DEFORMATION WORKSHEET
AS-Level Physics 9702

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

ON24/21/Q4

....

.... [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]

(iii) State the name of the quantity represented by the area under 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.

....

....

....

....

.... [3]

[Total: 7]

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2 **(a)** The variation of stress with strain for a metal P is shown in Fig. 3.1. **ON24/22/Q3**

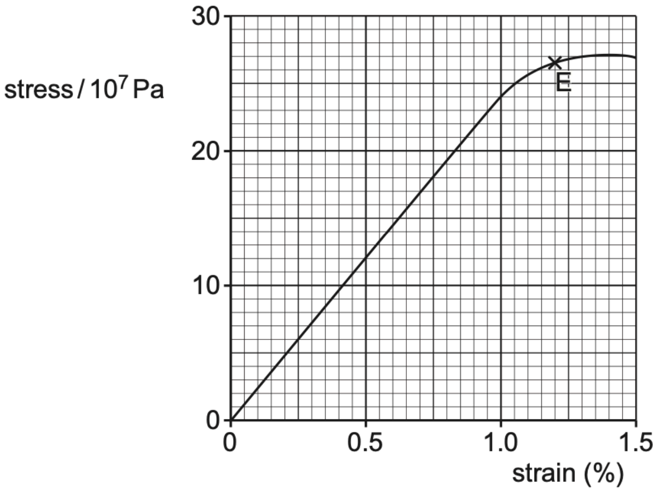


Fig. 3.1

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]

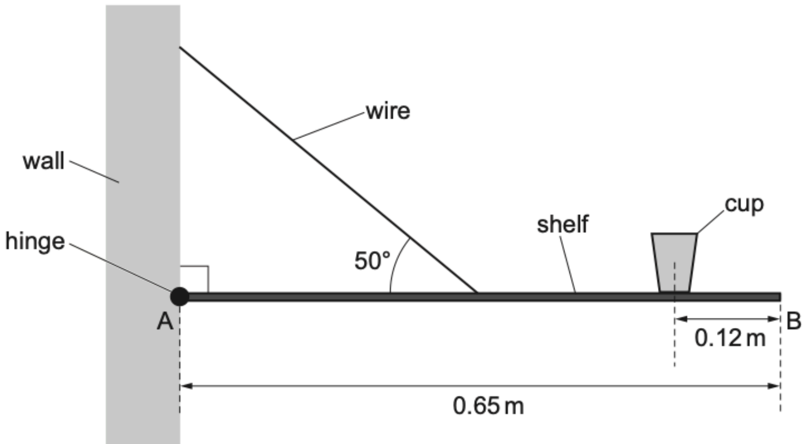
(b) State the conditions necessary for an object to be in equilibrium.

....

....

.... [2]

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



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.

(i) By taking moments about A, determine the tension in the wire.

tension = ... N [3]

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

Determine the radius of the wire.

radius = ... m [2]

(iii) More items are added to the shelf, doubling the stress in the wire. The wire is made of the metal P from **(a)**.

Use Fig. 3.1 to state and explain whether the wire will behave plastically or elastically as the stress doubles.

....

....

....

....

.... [2]

[Total: 12]

3 **(a)** Define: **ON24/23/Q4**

(i) stress

....

.... [1]

(ii) strain.

....

.... [1]

(b) Two wires X and Y, with equal unstretched lengths of 0.84 m, are suspended from fixed points that are at the same horizontal level. The lower ends of the wires are attached to a beam of negligible mass. The beam is horizontal and in equilibrium, as shown in Fig. 4.1.

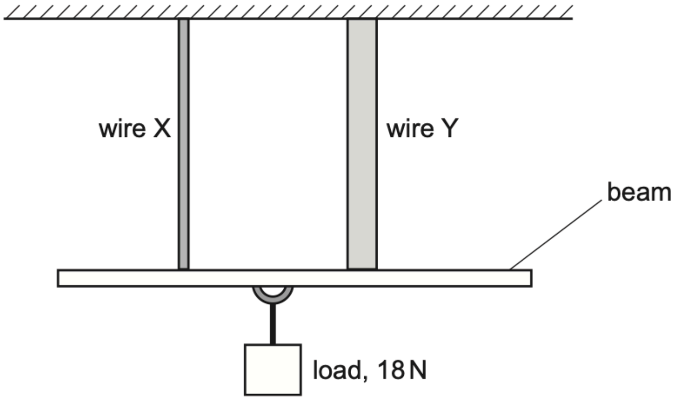


Fig. 4.1

Wire X is made from a metal that has a Young modulus of 1.9×10^9 Pa.
Wire Y is made from a different metal.

A load of weight 18 N is suspended from the beam at a point that is equidistant from the two wires. This load causes both wires to extend by 0.47 mm.

(i) Determine the cross-sectional area of wire X.

cross-sectional area = ... m^2 [3]

(ii) Wire Y has a greater diameter than wire X.

Explain, without calculation, whether the Young modulus of the metal from which wire Y is made is less than, the same as or greater than 1.9×10^{9} Pa.

....

....

....

.... [2]

[Total: 7]

4 (a) Define strain. **MJ24/21/Q4**

....

.... [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.

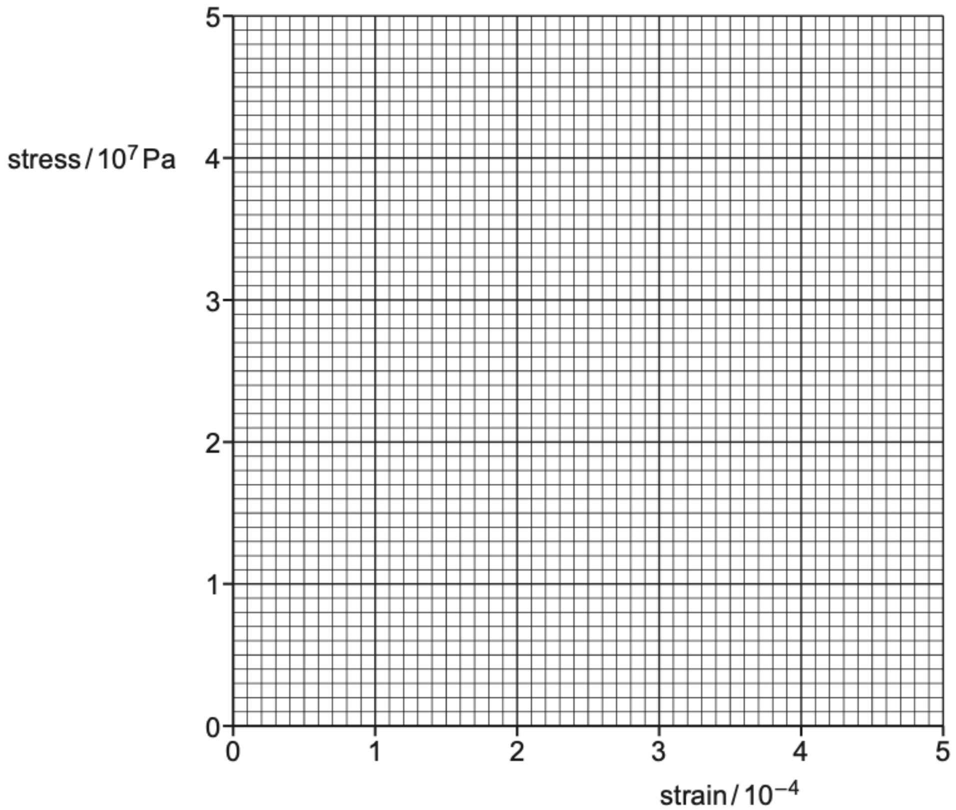


Fig. 4.1

[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]

[Total: 8]

5 A pinball machine uses a spring to launch a small metal ball of mass 4.5×10^{-2} kg up a ramp. The spring is compressed by 8.0×10^{-2} m and held in equilibrium, as shown in Fig. 4.1.

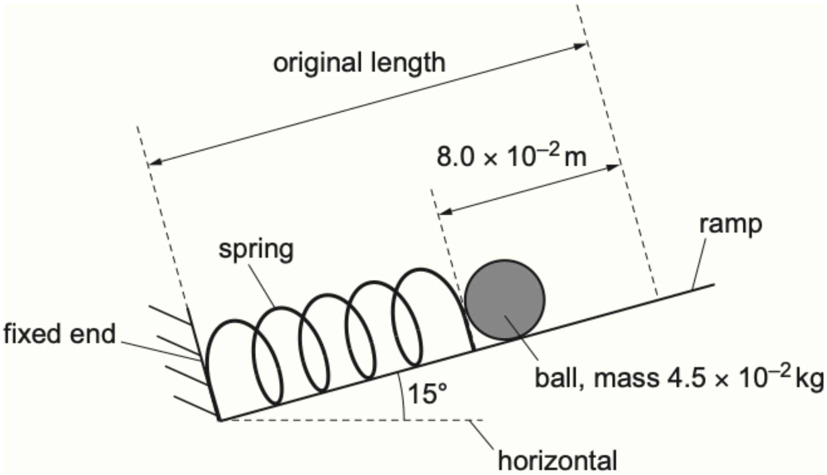


Fig. 4.1 (not to scale)

The ramp is at an angle of 15° to the horizontal.

(a) The spring obeys Hooke's law and has a spring constant of $29\,N\,m^{-1}$.

Calculate the elastic potential energy in the compressed spring.

elastic potential energy = ... J [2]

(b) The spring is released and expands quickly back to its original length.

(i) Calculate the increase in gravitational potential energy of the ball when the spring returns to its original length.

increase in gravitational potential energy = ... J [3]

(ii) The ball leaves the spring when the spring reaches its original length. Assume that all the elastic potential energy of the spring is transferred to the ball.

Calculate the speed of the ball as it leaves the spring.

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

(c) The ball comes to rest on a horizontal trapdoor of negligible mass at a distance *d* from its pivot.
A force *F* acts vertically downwards at a distance of 2.0 cm from the pivot, as shown in Fig. 4.2.

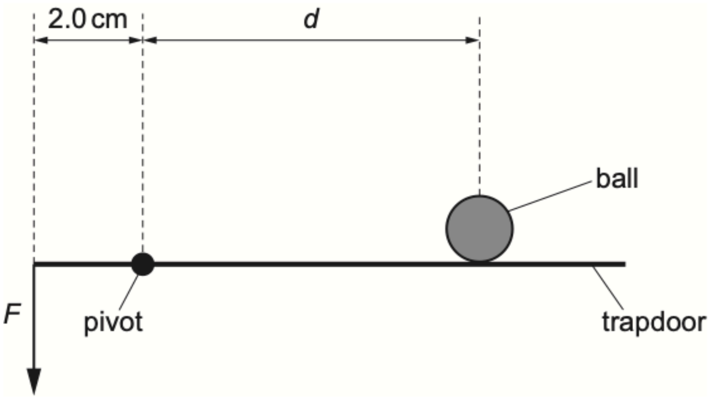


Fig. 4.2 (not to scale)

(i) The trapdoor is in equilibrium when *F* is 1.7 N.

Calculate *d*.

d = ... m [2]

(ii) Force *F* is decreased from 1.7 N.

State the direction of the resultant moment about the pivot on the trapdoor.

.... [1]

[Total: 11]

6 **(a)** State Hooke's law.

....

.... [1]

(b) The variation of the applied force with the extension for a sample of a material is shown in Fig. 3.1.

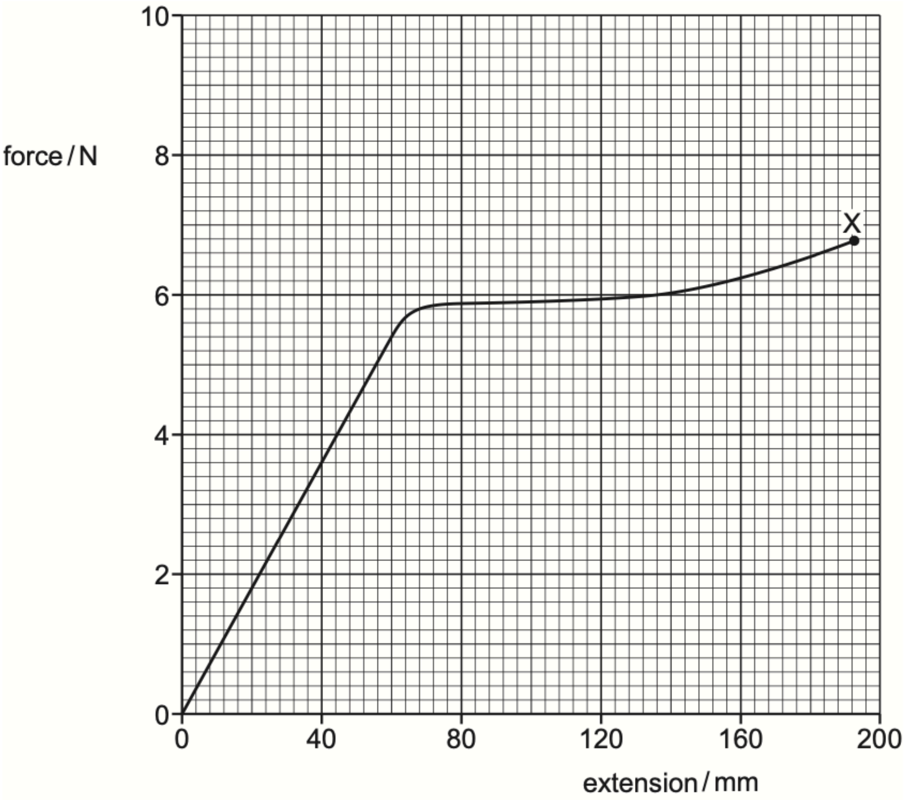


Fig. 3.1

The sample behaves elastically up to an extension of 80 mm and breaks at point X.

(i) On the line in Fig. 3.1, draw a cross (×) to show the limit of proportionality. Label this cross with the letter P. [1]

(ii) On the line in Fig. 3.1, draw a cross (×) to show the elastic limit. Label this cross with the letter E. [1]

(c) The sample in **(b)** has a cross-sectional area of $0.40\,mm^2$ and an initial length of 3.2 m.

For deformations within the limit of proportionality of the sample, determine:

(i) the spring constant of the sample

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

(ii) the Young modulus of the material from which the sample is made.

Young modulus = ... Pa [3]

(d) Determine an estimate of the work done on the sample as it is extended from zero extension to its breaking point. Explain your reasoning.

work done = ... J [2]

(e) A second sample of the same material has a larger cross-sectional area than the original sample but the same initial length. The two samples are each deformed with the limit of proportionality.

State and explain qualitatively how the spring constant of the second sample compares with that of the original sample.

....

....

.... [2]

[Total: 12]

7 A thin metal wire X, of diameter 1.2×10^{-3} m, is used to suspend a model planet, as shown in Fig. 3.1.

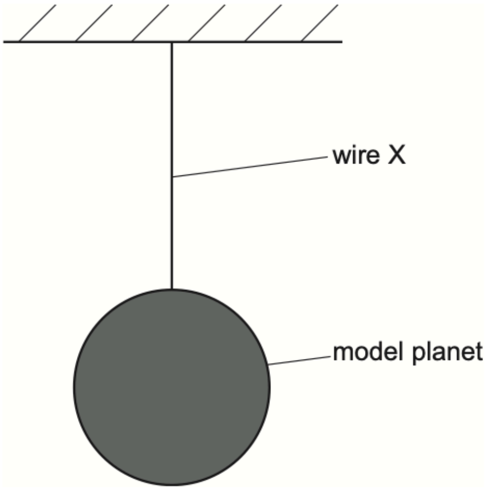


Fig. 3.1 (not to scale)

The variation with strain of the stress for wire X is shown in Fig. 3.2.

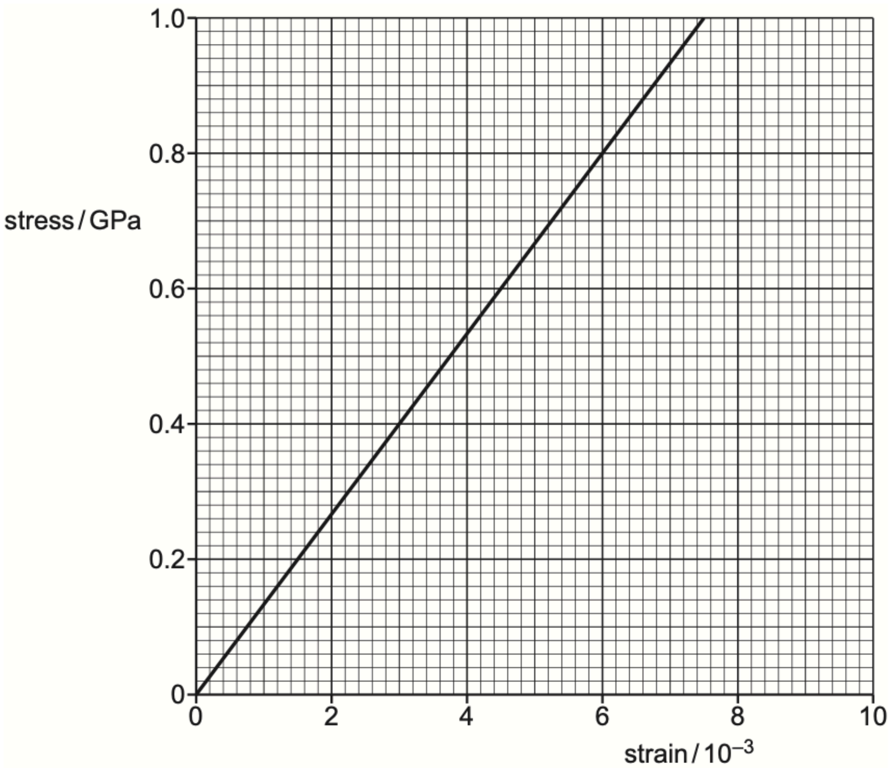


Fig. 3.2

(a) The strain in X is 5.4×10^{-3}.

(i) Use Fig. 3.2 to calculate the force exerted on the wire by the model planet.

force = ... N [3]

(ii) The elastic potential energy of X is 0.31 J.

Calculate the original length of the wire before the model planet was attached.

original length = ... m [3]

(b) Wire X is replaced by a new wire, Y, with the same original length and diameter but double the Young modulus of X. Wire Y also obeys Hooke's law.

On Fig. 3.2, draw a line representing the variation with strain of the stress for Y. [2]

[Total: 8]

8 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.

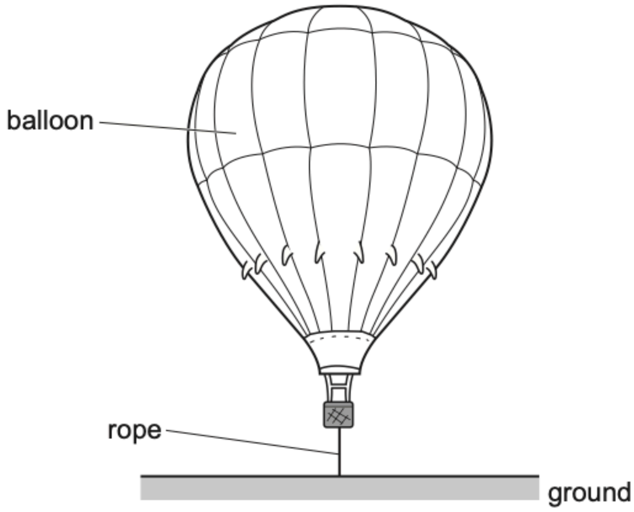


Fig. 2.1

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 $1.23\,\text{kg}\,\text{m}^{-3}$.

(a) **(i)** On Fig. 2.1, draw labelled arrows to show the directions of the three forces acting on the balloon. [2]

(ii) Calculate the volume, to three significant figures, of the balloon.

volume = ... m^3 [3]

(iii) The balloon is released from the rope.

Calculate the initial acceleration of the balloon.

acceleration = ... $\text{m}\,\text{s}^{-2}$ [3]

(b) The balloon is stationary at a height of 500 m above the ground. A tennis ball is released from rest and falls vertically from the balloon.

A passenger in the balloon uses the equation $v^2 = u^2 + 2as$ to calculate that the ball will be travelling at a speed of approximately $100\,\text{m}\,\text{s}^{-1}$ when it hits the ground.

Explain why the actual speed of the ball will be much lower than $100\,\text{m}\,\text{s}^{-1}$ when it hits the ground.

....

....

....

.... [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]

(ii) Calculate the elastic potential energy E_P of the rope.

E_P = ... J [2]

(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]

[Total: 16]

9 A vertical rod is fixed to the horizontal surface of a table, as shown in Fig. 3.1. **ON23/22/Q3**

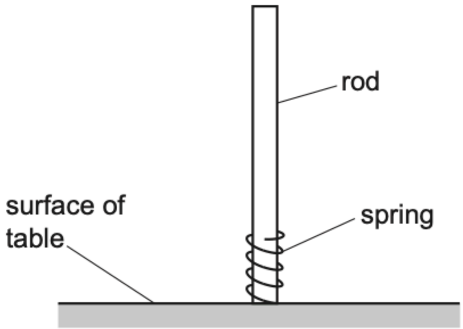


Fig. 3.1 (not to scale)

A spring of mass 7.5 g is able to slide along the full length of the rod.

The spring is first pushed against the surface of the table so that it has an initial compression of 2.1 cm. The spring is then suddenly released so that it leaves the surface of the table with a kinetic energy of 0.048 J and then moves up the rod.

Assume that the spring obeys Hooke's law and that the initial elastic potential energy of the compressed spring is equal to the kinetic energy of the spring as it leaves the surface of the table. Air resistance is negligible.

(a) By using the initial elastic potential energy of the compressed spring, calculate its spring constant.

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

(b) Calculate the speed of the spring as it leaves the surface of the table.

speed = ... $m s^{-1}$ [2]

(c) The spring rises to its maximum height up the rod from the surface of the table. This causes the gravitational potential energy of the spring to increase by 0.039 J.

(i) Calculate, for this movement of the spring, the increase in height of the spring after leaving the surface of the table.

increase in height = ... m [2]

(ii) Calculate the average frictional force exerted by the rod on the spring as it rises.

average frictional force = ... N [2]

(d) The rod is replaced by another rod that exerts negligible frictional force on the moving spring. The initial compression x of the spring is now varied in order to vary the maximum increase in height Δh of the spring after leaving the surface of the table. Assume that the spring obeys Hooke's law for all compressions.

On Fig. 3.2, sketch a graph to show the variation with x of Δh. Numerical values are not required.

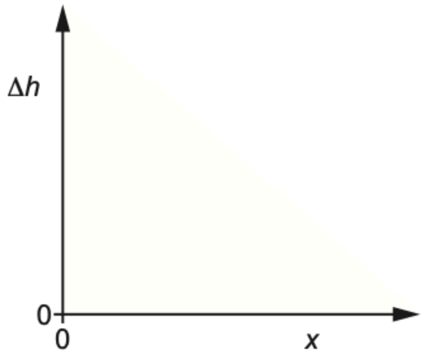


Fig. 3.2

[2]

[Total: 10]

10 Fig. 4.1 shows the variation with extension x of the tensile force F for two wires, G and H, made from the same material.

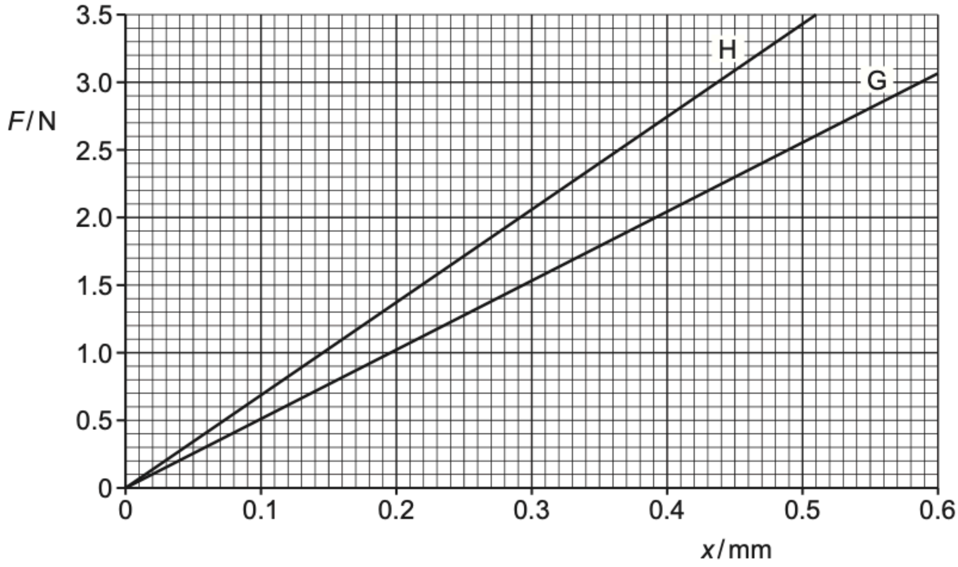


Fig. 4.1

The elastic limit has not been exceeded for G or H.

(a) For the lines in Fig. 4.1:

(i) state what is represented by the gradient

.... [1]

(ii) explain why the area under the line represents the elastic potential energy of the wire.

....

....

....

.... [2]

(b) Wires G and H are joined together end-to-end to form a composite wire of negligible weight. The composite wire hangs vertically from a fixed support.

A block of weight of 2.0 N is attached to the end of the wire, as shown in Fig. 4.2.

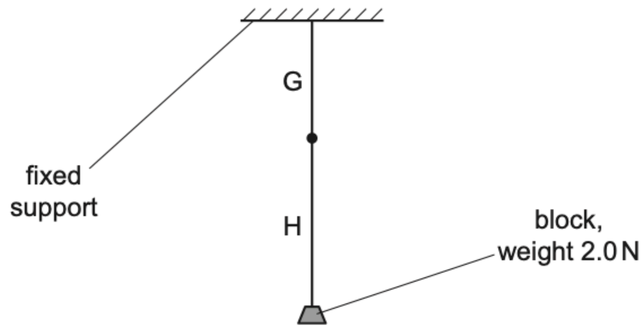


Fig. 4.2

(i) Use Fig. 4.1 to determine:

- the extension x_G of wire G

x_G = ... mm

- the extension x_H of wire H.

x_H = ... mm
[1]

(ii) Calculate the total elastic potential energy E_P of the composite wire due to the weight of the block.

E_P = ... J [2]

(iii) The original length of wire G is L and the original length of wire H is $1.5L$.

Calculate the ratio

$$\frac{\text{cross-sectional area of wire G}}{\text{cross-sectional area of wire H}}.$$

ratio = ... [3]

[Total: 9]

11 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.

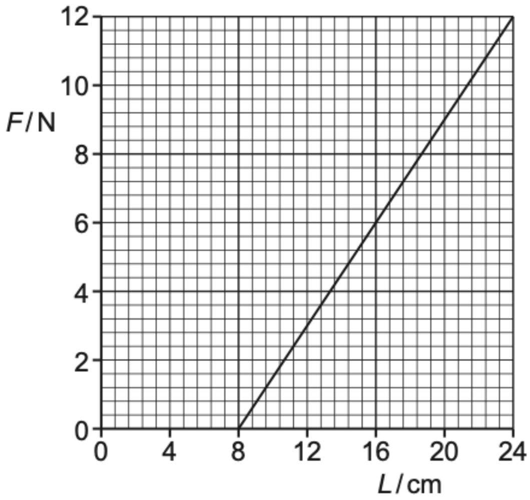


Fig. 4.1

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]

(c) determine the elastic potential energy when $F = 6.0 N$.

elastic potential energy = ... J [2]

[Total: 5]

12 **(a)** Define the Young modulus.

....

.... [1]

(b) A uniform wire is suspended from a fixed support. Masses are added to the other end of the wire, as shown in Fig. 6.1.

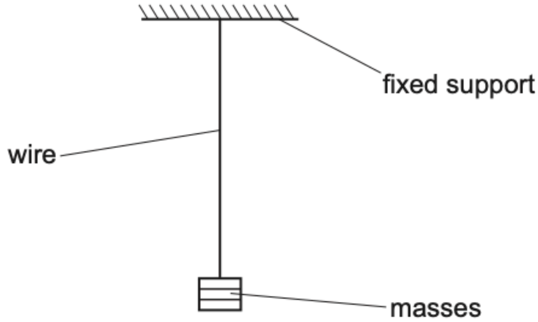


Fig. 6.1 (not to scale)

The variation of the length l of the wire with the force F applied to the wire by the masses is shown in Fig. 6.2.

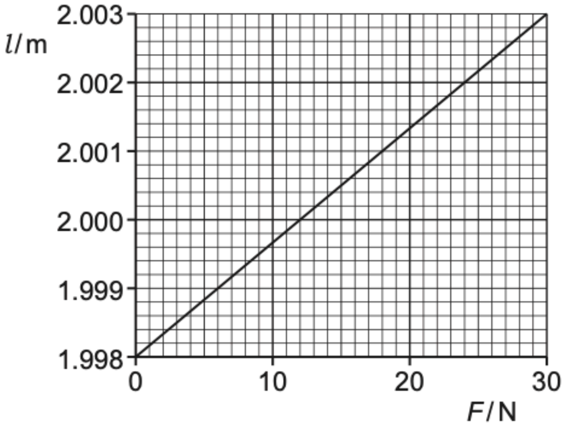


Fig. 6.2

The cross-sectional area of the wire is $0.95\,mm^2$.

(i) Determine the unstretched length of the wire.

unstretched length = ... m [1]

(ii) For an applied force F of 30 N, determine:

- the stress in the wire

stress = ... Pa

- the strain of the wire.

strain = ...
[3]

[Total: 5]

13 A motor uses a wire to raise a block, as illustrated in Fig. 2.1. **March23/22/Q2**

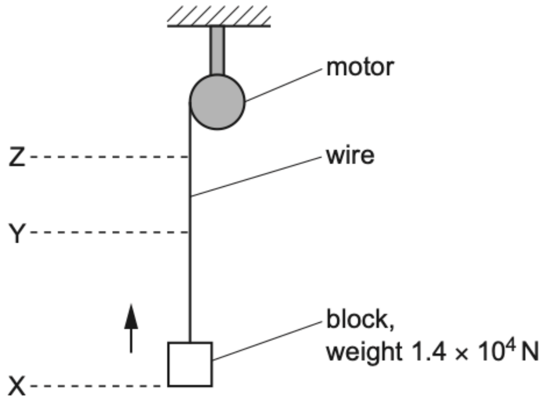


Fig. 2.1 (not to scale)

The base of the block takes a time of 0.49 s to move vertically upwards from level X to level Y at a constant speed of $0.64\,\text{m}\,\text{s}^{-1}$. During this time the wire has a strain of 0.0012. The wire is made of metal of Young modulus 2.2×10^{11} Pa and has a uniform cross-section.

The block has a weight of 1.4×10^{4} N. Assume that the weight of the wire is negligible.

(a) Calculate:

(i) the cross-sectional area *A* of the wire

A = ... m^2 [2]

(ii) the increase in the gravitational potential energy of the block for the movement of its base from X to Y.

increase in gravitational potential energy = ... J [3]

14 (b) A hollow plastic sphere is attached at one end of a bar. The sphere is partially submerged in water and the bar is attached to a fixed vertical support by a pivot P, as shown in Fig. 3.1.

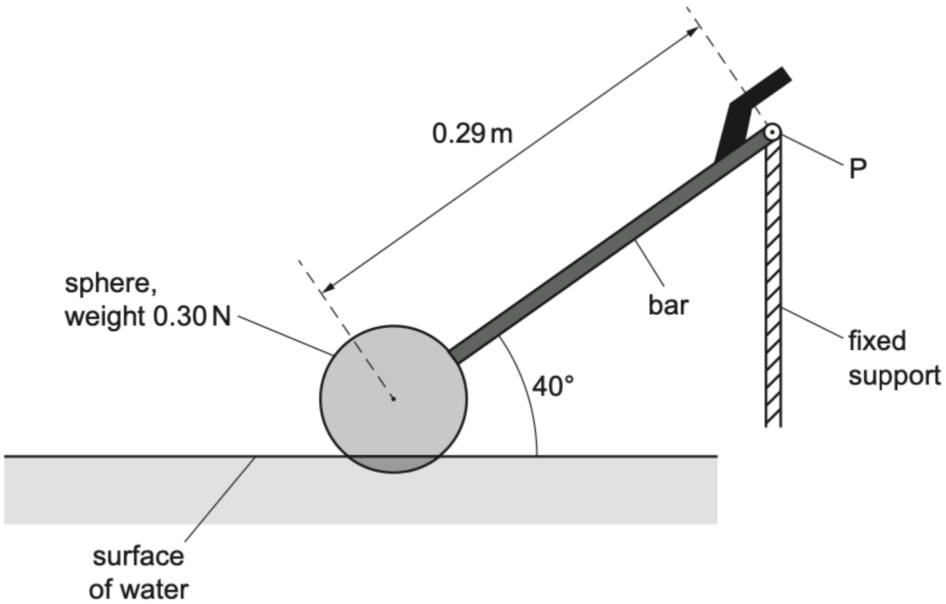


Fig. 3.1 (not to scale)

The sphere has weight 0.30 N. The distance from P to the centre of gravity of the sphere is 0.29 m. Assume that the weight of the bar is negligible.

Calculate the moment of the weight of the sphere about P.

moment = ... N m [2]

(c) The system shown in Fig. 3.1 is part of a mechanism that controls the amount of water in a tank.

Water enters the tank and causes the sphere to rise. This results in the bar becoming horizontal. Fig. 3.2 shows the system in its new position.

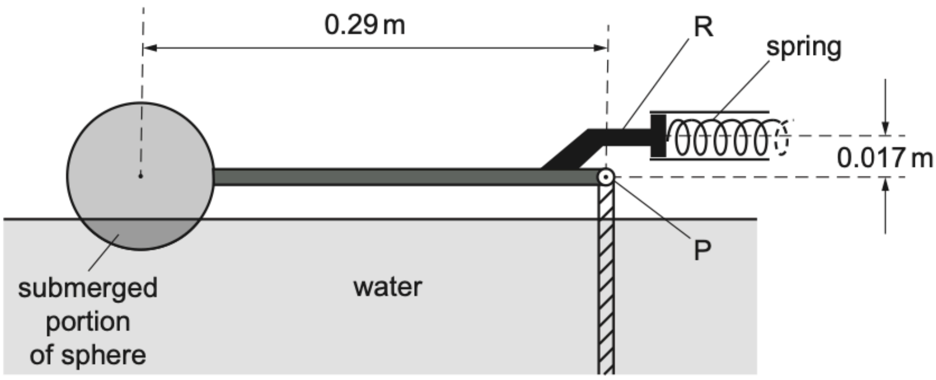


Fig. 3.2 (not to scale)

In this position the rod R exerts a force to compress a horizontal spring that controls the water supply to the tank. R is positioned at a perpendicular distance of 0.017 m above P.

The variation of the force F applied to the spring with compression x of the spring is shown in Fig. 3.3.

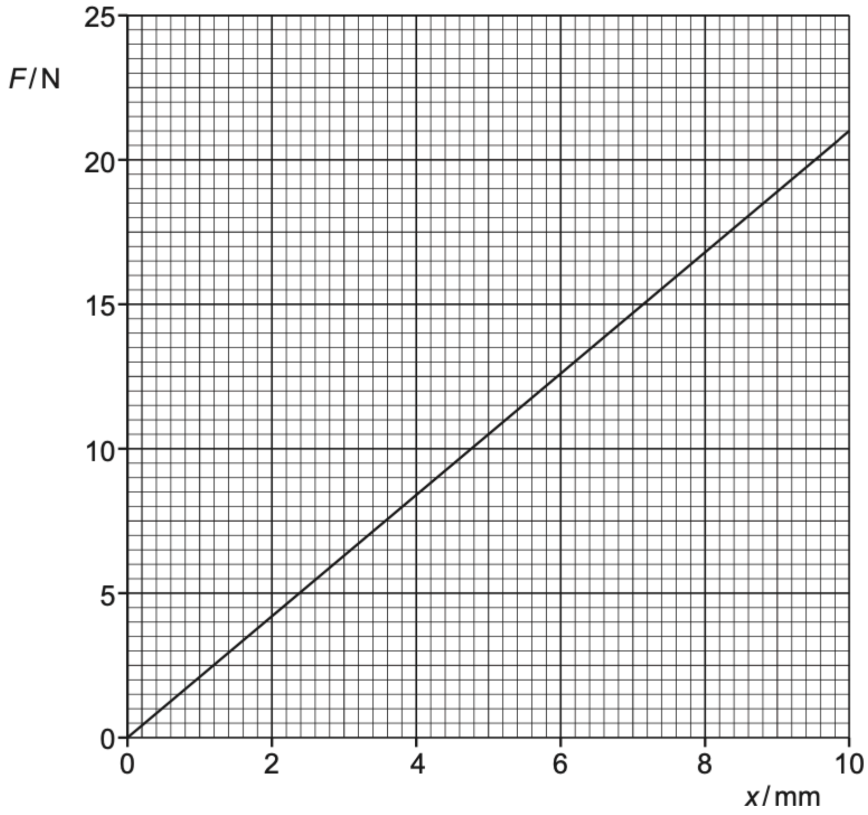


Fig. 3.3

(i) Use Fig. 3.3 to calculate the spring constant k of the spring.

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

(ii) At the position shown in Fig. 3.2, the system is stationary and in equilibrium.

The radius of the sphere is 0.0480 m and 26.0% of the volume of the sphere is submerged.
The density of water is $1.00 \times 10^{3}\,kg\,m^{-3}$.

Show that the upthrust on the sphere is 1.18 N.

[2]

(iii) By taking moments about P, determine the force exerted on the spring by the rod R.

force = ... N [2]

(iv) Calculate the elastic potential energy E_P of the compressed spring.

E_P = ... J [2]

(d) When the sphere moves from the position shown in Fig. 3.1 to the position shown in Fig. 3.2, the upthrust on the sphere does work.
Assume that resistive forces are negligible.

Explain why the work done by the upthrust is not equal to the gain in elastic potential energy of the spring.

....

.... [1]

15 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.

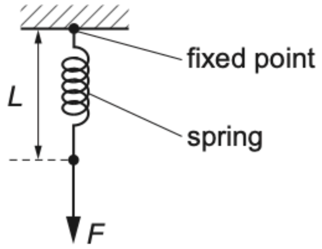


Fig. 4.1

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

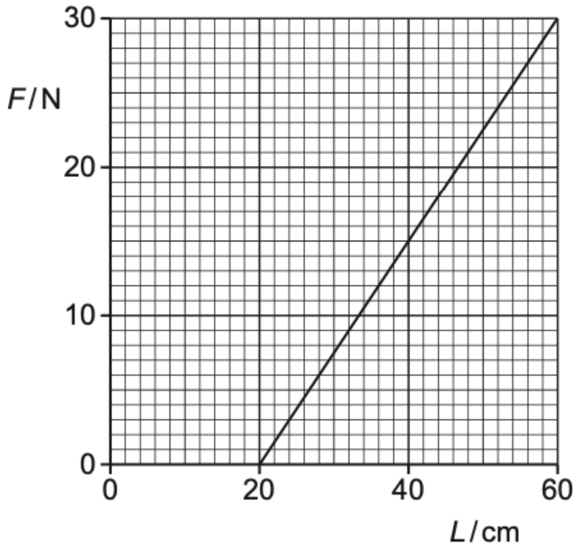


Fig. 4.2

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

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

(b) Determine the elastic potential energy in the spring when the applied force F is 15 N.

elastic potential energy = ... J [3]

[Total: 5]

16 A child moves down a long slide, as shown in Fig. 4.1.

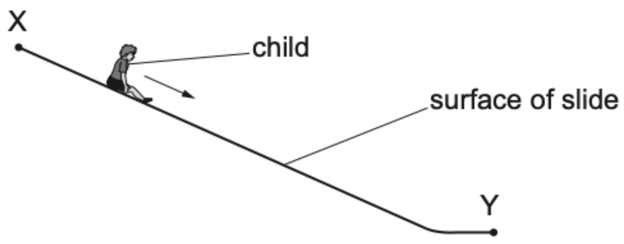


Fig. 4.1 (not to scale)

The child moves from rest at the top end X of the slide. An average resistive force of 76 N opposes the motion of the child as they move to the lower end Y of the slide. The kinetic energy of the child at Y is 300 J. The decrease in gravitational potential energy of the child as it moves from X to Y is 3200 J.

(a) Determine the ratio

$$\frac{\text{kinetic energy of the child at Y when the resistive force is 76 N}}{\text{kinetic energy of the child at Y if there is no resistive force}}.$$

ratio = ... [1]

(b) Use the answer in **(a)** to calculate the ratio

$$\frac{\text{speed of the child at Y when the resistive force is 76 N}}{\text{speed of the child at Y if there is no resistive force}}.$$

ratio = ... [2]

(c) Calculate the length of the slide from X to Y.

length = ... m [2]

(d) At end Y of the slide, the child is brought to rest by a board, as shown in Fig. 4.2.

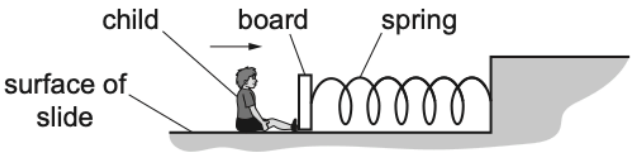


Fig. 4.2 (not to scale)

A spring connects the board to a fixed point. The spring obeys Hooke's law and has a spring constant of 63 N m^{-1}. The child hits the board so that it moves to the right and compresses the spring. The speed of the child becomes zero when the elastic potential energy of the spring has increased to its maximum value of 140 J.

(i) Calculate the maximum compression of the spring.

maximum compression = ... m [2]

(ii) Calculate the percentage efficiency of the transfer of the kinetic energy of the child to the elastic potential energy of the spring.

percentage efficiency = ... % [1]

(iii) The maximum compression of the spring is x_0. On Fig. 4.3, sketch a graph to show the variation of the elastic potential energy of the spring with its compression x from $x = 0$ to $x = x_0$. Numerical values are not required.

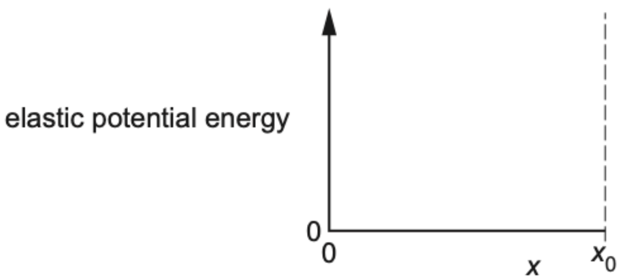


Fig. 4.3

[2]

[Total: 10]

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

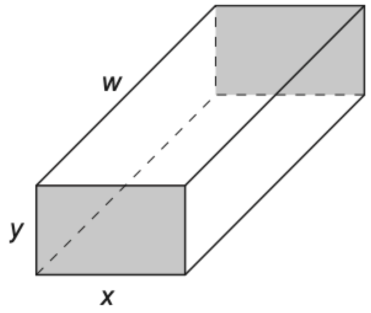


Fig. 3.1

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.

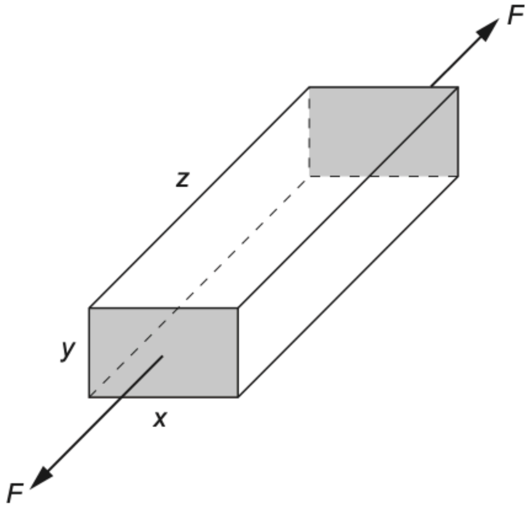


Fig. 3.2

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.

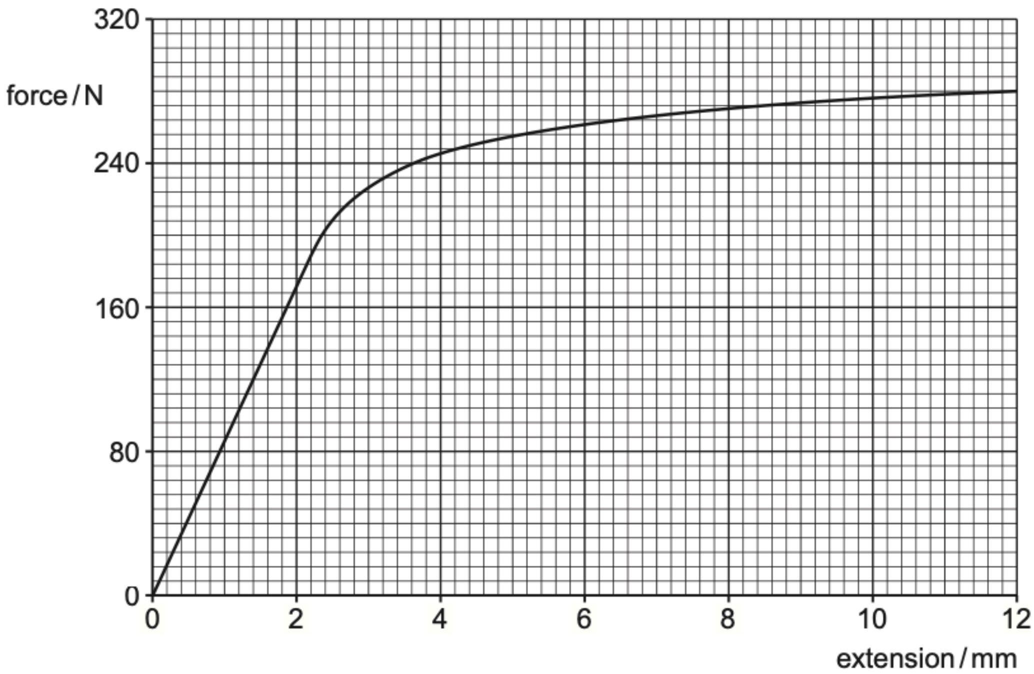


Fig. 3.3

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

extension = ... mm [1]

(ii) Use Fig. 3.3 to determine the strain energy in the wire when the tensile force is 120 N.

strain energy = ... J [3]

(iii) Explain why the work done in stretching the wire to an extension of 12 mm is not equal to the energy recovered when the tensile force is removed.

....

....

.... [2]

[Total: 10]

18 (a) Define, for a wire: **ON20/21/Q4**

(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.

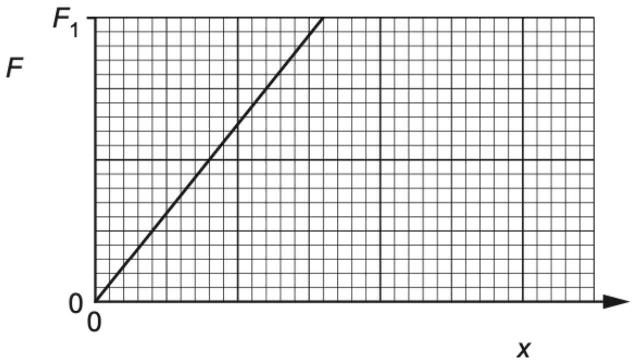


Fig. 4.1

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]

(iii) Another student repeats the original experiment in **(b)(i)**, increasing the force beyond F_1 to a new maximum force F_2. The new graph obtained is shown in Fig. 4.2.

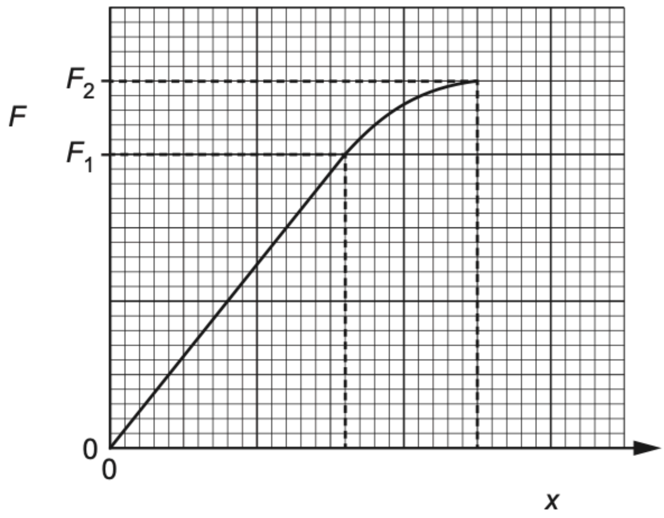


Fig. 4.2

1. On Fig. 4.2, shade an area that represents the work done to extend the wire when the force is increased from F_1 to F_2. [1]

2. Explain how the student can check that the elastic limit of the wire was not exceeded when force F_2 was applied.

 ....

 ....

 .... [1]

(iv) Each student in the class performs the experiment in **(b)(i)**. The teacher describes the values of the Young modulus calculated by the students as having high accuracy and low precision.

Explain what is meant by *low precision*.

....

.... [1]

[Total: 9]

19 (b) A wire hangs between two fixed points, as shown in Fig. 1.1.

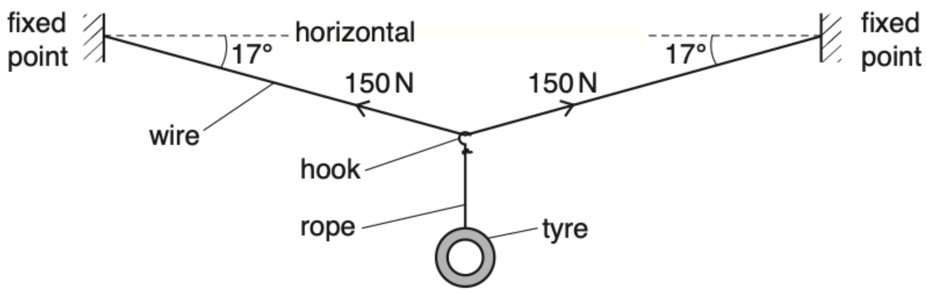


Fig. 1.1 (not to scale)

A child's swing is made by connecting a car tyre to the wire using a rope and a hook. The system is in equilibrium with the wire hanging at an angle of 17° to the horizontal. The tension in the wire is 150 N. Assume that the rope and hook have negligible weight.

(i) Determine the weight of the tyre.

weight = ... N [2]

(ii) The wire has a cross-sectional area of 7.5 mm^2 and is made of metal of Young modulus 2.1×10^{11} Pa. The wire obeys Hooke's law.

Calculate, for the wire,

1. the stress,

stress = ... Pa [2]

2. the strain.

strain = ... [2]

20 **(a)** Define the *Young modulus* of a material. **MJ18/23/Q4**

....

....[1]

(b) A metal rod is compressed, as shown in Fig. 4.1.

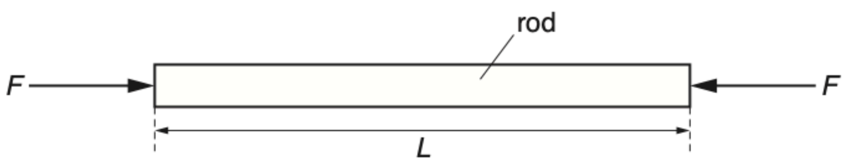


Fig. 4.1

The variation with compressive force F of the length L of the rod is shown in Fig. 4.2.

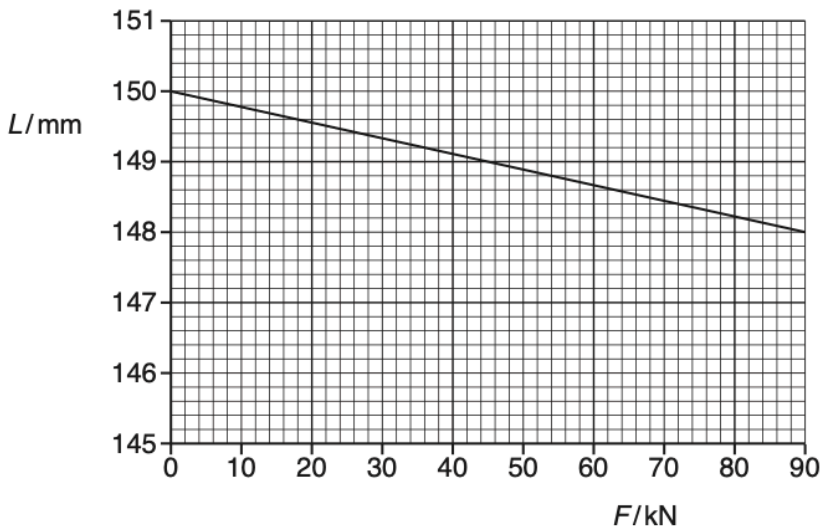


Fig. 4.2

Use Fig. 4.2 to

(i) determine the spring constant k of the rod,

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

(ii) determine the strain energy stored in the rod for $F = 90\,\text{kN}$.

strain energy = ... J [3]

(c) The rod in **(b)** has cross-sectional area A and is made of metal of Young modulus E. It is now replaced by a new rod of the same original length. The new rod has cross-sectional area $A/3$ and is made of metal of Young modulus $2E$. The compression of the new rod obeys Hooke's law.

On Fig. 4.2, sketch the variation with F of the length L for the new rod from $F = 0$ to $F = 90\,\text{kN}$. [2]

[Total: 8]

1 (a)	stress per unit strain	B1
4(b)(i)	straight line with positive gradient passing through origin	B1
4(b)(ii)	spring constant	B1
4(b)(iii)	elastic potential energy (stored in wire)	B1
4(c)	length (of Q) is half (the length of P)	B1
	extension is proportional to length, and inversely proportional to area and Young modulus	B1
	extension of Q is $= \frac{1}{2} / (2 \times 2)$ $= \frac{1}{8}$ times the extension of P	B1

2 (a)(i)	$E = \sigma / \varepsilon$ **or** E = gradient	C1
	E = e.g. $12 \times 10^7 / 0.0050$ $= 2.4 \times 10^{10}$ Pa	A1
3(a)(ii)	cross drawn at (1.0%, 24×10^7 Pa), labelled Q	B1
3(b)	resultant force (in any direction) is zero	B1
	resultant moment / torque (about any point) is zero	B1
3(c)(i)	(moment =) $33 \times 0.65 / 2$ **or** $1.5 \times (0.65 - 0.12)$ **or** $T \sin 50° \times (0.65 / 2)$	C1
	sum of clockwise moments = sum of anticlockwise moments $33 \times (0.65 / 2) + 1.5 \times (0.65 - 0.12) = T \sin 50° \times (0.65 / 2)$	C1
	tension = 46 N	A1
3(c)(ii)	$\sigma = F / A$	C1
	$\pi r^2 = 46 / (1.5 \times 10^7)$ $r = 9.9 \times 10^{-4}$ m	A1
3(c)(iii)	elastic limit is not reached **or** (new) stress is less than (stress at) elastic limit **or** (new) strain is less than (strain at) elastic limit	M1
	(so the wire behaves) elastically	A1

3 (a)(i)	(normal) force per unit cross-sectional area	B1
4(a)(ii)	extension per unit unstretched length	B1
4(b)(i)	$E = FL / Ax$	C1
	$A = (9.0 \times 0.84) / (1.9 \times 10^9 \times 0.47 \times 10^{-3})$	C1
	$= 8.5 \times 10^{-6}$ m^2	A1
4(b)(ii)	F, L and x are all the same (for both wires / as in X) **or** F and strain are the same	B1
	A is greater (for Y), so the Young modulus (for Y) is less than 1.9×10^9 Pa **or** less than that of wire X	B1

4(a)	extension / original length	B1
4(b)(i)	Young modulus = stress / strain	C1
	$= (18 / 4.5 \times 10^{-7}) / (1.4 \times 10^{-3} / 4.0)$	C1
	$= (4.0 \times 10^{7}) / (3.5 \times 10^{-4})$ $= 1.1 \times 10^{11}$ Pa	A1
4(b)(ii)	straight line through the origin	B1
	ending at the point (3.5, 4.0)	B1
4(c)	see table below	B2

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

5(a)	$E = ½kx^2$ **or** $E = ½Fx$ **and** $F = kx$	C1
	$E = ½ \times 29 \times (8.0 \times 10^{-2})^2$ **or** $E = ½ \times 2.32 \times 8.0 \times 10^{-2}$ $E = 9.3 \times 10^{-2}$ J	A1
4(b)(i)	$(\Delta)E_{(P)} = mg(\Delta)h$	C1
	$= 4.5 \times 10^{-2} \times 9.81 \times 8.0 \times 10^{-2} \sin 15°$	C1
	$= 9.1 \times 10^{-3}$ J	A1
4(b)(ii)	$E_{(K)} = ½mv^2$	C1
	$(9.3 \times 10^{-2} - 9.1 \times 10^{-3}) = ½ \times 4.5 \times 10^{-2} \times v^2$	C1
	$v = (2 \times 8.4 \times 10^{-2} / 4.5 \times 10^{-2})^{0.5}$ $= 1.9$ m s^{-1}	A1
4(c)(i)	$1.7 \times 2.0\ (\times 10^{-2})$ **or** $4.5 \times 10^{-2} \times 9.81 \times d$	C1
	$1.7 \times 2.0 \times 10^{-2} = 4.5 \times 10^{-2} \times 9.81 \times d$ $d = 7.7 \times 10^{-2}$ m	A1
4(c)(ii)	clockwise	B1

6(a)	extension is proportional to (applied) force	B1
3(b)(i)	P at (60, 5.4)	A1
3(b)(ii)	E at (80, 5.9)	A1
3(c)(i)	$k = F / x$ **or** k = gradient of (straight line section of) graph	C1
	e.g. gradient = 5.4 / 0.060 $k = 90$ N m^{-1}	A1
3(c)(ii)	Young modulus or $E = \sigma / \varepsilon$ **or** FL / Ax **or** kL / A	C1
	$E = (5.4 \times 3.2) / (4.0 \times 10^{-7} \times 0.06)$ **or** $90 \times 3.2 / (4.0 \times 10^{-7})$	C1
	$E = 7.2 \times 10^{8}$ Pa	A1
3(d)	work done = area under graph	B1
	$= (1.0 \pm 0.2)$ J	A1
3(e)	the extension will be smaller (for the same force on the thicker sample) **or** a greater force is required (to extend the thicker sample by the same amount) **or** spring constant is proportional to area	M1
	the spring constant (of the second sample) will be greater	A1

7 (a)(i)	$\sigma = 0.72 \times 10^9$	**C1**
	force $= \sigma \times A$ $= 0.72 \times 10^9 \times \pi \times (1.2 \times 10^{-3} / 2)^2$	**C1**
	$= 810$ N	**A1**
	or Young modulus = gradient of graph e.g. $= 0.80 \times 10^9 / 6.0 \times 10^{-3}$ $= 1.33 \times 10^{11}$	**(C1)**
	force = Young modulus × strain × A $= 1.33 \times 10^{11} \times 5.4 \times 10^{-3} \times \pi \times (1.2 \times 10^{-3} / 2)^2$	**(C1)**
	$= 810$ N	**(A1)**
3(a)(ii)	$E_{(P)} = ½ Fx$ or $E_{(P)} = ½ kx^2$ **and** $F = kx$	**C1**
	$x = 2E_P / F$ $x = 2 \times 0.31 / 810$ $x = 7.7 \times 10^{-4}$	**C1**
	$L = x / \varepsilon$ $L = 7.7 \times 10^{-4} / 5.4 \times 10^{-3}$ $L = 0.14$ m	**A1**
	or $E_{(P)} = ½ Fx+$ or $E_{(P)} = ½ kx^2$ **and** $k = EA/L$	**(C1)**
	$x = 2E_P / EA\,\varepsilon$ $x = 2 \times 0.31 / (1.33 \times 10^{11} \times \pi \times (1.2 \times 10^{-3} / 2)^2 \times 5.4 \times 10^{-3})$ $x = 7.6 \times 10^{-4}$	**(C1)**
	$L = x / \varepsilon$ $L = 7.6 \times 10^{-4} / 5.4 \times 10^{-3}$ $L = 0.14$ m	**(A1)**
3(b)	A straight line, passing through the origin with a larger gradient than wire X.	**M1**
	Gradient of the line is twice the gradient of wire X.	**A1**

8 (a)(i)	arrow upwards (↑) **and** labelled upthrust / U arrow downwards (↓) **and** labelled weight / W / mg arrow downwards (↓) **and** labelled tension / T *1 mark: One or two correctly labelled arrows* *2 marks: Three correctly labelled arrows*	**B2**
2(a)(ii)	$U = T + W$ **or** upthrust = tension + weight	**C1**
	$\rho Vg = T + W$ $V = [(4.00 \times 10^2) + (3.39 \times 10^4)] / (1.23 \times 9.81)$	**C1**
	$V = 2.84 \times 10^3$ m^3	**A1**
2(a)(iii)	$m = W / g$ **or** $a = F / m$	**C1**
	$a = (4.00 \times 10^2) / [(3.39 \times 10^4) / 9.81)]$	**C1**
	$a = 0.12$ m s^{-2}	**A1**
2(b)	there is air resistance (which increases with speed)	**B1**
	(average) resultant force is less (than weight)	**B1**
	(average) acceleration is less (than g / 9.81, so speed is less than 100 m s^{-1})	**B1**
2(c)(i)	(extension =) $2.5 \times 2.4 \times 10^{-5} = 6.0 \times 10^{-5}$ (m)	**A1**

2(c)(ii)	$E_{(P)} = ½ Fx$ **or** $E_{(P)} = ½ kx^2$ **and** $F = kx$	C1
	$E_{(P)} = ½ \times 4.00 \times 10^2 \times 6.0 \times 10^{-5}$ **or** $E_{(P)} = ½ \times 6.7 \times 10^6 \times (6.0 \times 10^{-5})^2$ $E_{(P)} = 0.012$ J	A1
2(c)(iii)	longer extension **or** smaller spring constant	M1
	elastic potential energy is greater	A1

9 (a)	$E_{(P)} = ½kx^2$ **or** $E_{(P)} = ½Fx$ **and** $F = kx$	C1
	$0.048 = ½ \times k \times (2.1 \times 10^{-2})^2$ $k = 220$ N m^{-1}	A1
3(b)	$E_{(K)} = ½mv^2$	C1
	$0.048 = ½ \times 7.5 \times 10^{-3} \times v^2$ $v = 3.6$ m s^{-1}	A1
3(c)(i)	$(\Delta)E = mg(\Delta)h$	C1
	$0.039 = 7.5 \times 10^{-3} \times 9.81 \times (\Delta)h$ $\Delta h = 0.53$ m	A1
3(c)(ii)	$F \times 0.53 = 0.048 - 0.039$	C1
	$F = 0.02$ N	A1
3(d)	sketch: curved line from the origin	M1
	curved line has increasing gradient	A1

10 (a)(i)	spring constant	B1
4(a)(ii)	area represents the work done (to extend the wire)	B1
	work done (to extend the wire) is equal to elastic potential energy	B1
4(b)(i)	$x_G = 0.39$ mm **and** $x_H = 0.29$ mm	A1
4(b)(ii)	$E = ½Fx$ **or** $E = ½kx^2$ **and** $F = kx$ **or** E = area under graph	C1
	for G: $E = ½ \times 2.0 \times (0.39 \times 10^{-3})$ **or** $½ \times 5.1 \times 10^3 \times (0.39 \times 10^{-3})^2$ for H: $E = ½ \times 2.0 \times (0.29 \times 10^{-3})$ **or** $½ \times 6.9 \times 10^3 \times (0.29 \times 10^{-3})^2$ $E_P = 3.9 \times 10^{-4} + 2.9 \times 10^{-4}$ $= 6.8 \times 10^{-4}$ J	A1
4(b)(iii)	$E = FL / Ax$ **or** stress / strain $= FL / Ax$	C1
	$A_G / A_H = 1 \times (0.29 \times 10^{-3}) / [1.5 \times (0.39 \times 10^{-3})]$	C1
	ratio = 0.50	A1

11 (a)	Hooke's (law)	**B1**
4(b)	$k = F / x$ **or** k = gradient	**C1**
	= e.g. 12.0 / (0.240 – 0.08) = 75 N m^{-1}	**A1**
4(c)	$E = \frac{1}{2}Fx$ **or** $E = \frac{1}{2}kx^2$ **or** E = area under graph	**C1**
	$E = \frac{1}{2} \times 6.0 \times 0.080$ **or** $\frac{1}{2} \times 75 \times 0.08^2$ = 0.24 J	**A1**

12 (a)	(Young modulus =) stress / strain	**B1**
6(b)(i)	unstretched length = 1.9980 m	**A1**
6(b)(ii)	stress = F / A	**C1**
	= 30 / 9.5 × 10^{-7} = 3.2 × 10^7 Pa	**A1**
	strain = 0.0050 / 1.9980 = 2.5 × 10^{-3}	**A1**

13 a)(i)	$E = \sigma / \varepsilon$ **or** $E = F / A\varepsilon$	**C1**
	A = 1.4 × 10^4 / (2.2 × 10^{11} × 0.0012) = 5.3 × 10^{-5} m^2	**A1**
2(a)(ii)	$(\Delta)h$ = 0.64 × 0.49 (= 0.3136)	**C1**
	$(\Delta)E = mg(\Delta)h$ **or** $W(\Delta)h$	**C1**
	= 1.4 × 10^4 × 0.64 × 0.49 = 4.4 × 10^3 J	**A1**

14 (b)	moment = 0.3(0) × 0.29 cos 40° **or** 0.3(0) × 0.222	**C1**
	= 0.067 N m	**A1**
3(c)(i)	$k = F / x$ **or** k = gradient	**C1**
	e.g. k = 21 / 10 × 10^{-3} k = 2100 N m^{-1}	**A1**
3(c)(ii)	$V_{(sphere)} = \frac{4}{3} \times \pi \times (0.0480)^3$	**C1**
	$F = \rho g V$ (upthrust =) 1000 × 9.81 × ($\frac{4}{3}$ × π × $(0.048)^3$) × 0.26(0) = 1.18 (N)	**A1**
3(c)(iii)	1.18 × 0.29 **or** 0.30 × 0.29 **or** F × 0.017	**C1**
	(1.18 × 0.29) = (0.30 × 0.29) + (F × 0.017) F = 15 N	**A1**

3(c)(iv)	$E_{(P)} = ½kx^2$ **or** $E_{(P)} = ½Fx$	C1
	$x = F / k = 15 / 2100$ **or** x determined from graph for $F = 15.0$ N $E_P = ½ \times 2100 \times (15 / 2100)^2$ **or** $E_P = ½ \times 15 \times (15 / 2100)$ $E_P = 0.054$ J	A1
3(d)	the <u>sphere</u> has gained gravitational potential energy	B1

15 a)	$k = F / \Delta L$ **or** F / x **or** gradient	C1
	= e.g. 30 / (0.60 – 0.20) = 75 N m^{-1}	A1
4(b)	$E = \frac{1}{2}F\Delta L$ **or** $\frac{1}{2}Fx$ **or** $\frac{1}{2}k(\Delta L)^2$ **or** $\frac{1}{2}kx^2$ **or** area under graph	C1
	$= \frac{1}{2} \times 15 \times 0.20$ **or** $\frac{1}{2} \times 75 \times 0.20^2$	C1
	= 1.5 J	A1

16 (a)	ratio = 300 / 3200 = 0.094	A1
4(b)	$E = ½mv^2$ or $E \propto v^2$	C1
	ratio = $(0.094)^{0.5}$ = 0.31	A1
4(c)	work (done against frictional force) = 3200 – 300 (=2900)	C1
	length = 2900 / 76 = 38 m	A1
4(d)(i)	$E = ½kx^2$ or $E = ½Fx$ <u>and</u> $F = kx$ $140 = ½ \times 63 \times x^2$ or $140 = ½Fx$ <u>and</u> $F = 63x$	C1
	$x = 2.1$ m	A1
4(d)(ii)	percentage efficiency = (140 / 300) × 100 = 47%	A1
4(d)(iii)	curved line from the origin	M1
	gradient of line increases	A1

17 (a)(i)	$\sigma = F / xy$	B1
3(a)(ii)	$\varepsilon = (z - w) / w$	B1
3(a)(iii)	$E = \sigma / \varepsilon$	C1
	$= Fw / xy(z - w)$	A1
3(b)(i)	extension = 2.2 mm (*allow* 2.0–2.4 mm)	A1
3(b)(ii)	strain energy = area under graph/line **or** $½Fx$ **or** $½kx^2$	C1
	$= ½ \times 120 \times 1.4 \times 10^{-3}$ **or** $½ \times 8.6 \times 10^4 \times (1.4 \times 10^{-3})^2$	C1
	= 0.084 J	A1
3(b)(iii)	(some of the) deformation of the wire is plastic/permanent/not elastic **or** wire goes past the elastic limit/enters plastic region	B1
	energy (that cannot be recovered) is dissipated as thermal energy/becomes internal energy	B1

18 (a)(i)	(stress =) force / cross-sectional area	**B1**
4(a)(ii)	(strain =) extension / original length	**B1**
4(b)(i)	$E = FL / Ax$	**C1**
	$= GL / A$	**A1**
4(b)(ii)	straight line from origin above the original line	**M1**
	line ends at point (4 small squares, F_1).	**A1**
4(b)(iii)	**1.** shaded area below the graph line and between the two vertical dashed lines	**B1**
	2. remove the force/F/F_2 and the wire goes back to original length/zero extension	**B1**
4(b)(iv)	values have a large range	**B1**

19 (b)(i)	$W = 2 \times (150 \times \sin 17°)$ **or** $2 \times (150 \times \cos 73°)$	**C1**
	$W = 88\,\text{N}$	**A1**
1(b)(ii)	**1.** $\sigma = F / A$	**C1**
	$= 150 / (7.5 \times 10^{-6})$ $= 2.0 \times 10^{7}\,\text{Pa}$	**A1**
	2. $\varepsilon = \sigma / E$	**C1**
	$= 2.0 \times 10^{7} / (2.1 \times 10^{11})$ $= 9.5 \times 10^{-5}$	**A1**

20 (a)	(Young modulus =) stress / strain	**B1**
4(b)(i)	$k = F / \Delta L$ **or** 1 / gradient	**C1**
	$= 90 \times 10^{3} / (2 \times 10^{-3})$ (*or other point on line*) $= 4.5 \times 10^{7}\,\text{N m}^{-1}$	**A1**
4(b)(ii)	$E = ½F\Delta L$ **or** $E = ½k(\Delta L)^2$	**C1**
	$= ½ \times 90 \times 10^{3} \times 2 \times 10^{-3}$ **or** $½ \times 4.5 \times 10^{7} \times (2 \times 10^{-3})^2$	**C1**
	$= 90\,\text{J}$	**A1**
4(c)	straight line starting from (0, 150) and below original line	**M1**
	line ends at (90, 147)	**A1**