

Covalent Bonding

Some elements bond ionically (see page 47) but others form strong covalent bonds. This is where atoms share electrons with each other so that they've got full outer shells.

Covalent Bonds — Sharing Electrons

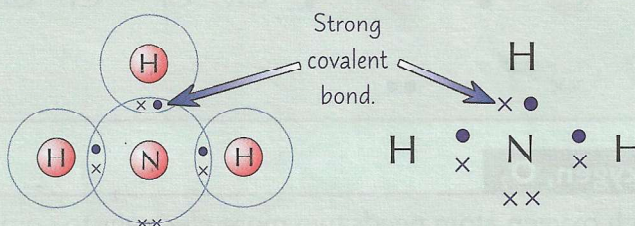
- 1) When non-metal atoms bond together, they share pairs of electrons to make covalent bonds.
- 2) The positively charged nuclei of the bonded atoms are attracted to the shared pair of electrons by electrostatic forces, making covalent bonds very strong.
- 3) Atoms only share electrons in their outer shells (highest energy levels).
- 4) Each single covalent bond provides one extra shared electron for each atom.
- 5) Each atom involved generally makes enough covalent bonds to fill up its outer shell. Having a full outer shell gives them the electronic structure of a noble gas, which is very stable.
- 6) Covalent bonding happens in compounds of non-metals (e.g. H_2O) and in non-metal elements (e.g. Cl_2).

There are Different Ways of Drawing Covalent Bonds

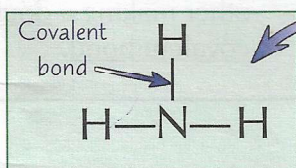
- 1) You can use dot and cross diagrams to show the bonding in covalent compounds.
- 2) Electrons drawn in the overlap between the outer orbitals of two atoms are shared between those atoms.
- 3) Dot and cross diagrams are useful for showing which atoms the electrons in a covalent bond come from, but they don't show the relative sizes of the atoms, or how the atoms are arranged in space.

You don't have to draw the orbitals in dot and cross diagrams. The important thing is that you get all the dots and crosses in the right places.

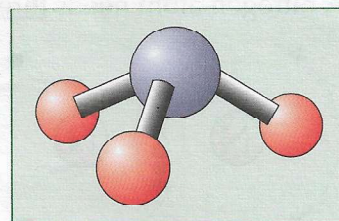
Nitrogen has five outer electrons...



...so it needs to form three covalent bonds to make up the extra three electrons needed.



- 4) The displayed formula of ammonia (NH_3) shows the covalent bonds as single lines between atoms.
- 5) This is a great way of showing how atoms are connected in large molecules. However, they don't show the 3D structure of the molecule, or which atoms the electrons in the covalent bond have come from.
- 6) The 3D model of ammonia shows the atoms, the covalent bonds and their arrangement in space next to each other. But 3D models can quickly get confusing for large molecules where there are lots of atoms to include. They don't show where the electrons in the bonds have come from, either.
- 7) You can find the molecular formula of a simple molecular compound from any of these diagrams by counting up how many atoms of each element there are.

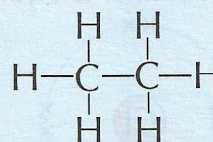


A molecular formula shows you how many atoms of each element are in a molecule.

EXAMPLE:

A diagram of the molecule ethane is shown on the right. Use the diagram to find the molecular formula of ethane.

In the diagram, there are two carbon atoms and six hydrogen atoms. So the molecular formula is C_2H_6 .



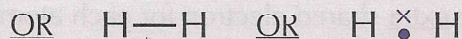
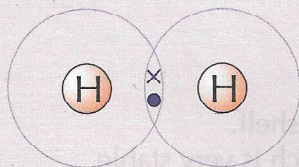
Covalent Bonding

Learn Some Examples of Simple Molecular Substances

Simple molecular substances are made up of molecules containing a few atoms joined together by covalent bonds. Here are some common examples that you should know...

Hydrogen, H_2

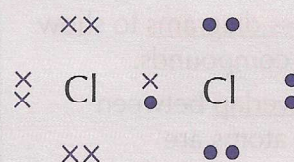
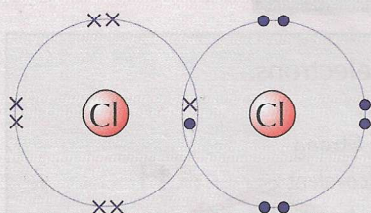
Hydrogen atoms have just one electron. They only need one more to complete the first shell...



...so they often form single covalent bonds, either with other hydrogen atoms or with other elements, to achieve this.

Chlorine, Cl_2

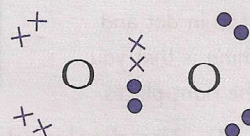
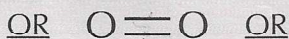
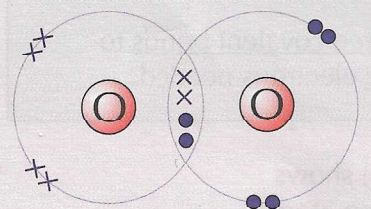
Each chlorine atom needs just one more electron to complete the outer shell...



...so two chlorine atoms can share one pair of electrons and form a single covalent bond.

Oxygen, O_2

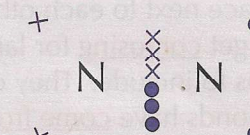
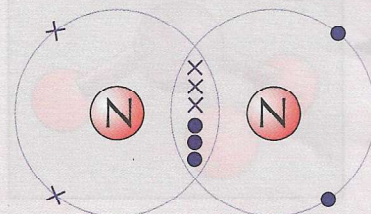
Each oxygen atom needs two more electrons to complete its outer shell...



...so in oxygen gas two oxygen atoms share two pairs of electrons with each other making a double covalent bond.

Nitrogen, N_2

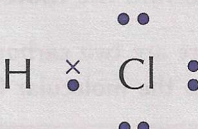
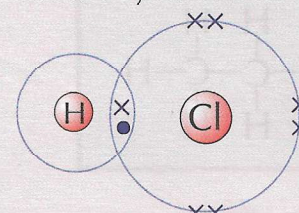
A nitrogen atom needs three more electrons to complete its outer shell...



...so two nitrogen atoms share three pairs of electrons to fill their outer shells. This creates a triple bond.

Hydrogen chloride, HCl

This is very similar to H_2 and Cl_2 ...

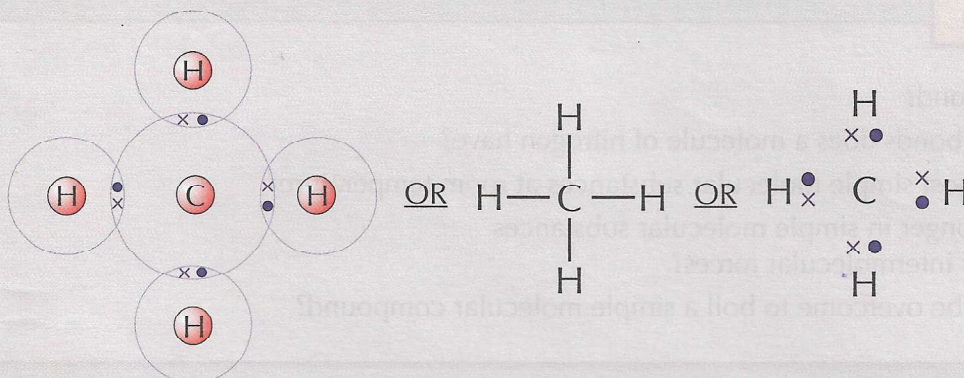


...again, both atoms only need one more electron to complete their outer shells.

Covalent Bonding

Methane, CH₄

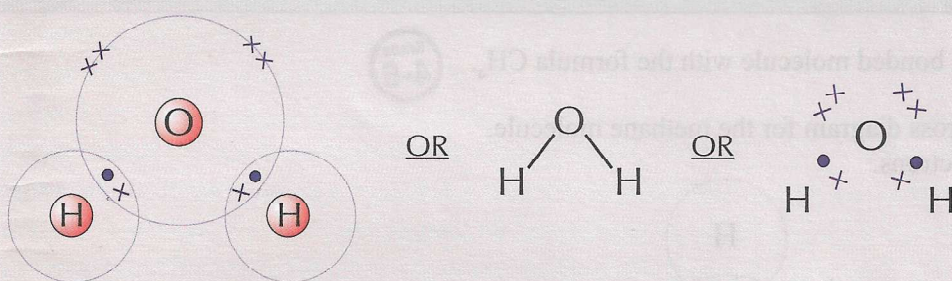
Carbon has four outer electrons, which is half a full shell...



It can form four covalent bonds with hydrogen atoms to fill up its outer shell.

Water, H₂O

Make sure you can also draw the dot and cross diagram of ammonia, NH₃, which is on page 53.

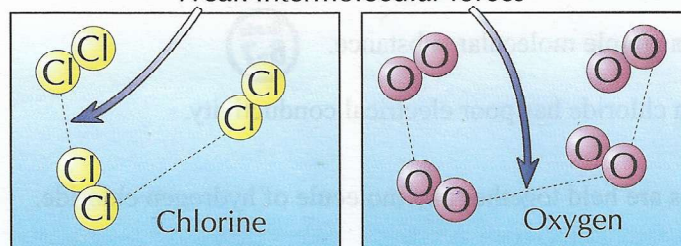


In water molecules, the oxygen shares a pair of electrons with two H atoms to form two single covalent bonds.

Properties of Simple Molecular Substances

- 1) Substances containing covalent bonds usually have simple molecular structures, like the examples shown above and on the previous page.
- 2) The atoms within the molecules are held together by very strong covalent bonds. By contrast, the forces of attraction between these molecules are very weak.
- 3) To melt or boil a simple molecular compound, you only need to break these feeble intermolecular forces and not the covalent bonds. So the melting and boiling points are very low, because the molecules are easily parted from each other.
- 4) Most molecular substances are gases or liquids at room temperature.
- 5) As molecules get bigger, the strength of the intermolecular forces increases, so more energy is needed to break them, and the melting and boiling points increase.
- 6) Molecular compounds don't conduct electricity, simply because they aren't charged, so there are no free electrons or ions.

Weak intermolecular forces



Covalent bonding involves sharing electrons

You might be asked to draw a dot and cross diagram for a simple molecule in the exam. The ones shown on the previous couple of pages are good ones to learn (oh, and ammonia is handy too).

Warm-Up & Exam Questions

The questions on this page are all about covalent bonding. Go through them and if you have any problems, make sure you look back at the relevant pages again until you've got to grips with it.

Warm-Up Questions

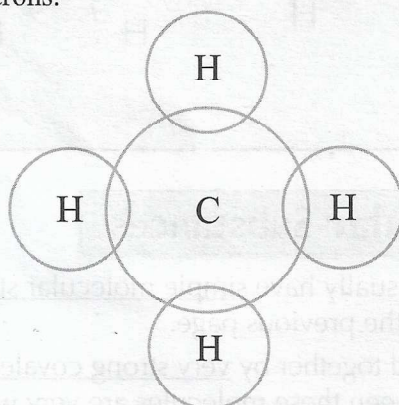
- 1) What is a covalent bond?
- 2) How many covalent bonds does a molecule of nitrogen have?
- 3) In which states are most simple molecular substances at room temperature?
- 4) Which forces are stronger in simple molecular substances — covalent bonds or intermolecular forces?
- 5) What forces need to be overcome to boil a simple molecular compound?

Exam Questions

- 1 Methane is a covalently bonded molecule with the formula CH_4 .



Complete the dot and cross diagram for the methane molecule.
Show only the outer electrons.



[2 marks]

- 2 Dot and cross diagrams can be used to show the position of electrons in covalent molecules.



- 2.1 Draw a dot and cross diagram for oxygen (O_2). Only show the outer electrons.

[2 marks]

- 2.2 Nitrogen is in Group 5 of the periodic table.

How many bonds does it need to make to gain a full outer shell?

[1 mark]

- 3 Hydrogen chloride is a simple molecular substance.



- 3.1 Explain why hydrogen chloride has poor electrical conductivity.

[1 mark]

- 3.2 Explain how the atoms are held together in a molecule of hydrogen chloride.

[2 marks]

- 3.3 A molecule of hydrogen chloride has a stronger bond than a molecule of chlorine (Cl_2). However, hydrogen chloride boils at -85°C , whereas chlorine boils at -34°C . Suggest and explain why chlorine has a higher boiling point than hydrogen chloride.

[3 marks]

Polymers

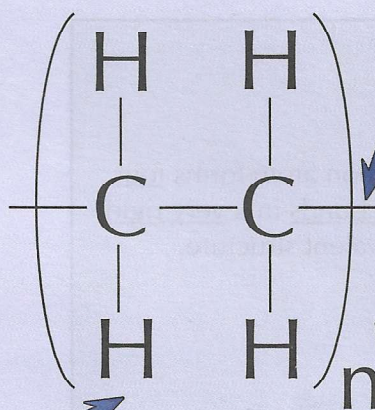
Most polymers are held together with covalent bonds. However, these molecules are a bit different to the simple covalent compounds you have already met...

Polymers Are Long Chains of Repeating Units

- 1) In a polymer, lots of small units are linked together to form a long molecule that has repeating sections. All the atoms in a polymer are joined by strong covalent bonds.

Instead of drawing out a whole long polymer molecule (which can contain thousands or even millions of atoms), you can draw the shortest repeating section, called the repeating unit, like this:

This polymer is called 'poly(ethene)'.



The bonds through the brackets join up to the next repeating unit.

'n' is a large number. It tells you that the unit's repeated lots of times.

The bit in brackets is the repeating unit.

To find the molecular formula of a polymer, write down the molecular formula of the repeating unit in brackets, and put an 'n' outside.

So for poly(ethene), the molecular formula of the polymer is $(C_2H_4)_n$.

- 2) The intermolecular forces between polymer molecules are larger than between simple covalent molecules, so more energy is needed to break them. This means most polymers are solid at room temperature.

- 3) The intermolecular forces are still weaker than ionic or covalent bonds, so they generally have lower boiling points than ionic or giant molecular compounds.

There's more about how polymers are made on p.141 and p.148 and more about their properties and uses on p.173.

Polymers are very large molecules

Make sure you can work out the molecular formula of a polymer. To do this you need to be comfortable with what the repeating unit of a polymer is. There's more on the repeating units of polymers on page 142.

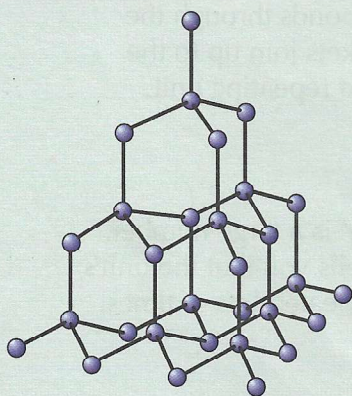
Giant Covalent Structures

Polymers and simple molecular substances aren't the only compounds held together by covalent bonds. Giant covalent structures are too — some are found in nature, while others can be made in a lab.

Giant Covalent Structures Are Macromolecules

- 1) In giant covalent structures, all the atoms are bonded to each other by strong covalent bonds.
- 2) They have very high melting and boiling points as lots of energy is needed to break the covalent bonds between the atoms.
- 3) They don't contain charged particles, so they don't conduct electricity — not even when molten (except for a few weird exceptions such as graphite, see next page).
- 4) The main examples are diamond and graphite, which are both made from carbon atoms only, and silicon dioxide (silica).

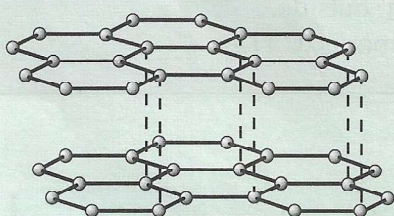
Diamond



Each carbon atom forms four covalent bonds in a very rigid giant covalent structure.

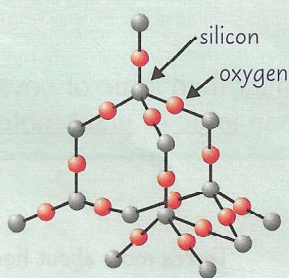
There's more about diamond and graphite, as well as other types of carbon structure on the next page.

Graphite



Each carbon atom forms three covalent bonds to create layers of hexagons. Each carbon atom also has one delocalised (free) electron.

Silicon dioxide



Sometimes called silica, this is what sand is made of. Each grain of sand is one giant structure of silicon and oxygen.

Giant covalent structures have high melting and boiling points

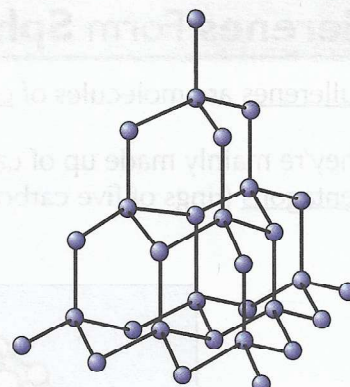
To melt or boil a giant covalent structure, you have to break very strong covalent bonds. The high melting and boiling points of diamond, graphite and silicon are caused by the strength of their covalent bonds.

Allotropes of Carbon

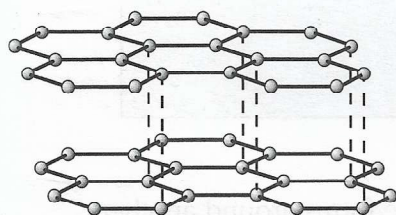
Allotropes are just different structural forms of the same element in the same physical state, e.g. they're all solids. Carbon has quite a few allotropes with lots of different properties.

Diamond is Very Hard

- 1) Diamond has a giant covalent structure, made up of carbon atoms that each form four covalent bonds. This makes diamond really hard.
- 2) Those strong covalent bonds take a lot of energy to break and give diamond a very high melting point.
- 3) It doesn't conduct electricity because it has no free electrons or ions.



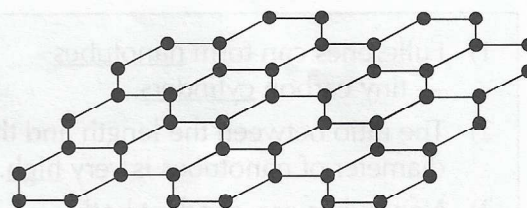
Graphite Contains Sheets of Hexagons



- 1) In graphite, each carbon atom only forms three covalent bonds, creating sheets of carbon atoms arranged in hexagons.
- 2) There aren't any covalent bonds between the layers — they're only held together weakly, so they're free to move over each other. This makes graphite soft and slippery, so it's ideal as a lubricating material.
- 3) Graphite's got a high melting point — the covalent bonds in the layers need loads of energy to break.
- 4) Only three out of each carbon's four outer electrons are used in bonds, so each carbon atom has one electron that's delocalised (free) and can move. So graphite conducts electricity and thermal energy.

Graphene is One Layer of Graphite

- 1) Graphene is a sheet of carbon atoms joined together in hexagons.
- 2) The sheet is just one atom thick, making it a two-dimensional compound.
- 3) The network of covalent bonds makes it very strong. It's also incredibly light, so can be added to composite materials to improve their strength without adding much weight.
- 4) Like graphite, it contains delocalised electrons so can conduct electricity through the whole structure. This means it has the potential to be used in electronics.



Diamond, graphite and graphene contain exactly the same atoms

The different substances on this page are made purely from carbon — there's no difference at all in their atoms. The difference in properties is all down to the way the atoms are held together.