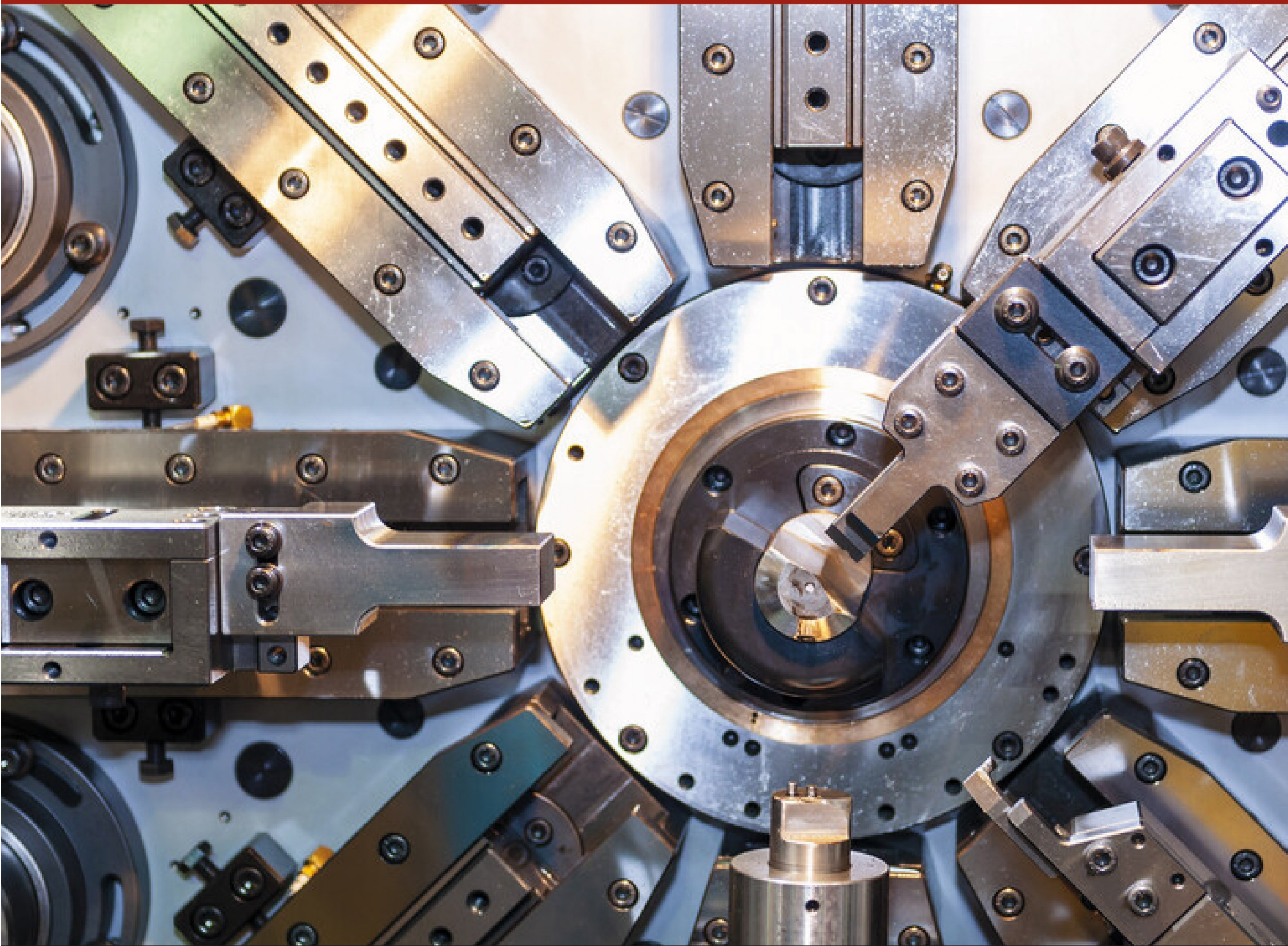
Fundamental MECHANICS

Materials Fundamentals



MATRIX

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Contents

Chapter 1 - Deflection of Beams - Introduction

The amount a beam will bend is an important factor to know when design certain products. Certain shapes or materials will bend more than others. This is due to the *second moment of area* and *Young's modulus.*

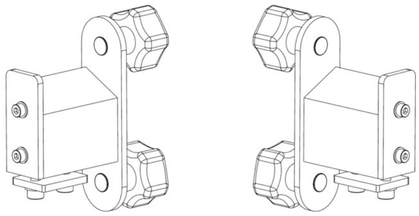
Sometimes it is important that structures resist deflection or deflect a certain amount, like in a diving board in the picture.

These worksheets look at multiple factors affecting the deflection of metal beams - the **dimension** of the beam, its **length, type of support used** and the **material** it is made from.

Over to you:

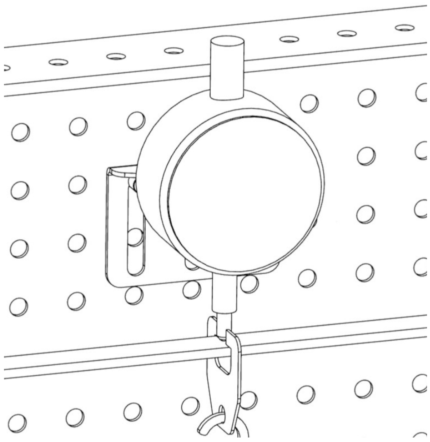
The apparatus:

The two supports can be place anywhere on the work panel by using the large thumb screws on the back.
Flipping the support over allows for the use of fixed support instead of a knife edge simply support.
Use the provide hex key to tighten and loosen the clamping plate for the fixed supports.



Support (left hand) Support (right hand)

The dial can move along the length of the beam specimen, but use the slot features to slide the dial into a good working position for accurate results.



Dial

Worksheet 1

Changing the load

This investigation looks at how much a beam bends when subjected to different loads.

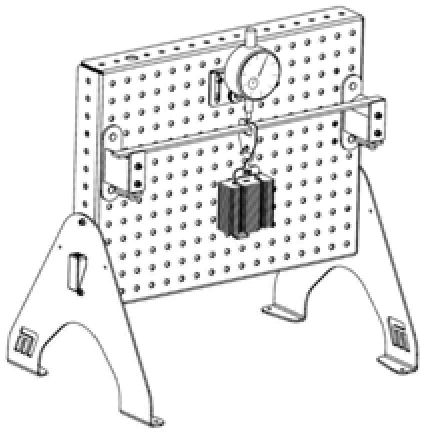
For the engineer, this can be a vital aspect of design - in bridges, buildings, machinery etc.

The photograph shows a crane lifting a heavy load. The crane designer certainly has to know about loading beams!

Over to you:

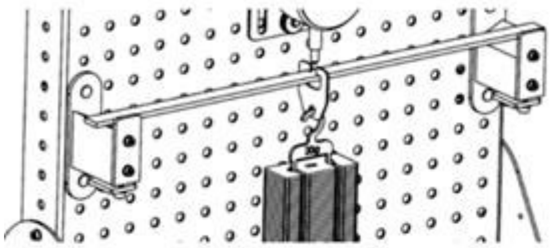
The apparatus:

The top diagram shows the arrangement of the apparatus for this investigation.



The second diagram gives a close-up view of the supported beam.

The (simple) end supports are positioned as far apart as possible on the work panel and point outwards, with the supports uppermost.



Place the aluminium beam centrally across the end supports.

Attach the dial gauge to the adjustable bracket. Fix it to the back panel so that its lower tip rests lightly on the beam. Adjust the bracket so that the dial gauge reads zero on the small (millimetre) dial and as close to zero as possible on the main dial when all nuts are tight.

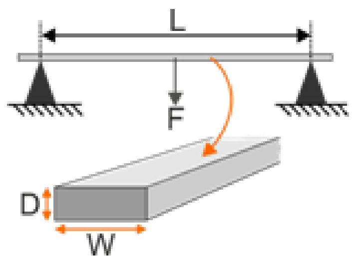
Finally, turn the outer rim of the dial gauge to zero the gauge accurately.

(There may still be a residual zero error. If so, make a note of it and add/subtract it, as appropriate, from readings made during the experiment.)

Worksheet 1

Changing the load

Over to you .....



- Measure the length **L** of the aluminium beam.
- Use vernier callipers to measure its width **W** and depth **D**.
- Record these measurements in the Student Handout.
- Hang a mass of 100g from the centre of the beam.
  (You can use the holes in the work panel as a guide.)
  The beam bends slightly.
- Gently tap on the bench to reduce the effect of friction on the equipment and measure the deflection, shown on the dial gauge.
- Record this in the table in the Student Handout.
- Add a further 100g to the mass hanger and repeat the process until the total mass on the beam is 500g.
- Use your results to plot a straight-line graph of deflection δ vs load **F**, using the axes provided in the Student Handout.

So what:

When the load is removed, the beam returns to its original condition.
The behaviour of the beam is hence elastic.

Some formulae:

For a beam loaded at its centre: deflection $\delta = \dfrac{\mathbf{F} \times \mathbf{L}^3}{48 \times \mathbf{E} \times \mathbf{I}}$

where **E** = Young's modulus
I = area moment of inertia of cross-section.

For a rectangular cross-section bar:

$$\mathbf{I} = \frac{\mathbf{W} \times \mathbf{D}^3}{12}$$

As **L**, **W**, **D** and **E** are constant for this beam,

δ = constant x **F** where this constant = $\dfrac{\mathbf{L}^3}{48 \times \mathbf{E} \times \mathbf{I}}$

Hence, the graph of deflection δ vs load **F** should be linear.

The largest error in this treatment comes from the measurement of length **L**, because this value is raised to the power 3 (i.e. cubed,) in the formula.

Worksheet 2

The material matters

Lead is not suitable for making lengthy beams for bridges. It is very dense, so the beams would be very heavy and it is malleable, so it bends easily.

Concrete has a great resistance to compression but is weak in tension. The steel, used in reinforcement bars ('rebar'), on the other hand has a high tensile strength. Combining the two results in a material that is strong both in tension and in compression.

The photograph shows rebar being prepared for casting in concrete.

Over to you:

- Repeat the procedure outlined in worksheet 1 for:
  1. the brass beam;
  2. the steel beam.
- Record all results in the tables provided in the Student Handout.
- Use the results to plot straight-line graphs of deflection δ vs load **F** for the brass beam and the steel beam, using the axes provided in the Student Handout.

So what:

Finding Young's modulus:

Option 1:

It was shown in the previous investigation that, for a beam loaded at its centre,

the deflection δ = constant x **F** where this constant = $\frac{\mathbf{L}^3}{48 \times \mathbf{E} \times \mathbf{I}}$

Hence, a graph of deflection δ vs load **F** is linear with a gradient **m** = $\frac{\mathbf{L}^3}{48 \times \mathbf{E} \times \mathbf{I}}$

In other words, Young's modulus **E** = $\frac{\mathbf{L}^3}{48 \times \mathbf{m} \times \mathbf{I}}$

- By measuring the gradients of the three graphs, for aluminium (from worksheet 1), for brass and for steel, calculate values for Young's modulus for the three metals.
- Record your answers in the table in the Student Handout.

Worksheet 2

The material matters

So what .....

Option 2:

For a beam loaded at its centre: deflection $\delta = \dfrac{\mathbf{F} \times \mathbf{L}^3}{48 \times \mathbf{E} \times \mathbf{I}}$

Re-arranging this:

$$\delta \times (48 \times \mathbf{E} \times \mathbf{I}) = \mathbf{F} \times \mathbf{L}^3$$

$$\delta \times \frac{(48 \times \mathbf{E} \times \mathbf{I})}{\mathbf{L}^3} = \mathbf{F}$$

i.e. $$\mathbf{F} = \mathbf{E} \times \frac{(48 \times \delta \times \mathbf{I})}{\mathbf{L}^3}$$

This is in the form of the straight-line equation 'y=mx+c'.

It implies that a graph of **F** vs (48 x **D** x **I**) / $\mathbf{L}^3$ (with all lengths converted to metres) has a gradient equal to Young's modulus.

For each metal:

- Use the measurements made in worksheets 1 and 2, for aluminium, brass and steel, to complete the table of results in the Student Handout.
- Plot a graph of **F** vs (48 x **D** x **I**) / $\mathbf{L}^3$ for each metal.
- By measuring the gradient of the graph, obtain values for Young's modulus for the metal.
- Record your answer in the Student Handout.

Worksheet 2

The material matters

So what .....

And finally:

The brass and steel beams have similar dimensions, **L**, **D** and **W,** to those for the aluminium beam used in worksheet 1.

Hence, they all have similar values for **I**, the area moment of inertia of cross-section.

The formulae on page 4 show that deflection δ for a given force **F** is proportional to 1 / **E**, where **E** is Young's modulus for the material.

In other words, **for a given load**,

$$\frac{\delta\ (\text{brass})}{\delta\ (\text{aluminium})} = \frac{\mathbf{E}\ (\text{aluminium})}{\mathbf{E}\ (\text{brass})}$$

and

$$\frac{\delta\ (\text{steel})}{\delta\ (\text{aluminium})} = \frac{\mathbf{E}\ (\text{aluminium})}{\mathbf{E}\ (\text{steel})}$$

and

$$\frac{\delta\ (\text{steel})}{\delta\ (\text{brass})} = \frac{\mathbf{E}\ (\text{brass})}{\mathbf{E}\ (\text{steel})}$$

- Using the measurements made for aluminium in worksheet 1 and those obtained here for brass and steel, calculate the following ratios, for a load of 5N:
    - deflection of brass / deflection of aluminium,
    - deflection of steel / deflection of aluminium,
    - deflection of steel / deflection of brass.

  and write the answers in the Student Handout.
- Compare these ratios with the ratios of the metals' Young's modulus given in the Student Handout.

Worksheet 3

Profile matters

A strong beam but light! That's the usual demand.

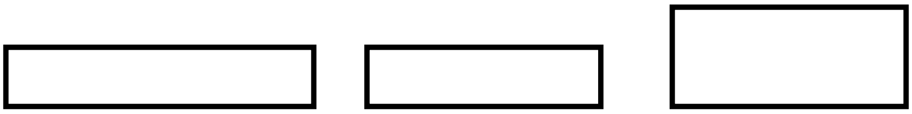
The thickness of the beam, its length and its profile all determine its strength.

As the photograph shows, there are a number of ways to achieve the required strength:

- thin beams are combined into one;
- they are linked with other materials to make a compound structure;
- sometimes they are used 'on edge'.

This investigation uses three beams of different cross-section to create three profiles. All use the same material, aluminium.

The diagram shows the three profiles.



Over to you:

- Measure the length **L,** width **W** and depth **D** of beam **1** and record them in the table in the Student Handout.
- Use the formula: $I = \frac{W \times D^3}{12}$ to calculate the area moment of area, **I**, for beam **1**, and record it in the table.
- With the end supports positioned as before, place beam **1** centrally across them.
- Attach the dial gauge and zero it.
- Hang a mass of 200g from the centre of the beam.
- Use the dial gauge to measure the deflection δ and record it in the Student Handout.
- Repeat this procedure for beam **2** and then beam **3**.

Worksheet 3

Profile matters

So what:

The formula for area moment of inertia,

$$\mathbf{I} = \frac{\mathbf{W} \times \mathbf{D}^3}{12}$$

suggests that the depth, **D**, of the beam has a greater influence on the deflection of the beam than does its width, **W**, as **I** depends on **D** cubed . Giving the **D** dimensions more impact of the deflection.

Since each beam is loaded at its centre, as before:

$$\text{deflection } \delta = \frac{\mathbf{F} \times \mathbf{L}^3}{48 \times \mathbf{E} \times \mathbf{I}}$$

In this investigation, the load **F** and the supported length **L** of the beam are kept constant**.**

The three beams have the same Young's modulus **E**, as they are all made from aluminium.

- Plot a graph of deflection δ vs 1 / **I** for the three beams.

  The deflection formula predicts that this graph should be linear and pass through the origin. However, defects in the surface of the material and errors in measuring the dimensions of the beams may account for discrepancies.

- In the Student Handout, comment on what this result suggests for the relationship between the area moment of inertia and the deflection for a given load.

Worksheet 4

Supports matter

The deflection of a beam depends partly on how it is supported. So far, the investigations have used only 'simple supports', that do not resist sideways movement.
In reality, bridge supports allow the deck to move sideways, to allow for expansion and contraction and the effects of seismic activity, for example. Some also allow it to move backwards and forwards or to twist slightly.

The general equation for the deflection of the beam is:

$$\text{deflection } \delta = \frac{\mathbf{F} \times \mathbf{L}^3}{\mathbf{K} \times \mathbf{E} \times \mathbf{I}}$$ where **K** depends on the type of supports used.

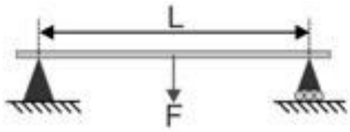
This investigation shows how to obtain the value of the constant, **K**, experimentally.

It uses the aluminium beam, beam **1**, used in the previous investigation where the values of, **E**, **L** and **I** were obtained. We will use these again here.

A graph of deflection δ vs (**F** x $\mathbf{L}^3$ / **E** x **I**) should be a straight line with a gradient of 1 / **K**.

Setup 1 - simple supports:

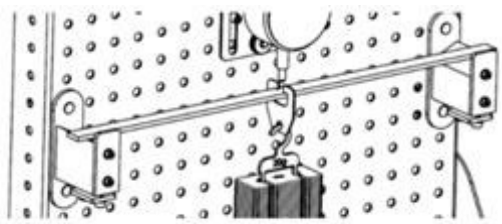
The first arrangement uses two simple supports, as shown in the diagram opposite:



Over to you:

- Position the aluminium beam (beam **1** in the last investigation,) centrally across the two simple supports.
- Attach the dial gauge and zero it.
- Hang a mass of 100g from the centre of the beam.

  The arrangement looks like the one shown in the diagram opposite.

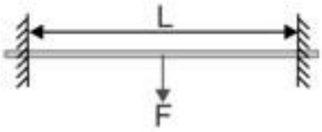


- Measure the deflection, shown on the dial gauge, having tapped on the bench to reduce friction.
- Record this in table **1** in the Student Handout.
- Add a further 100g to the mass hanger and repeat the process until the total mass on the beam is 500g.
- Complete the fourth and fifth columns of table **1**.
- Plot a graph of deflection **D** vs (**F** x $\mathbf{L}^3$ / **E** x **I**) and use the gradient to estimate **K**.

Over to you .....

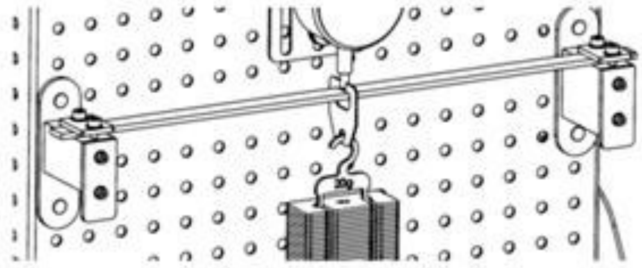
Setup 2 - fixed supports:

- Next, change to two fixed supports as shown below:



- Swap the two simple end supports for fixed ones.
- Unscrew the bar across the top of each sufficiently to allow the beam to slide beneath and then tighten the bars up.
- Hang a mass of 100g from the centre of the beam, as before.

  The arrangement looks like the one shown below.

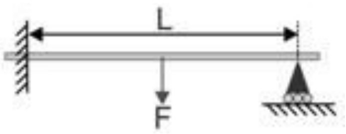


- Once again, tap gently on the bench to reduce the effect of friction on the equipment and measure the deflection, shown on the dial gauge.
- Record this in table **2** in the Student Handout.
- Add a further 100g to the mass hanger and repeat the process until the total mass on the beam is 500g.
- Complete the fourth and fifth columns in table **2**.
- Plot a graph of deflection δ vs (**F** x $\mathbf{L}^3$ / **E** x **I**) and use the gradient to estimate **K**.

Over to you .....

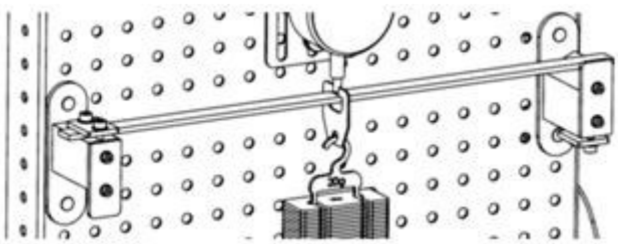
Setup 3 - propped cantilever support (one fixed and one simple support):

- Next, change to the supports shown below, one fixed and one simple:



- Swap one of the fixed supports for a simple end support.
- Secure the beam under the fixed support bar and allow it to rest on the simple support.
- Hang a mass of 100g from the centre of the beam, as before.

  The arrangement looks like the one shown below.



- Repeat the same procedure as before, increasing the load in 100g steps and recording the resulting deflections in table **3** in the Student Handout.
- Complete the fourth and fifth columns in table **3**.
- Plot a graph of deflection δ vs (**F** x **L**^{3} / **E** x **I**) and use the gradient to estimate **K**.

So what:

The results indicate that the more restricted the freedom of movement of the beam, the smaller the deflection for a given load and the higher the value of **K**.

The theoretical values for **K** are:

Setup 1 - **K** = 48
Setup 2 - **K** = 192
Setup 3 - **K** = 110

Worksheet 5

The cantilever

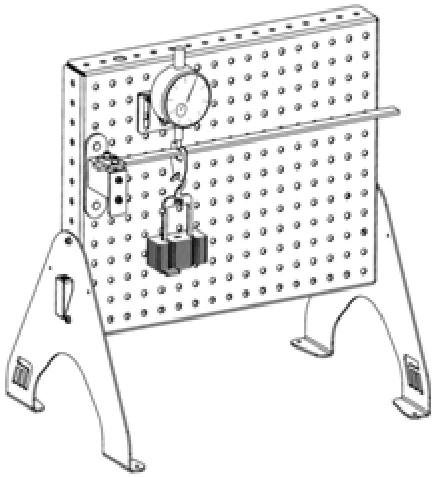
Cantilevers are common in engineering.
From traffic light support arms to suspended balconies to aircraft wings to the Grand Canyon Skywalk, they offer a number of advantages to the engineer, such as:

- allowing construction over deep valleys where access is limited;
- accommodating thermal and seismic movement relatively easily.

The photograph shows a famous cantilever crane on the river Clyde in Glasgow.

This investigation looks at the effect on deflection of the length of a cantilever beam.

Over to you:



- Clamp one end of the steel beam in one of the fixed supports, as shown in the diagram.
- Hang a mass of 200g at a distance of 80mm from the support.
- Attach the dial gauge over the point where the load is attached and zero it.
- Measure the deflection of the beam.
- Record it in the table in the Student Handout.
- Now repeat this procedure for the next load and distance given in the table - 180g hung at a distance of 140mm from the support.
- Repeat the procedure for the remaining three distances and loads. It aims to control the deflection and avoid damage to the beam.
- Complete the fourth and fifth columns in the table.
- Plot a graph of deflection δ vs $\mathbf{L}^3$ drawing a straight line passing through the origin, guided by the points.

So what:

The linear relationship between deflection and $(\text{length})^3$ means that the longer the beam, the more it will deform and explains why bridges that span large rivers are designed to have a number of supported sections rather than just one.

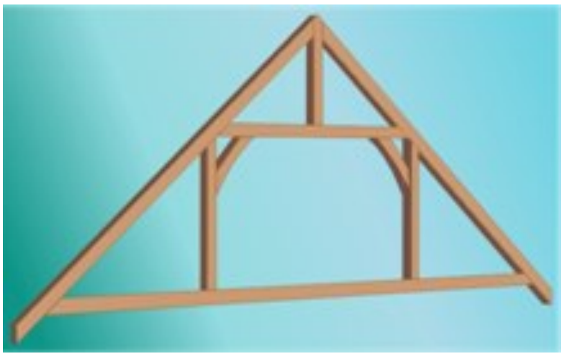
If the results don't go through the origin why would this be?
In the Student Handout, describe likely sources of error in this experiment.

Worksheet 6

Two loads

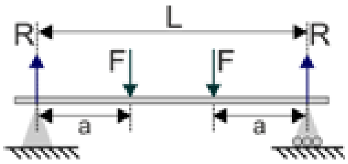
So far, the examples involve a beam subjected to a single load. In most cases, in real-life, however, a number of loads act on the beam.

That complicates the treatment considerably. As a step towards that more complicated situation, this worksheet looks at the case where there are two loads, positioned symmetrically either side of the centre of the beam.

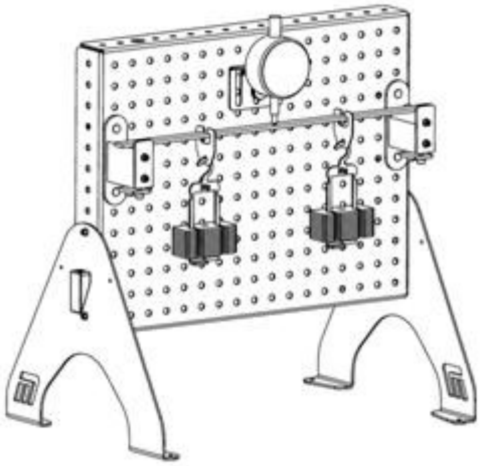


The diagram shows an example - known as a queenpost truss, used to support the roof in some buildings.

The situation is represented by the free-body diagram opposite.
Each load is positioned at distance 'a' from the end supports, which provide vertical reaction forces of R.



The apparatus for this investigation is shown below:



Over to you:

- Position the aluminium beam ('beam 1') 'flat' and centrally across the end supports.
- Attach the dial gauge at the centre of the beam and zero it.
- Hang two mass hangers, each of 200g and each at a distance '**a**' of 40mm from the end supports.
- Gently tap on the bench to reduce the effect of friction and measure the deflection at the centre of the beam, shown on the dial gauge.
- Record your result in the table in the Student Handout.
- Move the two mass hangers to a distance '**a**' of 80mm and repeat the process.
- Finally, do the same again with the mass hangers each 120mm from the end supports.

So what:

Under these circumstances, the maximum deflection of the beam (i.e. at its centre,) is given by the formula:

$$\text{deflection } \delta = \frac{\mathbf{F} \times \mathbf{a} \times (3\mathbf{L}^2 - 4\mathbf{a}^2)}{24 \times \mathbf{E} \times \mathbf{I}}$$

Data:

- The mass hangers each provide a load **F** of 5N.
- The length of the beam was measured in investigation 1.
- Young's modulus, **E**, for aluminium is 70GPa.
- The area moment of inertia, **I**, for this beam profile was calculated in worksheet 2.

- Use the above formula to calculate the theoretical deflection δ for each of the three load positions.
- Record the results of these calculations in the Student Handout.
- Compare them with the measured values and comment on this comparison.
- What were the likely sources of error?

Chapter 2 - Torsion of Rods - Introduction

Some materials twist easily, rubber for example, when a torque (twisting force) is applied. Others, such as steel, are more rigid. This difference in their behaviour is described by a property known as the *second polar moment of area*, related to the *modulus of rigidity* of the material.

Sometimes it is important that structures resist twisting. The photograph shows a car body which has been stiffened by adding steel tubes.

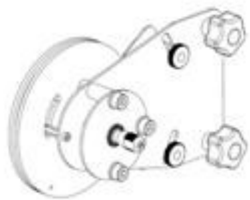
These worksheets look at three factors affecting the rigidity of metal rods - the **diameter** of the rod, its **length** and the **material** it is made from.

Over to you:

The apparatus:

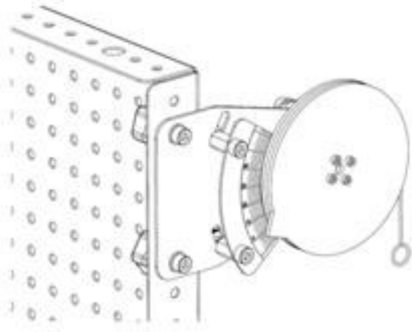
The sample under test is held between two clamps, one on a fixed plate, the other, the 'torsion meter', on a rotating disc which indicates torsion.

Fixed plate

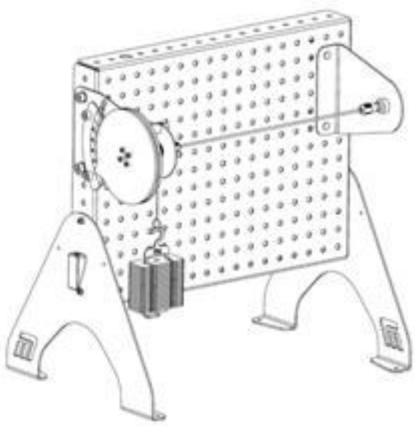


'Torsion meter'

The torsion meter is attached in the position shown:



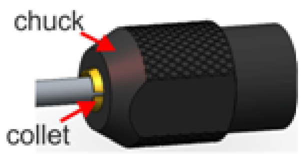
The sample is then clamped between the two as shown in the diagram opposite.



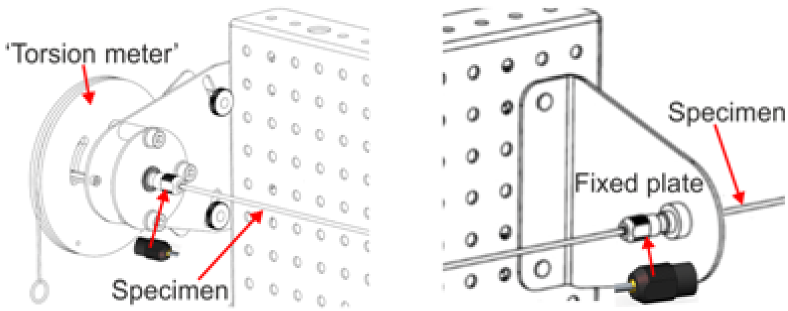
Chapter 2 - Torsion of Rods - Introduction

Setting up the apparatus:

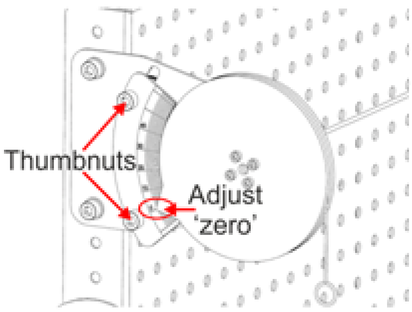
- Find two collets that match the size of the rod under investigation.
- Slide the rod through the hole in the fixed plate and place a collet and chuck over the rod as in the picture.



- Place the second collet and chuck over the rod, but facing the other way round.
- Slide the rod along so that it sits in the 'torsion meter'.



- Hold the rotating disc on the 'torsion meter' with the zero pointer pointing to 0^{O} and tighten up the collet on the fixed end till it tightly grips the rod.
- If the pointer has moved off the scale zero, loosen the thumbnuts and slide the protractor around until the pointer is back on zero..



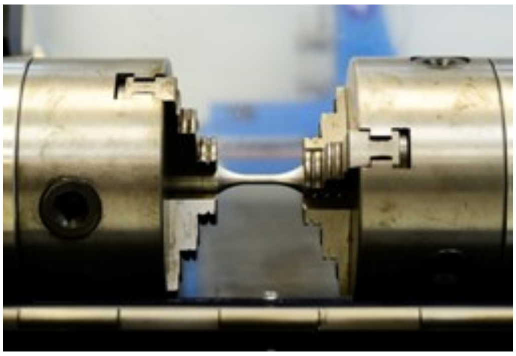
Worksheet 1

Torque

The first investigation looks at the effect of diameter on the rigidity of a metal rod.

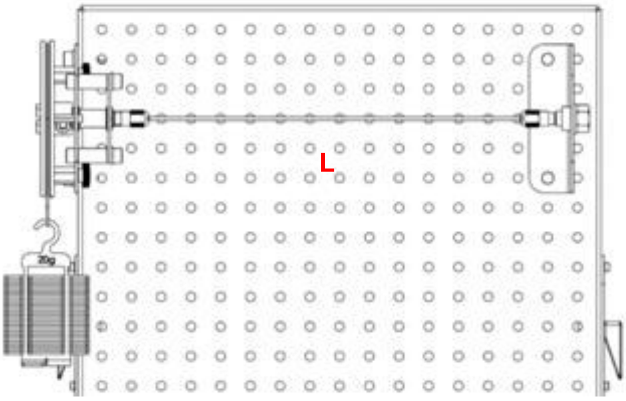
It compares the behaviour of two rods of the same material, having the same length but with different diameters

The photograph shows a test rig used to measure the torsion resulting from applied torque.



Over to you:

- Choose the thicker brass rod and measure its diameter using vernier callipers.
- Measure the length of the rod, '**L**', between the collets.



- Record these in the Student Handout, where this rod is referred to as 'specimen 1'.

- Place an empty hanger (mass 20g) onto the free-hanging hook on the 'torque meter'.
- Measure the torsion (twist angle) from the protractor.
- Record it in table 1 in the Student Handout.
- Add a 60g mass to the hanger and repeat the process.
- Continue in this way until the total mass is 380g.

- Repeat this experiment using the thinner brass rod, referred to as 'specimen 2'.
- Release the collet chucks on either end of the rod.
- Insert specimen 2, using smaller diameter collets and zero the 'torsion meter' as before.
- Increase the torque in steps and record the resulting torsion readings in table 2 of the Student Handout.

Over to you continued.....

- Now carry out the calculations of twist angles in radians and the theoretical values for the twist angles using the formulae provided in the Student Handout and complete the tables.
- Use the results to draw graphs of torque against twist angle for the two rods. The Student Handout includes scaled axes to speed up this element of the investigation.

So what:

A small change in the diameter of the rod has a large effect on the twist angle produced by a given torque.

This is because the polar second moment of area depends on diameter raised to the fourth power, rapidly increasing the rigidity of the specimen as rod diameter increases.

The behaviour shown in the graph is linear because the rod is twisting through the linear region (elastic region) of the material's properties.

Worksheet 2

Material

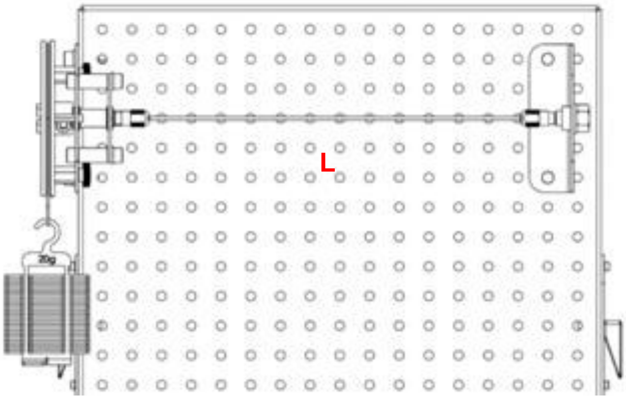
The next investigation looks at how the material itself affects the rigidity of a metal rod.

This time, the rods are made from different materials, brass, steel and aluminium.

Over to you:

- Measure the diameters of the brass, steel and aluminium rods using vernier callipers.
- Calculate the polar second moment of area **J** for each, using the formula given previously.
- Set up each one, in turn, in the same apparatus as in the last investigation.

- For each:
  - Measure the length of the rod, '**L**', held between the collets.



  - Starting with an empty hanger, increase the load in stages, as before.
  - Calculate the torque, **T**, exerted on the sample, using the formula given earlier.
  - Each time, measure the resulting torsion (twist angle) **θ**.

- Record all results in the Student Handout.
- Complete the columns for the quantities (**T** x **L**) and (**J** x **θ**).

Worksheet 2

Material

So what:

Twist angle, $\theta = \frac{\mathbf{T} \times \mathbf{L}}{\mathbf{J} \times \mathbf{G}}$ where **G** = modulus of rigidity.

Re-arranging this: $(\mathbf{T} \times \mathbf{L}) = \mathbf{G} (\mathbf{J} \times \theta)$

This is of the form $y = m \cdot x$ and predicts that a graph of (**T** x **L**) against (**J** x θ) produces a straight-line graph with a gradient equal to the modulus of rigidity, **G**.

- Plot a graph of (**T** x **L**) against (**J** x θ) for each material and calculate the gradient of each, using the scaled axes provided in the Student Handout.
- Use your results to populate the table showing the moduli of rigidity for the three metals.

The modulus of rigidity indicates the extent to which a material resists torsional distortion. The higher the modulus, the more rigid the material.

This is useful to know for applications such as designing the prop. shaft in a car. Knowing the lightest possible material able to withstand the torque delivered helps to save fuel.

Worksheet 3

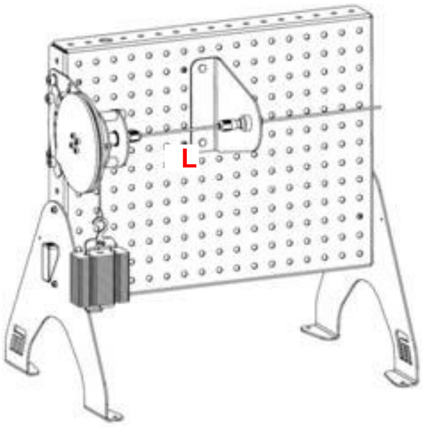
Length

The next investigation looks at how the length of a beam affects its rigidity.

The photograph shows a steel beam that will form part of a bridge. Notice the depth of beam needed to withstand the huge loads carried by the bridge.

Over to you:

This investigation uses a similar setup to that in worksheet 1 except that the fixed plate is moved along to create different lengths of rod.



- Choose the brass rod ‘specimen 1’ used in the first worksheet.
- Position the fixed plate so that the rod has a clamped length, **L**, of 100mm.
- Hang a load of 400g from the ‘twist meter’.
- Measure the torsion (twist angle) θ and record it in the table in the Student Handout.
- Move the fixed plate 40mm to the right (two holes) to increase length **L** to 140mm.
- Again measure and record the torsion (twist angle) θ.
- Repeat this process for rod lengths **L** of 180mm, 220mm and 260mm.

So what:

- Plot a graph of twist angle θ against length **L**, using the axes provided in the Student Handout.
- The result should indicate a straight-line relationship. This means that the twist angle is directly proportional to the length of the rod, so, for a given load, when you double the length of the rod, you double the resulting twist angle etc... .

Chapter 3 - Tensile Tester - Introduction

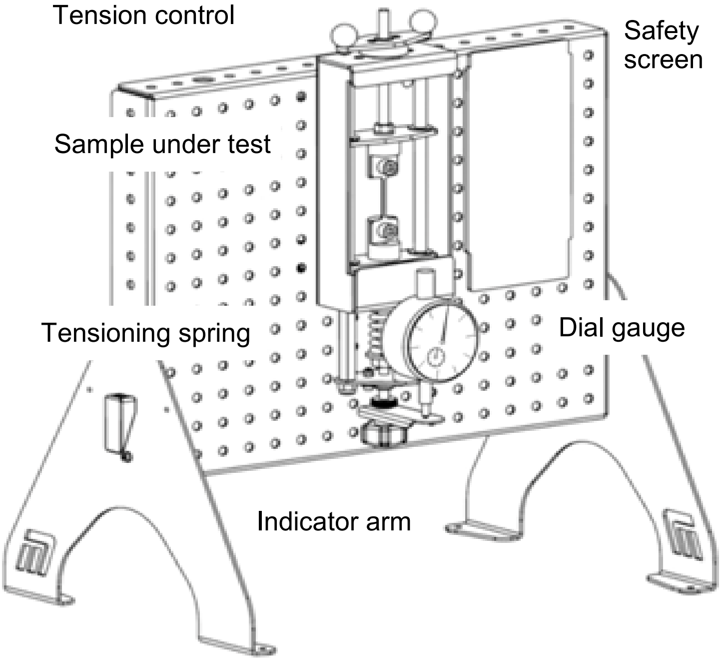
The properties of materials determine how and where they can be used. This module examines some effects of forces on them.

The top photograph shows a pole-vaulter in mid-flight. The pole stores elastic strain energy and later converts it back to kinetic energy. It must be light in weight. *It must not snap!*

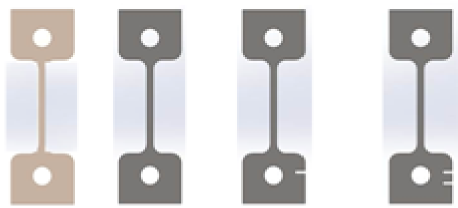
In the second photograph, long (and heavy) power cables are slung between pylons. They stretch under their own weight but must not get so long that they near the ground. *They must not snap!*

Both examples reflect properties of the materials used to make them.

The apparatus:



The samples:

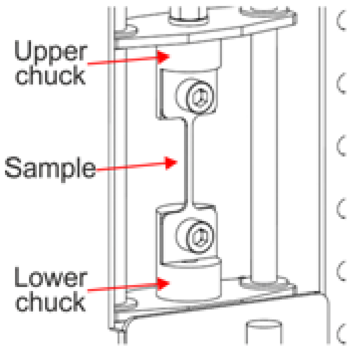


Over to you:

- Fix the tensile tester on the work panel in the position shown on the previous page, so that the tension control is above the top of the panel to allow free rotation.

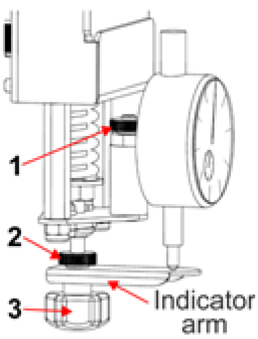
1. **Attaching the sample:**

- Connect the top of the sample to the upper chuck loosely with a M6 bolt.
- Turn the tension control handle to align the hole in other end of sample with that in the lower chuck.
- Connect the bottom of the sample to the lower chuck with a M6 bolt.
- Tighten both bolts.
- **Place the safety screen in position.**
- Slowly rotate the tension control handle until some resistance is felt.



2. **Zeroing the dial gauge:**

- Attach the dial gauge, using thumbnut **1**, facing forwards.
- Loosen the indicator arm using thumbnut **2** and lobe nut **3**.
- Adjust them so that the dial gauge reads zero on the small (millimetre) dial and as close to zero as possible on the main dial when both nuts are tight.
- Finally, turn the outer rim of the dial gauge to zero the gauge accurately.
  (There may still be a residual zero error. If so, make a note of it and add/subtract it, as appropriate, from readings made during the experiments.)



Worksheet 1

Tensile stress

This investigation highlights two areas of behaviour when a sample is subjected to tension.

Initially, the material behaves elastically, meaning that it returns to its original dimensions once the tension is released.

Eventually, the material exhibits plastic deformation and the changes are permanent, even after tension is removed.

Over to you:

- Select the aluminium 6082 sample and attach it to the tensile tester as described on the previous page.

Do not forget to place the safety screen in position!

- Using the circular scale on top of the tester, rotate the tension control handle through an angle of 45^0 to increase the tension on the sample.
- Observe the reading on the dial gauge and note it in the Student Handout.
- Repeat this process until the sample snaps.

  (You may find that ‘creep’ occurs in the later stages of this process. To reduce the effect this has, take readings promptly after each increase in tension.)
- Use the information given in the Student Handout to calculate the force applied to the sample and its resulting extension for each step. Hence complete the results table.
- Use the axes provided to plot a graph of extension versus applied force for this material.
- Repeat this process for the other samples - aluminium 1050, steel and ABS plastic.

  (Steel has a much higher tensile strength and takes a greater force to extend and finally fracture it. As a result, it is sufficient to increase the tension in 90^0 rather than 45^0steps for the steel sample.)

Challenge:

For each sample, determine the value of extension at which the length of the sample no longer returns to its initial value by removing the tension after each step and observing the result. This is the point at which the material is no longer behaving elastically.

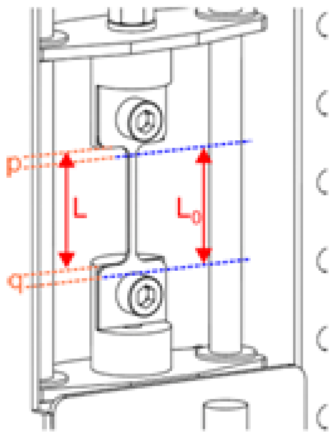
Worksheet 1

Tensile stress

So what:

The initial length of the sample is L_0.

When the torsion control handle rotates through 1 revolution, the top of the sample rises by 1mm.



Suppose at some point it has risen by distance '**p**'.

This can be calculated knowing how many revolutions the handle has turned through.

In the same time, the sample stretches. The bottom of the sample rises by the distance '**q**' shown by the reading on the dial gauge.

At any time, the length, '**L**', of the sample is given by:

$$L = L_0 + (p - q)$$

The extension of the sample, **e**, is given by:

$$e = L - L_0 = (p - q)$$

In doing this, the spring is compressed by the amount shown on the dial gauge.

Hence it exerts a force **F** given by:

$$F = q \times k \qquad \text{where } k = \text{spring constant} = 105\text{N.mm}^{-1}$$

Tensile stress σ is defined as **F** / **A** where **A** is the cross-sectional area of the sample.

The area will be around 2mm x 1.5mm depending on sample.

Tensile strain ε is defined as 'extension per unit length', i.e. $\varepsilon = e / L_0$

The results of this investigation could be used to produce a graph of tensile stress vs tensile strain from which a value for Young's modulus for the material could be obtained.

However, the techniques used here are not sufficiently accurate to make this worthwhile.

They do not provide sufficiently accurate measurement of stress and strain.

Instead, the results are used to produce a graph of extension **e** vs applied force **F**.

This graph reveals features such as:

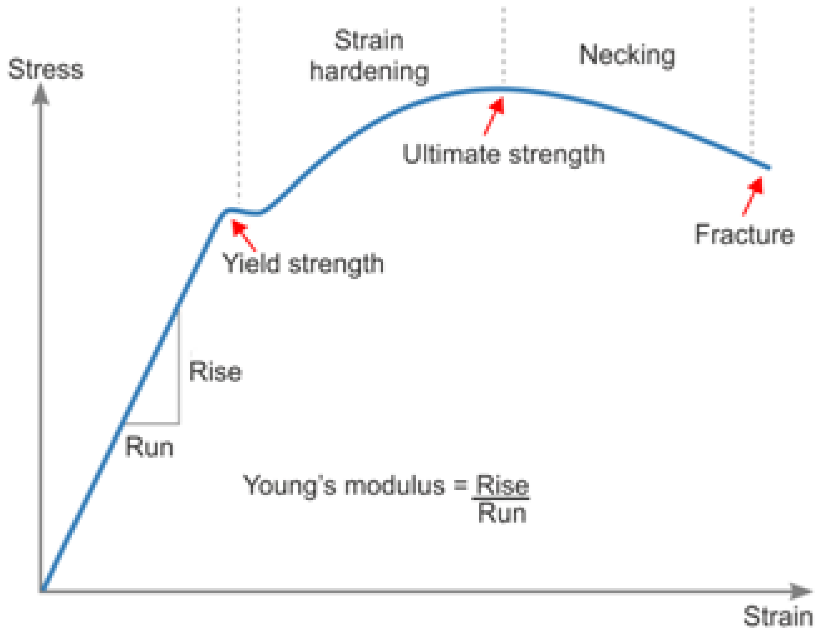
- elastic behaviour
- yield point
- plastic behaviour
- strain hardening
- necking
- fracture.

Worksheet 1

Tensile stress

So what .....

The diagram shows typical behaviour of a material when tensile stress is applied.



However, the exact shape varies from material to material.

Ductile materials show an elongated plastic deformation region, (to the right, after the 'yield strength' point. This is an important property for materials used in applications that must not critically fail. However, these materials usually have lower ultimate strength than a material such as steel.

Very hard and brittle materials such as ceramics have very high Young's modulus but show no plastic deformation. Their stress/strain curve therefore stops around the yield strength point.

The two types of aluminium samples in the kit use different alloys. The results demonstrate the effect that this has on yield strength and ductility. For example the aluminium 6082 alloy can withdrawn more stress than the 1050 alloy before reaching the yield point.

Worksheet 2

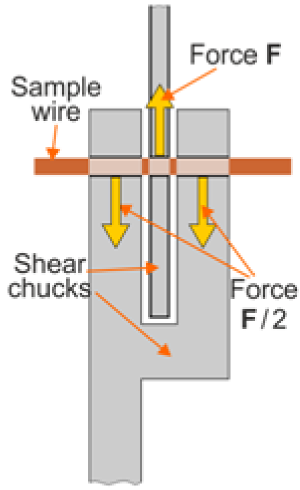
Shear stress

In the previous investigation, the force acted to stretch the sample, causing tensile stress.

This time, the force acts in such a way that slices of the material slide over each other, known as shear stress.

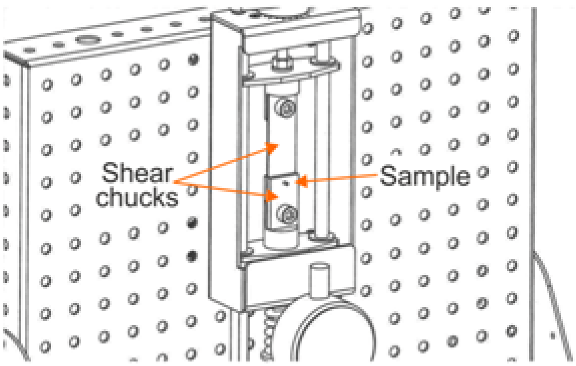
The photograph shows a common form of linkage, known as a clevis and pin.

Over to you:



- Cut a short length (around 2cm) of aluminium wire and insert it through the holes in the shear chucks.
- Set up the apparatus shown in the diagram below, with the two shear chucks bolted to the frame and the sample in place.

Do not forget to place the safety screen in position!



- Slowly rotate the tension control handle until some resistance is felt.
- Using the circular scale on top of the tester, rotate the tension control handle through an angle of 45^0 to increase the tension on the sample. As illustrated in the first diagram, this applied force **F** is shared between the two arms of the lower chuck.
- Observe the reading on the dial gauge and note it in the Student Handout.
- Repeat this process until the sample snaps.
- Use the information given in the Student Handout to calculate the force applied to the sample and its resulting extension for each step. Hence complete the results table.
- Use the axes provided to plot a graph of extension versus applied force for this material.
- Next, repeat the whole process for the other sample, the copper wire.

So what:

This exercise shows the result of applying a shear stress to a sample.

Shear strength is normally around half the tensile strength but this value varies from one material to another.

This has great significance in mechanical engineering, for predicting the results of stresses in shafts and in bolts attached to metal plates for example.

Student Handout

Chapter 1 - Deflection of Beams

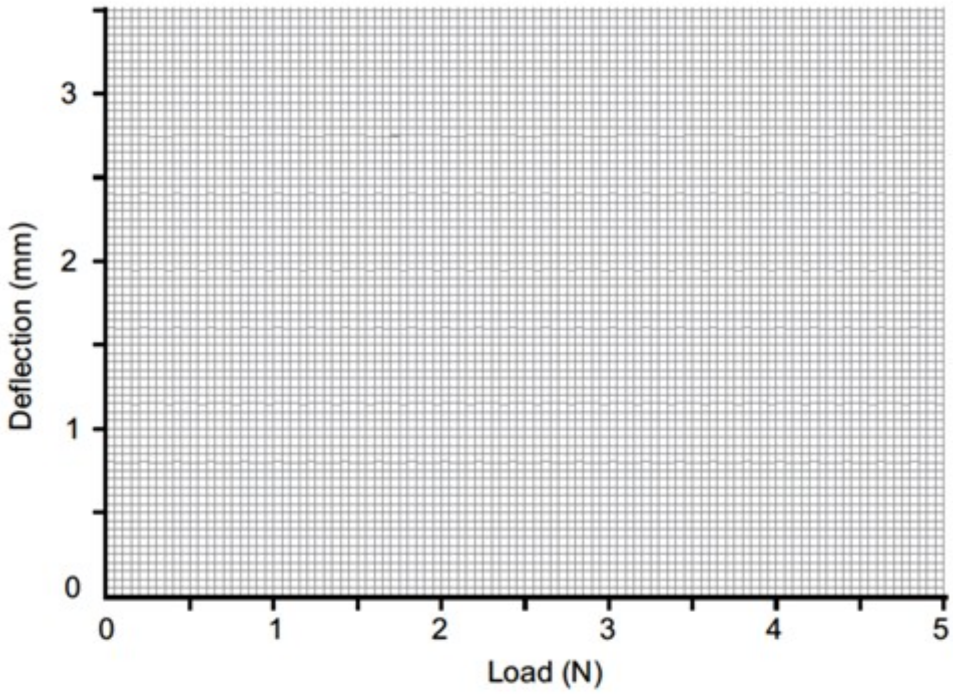
Worksheet 1 - Changing the load

Aluminium beam: Length **L** of beam = ...mm
Width **W** of beam = ...mm
Depth **D** of beam = ...mm

Suspended mass in g	Load F in N	Deflection of beam δ in mm
100	1	0
200	2	
300	3	
400	4	
500	5	

Graph of deflection vs load:

Show your measurements as small crosses.
They should suggest a straight-line relationship.



Student Handout

Worksheet 2 - The material matters

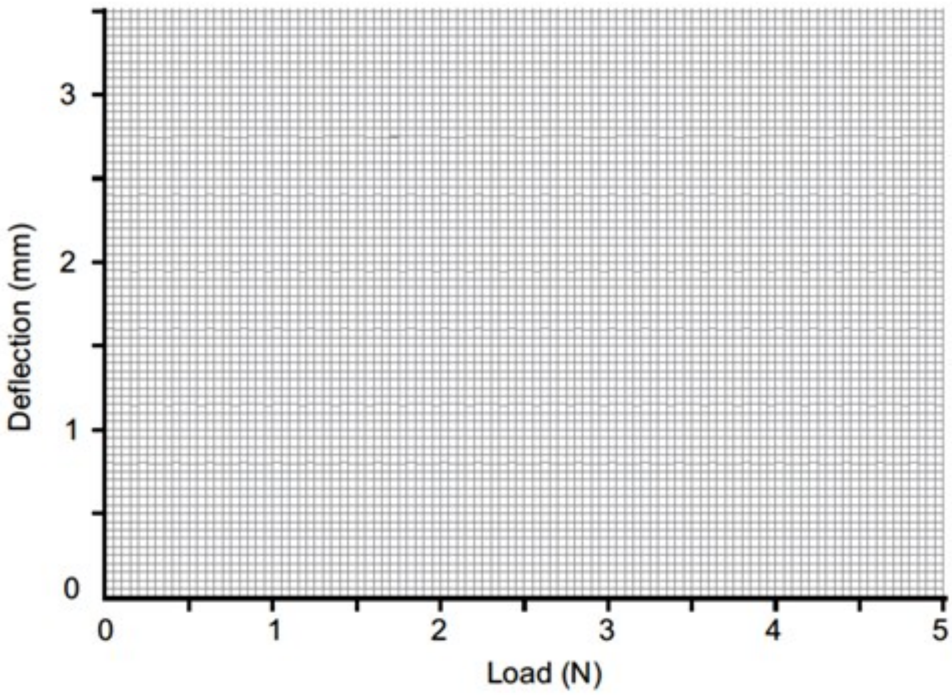
Brass beam:

Length **L** of beam = ...mm
Width **W** of beam = ...mm
Depth **D** of beam = ...mm

Suspended mass in g	Load F in N	Deflection of beam δ in mm
100	1	0
200	2	
300	3	
400	4	
500	5	

Graph of deflection vs load:

Show your measurements as small crosses. They should suggest a straight-line relationship.



Gradient **m** of graph ....

Worksheet 2 - The material matters

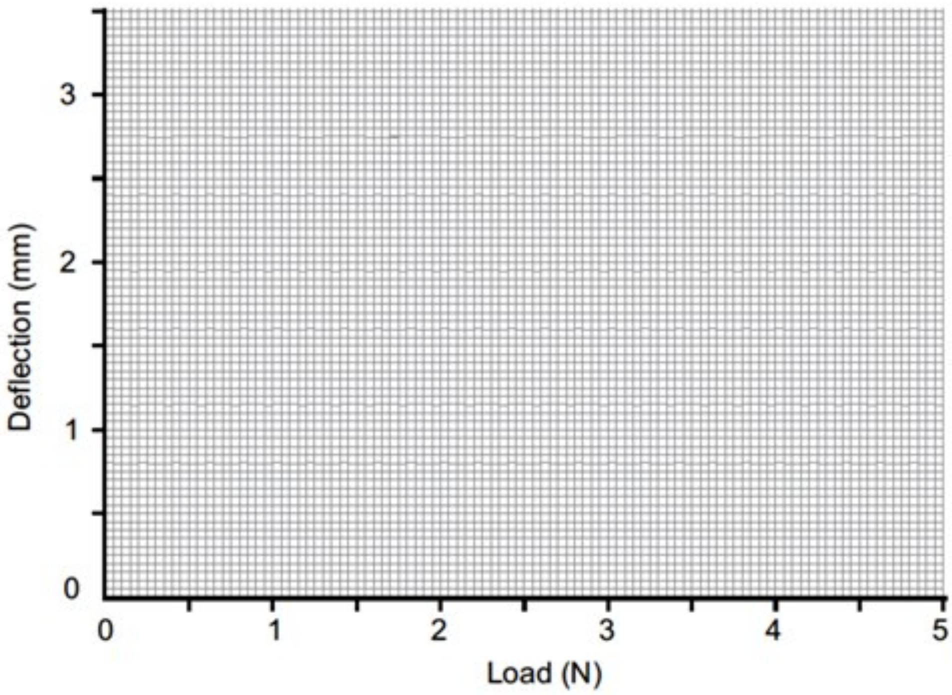
Steel beam:

Length **L** of beam = ...mm
Width **W** of beam = ...mm
Depth **D** of beam = ...mm

Suspended mass in g	Load F in N	Deflection of beam δ in mm
100	1	0
200	2	
300	3	
400	4	
500	5	

Graph of deflection vs load:

Show your measurements as small crosses. They should suggest a straight-line relationship.



Gradient **m** of graph ....

Student Handout

Fundamental MECHANICS

Worksheet 2 - The material matters

Option 1:

Brass -

Area moment of inertia of cross-section **I** $= \frac{W \times D^3}{12}$ = ...

Young's modulus for brass **E** = $\frac{L^3}{48 \times m \times I}$ = ...

Steel -

Area moment of inertia of cross-section **I** $= \frac{W \times D^3}{12}$ = ...

Young's modulus for steel **E** = $\frac{L^3}{48 \times m \times I}$ = ...

Aluminium -

Area moment of inertia of cross-section **I** $= \frac{W \times D^3}{12}$ = ...

Young's modulus for aluminium **E** = $\frac{L^3}{48 \times m \times I}$ = ...

Student Handout

Fundamental MECHANICS

Worksheet 2 - The material matters

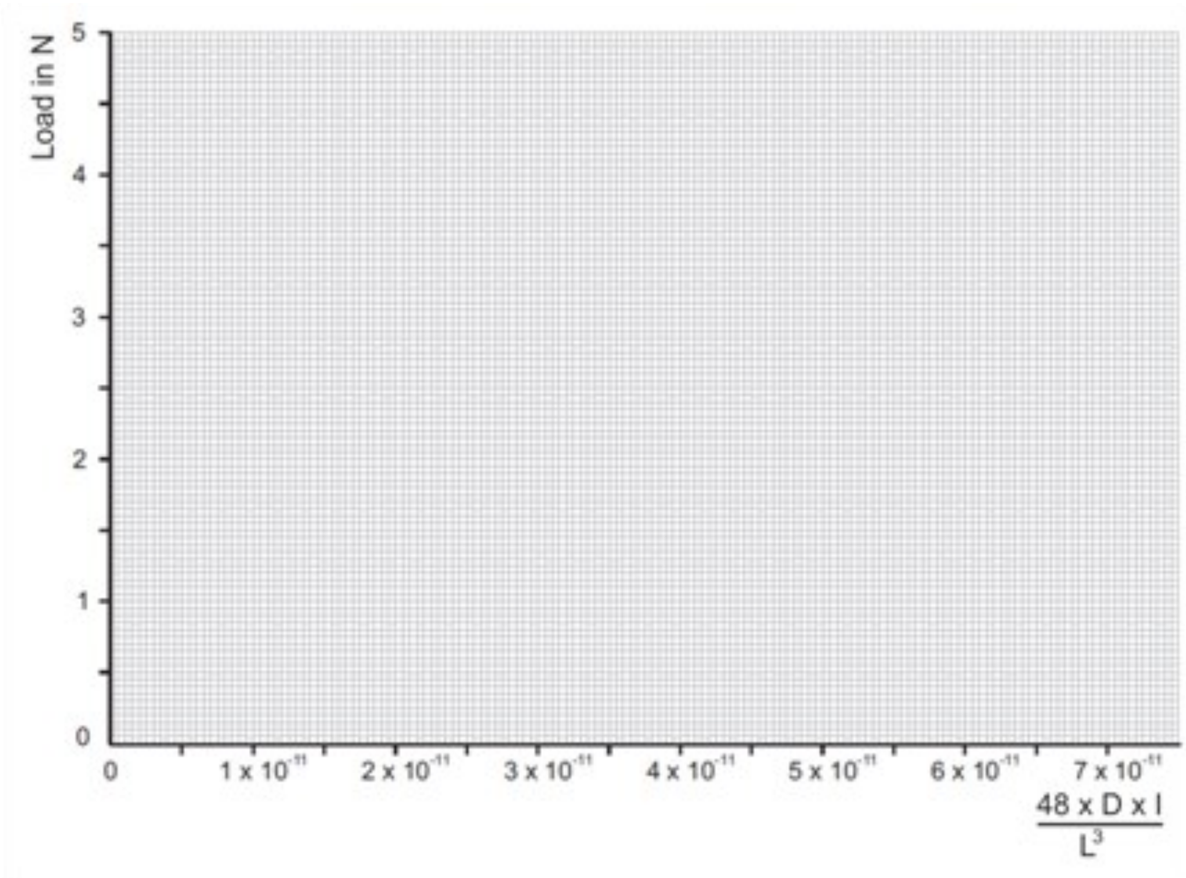
Option 2:

Metal ....

Suspended mass in g	Load F in N	Deflection of beam δ in mm	Deflection of beam D ιν μ	$\frac{48 \times D \times I}{L^3}$
100	1	0	0	
200	2			
300	3			
400	4			
500	5			

Graph of (48 x **D** x **I**) / **L**^{3} **vs load:**

Show your measurements as small crosses.
They should suggest a straight-line relationship.



Young’s modulus = gradient of graph = ...

Student Handout

Fundamental MECHANICS

Worksheet 2 - The material matters

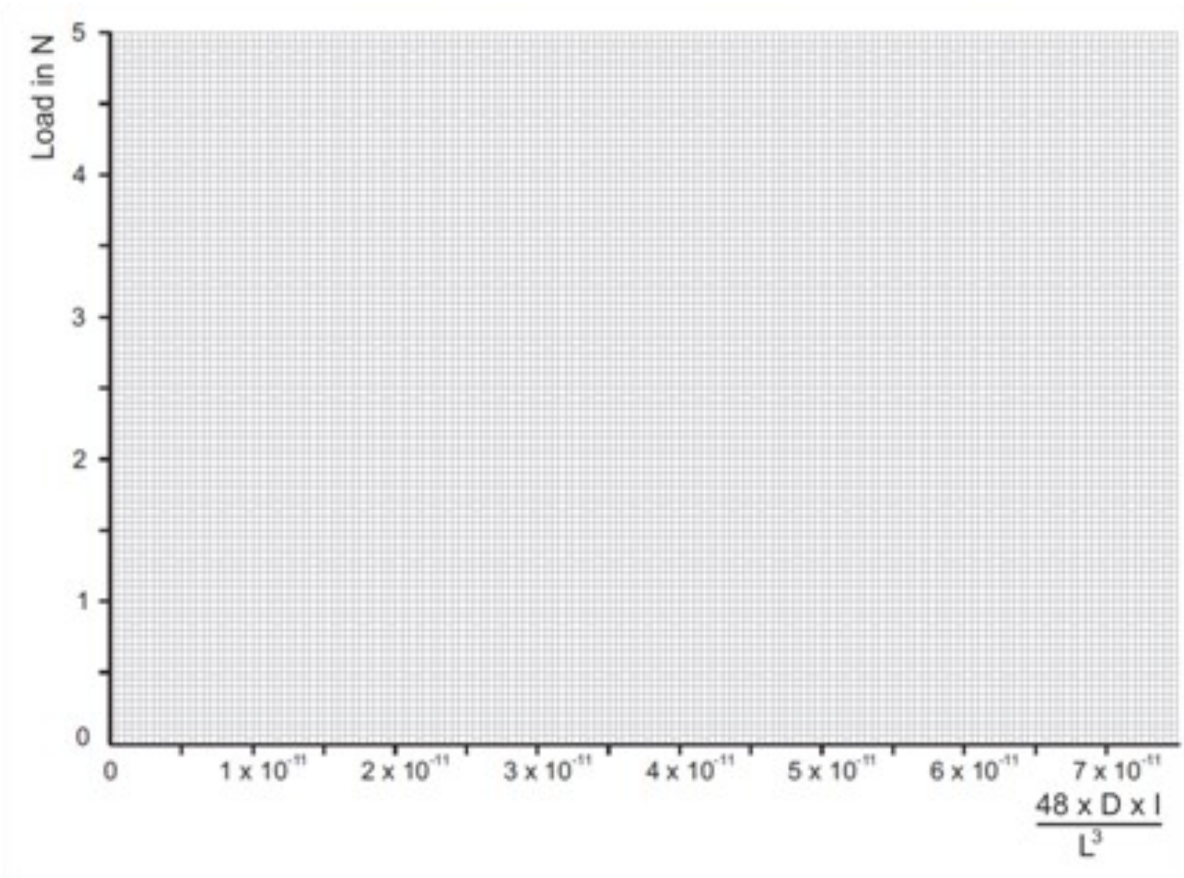
Option 2:

Metal ....

Suspended mass in g	**Load F in N**	**Deflection of beam δ in mm**	**Deflection of beam D ιν μ**	**48 x D x I / L^3**
100	1	0	0	
200	2			
300	3			
400	4			
500	5			

Graph of (48 x **D** x **I**) / **L^3** **vs load:**

Show your measurements as small crosses.
They should suggest a straight-line relationship.



Young's modulus = gradient of graph = ...

Student Handout

Worksheet 2 - The material matters

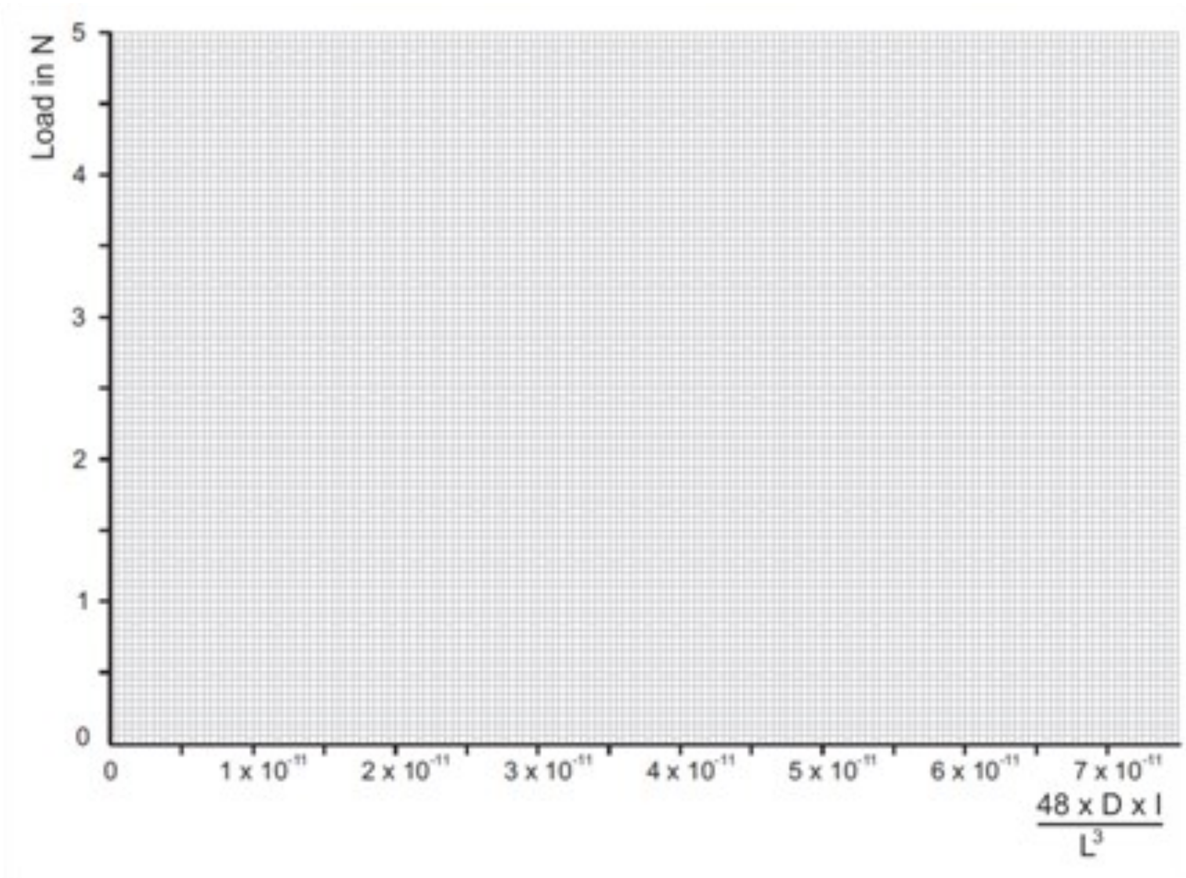
Option 2:

Metal ....

Suspended mass in g	**Load F in N**	**Deflection of beam δ in mm**	**Deflection of beam D ιν μ**	**48 x D x I / L^3**
100	1	0	0	
200	2			
300	3			
400	4			
500	5			

Graph of (48 x **D** x **I**) / **L^3 vs load:**

Show your measurements as small crosses.
They should suggest a straight-line relationship.



Young's modulus = gradient of graph = ...

Student Handout

Fundamental MECHANICS

Worksheet 2 - The material matters

And finally:

Data:

For a load of 5N:

deflection of aluminium = ... (taken from worksheet 1 results.)
deflection of brass = ... (taken from worksheet 2 results.)
deflection of steel = ... (taken from worksheet 2 results.)

Calculations:

Using these:

$$\frac{\text{deflection of brass}}{\text{deflection of aluminium}} = \text{...}$$

$$\frac{\text{deflection of steel}}{\text{deflection of aluminium}} = \text{...}$$

$$\frac{\text{deflection of steel}}{\text{deflection of brass}} = \text{...}$$

The table shows typical values of Young's modulus, **E**, for the three metals.

Metal	Young's modulus E in GPa
Aluminium	70
Brass	100
Steel	200

Using these values:

$$\frac{\textbf{E}\text{ (aluminium)}}{\textbf{E}\text{ (brass)}} = \text{....................} \qquad \frac{\textbf{E}\text{ (aluminium)}}{\textbf{E}\text{ (steel)}} = \text{....................} \qquad \frac{\textbf{E}\text{ (brass)}}{\textbf{E}\text{ (steel)}} = \text{....................}$$

Compare these with the ratios of deflections calculated above.

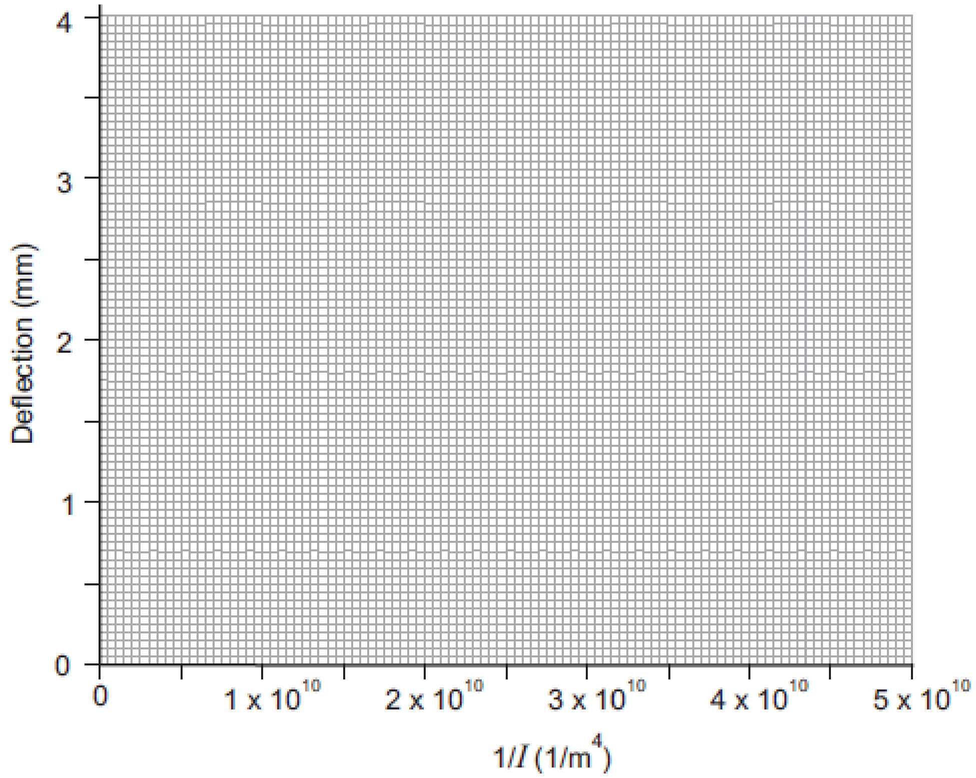
Student Handout

Worksheet 3 - Profile matters

Beam	Width W in mm	Depth D in mm	Area moment of inertia I in mm^4	1 / I in mm^{-4}	Beam Deflection δ in mm
1					
2					
3					

Graph of deflection δ vs 1 / I :

Show your measurements as small crosses.
They should suggest a straight-line relationship.



What does this graph suggest about the relationship between the area moment of inertia and the deflection for a given load?

....

....

....

....

Student Handout

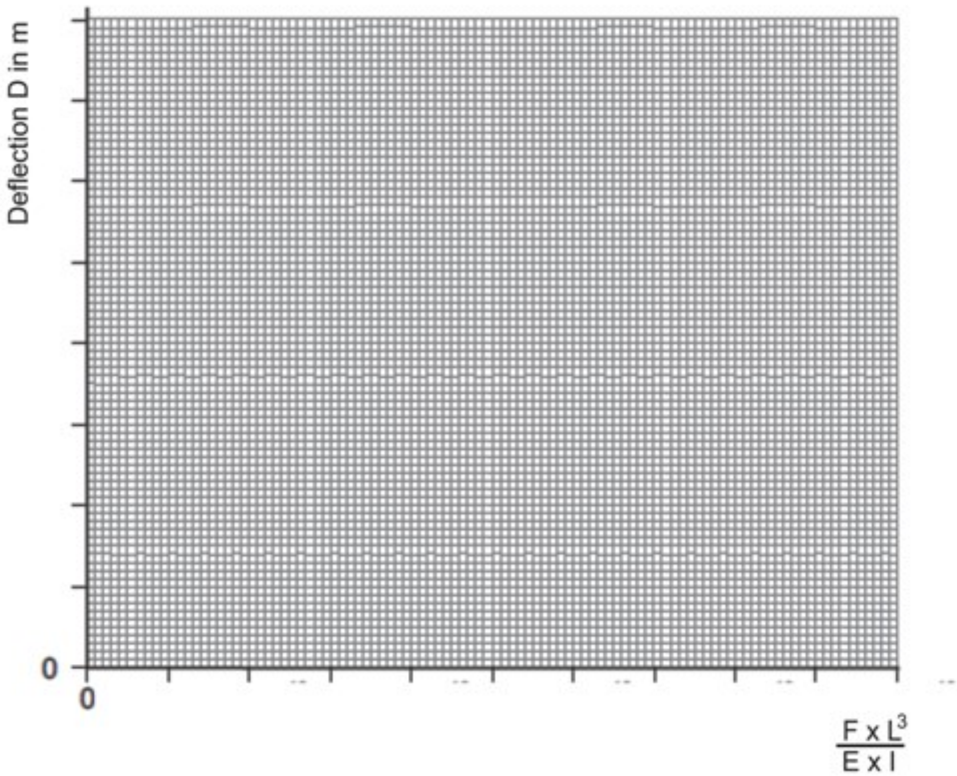
Worksheet 4 - Supports matter

Setup 1 - simple supports:

Suspended mass in g	Load F in N	Deflection of beam δ in mm	Deflection of beam D ιν μ	$\frac{F \times L^3}{E \times I}$
0	0	0	0	0
100	1			
200	2			
300	3			
400	4			
500	5			

Graph of deflection δ vs $(F \times L^3) / (E \times I)$:

Show your measurements as small crosses.
They should suggest a straight-line relationship.



Use the gradient to obtain a value of **K** for propped cantilever supports:

....

....

....

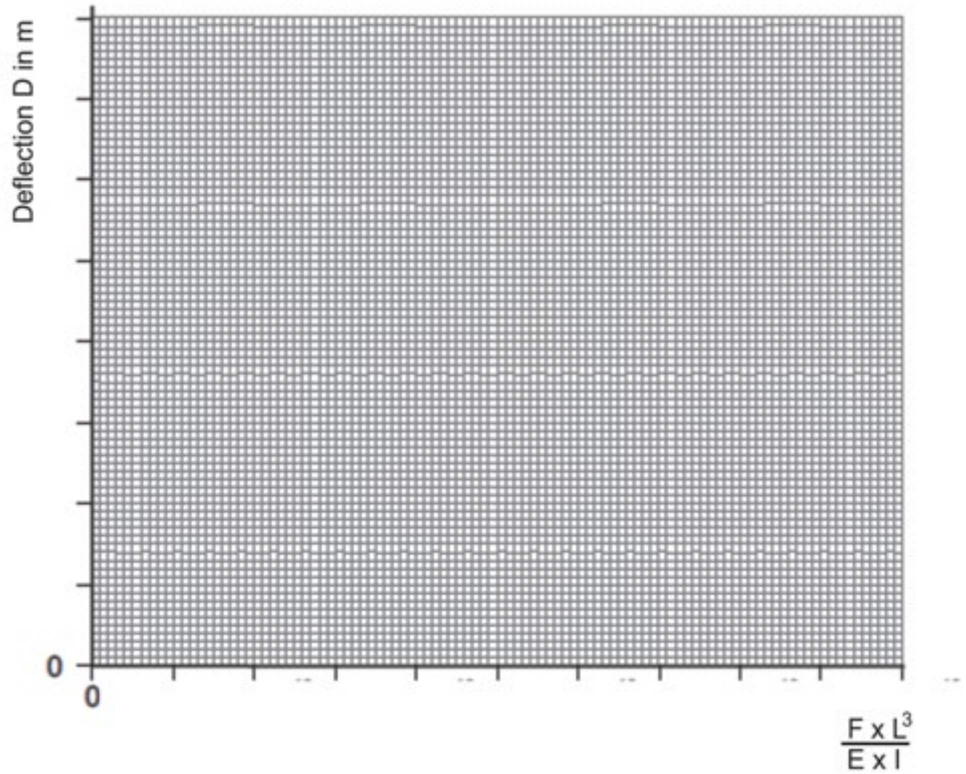
Worksheet 4 - Supports matter

Setup 2 - fixed supports:

Suspended mass in g	Load F in N	Deflection of beam δ in mm	Deflection of beam D ιν μ	$\frac{F \times L^3}{E \times I}$
0	0	0	0	0
100	1			
200	2			
300	3			
400	4			
500	5			

Graph of deflection δ vs $(F \times L^3) / (E \times I)$:

Show your measurements as small crosses.
They should suggest a straight-line relationship.



Use the gradient to obtain a value of **K** for propped cantilever supports:

....

....

....

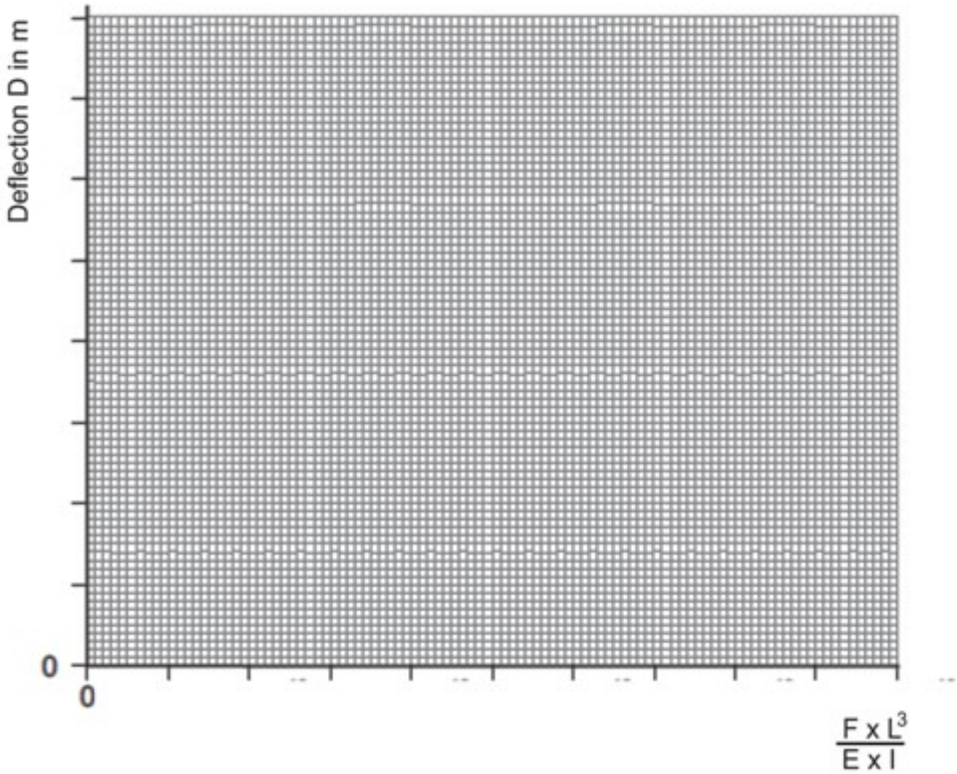
Worksheet 4 - Supports matter

Setup 3 - propped cantilever supports:

Suspended mass in g	Load F in N	Deflection of beam δ in mm	Deflection of beam D ιν μ	$\frac{F \times L^3}{E \times I}$
0	0	0	0	0
100	1			
200	2			
300	3			
400	4			
500	5			

Graph of deflection δ vs $(F \times L^3) / (E \times I)$:

Show your measurements as small crosses.
They should suggest a straight-line relationship.



Use the gradient to obtain a value of **K** for propped cantilever supports:

....

....

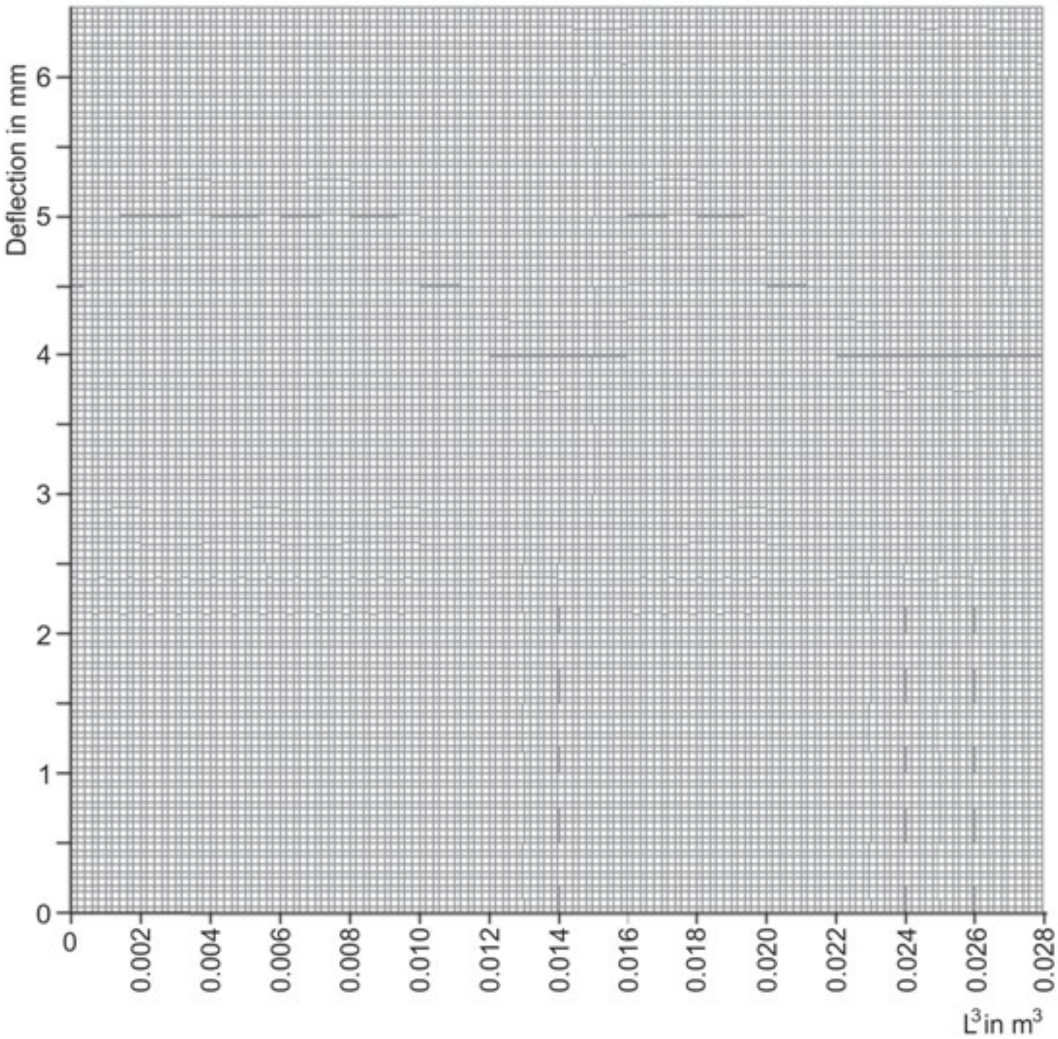
....

Student Handout

Worksheet 5 - The cantilever

Beam length l in mm	Beam length L in m	L^3 in m^3	Suspend-ed mass in g	Load F in N	Beam Deflection δ in mm
0	0	0	0	0	0
80	0.08	0.0005	200	2.0	
140	0.14	0.003	180	1.8	
200	0.20	0.008	140	1.4	
260	0.26	0.0176	100	1.0	
300	0.30	0.027	60	0.6	

Graph of deflection δ vs L^3:



What are the likely sources of error? ....

....

....

Worksheet 6 - Two loads

Load F in N	Distance a from support in m	Beam Deflection δ in mm	Beam Deflection δ in m	Theoretical Beam Deflection δ in mm
2	0.04			
2	0.08			
2	0.12			

Compare the measured results with the calculated results:

....

....

....

....

....

What are the likely sources of error?

....

....

....

....

Chapter 2 - Torsion of Rods

Worksheet 1 - Torque

Specimen 1:

Diameter of rod, **d** ....mm = ...m
Length of rod between collets, **L** ....mm = ...m

Load			**Applied torque in N.m**	**Twist angle θ**		**Calculated twist angle θ in radians**
in g	in kg	F in N		in degrees	in radians	
0	0	0	0	0	0	0
20	0.02	0.2				
80	0.08	0.8				
140	0.14	1.4				
200	0.20	2.0				
260	0.26	2.6				
320	0.32	3.2				
380	0.38	3.8				

Table 1

Specimen 2:

Diameter of rod, **d** ....mm = ...m
Length of rod between collets, **L** ....mm = ...m

Load			**Applied torque in N.m**	**Twist angle θ**		**Calculated twist angle θ in radians**
in g	in kg	F in N		in degrees	in radians	
0	0	0	0	0	0	0
20	0.02	0.2				
80	0.08	0.8				
140	0.14	1.4				
200	0.20	2.0				
260	0.26	2.6				
320	0.32	3.2				
380	0.38	3.8				

Table 2

Student Handout

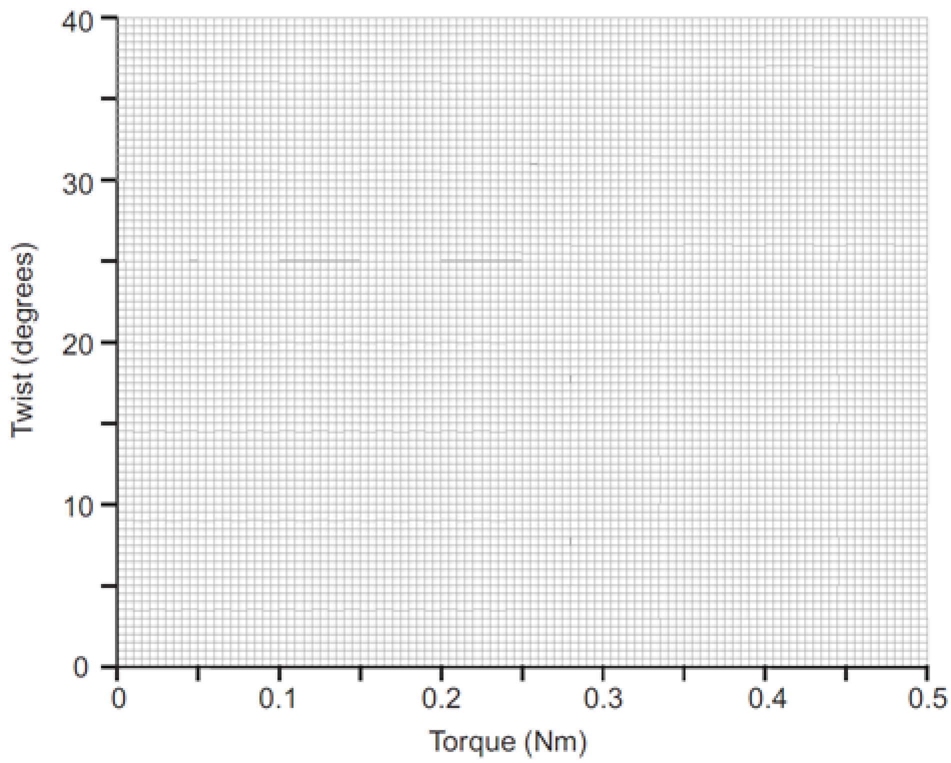
Worksheet 1 - Torque continued...

Useful formulae:

- To convert from degrees to radians:
  angle in radians = angle in degrees x 0.0175
- Applied torque **T** = **F** x **r** where **F** = load in N;
  r = radius of 'twist meter' disc = 0.005m
- Polar second moment of area $\mathbf{J} = \frac{\pi \times \mathbf{d}^4}{32}$
- Twist angle, $\theta = \frac{\mathbf{T} \times \mathbf{L}}{\mathbf{J} \times \mathbf{G}}$ where **G** = modulus of rigidity = 38GPa (for brass)

Graph of twist angle vs torque:

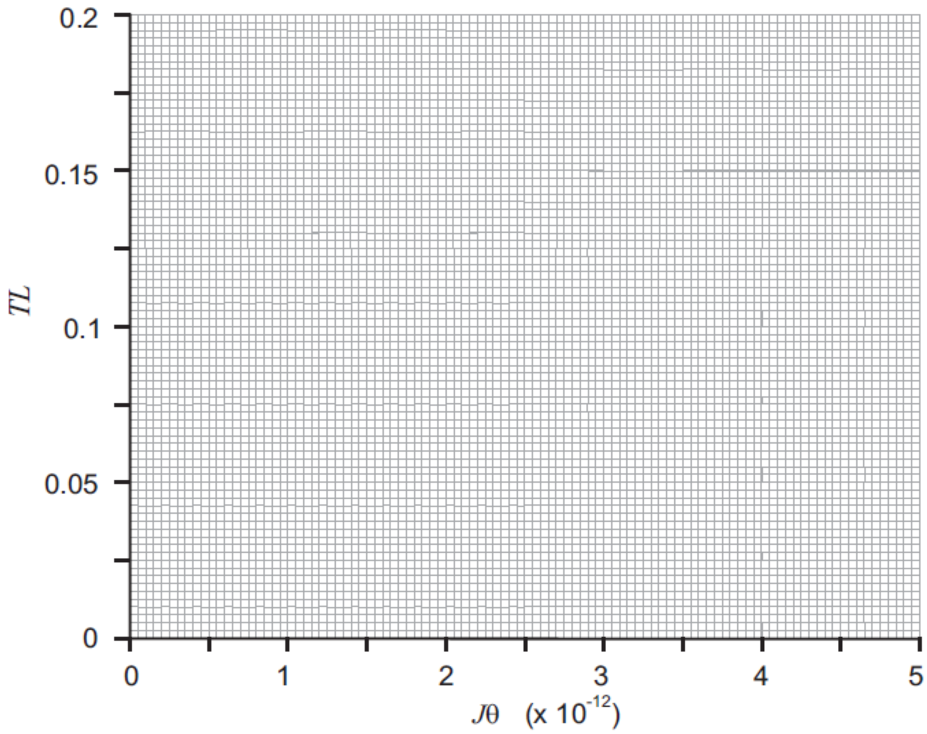
Use the axes provided below.
Show your measurements as small crosses.
Your results should suggest a straight-line relationship.



Worksheet 2 - Material continued...

Graph of (T x L) vs (J x θ):

Use the axes provided below. Show your measurements as small crosses.
Draw a separate straight-line graph for each material using these results.
Calculate the gradient of each and use it to populate the table below the graph.



Material	Modulus of rigidity in Pa x 10^9
Brass	
Steel	
Aluminium	

Student Handout

Worksheet 3 - Length

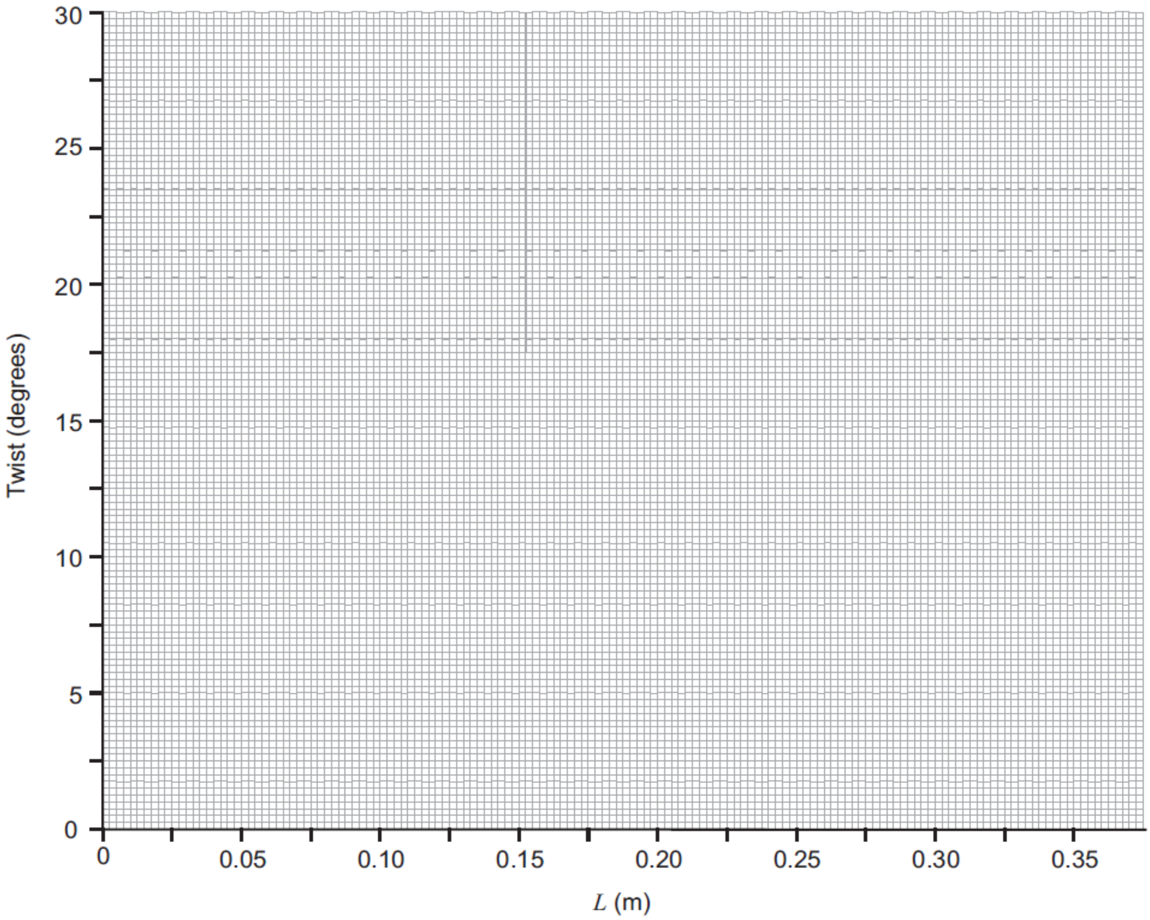
Load in g	Length of rod, L, in mm	Twist angle θ in degrees
400	100	
400	140	
400	180	
400	220	
400	260	

Graph of θ vs L:

Use the axes provided below. Show your measurements as small crosses.

Your results should suggest a straight line relationship.

Draw the 'best-fit' straight-line graph using these results.



Student Handout

Fundamental MECHANICS

Worksheet 1 - Tensile stress and strain

Aluminium 6082:

Rotation of torsion control, N in degrees	Movement p of top of sample in mm	Applied force F in N	Dial gauge reading q in mm	Extension e (= p - q) in mm
0	0	0	0	0

Worksheet 1 - Tensile stress and strain

Aluminium 6082:

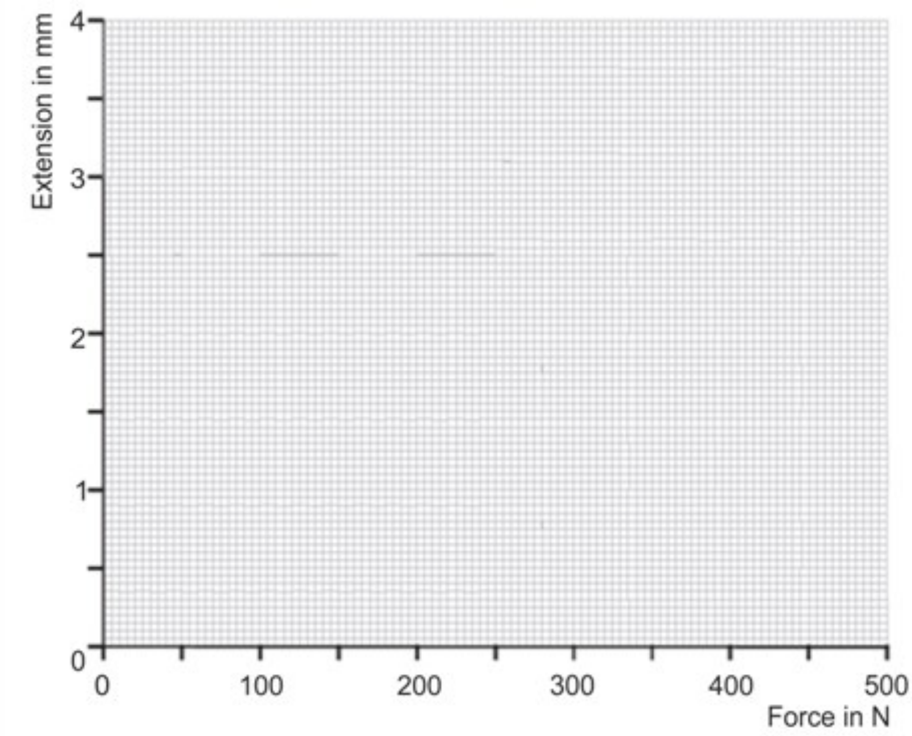
Graph of applied force vs extension:

When the torsion control handle rotates through 1 revolution (360^0), the top of the sample rises by 1mm.
In rotating through $\mathbf{N}^0$, the top of the sample rises by distance **p** = **N** / 360 mm.

In doing so, the spring is compressed by the amount **q** shown on the dial gauge.
Hence it exerts a force **F** given by **F** = **q** x **k** where **k** = spring constant = 105N.mm^{-1}.

The extension of the sample, **e**, is given by **e** = **L** - $\mathbf{L_0}$ = (**p** - **q**)

Use the axes provided below to draw a graph of extension **e** vs applied force **F**.
Show your measurements as small crosses and draw a smooth curve, using them as a guide.



Fundamental MECHANICS

Worksheet 1 - Tensile stress and strain

Aluminium 1050:

Rotation of torsion control in degrees	Movement ‘p’ of top of sample in mm	Applied force F in N	Dial gauge reading ‘q’ in mm	Extension ‘e’ (= p - q) in mm
0	0	0	0	0

Student Handout

Worksheet 1 - Tensile stress and strain

Aluminium 1050:

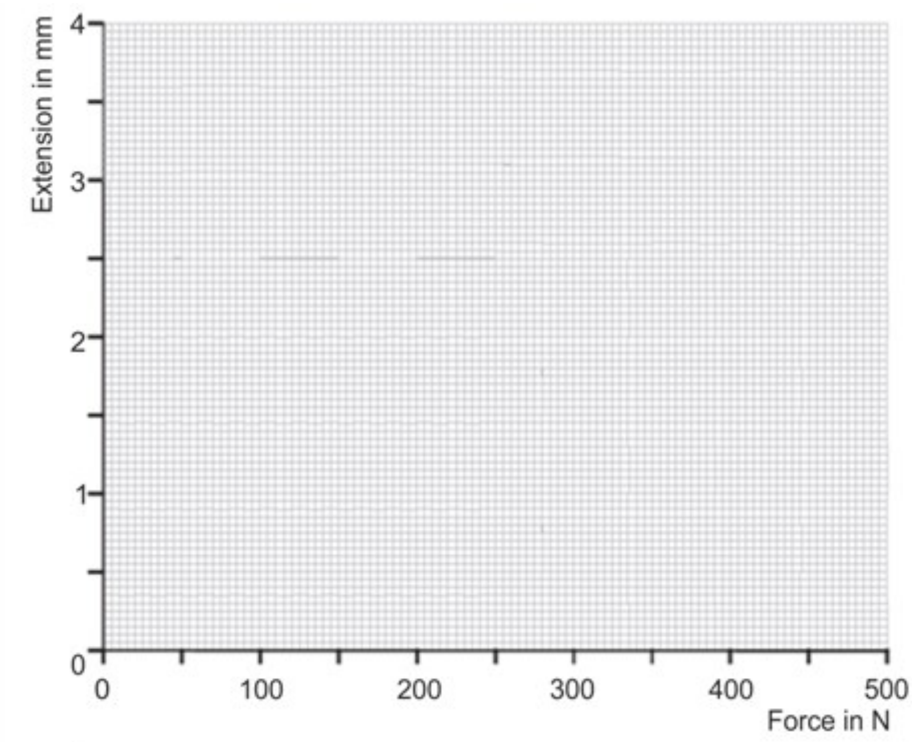
Graph of applied force vs extension:

When the torsion control handle rotates through 1 revolution (360^0), the top of the sample rises by 1mm.
In rotating through $\mathbf{N}^0$, the top of the sample rises by distance **p** = **N** / 360 mm.

In doing so, the spring is compressed by the amount **q** shown on the dial gauge.
Hence it exerts a force **F** given by **F** = **q** x **k** where **k** = spring constant = $105 N.mm^{-1}$.

The extension of the sample, **e**, is given by **e** = **L** - $\mathbf{L_0}$ = (**p** - **q**)

Use the axes provided below to draw a graph of extension **e** vs applied force **F**.
Show your measurements as small crosses and draw a smooth curve, using them as a guide.



Student Handout

Worksheet 1 - Tensile stress and strain

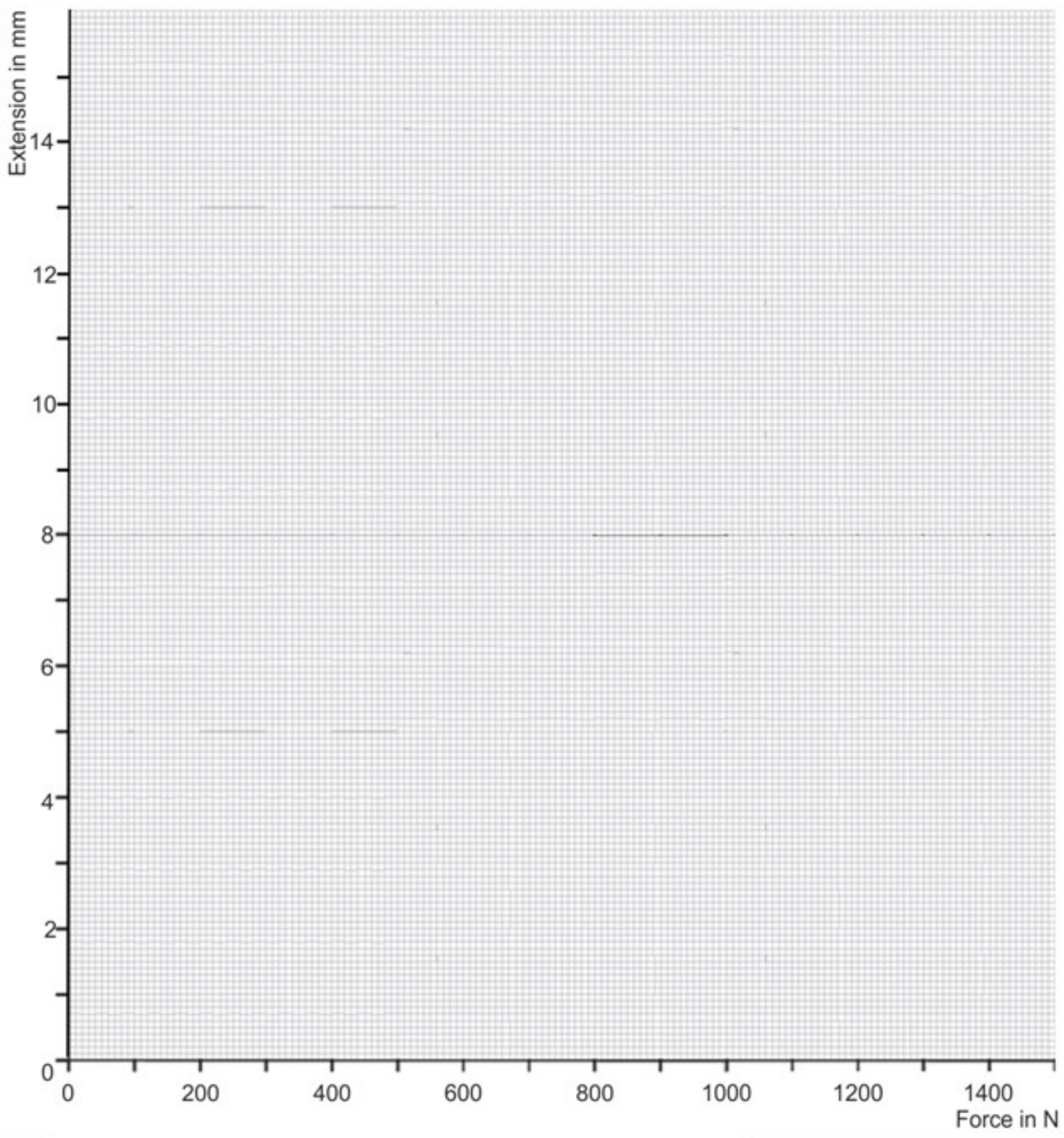
Rotation of torsion control in degrees	Movement ‘p’ of top of sample in mm	Applied force F in N	Dial gauge reading ‘q’ in mm	Extension ‘e’ (= p - q) in mm
0	0	0	0	0

Worksheet 1 - Tensile stress and strain

Steel:

Graph of applied force vs extension:

Use the axes provided below to draw a graph of extension e vs applied force **F**.
Show your measurements as small crosses and draw a smooth curve, using them as a guide.



Fundamental MECHANICS

Worksheet 1 - Tensile stress and strain

ABS plastic:

Rotation of torsion control in degrees	Movement 'p' of top of sample in mm	Applied force F in N	Dial gauge reading 'q' in mm	Extension 'e' (= p - q) in mm
0	0	0	0	0

Worksheet 1 - Tensile stress and strain

ABS plastic:

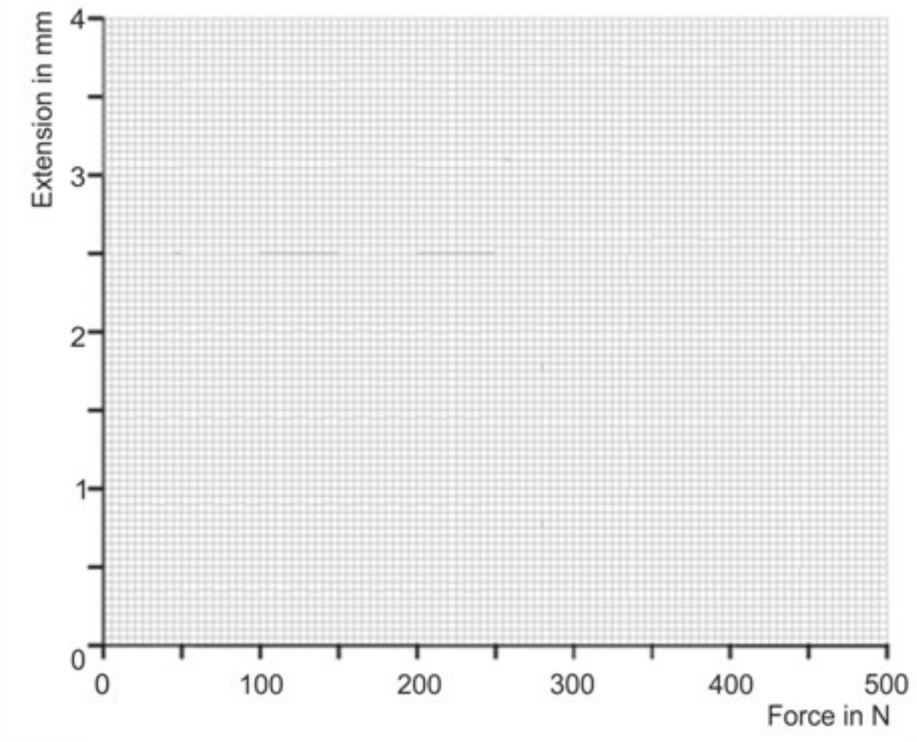
Graph of applied force vs extension:

When the torsion control handle rotates through 1 revolution (360^0), the top of the sample rises by 1mm.
In rotating through $\mathbf{N}^0$, the top of the sample rises by distance **p** = **N** / 360 mm.

In doing so, the spring is compressed by the amount **q** shown on the dial gauge.
Hence it exerts a force **F** given by **F** = **q** x **k** where **k** = spring constant = $105N.mm^{-1}$.

The extension of the sample, **e**, is given by **e** = **L** - $\mathbf{L_0}$ = (**p** - **q**)

Use the axes provided below to draw a graph of extension **e** vs applied force **F**.
Show your measurements as small crosses and draw a smooth curve, using them as a guide.



Student Handout

Worksheet 2 - Shear stress

Aluminium wire:

Rotation of torsion con-trol in degrees	Movement 'p' of upper chuck in mm	Applied force F in N	Force f = F / 2 in N	Dial gauge reading 'q' in mm	Extension 'e' (= p - q) in mm
0	0	0	0	0	0

Student Handout

Worksheet 2 - Shear stress

Aluminium wire:

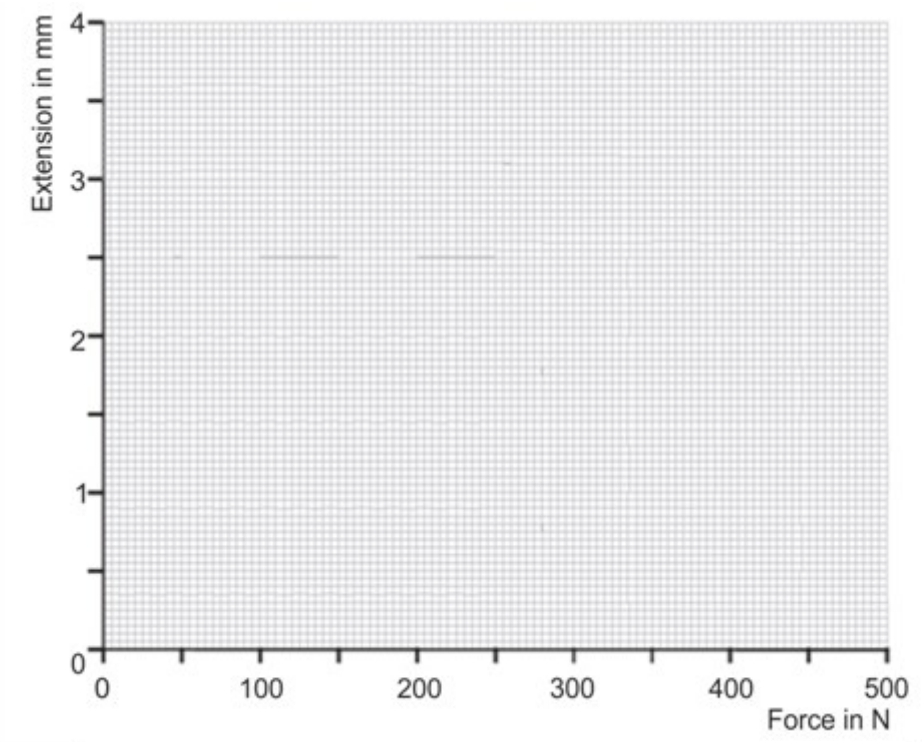
Graph of applied force vs extension:

When the torsion control handle rotates through 1 revolution (360^0), the top of the sample rises by 1mm.
In rotating through $\mathbf{N}^0$, the upper chuck rises by distance **p** = **N** / 360 mm.

In doing so, the spring is compressed by the amount **q** shown on the dial gauge.
Hence it exerts a force **F** given by **F** = **q** x **k** where **k** = spring constant = 105N.mm^{-1}.
This force is shared by the two arms of the lower chuck.
The force experienced by each, **f** = **F** / 2.

The extension of the sample, **e**, is given by **e** = **L** - $\mathbf{L_0}$ = (**p** - **q**)

Use the axes provided below to draw a graph of extension **e** vs component force **f**.
Show your measurements as small crosses and draw a smooth curve, using them as a guide.



Student Handout

Worksheet 2 - Shear stress

Copper wire:

Rotation of torsion con-trol in degrees	Movement ‘p’ of upper chuck in mm	Applied force F in N	Force f = F / 2 in N	Dial gauge reading ‘q’ in mm	Extension ‘e’ (= p - q) in mm
0	0	0	0	0	0

Student Handout

Worksheet 2 - Shear stress

Copper wire

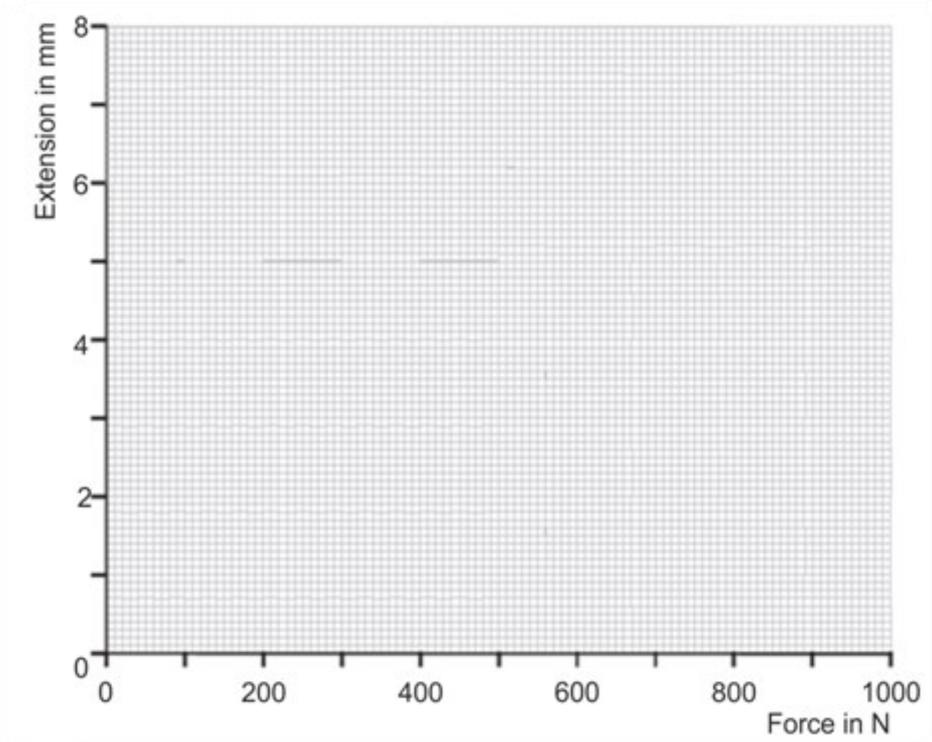
Graph of applied force vs extension:

When the torsion control handle rotates through 1 revolution (360^0), the top of the sample rises by 1mm.
In rotating through $\mathbf{N}^0$, the upper chuck rises by distance **p** = **N** / 360 mm.

In doing so, the spring is compressed by the amount **q** shown on the dial gauge.
Hence it exerts a force **F** given by **F** = **q** x **k** where **k** = spring constant = 105N.mm^{-1}.
This force is shared by the two arms of the lower chuck.
The force experienced by each, **f** = **F** / 2.

The extension of the sample, **e**, is given by **e** = **L** - $\mathbf{L_0}$ = (**p** - **q**)

Use the axes provided below to draw a graph of extension **e** vs component force **f**.
Show your measurements as small crosses and draw a smooth curve, using them as a guide.



Notes
for the
Instructor

Notes for the instructor

About this course

Introduction

The ‘Fundamental Mechanics - Materials’ module introduces students to the relationship between the applied force and resulting elongation, deflection, rigidity, and material properties of a number of common engineering materials.

The kit can assembled by the students and used with minimum supervision to complete a series of worksheets that illustrate a number of topics relating to torsion for BTEC National and Higher National courses.

Aim

The course teaches students to investigate the effects of types of supports, beam geometry and material on deflection. Torque and torsion and the factors that effect this for a variety of metal rods. Tensile and shear stress on a number of common engineering materials.

Prior Knowledge

It is expected that students have followed an introductory science course, enabling them to take, record and analyse scientific observations. Some mathematical capability is required - ability to take readings from an analogue scale, ability to understand the transposition of formulae, ability to use a calculator to perform calculations and ability to plot a graph.

Using this course:

It is expected that the Worksheets and Student Handout are printed / photocopied, preferably in colour, for the students’ use.

The worksheets have:

- an introduction to the topic under investigation;
- step-by-step instructions for the investigation that follows
- a guide to analysing the results.

The Student Handout is a record of measurements taken in each worksheet and questions relating to them. Students do not need a permanent copy of the worksheets but do require their own copy of the Student Handout

This format encourages self-study, with students working at a rate that suits their ability. It is for the instructor to monitor that their understanding is keeping pace with progress through the worksheets. One way to do this is to ‘sign off’ each worksheet, as the student completes it, and in the process have a brief chat to assess the student’s grasp of the ideas involved in the exercises it contains.

We realise that you as a subject area practitioner are the lead in determining how and what students learn. The worksheets are not meant to supplant this or any other supporting underpinning knowledge you choose to deliver.

For subject experts, the ’Notes for Instructors’ are provided simply to reveal the thinking behind the approach taken. For staff whose core subject knowledge is not in the field covered by the course, these notes can both illuminate and offer guidance.

Time:

It will take students between ten and fifteen hours to complete the worksheets.
A similar length of time will be needed to support the learning that takes place as a result.

Notes for the instructor

What the student will need:

To complete the course, the student will need the following equipment:

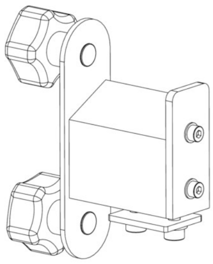
Bom Structure	Description	Quantity
FM2522	Work Panel for Fundamentals	1
FM3522	Strain Head Assembly	1
FM3026	Torsion Fixed End Assembly	1
FM2915	Hanging Weights	2
FM8292	Magnetic Bracket Assembly	1
FM1873	LH Multi Support Assembly for FM1292	1
FM1978	RH Multi Support Assembly for FM1292	1
FM2222	Balance Slider Plate Assembly	1
FM6021	Tensile Tster Assembly	1
MET1899	Steel tensile specimen	10
MET1944	Aluminium 60/82 tensile specimen	10
LAS1847	Plastic tensile specimen for FM1292	10
MET8271	Shear test tongue for FM1292	1
MET1497	Shear Chuck for FM1292	1
WIR1944-00	Aluminium wire 0.8mm diameter - 500mm length	3
WIR1349-00	Copper wire 1.5mm diameter - 500mm length	3
COM1499	Brass test beam 1 - 350mm x 1/2in x 1/8in Flat bar	1
COM9677	Aluminium test beam 2 - 350mm ½" x 1/8" flat bar	1
COM2588	Mild steel test beam 5 - 350mm x1/2in x 1/8in flat bar	1
MET9478	Knife edge hanger small for FM1292	2
COM8497	Stainless steel round bar 1/8in diam. - 300mm	1
COM6913	Aluminium round bar 1/8in diam. - 300mm	1
COM2846	Brass round bar 1/8in diam. - 300mm	1
HP8600	Crash Foam 360mm x 260mm, thickness 25mm	3
MET1376	Aluminium tensile specimen 1050	10
COM9855	Aluminium test beam 350mm 5/8"x1/8" 15.8mm x 3.2mm flat bar	1
COM2931	Hex allen key 5mm short arm 80mm long	1
COM2571	Hex allen key 3mm short arm 63mm long	1
COM9822	Aluminium test beam 350mm x ½" x ¼" 12.7mm x 3.2mm 6082T6	1
COM8574	Stainless steel test beam 3 - 350mm x 12mm x 3mm flat bar	1
COM4635	Mitutoyo dial indicator	1
FM2666	5g hanging weights pack of 5	2
COM1701	Brass round bar 2mm - 350mm in length for FM1292	1

Notes for the instructor

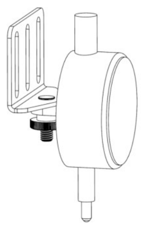
What the student will need, worksheet by worksheet:

Worksheet	Item
1, 2, 3	work panel
	Two multi support assembly
	Dial indicator bracket
	Knife edge hanger
	mass hanger
	Beam test samples

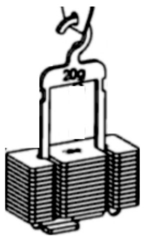
Identity parade:



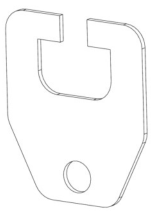
strain head assembly



torsion fixed end assembly



mass hanger



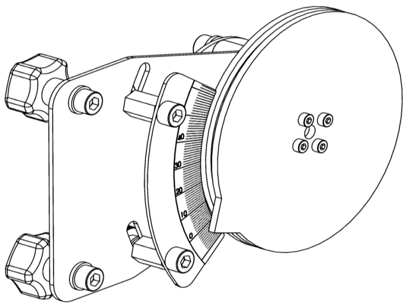
Knife edge hanger

Notes for the instructor

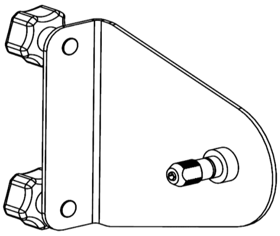
What the student will need, worksheet by worksheet:

Worksheet	Item
1, 2, 3	work panel
	strain head assembly
	torsion fixed end assembly
	mass hanger
	torsion test samples

Identity parade:



strain head assembly



torsion fixed end assembly

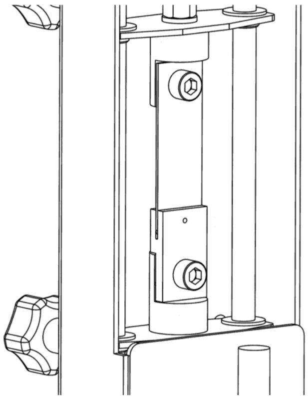
mass hanger

Notes for the instructor

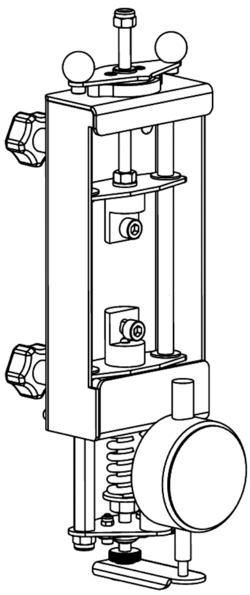
What the student will need, worksheet by worksheet:

Worksheet	Item
1	work panel
	tensile tester assembly
	tensile tester guard
	dial gauge
	dial plate
	tensile test samples
2	work panel
	tensile tester assembly
	tensile tester guard
	shear test chuck and tongue
	dial gauge
	dial plate
	wire test samples

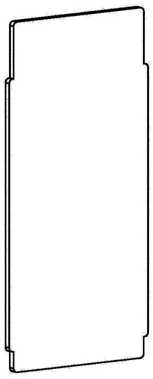
Identity parade:



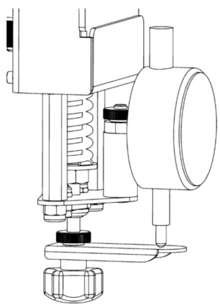
tensile tester with shear test chuck and tongue



tensile tester assembly



tensile tester guard



dial gauge and plate

Notes for the instructor

Learning Objectives for Chapter 1

On successful completion of this course, the student will be able to:

- distinguish between the following types of support:
    - simple;
    - fixed;
    - cantilever;
    - propped cantilever.
- explain the meaning of the term Young's modulus;
- use vernier callipers to measure the dimensions of a metal bar;
- use the formula 'deflection δ = **F**x$\mathbf{L}^3$ **/** 48x**E**x**I'** to explain why the graph of δ vs **F** should be linear;
- explain why errors in measuring L will have a significant effect on the the graph of δ vs **F**;
- outline three ways in which Young's modulus can be obtained from the graph of δ vs **F;**
- re-arrange the formula 'deflection δ = **F**x$\mathbf{L}^3$ **/** 48x**E**x**I'** so that the subject of the formula is load **F;**
- explain in qualitative terms the way in which the profile of a beam affects its rigidity;
- perform an experiment to compare the rigidity of beams of the same metal having different profiles;
- explain why the depth of the beam is more significant than its width in determining its rigidity;
- explain the significance of the constant **K** in the general formula for the deflection of a beam loaded at its centre;
- use a graph of deflection δ vs (**F** x $\mathbf{L}^3$ / **E** x **I**) to obtain **K** for a given type of support;
- give three examples of common structures that use a cantilever beam;
- give the significance of the result that a graph of deflection δ vs $\mathbf{L}^3$ is linear;
- use the equation 'δ = **F** x **a** x (3$\mathbf{L}^2$ - 4$\mathbf{a}^2$) / 24 x **E** x **I**' to calculate the maximum deflection at the centre of a beam subjected to two equally spaced point loads;
- describe one example of the use of such a beam.

Notes for the instructor

Learning Objectives for Chapter 2

On successful completion of this course, the student will be able to:

- explain the meaning of and distinguish between the terms *torque* and *torsion*;
- state the SI units of:
    - torque,
    - polar second moment of area,
    - modulus of rigidity.
- convert a mass expressed in grams to kilograms;
- calculate the weight of a given mass given the local gravitational field strength;
- use vernier callipers to measure the diameter of a metal rod;
- convert angles measured in degrees into radians;
- calculate the torque exerted by a given force at a given distance from an axis of rotation;
- calculate the polar second moment of area for a rod of given diameter;
- understand the meaning of the multiplier 'giga';
- calculate the theoretical twist angle for a rod, given the torque, polar second moment of area, length and modulus of rigidity of the material;
- explain why a change in the diameter of the rod has such a large effect on the twist angle produced by a given torque;
- recognise that an equation of the form 'y = m.x + c' will generate a straight line when the 'y' variable is plotted against the 'x' variable;
- calculate the gradient of a straight line graph in order to determine the modulus of rigidity of a specimen;
- explain what is meant by the elastic behaviour;
- describe the relationship between the length of a rod and the twist angle produced by a given torque;

Notes for the instructor

Learning Objectives for Chapter 3

On successful completion of this course, the student will be able to:

- define the terms tensile stress and tensile strain;
- distinguish between elastic and plastic behaviour when a material stretches;
- understand what is meant by ‘zero error’ in a measuring instrument and be able to allow for it when taking readings;
- use the value of spring constant to calculate the force exerted by a compressed spring;
- explain what is meant by the terms:
  - yield strength;
  - ultimate strength;
  - fracture;

  and recognise these on a graph of applied force vs extension;
- define Young’s modulus;
- give two reasons why this equipment is unsuitable for obtaining accurate values for Young’s modulus;
- explain what is meant by the terms strain hardening and necking and identify the regions where these occur on a graph of applied force vs extension;
- distinguish between the terms ‘ductile’ and ‘brittle’;
- distinguish between tensile stress and shear stress;
- process measurements and plot a graph of applied force vs extension, given results similar to those obtained in these investigations.

Notes for the instructor

Fundamental MECHANICS

Chapter 1	Notes
Worksheet 1 Changing the load Timing 20 - 30 mins	Concepts involved: simple support elastic behaviour weight mass gravitational field strength linear relationship reading an analogue scale Throughout this module, the instructor may wish to encourage the use of a spreadsheet to record and process the measurements. When setting up the equipment, initial adjustment of the dial gauge can be a delicate operation. The first step is to ensure that the small millimetre dial is set to zero. The large dial zero can be adjusted by rotating the outer rim of the gauge. Alternatively, students can be told to note any remaining 'zero error' and shown how to take this into account in later readings. Students may need an introduction to the use of vernier callipers to enable them to measure beam dimensions. Depending on their mathematical ability an experience, the students may need help in transposing formulae and also with the standard equation for a straight-line graph.
Worksheet 2 The material matters Timing 40 - 60 mins	There are no new concepts involved here. The practical work mirrors that in the previous investigation but uses brass and steel beams instead of aluminium. The main issue is the way in which the results are processed. The worksheet lists three options. The instructor could delegate different options to different groups. The second option lends itself to processing by spreadsheet, if students have the ability to do so. The third option needs an understanding of proportionality and may require support from the instructor.
Worksheet 3 Profile matters Timing 30 - 50 mins	Concepts involved: area moment of inertia The techniques are the same as those used in previous practical work. The area moment of inertia depends on the profile of the beam and so can vary for the same beam depending on how it is used. The instructor may wish to reinforce the point made about the significance of the depth of the beam. This is a good point for a discussion about reading errors.
Worksheet 4 Supports matter Timing 40 - 60 mins	Concepts involved: fixed supports propped cantilever supports This is an appropriate point at which to compare different types of support and the degrees of freedom and reaction forces they offer. The beam used is called 'beam 1' in the previous investigation. The numerical value in the denominator of the deflection formula depends on the type of support used, but can be obtained from a graph, as described here.

Notes for the instructor

	Notes
Worksheet 5 The cantilever Timing 30 - 50 mins	Concepts involved: cantilevers The method is the same as that in earlier worksheets. The time-consuming aspect is the need to re-attach and zero the dial gauge each time. The instructor may wish to highlight the need to reduce the load as the distance increases. The conclusion about the relationship between deflection and length could give rise to a class project.
Worksheet 6 Two loads Timing 20 - 40 mins	This investigation takes the student to a common situation where there is more than one load acting on the beam. It introduces a more complex formula which might pose difficulties for the less able mathematically. Once again, it provides a scenario in which to discuss errors and their significance.

Notes for the instructor

Chapter 2	Notes
Worksheet 1 Torque Timing 40 - 60 mins	Concepts involved: torque torsion degrees radians modulus of rigidity elasticity polar second moment of area Some students may need reminding about the difference between mass and weight, and the use of gravitational field strength. Instructors may need to demonstrate the use of vernier callipers. It could prompt a discussion about measurement errors, since the callipers have a typical accuracy of a fraction of a millimetre - far more sensitive than the instruments used for the other measurements.
Worksheet 2 Material Timing 30 - 50 mins	Concepts involved: equation for a straight line relationship (y = m.x + c) This is another exercise involving the same concepts as in worksheet 1. This time, the rods are made of different materials. Depending on their previous mathematical experience, some students may not feel happy about the algebraic juggling of the twist angle formula and its comparison to the general formula for a straight line relationship. Some support may be needed. Typical values for the modulus of rigidity in GPa are: brass 38 steel 80 aluminium 26.
Worksheet 3 Length Timing 40 - 60 mins	Concepts involved: proportionality best-fit straight line graph This is yet another exercise involving the same concepts as in worksheet 1. This time, the length of the rod is changed to see what effect it has on torsion. Depending on their previous mathematical experience, some students may need help with the notion of ‘directly proportional’. It may be appropriate to revisit the topic of measurement errors as the results are unlikely to lie perfectly on a straight line. It is certainly not appropriate to ‘join the dots up’!

Notes for the instructor

Fundamental MECHANICS

Chapter 3	Notes
Introduction Timing 20 - 30 mins	The diagram shows the final structure of the kit. Students need to assemble it in such a way that the 'torsion control' handle can rotate freely above the work panel. The kit comes with four types of sample for worksheet 1, distinguished by the slots cut into them or the colour (in the case of the ABS sample. Their dimensions are very similar. The instructor should stress the importance of the safety screen in the investigation. Setting the dial gauge to zero initially is a delicate operation. It is important that the small millimetre dial is set to zero. The large dial can be adjusted to zero by rotating the outer rim of the gauge. Alternatively, students can be told to note any remaining 'zero error' and shown how to take this into account in later readings.
Worksheet 1 Tensile stress Timing 40 - 60 mins	Concepts involved: elastic behaviour, plastic behaviour, tensile stress, tensile strain spring constant, yield point, fracture, strain hardening necking, ductile, brittle, Young's modulus In both this worksheet and the next, the instructor may wish to use a spreadsheet program such as 'Excel' to record the results and use them to generate a graph. The Student Handout offers the manual alternative to this. Depending on the ability of the students, it may be necessary to work through the process given on page 6 for extracting extension and applied force from the readings. It is important that the students recognise and realise the significance of the features shown in the graph on page 7 and relate them to the graphs that they produce for the four materials. This could be followed by a research task and classroom discussion on the significance of these features in engineering design.
Worksheet 2 Shear stress Timing 40 - 60 mins	Concepts involved: shear stress, shear strain, clevis and pin In setting up the apparatus, it may be necessary to bend over the end of the wire sample so that the safety screen can be put in place. The results are processed in similar fashion to those in the worksheet 1 and lead to force / extension graphs as before. Again, the instructor might wish to use a spreadsheet to do this. As the set-up involves a double shearing, at both places where the wire sample goes through the shear chuck, the applied force is divided into two equal components.