STRUCTURES

Torsion of rods

CP8231
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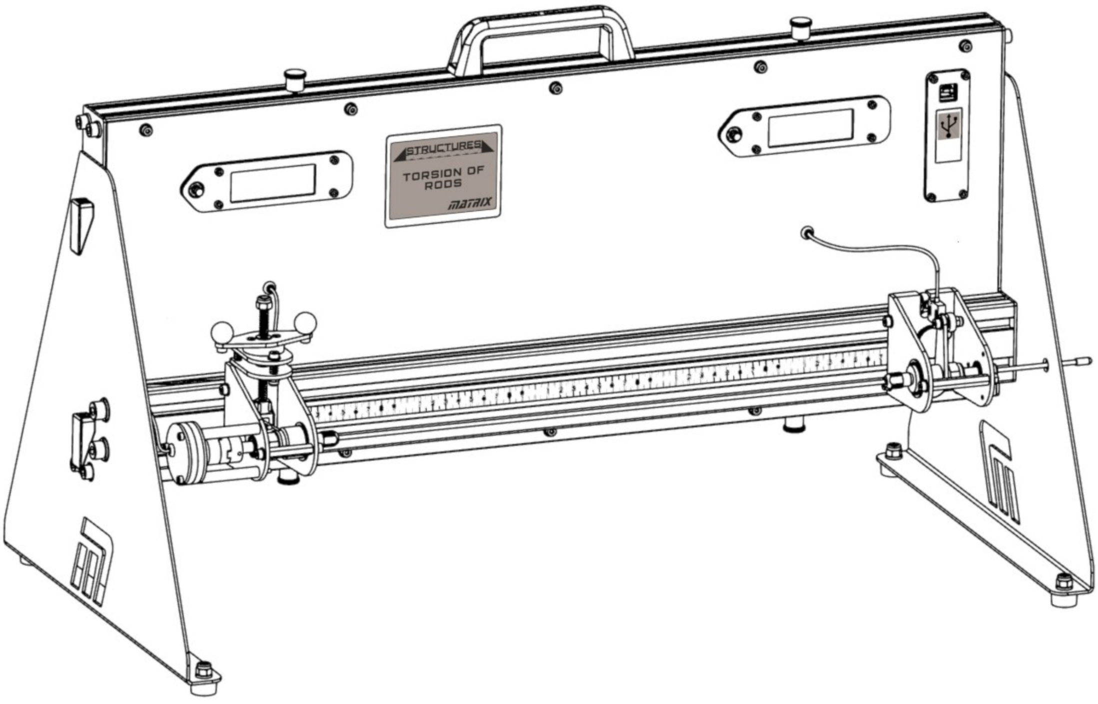
Contents

STRUCTURES

Torsion of rods

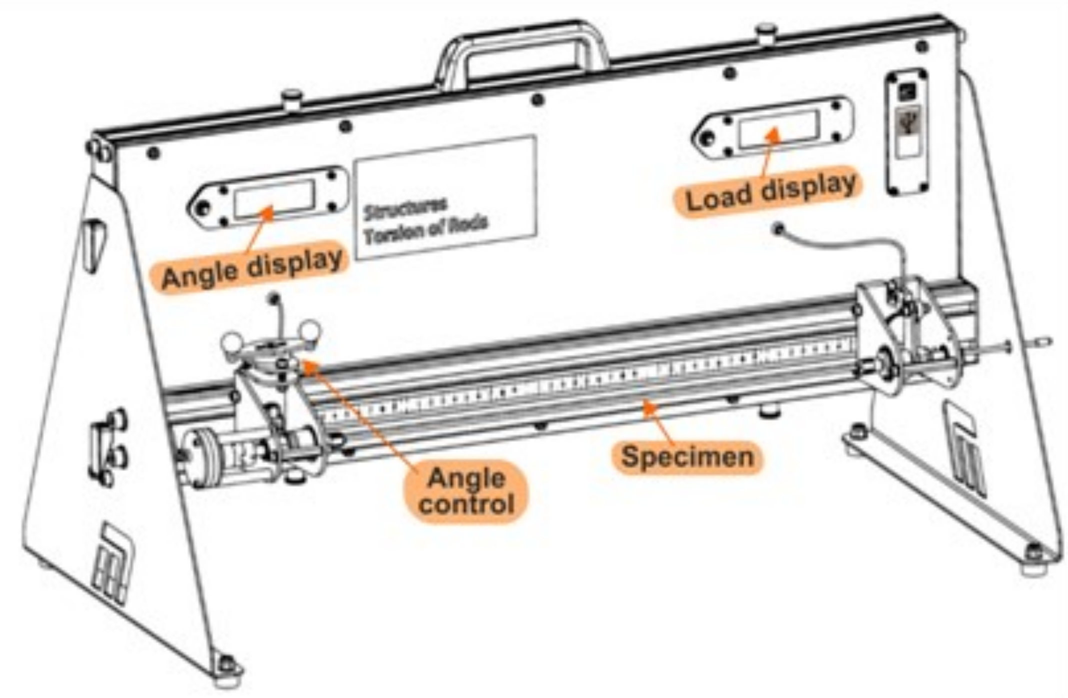
Introduction:



Introduction:

The equipment allows the user to measure the torsion resulting from twisting one end of a metal rod.

The investigations detailed in this module look at the effect of changing the **diameter** of the rod, changing the **metal** from which it is made and changing its **length**.



Turning the angle-control handle lowers the threaded bar and rotates the collet gripping the left-hand end of the rod. One full turn lowers it the bar by 1mm, causing the end of the rod to rotate by around 1.6^0.

This also turns the spindle of a potentiometer attached to the end bracket. The signal from this potentiometer determines the angle displayed on the left-hand LCD.

The force transmitted to the other end of the specimen is sensed by a load cell within the right-hand bracket. The load cell signal is converted into a force reading, displayed on the right-hand LCD.

The apparatus is designed to work off 5v power supply. This means that a USB cable plugged into either a computer or a plug will be sufficient. The data acquisition software only works through the computer, therefore the recommended setup is to have the USB plugged into the computer which is running the software. However, if you'd like to run the experiment without the software, a USB plug will need to be sourced for the correct local plug style.

Worksheet 1

Torque and diameter

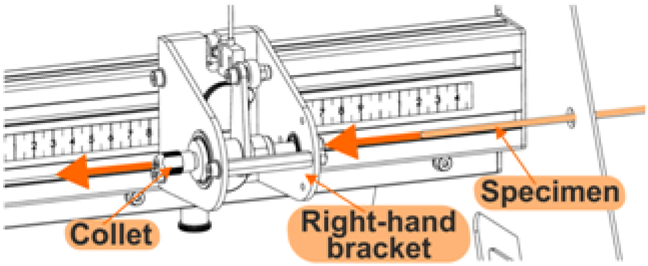
Many engineering applications use shafts to transfer energy, via torque, from one part of the system to another. One such application is the drive shaft in a vehicle.

It is important that this shaft remains undistorted when torque is applied. One property of interest here is the *polar second moment of area*, (also called *polar moment of inertia*), which depends on how mass in the object is distributed relative to a particular axis. The bigger this is, the more rigid the shaft. It is logical, then, to suspect that the diameter of a rod will affect its rigidity.

The first investigation looks for such a connection. It compares the behaviour of two rods of the same material, having the same length but with different diameters.

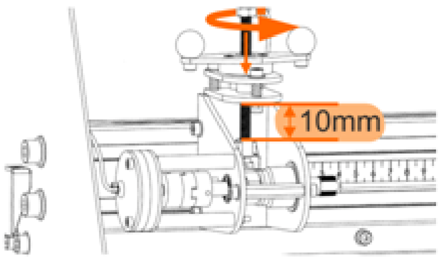
Over to you:

- Select the smaller of the two brass rods and measure its diameter using vernier callipers.
- Record the measurement in the Student Handout.



- Find the two collets that match the diameter of the rod.
- Slide the rod through the hole in the end plate of the equipment.
- Place the collets (and chucks) over the rod, facing in opposite directions. Attach the right-hand one loosely.
- Rotate the angle-control handle until the top of the clevis is around 10mm below the preload plates, as shown in the diagram.

  Going closer risks too much friction, preventing accurate results!



This is the starting position for all three experiments.

Worksheet 1
Torque and diameter

Over to you .....

- Now, fully tighten the collets - the one on the left-hand bracket first.

  While tightening the one on the right-hand bracket, hold the strain gauge to oppose the force, in order to protect the load cell.

  Don't let the load LCD reading go higher than 4000g or so, or it may be damaged !

- Turn the angle-control handle anticlockwise by one turn to eliminate any backlash.
- Now 'zero' both LCDs by pressing the push buttons next to the LCD screen.

- Measure the distance between the collets, i.e. the length, **L**, over which twisting occurs.
- Record this distance in the Student Handout.

- Rotate the angle-control handle in increments of half a turn until the angle shown on the LCD reaches 20^0 or so.

  The LCD screen turn green once the measurement has stabilised.

  Do not twist the rod much further than 20^0 as this may cause plastic deformation of the rod, leaving it permanently deformed.

- For each increment, record the twist angle and load cell readings, either directly into the table in the Student Handout or via the USB port directly to a spreadsheet.

  (The load LCD output is displayed in grammes. It needs to be converted into the corresponding force in newtons. The twist angle θ is given in degrees on the left-hand LCD. It needs to be converted into radians.

  Guidance on both conversions is given in the Student Handout.)

Worksheet 1
Torque and diameter

Over to you .....

- Repeat the experiment with the larger diameter rod of the same material.
- The Student Handout shows how to calculate the applied torque, **T**, for each applied force and the polar second moment of area, **J**, for each rod.
- Complete all columns in the table.
- Plot graphs of (**T** x **L**) against (**J** x θ) for both rods on the same graph, using the axes provided in the Student Handout. Add labels indicating your chosen scales.

Challenge:

In the Student Handout, use the relationship

$$\theta = \frac{T \times L}{J \times G} \qquad \text{where} \qquad G = \text{modulus of rigidity}$$

to explain why the graph of (**T** x **L**) against (**J** x θ) should be linear.

So what:

There is only a small change in diameter between the two rods. However, this has a large effect on the twist angle caused by a given torque.

This is because the twist angle depends directly (inversely) on the polar second moment of area. This however depends on the 4^{th} power of the diameter of the rod. Hence a small change in diameter makes a large difference in twist angle.

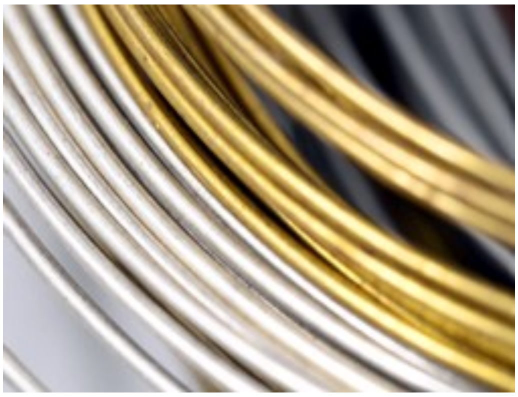
Worksheet 2

Torque and material

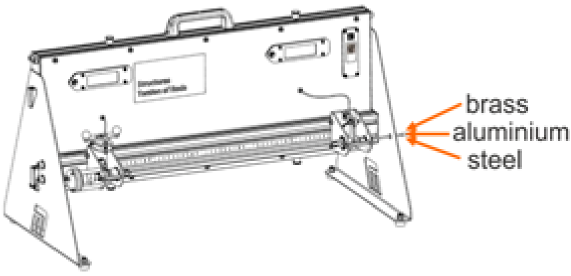
The properties of metals depend on the behaviour of the electrons in them.

The electrons are repelled by other electrons nearby and attracted to the positively-charged particles in the nuclei of atoms.

Their macroscopic properties, such as hardness, ductility and shear strength, depend on the number and distribution of the electrons inside them



This experiment compares the effects of three different materials on the twist angles produced by different torques.



Over to you:

- Select the three rods, of brass, aluminium and steel, that have the same diameter.
- Measure the diameter of each using vernier callipers.
- Record the measurement in the Student Handout.
- In the Student Handout, calculate the polar second moment of area, **J**, for each rod.
- For each material:
    - Insert the rod into the 'Torsion of Rods' apparatus and measure the distance, **L**, between the collets. Record it in the Student Handout.
    - Use the same procedure as in worksheet 1 to measure the torque needed to produce twist angles ranging from 0^0 to 20^0.
    - Record your measurements either directly into the table in the Student Handout or via the USB port directly to a spreadsheet.
    - Complete all columns in the table.
    - Plot linear graphs of (**T** x **L**) against (**J** x θ) for all three materials on the same axes, in the Student Handout, adding suitable scales.

Worksheet 2
Torque and material

Over to you .....

- The formula for the twist angle θ can be re-arranged to give:

modulus of rigidity $$G = \frac{T \times L}{J \times \theta}$$

Measure the gradients of the graphs.

These give estimates of the modulus of rigidity for the materials.

Enter the values in the table in the Student Handout.

So what:

The modulus of rigidity determines the extent to which a material resists torsional rotation.

The higher the modulus of rigidity the more rigid the material.

This is useful information when designing a system such as the drive shaft in a car. Choosing the least dense material that can withstand the expected torque without deformation can help to reduce inefficient fuel use.

Worksheet 3

Torque and length

It is easier to twist a long rubber band than a short one!

More precisely, the same torque produces a greater twist angle in a long rubber band than in a short one.

Is the same true for our metal rods?
The next investigation looks to answer this question.

Over to you:

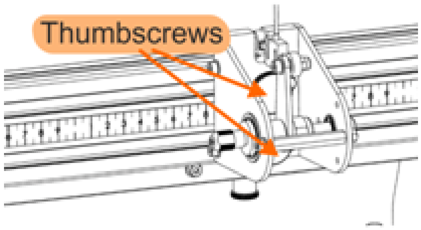
The constants:

This experiment uses a **fixed load** throughout and the **same material**, the smaller diameter brass rod.

The variables:

It varies the **length** of rod exposed to the torque.

To do so, slacken the thumbscrews on the right-hand bracket and slide it along the beam to the required position. The ruler attached to the beam can be used to measure the distance between the collets, as before.



- Position the right-hand bracket so that the distance between the collets is 100mm (0.1m). Insert and clamp the rod.
- Adjust the twist angle until the torque reading is 200g (**T** = 0.08N.m)..
- Record the twist angle in the Student Handout.
- Now increase the distance between the collets to 150mm (0.15m) and again adjust the twist angle until the torque reading is 200g (**T** = 0.08N.m).
- Record the new twist angle.
- Continue in this way, increasing the length of the rod in steps of 50mm until the length **L** is 450mm (0.45m). Each time, find the twist angle corresponding to a torque reading of 200g (**T** = 0.08N.m).
- Using the axes provided, plot a graph of twist angle θ against rod length, **L**.

So what:

The graph shows that twist angle is directly proportional to length, i.e. as length increases, so does the twist angle.

Student Handout

Worksheet 1 - Torque and diameter

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 = length of load cell arm = 0.04m
- Polar second moment of area $\mathbf{J} = \dfrac{\pi \times \mathbf{d}^4}{32}$

Brass rod 1:

Diameter of rod, **d** ....mm = ...m

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

Angular deflection		**Load**		**Torque T in N.m**	**T x L**	**J x θ**
in ^{0}	in rad	in g	in N			
0	0	0	0	0	0	0

Worksheet 1 .....

Brass rod 2:

Diameter of rod, **d** ....mm = ...m

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

Angular deflection		Load		Torque T in N.m	T x L	J x θ
in ^{0}	in rad	in g	in N			
0	0	0	0	0	0	0

Challenge:

The graph of (**T** x **L**) against (**J** x **θ**) should be linear because:

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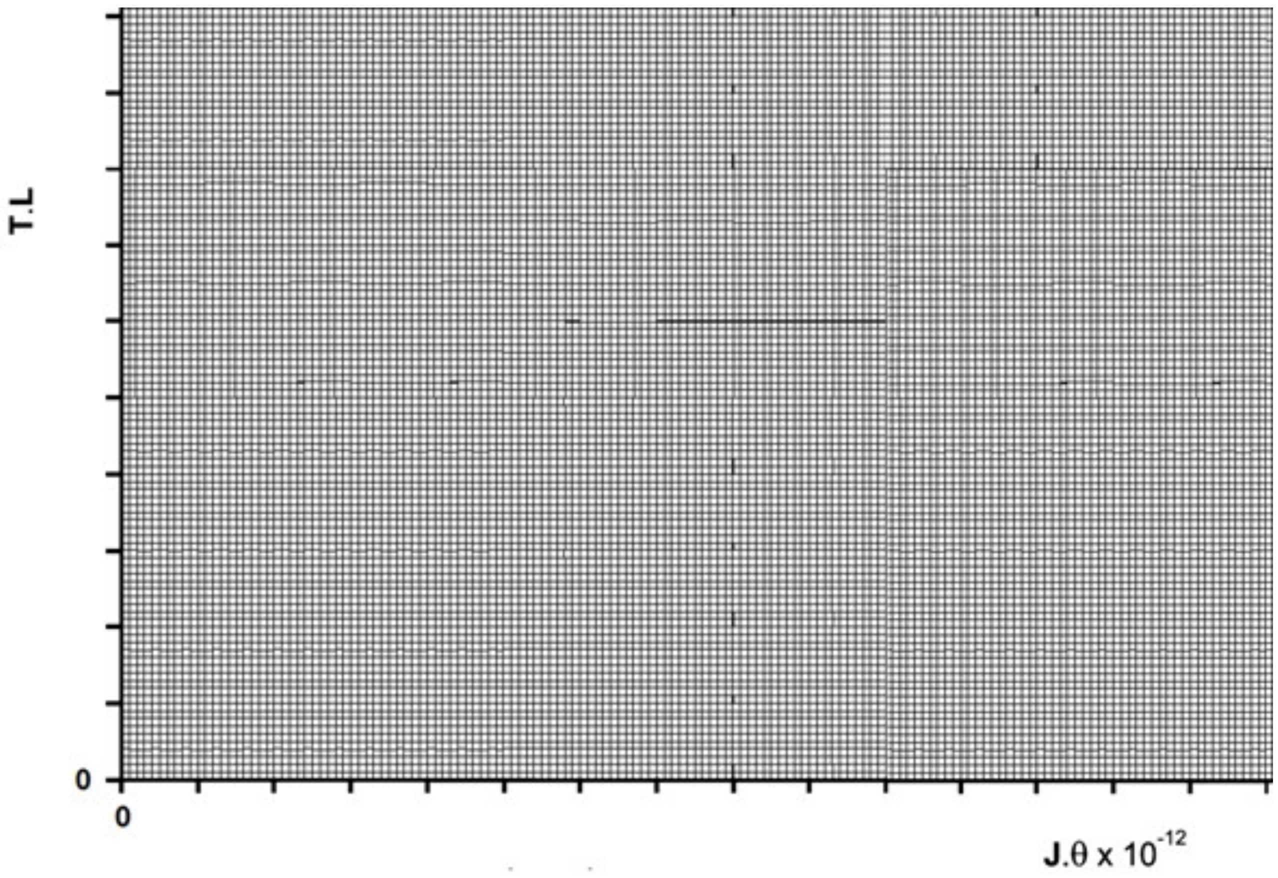
Worksheet 1 .....

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 trace for each rod.



Worksheet 2 - Torque and material

Brass rod :

Diameter of rod, **d** ....mm = ...m

Polar second moment of area $\mathbf{J} = \frac{\pi \times \mathbf{d}^4}{32}$ =

....

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

Angular deflection		**Load**		**Torque T in N.m**	**T x L**	**J x θ**
in ^{0}	in rad	in g	in N			
0	0	0	0	0	0	0

Student Handout

STRUCTURES

Worksheet 2 .....

Aluminium rod :

Diameter of rod, **d** ....mm = ...m

Polar second moment of area $\mathbf{J} = \frac{\pi \times \mathbf{d}^4}{32}$ =

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

Angular deflection		**Load**		**Torque T in N.m**	**T x L**	**J x θ**
in ^{0}	in rad	in g	in N			
0	0	0	0	0	0	0

Worksheet 2 .....

Steel rod :

Diameter of rod, **d** ....mm = ...m

Polar second moment of area $\mathbf{J} = \dfrac{\pi \times \mathbf{d}^4}{32} =$

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

Angular deflection		**Load**		**Torque T in N.m**	**T x L**	**J x θ**
in ^{0}	in rad	in g	in N			
0	0	0	0	0	0	0

Student Handout

Worksheet 2 .....

Graph of (T x L) vs (J x θ):

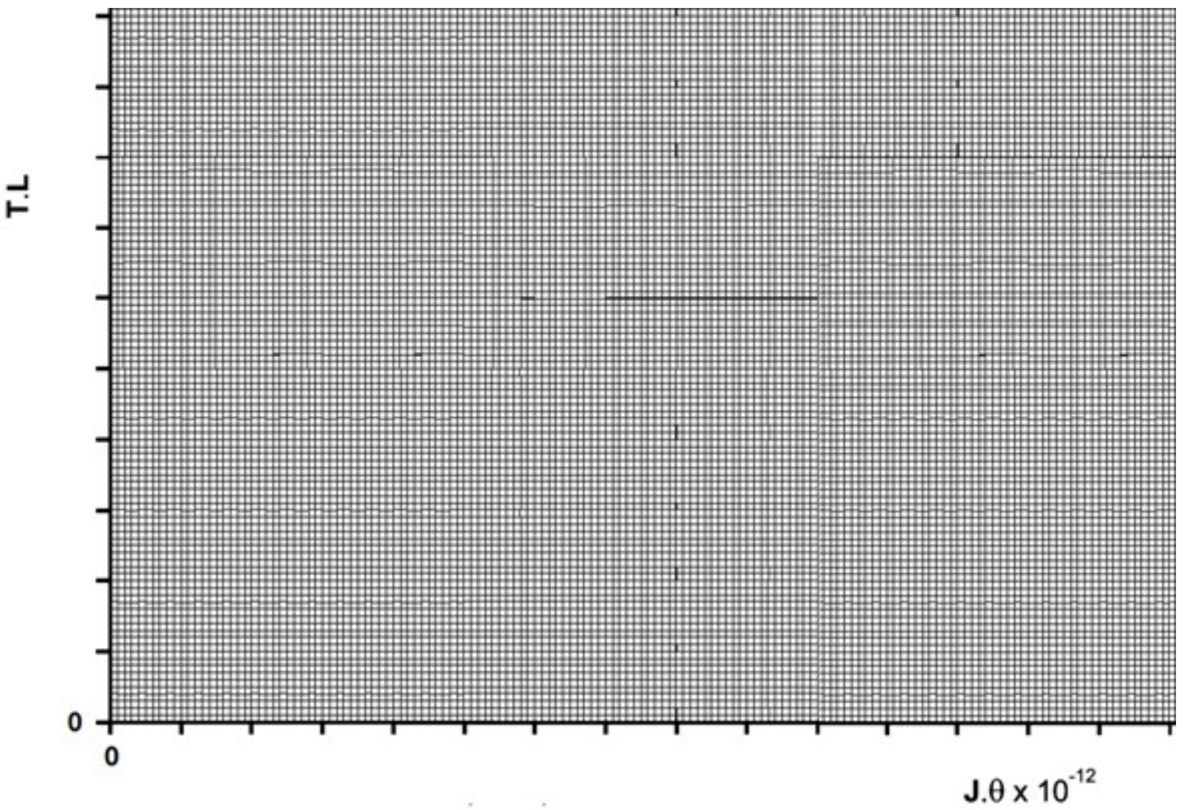
Use the axes provided below.

Show your measurements as small crosses.

Draw a separate straight-line trace for each material.

Measure the gradients of the graphs.

These give estimates of the modulus of rigidity for the materials.



Resulting values for modulus of rigidity:

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

Student Handout

Worksheet 3 - Torque and length

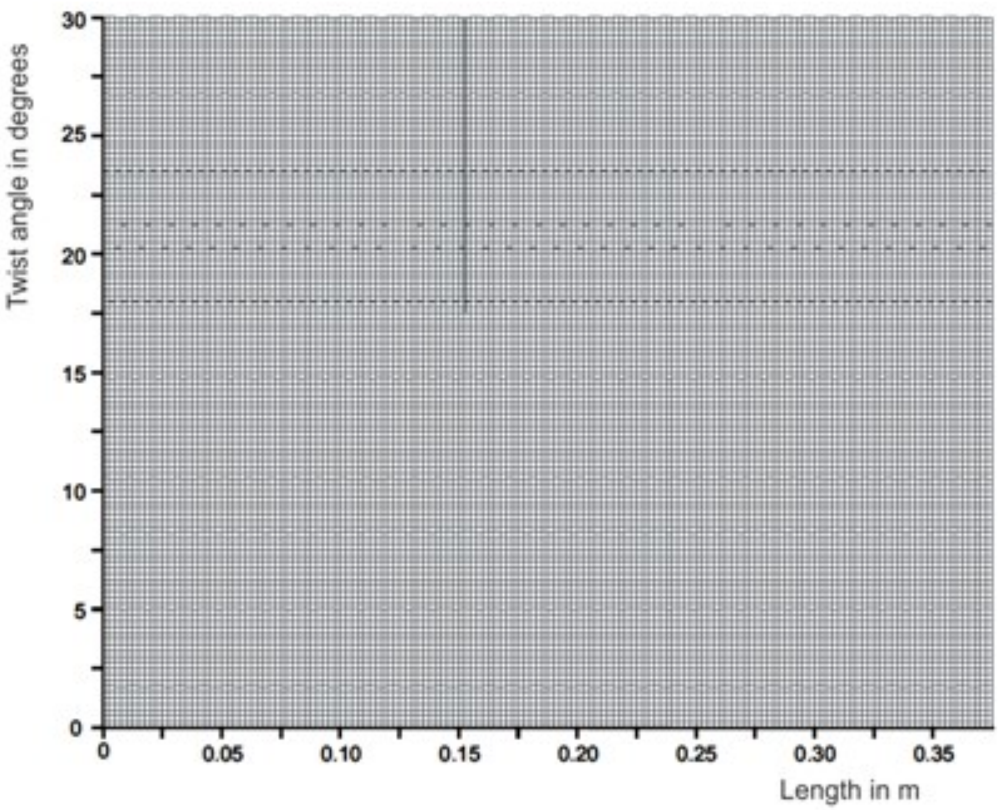
Rod length L in mm	Torque reading in g	Twist angle in ^{0}
100	200	0
150	200	
200	200	
250	200	
300	200	
350	200	
400	200	
450	200	

Graph of θ vs L:

Use the axes provided below.

Show your measurements as small crosses.

Draw a straight-line trace using your measurements as a guide.



Notes for the Instructor

About this course

Introduction

Using the 'Structures - Torsion of rods' module, students investigate the twisting effects of forces on a variety of samples through a series of practical investigations.

The kit can assembled and used by the students with minimum supervision to complete a series of worksheets focussed on a number of related topics for BTEC National and Higher National courses.

Aim

The course teaches students to investigate relationships between torque and the deformation that results and the factors that effect this for a variety of metal rods.

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 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 around two to four 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

Learning Objectives

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.
- 'zero' a load cell;
- convert a load cell reading in grammes into a force in newtons;
- calculate the weight of a given mass using 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;
- 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;
- describe the relationship between the length of a rod and the twist angle produced by a given torque.

Notes for the instructor

Worksheet	Notes
1 Torque and diameter Timing 40 - 60 mins	Concepts involved: torque torsion degrees radians load cell modulus of rigidity polar second moment of area equation for a straight line The instructor may need to explain the role of the load cell in this equipment. Designed to measure the mass of the load on it, in this case it is measuring a force. (Some students may need reminding about the difference between mass and weight, and the use of gravitational field strength.) Even then, that is not the end of the story as the target measurement is the torque that is applied to the rod. To calculate that, the length of the arm linking the cell to the rod is involved. Instructors may need to demonstrate use of vernier callipers to measure the diameter of the rods. It is important that the collets are fitted tightly to the rods to avoid any slipping. Some students may prefer to use data transfer via the USB port to direct manual recording of the measurements. The dependence of twist angle on the fourth power of diameter may need some amplification. The challenge requires understanding of the equation for a straight line and the ability to manipulate formulae. For some, the challenge may be too great but it is the end result that matters, not the process of obtaining it. For some, the idea
2 Torque and material Timing 40 - 60 mins	This exercise mirrors that in worksheet 1, except that, 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. Some support may be needed. Typical values for the modulus of rigidity in GPa are: brass 38 steel 80 aluminium 26.
3 Torque and length Timing 30 - 50 mins	This again involves the same concepts as in worksheet 1. This time, the length of the rod is changed to see what effect it has on torsion. The worksheet starts with a summary of what is kept constant and what is changed. The instructor may wish to develop the idea of a fair test using this summary. The success of this experiment depends in part on the attention paid to the tightness of the collets each time the length is changed. The load used could be varied between groups with the results compared later. Depending on their previous mathematical experience, some students may need help with the notion of ‘directly proportional’.