



CrackingCHEM

GCSE | A-LEVEL

UNDERSTAND • APPLY • SUCCEED

AQA CHEMISTRY 7405

BONDING II

SPECIFICATION-LED STUDENT NOTES

			
SPEC	CRACK IT	TEST IT	DONE WHEN

SPECIFICATION AND STUDENT NOTES

AQA SECTION	YOU WILL MASTER
3.1.3.5	Shapes and bond angles of simple molecules and ions
3.1.3.6	Electronegativity, polar bonds and permanent molecular dipoles
3.1.3.7	Forces between molecules and their effects on physical properties

SHAPE → BOND POLARITY → MOLECULAR POLARITY → INTERMOLECULAR FORCES → PROPERTIES

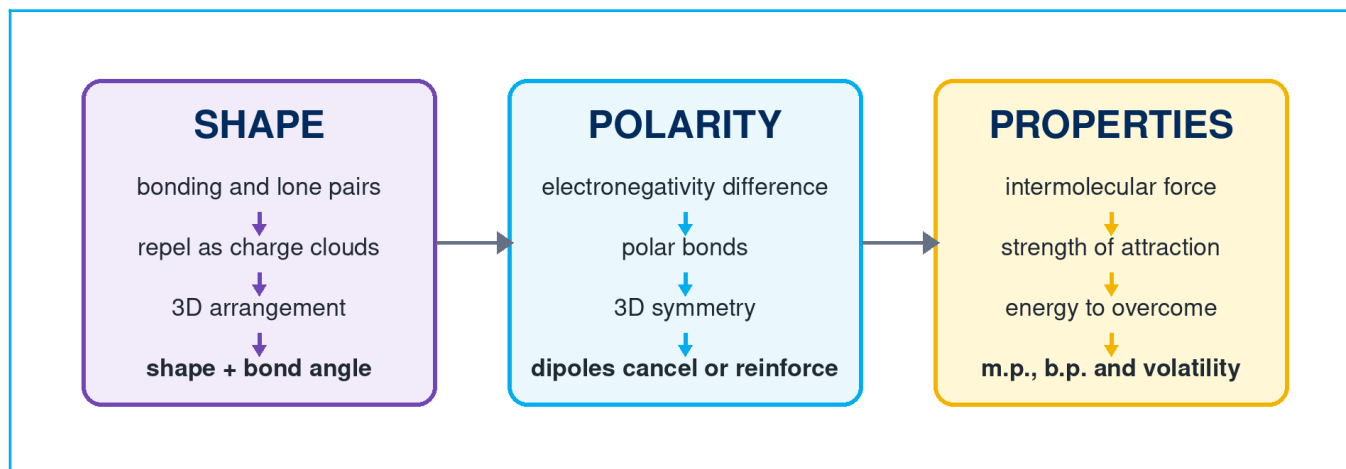
THE BIG PICTURE

WHY IT MATTERS

AQA questions link microscopic electron behaviour to a visible result. The marks come from naming the charge clouds, dipoles or attractions and then building the consequence.

YOU WILL MASTER

A repeatable route for shapes; bond and molecular polarity; all three intermolecular-force types; boiling, melting, volatility, ice and solubility explanations.



THE NON-NEGOTIABLE DISTINCTION Covalent bonds hold atoms together within a molecule. Intermolecular forces are weaker attractions between separate molecules. Boiling a molecular substance overcomes intermolecular forces; it does not break its covalent bonds.

BOUNDARY This pack covers AQA 3.1.3.5-3.1.3.7. Ionic, covalent, dative and metallic bonding and giant structures belong to Bonding I and are used only as retrieval.

✓ **DONE WHEN** you can choose the correct route before writing: shape, polarity or physical property.

FULL-MARK DEFINITION BANK



USE EXACTLY Learn the bold idea, then apply it to a named species. Avoid vague phrases such as “pulls electrons”, “strong forces” or “hydrogen bonds form with hydrogen”.

TERM	EXAM-READY DEFINITION
Charge cloud	A region of electron density around the central atom. Each bond region and each lone pair counts as one charge cloud.
Lone pair	A pair of outer-shell electrons that is not involved in bonding.
Electronegativity	The power of an atom to attract the pair of electrons in a covalent bond.
Polar covalent bond	A covalent bond in which the bonding electrons are distributed unequally, producing partial charges.
Bond dipole	A separation of partial charge across a polar covalent bond, with a $\delta+$ end and a $\delta-$ end.
Permanent dipole	A permanent separation of charge across a molecule because its bond dipoles do not cancel.
Polar molecule	A molecule with a resultant permanent dipole because its bond dipoles do not cancel.
Intermolecular force	An attractive force acting between molecules.
Induced dipole-dipole force	Electrostatic attraction between an instantaneous dipole and the dipole it induces in a neighbouring particle. These are also called Van der Waals forces.
Permanent dipole-dipole force	Electrostatic attraction between the $\delta+$ end of one polar molecule and the $\delta-$ end of a neighbouring polar molecule.
Hydrogen bond	A strong intermolecular attraction between a lone pair on N, O or F and a $\delta+$ hydrogen atom covalently bonded to N, O or F in another molecule.



TEST IT 1

Repair both weak statements so each would earn full marks: (a) “electronegativity is how much an atom wants electrons”; (b) “a hydrogen bond is a strong bond to hydrogen”. [4 marks]

Write one precise definition for each term.

.....

.....

.....

.....

✓ **DONE WHEN** you can define every key term without replacing the named particles or attractions with vague words.

1. Shapes: the VSEPR model



SPEC 3.1.3.5 Bonding pairs and lone pairs are charge clouds that repel. Electron pairs arrange as far apart as possible. Explain shapes and bond angles for species with up to six electron pairs around the central atom.



WHAT VSEPR MEANS VSEPR stands for Valence Shell Electron Pair Repulsion. The valence shell is the outer electron shell. Electron pairs in this shell of the central atom repel and arrange as far apart as possible. This lowest-repulsion arrangement determines the parent geometry and bond angles.

QUICK ELECTRON-PAIR COUNT total pairs = (central-atom group number + number of singly bonded atoms + negative charge - positive charge) ÷ 2

MOVE	APPLY THE METHOD
1	Choose the central atom. Its group number gives its outer-shell electrons; use 8 for a Group 0 atom.
2	Add 1 for every atom or group joined to the central atom by a single bond.
3	Adjust for charge: add 1 electron for each negative charge; subtract 1 for each positive charge.
4	Divide by 2. This gives the total electron pairs, or charge clouds, around the central atom.
5	Bonding pairs equal the number of single bonds. Any pairs left over are lone pairs.
6	Match the total pairs to the parent geometry, then ignore lone-pair positions when naming the molecular shape.

TOTAL PAIRS	2	3	4	5	6
PARENT GEOMETRY	linear	trigonal planar	tetrahedral	trigonal bipyramidal	octahedral
IDEAL ANGLES	180°	120°	109.5°	90°, 120°, 180°	90°, 180°

WORKED 1: NH₃

5 + 3 = 8; 8 ÷ 2 = 4 pairs. Three are bonding pairs, leaving one lone pair. The parent geometry is tetrahedral; the molecular shape is trigonal pyramidal, 107°.

WORKED 2: NH₄⁺

5 + 4 - 1 = 8; 8 ÷ 2 = 4 pairs. All four are bonding pairs, so there is no lone pair. Parent geometry and molecular shape: tetrahedral, 109.5°.

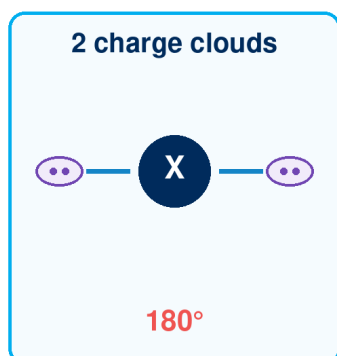
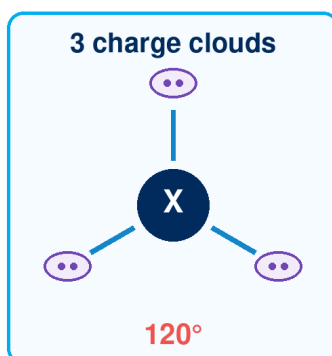
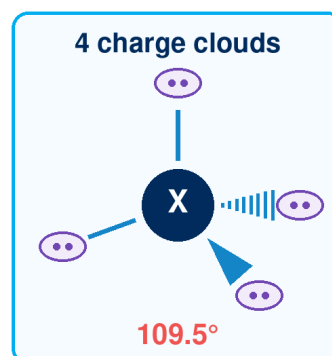
LIMIT OF THE SHORTCUT Use this count when the attached atoms or groups are singly bonded. If a multiple bond or electron diagram is shown, count regions of electron density directly: a single, double or triple bond is one charge cloud.

✓ **DONE WHEN** you can calculate the total pairs, identify bonding and lone pairs, match the parent geometry and then name the molecular shape.

VSEPR: charge-cloud repulsion



CRACK IT Every bonding region and every lone pair counts as one charge cloud around the central atom. VSEPR then places these negatively charged clouds as far apart as possible.



ELECTRON-PAIR ARRANGEMENT

Name the arrangement using every charge cloud, including lone pairs.

MOLECULAR SHAPE

Name the shape from atom positions only. Lone-pair positions are not included in the shape name.

REPULSION ORDER lone pair-lone pair > lone pair-bond pair > bond pair-bond pair. Lone pairs repel more strongly; as an A-level rule of thumb, each lone pair reduces the bond angle by approximately 2.5° from the parent tetrahedral angle.



TEST IT 2

Use the electron-pair counting method to determine the total number of pairs around oxygen in H₂O. State the numbers of bonding pairs and lone pairs, the molecular shape and the H-O-H bond angle. Explain why this angle is smaller than 109.5°. [6 marks]

Show the electron count before applying VSEPR.

.....

.....

.....

.....

.....

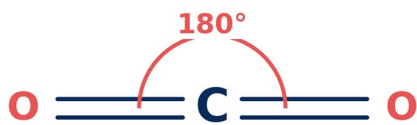
.....

✓ **DONE WHEN** you use the electron count and VSEPR repulsion to justify both the shape and bond angle.

2. Two and three charge clouds

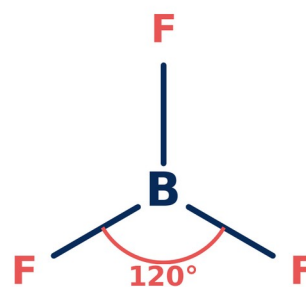


CRACK IT With no lone pairs on the central atom, equal charge clouds spread out symmetrically.



linear • two charge clouds

CO₂: linear, 180°



trigonal planar • 120°

BF₃: trigonal planar, 120°

SPECIES	BONDING REGIONS	LONE PAIRS	SHAPE	ANGLE
CO ₂	2	0	linear	180°
BeCl ₂	2	0	linear	180°
BF ₃	3	0	trigonal planar	120°
SO ₃	3	0	trigonal planar	120°

WORKED EXAMPLE SO₃ has three bonding regions and no lone pairs on sulfur. Three charge clouds repel equally into one plane, so SO₃ is trigonal planar with bond angles of 120°.



TEST IT 3

Deduce the shape and bond angle around carbon in CS₂. Then deduce the shape and bond angle around boron in BCl₃. [4 marks]
Use charge-cloud counts in both explanations.

.....

.....

.....

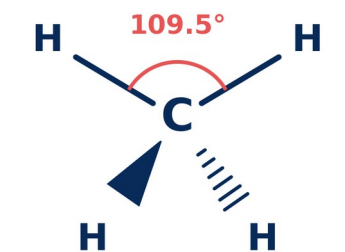
.....

✓ **DONE WHEN** you recognise two regions as linear and three regions as trigonal planar when the central atom has no lone pairs.

3. Four charge clouds: tetrahedral

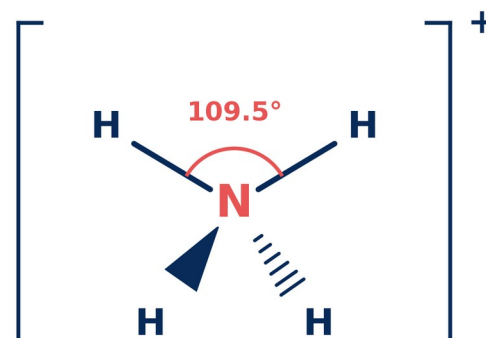


CRACK IT Four bonding regions repel towards the corners of a tetrahedron. The drawing must use two ordinary bonds, one solid wedge and one hashed wedge.



tetrahedral • 109.5°

CH₄: four bonding regions



NH₄⁺ • tetrahedral • 109.5°

NH₄⁺: charge changes the electron count

SPECIES	COUNT AROUND CENTRAL ATOM	SHAPE	ANGLE
CH ₄	4 bonding regions; 0 lone pairs	tetrahedral	109.5°
SiCl ₄	4 bonding regions; 0 lone pairs	tetrahedral	109.5°
NH ₄ ⁺	4 bonding regions; 0 lone pairs	tetrahedral	109.5°

ION COUNT For an ion, include the overall charge when counting electrons. In NH₄⁺, nitrogen has four N-H bonding pairs and no lone pair. Put square brackets and the overall charge around the whole ion.



TEST IT 4

BF₄⁻ has four B-F bonding regions and no lone pairs on boron. State its shape and bond angle, then explain how the charge clouds produce that shape. [4 marks]

Include the count, repulsion, 3D arrangement and angle.

.....

.....

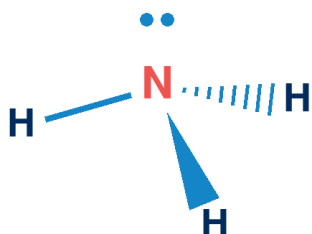
.....

.....

✓ **DONE WHEN** you draw tetrahedral species with consistent bond lengths and correct wedge-and-dash conventions.

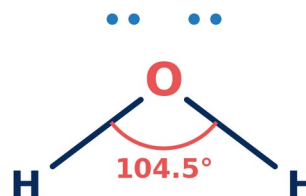
4. Lone pairs squeeze bond angles

CORE IDEA A lone pair is attracted to only one nucleus, so its charge cloud spreads out more than a bonding pair. It repels neighbouring charge clouds more strongly.



trigonal pyramidal • 107°

NH₃: one lone pair



non-linear (bent) • 104.5°

H₂O: two lone pairs

SPECIES	BONDING PAIRS	LONE PAIRS	SHAPE	TYPICAL ANGLE
SO ₂	2	1	non-linear (bent)	<120°
NH ₃	3	1	trigonal pyramidal	107°
H ₂ O	2	2	non-linear (bent)	104.5°
H ₃ O ⁺	3	1	trigonal pyramidal	do not assume 107° unless directed

ANGLE ROUTE Start from the ideal charge-cloud arrangement. Lone pairs repel more strongly than bonding pairs and compress the bond angle. Use approximately 2.5° less per lone pair as the A-level rule of thumb: 109.5° → 107° for NH₃ and → 104.5° for H₂O.



TEST IT 5

PCl₃ has three bonding pairs and one lone pair around phosphorus. Deduce its shape and explain why its Cl-P-Cl bond angle is smaller than 109.5°. [4 marks]

Do not name the tetrahedral electron-pair arrangement as the molecular shape.

.....

.....

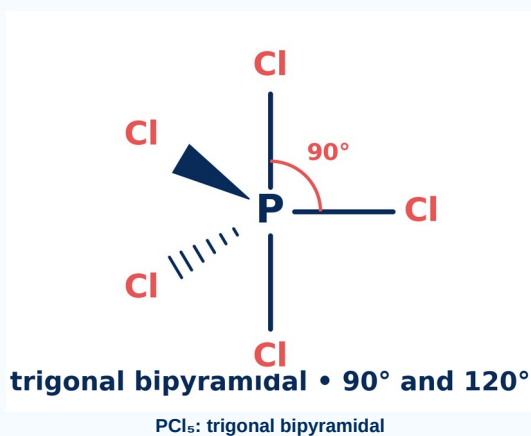
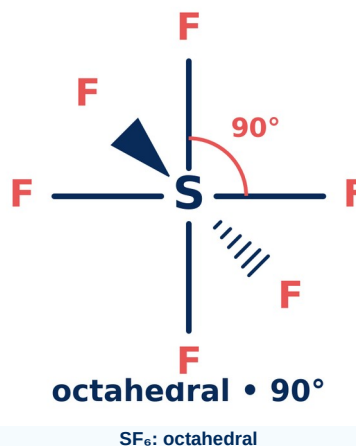
.....

.....

✓ **DONE WHEN** you use lone-pair repulsion to explain both the shape and the reduction in bond angle.

5. Five and six charge clouds

CRACK IT Five charge clouds form trigonal-bipyramidal positions. Six form octahedral positions. Removing atom positions occupied by lone pairs gives the molecular shape.



CHARGE CLOUDS	BONDING + LONE PAIRS	EXAMPLE	MOLECULAR SHAPE	ANGLES
5	5 + 0	PCl ₅	trigonal bipyramidal	90°, 120°, 180°
5	2 + 3	XeF ₂	linear	180°
6	6 + 0	SF ₆	octahedral	90°, 180°
6	4 + 2	XeF ₄	square planar	90°, 180°
6	5 + 1	BrF ₅	square pyramidal	about 90°

TRIGONAL BIPYRAMIDAL

Three equatorial bonds are 120° apart. Two axial bonds are perpendicular to the equatorial plane.

OCTAHEDRAL

Four bonds lie in a square plane. Two bonds are perpendicular to that plane.

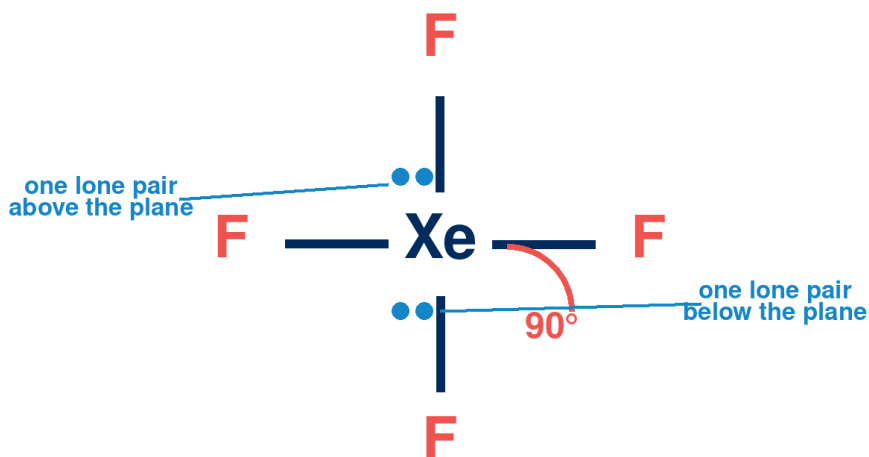
EXAM TRAP Do not draw five bonds as a flat pentagon or six bonds as a flat hexagon.

✓ **DONE WHEN** you can read five- and six-cloud geometries from a clear 3D diagram.

6. Deduce unfamiliar shapes without guessing



FIVE-MOVE METHOD central atom → bonding regions → lone pairs → electron-pair arrangement → molecular shape and bond angle



square planar • 90° and 180°

Worked example: XeF₄ has six charge clouds; two opposite positions contain lone pairs.

WORKED SPECIES	COUNT	REASONING	RESULT
NO ₂ ⁺	2 BP, 0 LP	two charge clouds move to opposite sides	linear, 180°
SO ₂	2 BP, 1 LP	three-cloud base; remove the lone-pair position	non-linear, <120°
XeF ₄	4 BP, 2 LP	six-cloud base; lone pairs occupy opposite positions	square planar, 90°



TEST IT 6

ClF₃ has three bonding pairs and two lone pairs around Cl. IF₅ has five bonding pairs and one lone pair around I. Deduce the shape and bond angles of both species. [6 marks]

Show the charge-cloud count before naming each shape.

.....

.....

.....

.....

.....

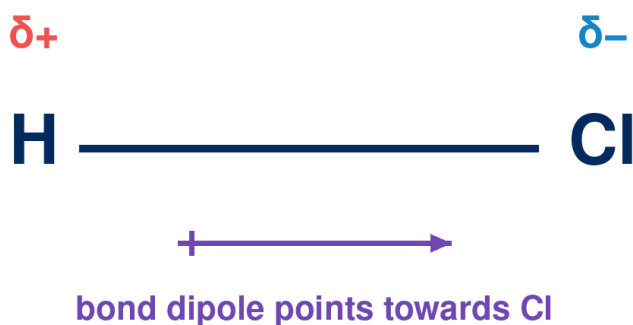
.....

✓ **DONE WHEN** you can deduce a shape from supplied bonding-pair and lone-pair information rather than memorising a flat picture.

7. Electronegativity and polar bonds



SPEC 3.1.3.6 Electronegativity is the power of an atom to attract the pair of electrons in a covalent bond. Unequal electron distribution produces a polar covalent bond.



Worked example: chlorine attracts the H-Cl bonding pair more strongly, so H is $\delta+$ and Cl is $\delta-$.

ELECTRONEGATIVITY DIFFERENCE

$\Delta\chi = |\text{electronegativity of atom 1} - \text{electronegativity of atom 2}|$. A larger difference normally means more unequal sharing and more polar character.

NO MAGIC CUT-OFF

Bond character is a continuum. Do not invent a universal number at which a covalent bond suddenly becomes ionic. Use the values and context given.

EXAM TRAP Do not average the two electronegativities. Calculate their difference.



TEST IT 7

Given P = 2.2, S = 2.6 and Cl = 3.2: rank the atoms in increasing electronegativity, calculate $\Delta\chi$ for P-Cl, and place $\delta+$ and $\delta-$ on the P-Cl bond. [4 marks]

Show the subtraction and identify which atom attracts the bonding pair more strongly.

.....

.....

.....

.....

✓ **DONE WHEN** you place partial charges from electronegativity, not from atom size or guesswork.

8. A polar bond does not guarantee a polar molecule

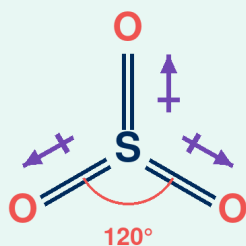


CRACK IT First identify every polar bond. Then use the 3D shape to decide whether the bond dipoles cancel or produce a net



MOVE	QUESTION TO ASK
1	Which bonds are polar?
2	In which direction does each bond dipole act?
3	What is the molecule's 3D shape?
4	Are the surrounding atoms and bond dipoles arranged symmetrically?
5	Do the dipoles cancel completely or leave a resultant dipole?

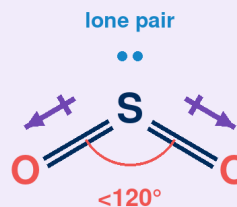
WORKED: SO₃



trigonal planar
bond dipoles cancel

Three equivalent S-O bond dipoles act symmetrically in a trigonal-planar molecule, so they cancel. SO₃ has no permanent dipole.

WORKED: SO₂



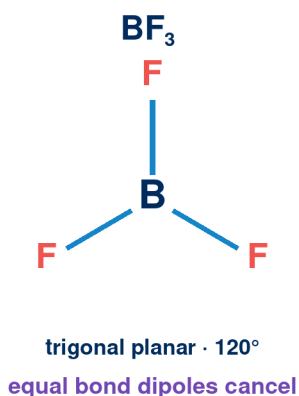
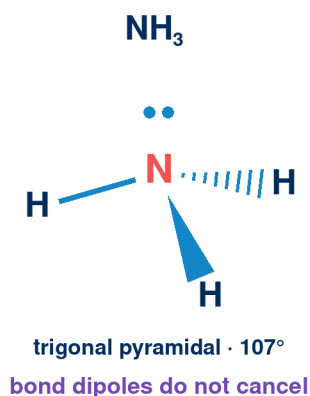
non-linear (bent)
bond dipoles do not cancel

The S-O bonds are polar, but the molecule is non-linear. The bond dipoles do not cancel, so SO₂ has a permanent dipole.

EXAMINER POINT "It contains polar bonds" is not enough. A full answer identifies the shape and states whether the vector dipoles cancel.

✓ **DONE WHEN** you decide whole-molecule polarity only after considering both bond polarity and 3D symmetry.

9. Symmetry decides whether dipoles cancel



BF_3 is symmetrical so its bond dipoles cancel. NH_3 is asymmetric because of the lone pair, so it has a net dipole.

MOLECULE	POLAR BONDS?	3D ARRANGEMENT	PERMANENT DIPOLE?
BF_3	yes	symmetrical trigonal planar	no; dipoles cancel
CO_2	yes	symmetrical linear	no; dipoles cancel
CCl_4	yes	symmetrical tetrahedral	no; dipoles cancel
H_2O	yes	non-linear	yes; dipoles reinforce
NH_3	yes	trigonal pyramidal	yes; dipoles do not cancel
CH_2Cl_2	yes	tetrahedral but not symmetrical	yes; dipoles do not cancel

SENSE CHECK Symmetry cancels only equivalent bond dipoles pointing in balanced directions. A tetrahedral molecule with different surrounding atoms is not automatically non-polar.



TEST IT 8

PF_5 is trigonal bipyramidal, SF_4 is seesaw and CH_3Cl is tetrahedral. All contain polar bonds. State whether each molecule has a permanent dipole and justify each answer using shape and symmetry. [6 marks]

Do not use "symmetrical" without saying what cancels.

.....

.....

.....

.....

.....

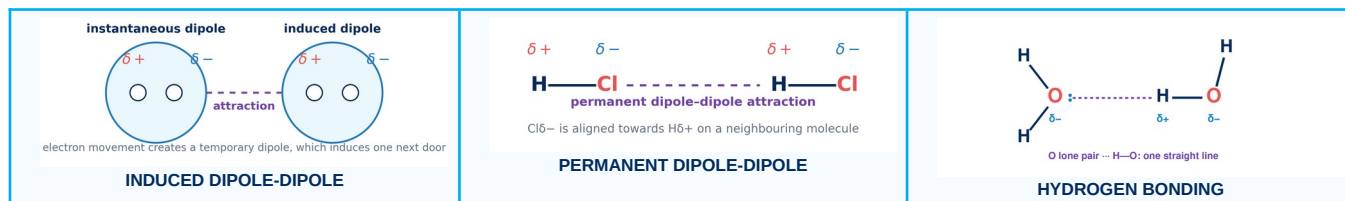
.....

✓ **DONE WHEN** you can explain why a molecule with polar bonds may still have no permanent dipole.

10. Forces between molecules: three types



SPEC 3.1.3.7 Explain induced dipole-dipole forces, permanent dipole-dipole forces and hydrogen bonding between familiar and unfamiliar molecules.



FORCE	WHEN PRESENT	WHAT ATTRACTS
induced dipole-dipole (Van der Waals)	between all atoms and molecules	opposite instantaneous and induced partial charges
permanent dipole-dipole	in addition, between polar molecules	permanent $\delta+$ and $\delta-$ ends of neighbouring molecules
hydrogen bonding	when the donor and acceptor conditions are met	$\delta+$ H bonded to N/O/F and a lone pair on N/O/F

CRUCIAL RULE All atoms and molecules experience induced dipole-dipole forces. Polar molecules also experience permanent dipole-dipole attractions. Hydrogen-bonding molecules still experience both other applicable forces.



TEST IT 9

State every intermolecular-force type present between molecules of CH_4 , CH_3Cl and CH_3OH . For CH_3OH , identify the hydrogen-bond donor and acceptor atoms. [5 marks]

List all applicable forces, not only the strongest one.

.....

.....

.....

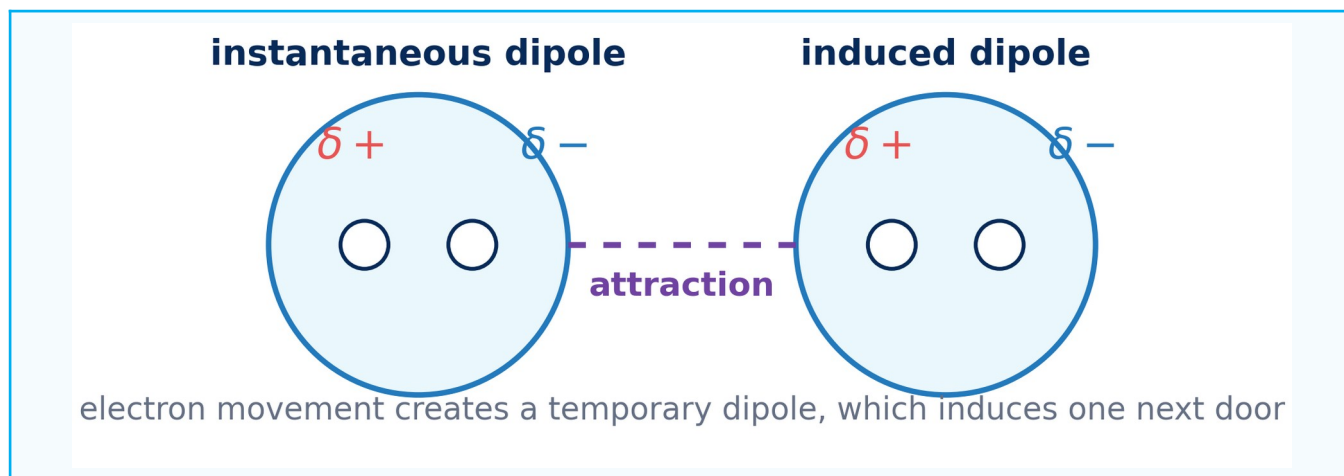
.....

.....

✓ **DONE WHEN** you identify every force present before deciding which one controls the comparison.

11. Induced dipole-dipole forces (Van der Waals forces)

FULL-MARK DEFINITION An induced dipole-dipole force is the electrostatic attraction between an instantaneous dipole and the dipole it induces in a neighbouring particle. These are also called Van der Waals forces.



STEP	WHAT HAPPENS
1	Electrons are moving constantly.
2	At one instant, an uneven electron distribution creates an instantaneous dipole.
3	That dipole distorts the electron cloud of a neighbouring particle and induces a dipole.
4	Opposite temporary partial charges attract electrostatically.

FACTOR	WHY THE FORCE BECOMES STRONGER
more electrons / larger electron cloud	the electron cloud is more polarisable, so larger temporary dipoles form
greater molecular surface contact	more of two neighbouring electron clouds can interact at the same time

WORKED TREND $\text{Cl}_2 < \text{Br}_2 < \text{I}_2$ in boiling point. Down the group the molecules contain more electrons, their electron clouds are more polarisable, stronger Van der Waals forces form, and more energy is required to separate the molecules.



TEST IT 10

Pentane and 2-methylbutane have the same molecular formula. Predict which has the higher boiling point and explain why. [4 marks]
Use molecular shape, surface contact, Van der Waals-force strength and energy.

.....

.....

.....

.....

✓ **DONE WHEN** you explain Van der Waals-force trends through electron number, polarisability or surface contact, not through "bigger bonds".

12. Permanent dipole-dipole forces

FULL-MARK DEFINITION Permanent dipole-dipole forces are electrostatic attractions between the $\delta+$ end of one polar molecule and the $\delta-$ end of a neighbouring polar molecule.



$\text{Cl}\delta-$ is aligned towards $\text{H}\delta+$ on a neighbouring molecule

The dotted line is an intermolecular attraction. It is not a new covalent bond.

F₂

Non-polar molecule. It has induced dipole-dipole forces only.

HCl

Polar molecule. It has induced dipole-dipole forces plus permanent dipole-dipole forces.

WORKED COMPARISON HCl and F₂ have similar relative molecular masses, but HCl has the higher boiling point because its molecules have additional permanent dipole-dipole attractions. More energy is required to overcome the overall stronger intermolecular forces.

EXAMINER POINT When comparing different molecules, consider both permanent polarity and the number of electrons. A large non-polar molecule can have stronger Van der Waals forces than a small polar molecule.



TEST IT 11

Propanone, CH₃COCH₃, and butane, CH₃CH₂CH₂CH₃, both have M_r = 58. Propanone has the higher boiling point. Explain why. [4 marks]
Name every force in each substance and identify the additional attraction.

.....

.....

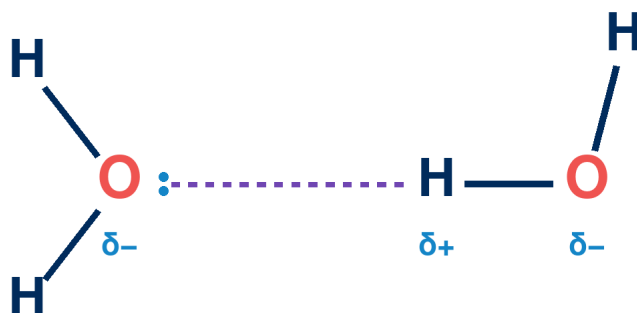
.....

.....

✓ **DONE WHEN** you locate the attraction between opposite partial charges on neighbouring polar molecules.

13. Hydrogen bonding: use the donor test

FULL-MARK DEFINITION A hydrogen bond is a strong intermolecular attraction between a lone pair on N, O or F and a $\delta+$ hydrogen atom covalently bonded to N, O or F in another molecule.



O lone pair ... H—O: one straight line

CHECK	QUESTION
1	Is there an H atom covalently bonded directly to N, O or F? This is the donor requirement.
2	Does a neighbouring molecule have a lone pair on N, O or F? This is the acceptor requirement.
3	Can the $\delta+$ H of one molecule attract the lone pair of another molecule?
4	Draw the hydrogen bond as a dotted intermolecular line, never as a solid covalent bond.

SUBSTANCE	SELF HYDROGEN-BONDING?	REASON
HF	yes	H-F donor and F lone-pair acceptor
H ₂ O	yes	O-H donors and O lone-pair acceptors
NH ₃	yes	N-H donors and an N lone-pair acceptor
CH ₃ F	no	its H atoms are bonded to C, not F
CH ₃ OCH ₃	no between its own molecules	it has an O acceptor but no O-H donor



TEST IT 12

Propan-1-ol, CH₃CH₂CH₂OH, and methoxyethane, CH₃OCH₂CH₃, have the same molecular formula. Explain why propan-1-ol has the higher boiling point. [5 marks]

Identify donor and acceptor requirements, force strength, energy and property.

.....

.....

.....

.....

.....

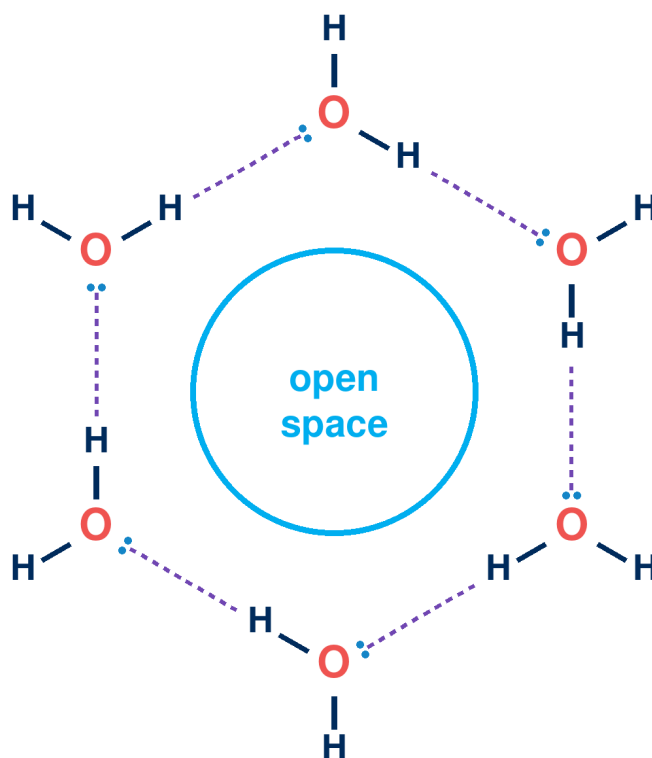
✓ **DONE WHEN** you can point to the donor H, the acceptor lone pair and the dotted intermolecular attraction.

14. Hydrogen bonding and physical properties



SPEC 3.1.3.7 Explain the anomalous boiling points of compounds and the importance of hydrogen bonding in the low density of ice.

EXAMPLE	KEY INTERMOLECULAR ATTRACTION	CONSEQUENCE
NH ₃	hydrogen bonding between N-H and an N lone pair	higher boiling point than PH ₃
H ₂ O	an extensive hydrogen-bonded network	unusually high boiling point
HF	hydrogen bonding between H-F and F lone pairs	higher boiling point than HCl



Ice: each dotted hydrogen bond runs in a straight line from a lone pair to a δ^+ hydrogen.

ICE-DENSITY CHAIN	EXPLANATION
1	Hydrogen bonds hold water molecules in an open lattice.
2	The open spaces keep molecules further apart than in liquid water.
3	The same mass occupies a larger volume, so ice has a lower density and floats.



TEST IT 13

Methanol, CH₃OH, has a higher boiling point than methanethiol, CH₃SH, even though methanethiol has the larger M_r . Explain this difference. [4 marks]

Identify the special attraction and link force strength to energy.

.....

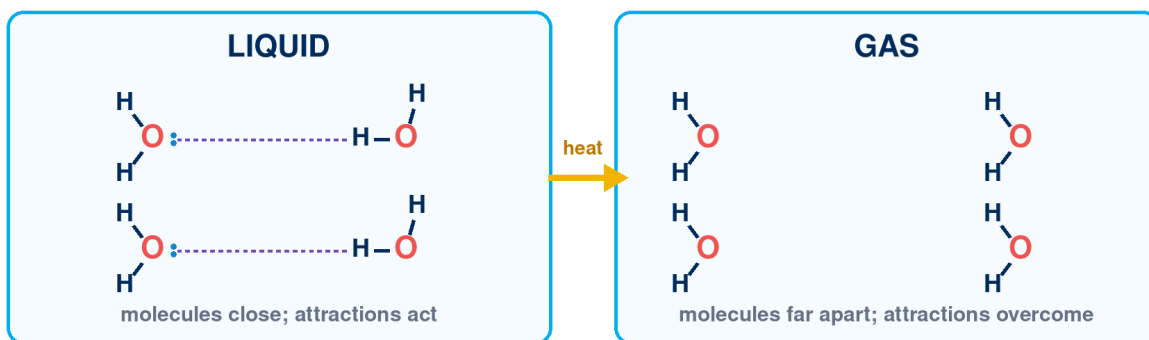
.....

.....

.....

✓ **DONE WHEN** you explain an anomalous boiling point or ice density by naming hydrogen bonds and building the full consequence.

15. Melting and boiling: what is actually overcome?



PROCESS	OVERCOME OR BROKEN	REMAINS INTACT
boiling water	hydrogen bonds between H_2O molecules	O-H covalent bonds
melting iodine	induced dipole-dipole forces between I_2 molecules	I-I covalent bonds



FIVE-MOVE EXPLANATION identify the molecules → state every force present → identify the stronger overall attraction and why → state that more energy is required → conclude with higher melting/boiling point and, where relevant, lower volatility

WORKED EXAMPLE Ethanol has a higher boiling point than ethane. Both have Van der Waals forces, but ethanol molecules also form hydrogen bonds. These make the overall intermolecular attractions stronger, so more energy is required to separate the ethanol molecules.



TEST IT 14

The boiling points are $\text{Ar} = -186^\circ\text{C}$, $\text{HBr} = -67^\circ\text{C}$ and $\text{H}_2\text{O} = 100^\circ\text{C}$. Explain the order $\text{Ar} < \text{HBr} < \text{H}_2\text{O}$. [6 marks]

Name the relevant particles and forces, then connect attraction strength to energy and boiling point.

.....

.....

.....

.....

.....

.....

✓ **DONE WHEN** you state exactly which intermolecular attraction is overcome and never claim that boiling breaks covalent bonds.

16. Solubility: attractions must be replaced



CRACK IT To dissolve, attractions between solute particles and between solvent particles must be disrupted. New attractions between solute and solvent particles must compensate for this.

PAIR	INTERACTION REASONING	PREDICTION
ethanol + water	both can donate and accept hydrogen bonds, so favourable new attractions form	ethanol mixes with water
hexane + water	hexane cannot replace enough of water's strong hydrogen-bonding attractions	hexane is not soluble in water
iodine + hexane	both are non-polar; compatible Van der Waals-force interactions can form	iodine dissolves better in hexane than in water

USEFUL START

"Like dissolves like" can guide a prediction.

FULL EXPLANATION

Name the attractions disrupted in both substances and the new attractions that form.

EXAM TRAP Do not say polar substances always dissolve in water. Solubility depends on the balance of all attractions disrupted and formed.



TEST IT 15

Propanone mixes with water, whereas propane does not. Explain this difference in terms of the attractions disrupted and formed. [4 marks]
Identify the interaction propanone can form with water and explain why propane cannot compensate for disrupted water-water attractions.

.....

.....

.....

.....

✓ **DONE WHEN** you explain solubility as an interaction replacement, not as a slogan.

MIXED AQA-STYLE PRACTICE

QUESTION A NF_3 contains three N-F bonds and one lone pair on nitrogen. CF_4 contains four C-F bonds and no lone pairs on carbon. Deduce each shape. State whether the F-N-F angle is greater than, equal to or less than 109.5° , and state the F-C-F angle. Explain whether each molecule has a permanent dipole. [6 marks]

.....

.....

.....

.....

.....

.....

QUESTION B The boiling points are $\text{C}_2\text{H}_4 = -104^\circ\text{C}$, $\text{CH}_2\text{O} = -19^\circ\text{C}$ and $\text{CH}_3\text{NH}_2 = -6^\circ\text{C}$. Explain this order using every relevant intermolecular force. [6 marks]

.....

.....

.....

.....

.....

.....

SELF-CHECK In each answer, underline the named force and circle the sentence linking stronger attraction to more energy.

✓ **DONE WHEN** you can combine shape, polarity and intermolecular-force reasoning without jumping between routes.

FINAL MASTERY CHECK

THE THREE ROUTES SHAPE: count and repel charge clouds. POLARITY: bond dipoles + 3D symmetry. PROPERTY: particles + forces + strength + energy + result.

	I CAN...	SPEC	CONFIDENCE
☐	count bonding regions and lone pairs around a central atom	3.1.3.5	R / A / G
☐	deduce shapes and bond angles for two to six charge clouds	3.1.3.5	R / A / G
☐	use lone-pair repulsion to explain reduced bond angles	3.1.3.5	R / A / G
☐	draw line, wedge and hashed-wedge bonds correctly	3.1.3.5	R / A / G
☐	define electronegativity exactly	3.1.3.6	R / A / G
☐	place $\delta+$ and $\delta-$ on a polar bond	3.1.3.6	R / A / G
☐	use shape and symmetry to decide molecular polarity	3.1.3.6	R / A / G
☐	explain induced dipole-dipole (Van der Waals) forces	3.1.3.7	R / A / G
☐	explain permanent dipole-dipole forces	3.1.3.7	R / A / G
☐	identify hydrogen-bond donors and acceptors	3.1.3.7	R / A / G
☐	compare boiling points using forces, energy and particles	3.1.3.7	R / A / G
☐	explain why melting and boiling do not break covalent bonds	3.1.3.7	R / A / G
☐	explain the low density of ice	3.1.3.7	R / A / G
☐	reason carefully about solubility from disrupted and formed attractions	3.1.3.7	R / A / G

SIX SENTENCES WORTH MEMORISING

- Electron pairs in the outer shell repel and arrange as far apart as possible.
- A multiple bond counts as one bonding region when predicting shape.
- Electronegativity is the power of an atom to attract the pair of electrons in a covalent bond.
- A molecule has a permanent dipole only if its bond dipoles do not cancel.
- Boiling a molecular substance overcomes intermolecular forces, not covalent bonds.
- Stronger intermolecular forces require more energy to overcome and usually give a higher boiling point.

✓ **DONE WHEN** every box is green and you can complete TEST IT 1-15 and the mixed practice without using the notes.

TEST IT ANSWERS 1-10

MARKING RULE Award each mark only where the required particle, attraction, direction or consequence is explicit.

1. Electronegativity: the power of an atom to attract the pair of electrons in a covalent bond. Hydrogen bond: a strong intermolecular attraction between a lone pair on N, O or F and a δ^+ H atom covalently bonded to N, O or F in another molecule.
2. Oxygen is in Group 6 and has two singly bonded H atoms: $6 + 2 = 8$; $8 \div 2 = 4$ electron pairs. Two are bonding pairs and two are lone pairs. The molecular shape is non-linear (bent) and the H-O-H angle is 104.5° . Lone pair-bond pair repulsion is stronger than bond pair-bond pair repulsion, so the angle is compressed below the tetrahedral value of 109.5° .
3. CS_2 around carbon: two bonding regions, no lone pairs; linear, 180° . BCl_3 around boron: three bonding regions, no lone pairs; trigonal planar, 120° .
4. BF_4^- has four bonding regions and no lone pairs around B. The four charge clouds repel as far apart as possible into a tetrahedral arrangement. Shape: tetrahedral; angle: 109.5° .
5. PCl_3 has three bonding pairs and one lone pair, so it is trigonal pyramidal. Lone pair-bond pair repulsion is stronger than bond pair-bond pair repulsion, so the Cl-P-Cl bond angle is compressed below 109.5° .
6. ClF_3 : five charge clouds, with two lone pairs occupying equatorial positions; T-shaped, approximately 90° and 180° . IF_5 : six charge clouds, with one lone pair; square pyramidal, approximately 90° .
7. Increasing electronegativity: $\text{P} < \text{S} < \text{Cl}$. $\Delta\chi(\text{P-Cl}) = 3.2 - 2.2 = 1.0$. P is δ^+ and Cl is δ^- because Cl attracts the bonding pair more strongly.
8. PF_5 : trigonal bipyramidal and symmetrical; the five P-F bond dipoles cancel, so it has no permanent dipole. SF_4 : seesaw and asymmetrical because one position is occupied by a lone pair; its S-F bond dipoles do not cancel, so it is polar. CH_3Cl : tetrahedral but not symmetrical because the surrounding atoms are not all identical; its bond dipoles do not cancel, so it is polar.
9. CH_4 : induced dipole-dipole (Van der Waals) forces only. CH_3Cl : induced dipole-dipole plus permanent dipole-dipole forces. CH_3OH : induced dipole-dipole, permanent dipole-dipole and hydrogen bonding. In CH_3OH the O-H hydrogen is the donor site and an O lone pair is the acceptor site.
10. Pentane has the higher boiling point. Its less-branched shape gives greater surface contact between neighbouring molecules, so its induced dipole-dipole (Van der Waals) forces are stronger. More energy is required to separate the molecules.

✓ **DONE WHEN** your answer uses the same precise nouns as the question and never hides behind "it" or "strong forces".

ANSWERS 11–15 + MIXED PRACTICE

11.

Both substances have Van der Waals forces. Propanone is polar because of its C=O bond and also has permanent dipole-dipole attractions; butane is non-polar. The overall attractions in propanone are stronger, so more energy is required to separate its molecules and its boiling point is higher.

12.

Both have Van der Waals forces and permanent dipole-dipole forces. Propan-1-ol has O-H donor bonds and O lone-pair acceptors, so its molecules also form hydrogen bonds. Methoxyethane has an O acceptor but no O-H donor, so it cannot hydrogen-bond to itself. More energy is required to overcome propan-1-ol's stronger attractions.

13.

Methanol molecules form hydrogen bonds because they contain O-H donor bonds and O lone-pair acceptors. Methanethiol does not form AQA-type hydrogen bonds because H is bonded to S. Hydrogen bonds in methanol are stronger overall, so more energy is required and methanol has the higher boiling point.

14.

Ar atoms have Van der Waals forces only and very few electrons, so their attractions are weakest. HBr molecules have more electrons and are polar, so they have stronger Van der Waals forces plus permanent dipole-dipole attractions. H₂O molecules form hydrogen bonds as well as the other applicable forces; these are strongest overall. Increasing energy is required to separate the particles, so boiling point increases $\text{Ar} < \text{HBr} < \text{H}_2\text{O}$.

15.

Dissolving requires some water-water hydrogen bonds to be disrupted. The oxygen atom in propanone has lone pairs and can accept hydrogen bonds from water, so favourable propanone-water attractions replace those disrupted attractions. Propane is non-polar and offers only weak Van der Waals interactions with water, which do not compensate sufficiently for disrupting water-water hydrogen bonds, so propane does not mix with water.

MIXED QUESTION A [6 marks]

NF₃: three bonding pairs and one lone pair around N; trigonal pyramidal; the F-N-F angle is less than 109.5° because lone pair-bond pair repulsion is stronger than bond pair-bond pair repulsion. Each N-F bond is polar and the asymmetric pyramidal arrangement means the bond dipoles do not cancel, so NF₃ has a permanent dipole.

CF₄: four bonding pairs and no lone pairs around C; tetrahedral; 109.5°. Each C-F bond is polar, but the four equal bond dipoles act symmetrically and cancel, so CF₄ has no permanent dipole.

MIXED QUESTION B [6 marks]

C₂H₄ molecules are non-polar and experience induced dipole-dipole (Van der Waals) forces only. CH₂O molecules are polar, so they experience both Van der Waals and permanent dipole-dipole attractions. CH₃NH₂ molecules experience both of those forces and also form hydrogen bonds through N-H donor bonds and the nitrogen lone pair. The overall attractions become stronger, so more energy is required to separate the molecules and boiling point increases $\text{C}_2\text{H}_4 < \text{CH}_2\text{O} < \text{CH}_3\text{NH}_2$.

FINAL SENSE CHECK Shape is about charge-cloud repulsion. Polarity is about unequal electron distribution and vector cancellation. Boiling point is about attractions between separate particles and the energy needed to overcome them.

✓ **DONE WHEN** you can move through the complete Bonding II chain without mixing up the three routes.