Trees as structures

Contents: Reading, questions, data analysis and practical work about trees as physical structures.

Time: 2 to 4 periods, depending on the time spent doing experimental work.

Intended use: GCSE Physics, Technology, and Science courses. Links with work on forces and elasticity.

Aims:

- To complement work on forces and elasticity
- To encourage an awareness of trees with their natural and commercial importance
- To provide opportunities to practise the skills involved in plotting and interpreting graphs
- To provide opportunities to use practical skills to investigate the properties of wood.

Requirements: Students' worksheets No.1009, graph paper and the apparatus for the investigations listed below.

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The unit views trees as systems for harnessing solar energy and considers their strategies for doing so. It also considers the importance of trees as a resource.

There are two experimental investigations. The first one is relatively quick and simple. The second is open-ended and proved popular in trials.

Part 1 Structures for harnessing the sun's energy

Notes on selected questions

Q.1 This activity gives the students practice in drawing to scale.

Q.4 Students will probably be able to apply intuitive notions of wind loading (wind resistance), centre of gravity and turning moment.

Q.5 The cherry has a higher centre of gravity and needs to be more strongly anchored by its root system.

Q.6 The result of plotting the data on height and girth of trees is shown on page iv. The pattern is that the deciduous trees with large canopies fall on the lower right-hand side. They experience a larger wind loading and tend to have a large girth for their height. The evergreen (coniferous) trees tend to be taller for their girth and fall on the upper left-hand side of the paper. Many conifers grow in regions where snow loading would snap branches if the trees were not conical in form. Note that the examples have been selected from common trees to exemplify the pattern. Deciduous trees with less dense canopies (such as ash or birch) lie closer to the conifers.

The ratio of elasticity of the wood to its density is also an important factor in determining the safe height of a tall structure. It gives a measure of the energy that can be stored per kilogram when the material is stressed.

$$(\text{height})^3 \text{ is proportional to } \frac{(\text{modulus of elasticity})}{(\text{density})} \times (\text{diameter})^2$$

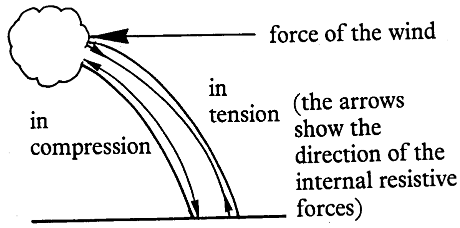
If time permits students might go outside and measure the heights and girths of mature trees in the school grounds, to add to the data in the table.

Q.8 Half the world's timber is burnt for fuel, but this tends to be in the developing nations. Methanol can be used as a fuel and is produced from wood, but the low efficiency of the process gives no overall energy yield. Timber as a material resource is used in buildings. (Its structural properties rival those of steel.) Pulped wood is used for paper making, manufacture of viscose fabrics, cellophane, etc. Turpentine, natural rubber and even maple syrup are obtained from tapping the sap of trees.

Part 2 Investigating the design of trees

Requirements for investigation A

Wooden dowelling about 50 cm long and 8 mm in diameter
1 kg mass
2 stands with bosses and clamps
ruler
sharp knife or saw to cut a notch
pencil sharpener to give a pointed end to the dowelling



The concepts of force and moment are essential to an understanding of how structures resist deformation and failure.

The experimental instructions ignore the slight reduction in perpendicular distance from the support to the weight as the deflection increases. Sharpening the end of the dowelling produces a useful pointer.

The bending moment applied by the wind increases rapidly as the tree gets taller.

When a tree bends in the wind, it experiences both tensile and compressive forces. A tree which is exposed to a prevailing wind lays down special tension or compression wood in response.

Specimen results:

length/cm	10	15	20	25	30	35	40
deflection/mm	2.5	16	14	23	36	53	76

These results are plotted on the graph shown on page iv.

Requirements for investigation B

4 or 5 pieces of dowelling with diameters in the range 5 – 12 mm
slotted masses, 10 × 100 g
2 stands with bosses and clamps
ruler
sharp knife or saw

The dowelling must be of circular cross section (because cross-sectional shape affects the stiffness — try bending a ruler). With four or five different samples, students should be able to obtain a curve relating diameter to deflection.

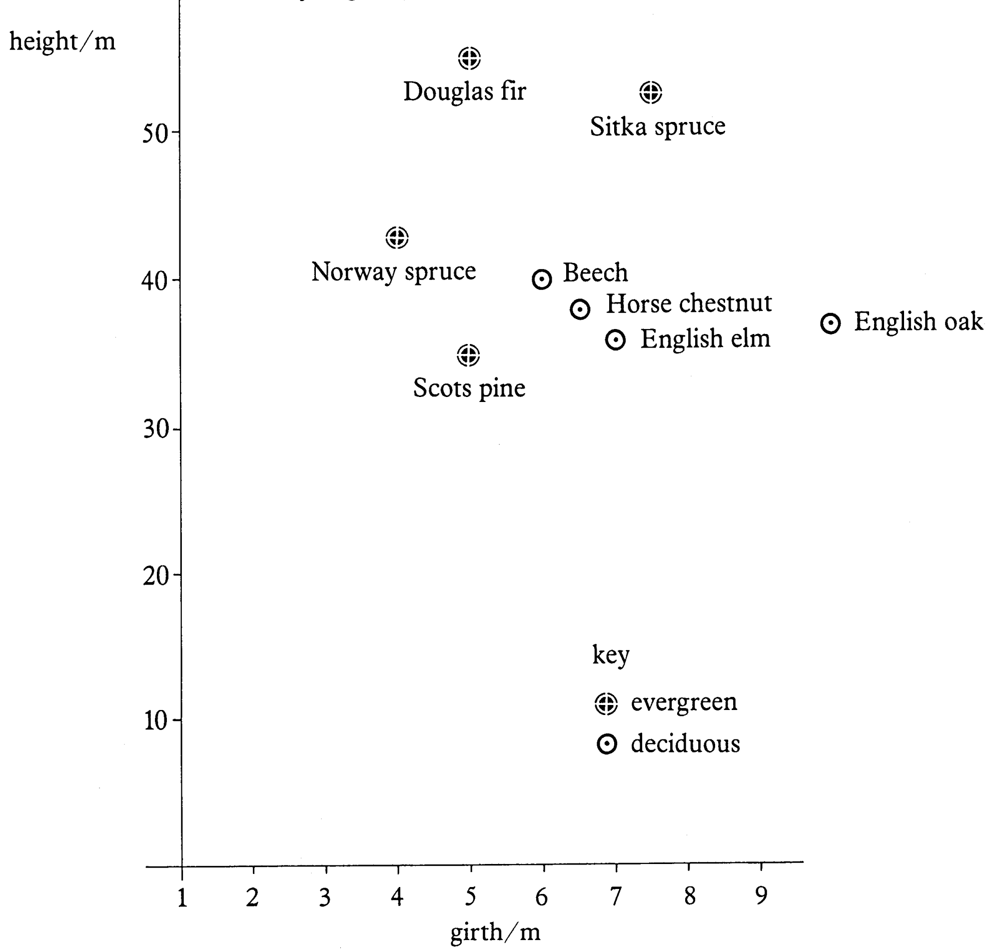
Specimen results:

Length: 20cm
Load: 0.50 kg

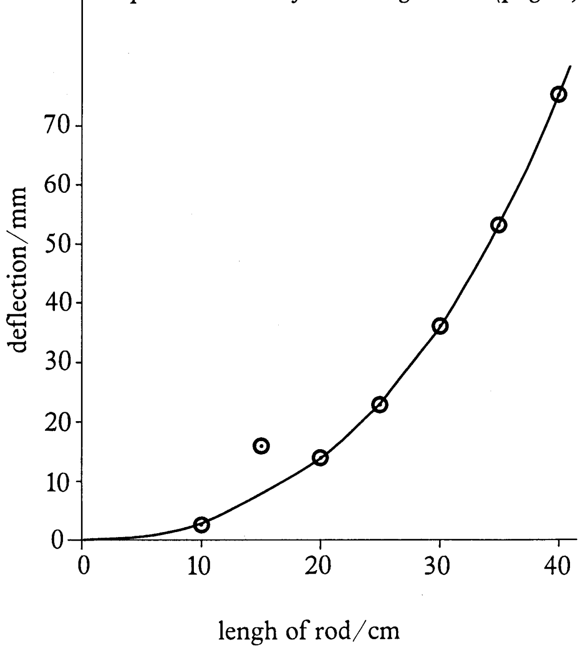
diameter/mm	5	6.15	8	10.15
cross-sectional area/mm^2	20	30	50	80
deflection/mm	28	15	6	5

These results are plotted on the graph shown on page iv.

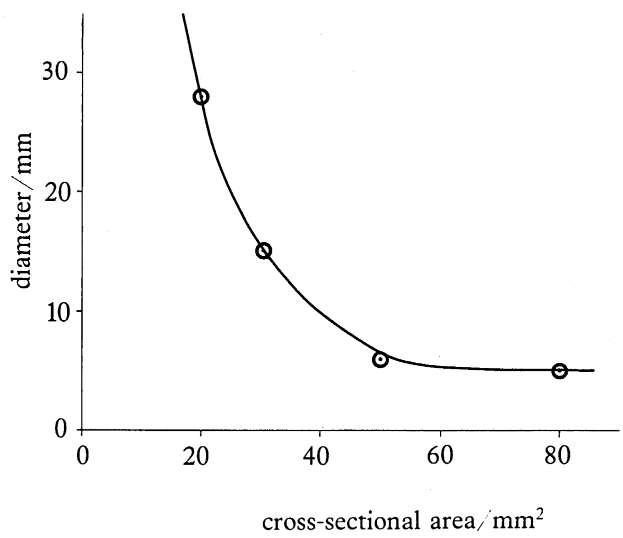
Plot of height against girth for trees (Question 6, page 2)



Specimen results for Investigation A (page 3)



Specimen results for Investigation B (page 3)



TREES AS STRUCTURES

Part 1 Structures for harnessing the sun's energy

The largest organisms that have ever existed are not elephants, whales or dinosaurs. They are trees.

Being big is a biological problem. Large organisms need more energy to survive. On land they have to be supported by very strong structures.

But being big can have benefits too. Size can help in the struggle for survival. Plants live and grow using energy from the sun. This is called photosynthesis. Tall trees capture the light before it reaches smaller plants growing in their shade.

Deciduous and evergreen trees have different strategies for harnessing the sunshine.

Question

1 *How big can they grow?*

Man (approximate height)	*2 m*
Elephant (height)	*4 m*
Blue whale (length) (the largest mammal)	*30 m*
Diplodocus (the longest dinosaur)	*30 m*
Giant Sequoia tree	*110 m*

Use a scale of 1 cm to represent 10 m. Draw and label lines to represent the height or length of these organisms (Scale 1:1000)

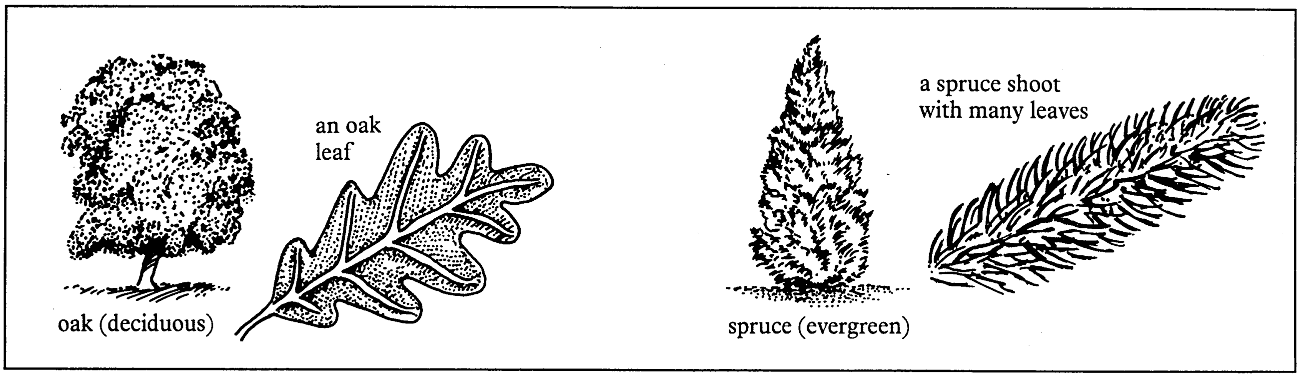


Figure 1 Deciduous and evergreen trees

In Britain deciduous trees lose their leaves in winter. They have to collect as much of the summer sunshine as possible. Their leaves have a large surface area. In windy weather, such trees suffer what engineers call a large wind loading. Their large leaves have a high wind resistance. A deciduous tree needs a strong trunk and branches together with well-anchored root systems so that it does not blow over in high winds.

Evergreen trees photosynthesise all year round. Their leaves are usually smaller and give less resistance to the wind, but they have to be able to survive storms in winter.

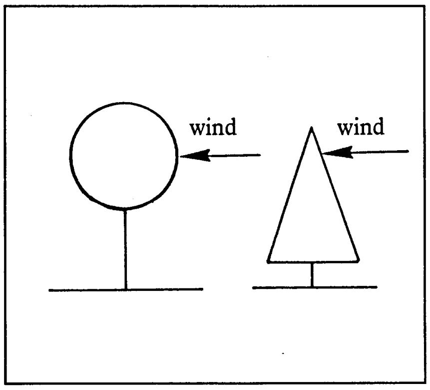


Figure 2 Tree shapes

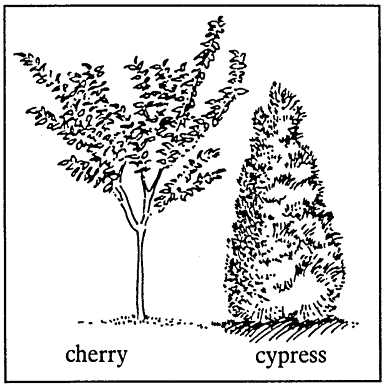


Figure 3 Cherry and cypress trees

Questions

2 *What is the strong structure which supports each of these large living things:*
(a) a giraffe
(b) an oak tree

3 *(a) Why do plants need sunlight?*
(b) Why do deciduous trees only grow during the summer?

4 *Look at Figure 2. Which shape of tree is more likely to topple over in the wind?*

5 *Which garden trees need to be anchored more strongly by their roots: deciduous trees like cherries or evergreens like cypresses?*

The figures in the table below compare the height and girth of evergreen and deciduous trees. The girth of a tree is the circumference of its trunk.

Table 1

Species of tree	*Deciduous or evergreen*	*Height (in m)*	*Girth (in m)*
Beech	deciduous	40	6
Douglas fir	evergreen	55	5
English elm	deciduous	36	7
English oak	deciduous	37	10
Horse chestnut	deciduous	38	6
Norway spruce	evergreen	43	4
Scots pine	evergreen	35	5
Sitka spruce	evergreen	53	7

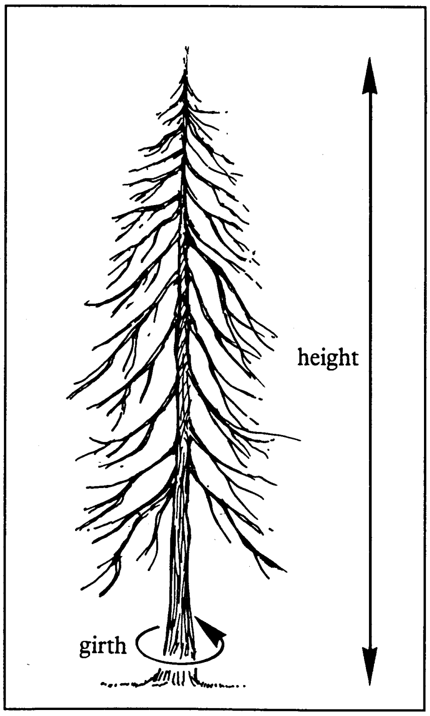


Figure 4

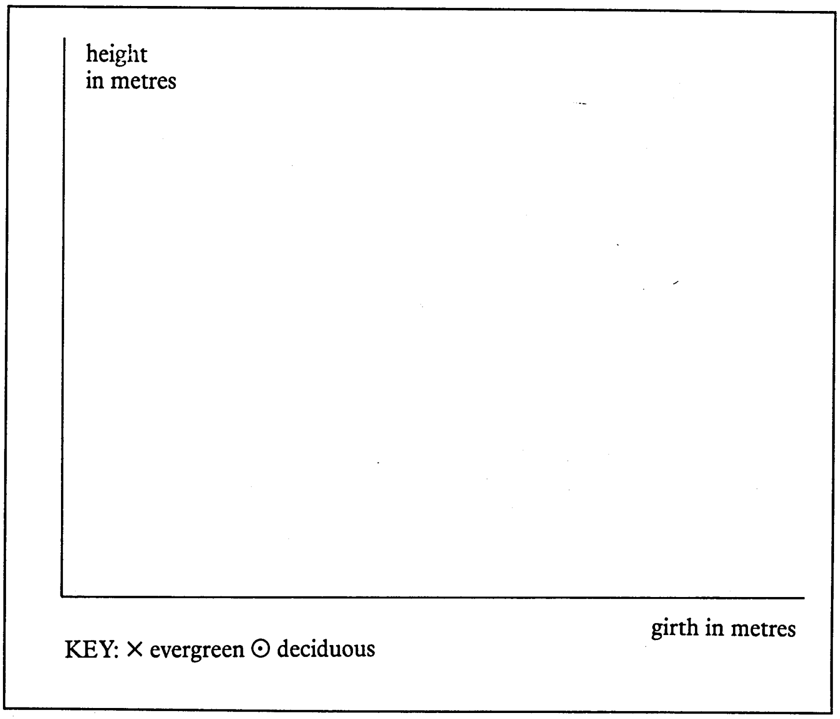


Figure 5

The tallest trees in the world are evergreens. The giant sequoias in California have reached a height of 110 metres. The oldest have been growing for 4000 years.

Deciduous trees are not so big. The tallest deciduous trees reach a maximum height of 60 metres.

Trees still dominate the landscape in many parts of the world. They provide us with a versatile building material as well as a renewable source of fuel. Many of Britain's native forests were felled for firewood, for building homes and ships, and to make charcoal for industry. This process continues in some parts of the world.

Now answer questions 6 to 8.

Questions

6 *(a) Plot height (y axis) against girth (x axis) for each tree in Table 1. Use the axes shown in Figure 5. Use crosses (×) to plot the values for evergreen trees and dots (⊙) for deciduous ones.*
(b) Can you see any patterns when you look at the points you have plotted? Can you suggest reasons for any patterns you may have noticed?

7 *How many trees can you see if you look out of the windows of the room you are in? How many different types of tree can you see?*

8 *How much do you depend on the wood from trees? Do you use wood as a fuel? Do you use things made from wood? How much wood is there in your home and what is it used for?*

Part 2 Investigating the design of trees

You can study some of the factors affecting the design of trees with these investigations.

The structure of a tree must support its own weight. It must also resist the turning force of the wind. Increasing height increases the wind's turning moment. So higher trees tend to bend more.

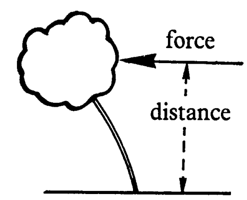


Figure 6

Investigation A How does the height of a tree affect how much the wind bends it?

Assume that the wind produces a force acting near the top of the tree. With ordinary apparatus, it is easier to experiment with the 'tree' on its side and hang weights on it to simulate the force of the wind.

You can use a length of wooden dowelling as your 'tree trunk'. Vary the height of the 'tree' by clamping the dowelling in different places.

Method

Start by using an arrangement similar to that in Figure 7. You can make your own improvements later.

Make a small notch in a wooden rod about 4 cm from one end. This will stop the mass sliding off the end.

Clamp the dowel horizontally at a point 10 cm from the notch.

Try hanging a 1kg mass from the notch. Remember that the pull of the Earth on 1 kilogram is 10 newtons (N). This will only bend the rod slightly. Decide how you can measure the deflection of the rod as accurately as possible. Change your apparatus if you find it necessary to get better results.

Obtain a set of values for the deflection of the rod for lengths between 10 cm and 40 cm.

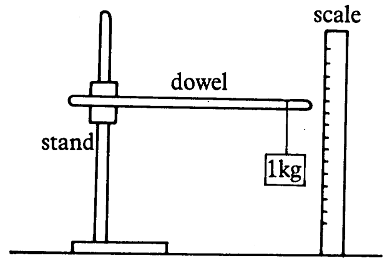


Figure 7

Question

9 (a) Plot a graph of the deflection (y axis) against the length of rod (x axis).
(b) The results should show that there is a pattern but it is not a simple one. What does the graph tell you?

Investigation B How does the girth of a tree affect how much the wind bends it?

Use pieces of dowelling of different diameters, a set of slotted masses (10 × 100g) and any other laboratory apparatus you need.

Method

Use a similar method to that used in investigation A. Beware! Thin dowelling will break if you hang too large a mass on it.

Question

10 What patterns can you find in your results?