Cambridge Assessment International Education

Teaching Pack

The Young Modulus

Cambridge International AS & A Level Physics 9702

Version 1

Cambridge Pathway

Contents

Icons used in this pack:

Briefing lesson

Planning lesson

Lab lesson

Debriefing lesson

Introduction

This pack will help you to develop your learners' experimental skills as defined by assessment objective 3 (AO3 Experimental skills and investigations) in the course syllabus.

Important note
Our *Teaching Packs* have been written by **classroom teachers** to help you deliver topics and skills that can be challenging. Use these materials to supplement your teaching and engage your learners. You can also use them to help you create lesson plans for other experiments.

This content is designed to give you and your learners the chance to explore practical skills. It is not intended as specific practice for Paper 3 (Advanced Practical Skills) or Paper 5 (Planning, Analysis and Evaluation).

This is one of a range of *Teaching Packs* and each pack is based on one experiment. The packs can be used in any order to suit your teaching sequence.

The structure is as follows:

Briefing lesson (1 hour*)
This lesson reinforces the key concepts, relevant skills, knowledge and understanding linked to the experiment.

↓

Planning lesson (1 hour*)
This lesson focuses on planning an experiment.
It ends with a demonstration video of the experiment.

↓

Lab lesson (1 hour*)
This lesson focuses on carrying out the experiment including the collection and recording of observations, measurements and estimates.

↓

Debriefing lesson (1 hour*)
This lesson focuses on the analysis and interpretation of data.
This includes making conclusions, evaluating methods and the quality of data and how improvements could be made.

** the timings are a guide only; you may need to adapt the lessons to suit your circumstances.*

In this pack you will find lesson plans, worksheets and teacher resource sheets.

Experiment: The Young modulus

This *Teaching Pack* focuses on a practical to find the Young modulus of a given material, using wire made from that material.

This experiment has links to the following syllabus content (see syllabus for detail):

- 6.1 Stress and strain
- 6.2 Elastic and plastic behaviour

The experiment covers the following experimental skills, as listed in **AO3: Experimental skills and investigations:**

- plan experiments and investigations
- collect, record and present observations, measurements and estimates
- analyse and interpret data to reach conclusions
- evaluate methods and quality of data and suggest improvements.

Prior knowledge

Knowledge from the following syllabus topics is useful for this experiment.

- 1.1 Physical quantities
- 1.2 SI Units
- 4. Forces, density and pressure

Going forward

Learners who intend to study engineering or physics in the future will find this an important introduction to Materials Science. For those studying Chemistry there are cross-curricular links where materials properties relate to atomic and molecular structure.

Briefing lesson: Hooke's Law and the Young modulus

<table>
<tr><td>Resources</td><td>At least: a set of Hooke's Law springs, 4–9 identical springs, clamp and stand, set of small masses and a mass hanger
The same number of thicker springs made from same material
The same number of springs of the same size, but made from a different material
Worksheet A</td></tr>
</table>

<table>
<tr><td>Learning objectives</td><td>By the end of the lesson:
all learners should be able to state Hooke's Law.
most learners should describe an experiment to model the behaviour of a material at the atomic level when it is under tensile stress.
some learners will be able to explain extension of thinner or longer springs in terms of arrangement of their atoms.</td></tr>
</table>

<table>
<tr><th>Timings</th><th>Activity</th></tr>
<tr><td>5 min</td><td>Starter / Introduction
Ask learners to recall Hooke's Law, sketch the graph shape, and label the graph. They should use either mini-whiteboards or rough paper for this.</td></tr>
<tr><td>10 min</td><td>Main lesson
Using the sets of springs demonstrate how extension is proportional to length, but inversely proportional to thickness.

In this demonstration the springs represent the bonds between atoms and the joins between springs represent the atoms themselves. At each stage your learners should record the results you generate in their books.
Set up one spring and measure its original length. Add a mass which is enough to give a reasonable extension and record that extension.
Leave the first spring in place. Next to it hang two identical springs connected 'in series'. Add the same mass and measure and record this extension.
Leaving the first two demonstrations in place, set up two springs so that they are in parallel. Add the same mass and measure and record this extension.
If time permits you can go on to make three springs in series, and a lattice of 4–6 springs in parallel.
If resources permit, demonstrate the difference seen when applying the same load to springs of different materials.
Ask your learners to look at the results and infer a relationship between spring length and thickness. They should see that as length doubles, so does extension. As thickness doubles, extension halves.</td></tr>
</table>

Timings	Activity
15 min	Ask your learners to discuss the limits of using Hooke's Law. Will a small spring and a large spring made from the same material show the same graph? Will two springs of exactly the same proportions but made from different materials show the same graph? Why not? What limitations does this put on the usefulness of Hooke's Law in the real world of engineering? Introduce the idea of a second way of measuring stiffness, but this will be a value which applies to the material. Learners will have encountered the difference between heat capacity and specific heat capacity at IGCSE, and this example can be used here. If you have already taught resistance versus resistivity this is also useful to mention. Encourage your learners to discuss in groups and infer what additional measurements could be made in the demonstration using Hooke's Law to make it specific for the material. This is a conceptual leap and your learners may need your guidance on this. Introduce the concept of stress. Stress is the applied load **per cross-sectional area**; your learners should be able to infer the units. Introduce the concept of strain. Strain is the extension **per original length**. It is a ratio, not a value. Learners should be able to infer the lack of units for themselves. Introduce the Young modulus equation, $E = stress / strain$.
20 min	Learners should practise calculations using the three new equations. Use the questions in Worksheet A. Check that your learners are writing their maths clearly and in full throughout.
10 min	**Plenary** Using the answer sheet, ask your learners to peer mark each other's calculations and make any necessary corrections. They may need help in understanding that maximum tensile stress is stress at breaking point and so uses the same equation.

Planning lesson: The Young modulus

Resources	• *Young modulus* video

Learning objectives	By the end of the lesson: • ***all*** learners should understand the Young modulus equation. • ***most*** learners should be able to design an experiment to derive the Young modulus of a material. • ***some*** learners will be able to link the data they could collect to the Young modulus equation.

Timings	Activity
10 min	**Starter / Introduction** Your learners should recall from the previous lesson: Hooke's Law, definition of stress, definition of strain, and the Young modulus equation.
30 min	**Main lesson** Ask your learners to devise an experiment which could be used to find the Young modulus of a wire. Suggest that they first write down which measurements they can take directly (the conceptual move from the equation above to measurable values will be difficult for some). Your learners should consider what their set-up might look like. How will it be different from the Hooke's Law experiment? Your learners also need consider how to reduce the effect of experimental errors in their measurements, e.g. by using long, thin wire; by taking repeat readings of diameter. They must be able to justify their choices in terms of percentage error and uncertainty. In addition your learners should also indicate what instruments they will use to make these measurements. Finally, they should make suggestions about safety and reducing risk. At this point your learners should look again at the Young modulus equation and suggest how they will reach a conclusion by graphing their results. Watch the *Young modulus* video.
20 min	**Plenary** Having seen the video ask your learners to read and assess each other's plans. They should look for: lists of apparatus, how measurements will be taken, what error reduction is in place and safety precautions. They should use what they have seen in the video to help to make judgements of their peers' work. Once they have their feedback, your learners should make any appropriate adjustments to their plans.

Lab lesson: The Young Modulus

Resources	• Equipment as outline in the Teacher notes • *Teacher walkthrough* video

Learning objectives	By the end of the lesson: • ***all*** learners should be able to state the measurements taken to find the Young modulus of a material. • ***most*** learners should be able to describe an experiment to find the Young modulus of a material, including safety and errors. • ***some*** learners will be able to explain the graph shape obtained from the Young .odulus experiment, identifying key areas.

Timings	Activity
5 min	**Starter / Introduction** Learners recall the meaning of the Young modulus and why is it more useful than *k*, the spring constant.
25 min	**Main lesson** Using the plan they made in the last lesson, learners should collect their equipment and find a large, clear area to work in. They must start by finding the diameter of the wire, and should remember to measure this in three places before starting. Learners are likely to need help in setting up and you should check that their ruler and wire are parallel and close and that their pointers are well-positioned before they start adding masses. Once you have checked their set up, learners should conduct the experiment. First they should test the thin copper wire. After this they should test one other, and if time permits two more materials. Note: groups may share results if there not time for them to each do three experiments If time and equipment allow then continue until wires show plastic deformation. **Safety** Make sure your learners do not go further than plastic deformation as snapping wires may cause injury. Circulate the classroom at all times during the experiment so that you can make sure that your learners are safe and that the data they are collecting is accurate.
20 min	Learners should use their results to calculate strain and stress. They should plot a graph which shows all three of their materials on one set of axes for comparison.
10 min	**Plenary** Learners share their graph shapes with the group. They should discuss why the lines have different gradients.

Teacher notes

Watch the *Teacher walkthrough* video and read these notes.

Each group will require:
- thin copper wire (approx. 1.5 m length per learner / group)
- wires of other materials, e.g. nichrome, brass, with the same thickness (approx. 1.5 m per learner / group)
- metre rule
- G-clamp
- 2 × wooden blocks
- bench pulley
- mass hanger
- slotted masses, 10 x 0.1 kg
- micrometer
- safety goggles
- box containing padding
- graph paper

Safety
- Wear a lab coat and eye protection.
- No eating or drinking in the lab.
- Falling masses may injure learners' feet. They should be wearing footwear which covers their toes and a box should be provided to catch falling weights.

It is your responsibility to carry out an appropriate risk assessment for this experiment.

Teacher method

This is your version of the method for this experiment that accompanies the *Teacher walkthrough* video.

Do not share this method with learners.

Before you begin

Plan how you will group your learners during the experiment session.

Think about:

- the number of groups you will need (group size 2–4 learners)
- the amount of equipment required
- how much space you have – each group needs room to set up their lengths of wire and have space to move about
- how many masses you have
- can your learners use a micrometer – if not then they will find this difficult, so build in a five minute explanation of this skill before they start
- whether you learners find the idea of creating their own fiduciary marker difficult – you may want to demonstrate this on one of their set-ups.

Experiment

Walk around the learners during the experiment in case they encounter any difficulties.

Steps	Notes
1. Learners should collect the equipment they require from the front of the class.	
2. They should find a space in the classroom where the equipment can be assembled safely.	
3. Learners are likely to find it difficult to set up the equipment so that the wire is horizontal, the ruler parallel to it and close behind and the pointer accurate.	*Encourage your learners to stand back and look critically at their set-up as they progress, identifying changes that need to be made.*
4. Finally, before starting learners should check that when they hang their masses on the wire everything remains stable.	*Check that the bases of the stands are turned and clamped correctly to give maximum stability.*
5. As they hang the masses the wire will stretch then retract a little. They should wait for this retraction before measuring extension.	
6. If time and equipment allow then encourage them to continue until their wires show plastic deformation.	

Clean-up

After the experiment learners should:

- tidy up their work space
- return all equipment to you.

Debriefing lesson: The Young modulus

Resources	• Access to internet • Worksheet B

Learning objectives	By the end of the lesson: • ***all learners*** should be able to identify the key areas of the Young modulus graph. • ***most learners*** should be able to explain the changing shape of the graph. • ***some learners*** will be able to describe two alternative methods for finding the Young modulus of a wire.

Timings	Activity
5 min	**Starter / Introduction** Your learners should have their graphs from the practical lesson and should now recall the behaviour of the materials which produced those graphs.
10 min 15 min 20 min	**Main lesson** Discuss with your learners how a graph can 'tell the story' of an investigation. Ask them to look at their graphs – how many parts are there to this story? They should see at least, an area of direct proportionality, a point where the limit of proportionality is reached, and a region of plastic deformation. Using Worksheet B, ask your learners to use their text books (and other resources if they have them) to label the regions of the graph shown. Your learners' graphs can now be used to identify, for their investigations, the tensile stresses under which their materials obeyed Hooke's Law; where they passed the limit of proportionality; where they passed the elastic limit and perhaps the ultimate tensile strength and fracture points. Ask your learners' to explain, in terms of energy, how this deformation must have occurred. They should now begin to understand that the same data can also be used to find the work done on their wires. Ask your learners to recall the equation for work done, and elicit from them that if the force changes (as it did in their investigation) then they will need an average value for force. Learners may make the connection independently that this means they can find the area underneath a force-extension graph to give work done. Using their own data ask learners to quickly sketch out the force-extension graph for their copper wire. What work was done on it during their investigation? They can complete the calculations in Worksheet B at this stage. There are several methods to find the Young modulus. Divide your learners into groups and ask them to research an alternative to the one they have practised. You may wish to direct them towards certain methods, for example, horizontally on a bench using a clamped wire and a pulley, or vertically using a Vernier scale comparing two samples. When your learners have completed their research they should share it with the group.

Timings	Activity
10 min	**Plenary** Discussion. A mouse is very light, with relatively long, thin legs, while an elephant is very heavy with relatively short, thick legs. If a mouse grew to the height of an elephant, could its legs support its mass? Ask your learners to justify their points using the concepts they have encountered in this lesson.

Worksheets and answers

	Worksheet	Answers
For use in *Briefing lesson*:		
A: Young modulus calculations	**16**	**19**
For use in Debriefing lesson:		
B: Young modulus and work done	**17–18**	**20–21**

Worksheet A: Young modulus calculations

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

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

(maximum tensile strength or stress is the highest value of σ before a material breaks)

Young modulus; $E = \frac{\sigma}{\varepsilon} = \frac{Fx}{A\Delta x}$

1. What is the strain on a copper wire if it is extended from 96 cm to 102 cm?

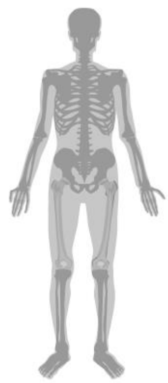
2. What is the tensile stress in an aluminium wire, hung vertically from a clamp, if it has a diameter of 0.55 mm and there is 1.5 kg of mass hanging from it?

3. A learner sets up an experiment to stretch a thick elastic band by hanging masses from it. The starting length is found to be 80 mm. After hanging 100g on the band, its new length is measured at 105 mm.

   a. What is the total applied force put on the elastic band?
   b. What is the tensile strain?
   c. Why does the value for strain have no units?
   d. How might the learner find the cross-sectional area of the band? Assume it is a thick one with a rectangular shape when seen in cross section (as seen in this picture)
   e. The learner finds the cross-sectional area is 10 mm^2. What is the stress on the band? (Hint: you will need to convert to m^2 first)
   f. What is the Young modulus of this band?

4. A 1 m length of wire with a diameter of 0.5 mm is set up horizontally using a pulley. Weights totalling 90 N are hung from the wire.
   a. What is the applied force?
   b. What is the stress?
   c. If the Young modulus = 150×10^{10} Nm^{-2}, what is the extension?

5. In another experiment a wire with a diameter of 2.0 mm is put under stress using a mass of 1.5 kg. The original length is 210 cm and the extension measured is 5 cm.
   a. Use the mass to find applied load, the diameter to find cross sectional area, and convert **all** the measurements into SI units.
   b. Find the stress on the wire.
   c. Find the tensile strain on the wire.
   d. Calculate the Young modulus of the wire

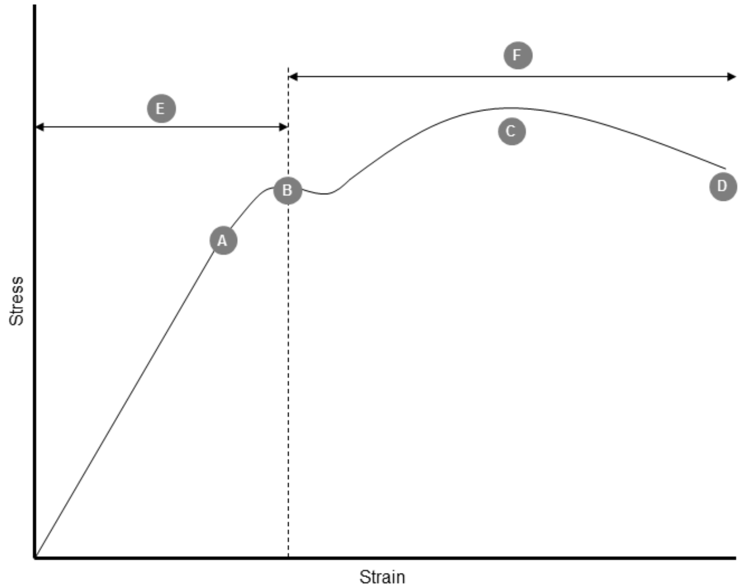


6. If your femur (the bone in your thigh) is 50 cm long and has a diameter of 30 mm, then what is the maximum applied force it can bear, and how much might it extend before fracturing?

Tensile strength of bone = 1.7×10^{8} Pa
Young modulus of bone = 9.4×10^{9} Pa

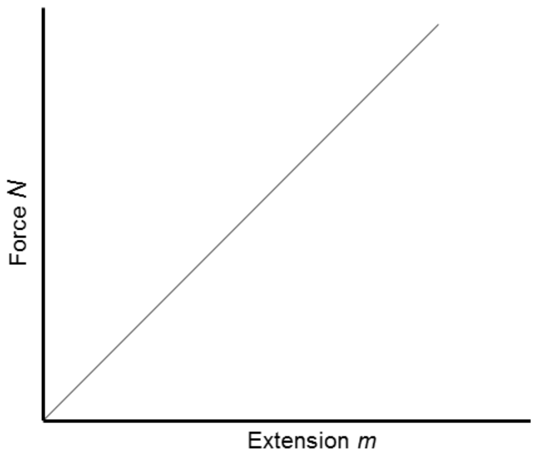
Worksheet B: Young modulus and work done

The graph below shows the behaviour of copper wire under tensile stress. Using the words in the table, label each lettered section correctly.



Elastic deformation	Plastic deformation	Elastic limit
Fracture point	Limit of proportionality	Ultimate tensile strength

This graph shows the force applied against the extension.



Since Work done = force × distance (in the direction of the force) we can use the area below the line (average force × distance) to find the work done.

What was the amount of work done extending this wire?

What units are represented by the area under the graph?

What units are represented by the gradient of the graph?

Worksheet B: Young modulus and work done, continued

Calculations

1. A spring has a length of 15.2cm. A load of 5.0N is hung from the spring, which then extends to a length of 16.1cm.
    a. What is the spring constant of the spring?
    b. What is the length of the spring when the load = 6.5N
    c. What assumption did you make when reaching your answers?

2. Explain the meaning of these terms:
    a. Strain energy
    b. Elastic deformation
    c. Plastic deformation

3. A boundary fence is made of steel, using wire with a diameter of 3.0×10^{-3}m. A force of 1800 N is applied to the fence. The Young modulus of steel is 210 GPa.
    a. Find the cross-sectional area of the wire.
    b. Calculate the stress in the wire of the fence.
    c. Calculate the extension in the wire if the fence is 25m long.

4. A bungee rope extends by a maximum of 15m when a 75kg person is hanging from it. What work was done on the rope by the jump? If the cross-sectional area of the rope is 1.4×10^{-4}m^2, then what is the tensile stress?

Worksheet A: Answers

1. What is the strain on a copper wire if it is extended from 96 cm to 102 cm?
   94

2. What is the tensile stress in an aluminium wire, hung vertically from a clamp, if it has a diameter of 0.55 mm and there is 1.5 kg of mass hanging from it?
   6.2×10^7 Pa

3. A learner sets up an experiment to stretch a thick elastic band by hanging masses from it. The starting length is found to be 80 mm. After hanging 100g on the band, its new length is measured at 105 mm.
   a. What is the total applied force put on the elastic band? $F = mg = 0.981$ N
   b. What is the tensile strain? $\varepsilon = x/L = 0.762$
   c. Why does the value for strain have no units? Dimensionless, ratio of extension per original length
   d. How might the learner find the cross-sectional area of the band? Assume it is a thick one with a rectangular shape when seen in cross section (as seen in this picture) Use a micrometer screw gauge or Vernier calliper to find thickness and width and multiply together.
   e. The learner finds the cross-sectional area is 10 mm^2. What is the stress on the band? (Hint: you will need to convert to m^2 first) $\sigma = F/A = 98\ 100$ Pa
   f. What is the Young modulus of this band? $E = \sigma / \varepsilon = 129$ kPa

4. A 1 m length of wire with a diameter of 0.5 mm is set up horizontally using a pulley. Weights totalling 90 N are hung from the wire.
   a. What is the applied force? $F = 90$ N
   b. What is the stress? 458 MPa
   c. If the Young modulus = 150 x 10^{10} Nm^{-2}, what is the extension? 0.306 mm = 3.06×10^{-4} m

5. In another experiment a wire with a diameter of 2.0 mm is put under stress using a mass of 1.5 kg. The original length is 210 cm and the extension measured is 5 cm.
   a. Use the mass to find applied load, the diameter to find cross sectional area, and convert **all** the measurements into SI units. $d = 2.0 \times 10^{-3}$ m, $A = 7.85 \times 10^{-7}$ m^2. $M = 1.5$ kg, $F = 14.7$ N. $x = 2.10$ m. $\Delta x = 0.05$ m.
   b. Find the stress on the wire. 18.7 MPa.
   c. Find the tensile strain on the wire. 0.024
   d. Calculate the Young modulus of the wire. 785 MPa

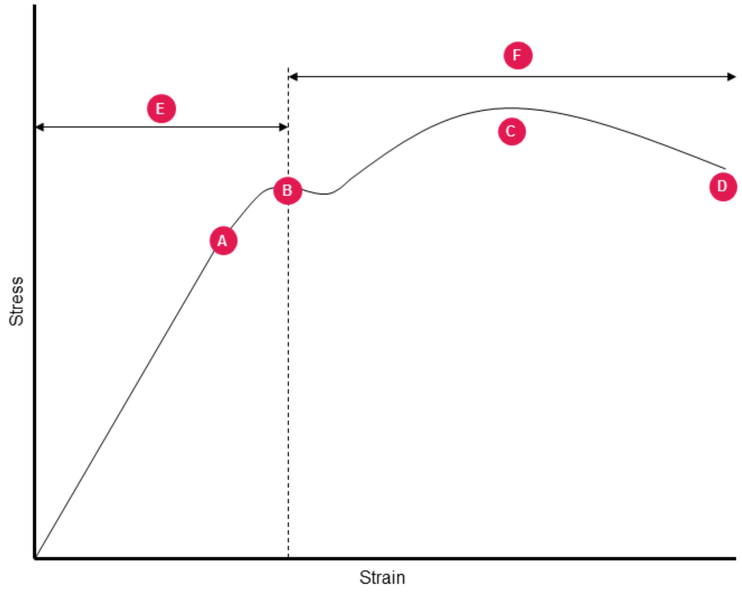
6. If your femur (the bone in your thigh) is 50 cm long and has a diameter of 30 mm, then what is the maximum applied force it can bear, and how much might it extend before fracturing?

   Tensile strength of bone = 1.7 x10^8 Pa.
   Young modulus of bone = 9.4 x 10^9 Pa.

   $F_{max} = 2.04 \times 10^{13}$ N. $\Delta x = 9.04 \times 10^{-3}$ m.

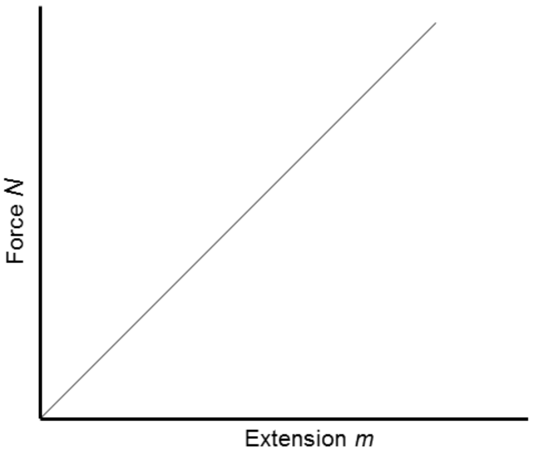
Worksheet B: Answers

The graph below shows the behaviour of copper wire under tensile stress. Using the words in the table, label each lettered section correctly.



Elastic deformation (*E*)	Plastic deformation (*F*)	Elastic limit (*B*)
Fracture point (*D*)	Limit of proportionality (*A*)	Ultimate tensile strength (*C*)

This graph shows the force applied against the extension.



Since Work done = force × distance (in the direction of the force) we can use the area below the line (average force × distance) to find the work done.

What was the amount of work done extending this wire? *0.8 J*

What units are represented by the area under the graph? *Nm or joules*

What units are represented by the gradient of the graph? *Nm^{-1}*

Worksheet B: Answers, continued

Calculations

1. A spring has a length of 15.2cm. A load of 5.0N is hung from the spring, which then extends to a length of 16.1cm.
   a. What is the spring constant of the spring? *5.6 Ncm^{-1}*
   b. What is the length of the spring when the load = 6.5N. *16.4 cm*
   c. What assumption did you make when reaching your answers? *The spring has not exceeded its limit of proportionality (it still obeys Hooke's Law)*

2. Explain the meaning of these terms:
   a. Strain energy: *The energy stored in a material due to its being deformed*
   b. Elastic deformation: *Deformation which is temporary due to being under stress. When the stress is removed the material will return to its original length / shape.*
   c. Plastic deformation: *Deformation which is permanent. When the applied load is removed the material will not return to its original length/ shape.*

3. A boundary fence is made of steel, using wire with a diameter of 3.0×10^{-3}m. A force of 1800 N is applied to the fence. The Young modulus of steel is 210 GPa.
   a. Find the cross-sectional area of the wire. *7.07×10^{-6}m^2*
   b. Calculate the stress in the wire of the fence. *2.55×10^{8} Pa*
   c. Calculate the extension in the wire if the fence is 25m long. *3cm*

4. A bungee rope extends by a maximum of 15m when a 75kg person is hanging from it. What work was done on the rope by the jump? If the cross-sectional area of the rope is 1.4×10^{-4}m^2, then what is the tensile stress?
   550J , 5.3×10^{-6} Pa

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