Q1. (a) Van der Waals' forces exist between all molecules.

Explain how these forces arise.

(3)

(b) The table shows the boiling points of methanol (CH_3OH) and methanethiol (CH_3SH).

Compound	**Boiling point / °C**
Methanol	65
Methanethiol	6

(i) Explain, in terms of their intermolecular forces, why the boiling points of these compounds are different.

(3)

(ii) Suggest how a mixture of methanol and methanethiol could be separated.

(1)

(c) Suggest why methaneselenol (CH_3SeH) has a higher boiling point than methanethiol (CH_3SH).

_____

_____

_____

_____

(2)

(d) Sulfur forms many molecular compounds with the halogens.

(i) Draw the shape of an SF_6 and of an SF_4 molecule.
Include any lone pairs that influence the shape.
State the bond angle(s) in SF_6 and in SF_4.
Name the shape of SF_6.

	SF_6	**SF_4**
Shape		
Bond angle(s)		
Name of shape		

(6)

(ii) SCl_2 reacts with NaF to form SF_4 and S_2Cl_2 and one other product.

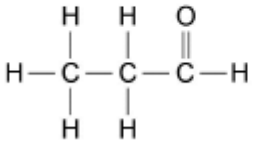
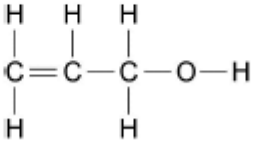
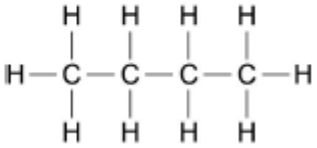
Write an equation for the reaction.

_____

(2)

(Total 17 marks)

Q2. The compounds in the table all have a relative molecular mass of 58.0

Name	Propanal	Prop-2-en-1-ol	Butane
Structure			

(a) Explain why determining the precise relative molecular mass of propanal and prop-2-en-1-ol by mass spectrometry could not be used to distinguish between samples of these two compounds.

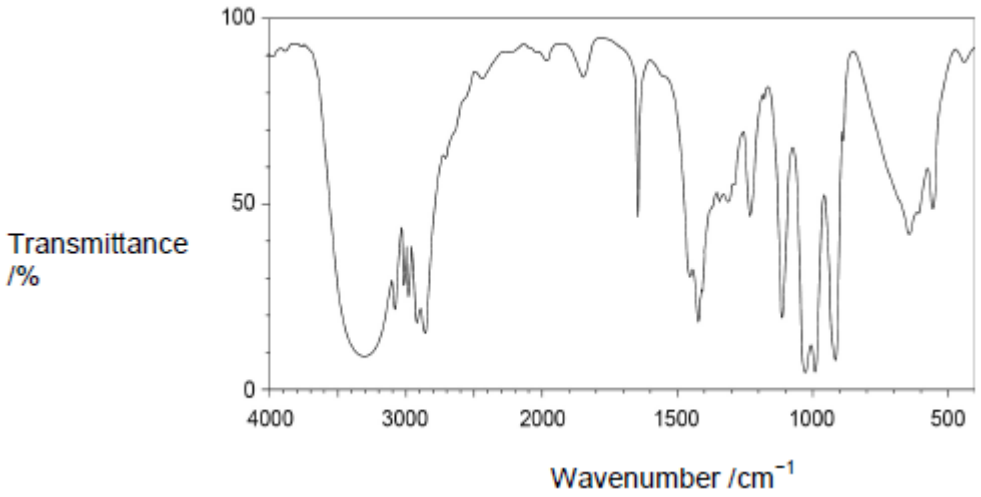
_____

_____

_____

(2)

(b) The infrared spectrum of one of these three compounds is shown below.



Use the spectrum to identify the compound.
State the bond that you used to identify the compound and give its wavenumber range.
You should only consider absorptions with wavenumbers greater than 1500 cm^{-1}.

Compound _____

Bond used to identify compound _____

Wavenumber range of bond used to identify compound _____ cm^{-1}

(2)

(c) Predict the relative boiling points of these three compounds from the highest to the lowest boiling points.

Justify this order in terms of intermolecular forces.

(6)
(Total 10 marks)

Q3. Fluorine forms many compounds that contain covalent bonds.

(a) (i) State the meaning of the term *covalent bond*.

_____

_____

(1)

(ii) Write an equation to show the formation of one molecule of ClF_3 from chlorine and fluorine molecules.

_____

(1)

(b) Draw the shape of a dichlorodifluoromethane molecule (CCl_2F_2) and the shape of a chlorine trifluoride molecule (ClF_3). Include any lone pairs of electrons that influence the shape.

Shape of CCl_2F_2 Shape of ClF_3

(2)

(c) Suggest the strongest type of intermolecular force between CCl_2F_2 molecules.

_____

(1)

(d) BF_3 is a covalent molecule that reacts with an F^- ion to form a BF_4^- ion.

(i) Name the type of bond formed when a molecule of BF_3 reacts with an F^- ion. Explain how this bond is formed.

Type of bond _____

Explanation _____

_____

_____

_____

(3)

(ii) State the bond angle in the BF_4^- ion

_____

(1)

(e) An ultrasound imaging agent has the formula C_4F_{10}
It can be made by the reaction of butane and fluorine as shown in the following equation.

$$C_4H_{10} + 10F_2 \rightarrow C_4F_{10} + 10HF$$

Calculate the percentage atom economy for the formation of C_4F_{10} in this reaction.
Give your answer to three significant figures.

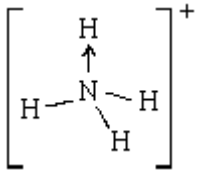
_____

_____

(2)

(Total 11 marks)

Q4. (a) An ammonium ion, made by the reaction between an ammonia molecule and a hydrogen ion, can be represented as shown in the diagram below.



(i) Name the type of bond represented in the diagram by N—H

_____

(ii) Name the type of bond represented in the diagram by N→H

_____

(iii) In terms of electrons, explain why an arrow is used to represent this N→H bond.

_____

_____

(iv) In terms of electron pairs, explain why the bond angles in the NH_4^+ ion are all 109° 28'

_____

_____

_____

(7)

(b) Define the term *electronegativity*.

_____

_____

(2)

(c) A bond between nitrogen and hydrogen can be represented as $\overset{\delta-}{N}—\overset{\delta+}{H}$

(i) In this representation, what is the meaning of the symbol δ+ ?

_____

(ii) From this bond representation, what can be deduced about the electronegativity of hydrogen relative to that of nitrogen?

_____

_____

(2)

(Total 11 marks)

Q5. (a) Explain how the electron pair repulsion theory can be used to deduce the shape of, and the bond angle in, PF_3

(6)

(Total 6 marks)

Q6. The table below shows the electronegativity values of some elements.

	H	C	N	O
Electronegativity	2.1	2.5	3.0	3.5

(a) State the meaning of the term *electronegativity*.

_____

_____

_____

(2)

(b) State the strongest type of intermolecular force in the following compounds.

Methane (CH_4) _____

Ammonia (NH_3) _____

(2)

(c) Use the values in the table to explain how the strongest type of intermolecular force arises between two molecules of ammonia.

_____

_____

_____

_____

_____

(3)

(d) Phosphorus is in the same group of the Periodic Table as nitrogen.
A molecule of PH_3 reacts with an H^+ ion to form a PH_4^+ ion.
Name the type of bond formed when PH_3 reacts with H^+ and explain how this bond is formed.

Type of bond _____

Explanation _____

_____

_____

(3)

(e) Arsenic is in the same group as nitrogen. It forms the compound AsH_3
Draw the shape of an AsH_3 molecule, including any lone pairs of electrons. Name the shape made by its atoms.

Shape

Name of shape _____

(2)

(f) The boiling point of AsH_3 is –62.5 °C and the boiling point of NH_3 is –33.0 °C.
Suggest why the boiling point of AsH_3 is lower than that of NH_3

_____

_____

_____

(1)

(g) Balance the following equation which shows how AsH_3 can be made.

..... $AsCl_3$ + ... $NaBH_4$ → ..... AsH_3 + ... NaCl + ... BCl_3

(1)

(Total 14 marks)

Q1.

(a) Electron movement in first molecule / temporary dipole

Allow description

1

Induces a dipole in another molecule

Allow description

1

(Induced-temporary) attraction or δ+ attracts δ- in different/adjacent molecules

M3 dependent on M1 <u>and</u> M2

Allow electrostatic attraction

M3 could be scored in diagram

If other type of force / metallic / ionic / polar bonds / permanent dipoles / difference in electronegativity mentioned CE = 0

1

(b) (i) (Methanol) H-bonds / hydrogen bonding

1

(Methanethiol) dipole-dipole forces or van der Waals

1

H-bonds are a strong<u>er</u> / are the strongest IMF

Allow H-bonds require more energy to overcome

If M1 and M2 not scored, allow 1 for methanol has stronger IMFs

If breaking covalent bonds then CE=0

1

(ii) (Fractional) distillation

Allow description

Do not allow heating unqualified

1

(c) (Methaneselenol is a) bigger molecule / larger Mr / larger no of electrons / Se bigger atom

1

With <u>stronger/more</u> <u>vdw</u> forces <u>between molecules</u>

If breaking covalent bonds then CE=0

1

(d) (i)

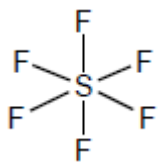


Diagram showing 6 bond pairs

1

(Bond angle) 90° for SF_6

Ignore 180°

1

Octahedral

1

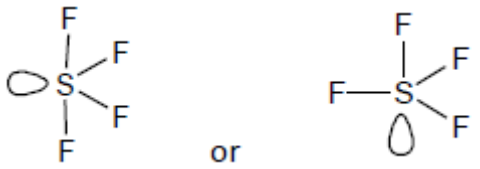


Diagram showing 4 bond pairs <u>and 1 lone pair</u>

1

(Bond angles) for SF_4

If shape of SF_4 is not based on 4 bond pairs <u>and 1 lone pair</u> cannot score M4 or M5

Any **two** from:
Allow 85 – 89°

Do not allow 90°

Allow 100 – 119°

Do not allow 120°

Allow 170 – 179°

Do not allow 180°

2

(ii) NaCl (as product in any equation)

1

$3\ SCl_2 + 4\ NaF \rightarrow SF_4 + S_2Cl_2 + 4\ NaCl$

Allow multiples

Ignore states

1

[17]

Q2.

(a) M1 have the same molecular formula
or are C_3H_6O
or both have the same number/amount of each type of atom or same amount of each element
or are isomers

Not just the same atoms;

1

M2 <u>identical / exactly the same / same precise</u> (relative) molecular mass / formula mass / M_r

Same (relative) molecular mass / formula mass / M_r is NOT enough got score M2

Allow <u>same accurate</u> (relative) molecular mass / formula mass / M_r

Ignore reference to number of decimal places

1

(b) M1 prop-2-en-1-ol

Must refer to this compound clearly by name or structure (not to alcohol alone); ignore minor slips in name/structure

1

M2 <u>O</u>(-)<u>H</u> (alcohol) and 3230–3550 (cm^{-1}), or
<u>C=C</u> and 1620–1680 (cm^{-1})

Marked independently from M1

Could score from bond labelled on correct signal on spectrum

Allow any value within these ranges

If additional incorrect signals given penalise M2

Ignore signals below 1500 cm^{-1} and C-H signals

1

(c) (i) Determine the level by looking at the chemical content. (**NB** - If there is clear breakage of covalent bonds then max level 2 (max 3 marks).

(ii) The mark within that level is then determined by looking at how coherent and logical the answer is and by use of terminology; start at the higher mark and penalise poor terminology/explanation; examples of terminology that would reduce the mark to the lower one:

- reference to van der Waals 'bonds' or dipole-dipole 'bonds in relevant compounds that are being credited
- uncertainty about whether hydrogen bonds are the O-H bonds within or are forces/bonds between molecules (if the alcohol is being credited)
- use of 'vdw' or 'dip-dip' unless these terms 'van der Waals' for 'dipole-dipole' have been used elsewhere in answer (note that IMF and H-bond would not be penalised)

(iii) If the answer does not achieve level 1, then 1 mark maximum could be scored for any correct point from the list of indicative content

Level 3
- **Relative order** of boiling points of **all three** compounds
- Strongest intermolecular force of **all three** compounds identified
- Answer explains this coherently and logically and uses correct terminology for all **three** compounds

5-6 marks

Level 2
- **Relative** boiling points of **two** compounds correctly compared
- Strongest intermolecular force for these **two** compounds correctly identified
- Answer explains this coherently and logically and uses correct terminology for **these two** compounds

3-4 marks

Level 1
- **One** compound with the **highest** or **lowest** boiling point is correctly identified
- Strongest intermolecular force for that **one** compound identified
- Answer explains this coherently and logically and uses correct terminology for **this one** compound
- Allow 1 mark for individual correct point from indicative content on the right if no other mark scored

1-2 marks

Level 0
None of the indicative chemistry content given.

0 marks

Indicative chemistry content:

• Correct order (highest to lowest) = prop-2-en-1-ol > propanal > butane

• Prop-2-en-1-ol has hydrogen bonds

• *Propanal has (permanent) dipole-dipole forces*

• *Butane has van der Waals' forces*

• *Strength of intermolecular forces:*
hydrogen bonds > dipole-dipole > van der Waals

(Note - actual values for reference are prop-2-en-1-ol 97°C, propanal 46°C and butane −1°C)

[10]

Q3.

(a) (i) shared <u>pair of electrons</u>

Can have one electron from each atom contributes to the bond
Not both electrons from one atom

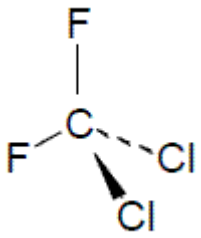
1

(ii) $\frac{1}{2}Cl_2 + \frac{3}{2}F_2 \rightarrow ClF_3$

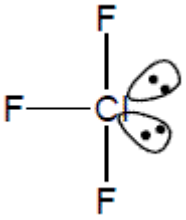
1

Only
Ignore state symbols even if wrong

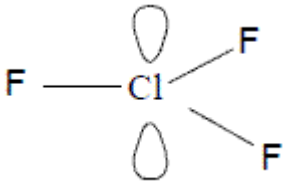
(b)



1



OR

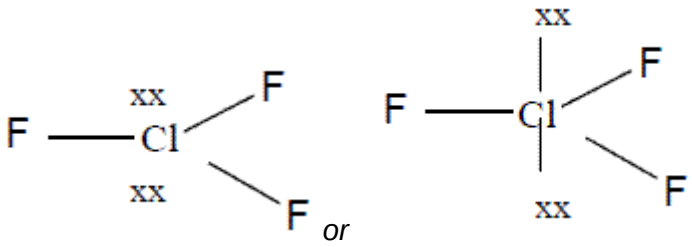


Allow any structure with 4 bp

In $CClF_2$, watch for Cl in centre- it must be C

Ignore wrong bond angles

Representations of lone pairs allowed are the two examples shown with or without the electrons in the lobe.
Also they can show the lone pair for either structure by two crosses/dots or a line with two crosses/dots on it e.g.



Or a structure with 3 bp and 2 lp

1

(c) Dipole – dipole

Allow van der Waals/vdw/London/dispersion/temporary dipole – induced dipole
Not dipole alone

1

(d) (i) Coordinate/dative (covalent)

If wrong CE = 0/3 but if 'covalent' or left top line blank, mark on.

1

(Lone) pair of electrons/both electrons (on F^-)

CE if lone pair is from B

1

Donated from F^-/fluoride or donated to the BF_3

Must have the – sign on the F ie F^-
Ignore Fl^-
M3 dependent on M2

1

(ii) 109° to 109.5°

1

(e) $\frac{238 \times 100}{438}$

For 1 mark allow 238 as numerator and 438 as denominator or correct strings

1

= 54.3%

2 marks if correct answer to 3 sig figs.
54% or greater than 3 sig figs = 1 mark

1

[11]

Q4.

(a) (i) Covalent **(1)**

(ii) Co-ordinate **(1)** (or dative)

(iii) Both / two / pair electrons come from nitrogen **(1)**

(iv) 4 bonding / electron pairs **(1)**

repel equally **(1)**

OR are identical

as far apart as possible **(1)**

OR to position of minimum repulsion

tetrahedron **(1)**

7

(b) Power (or ability) of an element / atom to attract electron pair**/**electrons/ an electron/electron density **(1)**

in a covalent bond **(1)**

Allow attract from, withdraw in, do not allow remove from, withdraw from.

2

(c) (i) Electron deficient **(1)**

Or small, slight, partial positive charge

(ii) H < N **(1)**

2

[11]

Q5.

(a) This question is marked using levels of response. Refer to the Mark Scheme Instructions for Examiners for guidance on how to mark this question.

All stages are covered and the explanation of each stage is generally correct and virtually complete.

Answer is communicated coherently and shows a logical progression from stage 1 to stage 2 then stage 3.

Level 3
5 – 6 marks

All stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies OR two stages are covered and the explanations are generally correct and virtually complete.

Answer is mainly coherent and shows progression from stage 1 to stage 3.

Level 2
3 – 4 marks

Two stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies, OR only one stage is covered but the explanation is generally correct and virtually complete

Answer includes isolated statements but these are not presented in a logical order or show confused reasoning.

Level 1
1 – 2 marks

Insufficient correct chemistry to gain a mark.

Level 0
0 marks

Indicative chemistry content

Stage 1: Electrons round P
- P has 5 electrons in the outside shell
- With 3 electrons from 3 fluorine, there are a total of 8 electrons in outside shell
- so 3 bond pairs, 1 non-bond pair

Stage 2: Electron pair repulsion theory
- Electron pairs repel as far as possible
- Lone pair repels more than bonding pairs

Stage 3: Conclusions
- Therefore, tetrahedral / trigonal pyramidal shape
- With angle of 109(.5)° decreased to 107°

6

(b) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^7$

Allow correct numbers that are not superscripted

1

(c) Too many electrons in d sub-shell / orbitals

1

(d) Tetrahedral (shape)

1

109.5°

Allow 109°

1

[10]

Q6.

(a) Ability/power of an atom/element/nucleus to withdraw electron density or electron cloud or a pair of electrons (towards itself);

Not withdraw an electron
If ref to ionic, metallic , imf etc then CE = 0

1

From a <u>covalent bond</u> or from a shared pair of electrons;

Not distort
Not remove electrons

1

(b) Van der Waals/ vdw/London/ <u>temporary</u> (induced) dipole/ dispersion forces;

1

Hydrogen bonds/H bonds;

Not just hydrogen

1

(c) (Large) electronegativity difference between N + H/ difference of 0.9/ N very electronegative;

Insufficient to say N= 3.1 and H = 2.1

1

Forms N δ– / H δ+ or dipole explained in words;

Not N becomes (fully) negative or vice versa

1

Lone pair on N attracts/forms weak bonds with H (δ+);

QWC
Can score M2 and 3 from a diagram

1

(d) Co-ordinate/dative;

If not correct then CE = 0. If covalent/blank mark on.

1

Both electrons/ lone pair (on P/PH_3)

Not lone pair on hydrogen

1

Shares/donated from P(H_3)/ to H(δ+);

1

(e) 3 bonds and 1 lp attached to As;

Must label H and As atoms
Accept distorted tetrahedral not bent tetrahedral

1

Pyramidal/tetrahedral/ trigonal pyramidal;

Not bipyramidal/triangular

1

(f) (Only) weak Van der Waals forces between molecules /AsH_3 has weaker IMF /ammonia has hydrogen bonding/ more energy needed to break IMF's in ammonia/ Van der Waals weaker than H bonds;

Accept has no H bonds.
Ignore dp-dp in AsH_3 provided ammonia has stronger IMF.
If between atoms mentioned CE=0
Break bonds CE = 0

1

(g) $4AsCl_3 + 3NaBH_4 \rightarrow 4AsH_3 + 3NaCl + 3BCl_3$;

Accept multiples

1

[14]