2.2 Bonding and Structure: 1-hour Pack

AQA 7405 · Calculator allowed · about 60 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 This question is about covalent bonding, including dative covalent (coordinate) bonding.

(a) Define the term covalent bond. **(1)**

(b) Describe the covalent bonding present in a molecule of methane, CH_4. **(2)**

(c) Define the term dative covalent (coordinate) bond. **(1)**

(d) Ammonia, NH_3, reacts with a hydrogen ion, H^+, to form the ammonium ion, NH_4^+. Explain how this bond forms, identifying which atom donates the electron pair. **(3)**

(e) State the shape of the ammonium ion, NH_4^+, and its bond angle. **(2)**

(Total for Question 1 is 9 marks)

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2 This question is about predicting the shapes of molecules and ions using electron-pair repulsion theory.

(a) State the electron-pair repulsion theory used to predict the shapes of molecules and ions. **(2)**

(b) Predict the shape and bond angle of a molecule of boron trifluoride, BF_3, explaining your answer. **(3)**

(c) Predict the shape and bond angle of a molecule of ammonia, NH_3, explaining why its bond angle differs from that in methane, CH_4 (109.5 degrees). **(3)**

(d) Predict the shape and bond angle of a molecule of water, H_2O, explaining the effect of having two lone pairs. **(3)**

(Total for Question 2 is 11 marks)

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3 This question is about the giant covalent structures of diamond, graphite and graphene, all forms of carbon.

(a) Describe the structure of diamond. **(2)**

(b) Explain why diamond has a very high melting point. **(2)**

(c) Describe the structure of graphite and explain why graphite conducts electricity while diamond does not. **(4)**

(d) Explain why graphite is used as a lubricant. **(2)**

(e) Graphene is a single, isolated layer of graphite, one atom thick. Suggest one property of graphene that would make it useful in electronics, referring to its structure. **(2)**

(Total for Question 3 is 12 marks)

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4 This question is about predicting the shapes and bond angles of molecules and ions using electron-pair repulsion theory.

(a) Determine the number of bonding pairs and lone pairs of electrons around the central phosphorus atom in PF_5, and hence give its shape and bond angles. **(3)**

(b) SF_6 has 6 bonding pairs and no lone pairs around the central sulfur atom. State its shape and bond angle. **(2)**

(c) The ion ICl_4^- has 4 bonding pairs and 2 lone pairs of electrons around the central iodine atom. State its shape and bond angle. **(2)**

(d) In the nitrite ion, NO_2^-, there are 2 bonding regions and 1 lone pair of electrons around the central nitrogen atom. State the shape of the ion and estimate its bond angle, explaining why the angle differs from that of a molecule with 3 bonding pairs and no lone pairs. **(2)**

(Total for Question 4 is 9 marks)

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5 Table 2 shows the boiling points of the hydrides of Group 14 and Group 16.

Table 2: boiling points of Group 14 and Group 16 hydrides

Group 14 hydride	Mr	Boiling point / C
CH_4	16	-162
SiH_4	32	-112
GeH_4	77	-88
SnH_4	123	-52

Group 16 hydride	Mr	Boiling point / C
H_2O	18	100
H_2S	34	-60
H_2Se	81	-41
H_2Te	130	-2

Explain, using ideas about intermolecular forces, why the boiling points of the Group 14 hydrides increase steadily down the group, but the boiling point of H_2O is anomalously high compared with the trend shown by the other Group 16 hydrides.

(Total for Question 5 is 6 marks)

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Mark scheme · 2.2 Bonding and Structure: 1-hour Pack

Question 1

(a) a shared pair of electrons, attracted to the nuclei of both atoms oe **B1**

(a) Answer: A shared pair of electrons, attracted to the nuclei of both bonded atoms.

(b) carbon shares one electron with each of four hydrogen atoms, forming four single covalent bonds oe **B1**

(b) each shared (bonding) pair consists of one electron from carbon and one electron from the hydrogen atom, giving carbon a share in 8 electrons (a full outer shell/octet) oe **B1**

(b) Answer: Carbon forms four single covalent bonds, each a shared pair (one electron from C, one from H), giving carbon a share of 8 outer electrons.

(c) a shared pair of electrons in which both electrons are provided (donated) by only one of the two bonded atoms oe **B1**

(c) Answer: A covalent bond in which both shared electrons come from only one of the two atoms.

(d) the nitrogen atom in NH_3 has a lone pair of electrons oe **B1**

(d) the H^+ ion has an empty (1s) orbital and no electrons of its own to contribute oe **B1**

(d) nitrogen donates its lone pair into the empty orbital on H^+, forming a new dative covalent bond oe **B1**

(d) Answer: The nitrogen lone pair in NH_3 is donated into the empty orbital of H^+, forming a new N-H dative covalent bond.

(e) tetrahedral **B1**

(e) 109.5 degrees **B1**

(e) Answer: Tetrahedral, with a bond angle of 109.5 degrees.

Question 2

(a) electron pairs (bonding and lone pairs) around a central atom repel one another and arrange themselves as far apart as possible, to minimise repulsion oe **B1**

(a) the order of repulsion strength is: lone pair-lone pair > lone pair-bonding pair > bonding pair-bonding pair oe **B1**

(a) Answer: Electron pairs around a central atom repel each other and arrange as far apart as possible; lone pair-lone pair repulsion is strongest, then lone pair-bonding pair, then bonding pair-bonding pair.

(b) boron has three bonding pairs and no lone pairs of electrons around it **B1**

(b) shape is trigonal planar **B1**

(b) bond angle is 120 degrees, since the three bonding pairs repel equally and spread out as far apart as possible oe **B1**

(b) Answer: Trigonal planar, bond angle 120 degrees.

(c) shape is trigonal pyramidal **B1**

(c) bond angle is 107 degrees **B1**

(c) the lone pair on nitrogen repels the three bonding pairs more strongly than a bonding pair repels another bonding pair, pushing the N-H bonds closer together and reducing the angle from 109.5 to 107 degrees oe **B1**

(c) Answer: Trigonal pyramidal, bond angle 107 degrees; the extra repulsion from the lone pair compresses the angle below the tetrahedral 109.5 degrees.

(d) shape is non-linear/bent (V-shaped) **B1**

(d) bond angle is 104.5 degrees **B1**

(d) two lone pairs on oxygen cause even greater repulsion than one lone pair, pushing the two O-H bonding pairs even closer together, reducing the angle further than in NH_3 (107 to 104.5 degrees) oe **B1**

(d) Answer: Non-linear (bent), bond angle 104.5 degrees; two lone pairs cause greater repulsion than one, compressing the angle further than in NH_3.

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Question 3

(a) a giant covalent (macromolecular) structure/lattice oe **B1**

(a) each carbon atom is covalently bonded to four other carbon atoms in a tetrahedral arrangement, extending throughout the whole structure oe **B1**

(a) Answer: A giant covalent lattice in which each carbon atom is bonded to four others tetrahedrally, throughout the whole structure.

(b) diamond has a giant covalent structure containing many strong covalent bonds extending throughout the lattice oe **B1**

(b) a very large amount of energy is needed to break these many strong covalent bonds, giving a very high melting point oe **B1**

(b) Answer: Diamond's giant covalent lattice has many strong covalent bonds; a very large amount of energy is needed to break them, giving a very high melting point.

(c) graphite consists of layers of carbon atoms, each covalently bonded to only three other carbon atoms, arranged in hexagonal rings oe **B1**

(c) there are strong covalent bonds within each layer, but only weak London (van der Waals) forces between layers oe **B1**

(c) each carbon atom in graphite has one delocalised electron (not used in bonding), which is free to move within a layer, allowing graphite to conduct electricity oe **B1**

(c) in diamond, all four outer electrons of every carbon atom are used in (localised) covalent bonds, so there are no delocalised electrons/free charge carriers, and diamond does not conduct oe **B1**

(c) Answer: Graphite has layers of carbon atoms each bonded to 3 others (hexagonal rings), with one delocalised electron per atom free to move within each layer, allowing conduction; diamond has all 4 outer electrons localised in covalent bonds, so it cannot conduct.

(d) the layers in graphite are held together only by weak London (van der Waals) forces oe **B1**

(d) these weak forces allow the layers to slide over one another easily (and flake off), reducing friction between surfaces oe **B1**

(d) Answer: Weak forces between graphite's layers let them slide over each other easily, reducing friction, so graphite acts as a lubricant.

(e) identifies a valid property, e.g. very high electrical conductivity (or extremely high strength/thinness/flexibility) oe **B1**

(e) links the property to its structure/usefulness, e.g. every delocalised electron is at the surface (none are "wasted" between internal layers as in graphite), giving very low resistance/fast electron movement, useful in very thin, flexible electronic components oe **B1**

(e) Answer: Graphene has very high electrical conductivity, since all its delocalised electrons are at the exposed single layer, useful for extremely thin, flexible conducting components.

Question 4

(a) 5 bonding pairs and 0 lone pairs around P **B1**

(a) trigonal bipyramidal **B1**

(a) bond angles of 90 degrees (axial to equatorial) and 120 degrees (equatorial to equatorial) **B1**

(a) Answer: 5 bonding pairs, 0 lone pairs; trigonal bipyramidal; 90 degrees and 120 degrees.

(b) octahedral **B1**

(b) 90 degrees **B1**

(b) Answer: Octahedral; 90 degrees.

(c) square planar **B1**

(c) 90 degrees **B1**

(c) Answer: Square planar; 90 degrees.

(d) bent (V-shaped, non-linear) **B1**

(d) bond angle of about 115 degrees, which is less than 120 degrees because a lone pair repels neighbouring electron pairs more strongly than a bonding pair does, compressing the O-N-O angle, oe **B1**

(d) Answer: Bent, approximately 115 degrees.

Question 5

Level 3 A full and coherent explanation addressing both patterns: correctly identifies that the Group 14 hydrides are non-polar, symmetrical (tetrahedral) molecules held together only by London (dispersion) forces, and correctly explains that these forces strengthen down the group as the number of electrons (and Mr) increases; and correctly identifies that H_2O (unlike H_2S, H_2Se, H_2Te) can form hydrogen bonds, because its H atoms are bonded directly to the small, highly electronegative O atom which has lone pairs available, and explains that hydrogen bonds are much stronger than the London and permanent dipole-dipole forces present in the other Group 16 hydrides, requiring significantly more energy to overcome and giving H_2O an anomalously high boiling point. **5-6**

Level 2 The explanation addresses most of the required chemistry for both patterns but is incomplete in at least one respect (for example, does not fully explain why H_2O can hydrogen bond and H_2S cannot, or omits reference to the number of electrons/Mr in the Group 14 trend), or contains minor inaccuracies; both the Group 14 trend and the Group 16 anomaly are attempted. **3-4**

Level 1 A basic or partial explanation with limited use of correct terminology; may address only one of the two patterns (for example, only explains the Group 14 trend, or only states "hydrogen bonding" without further detail linking it to boiling point). **1-2**

Level 0 No relevant chemistry, or the answer does not relate to the question. **0**

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Indicative content:

- The Group 14 hydrides (CH_4, SiH_4, GeH_4, SnH_4) are non-polar, symmetrical, tetrahedral molecules with no permanent dipole, so the only intermolecular force present between them is London (dispersion) forces.
- The number of electrons (and Mr) increases down Group 14 from CH_4 to SnH_4.
- A greater number of electrons gives a larger electron cloud, allowing larger instantaneous and induced dipoles to form, so the strength of the London forces increases down the group.
- Stronger London forces require more energy to overcome, so the boiling point of the Group 14 hydrides increases steadily down the group.
- The Group 16 hydrides H_2S, H_2Se and H_2Te also show an increasing boiling point down the group, for the same reason (increasing number of electrons strengthens London forces); these three are also weakly polar, adding weak permanent dipole-dipole forces.
- H_2O is different because its hydrogen atoms are bonded directly to oxygen, which is small and highly electronegative and has two lone pairs, satisfying the conditions needed for hydrogen bonding.
- Hydrogen bonds are much stronger than permanent dipole-dipole forces and London forces.
- Significantly more energy is needed to overcome the additional hydrogen bonding between H_2O molecules, giving H_2O a much higher boiling point than the trend (based on Mr/London forces alone) would predict.
- H_2S, H_2Se and H_2Te cannot form hydrogen bonds because S, Se and Te are larger and less electronegative than O, so their H-S, H-Se and H-Te bonds are not polar enough to meet the conditions for hydrogen bonding.

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