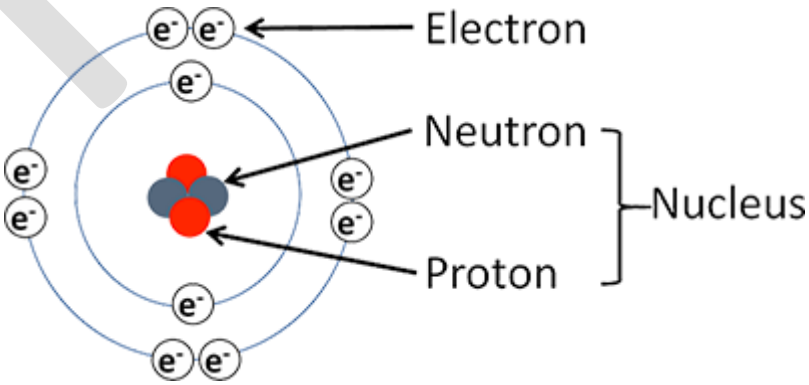
Cambridge AS level Chemistry

CODE: (9701)

Chapter 02

Atomic Structure



Elements and atoms

Chemical elements, such as nitrogen and gold, are found naturally in compounds, while most elements are found in their form, such as nitrogen and gold, which cannot be broken down into simpler substances. Every element has its chemical symbol. The symbols are often derived from Latin or Greek words. Some examples are shown in Table 2.1.

Element	Symbol
carbon	C
lithium	Li (from Greek 'lithos')
iron	Fe (from Latin 'ferrum')
potassium	K (from Arabic 'al-qualyah' or from the Latin 'kalium')

Table 2.1 Some examples of chemical symbols.

Inside the atom, the structure of an atom Every atom has nearly all its mass concentrated in a tiny region in the centre of the atom called the **nucleus**. The nucleus is made up of particles called nucleons.

There are two types of nucleons: **protons** and **neutrons.** Atoms of different elements have different numbers of protons. Outside the nucleus, particles called **electrons** move around in regions of space called orbitals.

Chemists often use electron shell models to understand atoms, where electrons move around the nucleus at specific energy levels. In a neutral atom, the number of electrons equals the number of protons. A simple model of a carbon atom is shown in Figure 2.3.

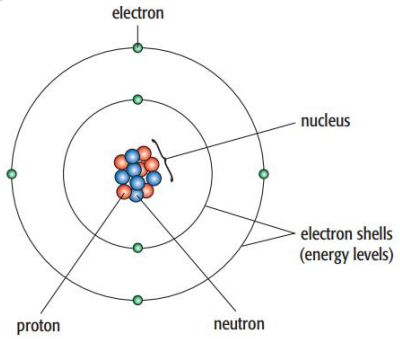


Figure 2.3 A model of a carbon atom. This model is not very accurate but it is useful for understanding what happens to the electrons during chemical reactions.

Masses and charges: a summary

Electrons, protons, and neutrons have characteristic charges and masses, but their values are too small for general chemical properties. Comparing their masses and charges using relative charges and masses is shown in Table 2.2.

Subatomic particle	Symbol	Relative mass	Relative charge
electron	e	$\frac{1}{1836}$	−1
neutron	n	1	0
proton	p	1	+1

Table 2.2 Comparing electrons, neutrons and protons.

Numbers of nucleons

Proton number and nucleon number

The number of protons in the nucleus of an atom is called the proton number (Z). It is also known as the atomic number. Every atom of the same element has the same number of protons in its nucleus. It is the proton number that makes an atom what it is.

The **nucleon number** (A) is the number of protons plus neutrons in the nucleus of an atom. This is also known as the **mass number.**

How many neutrons?

We can use the nucleon number and proton number to find the number of neutrons in an atom. As:

nucleon number = number of protons + number of neutrons

Then:

number of neutrons = nucleon number – number of protons = A – Z

Isotopes

All atoms of the same element have the same number of protons. However, they may have different numbers of neutrons. Atoms of the same element that have differing numbers of neutrons are called **isotopes.**

Isotopes are atoms of the same element with different nucleon (mass) numbers.

Isotopes of an element share chemical properties due to the same number of electrons, but have slightly different physical properties, like density differences. Isotope symbols include the nucleon number and proton number.

The symbol for the isotope of boron with 5 protons and 11 nucleons is written:

nucleon number ⟶ 11
proton number ⟶ 5 **B**

Hydrogen has three isotopes, with their atomic structure and symbols shown in Figure 2.8. Chemists name these isotopes by omitting the proton number and placing the nucleon number after it, like hydrogen-1, -2, and-3.

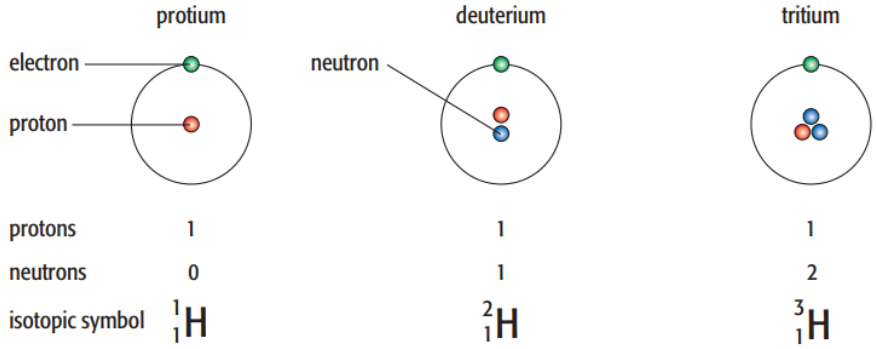


Figure 2.8 The atomic structure and isotopic symbols for the three isotopes of hydrogen.

Isotopes, either radioactive or non-radioactive, are utilized in various fields, including checking pipeline leaks, assessing paper thickness, treating certain cancers, and monitoring thyroid gland activity in the throat.

How many protons, neutrons and electrons?

In a neutral atom, the number of positively charged protons in the nucleus equals the number of negatively charged electrons outside the nucleus. When an atom gains or loses electrons, ions are formed, which are electrically charged. For example:

Cl	+	e^-	⟶	Cl^-
chlorine atom		1 electron gained		chloride ion
17 protons				17 protons
17 electrons				18 electrons

The chloride ion has a single negative charge because there are 17 protons (+) and 18 electrons (–).

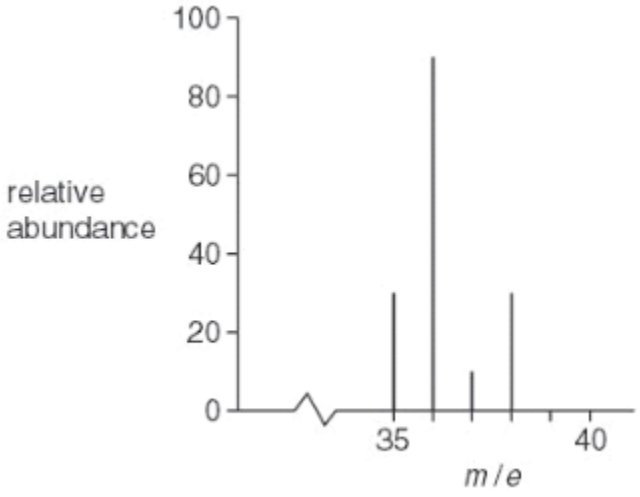
Mg	⟶	Mg^{2+}	+	$2e^-$
magnesium atom		magnesium ion		2 electrons removed
12 protons				12 protons
12 electrons				10 electrons

The magnesium ion has a charge of 2+ because it has 12 protons (+) but only 10 electrons (–). The isotopic symbol for an ion derived from sulfur-33 is $^{33}_{16}S^{2-}$. This sulfide ion has 16 protons, 17 neutrons (because 33 – 16 = 17) and 18 electrons (because 16 + 2 = 18)

Revision questions

(1) (a) Define an isotope in terms of its sub-atomic particles.

(b) In a mass spectrometer some hydrogen chloride molecules will split into atoms. The mass spectrum of HCl is given. Chlorine has two isotopes. The hydrogen involved here is the isotope $^{1}_{1}H$ only.



(i) What particle is responsible for the peak at mass 35?
(ii) What particle is responsible for the peak at mass 38?
(c) Use the relative heights of the peaks to determine the proportions of the two isotopes of chlorine. Explain simply how you obtained your answer.
(d) Use your answer to (c) to explain why chlorine has a relative atomic mass of 35.5.

2)Iron and cobalt are adjacent elements in the Periodic Table. Iron has three main naturally occurring isotopes, cobalt has one.
(a) Explain the meaning of the term isotope.

	number of		
isotope	protons	neutrons	electrons
^{56}Fe			
^{59}Co			

(b) The most common isotope of iron is ^{56} Fe; the only naturally occurring isotope of cobalt is ^{59} Co.
Use the Data Booklet to complete the table below to show the atomic structure of ^{56}Fe and ^{59} Co.

(c) A sample of iron has the following isotopic composition by mass.

isotope mass	54	56	57
% by mass	5.84	91.68	2.17

(i) Define the term relative atomic mass.
(ii) By using the data above, calculate the relative atomic mass of iron to three significant figures.

(3) Hydrogen sulphide is a weak diprotic (dibasic) acid. Its solution in water contains HS^- and a few S^{2-} ions.
(i) What is meant by the term weak acid?
(ii) Write an equation, with state symbols, for the first ionisation of HS when it dissolves in water.

(4) This question is about the elements in Group II of the Periodic Table, magnesium to barium.
(a) Complete the table below to show the electronic configuration of calcium atoms and strontium ions, Sr^{2+}.

	1s	2s	2p	3s	3p	3d	4s	4p	4d
Ca	2	2	6						
Sr^{2+}	2	2	6						

(b) Explain the following observations.
(i) The atomic radii of Group II elements increase down the Group.
(ii) The strontium ion is smaller than the strontium atom.
(iii) The first ionisation energies of the elements of Group II decrease with increasing proton number.

(5) Magnesium, Mg, and radium, Ra, are elements in Group II of the Periodic Table.
Magnesium has three isotopes.
(a) Explain the meaning of the term isotope.

A sample of magnesium has the following isotopic composition by mass.

isotope mass	24	25	26
% by mass	78.60	10.11	11.29

(b) Calculate the relative atomic mass, A, of magnesium to four significant figures.

Radium, proton number 88, and uranium, proton number 92, are radioactive elements. The isotope ^{226}Ra is produced by the radioactive decay of the uranium isotope ^{238}U.
(c) Complete the table below to show the atomic structures of the isotopes ^{226}Ra and ^{238}U.

	number of		
isotopes	protons	neutrons	electrons
^{226}Ra			
^{238}U			

(6) The element magnesium, Mg, proton number 12, is a metal which is used in many alloys which are strong and light.
Magnesium has several naturally occurring isotopes.
(a) What is meant by the term isotope?
(b) Complete the table below for two of the isotopes of magnesium.

isotope	number of protons	number of neutrons	number of electrons
^{24}Mg			
^{26}Mg			

A sample of magnesium had the following isotopic composition: ^{24}Mg, 78.60%; ^{25}Mg, 10.11%; ^{26}Mg, 11.29%.
(c) Calculate the relative atomic mass, A_r, of magnesium in the sample. Express your answer to an appropriate number of significant figures.
Antimony, Sb, proton number 51, is another element which is used in alloys. Magnesium and antimony each react when heated separately in chlorine.
(d) Construct a balanced equation for the reaction between magnesium and chlorine.

(7) Sulfur, S, and polonium, Po, are both elements in Group VI of the Periodic Table.
Sulfur has three isotopes.
(a) Explain the meaning of the term isotope.
(b) A sample of sulfur has the following isotopic composition by mass.

isotope mass	32	33	34
% by mass	95.00	0.77	4.23

Calculate the relative atomic mass, A_r of sulfur to two decimal places.
(c) Isotopes of polonium, proton number 84, are produced by the radioactive decay of several elements including thorium, Th, proton number 90.
The isotope ^{213}Po is produced from the thorium isotope ^{232}Th.
Complete the table below to show the atomic structures of the isotopes ^{213}Po and ^{232}Th.

	number of		
isotope	protons	neutrons	electrons
^{213}Po			
^{232}Th			