FACTFILE: GCSE CHEMISTRY: UNIT 1.1

Rewarding Learning

Atomic Structure

Learning outcomes

Students should be able to:

1.1.1 demonstrate knowledge and understanding of how ideas about the atom changed over time, with reference to:

- the Plum Pudding model;
- Rutherford's model of a nucleus surrounded by electrons; and
- the discovery of the neutron by Chadwick, leading to today's model of an atom;

1.1.2 describe the structure of an atom as a central positively charged nucleus containing protons and neutrons (most of the mass) surrounded by orbiting electrons in shells;

1.1.3 state the relative charges and approximate relative masses of protons, neutrons and electrons;

1.1.4 define atomic number as the number of protons in an atom; and

1.1.5 define mass number as the total number of protons and neutrons in an atom.

1.1.6 demonstrate knowledge and understanding that an atom as a whole has no electrical charge because the number of protons in equal to the number of electrons;

1.1.7 calculate the number of protons, neutrons and electrons in an atom or an ion and deduce the charge on an ion or determine the number of subatomic particles given the charge;

1.1.8 write and draw the electronic configuration (structure) of atoms and ions with atomic number 1–20;

1.1.9 recall that atoms have a radius of about 0.1 nm (1×10^{-10} m) and that the nucleus is less than 1/10 000 of that of the atom (less than 1×10^{-14} m);

1.1.10 define isotopes as atoms of an element with the same atomic number but a different mass number, indicating a different number of neutrons;

1.1.11 interpret data on the number of protons, neutrons and electrons to identify isotopes of an element;

1.1.12 calculate the relative atomic mass of elements from mass number and abundances of isotopes;

1.1.13 recall that a compound is two or more elements chemically combined.

Ideas about the atom over time

One of the early models of an atom, was of the **plum pudding** model. This model was developed by Thomson and suggested that the atom was a sphere of positive charge with negative electrons embedded in it. **Rutherford** developed a model in which the atom had a positive nucleus at the centre, with electrons orbiting it. **Chadwick** discovered a new particle in the nucleus – he called it the neutron.

Today's model of an atom is of a central positively charged nucleus containing protons and neutrons (most of the mass) and surrounded by electrons, orbiting in shells.

Atomic Structure

All atoms consist of a number of fundamental, sub-atomic particles. There are three, the electron, the proton and the neutron. Different atoms (and therefore elements) have different numbers of these three fundamental particles.

Particle	Relative Charge	Relative Mass	Position in Atom
Protons	+1	1	Nucleus
Neutrons	0	1	Nucleus
Electrons	–1	1/1840	Shells

Protons and neutrons are found in the nucleus, in the centre of the atom. As a result, most of the mass of an atom is concentrated in the nucleus. Electrons orbit the nucleus in shells; there are a maximum number of electrons that fit in each shell. Two electrons can fit in the first shell and a maximum of eight electrons in each subsequent shell. The electronic configuration gives the arrangement of the electrons in shells.

Each element has two unique numbers associated with it. These are known as the atomic number and mass number and they give us important information about the number of each sub-atomic particle present in the atom.

Atomic number

The atomic number of an atom is the number of protons in an atom. For an atom, this number also corresponds to the number of electrons. As a result, atoms have no electrical charge because the number of protons is equal to the number of electrons.

Mass number

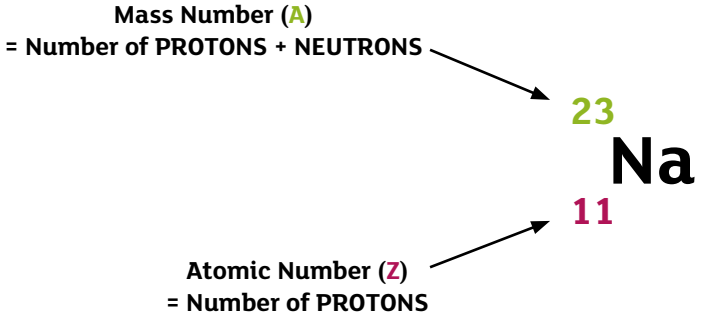
The mass number is the total number of protons and neutrons in an atom.

Remember that for an atom

number of protons = number of electrons = atomic number

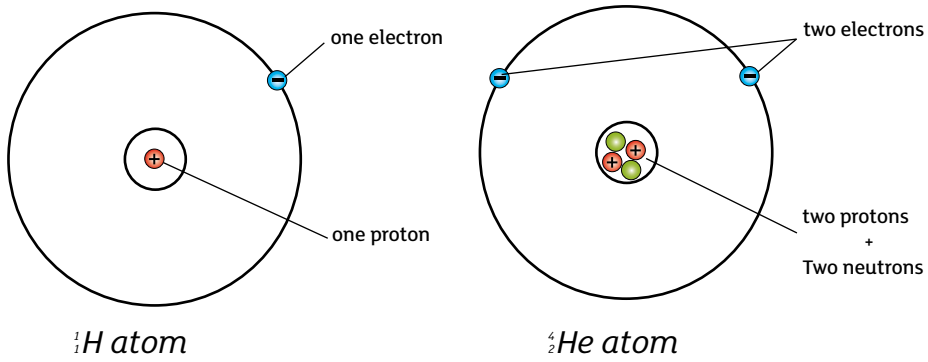
number of neutrons = mass number – atomic number

For example:



There are 11 protons, 11 electrons and 12 neutrons in a **sodium atom**. The electronic configuration is 2,8,1.

The element chlorine has atoms with mass number 35 and atomic number 17. Each atom therefore contains 17 protons, 17 electrons and 18 neutrons.



$^{1}_{1}H$ *atom* $^{4}_{2}He$ *atom*

Atoms of $^{1}_{1}H$ *and* $^{4}_{2}He$

Isotopes

Isotopes are atoms of an element with the same atomic number but a different mass number, indicating a different number of neutrons.

For example, ^{12}C contains 6 neutrons, whereas ^{13}C contains 7 neutrons and ^{14}C contains 8 neutrons. All three carbon isotopes contain 6 protons and 6 electrons.

Chlorine has two main isotopes: ^{35}Cl and ^{37}Cl. For every 100 chlorine atoms, 75 are chlorine-35 and 25 are chlorine-37. The mass number for chlorine given on the Periodic Table (and for every other element) reflects the abundance of all the known isotopes for the element and is more correctly known as the relative atomic mass (A_r). This is defined as:

"The average (weighted mean) mass of an atom of an element relative to one-twelfth of the mass of an atom of carbon-12."

The relative atomic mass for an atom is calculated by adding together the product of each isotope's mass number multiplied by its abundance for each isotope and then dividing by the total abundance. For the chlorine example this is given by:

$$\text{Relative atomic mass } (A_r) = \frac{(\text{mass number} \times \text{abundance}) + (\text{mass number} \times \text{abundance})}{\text{total abundance}}$$

$$A_r = \frac{(35 \times 75) + (37 \times 25)}{100} = 35.5$$

As the relative atomic mass is compared to a particular isotope (carbon-12), it has no units.

Ions

When metal atoms react with non-metal atoms, they chemically combine to form compounds. To do this, the metal atom transfers one or more electrons to the non-metal atom so that both end up with full outer shells of electrons. As the number of electrons is different to the number of protons, the atoms are now charged particles known as ions, which are attracted to each other by electrostatic attraction. **An ion is a charged particle formed when an atom gains or loses electrons (eg Cl^-) and a molecular ion is a charged particle containing more than one atom (eg SO_4^{2-})**

Metals lose electrons to form positive ions (cations) whilst non-metals gain electrons to form negative ions (anions). The number of electrons gained or lost by an atom is related to the group in which the element is found.

Group	1	2	3	4	5	6	7	0
Charge	1+	2+	3+	N/A	3–	2–	1–	N/A
Example	Na^+	Mg^{2+}	Al^{3+}	N/A	N^{3-}	O^{2-}	F^-	N/A

For example, when sodium reacts with chlorine to form sodium chloride (common salt), the sodium atom loses one electron to form the Na^+ cation, which has electronic configuration 2,8. The chlorine atom gains this electron to form the Cl^- anion, with electronic configuration 2,8,8. The number of protons and neutrons in each ion remains unchanged from the original atom.

When atoms react compounds are formed. **A compound is two or more elements chemically combined.**

The size of atoms

Atoms are very small and have a **radius** of about **0.1 nanometres(nm)**. This is written in metres in standard form as 1.0×10^{-10} m

1 nanometre is 1×10^{-9} m, so an atom has a radius of approximately $0.1 \times 1 \times 10^{-9}$ m= 1.0×10^{-10} m.

The nucleus of an atom is very tiny compared to the size of an atom as a whole. It is less than 1/10000th of that of an atom.

$1/10000 \times 1.0 \times 10^{-10} = 1.0 \times 10^{-14}$ m so the radius of a nucleus is less than 1.0×10^{-14} m.

Revision Questions

1.

Carbon-12 ($^{12}_{6}C$) atoms have 6 electrons, 6 protons and 6 neutrons.

(a) Complete the table to show the relative charge and relative mass of the different particles found in an atom.

Particle	Relative charge	Relative mass
electron		
proton		
neutron		

[3]

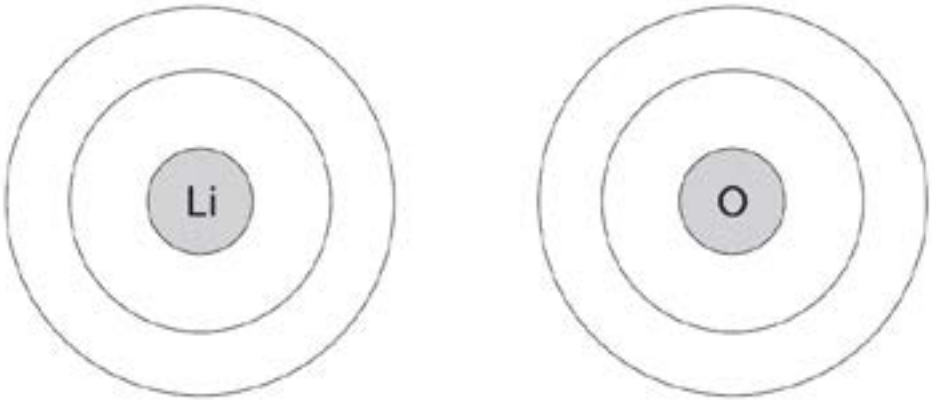
(b) Carbon-14 ($^{14}_{6}C$) and carbon-12 ($^{12}_{6}C$) are isotopes of carbon.

Compare, in terms of the particles in the atoms, an atom of carbon-14 ($^{14}_{6}C$) with an atom of carbon-12 ($^{12}_{6}C$).

[3]

2.

(a) Lithium reacts with oxygen to form lithium oxide, a solid white compound.
Draw diagrams to show all the electrons in an atom of lithium and an atom of oxygen.



lithium atom oxygen atom [2]

(b) Explain how lithium and oxygen react to form the compound lithium oxide.

_____

_____

_____

_____

_____ [3]

3.

The atom is the smallest part of an element which can exist on its own.

Four terms associated with atoms are given below. Place a tick (✓) beside the correct description of the term. The first one has been done for you.

Term	Description	
atomic structure	A central nucleus surrounded by electrons in shells	✓
	A central nucleus containing moving electrons	
	A mass number and an atomic number	
proton	Has a relative mass of 1 and a charge of +1	
	Has a mass of 0 and a charge of +1	
	Has a relative mass of 1 and a charge of –1	
mass number	The total number of elements in an atom	
	Total number of protons and neutrons in an atom	
	Total number of protons, neutrons and electrons in an atom	
atomic number	The number of protons in an atom	
	The number of electrons in an atom	
	The total number of protons and neutrons in an atom	

[3]

4.

The table below shows the atomic numbers and mass numbers for six elements.

element	carbon	nitrogen	oxygen	fluorine	neon	sodium
atomic number	6	7	8	9	10	11
mass number	12	14	16	19	20	23

(a) The electrons in atoms are arranged in shells.

What is the largest number of electrons that can fit into the **first** shell of each of the atoms in the table?

_____ [1]

(b) Which element in the table has 8 protons in the nucleus of its atoms?

_____ [1]

(c) What is the electronic configuration of a sodium atom?

_____ [1]

(d) Explain why the sodium atom has no electrical charge.

_____

_____ [1]

5.

The table below shows some information for several atoms and simple ions. Complete the table.

Atom/Ion	Number of protons	Electronic configuration
	7	2, 5
O^{2-}		
Al^{3+}		
	12	2, 8

[6]

6.

Neon has several isotopes.

(a) Complete the table below.

	Number of protons	Number of electrons	Number of neutrons
Neon-20			
Neon-21			
Neon-22			

[2]

(b) The table below gives the abundance of each isotope of neon.

Calculate the relative atomic mass of neon to two decimal places.

Isotope	% abundance
Neon-20	90.92
Neon-21	0.26
Neon-22	8.82

_____

_____

_____ [2]

(c) Name the isotope used as the standard to compare the relative atomic mass of atoms.

_____ [1]