4

Properties of water

We are now going to broaden our view of water to include the solid and gaseous forms, ice and water vapour, both of which play important roles in the story of life. We shall look in some detail at the floating of ice on water, the evaporation of water to form water vapour, and the capacity of water to dissolve substances, and at the consequences for living organisms. Then at the end of the section we shall look at the overall recycling of water that occurs on Earth — the water cycle.

Most of the study time for this section will be dedicated to learning about important properties of water and their significance for life. However, you will also develop more maths skills, particularly those relating to calculating areas, volumes and densities, and you will learn more about effective study and the use of diagrams. Because this section contains more scientific concepts than previous ones, you may need to spend more time on it than you did on the previous sections.

Scanning a section

The previous two paragraphs have given a brief overview of the science and skills covered in this section, and you will find that there are similar 'introductions' at the start of each major section in this book. But to give yourself a more complete view of what a section contains, we recommend that you quickly scan through it before studying it more thoroughly. Your aim should be to identify the main topics and the key ideas. You should skip over the questions and activities, and not worry about highlighting or making notes. Pay particular attention to the first and last paragraphs in each section (e.g. Section 4.1, Section 4.2, etc.) because these will often give a good indication of what the sections are about. Make sure that you read the summary at the end of Section 4 too, since this will contain the most important points. As you are scanning the section, you may find it helpful to note down in your Study File the main topics, and to mark any of these that look particularly straightforward or difficult.

Activity 4.1 Reading to learn: scanning a section

So scan through Section 4 now, and note down the main topics before you start to study the section in detail. ◀

Active reading: making notes

In Section 3 you were introduced to the idea of thinking actively about the text as you read it. We suggested that you keep asking yourself 'what are the key points of this section?' and that you highlight (or underline) the important ideas in the book as you are studying. Another activity that most students find helpful is making notes as they are reading. These notes might include examples that illustrate what is being discussed in the text, thoughts that you have as you read that help you understand the arguments presented, connections with other topics that you have studied, or something that helps jog your memory. It is also very useful to make a note of parts of the text that you don't understand, so that you can come back to re-study them later, or can discuss them with other students or your tutor. Of course, the 'notes' that you make don't just have to be words; your own sketches and diagrams are equally valuable ways of recording your thoughts and responses to the text. We give help with this in a later section. You will find that your notes are extremely valuable when you come back to a section at a later stage in the course, particularly when you need to answer assignment questions.

The margins of the book are generally the best place for most notes, and if you make these notes in pencil you can erase any of them that are no longer appropriate. For example, when the meaning of a paragraph that initially puzzled you eventually becomes clear, then you can erase your note that indicated that you didn't understand it. There will be places in the book where there isn't enough space for the notes you want to make, and you can then use sheets of paper that you file in your Study File with your responses to questions and activities. To remind yourself that you've made such notes you will probably want to write 'see Study File' at the appropriate place in the book.

Activity 4.2 Making notes as you read the text

As you study Section 4.1, highlight key points in the text and make notes in the margins, as we suggested above. When you have completed this section, you can compare your notes and highlighted phrases with a sample produced by a student. ◀

4.1 Water, ice and water vapour

The discussion in this book has so far concentrated on liquid water. That is not surprising, since the most obvious signs of the huge quantities of water on our planet are liquid — rivers, lakes, seas, oceans and rain. Moreover, when water is playing its most important roles in living organisms, it is a liquid. Indeed, the word water generally conveys a picture of a liquid. If, however, you were shivering on a polar ice-cap, the most obvious form of water all around you would be snow and ice, that is, you would see plenty of evidence for water as a *solid*. On the other hand, if you were to boil water in a kettle, you would generate **water vapour**, which is a *gas*, and if the water were left boiling for long enough, all of the liquid water in the kettle would be converted to water vapour. The hot water vapour that emerges from the spout is not visible, but it cools as it meets the cold air, and it condenses into tiny droplets of *liquid* water, rather like a hot mist or cloud (Figure 4.1). As these water droplets move further away from the spout, they evaporate to become water vapour once more.

It is worth noting in passing that scientists use the word 'steam' to describe the *gaseous* form of water. So it is steam that emerges from the spout, and it is steam that is formed again when the cloud evaporates. The intermediate stage, where you can see a cloud of tiny water droplets, is *not* steam according to the scientific use of the word. This is rather different from the everyday use of the word: most people think of the cloud of liquid water droplets as being steam, but this is not the correct scientific use of the word.

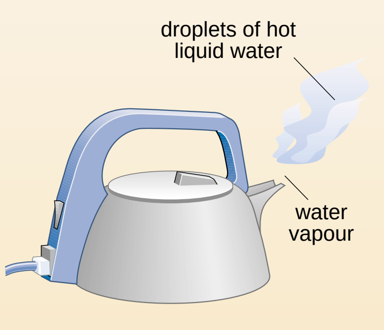


Figure 4.1 Conversion of boiling liquid water to water vapour (evaporation), then to liquid water droplets (condensation).

You will find examples of other words in this book that have a precise scientific meaning but that are used more loosely in everyday language (recall the use of the words *mass* and *weight* in Box 3.1). You need to be aware of the scientific meaning of such words and make sure that you use them correctly in your own writing. Newspapers quite often use scientific words incorrectly, and as you become more familiar with scientific language you will be able to spot when words are misused.

However, some scientific terms are generally used correctly in everyday language. For example, the processes of **evaporation** and **condensation**, both of which are demonstrated in Figure 4.1, are terms that refer to the changes from a liquid to a gas and from a gas to a liquid, respectively. The conversion of a liquid into a gas is also often called **vaporization**. The terms 'evaporation'and 'vaporization' are frequently used interchangeably.

In fact, the air around us contains water vapour all of the time. It is not visible to the human eye, so you might wonder why we are convinced that it is there. Its presence can be detected with scientific instruments, but you may be able to think of some observations or experiments that provide further evidence for the presence of water vapour in the air.

Condensation of water on cold objects is evidence for the presence of gaseous water in the air. If you take a can or bottle out of the refrigerator, drops of liquid water — condensation — will appear on its sides. This water must have come from the air. When water vapour in the air comes into contact with a cold surface, it tends to condense as liquid water on that surface. There is an important reason for this occurrence: cold air cannot hold as much water vapour as warm air. The chilled can cools the surrounding air so that it is not capable of holding as much water vapour and the 'rejected' water condenses as a liquid on the cold surface of the can. You will also have observed condensation on the inside of windows when the temperature is cold outside.

Mist, fog, clouds, rain and snow are also consequences of water vapour in the air. All are formed when moist air cools. As the air temperature falls, the air cannot hold all of the water vapour it contains and some of it condenses into very tiny droplets. If these droplets are very small, they remain suspended in the air, either as clouds if at high altitudes, or as mist or fog if near the Earth's surface.

Thus, ice, water vapour and water are different forms of one and the same substance. In science, the three different forms — **solid**, **liquid** and **gas** — are called the different **states** of substances. The observation of these three states begs several questions.

- What are the differences between the solid, liquid and gaseous states?
- Are ice, liquid water and water vapour composed of the same substance?
- What determines whether water exists as a solid, liquid or gas?

To answer these questions fully, we would have to delve prematurely into the physics and chemistry that you will meet later in the course, so for now we shall just formulate some preliminary answers.

4.1.1 Differences between solid, liquid and gaseous states

Let's think about how we might define solids, liquids and gases so that we can distinguish between them easily. A good definition of each of these three states should be applicable to any solid, liquid or gas that you can think of, but it will simplify matters if we take familiar examples of each of these states and think about their properties.

Question 4.1 By thinking of a piece of iron, some cooking oil, and the air, note down the main features of a solid, a liquid and a gas that allow each to be distinguished from the other two. It may help to think about how permanent the shapes of solids, liquids and gases are, and how easy it is to change their shape or the volume of the space they occupy. ◀

Since water is the theme of this book, let's see how our descriptions of solids, liquids and gases apply to ice, liquid water and water vapour. An ice cube has a fixed shape and volume whatever type of glass you put it in. When it melts, however, the resulting liquid water flows so that it adapts to the shape of the bottom of the glass.

However, the volume of the liquid water doesn't change when you swirl it around in the glass or when you tip it into the sink. Leave the liquid water for long enough though and it will evaporate. If this happened within a sealed room then the gaseous water would be uniformly spread out through the air in the whole room. In other words, gaseous water does not have a fixed volume — it fills any space into which it is put. This property distinguishes a gas from a liquid.

You have probably experienced the capacity of a gas to expand to fill its container without realizing it. When a person wearing perfume enters a room, you can smell the perfume almost straight away. You do not have to put your nose very close to the person wearing the perfume to get the benefit. This observation should tell you that the gas that has evaporated from the liquid perfume pervades the room very quickly.

4.1.2 Are ice, liquid water and water vapour the same substance?

How can we be sure that the liquid that we call water does not change into a different substance as water freezes into ice or as water is boiled to produce water vapour? There are various chemical experiments that prove that ice, liquid water and water vapour are all composed of the same substance, but how could you convince yourself without doing experiments?

Ice brought out of a freezer into a warm room soon turns to water, and if the water is put back into the freezer, it becomes ice again. Likewise, the substance that escapes into the air as a gas when water boils, can condense on a cold surface such as a window and become liquid water again. You could convince yourself of this by holding a cold spoon over the spout of a kettle while the water is boiling; you would soon see droplets of water on the spoon.

These changes from one state to another and back again do not demonstrate beyond doubt that ice, liquid water, and water vapour are all made from the same substance. However, scientists generally assume that *the simplest explanation of the facts is correct until some new evidence disproves it.* The fact that ice, liquid water and water vapour share a lack of colour, smell and taste is also consistent with the view that they are all the same substance.

4.1.3 What determines whether water is a solid, liquid or gas?

A major factor that determines the state of water is the temperature. When ice is brought out of a freezer, it warms up until it reaches a temperature at which the ice melts to form liquid water. If the liquid water is then heated in a saucepan, it eventually reaches a temperature at which the liquid boils, and if heated long enough it is completely transformed into water vapour. The same is true of other substances. If you heat a lump of fat and a block of iron, they will eventually reach temperatures at which they melt to become liquids, and if heated further they will boil and be converted to fat vapour and iron vapour, respectively. However, the temperatures at which ice, fat and iron melt are different, and the temperatures at which the three substances boil are all different.

So changing the temperature of a substance can lead to a change of state; but this raises more questions than it answers. For example, you may now be wondering why changing the temperature can cause the state of a substance to change, or why different substances have different melting temperatures. There is a lot more science to be discovered here, but this must wait until the next block of the course. For now, we shall just look a little more closely at the subject of temperature in Box 4.1, *Temperature scales*.

Box 4.1 Temperature scales

There are many different scales of hotness or coldness, and any of them give us a measure of temperature. Perhaps the commonest scale is degrees Celsius, abbreviated to °C, which was named in honour of a Swedish astronomer, Anders Celsius, who devised the scale in 1743. He defined the freezing temperature of water as 0 °C on this scale and the boiling temperature of water as 100 °C. The **Celsius scale** is widely referred to as the centigrade scale, because there are 100 divisions — or degrees — between the freezing and boiling temperatures of water. However, the correct scientific name of the scale is Celsius. On this scale, the normal human body temperature is around 37 °C though this varies slightly between individuals.

We now know that the freezing and boiling temperatures of water are not fixed temperatures — water boils at about 71 °C at the top of Mount Everest, for example. To define the Celsius scale we therefore have to specify more precisely the conditions under which the water freezes or melts. Thus we say that 0 °C (spoken as ‘zero degrees Celsius’) is the temperature at which water freezes at sea-level under normal atmospheric conditions, and this is called the *normal* **freezing temperature** of water. (Block 2 explains what we mean by ‘normal atmospheric conditions’.) Similarly, 100 °C is the temperature at which water boils at sea-level under normal atmospheric conditions, and this is called the *normal* **boiling temperature** of water.

You may be more familiar with degrees Fahrenheit (°F), although this scale has largely been phased out in Britain. On the Fahrenheit scale, water normally freezes at 32 °F and boils at 212 °F, and the average temperature of a healthy human body is about 98.4 °F. In this course we shall deal mainly with the Celsius scale of temperature.

The Celsius scale is not limited to the range between 0 °C and 100 °C; for example, the temperature of the surface of the Sun is about 5 500 °C, and air temperatures frequently drop well below 0 °C in winter. When the temperature falls five degrees below 0 °C, then we say that it is minus five degrees Celsius, or –5 °C, and if it falls even further to ten degrees below zero then it is –10 °C. Mathematically, five degrees below zero means 0 °C – 5 °C, and if you do this subtraction the answer is –5 °C, as you can easily confirm by doing the following subtraction on your calculator:

$\boxed{0}\ \boxed{-}\ \boxed{5}\ \boxed{=}$

So the minus sign in front of a temperature tells you that it is ‘less than zero’ and the number tells you how many degrees less than zero. In other words, the larger the number that follows the minus sign, the further the temperature is below zero degrees. (If you are not used to thinking about negative numbers, then it may help to think in terms of money. If your account is overdrawn by £50 pounds, then it has ‘£50 less than nothing’ in it, and your balance is –£50. You would have to add £50 to bring the balance up to zero. In a similar way, if the temperature is –50 °C — that is, 50 °C ‘less than nothing’ — then you would have to increase the temperature by 50 °C to bring it up to zero.)

A wide range of Celsius temperatures is shown in Figure 4.2. The highest temperature we have marked is that of a hot oven. The temperatures decrease to 0 °C, and as the temperatures get still colder they are represented by negative numbers, in which the numbers following the minus sign get larger and larger. At the lowest temperature shown, –196 °C (that is 196 degrees Celsius below zero), nitrogen gas, which is the main component of the air we breathe, condenses and becomes a liquid; you will see this demonstrated in a video activity in Block 2.

Question 4.2 In each of the following pairs of temperatures, which one is the hotter: (a) 57 °C and 65 °C; (b) 57 °C and –65 °C; (c) –57 °C and –65 °C; (d) –57 °C and 65 °C? ◀

Question 4.3 Arrange the following temperatures in increasing order, i.e. starting with the lowest temperature and ending with the highest temperature: 210 °C, 0 °C, –27 °C, 1 750 °C, –85 °C, –26 °C, –210 °C, 85 °C. ◀

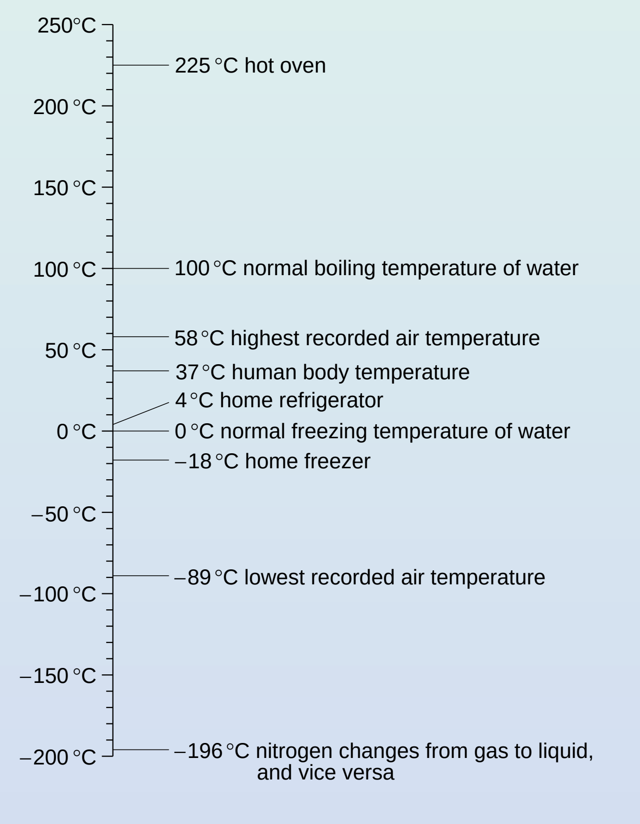


Figure 4.2 Temperatures on the Celsius scale. Note that we always use minus signs to denote negative temperatures, but we don't use plus signs in front of the positive temperatures.

The most familiar way of converting water to a gas is by heating the liquid up to the normal boiling temperature and this produces vapour at 100 °C. But liquid water does not have to be heated to its boiling temperature to convert it to gas. For example, a puddle in the road does not last forever; the water evaporates and the road becomes dry again, and the higher the temperature the more rapidly the water evaporates.

On the other hand, the most familiar way of converting water to a solid is by cooling the liquid down to below the freezing temperature, and this produces ice at below 0 °C. We look at the formation of ice in more detail in the next section.

Activity 4.2 Making notes as you read the text (continued)

We suggested that you highlighted (or underlined) parts of the text and made notes as you read this section, with the aim of identifying key points. There is an example of annotated text in the comments for this activity, and you should now compare this with what you have done. ◀

4.2 Why does ice float?

This section looks at a property of water with which you will be very familiar, but that is, in fact, exceptional and has important consequences for life. That property is illustrated by ice floating on water. Put some ice cubes in a glass of water and they float at the top; they don't sink to the bottom. On a much larger scale, icebergs float in the open seas when they break away from the ice shelf. You may never have thought of this as being particularly strange, but if you put a lump of fat into a chip pan full of melted fat then it sinks to the bottom.

Activity 4.3 Annotating text: floating and sinking

As you read Section 4.2, annotate the text to pick out information that explains why some objects float on water while others sink. You will use your annotations at the end of the section to write an explanation of why ice floats on water but a block of steel sinks in water. ◀

But how can we tell if a solid will float on a liquid? Wood floats on water, but steel doesn't. You might think that the reason for this is because steel is heavier than wood, but though that is the start of an explanation, we need to be more precise. After all, a small steel screw will sink in water but a large tree trunk will float. It isn't the mass of the steel screw that is important, it's the fact that the screw is heavier (it has a greater mass) than the amount of water that has the same volume as the screw. Conversely the tree trunk floats because it is lighter (its mass is less) than the amount of water that has the same volume as the tree trunk.

Activity 4.4 Understanding complex ideas

You will find that there are some concepts in the course that are difficult to grasp on first reading. One technique that you may find helpful in such cases is to rephrase the concept in your own words. Try doing this for the preceding paragraph, then compare your rephrasing with ours in the comments on this activity. ◀

Before looking at floating in more detail, we need to be clear about the units that are used to measure area and volume. In Box 3.1, we discussed the metric unit of mass, the kilogram (kg), and the metric unit of length, the metre (m). You may wish to refresh your memory of these units before studying Box 4.2, *Measuring areas and volumes*, which introduces the metric units of area and of volume.

Box 4.2 Measuring areas and volumes

In continental Europe, estate agents' descriptions of houses and flats always contain details of the overall area of the floor, that is, the area of a fitted carpet. In the UK this information is not a requirement; house details usually give the maximum length and width of a room, measured into bay windows and alcoves, which may give a misleading impression of the size of the room. How can you work out the floor area to give a more accurate measure of room size?

Area

For squares and rectangles, the **area** is found by multiplying the length by the width. So a simple square with 1 m long sides (Figure 4.3), has an area of 1 m × 1 m = 1 square metre or 1 metre squared, abbreviated to 1 m^2. (A number written above the line and in a smaller type, as in the case of the 2 in m^2, is called a **superscript**. This kind of notation — using m^2 as a shorthand for m × m — is explained in more detail later in this block.) In SI units, area is measured in square metres.

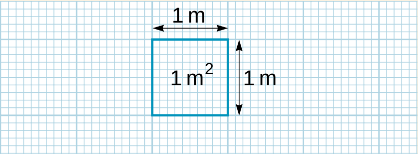


Figure 4.3 One square metre (1 m^2).

The rectangular garden pond shown in Figure 4.4 has an area of 3 m × 4 m = 12 square metres (12 m^2), and you can see that it is made up of 12 squares, each with sides 1 m long.

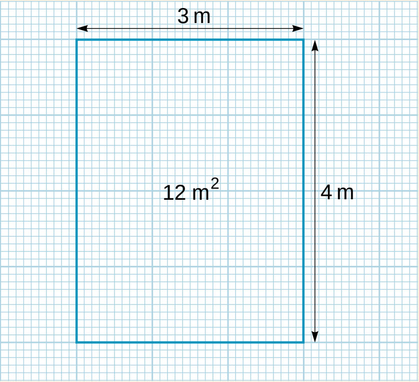


Figure 4.4 Plan of a rectangular garden pond of area 12 m^2.

What is the area of a rectangular garden pond that measures 5 m × 4 m?

The area is 20 m^2.

The rectangular garden pond shown in Figure 4.5 has an area of 3.5 m × 4.2 m = 14.7 m^2, which you can check with your calculator. The area is still the length multiplied by the width, and if you count up 12 whole squares and eight part squares you should be able to see that the pond covers the equivalent of about 15 whole squares, each of which has 1 m side length.

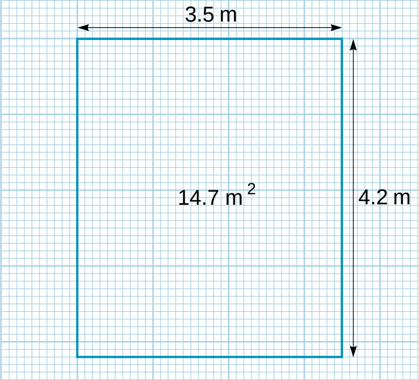


Figure 4.5 Plan of a rectangular garden pond of area 14.7 m^2.

There are two ways of calculating the area of the L-shaped garden pond in Figure 4.6; can you see what these are?

You could think of the pond as being a large rectangle, with a smaller rectangle taken out of it, as shown in Figure 4.7a. Or you could think of it as being made up of two rectangles, so that its total area is the sum of the areas of the two parts, as shown in Figure 4.7b.

We can check that these two ways of calculating the area give the same answer.

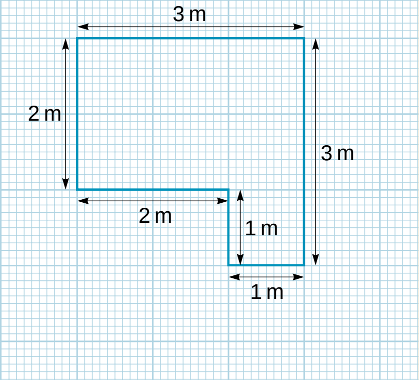


Figure 4.6 Plan of an L-shaped garden pond.

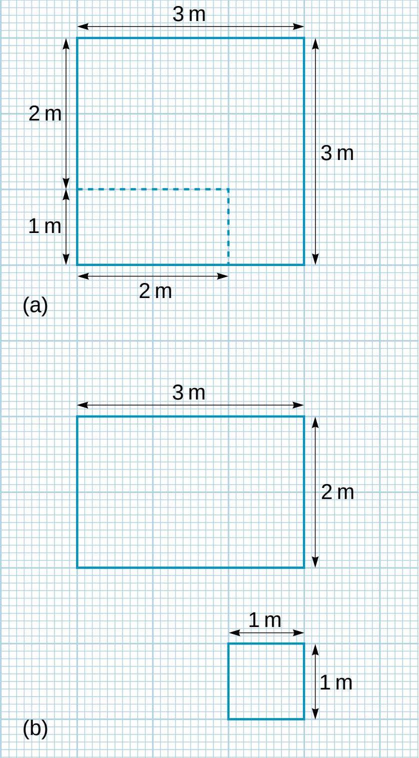


Figure 4.7 Two ways of calculating the area of an L-shaped garden pond.

Following the first method, in Figure 4.7a, the area is: 3 m × 3 m minus (or less) 2 m × 1 m. Adding brackets to a problem of this type makes it look clearer and also emphasizes the mathematical rule of carrying out the multiplying before subtracting:

$$\begin{aligned}\text{area} &= (3\,\text{m} \times 3\,\text{m}) - (2\,\text{m} \times 1\,\text{m}) \\ &= 9\,\text{m}^2 - 2\,\text{m}^2 = 7\,\text{m}^2\end{aligned}$$

If you work this out on your calculator, brackets are not essential because your calculator follows the mathematical rules and will do the multiplying before the subtracting.

Following the second method, in Figure 4.7b, the area is: 2 m × 3 m plus 1 m × 1 m, and again if we add brackets it makes the problem look clearer:

$$\begin{aligned}\text{area} &= (2\,\text{m} \times 3\,\text{m}) + (1\,\text{m} \times 1\,\text{m}) \\ &= 6\,\text{m}^2 + 1\,\text{m}^2 = 7\,\text{m}^2\end{aligned}$$

The concept of area is useful even for irregular-shaped objects; the irregular-shaped pond in Figure 4.8 has an area of about 5 square metres, and again you can verify this approximately, by counting up the metre squares and part squares.

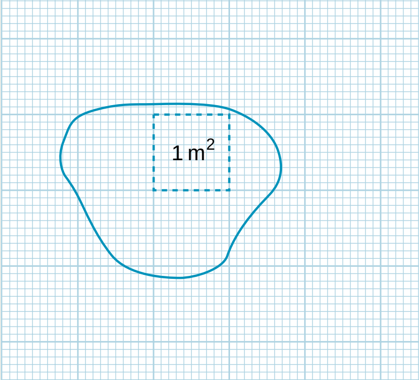


Figure 4.8 An irregular-shaped pond with an area of about 5 square metres (5 m^2). The dotted square is 1 m^2.

Volume

The information about water use in Section 2 was given as volumes of water measured in litres, and we will now define what is meant by volume and explain how it is measured.

Volume is a measure of the space that a three-dimensional object occupies. The volume of a rectangular block is found by multiplying its length by its width by its height. A simple cube, with 1 m long sides, has a volume of 1 m × 1 m × 1 m = 1 cubic metre, which is written as 1 m^3 (Figure 4.9). In SI units, volume is measured in cubic metres.

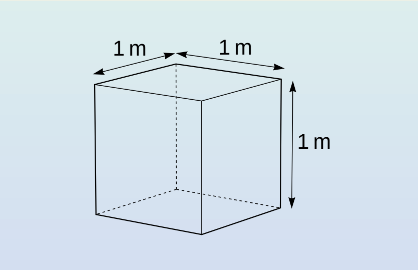


Figure 4.9 A cube with 1 m long sides and a volume of 1 cubic metre (1 m^3).

The fish tank shown in Figure 4.10 has a volume of:

3 m × 2 m × 1 m = 6 cubic metres (or 6 m^3)

and 6 cubes with 1 m sides could, in principle, be neatly stacked in the tank, as the dashed lines on the diagram indicate. For any rectangular block-like structure, such as a brick or a plank of wood, you can use the same method for measuring the volume — just multiply together the length, the width and the height, as we did for the tank in Figure 4.10.

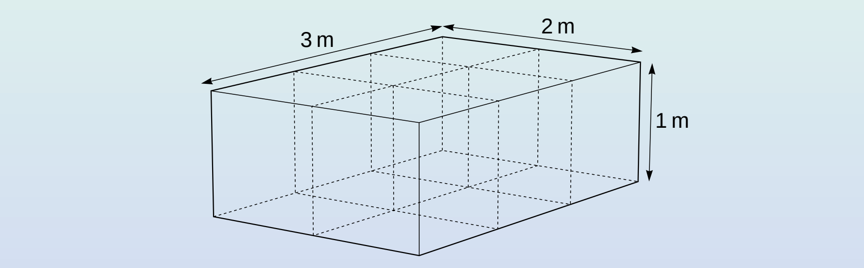


Figure 4.10 A fish tank and its dimensions.

● Suppose you had measured the dimensions of a tank in centimetres, what would be the unit of its volume?

○ The unit would be cm × cm × cm, or cubic centimetres, which is abbreviated to cm^3.

However, if you had measured one dimension in mm and the other two dimensions in cm, then before calculating the volume you would have to ensure all the dimensions were in the same unit.

● What is the volume of a carton of fruit juice that has length 8 cm, width 45 mm, and height 12 cm?

○ Since 45 mm = 4.5 cm, volume of carton = 8 cm × 4.5 cm × 12 cm = 432 cm^3

Unless you're in the building trade, you are probably not used to measuring volumes in cubic metres. A unit that is much more commonly used for measuring volumes of liquids is the **litre** (abbreviated to **l**). Fruit juices and emulsion paint, for example, are sold in litre volumes. A litre is the volume of a cube that has 10 cm sides.

If you think about stacking cubes with 10 cm long sides in a 1 m cube (Figure 4.11), then you can see that we would need 10 × 10 × 10 = 1 000 of the 10 cm cubes to fill a cubic metre (1 m^3), so

1 000 litres = 1 cubic metre (1 m^3)

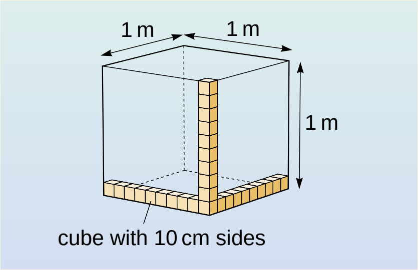


Figure 4.11 How many of the small yellow 10 cm cubes could be stacked in 1 m^3?

● How many cubic centimetres (cm^3) are there in 1 litre?

○ A cube with 10 cm sides has a volume of 1 litre. If you think about stacking 1 cm cubes in a 10 cm cube, then you can see that there are 10 × 10 × 10 = 1 000 of the 1 cm cubes in 1 litre, so 1 000 cm^3 = 1 litre.

Question 4.4 A rectangular swimming pool has the following dimensions: 6 m long by 7 m wide and 2 m deep. What is the area of the bottom of the pool and what is the volume of the pool? ◀

Question 4.5 A reservoir is known to have the capacity to store 2.5 million litres of water. How many cubic metres is this? ◀

4.2.1 Density

We can now return to our original question, 'How can we tell if a solid will float on a liquid?'. To answer this, we need to compare the mass of a particular volume of the solid, such as steel, with the mass of the same volume of water. Table 4.1 lists the masses of one cubic metre (1 m^3) of a number of solids and liquids. Clearly all these materials have different masses for the same 1 m^3 volume. The table shows that one cubic metre of steel has a mass of 7 800 kg, and that one cubic metre of water has a mass of 1 000 kg. The ratio of these masses is 7 800 kg : 1 000 kg, which is the same as 78 : 10 or 7.8 : 1; by using a ratio in which the smallest number is 1, you can see that the mass of the steel is 7.8 times greater than the mass of the water. So, since the mass of one cubic metre of steel is greater than the mass of one cubic metre of water, the steel will sink in the water. Conversely, one cubic metre of oak will float in water because its mass is less than that of one cubic metre of water.

Table 4.1 Mass of one cubic metre of various materials.

Material	Mass/kg
gold	19 280
silver	10 500
steel	7 800
rock (granite)	2 700
bone	1 800
water	1 000
olive oil	920
petrol	800
wood (oak)	650
expanded polystyrene	20

Fortunately, if we want to know whether a 2 m^3 steel block floats or sinks in water, we don't need to work out the mass of that block and compare it with the mass of 2 m^3 of water. That's because if 1 m^3 of steel has 7.8 times the mass of 1 m^3 of water, then 2 m^3 of steel will have 7.8 times the mass of 2 m^3 of water. Similarly 10 m^3 of steel will also have 7.8 times the mass of 10 m^3 of water. The reason for this is that, for any material, if we double the volume, we will double the mass, and if we increase the volume ten-fold, then the mass also increases ten-fold. The mass and the volume of objects made from the same material increase and decrease in step with each other.

This close link between the masses and volumes of objects leads us to introduce a concept known as density. You may already be familiar with this concept. It is quite easy to lift a cubic metre of expanded polystyrene (the white synthetic material used for insulation and packaging), but you would need a crane to lift a cubic metre of steel. This is because there is far less mass for a cubic metre of polystyrene than for the same volume of steel. This concept of the amount of mass for a given volume is density.

Let's make this concept more precise. The **density** of any object, such as a steel screw, is defined as its mass divided by its volume, so

density *equals* mass *divided by* volume, or

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

You will find that certain important key points and equations are highlighted in this way to emphasize them.

This is a *word equation*, and it gives us a way of working out the density of any object, as long as we know the mass of the object and its volume. We simply replace the word 'mass' in the equation by the actual value of the mass of the object, and replace the word 'volume' by the actual volume.

Let's take our one cubic metre block of steel as an example. From Table 4.1 we know that the mass of this block is 7 800 kg, and the volume is 1 m^3. So

$$\text{density} = \frac{\text{mass}}{\text{volume}} = \frac{7\,800\,\text{kg}}{1\,\text{m}^3} = 7\,800\ \frac{\text{kg}}{\text{m}^3}$$

Notice that we included the unit of mass and the unit of volume in the equation, and we've ended up with the unit of kg/m^3 — kilograms per cubic metre. This is the SI unit for density. It may look complicated, but it specifies clearly what density is measuring — the amount of mass (kg) in a certain volume ($1\ \text{m}^3$). Later in the block we shall show you another way of writing the unit of density.

The reason that this concept of density is so important is that *the density of any material doesn't depend on the size or shape of the object made from the material.* This means that the density of a steel bar is the same as the density of our $1\ \text{m}^3$ steel block,* as you can confirm by answering the following question.

● A steel bar has a mass of 234 kg and a volume of $0.030\ \text{m}^3$. What is the density of this bar?

○ Density = mass/volume = $234\ \text{kg}/0.030\ \text{m}^3 = 7\,800\ \text{kg/m}^3$

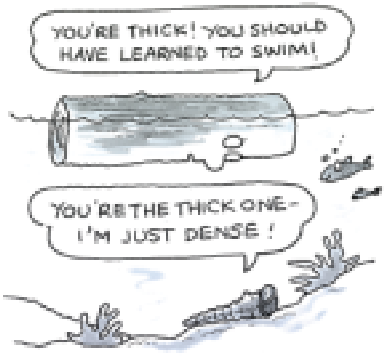
So although the mass of the bar is about 30 times smaller than the mass of the steel block, its density is exactly the same as the value we calculated above for the block. What is more, a steel screw or any other object made from the same steel would also have the same density, $7\,800\ \text{kg/m}^3$. So once the density of the steel, or any other material, has been measured, we don't have to measure it again for every object that we make. We simply look up the value of the density of the material in reference tables.

Now Table 4.1 lists the masses in kilograms of a cubic metre of various materials, so the numbers in the table are in fact the same as the densities of the materials in units of kg/m^3. You might, therefore, like to pencil in an alternative title for the table — 'Density of various materials' — and an alternative heading for the second column — 'Density/kg per m^3'.

Before leaving this section, note the value of $0.030\ \text{m}^3$ for the volume of the steel bar given above. Recall that the last zero in a decimal number contains important information. If you are not certain what this zero tells you, reread the last paragraph of Box 3.2.

4.2.2 Sink or float?

Earlier we said that you could tell whether a piece of steel would sink or float if you compared the mass of that piece of steel with the mass of an amount of water that has the same volume as the steel. That experimental approach to deciding whether something sinks or floats is no longer necessary if we have tables of density values available, such as Table 4.1.



If you want to know whether a material sinks or floats in a liquid, all you have to do is to compare the density of the material with the density of the liquid. If the material has a higher density than the liquid, it will sink. So, for example, steel will sink in water because its density ($7\,800\ \text{kg/m}^3$) is greater than that of water ($1\,000\ \text{kg/m}^3$). The mass of a cubic metre of steel is 7.8 times greater than the mass of a cubic metre of the water — so a cubic metre of steel would sink — and the mass of any other volume of steel will be 7.8 times greater than the mass of the same volume of water

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*We are assuming that the bar and block are made from the same type of steel. There is a range of different types of steel (e.g. mild, stainless) that are manufactured from different proportions of various constituents, and the densities of the different steels vary slightly.

— so they would also sink. Similarly, you can see from Table 4.1, that the densities of gold, silver, granite and bone are very much greater than that of water; these materials will also sink in water. However, materials that have a density lower than that of water will float.

Which of the materials listed in Table 4.1 will float on water?

Olive oil, petrol, wood and polystyrene will float on water because their densities are less than that of water.

The idea that a material floats or sinks in a liquid depending on whether its density is less than or greater than the density of the surrounding liquid provides the answer to the question of why ice floats on water.

A rectangular sheet of ice on a pond has dimensions 2.5 m × 2.0 m × 0.10 m and its mass is 460 kg. What is the density of the ice?

The volume of the ice is 2.5 m × 2.0 m × 0.10 m = 0.50 $\mathrm{m^3}$, so the density of ice is 460 kg/0.50 $\mathrm{m^3}$ = 920 kg/$\mathrm{m^3}$.

Thus the density of ice is lower than that of water (1 000 kg/$\mathrm{m^3}$) so ice will float on top of water. Hence a pond or lake will ice over on the top.

This capacity of ice to float on water is very important for life in ponds and lakes. To understand its significance, consider what would happen if ice sank to the bottom of water. Think about a pond or lake in winter, with the air temperature below 0 °C. The surface of the water will cool down, and eventually ice will form. If this ice sank to the bottom, then more ice would form at the surface and sink, and more and more ice would form and sink. This would be a very efficient way of cooling down the pond and freezing it solid, with fatal consequences for the fish and other aquatic life. But because ice floats on water, it forms an insulating blanket on the top, which then often gets covered with a further insulating blanket of snow. Conditions have to be very much more severe before the pond will freeze completely. If ice did not float, aquatic life would be restricted to parts of the world where temperatures did not fall below freezing.

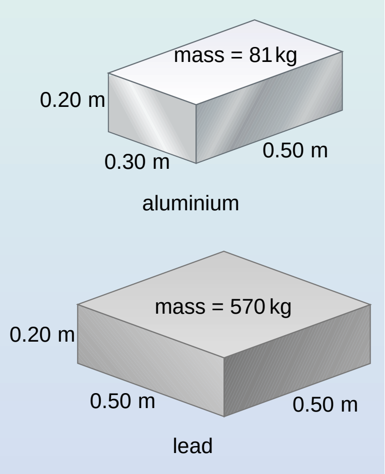


Figure 4.12 Two blocks of metal and their dimensions, for use with Question 4.6. Note that all of the dimensions are expressed to two decimal places because they were measured to the nearest centimetre (0.01 m). If the final zeros were omitted, we would assume that the dimensions were only measured to the nearest 0.1 m, or ten centimetres.

Question 4.6 What are the densities of the blocks shown in Figure 4.12? Will either of the two blocks float in water? ◀

Activity 4.3 Annotating text: floating and sinking (continued)

With the help of your highlighted phrases and notes for Section 4.2, write a few sentences explaining why ice floats on water but a block of steel sinks in water. ◀

4.3 Sweating to keep cool

In Section 4.2 we considered what happens to water when its temperature drops to 0 °C and below, causing the water to change from the liquid state to the solid state. In this section we shall look at some of the consequences of water changing from the liquid state to the gaseous state.

When the air temperature reaches 25 °C or more we feel hot and begin to sweat. You learnt in Section 3.3 that one way in which animals, including humans, lose water is by means of sweating. The real purpose of sweating, however, is not to lose water, but to cool the body. But sweating itself doesn't produce cooling. If you wrap up in tight clothes in a hot place, then sweating doesn't cool you down. Sweat needs to be able to evaporate, and it's the evaporation of the water — the change from a liquid to a vapour — that produces the cooling effect.

In order to understand this cooling effect, let's first think about what happens when you heat water. You can do this in all kinds of ways: in an electric kettle or using various fuels — for example, gas, paraffin or wood. These all provide energy, in one form or another, and the energy they supply will raise the temperature of a kettle of water. But let's focus on an electric kettle: the temperature of the water rises steadily as the heating element in the kettle provides energy to the water. When the water reaches its normal boiling temperature, 100 °C, the temperature stops rising; it stays at 100 °C while the water boils merrily away. Energy is still being supplied to the water — your electricity meter shows this — but now, rather than raising the temperature of the water, the energy supplied is being used to convert the water to vapour, that is to evaporate it (Section 4.1). This demonstrates that it takes energy to raise the temperature of a liquid (or a solid) and it also takes energy to evaporate a liquid, and if we're using an electric kettle then the energy comes from the electricity supply.

So what is the connection between an electric kettle of boiling water and the process of sweating? Sweat on the skin will evaporate into the air. Unlike the boiling water in the kettle, the skin isn't at 100 °C, but energy is still required in order for the water to evaporate. The energy to evaporate the sweat comes from the body. We usually refer to the energy that is supplied in this way as heat, so the body has to provide heat to evaporate the sweat from the skin. The loss of heat from the surface of the body to the water vapour means that the skin cools down. This cooling effect is even more noticeable when you put perfume or aftershave on the skin; your skin immediately feels cool because it supplies heat to evaporate the liquid.

You are probably aware of applications of the principle that evaporation of water produces a cooling effect. Suppose you don't have a refrigerator and are expecting friends for a meal. You want to cool a bottle of wine or fruit juice; how would you do it? A very effective way is to put a wet towel round the bottle and put it on an outdoor window ledge. The water evaporates from the towel, and the heat required to evaporate the water comes from the bottle. So the evaporation of the water from the towel cools the wine or fruit juice in the same way that evaporation of your sweat cools you down on a hot day.

Question 4.7 Does the process of evaporation of water occur only at its boiling temperature? Give examples to support your answer, some of which might be from earlier parts of Section 4. ◀

4.4 Dissolving

So far in Section 4 we have considered some of the consequences for life, both when liquid water forms ice and when it forms water vapour. We now consider a third property of water — this time when it is in the liquid state — the fact that substances **dissolve** in water.

Put a teaspoonful of table salt in a pan of boiling water and it disappears — it dissolves. However, although the salt seems to have disappeared, in fact it is still present in the water. You can convince yourself by tasting the water. The liquid is now a **solution** of salt in water. The salt can no longer be seen because it has separated into very small particles that are dispersed in the water. If you poured the salty water onto a dinner plate and left it overnight in a warm place, the water would evaporate and the solid salt crystals would reappear, coating the bottom of the plate, and thus providing evidence that it was there all the time. This observation also reveals that dissolving is a reversible process.

Any substance that dissolves in water is said to be **soluble** in water.

● What other examples of solid substances that dissolve in water are you familiar with?

○ You may have thought of some of the following: sugar, bicarbonate of soda, soluble aspirin, soda crystals, washing powder, instant coffee. There are many others.

The first living organisms on Earth evolved in liquid water, and one important reason for this is that many substances needed to sustain life are soluble in water. The water-based fluids found in living organisms, such as blood, urine and sweat (Section 2.5), all contain different dissolved substances. Equally significant for life is the fact that some substances do not dissolve in water, they are **insoluble** in water. Amongst the important insoluble substances are those that form the surface layer of organisms, such as the skin of humans. Hence you don’t dissolve when you take a swim!

● Make a list of substances you put in water that are insoluble in water.

○ China and pottery (crockery), metal (cutlery), wood and plastic (utensils), cotton and wool (clothes), leather (shoes), sand, cooking oil and flowers, to name but a few.

A liquid that dissolves another substance is called a **solvent**. Water is only one kind of solvent. Oil, grease and gloss paints (which are oil-based), for example, do not dissolve in water but do dissolve in white spirit. Even white spirit will not dissolve the spray paint used on cars. It needs another kind of solvent. But no other liquid dissolves such a large variety of substances as water, which is why water is an ideal solvent for scientists, industrialists and cooks.

In order to appreciate the importance of the capacity of water to dissolve substances, we shall consider the quality of drinking water, and the fate of a glass of water when you drink it.

Question 4.1 A solid, like a piece of iron, is rigid — it has a shape and a volume that stay the same when you pick it up and handle it, and it keeps its shape irrespective of where it is placed. A liquid, like cooking oil, has a fixed volume, but has no shape of its own; its shape depends on the shape of the container into which it is put. {You can’t pick up oil without using some sort of container. When you pour it from a bottle into a pan, the oil flows and changes its shape but the volume of the oil doesn’t change; it has the same volume in the pan as it had in the bottle.} A gas, like air, has no fixed shape, and nor does it have a fixed volume. It also flows, like a liquid, and takes the shape of its container — for example, think of blowing up a balloon. What distinguishes a gas from a liquid is that a gas fills the whole volume of its container *completely*: it doesn’t just remain in a fixed volume at the bottom of the container.

Question 4.2 (a) 65 °C; (b) 57 °C; (c) –57 °C; (d) 65 °C. {Positive temperatures are higher than negative temperatures. When two negative temperatures are compared, the one with the smaller number following the minus sign is hotter, e.g. –10 °C is hotter than –20 °C.}

Question 4.3 –210 °C, –85 °C, –27 °C, –26 °C, 0 °C, 85 °C, 210 °C, 1 750 °C. {Note that the negative temperatures are lower than the positive temperatures, and the larger the number following the minus sign the lower is the temperature, e.g. –20 °C is lower than –10 °C. Above 0 °C, higher numbers mean hotter temperatures, e.g. 20 °C is hotter than 10 °C.}

Question 4.4 Area of the bottom of the pool is $6\,\text{m} \times 7\,\text{m} = 42\,\text{m}^2$.

Volume of the swimming pool is $6\,\text{m} \times 7\,\text{m} \times 2\,\text{m} = 84\,\text{m}^3$.

Question 4.5 Since 1 000 litres = $1\,\text{m}^3$, then 2.5 million litres or 2 500 000 litres = $2\,500 \times 1\,000$ litres = $2\,500 \times 1\,\text{m}^3 = 2\,500\,\text{m}^3$.

Question 4.6 The volume of the aluminium block is $0.50\,\text{m} \times 0.30\,\text{m} \times 0.20\,\text{m} = 0.030\,\text{m}^3$, so its density is $81\,\text{kg}/0.030\,\text{m}^3 = 2\,700\,\text{kg/m}^3$. The volume of the lead block is $0.50\,\text{m} \times 0.50\,\text{m} \times 0.20\,\text{m} = 0.050\,\text{m}^3$, so the density of lead is $570\,\text{kg}/0.050\,\text{m}^3 = 11\,400\,\text{kg/m}^3$. Both blocks will sink because their density is greater than that of water.

{You may have noticed that your calculator didn’t display the final zeros in the values of the two volumes, $0.030\,\text{m}^3$ and $0.050\,\text{m}^3$; you will see why these zeros are significant and have been included in our answer when you study Block 2, Box 2.1, *Uncertainty and significant figures*.}

Question 4.7 Evaporation of water can occur at temperatures other than the boiling temperature. Several examples in the text illustrate this: evaporation of sweat from the body; evaporation of perfume or aftershave on the skin; cooling a bottle of wine or fruit juice by wrapping it in a wet towel and placing it on a window ledge; and drying of a puddle. In all these examples evaporation occurs at various temperatures that are below the normal boiling temperature of 100 °C.

Activity 4.1 Reading to learn: scanning a section

(*You should spend no more than 20–30 minutes on this activity.*)

Note the advice in the preceding paragraph of the book where you are advised to scan Section 4. To scan the text means to survey it in order to gain an overall impression of what it is about. Read the headings, bold terms, figures and figure captions, and the summary. Look at the rest of the text very quickly, concentrating on the first and last paragraphs in a subsection and pick out key words. Don't try to read every word of the text.

You should read the comments for this activity after scanning Section 4 and noting down the main topics and key ideas.

Activity 4.2 Making notes as you read the text

There are no additional notes for this activity. You should look at the comments when directed to do so after Section 4.1.

Activity 4.3 Annotating text: floating and sinking

(*You should spend no more than 10 minutes on the writing part of this activity.*)

There are no additional notes for this activity until you have completed Section 4.2.

After you have studied Section 4.2 you should go back and read just your highlighted phrases and notes on why some objects float on water while others sink. Then put your notes away and try to write down an explanation in your own words of why ice floats on water but a block of steel sinks in water. Once you have done this you can go back and look at your notes to check that you have included all the relevant points. You can then revise what you have written if necessary. Putting the notes away while you first write something down ensures that you try to express the explanation in your own words, which is a measure of how well you have understood a topic. Your notes are likely to use the same phrases as the text. (Remember that you first tried doing this in Activity 2.2.)

Activity 4.4 Understanding complex ideas

(*You should spend no more than 10 minutes on the writing part of this activity.*)

You might have found the preceding paragraph in the book hard to understand. However, if you've met the concept of density before, it might have seemed quite straightforward. But before long you *will* meet a section of text which doesn't immediately make sense. How do you react in this situation?

As you study *Discovering Science* we will be helping you to develop your own strategies for coping when you don't understand what is written. For example, we will be offering further guidance in Box 6.3 of this block. For now, look back at the paragraph that begins 'But how can we tell…' and try to rewrite it in your own words. Even if you think that you understand it, rephrasing the paragraph is a very good test, and you will understand it even better when you have done this. One strategy is to imagine that a friend has asked you 'Why is it that a tree trunk floats on water whereas a steel screw, which is much lighter, sinks?' (see the cartoon on p. 54 of Block 1). How would you explain this?

Activity 4.1

There is no ‘right’ list of main topics and key ideas but here is the list that we made as we scanned the text. Solid, liquid and gaseous states. Temperature. Ice floating — exceptional. Area, volume, density. Density of an object determines whether it will sink or float on water. Sweating — evaporation cools. Dissolving — water a solvent — harmful substances such as fertilizers. Water from a drink may reach any part of the human body. Water cycle on Earth — continuous.

Activity 4.2

How did you annotate the text — highlighting or underlining or something else? Did you use the margin of the book or a separate sheet of paper to write notes?

Your notes are your own personal record, and they will be quite different from those of other students. They need not be intelligible to anyone else, but they do need to be intelligible to you when you look back at them later in the course — so don’t make them too brief. We have provided an example in Figure 4.2.1 of the underlined words and the marginal notes that a student made for part of Section 4.1 and this will give you some idea of the sort of thing that this student found helpful. There are more activities to help with note-taking in this and subsequent blocks.

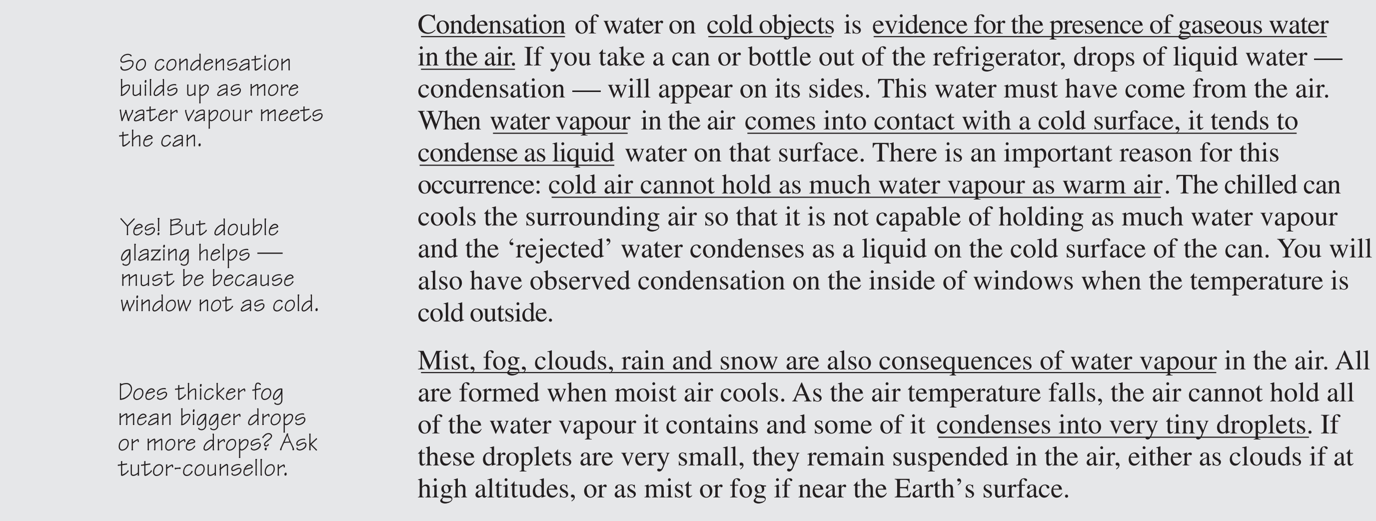
Did you notice that making notes stopped your mind from wandering whilst you studied and helped you to make sense of the words? Another advantage is that you can use your notes and highlighting to remind yourself of the ‘story so far’ at the start of a study session. Quickly skimming through your annotations to the text should refresh your memory of what you studied in the previous sessions, and get you off to a good start. Try this for yourself at the start of your next study session.

Activity 4.3

Your explanation may look very different from ours. The order of ideas may differ and you may have explained things in a different way. However, your answer should incorporate the following points.

> Ice floats on water whereas steel sinks. This is because ice and steel have different densities. Density is mass divided by volume, and materials with a density lower than that of water will float whereas those that have a density higher than that of water will sink.

Now compare your answer with ours. What is important is that you included all the points that we did:



So condensation builds up as more water vapour meets the can.

Condensation of water on cold objects is evidence for the presence of gaseous water in the air. If you take a can or bottle out of the refrigerator, drops of liquid water — condensation — will appear on its sides. This water must have come from the air. When water vapour in the air comes into contact with a cold surface, it tends to condense as liquid water on that surface. There is an important reason for this occurrence: cold air cannot hold as much water vapour as warm air. The chilled can cools the surrounding air so that it is not capable of holding as much water vapour and the ‘rejected’ water condenses as a liquid on the cold surface of the can. You will also have observed condensation on the inside of windows when the temperature is cold outside.

Yes! But double glazing helps — must be because window not as cold.

Mist, fog, clouds, rain and snow are also consequences of water vapour in the air. All are formed when moist air cools. As the air temperature falls, the air cannot hold all of the water vapour it contains and some of it condenses into very tiny droplets. If these droplets are very small, they remain suspended in the air, either as clouds if at high altitudes, or as mist or fog if near the Earth’s surface.

Does thicker fog mean bigger drops or more drops? Ask tutor-counsellor.

Figure 4.2.1 Example of underlined words and marginal notes for part of Section 4.1 of the book. (Activity 4.2)

- the reason for the behaviour of the solids in water is related to density;
- an explanation of what density is;
- the reason why ice floats and the reason why steel sinks.

Did you omit any of these points? You also need to make sure that what you have written is clear and we give help on this later in Block 1. Note that when you are answering questions like this, it is important to explain the meaning of the concept that you are applying — in this case density.

Writing about complex ideas or novel principles helps you to learn. Learning ideas involves understanding rather than memory and this requires a number of steps. First you need to make sense of the idea; making notes and rephrasing paragraphs (as you also did in Activity 4.4) helps you to make sense of the words. Then you need to think through the idea by relating it both to your existing understanding, and to your own observations, such as, in this case, the behaviour of ice cubes in a drink of fruit juice or a glass of whisky, or plastic toys and bits of soap in a bath. Finally communicating your understanding using your own words, as in this activity or in an assignment to send to your tutor-counsellor, consolidates your learning.

Activity 4.4

One student rephrased the ideas in the passage as follows.

> If I put a screw into water the screw will sink, because the steel screw is much heavier (greater mass) than the same volume of water. A big tree trunk would float because the tree weighs less (or has a smaller mass) than the same volume of water.

There are other ways of rephrasing the paragraph — this is just one example. The important thing is to use *your own words* in a way which makes the meaning clear *to you.* Did you find that rewriting the paragraph, like making notes, helped you to make sense of the words?