CHEMICAL BONDING TUTORIAL

Interatomic Bonding

1 Using the list below, give one example to each of the following solid lattices showing the given properties. Name the structure and type of bonding found in each lattice.

graphite, diamond, copper, iodine, sodium chloride

(a) A hard and brittle solid.
(b) A solid that conducts electricity and melts at 1085^{o}C.
(c) A solid that cuts through metal and does not conduct electricity.
(d) A substance that sublimates when heated.
(e) A solid that can be used as a lubricant.

	Structure	**Bonding type**	**Example**
(a)	ionic lattice	Ionic bonding	$\mathrm{NaC}l$
(b)	metallic lattice	Metallic bonding	Cu
(c)	Giant molecular structure	Covalent bonding	Diamond
(d)	Simple molecular structure	• Covalent bonding within molecule • Weak intermolecular force of attraction between molecules	I_2
(e)	Giant molecular structure	• Covalent bonding between atoms within a layer • Weak intermolecular force of attraction between layers	Graphite

2 Which statement(s) are correct?

I $\mathrm{HC}l$ (g) can conduct electricity.
II Covalent bond is a weak bond compared to ionic bond as boiling point of H_2O is lower than that of MgO.
III Ionic bonds and covalent bonds can both occur in the same compound.
IV Metals can be distinguished from ionic compounds by their electrical conductivity in the solid and liquid state.

A Statements **I** and **III** are correct.
B Statements **II** and **IV** are correct.
C Statement **III** and **IV** are correct.
D Statements **I, III** and **IV** are correct

I False. $\mathrm{HC}l$ (g) has simple molecular structure with no mobile charge carrier. $\mathrm{HC}l$ can dissociate into ions H^+(aq) and Cl^-(aq) in water, and conduct electricity in aq state.

II False. Both are strong bonds. The boiling of H_2O involves only the breaking of the weak hydrogen bonds between the H_2O molecules. However, the strong ionic bond is overcome in MgO when it undergoes phase change during boiling point.

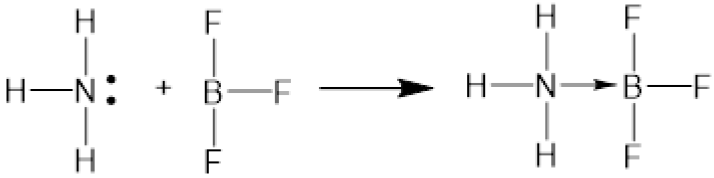
III True. Eg. Na_2SO_4. Ionic bonds between Na^+ and SO_4^{2-} ions, covalent bonds between S and O in SO_4^{2-} ion.

IV True. Metals conduct electricity in molten and solid state, while ionic compounds conduct electricity in molten state, not in solid state. Hence, this can be used to distinguish metal from ionic compounds.

3 Boron trifluoride and ammonia reacts in a 1:1 mole ratio to form a single compound. Describe the type of bond formed during this reaction.

N atom in ammonia **forms a dative bond** to B atom in BF_3.

B atom in BF_3 is electron deficient, hence B attains the octet by accepting a lone pair from N in ammonia into its empty p-orbital.



4 Explain the following observations in terms of structure and bonding.

i. MgO has a higher melting point than NaC*l*.

Both MgO and NaC*l* have ionic lattice structures.

- Product of charges ($q_+ \times q_-$) 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 NaC*l*.
- **MgO has a higher mp than NaC*l*.**

ii. At room temperature and pressure, CO_2 is a gas, while SiO_2 is a solid of high melting temperature.

CO_2 exists as **simple molecular structure** with **weak intermolecular forces/ instantaneous dipole - induced dipole (id-id) interactions between** CO_2 **molecules**. SiO_2 exists as a **giant molecular structure whereby all atoms are bonded to each other by strong covalent bonds**.

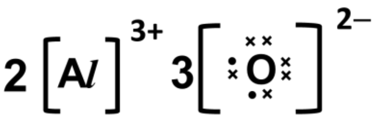
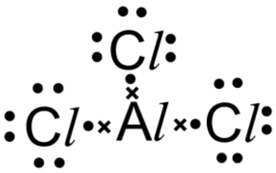
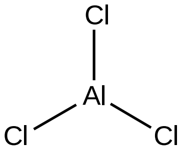
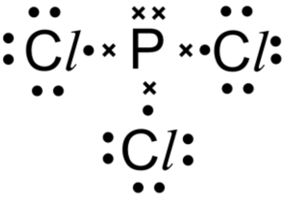
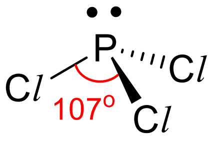
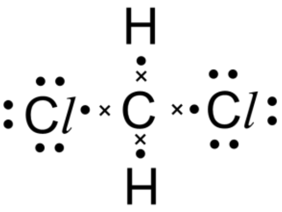
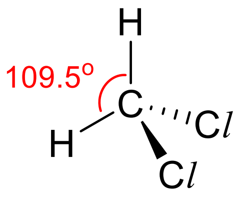
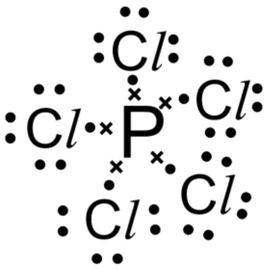
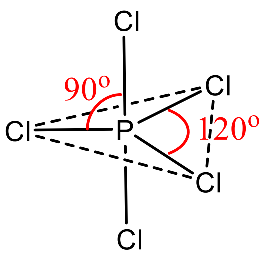
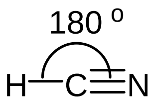
The **energy supplied at room temperature is sufficient to overcome weak intermolecular forces between CO_2 molecules** to allow **CO_2** to exist as a gas.

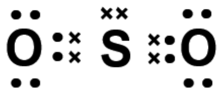
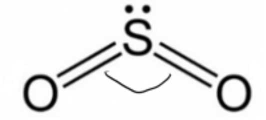
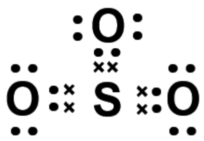
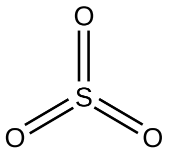
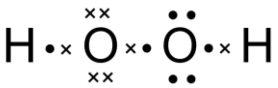
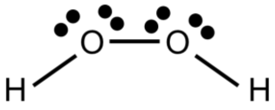
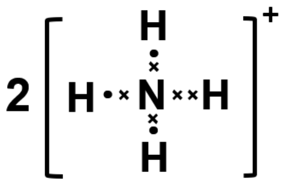
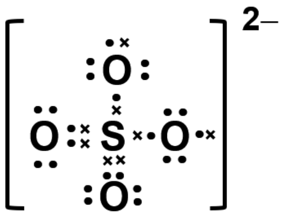
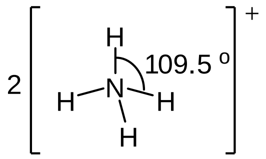
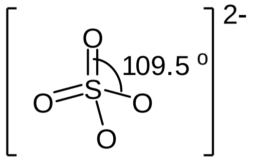
However, **energy is insufficient to overcome the strong covalent bonds in SiO_2** hence, SiO_2 exist as solids at room temperature.

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

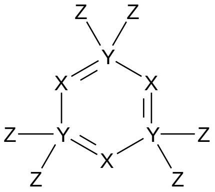
Dot-and-Cross Diagram and VSEPR

5 Fill up the table below for the following compounds:

compound	‘dot-and-cross’ diagram	(i) **Draw** and **name** the shape of the covalent molecule or polyatomic ion (ii) Indicate the **bond angle** in the diagram	Bonds or intermolecular forces broken during melting or boiling process
(i) Al_2O_3 (m.p. 2072°C) Ionic compound		NA	Ionic bond
(ii) $AlCl_3$ (m.p. 192°C) Covalent molecule		 Trigonal planar 120^{o}	Instantaneous dipole-induced dipole
(iii) PCl_3 (l)		 trigonal pyramidal, 107^{o}	Permanent dipole-permanent dipole & Id-id
(iv) CH_2Cl_2(l)		 tetrahedral, 109.5^{o}	Permanent dipole-permanent dipole & Id-id
(v) PCl_5(s)		 Trigonal bipyramidal	Instantaneous dipole-induced dipole
(vi) HCN		 Linear	Permanent dipole-permanent dipole & Id-id

compound	‘dot-and-cross’ diagram	(i) **Draw** and **name** the shape of the covalent molecule or polyatomic ion (ii) Indicate the **bond angle** in the diagram	Bonds or intermolecular forces broken during melting or boiling process
(vii) SO_2		 Bent, 118º (<120º)	Permanent dipole-permanent dipole & Id-id
(viii) SO_3		 Trigonal planar 120°	Instantaneous dipole-induced dipole
(ix) H_2O_2 (H-O-O-H arrangement)		 around each O Bent 105°	Hydrogen Bond & Id–id
(x) $(NH_4)_2SO_4$	 	 tetrahedral about N and S 	Ionic bond

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

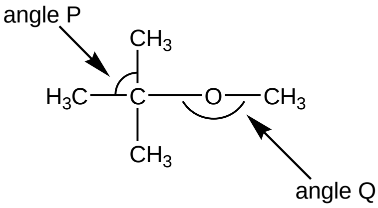


Which option is a possible combination of the elements?

	X	Y	Z
A	N	P	Cl
B	O	S	Cl
C	B	N	H
D	P	O	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 → 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?



MTBE

	angle P	angle Q
A	90°	105°
B	90°	180°
C	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

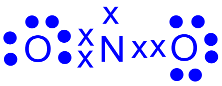
(a) BCl_3 has 3 electron regions (3 bond pairs) whereas NCl_3 has 4 electron regions (3 bond pairs and 1 lone pair).
By VSEPR theory, the electron regions around the central atom arrange themselves to be as far apart as possible to minimise mutual repulsion.
Therefore, BCl_3 has a trigonal planar shape and the bond angle is 120 ° whereas NCl_3 has a trigonal pyramidal shape and the bond angle is 107 °.
BCl_3 has a larger bond angle.

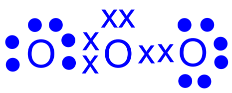
(b) H_2S and PH_3 has 4 electron regions each. H_2S has 2 bond pairs and 2 lone pairs whereas PH_3 has 3 bond pairs and 1 lone pair.
By VSEPR theory, lone pair-lone pair repulsion is stronger than lone pair-bond pair repulsion which is in turn stronger than bond pair-bond pair repulsion.
In H_2S, the 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 PH_3.
Therefore, **PH_3 has a larger bond angle**.

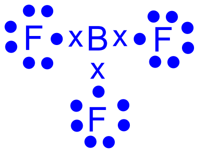
9 [N10/III/4c]

(a) Draw ‘dot-and-cross’ diagrams to show the bonding in the molecules of NO_2, O_3 and BF_3.

In the molecule NO_2, 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.

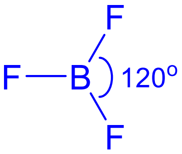




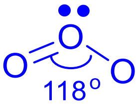


(b) Suggest a value for the bond angles in each of the three molecules, giving reasons for your choice.

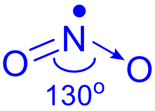
BF_3 – central atom has 3 bond pairs and 0 lone pair. Therefore, BF_3 has a trigonal planar shape and the bond angle is 120 °.



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 O_3 but less than 180 °, assuming that the repulsion of unpaired electron is less than the repulsion of bond pair ($2e^-$))



Polarity and Intermolecular Forces

10 **(a)** Classify the following molecules as polar or non-polar.

NH_3, SF_6, $CH_2{=}CH_2$, CH_3OH, ClF_3, CH_3OCH_3 , N_2H_4

Non-polar	**Polar**
SF_6, $CH_2{=}CH_2$	NH_3, CH_3OH, CH_3OCH_3, ClF_3 N_2H_4

(b) Hence, classify the molecules in **(a)** according to the main type of intermolecular forces present.

Instantaneous dipole-induced dipole	**Permanent dipole-permanent dipole**	**Hydrogen bonds**
SF_6, $CH_2{=}CH_2$	CH_3OCH_3, ClF_3	NH_3, CH_3OH, N_2H_4

Structure and Physical Properties

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

Compound	Boiling point/ °C
H_2O	100
CH_3OH	65
SiH_4	–107
CH_4	−164

Explain the differences in boiling point between

(a) CH_4 and SiH_4

Both CH_4 and SiH_4 are covalent compounds with simple molecular structures. They are non-polar and have instantaneous dipole-induced dipole (id-id) interactions between molecules.
SiH_4 has a larger electron cloud than CH_4 which is more easily distorted 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, SiH_4 has a higher boiling point than CH_4.

(b) H_2O and CH_3OH

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**	**M_r**	**Boiling point/°C**
A	$CH_3CH_2OCH_2CH_3$	74	35
B	$CH_3CH_2CH_2CH_2OH$	74	118
C	$(CH_3)_3COH$	74	83

Explain the differences in boiling point between

(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 $CH_3CH_2CH_2CH_2OH$ molecules

Therefore, compound A has a lower boiling point than compound B.

(b) **B** and **C**

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

$CH_3CH_2CH_2CH_2OH$ is a straight chain molecule and it has a **larger surface area** of contact, as compared to **branched chain $(CH_3)_3COH$. More energy is needed to overcome the stronger id-id interactions between $CH_3CH_2CH_2CH_2OH$ molecules** than those between $(CH_3)_3COH$ molecules. Therefore, $CH_3CH_2CH_2CH_2OH$ has a higher boiling point than $(CH_3)_3COH$.

(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) Al_2O_3 conducts electricity in molten state while $AlCl_3$ in molten state does not.

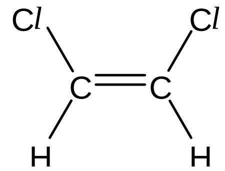
Al_2O_3 has an ionic lattice structure, while and $AlCl_3$ has a simple molecular structure.
In molten state, Al^{3+} and O^{2-} ions in Al_2O_3 act as mobile charge carrier to conduct electricity.
There is no mobile charge carrier in $AlCl_3$ molecules, hence it cannot conduct electricity in molten state.

(ii) Difference in physical state of PCl_3 and PCl_5.

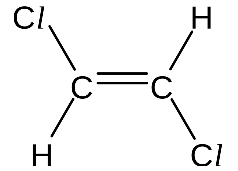
Both PCl_3 and PCl_5 have simple molecular structure.

- There is permanent dipole-permanent dipole (pd-pd) and instantaneous dipole-induced dipole (id-id) interaction between PCl_3 molecules, while there is id-id between PCl_5 molecules.
- PCl_5 has a larger electron cloud that can be more easily distorted, to give a stronger id-id interaction between PCl_5 molecules.
- At room temperature, there is sufficient energy to overcome pd-pd & id-id interactions between PCl_3 molecules, but not the stronger id-id interaction between PCl_5 molecules.
- Therefore, PCl_5 exists as solid while PCl_3 exists as liquid.

14 **(a)** The boiling point of cis-dichloroethene is 333 K, whereas that of trans-dichloroethene is 321 K.



cis-dichloroethene



trans-dichloroethene

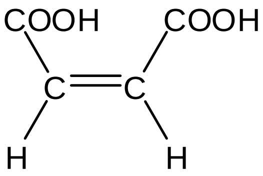
In cis-dichloroethene, the bond dipole moments are not cancelled out. Cis-dichloroethene has a net dipole moment and it is polar.

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

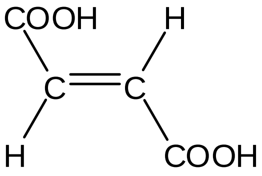
More energy is needed to overcome the stronger Permanent dipole-permanent dipole and instantaneous dipole-induced dipole (id-id) interactions between cis-dichloroethene molecules than the id-id interactions between trans-dichloroethene molecules.

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

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



Q



R

In **Q**, due to the **close proximity of the 2 COOH groups, intramolecular H-bonds 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

(a) CH_3CH_2OH is soluble in H_2O
Energy given out in the formation of H-bonds between CH_3CH_2OH and H_2O molecules is sufficient to compensate for the energy taken in to overcome the H-bonds between CH_3CH_2OH molecules and those between H_2O molecules.
Therefore, CH_3CH_2OH is soluble in H_2O.

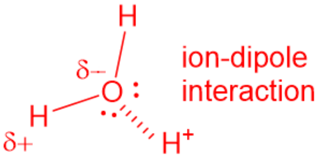
(b) NH_4NO_3 is soluble in benzene, C_6H_6.
NH_4NO_3 does not dissociate to give ions in a non-polar solvent (C_6H_6).
No favourable interaction is possible between NH_4NO_3 and C_6H_6. There is insufficient energy to overcome the strong ionic bonds between NH_4^+ and NO_3^- and instantaneous dipole-induced dipole interactions between C_6H_6.
Therefore, NH_4NO_3 is insoluble in C_6H_6.

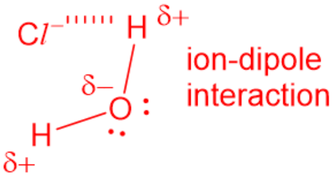
16 Ammonia and hydrogen chloride gases are soluble in water because they interact with the solvent.

$$HCl(g) + aq \rightarrow H^{+}(aq) + Cl^{-}(aq)$$
$$NH_3(g) + aq \rightarrow NH_3(aq)$$

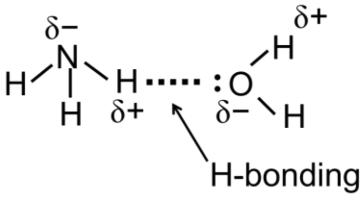
Use suitable diagrams to illustrate all the possible interactions between the dissolved gas and **a water molecule**.

For HC*l* (aq):





For NH_3(aq) :



Application questions

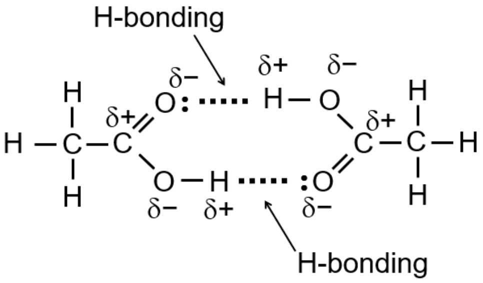
17 Provide an explanation for the following observations.

(a) Ice is less dense than water.

Due to the formation of four permanent 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. Therefore, ice is less dense than water.

(b) The relative molecular mass of ethanoic acid is 120 in benzene, C_6H_6.

In a non-polar solvent like benzene, ethanoic acid dimerises by forming H-bonds between 2 molecules. As a result, the apparent M_r is double of 60.

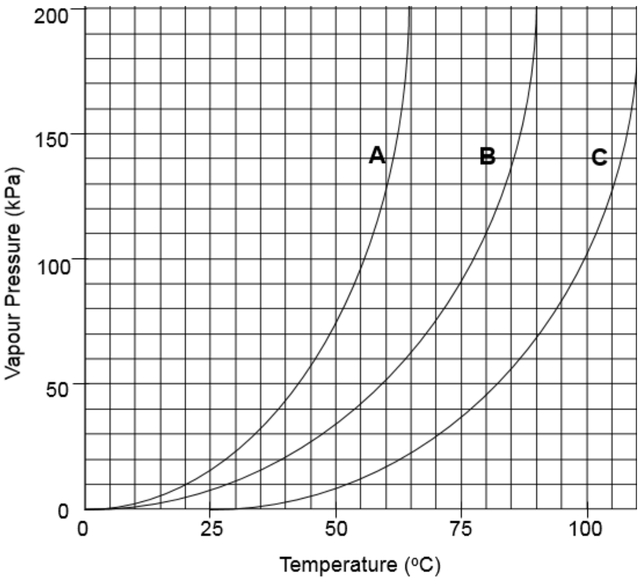


18 Vaporization occurs when some molecules in a liquid possesses enough kinetic energy to escape from the surface of the liquid at a given temperature.

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 (CH_3CH_2OH) and propanone (CH_3COCH_3). 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**.

H_2O, boiling point ≈100 °C (Temp = 100 °C when pressure = 101 kPa)