Atomic Structure and Bonding

Chapter 7

1. **[9 marks]** *(2005:02)*

For each species listed in the table below, draw the structural formula, representing all valence shell electron pairs either as **:** or as **-** .

[for example, water $\mathrm{H}:\underset{\cdot\cdot}{\ddot{\mathrm{O}}}:\mathrm{H}$ or $\mathrm{H}—\underset{\cdot\cdot}{\ddot{\mathrm{O}}}—\mathrm{H}$ or $\mathrm{H}—\underline{\overline{\mathrm{O}}}—\mathrm{H}$ and so on]

Species	Electron-dot diagram	Shape (name or sketch)
Silane (Silicon tetrahydride) SiH_4		
Phosphorus trichloride $PC\ell_3$		
Carbonate ion CO_3^{2-}		

2. **[8 marks]** *(2005:03)*

For each of the following substances, provide a common use and the property that is responsible for that use.

Substance	Use	Property
Aluminium		
Diamond		
Zinc		
Stainless steel		

3. **[3 marks]** *(2005:05)*

Explain in terms of intermolecular forces why methylated spirits (mainly ethanol) is more effective than water for removing grease from clothing.

4. **[2 marks]** *(2005:08)*

Buckyballs (Buckminsterfullerene molecules) are a molecular form of carbon with the formula C_{60}. Will buckyballs conduct electricity? Justify your answer.

5. **[6 marks]** *(2006:02)*

For each species listed in the table below, draw the structural formula, representing all valence shell electron pairs either as **:** or as **-** .

[for example, water $H\,:\!\underset{\cdot\cdot}{\ddot{O}}\!:\,H$ or $H-\underset{\cdot\cdot}{\ddot{O}}-H$ or $H-\underline{\overline{O}}-H$ and so on]

Species	Electron dot diagram
Hydrogen sulfide, H_2S	
Sulfuric acid, H_2SO_4	
Magnesium nitrate, $Mg(NO_3)_2$	

6. **[6 marks]** *(2006:03)*

Consider the following chemical substances.

CO_2 SO_3 NH_3 H_2O N_2 S_8 $C\ell_2$ $CC\ell_4$

List all the molecules that contain polar bonds.	
List all the polar molecules.	
List all the linear molecules.	

(Note: Substances can be listed in more than one category)

7. **[3 marks]** *(2006:04)*

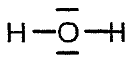
On Earth, water evaporates, forms clouds and falls back to the ground in a process known as the 'water cycle'.

On Saturn's moon Titan, where the average temperature is 94 K (–178°C), methane behaves in the same way as water does on Earth, evaporating and raining onto the surface as a liquid.

Using your knowledge of their structure and bonding, explain why water and methane undergo these processes at such different temperatures.

8. **[4 marks]** *(2007:02)*

For each species listed in the table below, draw the structural formula, representing all valence shell electron pairs either as **:** or as **–** .

[for example, water  or  or  and so on]

Species	Electron dot diagram
Ethanol	
Potassium hydroxide	

9. **[4 marks]** *(2007:03)*

On Earth, nitrogen exists as a gas. On Triton, the largest moon orbiting the planet Neptune, nitrogen can exist as a solid. The surface temperature of Triton is around –235°C.

Name the force of attraction that exists between nitrogen molecules.

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Explain how these forces arise and why the temperature needs to be so low for nitrogen to be a solid.

10. **[6 marks]** *(2008:P2:02)*

For each species listed in the table below, draw the structural formula, representing all valence shell electron pairs either as **:** or as **-** .

(for example, water $H:\ddot{\underset{..}{O}}:H$ or $H—\ddot{\underset{..}{O}}—H$ or $H—\overline{\underline{O}}—H$ and so on)

Species	Electron dot diagram
Nitrogen gas	
Sodium nitrate	
Hydrazine, N_2H_4	

11. **[9 marks]** *(2009:02)*

For each species listed in the table below, draw the structural formula, representing all valence shell electron pairs either as **:** or as **-** and state or draw the shape of the molecule or ion.

(for example, water $\mathrm{H{:}\underset{\cdot\cdot}{\ddot{O}}{:}H}$ or $\mathrm{H{-}\underset{\cdot\cdot}{\ddot{O}}{-}H}$ or $\mathrm{H{-}\underline{\overline{O}}{-}H}$ bent)

Species	Structural formula (showing all valence shell electrons)	Shape (draw or state name)
CO_2		
CH_2O		
HCO_3^-		

12. **[4 marks]** *(2009:07)*

(a) Explain why the first ionisation energy of elements increases going from left to right across row 3 of the periodic table, i.e. from Na to Ar. [2]

(b) Below are the successive ionisation energies (IE) for the magnesium atom. [2]

1st IE	744 kJ mol^{-1}
2nd IE	1457 kJ mol^{-1}
3rd IE	7739 kJ mol^{-1}
4th IE	10547 kJ mol^{-1}

(i) Explain why the second ionisation energy is greater than the first ionisation energy.

(ii) Explain the significant increase between the second and third ionisation energies.

13. **[12 marks]** *(2010:32)*

For each species listed in the table below, draw the structural formula, representing all valence shell electron pairs either as : or as — **and** state or draw the shape of the molecule **and** state the polarity of the molecule.

(for example, water H :Ö: H or H—Ö—H or H—Ō—H bent polar)

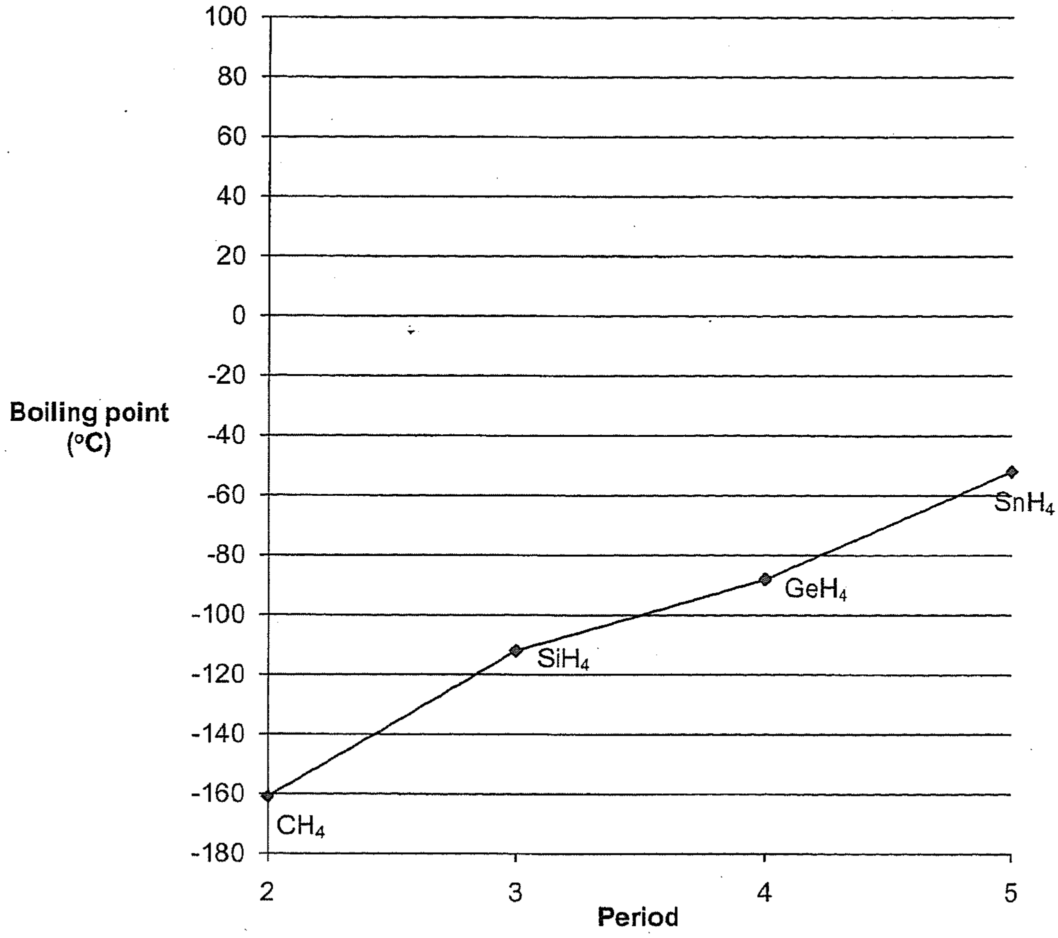
Species	Structure (showing all valence shell electrons)	Shape (sketch or name)	Polarity of molecule (polar or non-polar)
nitrogen trichloride $NC\ell_3$			
methanal HCHO			
sulfur dioxide SO_2			
carbon dioxide CO_2			

14. **[11 marks]** *(2010:34)*

The approximate boiling points of the Group 14, 15, 16 and 17 hydrides are listed below.

Group number	Hydride	Period	Boiling point (°C)
14	CH_4	2	–161
	SiH_4	3	–112
	GeH_4	4	–88
	SnH_4	5	–52
15	NH_3	2	–33
	PH_3	3	–88
	AsH_3	4	–62
	SbH_3	5	–17
16	H_2O	2	100
	H_2S	3	–60
	H_2Se	4	–41
	H_2Te	5	–2
17	HF	2	20
	$HC\ell$	3	–85
	HBr	4	–66
	HI	5	–34

(a) Plot the boiling points for each group on the axes below. The data for Group 14 have been plotted as an example. [3]



(b) The hydrides of Group 14 are non-polar molecules.

(i) Give the name of the shape of a Group 14 hydride molecule

or

Draw a diagram to illustrate the shape of a Group 14 hydride molecule. [1]

Diagram	or	Name

(ii) Apply your understanding of intermolecular interactions to explain the steadily increasing boiling points of the Group 14 hydrides CH_4, SiH_4, GeH_4 and SnH_4. [2]

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(c) The Group 15, 16 and 17 hydrides are polar molecules. Consider the Group 17 hydrides $HC\ell$, HBr and HI.

(i) List $HC\ell$, HBr and HI in order of increasing polarity. [1]

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(ii) Compare the trend in polarities of $HC\ell$, HBr and HI with the observed trend in their boiling points. Briefly explain your reasoning. [2]

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(d) The first member of each hydride series (NH_3 in Group 15, H_2O in Group 16 and HF in Group 17) has a much higher boiling point than the next hydride in its series. Apply your understanding of intermolecular interactions to explain the anomalous boiling points of NH_3, H_2O and HF. [2]

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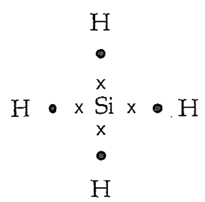
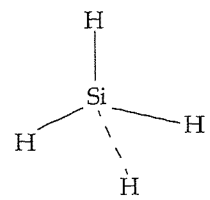
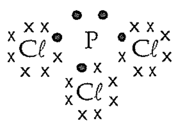
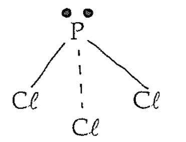
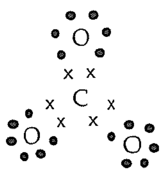
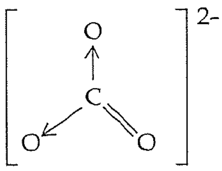
Chapter 7: Atomic Structure & Bonding

1.(2005:02)

Species	Electron-dot diagram	Shape (name or sketch)
SiH_4		 Tetrahedral
$PC\ell_3$		 Pyramidal
CO_3^{2-}		 Triangular planar

2.(2005:03)

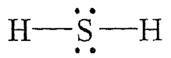
Substance	Use	Property
Aluminium	• Cooking pots and pans • Electrical cables • Frames for windows • Aircraft bodies	• High thermal conductivity • Good electrical conductivity • Prevents extensive corrosion • Low density
Diamond	• Drill bits for rock drilling, cutting and shaping other diamonds • Ornamental jewellery	• Very hard • High internal reflectivity
Zinc	• Galvanising iron roofs • Anodes in dry cells • Reducing agents in many reactions	• Prevents iron roof from corrosion by elements • Ease of oxidation • Low reduction potential
Stainless steel	• Knives, forks, spoons, surgical instruments, wood-working tools etc.	• Hardness • Rust resistance

3.(2005:05) The intermolecular forces of attraction between the water molecules and the grease molecules are much weaker compared to the hydrogen bond forces which hold water molecules together. On the other hand, the intermolecular forces between the methylated spirit molecules and the grease molecules are stronger than the intermolecular forces between the grease molecules, or between the methylated spirit molecules. Dispersion forces between the CH_3CH_2OH molecules and the grease molecules provide enough energy to break the attraction forces between the grease molecules. This is why CH_3CH_2OH molecules remove the grease molecules from the clothing.

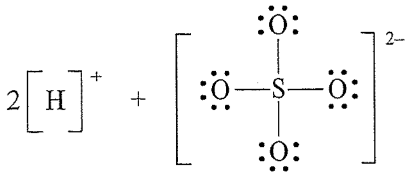
4.(2005:08) No. In a molecule of C_{60}, each carbon atom is attached to three other carbon atoms in much the same way as in graphite. This leaves one delocalised electron for each carbon atom in the molecule. However, Buckminsterfullerene is a covalent molecular substance and does not conduct electricity. The molecules are discrete with the delocalised electrons within each.

5.(2006:02) Structural formulae, representing all valence shell electrons:

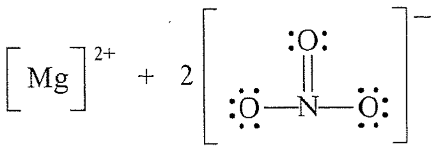
Hydrogen sulfide, H_2S



Sulfuric acid, H_2SO_4



Magnesium nitrate, $Mg(NO_3)_2$

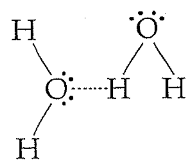


6.(2006:03)

All molecules that contain polar bonds	CO_2, SO_3, NH_3, H_2O, CCl_4
All the polar molecules	NH_3, H_2O
All the linear molecules	CO_2, N_2, Cl_2

7.(2006:04) Water (H_2O) has a boiling point of 100°C and freezing point of 0°C on earth at sea level and one atmospheric pressure. The relatively high boiling point and freezing point of water can be attributed to the fact that its molecules are bound by strong hydrogen bonding though water molecules are also weakly bound by dispersion forces. This hydrogen bonding is a special form of dipole-dipole interaction and the shared electrons are strongly attracted towards the more electronegative atoms. Since the hydrogen atom has a positive charge, it experiences a strong attractive force with lone pairs of electrons on the oxygen atoms of neighbouring molecules. Hydrogen bonding is also particularly strong in ice. Due to the strength of this strong intermolecular force, a higher temperature is necessary for breaking the H_2O molecules from ice and free H_2O molecules from water.

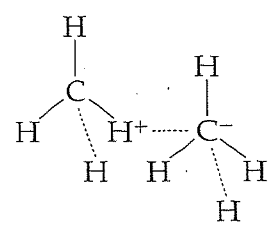
Hydrogen bonding in water



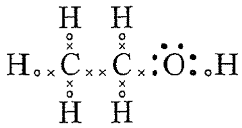
Methane (CH_4) is a gas at similar temperatures at which water is a solid or liquid. The only intermolecular force that binds the methane molecules is dispersion force of a temporary dipolar nature. These temporary dipoles occur at any moment when the electron clouds deviate from symmetry and influence the temporary polarity of other nearby molecules. These dispersion forces are of very small magnitude due to the small size and the number of atoms in methane. However, methane can be condensed to a liquid at low enough temperatures such as those which occur on Titan. This produces methane showers and evaporation under these conditions similar to our 'water cycle' on earth.

Intermolecular forces in methane

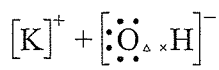
FORCES OF ATTRACTION BETWEEN TEMPORARY DIPOLES IN METHANE MOLECULES



8.(2007:02) Structural formula for ethanol



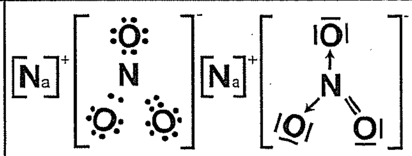
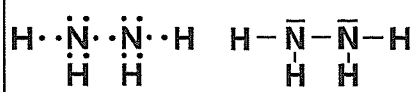
Structural formula for KOH



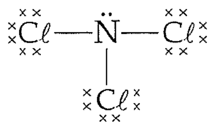
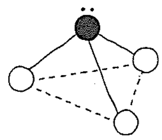
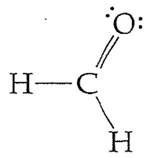
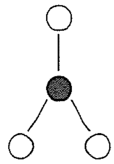
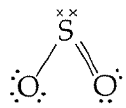
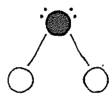
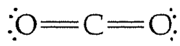
9.(2007:03) The force of attraction that exists between nitrogen molecules is due to dispersion or London forces.

Nitrogen must be cooled enough to condense as a liquid and then as a solid on further cooling, as the molecules do not possess permanent dipoles. Temporary dipoles occur all the time, as the electrons around the nuclei are not always evenly distributed. These forces are produced across the entire range of molecules at any instant. Molecules and atoms with temporary dipoles induce temporary dipoles in the neighbouring atoms or molecules. These temporary dipoles are short lived but continuously occur throughout the substance, keeping the molecules close in a liquid or solid state. Dispersion forces are also affected by the shape, size and symmetry of molecules along with the number of electrons present.

10.(2008:P2:02)

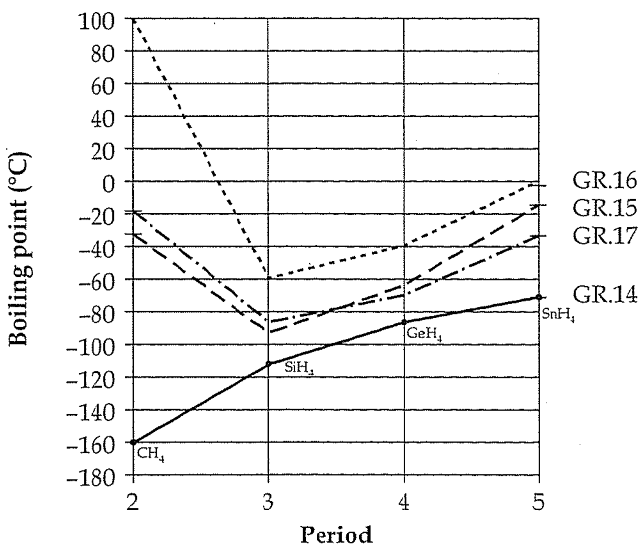
Species	Electron Dot Diagram
Nitrogen gas	
Sodium nitrate	
Hydrazine N_2H_4	

13.(2010:32)

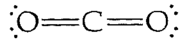
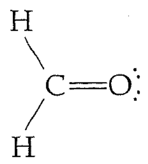
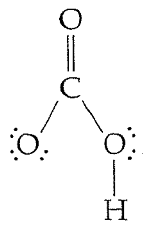
Species	Structure (showing all valence shell electrons)	Shape (sketch or name)	Polarity of molecule (polar or non-polar)
Nitrogen trichloride $NC\ell_3$		Triangular pyramidal 	Polar
Methanal HCHO		Triangular planar 	Polar
Sulfur dioxide SO_2		Bent or 'v' shaped 	Polar
Carbon dioxide CO_2		Linear 	Non-polar

14.(2010:34)

a) See the graph below:



11.(2009:2)

Species	Structural formula (showing all valence shell electrons)	Shape (draw or state name)
CO_2		Linear
CH_2O		Trigonal (or triangular) planar
HCO_3^-		Trigonal (or triangular) planar

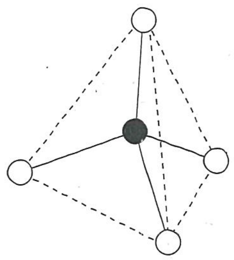
12.(2009:7)

a) Each successive electron comes from the same energy level. However each is at a diminishing distance from the nucleus. This is due to the decreasing size of the atom which is caused by the increasing force of attraction of the nuclear charge. Thus each successive electron experiences a slightly greater force of attraction by the increasing nuclear charge, which increases the energy required to remove it.

b) i) The first electron is removed from a neutral atom in which the numbers of electrons and protons are equal. The second electron is removed from a positively charged ion that contains more protons than electrons and thus the electron experiences a stronger attraction from the nucleus.

ii) The second electron is removed from the same energy level as the first. However, the third electron is removed from an inner energy level, which is closer to the nucleus and which experiences a stronger force of attraction by the nucleus.

b) i) The shape of the Group 14 hydride molecules is tetrahedral



ii) The steadily increasing boiling point is due to the increasing strength of the temporary dipole-dipole (dispersion) forces between the molecules which have increasing number of electrons (and size) that contribute to these forces. The dispersion forces, therefore increase from CH_4, SiH_4, GeH_4 to SnH_4 in that order.
c) i) The order of increasing polarity is $HC\ell$, HBr and HI.
c) ii) HI has the lowest polarity and $HC\ell$ has the highest polarity. HBr is in between. However, the boiling points show an opposite trend. HI has the highest boiling point and $HC\ell$ has the lowest boiling point and HBr is in between. This clearly indicates that the dipole-dipole forces are not the dominant forces that bind these molecules to form liquids or solids. If we take into account the increasing number of electrons and the correspondingly increasing size of the molecules from $HC\ell$ to HI, it will be clear that temporary dipole-dipole (dispersion) forces become increasingly very dominant as we go from $HC\ell$ to HI. This explains the increasing boiling points as we move from $HC\ell$, HBr to HI.
d) Given about equal size molecules, hydrogen bonding is the strongest of the intermolecular forces, approximately ten times stronger than dipole-dipole forces and one hundred times stronger than the temporary dipole-dipole (dispersion) forces between molecules. Hydrogen bonding occurs in molecules in which a hydrogen atom is directly bonded to an oxygen atom, or a nitrogen atom, or a fluorine atom (groups such as –OH, –NH and –FH). Also, -OH bonding is stronger than –FH bonding which is stronger than –NH bonding. When molecules with such similar groups come closer, they are attracted very strongly towards each other. H_2O, HF and NH_3 are all highly polar since they contain the three most electronegative elements O, F and N bonded to H which has a relatively low electronegativity. This produces very highly polar molecules and much stronger intermolecular forces than expected for dipole-dipole interactions.

Chapter 8: Chemical Reactions...

1.(2005:01) a) $2\,C_4H_{10}(g) + 13\,O_2(g) \rightarrow 8\,CO_2(g) + 10\,H_2O(\ell)$
The gas burns with an orangy/blue flame giving off a colourless and odourless gas and heat.
b) $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$
The yellow/grey solid dissolves and a solid of salmon/pink colour is deposited. The blue colour of the solution fades.
c) $2\,H_2O_2(\ell) \rightarrow 2\,H_2O(\ell) + O_2(g)$
(Note: $MnO_2(s)$ acts as a catalyst)
The solution effervesces and a colourless, odourless gas is produced.
d) $2\,Na(s) + 2\,H_2O(\ell) \rightarrow 2\,Na^+(aq) + 2\,OH^-(aq) + H_2(g)$
The soft, silvery solid dissolves vigorously forming a colourless solution. A colourless, odourless gas is produced which responds to a 'pop' test.