Unit 5 Atomic structure

What is an element made of?

When an element is being cut into a smaller and smaller piece, it will finally end up into a tiny particle which cannot be divided further. The particle is the basic unit of an element in which it cannot be divided into anything simpler without destroying the element.

All elements are made of atoms. The atoms of different elements are different.

How big is an atom?

Symbols for elements

Chemists use symbols to represent elements. For most of the elements, the symbols are taken from the first or the two letters including the first one of the names of the elements. Some examples are listed in the table below.

Symbols of some common elements					
Element	**Symbol (first letter of the names)**	**Element**	**Symbol (two letters from the name)**	**Element**	**Symbol (taken from the Latin name)**
Carbon	C	Aluminium	Al	Copper	Cu
Hydrogen	H	Argon	Ar	Iron	Fe
Nitrogen	N	Calcium	Ca	Potassium	K
Oxygen	O	Chlorine	Cl	Sodium	Na
Sulphur	S	Magnesium	Mg	Lead	Pb
		Silicon	Si		

The complete list of elements is shown on the **Periodic Table** of the elements.

States of elements

Elements exist in different states at **room temperature and pressure**. (25 ℃ and 1 atmospheric pressure)

Which elements exist as liquids at room temperature and pressure? ____Bromine, mercury__

How many elements exist as gases at room temperature and pressure?________11______

(Find the answers from the Periodic Table.)

How to classify elements?

Metals and non-metals

Comparing the general properties of metals and non-metals		
Property	Metals	Non-metals
State at room temperature and pressure	Solids (except mercury)	Can be solids, gases or liquids
Melting and boiling points	Usually high	Often low
Appearance	Shiny	Usually dull if solids
Electrical conductivity	**Good conductors**	**Non-conductors (except graphite)**
Heat conductivity	Good conductors	Poor conductors
Effect of hammering and bending	Can be bent or hammered into shape	Brittle, if they are solids

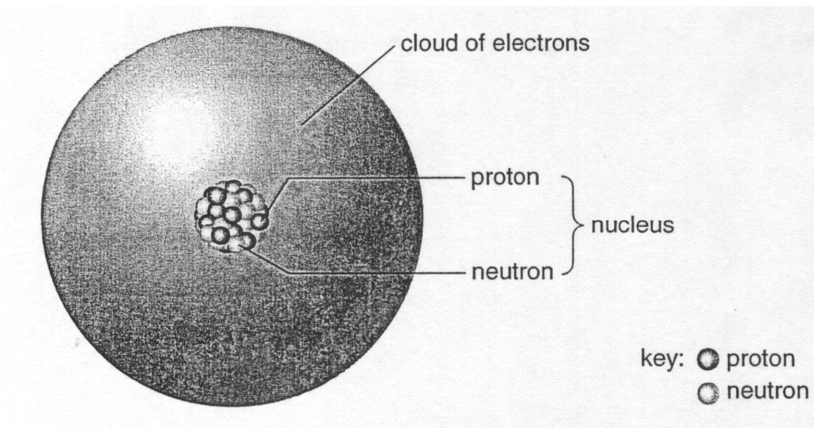
Metalloids

Some elements have some properties similar to those of metals and some properties similar to those of non-metals. They are called **metalloids**. Another name for metalloids is semi-metals. Silicon is an example of metalloid. Another examples include boron, germanium etc. You can find out the metalloids from the Periodic Table.

Some properties of silicon	
Property	Silicon (a metalloid)
State at room temperature and pressure	Solid
Melting and boiling points	High
Appearance	Grey and shiny crystals, or brown powder
Electrical conductivity	Crystalline form conducts electricity; powder form does not conduct electricity
Effect of hammering and bending	Brittle

Basic structure of an atom

An atom consists of a **nucleus** and a cloud of **electrons** moving around the nucleus. The nucleus contains two particles called **protons** and **neutrons**. **Protons, neutrons** and **electrons** called **sub-atomic particles**. The diagram below shows a simple model of an atom.



The table below lists the main properties of the three sub-atomic particles.

Name	Symbol	Position in atom	Relative charge	Relative mass
Proton	p	Inside the nucleus	+1	1
Neutron	n	Inside the nucleus	0	1
Electron	e^-	Moving around the nucleus	-1	1/1840

Atomic number

The atoms of the **same element** have the **same number of protons** in the nuclei of the atoms. This property can be used to identify the atoms of an element.

Atomic number (symbol: **Z**) of an element is the **number of protons** in an atom of the element. Besides, an **atom is** a **neutral** particle. Therefore, the **number of protons must be equal to the number of electrons in an atom** of the element.

Each element is thus having a **unique atomic number**, which is used to identify elements. (Refer to the table on next page.)

Mass number

The **mass number** (symbol: **A**) of an atom is the **sum of the numbers of protons and neutrons** in an atom.

Mass number = number of protons + number of neutrons

Thus, number of neutrons = Mass number – Atomic number

Since the **atoms of the same element can have different number of neutrons**, the mass number of an element is NOT unique. **Mass numbers CANNOT** be used to **identify elements**.

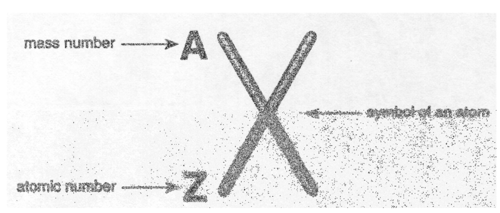
Number of subatomic particles in the atoms of the first 20 elements
(Only data of the most abundant atoms of the element is shown.)

Atom	Symbol	Number of protons (atomic number)	Number of neutrons	Number of electrons
*** Hydrogen**	H	1	0	1
Helium	He	2	2	2
Lithium	Li	3	4	3
Beryllium	Be	4	5	4
Boron	B	5	6	5
Carbon	C	6	6	6
Nitrogen	N	7	7	7
Oxygen	O	8	8	8
Fluorine	F	9	10	9
Neon	Ne	10	10	10
Sodium	Na	11	12	11
Magnesium	Mg	12	12	12
Aluminium	Al	13	14	13
Silicon	Si	14	14	14
Phosphorus	P	15	16	15
Sulphur	S	16	16	16
Chlorine	Cl	17	18	17
Argon	Ar	18	22	18
Potassium	K	19	20	19
Calcium	Ca	20	20	20

* Hydrogen atoms can have no neutron.

Full atomic symbol

It is sometimes convenient to use the full atomic symbol (below) to represent an atom of an element.



Complete the following tables.

Atom	Atomic number	Mass number	Number of		
			Protons	Neutrons	Electrons
$^{7}_{3}Li$	3	7	3	4	3
$^{27}_{13}Al$	13	27	13	14	13
$^{40}_{20}Ca$	20	40	20	20	20

Atom	Atomic number	Mass number	Number of		
			Protons	Neutrons	Electrons
Fluorine	9	19	9	10	9
Boron	5	11	5	6	5
Phosphorus	15	31	15	16	15

Isotopes

All the atoms of an element must have the same number of protons but they can have different number of neutrons.

Isotopes of an element are the different atoms of the same element which have the **same number of protons but different number of neutrons**.

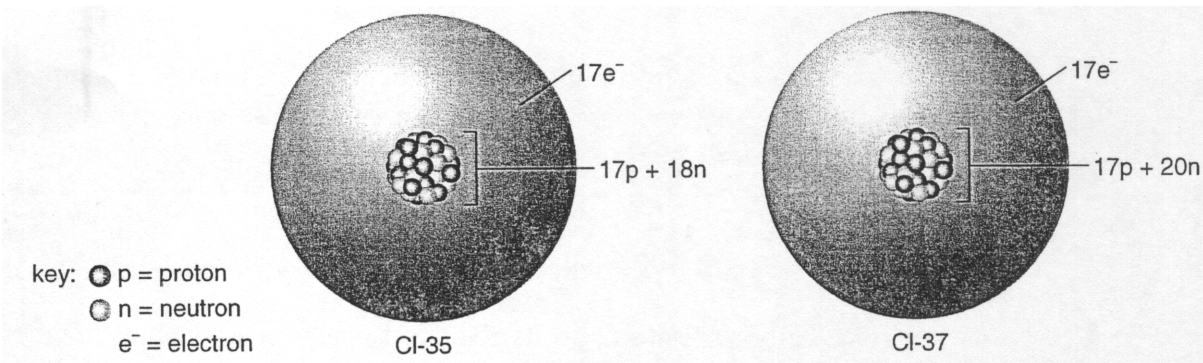
The number of isotopes of an element is not fixed. Some elements can have a large number of isotopes while some elements only have a few.

The **physical properties** of the different isotopes of an element are **different**.

The **chemical properties** of the different isotopes of an element are the **same** since they all have the same number of protons and are thus having the same number of electrons.

Different ways to represent isotopes

For example, chlorine element has two isotopes shown below:



The following ways can be used to represent the different isotopes of chlorine.

1. By their different names (name + mass number) chlorine-35 and Chlorine-37
2. By their different full atomic symbols $^{35}_{17}Cl$ and $^{37}_{17}Cl$
3. By their different simplified atomic symbols Cl-35 and Cl-37

More examples of elements with isotopes

Element	Name of isotope	Symbol	Mass number	Number of		
				protons	neutrons	electrons
Hydrogen	Hydrogen-1	$^{1}_{1}H$	1	1	0	1
	Hydrogen-2	$^{2}_{1}H$	2	1	1	1
	Hydrogen-3	$^{3}_{1}H$	3	1	2	1
Carbon	Carbon-12	$^{12}_{6}C$	12	6	6	6
	Carbon-13	$^{13}_{6}C$	13	6	7	6
	Carbon-14	$^{14}_{6}C$	14	6	8	6

Relative masses of atoms and the carbon-12 scale

Atoms are so light that it is difficult to weigh them. It is also inconvenient to use ordinary units to represent the mass of an atom. To represent the mass of an atom, the concept of relative mass and the carbon-12 scale are introduced.

Carbon-12 scale

Since the mass of a proton and that of a neutron is roughly the same and the mass of an electron is so small when comparing with that of a proton, we can simply treat that the mass of an atom practically comes from the total number of protons and neutrons in that atom (i.e. the mass number). Scientists use the mass of a $^{12}_{6}C$ isotope as the comparing standard and its mass is defined as 12.00 units.

Relative isotopic mass

The **relative isotopic mass of a particular isotope** (atom) of an element is the relative mass of one atom of that isotope on the $^{12}_{6}C$ = 12.00 scale.

In practice, the **relative isotopic mass of an isotope = mass number of the isotope**

What are the relative isotopic masses of the following isotopes?

a) $^{7}_{3}Li$ b) $^{27}_{13}Al$ C) $^{40}_{20}Ca$

Relative atomic mass

When the mass of the atoms of an element is required, all the different isotopes of the element (with different relative isotopic masses), with their different proportions in the element (relative abundance) have to be considered. Thus we have the following definition.

The **relative atomic mass of an element** is the **weighted average** of relative isotopic mass of all the naturally occurring isotopes of that element on the $^{12}_{6}C$ = 12.00 scale.

Calculations involving relative atomic masses

Example 1, chlorine has two isotopes: $^{35}_{17}Cl$ and $^{37}_{17}Cl$. The relative abundance of the isotopes in nature is shown below:

Isotope	Relative isotopic mass	Relative abundance (%)
$^{35}_{17}Cl$	35	75
$^{37}_{17}Cl$	37	25

Solution: Relative atomic mass of chlorine = $\frac{35 \times 75 + 37 \times 25}{100}$ = 35.5

Example 2, Neon in the air contains two isotopes: $^{20}_{10}Ne$ and $^{22}_{10}Ne$. The relative atomic mass of neon is 20.2. Calculate the relative abundance of the isotopes.

Solution: Let the relative abundance of $^{20}_{10}Ne$ and $^{22}_{10}Ne$ be y% and (100 – y)% respectively.

Relative atomic mass = weighted average relative isotopic mass of all isotopes

$20.2 = \frac{20y + 22(100 - y)}{100}$

$2020 = 20y + 2200 - 22y$ $y = 90$

The relative abundance of $^{20}_{10}Ne$ is 90% and that of $^{22}_{10}Ne$ is 10%.

It can be seen that the relative atomic masses of most elements are not whole numbers. It is because most elements are having more than one kind of isotopes.

Exercises

1. Calculate the relative atomic mass of magnesium   Ans. 24.327 ≈ 24.3

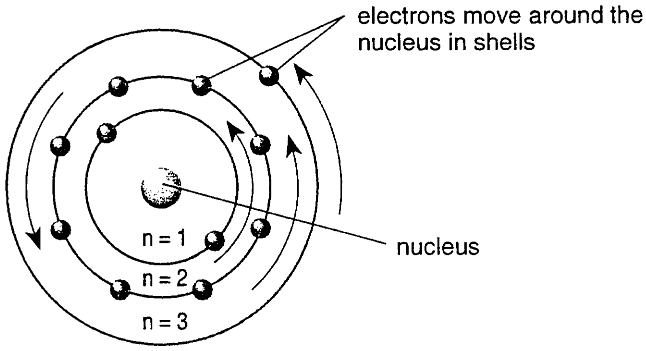
Isotope	^{24}Mg	^{25}Mg	^{26}Mg
Relative abundance (%)	78.6	10.1	11.3

2. Boron consists of two isotopes: $^{10}_{5}B$ and $^{11}_{5}B$. The relative atomic mass of boron is 10.8. Calculate the relative abundance of the isotopes.   Ans. B-10 20%   B-11 80%

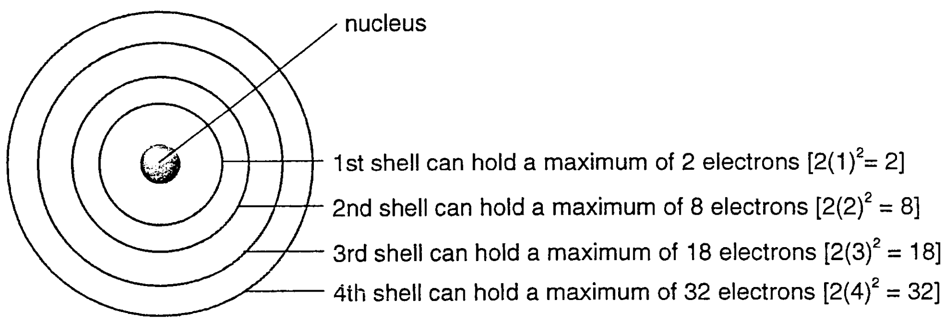
The arrangement of electrons in atoms

Electronic arrangement (Electronic configuration)

The way in which electrons are arranged in an atom is called its electronic arrangement (electronic configuration). The Bohr model (after the Danish scientist, Niels Bohr) is used to build up the electronic arrangement. According to the Bohr model, electrons are considered moving around the nucleus in circular orbits called shells.



Each shell can hold only a certain number of electrons. The maximum number of electrons a certain shell can hold is equal to $2n^2$. (n is the shell number, it is counted starting from the shell nearest to the nucleus and then outwards.)



The following principles are used to determine the electronic arrangement of an atom.

1. Place electrons into the shells, starting from the shell closest to the nucleus and then outward.
2. Start filling the next shell when one shell is completely filled.

The following tables show the electronic arrangement of the first 20 elements.

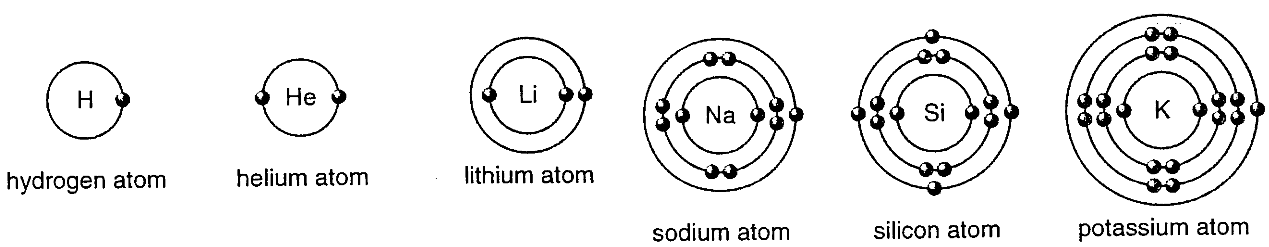
Atomic number	Element	Number of electrons in				Electronic arrangement
		1st shell	2nd shell	3rd shell	4th shell	
1	**Hydrogen**	1				1
2	**Helium**	2				2
3	**Lithium**	2	1			2,1
4	**Beryllium**	2	2			2,2
5	**Boron**	2	3			2,3
6	**Carbon**	2	4			2,4
7	**Nitrogen**	2	5			2,5
8	**Oxygen**	2	6			2,6
9	**Fluorine**	2	7			2,7
10	**Neon**	2	8			2,8

Atomic number	Element	Number of electrons in				Electronic arrangement
		1st shell	2nd shell	3rd shell	4th shell	
11	**Sodium**	2	8	1		2,8,1
12	**Magnesium**	2	8	2		2,8,2
13	**Aluminium**	2	8	3		2,8,3
14	**Silicon**	2	8	4		2,8,4
15	**Phosphorus**	2	8	5		2,8,5
16	**Sulphur**	2	8	6		2,8,6
17	**Chlorine**	2	8	7		2,8,7
18	**Argon**	2	8	8		2,8,8
* 19	**Potassium**					
* 20	**Calcium**					

* The electronic arrangement of the elements potassium and calcium cannot be fully explained by this simple model. Actually, in considering the electronic arrangement, each shell can be divided into small groups called subshells as described by a different model. Starting from the fourth shell, it will be accurate to consider the subshells. These will be dealt with at a higher level.

Electron diagrams

Electron diagrams are the pictorial ways of representing the electronic arrangements of atoms. Dots (or crosses) are used to represent electrons in an electron diagram. The diagrams below show the electron diagrams of some elements.



Exercise

Draw electron diagrams for atoms of the following elements.

a) carbon b) nitrogen c) magnesium

Electrons and orbitals

Since electrons are moving at high speed around the nucleus of an atom, it is difficult (actually impossible) to locate the exact position of an electron at a certain time. If a photograph of an electron is being shoot using the present day technology, only a blurred image is obtained.
Thus a new model (called quantum mechanics) can be used to describe the electrons of an atom. Under quantum mechanics, the exact location of an electron is not shown. The probabilities of finding the electron in every possible locations are calculated instead. An electron is said to exist in regions called orbitals in which there are high probabilities of finding the electron.