CHEMICAL BONDING TUTORIAL

Interatomic Bonding

Properties	substance	structure	Describe bonding and
			relate it to the physica
			properties
(a) A hard and	NaC <i>l</i>	Giant ionic	Strong ionic bonds requ
brittle solid.		lattice	great amt of energy to
			overcome. When the
			regular arrangement o
			the oppositely charged
			ions are disrupted,
			repulsion between like
			charges causes the latti
<u></u>			to break down.
(b) A solid that	Cu	Giant	Strong Metallic bo
conducts		metallic	require great amt
electricity and		structure	energy to overcome. S
			of delocalised electro
1065°C.			are the mobile char
			camers than enac
(c) A solid that	Diamond	Giant	Electrical conductivity.
cuts through	Diamona	covalent	bonds with 4 other
metal and does		lattice	atoms in a 3D tetrahed
not conduct		(Giant	arrangement, making t
electricity.		molecular	lattice verv strong.
y-		lattice)	All valence e used
			sigma bond formation
			absence of mobile char
			carriers.
(d) A substance	I ₂	Simple	Covalent bonding with
that sublimates		molecular	molecule
when heated.		structure	• Weak intermolecular
			force of attraction
			between molecules

				that can be easily		
				overcome with heat.		
	(a) A solid that	Graphite	Giant covalent	Eorms covalent bond with 3		
		Oraphice	lattice (Giant	other C atoms in a 2D network		
	can be used as			boxagonal carbon rings ->		
	a lubricant.			nexagonal carbon nings =>		
			lattice)	grapnene layer		
				Weak intermolecular force of		
				attraction between layers		
				causing the layers to slide		
				over each other easily.		
	2010 MCQ 6					
1(b)	Which diagram best repre	esents the struct	ure of solid magnes	sium oxide?		
			-			
	A		в			
	a a a		a a			
		φ				
			NY AN			
		4				
	a a a		No No			
	Y-Y-	-9		~		
	с		D			
	2 2		N 2			
		of of				
		Ĭ	A of a			
		4				
	2 de	4				
		0	Ŭ			
<u> </u>	Magnesium oxide is	an ionic comp	ound with formu	la MgO. In the solid state the		
	oppositely charged ior	ns are held in fi	xed positions by	strong ionic bonds. in an orderly		
	manner, forming a reg	ular 3-dimensi	onal crystal lattice	e structure.		
			-			
	From the formula, it o	an be deduced	that each Mg ²⁺	ion is surrounded by 6 O ²⁻ ions		
	while each O ²⁻ ion is surrounded by 6 Mg ²⁺ ions. Note: The arrangement should be					
	alternating between the two lons.					
	Ans: C					
1(c)						
1(C)	I he melting point of calci	um, 839°C, is mu	uch higher than the	e melting point of sodium, 98°C.		
	vvnich statement is most	relevant in expla	ining the difference	÷?		
	A The calcium atom	is larger than th	e sodium atom.			
	B The calcium atom is heavier than the sodium atom.					

	C	The calcium ion, Ca ²⁺ , has a higher charge than the sodium ion, Na ⁺ .				
	D	The calcium ion, Ca ²⁺ , contains more electrons than the sodium ion, Na ⁺ .				
	Calciu	m and sodium have giant metallic lattices.				
	Meltin	g point magnitude reflects metallic bond strength.				
	Giant	metallic lattice consists of cations in a sea of delocalized electrons, thus metallic bond strength				
	Increa	Ses with Greater number of valence electrons involved in delocalization				
	2)	Cation of higher charge over size ratio when factor 1 is the same.				
	,					
	Staten	nent C is the answer as it implies that there are greater number of valence electrons involved in				
	the se	a of delocalised electrons for calcium than sodium.				
2	Which	statement(s) are correct?				
	1	HCl (aq) cannot conduct electricity.				
	"	Covalent bond is a weak bond compared to ionic bond as boiling point of H_2O is lower than				
		Inal of MgO.				
		Motals can be distinguished from ionic compounds by their electrical conductivity in the				
	IV	solid state				
	Α	Statements I and III are correct.				
	В	Statements II and IV are correct.				
	С	Statement III and IV are correct.				
	D	Statements I, III and IV are correct				
	1	False. Simple covalent molecule with acidic or basic properties will dissociate in water to form				
		H ^{$+$} or OH lons. E.g HC <i>l</i> , HNO ₃ , NH ₃ . Thus HC <i>l</i> is an electrical conductor in aq medium.				
		False. Magnitude of B.pt of H ₂ O is not indicative of the covalent bond strength in H ₂ O since				
		boiling overcomes the intermolecular hydrogen bonding NOT the covalent bond.				
		lonic bond and covalent bond are interatomic bonds, they are relatively strong compared to				
		IMF.				
		Since ionic bonds are broken in the giant ionic lattice of MgO, its b,pt is much higher compared				
	Ш	True. Eg. Na ₂ SO ₄ . Ionic bonds between Na ⁺ and SO ₄ ²⁻ ions, covalent bonds between S and O				
		in SO ₄ ²⁻ ion.				
	IV	True. Metals conduct electricity in solid state due to the mobile sea of delocalised electrons,				
		while fonic compounds DO NOT conduct electricity in solid state as the fons are fixed in				
		positions. Hence, this can be used to distinguish metal non-tonic compounds.				
3(2)	Boron	trifluoride and ammonia reacts in a 1:1 mole ratio to form a single compound. Describe the				
J (a)	type o	f bond formed during this reaction.				
	N ator	n in ammonia forms a dative bond to B atom in BF ₃ .				
	BinB	F_3 is short of 2 electron to attain octet while N in NH ₃ has a lone pair.				
	hence	BE_2 and NH_2 reacts 1:1 ratio where lone pair of N in NH ₂ is used to form a coordinate (dative)				
	nence BF3 and NH3 reacts 1:1 ratio where ione pair of N in NH3 is used to form a coordinate (dative) covalent bond with B in BF2					



- 4 Explain the following observations.
 - i. Magnesium oxide is used in making bricks for lining high temperature furnaces; while sodium chloride cannot be used for this purpose. Explain this observation in terms of structure and bonding.

Both MgO and NaCl have giant ionic lattice structures.

- Product of charges (q₊ × q₋) is larger for MgO and interionic distance (r₊ + r₋) is smaller for MgO.
- Since $|L.E| \propto \left| \frac{q_+ \times q_-}{r_+ + r_-} \right|$, magnitude of lattice energy of MgO is greater than NaC*l*.
- More energy is needed to overcome the stronger ionic bonds in MgO than in NaCl.

- MgO has a higher mp than NaC*I*, hence can be used in lining of high temp. furnaces.
- ii. At room temperature and pressure, CO₂ is a gas, while SiO₂ is a solid of high melting temperature.
 CO₂ exists as simple molecular structure with weak intermolecular forces/ instantaneous dipole induced dipole (id-id) interactions between CO₂ molecules. SiO₂ exists as a giant covalent structure whereby all atoms are bonded to each other by strong covalent bonds.

The energy supplied at room temperature is sufficient to overcome weak intermolecular forces between CO_2 molecules to allow CO_2 to exist as a gas.

However, energy is insufficient to overcome the strong covalent bonds in SiO_2 hence, SiO_2 exist as solids at room temperature.

Note: must relate back to physical states of the compounds at rtp. The question is not focusing about the mp/bp.

iii. SiC has a higher melting point (2730 °C) than SiGe (1176 °C)

Both SiC and SiGe have giant covalent lattice structure. C atom has smaller atomic radius than that of Ge and hence there is more effective overlap of orbitals between Si and C atoms as compared to Si and Ge. More energy is required to break the stronger covalent bonds in SiC than that of SiGe. Therefore, SiC has higher melting point than SiGe.

Dot-and-Cross Diagram and VSEPR

5 Fill up the table below for the following compounds:

compound	'dot-and-cross' diagram	 (i) Draw the Lewis structure and name the shape wrt central atom (ii) Indicate the bond angle in the diagram 	Bonds or intermolecular forces broken during melting or boiling process
(i) Al ₂ O ₃ (m.p. 2072°C)	$2\left[Al\right]^{3+}3\left[\overset{*}{\cdot}\overset{*}{\overset{*}{\overset{*}{\Omega}}}\overset{*}{\overset{*}{\overset{*}{\Omega}}}\right]^{2-}$	NA	Ionic bond
(ii) A/C/₃ (m.p. 192°C)	:C <i>l</i> : :C <i>l</i> -×Å <i>l</i> וC <i>l</i> :	CI AI CI Trigonal planar 120°	Instantaneous dipole-induced dipole
(iii) PC <i>l</i> 3 (I)	:C/··× P ··C/: :C/:	Cl P. Cl 107° Cl trigonal pyramidal, 107°	Permanent dipole-permanent dipole & Id-id
(iv) CH ₂ C <i>l</i> ₂ (I)	H : Ċl··× Ċ H	H 109.5° H C'''Cl Cl tetrahedral, 109.5°	Permanent dipole-permanent dipole & Id-id
(v) PC <i>l</i> ₅ (s)	:C/: :C/·×Ř×·C/: :C/:C/:	CI 90° CI CI CI CI CI CI CI CI CI CI	Instantaneous dipole-induced dipole
(vi) HCN	HוC:×N ×	$H \xrightarrow{180^{\circ}} N$ Linear	Permanent dipole-permanent dipole & Id-id

compound	'dot-and-cross' diagram	 (i) Draw the Lewis structure and name the shape wrt central atom (ii) Indicate the bond angle in the diagram 	Bonds or intermolecular forces broken during melting or boiling process
(vii) XeF ₄	F ** F *Xe F ** F	F F F F Square planar 90°	Instantaneous dipole-induced dipole
(viii) H ₂ O ₂	H•× over set over the set of the	H around each O Bent 105°	Hydrogen Bond & Id–id
(ix) Na ₂ O ₂	$2\left(\operatorname{Na}\right)^{+}\left(\underbrace{\cdot}_{xx}\overset{xx}{\underset{xx}{\overset{xx}{x}}{\overset{xx}{\overset{xx}}{\overset{xx}{\overset{xx}{\overset{xx}{\overset{xx}{\overset{x}}{\overset{xx}{\overset{xx}}{\overset{xx}}{\overset{xx}{\overset{xx}{\overset{xx}{\overset{xx}{$	NA	Ionic bond
(x) (NH ₄) ₂ SO ₄ Salt formed from H ₂ SO ₄ and NH ₃ .	2 $\begin{bmatrix} H \\ H \cdot \cdot N \\ H \cdot \cdot N \\ H \end{bmatrix}^{+}$ $\begin{bmatrix} : \ddot{0} : : \\ \vdots \ddot{0} : \end{bmatrix}^{2-}$	$2 \begin{bmatrix} H \\ H \\ H \end{bmatrix}^{+}$ tetrahedral about N and S $\left[\begin{array}{c} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}^{2-}$	lonic bond

6 A stable molecule containing atoms of the elements, X, Y and Z has the following structure.



Which option is a possible combination of the elements?

	<u>X</u>	<u>Y</u>	<u>Z</u>
A	N	P	<mark>C/</mark>
В	0	S	C <i>l</i>
С	В	Ν	Н
D	Р	0	F

- Y formed 5 covalent bonds → Group 15, Period 3 and beyond
- X formed 3 covalent bonds. Could be Group 13 or 15.
- Z formed 1 covalent bond \rightarrow Either hydrogen or Group 17
- 7 MTBE is a constituent of petrol. What are the values of angle P and angle Q in a molecule of MTBE? angle P $H_3C - C - O - C$

	anyle r	angle Q
Α	90°	105°
В	90°	180°
С	109°	105°
D	109°	180°



Answer C

- Central atom, C, has 4 bond pairs and no lone pair → Tetrahedral in shape with bond angle of 109.5°
- Central atom, **O**, has 2 bond pairs and 2 lone pair → Bent in shape with bond angle of 105°
- **8** Using VSEPR theory, predict which compound in each of the following pair of molecules has a larger bond angle.
 - (a) BCl_3 and NCl_3 (b) H_2S and PH_3
 - (a) BC_b has 3 bond pairs whereas NC_b has 3 bond pairs and 1 lone pair. By VSEPR theory, the electron regions around the central atom arrange themselves to be as far apart as possible to minimise mutual repulsion. Therefore, BC_b has a trigonal planar shape and the bond angle is 120 ° whereas NC_b has a trigonal pyramidal shape and the bond angle is 107 °.
 BC_b has a larger bond angle.
 - (b) H₂S and PH₃ has 4 electron regions each, having tetrahedral electron geometry. H₂S has 2 bond pairs and 2 lone pairs whereas PH₃ has 3 bond pairs and 1 lone pair. By VSEPR theory, lone pair-lone pair repulsion is stronger than lone pair-bond pair repulsion which is in turn stronger than bond pair-bond pair repulsion. In H₂S, the stronger lone pair-lone pair repulsion forces the bond pairs to be closer together, decreasing the bond angle to 105° as compared to 107° in PH₃. Therefore, PH₃ has a larger bond angle.

9 [N10/III/4c]

(a) Draw 'dot-and-cross' diagrams to show the bonding in the molecules of NO₂, O₃ and BF₃.

In the molecule NO₂, the central atom is nitrogen. In each case you should distinguish carefully between electrons originating from the central atom and those from the two outermost atoms. Include all lone pairs in your diagrams.



(b) Suggest a value for the bond angles in each of the three molecules, giving reasons for your choice.

All molecules have electron geometry of trigonal planar.

 BF_3 – central atom has 3 bond pairs and 0 lone pair. Therefore, equal repulsive forces between the B-F bonds results in a bond angle of 120 °.



 O_3 – central atom has 2 bond pairs and 1 lone pair. Since lone pair-bond pair repulsion > bond pair-bond pair repulsion , estimated angle = 118 ° (slightly less than 120°).



 NO_2 – central N atom has 2 bond pairs (1 single covalent bond and 1 double bond) and 1 unpaired electron. The unpaired electron cause less repulsion than a lone pair so estimated angle = 130 ° (Note: accept angles greater than angle given for O₃ but less than 180 °, assuming that the repulsion of unpaired electron is less than the repulsion of bond pair (2e⁻))



(c) The compound FO₂ does not exist but ClO₂ does. By considering the possible types of bonding in the two compounds suggest reasons for this difference. (Assume the halogen atom occupies the central position in each of these molecules.)

C/O₂ - C/ would have to expand its octet of electrons to bond with 2 O as shown below. C/, being in period 3, has a total of 9 orbitals in n = 3 quantum shell to accommodate additional electrons from the bonded atoms. Thus, C/ can have expanded octet structure to form C/O₂.

 Image: Close of the bonded atoms of the bonded atoms of the bonded atoms. Thus, C/ can have expanded octet structure to form C/O₂.

 Image: Close of the bonded atoms of the bonded atoms. Thus, C/ can have expanded octet structure to form C/O₂.

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 Image: Close of the bonded atoms of the bonded atoms. Thus, C/ can have expanded octet structure would not exist.

 FO₂ does not exist as F is in period 2. The valence electrons of F are found in the n = 2 principal quantum shell can only accommodate a maximum of eight valence electrons since there are a total of 4 orbitals in n = 2 quantum shell. Therefore, F cannot have expanded octet structure to form FO₂.

		It would also not be favourable for F to form 2 dative bonds with O as F is too electronegative to form 2 dative bonds.						
(d)	Mod	Modified from 2016 P3 Q1 (b)						
	Car	bon monoxide reacts with	n boron hydride, BH ₃ , at	thigh pressure to give one product W .				
	(i)	Give the dot-and-cross showing the bonding in t covalent) bonds it conta	diagram of CO and the product W , clearly ir ins.	BH ₃ . Hence draw dot-cross diagram indicating any coordination bond (dative				
	(ii)	Use a Lewis diagram, in	dicate the bond angles	with respect to each central atom in W .				
	(i)	H·×B×∙H × H	:C:**O*	dative bond H ··· B ··· C ··· O ·· H ··· W H Product W				
	(ii)	0=C-B/109.5						

Polarity and Intermolecular Forces

10	(a)	Draw the Lewis structure of the following molecules and indicate for each one the polarity of each of the bonds it contains, and the overall polarity of the molecule. Hence classify the following molecules as polar or non-polar.							
		NH ₃ , SF ₆ , CH ₂ =CH ₂ , CH ₃ OH, C <i>l</i> F ₃ , CH ₃ OCH ₃ , N ₂ H ₄							
				H H _{Al}	C=C H bsence of blar bonds	•• H			
		Only show shape wrt atoms with polar bonds	F CI F F F	CI	H ₃ CH ₃	H H ··· Weak net dipole	1		
		Non-pola SF ₆ , CH ₂ =C	r H ₂	NH ₃ , CH	Pola H₃OH, CH₃C	ar DCH3, CIF3 N2H4			
	(b)	Hence, classify the molecules in (a) according to the main type of intermolecular forces present.							
		Instantaneous dipole- induced dipole	Permanent permanent	dipole- dipole	Hydr	ogen bonds			
		SF ₆ , CH ₂ =CH ₂	CH ₃ OCH ₃ , C <i>l</i> F ₃	3	NH ₃ , CH ₃	OH, N ₂ H ₄			
	2019	P2 01(b)							
	(c)	Table 1.2 shows the electron	egativity values of	the atoms i	in phosgene	e, Cl ₂ C=O.			
	. ,		Tabl	e 1.2					
			atom	electron	egativity				
			carbon	2.	.5				
			chionne	3.	.0 5				
			oxygon						
	(i)	Explain what is meant by the	term electronega	tivity.		[2]			
	\ ⁼∕	Electronegativity is a measur	e of the ability of	an element	to attract a	shared pair of ele	ctrons		
		in a covalent bond towards its	self.						
	(ii)	Predict all possible intermole Explain how these forces aris	cular forces which se.	could exist	between pl	hosgene molecule [3]	S.		
	(ii)	Explain how these forces arise. [3] Instantaneous dipole-induced dipole (Id-id) arises due to random movement of electrons giving rise to uneven distribution of electron cloud of a molecule, creating an instantaneous dipole. The instantaneous dipole induces an opposite dipole on adjacent molecules resulting in attractive forces between the molecules.							



Structure and Physical Properties

11 The boiling points of four compounds are given in the table below.

Compound	Boiling point/ °C
H ₂ O	100
CH ₃ OH	65
SiH ₄	-107
CH ₄	-164

Explain the differences in boiling point between

(a) CH₄ and SiH₄

Both CH₄ and SiH₄ are covalent compounds with simple molecular structures. They are nonpolar and have instantaneous dipole-induced dipole (id-id) interactions between molecules. SiH₄ has a larger electron cloud than CH₄, dipole is more easily induced resulting in stronger id-id interactions.

More energy is required to overcome the stronger id-id interactions between SiH $_4$ molecules than those between CH $_4$ molecules.

Therefore, SiH₄ has a higher boiling point than CH₄.

(b) H₂O and CH₃OH

Both H_2O and CH_3OH are covalent compounds with simple molecular structures. They are polar with H-bonds between molecules.

 H_2O have more extensive H-bonds (average 2 per molecule) than CH_3OH (average 1 per molecule).

More energy is required to overcome the more extensive H-bonds between H_2O molecules. Therefore, H_2O has a higher boiling point than CH_3OH . **12** The boiling points of three organic compounds are given in the table below.

Compound	Molecular formula	<i>M</i> r
Α	CH ₃ CH ₂ OCH ₂ CH ₃	74
В	CH ₃ CH ₂ CH ₂ CH ₂ OH	74
С	(CH ₃) ₃ COH	74

Explain, in the following pairs, why the first compound is more volatile than the second compound

(a) A and B

Both are covalent compounds with simple molecular structures. They are polar molecules with the same M_r .

Less energy is required to overcome the weaker permanent dipole-permanent dipole interactions between $CH_3CH_2OCH_2CH_3$ than the stronger H-bonds between $CH_3CH_2CH_2CH_2CH_2OH$ molecules

Therefore, compound A is easier to vaporise thus more volatile than compound B.

(b) C and B

Both are covalent compounds with simple molecular structures. They are polar molecules with the same M_r . Both compounds have hydrogen bonding (H- bond) and instantaneous dipole-induced dipole (id-id) interaction between the molecules.

CH₃CH₂CH₂CH₂OH is a straight chain molecule and it has a larger surface area of contact, dipoles are more easily induced as compared to branched chain (CH₃)₃COH. Less energy is needed to overcome the weaker id-id interactions between (CH₃)₃COH molecules than those between CH₃CH₂CH₂CH₂OH molecules. Therefore, (CH₃)₃COH is easier to vaporise thus more volatile than CH₃CH₂CH₂CH₂OH.

(Note: strengths of H-bond in $CH_3CH_2CH_2CH_2OH$ and in $(CH_3)_3COH$ are similar, so students have to recognise that it is the id-id (due to different surface area of contact) that explains their difference in boiling points.)

- **13** Referring to table in question **5**, explain the following observations.
 - (i) $A_{l_2}O_3$ conducts electricity in molten state while $A_lC_{l_3}$ in molten state does not. $A_{l_2}O_3$ has a giant ionic lattice structure, while and $A_lC_{l_3}$ has a simple molecular structure. In molten state, $A_{l^{3+}}$ and O^{2-} ions in $A_{l_2}O_3$ act as mobile charge carrier to conduct electricity. $A_lC_{l_3}$ molecules are electrically neutral, hence it cannot conduct electricity in molten state.
 - (ii) Difference in physical state of PCl_3 and PCl_5 .

Both PCl_3 and PCl_5 have simple molecular structure.

- There is permanent dipole-permanent dipole (pd-pd) and instantaneous dipole-induced dipole (id-id) interaction between PCl₃ molecules, while there is id-id between PCl₅ molecules.
- PCl₅ has a larger electron cloud, dipole is more easily induced, to give a stronger id-id interaction between PCl₅ molecules.
- At room temperature, there is sufficient energy to overcome pd-pd & id-id interactions between PC*l*₃ molecules, but not the stronger id-id interaction between PC*l*₅ molecules.
- Therefore, PCl₅ exists as solid while PCl₃ exists as liquid.

- 14 Explain why the following pairs of molecules differ in their boiling point despite having the same Mr and functional groups.
 - (a) The boiling point of cis-dichloroethene is 333 K, whereas that of trans-dichloroethene is 321 K.



In cis-dichloroethene, the bond dipole moments are not cancelled out. Cis-dichloroethene has a net dipole moment and it is polar.

In trans-dichloroethene, the bond dipole moments are cancelled out. Trans-dichloroethene has zero net dipole moment and it is non-polar.

More energy is needed to overcome the stronger permanent dipole-permanent dipole and instantaneous dipole-induced dipole (id-id) interactions between cis-dichloroethene molecules than the id-id interactions between trans-dichloroethene molecules.

Therefore, cis-dichloroethene has a higher boiling point than trans-dichloroethene.

(b) The boiling point of **R** is higher than **Q**.



In Q, due to the close proximity of the 2 COOH groups, intramolecular (internal) hydrogen bonding are formed, leaving fewer sites for intermolecular H-bonding. R forms only intermolecular H-bonds. More energy is required to overcome the more extensive intermolecular H-bonding between R molecules than between Q molecules.

Therefore, **R** has a higher boiling point than **Q**.

Solubility

- 15 Predict with explanations whether or not the following solute is soluble in the given solvent
 - Solute: CH₃CH₂OH / Solvent: H₂O (a)

Energy given out in the formation of hydrogen bonding (H-bonds) between CH₃CH₂OH and H₂O molecules is sufficient to overcome the H-bonds between CH₃CH₂OH molecules and those between H₂O molecules. Therefore, CH₃CH₂OH is soluble in H₂O.

(b) Solute: NH₄NO₃ / Solvent: benzene, C₆H₆.

> NH₄NO₃ does not dissociate to give ions in a non-polar solvent (C₆H₆). No favourable interaction is possible between NH₄NO₃ and C₆H₆. There is insufficient energy to overcome the strong ionic bonds between NH4⁺ and NO3⁻ and instantaneous dipole-induced dipole interactions between C₆H₆.

Therefore, NH₄NO₃ is insoluble in C₆H₆.

16 Ammonia and hydrogen chloride gases are soluble in water because they interact with the solvent.

 $\begin{array}{rcl} \mathsf{HC}l(\mathsf{g}) + \mathsf{aq} & \to & \mathsf{H}^+ \left(\mathsf{aq}\right) + \mathsf{C}l^- \left(\mathsf{aq}\right) \\ \mathsf{NH}_3(\mathsf{g}) + \mathsf{aq} & \to & \mathsf{NH}_3 \left(\mathsf{aq}\right) \end{array}$

Use suitable diagrams to illustrate all the possible interactions between the dissolved gas and **a water molecule**.



For NH₃(aq) :



Application questions

- 17 Provide an explanation for the following observations.
 - (a) Ice is less dense than water.

Due to the formation of four permanent hydrogen bonding (H-bonds) per H_2O molecule in ice, ice has a more open structure than liquid water. Ice occupies a larger volume than water for the same number of molecules/ same mass of water. Therefore, ice is less dense than water.

(b) The relative molecular mass of ethanoic acid is 120 in benzene, C₆H₆. Formation of intermolecular hydrogen bonding is more energetically favourable than instantaneous dipole induced dipole (id-id). Instead of forming id-id with non-polar solvent like benzene, two ethanoic acid molecules dimerises via intermolecular hydrogen bonding. As a result, the apparent M_r is double of 60.



18 Vaporization occurs when some molecules in a liquid possesses enough kinetic energy to escape from the surface of the liquid at a given temperature.

Saturated vapour pressure is the pressure on the walls of the container exerted by the gas molecules vaporized from the surface of the liquid in a closed container when the rates of condensation and evaporation are equal.

Boiling occurs when the vapour pressure is equal to the external pressure which is usually the atmospheric pressure (101 kPa).

The graph below shows the vapour pressures of three liquids at varying temperatures.



(a) The identities for liquids A and B could be ethanol (CH₃CH₂OH) and propanone (CH₃COCH₃). Based on the graph, identify liquids A and B and explain your reasoning. [4]
 A: propanone [1]. B: ethanol [1]

At any given temperature, **A** has a higher vapour pressure than B (**A** has a lower boiling point than B) [½], showing that the intermolecular forces in A are weaker than that in B.

Permanent dipole-permanent dipole interactions between propanone molecules [½] is weaker [½] than the hydrogen bonds between ethanol molecules [½]. [correct identification and comparison of strength of IMF] At any given temperature, more propanone molecules have enough kinetic energy to overcome the intermolecular forces and exist as vapour, resulting in a higher vapour pressure. Therefore, A is propanone and B is ethanol.

(b) Suggest a possible identity for C. H₂O, boiling point ≈100 °C (Temp = 100 °C when pressure = 101 kPa) **19** The type of bonding (covalent, ionic or metallic) present in a substance can be determined and predicted using the van Arkel triangle based on the values of electronegativity of the element.

Difference in electronegativity between the element(s) is plotted along the *y*-axis and the average electronegativity of the element(s) is plotted along the *x*-axis.

The electronegativity data for oxygen and germanium, Ge, and some selected elements from Period 3 of the Periodic Table are given below.

element	Na	Al	Si	Ge	S	Cl	0
electronegativity	0.93	1.61	1.90	2.01	2.58	3.16	3.61

In addition, some of the Period 3 elements and their compounds have been plotted on the van Arkel triangle given below.



- Using your knowledge of the Period 3 elements and their compounds plotted above, state the type of bonding present at each of these bonding extremes, labelled as A, B and C, on the triangle.
 - A Metallic bonding
 - B Ionic bonding
 - C Covalent bonding
- (ii) Germanium oxide has a giant molecular structure. On the van Arkel triangle above, plot the point corresponding to the oxide of germanium. Hence explain if the melting point of the oxide of germanium would be lower or higher than that of the oxide of silicon. [3]

average electronegativity for Ge and O = $\frac{2.01+3.61}{2}$ = 2.81 (accept 2.60 - 3.00) difference in electronegativity for Ge and O = 3.61 - 2.01 = 1.60 (accept 1.40 - 1.80) The coordinates for GeO₂ is (2.81,1.60) [1]

Oxide of germanium has a <u>lower</u> melting point (giant covalent lattice) [1] Ge is below Si in Group 14 with a <u>bigger atomic size</u>; overlap of the atomic orbitals of Ge and O will be <u>less effective</u> than those of Si and O; the covalent bonds between Ge and O are weaker. [1]