Edexcel

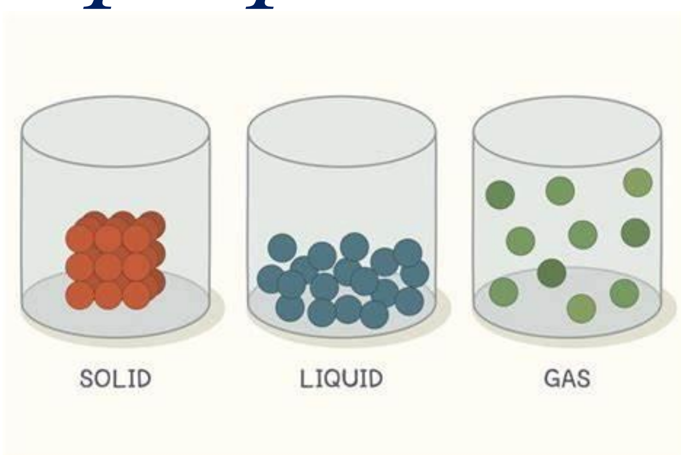
AS level

Physics

CODE: (4BI1)

Topic 2-Materials

2B- Solid material properties



Whenever a force acts on a material sample, the sample will be deformed to a different size or shape. If it is made longer, the force is referred to as **tension**, and the extra length is known as the **extension**. For a material being squashed to a smaller size, both the force and the decrease in size are called **compression**, although the decrease in size could be referred to as a negative extension.

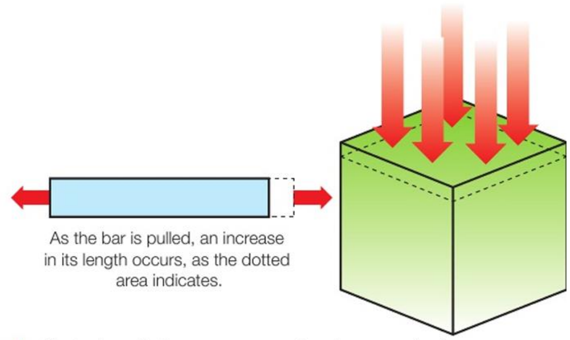


fig A A tensile force causes extension. A compressive force causes a negative extension.

2B.1 – Hooke's law

Hooke's law states that the force needed to extend a spring is proportional to the extension of the spring. A material only obeys Hooke's law if it has not passed what is called the **limit of proportionality.**

If an object is subject to only a small force, it will deform **elastically.** When the force is removed, it returns to its original size and shape, if the elastic limit was not passed. We will look in much more detail at elastic and plastic **deformation**.

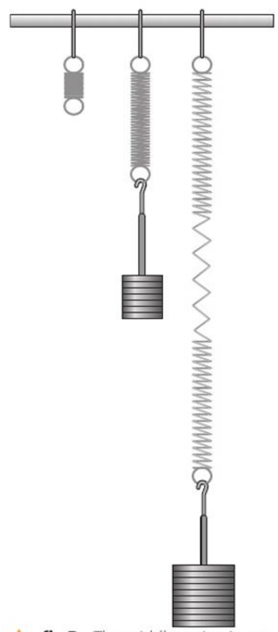


fig B The middle spring is extended in proportion to the applied load, obeying Hooke's law. The right-hand spring has been stretched beyond its limit of proportionality, so no longer obeys Hooke's law.

Hooke's law is best described mathematically with the equation:

force applied (N) = stiffness constant (N m^{-1}) × extension (m)

$$\Delta F = k\Delta x$$

Elastic strain energy

Elastic strain energy (Eel) is the work done in deforming a material sample before reaching its elastic limit. Hooke's law allows for different force values for different extensions, such as a spring with increasing masses. To calculate work done, use the average force over the extension distance.

$$\Delta E_{el} = \frac{1}{2}F\Delta x$$

Work from force – extension and force – compression graphs

Deforming a material involves multiplying extension or compression by an average force value. Non-linear force variations may complicate finding average force. The area between the line on a force-extension graph and the extension axis represents work done. Finding the area under the line is easy using a linear relationship.

$$\Delta E_{el} = \frac{1}{2}F\Delta x$$

If the relationship is non-linear, as shown in the example of fig D, the work done can still be found from the area under the line.

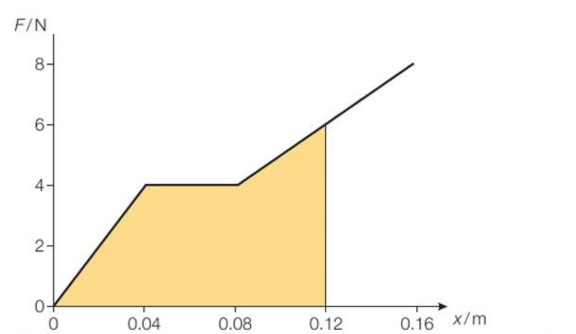


fig D The elastic potential energy stored in a material can be found from a non-linear force–extension graph by working out the area under the line up to the required extension.

SUBJECT VOCABULARY

tension a force acting within a material in a direction that would extend the material
extension an increase in size of a material sample caused by a tension force
compression a force acting within a material in a direction that would squash the material. Also the decrease in size of a material sample under a compressive force
limit of proportionality the maximum extension (or strain) that an object (or sample) can have, which is still proportional to the load (or stress) applied
deformation the process of alteration of form or shape
elastic limit the maximum extension or compression that a material can undergo and still return to its original dimensions when the force is removed
spring constant the Hooke's law constant of proportionality, *k*, for a spring under tension
hysteresis where the extension under a certain load will be different depending on its history of past loads and extensions
thermal connected with heat

2B.2 -Stress, strain and the young modules

Stress

Tensile (or compressive) **stress** is a measure of the force within a material sample, but it takes account of the cross-sectional area across the sample. This allows force comparisons to be made between samples of different sizes, so that they are measured under comparable conditions.

$$\text{stress (pascals, Pa, or N m}^{-2}\text{)} = \frac{\text{force (N)}}{\text{cross-sectional area (m}^2\text{)}}$$

$$\sigma = \frac{F}{A}$$

Strain

Tensile (or compressive) **strain** is a measure of the extension (or compression) of a material sample, but it takes account of the original length of the sample. This allows extension comparisons to be made between samples of different sizes, so that they are measured under comparable conditions.

$$\text{strain (no units)} = \frac{\text{extension (m)}}{\text{original length (m)}}$$

$$\varepsilon = \frac{\Delta x}{x}$$

Young modules

The **Young modulus** is a measure of a material's stiffness, which is proportional to stress and deformation under strain. It considers the shape and size of the sample, ensuring that different samples of the same material have the same young modulus value.

$$\text{Young modulus (Pa)} = \frac{\text{stress (Pa)}}{\text{strain (no units)}}$$

$$E = \frac{\sigma}{\varepsilon}$$

The definition for the young modulus also includes the fact that the material must be undergoing elastic deformation. Beyond the limit of proportionality, this equation will no longer work to calculate the stiffness of the material.

SUBJECT VOCABULARY

stress a proportionate measure of the force on a sample:

$$\text{stress (pascals Pa, or N m}^{-2}\text{)} = \frac{\text{force (N)}}{\text{cross-sectional area (m}^2\text{)}}$$

$$\sigma = \frac{F}{A}$$

strain a proportionate measure of the extension (or compression) of a sample:

$$\text{strain (no units)} = \frac{\text{extension (m)}}{\text{original length (m)}}$$

$$\varepsilon = \frac{\Delta x}{x}$$

Young modulus the stiffness constant for a material, equal to the stress divided by its corresponding strain

2B.3 – Stress – stain graphs

Stress – stain analyses

The Young modulus is a measure of a material's ability to withstand elastic deformation, indicating its ability to withstand stress and strain. A straight-line graph is obtained when stress against strain is plotted, but as the limit of proportionality is reached, the material's internal structure changes, leading to a curve in the graph.

Fig **A** is a generalised stress-strain graph for a metal, such as copper. Most metals will follow the shape shown here, and there are various areas of interest on the graph.

In the straight-line portion from the origin to **point A,** the metal extends elastically, and will return to its original size and shape when the force is removed. The gradient of the straight-line portion of the graph is equal to the Young modulus for the metal.

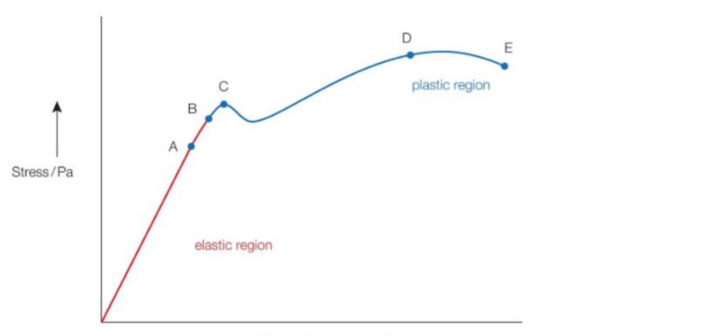


fig A The stress–strain graph for a metal gives detailed information about how the material behaves under different levels of stress. The gradient of the straight-line portion of the graph will be equal to the value of the Young modulus.

Point A is the limit of proportionality. Slightly beyond this point, the metal may still behave elastically, but it cannot be relied upon to increase strain in proportion to the stress.

Point B is the elastic limit. Beyond this point, the material is permanently deformed and will not return to its original size and shape, even when the stress is completely released.

Point C is the **yield point**, beyond which the material undergoes a sudden increase in extension as its atomic substructure is significantly re-organised. The metal 'gives' just beyond its yield point as the metal's atoms slip past each other to new positions where the stress is reduced.

Point D represents the highest possible stress within this material. It is called the Ultimate Tensile Stress, or UTS, σu.

Point E is the fracture stress, or breaking stress. It is the value that the stress will be in the material when the sample breaks.

SUBJECT VOCABULARY

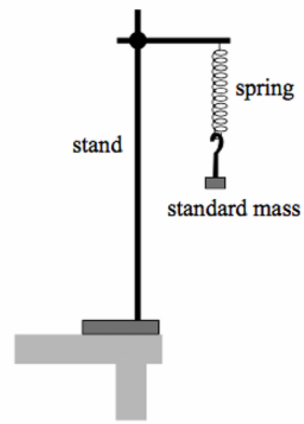
yield point a strain value beyond which a material undergoes a sudden and large plastic deformation

Revision questions

(1)(a) State Hooke's law.

(b) A student is asked to measure the mass of a rock sample using a steel spring, standard masses and a metre rule. She measured the unstretched length of the spring and then set up the arrangement shown in Figure 2.

Figure 2



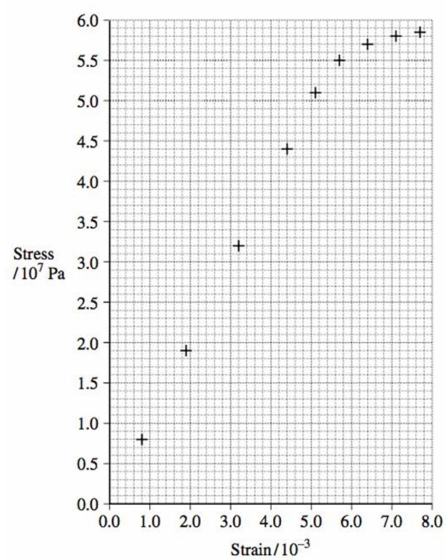
(i) Describe how you would use this arrangement to measure the mass of the rock sample. State the measurements you would make and explain how you would use the measurements to find the mass of the rock sample.
The quality of your written communication will be assessed in this question.

(b) (ii) State and explain one modification you could make to the arrangement in Figure 2 to make it more stable.

(2) (a) Describe how to obtain, accurately by experiment, the data to determine the Young modulus of a metal wire.
A space is provided for a labelled diagram.
The quality of your written answer will be assessed in this question.

(b)Figure 7 is a plot of some results from an experiment in which a metal wire was stretched.

Figure 7



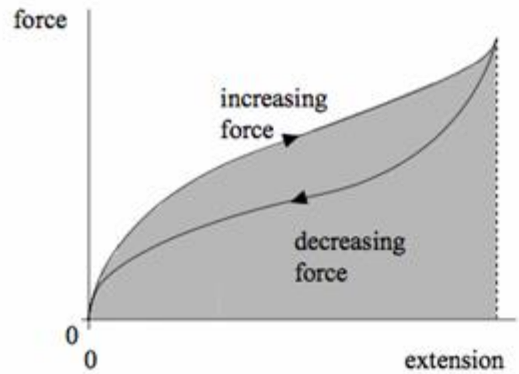
(b) (i) Draw a best-fit line using the data points.

(b) (ii) Use your line to find the Young modulus of the metal, stating an appropriate unit.

(c) After reaching a strain of 7.7 × 10, the wire is to be unloaded. On Figure 7, sketch the line you would expect to obtain for this.

(3)A student investigated how the extension of a rubber cord varied with the force used to extend it. She measured the extension for successive increases of the force and then for successive decreases. Figure 5 shows a graph of her results.

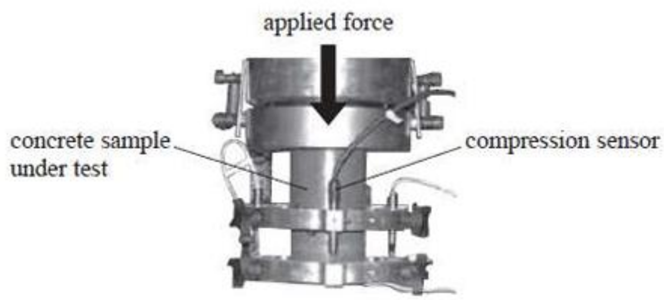
Figure 5



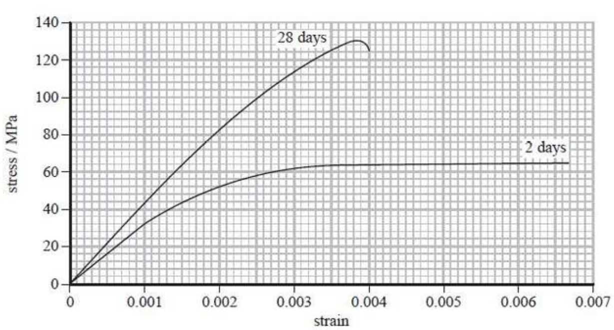
(a) (i) Give a reason why the graph shows the rubber cord does not obey Hooke's law.
(ii) Give a reason why the graph shows the rubber cord does not exhibit plastic behaviour.
(iii) What physical quantity is represented by the area shaded on the graph between the loading curve and the extension axis?

(b) Describe, with the aid of a diagram, the procedure and the measurements you would
make to carry out this investigation.
The quality of your written answer will be assessed in this question.

(4)When concrete is first made it has a high moisture content. As the concrete dries its properties change.
A manufacturer of concrete carried out compression testing of cylindrical samples of concrete using the equipment shown.



The diagram shows stress-strain graphs, up to the fracture point, for concrete samples 2 days and 28 days after being made.



(a) As the concrete dries its Young modulus increases.
Show that the value for the Young modulus of the concrete after it has dried is at least 1.3 times greater.

(b) The energy absorbed before fracture by the 28-day old sample is less than the energy absorbed before fracture by the 2-day old sample.
The area under a stress-strain graph gives the energy absorbed per unit volume of the sample.
The energy absorbed before fracture by the 2-day old sample is 0.35 MJ m3.
Determine the percentage reduction in the energy absorbed before fracture between the 2-day old and the 28-day old samples.
You may assume that the volumes of the cylindrical samples are the same.

(c) Manufacturers recommend leaving concrete blocks to dry for at least 28 days before use.Discuss why.

(5)(a) To make concrete suitable for use under large forces steel rods are sometimes embedded in the concrete. An external tensile force is applied to the steel rods. Concrete is poured into a mould around the rods. Once the concrete has set the external force is removed from the steel rods, placing the concrete in compression.

(i) Explain how this process increases the maximum tensile force that the concrete can withstand before fracture.

(ii) Explain why the external tensile force in the rods must not take the steel beyond its elastic limit.

(6) (i) Draw and label suitable apparatus required for measuring the Young modulus of a material in the form of a long wire.
(ii) List the measurements you would make when using the apparatus described in part (i).
iii) Describe briefly how the measurements listed in part (ii) would be carried out.
(iv) Explain how you would calculate the Young modulus from your measurements.

(7)(a)(i) Define the Young modulus for a material.
(ii) Explain what is meant by the elastic limit for a wire.
(b) A wire supported at its upper end, hangs vertically. The table shows readings obtained when stretching the wire by suspending masses from its lower end.

load/N	0	2.0	4.0	6.0	7.0	8.0	9.0	10.0	10.5
extension/mm	0	1.2	2.4	3.6	4.2	4.9	5.7	7.0	8.0

(i) Plot a graph of load against extension on the grid provided.
(ii) Indicate on your graph the region where Hooke's law is obeyed.
iii) The unstretched length of the wire is 1.6m and the area of cross-section 8.0×10^{-8} m ^{2} Calculate the value of the Young modulus of the material.