OCR A Level Physics

Your notes

Materials

Contents

Your notes

Deformation & Compression

- Forces don't just change the motion of a body, but can change the size and **shape** of them too
  - This is known as **deformation**
- Forces in opposite directions stretch or compress a body
  - When two forces **stretch** a body, they are described as **tensile**
  - When two forces **compress** a body, they are known as **compressive**

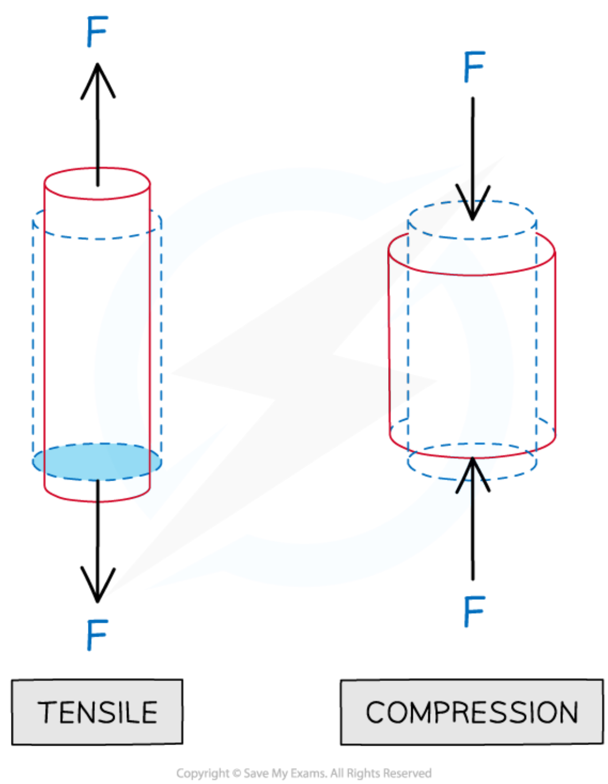

Diagram of tensile and compressive forces

- When a force (load) is applied to a spring, it produces a tensile force and causes the spring to **extend**
- When a force is applied in the opposite direction, the spring **compresses**

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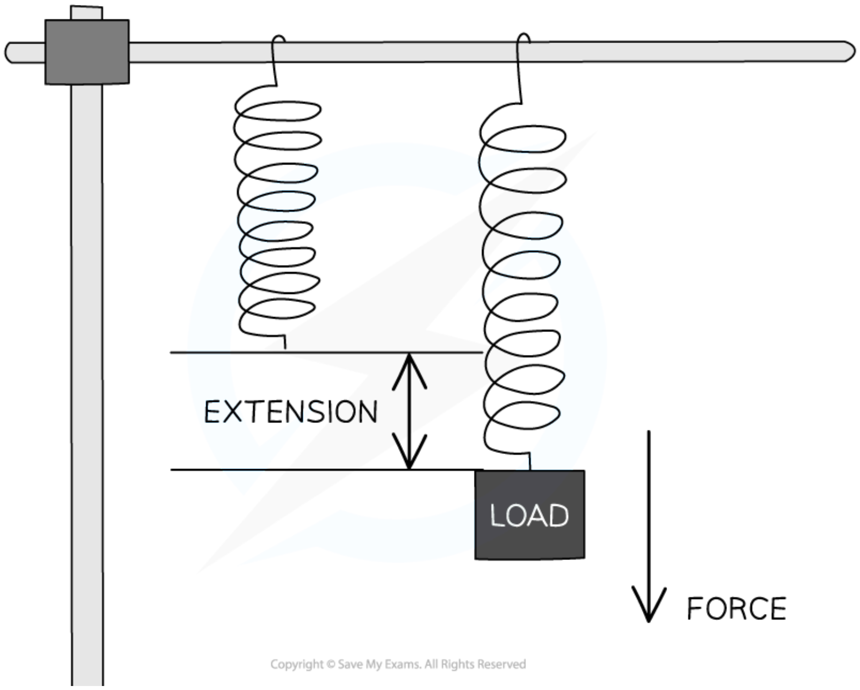


Stretching a spring with a load produces a force that leads to an extension

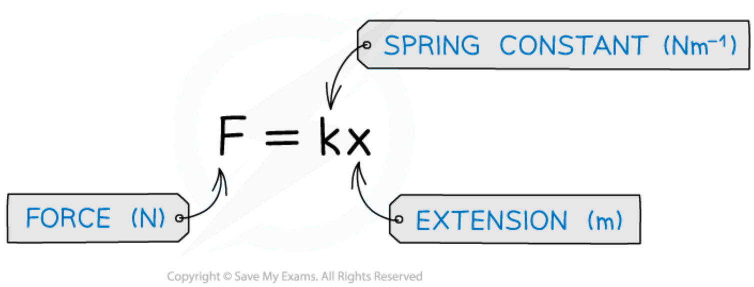
Your notes

Hooke's Law

Hooke's Law

- When a force F is added to the bottom of a vertical metal wire of length L, the wire **stretches**
- A material obeys Hooke's Law if:

  The extension of the material is directly proportional to the applied force (load) up to the limit of proportionality
- This linear relationship is represented by the Hooke's law equation:



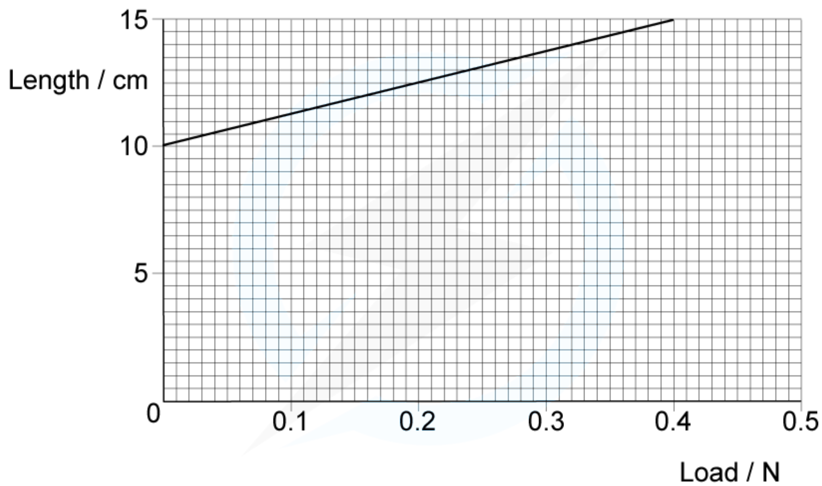
- The spring constant, which is sometimes called the **force constant** k, is a property of the material being stretched and measures the **stiffness** of a material
  - The larger the spring constant, the stiffer the material
- Hooke's Law applies to both **extensions** and **compressions**:
  - The extension of an object is determined by how much it has **increased** in length
  - The compression of an object is determined by how much it has **decreased** in length

Worked Example

A spring was stretched with increasing load.

The graph of the results is shown below.

Your notes



What is the spring constant?

Answer:

STEP 1

REARRANGE FROM HOOKE'S LAW, THE SPRING CONSTANT IS

$$k = \frac{F}{\Delta L}$$

STEP 2

THE GRADIENT OF A FORCE-EXTENSION GRAPH IS THE SPRING CONSTANT

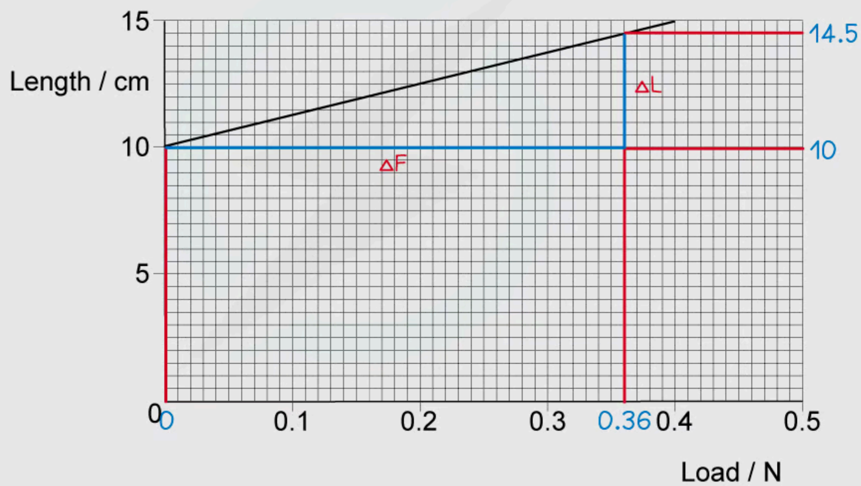
$$k = \frac{\Delta F}{\Delta L}$$

Your notes

STEP 3

THIS PARTICULAR GRAPH HAS THE LENGTH ON THE y-AXIS AND THE FORCE ON THE x-AXIS.

THEREFORE THE SPRING CONSTANT IS $\frac{1}{\text{GRADIENT}}$



STEP 4

FIND THE GRADIENT

$$\frac{\Delta L}{\Delta F} = \frac{(0.145 - 0.10)\text{m}}{0.36\text{ N}} = \frac{1}{8.0}\text{mN}^{-1}$$

GRADIENT $= \frac{\Delta y}{\Delta x}$

STEP 5

SPRING CONSTANT $= \frac{1}{\text{GRADIENT}}$

$$1 \div \frac{1}{8.0} = 8.0\text{ Nm}^{-1}$$

Examiner Tips and Tricks

Always double-check the axes before finding the force constant as the gradient of a force-extension graph. Exam questions often swap the force (or load) onto the x-axis and extension (or length) on the y-axis. In this case, the gradient is **not** the force constant, it is **1 ÷ gradient** instead.

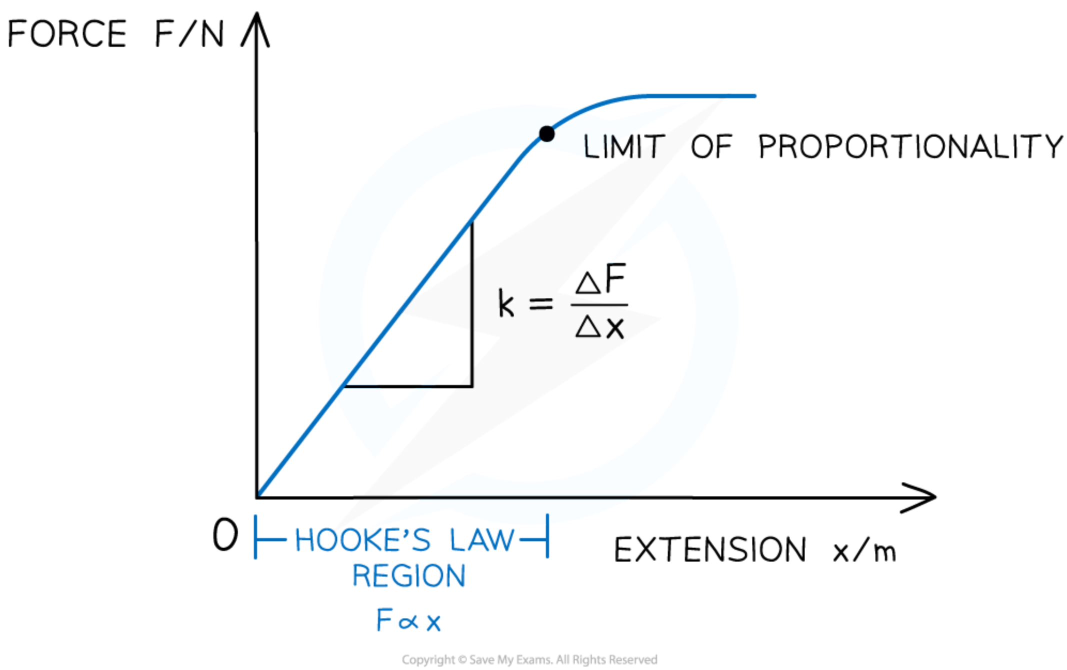
Your notes

Force-Extension Graphs

Your notes

Force-Extension Graphs

- The way a material responds to a given force can be shown on a force-extension graph
- Every material will have a unique force-extension graph depending on how **brittle** or **ductile** it is
- A material may obey Hooke's Law up to a point
  - This is shown on its force-extension graph by a **straight line through the origin**
- As more force is added, the graph may start to curve slightly



The Hooke's Law region of a force-extension graph is a straight line. The spring constant is the gradient of that region

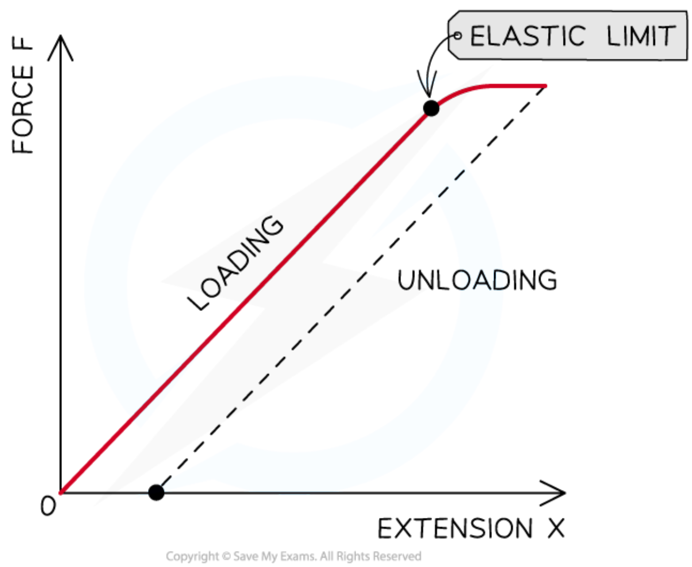
The key features of the graph are:

- **The limit of proportionality**
  - The point beyond which Hooke's law is no longer true when stretching a material i.e. the extension is no longer proportional to the applied force

Your notes

- The point is identified on the graph where the line starts to curve (flattens out)
- The force constant *k* is the **force per unit extension** up to the limit of proportionality, after which the material will not obey Hooke's law
  - This is the **gradient** of the straight part of the graph
- The graph might also include the **elastic limit**, this is:
  - The maximum amount a material can be stretched and still return to its original length (above which the material will no longer be **elastic**)
  - This point is always **after** the limit of proportionality
- Therefore, *k* is the **gradient** of the linear part of the graph ie. where Hooke's Law is obeyed

Metal Wire

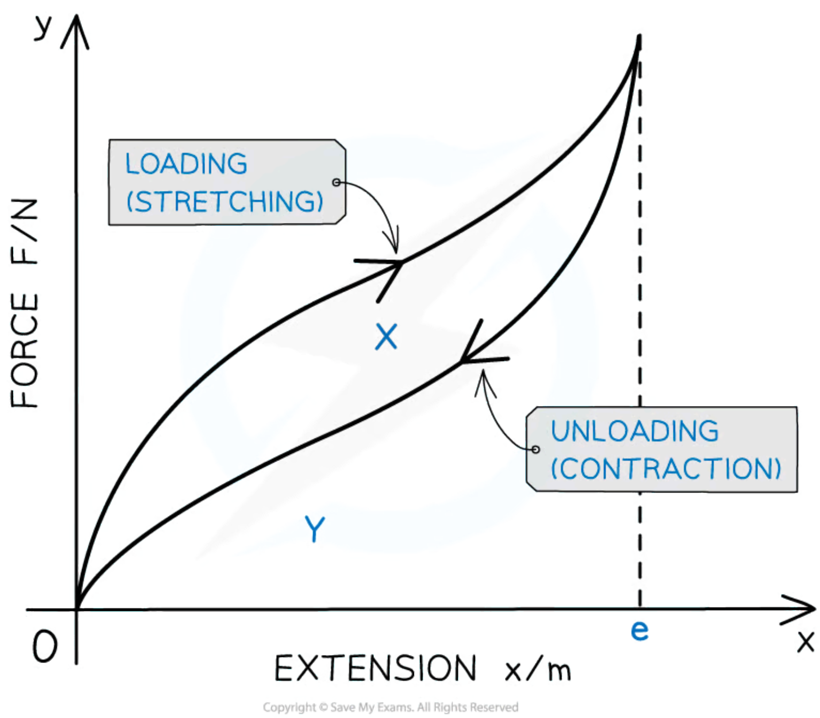


- A metal wire obeys Hooke's law and exhibits **elastic** deformation until its elastic limit
  - Up to this point, the loading curve is the same as the unloading curve
- Beyond this point, it experiences **plastic** deformation
  - The unloading curve has the same gradient as the loading curve
  - The plastic deformation causes a permanent extension of the wire

Rubber

Your notes

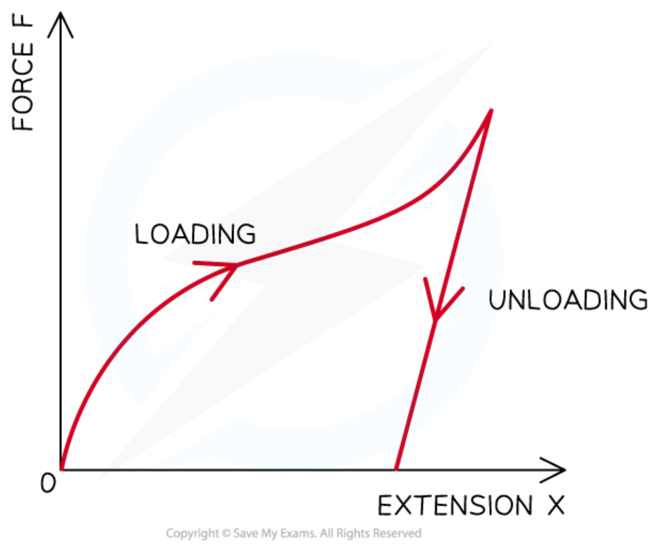
- Rubber is an elastic material, so it does not experience plastic deformation, nor does it obey Hooke's law
- The area between the loading and unloading curves is known as a **hysteresis loop**
  - This area represents the work done in stretching the material
  - This energy is transferred to thermal energy when the force is removed
- An example of a force-extension graph for such a material is:



- The curve for contraction is always below the curve for stretching
- The area **X** represents the **net work done** or the **thermal energy** dissipated in the material
- The area **X + Y** is the **minimum energy required** to stretch the material to extension e

Polymeric Materials (Polyethene)

Your notes



- Polyethene is a common polymer or polymeric material
- It does not obey Hooke's law and experiences plastic deformation when any force is applied to it
- This makes it very easy to stretch into new shapes, but difficult to return to its original shape

Investigating Force-Extension Characteristics

Aims of the Experiment

The aim of this experiment is to investigate the relationship between force and extension for three materials: metal springs, rubber bands and polythene strips

Variables

- Independent variable = Force / Load (N)
- Dependent variable = Extension (m)

Equipment List

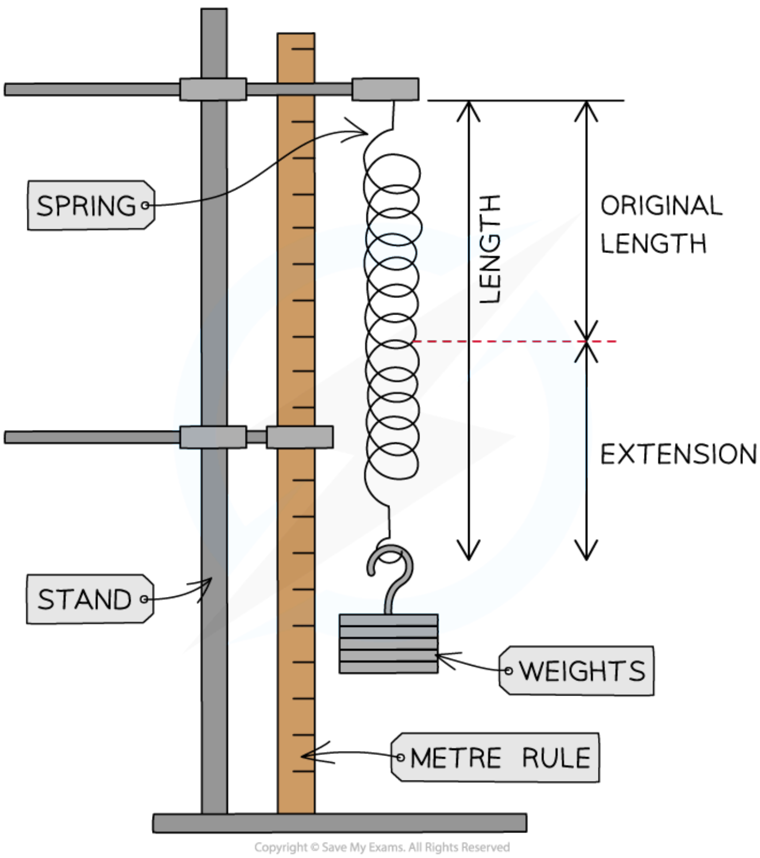
Your notes

Apparatus	Purpose
Extendable steel springs	Materials to use to investigate how much extension occurs when masses are attached to each
Rubber bands	
Polythene strips	
Clamp stand, clamp & boss	To suspend the materials from and to hold the metre ruler in place
G-clamp	To secure the clamp stand to the bench or table
Metre ruler	To measure the extension of each material
Mass hanger and 100g slotted masses	To provide the force which will lead to an extension
Set square	To ensure the ruler is perpendicular to the table
Fiducial Marker	To indicate the position of the original length of the materials

- Resolution of measuring equipment:
  - Metre ruler = 1 mm

Method

Your notes



Experimental set-up for investigating force-extension characteristics of a metal spring

1. Set up the apparatus as shown in the diagram. Hang a spring from the clamp and boss and secure it so that it will not fall off
2. Secure the metre rule vertically to the clamp, using the set square to ensure it is straight and place it adjacent to the spring
3. Record the metre rule reading at the bottom of the spring and place a fiducial marker on this point. This is its original length before any masses are hanging from it (no load)
4. Hang a mass hanger from the bottom of the spring. Record the new metre rule reading, the number of masses and the extension of the spring
5. Add another mass. Record the new metre rule reading, the number of masses, and the total extension of the spring from its original length
6. Repeat this until after the spring has become permanently stretched
7. Repeat the experiment for the rubber band and the polythene strip

- An example table might look like this:

LOAD = NUMBER OF MASSES × mg

EXTENSION = METRE RULE READING − ORIGINAL LENGTH

NUMBER OF MASSES	LOAD, F (N)	METRE RULE READING (cm)	TOTAL EXTENSION, x (cm)
1			
2			
3			
4			
5			
6			

Analysing the Results

- According to Hooke's Law:

$$F = kx$$

- Comparing this to the equation of a straight-line, y = mx
  - y = Load / force, *F*
  - x = Extension, *x*
  - Gradient = Force constant, *k*

- Plot a graph of the load applied on the horizontal axis and the extension of the spring on the vertical axis and draw a line of best fit
- The gradient of the linear part will be equal to the force constant, *k*
  - Make sure to measure the gradient of the **straight** section of the line only, as this is within the elastic limit of the material

Evaluating the Experiment

Your notes

Systematic errors:

- Reduce parallax error by reading the metre ruler at eye-level
- Use a set square to make sure the ruler is straight and perpendicular to the bench or table
- Use a fiducial marker to mark the original position of the material

Random errors:

- Ensure the material is stationary before a reading is made
- Repeat the experiment several times and calculate an average

Safety Precautions

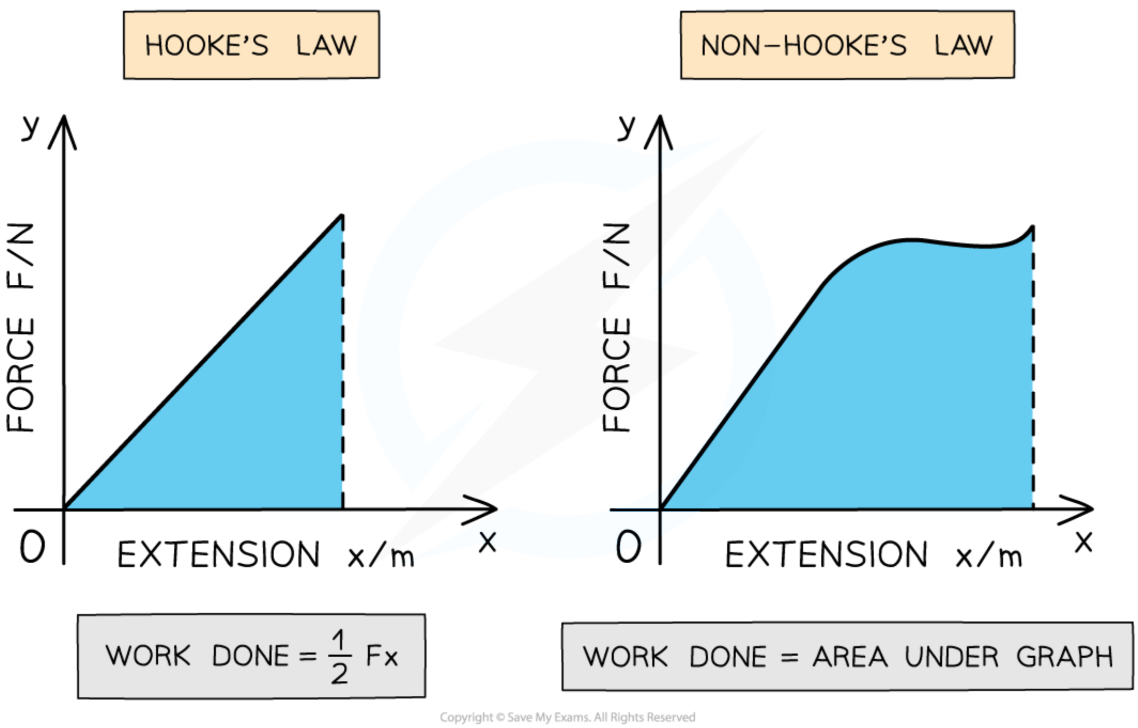
- When stretching materials, there is a danger that they may snap under the high tension
  - Eye protection should be worn
  - A box or landing mat should be placed below the hanger to catch the weight if it falls
  - Make sure to not stand directly underneath the hanging masses

Elastic Potential Energy

Your notes

Area under a Force-Extension Graph

- Work has to be done to stretch a material
- Before a material reaches its elastic limit (whilst it obeys Hooke's Law), all the work done is stored as **elastic strain energy**
- The work done, or the elastic strain energy is the **area under the force-extension graph**



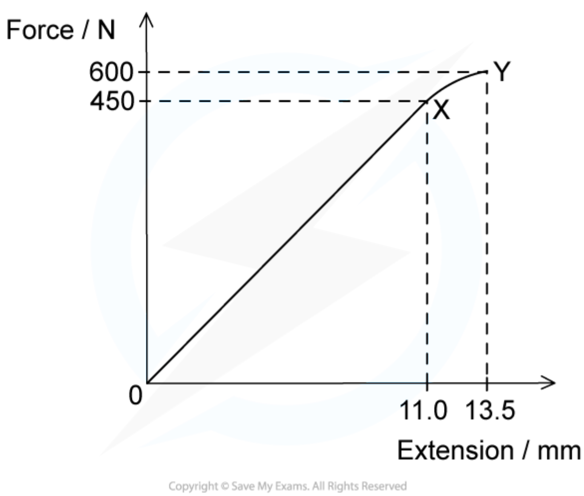
Work done is the area under the force-extension graph

- This is true for whether the material obeys Hooke's law or not
  - For the region where the material **obeys** Hooke's law, the work done is the area of a **right-angled triangle** under the graph
  - For the region where the material **doesn't obey** Hooke's law, the area is the **full region** under the graph. To calculate this area, split the graph into separate segments and add up the individual areas of each

Your notes

Worked Example

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



What is the total work done in stretching the sample from zero to 13.5 mm extension?

Simplify the calculation by treating the curve XY as a straight line.

Answer:

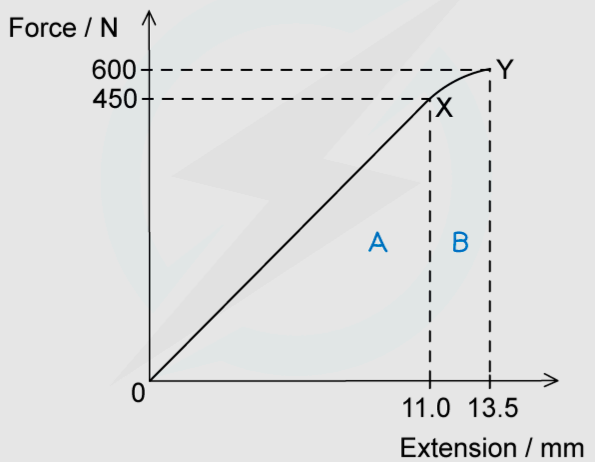
Your notes

STEP 1

WORK DONE = AREA UNDER THE FORCE–EXTENSION GRAPH

STEP 2

SPLIT GRAPH INTO THE TWO AREAS



STEP 3

CALCULATE AREA A

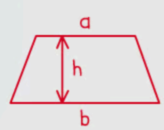
AREA OF A RIGHT ANGLED TRIANGLE = $\frac{1}{2}$ × BASE × HEIGHT

AREA = $\frac{1}{2} \times 11 \times 10^{-3} \times 450 = 2.475$ J

STEP 4

CALCULATE AREA B

AREA OF TRAPEZIUM = $\left(\frac{a+b}{2}\right) \times h$



AREA = $\left(\frac{450 + 600}{2}\right) \times 2.5 \times 10^{-3} = 1.313$ J

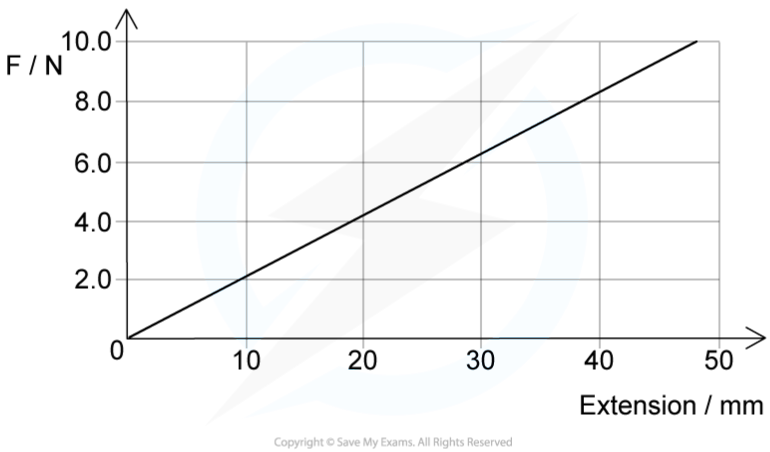
STEP 5

TOTAL AREA = 2.475 + 1.313 = 3.79 J (3 s.f.)

Your notes

Worked Example

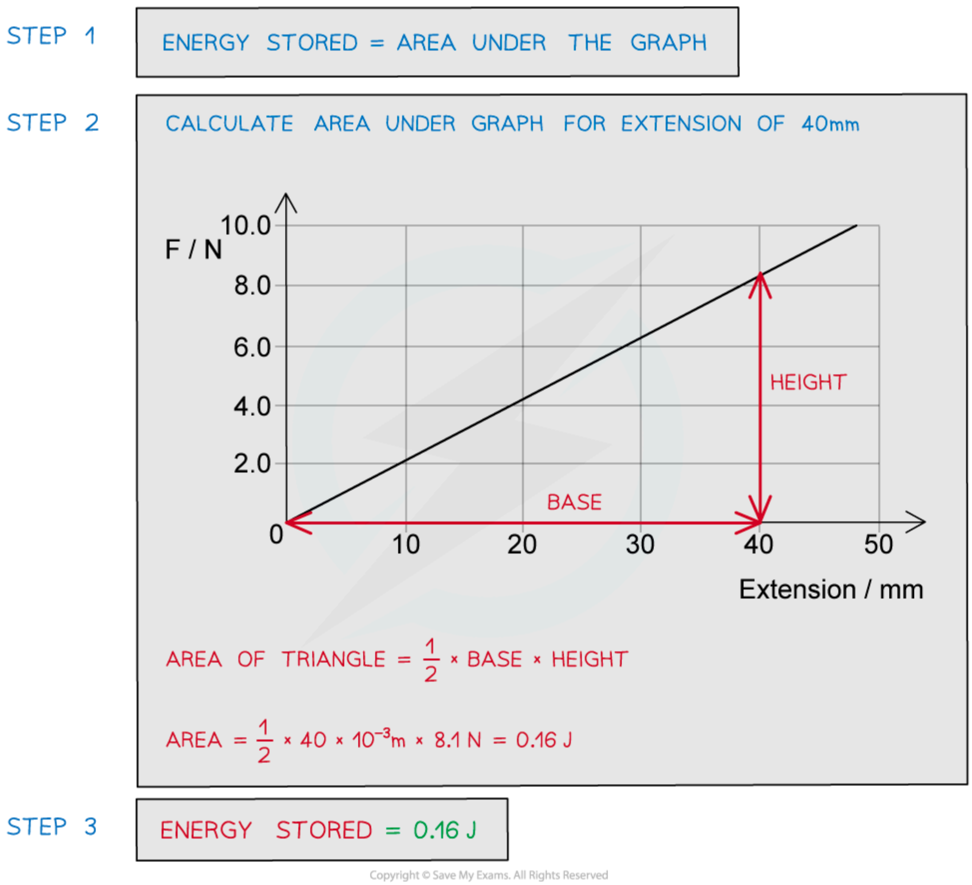
A spring is extended with varying forces; the graph below shows the results.



What is the energy stored in the spring when the extension is 40 mm?

Answer:

Your notes



Examiner Tips and Tricks

Remember to always double-check the units on the force and extension axes on the graph before using values from it for calculations. The force can sometimes be in kN and the extension in mm!

Elastic Potential Energy

- Elastic potential energy is defined as

  The energy stored within a material (e.g. in a spring) when it is stretched or compressed

- It can be found from the **area under the force-extension graph** for a material deformed within its limit of proportionality
- A material within its limit of proportionality obeys Hooke's law

- Therefore, for a material obeying Hooke's Law, elastic potential energy can be calculated using:

$$\text{HOOKE'S LAW: } F = kx$$

$$EPE = \frac{1}{2}Fx = \frac{1}{2}(kx)x$$

$$\boxed{\text{ELASTIC POTENTIAL ENERGY} = \frac{1}{2}kx^2}$$

- Where:
  - k = force constant of the spring (N m^{-1})
  - x = extension (m)
- It is very dangerous if a wire under stress suddenly breaks
- This is because the elastic potential energy of the strained wire is converted into kinetic energy

EPE = KE

$$\tfrac{1}{2}kx^2 = \tfrac{1}{2}mv^2$$

$$v \propto x$$

- This equation shows that the greater the extension of a wire, x, the greater the speed, v, it will have on breaking

Worked Example

A car's shock absorbers make a ride more comfortable by using a spring that absorbs energy when the car goes over a bump. One of these springs, with a force constant of 50 kN m^{-1} is fixed next to a wheel and compressed a distance of 10 cm. Calculate the energy stored by the compressed spring.

Answer:

Step 1: List the known values

- Force constant, k = 50 kN m^{-1} = 50 × 10^{3} N m^{-1}
- Compression, x = 10 cm = 10 × 10^{-2} m

Step 2: Write the relevant equation

$$EPE = ½ kx^2$$

Step 3: Substitute in the values

$$EPE = ½ \times (50 \times 10^3) \times (10 \times 10^{-2})^2 = \mathbf{250\ J}$$

Your notes

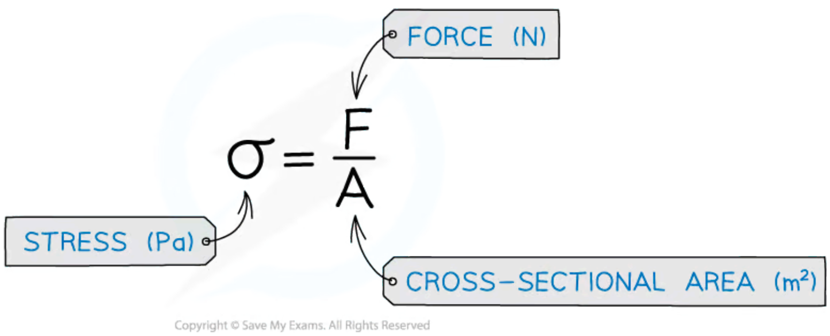
Your notes

Stress, Strain & Tensile Strength

- Opposite forces can deform an object
- If the forces **stretch** the object, then they are tensile forces
- Tensile forces lead to the two properties of materials known as **tensile stress** and **tensile strain**

Tensile Stress

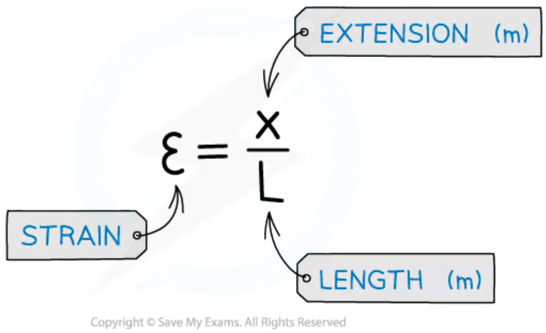
- Tensile stress is defined as the **force exerted per unit cross-sectional area** of a material



- The **ultimate tensile stress** is the **maximum** force per original cross-sectional area a wire is able to support until it breaks
- Stress has the units of pascals (Pa), which is the same units as pressure (also force ÷ area)

Tensile Strain

- Strain is the **extension per unit length**
- This is a deformation of a solid due to stress in the form of elongation or contraction



- The strain is a **dimensionless** unit because it's the ratio of lengths
- Sometimes strain might be written as a **percentage**
  - For example, extending a 0.1 m wire by 0.005 m would produce a strain of (0.005 ÷ 0.1) × 100 = 5 %

Ultimate Tensile Strength

- The ultimate tensile strength of a material is defined as:

  The maximum amount of load or stress a material can handle until it fractures and breaks

- The table lists some common materials and their tensile strength:

Tensile strength of various materials

Material	Tensile Strength (MPa)
Concrete	2–5
Rubber	16
Human skin	20
Glass	33
Human hair	200
Steel	840
Diamond	2800

Your notes

Worked Example

A brass wire of length 4.50 m and a radius of 0.2 mm is extended to a total length of 4.53 when a tensile force of 50 N is applied. Calculate for the brass wire:

a) The tensile stress

b) The tensile strain

Answer:

Part (a)

Step 1: Write down the tensile stress equation

Tensile stress = Force ÷ Cross-sectional area

Step 2: Calculate the cross-sectional area, *A* of the wire

Your notes

- A wire has a circular cross-sectional area = πr^2

$$\text{Area} = \pi \times (0.2 \times 10^{-3})^2 = 1.2566 \times 10^{-7}\ \text{m}^2$$

Step 3: Substitute values in the tensile stress equation

$$\text{Tensile stress} = 50 \div (1.2566 \times 10^{-7}) = 397.899 \times 10^6\ \text{Pa} = 400\ \text{MPa}$$

Part (b)

Step 1: Write down the tensile strain equation

$$\text{Tensile strain} = \text{Extension} \div \text{Original length}$$

Step 2: Determine the extension

- The extension is total length – the original length

$$\text{Extension} = 4.53 - 4.50 = 0.03\ \text{m}$$

Step 3: Substitute values in the tensile strain equation

$$\text{Tensile strain} = 0.03 \div 4.50 = 6.7 \times 10^{-3}$$

Examiner Tips and Tricks

Since strain is a ratio, the extension and original length do not have to be calculated in metres. As long as they **both** have the same units, the strain will be correct

Young's Modulus

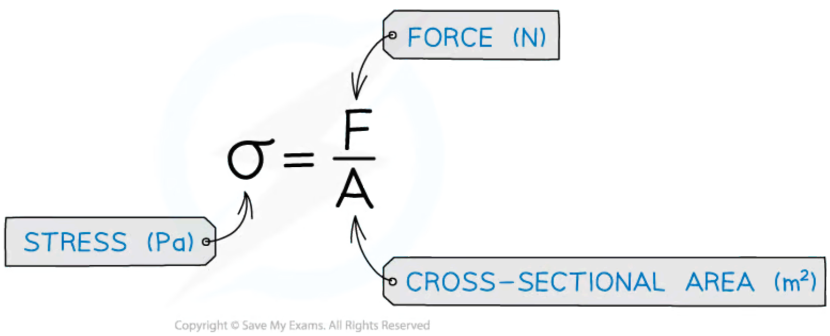
Your notes

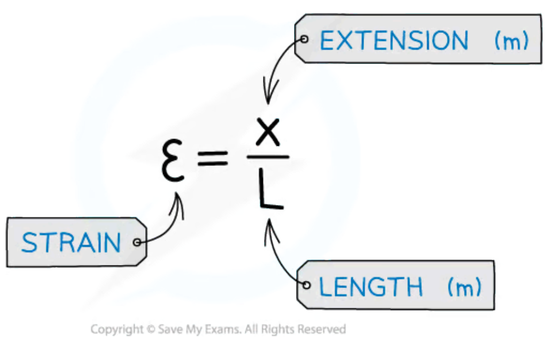
Young's Modulus

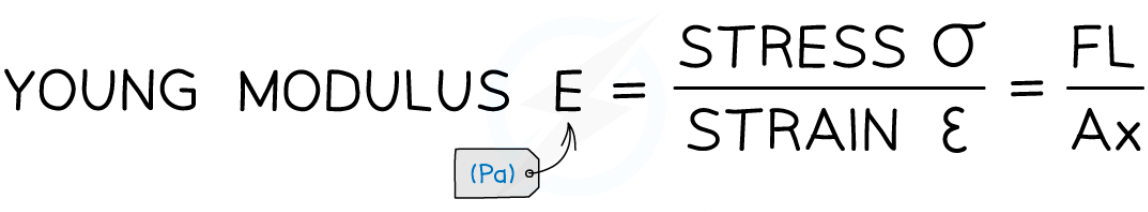
- The Young modulus is defined as

  The measure of the ability of a material to withstand changes in length with an added load

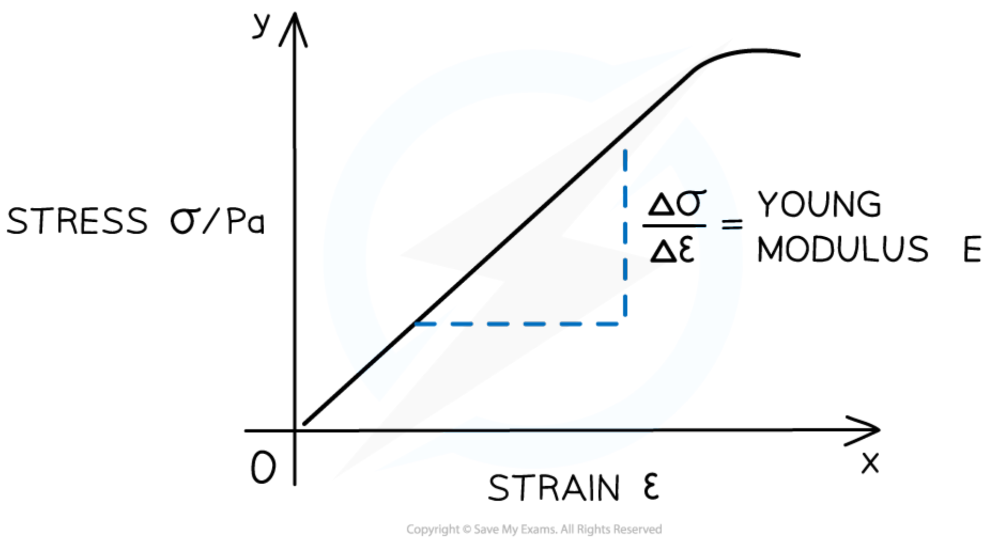
- This gives information about the elasticity of a material ie. how stiff a material is
- The Young Modulus, *E*, can be calculated from the **ratio of stress and strain**







- Its unit is the same as stress: **Pa** (since strain is unitless)
- Just like the Force-Extension graph, stress and strain are directly proportional to one another for a material exhibiting elastic behaviour



A stress-strain graph is a straight line with its gradient equal to Young modulus

- The **gradient** of a stress-strain graph when it is linear is equal to the **Young Modulus**

Worked Example

A metal wire that is supported vertically from a fixed point has a load of 92 N applied to the lower end.

The wire has a cross-sectional area of 0.04 mm^2 and obeys Hooke's law.

The length of the wire increases by 0.50%.What is the Young modulus of the metal wire?

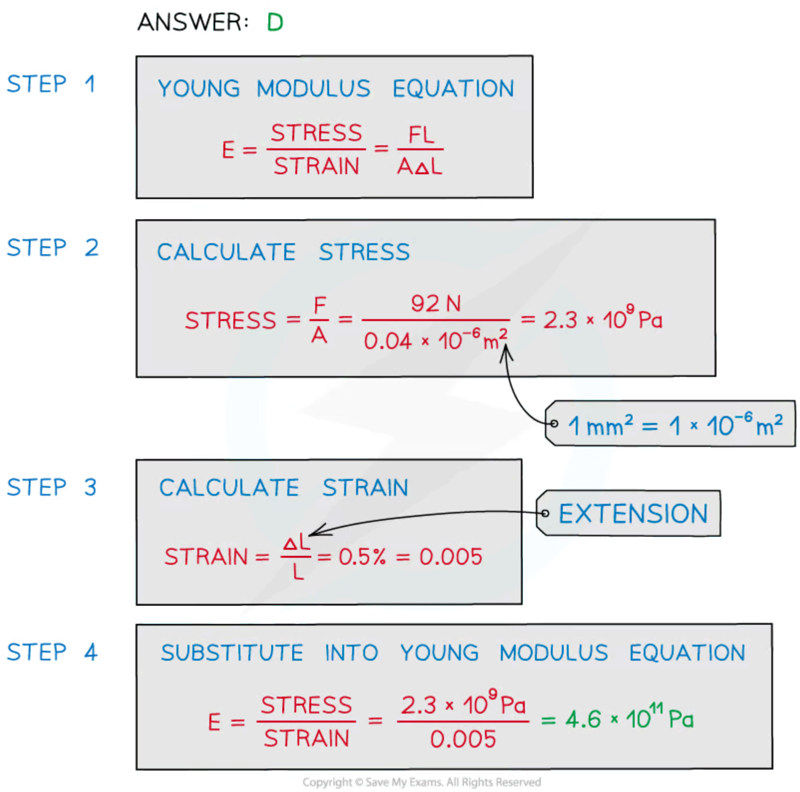
A. 4.6×10^7 Pa

B. 4.6×10^{12} Pa

C. 4.6×10^9 Pa

D. 4.6×10^{11} Pa

Your notes



Examiner Tips and Tricks

To remember whether stress or strain comes first in the Young modulus equation, try thinking of the phrase 'When you're stressed, you show the strain' ie. Stress ÷ strain.

Determining the Young Modulus

Aims of the Experiment

- The aim of the experiment is to measure the Young Modulus of a metal wire
- This requires a clamped horizontal wire over a pulley
- This experiment can also be done with a vertical wire attached to the ceiling with a mass attached

Variables

- Independent variable = Force (or load) (N)

Your notes

- Dependent variable = Extension (m)
- Control variables:
  - The original length of wire
  - The thickness of the wire
  - The metal used for the wire

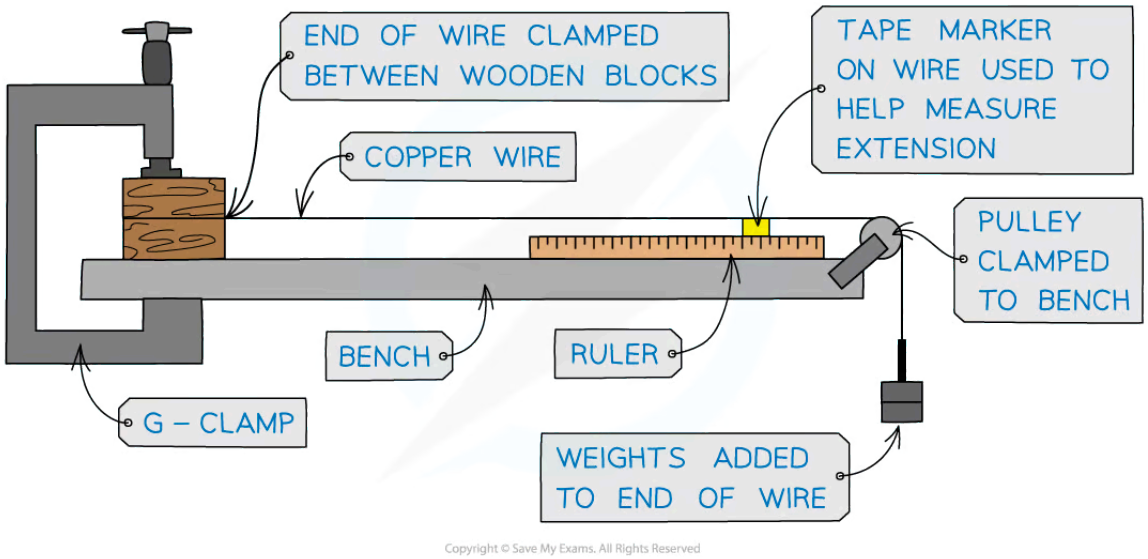
Equipment List

Equipment	Purpose
Bench	To hold the equipment
G-clamp	To stabilise the apparatus
Copper wire	Use to calculate the Young modulus of copper
Metre ruler	To measure the length of the wire and extension
Pulley	To allow the mass to hang vertically, and introduces less friction than the edge of the table
Tape marker	To accurately measure the extension with the applied load. This should touch the ruler
Wooden blocks	Clamps together the wire to keep it taut and straight
Mass hanger + 100g mass	To hang from the pulley and add a load to the wire to create an extension
Micrometer	Use to measure the diameter of the wire

- Resolution of measuring equipment:
  - Metre ruler = 1 mm

Method

Your notes



This method is an example of the procedure for varying load and measuring the extension of a copper wire. This is just one way of measuring the relationship between them

1. Measure the diameter of the wire with a micrometre screw gauge or digital callipers. Take at least 3 readings and find an average
2. Set up the apparatus so the wire is taut. No masses should be on the mass hanger just yet
3. Measure the original length of the wire using a metre ruler and mark a reference point with tape preferably near the beginning of the scale eg. at 1 cm
4. Record initial reading on the ruler of the reference point
5. Add a 100 g mass onto the mass hanger
6. Read and record the new reading of the tape marker from the meter ruler
7. Repeat this method by adding a 100 g mass (at least 5 – 10 times) and record the new scale reading from the metre ruler

- An example of a table with some possible loads and extensions might look like:

Your notes

MASS m/g	LOAD F/N	NEW MARKER READING / m	EXTENSION ΔL / m
100			
200			
300			
400			
500			
600			

Analysis of Results

1. Determine extension *x* from final and initial readings

Example table of results:

Your notes

Mass m / g	Load F / N	Initial length / mm	Final length / mm	Extension x ($\times 10^{-3}$) / m
200	2.0	500	500.1	0.1
300	2.9	500.1	500.4	0.3
400	3.9	500.4	501.0	0.6
500	4.9	501.0	501.9	0.9
600	5.9	501.9	503.2	1.3
700	6.9	503.2	504.9	1.7
800	7.8	504.9	507.0	2.1

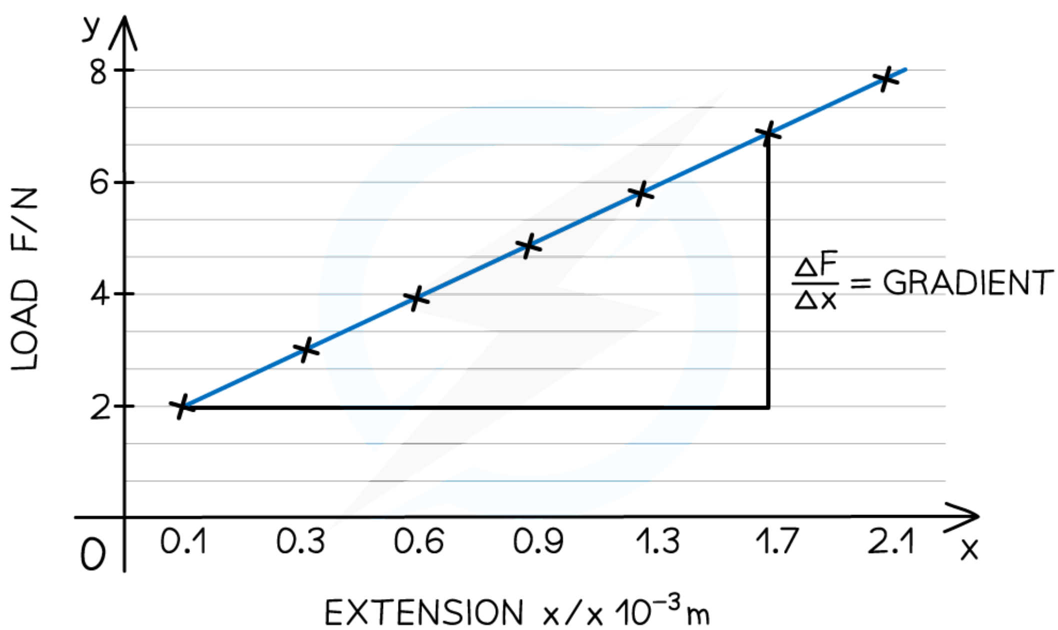
Table with additional data

Your notes

Length l / m	1.382
Diameter 1 / mm	0.277
Diameter 2 / mm	0.280
Diameter 3 / mm	0.275
Average Diameter d / mm	0.277
Cross-sectional area A / m^2	6.03×10^{-8}

2. Plot a graph of force against extension and draw line of best fit

3. Determine gradient of the force v extension graph



4. Calculate cross-sectional area from:

DIAMETER OF THE WIRE (m)

$$\text{CROSS-SECTIONAL AREA } A = \frac{\pi d^2}{4}$$

5. Calculate the Young's modulus from:

FORCE / LOAD (N)

LENGTH OF WIRE (m)

$$\text{YOUNG'S MODULUS } E = \frac{\text{STRESS}}{\text{STRAIN}} = \frac{FL}{Ax} = \text{GRADIENT} \times \frac{L}{A}$$

CROSS-SECTIONAL AREA (m^2)

EXTENSION (m)

Evaluating the Experiment

Systematic Errors:

- Use a vernier scale for more precise readings
  - This is more likely to produce an accurate value for the extension
- If the wire is extended past its elastic limit, it will be permanently deformed
  - To reduce the risk of this, remove the load and check the wire returns to its original length before taking any new readings

Random Errors:

- Parallax error from reading the marker on the ruler
- Random errors are reduced by repeating the experiment for all the loads and finding an average extension

Your notes

- Reduce the uncertainty on the cross-sectional area by measuring the diameter in several places and calculating an average

Safety Considerations

- Wear safety goggles at all times in case the wire snaps
- Make sure a cushion or soft surface is kept directly below the mass hanger, in case it falls off

Examiner Tips and Tricks

Although every care should be taken to make the experiment as reliable as possible, you will be expected to suggest improvements in producing more accurate and reliable results (e.g. repeat readings and use a longer length of wire)

Your notes

Your notes

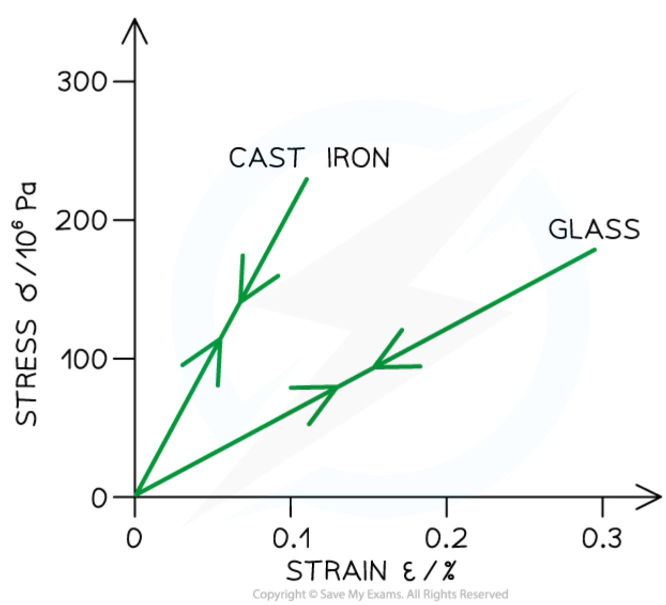
Stress-Strain Graphs

Stress-Strain Graphs

- Stress-strain curves give an indication of the properties of materials such as
  - Whether they are **brittle**, **ductile** or **polymeric**
  - Up to what stress and strain they obey Hooke's Law
  - Whether they exhibit elastic and/or plastic behaviour
  - The value of their Young Modulus
- Each material has a unique stress-strain curve

Brittle

- A brittle material is defined as **A material that fractures before plastic deformation**
- For a brittle material:
  - Elastic behaviour is shown until the breakpoint where the material snaps
  - There is no plastic deformation, and the loading and unloading curves are the same
  - Brittle materials include: glass, ceramic



The stress-strain graph for a brittle material

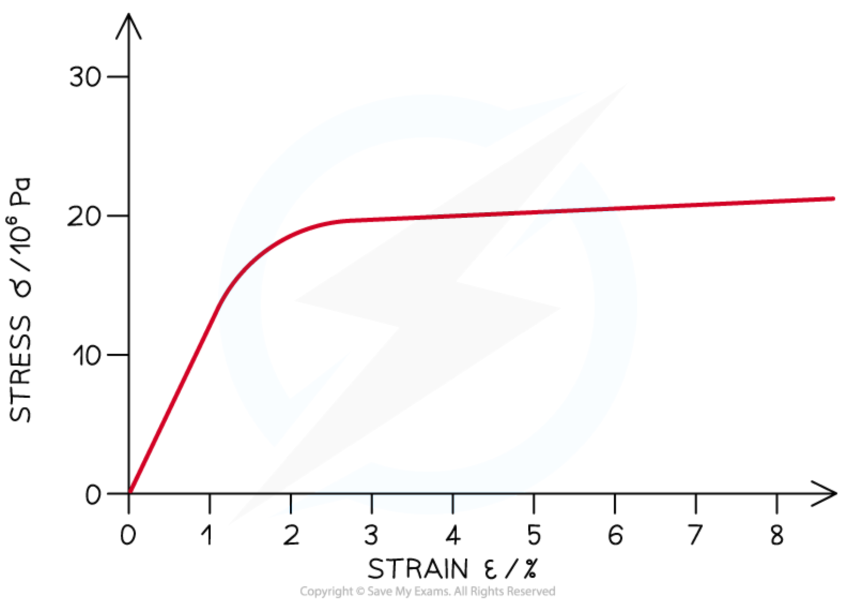
Your notes

Ductile

- A ductile material is defined as

  A material that can withstand large plastic deformation without breaking

- For a ductile material:
  - They generally experience elastic deformation up until their elastic limit
  - After this, they then undergo plastic deformation before reaching their ultimate tensile stress and breakpoint
  - For this reason, they can be easily hammered into thin sheets or drawn into long wires
  - Ductile materials include: copper



The stress-strain graph for a ductile material

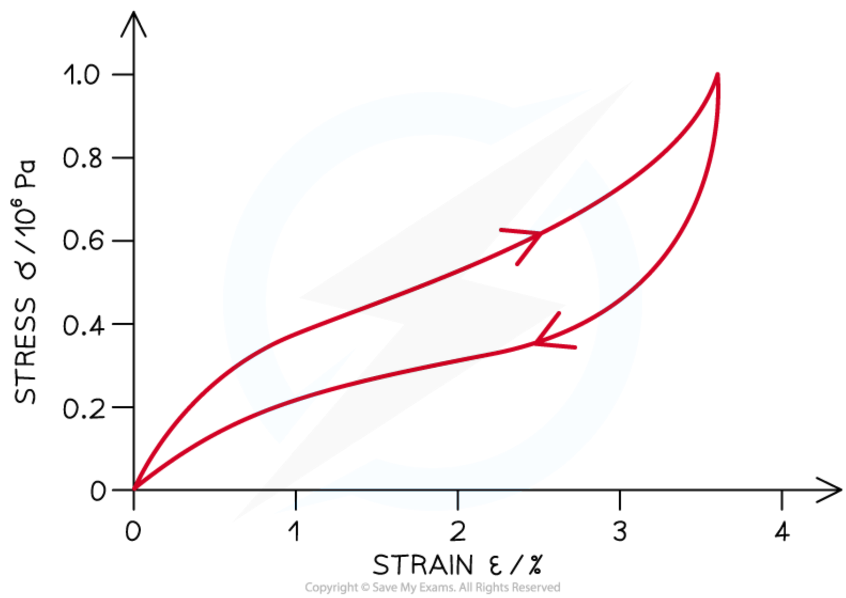
Polymeric

- A polymeric material is defined as:

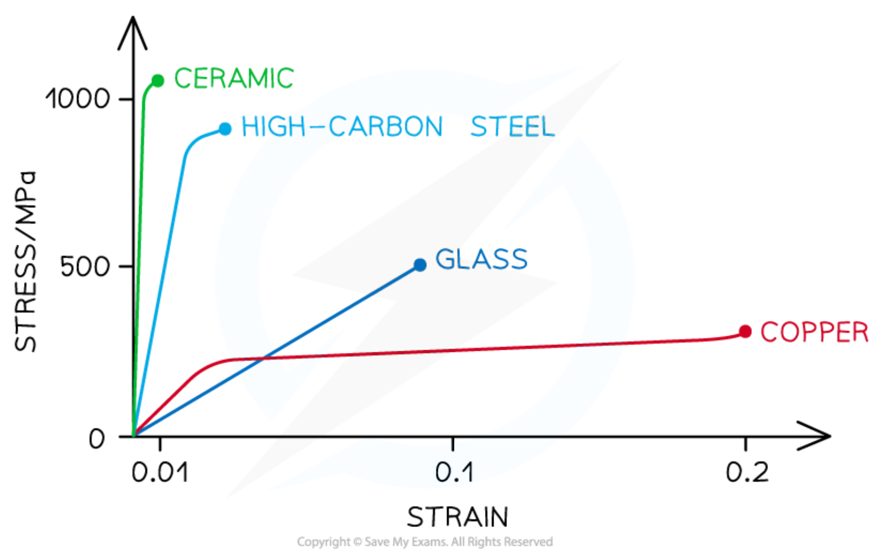
  A material made up of long, repeating chains of molecules

- For a polymeric material:

- They can endure a lot of tensile stress before breaking
- There is no plastic deformation, but the unloading curve is different to the loading curve, as some energy has been lost as thermal energy
- Polymeric materials include: rubber, polythene



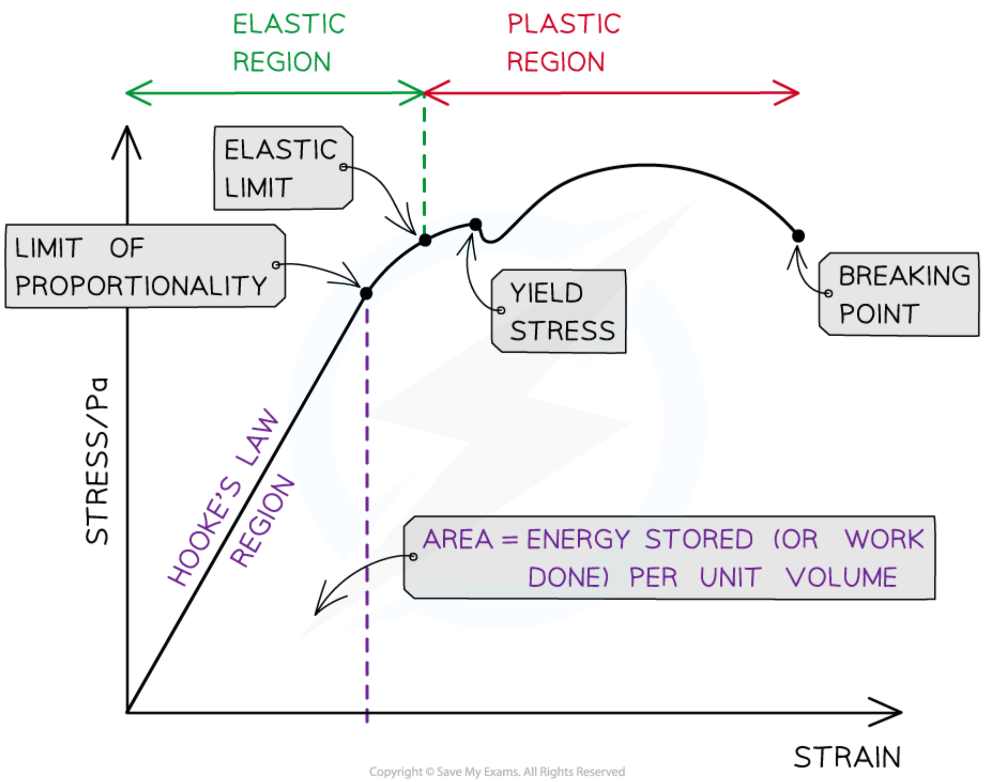
The stress-strain graph for a polymeric material



Your notes

Stress-strain graph for different materials up to their breaking stress

- There are important points on the stress-strain graph, some are similar to the force-extension graph



The important points shown on a stress-strain graph

- The key points that are unique to the stress-strain graph are:
  - The **elastic strain energy** stored per unit volume is the **area** under the Hooke's Law (straight line) region of the graph
- **Yield Stress:**
  - The force per unit area at which the material extends plastically for a small increase in stress
- **Breaking point:**
  - The stress at this point is the breaking stress
  - This is the maximum stress a material can stand before it fractures
- **Elastic region:**
  - The region of the graph up until the **elastic limit**

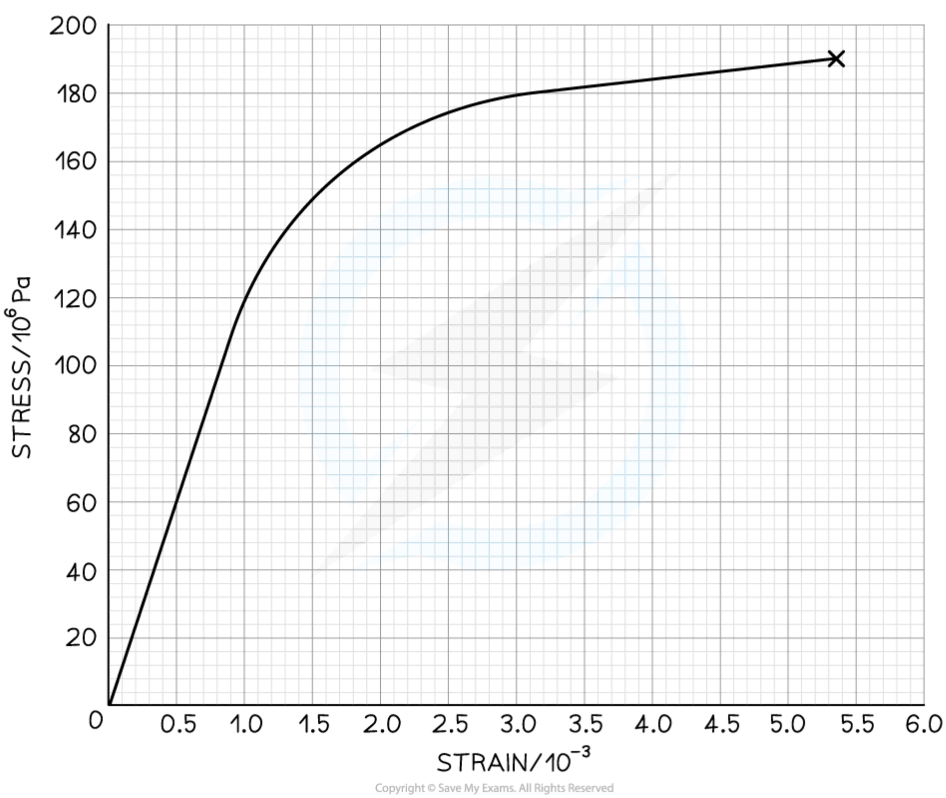
Your notes

- In this region, the material will **return to its original shape** when the applied force is removed
- **Plastic region:**
  - The region of the graph **after the elastic limit**
  - In this region, the material has **deformed permanently** and will **not** return to its original shape when the applied force is removed

Your notes

Worked Example

The graph below shows a stress-strain curve for a copper wire.



From the graph, state the value of:

(a) The breaking stress

(b) The stress at which plastic deformation begins

Answer:

Your notes

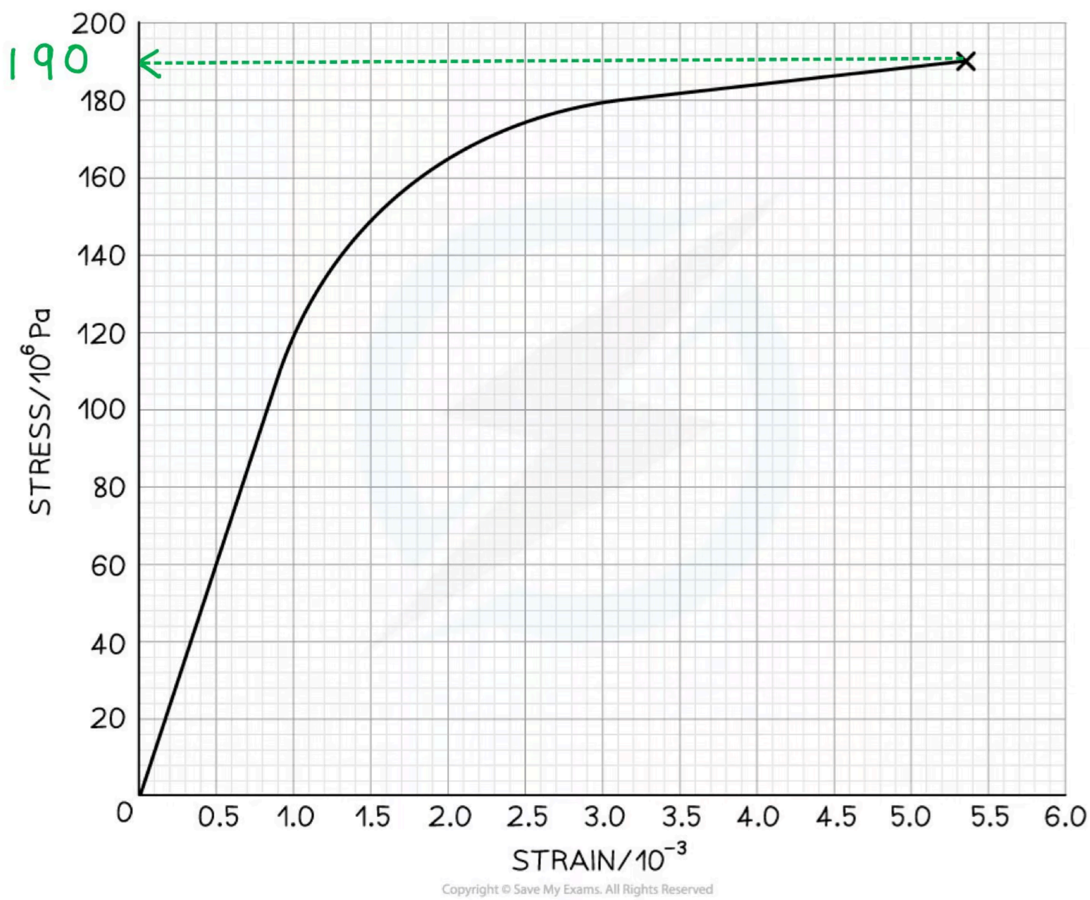
Part (a)

Step 1: Define breaking stress

- The breaking stress is the maximum stress a material can stand before it fractures. This is the stress at the final point on the graph

Step 2: Determine breaking stress from the graph

- Draw a line to the y axis at the point of fracture



The breaking stress is **190 MPa**

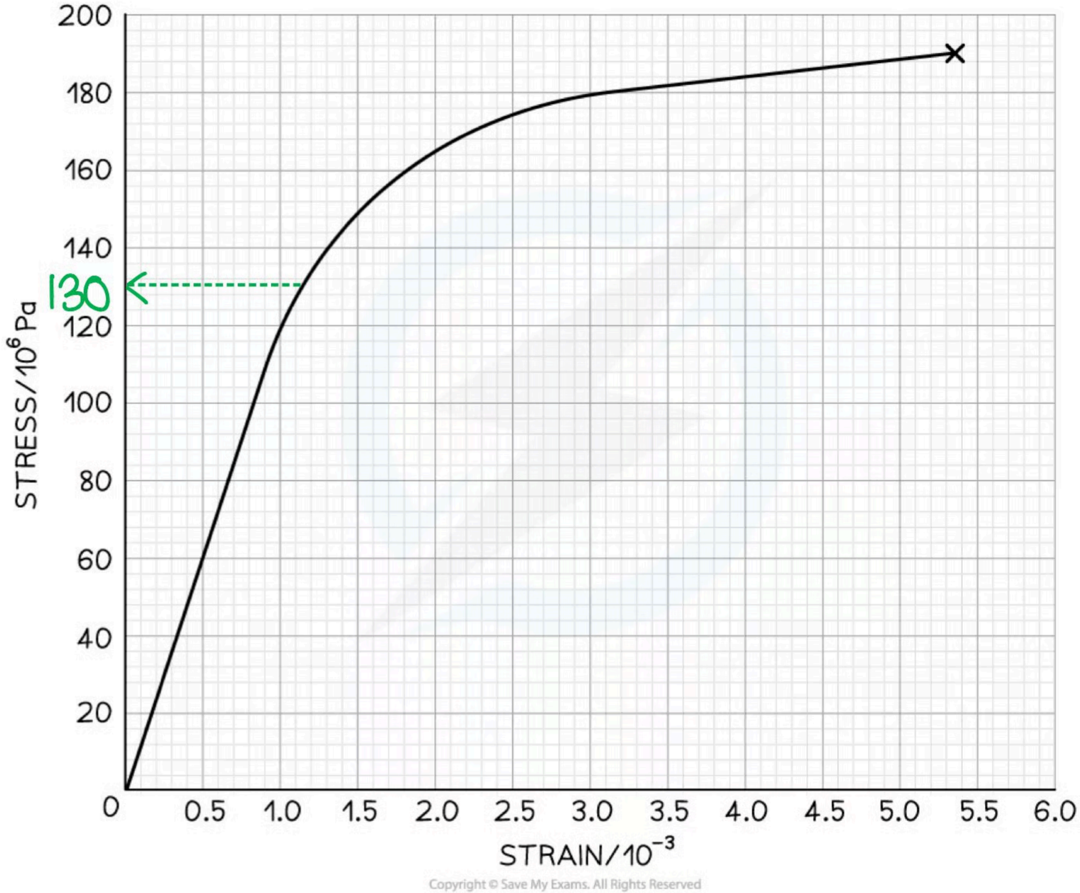
Part (b)

Step 1: Define plastic deformation

- Plastic deformation is when the material is deformed permanently and will not return to its original shape once the applied force is removed
- This is shown on the graph where it is curved

Step 2: Determine the stress of where plastic deformation beings on the graph

- Draw a line to the y axis at the point where the graph starts to curve



Plastic deformation begins at a stress of **130 MPa**

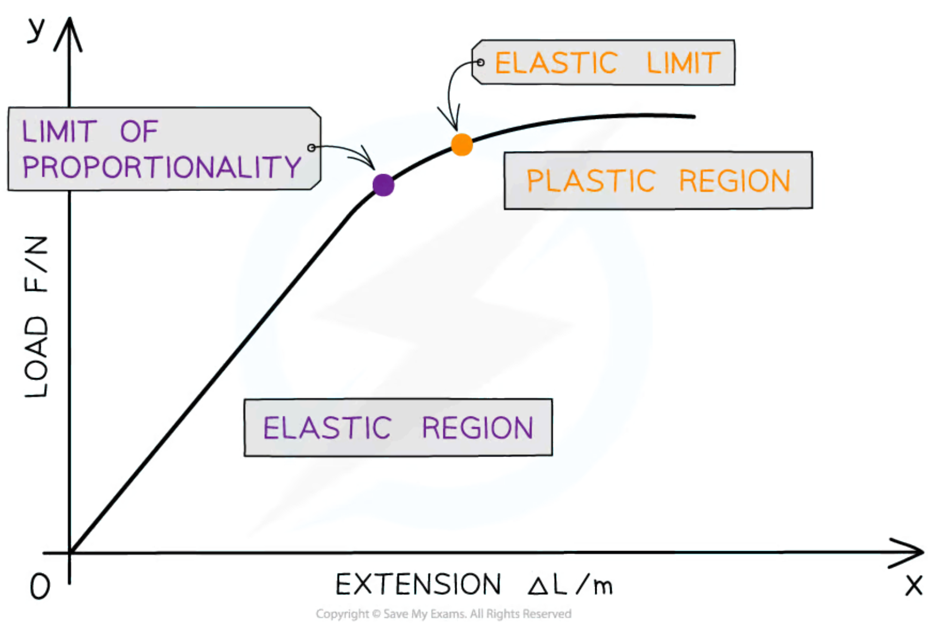
Your notes

Your notes

Elastic & Plastic Deformation

Elastic & Plastic Deformation

- Materials can undergo two types of deformations:
- **Elastic deformation**
  - When the load is removed, the object **will** return to its original shape
  - This is shown in the elastic region of the graph
- **Plastic deformation**
  - The material is permanently deformed
  - When the load is removed, the object **will not** return to its original shape or length
  - This is beyond the elastic limit and is shown in the plastic region of the graph
- These regions can be determined from a Force-Extension graph:



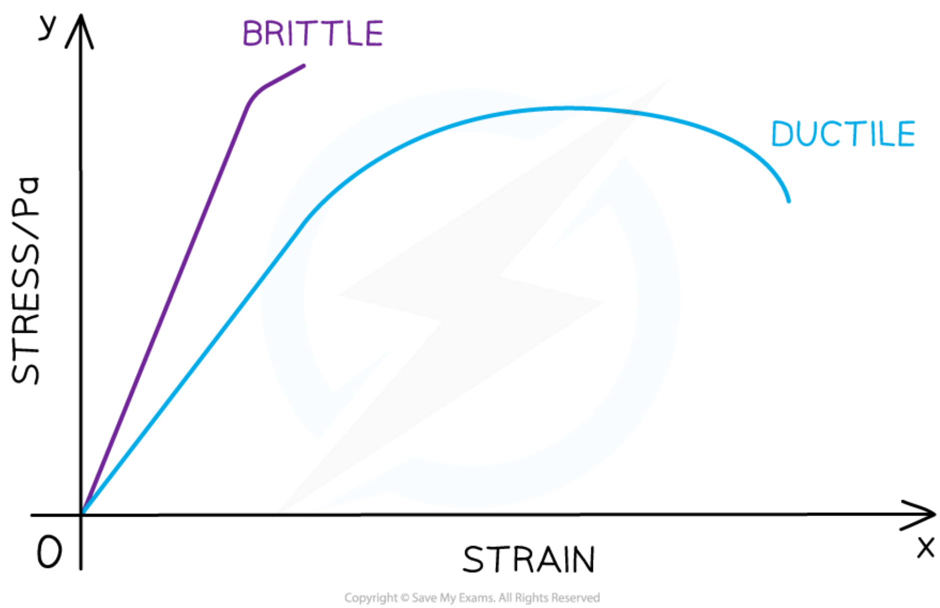
Below the elastic limit, the material exhibits elastic behaviour. Above the elastic limit, the material exhibits plastic behaviour

Your notes

- The **elastic** region is where the extension is proportional to the force applied to the material (**straight line**)
- The **plastic** region is where the extension is no longer proportional to the force applied to the material (graph starts to **curve**)
  - These regions are divided by the elastic limit
- The plastic region starts at the elastic limit and ends at the point of fracture (the material breaks)

Brittle & Ductile Materials

- **Brittle** materials have very little to no plastic region e.g. glass, concrete
  - The material breaks with little elastic and insignificant plastic deformation
- **Ductile** materials have a larger plastic region e.g. copper
  - The material stretches into a new shape before breaking



Brittle and ductile materials on a stress-strain graph. These are the same on a force-extension graph too

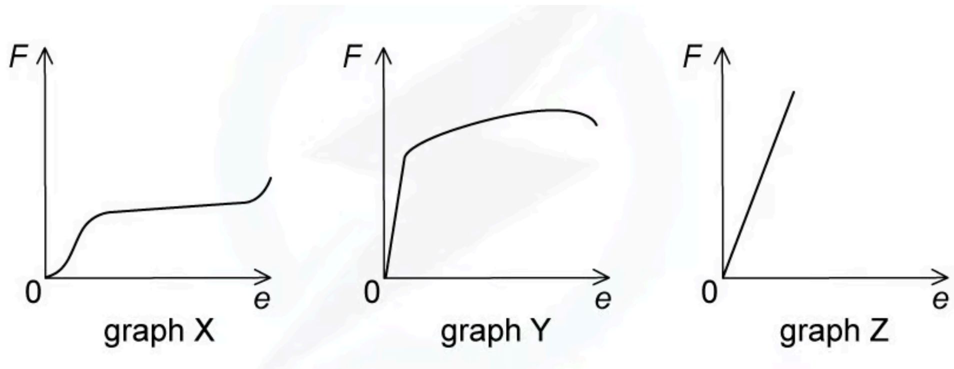
- To identify these materials on a stress-strain **or** force-extension graph up to their breaking point:
  - A **brittle** material is represented by a straight line through the origins with no or negligible curved region

- A **ductile** material is represented with a straight line through the origin then curving towards the x-axis

Your notes

Worked Example

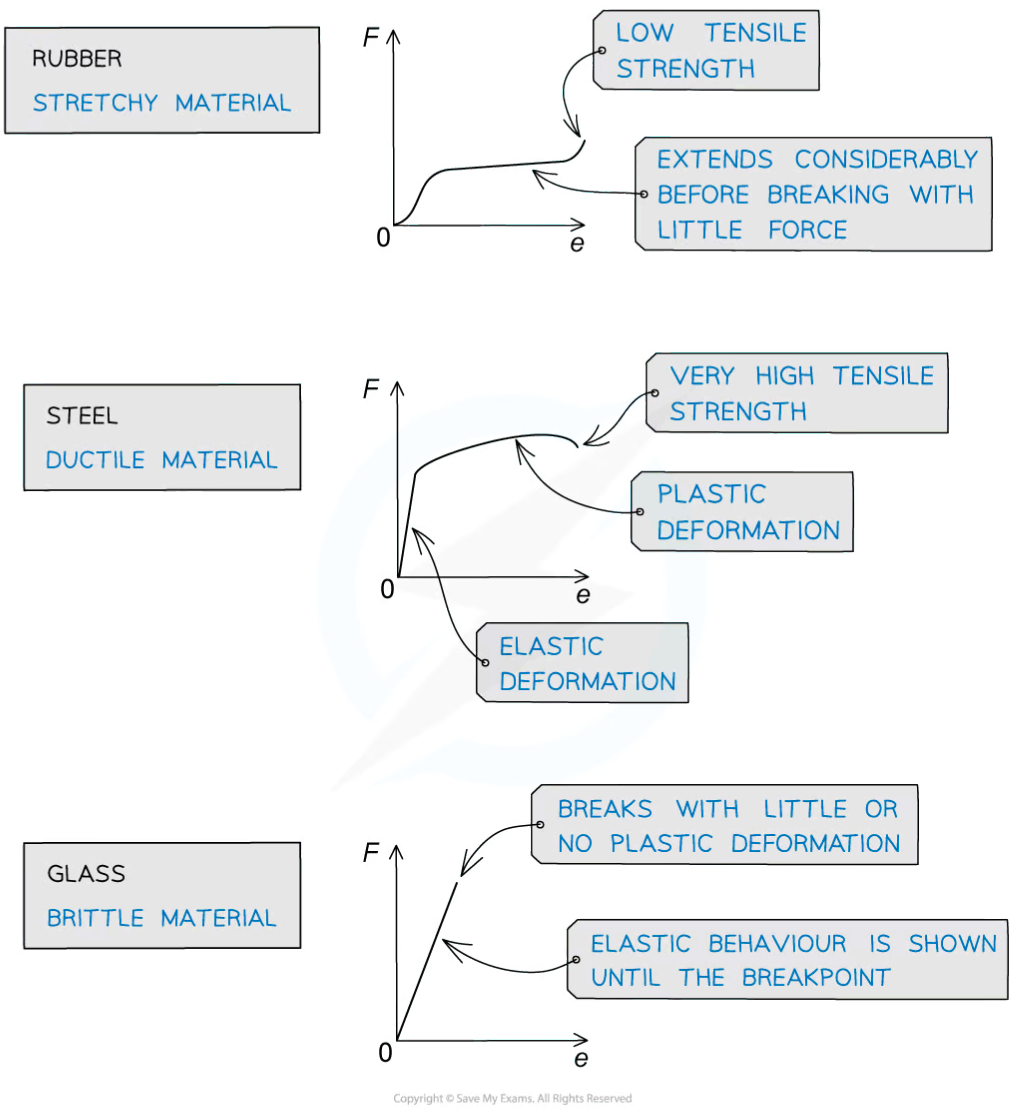
Cylindrical samples of steel, glass and rubber are each subjected to a gradually increasing tensile force *F*. The extensions e are measured and graphs are plotted as shown below.



Correctly label the graphs with the materials: **steel**, **glass**, **rubber**.

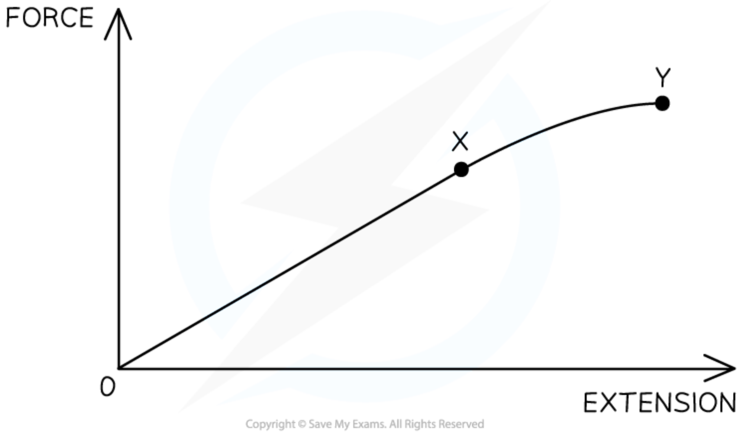
Answer:

Your notes



Worked Example

A sample of metal wire is subjected to a force which increases as a series of masses are added to the wire. The extension is measured and a force-extension graph of the data is plotted as shown below.



When the wire has been extended to **Y**, the point just before the wire fractures, the masses are removed one by one and the extension is re-measured.

a) Describe the behaviour of the metal at point **X**.

b) On the graph, sketch the result obtained after the masses are removed and explain why the graph has this shape.

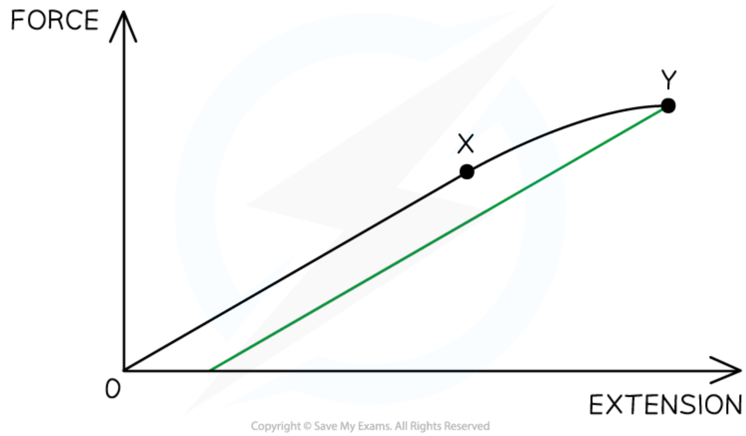
Answer:

Part (a)

At point **X**:

- The graph is a straight line at point X
- Therefore, the force and extension are directly proportional
- Point X is not beyond the elastic limit
- So the metal is behaving elastically

Part (b)



Your notes

- Plastic deformation has occurred which results in permanent extension
- As the load is decreased, the bonds in the metal are re-aligned hence the y-intercept is now not through the origin
- The gradient remains the same because the intermolecular forces (the forces between bonds) are identical to before

Examiner Tips and Tricks

Avoid describing plastic deformation as 'does not obey Hooke's law'. Although this is mostly correct, it should be described as the material being **permanently deformed**