6National 4/5 Chemistry

Unit 1b - Chemical Changes and Structure

Kirkcaldy High School

2013/2014

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Compounds (N4*)

Aim: What happens when elements join together?

Carry out Activity 1.12

A **compound** is a substance that is made up of two or more elements that are chemically joined together. Since they are joined together, it is difficult to separate out the elements that make up the compound … energy must be supplied to do this, *e.g.* silver oxide can be broken up into silver and oxygen by heat energy, electrical energy can be used to break up copper chloride solution.

Most of the substances that exist are not elements … they are compounds. A compound is very different from the elements that make it up, *e.g.* sugar (a white solid) is made from carbon (a black solid) and hydrogen and oxygen (both colourless gases), salt (another white solid) is made up of sodium (a very reactive metal) and chlorine (a poisonous green gas).

What is meant by a compound?

YOU MAY WISH TO REFER TO A PERIODIC TABLE.

Complete the following two tables.

Substance	Element or compound
copper	
salt	
water	
sugar	
iron	
oxygen	
alcohol	
sulphur	

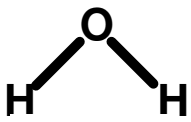
Substance	Element or compound
sodium oxide	
aluminium	
carbon chloride	
hydrogen	
argon	
potassium nitrate	
chlorine	
calcium carbonate	

Covalent bonding (N4*)

Aim: How do atoms join together?

Activty 1.13 use molecular model kits

The join between different atoms in an element or a compound is called a bond. One kind of bond is called a **covalent bond**, *e.g.* in water, a compound of hydrogen and oxygen, there are two **single covalent bonds** between hydrogen and oxygen atoms, each represented with a line (-).



single covalent bonds

A group of atoms held together by covalent bonds is called a **molecule**.

A substance made up of molecules has covalent bonds holding the atoms together.

Covalent bonds form when atoms of non-metal elements join with other atoms of non-metal elements. A covalent compound is a substance with covalent bonds.

double covalent bonds

Some molecules have more than one covalent bond between the same atoms, *e.g.* in carbon dioxide, a compound of carbon and oxygen, there are two **double covalent bonds** between carbon and oxygen atoms, each represented with two lines (=).

one triple covalent bond; two single covalent bonds

Some molecules have a **triple covalent bond** between atoms (≡), *e.g.* in acetylene, a compound of carbon and hydrogen, there is a triple covalent bond between the carbon atoms and two single covalent bonds between carbon and hydrogen atoms.

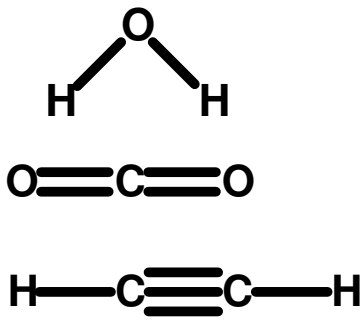
What is meant by a molecule?

Atoms of what kind of elements form covalent bonds?

Chemical formulae (N4*)

Aim: How can we represent the atoms in a molecule?

The **chemical formula** for a covalent substance gives the number of atoms of each element in a molecule. The number of atoms of each element in the molecule is indicated by a subscript after the symbol of the element (the subscript "1" is not written in).



Each molecule of water has two hydrogen atoms and one oxygen atom so the chemical formula for water is H_2O.

The chemical formula for carbon dioxide is CO_2.

The chemical formula for acetylene is C_2H_2.

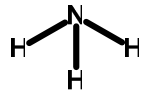
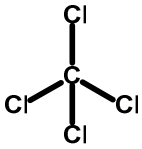
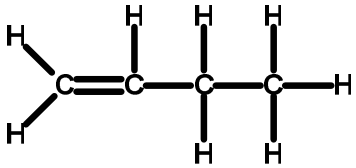
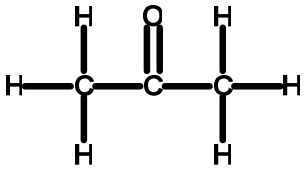
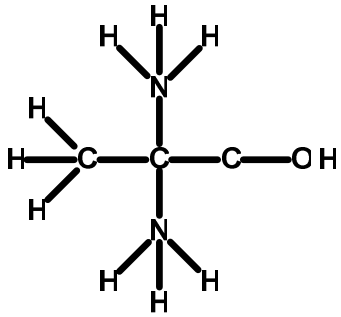
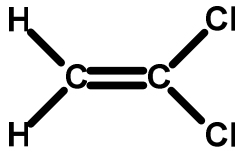
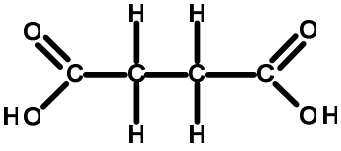
What information is given by the chemical formula for a covalent substance?

The chemical formula tells us the number and type of atoms present in the

Complete the following table.

Number of atoms of each kind of element	**Chemical formula**
one nitrogen/three hydrogen	
two hydrogen/one sulphur	
three carbon/eight hydrogen/one oxygen	
	CCl_4
	$C_2H_4O_2$
	C_3H_9N

Now write the chemical formula for each of the following compounds.
A molecule of each compound is shown.

Structure	Formula
	
	
	
	
	
	
	

Diatomic molecules (N4*)

Aim: What happens when two atoms join together?

Molecules made up of only two atoms are called **diatomic molecules** (two atom), *e.g.* hydrogen chloride, HCl (one carbon atom and one chlorine atom), and carbon monoxide, CO, (one carbon atom and one oxygen atom).

Certain elements normally exist as diatomic molecules. Since diatomic molecules contain two atoms, the chemical formula for an element that is made up of diatomic molecules is X_2, where X is the symbol for the element, *e.g.* hydrogen is written H_2.

Hydrogen has a single covalent bond between the two atoms in the molecule: **H-H**

Oxygen has a double covalent bond between the two atoms in the molecule: **O=O**

Nitrogen has a triple covalent bond between the two atoms in the molecule: **N≡N**

Complete the following table to show the seven common elements in the Periodic Table that exist as diatomic molecules.

Element	Chemical formula
Oxygen	
Nitrogen	
Fluorine	
Chlorine	
Hydrogen	
Iodine	
Bromine	

How are you going to remember these elements?

Find astatine (atomic number 85) in the Periodic Table. Do you think astatine is likely to exist as atoms or molecules? Explain.

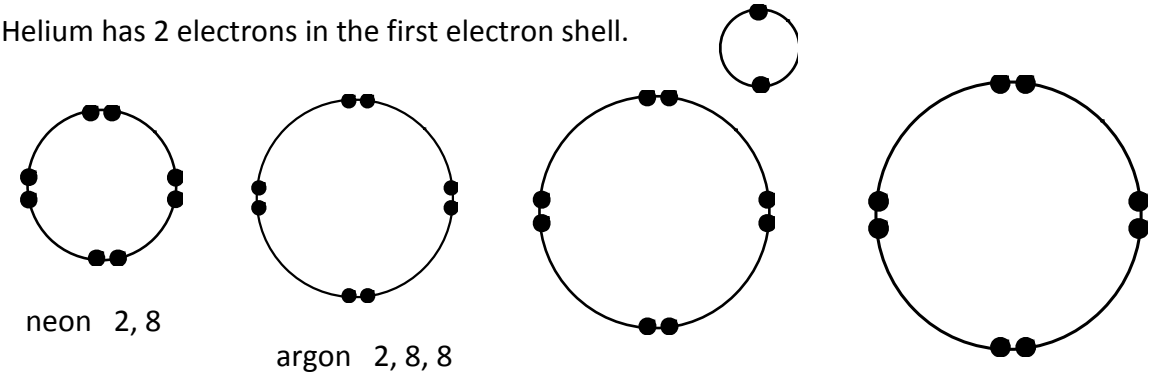
Covalent bonding – using outer electron shells (N4*)

Aim: How do atoms form covalent bonds?

The noble gases are **unreactive** elements.

Atoms of these elements have **filled outer electron shells (energy levels)**.

Helium has 2 electrons in the first electron shell.



neon 2, 8

argon 2, 8, 8

krypton 2, 8, 8, 8

xenon 2, 8, 8, 8, 8

Neon, argon, krypton and xenon have 8 electrons in the outer electron shell.

Covalent bonding involves the sharing of pairs of outer electrons between two non-metal atoms.

This enables the atoms that are bonded together to have the same electron arrangement as a noble gas.

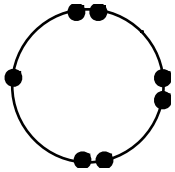
Only electrons in the outer energy level (the outside of the atom) are involved in the sharing.

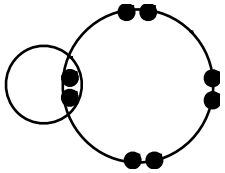
An electron sharing diagram can be used to show the sharing of electron pairs that make up covalent bonds. This can also be used to write the chemical formula for a covalent compound.

Example 1: hydrogen chloride

H
electron arrangement
1

Cl
electron arrangement
2. 8. 7



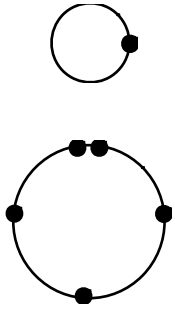


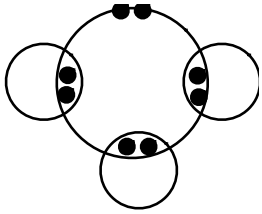
hydrogen chloride, HCl

In the molecule, the hydrogen can be considered to have 2 electrons in the first electron shell; in the molecule, the chlorine atom can be considered to have 8 electrons in the third electron shell.

Example 2: nitrogen hydride

H
electron arrangement
1





nitrogen hydride, NH_3

N
electron arrangement
2, 5

In the molecule, the hydrogen can be considered to have 2 electrons in the first electron shell; in the molecule, the nitrogen atom can be considered to have 8 electrons in the second electron shell.

Draw electron sharing diagrams to show the sharing of electron pairs that make up covalent bonds in molecules of each of the following compounds.

Use the diagram to write the chemical formula.

carbon chloride

sulphur fluoride

hydrogen fluoride

hydrogen oxide

carbon dioxide

phosphorus hydride

Electron clouds (N5)

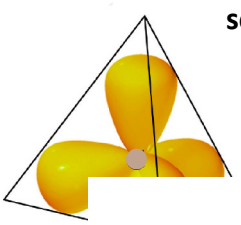
Aim: Why are molecules three-dimensional?

An electron cloud (or orbital) is a region of space in which one or two electrons can be found. A good model of an electron cloud is an inflated balloon without a skin and with no air in it. One (or two) electrons, like flies, can buzz around inside!

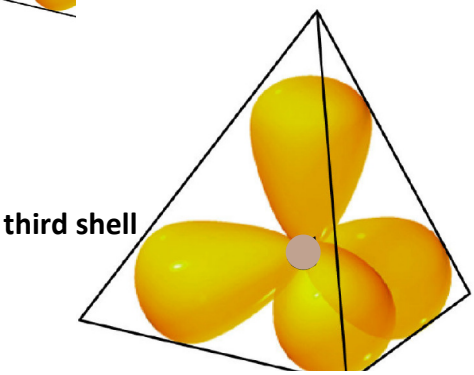
Electron clouds have particular shapes depending on the electron shell (energy level).

The electron cloud of the first shell (the one closest to the nucleus) is shaped like a sphere.

The four clouds of the second shell point towards the corners of a tetrahedron.



The third shell is an even larger tetrahedral shape. Each cloud can hold one or two electrons.



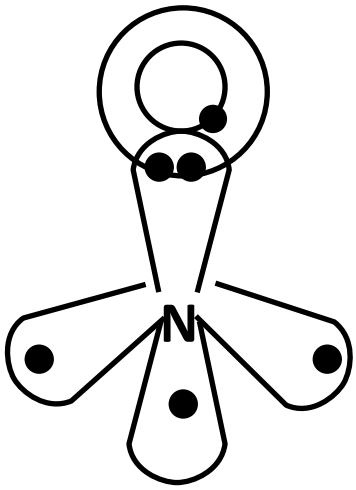
One electron in a half-filled cloud is unpaired; two electrons in a filled cloud are paired.

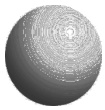
Electrons fill up electron clouds by entering empty clouds where possible,

i.e. pairing in the second and third shells only takes place when all four clouds are half-filled.

Using electron clouds, the arrangement for the one electron in a hydrogen atom can be represented:

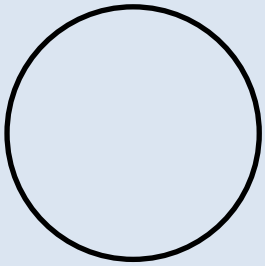
Using electron clouds, the arrangement for the five electrons in the outer shell of a nitrogen atom can be represented:



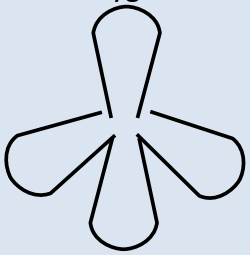


Draw a diagram to show the shape made by the outer electron cloud(s) in each of the following atoms. Go on to show how the outer electrons are arranged.

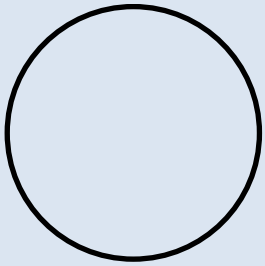
Sodium



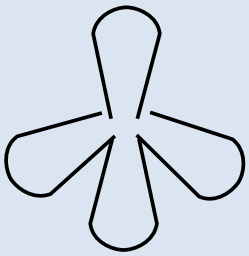
Oxygen



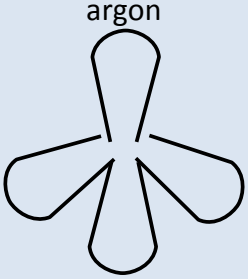
helium



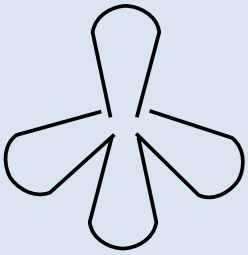
aluminium



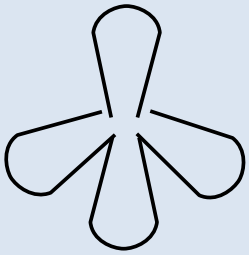
argon



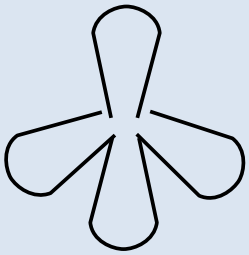
boron



fluorine



carbon



Covalent bonding - using electron clouds (N5)

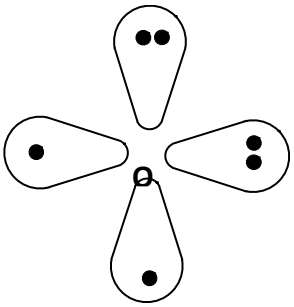
Aim: How do electron clouds make covalent bonds?

Atoms in a molecule have the stable electron arrangement of a noble gas. The covalent bonds are formed by the merging of half-filled outer electron clouds so that the electrons are shared in pairs.

When drawing diagrams to show how the outer electron clouds merge to form covalent bonds, the clouds tend to be drawn flattened down.

Hydrogen oxide

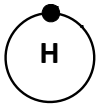
An atom of oxygen (atomic number 8) has 8 electrons arranged 2, 6.



The electrons in the outer shell are arranged in clouds that can be flattened down as shown.

The noble gas nearest to oxygen is neon (atomic number 10) with the 10 electrons arranged 2, 8.

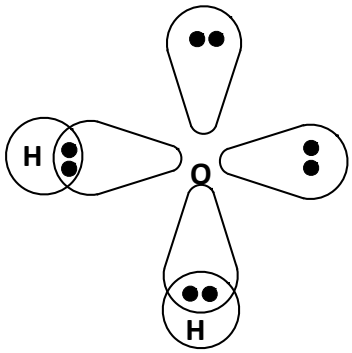
An atom of hydrogen (atomic number 1) has 1 electron in the first shell. This electron is in a flattened-down cloud shaped as shown.



The noble gas nearest to hydrogen is helium with 2 electrons in the outer shell.

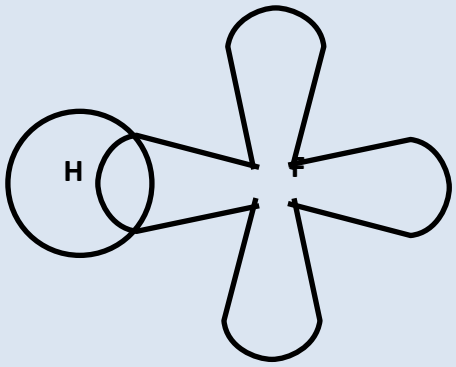
In a molecule of hydrogen oxide, one oxygen atom is joined to two atoms of hydrogen by the merging of half-filled clouds as shown.

Both atoms in the molecule can be considered to have the stable electron arrangement of a noble gas.

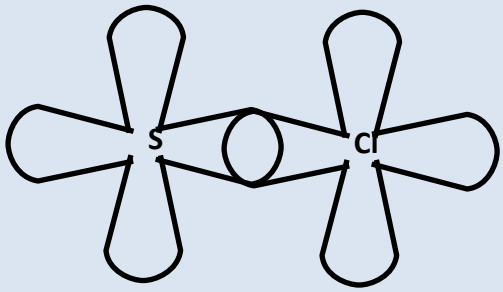


Draw diagrams to show how the outer electron clouds merge to form covalent bonds and hence obtain the formula for each of the following compounds.

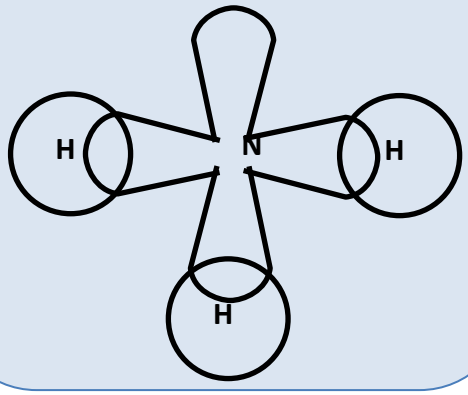
hydrogen fluoride



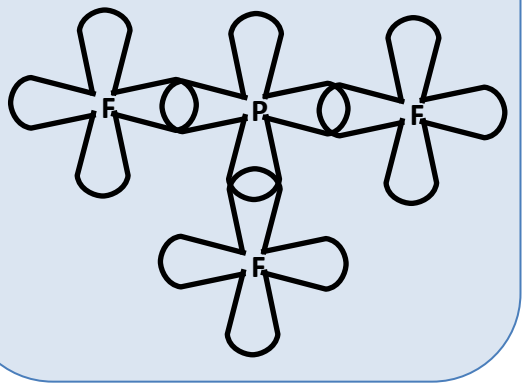
sulphur chloride



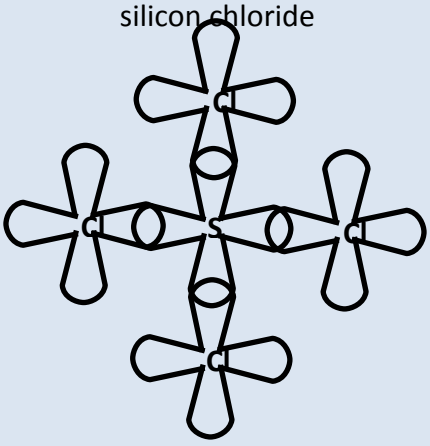
nitrogen hydride



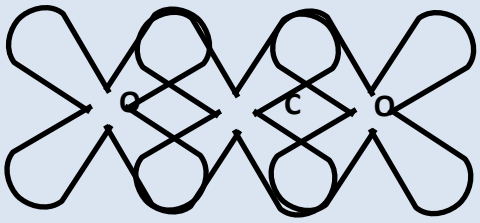
phosphorus fluoride



silicon chloride



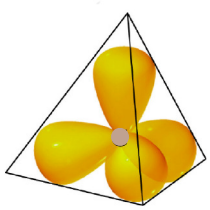
carbon dioxide



Shapes of molecules (N5)

Aim: What shapes are molecules?

The chemical formula for a covalent substance indicates the number of atoms of each element in the molecule.



It does not give any information about the shape of the molecules.

The shapes of molecules are based on the tetrahedron arrangement of electrons.

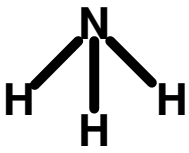
In some molecules the atoms are arranged in a straight line (linear),

e.g. hydrogen chloride, HCl.

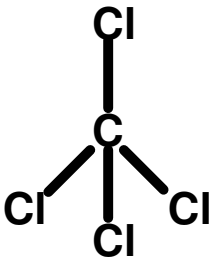
Some molecules are two dimensional (flat), *e.g.* water, H_2O.

Others are three-dimensional, *e.g.*

nitrogen hydride, NH_3



carbon tetrachloride, CCl_4



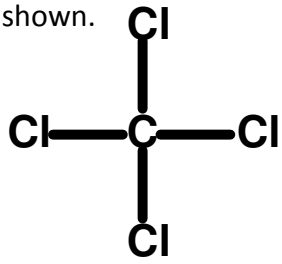
The **full structural formula** shows the shape of a molecule.

When drawing the full structural formula, an atom is shown by the symbol of the element. The structures are written so that the number of covalent bonds to each atom is shown.

Molecules are drawn 'flattened-down".

The structure of carbon tetrachloride is flattened down to look like:

This is the full structural formula.



What is the difference between the chemical formula and the full structural formula?

Diatomic molecules – the elements (N5)

Aim: Which elements form diatomic molecules?

Carry out Activity 1.14

The seven common elements that exist as molecules made up of two-atom units are hydrogen (H_2), oxygen (O_2), nitrogen (N_2), fluorine (F_2), chlorine (Cl_2), bromine (Br_2) and iodine (I_2).

In five elements, the two atoms in the molecule share electrons to form one covalent bond:

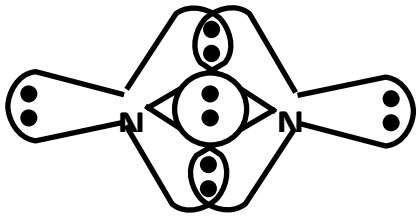
In oxygen, the two atoms in the molecule share electrons to form two covalent bonds:

In nitrogen, the two atoms in the molecule share electrons

to form three covalent bonds:

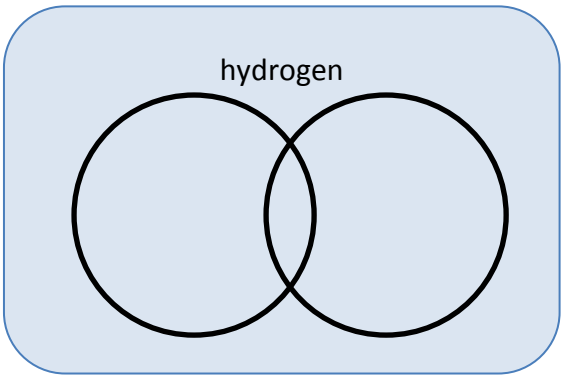
By the sharing of the outer electrons, atoms of these elements can be considered to have the outer electron arrangement of a noble gas.

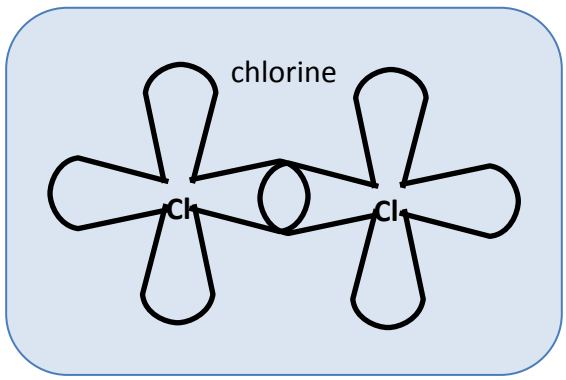
We have to think in terms of the three-dimensional arrangement of electron clouds in nitrogen to appreciate why the two atoms in the diatomic molecule form a triple covalent bond.

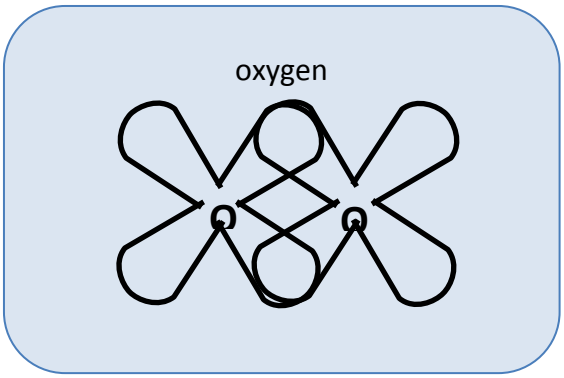


nitrogen

Draw diagrams to show how the outer electron clouds of each of the following merge to form covalent bonds.






oxygen

Energy considerations (N5)

Aim: Why are covalent bonds strong?

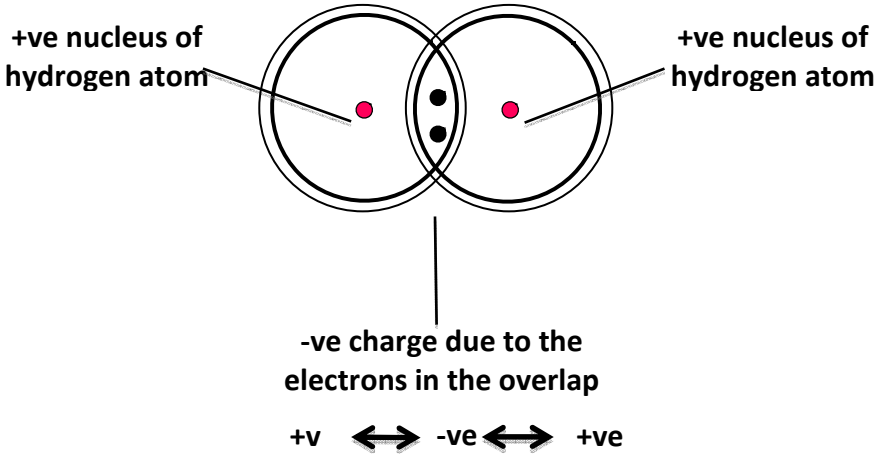
The protons give a positive charge to the nucleus of the atom.

The electrons give a negative charge to the part of the atom surrounding the nucleus.

In a covalent bond the sharing of electron pairs (merging of half-filled clouds) increases the negative charge in the overlap region.

The forces of attraction between the positive nuclei of both atoms and the electrons in the overlap region holds the atoms together,

e.g. hydrogen



A lot of energy is required to overcome the forces of attraction, *i.e.* to break covalent bonds. Covalent bonds are strong.

What is it that holds the atoms together in a covalent bond?

Why are covalent bonds difficult to break?

Covalent compounds with meaningful names (N4*)

Aim: How can we name covalent compounds?

The formula for some covalent compounds is indicated by the prefix in the second part of the name.

Prefix	**Meaning**
mono	one
di	two
tri	three
tetra	four
penta	five
hexa	six

Complete the table by writing the formula for each of the compounds.

Name	Formula
carbon dioxide	CO_2
carbon monoxide	
sulphur trioxide	
phosphorus pentachloride	
carbon tetrachloride	
uranium hexafluoride	

Writing formulae – using combining powers (valency) (N4*)

Aim: How can we write a chemical formula using valencies?

The chemical formula for a compound can always be worked out by considering the bonding. There is, however, a shorter method which uses the combining powers (valency). This method works for both covalent and ionic compounds

The combining power of an element can be found from the groups in the Periodic Table.

Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**	**Group 6**	**Group 7**
1	2	3	4	3	2	1

For metals that show variable charge the combining power corresponds to the charge on the ion,

e.g. in iron(II) oxide the combining power of the iron ion is 2,

in copper(I) oxide the combining power of the copper ion is 1.

For group ions, the combining power corresponds to the charge on the ion,

e.g. in SO_4^{2-} the combining power of the ion is 2,

in NO^{3-} the combining power of the ion is 1.

Example 1: hydrogen sulphide

Step 1 Write atoms with combining powers in this form:

1 2

H S

Step 2 Exchange the combining powers

1 2

H S

Step 3 Ignore the number 1 to give the chemical formula **H_2S**

Example 2: potassium sulphate

Step 1 Write atoms and group ion (in brackets) with combining powers:

1 2

K (SO_4)

Step 2 Exchange the combining powers

1 2

K (SO_4)

Step 3 Ignore the number 1 to give the chemical formula **$K_2(SO_4)$ or K_2SO_4**

Example 3: magnesium nitrate

Step 1 Write atoms and group ion (in brackets) with combining powers: 2 1

Mg (NO_3)

Step 2 Exchange the combining powers 2 ~~1~~

Mg (NO_3)

Step 3 Ignore the number 1 to give the chemical formula **$Mg(NO_3)_2$**

An extra step is sometimes necessary when the combining powers have a common denominator.

Example 4: silicon oxide

Step 1 Write atoms with combining powers: 4 2

Si O

Step 2 Cancel the numbers 4 and 2 to give 2 and 1 2 1

Si O

Step 3 Exchange the combining powers 2 ~~1~~

Si O

Step 4 Ignore the number 1 to give the chemical formula **SiO_2**

Write the formula for each of the following substances.

hydrogen fluoride

Combining powers

Atoms

aluminium chloride

Combining powers

Atoms

phosphorus chloride

Combining powers

Atoms

calcium oxide

Combining powers

Atoms

silicon iodide

Combining powers

Atoms

selenium fluoride

Combining powers

Atoms

iron(III) bromide

Combining powers

Atoms

Sodium carbonate

Combining powers

Atom/group ion

lead(II) hydroxide

Combining powers

Atom/group ion

ammonium nitrate

Combining powers

Atom/group ion

rubidium iodide

Combining powers		
Atoms		

barium sulphate

Combining powers		
Atom/group ion		

magnesium nitride

Combining powers		
Atoms		

ammonium phosphate

Combining powers		
Atom/group ion		

magnesium hydrogencarbonate

Combining powers		
Atom/group ion		

copper(II) carbonate

Combining powers		
Atom/group ion		

Writing formulae for covalent compounds (N4*)

Aim: How can we write the formula for a covalent compound?

Covalent compounds are (usually) made up of atoms of non-metal elements.

The formula for covalent compounds can be found by drawing electron sharing diagrams. These can be based on the sharing of electron pairs by the merging of outer electron shells.

The following is a quick way to write the formula for a covalent compound. It is based on the number of bonds that an atom forms. This is equal to the number of 'extra' electrons that an atom requires to reach the same electron arrangement as a noble gas.

	Group 4	**Group 5**	**Group 6**	**Group 7**
Number of outer electrons	4	5	6	7
Number of 'extra' electrons	4	3	2	1
Number of bonds formed	4	3	2	1

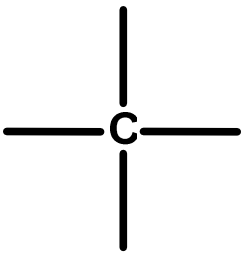
An atom of hydrogen is 1 electron short of an atom of helium so **hydrogen forms 1 bond**.

Example: carbon fluoride

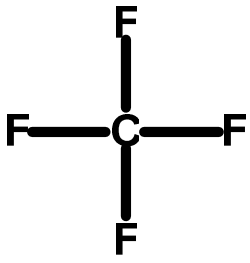
Step 1 Use the Periodic Table to write symbols for the elements.

C F

Step 2 Use the Periodic Table to put in the number of bonds which will be formed by each atom.



Step 3 Complete the bonding picture.



Step 4 Write the formula **CF_4**

Write the formula for each of the following covalent compounds.

hydrogen chloride

phosphorus fluoride

nitrogen hydride

selenium hydride

silicon chloride

carbon iodide