ATOMIC STRUCTURE AND ELECTRONIC STRUCTURE

Matter

This is anything that occupies space and has weight. Matter is made up of very tiny particles (& building blocks) i.e. atoms, molecules, and ions. In this section we are going to look at an atom.

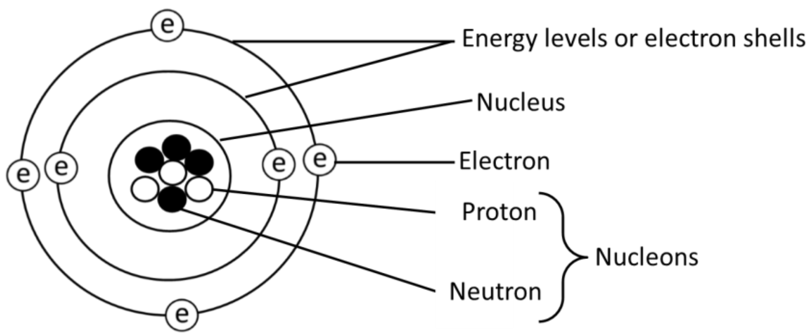
What is atom?

This is the smallest electrically neutral particle of an element that takes part in a chemical reaction.

Structure of an atom

An atom consists of a small and extremely dense region called the nucleus. The nucleus is surrounded by a cloud of negatively charged particles called electrons situated in definite paths called energy levels or electron shells. The electrons are held within an atom by an electrostatic force of attraction both themselves and a positive charge of the protons in the nucleus. The nucleus contains the protons and neutrons and they are collectively called nucleons.

The Diagram Showing a Simple Structure of an Atom



Protons, neutrons and electrons are collectively known as the ***fundamental particles*** of an atom or subatomic particles.

Protons are positively charged particles which are present in all atomic nuclei. They have a unit mass of 1 and each proton carries a charge of positive one (+1). Located in the nucleus.

Electrons are negatively charged particles surrounding the nucleus. They are carried in circular paths known as energy levels that surround the nucleus. Each electron has a mass of $\frac{1}{1840}$ of that of a proton and therefore its mass is said to be negligable. Each electron carries a charge of negative one (-1). The chemical reactions of an element are determined by the number of electrons.

Neutrons are uncharged particles and they are located in the nucleus of the atom. Neutrons have a unit mass of 1 but carry no charge i.e. they are neutral particles of an atom.

The table below summarizes the properties of the fundamental particles of an atom:

Particle	Location	Charge	Mass
Electron (e)	Energy levels	Negative (– 1)	$\frac{1}{1840}$
Proton (p)	Nucleus	Positive $(+1)$	1
Neutron (n)	Nucleus	No charge (neutral)	1

Atoms are not electrically charged although both electrons and protons are. This means that the positive charges on the protons are equal to the negative charges on the electrons so that they neutralize (make the atom neutral). Thus the number of electrons must be equal to the number of protons in a neutral atom.

The number of protons in the nucleus of an atom of an element is called the **proton number** or the **atomic number (Z)**.

The sum of the number of protons and neutrons in the nucleus of an atom of an element is called the **atomic mass or mass number (A)**.

The full symbol of an atom of an element X is given a notation ${}^{A}_{Z}X$ where: X is the symbol of the element, **A** is the mass number, **Z** is the proton number.

The atomic number provides some information about an element which may include:

- The position of an element in the periodic table.
- The number of protons present in the nucleus of an atom.
- The total number of electrons present in a neutral atom.

Assignment: Read about the discoveries of the following fundamental particles of an atom

- John Dalton Atomic Theory.
- J.J Thomson model of an atom
- Ernest Rutherford model of an atom
- Bohr's model of an atom
- Evidence for existence of energy levels
- Hydrogen spectrum absorption and emission spectrum
- John Dalton's Atomic Theory.

ELECTRONIC CONFIGURATION OF ATOMS.

Electronic configuration refers to the arrangement of electrons in the energy levels of an atom in an element. Within an atom, electrons are arranged in energy levels/ shells around the nucleus. Energy levels are given quantum numbers symbolized by *n* which specifies the energy level an electron is located and its distance from the nucleus.

The first energy level nearest to the nucleus has principle quantum number $n = 1$ and it is also called the ground state. The second principle quantum number $n = 2$ is called the excited state etc. As *n* increases, the size of the orbit increases and the electron far away from the nucleus. An increase in *n* also means that the electron has higher energy and is therefore less bound to the nucleus. Energy levels closer to the nucleus have lower energy. All orbitals having the same value of *n* are said to be in the same level.

The total number of electrons that can occupy an energy level is given by $2n^2$ where; *n* is the principle quantum number ($n = 1, 2, 3, \ldots$.)

Principal quantum number (*n*)	Maximum number of electrons
$n = 1$	2
$n = 2$	8
$n = 3$	18
$n = 4$	32

The Nature of Electron shells / Energy levels

The electron shells are divided into sub-shells which in turn are divided into orbitals which are conveniently denoted by boxes.

Definitions

Orbit is a path spaced by an electron revolving around the nucleus of an atom.

Orbital is a volume of space around the nucleus of an atom where the probability of finding an electron is highest.

Subshell is a group of orbitals of the same type within a given energy level.

Shell is a group of orbitals of different or of the same types with the same principle quantum number.

The shells are given principle quantum numbers 1, 2, 3, 4 etc. onwards from the nucleus. At times the letters K, L, M, N are used.

- The sub-shells are s, p, d, f.
- The s sub-shell has one orbital.
- The p sub-shell has three orbitals.
- The d sub-shell has five orbitals.
- The f sub-shell has seven orbitals.
- Each orbital has a maximum capacity of only two electrons.

The energy levels in a sub-shell increase in the order $s < p < d < f$.

Shell of quantum number 1 has only the s sub-shell.
number 2 has the s and p.
number 3 has s, p, d.
number 4 has s, p, d, f.

Each s sub-shell carries a maximum of 2 electrons.
Each p sub-shell is divided into three orbitals known as Px, Py, Pz and in total they carry 6 electrons.
Each d sub-shell has five orbitals and carries a maximum of 10 electrons.
Each f sub-shell has seven orbitals and carries a maximum of 14 electrons.

Subshell	Number of orbitals	Maximum number of electrons
s	1	2
p	2	6
d	5	10
f	7	14

Electronic Configurations of atoms and ions

The electronic configuration of an element describes how electrons of its atom are arranged in their shells, sub-shells and orbitals. The electronic configuration normally applies to atoms in their ground state not in their excited state.

The electronic configuration of an atom with one or more electrons in the excited state is called excited state configuration.

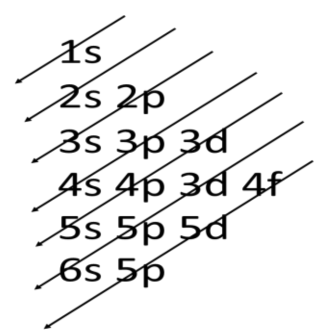
Principles for writing electronic configuration

There are three rules for writing ground state configuration of an element:

The Aufbau principle

Aufbau is a German word meaning "giving up or building up".
The Aufbau principle states that ***in their ground states electrons occupy the orbitals of the lowest energy first.***

The filling proceeds as: $1s\ 2s\ 2p\ 3s\ 3p\ 4s\ 3d\ 4p\ 5s\ 4d$ …….

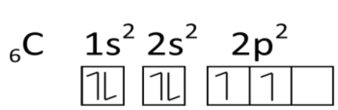


Pauli's exclusion principle

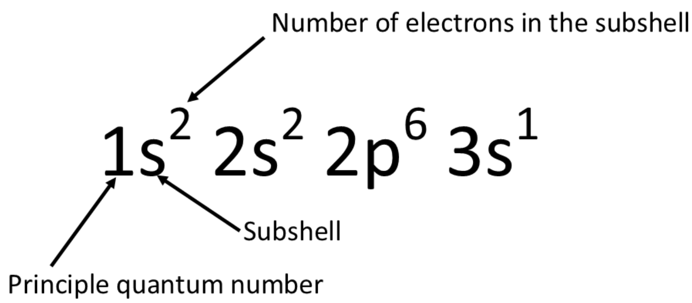
It states that ***an orbital cannot contain more than two electrons, pairing is only if the electrons have opposite spin.***

Hund's rule

It states that ***the electrons occupy the orbital of a sub-shell singly first and with parallel spins before pairing begins.***



Quantum numbers, subshells and number of electrons in an orbital then the sub-shell and hence the shell are shown in the electronic configuration.



Quick assessment.

1. State the number and type of orbitals in the shells with the following quantum numbers
   (a) n = 3
   (b) n = 5

2. Write the electronic configurations of the following elements

(a) Lithium ($z = 3$)
$1s^2\ 2s^1$

b) Oxygen ($z = 8$)
$1s^2\ 2s^2\ 2p^4$

c) Sodium ($z = 11$)
$1s^2\ 2s^2\ 2p^6\ 3s^1$

d) Argon ($z = 18$)
$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$

e) Vanadium ($z = 23$)
$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^3$

f) Chromium ($z = 24$)
$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1\ 3d^5$

Note the following.

- There is an overlap between the $4s$ and $3d$ sub-shell such that the $4s$ is nearer to the nucleus than the $3d$ but at a higher energy than $3d$. This overlap continues between $(n+1)s$ and nd where $n = 3, 4, 5$ ...
- These electronic configuration show distances of each-shell from the nucleus. If they are to show energy levels then the $4s$ should be after $3d$.

- The electronic configuration of copper is $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1\, 3d^{10}$ and not $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2\, 3d^9$ because half-filled and completely filled orbitals are stable. Therefore, noble gases with completely filled shells have stable configurations.

  Snacks

  Write the electronic configuration of the first 20 elements of the periodic table.

  Hydrogen Nitrogen Sodium Chlorine
  Helium Oxygen Magnesium Argon
  Lithium Potassium Aluminium
  Beryllium Calcium Silicon
  Boron Fluorine Phosphorus
  Carbon Neon Sulphur

IONS

An ion is a charged particle formed from an atom or a group of chemically combined atoms by gaining or losing one or more electrons.

Ions are either negatively charged (Anions) or positively charged (cations).

Ions are formed by either gaining electrons (anions) or losing electrons (cations). When writing their electronic configurations electrons are either removed or added to the outer most sub energy levels depending on the charge of the ion.

For cations of the elements in the first transition series (from scandium to zinc), electrons in the $4s$ sub-energy level are removed first before those in the $3d$ sub-energy level. Similarly, they can subtract or add electrons to the atomic number of a neutral atom and use the remaining electrons to write the configuration.

Task: Write the electronic configurations of the ions of the first twenty elements in the periodic table.

Element	Electronic configuration of the element	Ion	Electronic configuration of the ion
Li			
B			
B			
N			
O			
F			

Na			
Mg			
A			
Si			
P			
S			
Cl			
K			
Ca			

NOTE:

The electronic configuration of an atom of element can be used to provide important information about the element. This includes the following:

- The group to which an element belongs.
- The period to which an element belongs
- The block to which the element belongs can be identified by considering the outermost sub energy level e.g. sodium (Na) with electronic configuration $1s^2\ 2s^2\ 2p^6\ 3s^1$ belongs to group 1 because it has 1 electron in the outermost level, belongs to period 3 because it has 3 energy levels, belongs to the s block because its outer most energy level is in the s-subshell.

Snacks

Write the electronic configuration of the following ions;

Iron(III) ion Zinc ion Manganese(II)

Copper(II) ion Chromium(III) ion

Lead(II) ion Cobalt (II) ion

Iron(II) ion Vanadium(V)