4.1 Atomic structure and the periodic table

The periodic table provides chemists with a structured organisation of the known chemical elements from which they can make sense of their physical and chemical properties. The historical development of the periodic table and models of atomic structure provide good examples of how scientific ideas and explanations develop over time as new evidence emerges. The arrangement of elements in the modern periodic table can be explained in terms of atomic structure which provides evidence for the model of a nuclear atom with electrons in energy levels.

4.1.1 A simple model of the atom, symbols, relative atomic mass, electronic charge and isotopes

4.1.1.1 Atoms, elements and compounds

All substances are made of atoms. An atom is the smallest part of an element that can exist.

Atoms of each element are represented by a chemical symbol, eg O represents an atom of oxygen, Na represents an atom of sodium.

There are about 100 different elements. Elements are shown in the periodic table.

Compounds are formed from elements by chemical reactions.

Chemical reactions always involve the formation of one or more new substances, and often involve a detectable energy change.

Compounds contain two or more elements chemically combined in fixed proportions and can be represented by formulae using the symbols of the atoms from which they were formed.

Compounds can only be separated into elements by chemical reactions.

Chemical reactions can be represented by word equations or equations using symbols and formulae.

Students will be supplied with a periodic table for the exam and should be able to:

• use the names and symbols of the first 20 elements in the periodic table, the elements in Groups 1 and 7, and other elements in this specification

• name compounds of these elements from given formulae or symbol equations

• write word equations for the reactions in this specification

• write formulae and balanced chemical equations for the reactions in this specification.

(HT only) write balanced half equations and ionic equations where appropriate.

4.1.1.2 Mixtures

A mixture consists of two or more elements or compounds not chemically combined together. The chemical properties of each substance in the mixture are unchanged.

Mixtures can be separated by physical processes such as filtration, crystallisation, simple distillation, fractional distillation and chromatography. These physical processes do not involve chemical reactions and no new substances are made.

Students should be able to:

• describe, explain and give examples of the specified processes of separation

• suggest suitable separation and purification techniques for mixtures when given appropriate information.

4.1.1.3 The development of the model of the atom (common content with physics)

New experimental evidence may lead to a scientific model being changed or replaced.

Before the discovery of the electron, atoms were thought to be tiny spheres that could not be divided.

The discovery of the electron led to the plum pudding model of the atom. The plum pudding model suggested that the atom is a ball of positive charge with negative electrons embedded in it.

The results from the alpha particle scattering experiment led to the conclusion that the mass of an atom was concentrated at the centre (nucleus) and that the nucleus was charged. This nuclear model replaced the plum pudding model.

Niels Bohr adapted the nuclear model by suggesting that electrons orbit the nucleus at specific distances. The theoretical calculations of Bohr agreed with experimental observations.

Later experiments led to the idea that the positive charge of any nucleus could be subdivided into a whole number of smaller particles, each particle having the same amount of positive charge. The name proton was given to these particles.

The experimental work of James Chadwick provided the evidence to show the existence of neutrons within the nucleus. This was about 20 years after the nucleus became an accepted scientific idea.

Students should be able to describe:

• why the new evidence from the scattering experiment led to a change in the atomic model

• the difference between the plum pudding model of the atom and the nuclear model of the atom.

Details of experimental work supporting the Bohr model are not required. Details of Chadwick's experimental work are not required.

4.1.1.4 Relative electrical charges of subatomic particles

The relative electrical charges of the particles in atoms are:

Name of particle	Relative charge
Proton	+1
Neutron	0
Electron	-1

In an atom, the number of electrons is equal to the number of protons in the nucleus. Atoms have no overall electrical charge.

The number of protons in an atom of an element is its atomic number. All atoms of a particular element have the same number of protons. Atoms of different elements have different numbers of protons.

Students should be able to use the nuclear model to describe atoms.

4.1.1.5 Size and mass of atoms

Atoms are very small, having a radius of about 0.1 nm (1 x 10^{-10} m).

The radius of a nucleus is less than 1/10 000 of that of the atom (about 1 x 10^{-14} m).

Almost all of the mass of an atom is in the nucleus.

The relative masses of protons, neutrons and electrons are:

Name of particle	Relative mass
Proton	1
Neutron	1
Electron	Very small

The sum of the protons and neutrons in an atom is its mass number.

Atoms of the same element can have different numbers of neutrons; these atoms are called isotopes of that element.

Atoms can be represented as shown in this example:

$$\begin{matrix} (Mass\ no.) & 23 & \\ & & Na \\ (Atomic\ no.) & 11 & \end{matrix}$$

Students should be able to calculate the numbers of protons, neutrons and electrons in an atom or ion, given its atomic number and mass number.

Students should be able to relate size and scale of atoms to objects in the physical world.

4.1.1.6 Relative atomic mass

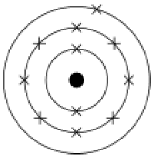
The relative atomic mass of an element is an average value that takes account of the abundance of the isotopes of the element.

Students should be able to calculate the relative atomic mass of an element given the percentage abundance of its isotopes.

4.1.1.7 Electronic structure

The electrons in an atom occupy the lowest available energy levels (innermost available shells). The electronic structure of an atom can be represented by numbers or by a diagram.

For example, the electronic structure of sodium is 2,8,1 or



showing two electrons in the lowest energy level, eight in the second energy level and one in the third energy level.

Students may answer questions in terms of either energy levels or shells.

4.1.2 The periodic table

4.1.2.1 The periodic table

The elements in the periodic table are arranged in order of atomic (proton) number and so that elements with similar properties are in columns, known as groups. The table is called a periodic table because similar properties occur at regular intervals.

Elements in the same group in the periodic table have the same number of electrons in their outer shell (outer electrons) and this gives them similar chemical properties.

Students should be able to:

• explain how the position of an element in the periodic table is related to the arrangement of electrons in its atoms and hence to its atomic number

• predict possible reactions and probable reactivity of elements from their positions in the periodic table.

4.1.2.2 Development of the periodic table

Before the discovery of protons, neutrons and electrons, scientists attempted to classify the elements by arranging them in order of their atomic weights.

The early periodic tables were incomplete and some elements were placed in inappropriate groups if the strict order of atomic weights was followed.

Mendeleev overcame some of the problems by leaving gaps for elements that he thought had not been discovered and in some places changed the order based on atomic weights.

Elements with properties predicted by Mendeleev were discovered and filled the gaps. Knowledge of isotopes made it possible to explain why the order based on atomic weights was not always correct.

Students should be able to describe these steps in the development of the periodic table.

4.1.2.3 Metals and non-metals

Elements that react to form positive ions are metals.

Elements that do not form positive ions are non-metals.

The majority of elements are metals. Metals are found to the left and towards the bottom of the periodic table. Non-metals are found towards the right and top of the periodic table.

Students should be able to:

- explain the differences between metals and non-metals on the basis of their characteristic physical and chemical properties. This links to Group 0, Group 1, Group 7 and Bonding, structure and the properties of matter.
- explain how the atomic structure of metals and non-metals relates to their position in the periodic table
- explain how the reactions of elements are related to the arrangement of electrons in their atoms and hence to their atomic number.

4.1.2.4 Group 0

The elements in Group 0 of the periodic table are called the noble gases. They are unreactive and do not easily form molecules because their atoms have stable arrangements of electrons.

The noble gases have eight electrons in their outer shell, except for helium, which has only two electrons.

The boiling points of the noble gases increase with increasing relative atomic mass (going down the group).

Students should be able to:

- explain how properties of the elements in Group 0 depend on the outer shell of electrons of the atoms
- predict properties from given trends down the group.

4.1.2.5 Group 1

The elements in Group 1 of the periodic table are known as the alkali metals and have characteristic properties because of the single electron in their outer shell.

Students should be able to describe the reactions of the first three alkali metals with oxygen, chlorine and water.

In Group 1, the reactivity of the elements increases going down the group.

Students should be able to:

- explain how properties of the elements in Group 1 depend on the outer shell of electrons of the atoms
- predict properties from given trends down the group.

4.1.2.6 Group 7

The elements in Group 7 of the periodic table are known as the halogens and have similar reactions because they all have seven electrons in their outer shell. The halogens are non-metals and consist of molecules made of pairs of atoms.

Students should be able to describe the nature of the compounds formed when chlorine, bromine and iodine react with metals and non-metals.

In Group 7, the further down the group an element is the higher its relative molecular mass, melting point and boiling point.

In Group 7, the reactivity of the elements decreases going down the group.

A more reactive halogen can displace a less reactive halogen from an aqueous solution of its salt.

Students should be able to:

- explain how properties of the elements in Group 7 depend on the outer shell of electrons of the atoms
- predict properties from given trends down the group.

4.1.3 Properties of transition metals (chemistry only)

4.1.3.1 Comparison with Group 1 elements

The transition elements are metals with similar properties which are different from those of the elements in Group 1.

Students should be able to describe the difference compared with Group 1 in melting points, densities, strength, hardness and reactivity with oxygen, water and halogens.

Students should be able to exemplify these general properties by reference to Cr, Mn, Fe, Co, Ni, Cu.

4.1.3.2 Typical properties

Many transition elements have ions with different charges, form coloured compounds and are useful as catalysts.

Students should be able to exemplify these general properties by reference to compounds of Cr, Mn, Fe, Co, Ni, Cu.