Intermolecular and Intramolecular Bonding

Question 1
Identify the following molecules as covalent, ionic or containing both:
Br_2, NaCl, $Mg(OH)_2$, PCl_3, HF, SiO_2, Al_2O_3, P_4O_{10}, Li_2O, NaF, NH_3, $MgSO_4$, Na_3PO_4

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Question 2
Arrange the following sets of substances in order of increasing boiling point (volatility):

a) NaCl, $SiCl_4$, CCl_4, HCl $SiCl_4, CCl_4, HCl, NaCl$
b) Br_2, HBr, CaBr2, PBr_3 $Br_2, PBr_3, HBr, CaBr_2$
c) C_4H_{10}, C_3H_7OH, C_3H_8, CH_3CH_2COOH, C_4H_9OH, $C_3H_8, C_4H_{10}, C_3H_7OH, C_4H_9OH, CH_3CH_2COOH$
d) SO_2, SiO_2, CO_2 CO_2, SO_2, SiO_2
e) $CH_3CH_2CH_3$, CH_3OCH_3, CH_3CH_2OH in order
f) CH_3COOH, $(CH_3)_2CHOH$, $(CH_3)_2CO$ $(CH_3)_2CO, (CH_3)_2CHOH, CH_3COOH$
g) $CH_3CH_2CH_2CH_2CH_3$, $CH_3CH(CH_3)CH_2CH_3$, $C(CH_3)_4$ $C(CH_3)_4, CH_3CH(CH_3)CH_2CH_3, C_5H_{12}$

Question 3
Arrange the following sets of substances in order of solubility in water (least soluble first):

a) NaCl, C_6H_{12}, $C_5H_{11}OH$ 3. 1. 2.
b) CH_3Cl, $CaCl_2$, CH_4 2. 3. 1.
c) CH_3CH_2CHO, CH_3COOH, $CH_3CH_2CH_2CH_3$ 2. 3. 1.

Question 4
Arrange the following sets in order of increasing melting point (lowest first):

a) Na, Li, K K, Na, Li
b) Al, Mg, Na Na, Mg, Al

Question 5
Arrange the following compounds in order of increasing C-C bond lengths: C_2H_6, C_2H_4, C_2H_2, C_6H_6

$C_2H_6, C_6H_6, C_2H_4, C_2H_2$ — = ≡ 1.5 ---

Question 6
Which species has the longest C-O bond length? CO, CH_3OH, $CH_3CO_2^-$, H_2CO_3

≡ — --- ---

Question 7
True or False?

a) The C–O bond lengths are equal in propanoic acid, C_2H_5COOH. F
b) The C–O bond length in carbon dioxide, CO_2, is longer than the C–O bond length in methanol, CH_3OH F
c) The C–O bond length in carbon dioxide, CO_2 is longer than the C–O bond length in carbon monoxide, CO. T
d) The C–O bond lengths are equal in ethyl ethanoate, $CH_3COOC_2H_5$. F

Question 8 :C≡O: :Ö=C=Ö: H–C(H)(H)–OH

a) Draw the Lewis structures for carbon monoxide, CO, carbon dioxide, CO_2 and methanol, CH_3OH.
b) List, with an explanation, the three compounds in order of increasing carbon to oxygen bond length (shortest first). CO (triple), CO_2 (double), CH_3OH (single)
c) List, with an explanation the three compounds in order of increasing boiling point (lowest first).

CO_2 (non polar) , CO (polar), CH_3OH (more H-bonds)
London dipole

Question 9
In terms of structure and bonding, explain the electrical conductivity of:

a) molten Na_2O and P_4O_{10} ✗ - covalent — Free moving charged particles.
b) Graphite and diamond ✗ — ✓ Free moving e⁻ b/n layers — No free moving charged particles
c) Chlorine gas and Na None — Free moving e⁻
d) Solid sodium chloride and molten sodium chloride ✗ — ✓ Free moving ions

Question 10
The electronegativity values of four elements are given.

C	N	O	F
2.6	3.0	3.4	4.0

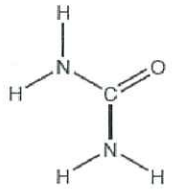
What is the order of **increasing** polarity of the **bonds** in the following compounds?

A. $CO < OF_2 < NO < CF_4$
B. $CF_4 < CO < OF_2 < NO$
✓ C. $NO < OF_2 < CO < CF_4$
D. $CF_4 < NO < OF_2 < CO$

CO : 0.8
O-F : 0.6
C-F : 1.4
N-O : 0.4

Question 11

Urea, $(H_2N)_2CO$, is excreted by mammals and can be used as a fertilizer.



a) Calculate the percentage by mass of nitrogen in urea to two decimal places using section 6 of the data booklet. 46.65 %.

b) The structural formula of urea is shown.

c) Predict the electron domain and molecular geometries at the nitrogen and carbon atoms, applying the VSEPR theory.

	Electron domain geometry	Molecular geometry
Nitrogen	tetrahedral	trig. pyramidal
Carbon	trig. planar.	trigonal planar

d) Suggest one reason why urea is a solid and ammonia a gas at room temperature. see Answers

e) Sketch **two** different hydrogen bonding interactions between ammonia and water. see answers

f) The combustion of urea produces water, carbon dioxide and nitrogen. Formulate a balanced equation for the reaction.

$2(H_2N)_2CO(s) + 3O_2(g) \rightarrow 2CO_2(g) + 4H_2O(g) + 2N_2(g)$.

Question 12

Calcium carbide, CaC_2, is an ionic solid.

a) Describe the nature of ionic bonding. ES FA b/w cations + anions in lattice.

b) Suggest **two** reasons why solid calcium has a greater density than solid potassium. see answers

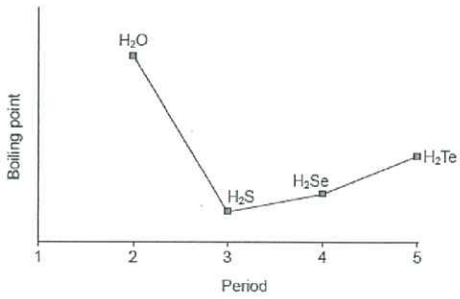
c) Outline why solid calcium is a good conductor of electricity. see answers.

Question 13

Some physical properties of molecular substances result from the different types of forces between their molecules.

a) Explain why the hydrides of group 16 elements (H_2O, H_2S, H_2Se and H_2Te) are polar molecules.

b) The graph shows the boiling points of the hydrides of group 16 elements. Explain the increase in the boiling point from H_2S to H_2Te.



c) Lewis structures show electron domains and are used to predict molecular geometry. Deduce the electron domain geometry and the molecular geometry for the NH_2^- ion.

Question 14

a) $TiCl_4$ reacts with water and the resulting titanium(IV) oxide can be used as a smoke screen. Describe the bonding in metals.

b) Explain why an aluminium-titanium alloy is harder than pure aluminium.

c) State the type of bonding in potassium chloride which melts at 1043 K.

d) A chloride of titanium, $TiCl_4$, melts at 248 K. Suggest why the melting point is so much lower than that of KCl.

Question 15

Bonds can be formed in many ways. The landing module for the Apollo mission used rocket fuel made from a mixture of hydrazine, N_2H_4, and dinitrogen tetraoxide, N_2O_4.

$$N_2H_4(l) + N_2O_4(l) \rightarrow 3N_2(g) + 4H_2O(g)$$

a) State and explain the difference in bond strength between the nitrogen atoms in a hydrazine and nitrogen molecule.

b) State why hydrazine has a higher boiling point than dinitrogen tetraoxide.

Intermolecular and Intramolecular Bonding
Worked Solutions.

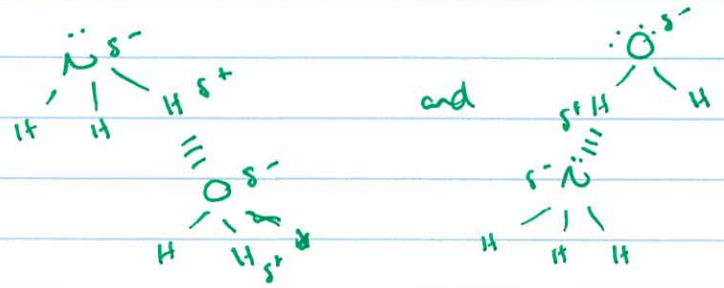
Q11. a) $M[(H_2N)_2CO] = (2\times(14.01+2.02) + 12.01 + 16.00)$
$= 60.07\ g\ mol^{-1}$

% mass $N = \frac{(2\times 14.01)}{60.07} \times 100 = 46.65\%$

b). N : tetrahedral, trigonal pyramidal
C : trigonal planar

c) Both have H-bonding but NH_3 lower molecular mass. As urea has higher molecular mass, e^- cloud is more easily polarised creating stronger London forces.

d)



e) $(H_2N)_2CO + \frac{3}{2}O_2 \rightarrow CO_2 + 2H_2O + N_2$
$\therefore 2(H_2N)_2CO_{(s)} + 3O_{2(g)} \rightarrow 2CO_{2(g)} + 4H_2O_{(g)} + 2N_{2(g)}$

Q12a). Electrostatic force of attraction between cations + anions in a lattice structure.

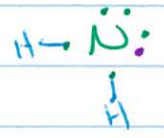
b) 1. Calcium has smaller atomic radius
2. Calcium in metal has a +2 charge whereas K has a +1 charge Meaning ESFoA b/n Ca^{2+} + sea of delocalised e^- stronger than in K.

12. c) sea of delocalised e^- can carry electrical charge.

13. a) All have bent molecular geometry generating overall dipole

b) BP increases as atomic radius of S → Te increases. Larger e^- cloud is more easily polarized ∴ stronger London forces b/n molecules

c) NH_2^- ion.



ϵ^- domain geometry = tetrahedral.

Molecular domain geometry = bent.

Q14. a) Electrostatic force of attraction between metal cation and sea of delocalised e^-s.

b) Titanium has different atomic radius to aluminium thereby disrupting non-directional bonding in lattice

c) ionic

d) KCl is ionic, $TiCl_4$ is covalent ∴ weak intermolecular bonds (London) between $TiCl_4$ molecules.

Q15. a) N_2H_4 N_2 N_2H_4 single : weaker than triple bond in N_2.

b). N_2H_4 N_2Cl_4

N_2H_4 has H-bonding which is stronger than dipole-dipole bonding in N_2Cl_4.