Lesson One

Substances, Particles and Solutions

Aims

By the end of this lesson you should be able to:

- understand the arrangement, movement and energy of the particles in each of the three states of matter: solid, liquid, and gas
- understand the interconversions of solids, liquids and gases in terms of the arrangement, movement and energy of particles, and recall the names used for these interconversions
- understand the terms 'solute', 'solvent', 'solution', **'solubility'** and 'saturated solution', **how to investigate the solubility of a solid in water**, and **how to plot and interpret solubility curves**
- understand the differences between elements, compounds and mixtures, and understand that a pure mixture has a fixed melting and boiling point but that a mixture does not
- understand how the results of experiments involving the dilution of coloured solutions and the diffusion of gases can be explained
- understand the terms atom and molecule

Context

This lesson covers sections 1.1 – 1.9 and 1.14 of the Edexcel IGCSE Chemistry specification. Aims indicated in bold print (above) are only relevant to the Unit 2 examination.

Edexcel IGCSE Chemistry pages 1–5 and 30-31.

Introduction

Chemistry is the study of materials, which chemists also call **substances** or “chemicals”. Chemists believe that all materials are made up of minute **particles** that are too small to see even with the most powerful microscope.

In this first lesson we are introduced to the different sorts of substances that exist, and to how these particles behave.

> *Get it right!* An “object” is a thing, and a “substance” is the material from which it is made. So a table is an object made of the substance wood. Chemists are interested in substances, not objects.

Elements, Compounds and Particles

Discovering the Elements

The earliest chemists looked at the thousands of different materials in the world, and felt dissatisfied. They believed that there *must* be something simpler hiding underneath all this complication. They guessed that all these materials are in fact made up of only a few basic, simple materials. They called these basic materials the **elements**.

But what were they? The chemists reasoned they’d know when they found an element: it would be impossible to split it up into two or more simpler substances. So they set out in search of the elements. They got hold of all the materials they could and tried splitting them up. When they found a substance that they couldn’t split, they assumed it must be an element.

They often got it wrong. The Ancient Greek scientists, for example, decided that there are only four elements: earth, air, fire and water. This was a good try, but we now know you can split each of these up. For example:

- If you make air extremely cold, it turns into liquid air. If you then warm it up slowly, different gases boil off separately, including oxygen and nitrogen. If you can split air into oxygen and nitrogen it cannot be an element.

- If you pass an electric current through water, it splits up into two gases, hydrogen and oxygen. If you can split water into hydrogen and oxygen it cannot be an element.

Eventually, however, the chemists got it right. Between 1669 and 1945 they gradually discovered all the elements that the universe is made up of. There turned out to be about 100 of them.

Get it right! There are exactly 92 naturally-occurring elements, but some extra ones have been made artificially in nuclear reactors. Appendix A shows only the first 89 elements.

You will find a complete list of the elements in a diagram called **The Periodic Table** at Appendix A at the back of this file. This lists, for each element, its name and its shorthand **symbol**. You will know quite a few of the elements already.

As you can see, each symbol has one or two letters. The first is always a capital letter. If there is a second it is always a small letter. Sometimes the letters don't seem to have anything to do with the name of the element, e.g. Fe for "iron". In this case the symbol is taken from the Latin name for the element: *ferrum* is Latin for "iron".

Log on to Twig and look at the film titled: **Introduction to the Periodic Table**

www.ool.co.uk/1395yh

In 1869, Russian scientist Dmitri Mendeleev designed a Periodic Table, ordering the naturally occurring elements by their structure and properties. His version of the Periodic Table changed the course of Chemistry forever, and even predicted the future.

Activity 1

Look at Appendix A. How many of the elements did you know already?

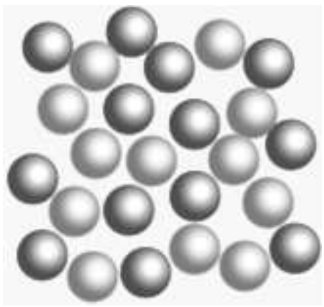
(a) Write down the symbols for the following elements. Make sure you write the capital and small letters correctly:

Oxygen, hydrogen, nitrogen, silver, gold, iron, magnesium, silicon, carbon, iodine.

(b) Now write down the names of the elements of which the following are the symbols. Be careful – often there are two or more elements whose symbols start with the same letter:
N, He, Pt, P, Mn, S, Cl, Na.

Elements and Atoms

There are about 100 different elements, and none of them can be split up into anything simpler. But why?
The answer was suggested by the English chemist John Dalton in the early 1800s. He proposed that all materials are made up of very small, unsplittable balls called **atoms**.



Dalton suggested that there are many different sorts of atom – with different sizes and weights - but that *an element contains only one sort of atom*. So iron is made up of identical iron atoms, oxygen is made up of identical oxygen atoms, and so on.

It follows that there are about 100 different sorts of atom, one for each element. It also follows that you cannot split elements up: if you split a lump of iron in two, both halves are still iron because they are both still made of iron atoms.

Compounds and Molecules

Dalton also suggested that atoms can join together into small groups called **molecules**. When they do this a **chemical reaction** occurs and a completely new substance is formed.

For example, oxygen and hydrogen atoms can join together to form a water molecule like this:

one oxygen atom and two hydrogen atoms

one water molecule

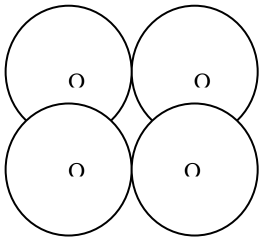
Substances like water, made up of two or more different sorts of atom combined together, are called **compounds**. The properties of a compound are often completely different to the properties of the elements it is made up of. For example, oxygen and hydrogen are both colourless gases, quite different to water which is a liquid.

The atoms in a compound always occur in a fixed ratio: in this case two hydrogen atoms for each oxygen atom.

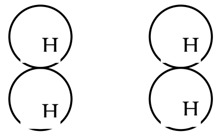
A compound can be split up into its elements by separating the atoms again. This is also a chemical reaction. This is what happens when an electric current is passed through water, as mentioned above.

Two sorts of Molecule

There is one confusing complication to note. In many elements, the atoms also join together to form molecules. For example, the particles of oxygen and hydrogen (both elements) look like this:



two oxygen molecules



two hydrogen molecules

So both elements and compounds can be made up of molecules. But *in elements the molecules contain only one sort of atom.*

Particles

Chemists use the word **particle** for the smallest unit of a substance that can move around on its own. Sometimes, as in iron, that is an individual atom. Sometimes, as in water or oxygen, it is a molecule. Sometimes, as in table salt, it is an atom which has gained or lost one or more electrons (see Lesson Two) called an **ion**.

Get it right! Chemists use two sorts of language, and it is important not to mix them up:

- "Substances" language is about materials you can see. Elements and compounds are both substances.
- "Particles" language is about the invisible bits that substances are made up of. Atoms, ions and molecules are all particles.

Pure Substances and Mixtures

Elements and compounds are both **pure substances**. But a **mixture** contains two or more substances mixed together. For example, air is a mixture, because it contains nitrogen (one substance) mixed with oxygen (another substance).

The particles of the different substances in a mixture *have not been joined together by a chemical reaction.* As a result, mixtures can also be separated without using a chemical reaction (by "physical means"). For example, you can separate a mixture of salt and sand (with the help of a magnifying glass and a pair of tweezers) by picking out the lumps of the two substances.

The different substances in a mixture are not present in fixed proportions. For example, sea water is a mixture, containing the substances salt and water. But the ratio of salt to water is not fixed: you can have more or less salt compared to the amount of water present.

Get it right! A compound is **not** a mixture. Although it contains more than one sort of atom, these atoms are chemically joined, in a fixed ratio, to form only a single pure substance.

Activity 2

Divide the following list into elements, compounds and mixtures. Elements are listed in the Periodic Table at Appendix A, mixtures are easily split up into separate parts, and the others are compounds:

Magnesium, sea water, salt, air, iodine, sodium, soil, citric acid, neon, alcohol

Log on to Twig and look at the film titled: **Chemical Classifications**

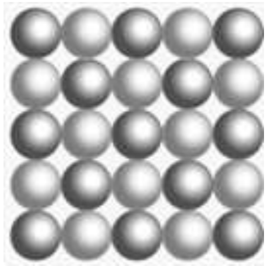
www.ool.co.uk/1466mc

Definitions and examples of three distinct chemical classifications: elements, compounds and mixtures.

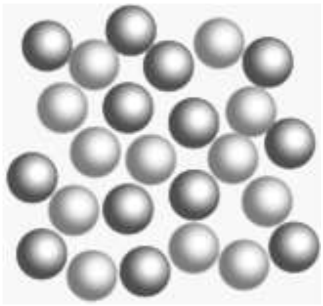
States of Matter

Chemists call solids, liquids and gases the three **states of matter**. These differ in their **properties** (characteristics), and this can be explained by the behaviour of the particles from which they are made.

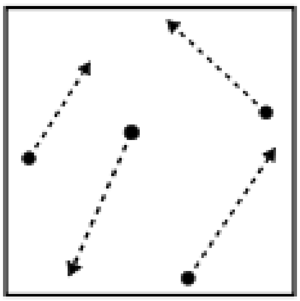
- In a **solid** the particles are packed closely together, which makes them quite dense. The particles can vibrate, but they are in fixed, regular positions and cannot slide past each other, which means that solids have a fixed shape.



- In a **liquid** the particles are still packed closely, but they are able to slide past each other and change positions. This means that a liquid is also dense, but has no fixed shape and can flow.



- In a **gas** the particles are very spread out with big spaces in between, which makes them much less dense. They shoot around at high speeds in straight lines unless they hit each other or the wall of their container. This means that a gas has no fixed volume (size) and will spread out to fill up any container it is placed in.



Objects which are moving possess a type of **energy** called **kinetic energy**. The faster an object moves, the more kinetic energy it has. It follows that:

- the particles of a liquid have more kinetic energy than the particles of solid and less kinetic energy than the particles of a gas

- to turn a solid into a liquid, or a liquid into a gas, you must add energy.

Twig

Log on to Twig and look at the film titled: **Solids, Liquids, Gases**

www.ool.co.uk/1471ew

What are the differences between solids, liquids and gases? How does each state behave?

Changes of State

When a liquid becomes a solid or a gas, or vice versa, this is called a **change of state**.

Melting

Let's start with a solid. Its particles are held together in fixed positions by forces of attraction between them. If you heat the solid, you give extra energy to its particles. As the particles gain energy, they vibrate harder. Eventually they vibrate so hard that they overcome the attractive forces keeping them fixed in place and they start to move around. The solid **melts** and becomes a liquid. The temperature at which this happens is called the **melting point** (**mp**) of the solid.

Boiling / evaporation

If you continue heating the liquid, its particles gain even more energy and move around faster. Eventually they are moving fast enough to overcome the attractive forces holding them close together, and they fly apart. The liquid **boils** and becomes a gas (also called a **vapour**). The temperature at which this happens is called the **boiling point** (**bp**) of the liquid.

At a lower temperature than its boiling point, the particles of a liquid will have a range of energies. Some at the surface will have enough energy to fly off and become gas particles. This results in **evaporation**: the slow "drying up" of a liquid at a temperature below its boiling point. As only the most energetic particles escape in this way, the average energy of the remaining particles is reduced. This lowers the temperature of the liquid that is left.

Condensing

If you cool a gas (vapour), the reverse happens and it turns back into a liquid. This is called **condensation**. It happens at the same temperature as boiling, i.e. at the boiling point. Condensation releases the extra energy of the particles as heat.

Freezing

If you cool a liquid, the reverse happens and it turns back into a solid. This is called **freezing** or **solidification**. It happens at the same temperature as melting, i.e. at the melting point. Once again, the extra energy of the particles is released as heat.

hotter

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melting boiling

solid ↔ **liquid** ↔ **gas**

freezing condensing

<---

colder

Sublimation

A few substances turn directly from a solid to a gas on heating, without going through a liquid stage. This is called **sublimation**. Carbon dioxide ("dry ice") and iodine both sublime when heated.

Water

The melting point of water is 0°C (say: "nought degrees Celsius"), and its boiling point is 100°C. Solid water is called **ice**, and water as a gas is called **water vapour** or **steam**.

The stronger the forces of attraction between the particles, the higher the melting point and boiling point of a substance. These forces are stronger between water molecules than between oxygen molecules, so water is a liquid at room temperature, whereas oxygen is a gas.

Log on to Twig and look at the film titled: **Changing States of Matter**

www.ool.co.uk/1472su

Water can either be a solid, a liquid or a gas. How does matter change state?

Activity 3	Name the change of state when:
	(a) ice turns to water (b) drops of water appear on a cold sheet of glass (c) wet clothes dry on a washing line (d) dry ice disappears in a warm room (e) a kettle of water is left for a long time on a gas stove (f) ice forms on a cold road in winter

Mixtures and melting points

A **pure** substance has a fixed and sharp melting point and boiling point. Pure water, for example, melts at *precisely* 0°C and boils at *precisely* 100°C. But this is not true of a mixture.

Get it right! However, the boiling point of a liquid changes if air pressure changes. Water only boils at 100°C at standard atmospheric pressure.

If a substance is **impure**, it means it has small amounts of one or more other substances, impurities, mixed with it – i.e. it is a mixture. This means that:

- its melting and boiling point will be *different* from that of the pure substance

- it will melt and boil over a *range* of temperatures, rather than at a precise temperature

The second difference is often used to test whether or not a substance is pure.

The presence of impurities usually depresses the melting point (makes it lower) and elevates the boiling point (makes it higher). For example, an ice-salt mixture may freeze at -3°C instead of at 0°C and boil at 102°C instead of at 100°C. In effect, the impurities make the substance “prefer” to be in the liquid state.

Activity 4	Suggest why salt is spread on the roads during very cold weather.

Solutions (from June 2019)

This course includes a number of topics and sub-topics which were not on the old specification. These do not need to be studied if you are sitting exams in June 2018.

If you add a solid to a liquid like water and stir, one of two things may happen:

- the solid may **dissolve** in the liquid to form a **solution**
- the solid may remain separate and not dissolve.

Solids which dissolve in water are said to be **soluble** in water. Those which do not are **insoluble** in water. It is possible for a solid to be soluble in one liquid but insoluble in another. For example, fat will dissolve in pure alcohol, but not in water.

Activity 5

Practical work:

Pour two glasses of tap water. Use glasses with clear sides so that you can see in easily. Into one put just a teaspoonful of sugar. Into the other put a teaspoonful of soil. Stir both vigorously for one minute, and then leave to stand. What do you see after (a) another minute? (b) another five minutes? Taste the water into which you stirred the sugar (<u>not</u> the other one).

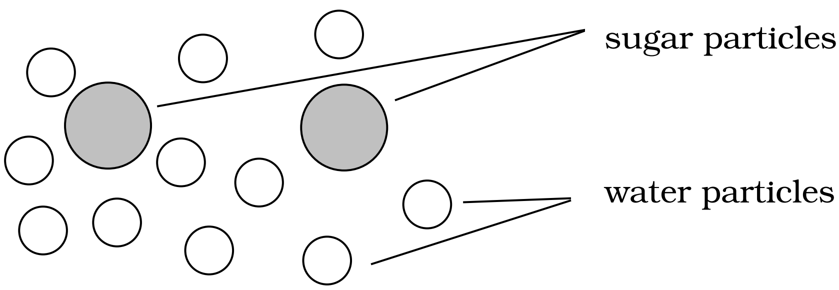
Now keep adding more sugar, stirring and standing as above. What happens if you add too much sugar?

In the experiment above, the sugar disappears completely into the water, but we know it is still there because the water tastes sweet. The water looks completely clear, not cloudy. The sugar has dissolved in the water to form a sugar solution.
When this happens, we have names for the liquid and solid involved:

- the liquid is called the solvent, while
- the solid is called the solute

Solutions, suspensions and particles

In a solution, the solute particles are separated from each other and fit in between the solvent particles like this.



Because the solute (sugar) particles are so small, and are not clumped together into solid lumps, you cannot see them and the solution looks clear.

You will have noticed that your water/soil mixture above looked *cloudy* when you stopped stirring it. Soil is insoluble in water – it will not dissolve in it. The particles in the solid lumps of the soil stay together and temporarily "hang" in the water. This is called a **suspension**. Suspensions always look cloudy, because the large solid lumps block the light trying to get through. Solutions always look clear, because this doesn't happen.

After a while, the solid lumps of soil start to settle out on the bottom, and the water gradually becomes less cloudy. This *never* happens with a solution – the solute particles stay dissolved in the liquid for ever without being stirred.

Solubility

There is a limit to how much solid will dissolve in a liquid at a particular temperature. The amount which will dissolve is called its **solubility**. A liquid which is "full up" with solid, and in which no more will dissolve, is called a **saturated solution**. Different solids have different solubilities.

Activity 6

Practical work:

Carry out an investigation to find out whether sugar or salt is more soluble in (a) cold water (b) warm water (use warm water from the hot tap for this, not water from a kettle).

Make a list of things you must keep the same to make your investigation a fair test.

Then carry it out. Which is more soluble?

The solubility of a solute is measured in the unit: **g per 100g of solvent**. To measure this accurately in a laboratory:

- the mass of solute is measured using a **balance**
- the solvent volume is usually measured using a **measuring cylinder**, and its mass is calculated from this (1cm^3 of water weighs 1g; this is different for other solvents)
- the temperature is monitored using a **thermometer** and kept constant using a **water bath**.

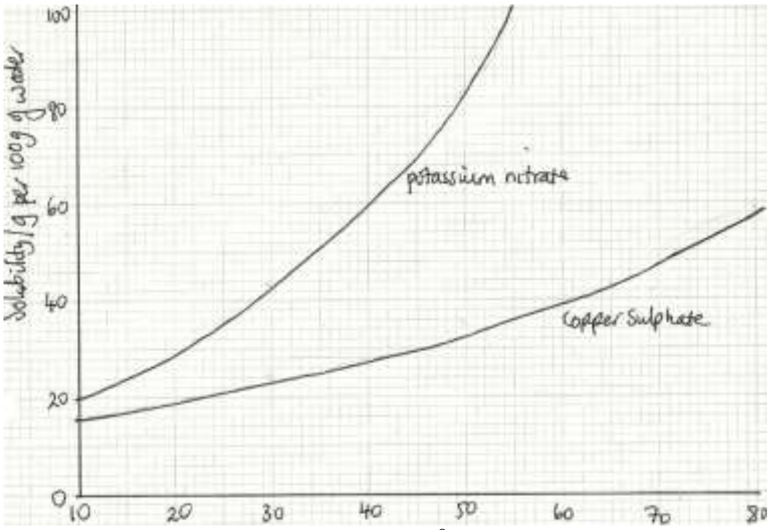
Activity 7	24g of solid dissolve in 80cm^3 of water. Calculate the solubility of the solid in water. Give the correct unit.

Solubility curves

As mentioned above, the solubility of a solute in a solvent changes with temperature. The solubility of a solid usually increases as temperature increases.

Get it right! Gases can also dissolve in liquids, for example carbon dioxide and oxygen both dissolve in water to different extents. Curiously, the solubility of gases goes down as the temperature goes up, so less oxygen dissolves in warm water than in cold water.

A graph of temperature against solubility is called a **solubility curve**. Here are two examples, for the compounds copper sulphate and potassium nitrate. As you can see, potassium nitrate shows a greater change of solubility with temperature than does copper sulphate.



Temperature/°C

You can use a solubility curve to calculate the mass of solute that comes out of a saturated solution as it cools. Read off the solubilities at the two given temperatures and take the difference. This gives the mass of solute that comes out of a solution *made with 100g of the solvent*. You will need to adjust this figure if the mass of solvent is different.

Activity 8	A saturated solution of potassium nitrate, made with 50 cm^3 of water, is cooled from 50°C to 30°C. Calculate the mass of solid potassium nitrate which comes out of the solution.
✎	

Rate of dissolving

A solubility curve shows you *how much* solute will dissolve in a solvent at a certain temperature. It does not tell you *how fast* the solute will dissolve.

To get a solid to dissolve *faster* in a liquid you can do three things:

- *stir*: because this keeps the concentration of the solution next to the solid lumps lower;

- increase the *temperature*: because the particles move faster, so fresh liquid particles get to the solid lumps quicker;

- reduce the *size of the lumps* of solid: because this gives the solid a larger surface area exposed to the liquid.

Investigating particles (all candidates)

As particles are too small to see, you might ask how we know anything about them. The following experiments give some clues.

Dilution of coloured solutions

Potassium manganate (VII), also called potassium permanganate, is a solid that dissolves in water to give a deep purple solution. If you keep diluting a solution of it down more and more, you can still see a faint pink colour with only 0.000000001g of it dissolved in each drop of water.

Assuming you can only see the pink colour if there is at least one particle per drop, this means a particle of the solid cannot weigh more than this.

(Actually the particles weigh much less than this, and you need millions per drop for the pink colour to show.)

Diffusion experiments

Diffusion is the process by which substances "spread out" through air or water, for example a smell spreading out through the still air in a room. Because the particles are moving at random, they tend over time to become evenly spread.

If you set up the experiment shown in figure 1.11 on page 4 of the textbook, ammonia gas diffuses down the tube from the left, and hydrogen chloride gas diffuses down the tube from the right. Where the two gases meet, they react to give the solid ammonium chloride which forms a white ring on the side of the tube. The white ring forms closer to the hydrogen chloride end. This shows that the ammonia particles diffuse faster than the hydrogen chloride particles. This is because the ammonia particles weigh less.

Activity 9

Experiment to investigate the size of ink particles.

Materials and equipment - Seven transparent plastic cups, dropping pipette (a "dropper"), blue or black water-soluble ink, water.

Method - Place the cups in a row. Pour about $10cm^3$ of ink into the first cup. Pour water into the other six cups; the levels of liquid in all seven cups should be the same. With the pipette, put one drop from cup 1 into cup 2 and swirl to mix. Then put one drop from cup 2 into cup 3. Continue like this until you reach cup seven. This process is called **serial dilution**. Your cups should now be set up as follows:

Cup	Contents
1	Undiluted ink
2	1 drop from cup 1 + water
3	1 drop from cup 2 + water
4	1 drop from cup 3 + water
5	1 drop from cup 4 + water
6	1 drop from cup 5 + water
7	1 drop from cup 6 + water

Results - The colour of the water in each successive cup is a fainter colour, from very dark in the first cup to a very slight trace in the seventh.

Explanation - By the seventh cup, the ink is very dilute indeed, but its colour is still visible. However many particles of dye are present in the first cup, there are millions fewer in the seventh. This means that the particles in ink must be very small in size.

Activity 10	Investigating the diffusion of ink particles through water.
	Materials and equipment - Small screw-capped bottle, large bowl, blue or black water-soluble ink, water. **Method** - Fill the bowl with water and put it where it can be left undisturbed for a few days. Place in it the screw-capped bottle full of a solution of ink. Carefully remove the cap of the bottle, leaving as much ink in the bottle as you can. Leave the bowl alone and inspect it every few hours over the next few days. **Results** - The particles of ink slowly diffuse through the water until it is all equally coloured.

Now read pages 1–5 and 30-31 of your textbook to consolidate your knowledge and understanding of this lesson.

The ‘Keywords’ sections at the end of each lesson contain important words whose meaning you should understand. They are all printed in **bold** and explained in the lesson. Check back if you find one you do not understand.

Keywords

atom
element
chemical reaction
symbol

mixture
molecule
compound
solid
liquid
gas (vapour)
properties
kinetic energy
melting
melting point (mp)
freezing (solidifying)
solute
solvent
solubility
sublimation
substance
particle
periodic table
states of matter
changes of state
boiling
boiling point (bp)
evaporating
condensing
impurity
solution
saturated solution

Summary

Lesson One: The Nature of Substances

- Elements, compounds and particles
- Pure substances and mixtures
- States of matter
- Solutions
- Investigating particles

What you need to know

- the meanings of the terms printed in **bold** in this lesson
- the differences between: elements and compounds; pure substances and mixtures; atoms, molecules and particles
- the names for the changes in state
- the unit of solubility

What you might be asked to do

- explain changes of state and solutions in terms of the behaviour of particles

- explain simple experiments to investigate particles
- interpret solubility curves and perform calculations using them

Self-Assessment Test: Lesson One

1. Choose the correct word or phrase in the brackets:
   a. When a cold solid is heated, the particles in it (expand/vibrate) more.
   b. When a solid melts, the particles in it (melt/move past each other).
   c. A cold solid has (cold/slowly vibrating) particles.
   d. The particles in a gas are moving (faster/slower) and are (closer/further apart) than those in a liquid.

2. What is the name for each of the following changes of state?
   a. when water changes from solid to liquid
   b. when water changes from liquid to gas at room temperature
   c. when water is cooled and changes from liquid to solid
   d. when solid carbon dioxide (dry ice) becomes carbon dioxide gas.

3. Correct the mistakes in the following:
   a. When a gas is compressed (squashed) its particles get smaller
   b. If you leave some spilled water on the floor, it condenses and turns into water vapour.
   c. In a gas, the gaps between the particles are filled with air.
   d. Water is a mixture because it contains two different elements
4. (from June 2019). Use the solubility curves in the lesson to calculate:
   a. The mass of copper sulphate dissolved in a saturated solution made with $20cm^3$ of water at 20^0C.
   b. How much more soluble potassium nitrate is than copper sulphate at 40^0C
   c. The mass of solid copper sulphate which would come out of a saturated solution, made with 100g of water at 60^0C, if it was cooled to 30^0C.

Suggested Answers are to be found at the end of the lesson.

Suggested Answers to Activities

Activity 1

(a) O, H, N, Ag, Au, Fe, Mg, Si, C, I.
(b) Nitrogen, Helium, Platinum, Phosphorus, Manganese, Sulphur, Chlorine, Sodium.

Activity 2

Elements: magnesium, iodine, sodium, neon
Compounds: salt, citric acid, alcohol
Mixtures: sea water, air, soil

Activity 3

(a) melting
(b) condensing (condensation)
(c) evaporation
(d) sublimation
(e) boiling
(f) freezing

Activity 4

The salt depresses the melting point of water below 0°C, so it needs to get even colder before the water on the roads freezes to form ice.

Activity 5

With the sugar, the first teaspoonful should dissolve and disappear completely. The water tastes sweet, however, which tells you the sugar particles are still there. If you keep adding sugar, eventually no more will dissolve and you are left with some solid sugar on the bottom which will not go away.

With the soil, the water should go cloudy. This cloudy mixture is called a **suspension**. After standing, the solid soil gradually settles to the bottom. As it does so, the water becomes clearer.

Activity 6

For a fair test: same volume of water, same temperature of water, same size spoonfuls added each time, same amount of stirring.

You should find that sugar has a higher solubility in *warm* water than salt, although it is much closer in *cold* water.

Activity 7

80 cm^3 of water weigh 80g. So the solubility is:

$\frac{24}{80} \times \mathbf{100} = \mathbf{30}$ g per 100g of water

Activity 8

From the solubility curve, the solubility of potassium nitrate is about 82 g per 100g of water at 50°C, and about 42g per 100g of water at 30°C.

So 82 – 42 = 40g of solid would come out of a solution made with 100g of water as it cools.

But 50cm^3 of water weighs only 50g.

So the mass of the solid will be $\mathbf{40} \times \frac{50}{100} = \mathbf{20g}$

Suggested Answers to Self-Assessment Test: Lesson One

1. a. vibrate
   b. move apart
   c. slowly vibrating
   d. faster; further apart

2. a. melting
   b. evaporating
   c. freezing
   d. sublimation

3. a. The particles stay the same size, but they are forced closer together.
   b. It *evaporates* and turns into water vapour.
   c. There is nothing at all in the gaps between particles.
   d. Water is a compound, a pure substance, because its hydrogen and oxygen atoms are joined together, in a fixed ratio.

4. a. From the graph, at 20^0C about 18g of copper sulphate dissolves in 100g of water.
   20cm^3 of water weighs 20g.
   So the mass is $\frac{20}{100} \times 18 = 3.6g$
   b. About 59 – 27 = 32 g per 100g of water.
   c. About 39 – 23 = 16g.