3 CHEMICAL FOUNDATIONS: ELEMENTS, ATOMS AND IONS

All matter is built up from chemical combinations of elements. As of 2003, there are 114 known elements, of which 88 are naturally occurring; the remaining 26 elements are synthetic.

The term element is used by chemists in several different ways. One way is to refer to atoms of an element. Atoms are the smallest indivisible form of an element. Another way is to refer to the natural chemical state of the element. For example, the element oxygen is found naturally in the microscopic state as a chemical association (molecule) of 2 oxygen atoms. Care must be taken when referring to an element to indicate whether the reference is to an atom or a molecule of the element.

3.1 An Introduction to Atomic Theory

The first (relatively) modern theory of the atom was introduced by the English scientist John Dalton in 1808.

3.1.1 DALTON'S ATOMIC THEORY (1808)

1. Elements are made up of tiny indivisible particles called atoms.
2. The atoms of each element are identical.
3. The atoms of any element are different from those of other elements.
4. Atoms of one element combine with atoms of other elements to form compounds. A given compound always has the same relative number and types of atoms.
5. Atoms are neither created nor destroyed in chemical processes. A chemical reaction simply changes the ways atoms are grouped together.

Dalton's atomic theory turned out to be incorrect in its details. However, it did provide a starting point for understanding the nature of matter and of chemical reactions.

3.1.2 THE STRUCTURE OF THE ATOM

By the late 19th century, studies on the interaction of light with matter revealed that the atom has a more complicated structure than Dalton had imagined.

1897: Plum-pudding Model

The English scientist J.J. Thomson discovered that atoms contained tiny negatively charged particles that are now referred to as <u>electrons</u> (literally, particles that carry electricity). On the principle that there must be positive charges to counterbalance the negative charges, Thomson postulated that the atom must also contain an overall positive charge of exactly the same magnitude but opposite in sign from the electrons.

Lord Kelvin (William Thomson) then proposed that the atom consists of a uniform "pudding" of positive charge with electrons dotted like raisins throughout.

1911: Nuclear Model of the Atom – Ernest Rutherford and Neils Bohr

1909 – Hans Geiger and Ernest Marsden (Rutherford's students) studied the scattering patterns of α-particle off a gold foil.

In 1911, Rutherford proposed that:

1. The atom is mostly empty space.
2. Most of the mass and all of the positive charge is concentrate.79489 dp0p

some atomic nuclei contained small neutrally charged particles called neutrons. Each neutron has approximately the same mass as a proton.

1913 – Neils Bohr, on the basis of experiments on the light emitted by gaseous atoms, proposed the so-called planetary model of the atom. In this model, the electrons do not move at random in the space outside of the nucleus. Rather, they may be found in orbits at fixed distances from their nucleus.

Introduction to the Modern Concept of Atomic Structure (1926)

For the purposes of chemistry, there are three particles that constitute the atom:

1. electron ( ) – this is the fundamental unit of negative charge ($e = -1.602 \times 10^{-19}\ C$); its mass is almost zero ($m_e = 9.109 \times 10^{-31}\ kg$).
2. proton ( ) – this is the fundamental unit of positive charge ($e = 1.602 \times 10^{-19}\ C$); its mass is $1.6726 \times 10^{-27}\ kg$.
3. neutron ( ) – this is a fundamental unit carrying no charge; its mass is approximately the same as that of a proton, $1.6749 \times 10^{-27}\ kg$.

The electrons move at random outside of the nucleus, although they do occupy preferred regions in space. Although the electrons move at random, they each have a very definite fixed energy. The physical and chemical properties of an atom really depend on the energy, number and arrangement of the electrons in the space outside of the nucleus.

When atoms combine to form molecules, the electrons of the different atoms intermingle to hold the nuclei together.

3.2 Isotopes

We know that the chemical properties and many of the physical properties of an atom depend on the energy, number and arrangement of its electrons. We also know that the number of protons must equal the number of electrons in a free atom. Thus the character of an atom is defined through its protons and electrons. The number of protons present in the nucleus identifies the atom uniquely as one of a particular element.

Unlike the electrons and protons, the neutrons do not contribute to the chemical or most of the physical properties of the atoms. Atoms of an element can have variable number of number of neutrons. Thus, for example, a sample of pure carbon atoms can contain carbon atoms having 6, 7, 8 or more neutrons (see the second-to-last column in the table below).

e.g.

Name	Symbol	Atomic Number	Number of Protons	Number of electrons	Number of neutrons	Mass Number
Carbon-8	${}^{8}_{6}C$	6	6	6	2	8
Carbon-9	${}^{9}_{6}C$	6	6	6	3	9
Carbon-10	${}^{10}_{6}C$	6	6	6	4	10 6

Note that all of these atoms are equally as “carbon” as any other (although the carbon atom having 6 neutrons is by far the most abundant). These different types of atoms of carbon, having different numbers of neutrons are called **isotopes**. The conventional notation for writing isotopes is as follows:

$$^{A}_{Z}Sy$$

Here,

= the one to two letter symbol for the atom;

= the atomic number of the atom (the number of protons, also equalling the number of electrons in the free atom); and

= the mass number of the isotope.

For each type of atom of an element, and are always the same. The mass number, , can vary depending on the number of neutrons present in the isotope. equals the sum of the number of protons ( ) and the number of neutrons ( ).

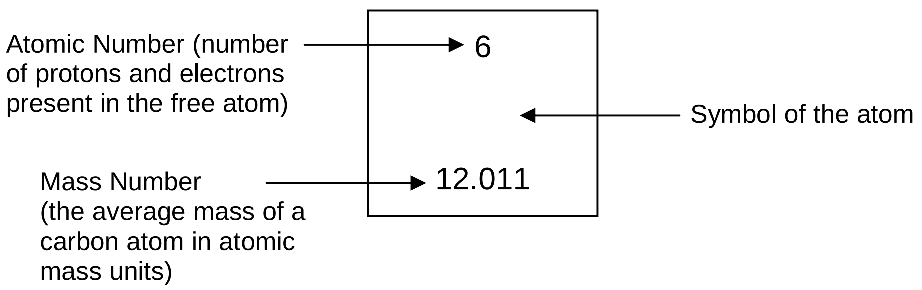
3.3 The Periodic Table of Elements

The Periodic Table of Elements is an organisation of atoms according to their properties. It was devised in 1867 by the Russian chemist, Dimitry Mendeleev and independently that same year by the German, Lothar Meyer. Mendeleev gets the title of “Father of Modern Chemistry” because Meyer did not make any further use of his table.

Mendeleev (and Meyer) noted that many of the known elements have very similar physical and chemical properties. Those atoms with such similar properties were put in columns. Thus, for example, atoms such as Na and K were soft, silvery, greyish metals which reacted explosively with water to form extremely strong alkaline solutions. These were placed in a column, called a ***group*** in the Periodic Table. This group is known as the . Other metals such as Mg and Ca found in the ground also formed alkaline solutions with water, but not in nearly the same explosive fashion as Na and K. These metals were known as the metals.

This arrangement of atoms according to their properties soon proved its value. Gaps in Mendeelev’s Table soon began to appear, and he was able to predict the existence of as yet unknown elements. Chemists began to search for these “missing” elements and found several of them.

The modern Periodic Table has three basic characteristics that provide information about the atom. The example of the carbon atom is shown below.



The elements may be classified according to whether they are metals, nonmetals or metalloids (or semimetals).

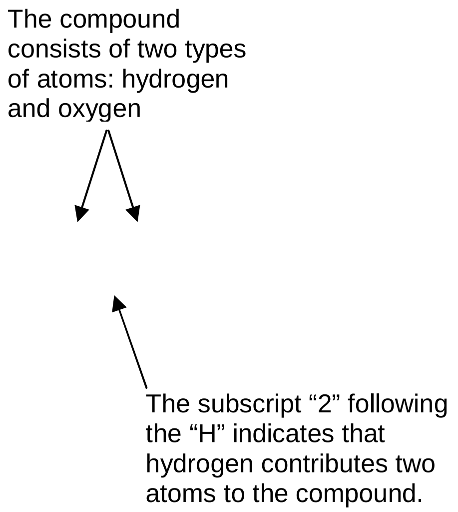
Students are expected to know the name and chemical symbol of the following elements (listed by atomic number): 1 – 38, 40, 42, 46 – 51, 53 – 57, 74, 78 – 80, 82.

3.5 Formulas of Compounds

A compound is a pure substance that:

1. composed of atoms of two or more different elements; and
2. always has the same relative masses of those elements.

The ***chemical formula*** of a compound is most conveniently expressed by the number and type of each atom present. Thus the compound water, a chemical combination of two atoms of hydrogen with one atom of oxygen, can be written as follows:



<u>Exercise</u>: For the following compounds, state the number of each type of atom present.

6. Dinitrogen monoxide:
7. Aluminium chloride:
8. Carbon monoxide:
9. Carbon tetrachloride:
10. Sulphur trioxide:
11. Dinitrogen pentoxide:
12. Periodic acid:
13. Nitric acid:
14. Potassium dichromate:
15. Glucose:

<u>Exercise</u>: Write the formulas for the following compound.

1. A compound consists of one atom of carbon and four atoms of hydrogen.
2. A compound consists of one atom of silicon and two atoms of oxygen.
3. A compound consists of two atoms of nitrogen and five atoms of oxygen
4. A compound consists of two atoms of carbon, two atoms of hydrogen and two atoms of chlorine.
5. A compound consists of two atoms of hydrogen, one atom of phosphorous and three atoms of oxygen.