Atomic theory

The modern atomic theory was developed from John Dalton's simple atomic model of 1802. Dalton believed (like some philosophers in ancient Greece) that all matter was composed of small, indivisible particles called atoms. Dalton proposed that each element was composed of unique atoms with different atomic weights. It wasn't until the end of the nineteenth century and early twentieth century that the sub-components of the atom were identified.

Glossary

Atom—the smallest unit of an element; composed of protons, neutrons and electrons

Atomic number (Z)—the number of protons in the nucleus of an atom

Electron—a negatively charged sub-atomic particle located outside and moving around the nucleus

Electron configuration—the arrangement of electrons in their shells

Isotopes—atoms with the same atomic number but different mass numbers

Mass number (A)—the number of protons plus neutrons in the nucleus of an atom

Nucleus—the central positive core of an atom

Proton—a positively charged subatomic particle located in the nucleus

Neutron—a neutral subatomic particle found in the nucleus

Shells—energy levels (or orbits) around the nucleus occupied by electrons

Structure of the atom

Atoms are not solid bodies as believed by John Dalton. They have an internal structure.

Atoms are composed of a small, central positive core called the **nucleus** surrounded by diffuse outer shells of negative charge.

Most of the mass of the atom is concentrated in the nucleus. The nucleus is composed of varying numbers of **positive protons** and **neutral neutrons**. Protons and neutrons have very similar masses.

Outside the nucleus is a region where the negatively charged electrons are located. Electrons are very light compared with protons and neutrons. The mass of an electron is about 1840 times smaller than that of a proton.

There are various models that have been developed to describe the arrangement of electrons around the nucleus. One of these models is discussed on page 46.

Table 2.1 Subatomic components

Subatomic particle	Relative mass	Charge	Location in the atom
Proton (p)	1.008	+1	nucleus
Neutron (n)	1.009	0	nucleus
Electron (e)	0.000 55	–1	outside the nucleus

In all neutral atoms the total positive charge of the protons in the nucleus is equal to the total negative charge of the electrons.

Example

In a sodium atom, there are 11 protons and 12 neutrons in the nucleus. Surrounding the nucleus are 11 electrons. Thus:

Total nuclear charge = +11

Total electron charge = −11

Total charge on a neutral atom
= (+11) + (−11) = 0.

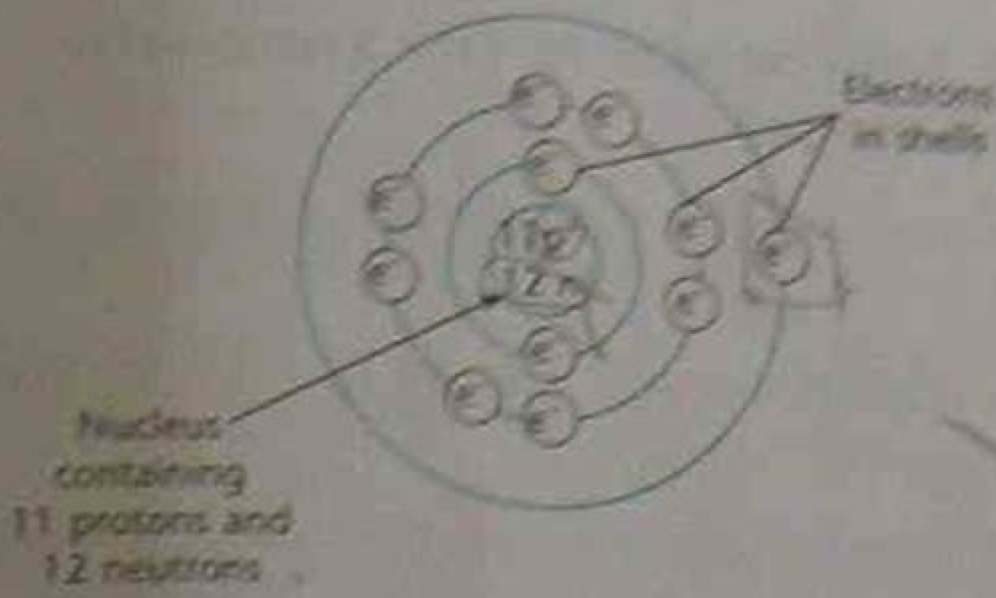

Figure 2.1 Sub-structure of a sodium atom

el
gr
Ea
nu
ca

Elements

Atomic number

Each element has a unique proton number. This is called the **atomic number**.

- **The atomic number (Z)** is the number of protons in the nucleus of an atom
- For all neutral atoms the number of protons equals the number of electrons.

Table 2.2 Elements and atomic number

Element	Atomic number Z	Symbol
Hydrogen	1	H
Helium	2	He
Lithium	3	Li
Beryllium	4	Be
Boron	5	B
Carbon	6	C
Nitrogen	7	N

Mass number

Elements have variable numbers of neutrons. For light elements the number of neutrons is approximately equal to the number of protons. However, for heavy elements the number of neutrons is much greater than the number of protons.

Each element is also characterised by the number of protons plus neutrons. This is called the **mass number**.

- **The mass number (A)** is the number of protons + neutrons in the nucleus.

  The number of neutrons in the nucleus of an atom is therefore the difference between the mass number and the atomic number.

- **The neutron number (N) = A – Z**

Each element can be represented symbolically using the atomic number and the mass number. For an element E, the symbol is written as:

Example

The element sodium has an atomic number of 11 and a mass number of 23. This information is symbolically represented as:

$$^{23}_{11}Na$$

Thus, sodium atoms contain 23 – 11 = 12 neutrons. There are also 11 protons and 11 electrons.

Isotopes

Elements can exist in various **isotopic** forms. They have the same atomic number but different mass numbers. This is caused by the presence of a variable number of neutrons in the nucleus.

- **Isotopes of an element have the same number of protons but different numbers of neutrons.**

Example

Oxygen-16: $^{16}_{8}O$ consists of 8 protons, 8 neutrons and 8 electrons.

Oxygen-17: $^{17}_{8}O$ consists of 8 protons, 9 neutrons and 8 electons.

- Some isotopic forms of an element are radioactive. These are radioisotopes.

Example

Carbon-12 is a stable and non-radioactive isotope of carbon. Carbon-14 is a radioisotope.

$$^{12}_{6}C = 6p + 6n + 6e$$

$$^{14}_{6}C = 6p + 8n + 6e$$

Worked example

Q Complete the following table.

Element	Symbol	Z	A	N	Proton number	Electron number
Nitrogen		7	14			
	Be		9	5		
	B			5		5

A The number of protons = number of electrons = Z (for neutral atoms).

Element	Symbol	Z	A	N	Proton number	Electron number
Nitrogen	N	7	14	7	7	7
Beryllium	Be	4	9	5	4	4
Boron	B	5	10	5	5	5

Atomic weight

The weights of individual atoms of an element are very small. Consequently chemists refer to the **relative atomic weight** of an element. This weight is compared to a standard which is the carbon-12 isotope. By setting its atomic weight as 12 units (exactly), the relative atomic weights of all other elements can be compared. Because elements consist of mixtures of isotopes, the relative atomic weight (which is an average) is not a whole number.

Examples of relative atomic weight

Sulfur: 32.06

Chlorine: 35.45

Calcium: 40.08

Modelling subatomic structure

In the first half of the twentieth century various models of the atom were develop to explain the observed properties of elements.

One of the early models was developed b Niels Bohr in 1913. This is known as the **shell model** of the atom.

The Bohr model of the atom—the shell model

The main features of the Bohr atomic mod are:

- Electrons occupy energy levels (or shell around the nucleus.
- Electron shells are labelled with the lette K, L, M, N, with the K shell being close to the nucleus.
- The maximum number of electrons tha can occupy a shell increases with distan from the nucleus. The **maximum** numbe of electrons in each shell is:

K shell—2 electrons

L shell—8 electrons

M shell—18 electrons

N shell—32 electrons.

- The outer shell that contains electrons is called the **valence shell** and it can have a maximum of 8 electrons. Electrons in the valence shell are called **valence electrons.**

- The arrangement of electrons in shells around the nucleus is called the electron **configuration** of the atom.
- Eight electrons (an **octet**) in a valence shell provides additional stability.

Examples

1. **Hydrogen** (Z = 1). This is the simplest element with only 1 electron in the K shell. This electron is the valence electron.
2. **Helium** (Z = 2). This element has 2

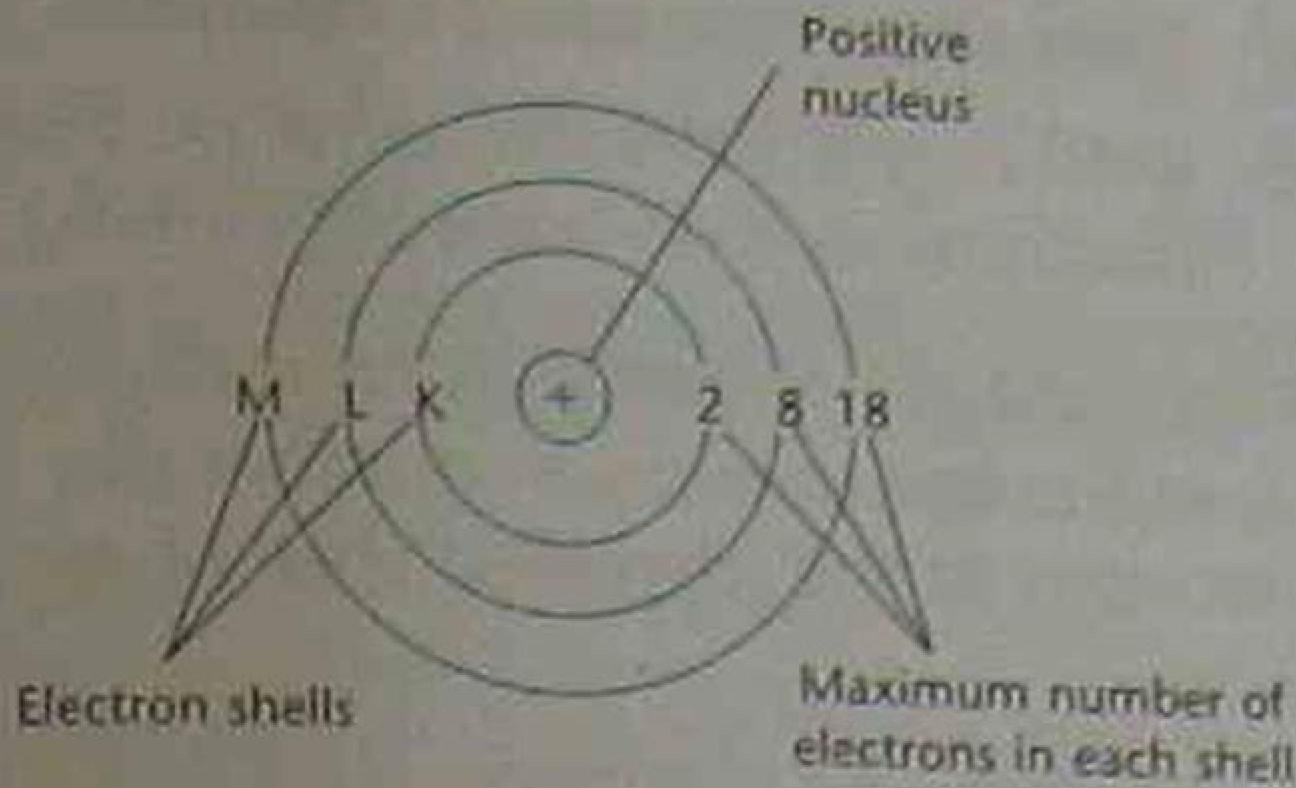

Figure 2.2 Bohr shell model of the atom

electrons, both of which occupy the K shell. The shell is now full and helium is a very stable, unreactive element.

3. **Lithium (Z = 3)**. There are 2 electrons in the K shell and 1 electron in the L (valence) shell. The electron configuration is thus K2, L1, or more simply 2,1.

4. **Sodium (Z = 11)**. The 11 electrons are distributed with 2 electrons in the K shell, 8 electrons in the L shell and 1 electron in the M shell. The M shell in this example is the valence shell. The electron configuration of sodium is therefore K2, L8, M1, or 2, 8, 1. Like lithium, sodium has 1 electron in the valence shell.

Electron configurations of elements beyond Z = 18

The need to keep the number of valence electrons at 8 or less leads to variations in the rules of filling shells with electrons.

Argon (Z = 18) has the electron configuration 2, 8, 8. The 8 electrons in the valence shell are the maximum number a valence shell can have. But the M shell can accommodate up to 18 electrons as long as it is *not* the valence shell. Thus, elements with atomic numbers between 19 and 30 have their valence electrons in the N shell and complete the filling of the M shell.

Examples

1. Potassium (Z = 19): 2,8,8,1

2. Calcium (Z = 20): 2, 8, 8, 2
3. Scandium (Z = 21): 2, 8, 9, 2
4. Titanium (Z = 22): 2, 8, 10, 2
5. Zinc (Z = 30): 2, 8, 18, 2

The Bohr model can be used to explain the physical and chemical properties of an element as well as the compounds formed when elements react together. This model is also consistent with the structure of the Periodic Table. (See page 50.)

Here are some general statements that will help you focus on the relationship between electrons, electron shells and the Periodic Table.

- **Metals are good electrical conductors.** Metals are elements that generally have 1, 2 or 3 electrons in their valence shell. These electrons are not bound to any one atom but are mobile in the metallic crystal. They are responsible for the conductivity of metals when a voltage is applied across the metal. (*Note*: Some metals have four valence electrons, eg. tin and lead.) Most elements in the Periodic Table are metals.

- **Non-metals are poor electrical conductors.** Non-metals are elements that generally have 5, 6, 7 or 8 electrons in their valence shell. These electrons are tightly bound to each atom and are not able to carry charges through the crystal when a voltage is applied across it. (*Note:* Carbon has 4 valence electrons and in the form of graphite it is a conductive non-metal due to the presence of some mobile electrons). There are very few non-metals in the Periodic Table.

- **Elements with eight valence electrons are highly unreactive.** The noble gases such as neon and argon have 8 electrons in their valence shell. They do not react with other elements, because an **octet** of electrons in the valence shell provides stability for the atom. (*Note*: Helium with a filled K shell is also very stable.)

- **Most metals with one valence electron are highly reactive.** Elements such as sodium and potassium have one valence electron. These elements are found on the far left column (group) of the Periodic Table. These are highly reactive metals that combine readily with non-metals such as oxygen and chlorine. During the reaction the valence electron is transferred into the valence shell of the non-metal. In this process the metal achieves a stable octet of electrons in its newly exposed outer shell.

- Most non-metals with seven valence electrons are very reactive. Elements such as fluorine and chlorine have seven valence electrons. They are highly reactive non-metals that combine readily with many metals. Electrons are transferred to the non-metals to complete an octet in their valence shell. This process stabilises the non-metal. Non-metals occupy the upper right-hand zone of the Periodic Table.

Elements

Elements are the basic building blocks of matter. There are about 90 natural elements and about another 28 synthetic elements that have been produced by nuclear processes. Elements can be classified into families on the basis of their atomic sub-structure and their properties.

Glossary

Group—a column of the Periodic Table containing a family of related elements

Molecules—aggregates of two or more atoms joined by bonds

Period—a row of elements of the Periodic Table

Periodic Table—the arrangement of the elements according to increasing atomic number

Atoms and molecules

An atom is the smallest unit of an element.

Some elements consist of **single atoms** in the gaseous state at room temperature. These include the noble gases such as helium, neon and argon.

Metals can be considered to be single atoms arranged in a crystalline lattice.

Most non-metallic elements exist as **molecules** rather than single atoms.

Molecules are aggregates of atoms that are strongly joined together by chemical bonds. They are much more stable in the molecular form than as single atoms. Some elements that consist of molecules are shown in Table 2.3. Many of these non-metals form **diatomic** molecules. Sulfur forms an octa-atomic molecule whereas the white form of phosphorus is a tetra-atomic molecule (P_4). Oxygen is normally present as a diatomic molecule (O_2) but there is a toxic triatomic form called ozone (O_3).