

DESIGNING AND MAKING A SHELVING SYSTEM

WHAT YOU WILL LEARN

After completing this project, you should understand:

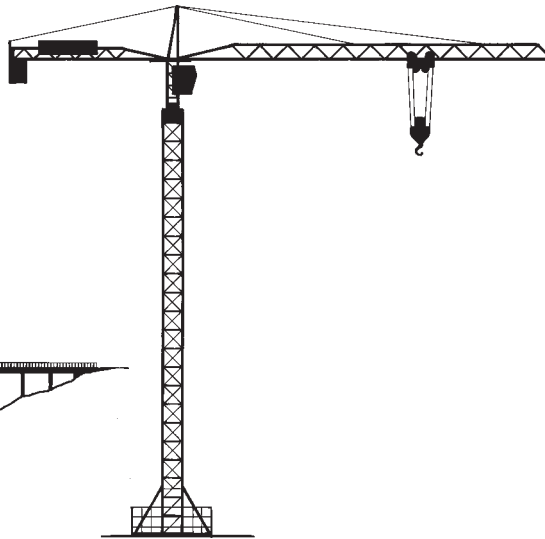
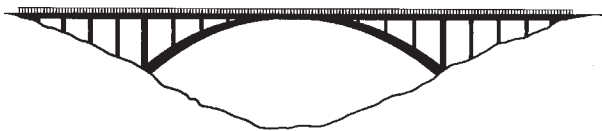
- How beams 'work'.
- How thin sheet materials can be stiffened for use in structures.
- The use of simple vector diagrams to calculate forces.
- How a material such as chipboard can fail in use.

You should be able to:

- Recognise and name parts of a structure - e.g. ties and struts.
- Work to a design brief and write a specification.
- Recognise constraints when designing.
- Design and make a stable shelf system.

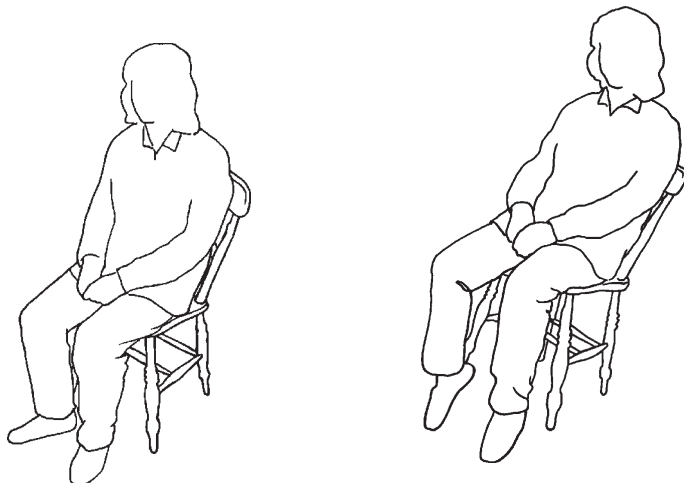
STRUCTURES - SHELVING SYSTEM

When you think of the term 'structure' you probably conjure up pictures of bridges or tower cranes. These are certainly structures but there are many more examples closer to home such as the furniture we use.



It is quite difficult to define what structures are but we can describe what they should do:

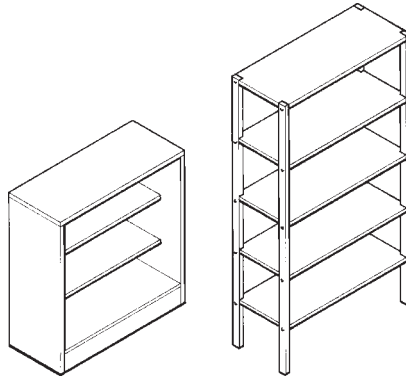
- Structures support loads or resist forces. When you sit on a chair you become a load supported by the legs.
- Structures should be stable. Tables and chairs, for example, should not be able to topple over easily.
- There should be a margin of safety built into a structure. For example, if you tip over backwards on a four legged chair, the back legs should not break.



A lot of furniture is now sold as flat-pack kits requiring assembly at home. Often, this is poorly designed because some very basic principles of structures have been forgotten. This unit will introduce you to some of these principles and invite you to design and make an unusual piece of furniture which a chain of shops wishes to sell.

SHELVING SYSTEMS AS STRUCTURES

One of the most common structures in a house is the shelf. There are hundreds of methods available for supporting shelves and countless designs for things such as bookcases. Although shelves appear simple enough, designing a new shelving system requires a good understanding of how they 'work'.

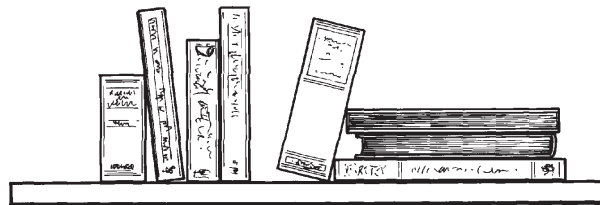


◀ NOTE

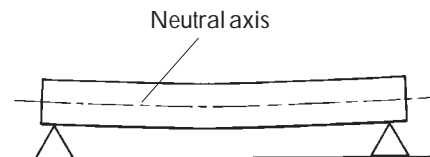
See Technology Study File 15 (Defining Terms)

SHELVES AS BEAMS

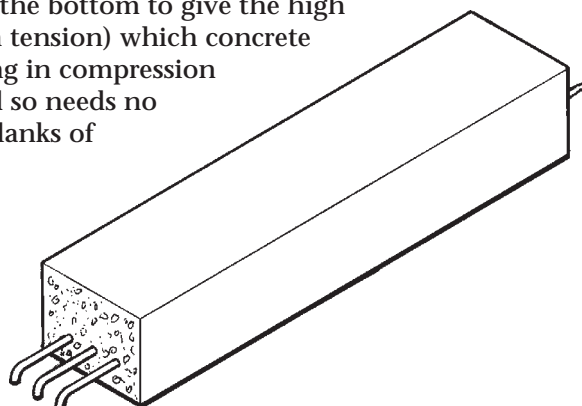
A shelf is an example of a simple *beam*. An ideal beam spans a gap to support a large load but stays flat.



In practice, when a load is applied at the centre of a beam, the beam always bends or *deflects*. If a line is drawn through the centre of a beam, the material above this line is in compression and that below is in tension.



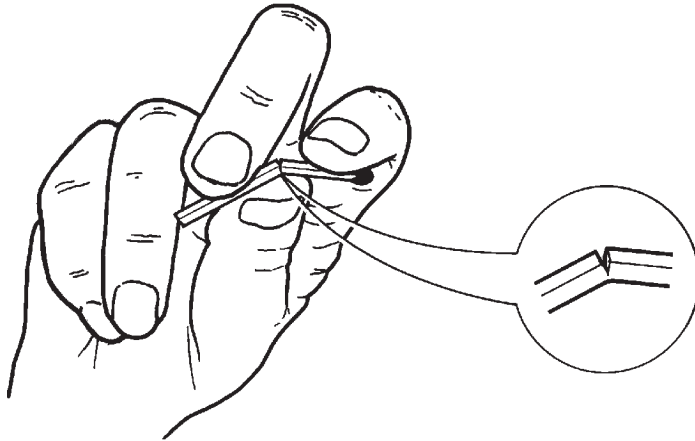
The line is called the neutral axis. The material of the beam is neither in tension nor compression at the neutral axis. If the beam is to be strengthened, it can be done by using reinforcing rods below the neutral axis. In reinforced concrete beams, steel rods are introduced at the bottom to give the high tensile strength (strength in tension) which concrete lacks. Concrete is very strong in compression (above the neutral axis) and so needs no reinforcement here. Long planks of wood used in scaffolding as temporary beams are sometimes reinforced with steel wires in tension running along the bottom. This makes them much stiffer and safer to use.



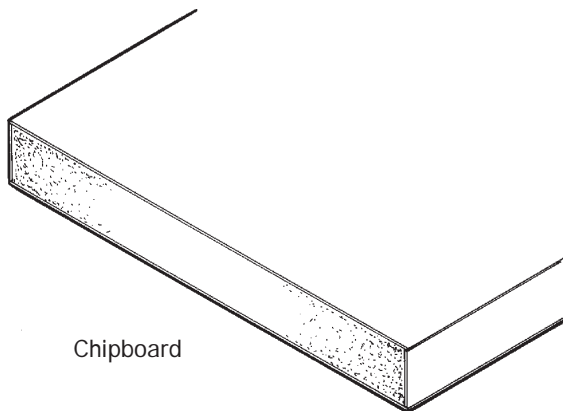
WOODEN SHELVES

Along its grain, wood has quite high strength in both tension and compression. (It is very weak across the grain - a fact which is exploited in karate demonstrations). But when a wooden shelf is overloaded, it normally suffers a tensile failure at the bottom - like a scaffold plank. This can be demonstrated on a small scale by breaking a matchstick between two fingers (supports) and your thumb (load). The matchstick always fails like the bottom of the shelf.

◀ SCIENCE OPPORTUNITY
Discuss strength anisotropy in materials.



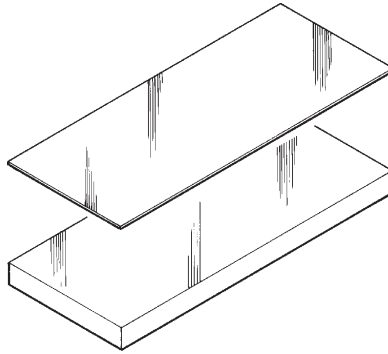
Most wooden shelves are made from melamine-faced chipboard. (Melamine is a hard plastic.) Chipboard consists of smaller chips of wood bonded together and is an inexpensive substitute for natural wood. It is weaker than natural wood (along the grain) but also suffers from a potentially serious problem called *creep*.



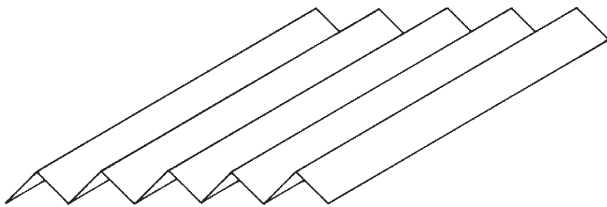
Chipboard, like other materials, behaves elastically, but will not deform plastically very much before it breaks. However, it deforms over a period a time if loaded, for example, with heavy books. This is called *creep* because it happens very slowly. Other materials can be similarly affected, and designers must be able to anticipate the effects of loads on structures over a period of time. The simple chipboard shelf is not quite so simple as it first seemed!

METAL SHELVES

If we substitute a piece of steel of similar dimensions for the chipboard, it would be far too heavy (and expensive) as a shelving material. A thinner piece of steel weighing the same as the wood and covering the same area would not be stiff enough to support the load without deflecting too much.

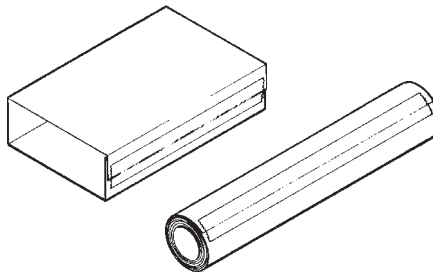


The answer to this problem is to form the sheet into a stiffer shape. You can do several experiments with paper to show how a thin flexible sheet material can be made much stiffer and able to support loads. For example, the paper can be folded into a number of 'V's.

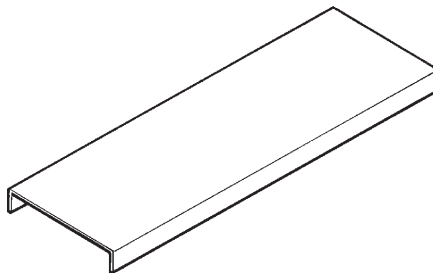


◀ SCIENCE OPPORTUNITY
To discuss strength derived from geometry.

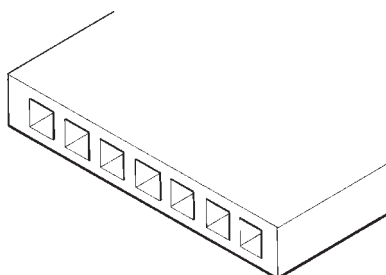
It can also be folded into a box section and sellotaped, or it can be rolled.



For shelving, it is common to find thin steel sheet folded over at its edges. This provides a combination of high stiffness and light weight.



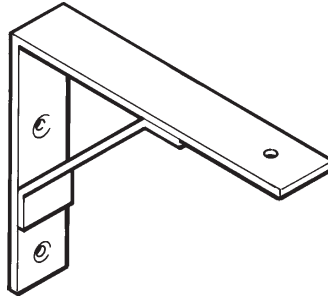
Solid plastic shelving is now becoming more common and often uses the same principle that gives stiffness to corrugated cardboard and plastic. The material is made into a stiff section.



◀ NOTE
See Technology Study File 3 & 4

HOLDING UP SHELVES

Unless they are built into furniture, shelves need to be held up with some kind of support structure. A simple method uses two or more shelf brackets as in this example. The bracket contains a strut and a tie. In designing even a simple structure like this, it is important to know what forces are acting on parts of the bracket. This can be done, for example, using an experimental test rig and computer modelling.



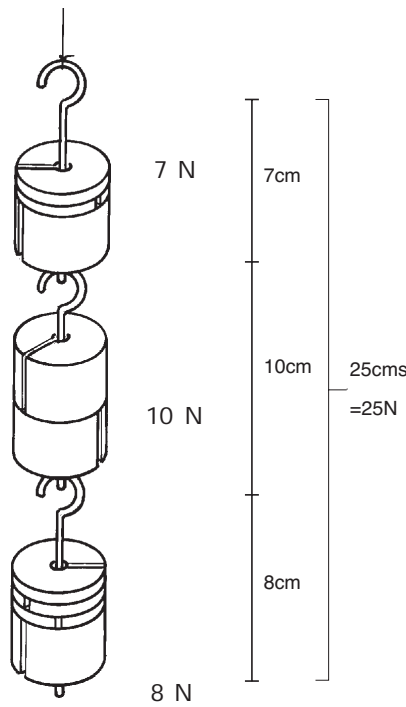
◀ NOTE
See Technology Study File 12

See Technology Study File 12

The forces acting on the strut and tie can also be determined using a *vector diagram*. A *vector* is a line that represents a force and its direction. In a vector diagram, lines at different angles represent the direction of forces and each is drawn to a scale - e.g. 1 cm = 1 Newton. If we hang three weights on a line, and each exerts a force as shown, the total force exerted is:

$$7\text{ N} + 10\text{ N} + 8\text{ N} = 25\text{ N}.$$

If we draw lines to represent each weight and each cm equals 1 N, the total length of the lines gives us the same answer: 25 cm or 25 N.

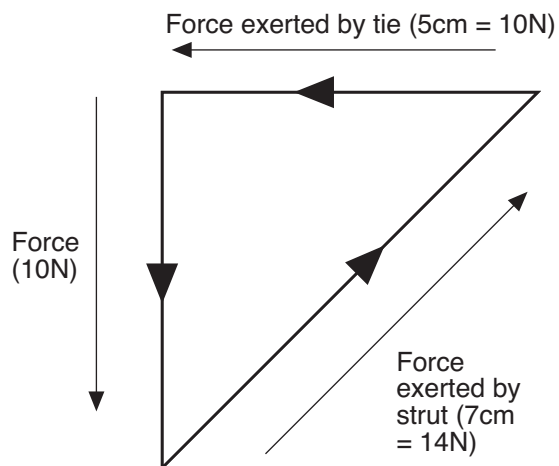
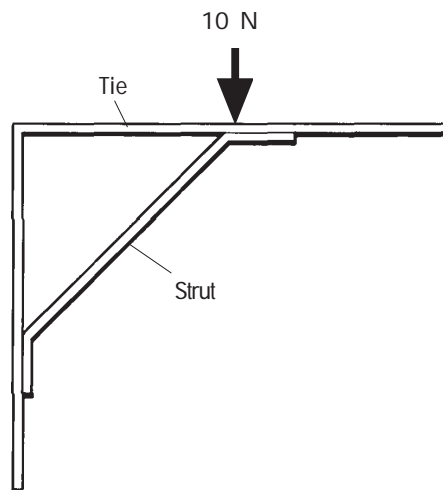


◀ SCIENCE/MATHS OPPORTUNITY

STRUCTURES - SHELVING SYSTEM

You can use the same method to work out the forces acting on the parts of the bracket.

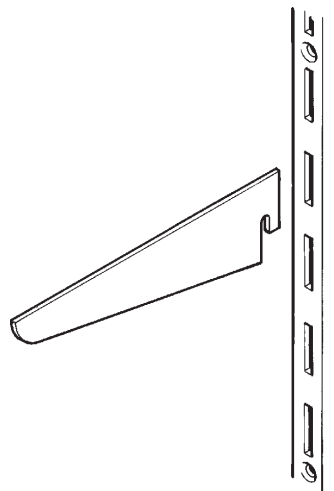
For simplicity, assume that a load 10 N is acting only on the end of the strut. The force is drawn first to an appropriate scale - e.g. 5 mm per Newton. A horizontal line is then drawn out parallel to the tie. Finally, a line drawn parallel to the strut completes the vector diagram. In the example, the force exerted by the strut is 14 N and that exerted by the tie is 10 N. The vector diagram shows the forces exerted and their directions.



← SCIENCE/MATHS OPPORTUNITY

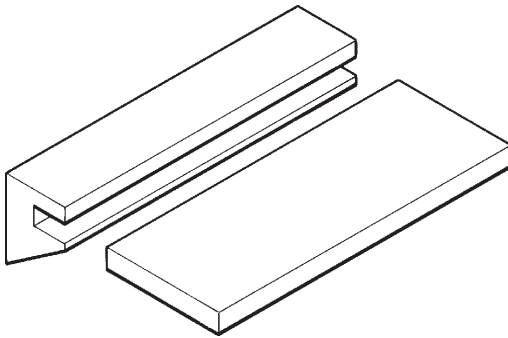
In many shelving systems, the shelf bracket is a triangular piece of metal which slots into a track.

A similar vector diagram can be drawn for this kind of bracket because the top of the bracket is in tension and the lower part is in compression. The forces acting at the rear of the bracket are relatively high. The slot-in joint between the bracket and the track therefore has to be very strong.



STRUCTURES - SHELVING SYSTEM

A newer type of shelf bracket consists of a triangular section which holds a shelf as shown below. It is attached to a wall with screws. If you think of the bracket and shelf together as similar to the triangular bracket on the tracking, it becomes clear that there can be very high forces acting to pull the screws from the wall. This type of shelf bracket therefore needs very careful wall fixing and recommended shelf sizes and loads should not be exceeded.



YOUR TASK

Design and make an inexpensive shelving system which can be sold by retailers in a flat pack box. To keep costs low, a suspended system is required where nylon cords, fastened to a wall by screws or masonry pins, are used as the main part of the structure. The shelf system you design can incorporate between one and three shelves each of which should be no larger than 600 mm long × 220 mm wide.

◀ DESIGN BRIEF

DESCRIBING YOUR TASK

First, you need to draw up a design specification for your shelving system. A specification is a more detailed description of what a product will be like, what it will do and who will use it.

◀ DESIGN SPECIFICATION

Here are some questions to help you produce your shelving specification:

- *Who is the shelving intended for?*
- *Where will the shelving be used?*
- *How large should the shelves be?*
- *What load will the shelves carry?*
- *How many shelves will the system contain?*
- *What size container will the shelving kit be sold in?*
- *Will the shelving system require any special tools for its assembly?*

WHAT YOU HAVE TO WORK WITH

Before you get on with your design work, you need to know what materials and equipment are available. Your teacher will provide you with some of the materials listed below. Make a note of what there is.

Melamine faced chipboard

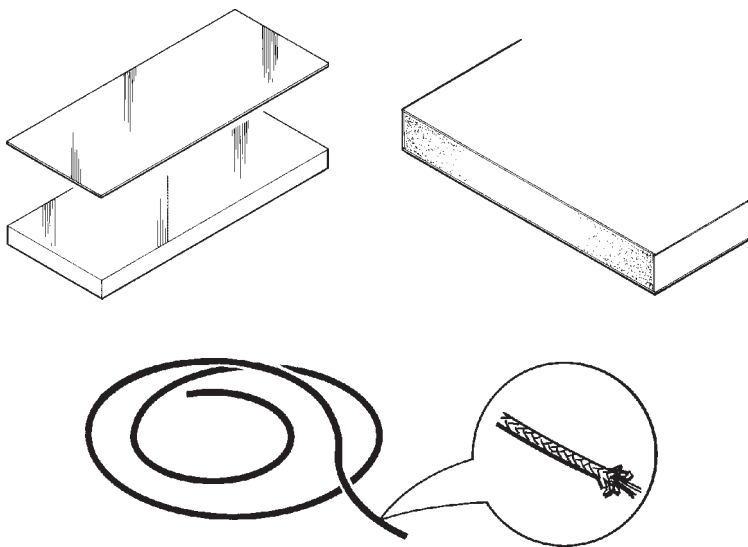
Aluminium sheet

Polystyrene sheet

Woven nylon cord (or similar)

Selection of softwood and plywood.

◀ DESIGN CONSTRAINTS



WORKING OUT YOUR DESIGN

Once you know what materials and equipment are available, you need to think about ideas for the shelving system.

- Set your ideas down on paper.
- Play around with your ideas.
- Check your ideas against your specification.
- Decide which is the best design.
- Do a detailed drawing of the design.
- You need to end up with a working drawing from which you or someone else can work to mark out, make, and assemble the parts. It is a good idea to draw the parts for your final design full size.

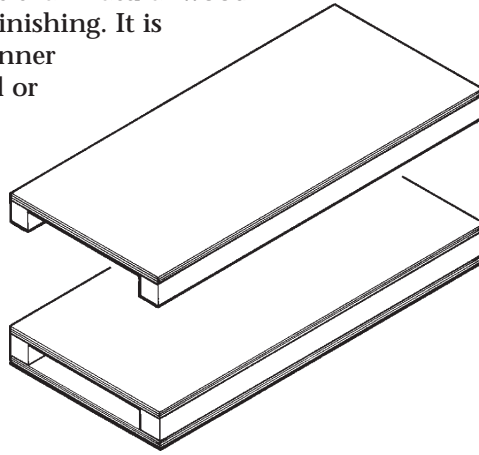
◀ NOTE

See Technology Study File 2.

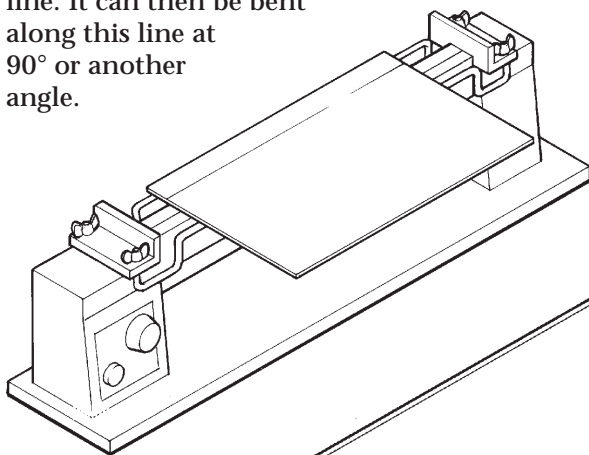
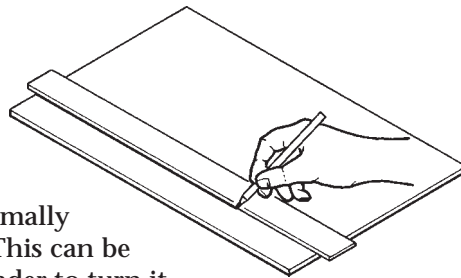
Before you start, the following notes will give you some ideas about how the parts of the shelving system can be designed and made. They do not give you the answer though! You must make the important decisions and put all the 'ingredients' together so that you end up with a working product.

WHAT MATERIAL WILL YOU USE FOR THE SHELVING?

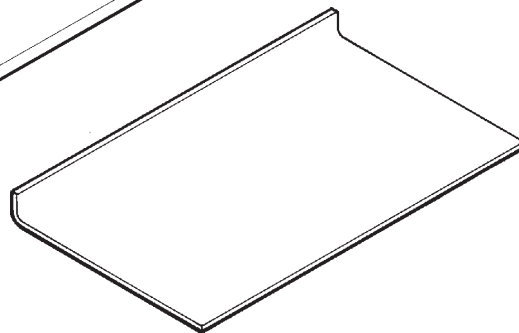
Chipboard is less expensive than natural wood and requires little surface finishing. It is quite heavy, though. A thinner material such as hardboard or thin plywood will require stiffening. This could be done, for example by adding strips of softwood or even making a thin rectangular box section using two 'skins'. Inexpensive house doors use this construction method.



If you are considering using plastic shelving, a material that is readily available is polystyrene (normally used for vacuum forming). This can be heat formed using a line bender to turn it into a stiff section. It is first marked out and then heated to soften it along a line. It can then be bent along this line at 90° or another angle.



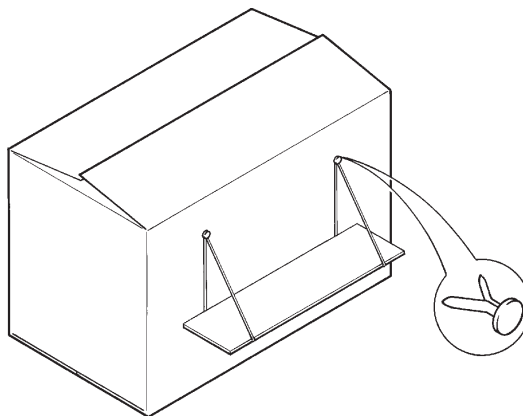
Line bending



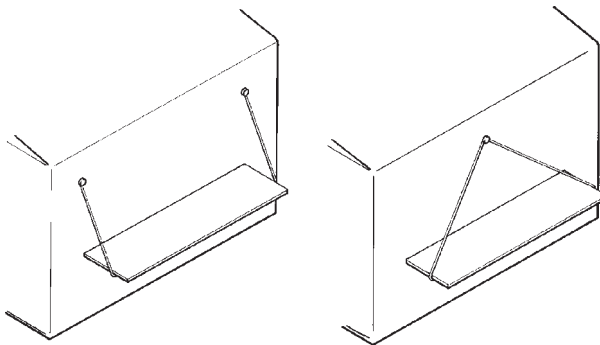
Sheet metal, such as aluminium, can also be formed by bending along a line but this can be difficult over long lengths without special bending equipment.

HOW WILL THE SHELVING BE SUPPORTED?

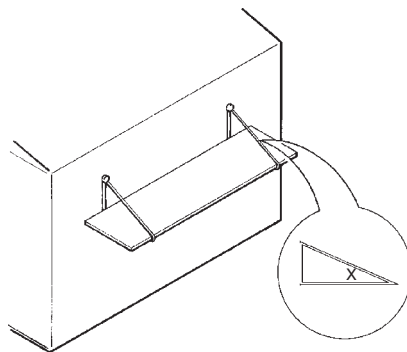
The design brief required the main structural material to be cord. This suggests that the shelving will need to hang down. How is this possible? To work out and examine solutions, you can make scale models using stiff card for the shelving and thin thread in place of cord. The model could be supported on the side of a packing case.



As well as standing up to a load placed on a shelf, your system must also be *stable*. Can you identify possible problems with the examples shown below?

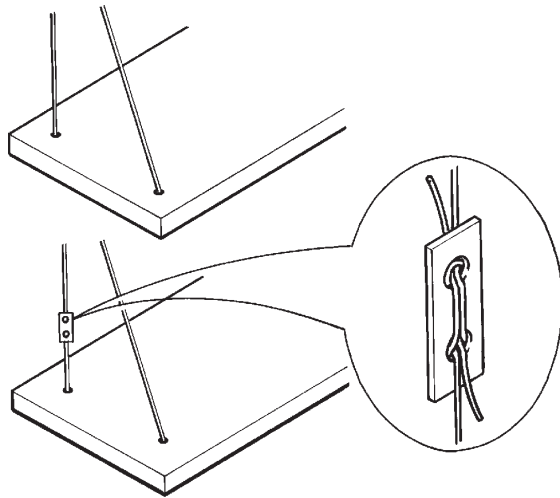


You will remember from the example of the vector diagram that a greater force is placed on a tie when the angle at 'X' is reduced. If you try to suspend your shelving as shown, there is a greater danger that the wall fixing (a screw in a Rawlplug or a masonry nail) is pulled out. What change would you make to the example to prevent this?



STRUCTURES - SHELVING SYSTEM

Once you have devised a system for suspending the shelf or shelves, you need to decide what method to use to attach the cord and ensure it does not slip off. There are several obvious methods. For example, the cord can pass through drilled holes and can be tied. For easy adjustment, the cord can be passed through a *stay* made by drilling or punching two holes in a small piece of metal or plastic. When the cord is threaded through these holes and pulled tight, friction prevents it slipping through any further. An example of a stay using this principle is shown; can you think of others?



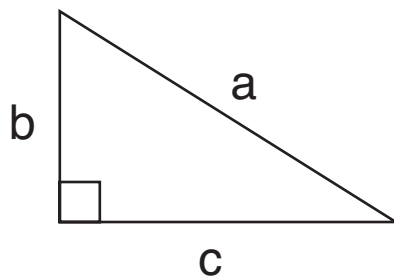
PUTTING IT ALL TOGETHER

Once you have decided on the overall design and materials needed for your shelving system, it should be easy to produce. It is possible to buy nylon cord in places such as camping suppliers and kite shops. The cord is normally identified with a figure for *breaking strain*, which is the maximum load it can suspend. You must make some assumptions about the maximum load your shelving system will cater for and select a cord safely within this limit. *The one you need depends on how many cords are used to actually suspend the system.* If all the total system is suspended on a single cord, this must be strong enough to support the total load. If, however, it is suspended on four cords, the load on each cord is the total load divided by four.

STRUCTURES - SHELVING SYSTEM

Work out the amount of cord needed by scaling up from a model. If simple triangles are involved, it can also be done by calculation using Pythagoras' theorem. This theorem makes use of the fact that, if the lengths of two sides of a right angled triangle are known, the third can be calculated. It states that:

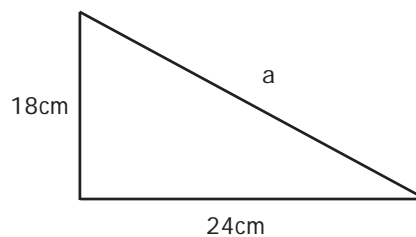
$$a^2 = b^2 + c^2$$



◀ SCIENCE/MATHS OPPORTUNITY

For example, if you have a shelf hanger as shown, the unknown length is:

$$\begin{aligned} a^2 &= 18^2 + 24^2 \\ &= 324 + 576 \\ &= 900 \\ a &= \sqrt{900} = 30\text{cm} \end{aligned}$$



EVALUATING YOUR SHELVING SYSTEM

There are a number of things to consider when evaluating the success of your shelving system:

- Does it meet the firm's requirements and your specification?
- Does it meet the requirements of a good structure?
- Does it support the intended load?
- Is it stable?

These questions can be answered by setting up the shelf system and placing a suitable load on it. This test can be done without fastening to screws or masonry pins in a wall. Small pins, for example, can be driven into the top of a door frame.