02 Chemical Bonding

Set B **Answer key**

A Multiple choice

4 MARKS

1 **C** 3 bond pairs, 1 lone pair: trigonal pyramidal, 107° [1]

Based on the number of bond pairs and lone pairs listed in the question, these are the corresponding geometries and bond angles:

A Bent, 118°

B Bent, 104.5°

D T-shaped, 88°

2 **A** giant covalent [1]

Giant covalent substances have high melting points and generally do not conduct electricity (except graphite) due to the absence of mobile charge carriers.

3 **D** Ice has a lower density than water at 0 °C. [1]

Intermolecular hydrogen bonding holds ice molecules in place in an orderly open structure with a large amount of empty space in between. This takes up more space than the more random arrangement of hydrogen bonds in liquid water, resulting in a larger volume and hence lower density.

A Group 1 hydroxides, M^+OH^-, possess the same anion, but the size of the cation, M^+, increases with increasing M_r. Hence the magnitude of lattice energy, $\propto \frac{q_+ \times q_-}{r_+ + r_-}$, decreases with increasing M_r, resulting in decreasing melting point.

B Alkanes are non-polar molecules. With increasing relative molecular mass, the number of electrons increases, the polarisability of the electron cloud increases and hence the strength of instantaneous dipole–induced dipole attractions increases. Since more energy is required to overcome the intermolecular interactions, boiling point increases.

C Both CH_3OCH_3 and $CH_3CH_2CH_3$ have a comparable number of electrons, so they are expected to have similarly strong instantaneous dipole–induced dipole interactions. CH_3OCH_3 is a slightly polar molecule, due to the polar C–O bonds, hence the molecules are held together by permanent dipole–permanent dipole interactions. $CH_3CH_2CH_3$ is non-polar, and its molecules are held together by only instantaneous dipole–induced dipole interactions, which are weaker. Therefore CH_3OCH_3 will have a higher boiling point than $CH_3CH_2CH_3$.

4 **A** 107° [1]

Since there are 3 bond pairs and 1 lone pair around each N atom in hydrazine, the shape is trigonal pyramidal and the most likely angle is 107°.

B Structured questions

40 MARKS

5 **(a)**

Electron pairs around the central N atom are arranged as far apart as possible to minimise repulsion. [½]

Lone pair–lone pair repulsion is greater than lone pair–bond pair repulsion, which is greater than bond pair–bond pair repulsion. [½]

NH_3: trigonal pyramidal about N and 107°, due to 1 lone pair and 3 bond pairs [1]

NH_2^-: bent about N and 104.5°, due to 2 lone pairs and 2 bond pairs [1]

or NH_2^- is bent about N with a bond angle of 104.5°, whereas NH_3 is trigonal pyramidal about N with a bond angle of 107°, as NH_2^- has lone pair–lone pair repulsion which is absent in NH_3.

(b)

More energy is needed to overcome the stronger ionic bonding between Na^+ and NH_2^- ions than the weaker hydrogen bonding between NH_3 molecules. [2]

NOTE Name the particles: "between Na^+ and NH_2^-" for the ionic bonding, and "between molecules" for the hydrogen bonding. Each was worth [½].

6 **(a)**

Electronegativity increases across a period. Nuclear charge increases (*or* number of protons increases) while shielding effect is relatively constant (*or* number of inner shell electrons is the same). [1]

Hence there is an increase in effective nuclear charge, leading to stronger attraction between the nucleus and the electrons, and so the ability of the atom to attract electrons to itself increases. [1]

(b)

Type of bonding in NaF: ionic

Type of bonding in SiF_4: covalent

Type of bonding in Mg-Al: metallic [2]

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The carbonate ion has 3 bond pairs and 0 lone pairs around the central C. [1]

To minimise (electrostatic) repulsion (between the electron pairs), the shape of the carbonate ion will be trigonal planar. [1]

8

For CH_3OCH_3, there are 2 bond pairs and 2 lone pairs of electrons around the O atom. [1]

By VSEPR theory, electron pairs around the central O atom are arranged as far apart as possible to minimise repulsion. Since lone pair–lone pair repulsion is greater than lone pair–bond pair repulsion, which is greater than bond pair–bond pair repulsion, the bond angle is 105° *or* 104.5°. [1]

NOTE Common mistakes: not stating the order of the three repulsions, and leaving out "arranged as far apart as possible to minimise repulsion".

9

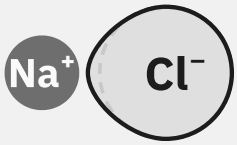
Both have simple molecular structures. $CH_3CH_2CH_2CH_3$ molecules form weaker instantaneous dipole–induced dipole interactions with one another, while $CH_3CH_2CH_2CH_2Cl$ molecules form stronger permanent dipole–permanent dipole interactions. [1]

Less energy is needed to overcome the weaker instantaneous dipole–induced dipole interactions than that needed to overcome the stronger permanent dipole–permanent dipole interactions. Hence, $CH_3CH_2CH_2CH_3$ has a lower boiling point than $CH_3CH_2CH_2CH_2Cl$. [1]

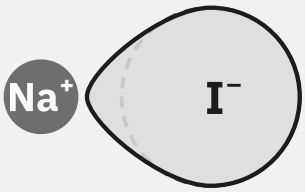
NOTE Boiling overcomes the intermolecular forces, not the covalent bonds. Write the names of the interactions in full.

10 **(a)**

NaI has greater covalent character as its anion is larger and more easily polarisable than that of NaCl. [1]



NaCl: Cl^- is distorted slightly

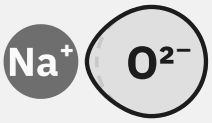


NaI: the larger I^- is distorted more

NaCl has the higher melting point as its lattice energy is more exothermic than that of NaI, since there is greater attraction between Na^+ and the smaller Cl^-. [1]

(b)

MgO has greater covalent character as its cation is more highly charged than Na^+, so it polarises O^{2-} to a greater extent. [1]



Na_2O: Na^+ distorts O^{2-} slightly



MgO: the smaller, more highly charged Mg^{2+} distorts O^{2-} more

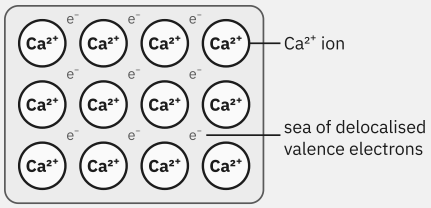
MgO has the higher melting point as Mg^{2+}, being more highly charged than Na^+, attracts the O^{2-} more strongly. Also, the ionic radius of Mg^{2+} is smaller than that of Na^+, so Mg^{2+} is closer to O^{2-}, causing the electrostatic attraction to be stronger. [1]

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In HF, each fluorine atom has three lone pairs and is bonded to only one hydrogen atom. In water, the oxygen atom has two lone pairs and is bonded to two hydrogen atoms. Since a hydrogen bond is formed between a hydrogen atom bonded to electronegative N, O or F and a lone pair of electrons on N, O or F, hydrogen bonding in H_2O is more extensive than between HF molecules. [1]

Thus, more energy is required to overcome the more extensive hydrogen bonds between water molecules than the hydrogen bonds between HF molecules, and water has a higher boiling point. [1]

12

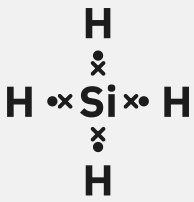


Calcium has a giant metallic structure. [1]

Electrostatic forces of attraction (metallic bonding) exist between the Ca^{2+} ions and the sea of delocalised valence electrons. [1]

13 **(a)**

[1]



x electron of Si, • electron of H

The molecular shape about Si is tetrahedral. [1]

(b)

Silane is non-polar, as the dipole moments of the four polar Si–H bonds, arranged tetrahedrally, cancel each other out, resulting in a net zero dipole moment. [1]

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Both diamond and silicon have giant molecular structures. During melting, the strong Si–Si and C–C covalent bonds between the atoms are broken in silicon and diamond respectively. [1]

Si–Si covalent bonds are weaker than C–C covalent bonds, as the valence orbitals of Si are more diffuse than those of C, so the overlap of the orbitals of Si is less effective. Hence less energy is required to break the weaker Si–Si bonds during melting than the C–C bonds in diamond. [1]

15 **(a)**

A σ bond is formed when two orbitals overlap head-on. In an oxygen molecule, the head-on overlap is between two p orbitals. [1]

A π bond is formed when the p orbitals of the two atoms overlap sideways. [1]

(b)

(i) C_2H_6: 7 σ, 0 π. (ii) C_2H_4: 5 σ, 1 π. (iii) C_2H_2: 3 σ, 2 π. (iv) CO_2: 2 σ, 2 π. [2]

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The size of the valence orbital of the atoms increases down the group from Cl to Br to I, so the overlap between the orbitals is less effective. The covalent bond formed is weaker and has a lower bond energy. [1] [1]

The halogens have a simple molecular structure and are non-polar, with instantaneous dipole–induced dipole interactions between the molecules. The electron cloud gets larger and more polarisable from Cl_2 to Br_2 to I_2, so these interactions get stronger. More energy is required to overcome them, so the boiling point increases. [1] [1]

17 **(a)**

$SiCl_4$ has a tetrahedral molecular shape, so it is non-polar and its dominant intermolecular forces of attraction are instantaneous dipole–induced dipole interactions. PCl_3 has a trigonal pyramidal molecular shape and is polar. It has both permanent dipole–permanent dipole and instantaneous dipole–induced dipole interactions. **[1]**

Even though PCl_3 (66 electrons) has fewer electrons than $SiCl_4$ (82 electrons), the additional, stronger permanent dipole–permanent dipole interactions cause the boiling point of PCl_3 to be higher than that of $SiCl_4$. **[1]**

(b)

The greater number of electrons in iodine (106 electrons) causes the electron cloud to be easily polarisable. **[1]**

This gives rise to relatively strong instantaneous dipole–induced dipole interactions, which are stronger than the hydrogen bonding in water (10 electrons). This results in a higher boiling point for iodine. **[1]**