4.4 Intermolecular forces

Understandings:

- Intermolecular forces include London (dispersion) forces, dipole–dipole forces, and hydrogen bonding.

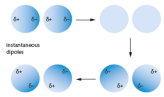
Guidance

The term 'London (dispersion) forces' refers to instantaneous dipole–induced dipole forces that exist between any atoms or groups of atoms and should be used for non-polar entities. The term 'van der Waals' is an inclusive term, which includes dipole–dipole, dipole–induced dipole, and London (dispersion) forces.

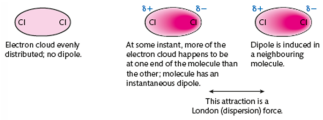
- The relative strengths of these interactions are London (dispersion) forces < dipole–dipole forces < hydrogen bonds.

London (dispersion) forces

Non-polar molecules have no permanent separation of charge across the molecule however the random movement of electrons can cause instantaneous/temporary dipoles .



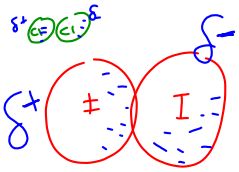
These instantaneous dipoles can have small polarising effect on neighbouring molecules - causing an induced dipole .



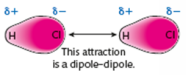
Properties of non-polar molecules - Low melting and boiling points

Element	M_r	Boiling point / °C	State at room temperature
F_2	38	−188	gas
Cl_2	71	−34	gas
Br_2	160	59	liquid
I_2	254	185	solid

Increasing



Dipole–dipole attraction → Must have polar molecules

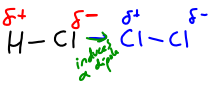


	C_2H_6	CH_3OCH_3
Molar mass / g mol^{-1}	44	46
Intermolecular attraction	London dispersion forces	London dispersion forces and dipole–dipole attraction
Boiling point / K	229	249

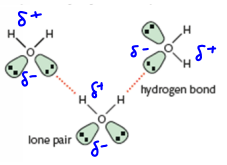
Similar in molar mass so that they have similar London forces.

Note: We could also have a dipole-induced dipole attraction

London dispersion force, e.g. Cl_2---Cl_2
dipole–dipole attraction HCl---HCl
dipole–induced dipole HCl---Cl_2
} van der Waals forces



Hydrogen bonding



Requirements:
- H bonded to an O, N or F

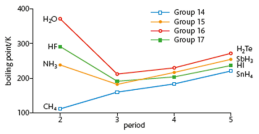
They each have at least 1 lone pair of electrons + they are very electronegative.

C–O–C –O–H

CH_3–O–CH_3	CH_3CH_2–O–H
methoxymethane	ethanol
M = 46 g mol^{-1}	M = 46 g mol^{-1}
does not form hydrogen bonds	forms hydrogen bonds
boiling point = −23 °C	boiling point = +79 °C

Same molar mass
Same elements in the molecule.

Explain 3 features of this graph...



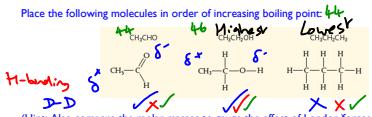
H_2O HF NH_3 CH_4
H_2S HCl PH_3 SiH_4
H_2Se HBr AsH_3 GeH_4
H_2Te HI SbH_3 SnH_4

How does H-bonding explain icebergs?

The relationship between IMF's and physical properties

Melting and boiling points

Place the following molecules in order of increasing boiling point:



Highest

Lowest

H-bonding

D-D

London

Anything with electrons has London forces

(Hint: Also compare the molar masses to gauge the effect of London forces

All similar → we can assume similar strength London forces

Solubility "Like dissolves like"

↳ How well something dissolves

Solute

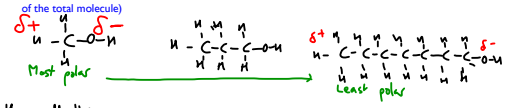
solvent

solution

We must consider whether the solute and solvent are polar or non-polar.

- Non-polar molecule in non-polar solvent → Hexane in Cl_2
- Polar molecule in polar solvent → Will dissolve eg. HCl in H_2O

(size of the polar molecule is relevant as the polar part will become only a small part of the total molecule)



Most polar

Least polar

How well they dissolve in water (polar)

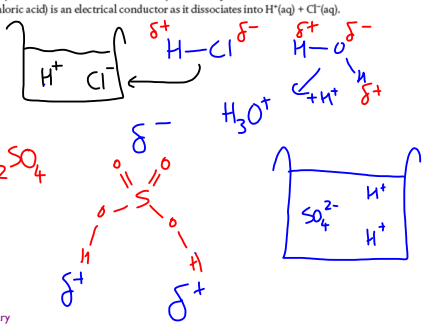
Less soluble

- Giant molecular/covalent structure — Don't dissolve in either because to dissolve them we would need to break actual covalent bonds.

eg. diamond

Electrical conductivity → require the movement of charged particles.

Covalent compounds do not contain ions, and so are not able to conduct electricity in the solid or liquid state. Some polar covalent molecules, however, in conditions where they can ionize will conduct electricity. For example, HCl dissolved in water (hydrochloric acid) is an electrical conductor as it dissociates into $H^+(aq) + Cl^-(aq)$.



Summary

	Ionic compounds	Polar covalent compounds	Non-polar covalent compounds	Giant covalent
Volatility	low	higher	highest	low
Solubility in polar solvent, e.g. water	soluble	solubility increases as polarity increases	non-soluble	non-soluble
Solubility in non-polar solvent, e.g. hexane	non-soluble	solubility increases as polarity decreases	soluble	non-soluble
Electrical conductivity	conduct when molten (l) or dissolved in water (aq)	non-conductors	non-conductors	non-conductors except graphite, graphene and semi-conductivity of Si and fullerene

Exercises

27 The physical properties of five solids labelled A, B, C, D, and E are summarized below. The substances are: an ionic compound, a non-polar molecular solid, a metal, a polar molecular solid, and a giant molecular substance. Classify each correctly.

	Sample	Solubility in water	Conductivity of solution	Conductivity of solid	Relative melting point
Metal	A	insoluble	–	yes	third to melt
GM	B	insoluble	–	no	highest
Polar	C	soluble	no	no	second to melt
Non-polar	D	insoluble	–	no	lowest
Ionic	E	soluble	yes	no	fourth to melt

28 Which substance is the most soluble in water?

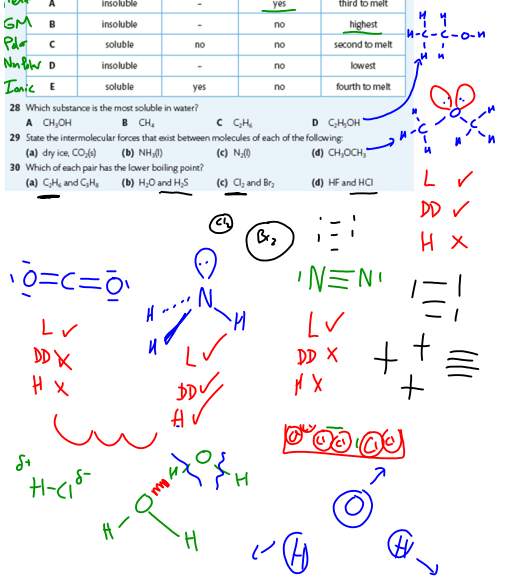
A CH_3OH **B** CH_4 **C** C_2H_6 **D** C_3H_7OH

29 State the intermolecular forces that exist between molecules of each of the following:

(a) dry ice, $CO_2(s)$ **(b)** $NH_3(l)$ **(c)** $N_2(l)$ **(d)** CH_3OCH_3

30 Which of each pair has the lower boiling point?

(a) C_2H_6 and C_3H_8 **(b)** H_2O and H_2S **(c)** Cl_2 and Br_2 **(d)** HF and HCl



Weakest

London dispersion forces

Instantaneous dipole

Dipole-dipole

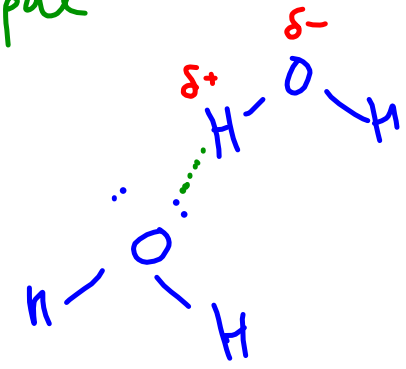
Permanent dipole

H-bonding

H–O

H–F

H–N



Strongest