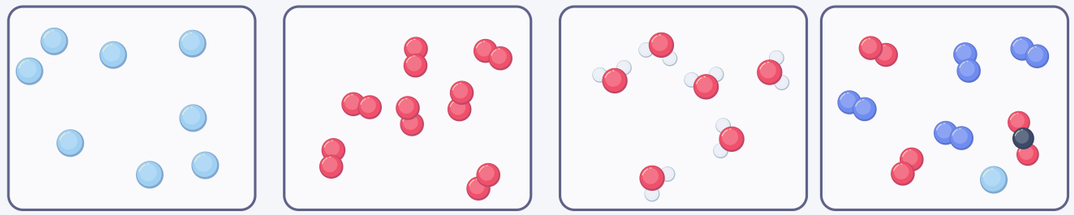
04–05 Chemical Bonding and Materials

1 Elements, Compounds and Mixtures

1.1 Comparing them

	Element	Compound	Mixture
Made of	one kind of atom	two or more elements _____	two or more substances _____ chemically combined
Ratio	not applicable	_____ ratio	no fixed ratio
Properties	its own	different from its elements	similar to its substances
Formed by	mostly occurs naturally	a **chemical reaction**	usually physical mixing
Melting and boiling	fixed points	fixed points	over a _____ of temperatures
Separated by	cannot be broken down by chemical methods	chemical methods only, e.g. **thermal decomposition** or **electrolysis**	_____ methods, e.g. filtration or distillation



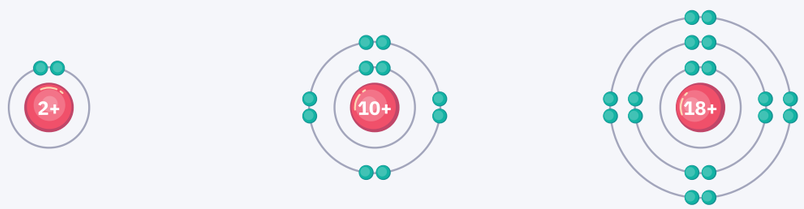
element: argon atoms | element: oxygen molecules | compound: water molecules | mixture: air

- An element can exist as single atoms (helium), molecules (O_2) or a metal lattice (copper).
- _____ all molecules are compounds: H_2 is an element and CO_2 is a compound.

2 Why Do Atoms Combine?

2.1 The noble gases are stable

The **noble gases** (Group 18) have a _____ outermost shell, so they are stable and unreactive. This is a **noble gas electronic configuration**.



He 2 | Ne 2.8 | Ar 2.8.8

- Helium has a **duplet**, 2 electrons in its only shell. Neon and argon have an **octet**: 8 outer electrons.
- Noble gases are **monoatomic**. They exist as single atoms.

2 Why Do Atoms Combine? (continued)

2.2 Three ways to a full outer shell

Other atoms combine and form **bonds** to reach a noble gas electronic configuration.

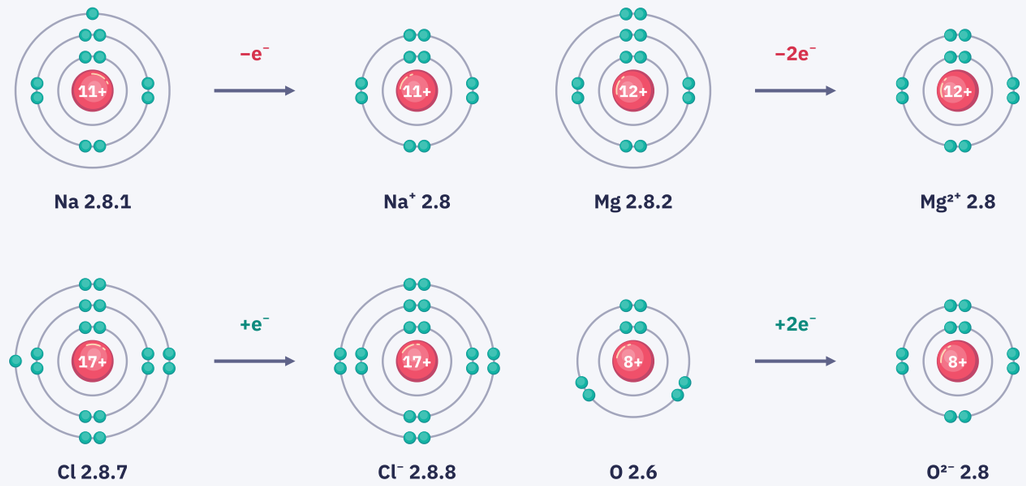
Lose electrons
Metals form _____.

Gain electrons
Non-metals form _____ _____.

Share electrons
Non-metals form _____ _____.

3 Ionic Bonding

3.1 Forming ions



Na 2.8.1 | Na^+ 2.8 | Mg 2.8.2 | Mg^{2+} 2.8

Cl 2.8.7 | Cl^- 2.8.8 | O 2.6 | O^{2-} 2.8

Metal atoms lose electrons
$Na \rightarrow Na^+ + e^-$
$Mg \rightarrow Mg^{2+} + 2e^-$

Non-metal atoms gain electrons
$Cl + e^- \rightarrow Cl^-$
$O + 2e^- \rightarrow O^{2-}$

- Na (2.8.1) loses 1 electron to become Na^+ (2.8). Cl (2.8.7) gains 1 electron to become Cl^- (2.8.8). Both ions have a _____ electronic configuration.
- Na could lose 1 electron or gain 7, and losing 1 is far more likely. Na^+ then has 11 protons and 10 electrons, so its charge is +1.
- A negative ion of a single element ends in **-ide**: chloride, oxide. Metal ions keep the name of the metal.

3 Ionic Bonding (continued)

3.2 Common ions

Charge	Positive ions (cations)	Negative ions (anions)
1	hydrogen H^+, sodium Na^+, potassium K^+, silver Ag^+, **ammonium NH_4^+ ★**	fluoride F^-, chloride Cl^-, bromide Br^-, iodide I^-, **hydroxide OH^- ★**, **nitrate NO_3^- ★**
2	magnesium Mg^{2+}, calcium Ca^{2+}, barium Ba^{2+}, iron(II) Fe^{2+}, copper(II) Cu^{2+}, zinc Zn^{2+}	oxide O^{2-}, **carbonate CO_3^{2-} ★**, **sulfate SO_4^{2-} ★**
3	aluminium Al^{3+}, iron(III) Fe^{3+}	phosphate PO_4^{3-}

NOTE Ions with more than one atom, such as NH_4^+ and SO_4^{2-}, are **polyatomic ions**. Learn the names, formulae and charges of the five marked **like this ★** by heart.

- The negative ions of Group 17 are **halide ions**. Ions with a charge above +3 are rare.
- Hydrogen is a non-metal that forms a positive ion. H^+ has no electrons: it is just a proton.

3.3 The ionic bond

An **ionic bond** is the mutual _____ between ions of opposite charges. It usually forms between a **metal** and a **non-metal**.



sodium chloride, NaCl

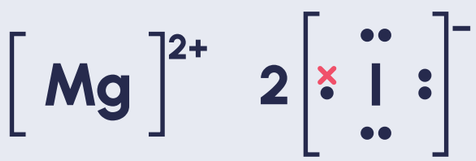
- Show only the **outer** electrons, as dots for one atom and crosses for the other.
- Put each ion in **square** brackets, with its charge outside.
- An ionic compound is neutral: total positive charge = total _____ charge.

WORKED EXAMPLE Magnesium reacts with iodine. Give the formula of the compound and draw its dot-and-cross diagram.

Magnesium forms Mg^{2+} (charge +2). Iodine forms I^- (charge −1).

To balance, one Mg^{2+} needs **two** I^-, as +2 + 2(−1) = 0.

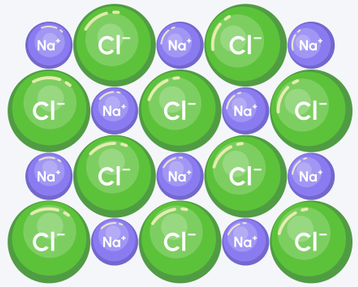
The formula is **MgI_2**. Show the number of each ion in front of its bracket.



EXAM TIP An ionic formula shows the simplest ratio of ions, with no charges.

3 Ionic Bonding (continued)

3.4 The giant ionic lattice

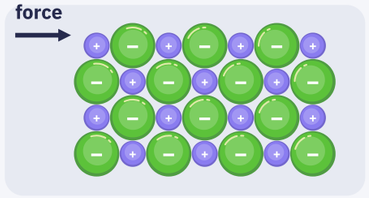


In the solid state, an ionic compound is a **giant ionic lattice**: a three-dimensional structure of _____ positive and negative ions in a regular, repeating pattern.

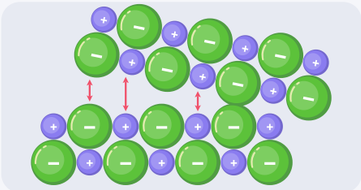
- Every ion attracts _____ the oppositely charged ions next to it. In sodium chloride, each Na^+ is surrounded by six Cl^-, and each Cl^- by six Na^+.

3.5 Properties of ionic compounds

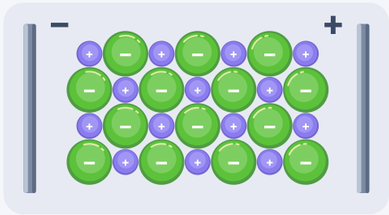
Property	Explanation
High melting and boiling points, solid at room temperature	The electrostatic attraction between oppositely charged ions is strong, so a _____ is needed to overcome it.
Hard but **brittle**	A strong force moves the layers so that ions of the same charge meet. They _____ and the lattice shatters.
Usually **soluble in water**, insoluble in organic solvents	Water pulls the ions out of the lattice.
Conduct electricity when **molten or aqueous**, not as a solid	The ions are _____ only when molten or dissolved. In the solid they only vibrate about fixed positions.



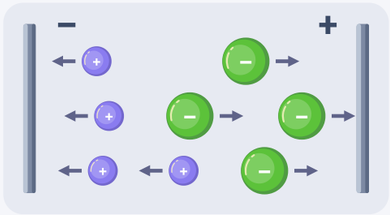
before the force



like charges repel: the crystal splits



solid: ions in fixed positions



molten or aqueous: mobile ions

WORKED EXAMPLE Explain why sodium chloride has a high melting point.

Sodium chloride has a **giant ionic lattice** structure.

There are strong electrostatic forces of attraction between the oppositely charged Na^+ and Cl^- ions.

A **large amount of energy** is needed to overcome these forces, so the melting point is high.

4 Covalent Bonding

4.1 Sharing electrons

DEFINITION A **covalent bond** is formed when two atoms _____ a pair of electrons (a **bonding pair**), so each atom gains a noble gas electronic configuration. It forms between **non-metal** atoms.

Valency is the number of electrons an atom must lose, gain or share to reach a noble gas electronic configuration. For a non-metal, the bonds it forms = 8 – number of valence electrons (hydrogen: 2 – 1 = 1).

Element	Group	Valence electrons	Valency
hydrogen	1	1	1
carbon, silicon	14	4	4
nitrogen, phosphorus	15	5	3
oxygen, sulfur	16	6	2
fluorine, chlorine, bromine, iodine	17	7	1

4.2 Dot-and-cross diagrams of molecules



Cl_2: single bond, Cl–Cl



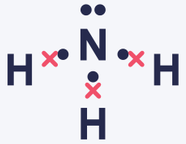
O_2: double bond, O=O



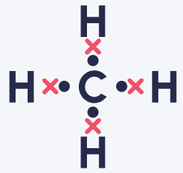
N_2: triple bond, N≡N



water, H_2O



ammonia, NH_3



methane, CH_4



carbon dioxide, CO_2

- Draw each shared pair **between** the two symbols, and the other outer electrons in pairs.
- Cl_2, O_2 and N_2 are **diatomic**: each molecule has two atoms. A **structural formula** shows each shared pair as a line, as in Cl–Cl, O=O and N≡N.

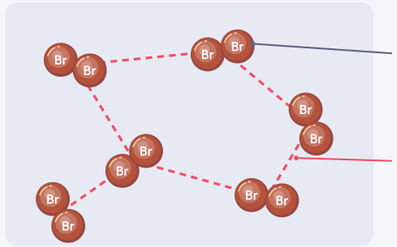
WORKED EXAMPLE Draw a dot-and-cross diagram for hydrogen sulfide, H_2S.

Hydrogen has valency 1. Sulfur has 6 outer electrons, so its valency is 2.
Sulfur forms **two** single bonds, one to each hydrogen atom.
Sulfur keeps its other 4 outer electrons as 2 lone pairs.



4 Covalent Bonding (continued)

4.3 Properties of simple covalent substances



- **Strong** covalent bonds _____ each molecule.
- **Weak** intermolecular forces of attraction _____ the molecules.
- Larger molecules have stronger forces between them, so higher melting and boiling points. At room temperature methane is a gas, bromine a liquid and iodine a solid.
- At low temperatures, some simple molecules form a lattice, as water does in ice.

Property	Explanation
Low melting and boiling points, often **volatile**	A _____ amount of energy overcomes the weak intermolecular forces.
Usually insoluble in water but soluble in organic solvents	They are neutral molecules.
Do not conduct electricity	No mobile ions or electrons. Hydrogen chloride conducts only after it dissolves in water and forms H^+ and Cl^-.

EXAM TIP When a simple covalent substance melts or boils, the weak intermolecular forces **between** molecules are overcome. The covalent bonds inside the molecules do not break.

5 Giant Covalent Structures

5.1 Simple and giant molecules

Simple molecules
A _____ number of atoms in a fixed ratio, e.g. H_2O, CO_2 and Br_2.

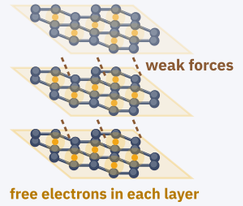
Giant molecules
An _____ number of atoms all joined by covalent bonds, e.g. diamond and silicon dioxide.

5.2 Diamond, graphite and silicon dioxide

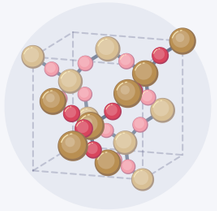
Allotropes are different forms of the same element with different arrangements of atoms. Diamond and graphite are allotropes of carbon.



diamond



graphite



silicon dioxide: Si larger, O smaller

	Diamond	Graphite	Silicon dioxide
Bonding	each C bonded to **4** C, tetrahedral	each C bonded to **3** C, in layers of hexagons	each Si bonded to 4 O, SiO_2, as in quartz and sand
Hardness	_____	soft and slippery	hard
Conducts?	no	_____	no

- Diamond coats drill bits and cutting tools. Graphite is used as a solid lubricant and in pencil lead.

5 Giant Covalent Structures (continued)

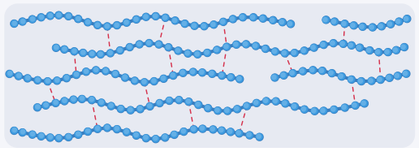
5.3 Properties of giant covalent substances

Property	Explanation
Very high melting and boiling points, solids	Many strong covalent bonds link all the atoms, so a _____ is needed to break them.
Graphite is **soft and slippery**	Only weak forces hold the layers together, so the layers _____ over each other.
Graphite **conducts** electricity	Each carbon uses 3 of its 4 outer electrons in bonds. The fourth is _____ and moves along the layers.
Diamond and silicon dioxide do not conduct	All outer electrons are used in bonds, so there are no mobile electrons.

- Giant covalent substances are insoluble in water and in organic solvents.

NOTE Graphene (a single layer of graphite), carbon nanotubes and fullerenes are other allotropes of carbon.

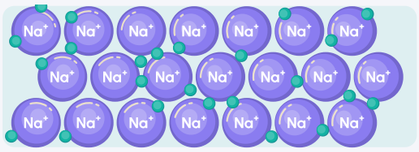
5.4 Macromolecules



- A **polymer** is many small molecules joined into long chains, e.g. poly(ethene), nylon, starch and silk.
- The chains have different lengths, so polymers have _____ _____ and soften gradually on heating.
- Most do not conduct electricity. Most are insoluble in water but soluble in organic solvents.

6 Metallic Bonding and Alloys

6.1 A sea of delocalised electrons



A **metallic bond** is the mutual electrostatic attraction between the _____ and the _____ _____.

- Metal atoms lose their outer electrons and form a **giant metallic lattice** of positive ions.
- The electrons no longer belong to any one atom. They are **delocalised** and move freely between the ions.
- Metal atoms form only positive ions, so ionic bonding between them is unlikely.

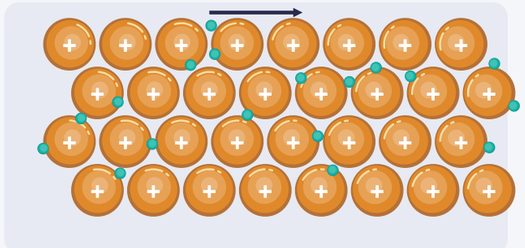
6 Metallic Bonding and Alloys (continued)

6.2 Properties of metals

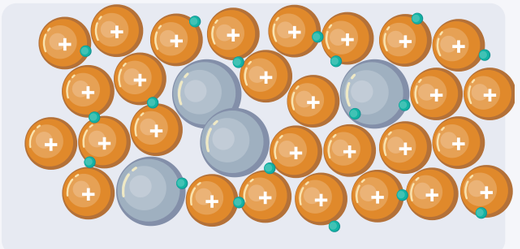
Property	Explanation
High melting and boiling points	The strong attraction between the ions and the delocalised electrons needs a _____ to overcome.
Conduct **electricity** as a solid and when molten	The delocalised electrons are _____ and carry the current.
Conduct **heat**	The delocalised electrons pass on thermal energy through the lattice.
Malleable and ductile	The layers of identical ions _____ over one another, and the sea of electrons keeps holding them together.

6.3 Alloys

An **alloy** is a mixture of a metal with one or more other elements.



pure metal: layers slide



alloy: different-sized atoms stop sliding

- Different-sized atoms _____ the orderly layers, so the layers cannot slide easily. Alloys are **harder and stronger** than the pure metal.
- An alloy is a mixture, so it melts over a _____ of temperatures. Its make-up is given as approximate percentages by mass, not as a formula.

WORKED EXAMPLE Brass is an alloy of copper and zinc. Explain why brass is harder than pure copper.

In pure copper, the layers of identical copper ions can **slide** over one another.

In brass, the zinc atoms are a **different size** and disrupt the orderly layers.

The layers cannot slide over one another easily, so brass is **harder**.

6 Metallic Bonding and Alloys (continued)

6.4 Uses of alloys

Alloy	Made from	Why it is used
bronze	copper and tin	harder and stronger, e.g. statues and bells
brass	copper and zinc	harder than copper
solder	tin and lead	lower melting point
steel	iron and carbon	harder than iron
stainless steel	iron, carbon, chromium, nickel	resists corrosion

7 Structure and Properties

7.1 The three types of bond

	Ionic	Covalent	Metallic
Between	metal and non-metal	non-metals	metal atoms
Electrons	_____	_____	_____
Held by attraction between	oppositely charged ions	a shared pair of electrons and both nuclei	positive ions and delocalised electrons

EXAM TIP To state the type of bonding, look at the elements: a metal and a non-metal are ionic, non-metals only are covalent, and a metal element is metallic.

7 Structure and Properties (continued)

7.2 Which type of structure is it?

	Ionic	Simple covalent	Giant covalent	Metallic
Particles	ions	molecules	atoms	ions and electrons
Melting point	high	_____	very high	high
Conducts	molten, aqueous	no	no (graphite yes)	solid and molten
Soluble in water	usually	usually not	no	no

1. Is the melting point low? Yes: a _____ substance. No: go on.

2. Does it conduct as a solid? Yes: a _____ or graphite. No: go on.

3. Does it conduct when molten or aqueous? Yes: an _____. No: a _____ substance.

NOTE A substance that melts over a range of temperatures is a mixture, such as an alloy, or a polymer.

WORKED EXAMPLE Solid A is an insulator but conducts when dissolved in water. Solid B is insoluble in water but conducts as a solid. What bonding do they have?

A conducts only when dissolved, so its ions are mobile in solution. A has **ionic** bonding.

B conducts as a solid, so it has mobile electrons. B has **metallic** bonding.

WORKED EXAMPLE Solids X, Y and Z are graphite, sodium chloride and silicon dioxide. X is soft and slippery and conducts electricity. Y and Z have very high melting points. Y conducts when dissolved in water but not as a solid. Z does not conduct. Identify X, Y and Z.

X conducts as a solid and is slippery, so X is **graphite**.

Y conducts only when dissolved, so it is ionic: Y is **sodium chloride**.

Z has a very high melting point but never conducts, so it is giant covalent: Z is **silicon dioxide**.