A-LEVEL CHEMISTRY • EXERCISE SHEET

3.6 Intermolecular forces, electronegativity and bond properties

Name: _____ Class: _____ Date: _____ **Total: 31 marks**

KEY WORDS dipole 偶极 • intermolecular forces 分子间作用力 • hydrogen bonding 氢键 • permanent dipole 永久偶极 • induced dipole 诱导偶极

Objective

Build the skills to answer exam questions on **intermolecular forces** — **bond polarity** 键极性 and dipoles, **van der Waals' forces** 范德华力, **hydrogen bonding** 氢键, and the anomalous properties of water.

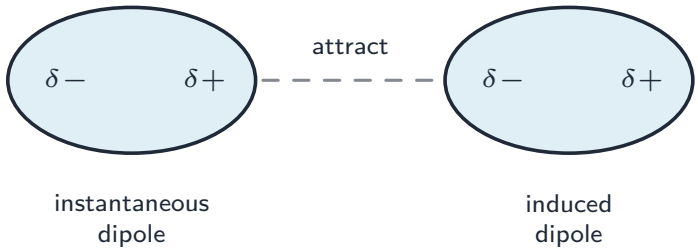
You must be able to:

- explain bond polarity and dipole moments using electronegativity
- describe London (id–id) and permanent dipole (pd–pd) forces, and hydrogen bonding
- use hydrogen bonding to explain the anomalous properties of water

1 Worked examples

■ Polarity and van der Waals' forces

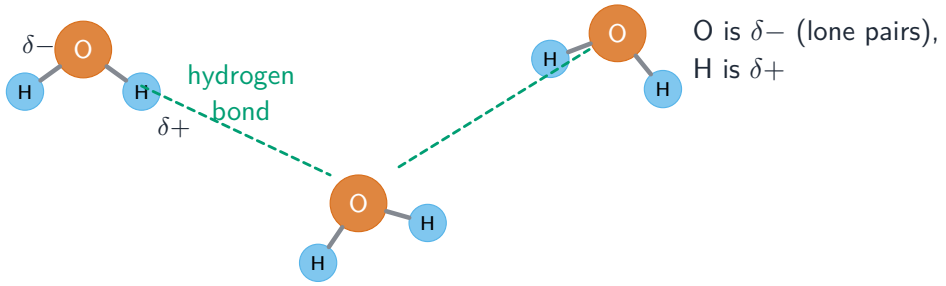
A bond between atoms of different electronegativity has a **dipole** 偶极 ($\delta-$ / $\delta+$). If the dipoles do not cancel, the molecule is **polar**. **Van der Waals' forces** is the general term for all intermolecular forces.



London (id–id) force: a momentary dipole induces one in a neighbour — acts between all molecules, stronger with more electrons

- **London (id–id)** force — acts between all molecules; stronger when there are more electrons.
- **permanent dipole (pd–pd)** force — between always-polar molecules.

Hydrogen bonding and water



Hydrogen bonding: a δ+ H (bonded to N, O or F) is attracted to a lone pair on a δ− N, O or F

Hydrogen bonding (a strong pd–pd case) explains water's anomalies: high melting/boiling point (many H-bonds to break); high surface tension; and **ice is less dense** than water (H-bonds hold an open structure), so ice floats.

The three forces, in the order you should check for them

Every molecule has **van der Waals' forces** (induced dipole–induced dipole). A polar molecule has those **plus** permanent dipole–dipole. A molecule with H bonded to N, O or F has those **plus** hydrogen bonding. So the forces stack; the question is which one dominates.

Force	Between	Strength
van der Waals' 范德华力	all molecules; arise from instantaneous, fluctuating dipoles inducing dipoles in neighbours	weakest, but grows with the number of electrons and with surface contact
permanent dipole–dipole 永久偶极	polar molecules, from a difference in electronegativity across a bond	intermediate
hydrogen bonding 氢键	a lone pair on N, O or F and an H attached to N, O or F	strongest of the three

A polar bond does not make a polar molecule. CO_2 has two strongly polar bonds, but they are opposite and equal in a linear molecule, so the dipoles cancel and the molecule is non-polar. **Check the shape before deciding.**

Reading a boiling-point trend — the two-part answer the mark scheme wants:

1. Name the force being broken.
2. Explain why it is stronger or weaker here.

So along the alkanes: van der Waals' forces increase with more electrons and greater surface contact, so boiling point rises. A branched isomer boils lower than its straight-chain isomer because branching reduces the surface contact, weakening the van der

Waals' forces — **the covalent bonds are never broken on boiling**, and saying so loses the mark.

Worked example. Explain why H_2O boils at 100 °C but H_2S at −60 °C, even though H_2S has more electrons.

1. Both are polar bent molecules with dipole–dipole forces and van der Waals' forces.
2. In water, H is bonded to the highly electronegative, small oxygen atom, which also has lone pairs, so **hydrogen bonding** occurs; sulfur is not electronegative enough for it.
3. Hydrogen bonds are much stronger than the dipole–dipole and van der Waals' forces in H_2S, so far more energy is needed to separate water molecules — outweighing the larger number of electrons in H_2S.

Ice is less dense than water for the same reason: hydrogen bonds hold the molecules in an **open tetrahedral lattice** with gaps, so the same number of molecules occupies more volume.

2 Practice

2.1 Name the **two** atoms (besides hydrogen) that must be present for hydrogen bonding in water and ammonia. [2]

2.2 State which intermolecular force acts between all molecules. [1]

2.3 Explain why CO_2 is non-polar despite having polar bonds. [2]

2.4 State the three conditions needed for hydrogen bonding. [2]

2.5 Explain why 2-methylpropane boils at a lower temperature than butane. [2]

3 Exam-style questions

3.1 Why does ice float on water? [1]

A B
C D

A ice is warmer
B hydrogen bonds hold ice in an open structure, so it is less dense
C ice has no hydrogen bonds
D ice contains air

3.2 Which has the **strongest** intermolecular forces? [1]

A B
C D

A CH_4
B Cl_2
C H_2O
D O_2

3.3 (a) Explain why water has a relatively high boiling point. [2]

(b) Explain why the boiling points of the noble gases increase down the group. [2]

3.4 Draw and label a diagram to show hydrogen bonding between two water molecules (show the δ charges and the lone pair). [3]

3.5 The table gives the boiling points of four hydrides.

Hydride	**NH_3**	**PH_3**	**H_2O**	**H_2S**
boiling point / °C	−33	−88	100	−60

(a) Name all the intermolecular forces present in PH_3. [2]

(b) Explain why NH_3 boils at a much higher temperature than PH_3, even though PH_3 has more electrons. [4]

(c) Explain why H_2O boils higher than NH_3, given that both form hydrogen bonds. [2]

(d) State what is broken when H_2O boils, and what is NOT broken. [2]

(e) Explain, in terms of hydrogen bonding, why ice floats on water. [3]