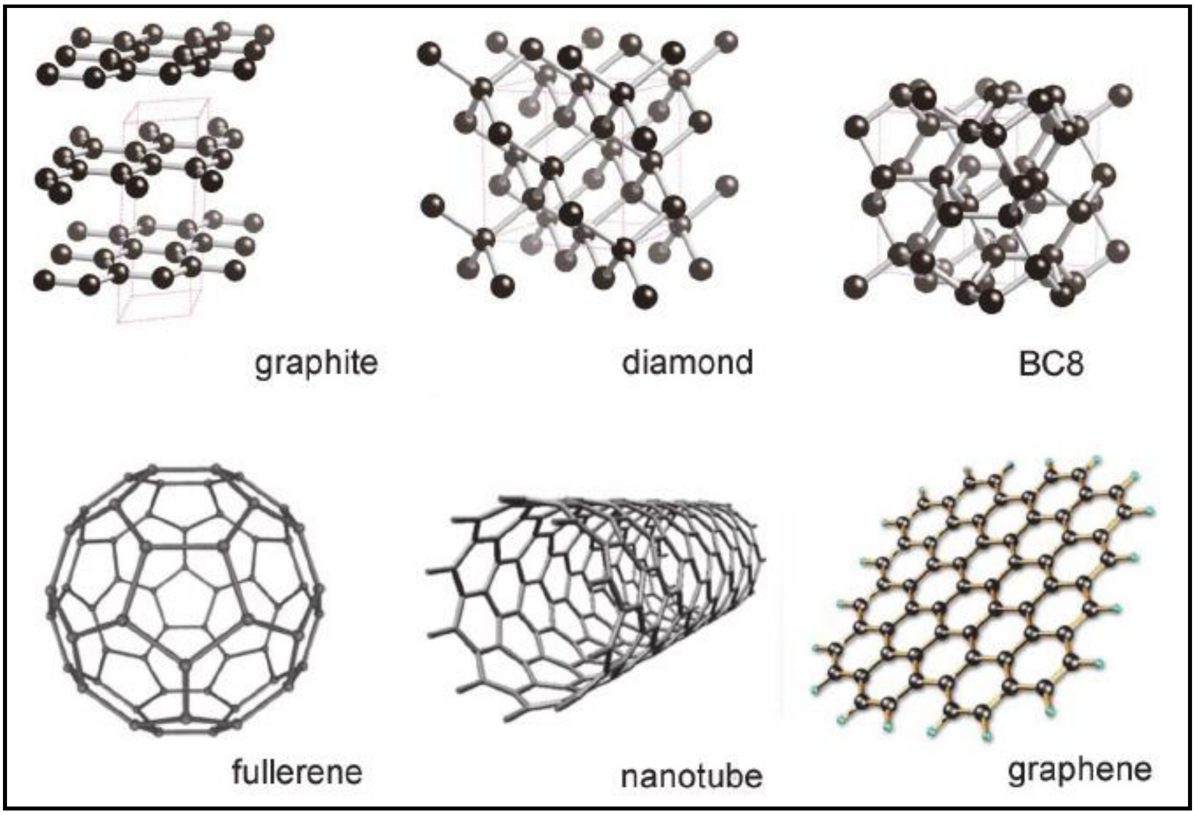

UNIT 1 CHEMISTRY

AOS-1: CHEMICAL BONDING

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CHEMICAL BONDING

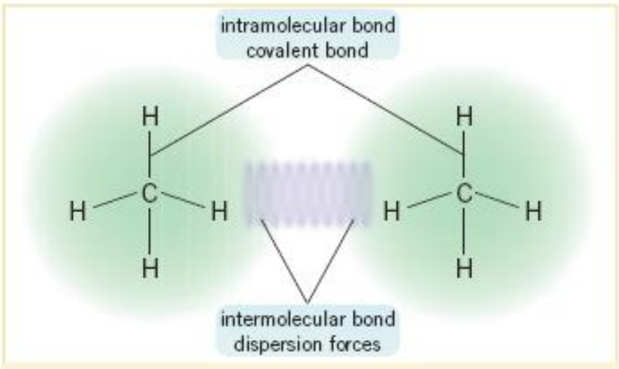
There are two types of bonding that exist between particles – interparticle and intraparticle bonding.

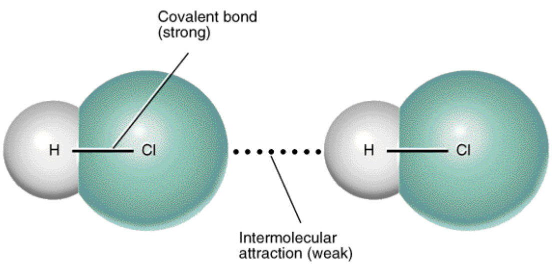
Intraparticle bonding describes the forces that exist within a particle such as a molecule or ionic compound. Examples include:

- Metallic bonds
- Covalent bonds

The forces acting between particles are referred to as **interparticle** bonding.
Examples include:

- Ion – ion bonding
- Ion – dipole bonding
- Hydrogen bonding
- Dipole – dipole bonding
- Dispersion forces





INTRAPARTICLE BONDING

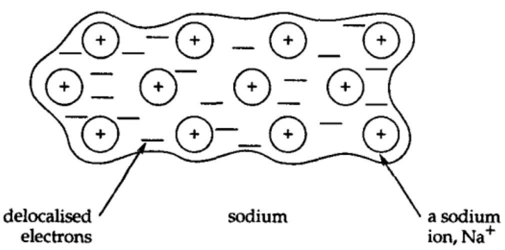
Atoms, other than the noble gases, become more stable by gaining or losing enough electrons to achieve a full outer shell electron configuration.

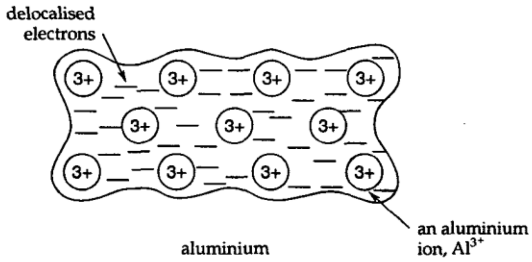
Atoms can become stable by:

- Giving electrons to another atom;
- Taking electrons from another atom;
- Sharing electrons with another atom.

When atoms combine to achieve more stable structures, three types of bonding result.

- When **metallic atoms** combine with each other, **metallic bonding** results and a **metallic lattice** is formed. A lattice is a three dimensional regular arrangement of particles.

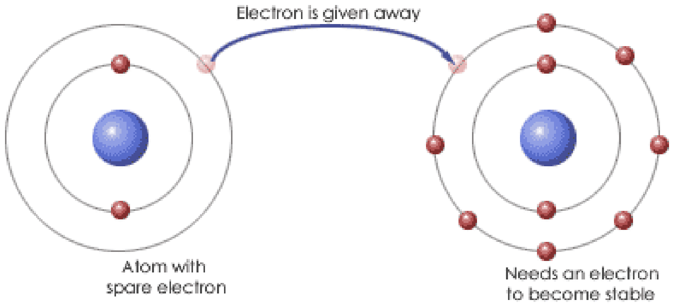




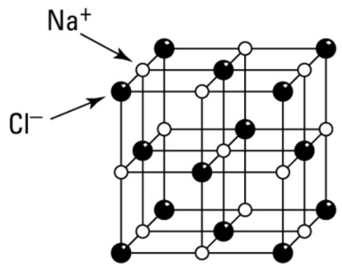
Metallic solids are often described as "a group of nuclei surrounded by a ***sea of mobile electrons***." In other words, the electrons in metallic solids are **delocalised** and are free to move about, making metals good conductors of electricity.

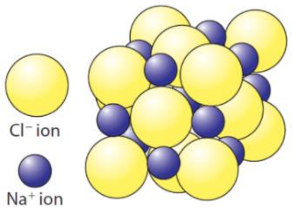
The metallic bond is the weakest of the intraparticle bonds.

- When **metallic atoms** combine with **non-metallic atoms**, **ionic bonding** results and an **ionic lattice** is formed.



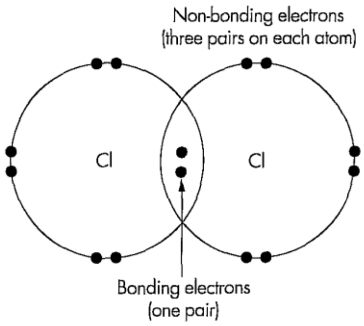
For example: Sodium chloride ($NaCl$)





- When **non-metallic atoms** combine, either **molecules** or **covalent lattices** form. This is called **covalent bonding**.

For Example: The chlorine molecule (Cl_2)



Note: Covalent bonds are the strongest intraparticle bond.

QUESTION 1
Classify the bonds in the below compounds as ionic or covalent.

(a) $NaCl$
(b) CO
(c) ICl
(d) H_2

Solution

QUESTION 2
Why do atoms share electrons in covalent bonds?

A To become ions and attract each other
B To attain a noble-gas electron configuration
C To become more polar
D To increase their atomic numbers

Solution

POLARITY OF MOLECULES

Consider the molecule H_2:

$H - H$ **Non Polar Molecule**

↙

Non Polar Covalent Bond

Each H atom is identical, has the same electronegativity and so attracts the electron pair in the covalent bond equally. The covalent bond is said to be a **non-polar covalent bond** and the molecule is **non-polar**.

Consider the HCl molecule:

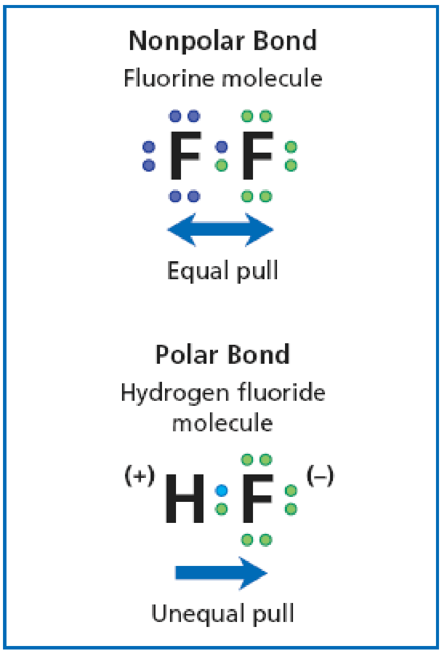
$\overset{\delta^+}{H} - \overset{\delta^-}{Cl}$ **Polar Molecule**

↙

Polar Covalent Bond

The Cl atom has the higher electronegativity so it attracts electrons more strongly than H. The pair of bonding electrons is not shared equally and spends more of its time closer to the Cl atom, giving it a slightly negative charge. The H atom has a slightly positive charge. These are called **partial charges** (differing from the full charges present on the particles in ionic compounds). The bond within HCl is called a **polar covalent bond** and the molecule is called a **polar molecule**.

Note: $\delta +$ represents a small amount of positive charge.
$\delta -$ represents a small amount of negative charge.



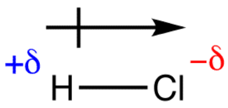
The degree of polarity of covalent bonds can be predicted from the electronegativity table. The greater the difference in electronegativity, the more polar the bond.

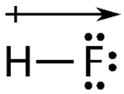
In non metal compounds, the order of electronegativities is:

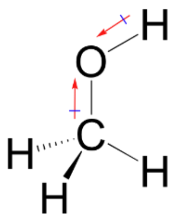
$$F > O > N, Cl > Br > P > S > C, H$$

A polar molecule is said to possess a permanent dipole. The symbol for a dipole is: 

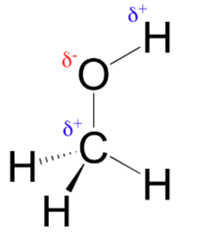
For example:







bond dipole arrows



partial charge notation

IDENTIFYING POLAR MOLECULES

Do atoms in the molecule differ in electronegativity?

Yes → Are atoms in the molecule arranged symmetrically? Are the charges evenly distributed over the molecule?

No → Molecule is **non-polar**

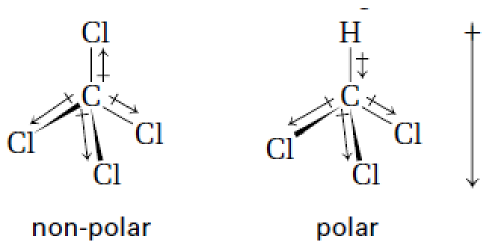
Are atoms in the molecule arranged symmetrically? Are the charges evenly distributed over the molecule?

- Yes — **Even arrangement cancels out charges** → Molecule is **non-polar**
- No — **Uneven arrangement leads to a +ve and a –ve end to the molecule** → Molecule is **polar**

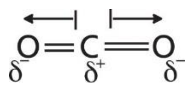
Note:

- When different atoms join in a covalent bond, there may be an unequal sharing of electrons resulting in polar covalent bonds, but the molecule may not be polar.

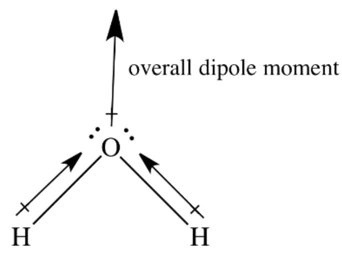
  If the species are arranged in such a manner that no net positive and negative poles are created, the molecule will be non-polar as well. For example: CCl_4



  As the geometry of carbon dioxide atoms is linear, there is no net positive and no net negative end, and hence CO_2 is a non-polar molecule.

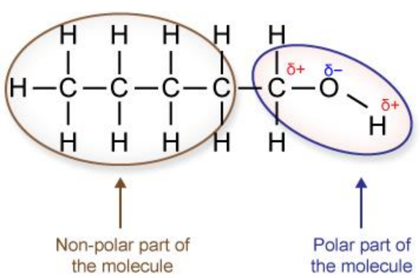


  The geometry of the water atoms is angular meaning that H_2O has a permanent dipole. Water is therefore classified as a polar molecule.



- If a diatomic species is made up of the same element (eg. Cl_2), the bond joining the atoms is non-polar. The electronegativities of both atoms are the same, hence the distribution of electrons is the same for each.

- Molecules may display both non polar and polar ends. For example:



QUESTION 3
In a polar covalent bonding, electrons are

A Unequally shared
B Equally shared
C Completely transferred
D Destroyed

QUESTION 4
Which of the following covalent bonds is the most polar?

A H—F
B H—H
C H—C
D H—N

QUESTION 5
Which one of the following pairs of atoms would form a non-polar covalent bond?

A C and O
B Na and Cl
C Ne and Ne
D Cl and Cl

QUESTION 6
State whether the bonds between the below atoms will be polar, non-polar or ionic.

(a) Cl and Cl

(b) H and H

(c) C and H

(d) Li and F

(e) O and O

QUESTION 7
Which of the following is a non-polar molecule?

A OF_2

B NH_3

C CS_2

D NF_3

QUESTION 8
Which of the following molecules is polar?

A PCl_5

B Cl_2O

C F_2

D CS_2

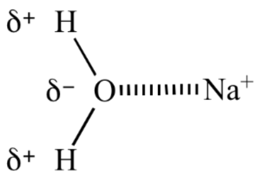
INTERPARTICLE BONDING

Interparticle Force	Bond Strength	Interacting Species
Ion – Ion	Strongest	Two ions with opposite charges (Ionic Bonds)
Ion – Dipole		Ions and polar molecules
Hydrogen Bonds		FON on 1 molecule and H attached to a FON on another
Dipole – Dipole		Polar molecules
Dispersion	Weakest	All types of compounds and ions

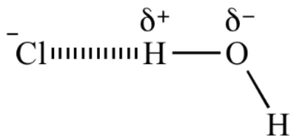
ION – DIPOLE BONDING

An ion-dipole force is an attractive force that results from the electrostatic attraction between an ion and a neutral molecule that has a permanent dipole.

A positive ion (cation) attracts the partially negative end of a neutral polar molecule.

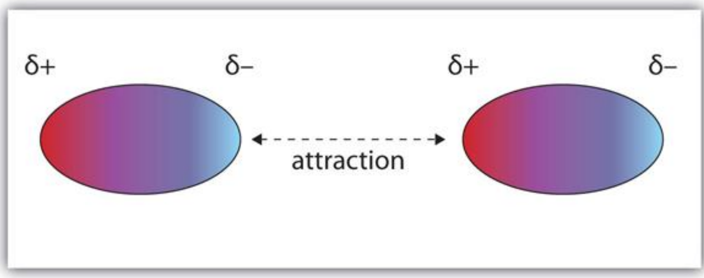


A negative ion (anion) attracts the partially positive end of a neutral polar molecule.



Ion-dipole attractions become stronger as either the charge on the ion increases, or as the magnitude of the dipole of the polar molecule increases.

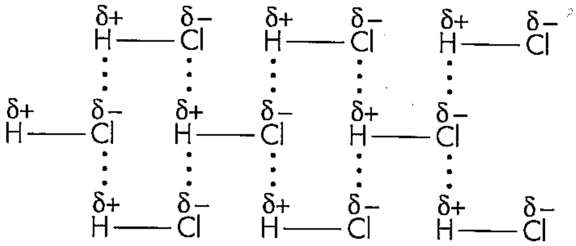
DIPOLE – DIPOLE ATTRACTIONS



Polar molecules are attracted to each other because of the permanent partial charges. These interactions between oppositely charged ends of polar molecules are referred to as **dipole – dipole attractions.**

For Example: HCl

The Cl atom attracts bonding electrons more than H in the HCl molecule, i.e. the Cl atom has a greater electronegativity than H. This means that bonding electrons are closer to the Cl atom and the Cl end of the HCl molecule becomes slightly negative and the H end slightly positive.

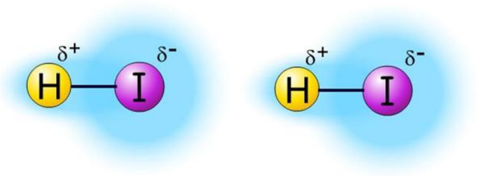


The covalent bond in the HCl molecule is **polar** and the molecule itself a **polar molecule**.

As the molecule is polar, the positive end of one molecule is attracted to the negative end of another molecule, resulting in the formation of a dipole-dipole bond.

Important Notes:

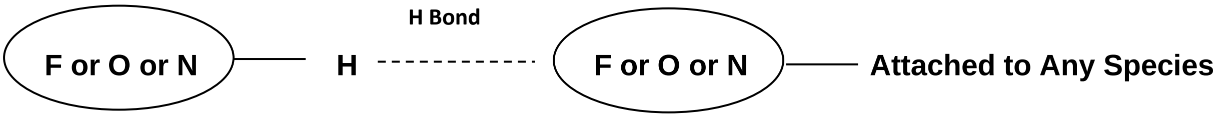
- Dipole-dipole bonding will only occur between polar molecules.
- The greater the polarity (difference in electronegativity of the atoms in the molecule), the stronger the dipole-dipole attraction.
- Melting may overcome the attraction between dipoles, but they still exist.



HYDROGEN BONDING

In molecules where hydrogen bonds to nitrogen, oxygen or fluorine, an unusually strong polar covalent bond exists. Such a bond results in a stronger dipole-dipole interactions called **hydrogen bonding**.

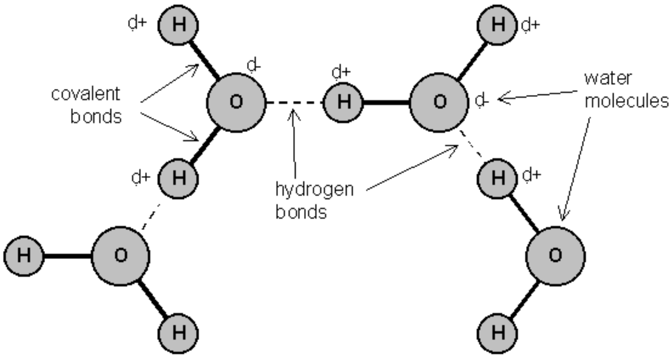
Hydrogen bonds can form between the positively charged H attached to a(n) F, O or N on one molecule (the hydrogen bond donor), and the negatively charged end of F, O or N on another molecule (the hydrogen bond acceptor).



H Bond Donor ***H Bond Acceptor***

For example:

Hydrogen bonding between water molecules.



Hydrogen bonding also exists between the following sets of molecules:

NH_3 and NH_3

HF and HF

$R-OH$ and $R-OH$

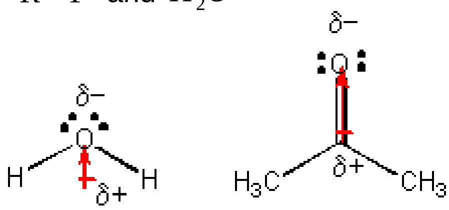
NH_3 and H_2O

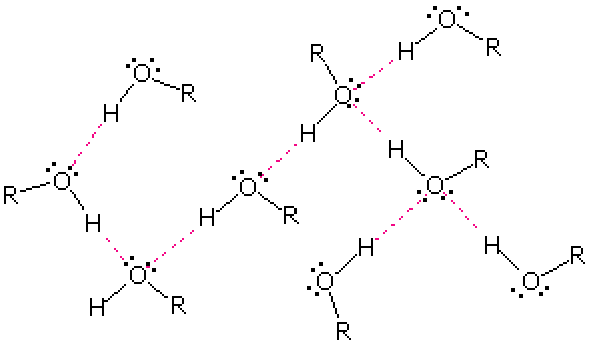
HF and H_2O

$R-OH$ and H_2O

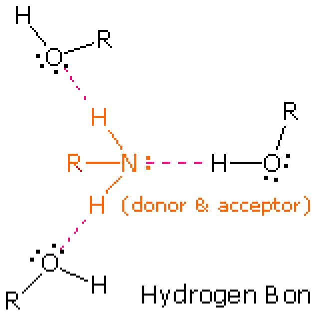
$R-F$ and H_2O

Acetone $(CH_3)_2CO$ and H_2O

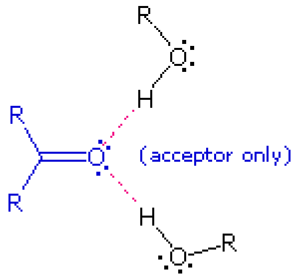




Hydrogen Bonding in Alcohols and Water (R=H)



Hydrogen Bonding to an Amine



Hydrogen Bonding to a Carbonyl Group

Hydrogen bonding will <u>not</u> occur between the following sets of molecules:

- F_2 and H_2O as F_2 is a non-polar molecule.
- F_2 and F_2 as F_2 is a non-polar molecule.
- $(CH_3)_2CO$ and $(CH_3)_2CO$ as the oxygen atom in one molecule is not directly attached to a hydrogen atom.

Important Notes:

- Hydrogen bonds are strong intermolecular forces as the hydrogen atom involved in this bonding essentially gives its single electron to form a bond and is therefore left unshielded.
- Those species that are both hydrogen bond donors and acceptors are able to form hydrogen bonds between themselves. For example, alcohols and carboxylic acids.
- If a substance can form hydrogen bonds with water, it will dissolve in aqueous solutions. As water is both a donor and acceptor, the solute only needs to be either a donor or acceptor (or both) to dissolve.

QUESTION 9
Which of the following substances exhibits hydrogen bonding?

(a) C_2H_6

(b) CH_3OH

(c) H_3CCONH_2

(d) H_3CCOOH

(e) H_3CCH_2OH

(f) H_3CCOCH_3

QUESTION 10
Does H-bonding exist between the following molecules?
Give a reason for your answer.

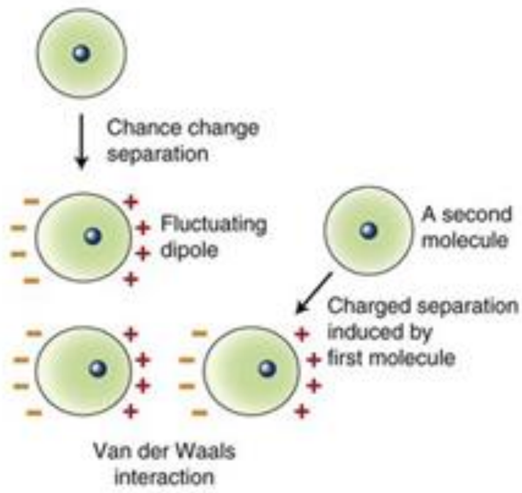
$$\begin{array}{c} O \\ \| \\ H-C-H \end{array}$$

Solution

DISPERSION FORCES

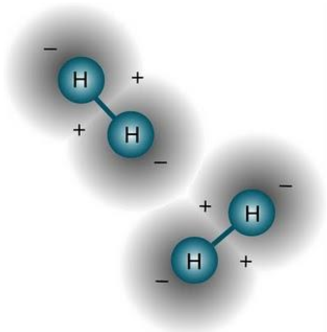
Dispersion forces (van de Waal's forces) are the weakest bonding forces that exist between particles, and arise due to the formation of instantaneous dipoles in atoms.

When the electrons arrange themselves in such a manner that an overall negative end is formed ($\delta -$), an instantaneous dipole is created.



This instantaneous dipole in one atom can distort the electron arrangement in another atom and cause another dipole to be produced.

Oppositely charged ends can form electrostatic attractions that are weak, and that disappear when electrons move away from the poles.



The strength of dispersion forces depends upon:

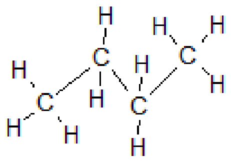
- How often the electrons can cluster to produce an overall negative end.
- How easily electron arrangements in adjacent atoms may be distorted to create other dipoles.
- The number of electrons in an atom, or molecule. The bigger the molecule, for example, the stronger the dispersion forces.

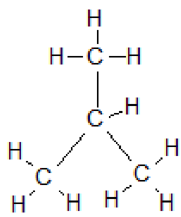
Important Notes:

- If the shapes of the molecules are the same, the strength of the dispersion forces will depend on the size of the molecule. This trend is shown in the halogen series, all of which form linear diatomic molecules.

Molecule	Molecular weight	Boiling point °C
F – F	38	-188
Cl – Cl	71	-34
Br – Br	160	59
I – I	254	184

- If the size of the molecules are the same (eg. when comparing isomers), then the strength of the dispersion forces is likely to depend on the shape of the molecules.
- Molecules that can pack more closely together will experience stronger attractions to one another due to dispersion forces and have higher melting and boiling points.





- Dispersion forces exist in all substances and is the **only attractive** force that exists between noble gas atoms and non-polar molecules such as H_2, N_2, O_2, P_4, S_8.
- The strength of dispersion forces between polar molecules is usually stronger than their dipole-dipole interactions.

QUESTION 11
Which particles play the most active role in chemical bonding?

A Valence electrons
B Neutrons
C Electrons
D Protons

QUESTION 12
When a partial electrical charge exists across a molecule, it is called a(n):

A Nonpolar bond
B Ionic compound
C Dipole
D Ion

QUESTION 13
Which one of the following describes the major intermolecular force in $I_{2(s)}$?

A Covalent bonds
B Hydrogen bonds
D Dispersion forces
E Dipole-dipole forces

QUESTION 14

Identify the bonds in the following by circling one bond type for each compound.

a. The bonds in HF.	ionic	polar covalent	nonpolar covalent	metallic
b. The bond in F_2.	ionic	polar covalent	nonpolar covalent	metallic
c. The bonds in K_2O.	ionic	polar covalent	nonpolar covalent	metallic
d. The bonds in Cu.	ionic	polar covalent	nonpolar covalent	metallic
e. The bonds in CO.	ionic	polar covalent	nonpolar covalent	metallic
f. The bonds in O_2.	ionic	polar covalent	nonpolar covalent	metallic
g. The bond in $MgCl_2$.	ionic	polar covalent	nonpolar covalent	metallic
h. The bonds in NO.	ionic	polar covalent	nonpolar covalent	metallic
i. The bonds in Br_2.	ionic	polar covalent	nonpolar covalent	metallic
k. The bonds in NiO.	ionic	polar covalent	nonpolar covalent	metallic

QUESTION 15
identify the dominant intermolecular forces that exist between the following substances.

(a) $MgCl_2$

(b) PCl_3

(c) H_3CNH_2

(d) CH_3F

(e) CH_3OH

(f) CH_3CH_2OH

(g) Hexane

SOLUTIONS

QUESTION 1

(a) Ionic ($NaCl$ is formed from a metal and a nonmetal.)
(b) Covalent (CO is formed from two nonmetals.)
(c) Covalent (ICl is formed from two nonmetals.)
(d) Covalent (H_2 is formed from two identical atoms.)

QUESTION 2 Answer is B

QUESTION 3 Answer is A

QUESTION 4 Answer is A

QUESTION 5 Answer is D

QUESTION 6

(a) Cl and Cl non-polar; since there is no electronegativity difference between the atoms sharing the electrons, the electrons are shared equally.

(b) H and H non-polar; there is no electronegativity difference between the atoms sharing the electrons, the electrons are shared equally.

(c) C and H non-polar or only very slightly polar; the electronegativity difference between carbon and hydrogen (0.4) is negligibly small, thus the electrons are shared essentially equally.

(d) Li and F ionic; the electronegativity difference between fluorine and lithium is large and also the bond is between a metal and a nonmetal.

(e) O and O non-polar; since there is no electronegativity difference between the atoms sharing the electrons, the electrons are shared equally.

QUESTION 7 Answer is C

QUESTION 8 Answer is B

QUESTION 9

(a) No
(b) Yes
(c) Yes
(d) Yes
(e) Yes
(f) No

QUESTION 10

No.

Even though the molecule contains both hydrogen and oxygen atoms, there is no H-bonding between these types of molecules since the H is not directly bonded to the oxygen.

QUESTION 11 Answer is A

QUESTION 12 Answer is C

QUESTION 13 Answer is C

QUESTION 14

(a) Polar covalent
(b) Nonpolar covalent
(c) Ionic
(d) Metallic
(e) Polar covalent
(f) Nonpolar covalent
(g) Ionic
(h) Nonpolar covalent
(i) Nonpolar covalent
(k) Ionic

QUESTION 15

(a) $MgCl_2$

Ion – dipole forces
Dispersion forces

(b) PCl_3

Dipole – dipole forces
Dispersion forces

(c) H_3CNH_2

Hydrogen bonding
Dipole – dipole forces
Dispersion forces

(d) CH_3F

Dipole – dipole forces
Dispersion forces

(e) CH_3OH

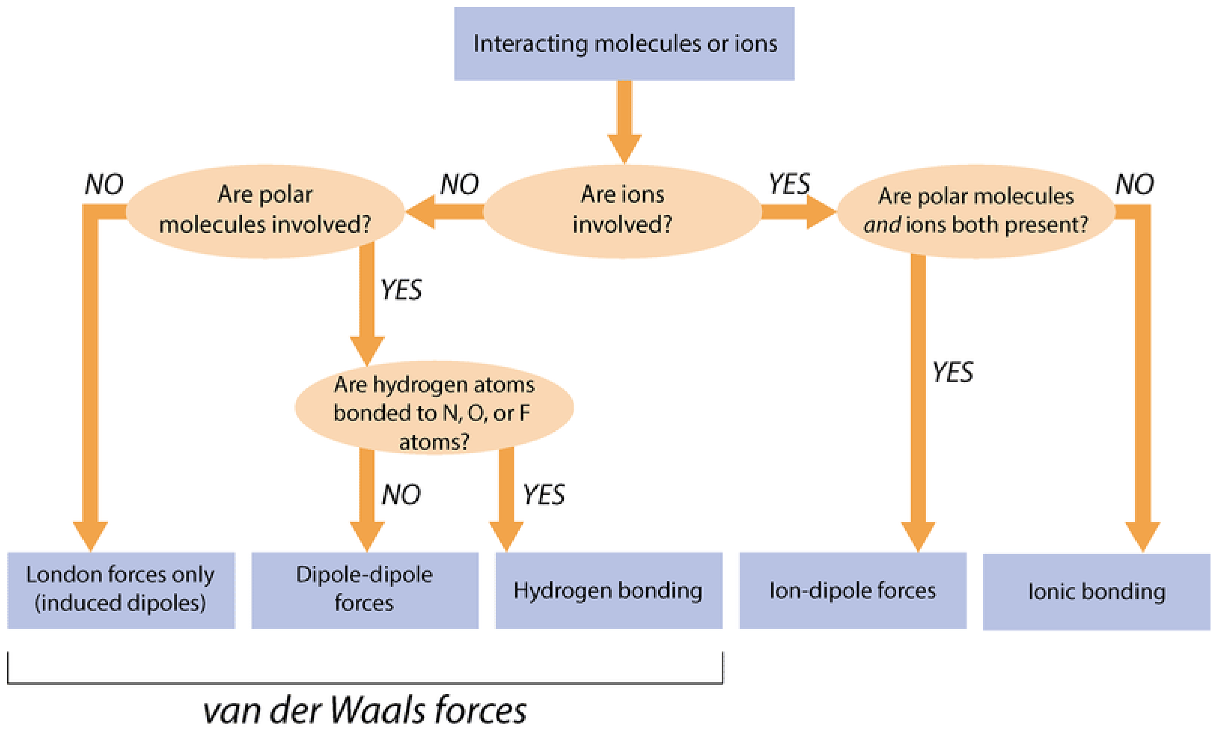
Hydrogen bonding
Dipole – dipole forces
Dispersion forces

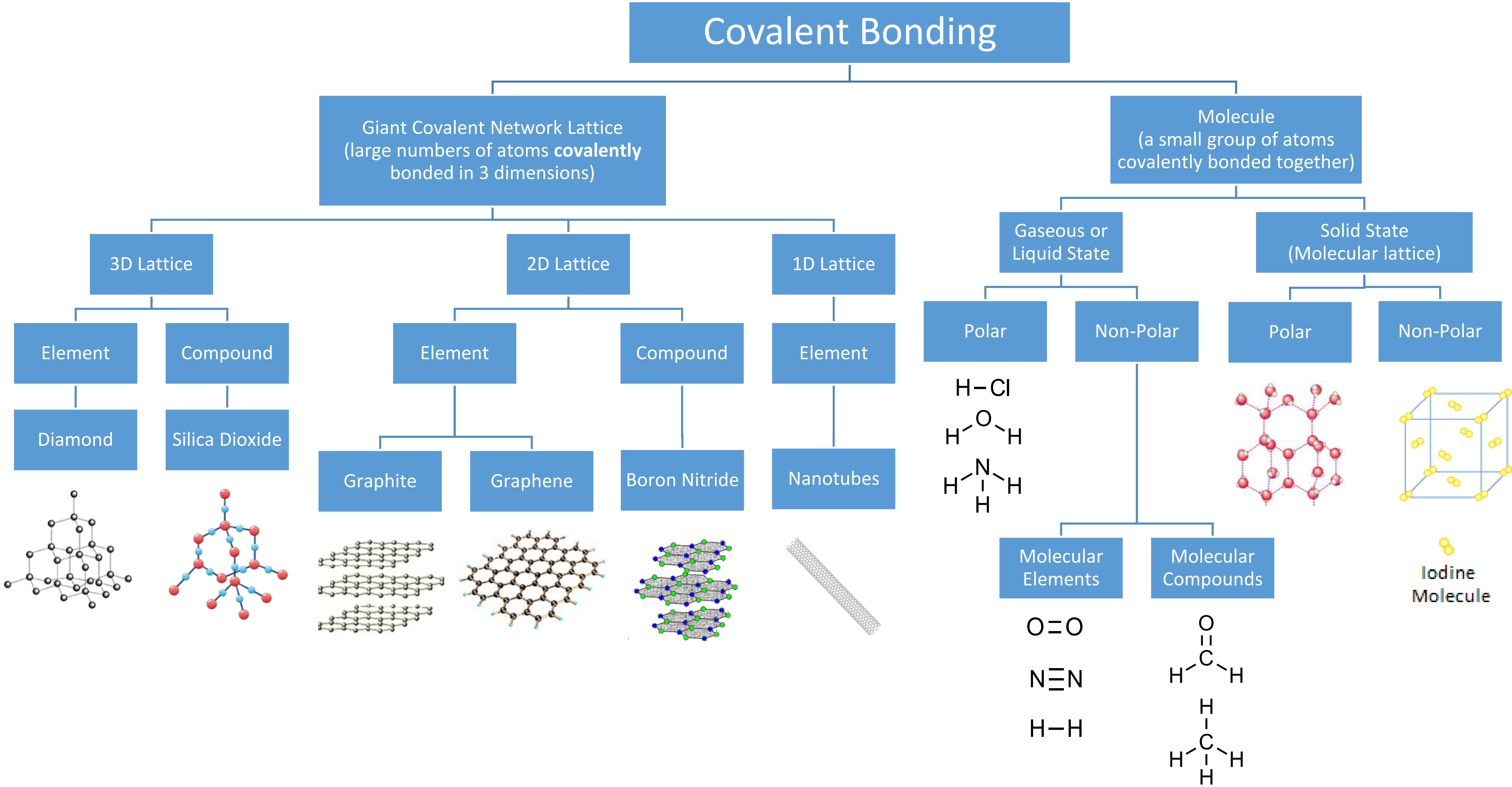
(f) CH_3CH_2OH

Hydrogen bonding
Dipole – dipole forces
Dispersion forces

(g) Hexane

Dispersion forces


Interacting molecules or ions
Are ions involved?
NO
YES
Are polar molecules involved?
NO
YES
Are polar molecules *and* ions both present?
NO
YES
Are hydrogen atoms bonded to N, O, or F atoms?
NO
YES
London forces only (induced dipoles)
Dipole-dipole forces
Hydrogen bonding
Ion-dipole forces
Ionic bonding
van der Waals forces



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MOLECULAR SHAPES

When an atom forms a covalent bond with another atom, the electrons in the different bonds and the non-bonding electrons in the outer shell all behave as negatively charged clouds and repel each other. In order to minimise this repulsion, all the outer shell electrons spread out as far apart in space as possible.

Molecular shapes and the angles between bonds can be predicted by the VSEPR theory
VSEPR = valence shell electron pair repulsion

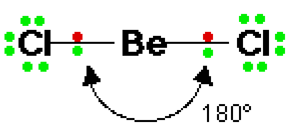
VSEPR theory consists of two basic rules:

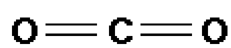
i) All σ-bonded electron pairs and all lone pairs arrange themselves as far apart in space as is possible. π-bonded electron pairs are excluded.
ii) Lone pairs repel more strongly than bonding pairs.

These two rules can be used to predict the shape of any covalent molecule or ion, and the angles between the bonds.

a) 2 electron pairs

If there are two electron pairs on the central atom, the angle between the bonds is 180°.

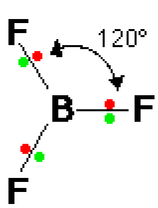


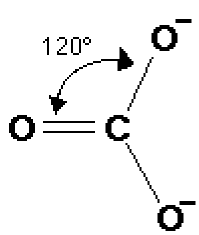


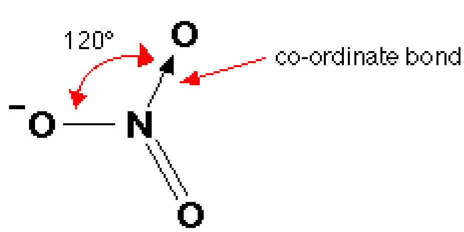
Molecules which adopt this shape are said to be LINEAR.
E.g. $BeCl_2$, CO_2

b) three electron pairs

If there are three electron pairs on the central atom, the angle between the bonds is 120°.

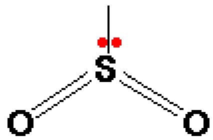






Molecules which adopt this shape are said to be TRIGONAL PLANAR.
E.g. BF_3, $AlCl_3$, CO_3^{2-}, NO_3^-

If one of these electron pairs is a lone pair, the bond angle is slightly less than 120º due to the stronger repulsion from lone pairs, forcing them closer together.



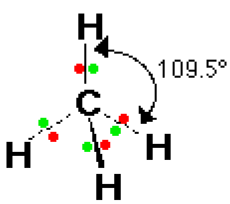
bond angle = 118º

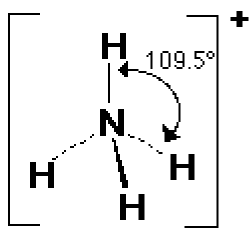
Molecules which adopt this shape are said to be BENT.

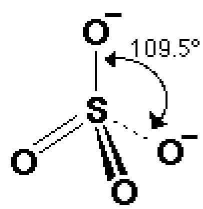
E.g. SO_2, NO_2^-

c) Four electron pairs

If there are four bonded pairs on the central atom, the angle between the bonds is approx 109º.



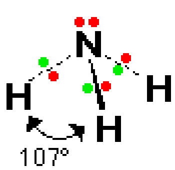




Molecules which adopt this shape are said to be TETRAHEDRAL.

E.g. CH_4, $SiCl_4$, NH_4^+, SO_4^{2-}

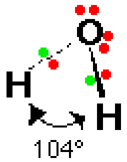
If one of the electron pairs is a lone pair, the bond angle is slightly less than 109º, due to the extra lone pair repulsion which pushes the bonds closer together (approx 107º).



Molecules which adopt this shape are said to be TRIGONAL PYRAMIDAL.

E.g. NH_3, PCl_3

If two of the electron pairs are lone pairs, the bond angle is also slightly less than 109^o, due to the extra lone pair repulsion (approx 104^o).

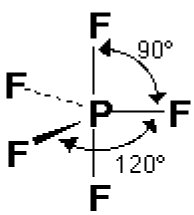


Molecules which adopt this shape are said to be BENT.

E.g. H_2O, OF_2

d) Five electron pairs

If there are five bonded pairs on the central atom, the three bonds are in a plane at 120^o to each other, the other 2 are at 90^o to the plane.

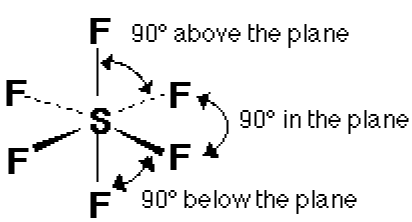


Molecules which adopt this shape are said to be TRIGONAL BYPRYMIDAL**.**

E.g. PF_5, PCl_5

d) Six electron pairs

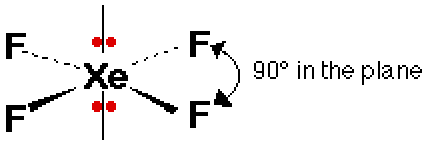
If there are six electron pairs on the central atom, the angle between the bonds is 90^o.



Molecules which adopt this shape are said to be OCTAHEDRAL.

E.g. SF_6

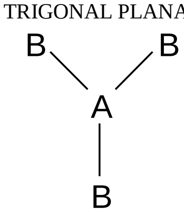
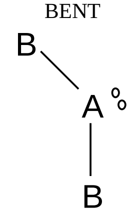
If there are 4 bonding pairs and 2 lone pairs, the bonded pairs are at 90° in the plane and the lone pairs at 180°. The angles are still exactly 90° because the lone pairs are opposite each other so their repulsion cancels out.

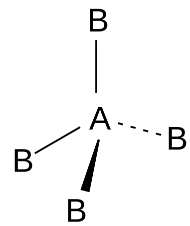
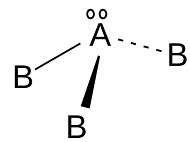
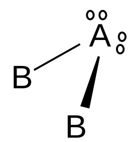
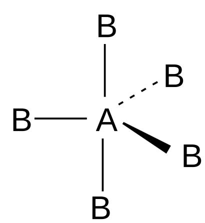
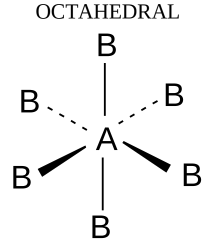
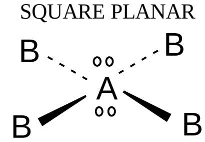


Molecules which adopt this shape are said to be SQUARE PLANAR.

E.g. XeF_4, ClF_4^-

SUMMARY OF MOLECULAR SHAPES

Valence shell electron pairs	Bonding pairs	Lone pairs	shape	Bond Angle (°)
2	2	0	LINEAR B — A — B	180
3	3	0	TRIGONAL PLANAR 	120
3	2	1	BENT 	115 - 118

4	4	0	TETRAHEDRAL 	109.5
4	3	1	TRIGONAL PYRAMIDAL 	107
4	2	2	BENT 	104.5
5	5	0	TRIGONAL BIPYRAMIDAL 	90 and 120
6	6	0	OCTAHEDRAL 	90
6	4	2	SQUARE PLANAR 	90

SUMMARY OF DIFFERENT TYPES OF COMPOUND AND THEIR PROPERTIES

SUBSTANCE	Nature of bonding	Physical properties
IONIC **Eg NaCl**	Attraction between oppositely charged ions. Infinite lattice of oppositely charged ions in three dimensions	High mpt, bpt Good conductors in liquid state Poor conductors in solid state Hard, strong, brittle
METALLIC **Eg Mg**	Attraction between cations and delocalised electrons. Infinite lattice of cations in three dimensions, with delocalized electrons in the spaces	High mpt, bpt Good conductors in solid state Good conductors in liquid state Strong, malleable
GIANT COVALENT **Eg diamond**	Infinite lattice of atoms linked by covalent bonds in three dimensions. Covalent bonds are pairs of electrons shared between two atoms	Very high mpt, bpt Poor conductors in solid state Poor conductors in liquid state Hard, strong, brittle
MOLECULAR **Eg I_2**	Discrete molecules. Atoms in molecule linked by covalent bonds. (σ or π, normal or dative) Weak intermolecular forces between molecules.	Low mpt, bpt Poor conductors in solid state Poor conductors in liquid state Soft, weak, powdery
GIANT COVALENT LAYERED **Eg graphite**	Infinite lattice of atoms linked by covalent bonds in two dimensions to form planes. Planes held together by intermolecular forces. Delocalised electrons in between layers	High mpt, bpt Good conductors parallel to planes Poor conductors perpendicular to planes Soft