1 States of matter

There are three states of matter – solid, liquid and gas. For example, water can exist as solid ice, liquid water or as steam, which is a gas.

Many substances can be converted to a different state depending on the temperature and pressure. Some solid substances may decompose before they are converted to a liquid.

The names of the different changes of state are shown below:

$$\text{solid} \underset{\text{freezing}}{\overset{\text{melting}}{\rightleftharpoons}} \text{liquid} \underset{\text{condensation}}{\overset{\text{evaporation}}{\rightleftharpoons}} \text{gas}$$

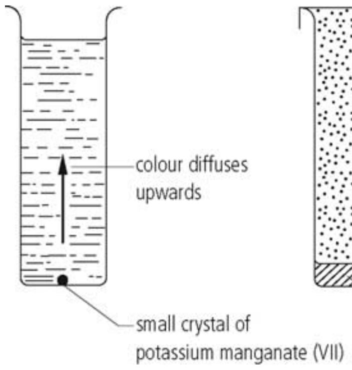
A liquid can be converted to its vapour by evaporation or by boiling. Evaporation can take place at any temperature and pressure. But a liquid boils at a specific temperature depending on the pressure. For example, water boils at 100 °C when the atmospheric pressure is 760 mmHg.

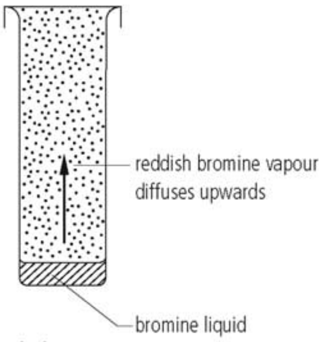
Nature of matter

Matter is made up of particles. The following section provides evidence to support this theory.

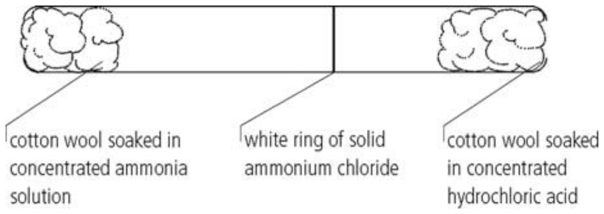
Diffusion

A crystal of potassium manganate (VII) is placed at the bottom of a gas jar to which water is gently added. After a short time the whole solution will be coloured purple because the potassium manganate (VII) particles move upwards and spread throughout the liquid. This is known as **diffusion**. Similarly, if a few drops of bromine liquid are placed at the bottom of a gas jar and the gas jar is covered, the whole gas jar will soon be filled with bromine vapour. The bromine vapour diffuses upwards, although it is heavier than air.





Different gases diffuse at different rates, as demonstrated by the following experiment.



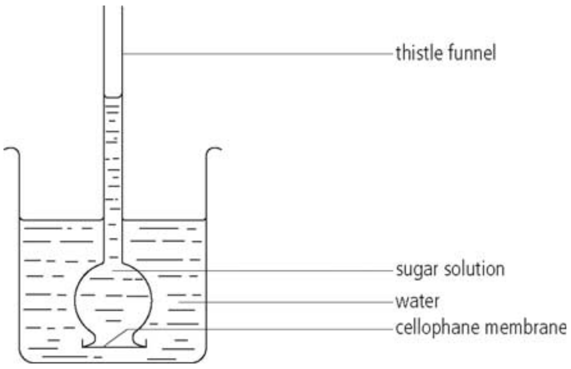
A white ring of ammonium chloride forms where the two gases meet. The experiment shows that not only do gases diffuse, but they do so at different rates. Which gas particles move faster? Why do you say so?

Brownian motion

Observation of brightly illuminated smoke particles in a small glass container will show the particles moving with a haphazard kind of movement. This same kind of movement was observed by the botanist Robert Brown as he observed pollen dust on water. These jerky, haphazard movements were caused by particles in the air or water colliding with the particles of smoke or pollen dust. This type of movement is called **Brownian motion**.

Osmosis

A sugar solution (about 15%) is placed in a thistle funnel covered with a Cellophane membrane. This is then placed in a beaker of water as shown below. The level of the solution in the thistle funnel rises. This is due to water particles passing through the membrane into the thistle funnel. No sugar particles pass into the beaker. The membrane is said to be semi-permeable. It allows solvent particles to pass through, to dilute a solution on the other side. This is known as **osmosis**. The same effect will be observed if a sugar solution of weaker concentration (10%) is placed in the beaker in place of the water. The process continues until the concentrations of both solutions are equal.



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Dilution

A small crystal of potassium manganate (VII) is dissolved in a test tube of water. One-tenth of this solution is placed in another test tube which is filled with water and stirred. This process can be repeated many times before the colour of the manganate (VII) disappears. The solution is coloured because of the presence of particles of potassium manganate (VII). The fact that the solution retains a colour although diluted thousands of times suggests that the one crystal of potassium manganate (VII) must be made up of many tiny particles. (See Chapter 3 for an idea of the size of particles in matter.)

Arrangement of particles in solids, liquids and gases

In a solid, the particles are close to each other with strong forces of attraction between them. The particles are capable of small to-and-fro movements, called vibrational motion.

In a liquid, the forces of attraction are weaker than in a solid, hence they are further apart and capable of greater movement – haphazard movement called Brownian motion.

In a gas, there is little or no attraction between the particles, which are relatively further apart than in a liquid. These particles move at rapid speeds, thus possessing greater energy than those in a liquid.

Sublimation is when a solid goes directly to the gaseous state without passing through a liquid state. On cooling, the gas is also converted directly to a solid. Examples are iodine, ammonium chloride and dry ice.

Questions

1 Put in decreasing order the average energy that the particles in a solid, liquid and gas will possess.

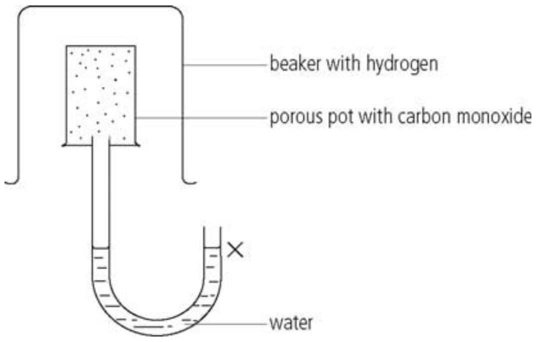
2 1 g of potassium manganate (VII) is dissolved to make 100 cm^3 of the solution. 10 cm^3 of this solution is placed in another beaker and the solution is made up to 100 cm^3. This process can be repeated nine more times before the colour of the manganate (VII) becomes very faint. Assuming that the faint colour of the manganate (VII) must be caused by at least one particle of potassium manganate (VII), calculate the least number of particles that must be present in the 1 g.

3 One experiment that is frequently used to estimate the size of particles in a substance is the oil layer experiment. In one such experiment, a solution containing 0.1 cm^3 of oleic acid in 1 dm^3 of solution was used. One drop of this solution was placed on water in a trough. The water was sprinkled with a fine powder such as **lycopodium powder**.

The area occupied by the oil film was estimated to be about 15 cm^2. 50 drops of the acid solution had a volume of 2.5 cm^3.

- a Find the volume of one drop of the acid solution.
- b Find the volume of oleic acid in one drop of solution.
- c Assuming that the layer is a monomolecular layer, find the thickness of the layer giving the thickness of one molecule of oleic acid.

4 A beaker filled with hydrogen gas is placed over a porous pot containing carbon monoxide gas as shown in the diagram below. What will happen to the water level at X. Why?



5 This question concerns the following table.

Substance	Melting point (°C)	Boiling point (°C)
A	−20	350
B	−285	−183
C	800	1 400
D	190	180
E	0	100
F	−7	59

- a Which substance(s) will be solid(s) at room temperature (25 °C)?
- b Which substance(s) will have fast-moving particles at room temperature?
- c Which substance(s) will sublime when heated?
- d Which substance will be liquid over the widest range of temperatures?
- e Which substance(s) will be liquid(s) at room temperature?
- f Which substance(s) will completely fill a container?

2 Separation of mixtures

Substances occur naturally as mixtures. Thus, knowing how to obtain pure substances from mixtures is of great importance. For example, common salt (sodium chloride) occurs naturally as rock salt with sand being the major impurity. The salt can be separated from the sand to obtain a pure salt substance.

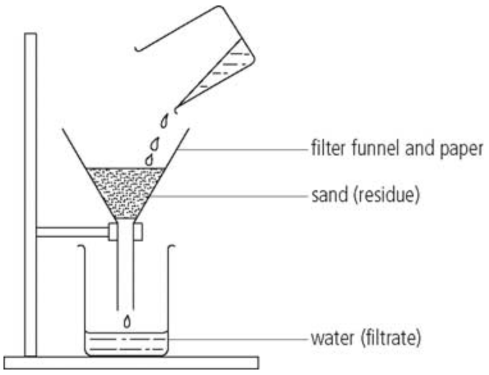
A **pure substance** is one that contains particles of that substance only, for example, pure sodium chloride contains crystals of sodium chloride only. The addition of any other substance causes it to become a mixture.

Methods of separation

Filtration

Filtration is used to separate a solid from a liquid in which the solid is not dissolved. This is called a **suspension**, for example, sand and water or undissolved zinc in a solution of zinc sulphate.

A filter funnel and filter paper are used to separate the solid and liquid, as shown below.



Evaporation

Evaporation is used to obtain a solid from a solution of a solid and a liquid. For example, if you have a solution of sodium chloride and water, you can recover the sodium chloride by evaporating all the water from the solution leaving the less volatile sodium chloride behind. This process is limited to salts that will not decompose on heating, and those that do not need water for the crystals to form. Such crystals can be obtained from a solution by crystallisation.

Note: In a **solution** the solid is dissolved in the liquid.

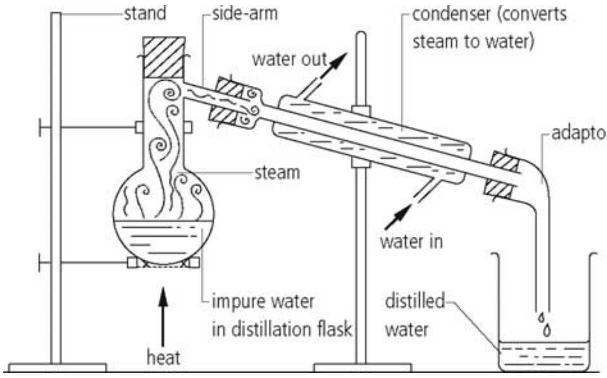
Crystallisation

At any particular temperature, only a fixed amount of a solid can dissolve in a fixed amount of liquid. This is normally referred to as the **solubility** of the solid.

Consider a solution of solid in a liquid in which almost all of the liquid is evaporated. The little liquid that is left cannot dissolve all of the solid. As the solution is cooled, the solid therefore starts to separate from the solution as crystals. The crystals can then be obtained by filtration.

Simple distillation

This is a process by which pure water can be obtained from impure water.



The less volatile solid impurities are left in the distillation flask.

Separation of miscible and immiscible liquids

Fractional distillation

This process is used to separate mixtures of miscible liquids, i.e. liquids that dissolve in each other. The most popular example is the separation of a mixture of ethanol and water.

Ethanol normally boils at around 78 °C and water at 100 °C. If a 40 : 60 mixture is heated in a distillation flask, the first distillate collected will be much richer in alcohol (about 70–80%). A better separation is normally obtained using a fractionating column (shown on page 4).

In the fractionating column, several distillations take place at the same time. As vapour ascends the column, it condenses to a liquid. Hot vapour ascends and redistills the condensed liquid driving it forward. This continues along the length of the column. Each time the liquid is redistilled, the vapour driven forward is richer in the more volatile (low-boiling) component. In this case, a 95% : 5% separation can be obtained by this method.

Oil refineries use this method to separate petroleum into fractions such as gasoline, kerosene or gas oil.

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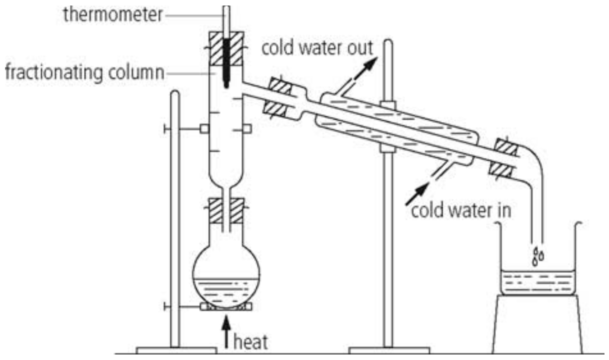
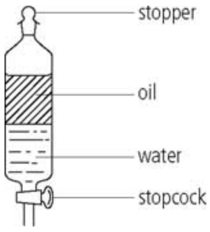


Separation of immiscible pairs of liquids – by separating funnel

A pair of immiscible liquids, i.e. liquids that do not dissolve in each other, such as oil and water, can be separated using a separating funnel. This is a funnel with a stopcock at the end.



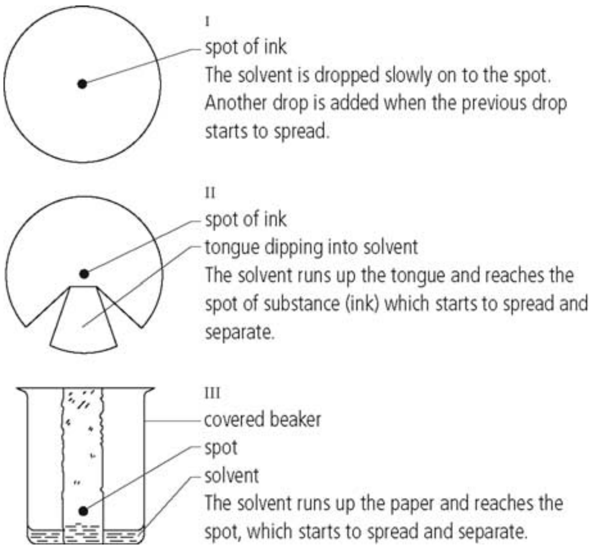
Oil and water do not dissolve in each other so will occupy separate layers when mixed, with the lighter substance (oil) floating on top of the water. The mixture is placed in a separating funnel and the water is run off first, followed by the oil. It is often very difficult to allow all of the water to run out leaving the oil behind. Usually, most of the water is allowed to run out and then the tap is turned off. The small quantity of water remaining is then run out along with a little of the oil, into a separate container. The oil can then be safely run out.

Other methods of separation

Paper chromatography

This is used for separating mixtures of dyes, for example, ink. Several methods can be used, as illustrated in the next column. All the methods involve putting a spot of a concentrated solution of the substance on the paper and allowing it to dry.

The different dyes separate out because each dye moves at a different rate on the paper. This is due to two factors: (a) solubility in the solvent: the more soluble the dye is in the solvent, the faster its rate of movement, and (b) the attraction of the dye for the paper: the greater the attraction, the slower the movement. Paper chromatography is also used to identify and separate mixtures of, for example, amino acids or sugars.



Solvent extraction

This process is mainly used to separate organic substances from aqueous solutions. An organic solvent (nearly always ether) is used to extract the organic compound. Once the ether is added, the organic substance dissolves in it. There will be two layers which can be separated using a separating funnel. The organic substance can then be obtained by distillation and the solvent can also be recovered. This process is used in the manufacture of penicillin.

Solvent extraction can also be used for extracting vegetable oils from substances such as nuts or soya beans. The nuts are crushed and the solvent is used to extract the oils. The mixture can then be filtered and distilled, separating the oil from the solvent, which is recovered.

Sublimation

This is used to separate a mixture of two solids, only one of which sublimes, for example, ammonium chloride and sodium chloride. The mixture is heated causing the ammonium chloride to sublime and leaving the sodium chloride behind. The ammonium chloride cools to a solid and can be recovered. Iodine can be purified in this way.

Questions

1 Water is added to a mixture of copper(II) sulphate crystals and copper(II) oxide. The mixture is warmed, stirred and then filtered.
  a Explain what will be achieved by the above operations.
  b Why is the mixture stirred and warmed?
  c On filtering, what will be (i) the residue, and (ii) the filtrate?
  d Can any crystals be obtained from the filtrate? If so, how?
2 List three differences between colloids and suspensions.

3 Atomic structure

An atom of an element consists of three particles:

Particles	Mass/atomic mass unit (a.m.u.)	Charge
Protons	1	+
Neutrons	1	0
Electrons	1/1850	–

The protons and neutrons are in the nucleus at the centre of the atom. The electrons orbit the nucleus at distances representing different energy levels. Each energy level is referred to as a shell.

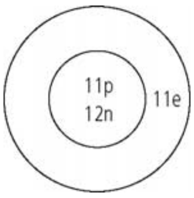
The atomic number of an element is the number of protons in the nucleus of the atom.

The mass number is the sum of the protons and neutrons in the nucleus of an atom of the element.

In any atom, the number of protons is equal to the number of electrons. Consider the notation $^{23}_{11}\text{Na}$. Na is the symbol of the element sodium. The upper figure represents the mass number (23). The lower figure represents the atomic number (11). Thus, in an atom of sodium, there will be:

- protons: atomic number (11)
- electrons: atomic number (11)
- neutrons: mass number – atomic number (23 – 11).

The number of neutrons is obtained by subtracting the atomic number from the mass number. The sodium atom can be represented simply like this.

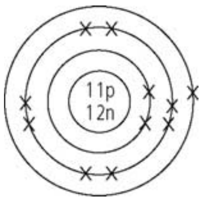


Arrangement of electrons in atoms

The electrons are arranged in shells around the nucleus. Each shell represents a different energy level. The first shell is the K shell, followed by the L shell, M shell, etc. The maximum number of electrons in a shell is given by the formula $2n^2$, where n is the number of the shell. For example:

Shell	Maximum number of electrons
K shell, $n = 1$	$2n^2 = 2 \times 1^2 = 2$
L shell, $n = 2$	$2n^2 = 2 \times 2^2 = 8$
M shell, $n = 3$	$2n^2 = 2 \times 3^2 = 18$

Consider the sodium atom with 11 electrons. These electrons will be arranged as follows: 2 in the first shell, 8 in the second and 1 in the third. This can be represented as 2)8)1 and is referred to as the **electronic configuration**. The sodium atom can be represented like this:



In working out electronic configurations the following rules must be observed:

a A shell cannot accommodate more than its maximum electrons, but may have less.
b The outermost shell of an atom can never have more that eight electrons. If such a situation arises, electrons in excess of eight are put into a new shell.

For example: potassium has an atomic number of 19, therefore the atom will have 19 electrons. It should have been possible to write the electronic configuration as 2)8)9. However, this would violate rule b. The electronic configuration is therefore 2)8)8)1.

Isotopy

Very often an atom may have more than one type of atom, for example, $^{35}_{17}\text{Cl}$ and $^{37}_{17}\text{Cl}$. Notice that the atomic number is the same in both cases but the mass numbers are different. Work out the number of protons, neutrons and electrons in each of these atoms. As you can see, they have the same number of protons and electrons but a different number of neutrons. This phenomenon is known as **isotopy** and the different types of atoms are isotopes of the element. These isotopes are not present in the same proportion. In a sample of chlorine, there are 75% of $^{35}_{17}\text{Cl}$ atoms to 25% of $^{37}_{17}\text{Cl}$ atoms. Thus, the relative atomic mass of chlorine will be:

$$\frac{(75 \times 35) + (25 \times 37)}{100}$$

$$= 35.5, \text{ taking 100 atoms into account.}$$

Because isotopes have the same number of electrons arranged in the same way, they will show similar chemical behaviour.

Absolute mass and relative mass

The absolute mass of a single atom is too low for it to be weighed accurately. For example, the mass of a hydrogen atom is approximately:

$$\frac{1}{6 \times 10^{23}}\ \text{g}$$

Masses of atoms are therefore compared with a standard atom. This mass is referred to as the **relative atomic mass**. The standard first chosen was hydrogen. Nowadays the standard used is carbon-12 which is assigned a mass of 12 atomic mass units. Atoms of all other elements are compared to that of carbon-12. Thus, if an atom is twice as heavy as a carbon atom, it will have a relative atomic mass of 24.

Questions

1 a How many protons, electrons and neutrons are present in each of the following elements?

i ${}^{40}_{20}\text{Ca}$

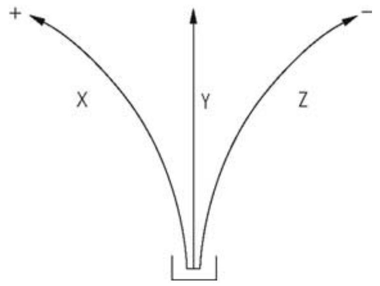
ii ${}^{40}_{18}\text{Ar}$

iii ${}^{1}_{1}\text{H}$

iv ${}^{2}_{1}\text{H}$

b Draw diagrams to represent the calcium and argon atoms.

2 Protons, neutrons and electrons are passed through an electric field, as shown in the diagram.



Which letters represent the protons, neutrons and electrons respectively?

3 a X and Y are two isotopes of the same element. Complete the following table.

Isotope	X	Y
Number of protons	48	
Number of electrons		
Number of neutrons	48	50

b A sample of the element contains 70% of isotope X and 30% of isotope Y. What is the relative atomic mass of the element?

4 The table below contains information about various atoms.

Atom	Number of protons	Number of neutrons
A	17	18
B	22	26
C	17	20
D	22	28
E	28	31

a Which pairs of atoms are isotopes of the same element?

b What is the mass number of atom B?

c What is the electronic configuration of atom C?

d Which element will have the electronic configuration 2)8)16)2?

5 The number of protons in the atom ${}^{A}_{Z}\text{M}$ is:
A Z **B** A – Z **C** A **D** Z – A

6 The number of protons in the atom ${}^{A}_{Z}\text{M}$ is:
A Z **B** A – Z **C** A **D** Z – A

7 The number of neutrons in the atom ${}^{A}_{Z}\text{M}$ is:
A Z **B** A – Z **C** A **D** Z – A

8 The electronic configuration of an element with atomic number 19 and mass number 20 will be:
A 2)8)9 **B** 2)8)8)1 **C** 2)8)8)2 **D** 2)8)18)8)3

9 Two isotopes of an element are present in equal proportions. If the mass numbers of the isotopes are 88 and 90 respectively, what is the relative atomic mass of the element?
A 88.5 **B** 89 **C** 89.5 **D** 90

10 Which of the following elements contain the same number of neutrons as ${}^{40}_{20}\text{Ca}$?
A ${}^{20}_{10}\text{Ne}$ **B** ${}^{40}_{18}\text{Ar}$ **C** ${}^{27}_{13}\text{Al}$ **D** ${}^{39}_{19}\text{K}$

4 Ionic combination

The basic units of all substances are **elements**. An element is any substance which cannot be split up into simpler substances by any known chemical process. Elements combine with each other to form **compounds**. A compound is any substance formed when two or three elements are chemically combined.

Why and how do elements combine?

Helium, neon, argon, etc., the noble gases, are chemically inert, i.e. they are stable. All of them, except helium, have eight (an octet of) electrons in their outermost shell. It is this octet of electrons which makes these elements so stable. In the case of helium, which has only one shell, a duplet is enough to fill the shell and thus ensure stability. All elements try to attain this electronic stability, i.e. they try to attain the electronic configuration of the nearest inert gas. It is the electrons in atoms and their instability that are responsible for chemical reactivity. How they have this effect leads us to chemical combination.

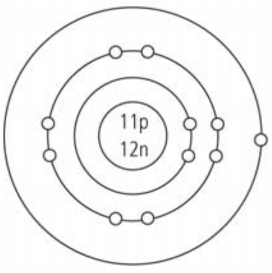
Ionic or electrovalent combination

This type of combination takes place when a metal combines with a non-metal. Consider the elements sodium ($^{23}_{11}$Na) and chlorine ($^{35}_{17}$Cl). The electronic configuration of sodium is 2)8)1 and that of chlorine 2)8)7. Sodium needs to lose 1 electron to attain the electronic configuration of neon 2)8 whereas chlorine needs to gain 1 electron to attain the electronic configuration of argon 2)8)8. When the two elements react together, sodium gives an electron to chlorine which accepts it. Each atom has now attained electronic stability.

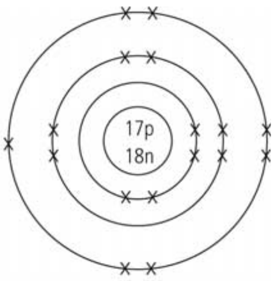
By losing an electron, sodium now has one more proton (+) than electron (–). Thus, the sodium atom is no longer neutral. It now has a positive charge, Na^+. A charged atom is called an **ion**. Chlorine now has one more electron than proton. It has therefore acquired a negative charge. Ions, because they are oppositely charged, attract each other by an electrostatic force of attraction. This electrostatic force of attraction is called an **ionic** or **electrovalent** bond.

In ionic compounds, the ions are arranged in cubes with negative ions surrounded by positive ions and vice versa. For example, in sodium chloride, each sodium ion is surrounded by six chloride ions and each chloride ion is surrounded by six sodium ions.

Before combination

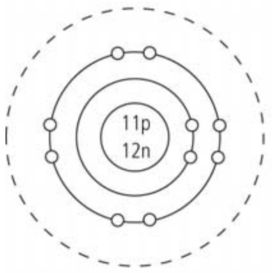


sodium atom 2)8)1

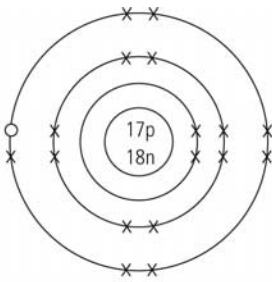


chlorine atom 2)8)7

After combination



sodium ion (Na^+) 2)8



chloride ion (Cl^-) 2)8)8

If sodium 2)8)1 combines with sulphur 2)8)6, two sodium atoms will combine with one atom of sulphur.

Before combination:

Na 2)8)1 Na 2)8)1 S 2)8)6

After combination:

Na^+ 2)8 Na^+ 2)8 S^{2-} 2)8)8

How will magnesium $^{24}_{12}$Mg combine with chlorine $^{37}_{17}$Cl? Write your answer as shown above.

Properties of ionic compounds

1 Ionic compounds normally have a giant structure of oppositely charged ions. These ions strongly attract each other. As a result, all ionic compounds are solids with high melting points, high boiling points and high heats of vaporisation.
2 Ionic compounds do not conduct electricity when solid but do so in aqueous solution or when molten (liquid). Ions move only slightly in the solid as they are strongly attracted to each other. In the liquid

state, or in aqueous solution, the forces of attraction between the ions are broken down by heat and the solvent respectively. The **ions** become more mobile and are able to conduct an electric current.

3 It is an adage in chemistry that 'like dissolves like'. Thus, ionic compounds are soluble in polar solvents like water and insoluble in non-polar solvents like gasoline or methylbenzene (toluene).

Ionic equations

In many equations there are ions which remain unchanged in state or in valency across an equation. These are called **spectator ions**. If these are removed from an equation, an ionic equation is formed.

Here are the steps to write an ionic equation:

Step 1 Write the balanced chemical equation:
$Pb(NO_3)_2(aq) + 2NaCl(aq) \rightarrow PbCl_2(s) + 2NaNO_3(aq)$

Step 2 Break up the compound into ions:
$Pb^{2+}(aq) + 2NO_3^-(aq) + 2Na^+(aq) + 2Cl^-(aq) \rightarrow$
$Pb^{2+}(s) + 2Cl^-(s) + 2Na^+(aq) + 2NO_3^-(aq)$

Step 3 Eliminate the ions which are not changed:
$Pb^{2+}(aq) + \cancel{2NO_3^-}(aq) + \cancel{2Na^+}(aq) + 2Cl^-(aq) \rightarrow$
$Pb^{2+}(s) + 2Cl^-(s) + \cancel{2Na^+}(aq) + \cancel{2NO_3^-}(aq)$

Step 4 Rewrite the equation with whatever is left:
$Pb^{2+}(aq) + 2Cl^-(aq) \rightarrow PbCl_2(s)$

Tips for writing ionic equations

1 The element always has a valency of 0.
2 Covalent compounds cannot be broken into, for example, H_2O, CO_2 and NH_3.
3 Two ions that come from the same compound on the same side of the equation are rejoined in the final ionic equation.

Types of chemical reactions

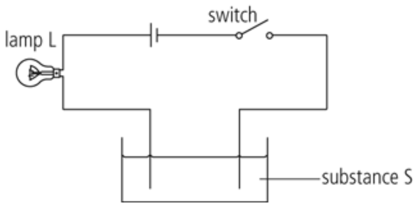
1 A **combined reaction** is when two reactions combine to give one product, for example:
  a $S(s) + O_2(g) \rightarrow SO_2(g)$
  b $Na_2O(s) + CO_2(g) \rightarrow Na_2CO_3(s)$
2 When some substances are heated, they can break down or decompose. This break down is called **decomposition**, for example:
  $2NaNO_3(g) \rightarrow 2NaNO_2(s) + O_2(g)$
3 Neutralisation occurs when acids and bases react until their pH is exactly 7 or neutral, for example:
  $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$
4 A metal or non-metal may displace another from its salts. This is called **displacement**, for example:
  a $Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$
  b $Cl_2(g) + 2KI(aq) \rightarrow 2KCl(aq) + I_2(aq)$
5 When salt solutions are mixed together, they exchange ions. This is known as **double displacement**, for example:
  $2NaNO_3(aq) + ZnSO_4(aq) \rightarrow Zn(NO_3)(aq) + Na_2SO_4(aq)$

Questions

1 Draw diagrams to show the combination between:
  a sodium and oxygen
  b magnesium and chlorine.
2 Use the electronic configurations of the elements to write the formula of the following compounds:
  a lithium oxide b sodium sulphate
  c magnesium oxide d calcium chloride.
  In each case show the charges on the ions.
3 Complete the following table.

Element	Atomic number	Number of protons	Number of electrons	Charge on ions
A	17		18	
B		20		B^{2+}
C			18	C^{2-}
D		1		D^+
E		8	10	

4 Consider the following diagram.

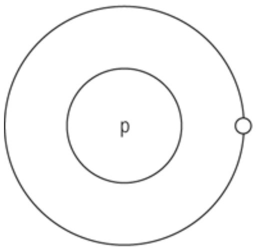


When the switch is closed, the lamp L lights up if substance S is aqueous or molten magnesium chloride. When S is solid magnesium chloride, the lamp does not light up. Explain this.

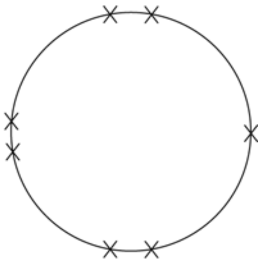
5 Why is it that ionic compounds have high melting and boiling points?
6 During ionic combination:
  A a non-metal donates electrons to a non-metal
  B a metal accepts electrons from a non-metal
  C a metal loses its valency electrons to a non-metal
  D a metal donates one electron to a non-metal.
7 During ionic combination, atoms:
  I try to attain the electronic structure of the nearest noble gas
  II seek to obtain a stable electronic structure by losing or gaining electrons
  III share electrons to attain a stable electronic structure.
  Choose the correct answer:
  A I, II and III **C** II and III only
  B I and II only **D** I only

5 Covalent combination

This type of combination takes place mainly between non-metals. Consider the $^{1}_{1}$H (hydrogen) and $^{35}_{17}$Cl (chlorine) atoms.

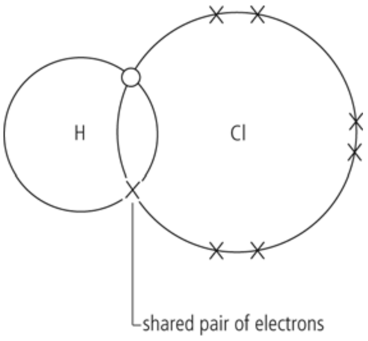


hydrogen atom

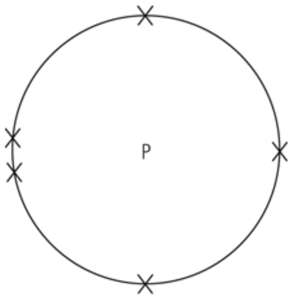


chlorine atom

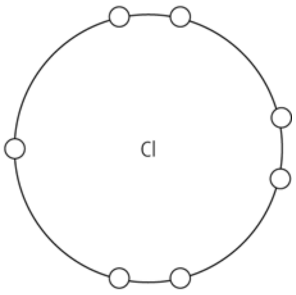
Hydrogen needs one electron to complete its shell and attain the electronic structure of helium. Chlorine also needs one electron to complete its octet and attain the electronic structure of argon. Chlorine and hydrogen do this by sharing electrons. The hydrogen electron orbits around its own nucleus, and also around the chlorine nucleus, thus completing the octet for chlorine. Chlorine, in turn, allows one of its electrons to orbit around its own nucleus and also the hydrogen nucleus. The hydrogen duplet is thus completed. The two atoms are sharing electrons to attain stability. This sharing of electrons can be represented as follows.



This shared pair of electrons forms a covalent bond. Consider the combination between phosphorus and chlorine.

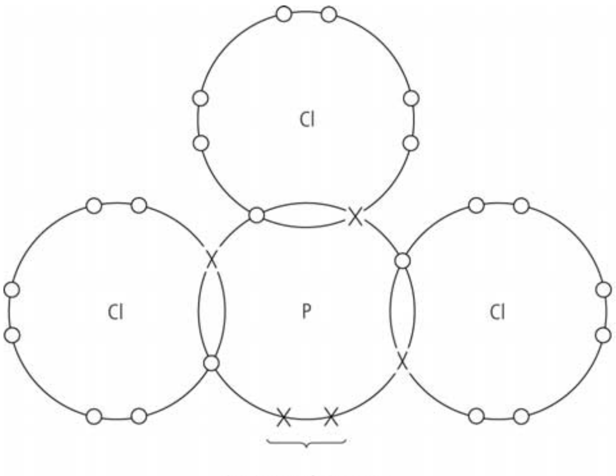


phosphorus atom



chlorine atom

Phosphorus needs three more electrons to complete the octet and chlorine needs one electron to complete its octet. Phosphorus will therefore have to share one electron with each of three chlorine atoms, which will in turn share one electron each with the phosphorus atoms, for example:

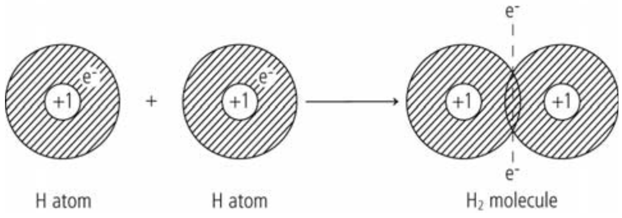


PCl_3
molecule of phosphorus trichloride

Thus, three covalent bonds are produced.

Covalent bonds

The simplest example to illustrate the concept of a covalent bond is the hydrogen molecule. A hydrogen molecule consists of two hydrogen atoms in which the two valence electrons are shared between the two atoms. This diagram shows covalent bonds in a hydrogen molecule.

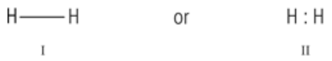


The shaded region on each atom is known as an **orbital** – it is the region in which the electrons will be found. When the orbitals overlap, the two electrons, one from each atom, are attracted to the two nuclei at the same time, thereby forming a single covalent bond.

It is important to note the following:

1 The atoms do not lose or gain the electrons.
2 Covalent bonds are electrostatic in nature.
3 The chemical bond in the hydrogen molecule forms because each of the two electrons is attached to two protons simultaneously. The bonding electrons are often said to be shared by two nuclei.
4 Substances such as hydrogen, in which the bonding between the atoms in the molecule is covalent, are called **covalent molecular substances**. The covalent bond is also found in a network of solids such as diamond and graphite (see Chapter 6). However, by sharing the two electrons, the atoms in the hydrogen molecule have achieved the electron configuration of the noble gas atom, helium.

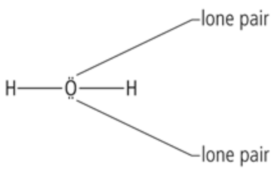
A simpler way of representing the bonding in the hydrogen molecule is as follows.



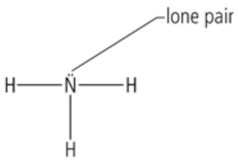
Note that in I the line represents a shaded pair of electrons, while in II the hydrogen bond can be expressed as an electron pair on the electron dot diagram.

Lone pairs are the valence electrons, which are not involved in the covalent bonds.

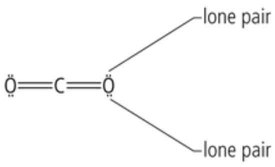
Examples of lone pairs:



H_2O (water)



NH_3 (ammonia)



CO_2 (carbon dioxide)

The difference between ionic compounds and covalent molecular substances can be set out as follows.

Ionic compounds	**Covalent molecular compounds**
Generally crystalline solids, for example, salts.	Generally liquids or gases.
High melting and boiling point – non-volatile.	Low melting and boiling point – volatile.
Electrolytes.	Non-electrolytes.
Generally soluble in water, but insoluble in organic solvents.	Generally soluble in organic solvents, but insoluble in water.
Bonding is non-directional.	Bonding is highly directional.
Reactions are fast.	Reactions are often slow.

Questions

1 a Use electronic configurations to write formulae for compounds formed between:
  i carbon and chlorine
  ii nitrogen and hydrogen
  iii sulphur and chlorine.
  b Draw diagrams to illustrate the combination in the above compounds.
2 What kind of combination (if any) will be expected to take place between the following?
  a sodium and oxygen
  b carbon and oxygen
  c phosphorus and oxygen
  d phosphorus and chlorine
  e hydrogen and chlorine
  f sodium and sulphur
  g sodium and magnesium
  h helium and oxygen
3 Are these chlorides formed by ionic or covalent combination?
  A is a gas at room temperature.
  B is a high melting solid at room temperature.
  C has a boiling point of –1 °C.
  D is a gas at room temperature that conducts electricity when dissolved in water.
  E is insoluble in water, but conducts electricity when molten.
4 Covalent combination:
  A usually takes place between a metal and a non-metal
  B occurs because metals are unstable
  C usually takes place between two non-metals
  D takes place by the transference of electrons from one non-metal to another.
5 Covalent compounds are usually gases or liquids at room temperature because:
  A the covalent bonds are weak
  B there is little attraction between the molecules
  C the atoms are closely attached to each other
  D the particles are capable of rapid movement.