HL IB Chemistry

Your notes

The Nuclear Atom

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Nuclear Model of the Atom

Your notes

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 x 10^{-19} coulombs, whereas the charge of a **proton** is +1.602189 x 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

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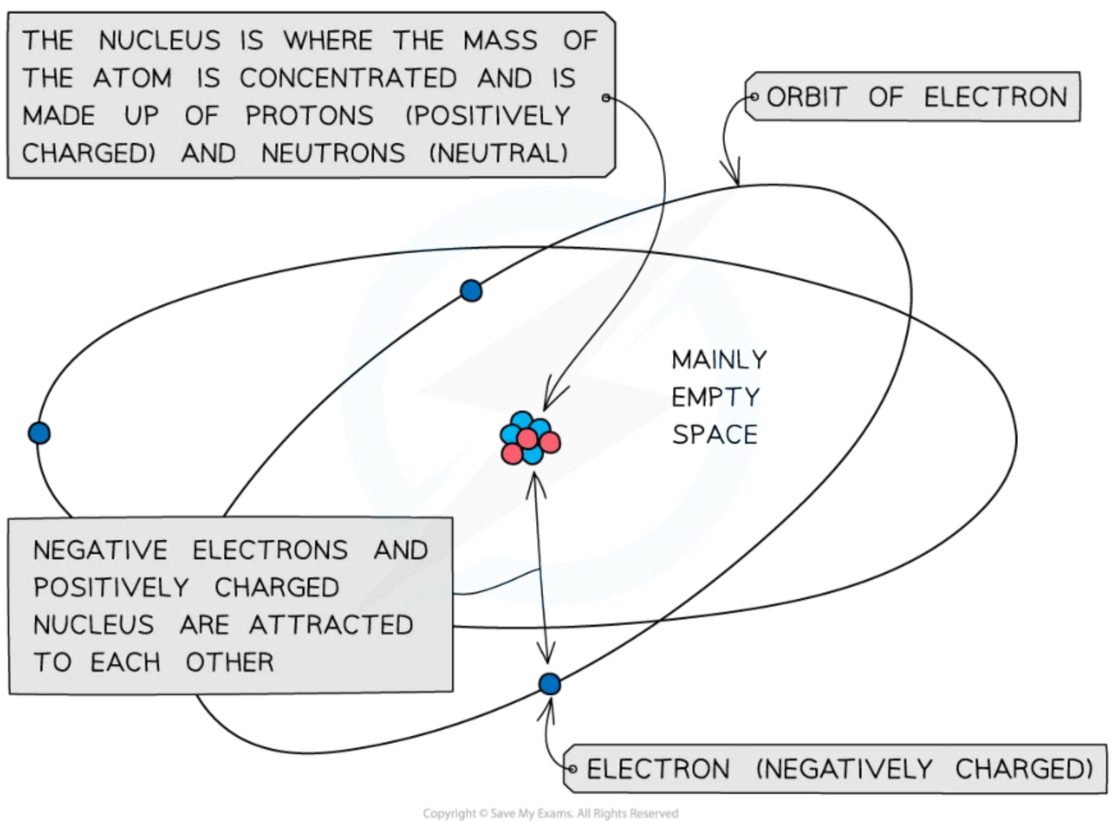
- The nucleus is dense because mass of an atom is **concentrated** in the nucleus, which contains the heaviest subatomic particles
  - The subatomic particles in the nucleus can generally be called **nucleons**, although they are specifically the neutrons and protons
- Negatively charged electrons occupy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

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

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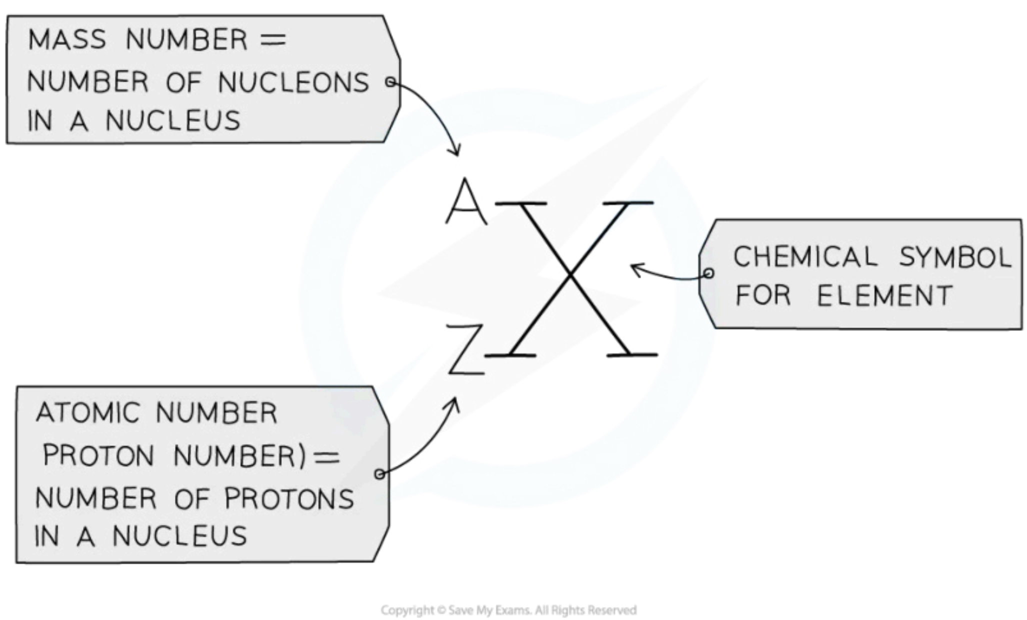
Subatomic Particles

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

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**

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- 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

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*)

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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

Isotopes

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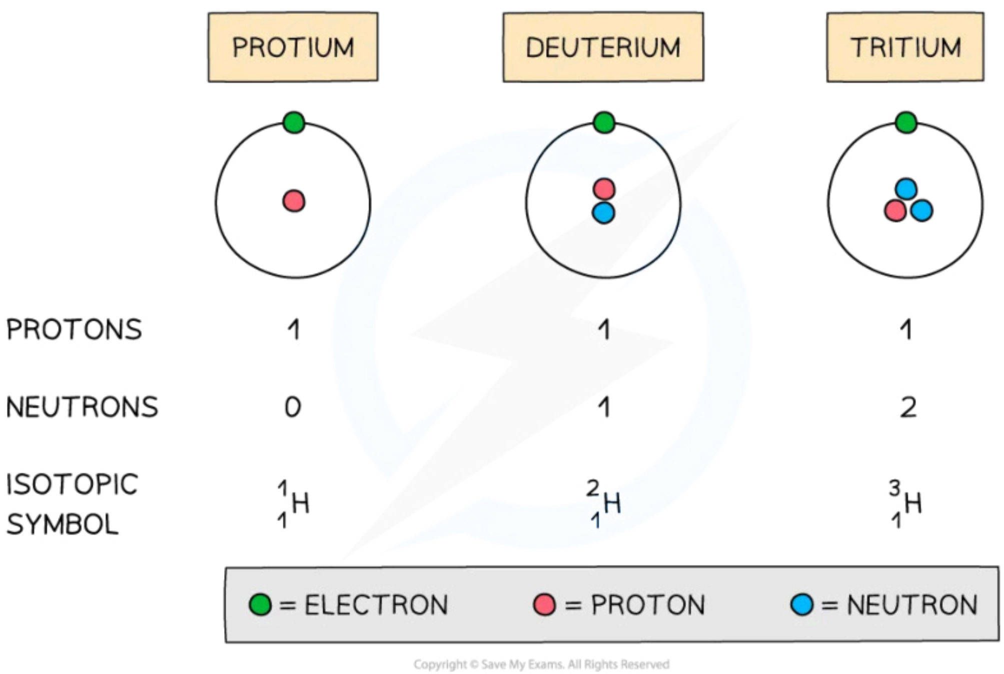
Isotopes

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

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Calculating Relative Atomic Mass

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:

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

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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Interpreting Mass Spectra (HL)

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Mass Spectra

- The percentage abundance of the isotopes in an element can be found by the use of a **mass spectrometer**
- The basic processes of mass spectrometry are:
  - The sample is **vapourised**
  - The sample is **ionised** to form positive ions
  - The ions are **accelerated**
  - Each ion produces a signal which is **detected** as a mass-to-charge ratio, written as *m* / e

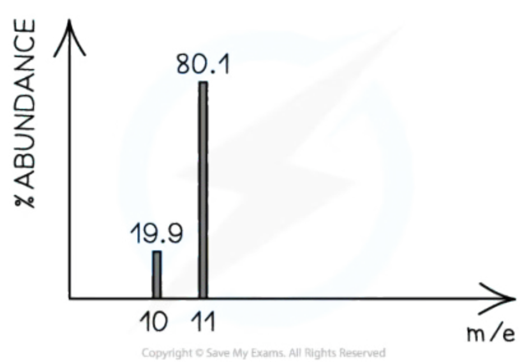
Examiner Tip

Specific details of the processes involved in mass spectrometry are not assessed.

- The mass spectra produced can be used to calculate the relative atomic mass of an element and its isotopes:

Worked example

Calculate the relative atomic mass of boron using its mass spectrum, to 2 dp:



Answer:

- Total mass of 100 atoms = (19.9 x 10) + (80.1 x 11) = 1080.1
- Mass of 1 atom = $\frac{1080.1}{100}$ = 10.801
- So, the relative atomic mass of boron, rounded to 2 decimal places, is 10.80