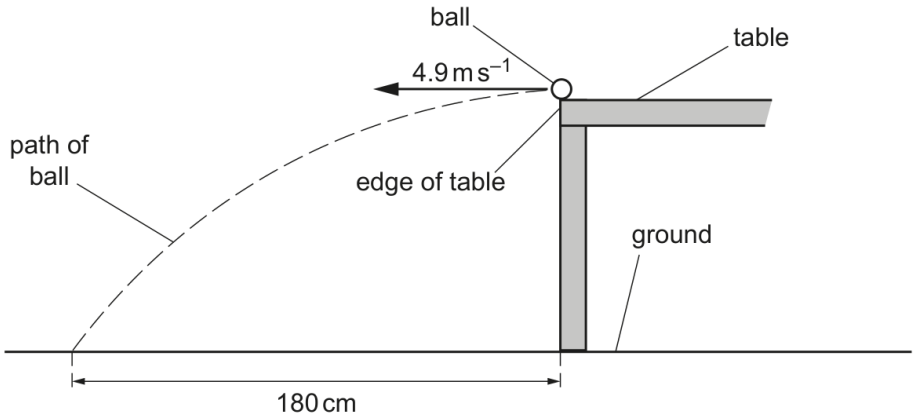


Fig. 2.1 (not to scale)

The ball is projected horizontally at a speed of 4.9 m s^{-1}. The ball lands on the ground a horizontal distance of 180 cm from the edge of the table.

Assume that air resistance is negligible.

(b) The ball is projected by means of a compressed spring which is attached to a fixed block as shown in Fig. 2.2.

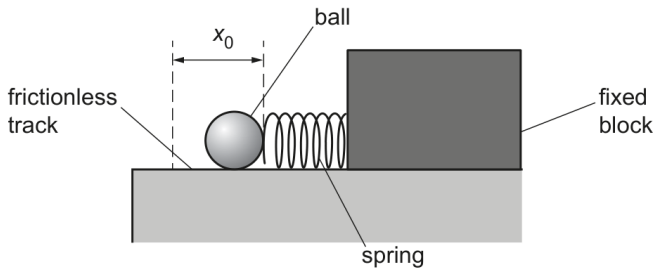


Fig. 2.2

The ball is placed on a frictionless track in front of the spring. The ball is then pulled back so that the spring has compression x_0.

When the spring is released, the ball is projected horizontally as shown in Fig. 2.3.

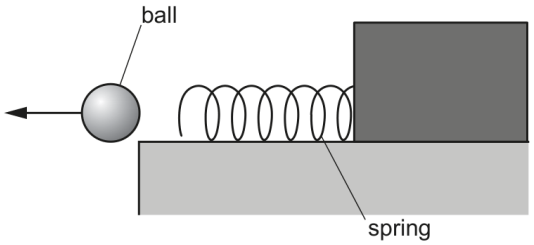


Fig. 2.3

The variation with compression x of the applied force F for the spring is shown in Fig. 2.4.

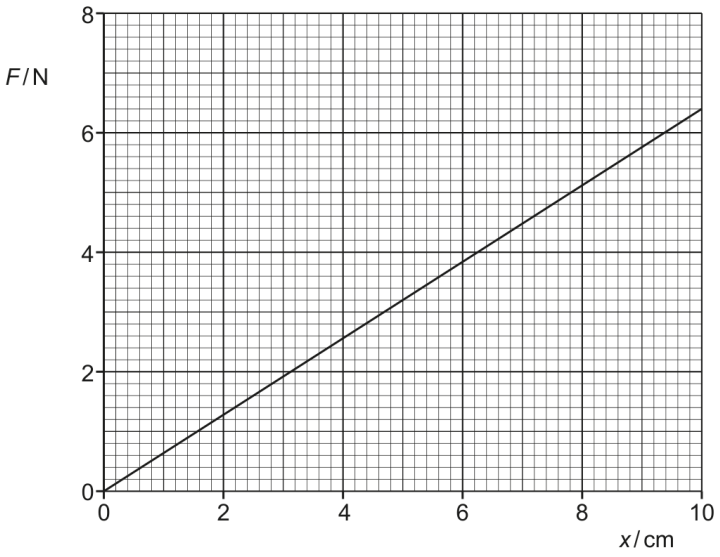


Fig. 2.4

The ball is a uniform sphere of steel of diameter 0.016 m and mass 0.017 kg.

(iii) Use Fig. 2.4 to determine the spring constant k of the spring.

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

10 (b) A uniform beam AB is attached by a frictionless hinge to a vertical wall at end A. The beam is held so that it is horizontal by a metal wire CD, as shown in Fig. 3.1.

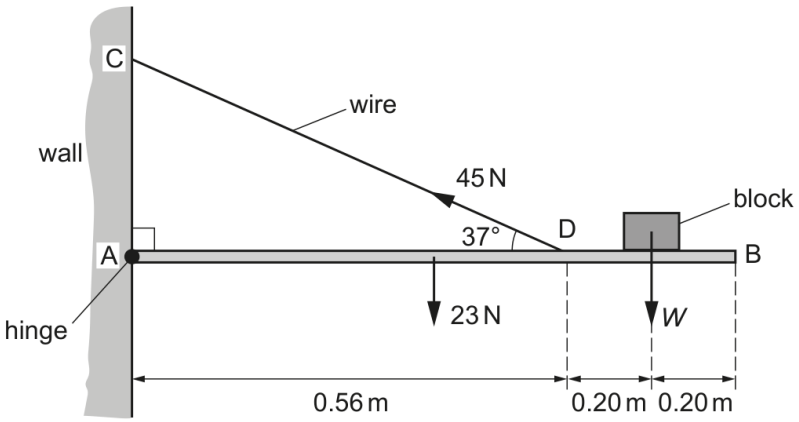


Fig. 3.1 (not to scale)

The beam is of length 0.96 m and weight 23 N. A block of weight *W* rests on the beam at a distance of 0.20 m from end B. The wire is attached to the beam at point D which is a distance of 0.40 m from end B. The wire exerts a force on the beam of 45 N at an angle of 37° to the horizontal. The beam is in equilibrium.

(v) The stress in the wire is 5.3×10^7 Pa. The wire is now replaced by a second wire that has a radius which is three times greater than that of the original wire. The tension in the wire is unchanged.

Calculate the stress in the second wire.

stress = ... Pa [2]

11 (c) A floating solid cylinder is attached by a wire to the sea bed, as shown in Fig. 1.1.

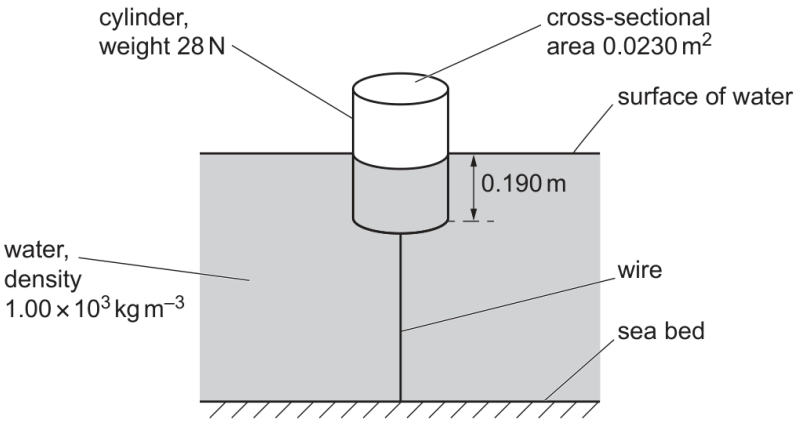


Fig. 1.1 (not to scale)

The density of the water is $1.00 \times 10^3\,\text{kg m}^{-3}$. The base of the cylinder is at a depth of 0.190 m below the surface of the water. The cylinder has a weight of 28 N and a cross-sectional area of $0.0230\,\text{m}^2$.

The wire and the central axis of the cylinder are both vertical. The cylinder is in equilibrium.

(iii) The wire has a cross-sectional area of $3.2\,\text{mm}^2$.

Calculate the stress in the wire.

stress = ... Pa [2]

12 (a) A uniform metal bar, initially unstretched, has sides of length *w*, *x* and *y*, as shown in Fig. 3.1.

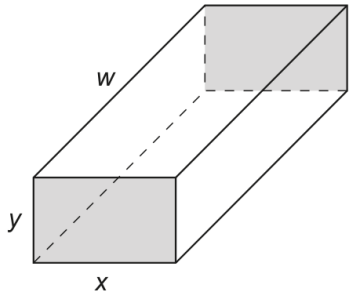


Fig. 3.1

The bar is now stretched by a tensile force *F* applied to the shaded ends. The changes in the lengths *x* and *y* are negligible. The bar now has sides of length *x*, *y* and *z*, as shown in Fig. 3.2.

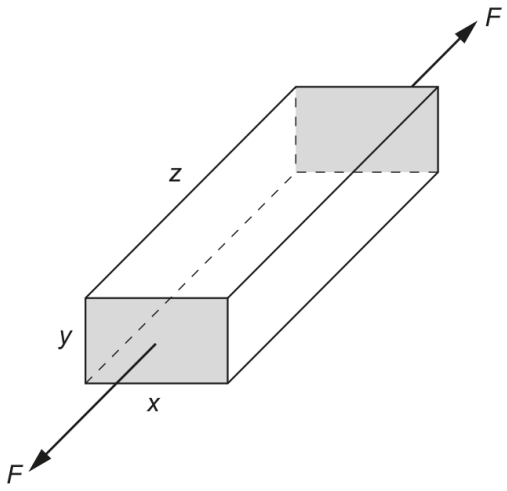


Fig. 3.2

Determine expressions, in terms of some or all of *F*, *w*, *x*, *y* and *z*, for:

(i) the stress σ applied to the bar by the tensile force

σ = ... [1]

(ii) the strain ε in the bar due to the tensile force

ε = ... [1]

(iii) the Young modulus *E* of the metal from which the bar is made.

E = ... [2]

(b) A copper wire is stretched by a tensile force that gradually increases from 0 to 280 N. The variation with extension of the tensile force is shown in Fig. 3.3.

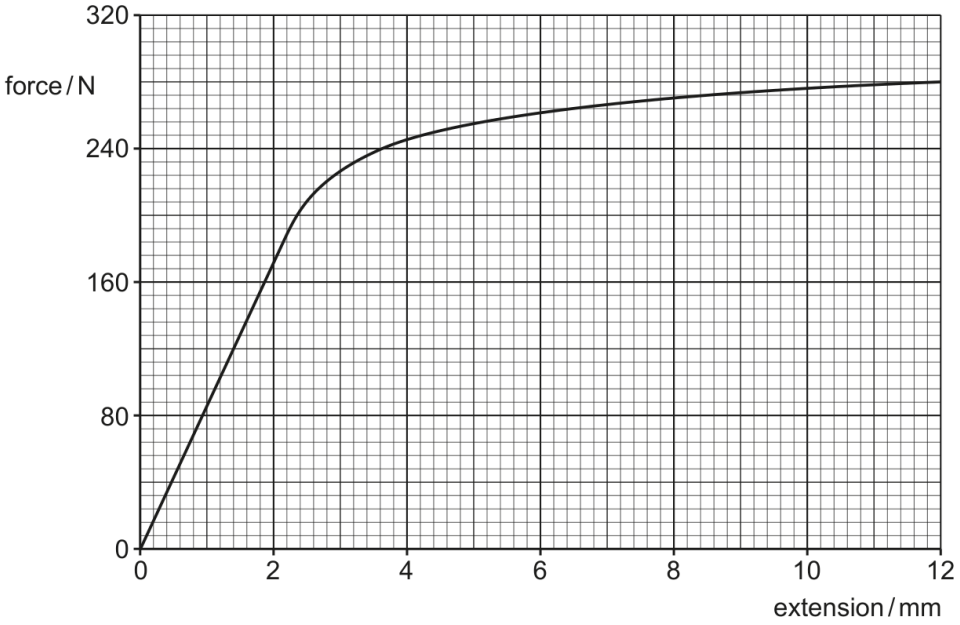


Fig. 3.3

(i) State the maximum extension of the wire for which it obeys Hooke's law.

extension = ... mm [1]

13 (b) A sphere of weight 2.4 N is suspended by a wire from a fixed point P. A horizontal string is used to hold the sphere in equilibrium with the wire at an angle of 53° to the horizontal, as shown in Fig. 3.1.

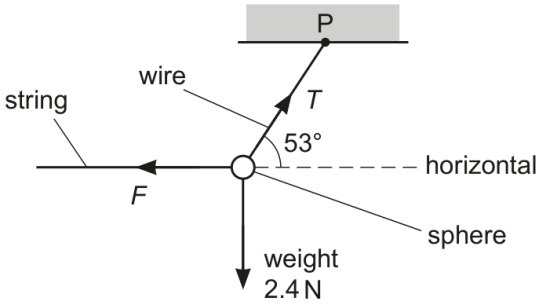


Fig. 3.1 (not to scale)

(ii) The wire has a circular cross-section of diameter 0.50 mm. Determine the stress σ in the wire.

σ = ... Pa [3]

14 One end of a wire is attached to a fixed point. A force F is applied to the wire to cause extension x. The variation with F of x is shown in Fig. 5.1.

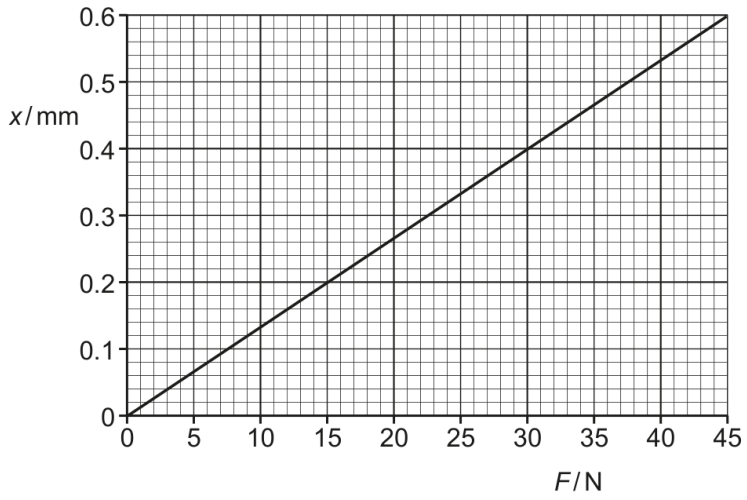


Fig. 5.1

The wire has a cross-sectional area of $4.1 \times 10^{-7}\,m^2$ and is made of metal of Young modulus $1.7 \times 10^{11}\,Pa$. Assume that the cross-sectional area of the wire remains constant as the wire extends.

(a) State the name of the law that describes the relationship between F and x shown in Fig. 5.1.

..... [1]

(b) The wire has an extension of 0.48 mm.

Determine:

(i) the stress

stress = ... Pa [2]

(ii) the strain.

strain = ... [2]

15 (a) Define, for a wire:

(i) *stress*

.....

..... [1]

(ii) *strain*.

.....

..... [1]

(b) (i) A school experiment is performed on a metal wire to determine the Young modulus of the metal. A force is applied to one end of the wire which is fixed at the other end. The variation of the force F with extension x of the wire is shown in Fig. 4.1.

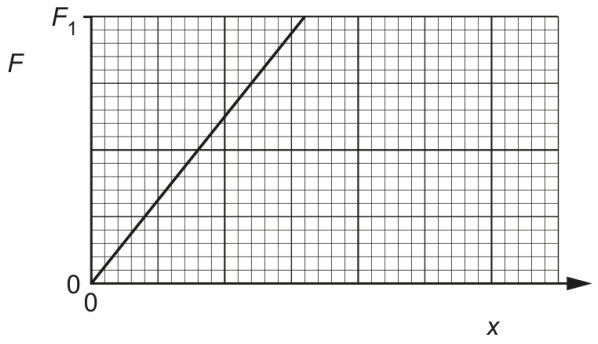


Fig. 4.1

The maximum force applied to the wire is F_1.

The gradient of the graph line in Fig. 4.1 is G. The wire has initial length L and cross-sectional area A.

Determine an expression, in terms of A, G and L, for the Young modulus E of the metal.

E = ... [2]

(ii) A student repeats the experiment in **(b)(i)** using a new wire that has twice the diameter of the first wire. The initial length of the wire and the metal of the wire are unchanged.

On Fig. 4.1, draw the graph line representing the new wire for the force increasing from $F = 0$ to $F = F_1$. [2]

16 (a) A spring is fixed at one end and is compressed by applying a force to the other end. The variation of the force F acting on the spring with its compression x is shown in Fig. 3.1.

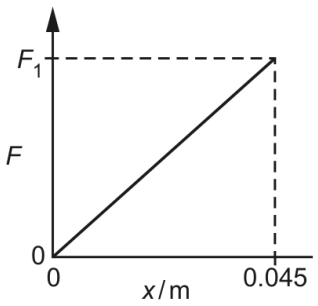


Fig. 3.1

A compression of 0.045 m is produced when a force F_1 acts on the spring. The spring has a spring constant of 800 N m^{-1}.

(i) Determine F_1.

F_1 = ... N [2]

17 (c) A short time later, the car in **(b)** is travelling at a constant speed and the tension in the tow-bar is 480 N.

The tow-bar is a solid metal rod that obeys Hooke's law. Some data for the tow-bar are listed below.

Young modulus of metal = 2.2×10^{11} Pa

original length of tow-bar = 0.48 m

cross-sectional area of tow-bar = 3.0×10^{-4} m^2

Determine the extension of the tow-bar.

extension = ... m [3]

18 The variation with extension x of the force F applied to a spring is shown in Fig. 4.1.

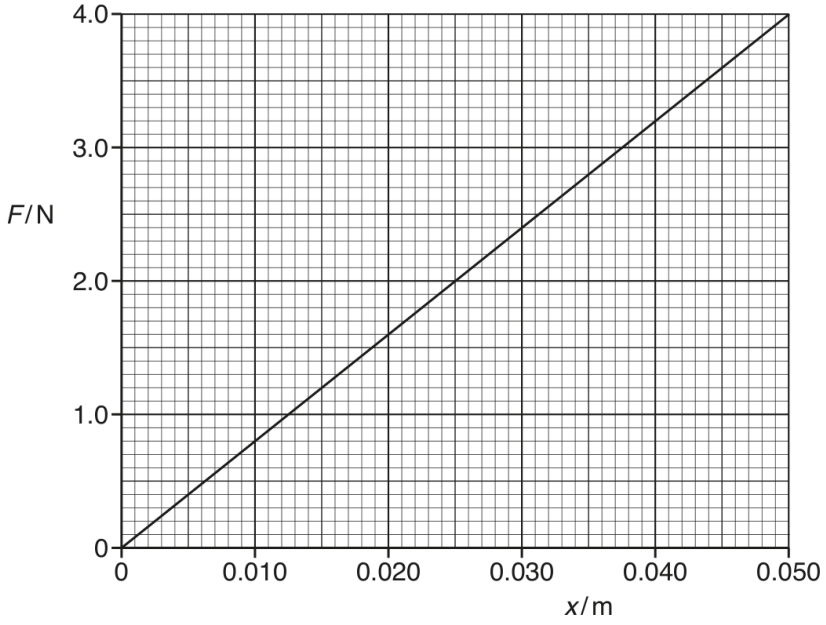


Fig. 4.1

The spring has an unstretched length of 0.080 m and is suspended vertically from a fixed point, as shown in Fig. 4.2.

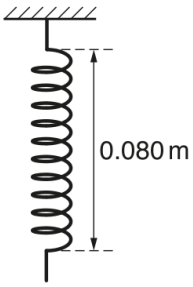


Fig. 4.2

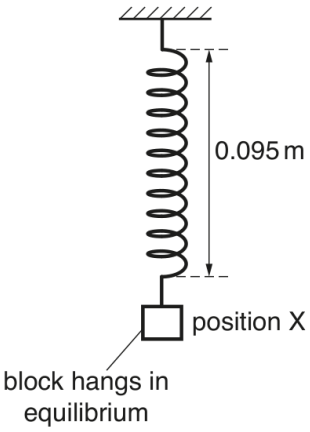


Fig. 4.3

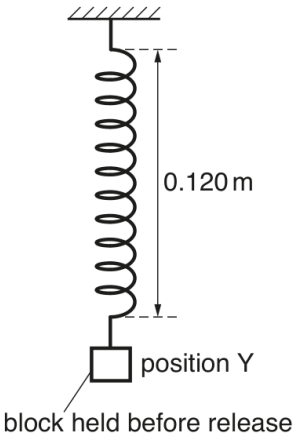


Fig. 4.4

A block is attached to the lower end of the spring. The block hangs in equilibrium at position X when the length of the spring is 0.095 m, as shown in Fig. 4.3.

The block is then pulled vertically downwards and held at position Y so that the length of the spring is 0.120 m, as shown in Fig. 4.4. The block is then released and moves vertically upwards from position Y back towards position X.

(a) Use Fig. 4.1 to determine the spring constant of the spring.

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

19 (b) A block of weight 15 N hangs by a wire from a remotely controlled aircraft, as shown in Fig. 2.1.

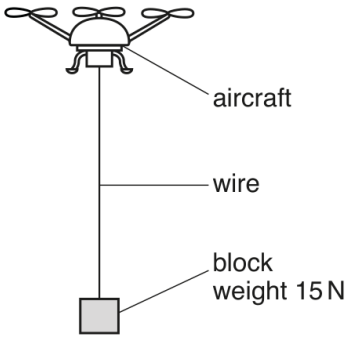


Fig. 2.1

The aircraft is used to move the block only in a vertical direction. The force on the block due to air resistance is negligible.

The variation with time t of the vertical velocity v of the block is shown in Fig. 2.2.
The velocity is taken to be positive in the upward direction.

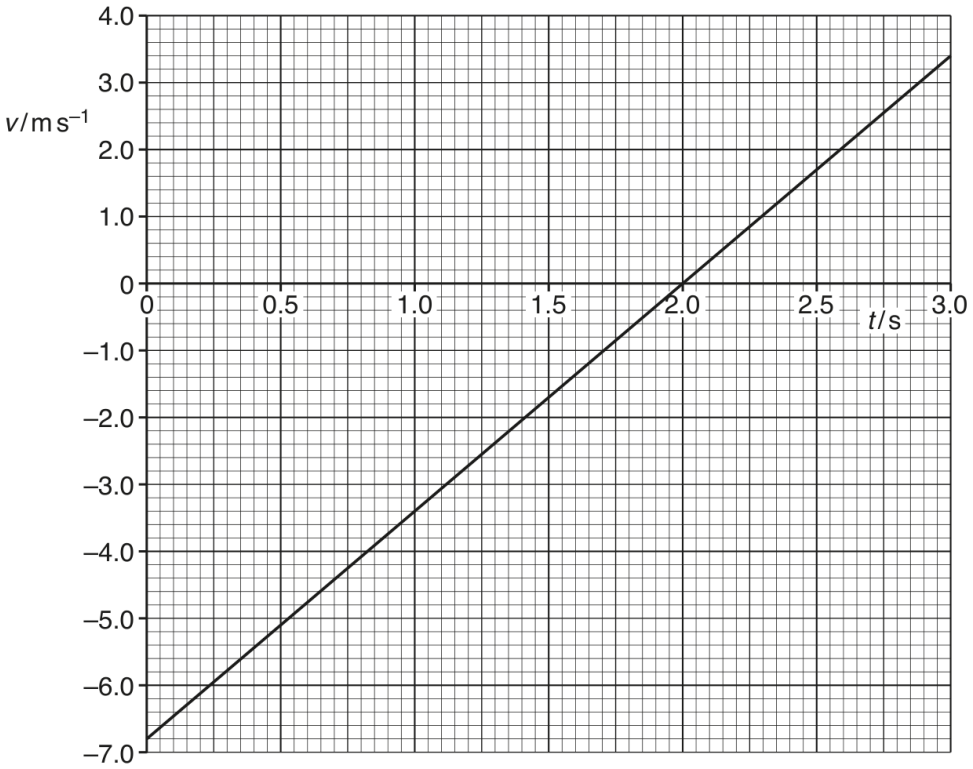


Fig. 2.2

(iv) The wire has a cross-sectional area of $2.8 \times 10^{-5}\,m^2$ and is made from metal of Young modulus 1.7×10^{11} Pa. The wire obeys Hooke's law.

Calculate the strain of the wire at time $t = 2.0$ s.

strain = ... [3]