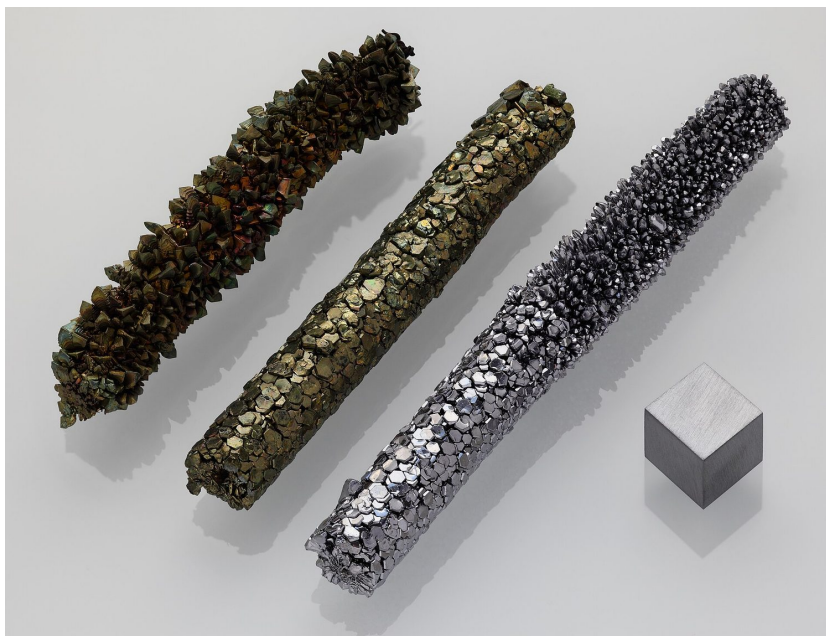


Atoms, elements and compounds

IGCSE Chemistry

Elements, compounds and mixtures



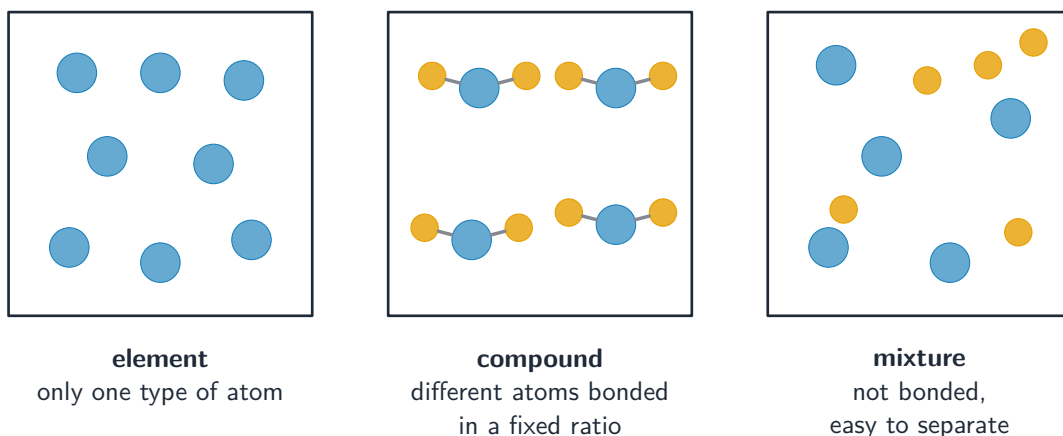
A pure element (vanadium): elements are the simplest substances.

Image: Alchemist-hp (pse-mendejew.de), FAL (commons.wikimedia.org)

All substances are made from about 100 simple building blocks. Knowing how they are joined lets you sort every substance into one of three groups.

- An **element** 元素 is a substance made of only one type of **atom** 原子. You cannot break it into anything simpler by a chemical reaction. Examples: copper, oxygen, carbon.
- A **compound** 化合物 is two or more elements chemically joined (bonded) together. The atoms are joined in a fixed ratio. Examples: water, carbon dioxide. A compound has different properties from the elements in it.
- A **mixture** 混合物 is two or more substances that are just mixed, not chemically joined. The parts keep their own properties and can be separated by physical methods. Example: air.

The key difference: in a compound the elements are **bonded** and can only be separated by chemical reactions; in a mixture they are not bonded and are easy to separate.

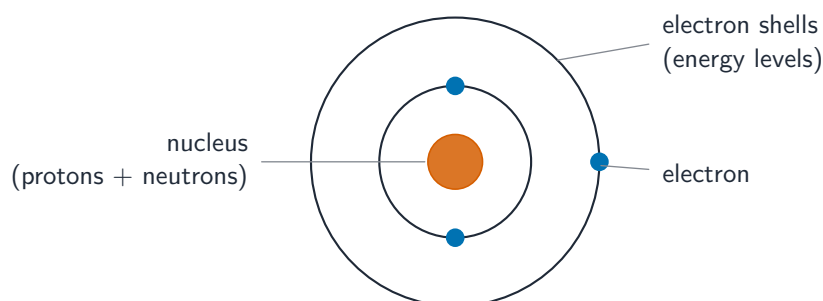


An element has one type of atom; a compound has different atoms bonded in a fixed ratio; a mixture is not bonded

Atomic structure

Inside the atom

Every atom has a small, dense centre called the **nucleus** 原子核. Around it, **electrons** 电子 move in **shells** 电子层 (energy levels). The nucleus contains two kinds of particle: **protons** 质子 and **neutrons** 中子.



lithium, Li: 3 protons, 4 neutrons
electron configuration 2,1

An atom has a tiny nucleus of protons and neutrons, with electrons in shells around it

Each particle has a **relative mass** and a **relative charge** 电荷. You must learn these values:

Particle	Relative mass	Relative charge
proton	1	+1
neutron	1	0
electron	$\frac{1}{1840}$ (almost 0)	-1

An atom has no overall charge because it has equal numbers of protons (+1 each) and electrons (−1 each).

Proton number and mass number

Two numbers describe an atom:

- The **proton number** 质子数 (also called the **atomic number** 原子序数) is the number of protons in the nucleus. It tells you which element the atom is.
- The **mass number** 质量数 (also called the **nucleon number** 核子数) is the total number of protons and neutrons in the nucleus.

So the number of neutrons = mass number − proton number.

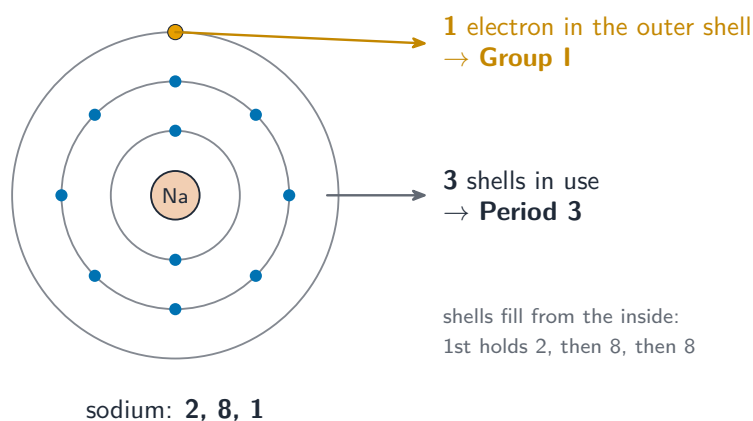
Electronic configuration

The electrons fill the shells from the inside out. The first shell holds up to 2 electrons; the next shells hold up to 8 each (for the first 20 elements). The **electronic configuration** 电子排布 lists how many electrons are in each shell, starting from the inside.

For example, an atom with 13 electrons has the configuration 2, 8, 3. Sodium (proton number 11) is 2, 8, 1. Calcium (proton number 20) is 2, 8, 8, 2.

The configuration links to the **Periodic Table** 周期表:

- A **Group** 族 number (Groups I to VII) equals the number of electrons in the outer shell. So 2, 8, 1 is in Group I.
- A **Period** 周期 number equals the number of shells that hold electrons. So 2, 8, 1 has three shells, so it is in Period 3.
- The **noble gases** 稀有气体 in Group VIII (or 0) have a full outer shell, which makes them very unreactive.



Sodium's configuration 2,8,1 links to the Periodic Table: one outer electron means Group I, three shells means Period 3

Isotopes

Isotopes 同位素 are atoms of the same element that have the same number of protons but different numbers of neutrons. Because the proton number is the same, they are the same element. Because the neutron number is different, they have different mass numbers.

You write an atom with its mass number on top and proton number below, like ${}^6_2\text{C}$. For an ion you add the charge, like ${}^{35}_{17}\text{Cl}^-$.

Isotopes of an element have the **same chemical properties**. This is because chemical reactions only involve electrons, and isotopes have the same number of electrons and the same electronic configuration. (The extra neutrons change only the mass.)

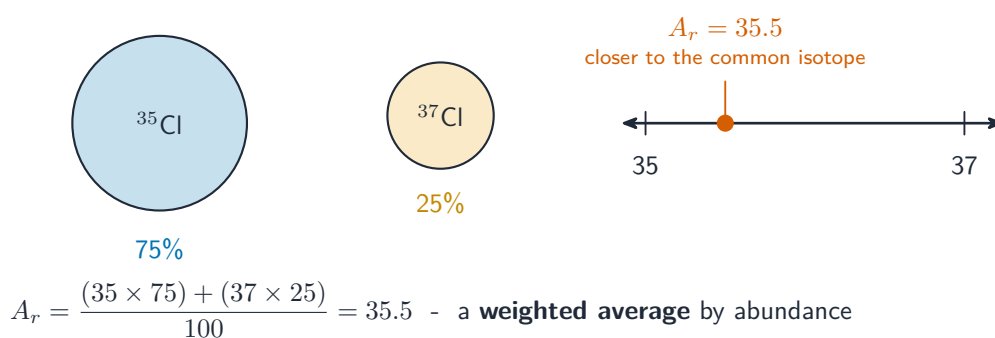
Calculating relative atomic mass

The **relative atomic mass** 相对原子质量 (A_r) of an element is the average mass of its atoms, taking into account how common each isotope is. The **abundance** 丰度 is the percentage of each isotope.

$$A_r = \frac{\sum(\text{isotope mass} \times \text{abundance})}{100}$$

For example, chlorine is 75% ${}^{35}\text{Cl}$ and 25% ${}^{37}\text{Cl}$:

$$A_r = \frac{(35 \times 75) + (37 \times 25)}{100} = 35.5$$



Relative atomic mass is a weighted average: chlorine is 75 percent Cl-35 and 25 percent Cl-37, so A_r is 35.5

Worked example. Boron has two isotopes, ${}^{10}\text{B}$ and ${}^{11}\text{B}$, and its A_r is 10.8. Find the percentage of each. Let the abundance of ${}^{11}\text{B}$ be x , so the abundance of ${}^{10}\text{B}$ is $(100 - x)$. Then

$$\frac{11x + 10(100 - x)}{100} = 10.8$$

so $11x + 1000 - 10x = 1080$, giving $x = 80$. Boron is **80%** ^{11}B and **20%** ^{10}B . Check it against common sense: 10.8 lies closer to 11, so the heavier isotope must be the more common one. If your answer gives the majority to the isotope further from A_r , you have them the wrong way round.

Ions and ionic bonds

An **ion** 离子 is an atom (or group of atoms) that has lost or gained electrons, so it has an electric charge.

- A metal atom **loses** electrons to form a positive ion, called a **cation** 阳离子.
- A non-metal atom **gains** electrons to form a negative ion, called an **anion** 阴离子.

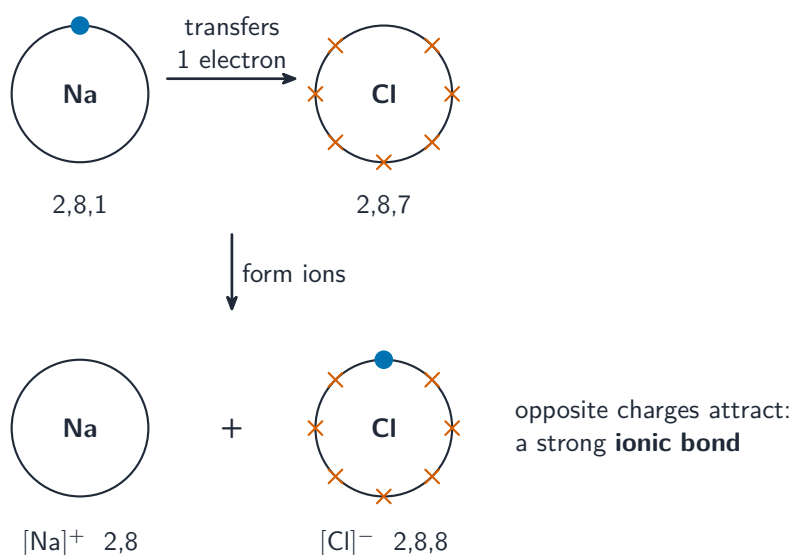
Atoms do this to get a full outer shell, like a noble gas.

How an ionic bond forms

An **ionic bond** 离子键 is a strong **electrostatic attraction** 静电引力 between oppositely charged ions (a $+$ ion and a $-$ ion pull together).

Ionic bonds form between a **metal** 金属 and a **non-metal** 非金属. Take sodium chloride, NaCl . Sodium (2, 8, 1) gives its one outer electron to chlorine (2, 8, 7). Now sodium is Na^+ (2, 8) and chlorine is Cl^- (2, 8, 8). Both have full outer shells, and the opposite charges attract.

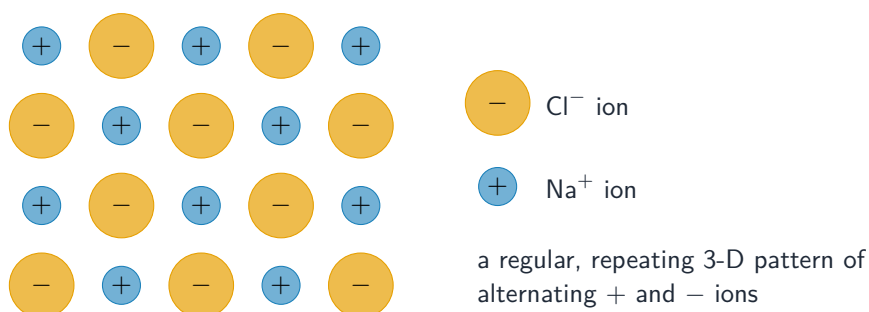
You can show this with a **dot-and-cross diagram**: draw each atom's outer-shell electrons as dots for one element and crosses for the other, then show the electron moving from the metal to the non-metal.



Sodium gives its outer electron to chlorine; both reach full outer shells and the opposite charges attract (the blue electron came from sodium)

The structure and properties of ionic compounds

An **ionic compound** 离子化合物 is not made of separate **molecules** 分子. The ions pack together into a giant **lattice** 晶格—a regular pattern of huge numbers of **alternating** 交替 positive and negative ions.



Ions pack into a giant lattice: a regular, repeating pattern of alternating positive and negative ions

This structure explains the properties:

Property	Reason
high melting point 熔点 and boiling point 沸点	the strong electrostatic attraction between ions needs a lot of energy to break
poor electrical conductivity 导电性 when solid	the ions are fixed in place and cannot move
good conductor when molten 熔融 or aqueous 水溶液	the ions are now free to move and carry charge

Simple molecules and covalent bonds



A model of a water molecule: atoms share electrons in covalent bonds.

Image: 山本海行, CC BY-SA 4.0 (commons.wikimedia.org)

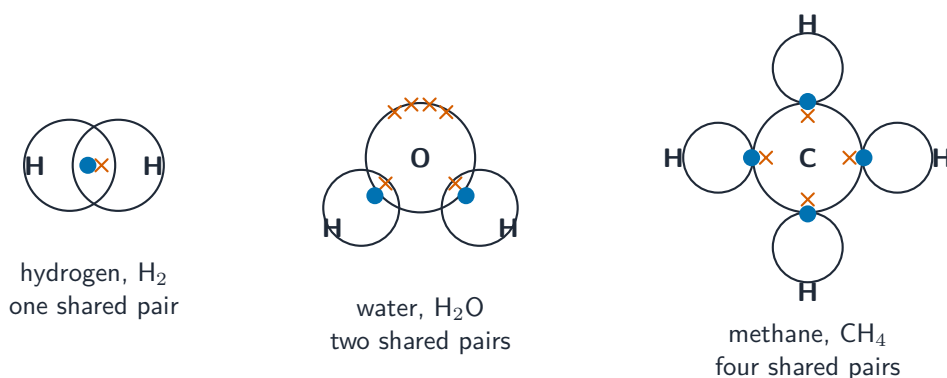
A **covalent bond** 共价键 forms when two atoms **share** a pair of electrons. By sharing, each atom gets a full outer shell (a noble gas configuration). Covalent bonds form between

non-metal atoms.

Some molecules to know:

- H_2 —two hydrogen atoms share one pair of electrons (a single bond).
- Cl_2 , HCl —one shared pair each.
- H_2O —oxygen shares one pair with each of two hydrogen atoms.
- NH_3 —nitrogen shares a pair with each of three hydrogen atoms.
- CH_4 —carbon shares a pair with each of four hydrogen atoms.
- O_2 and CO_2 have double bonds (two shared pairs); N_2 has a triple bond (three shared pairs); C_2H_4 and CH_3OH also use shared pairs.

In a dot-and-cross diagram for a molecule, you draw the outer electrons of each atom and show which pairs are shared in the overlap between the atoms.



In a covalent bond, atoms share pairs of electrons so each reaches a full outer shell

Properties of simple molecular compounds

These substances are made of small, separate molecules.

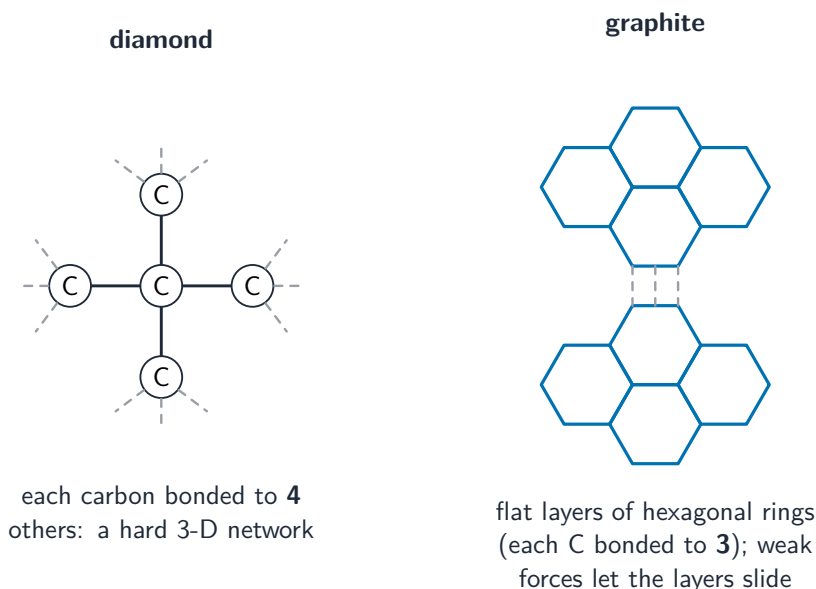
- They have **low** melting points and boiling points. The covalent bonds inside each molecule are strong, but the **intermolecular forces** 分子间作用力 (the forces between one molecule and the next) are weak, so little energy is needed to separate the molecules.
- They are **poor conductors** of electricity, because the molecules have no overall charge and no free electrons or ions to carry charge.

Giant covalent structures

Some covalent substances are not small molecules. Instead, millions of atoms are joined by covalent bonds into one **giant covalent structure** 巨型共价结构. The two you must know are both forms of carbon.

Diamond 金刚石: each carbon atom is bonded to four other carbon atoms. This makes a very strong, rigid 3-D network. Diamond is extremely hard, so it is used in **cutting tools** 切割工具.

Graphite 石墨: each carbon atom is bonded to only three others, forming flat **layers** 层. There are weak forces between the layers, so the layers can slide over each other — this makes graphite a good **lubricant** 润滑剂. The fourth outer electron of each carbon is free; these **delocalised electrons** 离域电子 can move, so graphite conducts electricity and is used as an **electrode** 电极.

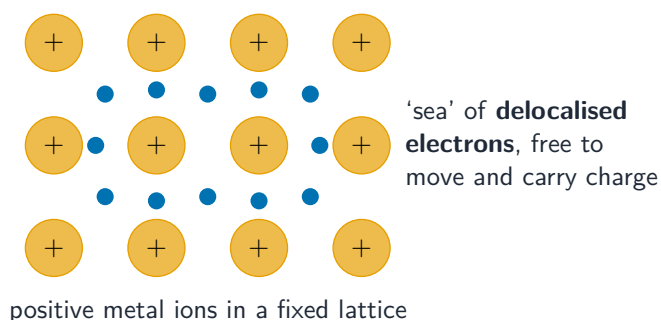


Diamond bonds each carbon to four others (hard); graphite forms flat layers with weak forces between them (slippery)

Silicon(IV) oxide 二氧化硅 (SiO_2) has a giant covalent structure like diamond, so it is also very hard and has a very high melting point.

Metallic bonding

A metal is a giant structure of positive ions surrounded by a 'sea' of **delocalised electrons** that are free to move through the whole metal. **Metallic bonding** 金属键 is the strong electrostatic attraction between these positive ions and the sea of electrons.



A metal is positive ions in a 'sea' of delocalised electrons that are free to move and carry charge

This explains two key properties of metals:

- **Good electrical conductivity:** the delocalised electrons are free to move and carry charge through the metal.
- **Malleability** 展性 (can be hammered into sheets) and **ductility** 延性 (can be pulled into wires): the layers of positive ions can slide over each other without breaking the metallic bond, so the metal changes shape instead of shattering.

Exam tips

- Number of neutrons = mass number – proton number. The **proton number** is what decides which element an atom is.
- **Isotopes** have the same chemical properties because reactions involve only electrons, and isotopes share the same electron configuration; only the mass differs.
- Match structure to properties: **ionic** = giant lattice (high melting point; conducts only when molten or aqueous); **simple molecular** = weak forces *between* molecules (low melting point; no conduction); **giant covalent** = very hard, very high melting point.
- **Graphite** conducts and is slippery (one free electron per carbon; layers slide); **diamond** does neither (all four electrons bonded, so hard and non-conducting). Metals conduct and bend thanks to the sea of **delocalised electrons**.
- For relative atomic mass, take the weighted average: $A_r = \frac{\sum(\text{isotope mass} \times \text{abundance})}{100}$.