SL IB Chemistry

Your notes

The Nuclear Atom

Contents

Nuclear Model of the Atom

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The Nuclear Atom

What are subatomic particles?

- The **protons**, **neutrons** and **electrons** that an atom is made up of are called **subatomic particles**
- These subatomic particles are so small that it is not practical to measure their masses and charges using **conventional units** (such as grams or coulombs)
- Instead, their masses and charges are compared to each other, and so are called '**relative atomic masses**' and '**relative atomic charges**'
- These are not actual charges and masses, but rather charges and masses of particles relative to each other
  - Protons and neutrons have a very similar mass, so each is assigned a relative mass of **1**
  - Electrons are 1836 times smaller than a proton and neutron, and so their mass can be considered negligible
- The relative mass and charge of the subatomic particles are:

Relative Mass & Charge of Subatomic Particles Table

Subatomic particle	Relative charge	Relative mass
Proton	+1	1
Neutron	0	1
Electron	-1	negligible

Examiner Tip

The **charge** of a single **electron** is $-1.602189 \times 10^{-19}$ coulombs, whereas the charge of a **proton** is $+1.602189 \times 10^{-19}$ coulombs.

However, relative to each other, their charges are -1 and +1 respectively.

This information can also been found in the IB Data Booklet

Where are the subatomic particles located?

- Atoms contain a **positively charged**, **dense** nucleus
  - The nucleus is positively charged due to the protons

- The nucleus is dense because mass of an atom is **concentrated** in the nucleus, which contains the heaviest subatomic particles
- The subatomic particles in the nucleus can generally be called **nucleons**, although they are specifically the neutrons and protons

- Negatively charged electrons occupy the space outside the nucleus
  - They can be described as orbiting the nucleus where they create a '**cloud**' of negative charge
- The **electrostatic attraction** between the **positive nucleus** and **negatively charged electrons** orbiting around it is what holds an atom together

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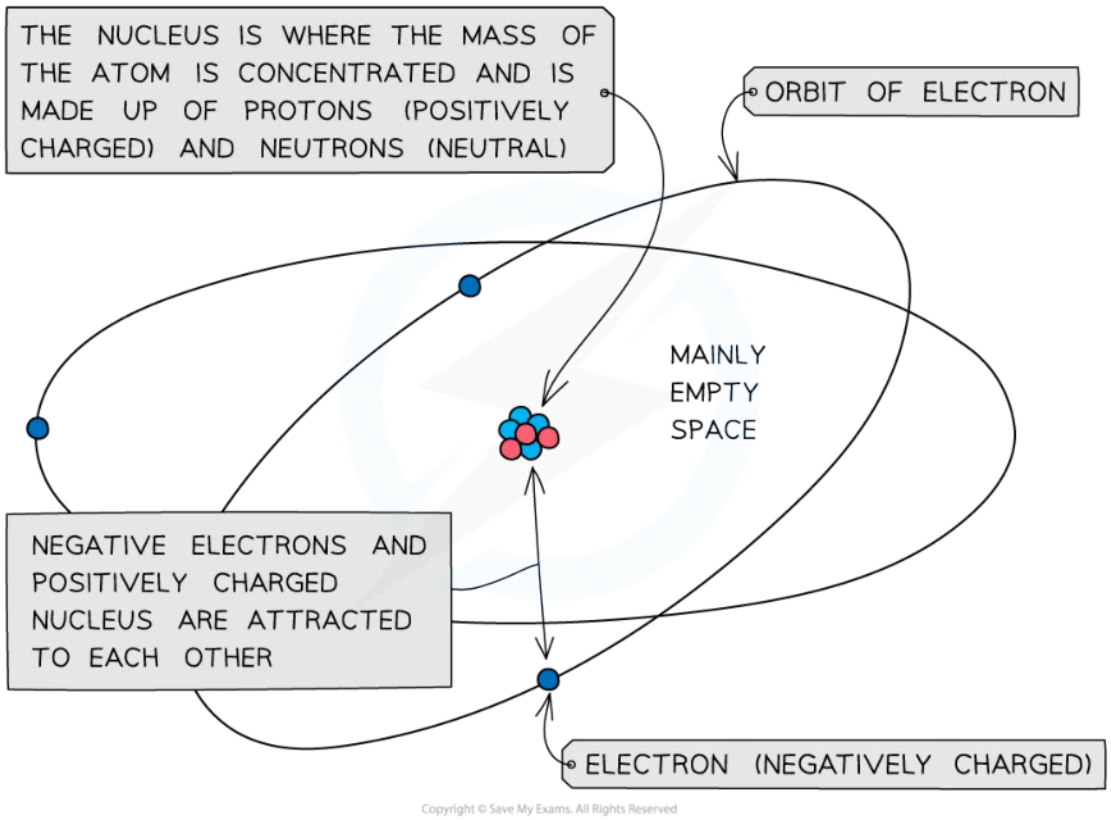
Atomic Structure Diagram



The mass of the atom is concentrated in the positively charged nucleus which is attracted to the negatively charged electrons orbiting around it

Subatomic Particles

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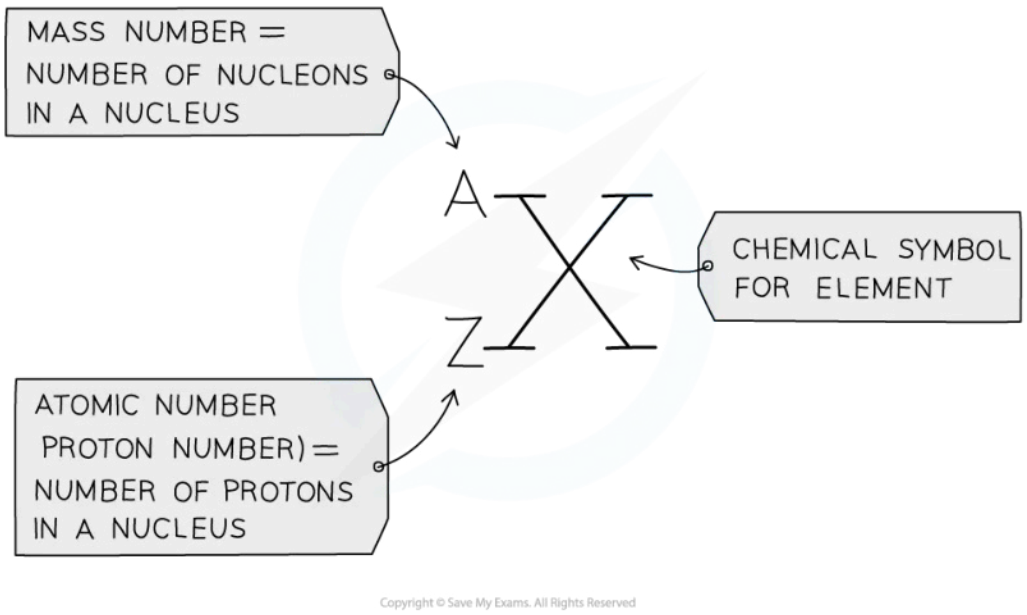
Subatomic Particles

- The **atomic number** (or **proton number**) is the number of protons in the nucleus of an atom and has the **symbol *Z***
  - The atomic number is also equal to the number of electrons that are present in a **neutral atom** of an element
  - E.g. the atomic number of lithium is 3
    - This means that a neutral lithium atom has 3 protons and, therefore, also has 3 electrons

The chemical symbol of a general element



The mass (nucleon) and atomic (proton) number are given for each element in the Periodic Table

- The **mass number** (or **nucleon number**) is the total number of **protons + neutrons** in the nucleus of an atom, and has the **symbol *A***
  - Protons and neutrons are also called **nucleons**, because they are found in the nucleus
- The number of **neutrons** can be calculated by:

Number of neutrons = mass number – atomic number

How to work out protons, neutrons and electrons

- An atom is **neutral** and has no overall charge
- Ions on the other hand have either **gained** or **lost** electrons causing them to become **charged**
- The number of **subatomic particles** in atoms and ions can be determined given their:

- Atomic (proton) number
- Mass (nucleon) number
- Charge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Protons

- The atomic number of an atom and ion determines which element it is
- Therefore, all atoms and ions of the **same element** have the same number of protons (atomic number) in the nucleus
  - E.g. lithium has an atomic number of 3 (three protons) whereas beryllium has atomic number of 4 (4 protons)
- The number of protons equals the **atomic (proton) number**
- The number of protons of an **unknown** element can be calculated by using its mass number and number of neutrons:

Mass number = number of protons + number of neutrons

Number of protons = mass number – number of neutrons

Worked example

Determine the number of protons in the following ions and atoms:

1. Mg^{2+} ion
2. Carbon atom
3. An unknown atom of element **X** with mass number 63 and 34 neutrons

Answer 1:

- The atomic number of a magnesium atom is 12
- This means that the number of protons in the nucleus of a magnesium atom is 12
- Therefore, the number of protons in a **Mg^{2+} ion** is also 12
  - **Remember:** The number of protons does not change when an ion is formed

Answer 2:

- The atomic number of a carbon atom is 6
- This means that a carbon atom has 6 protons in its nucleus

Answer 3:

- Use the formula to calculate the number of protons
  - **Number of protons = mass number – number of neutrons**
  - **Number of protons = 63 – 34**
  - **Number of protons = 29**
- Therefore, element **X** is **copper**

Electrons

- An atom is **neutral** and therefore has the **same number of protons and electrons**

- Ions have a different number of electrons to the number of protons, depending on their charge
  - A positively charged ion has **lost** electrons and, therefore, has **fewer** electrons than protons
  - A negatively charged ion has **gained** electrons and, therefore, has **more** electrons than protons


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Worked example

Determine the number of electrons in the following ions and atoms:

1. Mg^{2+} ion
2. Carbon atom
3. An unknown atom of element **X** with mass number 63 and 34 neutrons

Answer 1:

- The atomic number of a magnesium atom is 12
- This means that the number of protons in the nucleus of a magnesium atom is 12
- However, the 2+ charge in Mg^{2+} ion indicates that it has **lost** two electrons
- Therefore, an Mg^{2+} ion only has 10 electrons

Answer 2:

- The atomic number of a carbon atom is 6
- This means that a carbon atom has 6 protons in its nucleus
- Since there is no overall charge on a neutral carbon atom, there must be 6 negative electrons to balance the charge of the 6 positive protons

Answer 3:

- Use the formula to calculate the number of protons
  - **Number of protons = mass number – number of neutrons**
  - **Number of protons = 63 – 34**
  - **Number of protons = 29**
- Since element **X** is neutral, there must be 29 negative electrons to balance the charge of 29 positive protons

Neutrons

- The **mass** and **atomic numbers** can be used to find the number of **neutrons in ions and atoms**:

Number of neutrons = mass number (*A*) – number of protons (*Z*)

Worked example

Determine the number of neutrons in the following ions and atoms:

1. Mg^{2+} ion
2. Carbon atom
3. An unknown atom of element **X** with mass number 63 and 34 neutrons

Answer 1:

- The atomic number of a magnesium atom is 12 and its mass number is 24
  - **Number of neutrons = mass number (*A*) – number of protons (*Z*)**
  - **Number of neutrons = 24 – 12**
  - **Number of neutrons = 12**
- The **Mg^{2+} ion** has 12 neutrons in its nucleus

Answer 2:

- The atomic number of a carbon atom is 6 and its mass number is 12
  - **Number of neutrons = mass number (*A*) – number of protons (*Z*)**
  - **Number of neutrons = 12 – 6**
  - **Number of neutrons = 6**
- The **carbon atom** has 6 neutrons in its nucleus

Answer 3:

- The atomic number of an element **X** atom is 29 and its mass number is 63
  - **Number of neutrons = mass number (*A*) – number of protons (*Z*)**
  - **Number of neutrons = 63 – 29**
  - **Number of neutrons = 34**
- The **neutral atom** of element **X** has 34 neutrons in its nucleus

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Isotopes

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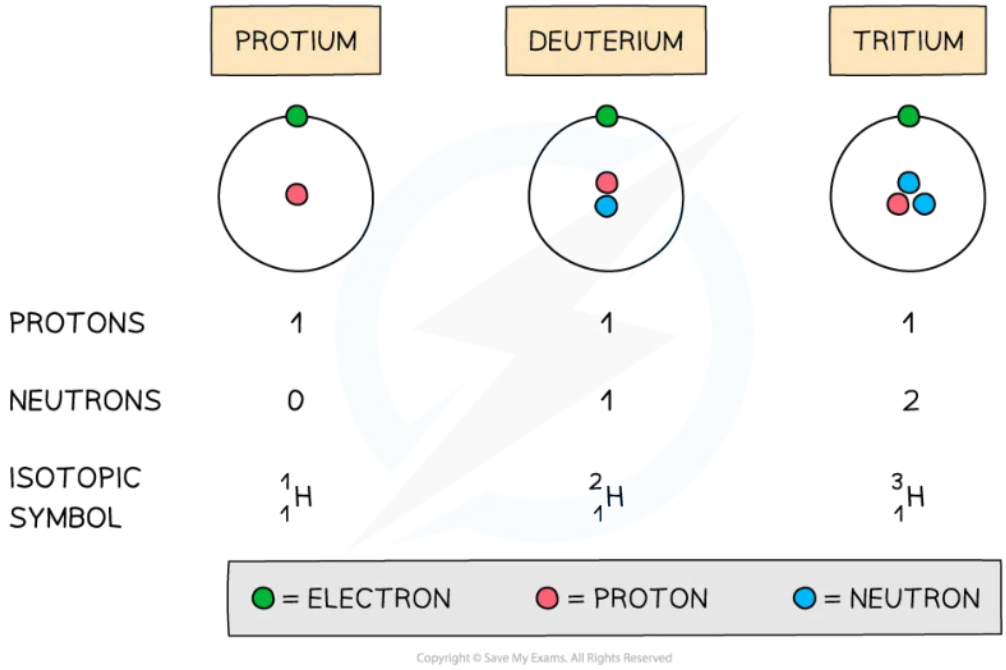
Isotopes

What are isotopes?

- **Isotopes** are different atoms of the **same element** that contain the **same number of protons** and electrons but a **different number of neutrons**
  - These are atoms of the same **elements** but with different mass numbers
- The way to represent an isotope is to write the **chemical symbol** (or the word) followed by a **dash** and then the **mass number**
  - E.g. carbon-12 and carbon-14 are isotopes of carbon containing 6 and 8 neutrons respectively
  - These isotopes could also be written as 12C or C-12, and 14C or C-14 respectively

Isotopes of hydrogen



Using the chemical symbols of hydrogen to determine the number of subatomic particles in each isotope

Calculating Relative Atomic Mass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What is relative atomic mass?

- The **relative atomic mass (A_r)** of an element is the **ratio** of the average mass of the atoms of an element to the **unified atomic mass unit**
- The definition of relative atomic mass is:
  '**the average mass of one atom of an element compared to one twelfth of the mass of an atom of carbon-12**'

How to calculate relative atomic mass

- The mass of an element is given as **relative atomic mass (A_r)** by using the average mass of all of the isotopes
- The relative atomic mass of an element can be calculated by using the **percentage abundance** values
  - The percentage abundance of an isotope is either given or can be read off the mass spectrum
- For example, if you have two isotopes A and B:
  - Find the mass of 100 atoms by multiplying the percentage abundance by the mass of each isotope:

    total mass of 100 atoms = (% abundance$_A$ x mass$_A$) + (% abundance$_B$ x mass$_B$)

  - Then divide by 100, to find the average / relative atomic mass:

$$\text{relative atomic mass} = \frac{\text{total mass of 100 atoms}}{100}$$

Worked example

A sample of oxygen contains the following isotopes:

Isotope	Percentage abundance
^{16}O	99.76
^{17}O	0.04
^{18}O	0.20

What is the relative atomic mass of oxygen to 2 dp?

A 16.00

B 17.18

C 16.09

D 17.00

Answer:

- The correct answer is **A**
- Total mass of 100 atoms = (99.76 x 16) + (0.04 x 17) + (0.20 x 18) = 1600.44
- Mass of 1 atom = $\frac{1600.44}{100}$ = 16.0044
- So, the relative atomic mass, rounded to 2 decimal places, is 16.00

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