States of matter

The three states of matter

‘Matter’ is anything which has mass and takes up space. Most of the matter in our world is either solid, liquid or gas. These are called the three states of matter. Most of the time, we can easily tell which is which:

• this book is solid;
• sea-water is liquid;
• air is a gas.

How can we tell the three states apart? We can tell because the states have different physical properties. Table 1.1 shows how the volume and shape of a substance changes when it is placed in a container.
### States of matter

<table>
<thead>
<tr>
<th>Property</th>
<th>Solid</th>
<th>Liquid</th>
<th>Gas</th>
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<tbody>
<tr>
<td>shape</td>
<td>keeps own shape</td>
<td>takes shape of container</td>
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</tr>
<tr>
<td>volume</td>
<td>keeps own volume</td>
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<td>takes volume of container</td>
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Table 1.1 The three states of matter in a container.

You can probably think of some materials which do not fit easily into one of these three categories.
- If you cool molasses, the liquid flows less and less easily as it gets colder. When does it become a solid?
- Glass, which looks and feels solid, is a type of liquid. A very old pane of window glass is measurably thicker at the bottom than at the top.
- ‘Potty Putty’ (figure 1.1) looks solid, and if hit with a hammer shatters into bits; but left on a bench it slowly spreads out into a puddle.

For the moment we do not need to study these substances.

### Matter is made of particles

We can explain the behaviour of solids, liquids and gases using the ideas that:
- matter is made up of particles; and
- the particles are in constant motion.

Robert Brown (1773–1858), a Scottish botanist, found good evidence for this when he was using a microscope to look at pollen grains in water. He saw that the grains were always moving – but in random, zig-zag paths. Brown suggested that the water was made of particles which were bombarding the pollen grains and knocking them about. We can see the same zig-zag motion if we look at smoke particles in the air through a microscope. It is called Brownian motion.

The theory that all matter is made up of separate, moving particles is called the kinetic theory of matter.

Whether a material is solid, liquid or gas depends on how regularly the particles are fitted together and how strongly they are bonded to each other. We will look at each of the three states of matter and then look for more evidence that the kinetic theory is a good theory.

### Solids

In a solid, the particles are touching each other and they fit together in a regular way. Because there are no big spaces between particles, the density of the solid is high. Solids in which the ‘fit’ is very good (the metals) have the highest densities of all. Because there is very little space between the particles, a solid cannot be compressed by squeezing. Squeezing or hammering a solid can change its shape (think of hammering a metal or a piece of glass or squeezing some putty) but its volume doesn’t change.

Because a solid normally keeps its own shape we know that the particles in a solid must be fixed in place with respect to their neighbours. There are strong bonds between them.

Once in position, there the particles stay, but they are not completely still. Each particle vibrates to and fro. If we heat the solid (add heat energy to it) the vibrations get stronger, and if we cool a solid (take heat energy out of it) the vibrations get weaker. When we say that something is ‘hot’ we mean that its particles are vibrating strongly. A substance in which the particles are only vibrating weakly is ‘cold’.

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**Figure 1.1** Some ‘Potty Putty’. Is this a solid or a liquid?

**Figure 1.2** Brownian motion.

**Figure 1.3** Particles in a solid vibrate to and fro.

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*kinetic theory*
Liquids

In a liquid the particles are almost as close together as in a solid, but there is no order in the way they are arranged. The particles in a liquid are slightly further apart than they are in a solid, so a liquid usually has a slightly lower density than its solid and the solid sinks in its own liquid. (Water is an exception – ice floats on water.)

The spaces between the particles in a liquid are not very large and so a liquid can only be compressed a very little. If liquids could be compressed a lot then hydraulic systems such as car brakes could not work.

As we all know, liquids do not keep their own shape – they flow. This means that the particles can move relative to each other and so they can change neighbours freely. But as it flows, a liquid keeps the same volume. Its particles stay close together. Like the particles in a solid, the particles in a liquid have strong bonds between them.

Gases

Gases have much lower densities than either liquids or solids. You can see this in action when bubbles rise through fizzy drinks! Gases can be compressed into small fractions of their ordinary volumes (think of pumping up a bicycle tyre). Gases can be compressed because the particles are far apart from each other.

Now imagine opening a bottle of perfume at one end of a room – it will not be long before you can smell it at the other end of the room. This tells us that the forces between the gas particles are weak, because if they were strong the particles would stick together. Instead, the particles are free to move anywhere in the room. If we could watch the movement of any of them, we would see something very like Brownian motion (see figure 1.2). The gas particles would move about randomly, in straight lines, only changing direction when they bumped into one another, into air particles, or bounced off the walls of the room.
Summary

Now we can summarise the properties of the three states of matter (table 1.2).

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<td>takes volume of container</td>
</tr>
<tr>
<td>density</td>
<td>high to very high</td>
<td>medium to high</td>
<td>low</td>
</tr>
<tr>
<td>can be compressed</td>
<td>not at all</td>
<td>only a little</td>
<td>a great deal</td>
</tr>
<tr>
<td>force between particles</td>
<td>strong</td>
<td>strong</td>
<td>weak</td>
</tr>
<tr>
<td>motion of particles</td>
<td>vibrate fixed with respect to each other</td>
<td>vibrate move within liquid volume</td>
<td>vibrate move anywhere</td>
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Table 1.2 Properties of the three states of matter.

Evidence for the kinetic theory

We have already learned about Brownian motion. When you look through a microscope at pollen grains or smoke particles we see them moving. What we do not see is also important – we do not see the particles of water or air! This tells us that these particles are very small. Even with the most powerful microscopes, you will not be able to see them. Instead, we rely on indirect evidence to show that particles exist. We can use diffusion and osmosis as evidence.

**Diffusion**

If we pour something smelly into a dish and leave it in one corner of a room, we shall soon smell it from the opposite corner of the room. This is because the ‘smell particles’ in the gas travel in all directions, bumping into air particles as they go, until they are spread throughout the room.

If we fill a jar with water and then use a glass tube to make a layer of coloured ink at the bottom of the jar, we shall see that over a few days the colour of the ink will spread through the liquid until the whole of the liquid is a uniform colour. (Try it!) The coloured particles, like the smelly gas particles, bump about in all directions until they fill the available liquid. This process is called diffusion.

**The movement of particles from a region of high concentration to a region of lower concentration.**

![Figure 1.10 Diffusion in a liquid.](image)
We can explain diffusion using the kinetic theory. Imagine the layer where the coloured liquid (we will use red) and the colourless water meet. This layer is AB in figure 1.11. At first there are many red particles below AB and none above it. All the rest of the particles, which not shown in the diagram, are colourless. The red particles are moving randomly – but at least one will be moving upwards.

After a little while the situation will look like figure 1.12. One red particle has moved into the top layer. Its place has been taken by a colourless water particle because some of the water particles on the layer AB were bound to have been moving downwards.

This process will go on until we reach the last stage, which is shown in figure 1.13. Now there are as many red particles above AB as there are below it, so at any moment there will be an equal number of red particles passing up and passing down through AB. The colour is uniform everywhere and will remain so.

This is exactly what happens when we do the experiment, so we believe that our explanation, based on the kinetic theory, is correct. The red particles, which were all concentrated in one part of the liquid, have now spread themselves out so that their concentration is the same everywhere.

\textbf{Diffusion in gases}

As we have seen already, if we pour something smelly into a dish and leave it in one corner of a room, we soon smell it from the opposite corner. This is because the smelly particles in the gas travel in all directions, bumping into air particles as they go, until they are spread throughout the room.

By making gas particles travel in a long tube we can get some information about their relative sizes. Practical activity 1.1 allows us to do this.
Osmosis

Try cutting some chips of Irish potato, pawpaw or carrot and leaving them for an hour in a strong solution of common salt (sodium chloride). You will see that the chips shrink as if they were partly dried out. Now put them into clean, unsalted water for an hour and they will be restored. It seems as though water can be made to flow out of or into the chips by changing the conditions of their surroundings.

Now try practical activity 1.2.