ATOMIC STRUCTURE

Chemistry of atoms

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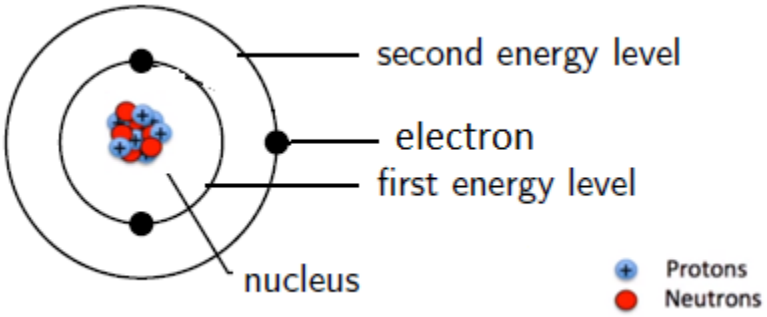
The Atom

An atom is the smallest particle of an element i.e. atoms of the same kind make up an element. Atoms are very small particles that can not be seen by a human's naked eye. The thickest human hair is over a million times bigger than an atom. The diameter of a single atom can be a small as 0.000000000001cm!

Structure of an Atom



Atoms are made of three sub-particles; protons, neutrons and electrons. Protons and neutrons make up the nucleus of the atom and are therefore called **nucleons.** Electrons are found outside the nucleus orbiting the nucleus in electron shells. Protons are positively charged and are denoted by $\mathbf{p^+}$, neutrons are neutral (i.e. they have zero charge) and are denoted by $\mathbf{n^0}$, electrons have a negative charge and are denoted by $\mathbf{e^-}$**.**

Since the sub-particles (neutrons and protons) have zero and positive charge the overall charge of the nucleus is positive. It is the overall positive charge of the nucleus that keep electrons orbiting around the nucleus in their electron shells. Strictly speaking, an **electron shell** is the outside part of an atom around the atomic nucleus. This part is made up of a space of different energy levels. Thus, the electron shells can also be referred to as energy levels. The innermost energy level or electron shell (the one closest to the nucleus) is called first energy level or shell, and the next one is the second energy level etc.

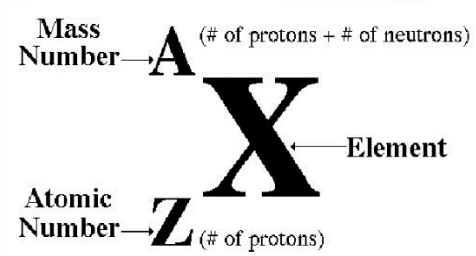
The mass of every atom is concentrated in its nucleus. If for example the mass of a proton was 1, the mass of the neutron would also be 1, but that of the electron would be 1836 times lesser than 1 (i.e. 1/1836 which is equal to 0.00054). The total mass of an atom with 1 proton, 1 neutron and 1 electron would thus be 2.00054. Thus, the mass of electrons is insignificant when calculating atomic mass, only the number of neutrons and protons are considered.

NB: The total number of protons plus neutrons in an atom is called the **nucleon number** (neutrons and protons are called nucleons). This nucleon number is equal to the *mass number,* which we will discuss in the next sub section.

The Nuclide Notation

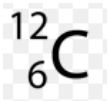
Atoms of all the elements in the universe are listed in an organised table called the *Periodic Table.* In this table the atoms of the elements are given different symbols e.g. the symbol for Carbon is **C** and that of sodium is **Na.** Note that it does not follow that since Sodium starts with 'S' then its symbol on the periodic table is **S**. Therefore, the symbols of each element on the Periodic Table must be memorised!

The number of protons and nucleons are also given along with each symbol in the Periodic table and this makes up what we call the **nuclide notation**.



The number represented by *Z*, is the Atomic number. It tells you what position element, *X* is on the periodic table and most importantly it tells us the number of protons the atom of element *X* has in its nucleus. Atoms with the same proton number belong to the same element. The number represented by *A*, is the mass number (also called nucleon number). It gives us the *Relative atomic Mass* (or simply mass) of atom *X*. Remember earlier we said only the number of protons and neutrons determine the mass of a given atom. Fittingly here the mass number is given as equal to the number of protons plus neutrons.

Q. The nuclide notation of Carbon element in the periodic table is given as:



What is the number of protons and neutrons in the Carbon atom?

A. *Z*, in the above nuclide notation is equal to 6, therefore the number of protons is equal to 6.

A, the mass number or more fittingly the nucleon number which is given by:

$$\text{Nucleon/mass number} = \text{number of } p^+ + \text{number of } n^0$$

$$12 = 6 + \text{number of } n^0$$

$$\text{number of } n^0 = 12 - 6$$

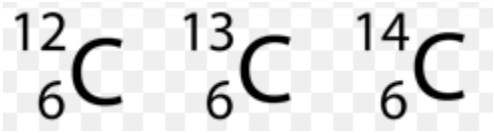
$$\text{number of } n^0 = 6$$

NB. In the Periodic Table the atoms of the elements are given in their neutral form, therefore the number of protons is equal to the number of electrons. In the Carbon ex-

ample above the atom will have 6 electrons (the same as the proton number)-is there any particular reason you do not put more emphasis on the electrons?

Isotopes

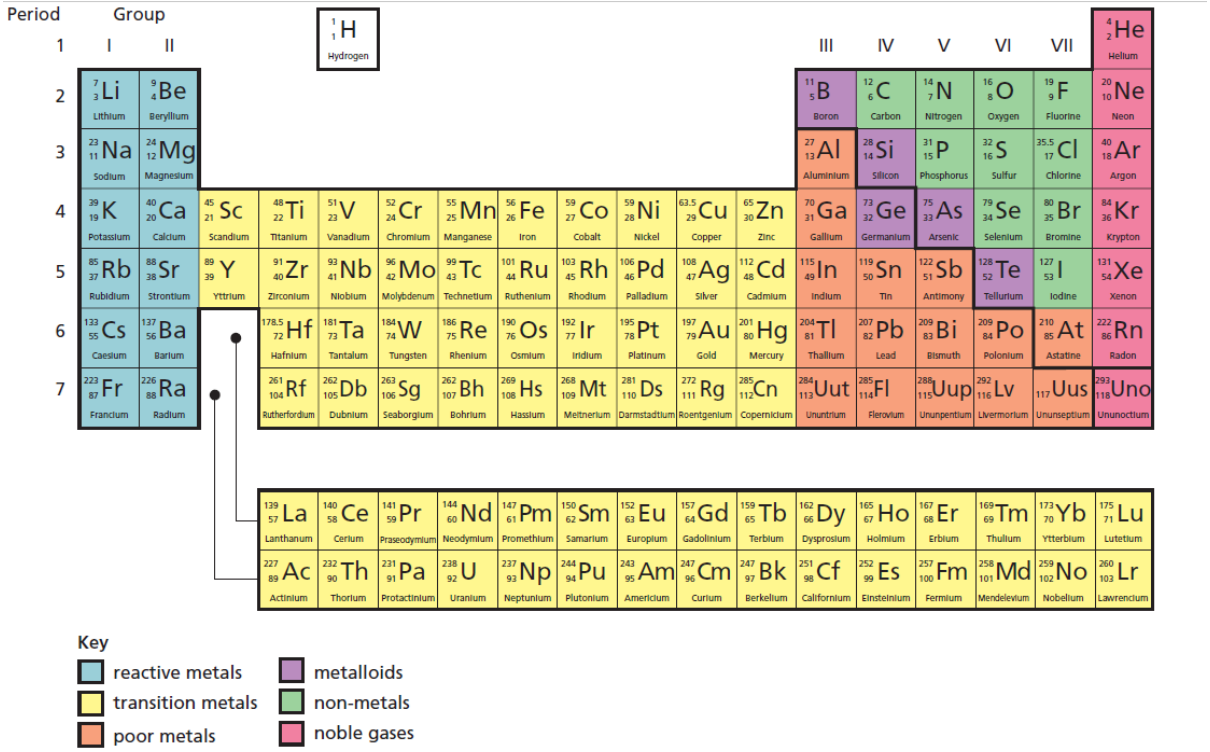
Atoms of the same element will always have the same number of protons but their number of neutrons can differ. When this happens the mass number of the atoms differ and the two atoms are called ***isotopes.*** Consider the carbon atoms below;



The three atoms above are isotopes of each other. They have the same proton number but different number of neutrons, this results in different mass numbers.

NB. Isotopes have the same 'everything' except for mass, i.e. they have the same reactivity, the same number of electrons and protons and their electrons are arranged the same. The only difference is the isotope with the bigger mass number form compounds that are heavier than their 'lighter' isotopes.

The Atomic Structure and the Periodic Table



A Periodic Table is a tabular display of the chemical elements in which the elements are arranged in order of increasing atomic number. The first element in the periodic table is Hydrogen which has the *Atomic Number* 1, followed by Helium with an *Atomic Number* 2 and so on. The elements are arranged in rows called *Periods.* There are seven rows on the Periodic table. The first row is Period 1, the second row is Period 2 and so forth. The Period number tells us the number of electron shells the elements in that particular period has (or the amount of energy levels?) e.g. Hydrogen and Helium are the only elements in Period 1 and they have one electron shell. Period 2 has elements from Lithium to Neon and they all have 2 electron shells etc.

The columns of the Periodic table are called *Groups* and they contain elements with the same number of electrons in their outermost shell (the shell furthest from the nucleus). The first column is Group 1 and is made up of Lithium, Sodium, Potassium, Rubidium, Caesium and Francium. These elements all have one electron in their outermost electron shell. Those in group 2 like Beryllium and Magnesium have two electrons in their outermost electron shell and so on. The manner in which electrons are arranged in electron shells around the nucleus of an atom is called the *Electronic Configuration* of the atom.

Question: Why are we interested in the Electronic Configuration of the atoms of elements in the periodic table?

Answer: The manner in which electrons are arranged in a given atom determines its reactivity or chemical behaviour.

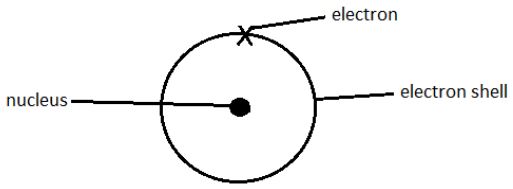
Electronic Configuration

Electronic configuration is the manner in which electrons are arranged in the electron shells around the nucleus.

Q. How are electrons arranged in an atom?

A. The electron shells around the nucleus have different sizes and therefore accommodate different number of electrons.

The first energy level or **electron shell** is the smallest and can only accommodate a maximum of 2 electrons. Consider atoms of the first three elements of the Periodic Table, Hydrogen (**H**), Helium (**He**) and Lithium (**Li**). The electronic configuration of the three atoms can be given as follows;

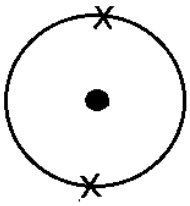


Hydrogen Atom

The hydrogen atom is in Period 1 of the periodic table and therefore has one electron shell. Being the first element in the periodic table its atomic number is 1. Remember that the atomic number is always equal to the number of protons in the nucleus of an atom and that we said the elements in the periodic table are given in their neutral state. It follows then that, hydrogen having its atomic number as 1 has one proton and one electron.

NB. In the atomic diagram of hydrogen above we have not shown the protons inside the nucleus because these diagrams are '**electronic' configuration** diagrams. We are interested in how the electrons are arranged so we can ignore the arrangement of nucleons in the nucleus and just represent it as a big 'dot'. (NICE!!!)

The helium atom is represented by the diagram below;



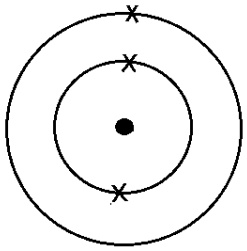
Helium Atom

Helium like hydrogen is in Period 1 and has one electron shell as well. But unlike hydrogen its atomic number is 2 and therefore has two electrons. (Note here that we have used the atomic number to deduce the number of electrons in the helium atom because

we are drawing neutral atoms and again like we have said before the atomic number, number of protons and number of electrons must be the same.)

Drawing the atomic diagram produces a different challenge. Earlier we said the first electron shell can accommodate a maximum of two electrons, Lithium's atomic number is 3 and therefore has three electrons. Where is the third electron going to go?

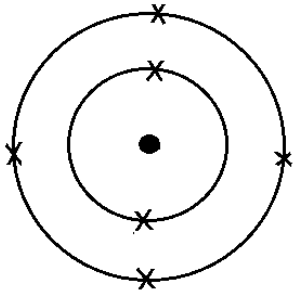
Look at the periodic table again, you will notice that Lithium is in Period 2 (second row) that means that it has two electron shells. The third electron therefore goes into this second shell and the atomic diagram will be as below;



Lithium Atom

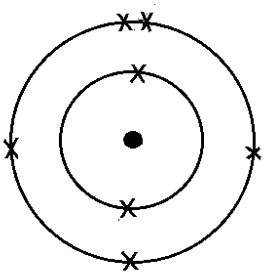
The second electron shell accommodates a maximum of eight electrons and is subdivided into four smaller ***orbitals*** and each orbital accommodates two electrons (please justify to me as to why the issue of Orbitals is introduced in this manner?). When filling electrons in the electron shells it is usually a good practice to put one electron in each orbital before we start pairing them up. What do I mean?

Consider the atomic structure of carbon and nitrogen. The carbon atom is drawn as shown below;



Carbon Atom

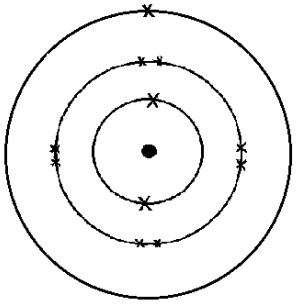
Notice that the four electrons in the second shell are not paired, we assume that each electron is occupying one of the sub-shell orbitals that make up the second shell (this is not entirely true but for the sake of your level of understanding it is sufficient!). When we move on to Nitrogen which has five electrons in the second shell, the electrons will now begin to pair up.



Nitrogen Atom

Oxygen will have two paired electrons and two single electrons in the its outermost shell, Fluorine has three pairs and one unpaired electron and Neon has four pairs. Neon therefore has a fully filled outermost shell since it has 8 electrons in the second shell (also the outermost).

Sodium comes after Neon and has atomic number 11. It has three shells of electrons since it is in Period three (third row). How are the eleven electrons in sodium arranged? Shell number 1 carries 2 electrons, the second will carry 8 and the remaining 1 electron will go into the third shell.

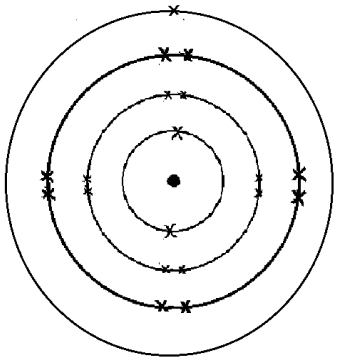


Sodium Atom

The third shell accommodates a maximum of eighteen electrons but at this stage we are going to treat it as if it accommodates a maximum of eight because we are only going to discuss these atomic structures up to atom number 20, Calcium (NICE!!!).

Q. Draw the atomic structure of Potassium.

A.

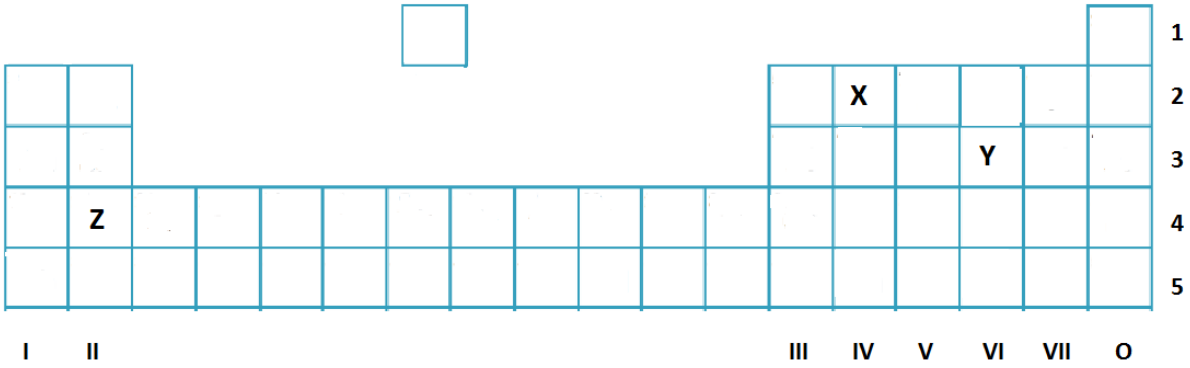


Potassium Atom

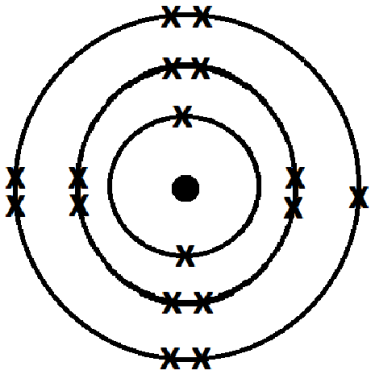
NB. The correct diagram above is drawn by assuming that the third shell is fully filled by 8 electrons like the second electron shell, even though its maximum capacity is 18 electrons!

Using the Periodic to Draw the Atomic Structure

Q. Below is a diagram of part of the Periodic Table, draw the atomic structures of the atoms of elements **a)** X **b)** Y **c)** Z



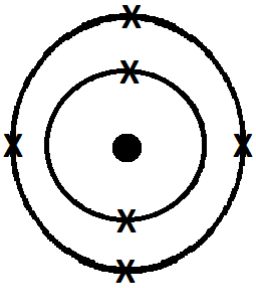
A. Let's start with element **b)** Y. The numbers on right hand side of the Periodic table shows Y is in row number 3 i.e. Period 3. This means the atomic structure of Y has 3 electron shells. The group numbers are given in Roman Numerals at the bottom of the periodic table. Y is in group VII i.e. Group 7. The group number tells us the number of electrons in the outermost shell. Y has seven electrons in its outermost shell. To draw the atomic structure of Y we draw an atom with 3 shells and put 7 electrons in the outermost shell. What do we do with the two inner shells? Remember the first shell always accommodates a maximum of two electrons and the second a maximum of eight. We therefore put two electrons in the first shell and eight electrons in the second shell. The result is an atomic structure of Y that has 3 shells with two electrons in the first shell, eight in the second and seven in the outermost shell.



Atomic Structure of Element **Y**

NB. The inner shells must always be filled to maximum capacity. Only the outermost shell can have a partially filled structure. Thus, if we know the period and the group in which an element is, the atomic structure can always be drawn by drawing an atom with shells that corresponds to the period number of the element. Electrons corresponding to the group number are placed in the outermost shell and then we make sure the inner shells are filled to full capacity!

Now try drawing **X** and **Z.**



Atomic Structure of **X**

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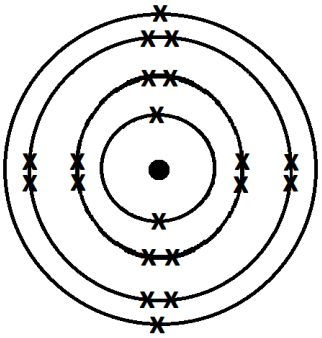

Atomic Structure of **Z**