Atoms, Elements and Bonding

Elements, compounds and mixtures, atomic structure and electronic configuration, isotopes and relative atomic mass, ionic bonding, covalent bonding and simple molecules, giant covalent structures, and metallic bonding.

2.1 Elements, compounds and mixtures

	Element	Compound	Mixture
what it is	one type of atom only	two or more different elements **chemically bonded** together	two or more substances **not chemically combined**
proportions	not applicable	fixed ratio, shown by its formula	any proportions
properties	has its own properties	different from the elements that formed it	the properties of each substance are kept
separation	cannot be broken down by chemical means	only by a chemical reaction	by physical methods such as filtration or distillation
examples	iron, oxygen, sodium	water, carbon dioxide, sodium chloride	air, sea water, steel

An element cannot be broken down into anything simpler by chemical means. A compound is made of two or more elements chemically bonded in a fixed ratio. A mixture is not chemically combined and can be separated by physical methods.

Iron and sulfur. A **mixture** of iron filings and sulfur powder can be separated with a magnet (the iron is attracted), and it can be any proportion of each. If the mixture is heated, the elements react to form the **compound** iron(II) sulfide, which is a different grey solid that the magnet does not attract. This cannot be separated by physical means.

$$\mathrm{Fe(s) + S(s) \longrightarrow FeS(s)}$$

2.2 Atomic structure and the Periodic Table

An atom has a very small, dense **nucleus** in the centre, containing **protons** and **neutrons**. The **electrons** move around the nucleus in **shells** (energy levels).

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Particle	Relative charge	Relative mass
proton	$+1$	1
neutron	0	1
electron	-1	$\frac{1}{1836}$ (negligible)

An atom is **neutral**: it has the same number of electrons as protons.

> **The proton number (atomic number) is the number of protons in the nucleus. The nucleon number (mass number) is the total number of protons and neutrons in the nucleus. The number of neutrons = nucleon number − proton number.**

Electronic configuration

Electrons fill the shells nearest the nucleus first. The first shell holds up to **2** electrons, and the second and third shells hold up to **8** each, for the elements with proton number 1 to 20. The arrangement is written as numbers, for example sodium is $2, 8, 1$.

Element	Proton number	Configuration	Element	Proton number	Configuration
hydrogen	1	1	sodium	11	2,8,1
helium	2	2	magnesium	12	2,8,2
lithium	3	2,1	aluminium	13	2,8,3
beryllium	4	2,2	silicon	14	2,8,4
boron	5	2,3	phosphorus	15	2,8,5
carbon	6	2,4	sulfur	16	2,8,6
nitrogen	7	2,5	chlorine	17	2,8,7
oxygen	8	2,6	argon	18	2,8,8
fluorine	9	2,7	potassium	19	2,8,8,1
neon	10	2,8	calcium	20	2,8,8,2

The link with the Periodic Table.

- For Groups I to VII, the **number of outer-shell electrons equals the group number**. Sodium $(2, 8, 1)$ is in Group I, and chlorine $(2, 8, 7)$ is in Group VII.

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- The **number of occupied shells equals the period number**. Sodium has three shells, so it is in Period 3.
- The **Group VIII noble gases** have a **full outer shell** (helium has 2, the others have 8), which is why they are so unreactive.

For an **ion**, the electronic configuration is that of the atom with the extra electrons added or removed: Na^+ is $2, 8$, and Cl^- is $2, 8, 8$.

> **TRY IT**
>
> Write the electronic configuration of an atom of phosphorus (proton number 15) and say which group and period it is in.

15 electrons fill the shells as $2, 8, 5$. There are 5 outer electrons, so it is in **Group V**, and three shells, so **Period 3**.

2.3 Isotopes

> **Isotopes are atoms of the same element that have the same number of protons but a different number of neutrons. They have the same proton number and different nucleon numbers.**

Isotopes of an element have the **same chemical properties**, because they have the same number of electrons and therefore the same electronic configuration. Chemical reactions depend on the electrons.

Symbols. An atom or ion is written with the nucleon number at the top and the proton number at the bottom, for example ${}^{12}_{6}\mathrm{C}$ and ${}^{35}_{17}\mathrm{Cl}^-$.

> **TRY IT**
>
> How many protons, neutrons and electrons are in ${}^{35}_{17}\mathrm{Cl}^-$?

Protons $= 17$. Neutrons $= 35 - 17 = 18$. The ion has gained one electron, so electrons $= 17 + 1 = 18$.

Relative atomic mass

The **relative atomic mass**, A_r, of an element is the average mass of its isotopes, taking account of how much of each there is, compared with $\frac{1}{12}$ of the mass of an atom of carbon-12.

$$A_\mathrm{r} = \frac{\sum(\text{isotope mass} \times \text{abundance})}{100}$$

> **TRY IT**

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> Chlorine has two isotopes: 75% is chlorine-35 and 25% is chlorine-37. Calculate the relative atomic mass of chlorine.

$A_{\mathrm{r}} = \frac{(35\times75)+(37\times25)}{100} = \frac{2625+925}{100} = 35.5$

2.4 Ions and ionic bonds

An atom becomes an **ion** when it gains or loses electrons so that it has a full outer shell, the electronic configuration of a noble gas.

- **Metal atoms lose** electrons to form **positive ions (cations)**: $\mathrm{Na} \longrightarrow \mathrm{Na}^{+} + \mathrm{e}^{-}$.
- **Non-metal atoms gain** electrons to form **negative ions (anions)**: $\mathrm{Cl} + \mathrm{e}^{-} \longrightarrow \mathrm{Cl}^{-}$.

The charge on the ion depends on the group:

Group	I	II	III	V	VI	VII
charge on the ion	$1+$	$2+$	$3+$	$3-$	$2-$	$1-$

> **An ionic bond is the strong electrostatic attraction between oppositely charged ions.**

Ionic bonds form between a **metal** and a **non-metal**. The metal atoms **transfer** electrons to the non-metal atoms.

Sodium chloride. A sodium atom $(2, 8, 1)$ gives its one outer electron to a chlorine atom $(2, 8, 7)$. Both ions now have a full outer shell: Na^{+} is $2, 8$ and Cl^{-} is $2, 8, 8$.

In a **dot-and-cross diagram** for an ionic compound, show only the **outer shell** of each ion, put the ions in square brackets, and write the charge at the top right. For **magnesium oxide**, magnesium transfers **two** electrons to oxygen, giving Mg^{2+} and O^{2-}. For **calcium chloride**, one calcium atom gives one electron to each of **two** chlorine atoms, giving Ca^{2+} and two Cl^{-}.

The giant ionic lattice

An ionic compound is a **giant lattice**: a regular, repeating arrangement of alternating positive and negative ions, held together by strong ionic bonds in every direction.

Note Academy

Properties of ionic compounds

Property	Explanation
high melting and boiling points	a large amount of energy is needed to overcome the many strong electrostatic attractions between the oppositely charged ions
do not conduct when solid	the ions are in fixed positions in the lattice and cannot move
conduct when molten or dissolved in water (aqueous)	the ions are free to move and carry the charge

2.5 Simple molecules and covalent bonds

> **A covalent bond is formed when a pair of electrons is shared between two atoms, so that each atom gains the electronic configuration of a noble gas.**

Covalent bonds form between **non-metal** atoms. A **molecule** is a group of atoms held together by covalent bonds. A **single** bond is one shared pair, a **double** bond is two shared pairs, and a **triple** bond is three shared pairs.

In a **dot-and-cross diagram**, the outer electrons of one atom are drawn as dots and the other atom's as crosses, and the overlap shows the shared pairs. Outer electrons that are not shared are shown as **lone pairs**.

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Molecule	Formula	Bonds shown by the diagram
hydrogen	H_2	one single bond
chlorine	Cl_2	one single bond, three lone pairs on each atom
hydrogen chloride	HCl	one single bond
water	H_2O	two single bonds, two lone pairs on oxygen
methane	CH_4	four single bonds
ammonia	NH_3	three single bonds, one lone pair on nitrogen
methanol	CH_3OH	three C–H, one C–O and one O–H single bond
oxygen	O_2	one **double** bond
carbon dioxide	CO_2	two **double** bonds (C=O)
ethene	C_2H_4	one **double** bond (C=C) and four C–H single bonds
nitrogen	N_2	one **triple** bond

TRY IT

Draw the dot-and-cross diagram for a molecule of hydrogen chloride and say how many lone pairs it has.

Hydrogen (1 electron) and chlorine ($2, 8, 7$) share one pair. The shared pair is drawn in the overlap of the two outer shells, and chlorine has **three lone pairs** (the other 6 outer electrons). Both atoms now have a noble gas configuration: hydrogen has 2 and chlorine has 8.

Properties of simple molecular substances

Property	Explanation
low melting and boiling points	the **weak forces between the molecules** (intermolecular forces) are easily overcome. The strong covalent bonds inside the molecules are **not** broken
do not conduct electricity	the molecules have no overall charge, and there are no free ions or electrons to carry charge

NOTE

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When a simple molecular substance melts or boils, it is the **weak forces between the molecules** that are overcome, **not the covalent bonds**. This is one of the most common mistakes in exams.

2.6 Giant covalent structures

Some covalent substances form a **giant covalent structure** (macromolecule): a huge network of atoms held together by strong covalent bonds. The three to know are diamond, graphite and silicon(IV) oxide.

	Diamond	Graphite	Silicon(IV) oxide, SiO_2
structure	each carbon bonded to **four** others by covalent bonds in a rigid tetrahedral arrangement	each carbon bonded to **three** others in flat **layers** of hexagons, with weak forces between the layers	each silicon bonded to **four** oxygen atoms and each oxygen to **two** silicon atoms, a structure like diamond
hardness	very hard	soft and slippery	hard
melting point	very high	very high	very high
electrical conductivity	does not conduct (no free electrons)	**conducts** (the fourth electron from each carbon is **delocalised** and free to move along the layers)	does not conduct

Uses related to structure.

- **Diamond** is used in **cutting tools** (drill bits and saws) because it is extremely hard.
- **Graphite** is used as a **lubricant** because the layers can slide over each other easily, as the forces between them are weak.
- **Graphite** is used as an **electrode** (in electrolysis) because it conducts electricity and is unreactive.

Diamond and silicon(IV) oxide have similar properties (hard, very high melting points, do not conduct) because both are giant covalent structures with each atom held by strong covalent bonds to the same number of neighbours.

2.7 Metallic bonding

Metallic bonding is the electrostatic attraction between the positive metal ions in a giant lattice and a "sea" of delocalised electrons.

The outer electrons of each metal atom leave the atom and move freely through the whole structure. The positive ions are left in a regular lattice.

Note Academy

Property	Explanation
good electrical conductivity	the delocalised electrons are free to move through the lattice and carry the charge
malleable (can be hammered into shape) and ductile (can be drawn into wires)	the layers of positive ions can **slide over each other**, and the delocalised electrons still hold the structure together

Comparing the structures

Structure	Particles	Bonding	Melting point	Conducts?
ionic compound	ions	strong attraction between ions	high	when molten or aqueous only
simple molecule	molecules	weak forces between molecules	low	no
giant covalent (diamond, SiO_2)	atoms	strong covalent bonds in a network	very high	no
graphite	atoms	covalent in layers, weak between layers	very high	yes
metal	positive ions and electrons	metallic bond	usually high	yes

Note Academy