5 Forces and matter

In this chapter, you will find out:

- that forces change the shape and size of a body
- how to carry out experiments to produce extension–load graphs
- S how to interpret extension–load graphs
- S about Hooke's law and how to apply it
- what factors affect pressure
- how to calculate pressure.

5.1 Forces acting on solids

Forces can change the size and shape of an object. They can stretch, squash, bend or twist it. Figure 5.1 shows the forces needed for these different ways of deforming an object. You could imagine holding a cylinder of foa rubber, which is easy to deform, and changing its shap in each of these ways.

Foam rubber is good for investigating how things deform, because, when the forces are removed, it springs back to its original shape. Here are two more examples of materials that deform in this way:

- When a football is kicked, it is compressed for a short while (see Figure 5.2). Then it springs back to its original shape as it pushes itself off the foot the player who has kicked it. The same is true for tennis ball when struck by a racket.

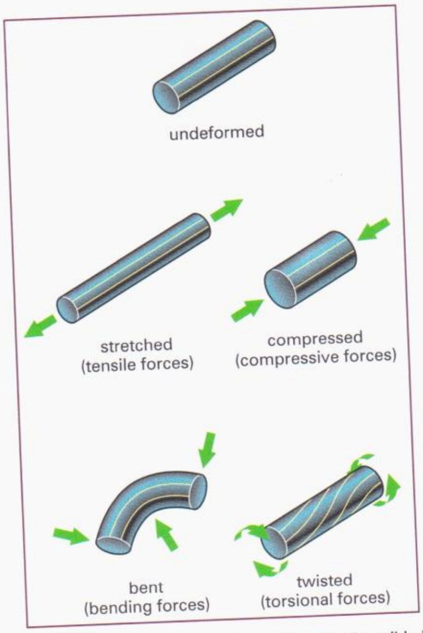

Figure 5.1 Forces can change the size and shape of a solid object. These diagrams show four different ways of deforming a solid object.

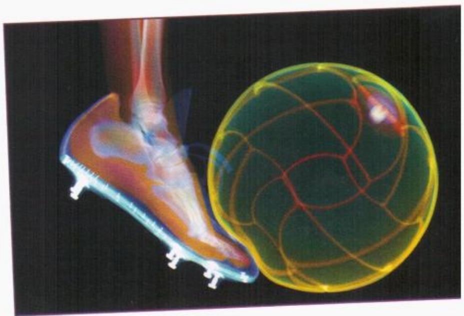

Figure 5.2 This remarkable X-ray image shows how a footl is compressed when it is kicked. It returns to its original sha as it leaves the player's boot. (This is an example of an elast deformation.) The boot is also compressed slightly but, bec is stiffer than the ball, the effect is less noticeable.

- Bungee jumpers rely on the springiness of the rubber rope, which breaks their fall when they jump from a height. If the rope became permanently stretched, they would stop suddenly at the bottom of their fall, rather than bouncing up and down and gradually coming to a halt.

Some materials are less springy. They become permanently deformed when forces act on them.

- When two cars collide, the metal panels of their bodywork are bent. In a serious crash, the solid metal sections of the car's chassis are also bent.
- Gold and silver are metals that can be deformed by hammering them (see Figure 5.3). People have known for thousands of years how to shape rings and other ornaments from these precious metals.

5.2 Stretching springs

To investigate how objects deform, it is simplest to start with a spring. Springs are designed to stretch a long way when a small force is applied, so it is easy to measure how their length changes.

Figure 5.4 shows how to carry out an investigation on stretching a spring. The spring is hung from a rigid clamp, so that its top end is fixed. Weights are hung on the end of the spring – these are referred to as the **load**. As the load is increased, the spring stretches and its length increases.

Figure 5.5 shows the pattern observed as the load is increased in regular steps. The length of the spring increases (also in regular steps). At this stage the spring will return to its original length if the load is removed. However, if the load is increased too far, the spring becomes permanently stretched and will not

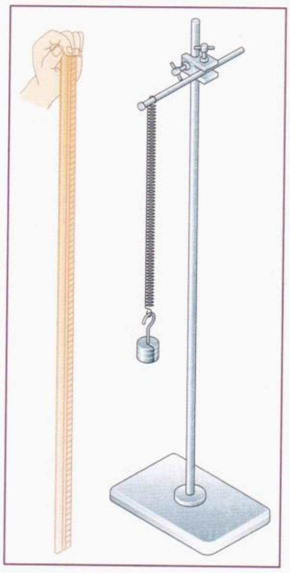

Figure 5.4 Investigating the stretching of a spring.

Figure 5.3 A Tibetan silversmith making a wrist band. Silver is a relatively soft metal at room temperature, so it can be hammered into shape without the need for heating.

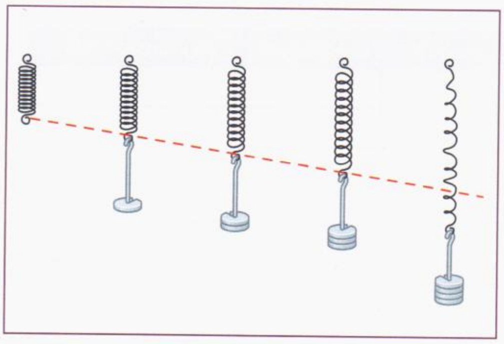

Figure 5.5 Stretching a spring. At first, the spring deforms elastically. It will return to its original length when the load is removed. Eventually, however, the load is so great that the spring is damaged.

return to its original length. It has been *inelastically deformed*.

Extension of a spring

As the force stretching the spring increases, it gets longer. It is important to consider the increase in length of the spring. This quantity is known as the **extension**.

length of stretched spring
= original length + extension

Table 5.1 shows how to use a table with three columns to record the results of an experiment to stretch a spring. The third column is used to record the value of the extension, calculated by subtracting the original length from the value in the second column.

To see how the extension depends on the load, we draw an extension–load graph (Figure 5.6). You can see that the graph is in two parts.

- At first, the graph slopes up steadily. This shows that the extension increases in equal steps as the load increases.
- Then the graph bends. This happens when the load is so great that the spring has become permanently damaged. It will not return to its original length.

(You can see the same features in Table 5.1. Look at the third column. At first, the numbers go up in equal steps. The last two steps are bigger.)

Load / N	Length / cm	Extension / cm
0.0	24.0	0.0
1.0	24.6	0.6
2.0	25.2	1.2
3.0	25.8	1.8
4.0	26.4	2.4
5.0	27.0	3.0
6.0	27.6	3.6
7.0	28.6	4.6
8.0	29.5	5.6

Table 5.1 Results from an experiment to find out how a spring stretches as the load on it is increased.

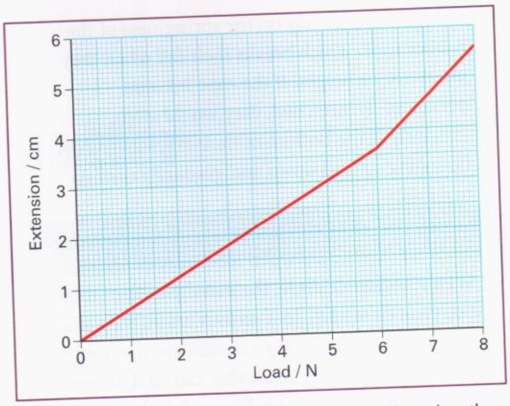

Figure 5.6 An extension–load graph for a spring, based on the data in Table 5.1.

Activity 5.1
Investigating springs

Skills

A03.1 Demonstrate knowledge of how to safely use techniques, apparatus and materials (including following a sequence of instructions where appropriate)
A03.3 Make and record observations, measurements and estimates
A03.4 Interpret and evaluate experimental observations and data

Use weights to stretch a spring, and then plot a graph to show the pattern of your results.

1. Select a spring.
2. Fix the upper end of the spring rigidly in a clamp.
3. Position a ruler next to the spring so that you can measure the complete length of the spring, as shown in Figure 5.4.
4. Measure the unextended length of the spring.
5. Prepare a table for your results, similar to Table 5.1. Record your results in your table as you go along.
6. Attach a weight hanger to the lower end of the spring. Measure its new length.
7. Carefully add weights to the hanger, one at a time, measuring the length of the spring each time.
8. Once you have a complete set of results, calculate the values of the extension of the spring.
9. Plot a graph of extension (y-axis) against load (x-axis) and comment on its shape.

Questions

5.1 A piece of elastic cord is 80 cm long. When it is stretched, its length increases to 102 cm. What is its extension?

5.2 The table shows the results of an experiment to stretch an elastic cord. Copy and complete the table, and draw a graph to represent this data.

Load / N	Length / mm	Extension / mm
0.0	50	0
1.0	54	
2.0	58	
3.0	62	
4.0	66	
5.0	70	
6.0	73	
7.0	75	
8.0	76	

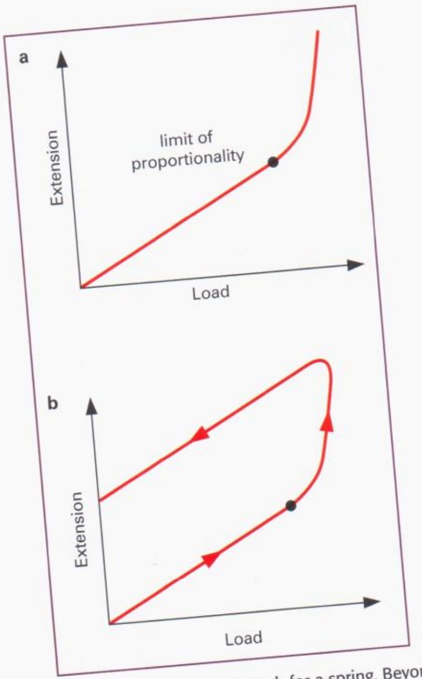

Figure 5.7 **a** An extension–load graph for a spring. Beyond the limit of proportionality, the graph is no longer a straight line, and the spring is permanently deformed. **b** This graph shows what happens when the load is removed. The extension does not return to zero, showing that the spring is now longer than at the start of the experiment.

5.3 Hooke's law

The mathematical pattern of the stretching spring was first described by the English scientist Robert Hooke. He realised that, when the load on the spring was doubled, the extension also doubled. Three times the load gave three times the extension, and so on. This shows up in the graph in Figure 5.7. The graph shows how the extension depends on the load. At first, the graph is a straight line, leading up from the origin. This shows that the extension is proportional to the load.

At a certain point, the graph bends and the line slopes up more steeply. This point is called the **limit of proportionality**. (This point is also known as the *elastic limit*.) If the spring is stretched beyond this point, it will be permanently damaged. If the load is removed, the spring will not return all the way to its original, undeformed length.

The behaviour of the spring is represented by the graph of Figure 5.7**a** and is summed up by **Hooke's law**:

The extension of a spring is proportional to the load applied to it, provided the limit of proportionality is not exceeded.

We can also write Hooke's law as an equation:

$$F = kx$$

In this equation, F is the load (force) stretching the spring, k is the **spring constant** of the spring, (a measure of its stiffness) and x is the extension of the spring.

Study tip

If you double the load that is stretching a spring, the spring will not become twice as long. It is the extension that is doubled.

Worked example 5.1

A spring has a spring constant $k = 20\,N/cm$. What load is needed to produce an extension of 2.5 cm?

Step 1: Write down what you know and what you want to find out.

load $F = ?$

spring constant $k = 20\,N/cm$

extension = 2.5 cm

Step 2: Write down the equation linking these quantities, substitute values and calculate the result.

$F = kx$

$F = 20 \times 2.5 = 50\,N$

So a load of 50 N will stretch the spring by 2.5 cm.

How rubber behaves

A rubber band can be stretched in a similar way to a spring. As with a spring, the bigger the load, the bigger the extension. However, if the weights are added with great care, and then removed one by one without releasing the tension in the rubber, the following can be observed:

- The graph obtained is not a straight line. Rather, it has a slightly S-shaped curve. This shows that the extension is not exactly proportional to the load. Rubber does not obey Hooke's law.
- Eventually, increasing the load no longer produces any extension. The rubber feels very stiff. When the load is removed, the graph does not come back exactly to zero.

Activity 5.2
Investigating rubber

Skills

A03.1 Demonstrate knowledge of how to safely use techniques, apparatus and materials (including following a sequence of instructions where appropriate)

A03.3 Make and record observations, measurements and estimates

A03.4 Interpret and evaluate experimental observations and data

Carry out an investigation into the stretching of a rubber band. This is a good test of your experimental skills. You will need to work carefully if you are to see the effects described above.

1 Hang a rubber band from a clamp. Attach a weight hanger at the lower end so that the band hangs straight down.
2 Clamp a ruler next to the band so that you can measure the length of the rubber band.
3 Prepare a table for your results.
4 One by one, add weights to the hanger. Record the length of the band each time. Add the weights carefully so that you do not allow the band to contract as you add them.
5 Next, remove the weights one by one. Record the length of the band each time. Remove the weights carefully so that you do not stretch the band or allow it to contract too much.
6 Calculate the extension corresponding to each weight.
7 Plot your results on a single graph. Can you see the effect shown in Figure 5.7b?

Hooke and springs

Why was Robert Hooke so interested in springs? Hooke was a scientist, but he was also a great inventor. He was interested in springs for two reasons:

- Springs are useful in making weighing machines, and Hooke wanted to make a weighing machine that was both very sensitive (to weigh very light objects) and very accurate (to measure very precise quantities).

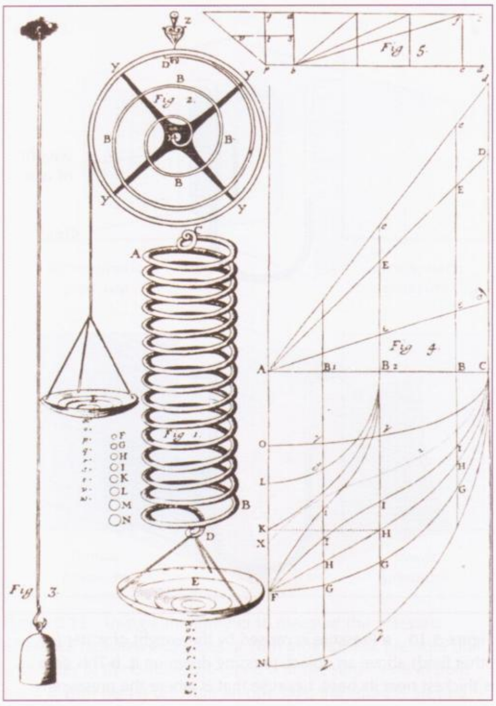

Figure 5.8 Robert Hooke's diagrams of springs.

- He also realised that a spiral spring could be used to control a clock or even a wristwatch.

Figure 5.8 shows a set of diagrams drawn by Hooke, including a long spring and a spiral spring, complete with pans for carrying weights. You can also see some of his graphs.

For scientists, it is important to publish results so that other scientists can make use of them. Hooke was very secretive about some of his findings, because he did not want other people to use them in their own inventions. For this reason, he published some of his findings in code. For example, instead of writing his law of springs as given above, he wrote this: *ceiiinosssttuv*. Later, when he felt that it was safe to publish his ideas, he revealed that this was an anagram of a sentence in Latin. Decoded, it said: *Ut tensio, sic vis*. In English, this is: 'As the extension increases, so does the force.' In other words, the extension is proportional to the force producing it. You can see Hooke's straight-line graph in Figure 5.8.

Questions

5.3 A spring requires a load of 2.5 N to increase its length by 4.0 cm. The spring obeys Hooke's law. What load will give it an extension of 12 cm?

5.4 A spring has an unstretched length of 12.0 cm. Its spring constant k is 8.0 N/cm. What load is needed to stretch the spring to a length of 15.0 cm?

5.5 The results of an experiment to stretch a spring are shown in table. Use the results to plot an extension–load graph. On your graph, mark the limit of proportionality and state the value of the load at that point.

Load / N	Length / m
0.0	0.800
2.0	0.815
4.0	0.830
6.0	0.845
8.0	0.860
10.0	0.880
12.0	0.905

5.4 Pressure

If you dive into a swimming pool, you will experience the pressure of the water on you. It provides the upthrust on you, which pushes you back to the surface. The deeper you go, the greater the pressure acting on you. Deep-sea divers have to take account of this. They wear protective suits, which will stop them being crushed by the pressure. Submarines and marine exploring vehicles (Figure 5.9) must be designed to withstand very great pressures. They have curved surfaces, which are less likely to buckle under pressure, and they are made of thick metal.

This pressure comes about because any object under water is being pressed down on by the