Structure 1.2

IB CHEMISTRY SL

Structure 1.2.1

Understandings:

- Atoms contain a positively charged, dense nucleus composed of protons and neutrons (nucleons). Negatively charged electrons occupy the space outside the nucleus.

Learning outcomes:

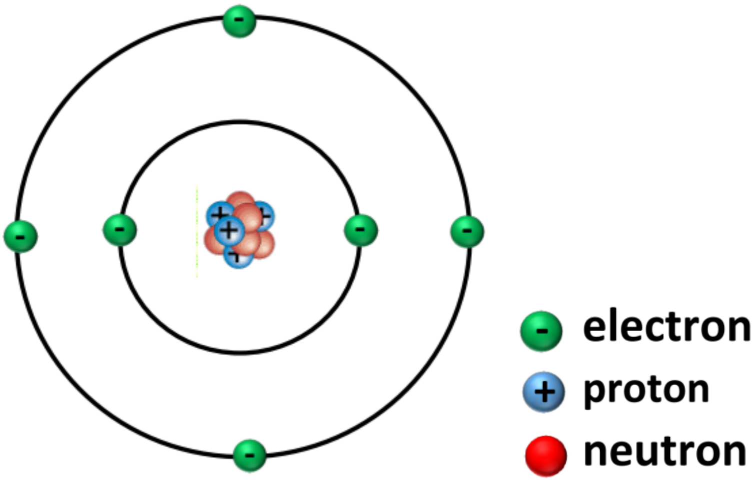
- Use the nuclear symbol to deduce the number of protons, neutrons and electrons in atoms and ions.

Additional notes:

- Relative masses and charges of the subatomic particles should be known; actual values are given in the data booklet. The mass of the electron can be considered negligible.

Structure of the atom and the sub-atomic particles

- The three sub-atomic particles are the proton, neutron and the electron.
- Protons and neutrons (nucleons) are located in the nucleus of the atom.
- The nucleus is very dense as it contains almost all of the mass of an atom.
- The electrons are located in energy levels (principal energy levels) within the atom.
- Atoms are electrically neutral because they have the same number of protons and electrons.



Exercises:

1. Complete the table below:

Sub-atomic particle	Relative mass	Relative charge
Proton		
Neutron		
Electron		

2. Explain why the nucleus is the most dense part of the atom.

3. Explain why atoms are electrically neutral.

Atomic number (*Z*) and mass number (*A*)

- The atomic number (or proton number) is the number of protons in the nucleus of an atom.
- The mass number is the number of protons and neutrons (nucleons) in the nucleus of an atom.
- To find the number of neutrons in the nucleus of an atom, subtract the atomic number from the mass number (*A* – *Z*).
- The notation used for the atomic number and mass number is shown below (the nuclear symbol notation).

$$^{A}_{Z}\mathrm{X} \qquad ^{19}_{9}\mathrm{F} \qquad ^{19}\mathrm{F}$$

- X is the symbol of the element
- *Z* is the atomic number (or proton number)
- *A* is the mass number (or nucleon number)

Note that the atomic number is sometimes omitted; it can be found by looking on the periodic table.

Example: The nuclear symbol for helium-4 is $^{4}_{2}\mathrm{He}$. Its atomic number is 2 and its mass number is 4. It has 2 protons and 2 neutrons in its nucleus.

$$^{4}_{2}\mathrm{He}$$

Exercises

1. Outline what the atomic number and mass number tell us about an atom.

2. Write the nuclear symbol notation for magnesium-24 and iron-54.

3. Deduce the number of protons, neutrons and electrons in the following.

Species*	Atomic number	Mass number	Number of protons	Number of neutrons	Number of electrons
${}^{2}_{1}\mathrm{H}$					
${}^{14}_{6}\mathrm{C}$					
${}^{14}_{7}\mathrm{N}$					
${}^{40}_{20}\mathrm{Ca}$					
${}^{37}_{17}\mathrm{Cl}$					
${}^{79}_{35}\mathrm{Br}$					
${}^{206}_{82}\mathrm{Pb}$					
${}^{235}_{92}\mathrm{U}$					

*The word species is used to refer to an atom, ion, or molecule.

4. Deduce the number of protons, neutrons and electrons in the following ions.

Ion	Atomic number	Mass number	Number of protons	Number of neutrons	Number of electrons
${}^{40}_{20}\mathrm{Ca}^{2+}$					
${}^{27}_{13}\mathrm{Al}^{3+}$					
${}^{35}_{17}\mathrm{Cl}^{-}$					
${}^{14}_{7}\mathrm{N}^{3-}$					

Structure 1.2.2

Understandings:

- Isotopes are atoms of the same element with different numbers of neutrons.

Learning outcome(s):

- Perform calculations involving non-integer relative atomic masses and abundance of isotopes from given data.

Additional notes:

- Differences in the physical properties of isotopes should be understood.

Isotopes

- Isotopes are atoms of the same element that have the same number of protons (same atomic number, *Z*) but different numbers of neutrons (different mass number, *A*).
- The two isotopes shown below, carbon-12 (^{12}C) and carbon-14 (^{14}C), have the same number of protons but different numbers of neutrons.

$^{12}_{6}C$ 6 protons **6 neutrons** 6 electrons

$^{14}_{6}C$ 6 protons **8 neutrons** 6 electrons

Exercise:

Deduce the number of protons, neutrons and electrons in the following isotopes.

Isotope	Atomic number	Mass number	Number of protons	Number of neutrons	Number of electrons
$^{10}_{5}B$					
$^{11}_{5}B$					
$^{16}_{8}O$					
$^{17}_{8}O$					

Physical and chemical properties of isotopes

- Isotopes have the same number of electrons, therefore they have identical chemical properties.
- Isotopes have different numbers of neutrons; therefore, their masses are different.
- Isotopes have different physical properties such as density and boiling point.

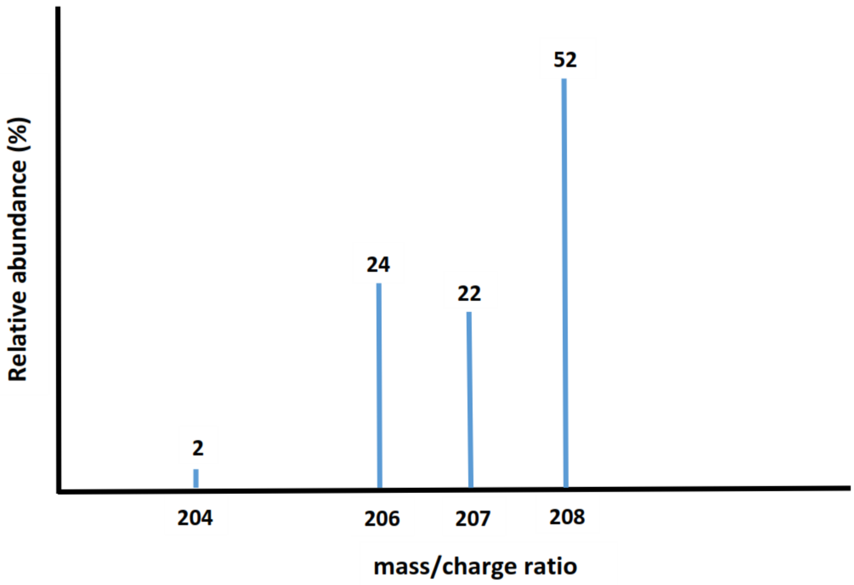
Isotope	Boiling point (K)	Melting point (K)	Density (g cm^{-3})
$^{1}_{1}H$	20.4	14.0	0.09
$^{2}_{1}H$	23.7	18.7	0.18
$^{3}_{1}H$	25.0	20.6	0.27

Relative atomic mass (A_r)

- The mass of atoms is so small (in the range of 10^{-24} to 10^{-22} kg) therefore a relative scale is used.
- The standard for the relative scale is carbon-12, which is given a relative mass of exactly 12.00.
- The relative atomic mass is the weighted average mass of an atom compared to an atom of the isotope carbon-12.
- Relative atomic masses do not have units because it is a relative scale.

The mass spectrometer

- A mass spectrometer is used to determine the isotopes of an element, together with their relative abundances.
- The relative abundance of an isotope is the percentage of atoms with a specific atomic mass found in a naturally occurring sample of an element.
- A mass spectrometer produces a mass spectrum which shows relative abundance on the *y*-axis against mass to charge ratio (m/z) on the *x*-axis. The mass spectrum for lead (Pb) is shown below.



Exercise: Based on the mass spectrum above, is the relative atomic mass of lead likely to be closer to 204 or 208? Explain your answer.

Calculating relative atomic mass, A_r

- To calculate the relative atomic mass of an element, multiply the mass of each isotope by its relative abundance, add together for all the isotopes, and then divide by 100.
- For example, to calculate the relative atomic mass of an element with two isotopes:

$$A_r = \frac{(\text{mass of isotope 1 } \times \% \text{ abundance}) + (\text{mass of isotope 2 } \times \% \text{ abundance})}{100}$$

Exercises:

1. Rhenium has two naturally occurring isotopes with the following percentage abundances. Calculate the relative atomic mass of rhenium to two decimal places.

Isotope	% abundance
^{185}Re	37.40
^{187}Re	62.60

2. Europium has two naturally occurring isotopes, Europium-151 and Europium-153, and a relative atomic mass of 151.96. Calculate the percentage abundance of each isotope of europium.