Unit 8 Covalent bonds

Covalent bonds

Ionic bonds are formed by the **transfer of electrons** from metal atoms to non-metal atoms.
Covalent bonds are formed by the **sharing of electrons** between non-metal atoms.

Covalent bonds in non-metallic elements

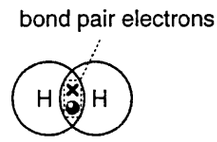
Atoms of non-metallic elements can join together to form groups called **molecules**. When the same kinds of atoms join together, they form a molecule of an element.

The hydrogen molecule

A hydrogen atom has an electronic arrangement of 1. It needs one more electron to obtain the electronic arrangement of a stable helium atom (2).
A hydrogen atom can obtain the stable electronic configuration of helium by sharing its only one outermost shell electron with another hydrogen atom. A stable **molecule** is formed. Each hydrogen molecule consists of **two atoms**, so it can be called a **diatomic molecule**.

A molecule is usually made of a group of atoms which are held together by covalent bonds. However, a **molecule which consists of one atom** only (**monatomic molecule**) does exist. As noble gases exist as single atoms which are stable, we can also say noble gases exists as monatomic molecules.

The shared pair of electrons will attract and hold the two positively charged nuclei of hydrogen atoms together. A covalent bond is formed. Bonds in which only **one pair of electrons is shared** are called **single bonds**.

Electron diagrams of the two hydrogen atoms		Electron diagram of a hydrogen molecule
		

A **covalent bond** is formed when one or more pairs of outermost shell **electrons are shared** between two atoms.

A **covalent bond** is the **strong electrostatic forces of attraction** between the **shared electrons and** the **two positively charged nuclei** of the bonding atoms.

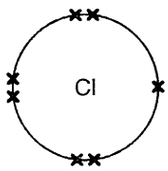
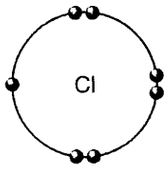
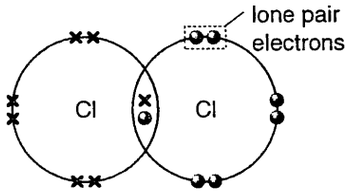
The pair of electrons shared between two atoms is called **bond pair electrons**.

Representations of hydrogen molecule

1. by names - **hydrogen molecule**
2. by formula
   a) **molecular formula** (The molecular formula of a substance gives the actual number of each elements in each molecule of the substance.) **H_2**
   b) **structural formula** (The structural formula of a substance gives the actual number of each elements and the ways that the covalent bonds are formed between the atoms in each molecule of the substance.) **H—H**
   The '**—**' means that the two hydrogen atoms are joined together by a **single bond**.

The chlorine molecule

A chlorine atom has an electronic arrangement of 2,8,7. It needs one more electron to obtain the electronic arrangement of a stable argon atom (2,8,8). Just like hydrogen atom, each chlorine atom can obtain the stable electronic arrangement by sharing one of its outermost shell electrons with another chlorine atom.

Electron diagrams of the two chlorine atoms (showing the outermost shell only)		Electron diagram of a chlorine molecule (showing the outermost shell only)
		

In a chlorine molecule, each chlorine atom has three electron pairs in the outermost shell that are not involved in the bonding.

The pair of electrons in the outermost shell that is **not involved in bonding** is called **lone pair electrons**.

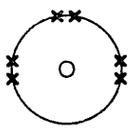
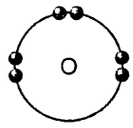
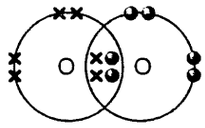
Representations of chlorine molecule

Name	Molecular formula	Structural formula
Chlorine molecule	Cl_2	Cl—Cl

The oxygen molecule

An oxygen atom has an electronic arrangement of 2,6. It needs two more electrons to obtain the electronic arrangement of a stable neon atom (2,8). Each oxygen atom can obtain the electronic arrangement of neon atom by sharing two of its electrons with another hydrogen atom.

Since the oxygen atoms in the oxygen molecule **shared two pairs of electrons**, the bond between them is called a **double bond**.

Electron diagrams of the two oxygen atoms (showing the outermost shell only)		Electron diagram of an oxygen molecule (showing the outermost shell only)
		

Representations of oxygen molecule

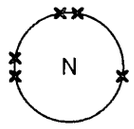
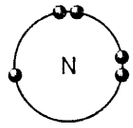
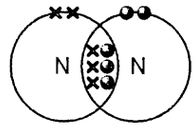
Name	Molecular formula	Structural formula
Oxygen molecule	O_2	O=O

The '**=**' means that the two oxygen atoms are joined together by a **double bond**.

The nitrogen molecule

A nitrogen atom has an electronic arrangement of 2,5. It needs three more electrons to obtain the electronic arrangement of a stable neon atom (2,8).Each nitrogen atom can obtain the electronic arrangement of a neon atom by sharing three of its outermost shell electrons with another nitrogen atom.

Since the nitrogen atoms **share three pairs of electrons**, the bond between them is called a **triple bond**.

Electron diagrams of the two nitrogen atoms (showing the outermost shell only)		Electron diagram of a nitrogen molecule (showing the outermost shell only)
		

Representations of nitrogen molecule

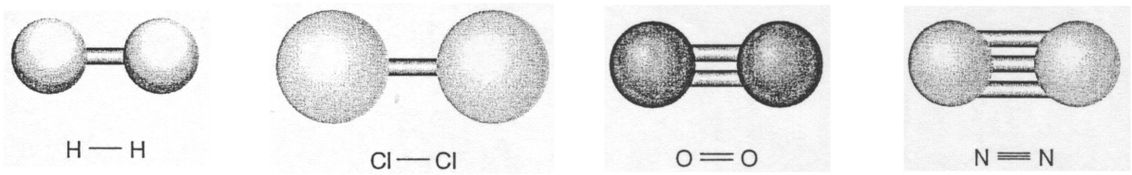
Name	Molecular formula	Structural formula
Nitrogen molecule	N_2	N≡N

The '≡' means that the two nitrogen atoms are joined together by a **triple bond**.

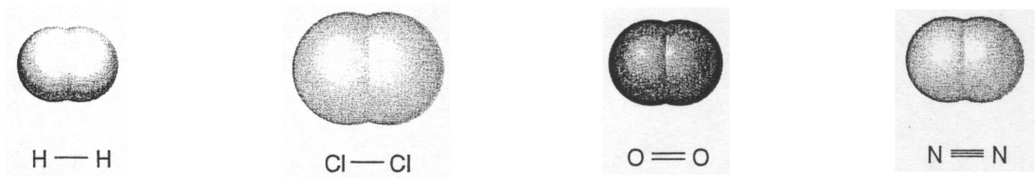
A bond in which **one pair of electrons is shared** between two atoms is called a **single bond**.
A bond in which **two pairs of electrons are shared** between two atoms is called a **double bond**.
A bond in which **three pairs of electrons are shared** between two atoms is called a **triple bond**.

Molecular models

We can build models of the molecules. The simplest models are ball-and stick models. E.g.



To get a more accurate idea of how close together the atoms in a molecule are, we use space-filling models. E.g.

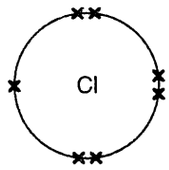
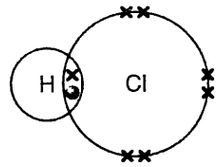


Covalent compounds

Atoms of different non-metallic elements can also join together to form molecules by sharing their outermost shell electrons. If the molecule is formed by atoms of more than one element, a compound is obtained. The kinds of **compounds formed by non-metallic elements through covalent bonds formation** are called **covalent compounds**. The following are examples.

The hydrogen chloride molecule

A hydrogen atom has an electronic arrangement of 1. It needs one more electron to obtain the electronic arrangement of a stable helium atom (2).
A chlorine atom has an electronic arrangement of 2,8,7. It needs one more electron to obtain the electronic arrangement of a stable argon atom (2,8,8).
A hydrogen atom can then form a single bond with a chlorine atom to form a hydrogen chloride molecule.

Electron diagram (showing the outermost shell only) of hydrogen atom	Electron diagram (showing the outermost shell only) of chlorine atom	Electron diagram (showing the outermost shell only) of hydrogen chloride
		

Representations of hydrogen chloride molecule

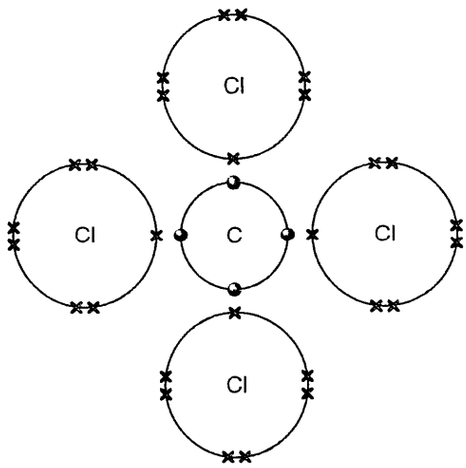
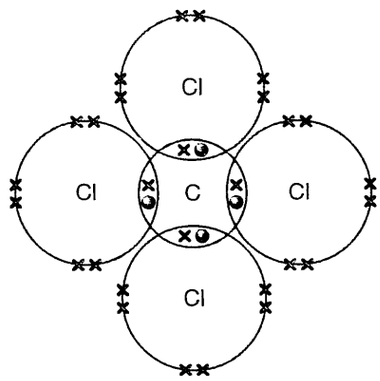
Name	Molecular formula	Structural formula
Hydrogen chloride	HCl	H—Cl

The tetrachloromethane molecule

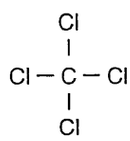
A carbon atom has an electronic arrangement of 2,4. It needs four more electrons to obtain the electronic arrangement of a stable neon atom (2,8).

A chlorine atom has an electronic arrangement of 2,8,7. It needs one more electron to obtain the electronic arrangement of a stable argon atom (2,8,8).

One carbon atom can form four single bonds with four chlorine atoms to form a stable tetrachloromethane molecule.

Electron diagram (showing the outermost shell only) of the carbon and chlorine atoms	Electron diagram (showing the outermost shell only) of tetrachloromethane
	

Representations of tetrachloromethane molecule

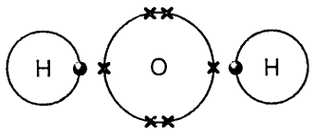
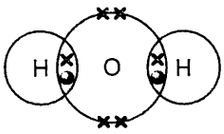
Name	Molecular formula	Structural formula
Tetrachloromethane	CCl_4	

The water molecule

A hydrogen atom has an electronic arrangement of 1. It needs one more electron to obtain the electronic arrangement of a stable helium atom (2).

An oxygen atom has an electronic arrangement of 2,6. It needs two more electrons to obtain the electronic arrangement of a stable neon atom (2,8).

One oxygen atom can form two single bonds with two hydrogen atoms to form a stable water molecule.

Electron diagram (showing the outermost shell only) of the hydrogen and oxygen atoms	Electron diagram (showing the outermost shell only) of water
	

Representations of water molecule

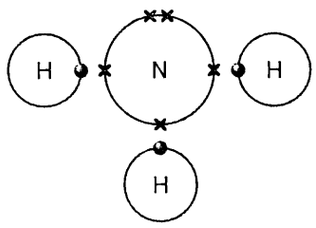
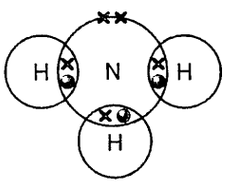
Name	Molecular formula	Structural formula
Water	H_2O	H—O—H

The ammonia molecule

A nitrogen atom has an electronic arrangement of 2,5. It needs three more electrons to obtain the electronic arrangement of a stable neon atom (2,8).

A hydrogen atom has an electronic arrangement of 1. It needs one more electron to obtain the electronic arrangement of a stable helium atom (2).

One nitrogen atom can form three singles bonds with three hydrogen atoms to form a stable ammonia molecule.

Electron diagram (showing the outermost shell only) of the hydrogen and nitrogen atoms	Electron diagram (showing the outermost shell only) of ammonia
	

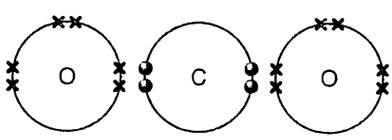
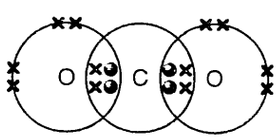
Representations of ammonia molecule

Name	Molecular formula	Structural formula
Ammonia	NH_3	H−N−H | H

The carbon dioxide molecule

A carbon atom has an electronic arrangement of 2,4. It needs four more electrons to obtain the electronic arrangement of a stable neon atom (2,8).

An oxygen atom has an electronic arrangement of 2,6. It needs two more electrons to obtain the electronic arrangement of a stable neon atom (2,8).

Electron diagram (showing the outermost shell only) of the carbon and oxygen atoms	Electron diagram (showing the outermost shell only) of carbon dioxide
	

Representations of carbon dioxide molecule

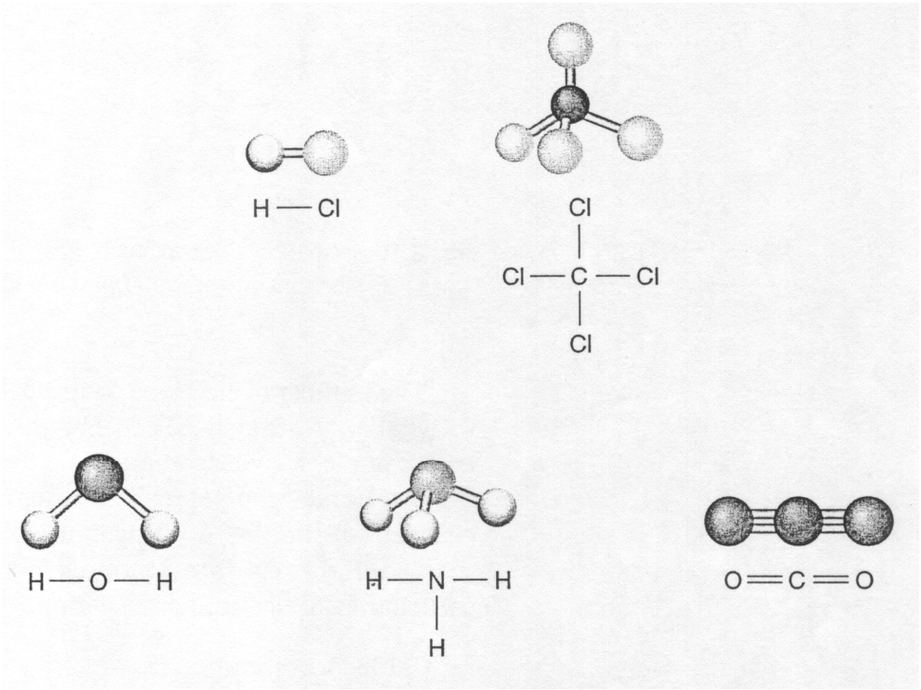
Name	Molecular formula	Structural formula
Carbon dioxide	CO_2	O=C=O

In general, the number of electrons contributed by an atom for sharing is equal to what that atom needs to obtain a stable electronic arrangement. Thus, we can have the following relationship.

Number of electrons shared by an atom = 8 – group number of the atom (except period 1 element)

Molecular models

The following shows the ball-and-stick models of the above molecules.



Exercises

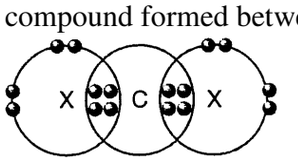
1. Draw the electron diagrams, showing the outermost shell only, of the compounds formed by the following pairs of elements.

   (a) hydrogen and sulphur

   (b) phosphorus and chlorine

2. Show the bonding in HCN using an electron diagram.

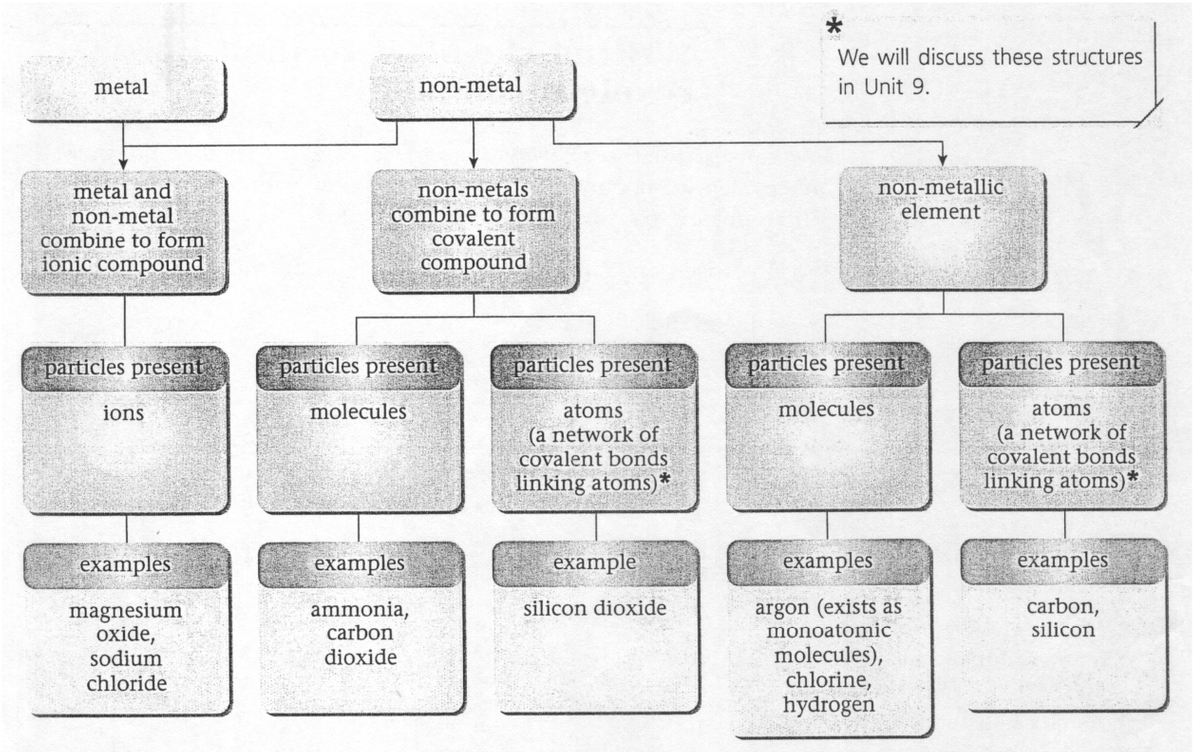
3. A compound formed between carbon and element X has the following structure:

   (only electrons in the outermost shell are shown)

   How many electrons are there in the outermost shell of X? Explain your answer.

The diagram below summarizes the constituent particles in ionic compounds, covalent compounds and non-metallic elements.



Writing chemical formulae of covalent compounds

The following steps can be used to work out the formulae of covalent compounds. Refer to the examples below.

	Step	Compound formed from hydrogen and sulphur	Compound formed from silicon and chlorine
1	Write down the electronic arrangements of the atoms involved.	H 1 ; S 2,8,6	Si 2,8,4 ; Cl 2,8,7
2	Decide the number of electrons each atom needs to obtain a stable electronic arrangement. Write down the number on the top of each atom.	A hydrogen atom needs 1 electron, while a sulphur atom needs 2 electrons. 1 2 H S	A silicon atom needs 4 electrons, while a chlorine atom needs 1 electron. 4 1 Si Cl
3	Decide the number of each type of atoms in one molecule (cross multiply the numbers and the symbols).	1 2 H S $= H_2$ $= S_1$	4 1 Si Cl $= Si_1$ $= Cl_4$
4	Combine the symbols and simplify the ratio if necessary.	H_2S (Omit the number of 1 for S.)	$SiCl_4$ (Omit the number of 1 for Si.)

Predicting the formation of ionic and covalent compounds

We can predict whether the compound formed is ionic or covalent from the information concerning the elements combined.

Remember:

When a metal combines with a non-metal, an ionic compound forms. When non-metal combines, a covalent compound forms.

Usually, a metal is on the left hand side of the periodic table with 3 or less than 3 electrons on its outermost shell. A non-metal is often on the right hand side of the periodic table with more than 3 electrons in its outermost shell.

Example

Consider the following pairs of elements:

(a) calcium and fluorine; and (b) nitrogen and fluorine

For each pair of elements,

(i) predict the type of compound (ionic or covalent) formed when they combine;

(ii) state the chemical formula of the compound;

(iii) name the compound.

Solution

a) i) When calcium (a metal) combines with fluorine (a non-metal), an ionic compound is formed.

ii) Work out the chemical formula of the compound by the following steps:

Step	Compound formed from calcium and fluorine
1 Write down the symbols of ions in the compound.	Ca F
2 Write down the number of charges of each ion on the top of each symbol.	2 1 Ca F
3 Cross multiply the numbers and the symbols.	2 1 Ca F $= Ca_1$ $= F_2$
4 Combine the symbols and simplify the ratio if necessary. (Omit the number of 1 for Ca.)	CaF_2

iii) Calcium fluoride

b) i) When nitrogen and fluorine (non-metals) combine, a covalent compound is formed.

ii) Work out the chemical formula of the compound by the following steps:

Step	Compound formed from nitrogen and fluorine
1 Write down the electronic arrangements of the atoms involved.	N F 2,5 2,7
2 Decide the number of electrons each atom needs to obtain a stable electronic arrangement. Write down the number on the top of each atom.	A nitrogen atom needs 3 electrons, while a fluorine atom needs 1 electron. 3 1 N F
3 Decide the number of each type of atoms in one molecule (cross multiply the numbers and the symbols).	3 1 N F $= N_1$ $= F_3$
4 Combine the symbols and simplify the ratio if necessary. (Omit the number of 1 for N.)	NF_3

iii) Nitrogen trifluoride

Exercises

1. For each pairs of elements stated below,
   (i) predict the type of compound (ionic or covalent) formed when they combine;
   (ii) state the chemical formula of the compound;
   (iii) name the compound if it is an ionic compound.

   (a) oxygen and fluorine
   (i)

   (ii)

   (iii)

   (b) potassium and sulphur
   (i)

   (ii)

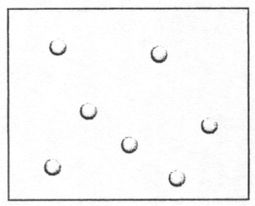
   (iii)

2. Consider the substances listed below:

   Ammonia, carbon dioxide, chlorine, neon and potassium chloride

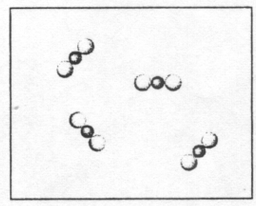
   Diagram I, II and III below show the arrangements of particles, which can be atoms, ions or molecules. For each diagram, choose form the above list ONE substance which has the arrangement of particles as shown below at room temperature and pressure.

   Diagram I



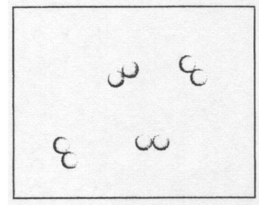
   The substance is:

   Diagram II



   The substance is:

   Diagram III

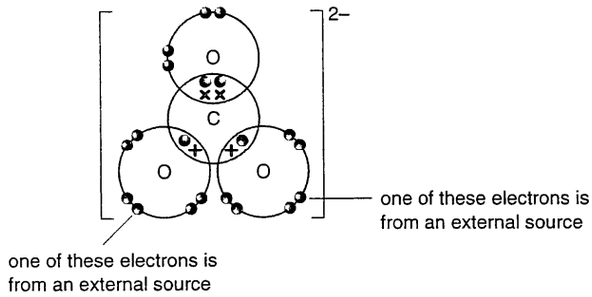


   The substance is:

Bonding in polyatomic ions

In a polyatomic ion, a group of atoms is covalently bonded together. The group as a whole has an overall charge. A further example comes from the carbonate ion (CO_3^{2-}).

A carbon atom has an electronic arrangement: 2,4 and an oxygen atom has an electronic arrangement: 2,6. The simplest combination of elements is the molecule CO_2. However, they can also combine to form a carbonate ion (CO_3^{2-}). Refer to the diagram below.



(Electron diagrams of polyatomic ions are not required in the tests and examinations of F.3)

In substances containing the carbonate ion, such as calcium carbonate ($CaCO_3$), the cations and anions are held together by ionic bonds but each anion is a group of four atoms held together by covalent bonds. Thus, we have the following:

In ionic compounds containing polyatomic ions, both ionic bonding and covalent bonding exist.