13 Density

- The density of some common materials
- Measuring the density of a rectangular block
- Measuring the density of a liquid
- The density of gases

Figure 13.1 Timber can be transported by water because wood is less dense than water, so it floats at the surface.

Which is heavier – the wood in the trunk of a tree or the metal in a coin? Your first answer might be to say the trunk of the tree, but it can float on water while a coin would quickly sink to the bottom.

To be a fair comparison we need to find the masses of equal volumes. If we found the mass of a piece of wood the size of a coin we would see it was lighter.

Comparing densities

The **density** of a substance is a measure of the amount of matter that is present in a certain volume of it. The following equation shows how the density of a substance can be calculated:

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

The basic SI unit of density is found by dividing the unit of mass by the unit of volume, so it is kg/m^3. This is pronounced 'kilograms per metre cubed'. Table 13.1 shows the densities of some solid materials.

In the school laboratory, when small amounts of materials are used, the density of a substance is often calculated using masses measured in grams and volumes in centimetres cubed, giving a density value in g/cm^3. The density value in units of g/cm^3 can be converted to a value in kg/m^3 by multiplying it by 1000. For example, ice was found to have a density of $0.920\,g/cm^3$. This can also be expressed as $0.920 \times 1000 = 920\,kg/m^3$.

1 Arrange the materials in Table 13.1 in order of density, starting with the least dense material.

2 Which is heavier, 1 m^3 of steel or 1 m^3 of aluminium?

3 Which is heavier, 1 kg of steel or 1 kg of cork?

Table 13.1 The density of some common solid materials

Material	Density/kg/m^3
ice	920
cork	250
wood	650
steel	7900
aluminium	2700
copper	8940
lead	11350
gold	19320
polythene	920
perspex	1200
expanded polystyrene	15

Measuring the density of a rectangular solid block

The mass of the block is found by placing the block on a balance (check the balance reads zero first) and reading the scale. The mass in grams is recorded. The volume is found by multiplying the length, width and height of the block together and recording the value in centimetres cubed. The density of the material in the block is found by dividing the mass by the volume and expressing the quantity in the unit g/cm^3.

4 A block of material is 8 cm long, 2 cm wide and 3 cm high, and has a mass of 46 g. What is its density?

5 **a)** Convert the value you found for the density in question **4** to kg/m^3.

b) Compare the density of the material in the block with those in Table 13.1. Which materials in the table have densities closest to that of the block?

c) How could you convert the value of a density given in kg/m^3 to g/cm^3?

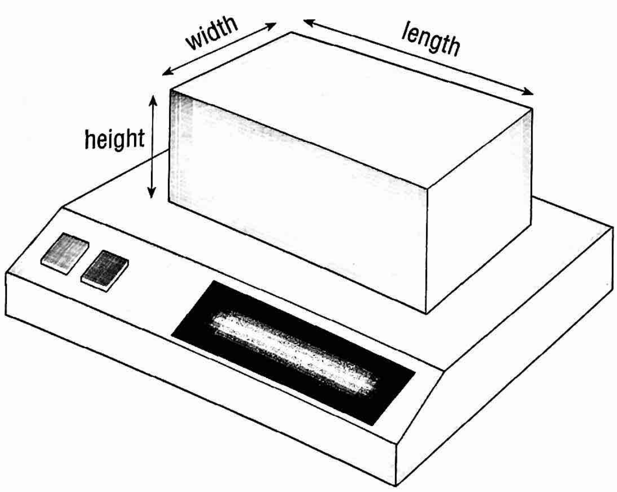

Figure 13.2 Finding the mass of a block using a top-pan balance

Measuring the density of an irregularly shaped solid

The density of an irregularly shaped solid, such as a pebble, can be found in the following way.

The mass of the pebble is found by placing it on a top-pan balance, as for a solid of a regular shape. The volume is found by pouring water into a measuring cylinder until it is about half full. The volume of the water is read on the scale and then the pebble is carefully lowered into the water on a thin string. When the pebble is completely immersed in the water, the volume of the water is read again on the scale. The volume of the pebble is found by subtracting the first reading from the second. The density of the pebble is found by dividing the mass of the pebble by its volume.

6 The mass of a pebble was 88.4 g. The original volume of water in the measuring cylinder was 50 cm^3 and the combined volume of water and pebble was 84 cm^3. What is the density of the rock in the pebble?

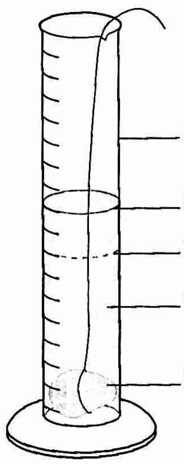

Figure 13.3 Measuring the volume of a pebble

Measuring the density of a liquid

The density of a liquid is found in the following way.

1. A measuring cylinder is put on a balance and its mass found (A).
2. The liquid is poured into the measuring cylinder and its volume measured (V).
3. The mass of the measuring cylinder and the liquid it contains is found (B).
4. The mass of the liquid is found by subtracting A from B.
5. The density of the liquid is calculated by dividing the mass of the liquid by its volume:

$$\text{density} = \frac{B-A}{V}$$

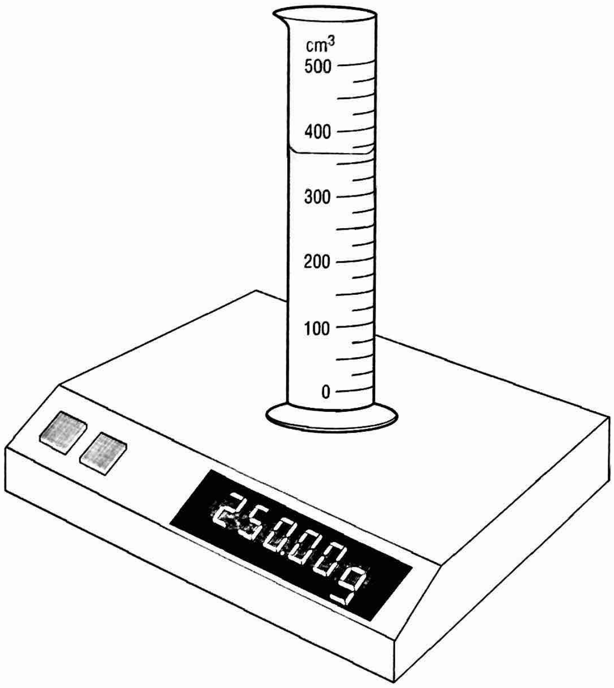

Figure 13.4 Finding the mass of a measuring cylinder and the liquid it contains

Table 13.2 shows the densities of some liquids.

Table 13.2 The densities of some liquids

Liquid	Density/kg/m³
mercury	13 550
water at 4 °C	1000
corn oil	900
turpentine	860
paraffin oil	800
methylated spirits	790

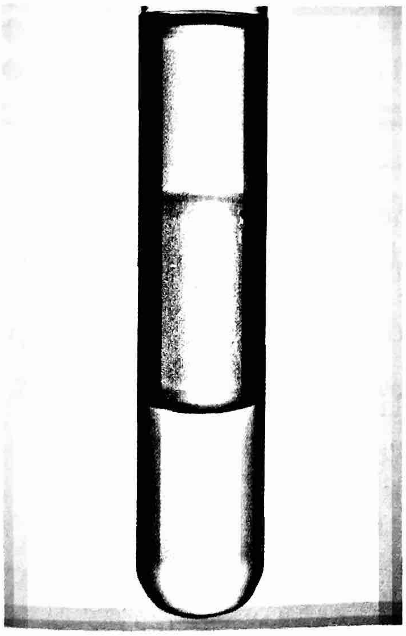

Figure 13.5 Liquids of different densities form layers when they are mixed

Floating and sinking

When a piece of wood is placed in water, the wood floats. This is due to the difference in the densities of the wood and the water. From Tables 13.1 and 13.2 you can see that wood is less dense than water. When two substances, such as a solid and a liquid or a liquid and a liquid, are put together the less dense substance floats above the denser substance.

When full-fat milk is poured into a container, such as a bottle, the cream, which contains fat and is less dense than the more watery milk, rises to the top.

7 When paraffin oil and water are poured into a container they separate and the paraffin oil forms a layer on top of the water. When water and mercury are mixed the water forms a layer on top of the mercury.

a) What can you conclude from these two observations?

b) What do you predict would happen if water and corn oil were mixed together? (Refer to Table 13.2.)

8 What do you think would happen if the following solids were placed in water?

a) expanded polystyrene

b) polythene

c) perspex

Explain your answers.
(Refer to Table 13.1.)

9 What do you think would happen if the following solids were placed in mercury?

a) steel

b) gold

c) lead

Explain your answers.

10 Why do you think the temperature of water is shown when the value of its density is given?

11 Most people can just about float in water (Figure 13.6). What does this tell you about the density of the human body?

12 When salt is dissolved in water the solution that is produced has a greater density than pure water. An object that floats on pure water is shown in Figure 13.7. When it is placed in salt solution do you predict that it will rise higher in the solution than it did in pure water, or sink lower?

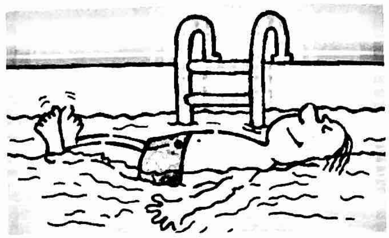

Figure 13.6

pure water

Figure 13.7

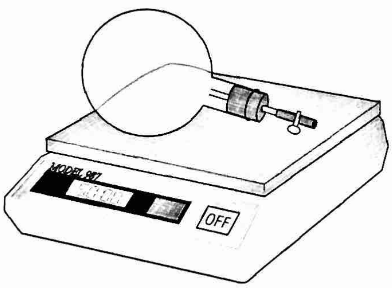

Figure 13.8 Finding the mass of a flask of air using a top-pan balance

13 How is the process of finding the mass of a gas different from that of finding the mass of a liquid? Why is the difference necessary?

14 How can gas density be used to explain why hydrogen rises in air and carbon dioxide sinks?

Density of gases

Air is a mixture of gases. Its density can be found in the following way.

1. The mass of a round-bottomed flask with its stopper, pipe and closed clip is found by placing it on a sensitive top-pan balance. The flask is then attached to a vacuum pump and the air is removed from the flask and the clip is closed.
2. The mass of the evacuated flask, stopper, pipe and closed clip is found by placing it back on the balance. The mass of the air in the flask is found by subtracting the second reading from the first.
3. The volume of the air removed is found by opening the clip under water so that water enters to replace the vacuum. The water is then poured into a measuring cylinder to find the volume.

Table 13.3 shows the densities of some gases.

Table 13.3 The densities of some gases

Gas	Density / kg/m^3
hydrogen	0.089
air	1.29
oxygen	1.43
carbon dioxide	1.98

The density of a gas changes as its temperature and pressure change. The densities of gases are compared by measuring them at the same temperature and pressure. This is called the standard temperature and pressure (STP). The standard temperature is 0 °C. The standard pressure of a gas is the pressure that will support 760 mm of mercury in a vertical tube.

When two gases meet the less dense gas rises above the denser gas.

◆ SUMMARY ◆

- The density of a substance is a measure of the amount of matter in a certain volume of it (*see page 170*).
- Common materials have a wide range of densities (*see page 171*).
- The density of a solid can be found by making measurements (*see page 171*).
- The density of a liquid can be found by making measurements (*see page 172*).
- The density of a gas can be found by making measurements (*see page 174*).

End of chapter questions

1 It is claimed that if you could find a lake of water large enough you could float the planet Saturn in it. The density of Saturn is 687 kg/m^3. Look at Table 13.2 and decide if your agree. Explain how you came to your decision.

2 Use Table 13.3 to help you answer this question.

a) A hydrogen balloon floats in air but would it float in the atmosphere on Mars, which has a density of 0.020 kg/m^3? Explain your answer.

b) Could an air balloon float in the Martian atmosphere? Explain your answer.

c) The Martian atmosphere is made up mostly of one gas in Table 13.3. Which gas is it? Explain your answer.

3 If you were writing a science fiction story and wanted to have buildings floating in the atmosphere of Venus (density 65 kg/m^3) which solid could you use? Look at Table 13.1 to decide.

14 Pressure

- Pressure on a surface
- Reducing pressure
- Increasing pressure
- Pressure in liquids
- Pressure in gases

If you hold out your left hand with the palm upwards and press down on the fingertips with the fingertips of the right hand what do you feel? You may say that there is a **force** pushing down from your right hand or you may say that your fingertips are feeling a pressure. Both explanations would be correct. Now repeat with the left hand pushing on the right hand. Is there a difference? You may answer using words such as 'force' and 'pressure', but what is the connection between them? You will find out in this chapter.

Pressure on a surface

When a force (such as the push of your hand) is exerted over an area (such as the area of your fingertips) we describe the effect in terms of **pressure**. Pressure can be defined by the equation:

$$\text{pressure} = \frac{\text{force}}{\text{area}}$$

The SI unit for pressure is N/m^2 but it can also be measured in N/cm^2.

An object resting on a surface exerts pressure on the surface because of the object's weight. **Weight** is the force produced by gravity acting on a solid, a liquid or a gas, pulling the material downwards towards the centre of the Earth. The weight acts on the mass of that material. For example, the weight of a solid cube acts on that cube (Figure 14.1).

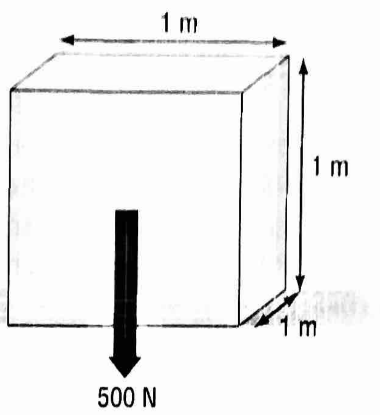

Figure 14.1 The weight acting on a cube of material

The cube pushes down on the ground (or other surface that it rests on) with a force equal to its weight. The pressure that the cube exerts on the ground is found by using the equation above. For example, if the cube has a weight of 500 N and the area of its side is 1 m², the pressure it exerts on the ground is:

$$\text{pressure} = \frac{500}{1} = 500\,\text{N/m}^2$$

If the cube has a weight of 500 N and the area of its side is 2 m², the pressure it exerts on the ground is:

$$\text{pressure} = \frac{500}{2} = 250\,\text{N/m}^2$$

An object exerts a pressure on the ground according to the area of its surface that is in contact with the ground. For example, a block with dimensions 1 m × 1 m × 2 m and a weight of 200 N will exert a pressure of 200 ÷ 1 = 200 N/m² when it is stood on one end (Figure 14.2a) but a pressure of only 200 ÷ 2 = 100 N/m² when laid on its side (Figure 14.2b).

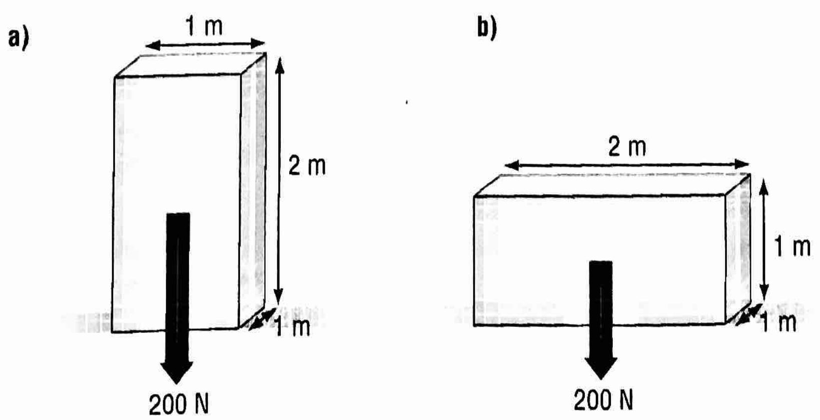

Figure 14.2 The weight acting on a block in two positions

1 What is the pressure exerted on the ground by a cube which has a weight of 600 N and a side area of:
   a) 1 m²
   b) 3 m²?

2 What is the pressure exerted on the ground by an object that has a weight of 50 N and a surface area in contact with the ground of:
   a) 1 cm²
   b) 10 cm²
   c) 25 cm²?

3 **a)** What pressure does a block of weight 600 N and dimensions 1 m × 1 m × 3 m exert when it is:
   i) laid on its side
   ii) stood on one end?
   b) Why does it exert different pressures in different positions?

Your weight acting downwards causes you to exert a force on the ground through the soles of your shoes. If you lie down, this force acts over all the areas of your body in contact with the ground. These areas together are larger than the areas of the soles of your shoes and you therefore push on the ground with less pressure when lying down than when you are standing up.

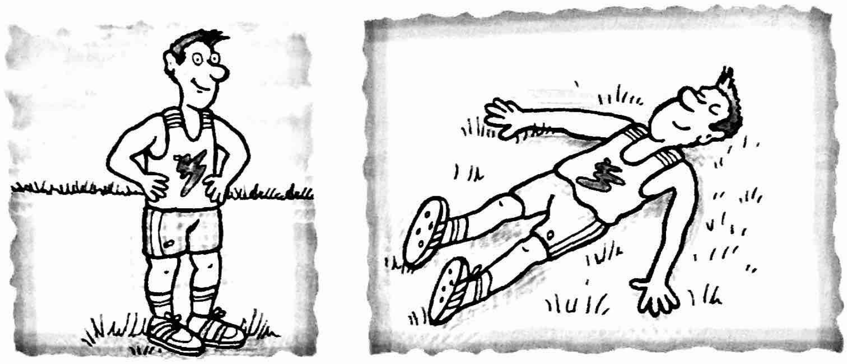

Figure 14.3 The force you exert downwards acts over a larger area when you lie down.

Reducing the pressure

When people wear skis, the force due to their weight acts over a much larger area than the soles of a pair of shoes. This reduces the pressure on the soft surface of the snow and allows the skier to slide over it without sinking.

Figure 14.4 Skis stop you sinking into the snow.

4 Drivers in Iceland, when going out on the snow, let their tyres down until they are very soft. The tyres spread out over the surface of the snow as they drive along. Why do you think the drivers do this?

Increasing the pressure

Studs

Sports boots for soccer and hockey have studs on their soles. They reduce the area of contact between your feet and the ground. When you wear a pair of these boots your downward force acts over a smaller area than the soles of your feet and you press on the ground with increased pressure. Your feet sink into the turf on the pitch and grip the surface more firmly. This makes it easier to run about without slipping while you play the game.

Pins and spikes

When you push a drawing pin into a board, the force of your thumb is spread out over the head of the pin so the low pressure does not hurt you. The same force, however, acts at the tiny area of the pin point. The high pressure at the pin point forces the pin into the board.

Sprinters use sports shoes that have spikes in their soles. The spike tips have a very small area in contact with the ground. The weight of the sprinter produces a downward force through this small area and the high pressure pushes the spikes into the hard track, so the sprinter's feet do not slip when running fast.

Figure 14.5 The spikes stop the sprinter from slipping on the track. In a similar way, the studs on a soccer boot help the player to grip the turf.

5 A girl wearing trainers does not sink into the lawn as she walks across it but later when she is wearing high-heeled shoes she sinks into the turf. Why does this happen?

Knives

As we have seen, high pressure is made by having a large force act over a small area. The edge of a sharp knife blade has a very small area but the edge of a blunt knife blade is larger. If the same force is applied to each knife, the sharp blade will exert greater pressure on the material it is cutting than the blunt knife blade and will therefore cut more easily than the blunt blade.

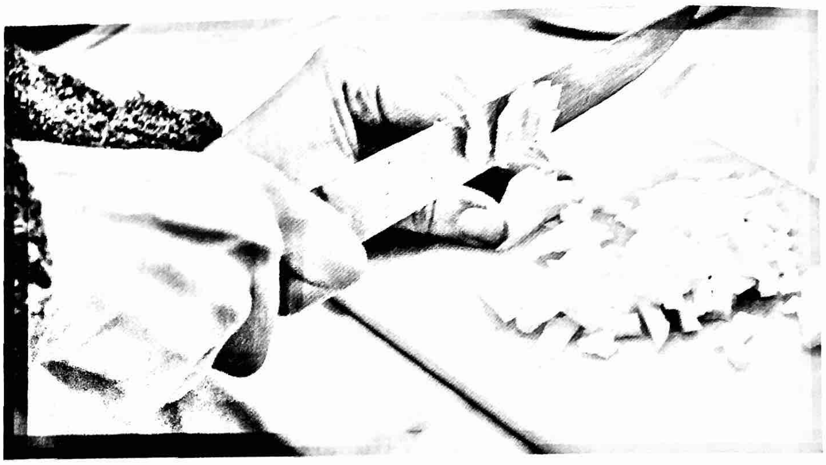

Figure 14.6 Knives cut well when they are sharp because of the high pressure under the blade.

Particles and pressure

Matter is made from particles. In solids the particles are held in position. In liquids the particles are free to move around each other and in gases the particles are free to move away from each other.

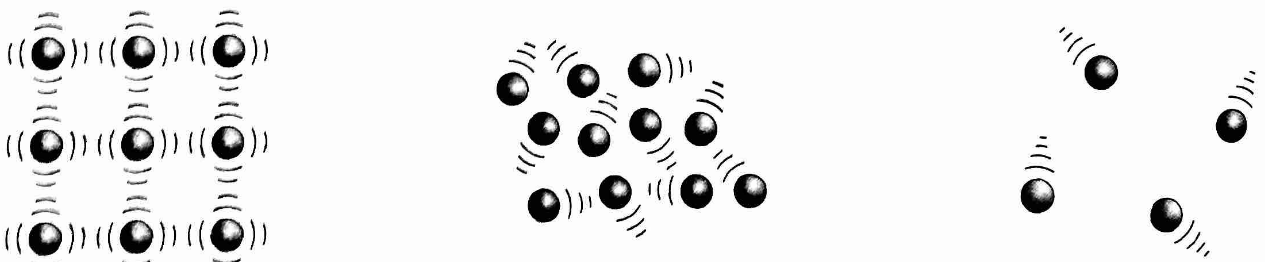

Figure 14.7 Arrangement of particles in a solid, a liquid and a gas

Pressure in liquids

In a solid object the pressure of the particles acts through the area in contact with the ground. In a liquid the pressure of the particles acts not only on the bottom of the container but on the sides too (Figure 14.8).

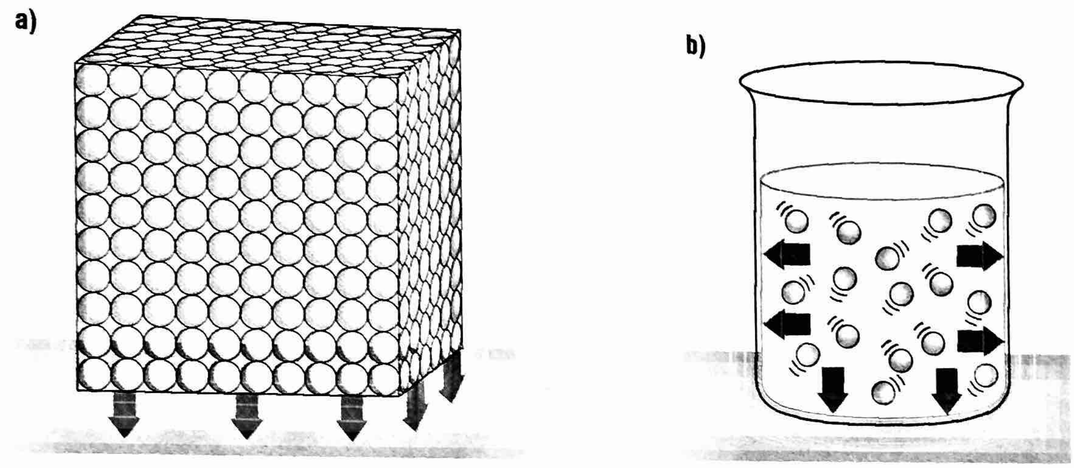

Figure 14.8 Pressure exerted by **a)** particles in a solid block and **b)** particles in a liquid

Pressure and depth of a liquid

The change in pressure with depth in a liquid can be demonstrated by setting up a can as shown in Figure 14.9. When the clips are removed from the three rubber tubes, water flows out as shown. All three jets of water leave the can horizontally but the force of gravity pulls them down. The water under the greatest pressure travels the furthest horizontally before it is pulled down. The water under the least pressure travels the shortest distance horizontally before it is pulled down.

6 How does the path of the jet of water at the bottom of the can in Figure 14.9 change as the water level in the can falls? Why does it change?

7 Why does a dam need a wall shaped like that in Figure 14.10?

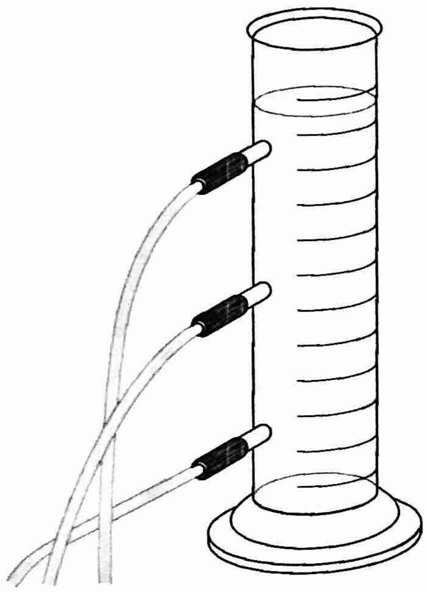

Figure 14.9 Jets of water leaving a can at different depths

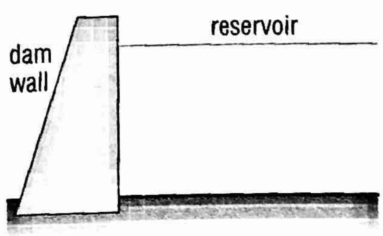

Figure 14.10 Cross-section of a dam wall

Hydraulic equipment

If pressure is applied to the surface of a liquid in a container, the liquid is not squashed. It transmits the pressure so that pressure pushes on all parts of the container with equal strength.

In hydraulic equipment a liquid is used to transmit pressure from one place to another. The pressure is applied in one place and released in another. If the area where the pressure is applied is smaller than the area where the pressure is released, the strength of the force is increased, as Figure 14.11 shows.

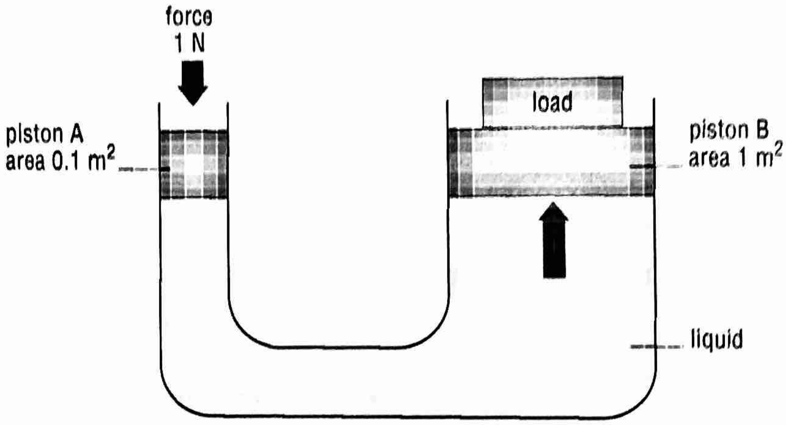

Figure 14.11 A simple hydraulic system

A car may be raised with a small force by using a hydraulic jack. When a small force is applied to a small area of the liquid in the jack, a larger force is released across a larger area and acts to raise the car.

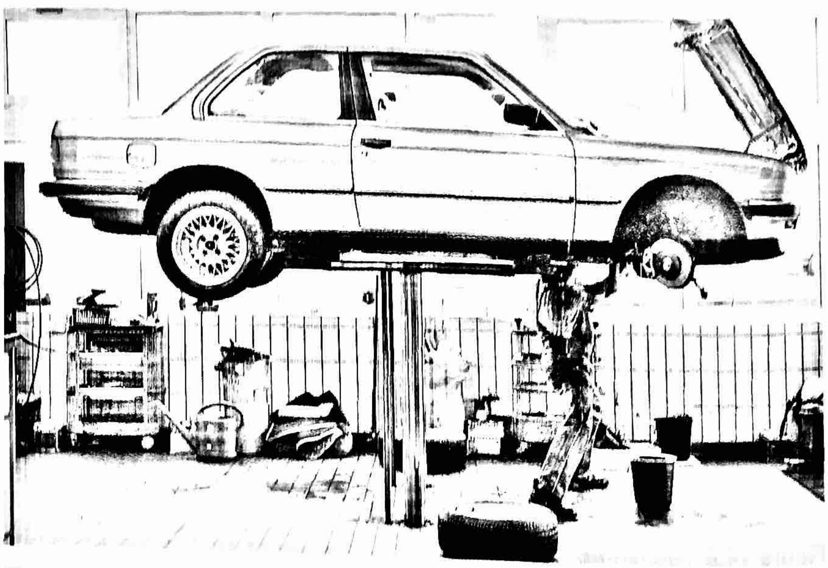

Figure 14.12 This car has been raised into the air for repairs by a hydraulic jack.

8 Why are hydraulic systems known as 'force multipliers'?

The brake system on a car is a hydraulic mechanism. The small force exerted by the driver's foot on the brake pedal is converted into a large force acting at the brake pads. This results in a large frictional force that makes it harder for the wheels to turn and so stops the car.

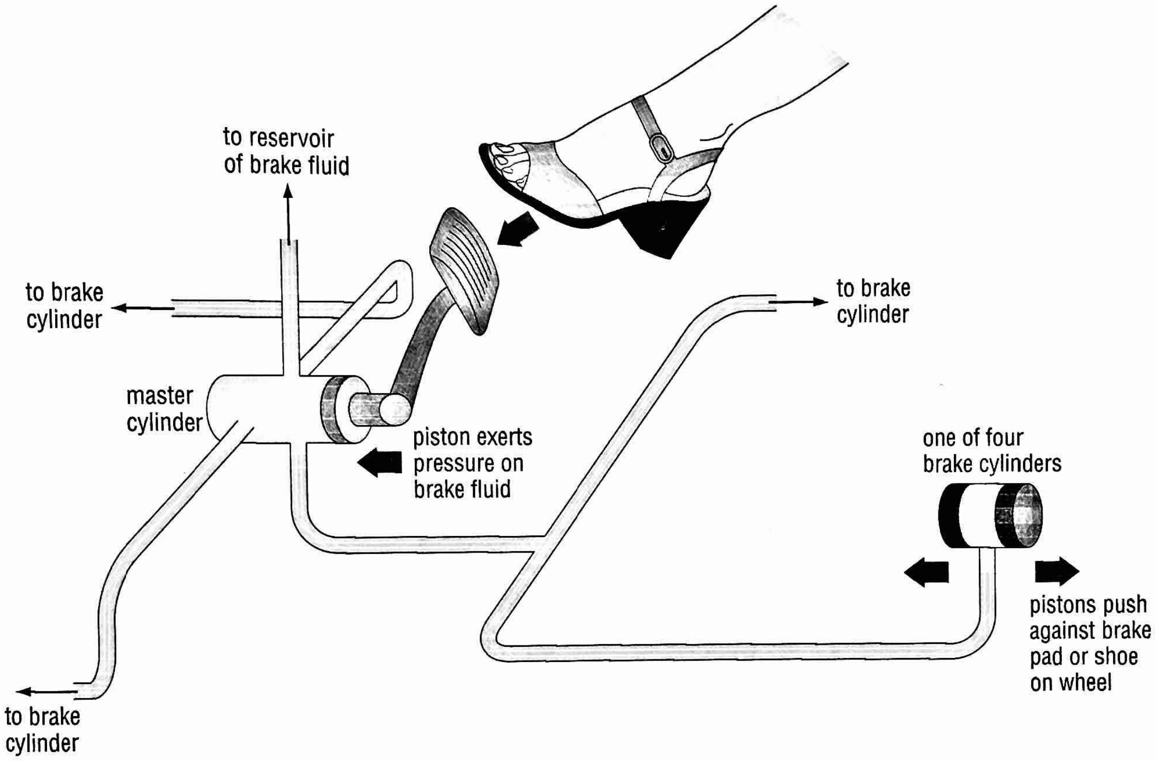

Figure 14.13 Hydraulic car brakes

Pressure in gases

Pressure of the atmosphere

The atmosphere is a mixture of gases. The molecules from which the gases are made move around but are pulled down by the force of gravity exerted on them by the Earth. The atmosphere forms a layer of gases over the surface of the Earth that is about 1000 km high. This creates a pressure of about 100 000 N/m^2 – equivalent to a mass of 10 tonnes on 1 m^2 – although this gets less as you go up through the atmosphere.

You do not feel the weight of this layer of air above you pushing down because the pressure it exerts acts in all directions, as it does in a liquid. Thus, the air around you is pushing in all directions on all parts of your body. You are not squashed because the pressure of the blood flowing through your circulatory system is strong enough to balance atmospheric pressure.

The atmosphere does not crush ordinary objects around us. For example, the pressure of the air pushing down on a tabletop is balanced by the pressure of the air underneath the table pushing upwards on the tabletop.

Ear popping

The middle part of the ear (Figure 14.14) is normally filled with air at the same pressure as the air outside the body. The air pressure can adjust because when you swallow, the Eustachian tubes in your throat open and air freely enters or leaves the middle ear. For example, if the air pressure is greater outside the body and in the mouth, when you swallow more air will enter the middle ear to raise the air pressure there.

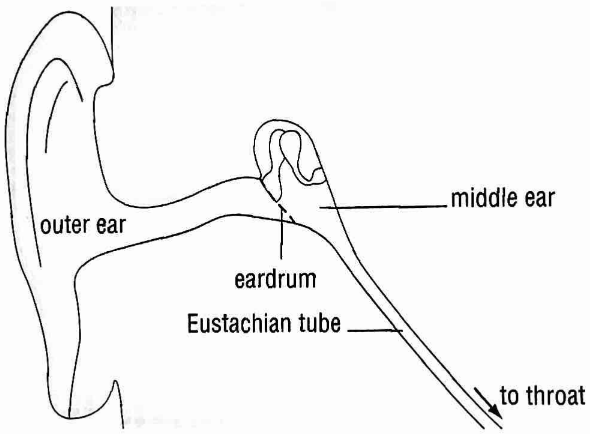

Figure 14.14 The ear and throat

If you travel in a car that quickly climbs a steep hill, your ears sometimes 'pop'. This is because you are rising rapidly into the atmosphere where the pressure is lower. The popping sensation is caused by the air pressure being lower in the throat and outside the body than in the middle ear. The difference in pressure causes the eardrum to push outwards. When you swallow, the air pressure in your middle ear reaches the same pressure as the air in your throat and outside, and the eardrum moves quickly back – or 'pops' – into place.

9 What happens if the air pressure in the throat and outside the body is less than the air pressure in your middle ear when you swallow?

10 If you ride quickly down a hill on a bicycle your eardrums are pushed in before they pop back. Why is this?

How a sucker sticks

When an arrow with a sucker on the end hits a target the arrow stays in place due to air pressure. As the elastic sucker hits the flat surface it deforms and pushes out some of the air from beneath the cup. The pressure of the remaining air in the cup is less than that of the air pressure outside the cup. The higher pressure of the air outside the cup holds the sucker in place (Figure 14.15).

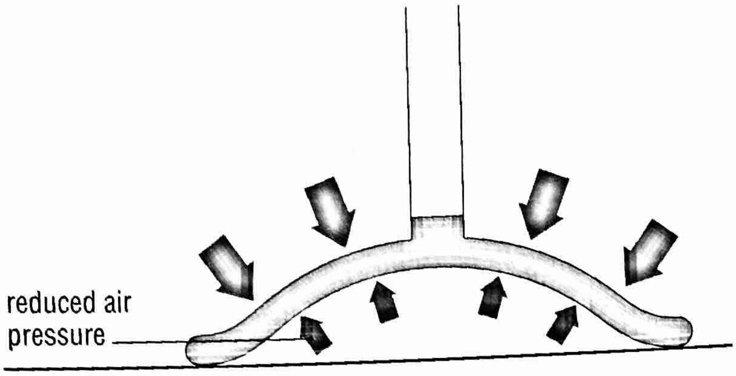

Figure 14.15 Side view through a sucker

Crushing a can

The strength of the air pressure in the atmosphere can be demonstrated by taking the air out of a can. This can be done in two ways.

Using steam

The can has a small quantity of water poured into it and is heated from below. As the water turns to steam it rises and pushes the air out of the top of the can. If the heat source is removed and the top of the can immediately closed, the remaining steam and water vapour in the can will condense, leaving only a small quantity of air in the can. This air has a much lower pressure than the air pressure outside the can and the higher pressure crushes the can.

Using a vacuum pump

A vacuum pump can reduce the pressure in containers. If one is used to remove air from a can, the can collapses due to the greater pressure of the air on the outside (Figure 14.16).

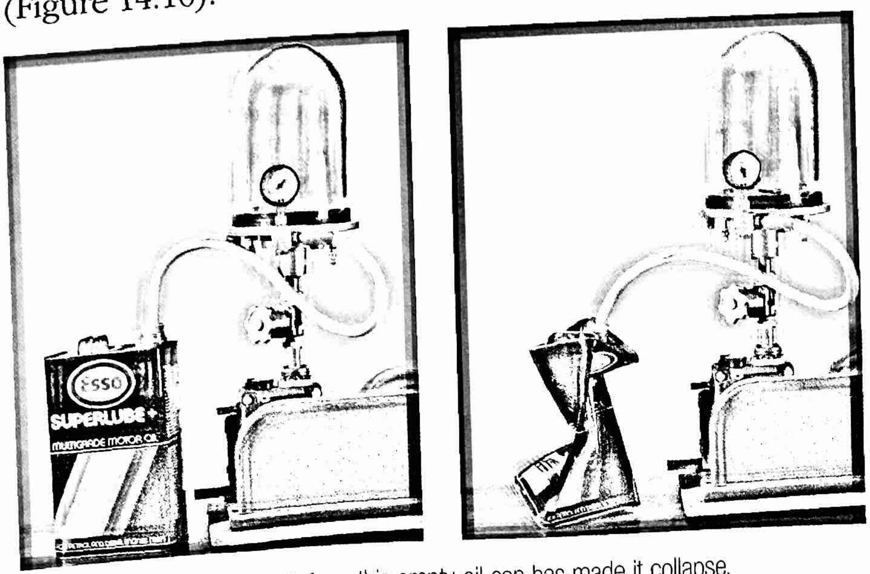

Figure 14.16 Removing air from this empty oil can has made it collapse.

Aerosols

An aerosol spray can contains a gas that is at a higher pressure than air pressure. It is held in the can by a valve in the nozzle (Figure 14.17). When the nozzle is pressed down a spring is squashed and the nozzle opening enters the inside of the can, effectively opening the valve. The higher pressure of the gas in the can pushes on the liquid in the can and it rushes up the tube and through the jet where it forms a fine spray of liquid droplets (an 'aerosol'). When the nozzle is released the spring is no longer squashed and it pushes the nozzle upwards. This removes the nozzle opening from inside the can, effectively closing the valve, and stops the flow of spray.

Aerosol cans used to contain a gas made from chlorofluorocarbons (CFCs). These chemicals are now known to damage the ozone layer. In many countries they have now been replaced with gases such as gases produced at oil refineries that do not damage the ozone layer.

11 How many uses of aerosol cans in the home can you think of?

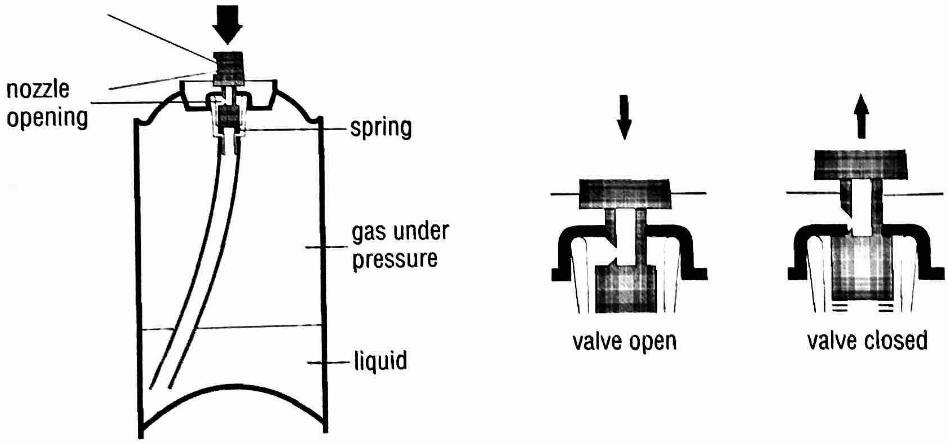

Figure 14.17 Inside an aerosol can

Hovercraft

A hovercraft uses the pressure of air to raise it from the ground. It does this by drawing air from above with powerful fans (Figure 14.18). There is a skirt around the edge of the hovercraft, which prevents the air from escaping quickly, and the air pressure beneath the hovercraft increases. The upward pressure of the air trapped beneath the hovercraft lifts the hovercraft off the ground. The fans continue to spin to replace air that is lost from the edges of the skirt.

The cushion of air beneath the hovercraft reduces friction between it and the ground. The cushion of air is also maintained when the hovercraft moves over water. The forward or backward thrust on the hovercraft is provided by propellers in the air above the hovercraft.

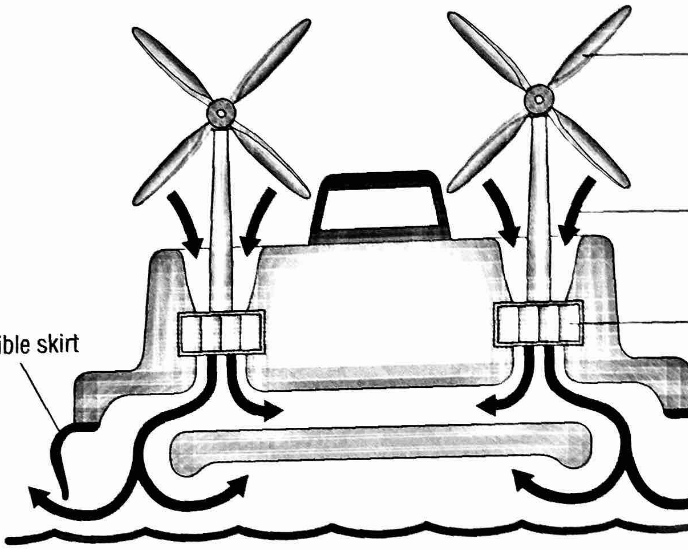

Figure 14.18 Hovercrafts work by riding on a cushion of air above the ground or water surface.

12 What are the advantages of using a hovercraft as a means of transport?

◆ SUMMARY ◆

- ◆ Pressure acts when a force acts over an area of surface (*see page 176*).
- ◆ When a solid object exerts a pressure on the surface below it, the smaller the area of contact, the greater the pressure (*see page 177*).
- ◆ Pressure in a liquid acts in all directions and increases with the depth of the liquid (*see page 181*).
- ◆ In hydraulic systems pressure is transmitted through a liquid (*see page 182*).
- ◆ The atmosphere exerts a pressure (*see page 183*).
- ◆ Use is made of the pressure of air in various devices such as suckers, pumps and hovercraft. Use is made of the pressure of other gases in aerosols (*see pages 184–188*).

End of chapter question

How could you explain the following, using the model of air made up of particles which move freely?

a) How air pushes on a surface.

b) Why the pressure in an inflated tyre is higher than the air pressure outside.

c) Why a sucker stays in place on a flat surface.