



UNDERSTAND



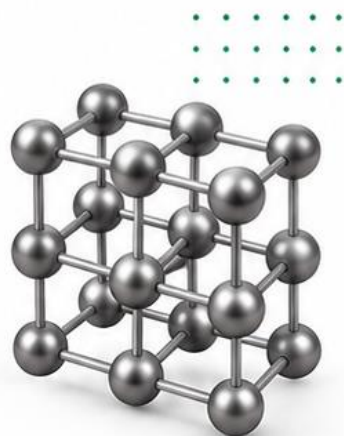
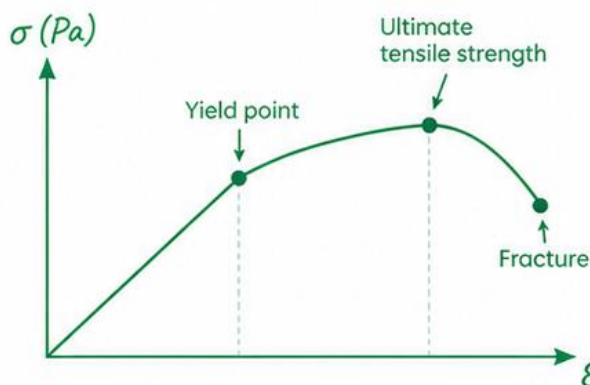
APPLY



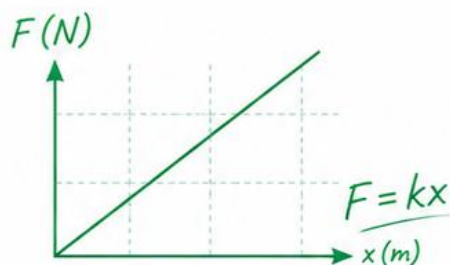
PRACTISE



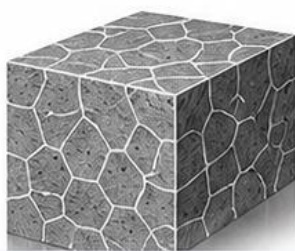
IMPROVE



Materials



$$E = \frac{\text{stress}}{\text{strain}} = \frac{\Delta L}{L}$$



OWNER DETAILS



NAME:

GROUP:

TEACHER:





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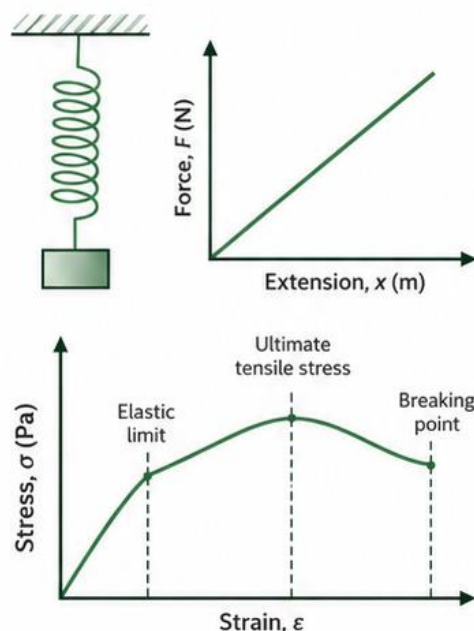
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Built by a UK physics teacher and examiner.

Welcome to the Materials workbook

This book is here to help you build a secure understanding of the Materials section of OCR A A-level Physics. You will practise the key maths carefully, develop your ability to explain the ideas, and apply your knowledge to a range of exam-style questions.

You will be expected to **think, sketch, calculate and explain** throughout this book.



What this book includes



Springs

Deformation, tension and compression, Hooke's law, force constant, force-extension graphs, energy stored in springs, springs in series and parallel.



Stress-strain graphs

Brittle, ductile and polymeric materials, ultimate tensile stress, elastic limit and breaking point.



Checks for understanding

Short multiple-choice questions to test key ideas and calculations.



Practical work

Investigations such as loading and unloading materials and determining Young modulus.



Mechanical properties of matter

Stress, strain, Young modulus, elastic and plastic behaviour.



Teacher modelling pages

Worked examples, diagrams, discussion prompts and space for notes.



Exam-style questions

Structured questions to build confidence with OCR A style problems.



Ratio and comparison questions

Mathematically demanding problems that compare materials, wires and extensions.

How to use this book

- 1 Complete diagrams and graphs carefully.
- 2 Show your working clearly in calculations.
- 3 Use the modelling pages to improve your written explanations.
- 4 Use the check questions to spot gaps early.
- 5 Return to difficult pages and improve your answers after feedback.

“Take your time with the maths in this topic. If you can explain what the equations mean, the calculations become much easier.”



5-A-Day

Define each of the following:

1. Upthrust
2. Work done
3. The newton (N)
4. Power
5. The watt (W)

5-A-Day

Use $g = 9.81 \text{ m s}^{-2}$. Assume light springs that obey Hooke's law.

1. Define the term spring constant.
2. State Hooke's law, including the condition under which it applies.
3. A 200 g mass hangs at rest from a vertical spring, extending it by 14 cm. Calculate the spring constant.
4. Sketch spring length against suspended mass, with length on the vertical axis. Show the intercept at zero mass.
5. A second spring has twice the spring constant of the first. A 100 g mass hangs at rest from it. Calculate its extension.

5-A-Day

Use $g = 9.81 \text{ m s}^{-2}$. Assume light, uniform springs that obey Hooke's law.

1. Two identical springs, each of spring constant 15 N m^{-1} , are connected in parallel. Calculate their effective spring constant.
2. The two whole springs are reconnected in series. Calculate their effective spring constant.
3. A 300 g mass hangs at rest from the springs in series. Calculate the total extension.
4. One original spring is cut into two equal halves. These halves support a 300 g mass at rest in parallel. Calculate their common extension.
5. The other whole spring supports a 300 g mass vertically. The mass is pulled down until the spring's total extension is 30 cm, then released from rest. Calculate its initial acceleration.

5-A-Day

Use $g = 9.81 \text{ m s}^{-2}$. Assume a light spring that obeys Hooke's law and no air resistance.

1. A 250 g mass hangs at rest from a vertical spring of spring constant 13 N m^{-1} . Calculate the extension.
2. Calculate the elastic potential energy (EPE) stored at this extension.
3. The mass is pulled slowly down to a greater extension and held at rest. Explain how the EPE changes.
4. The mass is released from rest. Describe the changes in EPE, gravitational potential energy and kinetic energy as it accelerates upwards towards equilibrium.
5. Calculate the EPE stored when the spring's total extension is 15 cm.

5-A-Day

Assume the beam remains in the linear elastic region.

1. Define tensile stress.
2. Define tensile strain.
3. A metal beam has a cross-sectional area of 25 cm^2 . A tensile force of 260 kN stretches it. Calculate the stress.
4. The beam has an original length of 3.2 m and extends by 2.5 mm under this force. Calculate the strain.
5. Calculate the Young's modulus of the beam's material.

5-A-Day

Assume all wires are uniform, their weight is negligible and they remain in the linear elastic region.

1. A copper wire of Young's modulus 110 GPa has a tensile strain of 0.00012. Calculate the tensile stress.
2. The wire has a radius of 0.70 mm. Calculate the tensile force producing this stress.
3. A second copper wire has twice the radius and carries the same tensile force as in Q2. Compare its stress and Young's modulus with those of the first wire.
4. Wires A and B have the same radius and are made of the same metal. Each supports a mass at rest. A's original length is twice B's, but A supports half the mass. Calculate extension of A / extension of B.
5. Wire B extends by 4.0 mm. Calculate the extension of wire A.

5-A-Day

1. Define elastic deformation and plastic deformation.
2. Sketch a tensile stress–strain graph for a brittle material, up to fracture. Put stress on the vertical axis and label the curve B.
3. On the same axes, add a curve for a ductile material, up to fracture. Label it D.
4. Add a curve for another brittle material with a higher Young’s modulus than B. Label it Y.
5. Mark X on curve D at its elastic limit, where plastic deformation begins.

5-A-Day

Assume both springs obey Hooke's law.

1. State the equation for Young's modulus and define each symbol.
2. State Hooke's law, including the condition under which it applies.
3. The first spring has a spring constant of 250 N m^{-1} . Calculate its extension when a tensile force of 120 N is applied.
4. Name the energy stored in the first spring and calculate its value at this extension.
5. The second spring extends by half as much under twice the force. Calculate k_1/k_2 , where k_1 and k_2 are the spring constants of the first and second springs.

5-A-Day - Recall

Use $g = 9.81 \text{ m s}^{-2}$. Ignore air resistance on the projectile.

1. Define velocity and acceleration.
2. A projectile is launched at 8.0 m s^{-1} at 25° above the horizontal and lands at its launch height. Calculate its horizontal range.
3. Explain why the projectile's horizontal velocity remains constant during flight.
4. A 750 kg car travels at 5.0 m s^{-1} on a level road. A net work of 1200 J is done on it. Calculate its new speed.
5. The car then stops over 45 m on the same road. Assuming braking provides the only horizontal force, calculate the average braking force.

3.4.1 Springs



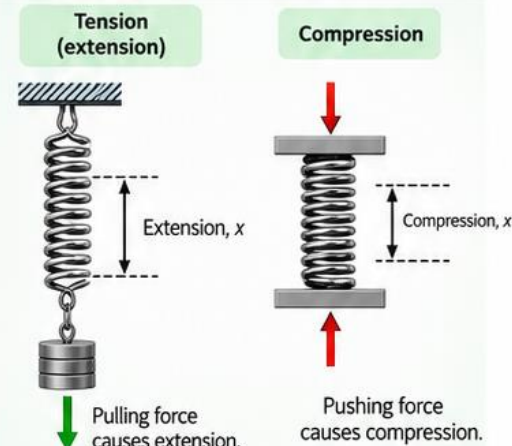
From deformation
to Hooke's law

Learning outcomes

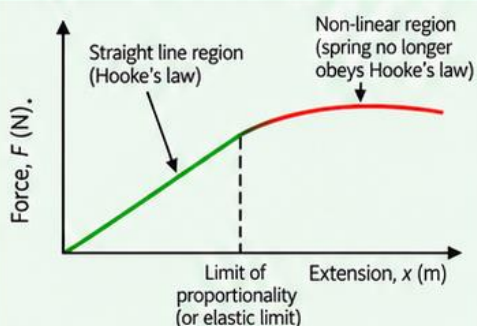
Learners should be able to demonstrate and apply their knowledge and understanding of:

- (a) tensile and compressive deformation; extension and compression
- (b) Hooke's law
- (c) force constant k of a spring or wire; $F = kx$
- (d) (i) force–extension (or compression) graphs for springs and wires
- (ii) techniques and procedures used to investigate force–extension characteristics for arrangements which may include springs, rubber bands, polythene strips.

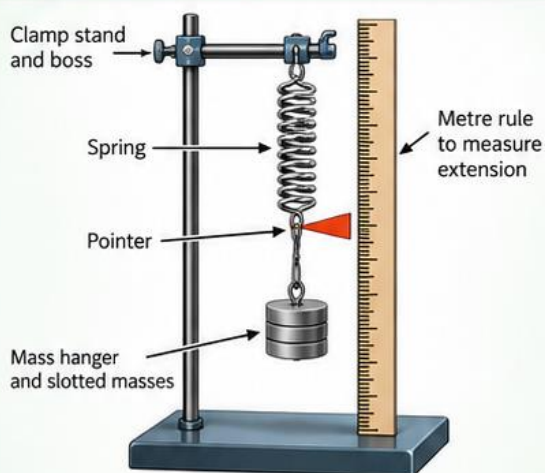
Tension and compression



Force–extension graph



Experimental setup



Different materials

Metal spring



Usually shows a straight-line force–extension graph (elastic behaviour).

Rubber band



Non-linear graph; extension increases more rapidly as force increases.

Polythene strip (or wire)



Non-linear graph; different behaviour to a metal spring.

Key idea 1



Hooke's law ($F = kx$) only applies while extension is directly proportional to force (straight-line region).

Key idea 2



The gradient of a force–extension graph equals the spring constant k (in N m^{-1}). A steeper gradient means a stiffer spring.

Key idea 3



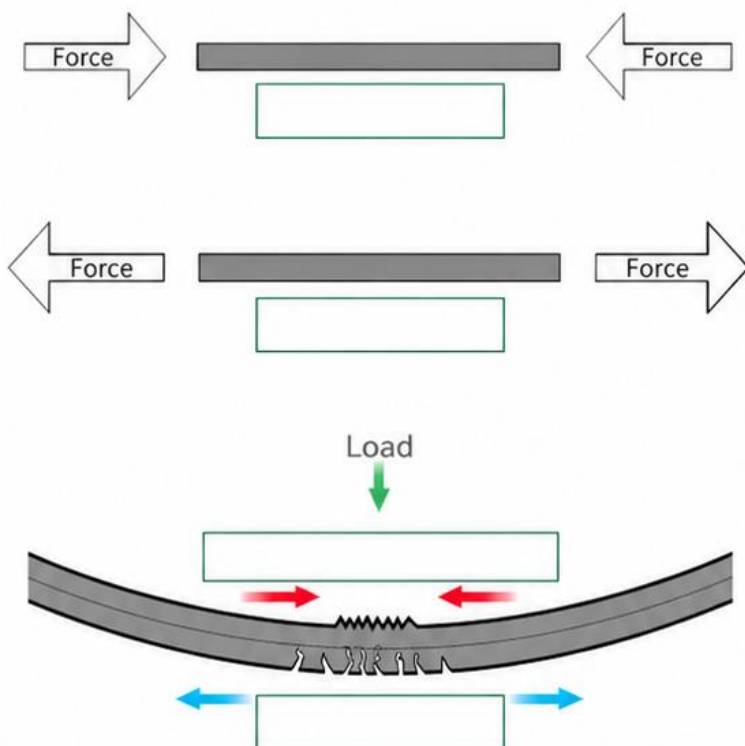
Different materials show different force–extension behaviour, for example springs, rubber bands and polythene strips.



Tension and compression

1 Labelling tension and compression

Label the following with the terms 'tension' and 'compression'.



Key ideas

Tension

A force that pulls a material, trying to stretch it and increase its length.

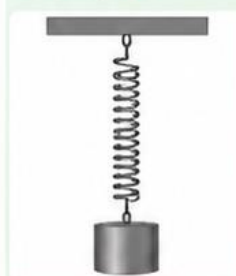


Compression

A force that pushes a material, trying to shorten it and decrease its length.



Examples



Springs in tension are stretched.



Springs in compression are squashed.

2 Check your understanding

(a) Which of the following describes a tensile force?

- A A force that pushes a material together
- B A force that pulls a material apart
- C A force that causes a material to bend
- D A force that has no effect on length

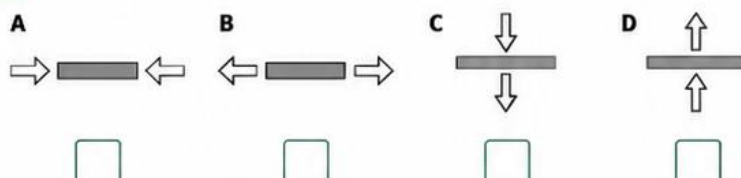
☐

(b) A spring is placed between two supports and is pushed in at each end. The spring is in:

- A tension
- B compression
- C shear
- D bending

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(c) Which of the diagrams shows a rod in tension?



Your notes

Determining a spring constant

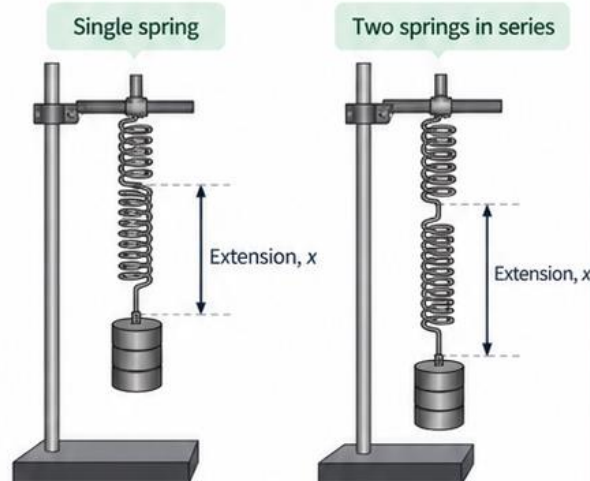
Aim

Collect a spring and a set of masses. Find the spring constant of your spring and compare it with two identical springs connected in series.

Method

- 1 Set up a spring and clamp it to a stand. Attach a mass hanger to the bottom.
- 2 Add masses in steps and record the total force (weight) and the extension of the spring.
- 3 Repeat for a second spring, or use the same spring and then connect two identical springs in series.
- 4 Record your results in the table below.

Apparatus (example)

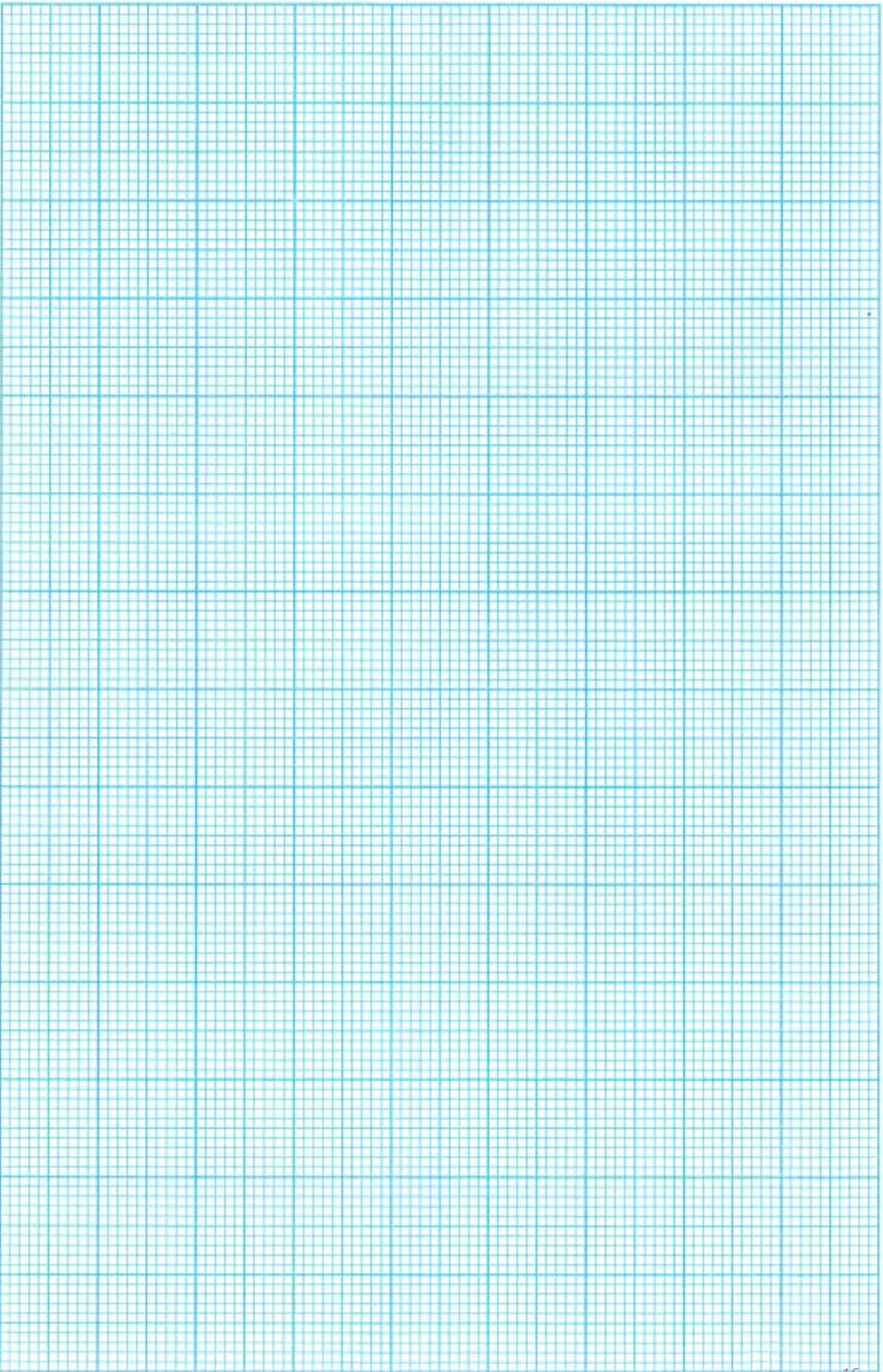


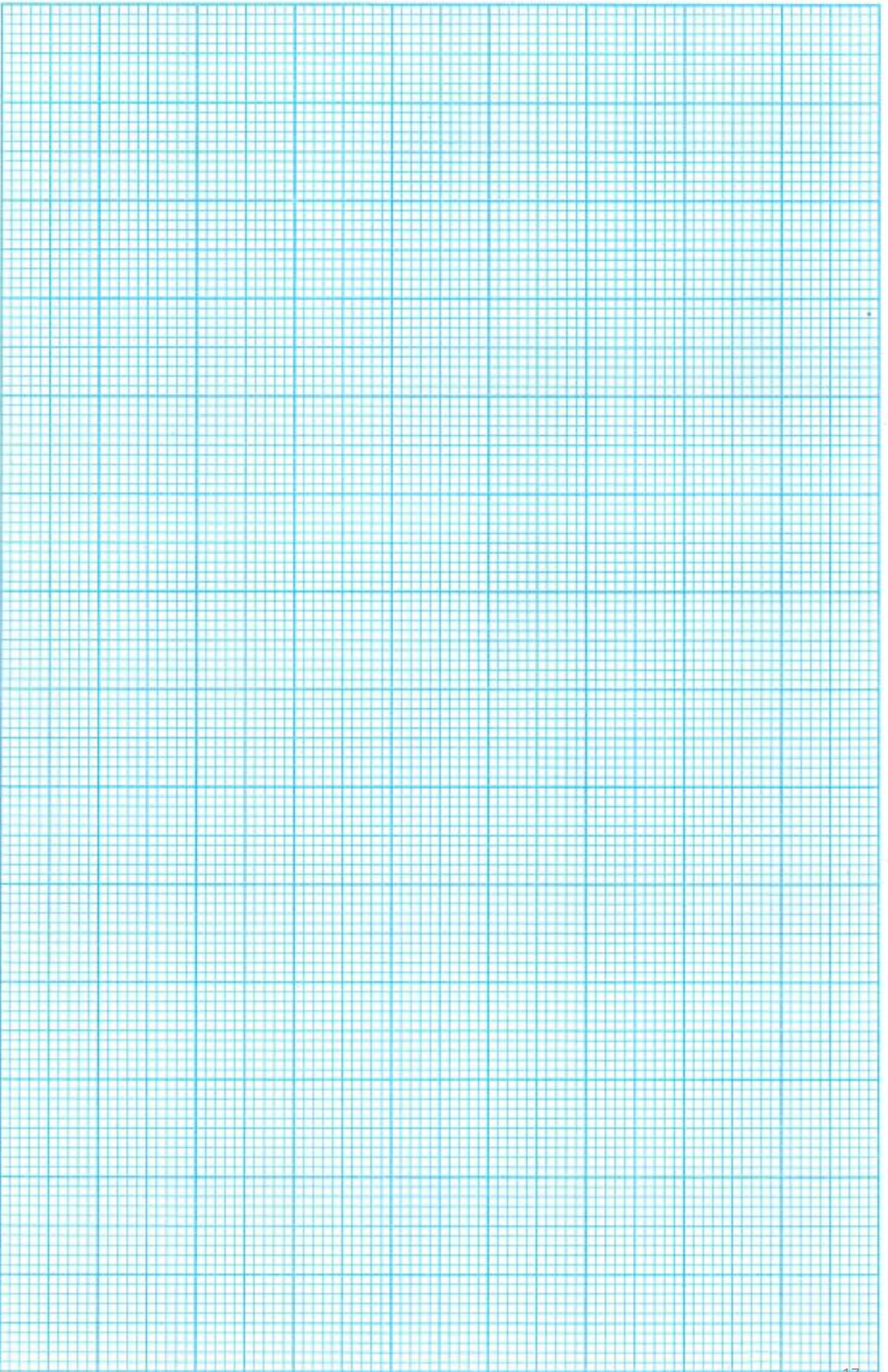
Results table

Force, F (N)	Extension, x (m) (single spring)	Extension, x (m) (two springs in series)

Discussion questions

- 1 Describe the shape of the force–extension graph for each system.
- 2 What did you notice about the gradients of the two graphs?
- 3 What does this tell you about the spring constant of the two springs in series compared to a single spring?
- 4 For the same extension, which system requires a larger force? Explain your answer.





Springs in series and parallel equations

Series

Teacher modelling space

Parallel

Teacher modelling space

Check for understanding

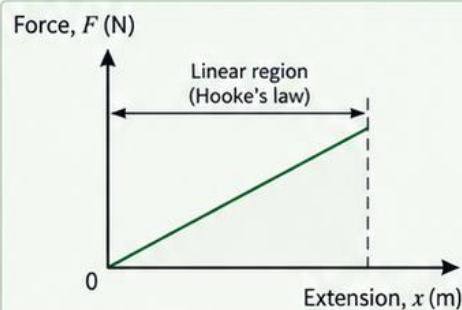
Two identical springs each have spring constant k . Which row gives the effective spring constant for the two springs when connected in series and when connected in parallel?

	Series	Parallel
A	$2k$	$k/2$
B	$k/2$	$2k$
C	k	$2k$
D	$k/2$	k

Hooke's law

- (a) State Hooke's law. Use force–extension graphs in your answer.

[2]



- (b) Define the term spring constant, k .

[2]

- (c) Describe an experiment that could be used to determine the spring constant, k , of a spring or material. Your answer should include the apparatus used, the measurements taken, and how the value of k would be determined from the results.

[5]

- (d) A spring obeys Hooke's law. Explain how cutting the spring in half affects its spring constant.

[3]

Extension: Suggest why the force–extension graph may stop being linear for some materials.

Springs – Exam-style questions

- 1** (a) Define the term *spring constant*. [1]
(b) State the unit of spring constant. [1]
-
- 2** A spring is extended by 12 cm due to a force of 15 N.
(a) Calculate the spring constant of the spring. [2]
(b) The same spring is now acted on by a force of 22 N. Calculate the extension of the spring. [2]
-
- 3** A force–extension graph is plotted for a standard spring that is loaded with small masses.
(a) Describe the graph that would be obtained. [2]
(b) Explain what the graph shows about the behaviour of the spring. [2]
-
- 4** A spring with spring constant 2.5 N/m is used to support a mass of 320 g.
Calculate the extension of the spring. [3]
-
- 5** Two identical springs, each with spring constant 2.5 N/m, are arranged in parallel and used to support a mass of 320 g.
Calculate the extension of the spring system. [3]
-
- 6** A metal girder is used as a bridge between two supports. A person walks across the girder.
With the aid of a suitable diagram, explain where the girder experiences tension and compression. [3]
-
- 7** Two springs with spring constants $k_1 = 12 \text{ N/cm}$ and $k_2 = 102 \text{ N/m}$ are connected in series.
A mass of 9.0 kg is attached to the system.
Calculate the extension of the system. [4]
-
- 8** A spring with spring constant 350 N/m is connected in series with a spring of unknown spring constant. When a force of 30 N is applied, the system extends by 12 cm.
Calculate the unknown spring constant. [4]

Working space:

Springs – Mark scheme

- 1** (a) Spring constant: force per unit extension / constant of proportionality between force and extension. [1]
 (b) Unit: N m^{-1} . [1]

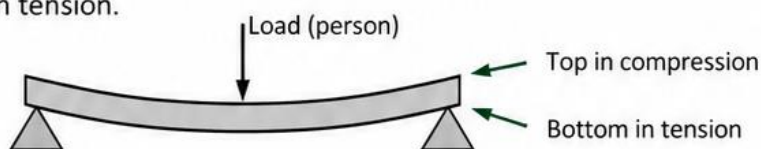
- 2** (a) $x = 12 \text{ cm} = 0.12 \text{ m}$. $k = \frac{F}{x} = \frac{15}{0.12} = 125 \text{ N m}^{-1}$. [2]
 (b) $x = \frac{F}{k} = \frac{22}{125} = 0.176 \text{ m} \approx 0.18 \text{ m}$ (17.6 cm acceptable). [2]

- 3** (a) Straight line through the origin on a force–extension graph. [2]
 (b) Shows force is proportional to extension / spring obeys Hooke's law / elastic behaviour up to the limit of proportionality. [2]

- 4** $m = 0.320 \text{ kg}$; $F = mg = 3.14 \text{ N}$.
 $x = \frac{F}{k} = \frac{3.14}{2.5} = 1.26 \text{ m}$. [3]

- 5** For two identical springs in parallel:
 $k_{\text{total}} = 2.5 + 2.5 = 5.0 \text{ N m}^{-1}$.
 $F = 3.14 \text{ N}$.
 $x = \frac{F}{k_{\text{total}}} = \frac{3.14}{5.0} = 0.628 \text{ m} \approx 0.63 \text{ m}$. [3]

- 6** When the girder bends under the person's weight, the top of the girder is in compression and the bottom is in tension.



- 7** Convert $k_1 = 12 \text{ N cm}^{-1} = 1200 \text{ N m}^{-1}$.
 Mass 9.0 kg gives $F = mg = 88.3 \text{ N}$.
 For springs in series: $\frac{1}{k_{\text{total}}} = \frac{1}{1200} + \frac{1}{102}$, so $k_{\text{total}} \approx 94.0 \text{ N m}^{-1}$.
 Extension: $x = \frac{F}{k_{\text{total}}} = \frac{88.3}{94.0} = 0.94 \text{ m}$. [4]

- 8** $k_{\text{total}} = \frac{F}{x} = \frac{30}{0.12} = 250 \text{ N m}^{-1}$.
 For series springs: $\frac{1}{250} = \frac{1}{350} + \frac{1}{k}$.
 Therefore $\frac{1}{k} = \frac{1}{250} - \frac{1}{350} = \frac{1}{875}$, so $k = 875 \text{ N m}^{-1}$. [4]

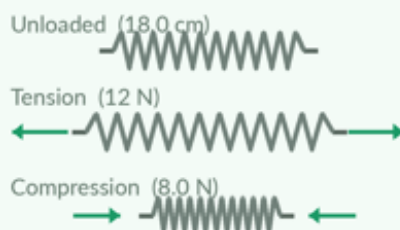
Springs – Multiple choice questions

Choose one answer (A–D) for each question.

- 1** A spring has a natural length of 18.0 cm. A tensile force of 12 N increases its length to 24.0 cm. Assuming Hooke's law applies in both directions, what is its length under a compressive force of 8.0 N? [1]

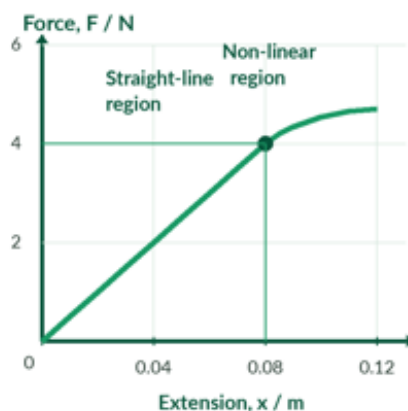
- A 10.0 cm
B 14.0 cm
C 16.0 cm
D 22.0 cm

Spring configurations



- 2** A spring gives a straight-line force–extension graph up to an extension of 0.080 m at a force of 4.0 N. Beyond this, the graph curves. Which conclusion is justified? [1]

- A The spring constant is 0.020 N m^{-1} .
B The spring constant is 50 N m^{-1} ; beyond 0.080 m, force is no longer proportional to extension.
C The spring constant is 50 N m^{-1} ; permanent deformation must start at exactly 0.080 m.
D The spring constant is 4.0 N m^{-1} .



- 3** A pupil compares a metal spring, rubber band and polythene strip. Which procedure best compares their force–extension behaviour and tests whether loading and unloading give different results? [1]

- A Measure each unloaded length. Increase and then decrease the force in steps; calculate extension and plot F against x for both loading and unloading.
B Apply one identical load to each material and compare the stretched lengths, without measuring unloaded length.
C Measure unloaded lengths and plot extension against force, then use each graph's gradient directly as the spring constant k .
D Increase force until each material breaks, then compare the maximum extensions to determine k .

A light spring of unextended length 2.0 cm is hung from a fixed point. An object of weight 3.0 N is hung from the other end of the spring. Fig. 7.1 shows the length of the spring when the object is in equilibrium.

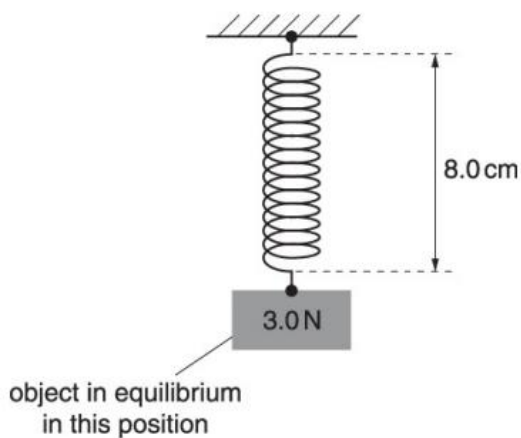


Fig. 7.1

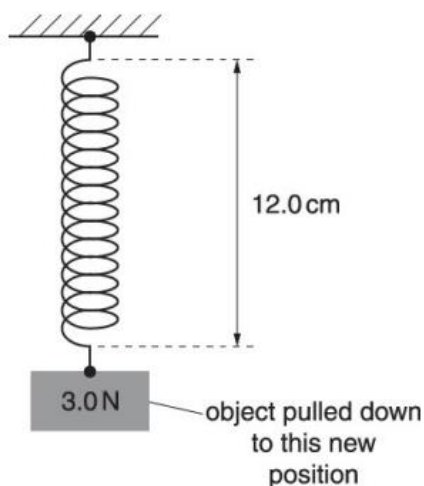
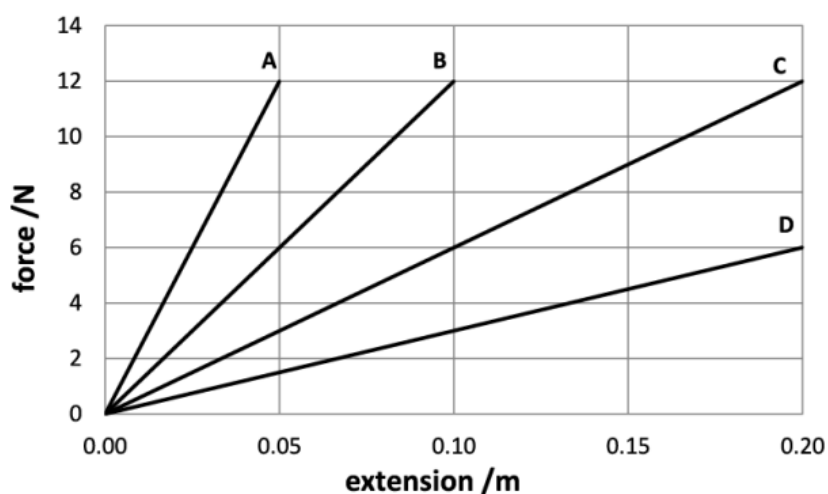


Fig. 7.2

Show that the force constant of the spring is 50 N m^{-1} .

The force constant of a spring X is 1.2 N cm^{-1} .

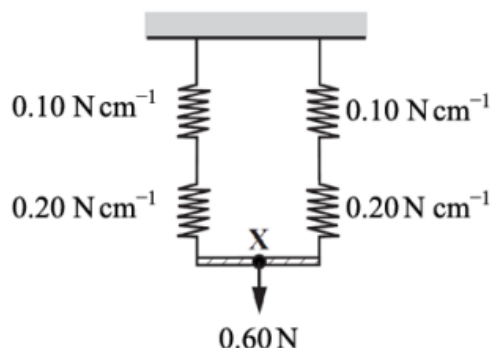
The force-extension graphs for four different springs A, B, C and D are shown below.



Which spring has a force constant equal to half that of spring X?

Your answer

A spring with force constant 0.10 N cm^{-1} is placed in series with one of 0.20 N cm^{-1} . These are then placed in parallel with an identical set of springs as shown. A force of 0.60 N is applied.



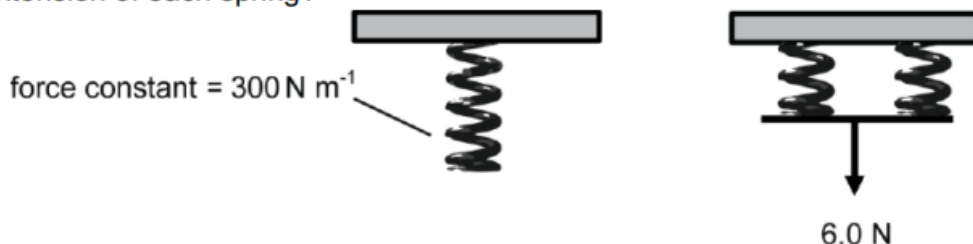
What distance does the point X move down when the 0.60 N force is applied?

- A 2.0 cm
- B 3.0 cm
- C 4.5 cm
- D 9.0 cm

Your answer

A spring of force constant 300 N m^{-1} is cut in half. The two halves are then placed in **parallel** with each other. A force of 6.0 N is then applied to this parallel arrangement.

What is the extension of each spring?



- A 0.5 cm
- B 1.0 cm
- C 2.0 cm
- D 4.0 cm

Your answer

[1]

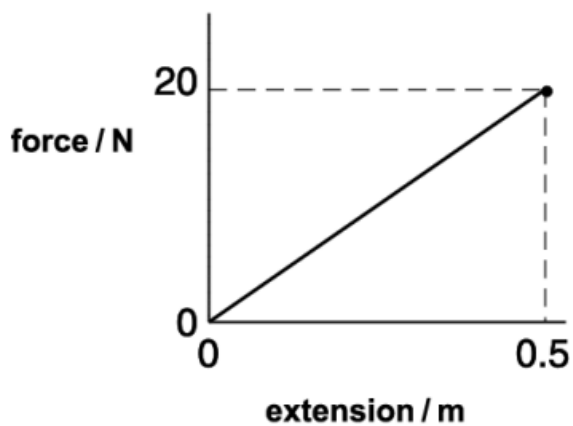


Fig. 20.1

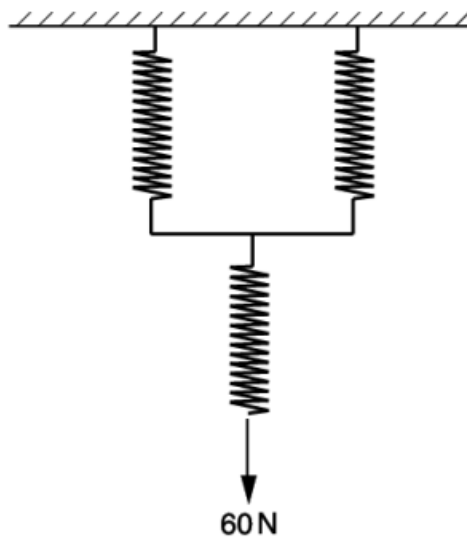


Fig. 20.2

Three of these springs are joined together as shown in Fig. 20.2 and a force of 60 N applied. What is the distance moved by the 60 N force (to 2 s.f.)?

- A 1.5 m
- B 2.0 m
- C 2.3 m
- D 3.0 m

Your answer

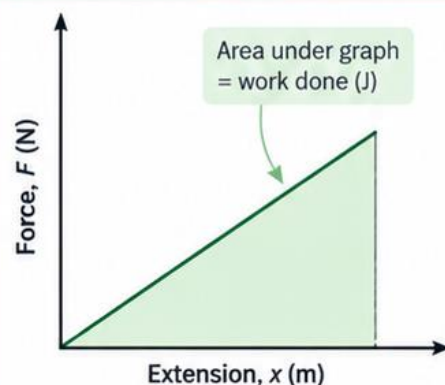
3.4.2 Mechanical properties of matter

Learning outcomes

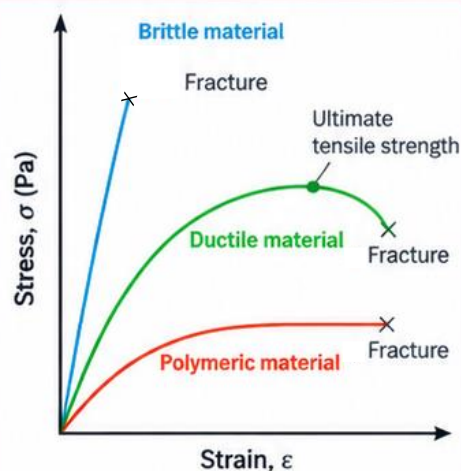
Learners should be able to demonstrate and apply their knowledge and understanding of:

- (a) force–extension (or compression) graph; work done is area under graph
- (b) elastic potential energy; $E = \frac{1}{2}Fx$; $E = \frac{1}{2}kx^2$
- (c) stress, strain and ultimate tensile strength
- (d) (i) Young modulus = $\frac{\text{tensile stress}}{\text{tensile strain}}$, $E = \frac{\sigma}{\epsilon}$
 (ii) techniques and procedures used to determine the Young modulus for a metal
- (e) stress–strain graphs for typical ductile, brittle and polymeric materials
- (f) elastic and plastic deformations of materials.

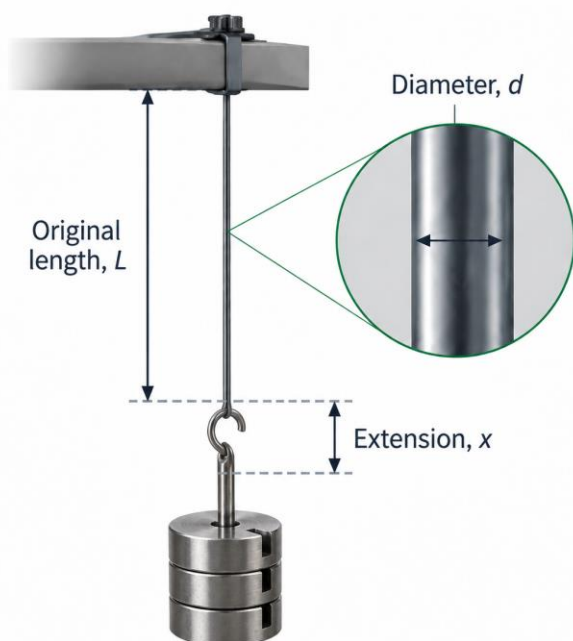
Force–extension graph



Stress–strain graphs



Young modulus experiment



Key idea 1



Work done and elastic potential energy

The work done stretching (or compressing) a material is equal to the area under the force–extension graph. For a linear spring, the elastic potential energy stored can be written as

$$E = \frac{1}{2}Fx = \frac{1}{2}kx^2.$$

Key idea 2



Stress and strain

Stress is the force per unit cross-sectional area. Strain is the fractional change in length. The Young modulus is the gradient of the initial linear section of a stress–strain graph: $E = \frac{\sigma}{\epsilon}$.

Key idea 3

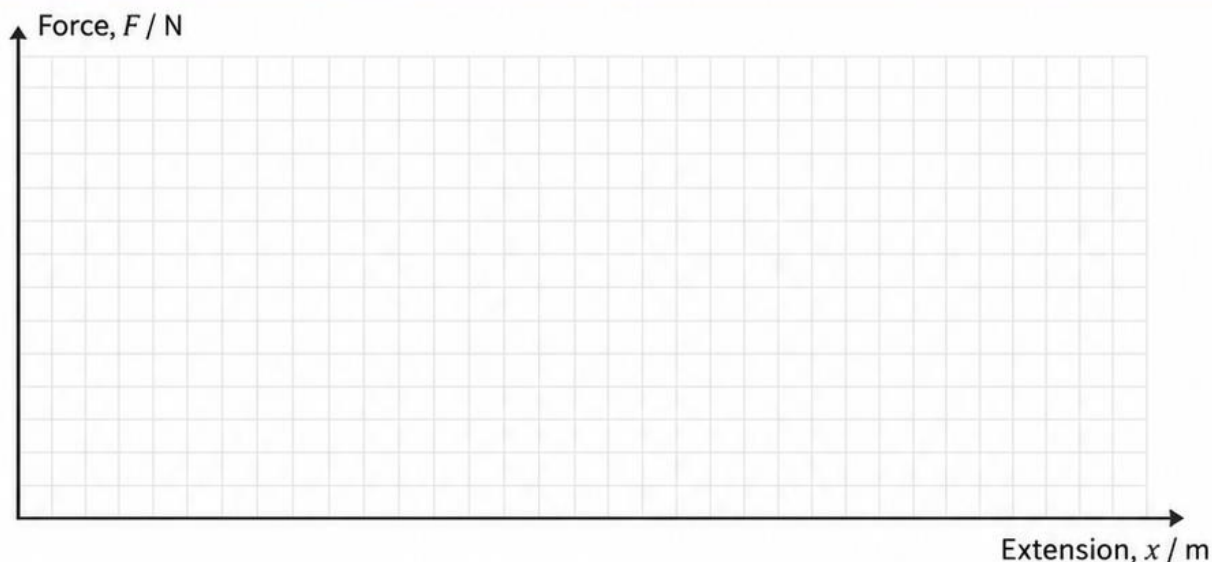


Material behaviour

Different materials show different stress–strain behaviour. Ductile materials undergo plastic deformation, brittle materials fracture with little plastic deformation, and polymers have a lower Young modulus and larger strains.

Force–extension graphs

- 1 Sketch a graph of force against extension for a spring obeying Hooke's law. Label the axes and identify the gradient.



Teacher model and pupil notes

- 1 Determine the base units of the area under the graph.
.....
.....
- 2 Explain what physical quantity the area under the graph represents.
.....
.....
.....
- 3 Write an equation for the area of the graph for a spring obeying Hooke's law.
.....
.....
.....
- 4 Use $F = kx$ to show that the elastic potential energy stored is $E = \frac{1}{2}kx^2$.
.....
.....
.....

Check for understanding

A spring obeys Hooke's law and is stretched from extension x to extension $2x$. Which statement is correct?

- A** The force doubles and the elastic potential energy doubles.
- B** The force stays the same and the elastic potential energy doubles.
- C** The force doubles and the elastic potential energy becomes four times greater.
- D** The force becomes four times greater and the elastic potential energy becomes four times greater.

Work done and elastic potential energy

CHECK FOR UNDERSTANDING | THREE MULTIPLE-CHOICE QUESTIONS

Take $g = 9.81 \text{ N kg}^{-1}$. Assume ideal spring behaviour unless stated.

1 A loaded spring

[1]

A mass of 0.300 kg is attached to a vertical spring of spring constant 25 N m^{-1} . The mass is lowered slowly from the spring's natural length until it hangs at rest.

How much elastic potential energy is stored in the spring?

A 0.086 J

B 0.17 J

C 0.35 J

D 0.69 J

Spring and hanging mass

 $k = 25 \text{ N m}^{-1}$

2 A tendon as an elastic spring

[1]

An Achilles tendon is modelled as a linear spring with spring constant $4.0 \times 10^5 \text{ N m}^{-1}$. Its extension increases from 1.0 mm to 3.0 mm during a movement.

What is the increase in elastic potential energy stored?

A 0.80 J

B 1.8 J

C 1.6 J

D 3.2 J

Achilles tendon (lower leg)



3 A vertical spring launcher

[1]

A light vertical spring is compressed by 5.0 cm using a force of 6.0 N . A 9.0 g ball is placed on top and the spring is released. Ignore air resistance and energy losses; the spring has negligible mass.

What is the greatest height reached by the ball above its starting position?

A 1.7 m

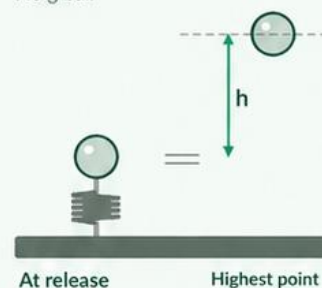
B 0.17 m

C 3.4 m

D 0.85 m

Launch and maximum height

9.0 g ball

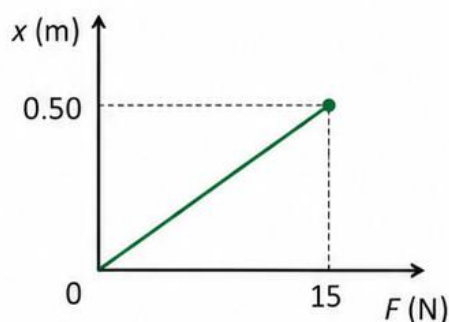


Springs – Exam-style questions

Elastic potential energy in springs

1. A force of 32 N causes a spring to extend by 12 cm. Calculate the elastic potential energy stored in the spring. [2]
2. A spring has a spring constant of 120 N m^{-1} and is extended by 42 cm. Calculate the elastic potential energy stored in the spring. [2]
3. An experiment is carried out to measure the energy stored in a spring. The spring has an original length of 13 cm. When a force of 20 N is applied, its length increases to 18 cm.
 - (a) Calculate the extension of the spring. [1]
 - (b) Calculate the spring constant of the spring. [2]
 - (c) Calculate the elastic potential energy stored in the spring. [2]
4. One end of a spring is fixed and a force F is applied to the other end. The spring obeys Hooke's law. When the extension is x , the elastic potential energy stored is E .

The force is increased so that the elastic potential energy becomes $3E$. Determine the new extension of the spring in terms of x . [3]
5. The graph below shows extension x against force F for a spring.



- (a) Determine the spring constant of the spring. [2]
- (b) Calculate the elastic potential energy stored when the spring is extended to 1.2 m. [2]

Springs – Mark scheme

Elastic potential energy in springs | OCR A 3.4.2 | 16 marks

1 Force and extension

[2]

M1 Elastic energy = $\frac{1}{2}Fx$, with $x = 12 \text{ cm} = 0.12 \text{ m}$

A1 $E = \frac{1}{2} \times 32 \times 0.12 = 1.92 \text{ J}$

2 Spring constant and extension

[2]

M1 Use $E = \frac{1}{2}kx^2$, with $k = 120 \text{ N m}^{-1}$ and $x = 0.42 \text{ m}$

A1 $E = \frac{1}{2} \times 120 \times (0.42)^2 = 10.584 \text{ J} \approx 10.6 \text{ J}$

3 Extension, spring constant and energy

[5]

(a) B1 $x = (18 - 13) \text{ cm} = 5.0 \text{ cm} = 0.050 \text{ m}$

(b) M1 $k = F/x = 20/0.050$

A1 $k = 400 \text{ N m}^{-1}$

(c) M1 $E = \frac{1}{2}Fx$ (or $\frac{1}{2}kx^2$)

A1 $E = \frac{1}{2} \times 20 \times 0.050 = 0.50 \text{ J}$

4 Energy increased to three times its value

[3]

M1 $E = \frac{1}{2}kx^2$; new energy $3E = \frac{1}{2}k(x_{\text{new}})^2$

M1 Divide the expressions: $(x_{\text{new}}/x)^2 = 3$

A1 $x_{\text{new}} = \sqrt{3} x \approx 1.73x$

5 Interpreting the extension–force graph

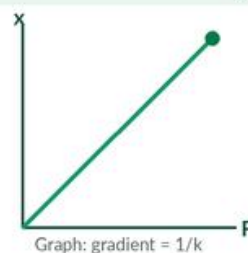
[4]

(a) M1 Use $k = F/x$ at 15 N and 0.50 m

A1 $k = 15/0.50 = 30 \text{ N m}^{-1}$

(b) M1 $E = \frac{1}{2}kx^2$

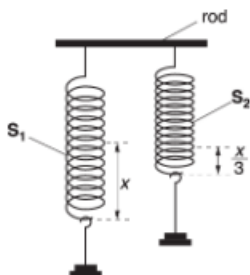
A1 $E = \frac{1}{2} \times 30 \times (1.2)^2 = 21.6 \text{ J}$



Examiner note – Question 5(b)

The graph only shows measurements up to $x = 0.50 \text{ m}$. Extrapolating to 1.2 m requires the assumption that Hooke's law remains valid. State this explicitly in the question; otherwise 21.6 J cannot be justified from the graph alone.

The top ends of two springs, S_1 and S_2 , are attached to a rod.



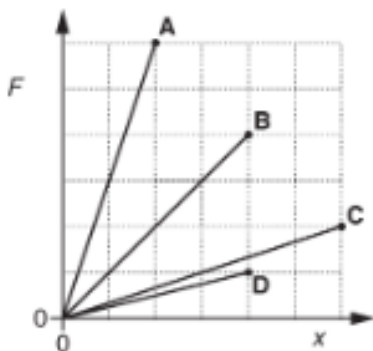
A mass is hung from the bottom end of S_1 . The extension of S_1 is x . The elastic potential energy in the spring is E . The same mass is hung from the bottom end of S_2 . The extension of S_2 is $\frac{x}{3}$.

What is the elastic potential energy in the spring S_2 ?

- A $\frac{E}{9}$
- B $\frac{E}{3}$
- C $3E$
- D $9E$

Your answer

The force F against extension x graphs for four different wires A, B, C and D up to their breaking points are shown below.



Which wire has the greatest work done on it before it breaks?

Your answer

[1]

30(a). A light spring of unextended length 2.0 cm is hung from a fixed point. An object of weight 3.0 N is hung from the other end of the spring. Fig. 7.1 shows the length of the spring when the object is in equilibrium.

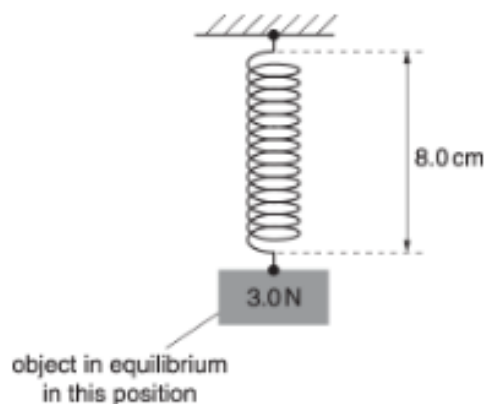


Fig. 7.1

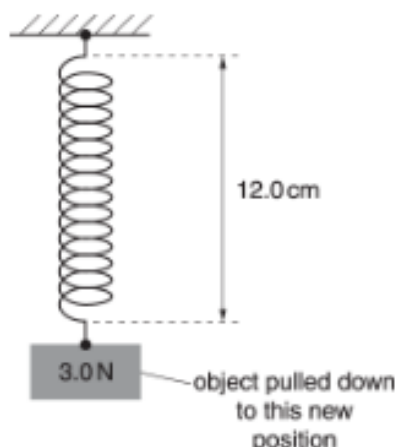


Fig. 7.2

The object is pulled vertically downwards. Fig. 7.2 shows the new length of the spring.

i. Calculate the change in the elastic potential energy ΔE in the spring.

$$\Delta E = \dots\dots\dots \text{J} \quad [3]$$

ii. The object is released from its position shown in Fig. 7.2. Calculate the initial upward acceleration a of the object.

$$a = \dots\dots\dots \text{m s}^{-2} \quad [3]$$

Stress and strain

Use the space below to develop the ideas of stress and strain.

Stress

Equation:

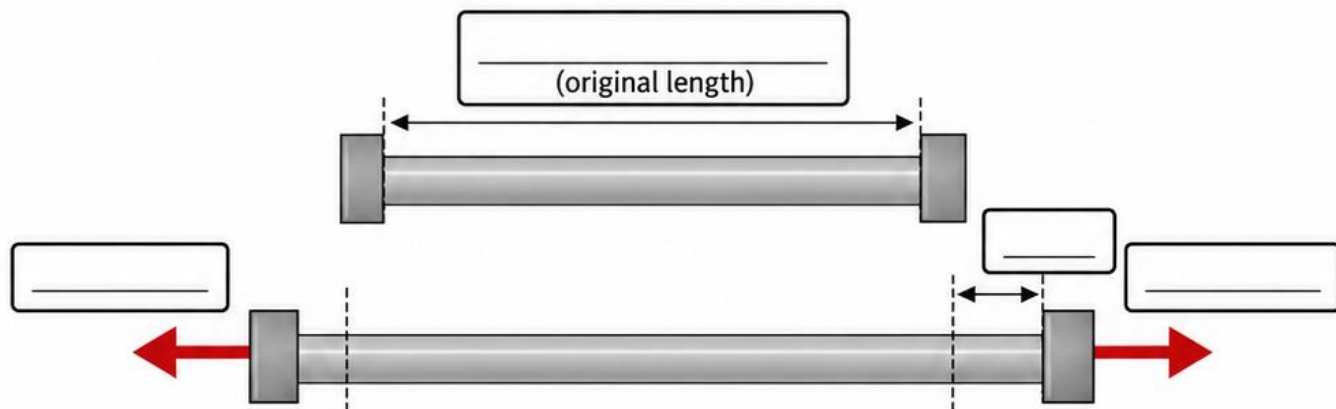
Units:

Strain

Equation:

Units:

A wire/material under tension



Annotate the diagram to show the quantities involved.

Check for understanding

A wire has an original length of 2.0 m. When a tensile force is applied, its length increases by 4.0 mm. What is the strain in the wire?

A 2.0×10^{-3}

B 4.0×10^{-3}

C 2.0×10^{-4}

D 4.0×10^{-4}

Stress and strain

CHECK FOR UNDERSTANDING

3 multiple-choice questions

- 1** A soft rubber sample has an original length of 50 cm and a cross-sectional area of 6.0 cm^2 . A tensile force of 20 N causes an extension of 0.50 cm. Which row gives the stress and strain? [1]

	Stress / Pa	Strain
A	3.3×10^3	0.010
B	3.3×10^4	0.010
C	3.3×10^4	0.10
D	6.7×10^4	0.0010

Soft rubber test sample



$F = 20 \text{ N}$
not to scale

Working

- 2** A wire of circular cross-section has a diameter of 0.80 mm. It is stretched by a force of 40 N. What is the tensile stress in the wire? [1]

- A 8.0 MPa
- B 20 MPa
- C 80 MPa
- D 320 MPa

Circular cross-section



Diameter = 0.80 mm
Force = 40 N

Working

- 3** A uniform steel girder has a rectangular cross-section of $15 \text{ cm} \times 9.0 \text{ cm}$ and a length of 2.0 m. An axial tensile load of 300 kN produces an extension of 0.20 mm. Which row gives the tensile stress and strain? [1]

	Stress / Pa	Strain
A	2.2×10^6	1.0×10^{-4}
B	2.2×10^7	1.0×10^{-3}
C	2.2×10^7	2.0×10^{-4}
D	2.2×10^7	1.0×10^{-4}

Steel girder (schematic)



Working

Build the definition, equation and units

Definition

What does Young's modulus describe?

Equation

SI unit

1 From stress and strain

A steel sample experiences a tensile stress of 8.0×10^7 Pa and a tensile strain of 4.0×10^{-4} .
Calculate the Young modulus of the steel.

Teacher working / pupil notes

2 Using force, length, extension and area

A steel wire has original length 2.0 m and diameter 0.50 mm.
Under a tensile force of 20 N, it extends by 1.0 mm.
Calculate the Young modulus of the material.



Teacher working / pupil notes

Check for understanding

Two wires are made from the same material and stretched by the same force. Wire B is half as long and has twice the diameter of wire A.

What is the extension of wire B compared with wire A?

A One eighth

B One quarter

C One half

D Twice as much

Check for Understanding: Young's modulus

Choose the best answer for each question. Show your working in the space provided.

1

A metal wire experiences a tensile stress of $2.5 \times 10^8 \text{ Pa}$ and a tensile strain of 1.0×10^{-3} .

What is the Young's modulus of the metal?

Working space

A $2.5 \times 10^5 \text{ Pa}$

B $2.5 \times 10^8 \text{ Pa}$

C $2.5 \times 10^{11} \text{ Pa}$

D $4.0 \times 10^{11} \text{ Pa}$

2

A steel wire has an original length of 2.0 m and a diameter of 0.50 mm. It is stretched by a force of 100 N and extends by 5.0 mm.

What is the Young's modulus of the steel?



Working space

A $5.0 \times 10^{10} \text{ Pa}$

B $1.0 \times 10^{11} \text{ Pa}$

C $2.0 \times 10^{11} \text{ Pa}$

D $4.0 \times 10^{11} \text{ Pa}$

3

Two wires, A and B, are made from the same material.

- Wire A has length L and diameter d .
- Wire B has length $2L$ and the same diameter d .
- The two wires are each stretched by the same tensile force F and remain within their elastic limit.

Which statements are correct?

- 1 The extension of wire B is twice the extension of wire A.
- 2 The strain in wire B is twice the strain in wire A.
- 3 The stress in wire A is the same as the stress in wire B.

Working space

A 1 and 2 only

B 1 and 3 only

C 2 and 3 only

D 1 only

Young's modulus – PAG 2.1

Determining Young modulus for a metal



Aim

To determine a value for the Young modulus of a metal wire.



Introduction

In this experiment you will measure how a metal wire extends when a load is applied. You will use the measurements of force and extension to calculate the stress and strain, and use these to determine the Young modulus of the wire.



Apparatus

- Test wire (e.g. 28 swg copper)
- Clamp/support to hold measuring apparatus (e.g. wooden blocks and G clamp)
- Metre rule or Vernier scale
- Masses (and mass hanger)
- Pulley (if working horizontally)
- G clamp (if working horizontally)
- Micrometer
- Safety goggles

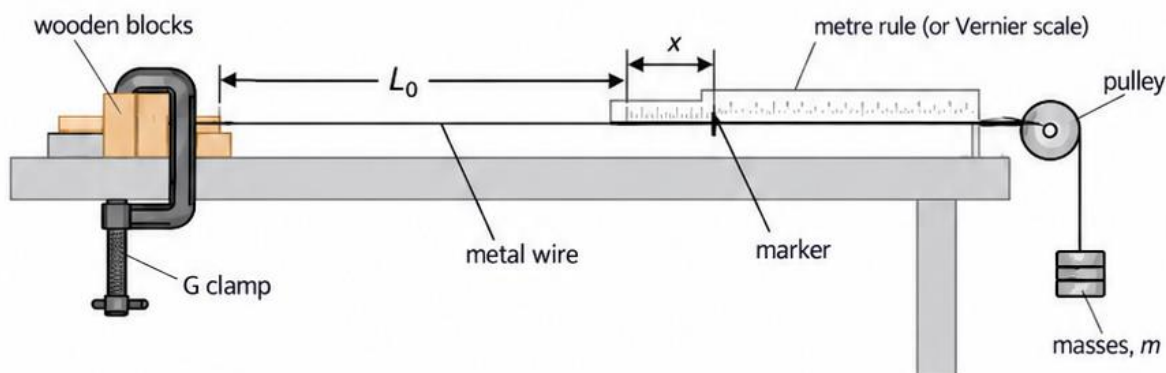


Safety

- Wear safety goggles or spectacles at all times due to the risk of the wire snapping.
- Do not exceed the maximum load set by your teacher.
- Avoid standing directly beneath or next to the hanging masses and cushion their landing if possible.



Apparatus diagram



Method

- 1 **Measure the wire diameter** using a micrometer. Take repeated readings at different points and calculate a mean to improve repeatability.
- 2 **Calculate the cross-sectional area, A ,** of the wire using your mean diameter. Record the value with units.
- 3 **Set the original length, L_0 ,** of the wire. Measure and clearly mark this length. A small load may be needed to straighten the wire.
- 4 **Add the load in stages** up to the maximum set by your teacher.
- 5 **For each load, measure the extension, x ,** of the wire from the original mark.
- 6 **Convert the mass, m ,** to a force, F ($F = mg$).

Young's modulus – PAG 2.1

Analysis, uncertainty and evaluation

1 Analysis

- 1 Plot a graph of stress, σ (y-axis) against strain, ϵ (x-axis).
- 2 Draw a best-fit straight line through the linear region of the graph.
- 3 Calculate the gradient of your line. Include appropriate units.
- 4 The gradient is the Young modulus, E , for the metal.

2 Key equations

Stress:	$\sigma = \frac{F}{A}$	σ = stress (Pa) F = force (N) A = cross-sectional area (m ²)
----------------	------------------------	---

Strain:	$\epsilon = \frac{x}{L_0}$	ϵ = strain (no unit) x = extension (m) L_0 = original length (m)
----------------	----------------------------	---

Young modulus:	$E = \frac{\sigma}{\epsilon}$	E = Young modulus (Pa) σ = stress (Pa) ϵ = strain (no unit)
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3 Uncertainties

- Determine the percentage uncertainty in F , A , x and L_0 , showing how you calculate each value.
- Combine these uncertainties to estimate the percentage uncertainty in your value for the Young modulus.
- State your final value for Young's modulus with an appropriate uncertainty.
- Comment on which measurement contributes the largest uncertainty and suggest how this could be reduced.
- Consider any additional sources of uncertainty (e.g. alignment, zero error, resolution) and how they might affect your result.

4 Evaluation

- Compare your calculated value for Young's modulus with an accepted value from a data book or table of materials.
- Discuss the agreement between your result and the accepted value, taking your estimated uncertainty into account.
- Suggest possible reasons for any differences (e.g. measurement uncertainties, non-ideal behaviour, material not perfectly uniform, plastic deformation).
- Comment on the validity of your method and any assumptions made.
- Consider how the size of the load increments might affect your results.

5 Extension opportunities

- Identify and discuss sources of uncertainty in your measurements.
- Comment on the repeatability of your results.
- Discuss whether the wire remained in the elastic region during your measurements. How could you tell?
- Suggest improvements to the method to reduce uncertainty or increase the accuracy of your result.
- Consider how you could investigate the effect of factors such as wire diameter or material type on Young's modulus.
- Design a follow-up experiment or research task to extend this investigation.

Young's modulus – practical preparation

Three MCQs before the six-mark experimental-design question

CHECK FOR UNDERSTANDING

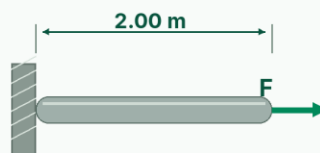
- 1** An engineer tests three candidate cable materials using metal wire samples of different lengths and diameters. Which analysis gives a valid comparison of their Young moduli?



Three test specimens

- A** Compare the gradients of force–extension graphs without adjusting for dimensions.
- B** Compare gradients of the initial straight-line regions of stress–strain graphs.
- C** Compare the areas under the stress–strain graphs for each sample.
- D** Compare breaking forces and rank the materials from largest to smallest force.

- 2** A metal wire has original length 2.00 m and diameter 0.80 mm. Under a tensile force of 25 N, it extends by 0.50 mm. What is the Young modulus of the material?



Diameter: 0.80 mm
Extension: 0.50 mm

- A** 5.0×10^{10} Pa
- B** 1.0×10^{11} Pa
- C** 2.0×10^{11} Pa
- D** 8.0×10^{11} Pa

- 3** An engineer plans to determine the Young modulus of three metals. Which of the following statements are correct?

- 1** Measure wire diameters at several positions and orientations, and check for micrometer zero error.
- 2** Include loads beyond the proportional region so that larger extensions improve the gradient measurement.
- 3** Determine the gradient from the initial straight-line region of each stress–strain graph.

- A** 1 only
- B** 1 and 2 only
- C** 1 and 3 only
- D** 2 and 3 only

Evaluating six-mark practical answers

Young's modulus | PAG 2.1 | Building a better extended response

THE QUESTION

A company is comparing three materials for bridge cables (diameter 22 mm). Explain how Young's modulus could be measured for each material and how the results could inform the final choice. [6 marks]



Both answers include creditworthy science and mistakes. Annotate them before judging their quality.

A Pupil response A

- Secure a 2.0 m test length of each of the three cable materials in a tensile-testing rig.
- All cables are 22 mm wide, so measure the diameter of one cable once using a ruler and use that area for every sample.
- Measure the original length between two marked positions on each specimen.
- Apply several known tensile forces, ensuring the cable stays within its elastic region.
- Measure the extension for each force and plot force (vertical axis) against extension (horizontal axis).
- The gradient of this graph is Young's modulus, measured in N m^{-1} .
- Choose the material with the largest Young's modulus, because it must also have the highest breaking force.

What earns credit?

What needs correcting or adding?

Mark: __/6 (justify your score below)

B Pupil response B

- Clamp a sample of each cable material securely and measure its diameter at several positions using a micrometer.
- Calculate the cross-sectional area using $A = \pi d^2/4$.
- Assume that all three samples have the same original length, so it does not need measuring.
- Hang one known load on each specimen and measure its extension once.
- Calculate tensile stress from F/A and tensile strain from extension divided by original length.
- Calculate Young's modulus from stress divided by strain, reporting the value in Pa.
- If the extension is too small to measure, increase the load beyond the elastic limit to make it easier to read.
- Compare the moduli for stiffness, but check tensile strength separately before selecting a bridge cable.

What earns credit?

What needs correcting or adding?

Mark: __/6 (justify your score below)

Your evaluation

- 1 Which answer would you award more marks? Explain your decision using specific examples.
- 2 Which two improvements will you remember when writing your own six-mark response?

6-mark practical question

3.4.2 MECHANICAL PROPERTIES OF MATTER

Selecting materials for bridge cables

The scenario

An engineering company is comparing three different materials for use in the suspension cables of a new bridge.

The company prepares an equal-length sample of each material. Each sample has a diameter of 22 mm.

Suspension cable application





Practical video resource
bit.ly/35b538s
Scan to revisit the method.

The question

[6]

Describe how the engineers could determine the Young modulus of each cable material experimentally. Explain how the measurements and results would be used to make a valid comparison between the three materials.

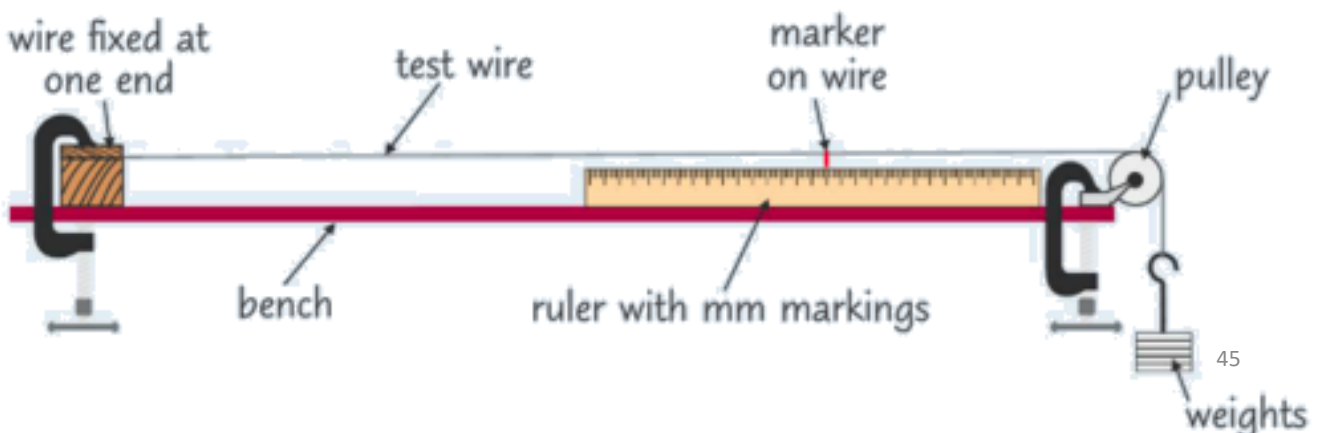
Answer _____

Stress-Strain graphs

Aims: Understand how gradients of stress-strain graphs relate to Young's modulus and how different factors may affect stress-strain graphs.



1. On the graph above, sketch the expected output for a metal undergoing tensile stress. Label this M_A
2. Label a point (EL) as the elastic limit of the metal.
3. Sketch a second line for a stronger metal. Label this M_B .
4. The elastic limit of M_A appears at a stress of 1.2GPa and a strain of 0.01. Calculate the Young's modulus of the M_A .

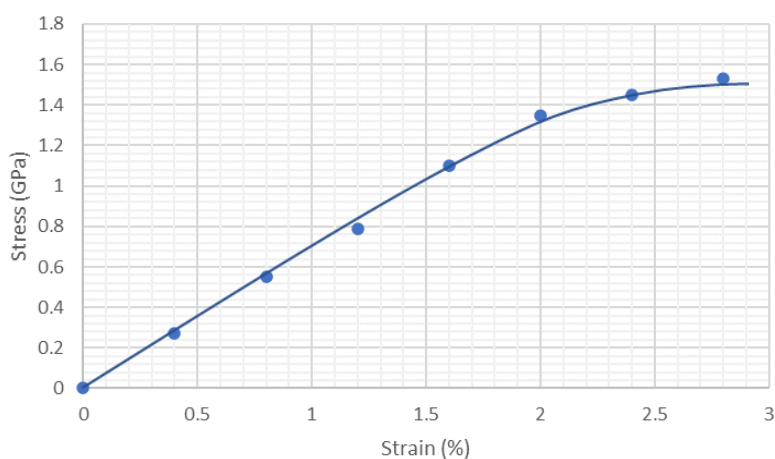


Pre-task assessment

1. A wire of diameter 1.2mm and length 2m has a mass of 900g fixed to one end so that it hangs vertically. As a result, the material extends to 2.02m. Calculate the Young's modulus.

- A. $8.0 \times 10^8 \text{ Pa}$
- B. $7.8 \times 10^8 \text{ Pa}$
- C. $2.0 \times 10^7 \text{ Pa}$
- D. $7.8 \times 10^{11} \text{ Pa}$

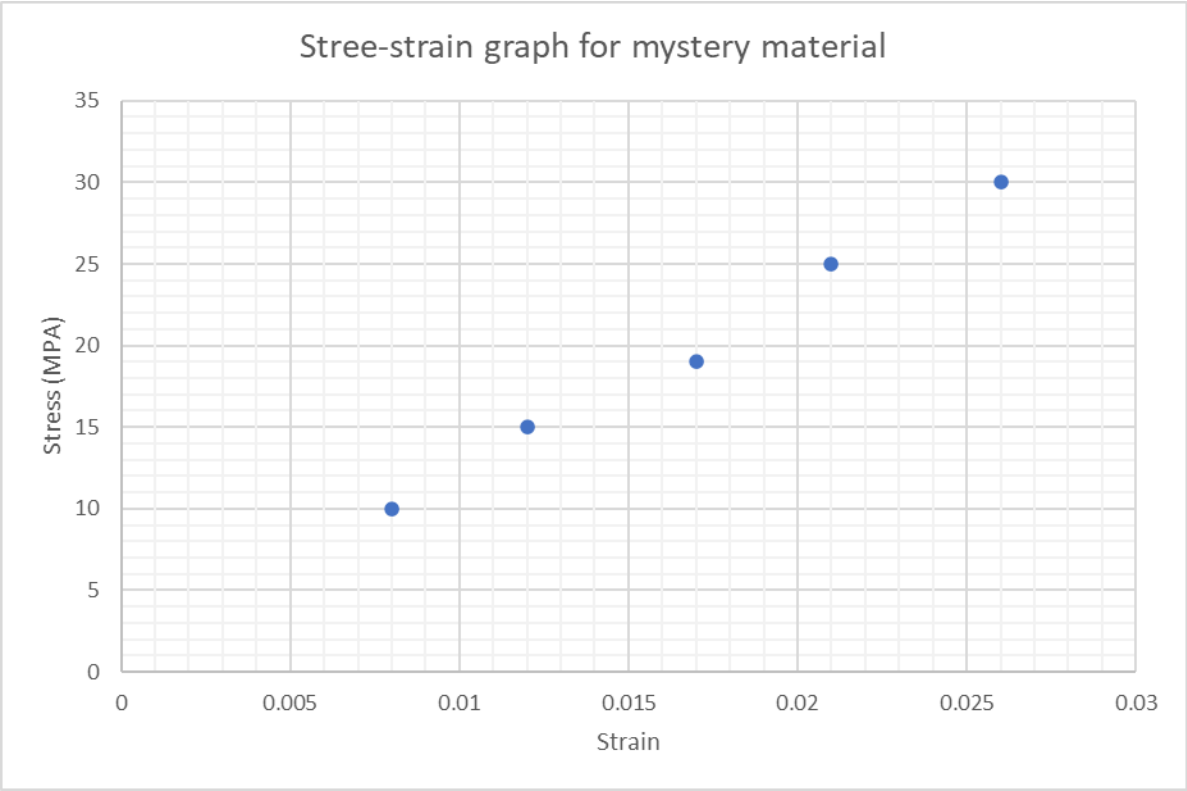
2. Select the incorrect statement regarding the graph below.



- A. The elastic limit of the material occurs at approximately 1.1GPa
 - B. The Young's modulus of the material is approximately $7 \times 10^{10} \text{ Pa}$
 - C. Increasing the diameter of the wire will decrease the gradient of the graph
 - D. The material obeys Hooke's law until it reaches 1.1GPa
3. Which of the following sentences correctly describes the graph in Q2?
- A. The material obeys Hooke's law until the gradient changes at a strain of 2.5%
 - B. Stress is inversely proportional to strain causing a curve on the graph after 1.1GPa
 - C. The Young's modulus of the material is found by calculating the reciprocal of the gradient
 - D. The Young's modulus can be found by evaluating $\frac{1 \times 10^9}{0.0145}$

Main task

- 1. Draw a line of best fit on the graph below and use this to show that the Young's modulus of the material is approximately $1.2 \times 10^9 \text{Pa}$
- 2. **Explain** how the gradient would change once the elastic limit of the material had been reached. (Here you must discuss the extension per unit force applied)



3. Calculate the diameter of the wire used knowing that the force applied to cause a stress of 18MPa was 46N .
4. The original length of the wire was 1.2m . Calculate the extension experienced by the wire due to a stress of 20MPa .

Challenge question

A second wire with identical dimensions is tested and found to have twice the Young's modulus as the wire in the previous graph. **Explain** the change, if any in the elastic potential energy stored in the second wire compared to the first when tested with the same force. (Assume the wire has the same dimensions)

Summary

The extension of a metal wire is x when the tension in the wire is F . The table in Fig. 23.1 shows the results from an experiment, including the stress and the strain values.

F / N	$x / 10^{-3} \text{ m}$	stress / 10^7 Pa	strain / 10^{-3}
1.9	0.4	1.73	0.20
4.0	0.8	3.50	0.40
5.9	1.2	5.21	0.60
8.0		7.00	0.80
9.0	1.8	7.95	0.90

Fig. 23.1

Fig. 23.2 shows a graph of stress against strain for the metal.

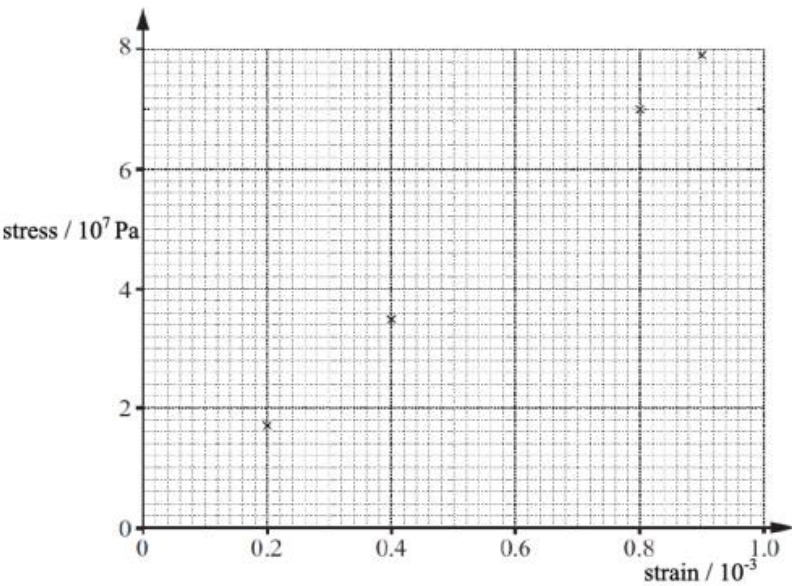


Fig. 23.2

ii. Use Fig. 23.2 to determine the Young modulus of the metal.

Young modulus = ... Pa [2]

The **micrometre** used to measure the diameter had an error. The diameter measured by the student was **larger** than the actual value of the wire. How would this have affected the value of the student's Young's modulus **and** the gradient of the graph in the experiment?

- A) Young's modulus would be larger and the gradient would be lower
- B) Young's modulus would be lower and the gradient would be greater
- C) Young's modulus would be lower and the gradient would be lower
- D) Young's modulus would be larger and the gradient would be greater

Young's modulus – Exam-style questions

OCR A Physics 3.4.2 | Use the graph on this page. Show all other working in your exercise book.

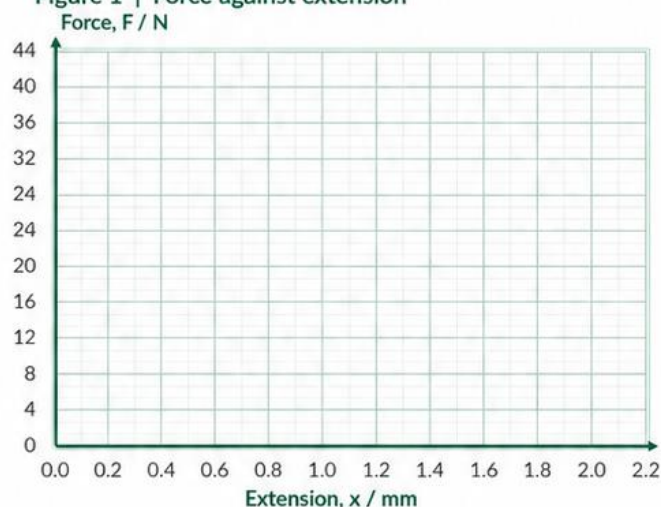
1 Experimental data: Young's modulus

A high-strength steel wire has an original length of 2.00 m and a mean diameter of 0.50 mm. Its extension is measured for a range of tensile forces while it obeys Hooke's law.

Table 1 | Recorded measurements

Force, F / N	Extension, x / mm
0	0.00
8	0.41
16	0.80
24	1.20
32	1.61
40	2.01

Figure 1 | Force against extension



- Plot the readings in Figure 1 and draw a suitable line of best fit. [3]
- Using the gradient, calculate the Young modulus of the wire. [4]
- A pupil says these data prove the wire will return to its original length when unloaded. Explain why the data alone do not show this. [2]
- Describe how you would measure the mean diameter accurately. [2]

2 Applying Young's modulus

A second wire is 1.50 m long and has diameter 0.80 mm. The material has Young modulus 2.0×10^{11} Pa. Calculate the tensile force needed to produce an extension of 0.60 mm. [3]

3 Density of a metal wire

A metal wire has diameter 1.20 mm and mass per unit length 8.8 g m^{-1} . Calculate its density and comment on whether it could be steel (density $7.8 \times 10^3 \text{ kg m}^{-3}$). [4]

4 Stretching two different wires

Wires A and B have the same original length and support the same tensile force. Wire A has diameter 0.60 mm. Wire B has diameter 0.80 mm and a Young modulus 23% greater than that of A.

Wire A extends by 2.0 mm. Calculate the extension of B, assuming both wires remain in the proportional region. [4]

Young's modulus – Mark scheme

OCR A Physics 3.4.2 | Answers for the 22-mark exam-style worksheet

1 Experimental data: Young's modulus

[11]

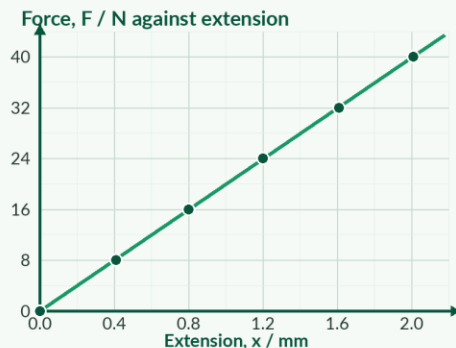
(a) Graph and line of best fit

B1 At least four non-zero data points correctly plotted.

B1 All six plotted readings accurate (including origin).

B1 Suitable straight best-fit line through or close to the origin.

The completed graph is shown opposite.



(b) Calculating the Young modulus

[4]

M1 Gradient $\approx 40 \text{ N} / 2.01 \text{ mm} \approx 19.9 \text{ N mm}^{-1} = 1.99 \times 10^4 \text{ N m}^{-1}$

B1 $A = \pi d^2 / 4 = \pi(0.50 \times 10^{-3})^2 / 4 = 1.96 \times 10^{-7} \text{ m}^2$

M1 $Y = (\text{gradient} \times \text{original length}) / \text{cross-sectional area}$

$$\text{A1 } Y \approx (1.99 \times 10^4 \times 2.00) / (1.96 \times 10^{-7}) = 2.0 \times 10^{11} \text{ Pa}$$

(c) Elastic recovery

[2]

B1 Only loading data were taken; reversible behaviour has not been tested.

B1 Unload and check that extension returns to zero (no permanent deformation).

(d) Measuring diameter

[2]

B1 Use a micrometer screw gauge (check/correct zero error).

B1 Measure at several positions and orientations; calculate a mean.

2 Applying Young's modulus

[3]

B1 $A = \pi(0.80 \times 10^{-3})^2 / 4 = 5.03 \times 10^{-7} \text{ m}^2$

M1 $Y = FL / (Ax)$ therefore $F = YAx / L$

$$\text{A1 } F = (2.0 \times 10^{11})(5.03 \times 10^{-7})(0.60 \times 10^{-3}) / 1.50 = 40 \text{ N}$$

3 Density of a metal wire

[4]

B1 Mass per unit length $= 8.8 \times 10^{-3} \text{ kg m}^{-1}$

B1 $A = \pi(1.20 \times 10^{-3})^2 / 4 = 1.13 \times 10^{-6} \text{ m}^2$

M1 $\rho = (\text{mass per unit length}) / A = 7.78 \times 10^3 \text{ kg m}^{-3}$

B1 This is consistent with steel ($7.8 \times 10^3 \text{ kg m}^{-3}$).

4 Stretching two different wires

[4]

M1 For equal F and L : extension $x = FL / (YA)$; x is inversely proportional to YA .

B1 $Y_B = 1.23 Y_A$ (a 23% greater Young modulus).

M1 $AA / AB = (dA / dB)^2 = (0.60 / 0.80)^2 = 0.5625$.

$$\text{A1 } x_B = (2.0 \text{ mm})(0.5625 / 1.23) = 0.915 \text{ mm} \approx 0.91 \text{ mm}$$

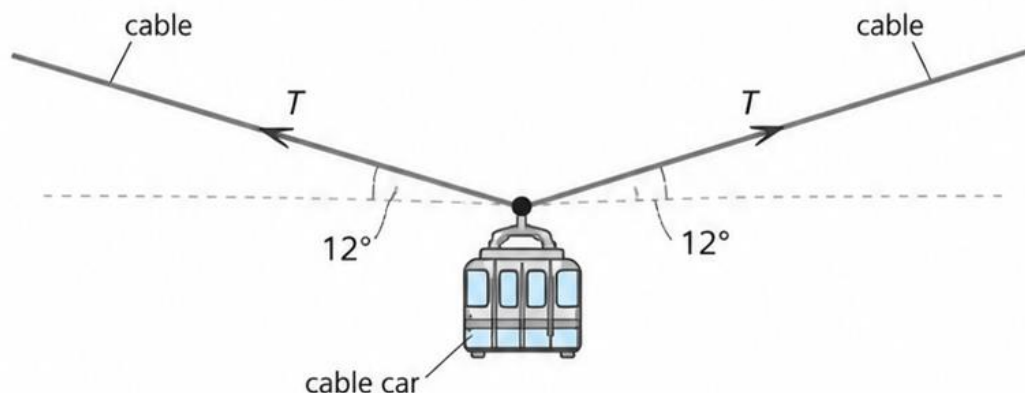
Accept equivalent methods, sensible rounding and correct units.

Total: 22 marks

Young's modulus – application

1

A stationary cable car is supported by two identical cables as shown below.



The cable on both sides of the car is at an angle of 12° to the horizontal.

The radius of the cable is 2.6×10^{-2} m.

The stress in the cable is 1.8×10^7 Pa.

The Young's modulus of the material of the cable is 2.0×10^{11} Pa.

(i) Calculate the strain experienced by the cable.

strain = _____ [2]

(ii) Calculate the tension T in the cable.

$T =$ _____ N [2]

(iii) Calculate the weight of the cable car.

weight = _____ N [3]

3.4.2 Mechanical properties of matter

Introduction: types of materials



Learning outcomes

By the end of this section, you should be able to:

- define and use the terms stress, strain and ultimate tensile strength
- interpret and compare stress–strain graphs for typical ductile, brittle and polymeric materials
- explain elastic and plastic deformation of materials

1 Meet the materials

Here are four common materials and how they behave in everyday life.

Glass



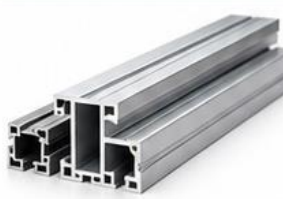
Brittle and stiff.
Breaks suddenly with very little stretching.

Carbon steel



Strong and ductile.
Can withstand large forces and undergoes plastic deformation.

Aluminium



Lighter than steel and ductile. Can be bent and shaped without breaking.

Rubber



Flexible and stretchy.
Undergoes very large strains and returns to its original shape.

2 Predict before you learn

Think about the materials above and the graph below. Make a prediction for each question.

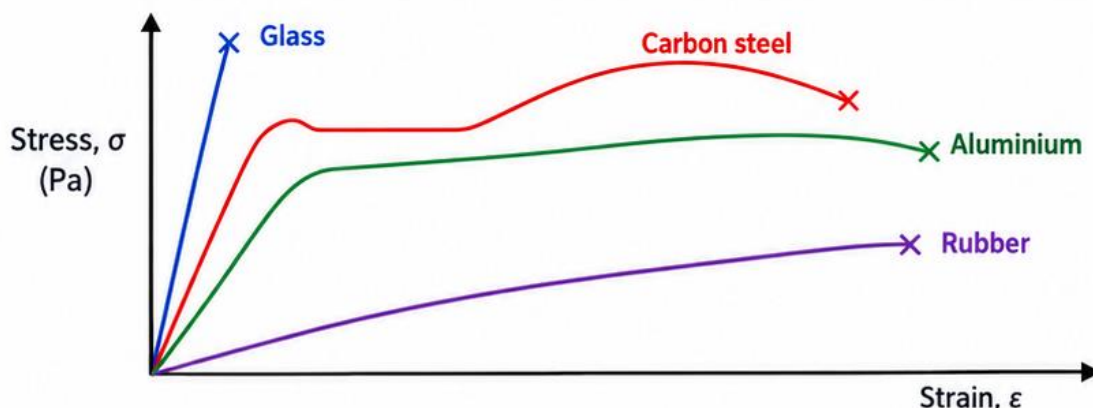
1 Which material do you think stretches the least before breaking?

2 Which material is likely to show plastic deformation?

3 Which material would need the greatest stress to break?

3 Stress–strain behaviour

The graph shows typical stress–strain curves for four common materials.



Big idea

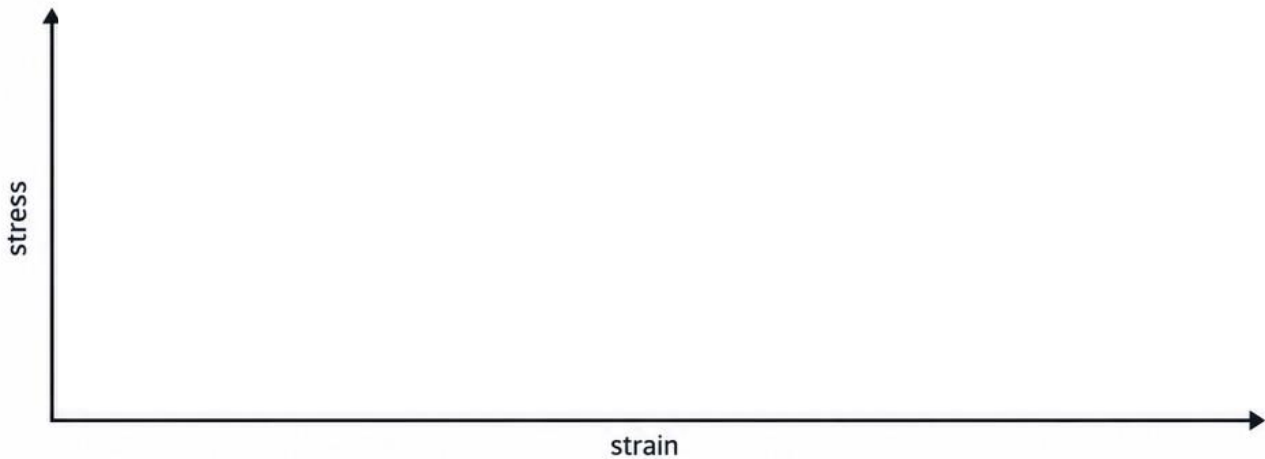
Different materials respond differently to applied forces. Stress–strain graphs help us compare stiffness, strength, elasticity and plastic behaviour, and allow us to identify brittle, ductile and polymeric materials.

Mechanical properties of matter – Teacher modelling

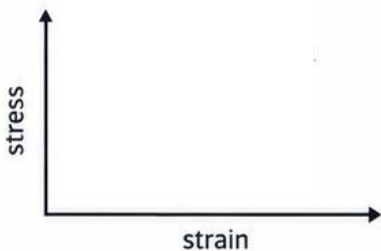
Stress–strain graphs and material behaviour

Use this page to model how different materials behave on stress–strain graphs. Sketch, label and compare brittle, ductile and polymeric materials.

Stress–strain graph (model and annotate)



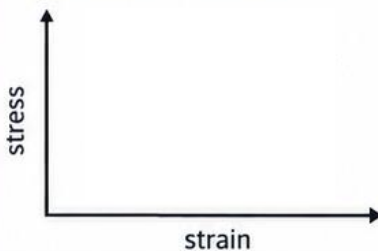
Brittle material



Ductile material



Polymeric material



Key ideas to model

- Define brittle. _____
- Define ductile. _____
- Describe a polymeric material. _____
- Explain what UTS means. _____
- Compare elastic and plastic deformation. _____

Thinking prompts

1. Which material shows the greatest strain before breaking?

2. Which material would be best for a structure that must deform before failure?

3. Why is a brittle material dangerous in some applications?

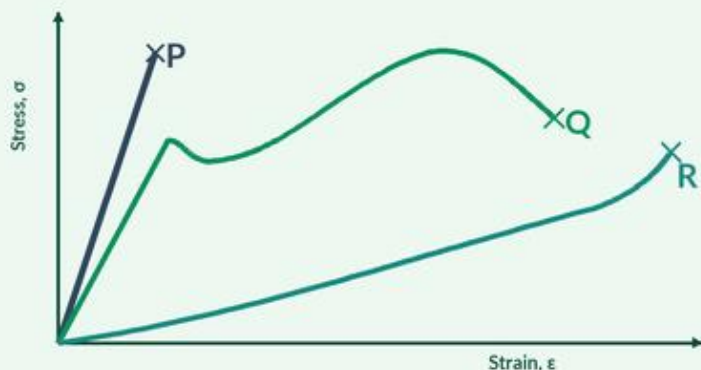
Stress-strain behaviour

CHECK FOR UNDERSTANDING

OCR A Physics A • 3.4.2 Mechanical properties of matter

- 1** The curves show three materials tested in tension. Which row correctly identifies the brittle, ductile and polymeric materials?

Schematic stress-strain curves

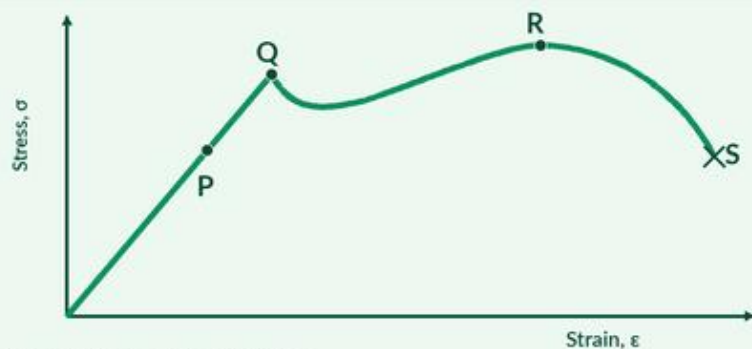


Select one row

P Q R

- | | | | |
|----------|-----------|-----------|-----------|
| A | brittle | ductile | polymeric |
| B | ductile | brittle | polymeric |
| C | brittle | polymeric | ductile |
| D | polymeric | ductile | brittle |

- 2** A ductile metal is loaded until fracture. Which labelled point represents its ultimate tensile strength (UTS)?



Schematic curve; points marked P-S

- | | |
|----------|---|
| A | P |
| B | Q |
| C | R |
| D | S |

- 3** Two wires, X and Y, have identical original lengths and cross-sectional areas. Their stress-strain graphs show:

Wire X has a steeper initial linear gradient; wire Y has a larger plastic region and reaches a greater maximum stress.

Which statements are correct?

- Wire X has the greater Young modulus.
- Wire X has the greater ultimate tensile strength.
- Wire Y is more ductile than wire X.

- | | | | |
|----------|--------------|----------|--------------|
| A | 1 only | B | 1 and 2 only |
| C | 1 and 3 only | D | 2 and 3 only |

Elastic band loading and unloading

This is a short practical investigation into how an elastic band behaves when forces are increased and then decreased.

Learning focus

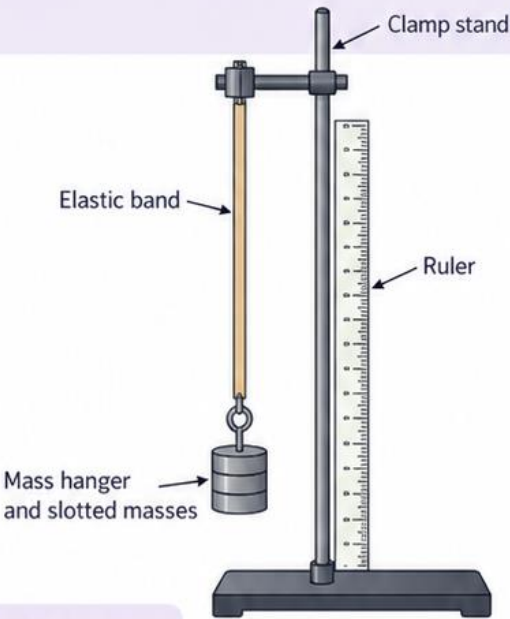
- Investigate how the extension of an elastic band changes as load is increased and then decreased.
- Collect data that can be plotted on loading and unloading graphs.

Equipment

- Elastic band
- Clamp stand
- Mass hanger and slotted masses
- Ruler fixed beside the band
- Pointer or fiducial marker

Method

- 1 Set up the elastic band vertically next to a ruler.
- 2 Measure and record the original length of the elastic band.
- 3 Add masses in equal steps, allowing the band to come to rest each time.
- 4 Record the length or extension for each load as the load is increased.
- 5 Continue up to a safe maximum load chosen by the teacher.
- 6 Remove the masses in the same equal steps.
- 7 Record the length or extension for each load as the load is decreased.
- 8 Use your data to plot loading and unloading graphs in the graph space elsewhere in the book.



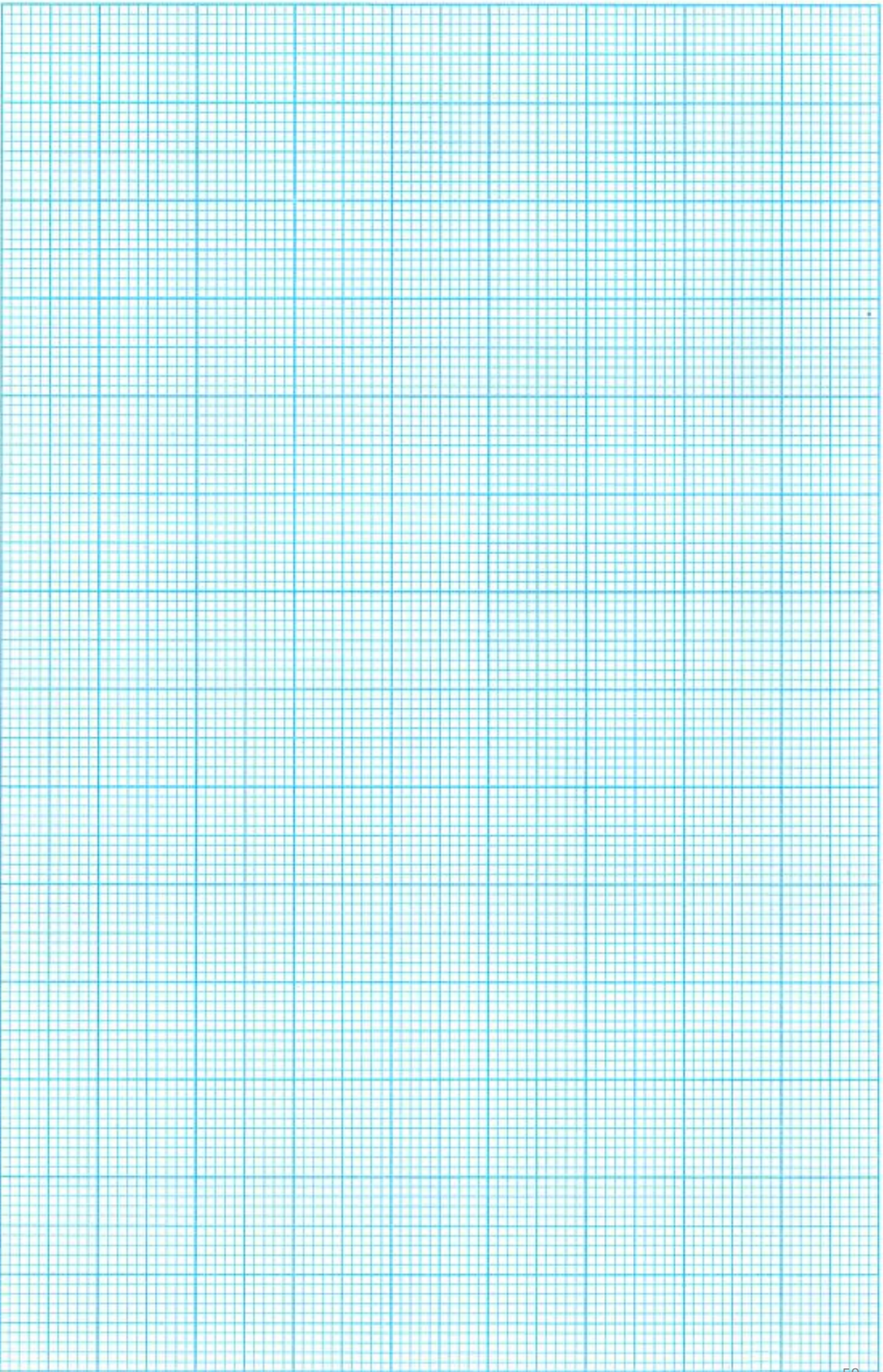
Safety note: Wear eye protection if instructed, do not overload the elastic band, and keep clear in case it snaps.

Results table

Load / N	Mass / kg	Length on loading / cm	Extension on loading / cm	Length on unloading / cm	Extension on unloading / cm

After collecting your data

- 1 Describe the pattern in your results.
- 2 Compare your loading data with your unloading data.
- 3 Suggest what your graphs may show.



Types of materials – application

Specification link (OCR A 3.4.2)

- Stress–strain graphs for different materials
- Ductile, brittle and polymeric behaviour

1 Fig. 1 shows the stress–strain graphs of two materials **X** and **Y**.

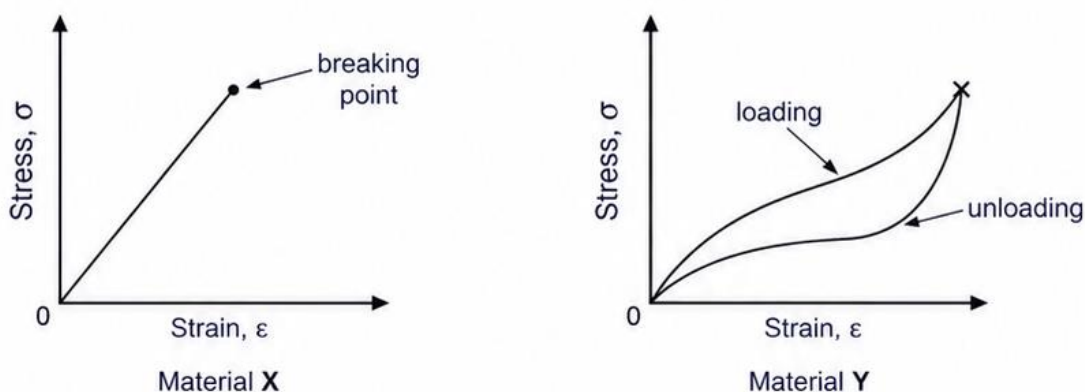


Fig. 1

(a) State the type of material for **X** and for **Y**. [2]

X: _____ **Y:** _____

(b) Describe, with reference to the graphs, why material **X** and material **Y** behave in this way. [2]

Material **X**:

Material **Y**:

(c) State, with a reason, whether each material obeys Hooke's law. [2]

Material **X**: _____

Material **Y**: _____

Material X	
It is a <i>brittle</i> material	B1
No plastic deformation / It is elastic / It returns to same length when stress / force is removed	B1
Material Y	
It is a polymeric / polymer (material)	B1
It is elastic / It returns to same length when stress / force is removed	B1
X obeys Hooke's law / Y does not obey Hooke's law	B1

Ratio problems in materials

Specification link (OCR A)

- 3.4.1 Springs and Hooke's law
- 3.4.2 Young's modulus and extension of a wire

Key ideas

- Ratio questions compare two situations.
- Identify what stays the same and what is different.
- Write the relevant equation in a general form.
- Use ratios to find how a quantity changes.
- Cancel common terms before calculating.
- Keep track of units and powers.

General approach

- 1 Identify the relevant equation (e.g. $F = kx$ or $\Delta L = FL/AE$).
- 2 Write it in a general form for each situation.
- 3 Decide which quantities are the same and which are different.
- 4 Form a ratio (situation 2 $\div$ situation 1).
- 5 Cancel any quantities that are the same.
- 6 Simplify the ratio and calculate a numerical value if required.

Example 1 – Springs

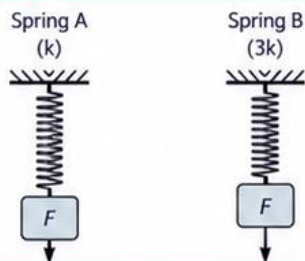
Question

Two springs, **A** and **B**, have different spring constants. Identical forces are applied to both springs.

The spring constant of spring **B** is three times the spring constant of spring **A**.

What is the ratio of the extensions of spring **A** to spring **B** when the same force is applied?

Diagram



Teacher modelling and working

Example 2 – Extension of two materials

Question

Two wires, **X** and **Y**, have the same original length and the same cross-sectional area.

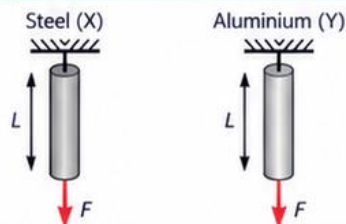
Wire **X** is made of steel with a Young's modulus of 2.0×10^{11} Pa.

Wire **Y** is made of aluminium with a Young's modulus of 7.0×10^{10} Pa.

The same tensile force is applied to both wires.

What is the ratio of the extension of wire **X** to the extension of wire **Y**?

Diagram



Teacher modelling and working

? Things to think about

- What happens to the ratio if the force is doubled?
- How would the ratio change if the wires had different lengths?
- Why is using a ratio often quicker and less error-prone than calculating each extension separately?

Ratio problems in materials – Check for understanding

Show your working for each question.

1 Springs and Hooke's law

Two springs obey Hooke's law. Spring A has spring constant 120 N m^{-1} and spring B has spring constant 240 N m^{-1} . The same force is applied to both springs. If spring A extends by 8.0 cm , what is the extension of spring B?

A 2.0 cm

B 4.0 cm

C 8.0 cm

D 16.0 cm

2 Extension ratios for wires

Two wires of the same material and length are stretched by the same tensile force.

Wire X has a diameter of 2.0 mm ; wire Y has a diameter of 4.0 mm .

If wire X extends by e , what is the extension of wire Y in terms of e ?

A $2e$

B $0.5e$

C e

D $0.25e$

3 Two metal wires – comparing extensions

Two metal wires, A and B, are stretched by the same tensile force.

Both wires remain in the proportional region.

Wire A – steel

Length L | Diameter d | $Y = 2.0 \times 10^{11} \text{ Pa}$

Wire B – brass

Length $2L$ | Diameter $2d$ | $Y = 1.0 \times 10^{11} \text{ Pa}$

Which statements are correct?

- 1** Wire B has the same extension as wire A.
- 2** The tensile stress in wire B is half that in wire A.
- 3** The tensile strain in wire B is half that in wire A.

Choose one answer:

A 1 only

B 2 and 3 only

C 1 and 3 only

D 1, 2 and 3

The table below shows some data on two wires X and Y.

Wire	Young modulus of material / GPa	Cross-sectional area of wire / mm ²
X	120	1.0
Y	200	2.0

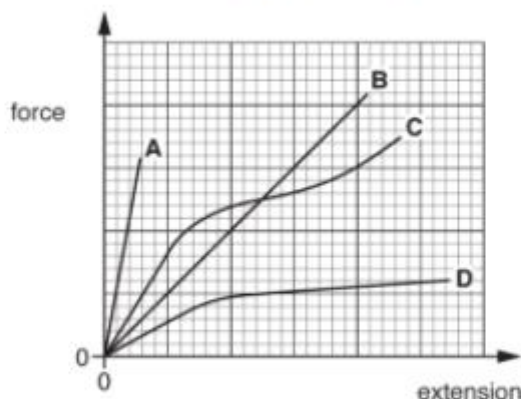
The wires X and Y have the same original length. The tension in each wire is the same. Both wires obey Hooke's law.

$$\frac{\text{extension of X}}{\text{extension of Y}}$$

What is the value of the ratio ?

- A 0.30
- B 1.7
- C 2.0
- D 3.3

Four materials A, B, C and D have the same length and cross-sectional area. The force against extension graph for each material up to the breaking point is shown below.



Which material is brittle and has the greatest ultimate tensile strength?

A student is investigating two wires of different diameters made from the **same** metal. She plots graphs of force against extension and graphs of stress against strain for both wires.

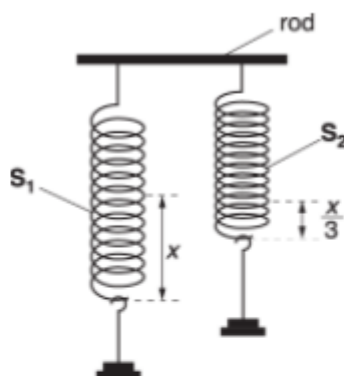
The wires behave elastically.

Which of the following statements is / are correct?

- 1 Young modulus is equal to the gradient of the stress against strain graph.
- 2 Force constant is equal to the gradient of the force against extension graph.
- 3 The graphs of stress against strain have different gradients.

- A 1, 2 and 3
B Only 1 and 2
C Only 2
D Only 1

The top ends of two springs, S_1 and S_2 , are attached to a rod.



A mass is hung from the bottom end of S_1 . The extension of S_1 is x . The elastic potential energy in the spring is E . The same mass is hung from the bottom end of S_2 . The extension of S_2 is $\frac{x}{3}$.

What is the elastic potential energy in the spring S_2 ?

- A $\frac{E}{9}$
B $\frac{E}{3}$
C $3E$
D $9E$

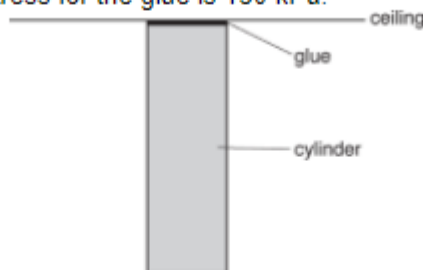
Two guitar strings of equal length, but of different thickness, are under the same tension. The strings are made of the same material.

The thinner string has a diameter of 0.20 mm and the thicker string has a diameter of 0.80 mm.

What is the value of the ratio $\frac{\text{elastic potential energy in the thinner string}}{\text{elastic potential energy in the thicker string}}$?

- A 0.125
- B 0.25
- C 4.0
- D 16

The flat end of a uniform steel cylinder of weight 7.8 N is glued to a horizontal ceiling. The cylinder hangs vertically. The breaking stress for the glue is 130 kPa.



The glue only just holds the cylinder to the ceiling.

What is the cross-sectional area of the cylinder?

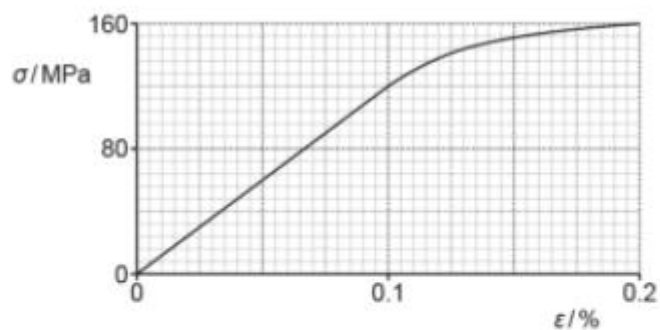
- A $6.0 \times 10^{-2} \text{ m}^2$
- B $6.0 \times 10^{-5} \text{ m}^2$
- C $1.7 \times 10^{-2} \text{ m}^2$
- D $1.7 \times 10^1 \text{ m}^2$

A tensile force of 4.5 N is applied to a spring. The spring extends elastically by 3.2 cm.

What is the elastic potential energy of the spring?

- A 0.072 J
- B 0.14 J
- C 2.4 J
- D 14 J

A graph showing the variation of the stress σ with strain ϵ for a material is shown below.



What is the Young modulus of the material?

- A $6.0 \times 10^4 \text{ Pa}$
- B $1.2 \times 10^9 \text{ Pa}$
- C $8.0 \times 10^{10} \text{ Pa}$
- D $1.2 \times 10^{11} \text{ Pa}$

Additional challenge

Two wires **X** and **Y** have the same extension for the same load.
X has a diameter d and is made of a metal of density ρ and Young modulus E .
Y has the same mass and length as **X** but its diameter is $2d$.

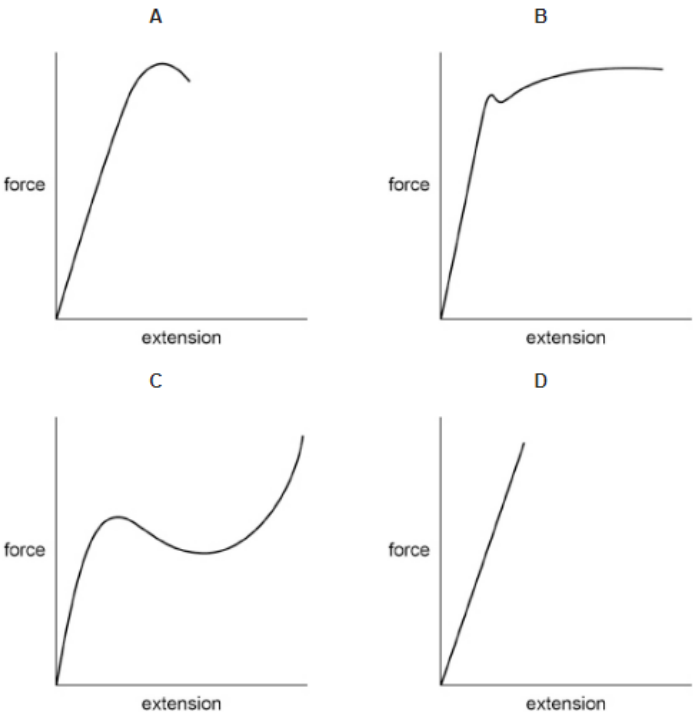
What are the density and the Young modulus of the metal from which **Y** is made?

	Density	Young modulus	
A	$\frac{\rho}{2}$	$\frac{E}{4}$	☐
B	$\frac{\rho}{2}$	$4E$	☐
C	$\frac{\rho}{4}$	$\frac{E}{4}$	☐
D	$\frac{\rho}{4}$	$4E$	☐

(Total 1 mark)

C

Which is a force–extension graph for a brittle material?



- A ☐
- B ☐
- C ☐
- D ☐

(Total 1 mark)

A wire is made from a material of density ρ .
 The wire has a mass m and an initial length L .
 When the tensile force in the wire is F the extension of the wire is ΔL .
 What is the Young modulus of the material?

A $\frac{F\rho L^2}{m\Delta L}$ ☐

B $\frac{FL^2}{m\rho\Delta L}$ ☐

C $\frac{F\rho}{m\Delta L}$ ☐

D $\frac{FmL^2}{\rho\Delta L}$ ☐

A

(Total 1 mark)

A mass m is added to a vertical spring that is initially unextended, as shown in **Diagram 1**.
 The mass is then lowered until it hangs stationary on the spring, as shown in **Diagram 2**.
 The extension of the spring is now ΔL .

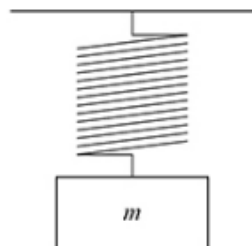


Diagram 1

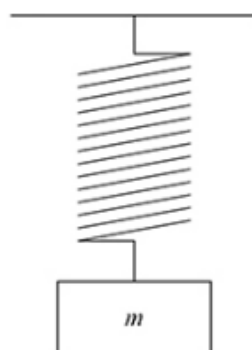


Diagram 2

How much energy is transferred from the mass–spring system?

A $\frac{mg\Delta L}{2}$ ☐

B $mg\Delta L$ ☐

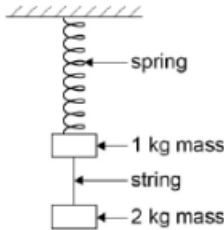
C $\frac{3mg\Delta L}{2}$ ☐

D $2mg\Delta L$ ☐

A

(Total 1 mark)

Two masses hang at rest from a spring, as shown in the diagram. The string separating the masses is burned through.



Which of the following gives the accelerations of the two masses as the string breaks?

acceleration of free fall = g

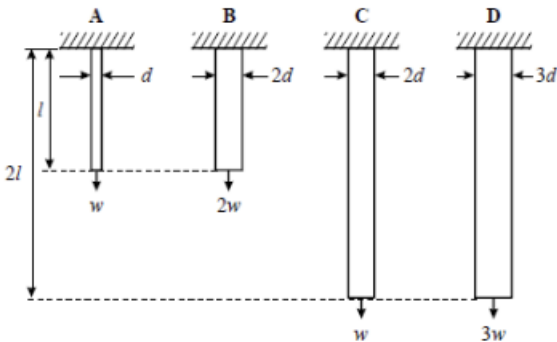
	acceleration of 1 kg mass upwards in m s^{-2}	acceleration of 2 kg mass downwards in m s^{-2}	
A	$3g$	$1g$	☐
B	$2g$	$2g$	☐
C	$2g$	$1g$	☐
D	$1g$	$1g$	☐

(Total 1 mark)

C

The four bars A, B, C and D have diameters, lengths and loads as shown. They are all made of the same material.

Which bar has the greatest extension?



(Total 1 mark)

A

Additional notes

★

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