Cambridge (CIE) A Level Chemistry

Your notes

Particles in the Atom & Atomic Radius

Contents

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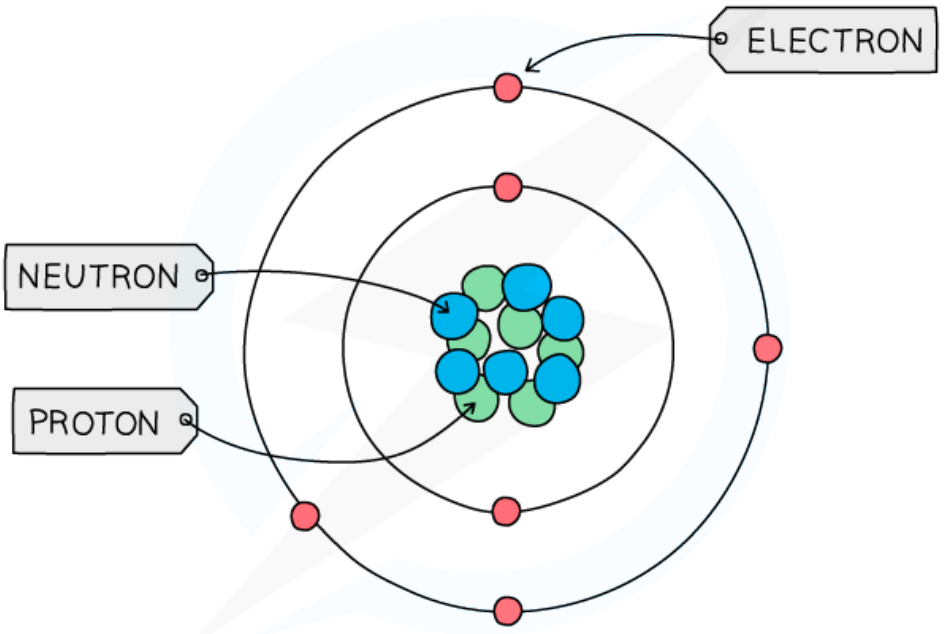
Structure of the Atom

- All matter is composed of **atoms**, which are the smallest parts of an element that can take place in **chemical reactions**
- Atoms are mostly made up of **empty space** around a very small, dense **nucleus** that contains **protons** and **neutrons**
- The nucleus has an overall **positive charge**
  - The protons have a positive charge and the neutrons have a neutral charge
- **Negatively charged** electrons are arranged in shells (also known as energy levels) that surround the nucleus

The structure of an atom



Atoms contains protons, neutrons and electrons

Mass & Charge of Subatomic Particles

- Atoms are made up of **protons**, **neutrons**, and **electrons**, collectively known as **subatomic particles**.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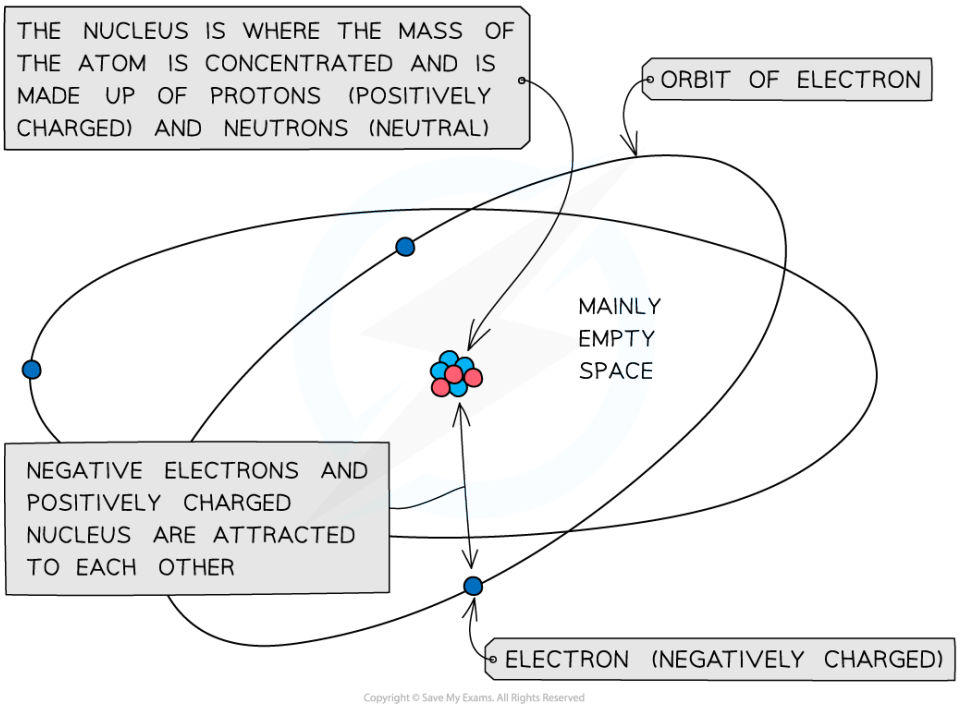
- These particles are **very small**, so their **actual masses and charges** cannot be measured easily in standard units like grams or coulombs
- Instead, chemists use **relative masses and relative charges**, comparing each particle to the others
- These are not absolute values, but **scaled values** used for easier comparison.
- **Protons and neutrons** have almost the same mass, so each is assigned a **relative mass of 1**
- **Electrons** are about $\frac{1}{1836}$ **the mass** of a proton or neutron, so their mass is considered **negligible** in most calculations

- The relative mass and charge of the subatomic particles are:
  - Proton
    - Relative charge: +1
    - Relative mass: 1
  - Neutron
    - Relative charge: 0
    - Relative mass: 1
  - Electron
    - Relative charge: -1
    - Relative mass: $\frac{1}{1836}$

- The **mass of an atom** is concentrated in the **nucleus**, which contains the heavier subatomic particles: **protons** and **neutrons**
- The **mass of an electron** is **negligible** in comparison
- The **nucleus is positively charged**, due to the presence of **protons**
- **Electrons orbit** the nucleus in energy levels, forming a **cloud of negative charge** around it
- The atom is held together by the **electrostatic attraction** between the **positively charged nucleus** and the **negatively charged electrons**

The distribution of mass in an atom



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

Examiner Tips and Tricks

- You can see from the table how the **relative mass** of an electron is **almost negligible**
- The **charge** of a single **electron** is -1.602×10^{-19} coulombs, whereas the charge of a **proton** is $+1.602 \times 10^{-19}$ coulombs
- So, relative to each other, their charges are -1 and +1 respectively

Behaviour of Subatomic Particles in an Electric Field

- When **protons, neutrons, and electrons** travel at the **same velocity** through an electric field, they behave differently due to differences in **charge and mass**
  - A **beam of electrons** is deflected **strongly toward the positive plate**
    - This shows that **electrons are negatively charged**, since they are repelled by the negative plate and attracted to the positive one
    - The **large deflection** also indicates that electrons have a **very small mass**.
  - A **beam of protons** is deflected **slightly toward the negative plate**

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- This observation confirms that protons carry a **positive charge**, as they are attracted to the negative plate
- The smaller deflection (compared to electrons) shows that **protons are much heavier**

- A **beam of neutrons** passes through **without deflection**
  - This confirms that **neutrons are neutral**, they have **no charge** and are unaffected by the electric field

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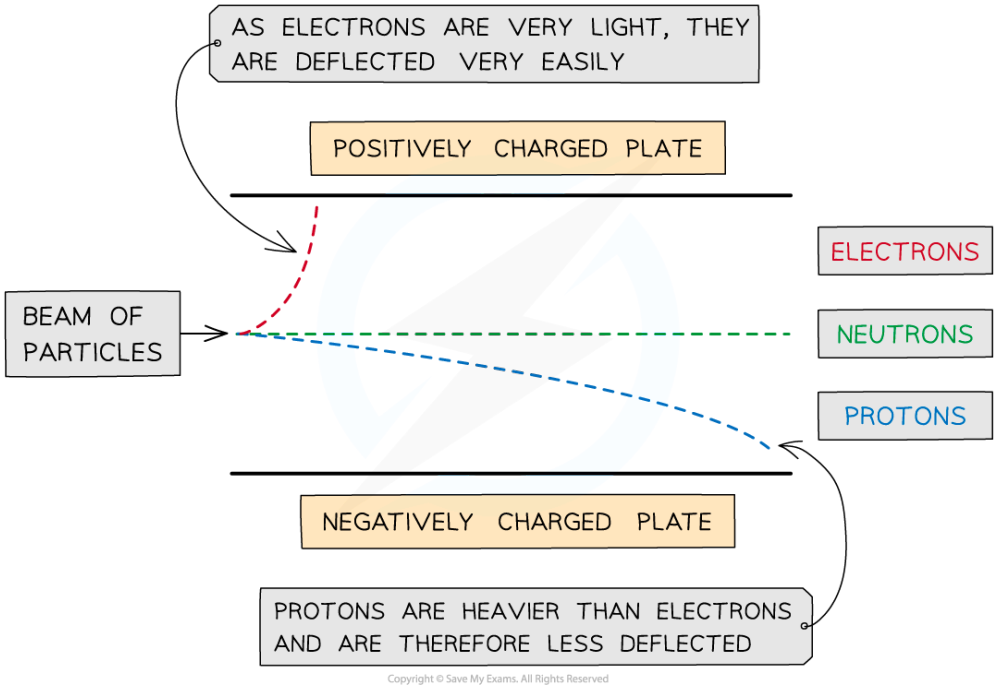
Subatomic particles passing through an electric field



The lighter electrons undergo much more deflection than the protons

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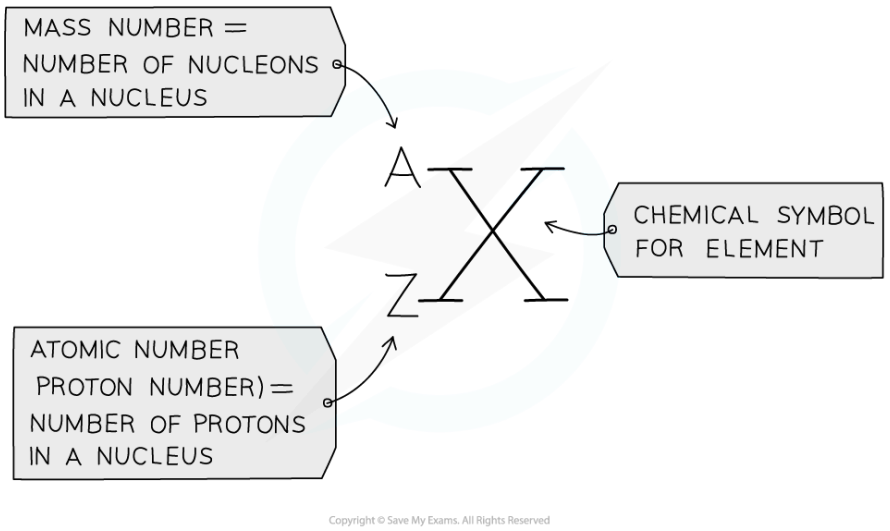
Key Terms of Atomic Structure

- The **atomic number** (also called the **proton number**) is the number of **protons** in the nucleus of an atom
  - Symbol: **Z**
  - In a **neutral atom**, the number of **electrons equals the number of protons**
  - E.g. Lithium has an atomic number of **3**, so it has **3 protons** and **3 electrons**
- The **mass number** (also called the **nucleon number**) is the total number of **protons and neutrons** in the nucleus
  - Symbol: **A**
  - To calculate the number of **neutrons**:

$$\text{Number of neutrons} = A - Z$$

- **Protons and neutrons** are collectively known as **nucleons**, since they are located in the nucleus

Mass and atomic numbers



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

Determining the Subatomic Structure of Atoms & Ions

- An atom is electrically **neutral**, meaning the number of protons = electrons

- An ion forms when an atom gains or loses electrons, giving it an overall charge:
  - **Positive** ions (cations) **lose** electrons
  - **Negative** ions (anions) **gain** electrons

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Protons

- The **atomic number** (**Z**) tells you the number of **protons** in the nucleus.
- All atoms and ions of the **same element** have the **same number of protons**.
  - **Lithium**: Atomic number = 3 = 3 protons
  - **Beryllium**: Atomic number = 4 = 4 protons

mass number (A) = number of protons (Z) + number of neutrons

number of protons = A – 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 suggesting that the number of protons in the magnesium element is 12
- Therefore, the number of protons in a **Mg^{2+} ion** is also 12

Answer 2:

- The atomic number of a carbon atom is 6 suggesting 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
- Element **X** is therefore copper

Electrons

- A **neutral atom** has the **same number of electrons and protons**
- In ions, the number of electrons differs:
  - Positive ions: fewer electrons than protons (electrons lost)
  - Negative ions: more electrons than protons (electrons gained)

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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 suggesting that the number of protons in the **neutral** magnesium **atom** is 12
- However, the 2+ charge in the Mg^{2+} ion suggests it has **lost** two electrons
- It only has 10 electrons left now

Answer 2:

- The atomic number of a carbon atom is 6 suggesting that the **neutral** carbon **atom** has 6 electrons orbiting around the nucleus

Answer 3:

- The number of protons of element **X** can be calculated by:
  - Number of protons = mass number - number of neutrons
  - Number of protons = 63 - 34
  - Number of protons = 29
- The **neutral atom** of element **X** therefore also has 29 electrons

Neutrons

- Use the **mass number (A)** and **atomic number (Z)**:

$$\textit{Number of neutrons} = \textit{mass number (A)} - \textit{number of protons (Z)}$$

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 an atomic number of 29 and a mass number of 63

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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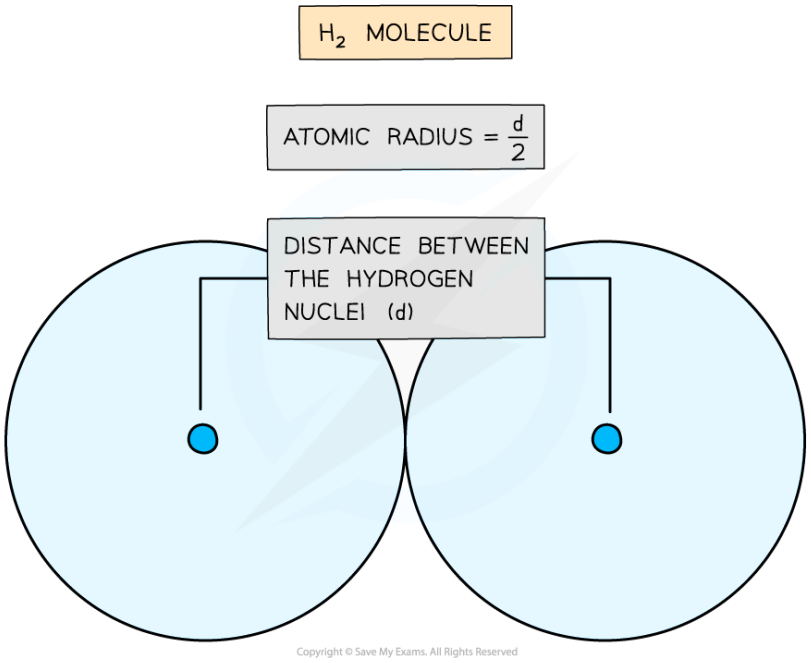
Atomic & Ionic Radius

Atomic radius

- The **atomic radius** of an element is a measure of the size of an atom
- It is **half** the distance between the two **nuclei** of two covalently bonded atoms of the same type

Diagram showing the atomic radius of hydrogen



The atomic radius of a hydrogen atom is determined by halving the distance between the nuclei of two hydrogen atoms covalently bonded

- Atomic radii show predictable patterns across the Periodic Table
  - They generally **decrease** across each period
  - They generally **increase** down each group
- These trends can be explained by the **electron shell theory**
  - Atomic radii decrease as you move across a Period as the atomic number increases (increased positive **nuclear charge**) but at the same time extra electrons are added to the same **principal quantum shell**
  - The larger the nuclear charge, the greater the pull of the nuclei on the electrons
    - This results in **smaller** atoms

- Atomic radii increase moving down a group as there is an increased number of shells going down the group
- The electrons in the **inner shells** repel the electrons in the **outermost shells**, **shielding** them from the positive nuclear charge
- This weakens the pull of the nuclei on the electrons, resulting in larger atoms

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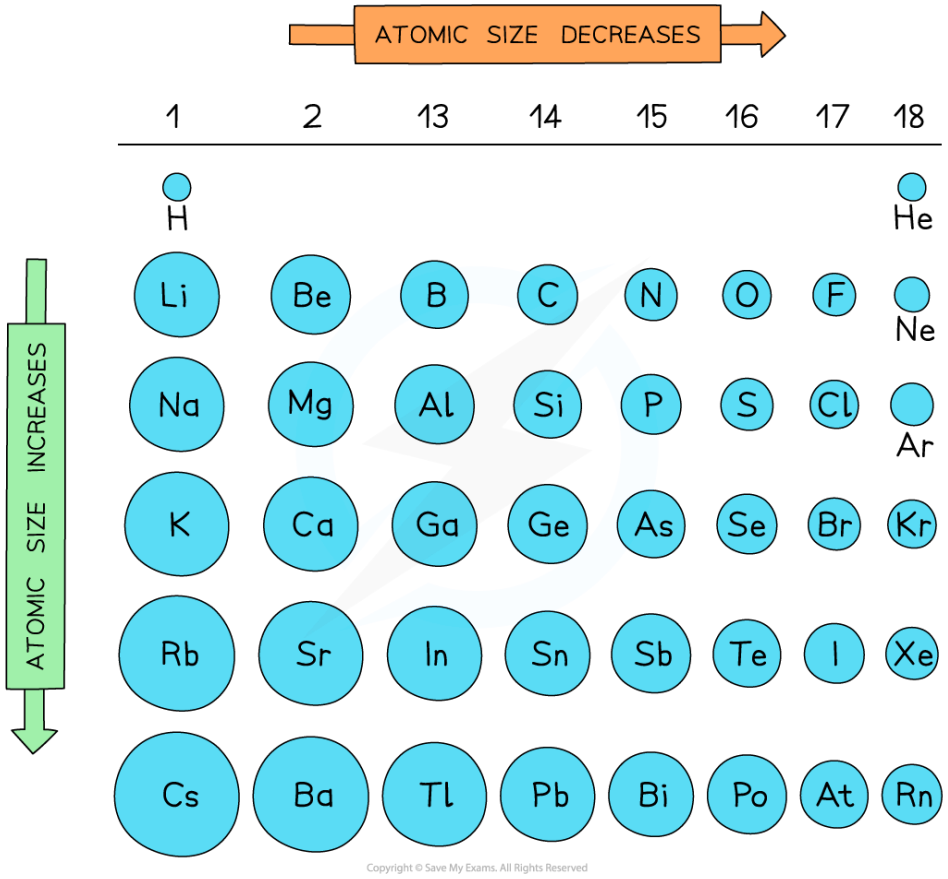
Summary of atomic radii



Atomic radius increases down a group and decreases across a period

- The diagram shows that the atomic radius increases sharply between the **noble gas** at the end of each period and the **alkali metal** at the beginning of the next period
- This is because the **alkali metals** at the beginning of the next period have **one** extra principal quantum shell
  - This increases shielding of the outermost electrons and therefore increases the atomic radius

Ionic radius

- The **ionic radius** of an element is a measure of the size of an ion
- Ionic radii show predictable patterns
  - Ionic radii **increase** with increasing **negative charge**

- Ionic radii **decrease** with increasing **positive charge**

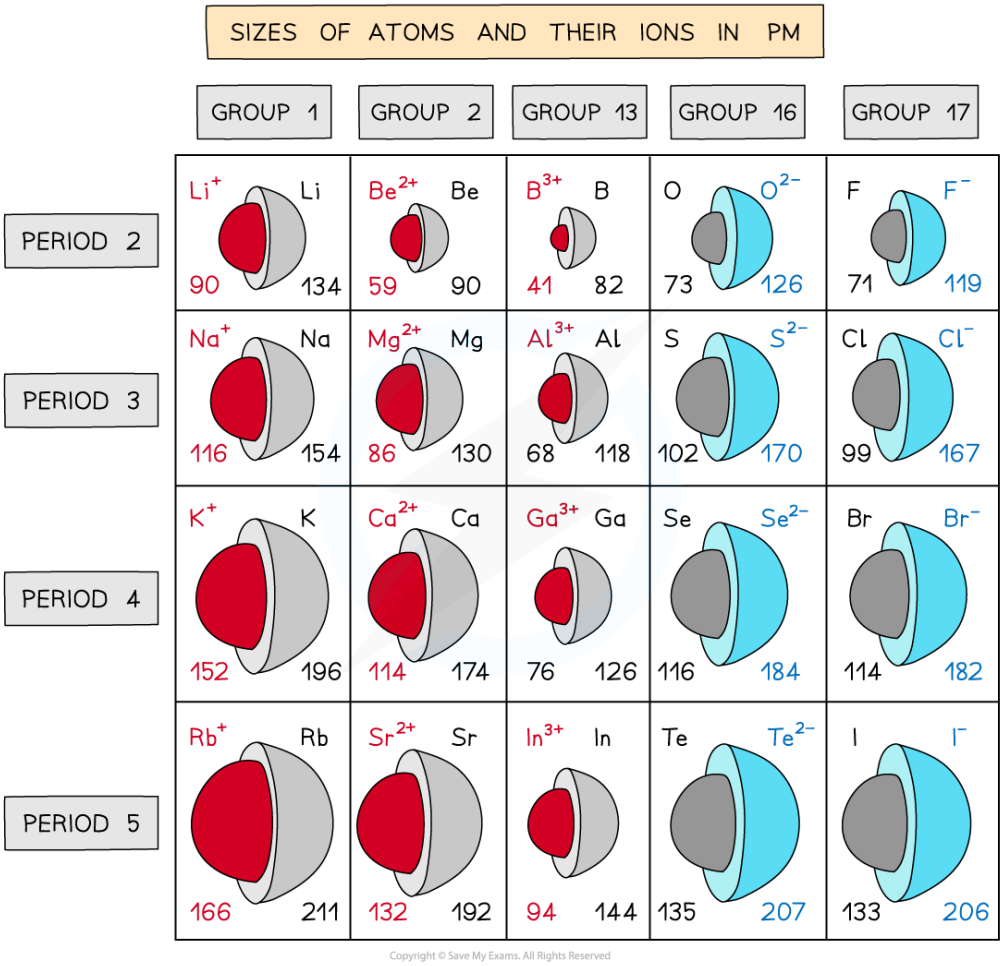
Negative ions

- These trends can also be explained by the **electron shell theory**
  - Ions with **negative** charges are formed by atoms **accepting** extra electrons while the **nuclear charge** remains the same
  - The **outermost** electrons are further away from the positively charged nucleus and are therefore held only **weakly** to the nucleus which increases the ionic radius
  - The greater the negative charge, the larger the ionic radius

Positive ions

- **Positively** charged ions are formed by atoms **losing** electrons
- The **nuclear charge** remains the same but there are now fewer electrons which undergo a **greater electrostatic force of attraction** to the nucleus which decreases the ionic radius
- The greater the positive charge, the smaller the ionic radius

Summary of atom and ion sizes



Trends in the ionic radii across a period and down a group

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