Cambridge (CIE) IGCSE Chemistry

Your notes

Atomic Structure & the Periodic Table

Contents

Elements, compounds & mixtures

- All substances can be classified into one of these three types
  - Elements
  - Compounds
  - Mixtures

What is an element?

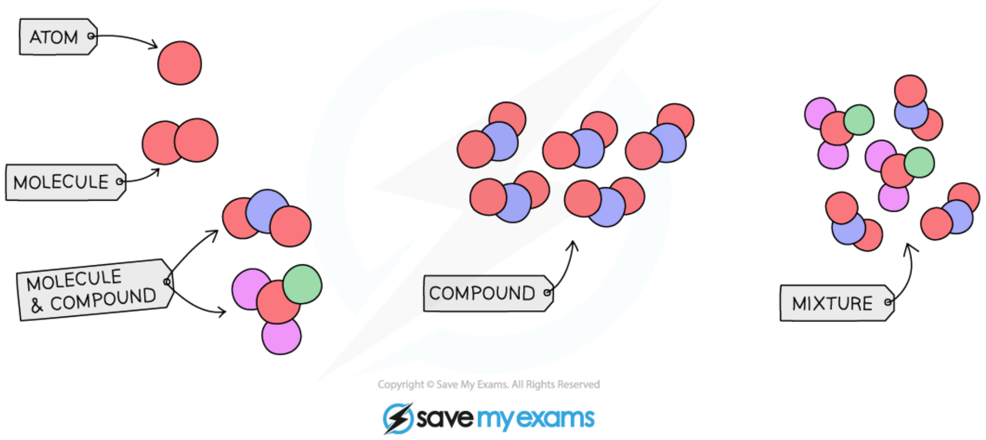
- A substance made of atoms that all contain the **same number of protons** and cannot be split into anything simpler **by chemical means**
- There are around 118 elements in the Periodic Table

What is a compound?

- A pure substance made up of two or more elements **chemically combined**
- There is an **unlimited** number of compounds
- Compounds cannot be separated into their elements by physical means
- E.g. copper(II) sulfate ($CuSO_4$), calcium carbonate ($CaCO_3$), carbon dioxide (CO_2)

What is a mixture?

- A combination of two or more substances (elements and/or compounds) that are **not** chemically combined
- Mixtures can be separated by **physical methods** such as filtration or evaporation
- E.g. sand and water, oil and water, sulfur powder and iron filings



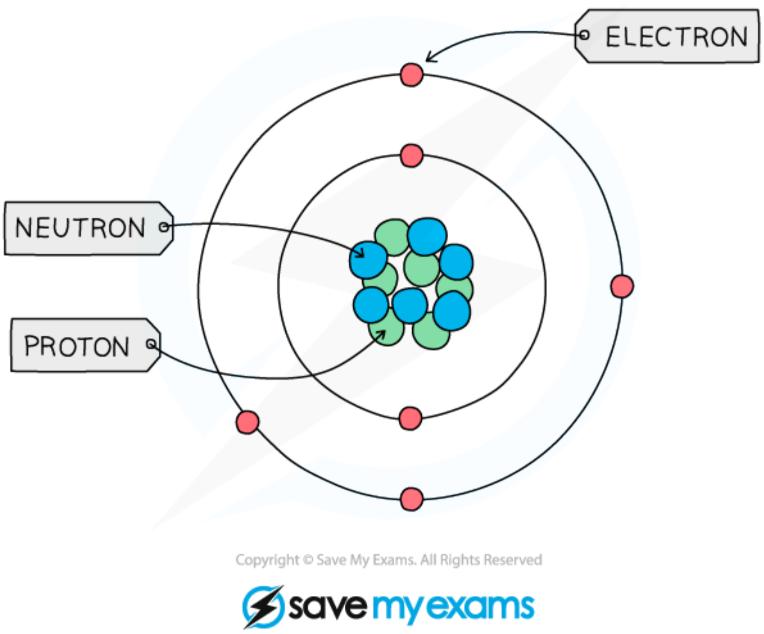
Particle diagram showing elements, compounds and mixtures

Your notes

What is atomic structure?

- All substances are made of tiny particles of matter called **atoms** which are the building blocks of all matter
- Each atom is made of subatomic particles called **protons**, **neutrons**, and **electrons**
- The protons and neutrons are located at the centre of the atom, which is called the **nucleus**
- The electrons move very fast around the nucleus in orbital paths called **shells**
- The mass of the electron is negligible, hence the mass of an atom is contained within the nucleus where the protons and neutrons are located

The structure of an atom



The structure of the carbon atom

Protons, neutrons & electrons

- The size of atoms is so tiny that we can't really compare their masses in conventional units such as kilograms or grams, so a unit called the relative atomic mass is used
- One **relative atomic mass** unit is equal to 1/12th the mass of a carbon-12 atom.
- All other elements are measured relative to the mass of a carbon-12 atom, so relative atomic mass has no units
- Hydrogen for example has a relative atomic mass of 1, meaning that 12 atoms of hydrogen would have exactly the same mass as 1 atom of carbon

Table of subatomic particles

Particle	Relative mass	Charge
Proton	1	1+
Neutron	1	0 (neutral)
Electron	$\frac{1}{1840}$	1–

Examiner Tips and Tricks

Knowing the exact mass of an electron is not in the specification and saying it is almost nothing or negligible will be sufficient. It does, however, sometimes appear in particle identification questions, but you can usually deduce that it is the electrons from other information in the question.

Defining proton number

- The **atomic number** (or **proton number**) is the number of protons in the nucleus of an atom
- The symbol for atomic number is ***Z***
- It is also the number of electrons present in a neutral atom and determines the **position** of the element on the Periodic Table

Defining mass number

- The **Nucleon number** (or **mass number**) is the total number of protons **and** neutrons in the nucleus of an atom
- The symbol for nucleon number is ***A***
- The nucleon number **minus** the proton number gives you the number of **neutrons** of an atom
- Note that protons and neutrons can collectively be called **nucleons**.
- The atomic number and mass number of an element can be shown using **atomic notation**
- The **Periodic Table** shows the elements together with their atomic (proton) number at the top and relative atomic mass at the bottom - there is a difference between relative atomic mass and mass number, but for your exam, you can use the relative atomic mass as the mass number (with the exception of chlorine)

Atomic number & mass number diagram

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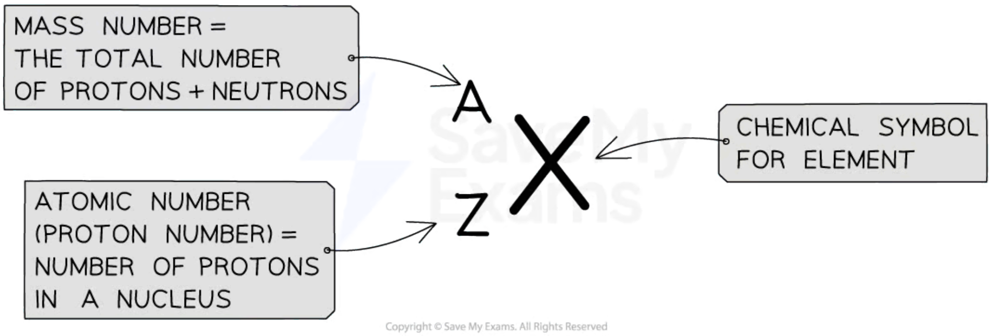

Diagram showing the notation used on the periodic table

How to calculate numbers of protons, neutrons and electrons

Protons

- The atomic number of an atom and ion determines which element it is
- E.g. lithium has an atomic number of 3 (three protons) whereas beryllium has atomic number of 4 (four protons)Therefore, all atoms and ions of the **same element** have the same number of protons (atomic number) in the nucleus
- 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

Electrons

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

Neutrons

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

Number of neutrons = mass number – number of protons

Worked Example

Determine the number of protons, electrons and neutrons in an atom of element X with atomic number 29 and mass number 63

Answer

Protons

- The number of protons of element **X** is the same as the atomic number
  - Number of protons = 29

Electrons

- The **neutral atom** of element **X** therefore also has **29 electrons**

Neutrons

- The atomic number of an element **X** atom is 29 and its mass number is 63
  - Number of neutrons = mass number – number of protons
  - Number of neutrons = 63 – 29
  - Number of neutrons = 34

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Examiner Tips and Tricks

Both the atomic number and the relative atomic number (which you can use as the mass number) are given on the Periodic Table but it can be easy to confuse them.

Think **MASS = MASSIVE**, as the mass number is **always** the bigger of the two numbers, the other smaller one is thus the atomic / proton number.

Beware that some Periodic Tables show the numbers the other way round with the atomic number at the bottom!

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What is electronic configuration

Electronic configuration

- We can represent the structure of the atom in two ways: using diagrams called **electron shell diagrams** or by writing out a special notation called the **electronic configuration** (or electronic structure or electron distribution)

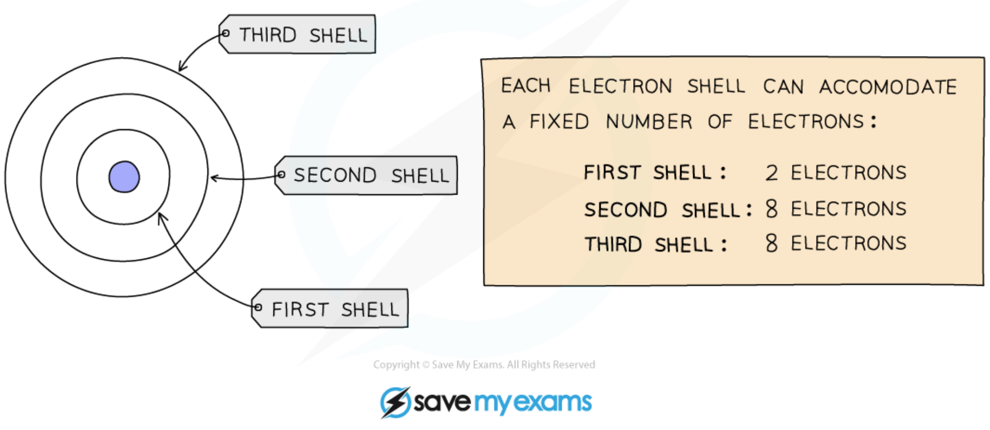
Electron shell diagrams

- Electrons orbit the nucleus in **shells** (or **energy levels**) and each shell has a different amount of energy associated with it
- The further away from the nucleus, the more energy a shell has
- Electrons fill the shell closest to the nucleus
- When a shell becomes full of electrons, additional electrons have to be added to the next shell
  - The first shell can hold 2 electrons
  - The second shell can hold 8 electrons
  - The third shell can hold 8 electrons
  - Then the fourth shell starts to fill

Examiner Tips and Tricks

The third shell can actually hold up to 18 electrons but a simplified 8 electron model is used at this level

- The outermost shell of an atom is called the **valence** shell and an atom is much more stable if it can manage to completely fill this shell with electrons



A simplified model showing the electron shells

- The arrangement of electrons in shells can also be explained using numbers

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- Instead of drawing electron shell diagrams, the number of electrons in each electron shell can be written down, separated by commas
- This notation is called the electronic configuration (or electronic structure)
  - E.g. Carbon has 6 electrons, 2 in the 1st shell and 4 in the 2nd shell
    - Its electronic configuration is 2,4
- Electronic configurations can also be written for ions
  - E.g. A sodium atom has 11 electrons, a sodium ion has lost one electron, therefore has 10 electrons; 2 in the first shell and 8 in the 2nd shell
    - Its electronic configuration is 2,8

The electronic configuration of the first twenty elements

Element	Atomic Number	Electronic Configuration
hydrogen	1	1
helium	2	2
lithium	3	2,1
beryllium	4	2,2
boron	5	2,3
carbon	6	2,4
nitrogen	7	2,5
oxygen	8	2,6
fluorine	9	2,7
neon	10	2,8
sodium	11	2,8,1
magnesium	12	2,8,2
aluminium	13	2,8,3
silicon	14	2,8,4
phosphorus	15	2,8,5
sulfur	16	2,8,6

chlorine	17	2,8,7
argon	18	2,8,8
potassium	19	2,8,8,1
calcium	20	2,8,8,2

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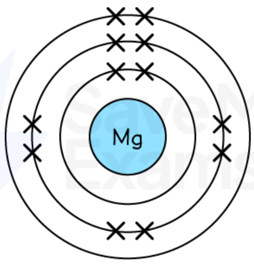
Note: although the third shell can hold up to 18 electrons, the filling of the shells follows a more complicated pattern after potassium and calcium. For these two elements, the third shell holds 8 and the remaining electrons (for reasons of stability) occupy the fourth shell first before filling the third shell.

Worked Example

Draw and write the electronic structure of magnesium.

Answer:

- Magnesium has 12 electrons in total.
- A maximum of two can fit in the first shell and eight in the second shell.
- The remaining two will occupy the third shell.



- The written form of this electronic structure is 2,8,2

Examiner Tips and Tricks

You need to be able to write the electronic configuration of the first twenty elements and their ions. You may see electronic configurations using full stops or '+' signs instead of commas. You would not be penalised for using full stops.

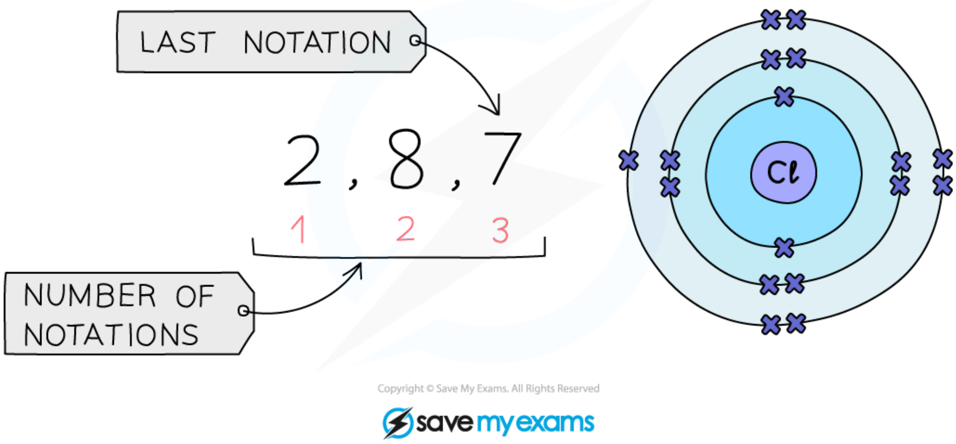
Electron shells & The Periodic Table

How does the electronic structure of an element relate to its location in the Periodic Table?

- There is a clear **relationship** between the electronic configuration and how the Periodic Table is designed

- The number of notations in the electronic configuration will show the number of occupied shells of electrons the atom has, showing the **period** in which that element is in
- The last notation shows the number of outer electrons the atom has, showing the **group** that element is in (for elements in Groups I to VII)
- Elements in the **same group** have the **same** number of outer **shell electrons**

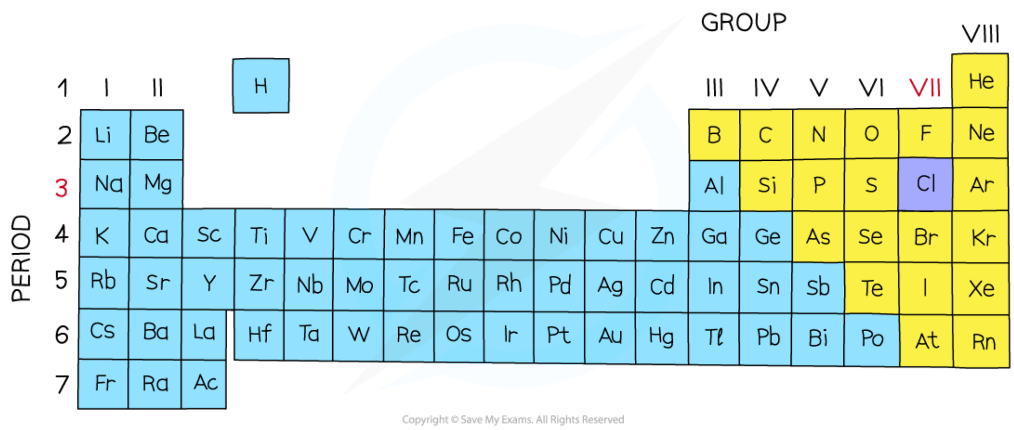
Diagram showing the relationship between the electronic configurations



The electronic configuration for chlorine

- **Period:** The red numbers at the bottom show the number of notations
  - The number of notations is 3
  - Therefore chlorine has 3 occupied shells
- **Group:** The last notation, in this case 7
  - This means that chlorine has 7 electrons in its outer shell
  - Chlorine is therefore in Group 7

The Periodic Table showing the location of chlorine



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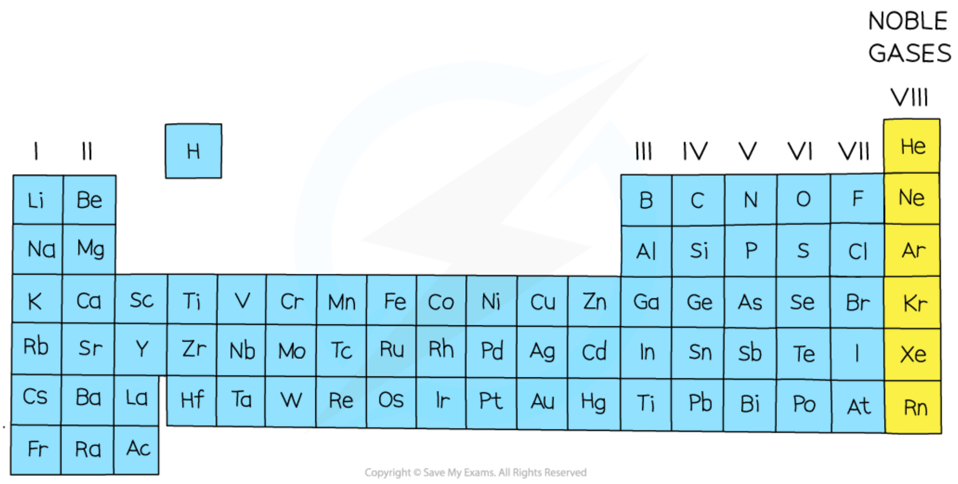
The position of chlorine on the Periodic Table

The noble gases

- In most atoms, the outermost shell is not full
- These atoms react with other atoms in order to achieve a full outer shell of electrons making them more stable
- In some cases, atoms lose electrons to entirely empty this shell so that the next shell below becomes a (full) outer shell
  - They then have the electronic structure of a noble gas (Group VIII)
- All of the noble gases are **unreactive** as they have full outer shells and are thus very stable

The Periodic Table showing the location of the noble gases



The noble gases are on the Periodic Table in Group 8/0

Examiner Tips and Tricks

The electrons in the outer shell are also known as valency electrons.

Your notes

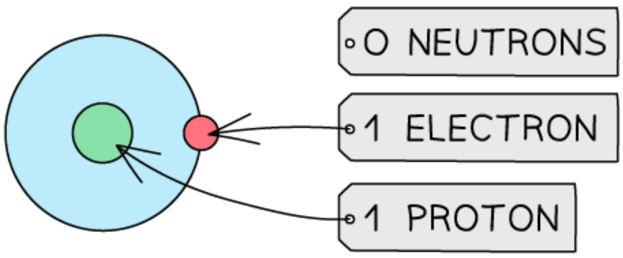
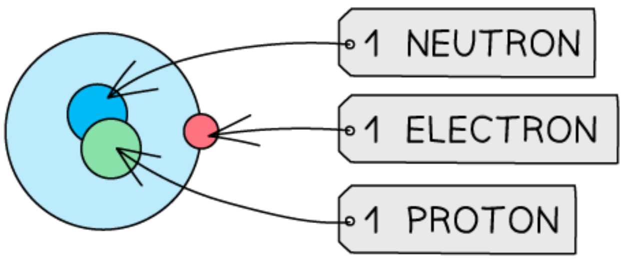
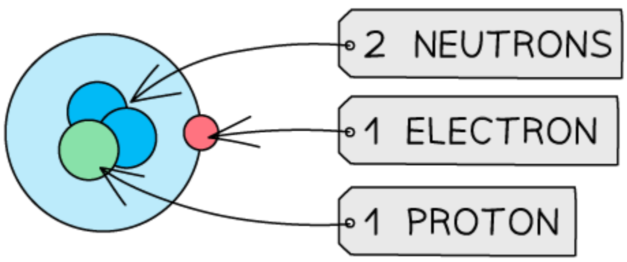
Isotopes

Your notes

Defining isotopes

- Isotopes are different atoms of the **same element** that contain the same number of **protons** but a different number of **neutrons**
- The symbol for an isotope is the chemical symbol (or word) followed by a dash and then the mass number
- So C-14 (or carbon-14) is the isotope of carbon which contains 6 protons, 6 electrons and 14 - 6 = 8 neutrons
    - It can also be written as ^{14}C or $^{14}_{6}C$

Table to show the structures of isotopes of hydrogen

Isotope	Atomic Structure	Symbol
Hydrogen – 1		$^{1}_{1}H$
Hydrogen – 2		$^{2}_{1}H$
Hydrogen – 3		$^{3}_{1}H$

Your notes

Why isotopes share properties

Extended tier only

- Isotopes display the **same chemical characteristics**
- This is because they have the same number of electrons in their outer shells, and this is what determines their chemistry
- The difference between isotopes is the neutrons which are neutral particles within the nucleus and add mass only
- The difference in mass affects the physical properties, such as density, boiling point and melting point
- Isotopes are identical in appearance, so a sample of C-14 would look no different from C-12

Calculating relative atomic mass

Extended tier only

Relative atomic mass

- Atoms are so tiny that we cannot really compare their masses in conventional units such as kilograms or grams, so a unit called the **relative atomic mass** (A_r) is used
- The **relative atomic mass** unit is equal to 1/12th the mass of a carbon-12 atom
- All other elements are measured by comparison to the mass of a carbon-12 atom and since these are ratios, the relative atomic mass has no units
- For example, hydrogen has a relative atomic mass of 1, meaning that 12 atoms of hydrogen would have exactly the same mass as 1 atom of carbon

How do I calculate relative atomic mass?

- The relative atomic mass of each element is calculated from the **mass number** and **relative abundances** of all the isotopes of a particular element
- The equation below is used where the top line of the equation can be extended to include the number of different isotopes of a particular element present

$$A_r = \frac{(\text{\% of isotope A x mass of isotope A}) + (\text{\% of isotope B x mass of isotope B})}{100}$$

- So, if there were 3 isotopes present then the equation would read:

$$\frac{(\text{\% of isotope A x mass of isotope A}) + (\text{\% of isotope B x mass of isotope B}) + (\text{\% of isotope C x mass of isotope C})}{100}$$

Worked Example

The table shows information about the isotopes in a sample of rubidium

Isotope	Mass Number	Percentage abundance
1	85	72

2	87	28

Use information from the table to calculate the relative atomic mass of this sample of rubidium.

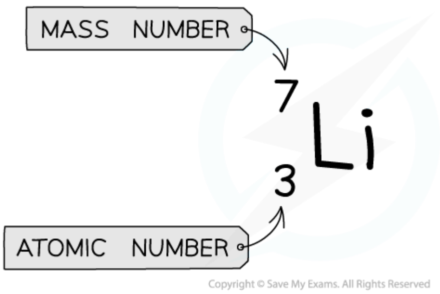
Give your answer to one decimal place.

Answer:

- Relative atomic mass = $\frac{(72 \times 85) + (28 \times 87)}{100}$
- Relative Atomic Mass = **85.6**

Is mass number and relative atomic mass the same thing?

- On the Periodic Table provided in your exam you will see that lithium has a relative atomic mass of **7**
- Although it seems that this is the same as the mass number, they are not the same thing because the relative atomic mass is a **rounded** number
- Relative atomic mass takes into account the existence of isotopes when calculating the mass
- Relative atomic mass is an **average mass** of all the isotopes of that element
- For simplicity **relative atomic masses** are often shown to the nearest whole number



The relative atomic mass of lithium to two decimal places is 6.94 when rounded to the nearest whole number, the RAM is 7, which is the same as the mass number shown on this isotope of lithium

Your notes