Revision Guide: 4.1 Atomic Structure and the Periodic Table

Atoms, Elements and Compounds

Atoms
All substances are made of atoms. An atom is the smallest part of an element that can exist.
Atoms of each element are represented by a chemical symbol, eg O represents an atom of oxygen, Na represents an atom of sodium.

Elements and the periodic table
An element is a substance with only one type of atom.
Elements are listed in the periodic table. There are about 100 different elements.
Elements can be classified as metal or non-metal depending on their properties.
The columns in the periodic table are called groups and contain **similar** elements.
The rows in the periodic table are called periods. Elements show a gradual change in properties across a period.

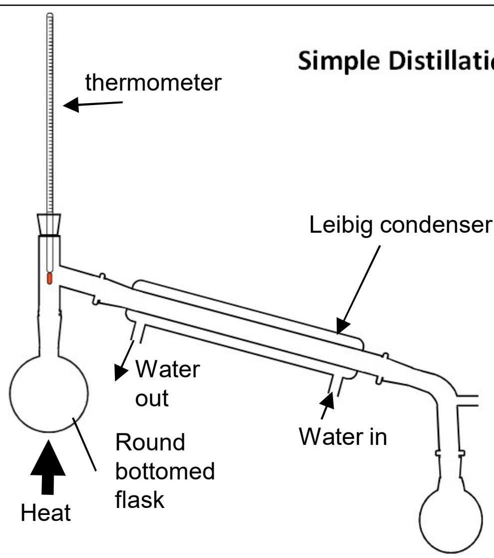
Compounds
Some elements combine through chemical reactions to form compounds.
Compounds are made from two or more different elements (types of atoms) combined together in **fixed proportions** and can be represented by formulae using the symbols of the atoms from which they were formed, e.g CO_2

Compounds have **different properties** from the elements they are made from.
Compounds can only be separated into elements by chemical reactions.

Mixtures
A mixture consists of two or more elements or compounds not chemically combined together.
The chemical properties of each substance in the mixture are unchanged.

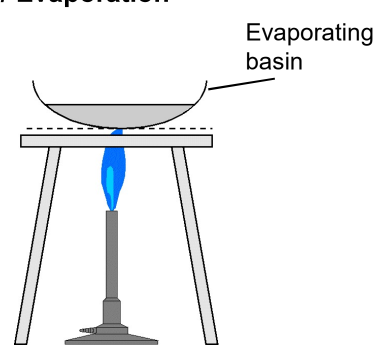
Separating Techniques
Mixtures can be separated by physical processes such as filtration, crystallisation, simple distillation, fractional distillation and chromatography. These physical processes do not involve chemical reactions.

Simple Distillation



Type of mixture separated:
soluble solid dissolved in a liquid (usually water) e.g. salty water
explanation:
liquid boils off and condenses in the condenser. The thermometer will read the boiling point of the pure liquid.

Crystallisation/ Evaporation

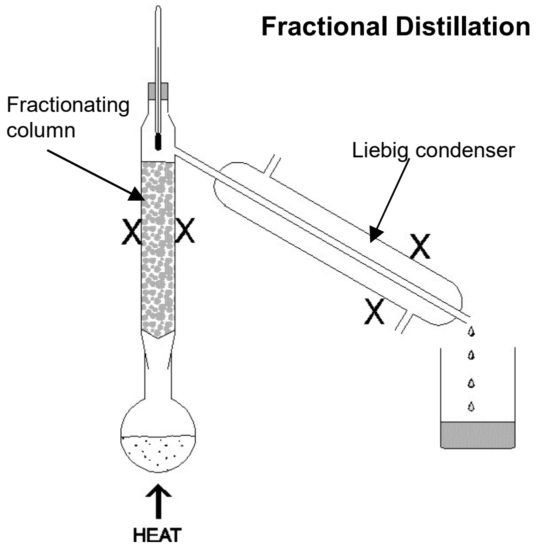


Type of mixture separated: A soluble solid and a liquid (E.g. salt and water)

To separate a soluble solid from a (non-flammable) liquid we use evaporation. If we want to create hydrated salt crystals then do not evaporate all the water from the mixture

The evaporating basin is wide and shallow, which gives the liquid a large surface area for quicker evaporation

Fractional Distillation

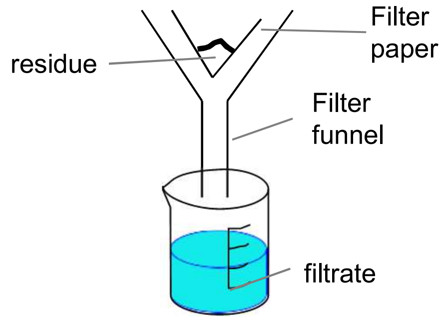


Type of mixture separated:
Soluble liquids with different boiling points e.g. crude oil

The fractionating column has a temperature gradient and is hotter at the bottom than at the top

Explanation: When a mixture of soluble liquids is heated all liquids are evaporated. The liquid with the lower boiling point, however, forms the greatest percentage of vapour. As the vapour moves up the fractionating column it becomes more rich with the component that has the lowest boiling point. This is due to the vapour mixture condensing and evaporating as it moves up the column.
A thermometer measures the temperature of the fractions before they condense. The liquid with the lowest boiling point will be the first 'fraction' to collect.

Filtration



Type of mixture separated:
insoluble solid suspended in a liquid (usually water) e.g. sand and water.

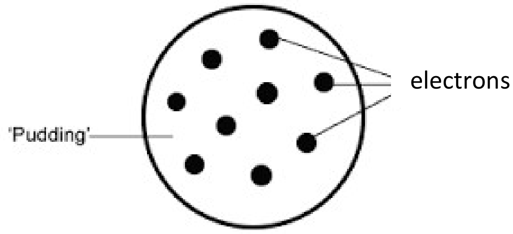
Explanation:
The insoluble solid (called residue) gets caught in the filter paper, because the particles are too big to fit through the holes in the paper.
The filtrate is the substance that comes through the filter paper.

See **chapter 4.8** for information about chromatography

History of Development of the Atom

Before the discovery of the electron atoms were thought to be tiny spheres that could not be divided

Plum-pudding model
The discovery of the electron led to the plum-pudding model of the atom. The **plum-pudding model** suggested that the atom was a ball of positive charge with negative electrons embedded in it.

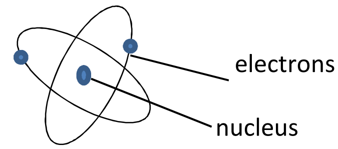


Nuclear model

The results from the Rutherford and Marsden's alpha scattering experiments led to the plum-pudding model being replaced by the nuclear model.
In this model the centre of the atom was called the nucleus.
This experiment showed:

- that all the **mass of the atom** was in **the nucleus**.
- that all the **positive charge** of the atom was in the **nucleus**

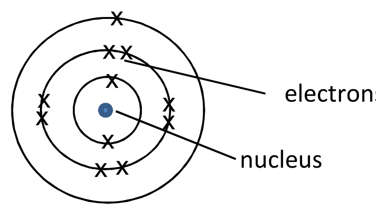
The electrons were thought to orbit the nucleus, like planets around the sun.



Nuclear model

In the experiment **most of the** alpha particles directed at thin gold foil passed through showing that that all the **mass of the atom** was in **the nucleus**.
But a few were deflected or bounced back, suggesting the positive charge was concentrated at the centre of each gold atom.

Bohr Model
Neils Bohr adapted the nuclear model by suggesting that electrons orbit the nucleus at **specific distances**.
The electrons are on **energy levels** or shells.
The theoretical calculations of Bohr agreed with experimental observations.



Bohr Model

Later experiments led to the idea that the positive charge of any nucleus could be subdivided into a whole number of smaller particles, each particle having the same amount of positive charge. The name **proton** was given to these particles.

Chadwick
The experimental work of James Chadwick provided the evidence to show the existence of **neutrons** within the nucleus. This was about 20 years after the nucleus became an accepted scientific idea. This could help explain the existence of isotopes

The Atom

Atoms have a small central nucleus made up of protons and neutrons around which there are electrons.

Particle	Relative Mass	Relative Charge
Proton	1	+1
Neutron	1	0
Electron	Very small	-1

In an atom, the number of electrons is equal to the number of protons in the nucleus. Atoms have no overall electrical charge.

Size of atom
Atoms are very small, having a radius of about **0.1 nm (1×10^{-10} m).**
The radius of a nucleus is less than **1/10 000** of that of the atom (about **1×10^{-14} m**).

All atoms of a particular element have the same number of protons.
Atoms of different elements have different numbers of protons.

The number of protons in an atom is called its atomic number (proton number). Atoms are arranged in the modern periodic table in order of their **atomic number (proton number)**.

Most of the mass of an atom is in the nucleus

The total number of protons and neutrons in an atom is called its **mass number**

To work out the number of neutrons in an atom subtract the atomic number from the mass number
Example Beryllium : atomic number 4, mass number 9.
It has 4 protons, 4 electrons
and 9-4 =5 neutrons

An atom of Lithium (Li) can be represented as follows:

Mass Number → 7 Li ← Atomic Symbol
Atomic Number → 3

$$^{7}_{3}\mathrm{Li}$$

The **atomic number**, is the number of protons in the nucleus.
The **mass number** is the total number of protons and neutrons in the atom.

Number of neutrons = Mass number – Atomic number

Isotopes
Atoms of the same element can have different numbers of neutrons; these atoms are called **isotopes** of that element.
Isotopes of an element have the same chemical properties because they have the same electronic structure

Calculating Relative Atomic Mass

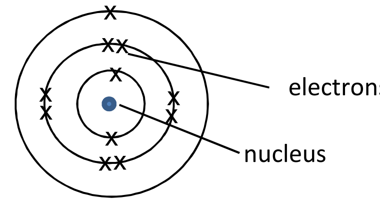
The relative atomic mass of an element is an average value that takes account of the abundance of the isotopes of the element.

$$\text{R.A.M} = \frac{\Sigma\,(\text{isotopic mass} \times \%\ \text{abundance})}{100}$$

Example 1. Chlorine has two isotopes ^{35}Cl and ^{37}Cl. 75% of a sample of chlorine is ^{35}Cl and 25% is ^{37}Cl.
Calculate the relative atomic mass of chlorine.
R.A.M = [(75 x 35) + (25 x 37)] /100
= 35.5

Electronic Structure

Electrons occupy particular energy levels. Each electron in an atom is at a particular energy level.
The electrons in an atom occupy the lowest available energy levels .
The first energy level can hold a maximum of **2** electrons, the 2nd and 3rd can hold up to **8**. (not really true for 3rd).



Elements in the same **group** in the periodic table have the same number of electrons in the highest energy levels (outer electrons) and this gives them similar properties. E.g. group 1 elements all have 1 electron in their outer shell.

Elements in the same **period** have the same number of energy levels.

The elements in Group 0 of the periodic table are called the noble gases. They are unreactive because their atoms have stable arrangements of electrons.

The Periodic Table

Modern Periodic Table
The elements in the periodic table are arranged in order of **atomic (proton) number** and so that elements with similar properties are in columns, known as **groups**.
The table is called a periodic table because similar properties occur at regular intervals.
Elements in the **same group** in the periodic table have the **same number of electrons in their outer shell** (outer electrons) and this gives them similar chemical properties.

The modern periodic table can be seen as an arrangement of the **elements in terms of their electronic structures.**

- atomic number gives number of protons or electrons
- **Elements in the same group have the same number of electrons** in their **highest occupied energy level** (outer shell). (This explains their similar reactivity)
- Elements in the same period have the same number of shells
- As you go down a group the number of shells increases.

Early Periodic Tables
Before the discovery of protons, neutrons and electrons, scientists attempted to classify the elements by arranging them in order of their atomic weights.

The early periodic tables were i**ncomplete** and some elements were placed in **<u>inappropriate</u> groups** if the **strict order of atomic weights was followed**.

Knowledge of isotopes made it possible to explain why the order based on atomic weights was not always correct.

Mendeleev – leaving gaps

- Mendeleev overcame some of the problems by
- **leaving gaps** for elements that he thought had not been discovered
- in **some places changing the order based on atomic weights** e.g. I and Te because the properties of iodine were similar to the properties of other group 7 elements.

Mendeleev predicted the properties of the missing elements. Elements with properties predicted by Mendeleev were discovered and filled the gaps.

Metals and non-metals
Elements that react to form positive ions are metals.
Elements that do not form positive ions are non-metals.
(note- hydrogen is an exception to this rule)

The majority of elements are metals. Metals are found to the left and towards the bottom of the periodic table. Non- metals are found towards the right and top of the periodic table.

Noble Gases

The elements in **Group 0** of the periodic table are called the **noble gases**. They are **unreactive** and do not easily form molecules because their atoms have **stable arrangements of electrons.**

The noble gases have eight electrons in their outer energy level, except for helium, which has only two electrons

The **boiling points** of the noble gases **increase** with increasing relative atomic mass (going down the group).

Group 1: the Alkali Metals

The elements in Group 1 of the periodic table

- all have 1 electron in their highest energy level
- are metals with **low density** (the first three elements in the Group are less dense than water)
- are **stored under oil** to prevent them from reacting with oxygen or water.

Reactions of Group 1

- Group 1 metals **react in a similar way** as they all have **1 electron in their outer shell**
- react with non-metals to form ionic compounds in which the metal ion carries a charge of + 1. The compounds are white solids which dissolve in water to form colourless solutions.
- e.g. $2 Na + Cl_2 \rightarrow 2NaCl$

Reaction with water

- Group 1 metals react with water releasing **hydrogen** and form **hydroxides** which dissolve in water to give alkaline solutions. (this is why they are known as alkali metals)
- They **react vigorously** with water **fizzing** and **moving around** on the **surface** of the water.
- e.g. $2Na + 2H_2O \rightarrow 2NaOH + H_2$

Increasing Reactivity down the Group

In group 1, **the further down** the group an element is the **more reactive** it becomes.

As the **atoms get larger** the **outer electron** is **further from the nucleus.**

Thus the outer **electron** is le**ss attracted to the nucleus** and so can **more easily be lost.**

Group 7: The Halogens

The elements in group 7 of the periodic table :

- all have 7 electrons in their highest energy level
- have coloured vapours . (These are toxic vapours)
- consist of molecules which are made up of pairs of atoms (Cl_2, Br_2, I_2)
- form **ionic salts with metals** in which the chloride, bromide or iodide ion (halide ion) carries a charge of -1
- form molecular (simple covalent) compounds with other non-metallic elements.

Trends in Group 7

In Group 7, the further **down** the group an element is:

- the higher its relative molecular mass
- the **higher** its **melting point** and boiling point (due to increased intermolecular forces. See 4.2 bonding and structure for more detail)
- the **less reactive** the element.

Displacement Reactions

A more reactive halogen can displace a less reactive halogen from an aqueous solution of its salt.

$Cl_2 + 2 NaBr \rightarrow Br_2 + 2 NaCl$ or $Cl_2 + 2Br^- \rightarrow Br_2 + 2 Cl^-$

- in this reaction an **orange** colour of Br_2 would appear

$Cl_2 + 2 NaI \rightarrow I_2 + 2 NaCl$ or $Cl_2 + 2I^- \rightarrow I_2 + 2 Cl^-$

$Br_2 + 2 NaI \rightarrow I_2 + 2 NaBr$ or $Br_2 + 2I^- \rightarrow I_2 + 2 Br^-$

- in these two reactions a **brown** colour of I_2 would appear

Decreasing Reactivity down the Group

Going down the group:

- The atoms get bigger
- and so outer shell electrons are further from nucleus
- Outer electrons less strongly attracted to nucleus
- can **less easily gain** electrons.

Transition Metals

Chemistry only

In the periodic table between Groups 2 and 3 is a block of elements known as the transition elements. These elements are all metals.

Compared with the elements in Group 1, transition elements:

- have higher melting points (except for mercury)
- have higher densities
- are stronger
- are harder
- are much less reactive and so do not react as vigorously with water or oxygen.

Many transition elements

- have **ions with different charges**,
- form **coloured compounds**
- are useful as **catalysts**.