SECTION 1

BASIC DEFINITIONS AND VOCABULARY ON STRUCTURE OF MATTER

This section introduces terms and definitions which make up the vocabulary of the language of chemistry. Starting with atoms it progresses to elements, molecules and compounds. It shows how a substance can be simply represented by a chemical formula made up of both letters and numbers. Many of the terms may be familiar to the layperson, but not necessarily their precise definitions in the context of chemistry.

Chemistry: The study of matter, its composition and properties, and the changes it undergoes.

Matter: Anything that has rest mass.

To develop this topic we need to define the **atom**, the basic unit of common matter.

Atom: A neutral particle consisting of a **nucleus** containing most of its mass, and **electrons** occupying most of its volume.

Electron: A subatomic particle with a charge of -1.

Nucleus: Consists of two types of subatomic particles; **protons**, each with an electric charge of +1, and **neutrons** which have no charge.

Atomic number: Symbol Z, the number of protons in the atom.

Mass number: Symbol A, the sum of the number of protons and neutrons in the atom. (**Nucleon** is a term for either a proton or neutron. Thus A is the number of nucleons in an atom and the number of neutrons is A-Z.)

Element: A substance composed of **atoms** <u>all</u> of which have the same **atomic number**, i.e. the same number of protons in the nucleus, and thus the same number of electrons.

The **atomic number** defines the element. Each element has a name (of varying historic origin) and a shorthand symbol. The **periodic table** on the previous page lists the elements in order of increasing atomic number. The atomic number is at the top of each entry, then the full name and then the symbol. The symbol has one or two letters. The first letter is always in capitals and the second in lower case. The origin of some symbols which may appear to bear no relationship to the full name come from Latin, Greek or German [e.g. 26, iron, Fe].

Metallic element: Elemental substance which has a "metallic" lustre, conducts electricity and heat well, and is malleable and ductile [e.g. copper]. All the elements to the left of the bold line on the periodic table are **metals**.

Non-metallic element: Elemental substance which does not have metallic properties. [e.g. nitrogen] All the elements to the right of the dashed line on the periodic table are **non-metals**.

Metalloid or **Semimetal**: An element with the physical appearance and some of the properties of a metal, but which has the chemical properties of a non-metal [e.g. arsenic].

These are the elements between the bold and dashed lines on the periodic table.

Isotopes: Atoms of the same element (same atomic number) but with different numbers of neutrons and hence a different mass number [e.g. all atoms of carbon have six protons but may have six (^{12}C), seven (^{13}C), or eight (^{14}C) neutrons. ^{13}C is an isotope of carbon.]. Some isotopes are unstable and emit particles or radiation over a period of time and are called **radioactive**.

Radioactivity: The spontaneous breakdown of one type of atomic nucleus into another.

Relative atomic mass: Symbol, A_r, the mean mass of an atom of an element allowing for the relative abundance of its naturally occurring isotopes relative to (divided by) one twelfth of the mass of one atom of the isotope ^{12}C. (This topic is covered in *section 8*.) The value of A_r is given as the fourth item in each entry of the preceding periodic table.

The chemical properties (behaviour) of the different elements can be understood in terms of the number and arrangement of the electrons in their atoms. The arrangement of the elements in the periodic table is based on this electronic structure. This topic is covered in *section 3*.

Molecule: A discrete neutral particle consisting of a definite number of atoms bonded (held) together by **chemical bonds**. (Chemical bonds is the subject of *section 4*.)

Substance: A single, pure type of matter [e.g. water, sucrose (common sugar), sodium chloride (common salt), argon (gas in many light bulbs)].

A pure substance may be **elemental** [e.g. oxygen, aluminium] or a **compound** [e.g. water, sodium chloride].

A pure **elemental substance** may consist of individual atoms, [e.g. He, Ne, Ar]; molecules, [e.g. nitrogen - N_2, oxygen - O_2, sulfur - S_8, where the number of atoms in the molecule is given by a subscript number following the symbol for the element]; or large aggregates of atoms [e.g. all metals, carbon in the form of diamond or graphite].

Allotrope: Alternative form of an element differing in the way the atoms are linked [e.g. carbon - diamond and graphite; oxygen - O_2 (dioxygen) and O_3 (ozone)]. Each form is an **allotrope**.

Compound: A pure substance consisting of atoms, or **ions** of two or more elements in a definite number ratio. It may consist of (i) discrete molecules [e.g. water, H_2O; ammonia, NH_3; sucrose, $C_{12}H_{22}O_{11}$ where the number of atoms of each element in the molecule is given by the subscripted number immediately following it; or (ii) large aggregates of atoms [e.g. silica, $(SiO_2)_x$ where every silicon atom is bound (joined) to four oxygen atoms, and every O atom is joined to two silicon atoms]; or (iii) **ions**.

Binary compound: A compound containing only two elements [e.g. hydrogen chloride, HCl; water, H_2O].

Ion: A charged particle. A **cation** is a positively charged particle, one containing fewer electrons than protons; an **anion** is a negatively charged particle, one containing more electrons than protons.

An ion may be (i) monatomic, i.e. just one atom, [e.g. sodium ion, Na^+; magnesium ion,

Mg^{2+}; chloride ion, Cl^{-}; oxide ion, O^{2-}]; (ii) polyatomic, i.e. a discrete number of atoms jointed together, [e.g. sulfate, SO_4^{2-}; nitrate, NO_3^{-}; ammonium, NH_4^{+}] or (iii) polymeric, i.e. large aggregate of atoms joined together, [e.g. silicate $(SiO_3^{2-})_x$]. The overall charge is given as a superscript after the formula as shown.

Ionic compound: A compound consisting of ions. The total charge on the cations equals the total charge on the anions, as substances are neutral. An ionic compound is an aggregate of those ions. However the charge on the ions is <u>not</u> shown in its formula [e.g. sodium chloride, NaCl, is made up of monatomic sodium ions, (Na^{+}), and chloride ions, (Cl^{-}); sodium sulfate, Na_2SO_4, is made up of sodium ions, (Na^{+}) and sulphate ions, (SO_4^{2-}); ammonium sulfate, $(NH_4)_2SO_4$, is made up of ammonium ions, (NH_4^{+}), and sulfate ions, (SO_4^{2-}); sodium silicate, (Na_2SiO_3), is made up of Na^{+} cations and polymeric $(SiO_3^{2-})_x$ anions.].

Matter exists normally in three states - **gas** (g), **liquid** (l) or **solid** (s).

Phase: A particular state of matter [e.g. gas, liquid, solid].

Phase change: The change which occurs when a substance changes from one state to another, or undergoes a change in structure in the solid state. The common names for phase changes are:

$g \rightarrow l$	**condensation**	$l \rightarrow g$	**evaporation**
$l \rightarrow s$	**freezing**	$s \rightarrow l$	**melting** or **fusion**
$g \rightarrow s$	**deposition**	$s \rightarrow g$	**sublimation**

Crystalline solid: A solid in which there is an orderly array of its constituents (atoms, molecules or ions). A crystalline solid may exist as a single crystal or as numerous crystals [e.g. common salt, NaCl; common sugar, sucrose, $C_{12}H_{22}O_{11}$; diamond].

Mixture: A type of matter consisting of more than one substance and which can be separated into its components by making use of different physical properties of the substances present. Mixtures may be homogeneous or heterogeneous.

Homogeneous mixture: A mixture in which any two samples have the same composition and properties [e.g. air (a gas); seawater (a liquid)].

Heterogeneous mixture: A mixture containing entities of sufficient size such that all samples are not identical [e.g. concrete; smoke].

Solution: A homogeneous mixture (usually with one component in larger amount); normally a liquid [e.g. seawater; hydrochloric acid], but the term may be also apply to a solid, but not to a gas.

Solvent: The component of a solution in largest amount [e.g. the water of seawater].

Solute: The components of a solution in lesser amounts [e.g. the salts in seawater].

Aqueous solution: A solution with water as the solvent.

Crystallization: The process of a solute coming out of solution as crystals.

Colloid: A mixture consisting of a finely divided phase (the dispersed phase) distributed uniformally in a continuous phase (the dispersion medium). **Aerosols**, liquid in gas [e.g. mist, fog] or solid in gas [e.g. smoke]. **Emulsions**, liquid in liquid [e.g. cream, fat in water, and butter, water in fat]. **Sol** or **colloidal suspension**, solid in liquid; **slurry** or **paste** when concentrated. **Foam**, gas in liquid or gas in solid. **Gel**, a polymeric dispersed phase in a liquid. The dispersed phase has a huge surface area which gives colloids their distinctive properties. Colloids are **heterogeneous mixtures**.

Chemical formulae: Part of the language used by chemists to represent substances and compounds [e.g. H_2O is the formula for water].

Molecular formula: The formula for a discrete molecule. It gives the symbol of each different element and the number of atoms of that element as a subscript immediately after the symbol for the element [e.g. ammonia, NH_3; nitrogen, N_2; glucose,$C_6H_{12}O_6$; sulfuric acid, H_2SO_4]. There are now rules for the order in which the elements are listed based on chemical language which has evolved over time. However the order is best learned with experience (i.e. seeing it written). However, for indexes (listings) of organic compounds the order is C H O and then the remaining elements listed alphabetically. The formula may represent one discrete molecule of the substance or a macroscopic amount of it. Which is meant must be deduced from the context in which the formula is used.

Empirical formula: The formula for a substance giving the simplest ratio of the atoms [e.g. glucose, CH_2O].

Compounds which consist of large aggregates of atoms joined together are usually represented by their empirical formula [e.g. silica is normally represented by just SiO_2 not $(SiO_2)_x$]. Elements which consist of aggregates of atoms bound together are represented simply by the symbol for the element [e.g. aluminium metal, Al]. Ionic compounds are represented by the formula for their cations and anions in their simplest whole number ratio, without showing the charge on either the cations or anions [e.g. NaCl represents sodium chloride which consists of Na^+ and Cl^- ions in a 1:1 ratio; $Ca_3(PO_4)_2$ represents calcium phosphate which consists of Ca^{2+} and PO_4^{3-} ions in a ratio of 3:2; Na_2SiO_3 represents a sodium silicate which consists of discrete Na^+ ions and polymeric anions $(SiO_3^{2-})_x$]. Note the use of brackets around polyatomic ions when a subscript is needed.

A certain knowledge and experience of chemistry is required to understand fully what is meant by a given formula in a given context. (Further kinds of formulae giving more information on the structure of molecules and ions are discussed in *sections 4-6*.)

Mineral: A naturally occurring substance of a characteristic composition and a crystalline structure. Rocks are composed of a mixture of minerals. The term is also used for organic substances such as coal and oil which are obtained by mining, but strictly these are not minerals as they are mixtures without definite chemical formulae.

Chemical bonds: The forces holding atoms together in molecules or in aggregates. Commonly they are just called **bonds**. This topic is covered in *section 4*.

Valence: The number of bonds an atom of a particular element can form in a molecule. [e.g. In water, H_2O, one oxygen atom forms bonds to two hydrogen atoms, and each hydrogen atom forms one bond to an oxygen atom. The hydrogen atoms are not bonded to each other. The valency of O is two and of H is one. In silica, SiO_2, each Si atom is bound to four O atoms and each O atom to two Si atoms. The valency of Si is 4 and of O is 2.] In simple ionic compounds containing monoatomic cations and anions the valency is simply the charge on the ions. [e.g. In NaCl made up of Na^+ and Cl^- the valency of both Na and Cl is one.]

Polymer: A substance having large molecules consisting of repeated units (the **monomers**). Polymers do not have a definite formula as they consist of molecules of different chain length.
[e.g. polyethylene, H-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2- or H-(CH_2-CH_2)$_x$-H where *x* is a large number and the monomer is ethylene, C_2H_4; the polymeric silicates above.]

Free-radical: An atomic, molecular, or ionic particle with an unpaired valence electron [e.g. chlorine atom, Cl·]. Usually chemically reactive. See *sections 3 - 4*.

To understand why pure substances have particular compositions and properties we need to know about the "electronic structure" of the atoms (i.e. the way the electrons are arranged about the nucleus of the different elements). Then we can rationalise the ratio in which atoms combine and whether they are molecular, polymeric or ionic, [e.g. why gaseous nitrogen consists of discrete N_2 molecules; methane, ammonia, water and hydrogen fluoride consist of discrete molecules of CH_4, NH_3, H_2O, HF respectively (H_4C, H_3N, OH_2, FH are in principle equally valid formulae, but not normally used); why sodium chloride consists of Na^+ and Cl^- ions; why metals exist in nature mainly as cations, M^{x+}; why free-radicals are reactive]. The topic of electronic structure is covered in *section 3*.

Organic chemistry: The chemistry of the compounds of carbon. Originally meant chemistry of products formed in living systems.

Inorganic chemistry: The chemistry of compounds other than carbon, but includes CO, CO_2 and carbonates.

Nomenclature: The naming of substances. This is covered in *section 6* (organic) and in *section 13* (inorganic).

EXERCISES

From the periodic table give the name and symbol of the element, and the number of neutrons for the isotope, given the atomic number and the mass number.

1. *Example*: Z = 8 *A* = 16
   Answer: oxygen, O, *A*-*Z* = 8

2. *Z* = 19 *A* = 39 3. 3. *Z* = 29 *A* = 65 4. *Z* = 86 *A* = 222

Write the formula of the following compounds from the given compositions:

5. *Example*: Ethane, molecular, two carbons and six hydrogens
   Answer: C_2H_6

6. *Example*: Sodium carbonate, composed of Na^+ and CO_3^{2-} ions
   Answer: Na_2CO_3

7. Acetic acid, molecular, two carbons, four hydrogens and two oxygens

8. Glycine, molecular, two carbons, five hydrogens, two oxygens and one nitrogen

9. Cystine, molecular, two nitrogens, two sulfurs, twelve hydrogens, four oxygens and six carbons

10. Potassium bromide composed of K^+ and Br^- ions

11. Ammonium nitrate composed of NH_4^+ and NO_3^- ions

12. Magnesium nitrate composed of Mg^{2+} and NO_3^- ions

13. Aluminium sulfate composed of Al^{3+} and SO_4^{2-} ions