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IB DIPLOMA CHEMISTRY · FIRST ASSESSMENT 2025

Structure 2 Models of Bonding and Structure

Paper 1 Style Practice · Paper 1A and Paper 1B

Medium to hard exam-style questions on Structure 2.1 – 2.4, with full worked solutions

Standard Level & Higher Level

Timing and marks

Higher Level: answer every question. Section A: 32 marks; Section B: 27 marks. Total **59 marks**. Suggested time **about 90 minutes** (45 min for Section A, 45 min for Section B).

Standard Level: omit the questions marked HL. Section A: 26 marks; Section B: 22 marks. Total **48 marks**. Suggested time **about 80 minutes**.

These timings use the same rate as the real examination (SL Paper 1: 55 marks in 1 h 30; HL Paper 1: 75 marks in 2 h).

Inside this booklet

1. Section A — Paper 1A style: multiple-choice questions
2. Section B — Paper 1B style: data-based questions on experimental work
3. Answer key and worked solutions — Section A
4. Markscheme and worked solutions — Section B

Instructions

- Work under examination conditions: set a timer, and do not look at the solutions until you have finished.
- You need a **calculator** and a copy of the **IB Chemistry data booklet** (first assessment 2025). Electronegativity values are in Section 9 and the bonding triangle in Section 17.
- **Section A:** each question has one correct answer and is worth 1 mark. No marks are deducted for wrong answers, so answer every question. Record your answers in the grid at the end of Section A.
- **Section B:** write your answers in the spaces provided. Show your working in calculations. The marks for each part are shown in brackets.
- Questions tagged HL test Additional Higher Level material and are for HL students only.

Section A — Paper 1A style (multiple choice)

1. Which compound contains the greatest total number of atoms in one formula unit?

   A $(NH_4)_2SO_4$ B $Ca_3(PO_4)_2$

   C $Al_2(SO_4)_3$ D $Fe(NO_3)_3$

2. Which ion has the smallest radius?

   A F^- B Na^+

   C Mg^{2+} D Al^{3+}

3. Which statement best describes the bonding in solid ammonium sulfate, $(NH_4)_2SO_4$?

   A ionic bonding only

   B covalent bonding only

   C ionic bonding between NH_4^+ and SO_4^{2-} ions, and covalent bonding within each ion

   D covalent bonding between NH_4^+ and SO_4^{2-} ions, and ionic bonding within each ion

4. Which shows the compounds in order of **increasing** lattice enthalpy?

   A KBr < NaCl < CaO < MgO

   B NaCl < KBr < MgO < CaO

   C KBr < NaCl < MgO < CaO

   D NaCl < KBr < CaO < MgO

5. Which properties are typical of ionic compounds?

   I. high melting point II. conduct electricity when molten III. conduct electricity when solid

   A I and II only B I and III only

   C II and III only D I, II and III

6. How many non-bonding (lone) pairs of electrons are there in total in the Lewis formula of carbonyl chloride, $COCl_2$, in which carbon is the central atom?

   A 6 B 7

   C 8 D 9

7. Which species contain a coordination (dative covalent) bond?

I. H_3O^+ II. CO III. NH_3

A I only
B I and II only
C II and III only
D I, II and III

8. Which lists the species in order of **increasing** carbon–oxygen bond length?

A $CO < CO_2 < CH_3OH$
B $CO_2 < CO < CH_3OH$
C $CH_3OH < CO_2 < CO$
D $CO < CH_3OH < CO_2$

9. Which pair of species have the same molecular geometry?

A NH_3 and BF_3
B CO_2 and SO_2
C H_2O and NH_2^-
D PCl_3 and BCl_3

10. Which species has the smallest H–X–H bond angle, where X is the central atom?

A H_3O^+
B NH_4^+
C NH_2^-
D CH_4

11. Which molecules are polar?

I. SO_2 II. CS_2 III. $CHCl_3$

A I and II only
B I and III only
C II and III only
D I, II and III

12. Which lists the bonds in order of **increasing** polarity?

A C–H < C–Cl < O–H < H–F
B C–Cl < C–H < H–F < O–H
C C–H < O–H < C–Cl < H–F
D H–F < O–H < C–Cl < C–H

13. Which statement about the structure of silicon dioxide, SiO_2, is correct?

A Each silicon atom is covalently bonded to two oxygen atoms.
B Each oxygen atom is covalently bonded to four silicon atoms.
C Each silicon atom is covalently bonded to four oxygen atoms.
D SiO_2 molecules are held together by London (dispersion) forces.

14. Which property do diamond and graphite have in common?

A good electrical conductivity
B very high melting point
C every carbon atom forms four σ bonds
D soft and slippery

15. Why does buckminsterfullerene, C_{60}, have a much lower melting point than graphite?

A The covalent bonds in C_{60} are weaker than those in graphite.

B C_{60} molecules are held together only by London (dispersion) forces.

C Graphite contains delocalized electrons and C_{60} does not.

D Each carbon atom in C_{60} is bonded to fewer atoms than in graphite.

16. Which compound forms hydrogen bonds between its own molecules?

A CH_3OCH_3

B CH_3CHO

C CH_3F

D CH_3NH_2

17. Which lists the compounds in order of **increasing** boiling point?

A $CH_3CH_2CH_3 < CH_3CHO < CH_3CH_2OH < CH_3COOH$

B $CH_3CHO < CH_3CH_2CH_3 < CH_3CH_2OH < CH_3COOH$

C $CH_3CH_2CH_3 < CH_3CHO < CH_3COOH < CH_3CH_2OH$

D $CH_3CH_2CH_3 < CH_3CH_2OH < CH_3CHO < CH_3COOH$

18. Which forces are overcome when liquid bromine, Br_2, boils?

A covalent bonds between bromine atoms

B London (dispersion) forces only

C London forces and dipole–dipole forces

D London forces and hydrogen bonds

19. Which compound is the most soluble in water?

A hexan-1-ol, $C_6H_{13}OH$

B propan-1-ol, C_3H_7OH

C hexane, C_6H_{14}

D 1-chloropropane, C_3H_7Cl

20. In a paper chromatogram, the origin line was drawn 1.5 cm above the bottom of the paper. The solvent front reached 10.5 cm above the bottom of the paper, and the centre of a spot was 5.1 cm above the bottom of the paper. What is the R_F value of the spot?

A 0.40

B 0.49

C 0.57

D 2.5

21. A mixture was separated by thin layer chromatography on a silica plate using a non-polar solvent. Which component would have the highest R_F value?

A benzoic acid, C_6H_5COOH

B phenol, C_6H_5OH

C methylbenzene, $C_6H_5CH_3$

D benzene-1,2-diol, $C_6H_4(OH)_2$

22. Which shows the metals in order of **increasing** strength of metallic bonding?

A K < Na < Mg < Al

B Na < K < Mg < Al

C Al < Mg < Na < K

D K < Na < Al < Mg

23. Which statement best explains why metals are malleable?

A Delocalized electrons can move through the lattice when a voltage is applied.

B Layers of cations can slide over each other while the non-directional metallic bonding is maintained.

C The cations repel each other strongly, so the lattice is easily distorted.

D Metallic bonds are weak, so they break easily when a force is applied.

24. Use Sections 9 and 17 of the data booklet. Which compound lies in the polar covalent region of the bonding triangle?

A KBr

B $AlBr_3$

C CaO

D Na_2S

25. Why is brass, an alloy of copper and zinc, harder than pure copper?

A Zinc and copper atoms form strong covalent bonds.

B Brass contains more delocalized electrons than copper.

C Atoms of different sizes disrupt the regular layers, so the layers cannot slide easily.

D Brass is a compound with a fixed composition and a giant ionic lattice.

26. The repeating unit of an addition polymer is $-CH_2-C(CH_3)_2-$. Which is the monomer?

A $CH_3CH=CHCH_3$

B $(CH_3)_2C=CH_2$

C $CH_3CH_2CH=CH_2$

D $CH_2=CHCH_3$

27. HL Which species has a square planar molecular geometry?

A SF_4

B XeF_4

C BrF_5

D PCl_5

28. HL The preferred Lewis formula of dinitrogen monoxide is N≡N–O, with a lone pair on the terminal nitrogen and three lone pairs on oxygen. What is the formal charge on the central nitrogen atom?

A −1

B 0

C +1

D +2

29. HL How many σ and π bonds are present in propenenitrile, $CH_2=CH-C\equiv N$?

A 6 σ and 3 π

B 5 σ and 3 π

C 6 σ and 2 π

D 9 σ and 3 π

30. HL What is the hybridization of the carboxyl carbon atom and of the oxygen atom of the –OH group in ethanoic acid, CH_3COOH?

	carboxyl carbon	oxygen of –OH
A	sp^2	sp^2
B	sp^2	sp^3
C	sp^3	sp^3
D	sp	sp^2

31. HL In which species are all the carbon–oxygen or nitrogen–oxygen bonds the same length because of delocalized electrons?

I. CO_3^{2-} II. NO_3^- III. CH_3COOH

A I and II only
B I and III only
C II and III only
D I, II and III

32. HL Which pair of compounds can react together to form a condensation polymer?

A $HOCH_2CH_2OH$ and $HOOC(CH_2)_4COOH$
B $CH_2{=}CH_2$ and $CH_2{=}CHCl$
C CH_3COOH and CH_3CH_2OH
D $H_2N(CH_2)_6NH_2$ and CH_3COOH

Answer grid — Section A

1		9		17		25	
2		10		18		26	
3		11		19		27	
4		12		20		28	
5		13		21		29	
6		14		22		30	
7		15		23		31	
8		16		24		32	

Questions 27–32 are HL only. Section A total: SL 26 marks, HL 32 marks.

Section B — Paper 1B style (data-based questions on experimental work)

Question 1 Identifying structure types from experimental data (7 marks)

A student tested five unknown substances, V to Z. Each was a different one of the structure types: ionic, metallic, covalent network, simple molecular (non-polar) and simple molecular (polar). The results are shown below.

Substance	Melting point / °C	Solubility in water	Conducts as a solid?	Conducts when molten?	Aqueous solution conducts?
V	−114	very soluble	no	no	yes
W	801	soluble	no	yes	yes
X	1083	insoluble	yes	yes	—
Y	1710	insoluble	no	no	—
Z	114	very slightly soluble; soluble in hexane	no	no	—

(a) Deduce the structure type of W, X, Y and Z. **[4]**

(b) V is a covalent substance, yet its aqueous solution conducts electricity. Suggest an explanation. **[2]**

(c) The student wrote: "W conducts when molten because its electrons become free to move." Correct this statement. **[1]**

Question 2 Boiling points of alcohols and alkanes (8 marks)

The boiling points of five straight-chain alcohols and five alkanes are given. Each alcohol is paired with an alkane of similar molar mass.

Alcohol	M / g mol^{-1}	Boiling point / °C	Alkane	M / g mol^{-1}	Boiling point / °C
methanol, CH_3OH	32	65	ethane, C_2H_6	30	−89
ethanol, C_2H_5OH	46	78	propane, C_3H_8	44	−42
propan-1-ol, C_3H_7OH	60	97	butane, C_4H_{10}	58	−1
butan-1-ol, C_4H_9OH	74	118	pentane, C_5H_{12}	72	36
pentan-1-ol, $C_5H_{11}OH$	88	138	hexane, C_6H_{14}	86	69

(a) Calculate the difference in boiling point between methanol and ethane, and between pentan-1-ol and hexane. **[1]**

(b) Explain why each alcohol has a much higher boiling point than the alkane of similar molar mass. **[2]**

(c) Suggest why the difference calculated in (a) becomes smaller as the carbon chain gets longer. **[2]**

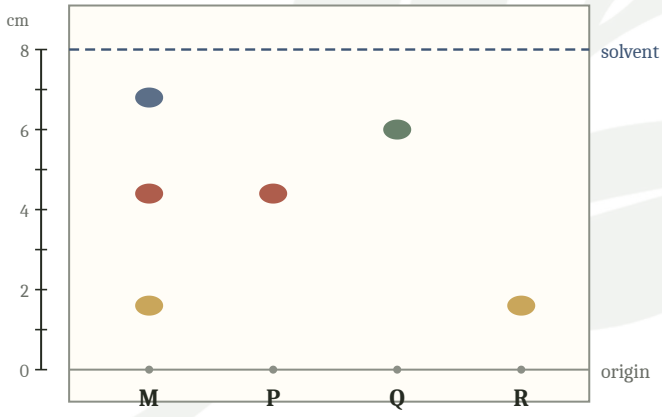
(d) Use the data to estimate the boiling point of hexan-1-ol, $C_6H_{13}OH$. **[1]**

(e) A student measured the boiling point of ethanol as 80.5 °C. Calculate the percentage error, and suggest one possible cause of a result higher than the literature value. **[2]**

Question 3 Thin layer chromatography (7 marks)

A mixture, M, was analysed by thin layer chromatography on a silica plate, using a mixture of hexane and ethyl ethanoate as the solvent. Three reference substances, P, Q and R, were run on the same plate. The chromatogram is shown, drawn to scale.

Distances from the origin: solvent front 8.0 cm; spots of M at 1.6 cm, 4.4 cm and 6.8 cm; P at 4.4 cm; Q at 6.0 cm; R at 1.6 cm.



(a) Calculate the R_F value of each of the three spots in M. **[2]**

(b) Identify which reference substances are present in M. **[1]**

(c) The spot at 6.8 cm does not match any reference. Deduce how its polarity compares with that of the other two components of M, and explain your answer with reference to the stationary phase. **[2]**

(d) Explain why the origin line is drawn in pencil, and why the plate is placed so that the origin is above the level of the solvent. **[2]**

HL Question 4 Bond lengths from X-ray crystallography (5 marks)

X-ray crystallography gives the following carbon–oxygen bond lengths.

Species	Carbon–oxygen bond lengths / pm
methanoic acid, HCOOH	120 and 134
sodium methanoate, $HCOO^-Na^+$	126 and 126

(a) Explain why the two carbon–oxygen bonds in the methanoate ion are the same length, whereas those in methanoic acid are different. **[2]**

(b) Explain why the bond length in the methanoate ion lies between the values of 120 pm and 134 pm. **[1]**

(c) Predict, with a reason, whether the carbon–oxygen bonds in the carbonate ion, CO_3^{2-}, are longer or shorter than those in the methanoate ion. **[2]**

Section B total: SL 22 marks (Questions 1–3); HL 27 marks.

End of questions

Answer key — Section A

Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	**C**	9	**C**	17	**A**	25	**C**
2	**D**	10	**C**	18	**B**	26	**B**
3	**C**	11	**B**	19	**B**	27	**B**
4	**A**	12	**A**	20	**A**	28	**C**
5	**A**	13	**C**	21	**C**	29	**A**
6	**C**	14	**B**	22	**A**	30	**B**
7	**B**	15	**B**	23	**B**	31	**A**
8	**A**	16	**D**	24	**B**	32	**A**

Worked solutions — Section A

1. **C.** Count atoms per formula unit: $(NH_4)_2SO_4 = 2 \times 5 + 5 = 15$; $Ca_3(PO_4)_2 = 3 + 2 \times 5 = 13$; $Al_2(SO_4)_3 = 2 + 3 \times 5 = 17$; $Fe(NO_3)_3 = 1 + 3 \times 4 = 13$. The subscript outside a bracket multiplies every atom inside it.

2. **D.** All four ions are isoelectronic (10 electrons, $1s^2\ 2s^2\ 2p^6$). Al^{3+} has the most protons (13), so the same electrons are pulled in most strongly.

3. **C.** The ammonium and sulfate ions are held together by ionic bonding (electrostatic attraction between oppositely charged ions); the atoms within each polyatomic ion are joined by covalent bonds.

4. **A.** Lattice enthalpy increases with ionic charge and decreases with ionic radius. The 2+/2− oxides are far larger than the 1+/1− halides. Within each pair, the smaller ions give the larger value: NaCl > KBr and MgO > CaO.

5. **A.** Ions are fixed in the lattice in the solid, so solid ionic compounds do not conduct.

6. **C.** Carbon forms one C=O and two C–Cl bonds and has no lone pairs. Oxygen has 2 lone pairs and each chlorine has 3: 2 + 3 + 3 = 8.

7. **B.** In H_3O^+, oxygen donates a lone pair to H^+. In CO, oxygen donates a lone pair to form the third bond of the triple bond. NH_3 has only ordinary covalent bonds; it *can* form a coordination bond (as in NH_4^+) but does not contain one.

8. **A.** Triple bond (CO) < double bonds (CO_2) < single bond (CH_3OH). More shared pairs give greater electron density between the nuclei, so a shorter bond.

9. **C.** H_2O and NH_2^- both have two bonding pairs and two lone pairs on the central atom: bent. NH_3 is trigonal pyramidal but BF_3 is triangular planar; CO_2 is linear but SO_2 is bent; PCl_3 has a lone pair (pyramidal) but BCl_3 does not (planar).

10. **C.** NH_2^- has two lone pairs (≈ 104.5°). H_3O^+ has one (≈ 107°); NH_4^+ and CH_4 have none (109.5°).

11. **B.** SO_2 is bent, so its bond dipoles do not cancel. $CHCl_3$ is tetrahedral but has different outer atoms, so the dipoles do not cancel. CS_2 is linear and symmetrical (and C and S both have $\chi = 2.6$), so it is non-polar.

12. **A.** $\Delta\chi$: C–H 0.4, C–Cl 0.6, O–H 1.2, H–F 1.8.

13. **C.** Each Si is bonded to four O atoms tetrahedrally and each O to two Si atoms, in a giant covalent network. There are no SiO_2 molecules.

14. **B.** Both are covalent networks, so melting means breaking many strong covalent bonds. Only graphite conducts and is soft; in graphite each carbon forms three σ bonds, not four.

15. **B.** C_{60} is a simple molecular substance: melting overcomes only weak London forces between molecules. Melting graphite requires breaking covalent bonds. Option D is true but does not explain the difference.

16. **D.** CH_3NH_2 has H bonded to N, and N has a lone pair. In CH_3OCH_3, CH_3CHO and CH_3F, every H is bonded to carbon.

17. **A.** The molar masses are similar (44–60). Propane has London forces only; ethanal adds dipole–dipole forces; ethanol hydrogen bonds; ethanoic acid hydrogen bonds more extensively (it forms hydrogen-bonded dimers) and has the largest molar mass, so it boils highest (118 °C).

18. **B.** Br_2 is non-polar. Boiling separates molecules; it does not break the Br–Br covalent bond.

19. **B.** Propan-1-ol hydrogen bonds with water and has a short non-polar chain. Hexan-1-ol has a long non-polar chain; hexane and 1-chloropropane cannot hydrogen bond with water.

20. **A.** Measure from the origin: spot = 5.1 − 1.5 = 3.6 cm; solvent = 10.5 − 1.5 = 9.0 cm; R_F = 3.6 / 9.0 = 0.40. (B uses distances from the bottom of the paper; D is inverted.)

21. **C.** Silica is polar. The least polar component, methylbenzene, which cannot hydrogen bond, is held least by the stationary phase and travels furthest with the non-polar solvent.

22. **A.** Down group 1 the cation radius increases (K weaker than Na). Across period 3 the cation charge and the number of delocalized electrons increase and the radius decreases (Na < Mg < Al).

23. **B.** A describes conductivity; D is false, because metallic bonding is strong.

24. **B.** $AlBr_3$: $\Sigma\chi = (1.6 + 3.0)/2 = 2.3$, $\Delta\chi = 1.4$ — polar covalent. KBr (1.9, 2.2), CaO (2.2, 2.4) and Na_2S (1.75, 1.7) all lie in the ionic region.

25. **C.** Brass is a mixture held together by metallic bonding; it has no fixed formula.

26. **B.** Restore a double bond between the two main-chain carbons: $CH_2{=}C(CH_3)_2$, methylpropene. A would give –$CH(CH_3)$–$CH(CH_3)$–.

27. **B.** XeF_4: 4 bonds + 2 lone pairs, octahedral domains with the lone pairs opposite: square planar. SF_4 is see-saw; BrF_5 is square pyramidal; PCl_5 is triangular bipyramidal.

28. **C.** Central N: V = 5, four bonds (½B = 4), no lone pairs: FC = 5 − (4 + 0) = +1. (Terminal N: 0; O: −1; sum 0.)

29. **A.** σ: three C–H, one in C=C, one C–C, one in C≡N = 6. π: one in C=C, two in C≡N = 3.

30. **B.** The carboxyl carbon has three electron domains (C–C, C=O, C–O): sp^2. The –OH oxygen has two bonds and two lone pairs, so four domains: sp^3.

31. **A.** Carbonate and nitrate each have three equivalent resonance structures, so all their bonds are identical. In CH_3COOH the two oxygen atoms are not equivalent (one carries H), so there is one C=O and one longer C–O bond.

32. **A.** Each monomer has two functional groups, and –OH reacts with –COOH to form ester links with loss of water. B gives an addition polymer; C and D contain a monomer with only one functional group, so they form a single ester or amide, not a chain.

Markscheme — Section B

Question 1 (7 marks)

(a) W ionic **[1]**; X metallic **[1]**; Y covalent network **[1]**; Z simple molecular, non-polar **[1]**.

Reasoning: W conducts only when molten or dissolved (mobile ions), and has a high melting point. X conducts as a solid and as a liquid (delocalized electrons). Y has a very high melting point and never conducts. Z has a low melting point and dissolves in a non-polar solvent (it behaves like iodine).

(b) V consists of polar molecules (it is the simple molecular, polar substance) **[1]**; in water it ionizes, forming mobile ions that carry charge (as HCl forms $H^+(aq)$ and $Cl^-(aq)$) **[1]**.

(c) W conducts when molten because its **ions** become free to move; there are no delocalized electrons in an ionic compound **[1]**.

Question 2 (8 marks)

(a) Methanol − ethane: 65 − (−89) = 154 °C; pentan-1-ol − hexane: 138 − 69 = 69 °C. Both values are needed **[1]**.

(b) Alcohol molecules form hydrogen bonds between them, because H is bonded to the highly electronegative O, which has lone pairs **[1]**. Alkanes have only London forces; hydrogen bonds are stronger, so more energy is needed to separate alcohol molecules **[1]**.

(c) Each alcohol has only one –OH group, so the contribution from hydrogen bonding stays roughly constant **[1]**; London forces increase with chain length (more electrons), so hydrogen bonding makes up a smaller proportion of the total intermolecular attraction **[1]**.

(d) Successive increases are 13, 19, 21, 20 °C, so add about 20 °C: **≈ 158 °C** (accept 154–162 °C) **[1]**. (Literature value: 157 °C.)

(e) % error = (80.5 − 78) / 78 × 100 = **3.2%** **[1]**. Any one cause: impurities in the sample raise the boiling point; the thermometer bulb was in the liquid rather than in the vapour; the thermometer was inaccurately calibrated; the atmospheric pressure was above standard **[1]**.

Question 3 (7 marks)

(a) 1.6 / 8.0 = **0.20**; 4.4 / 8.0 = **0.55**; 6.8 / 8.0 = **0.85**. Award [2] for all three correct; [1] for two correct.

(b) P and R (their R_F values of 0.55 and 0.20 match spots in M) **[1]**.

(c) It is the least polar component of M **[1]**. It is attracted least strongly to the polar silica stationary phase (for example, it cannot hydrogen bond with the –OH groups on the silica), so it spends more time in the mobile phase and travels furthest **[1]**.

(d) Pencil (graphite) does not dissolve in the solvent and run, whereas ink would **[1]**; if the origin were below the solvent level, the sample would dissolve into the solvent in the tank instead of moving up the plate **[1]**.

HL Question 4 (5 marks)

(a) The methanoate ion has two equivalent resonance structures, with the double bond to either oxygen **[1]**; the π electrons are delocalized over both C–O bonds, so the bonds are identical. In methanoic acid the two oxygens are not equivalent (one carries H), so there is a localized C=O and a C–O single bond **[1]**.

(b) Each bond in the methanoate ion is a hybrid of a single and a double bond (bond order 1.5), so its length is intermediate **[1]**.

(c) Longer **[1]**. In carbonate one π bond is delocalized over three C–O bonds (bond order about 1⅓), compared with two bonds in methanoate (1½), so there is less electron density in each bond **[1]**. (Experimental value about 129 pm.)

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