Sample of the IGCSE Science (Double Award) Course, from Chemistry Section 1

Topic 1

States of matter

Introduction

What is everything made from? In this topic you will study solids, liquids and gases and how they can be converted into one another. You will learn about how the particles are arranged inside solids, liquids and gases and how they move about.

You will probably need 1 hour to complete this topic.

Objectives

When you have completed this topic you should be able to:

- identify the three states of matter
- describe the arrangement, movement and energy of the particles in solids, liquids and gases
- explain how solids, liquids and gases change state
- define evaporation, diffusion and sublimation
- describe an experiment to demonstrate diffusion
- explain what is meant by the terms 'solvent', 'solute', solution' and 'saturated solution'.

What is matter made of?

Everything around us is made from particles. The particles may simply be single **atoms**. When different atoms join together they form **compounds**. You will be looking at the structure of those atoms, and the way in which atoms join together, later in this course.

Solids, liquids and gases

There are three **states of matter** – solid, liquid and gas. Many things can easily exist in all three states; for instance, we can find water as ice, water and steam, respectively. However, some solid substances don't readily form liquids or gases, as they may decompose or burn. At the other extreme it is quite difficult to liquefy or solidify some of the gases in the atmosphere.

Activity 1

(Allow 5 minutes)

1 How would you describe the difference between a solid, a liquid and a gas? Imagine you were explaining this to a small child.

2 Can you list some of the key characteristics that distinguish a solid from a liquid or gas?

1 There is no right or wrong answer to this question. You might have described a solid as hard, a liquid as wet and a gas as filling any container. Explaining a gas to a small child is very difficult!

2 Solids have a well-defined shape, and most solids require considerable forces to be applied to change that shape. Liquids don't have a well-defined shape, and take on the shape of anything they are poured into. Gases expand to fill any space and don't have a perceptible shape.

Solids

In a solid, particles are arranged in a regular pattern, and each is attracted or bonded to its neighbour. This bonding is what gives solids their rigidity and enables them to keep their shape. There are many possible arrangements of atoms, but one that is common in metals is what is called 'close packing', which is similar to the regular arrangement of oranges on a market stall, as in Figure 1.1.

Figure 1.1 'Close packing' of oranges on a market stall

Many solids are crystalline. This includes those that look like **crystals** to us, such as those in Figure 1.2, but also many that don't look crystalline to the naked eye at all. Figure 1.2 shows a collection of quartz crystals, in which you can see individual crystals with a well-defined shape and smooth sides.

Figure 1.2 Quartz crystals

Figure 1.3 shows a crystal of silicon, grown for the semiconductor industry. It does not have the faceted appearance that we associate with crystals, but it is nevertheless a perfectly crystalline solid.

Figure 1.3 A silicon crystal

The particles in a solid are not still, but are in continuous slight vibration centred on their allotted place.

When we raise the temperature, we give the solid more energy and the particles vibrate more and more. This has the effect of making the solid expand. Eventually we can give the particles in the solid sufficient energy to break away from their places. This is what happens when the solid melts. It follows that the particles in a liquid have more energy than the particles in a solid.

Liquids

The liquid that is formed when a solid melts has no definite shape of its own and it will take up the shape of its container. However, it still has a definite volume. Continuing the analogy with oranges on a market stall, the particles are now in a random arrangement, as shown in Figure 1.4.

Figure 1.4 Random arrangement of oranges

There is not much order in the way that the particles in a liquid are arranged, but they do still have some attraction for their neighbours. They are also attracted to other things like the surface of your skin. You will have noticed that raindrops stick a little to a window.

If we keep raising the temperature of the liquid it will eventually reach its boiling point, where it is converted into a gas.

Gases or vapours

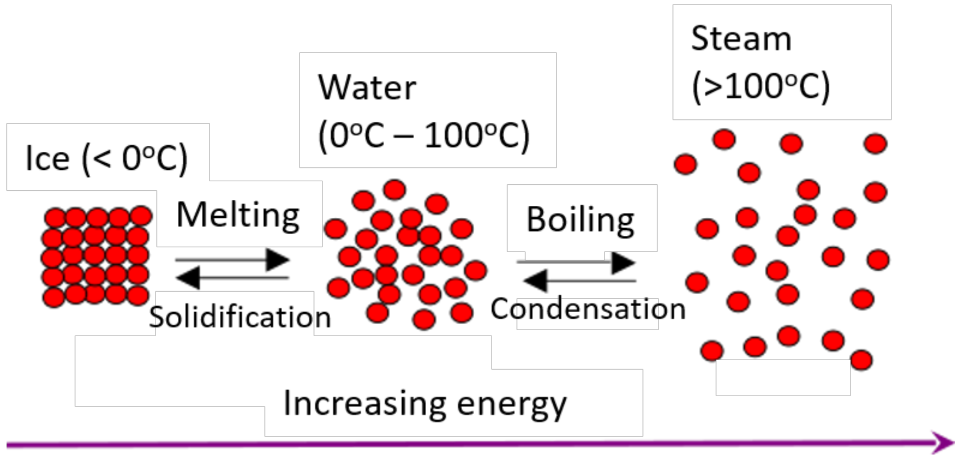
When the temperature of the liquid reaches its boiling point, all the particles can potentially escape when they have enough energy to break away completely from their neighbours. The particles in the vapour have more energy than when they were in liquid form.

When the particles have left, they form a gas or vapour. A gas has no definite volume. It can distribute itself into any space it is allowed.

In this state the particles are completely independent of one another. They are in continual motion and will occasionally collide with one another, and with the walls of whatever is holding them in. These collisions give rise to pressure in a gas.

Figure 1.5 summarises the particle arrangements for water.

Figure 1.5 Solids, liquids and gases



Changing the state

As you have seen above, temperature is crucial to the state of a substance. In order to increase the vibrations of the particles and give them enough energy to break away from one another, heat energy must be supplied to the substance.

Every substance has its own specific melting and boiling points, and these can be used to check the identity of a substance and whether it is pure.

Activity 2

(Allow 15 minutes)

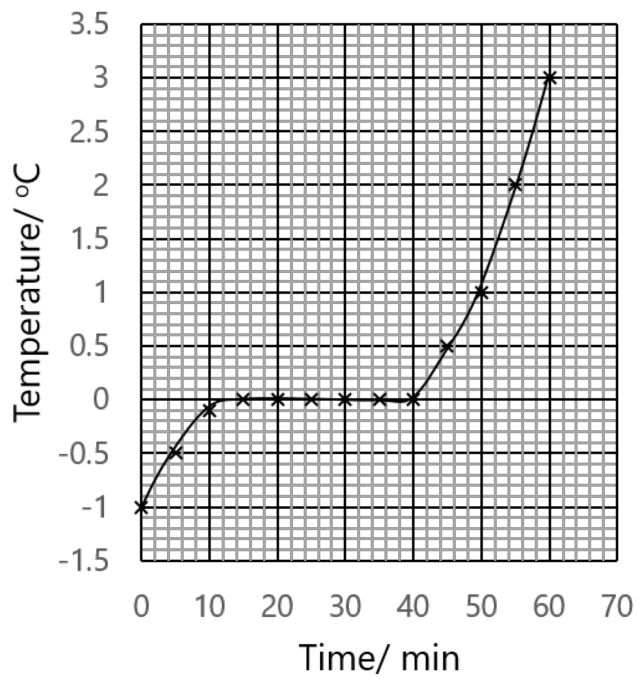
If you can, try this simple experiment. You also need some ice from the freezer in a container, such as a cup. You also need a thermometer that measures from approximately –10°C to +100°C.

Take a temperature reading of the contents of the cup at regular intervals until all the ice has melted, then plot a graph of temperature against time with temperature on the vertical axis and time (in minutes) on the horizontal axis.

Comment on your results.

Figure 1.6 shows some sample results.

Figure 1.6 Temperature of melting ice as a function of time



The ice warms up because it is in surroundings that are warmer than itself and thermal energy is supplied to the ice. When it reaches 0°C it starts to **melt**. While the ice is melting all the ice and water stay at 0°C. The ice and water are co-existing at this temperature, and the energy that is being supplied from the surroundings is being used to break the bonds that hold the particles in their regular solid array. Once all the ice has melted, the water starts to warm up and will eventually be at the same temperature as its surroundings.

We see similar behaviour when water is **boiled**. If you boil a pan of water, the water in the pan will stay at 100°C until all the water has been converted into steam.

If you were to dissolve a teaspoonful of ordinary table salt in a small cup of water, freeze the solution in your freezer, and repeat the experiment above, you would find that the ice would start melting below 0°C and would continue to melt while the temperature was rising. Impure water has no well-defined melting point. We use this fact in two ways:

- In the winter we put salt on the roads to lower the freezing point of water and prevent ice from forming.
- Scientists use the precise melting points of substances to help to identify them, and also to check that they are pure.

Evaporation

Evaporation is another mechanism for converting a liquid into a gas. This can happen at any temperature. In evaporation, any particles on the surface of the liquid or solid that have enough energy to do so leave the surface.

The consequence of the more energetic particles leaving the surface is that the remaining solid or liquid is colder. Our bodies make use of this in sweating. The beads of sweat on the surface of our skin evaporate, removing thermal energy and cooling the skin.

Sublimation

A few substances will convert directly from a solid into a gas without passing through a liquid stage. This is known as **sublimation**. We see this in the substance commonly known as 'dry ice' (Figure 1.7). Dry ice is solid carbon dioxide, which passes directly from a solid to a gas at normal air pressures. Dry ice is used for special effects in concerts, etc.

Figure 1.7 Dry ice – solid carbon dioxide subliming

The white 'smoke' that you can see in Figure 1.7 is the water vapour in the atmosphere condensing in the cold carbon dioxide to form a fog. This is similar to how you 'see' your exhaled breath on a frosty day. The moisture in your exhaled breath condenses to liquid droplets in the cold air and becomes visible. Carbon dioxide vapour itself is invisible, as is your exhaled breath in normal circumstances.

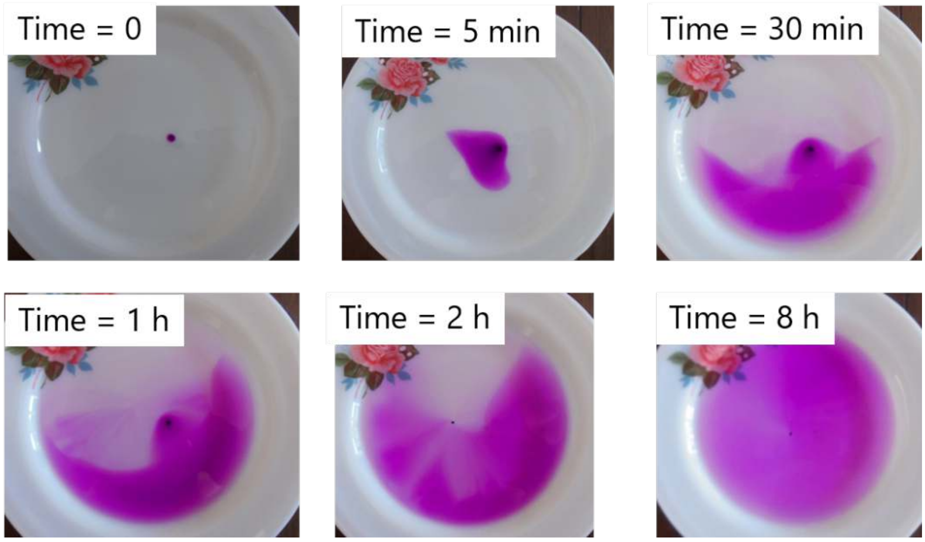
Another substance that sublimes is iodine. This is a metallic-grey solid element, which gives off a violet-coloured vapour.

Diffusion

Particles are in continual motion in all of the three states of matter – solid, liquid and gas. One consequence of this is that they can wander about. This is called **diffusion**.

Figure 1.8 is a sequence of six photographs taken over a period of time after an investigator placed a single crystal of a compound called potassium manganate (VII), which is a very deep purple, in a bowl of water.

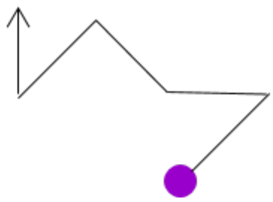
Figure 1.8 Diffusion of a solid dissolving in water



The temperature of the room was 25°C, and the water was left completely undisturbed throughout the experiment. We can see that within five minutes the compound was dissolving in the water and had already moved quite some distance away from the original crystal. Over the next two hours it spread to over three-quarters of the bowl. After eight hours, the concentration was almost uniform.

The individual particles in the liquid move around in a random fashion and disperse by a series of random excursions. Figure 1.9 shows a random wandering of a particle. Eventually these random excursions result in the whole solution becoming uniform.

Figure 1.9 The random motion of a particle



The process of diffusion is even more rapid in gases. Figure 1.10 shows a popular domestic product, aptly called a diffuser. Sticks of wood are immersed into a pot of scent. The scented fluid diffuses up the sticks and evaporates into the air. From there, the scent diffuses rapidly throughout the room.

Figure 1.10 A diffuser

Solutions

If we stir a spoonful of sugar into a cup of water, the sugar apparently disappears: it is said to have dissolved in the water. The sugar has not changed permanently and could potentially be recovered by evaporating the water.

We call the liquid the **solvent** (in this case, water) and the solid that has dissolved (in this case, sugar) the **solute**. When the solid has all dissolved we call it a **solution**, and if we have added so much of the solute that no more will dissolve we call it a **saturated solution**.

Solutions are transparent – you can see right through them, even if they are coloured.

Self check

(Allow 10 minutes)

1 What state is each of these substances in at 25°C? Are they solids, liquids or gases?

Substance A, melting point –114°C, boiling point +78°C.

Substance B, melting point –182°C, boiling point –164°C.

2 Why do local councils put salt on the road in winter?

3 What is sublimation?

4 If you add a solute to a solution, how would you know when the solution is saturated?

You will find feedback to self checks at the end of the section.

Summary

You now know how the particles in a sold, liquid and gas are arranged, and the relative energies in each. You know that a solid changes into a liquid by melting, and a liquid into a gas by boiling. While these changes take place the temperature of the mixture of, say, solid and liquid, does not change.

Diffusion is the random motion of particles that disperse in their surroundings.

A solution is produced by dissolving a solute in a solvent. When no further solute will dissolve, the solution is said to be saturated.

Key terms

atom: the smallest particle of matter that acts as the building block of an element

boiling: the change from liquid to a gas, at the boiling point of the substance

compound: a substance that contains two or more elements that are bonded together

crystal: a solid in which the particles are arranged in a regular pattern in three dimensions

diffusion: a process by which atoms or molecules can wander around and disperse

evaporation: the passage of a liquid into a gas without either boiling or melting

melting: the change from solid to liquid, at the melting point

saturated solution: a solution in which no more solute can be dissolved

solute: the substance that is dissolving in a solution

solution: a mixture of solvent and solute

solvent: the substance (e.g. water) that is dissolving the solute to make a solution

state of matter: matter exists in three states; solid, liquid and gas

sublimation: the change when a substance goes directly from solid to gas at normal pressures

References

Figure 1.1: By A G from Boston/Somerville, MA, USA – Flickr, CC BY 2.0

https://commons.wikimedia.org/w/index.php?curid=588087

Figure 1.2: By Rob Lavinsky, iRocks.com – CC-BY-SA-3.0, CC BY SA 3.0

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Figure 1.4: By Theresa Knott (Market stall) [CC BY-SA 2.0 (https://creativecommons.org/licenses/by-sa/2.0)], via Wikimedia Commons

Figure 1.5: adapted from Holger Hoffmeister [GFDL (http://www.gnu.org/copyleft/fdl.html)], via Wikimedia Commons

Figure 1.6: Author's own work

Figure 1.7: By Christopher from Salem, OR, USA - Fun with Dry Ice 1Uploaded by Diaa_abdelmoneim, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=7428539

Figure 1.8 to 1.10: Author's own work

