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IB DIPLOMA CHEMISTRY · FIRST ASSESSMENT 2025

Structure 3
Paper 2 Practice

Short-answer and extended-response questions · Structure 3.1 and 3.2

Five structured questions that link the periodic table, oxidation states and transition elements to the formulas, names, isomers and spectra of organic compounds

Exam practice with a full exam-style markscheme · Standard Level & Higher Level

How the level tags work in this paper

SL + HL **Questions for every student.** Questions 1–4 (except part 2(e)) test the common core: 3.1.1–3.1.6 and 3.2.1–3.2.6.

HL **Higher level only.** Part 2(e) (transition elements and colour) and the whole of Question 5 (MS, IR, ^{1}H NMR and enantiomers) test the additional higher level material. SL students leave these out.

Questions	5 structured questions; HL-only: part 2(e) and Question 5
Marks and time	SL 44 marks, about 80 minutes · HL 58 marks, about 95 minutes
Allowed	Calculator and the IB Chemistry data booklet

Inside this paper

1. How to use this paper
2. Q1 Periodicity: selenium and its neighbours
3. Q2 Groups 1 and 17, oxides and oxidation states
4. Q3 The carboxylic acids
5. Q4 Naming compounds and structural isomers
6. Q5 Identifying an unknown compound (HL)
7. Markscheme

1 How to use this paper

This paper tests the whole of **Structure 3 — Classification of matter**, Structure 3.1 (the periodic table) and Structure 3.2 (functional groups and organic compounds), in the style of **Paper 2** of the IB Diploma Chemistry course (first assessment 2025): short-answer and extended-response questions, with parts that draw on more than one understanding.

Question	Topic	Standard Level	Higher Level
1	Periodicity: selenium and its neighbours (3.1.1–3.1.3)	10	10
2	Groups 1 and 17, oxides and oxidation states (3.1.4–3.1.6)	11	11
	part (e): transition elements and colour (3.1.8–3.1.10) HL	—	3
3	The carboxylic acids (3.2.1–3.2.4)	11	11
4	Naming compounds and structural isomers (3.2.5–3.2.6)	12	12
5	Identifying an unknown compound (3.2.7–3.2.12) HL	—	11
Total		**44 marks · about 80 minutes**	**58 marks · about 95 minutes**

- **Timing.** The real Paper 2 runs at about 1.7–1.8 minutes per mark (SL: 50 marks in 1 hour 30 minutes; HL: 90 marks in 2 hours 30 minutes), and this paper is set at the same pace.
- Write your answers in the spaces provided. The number of lines is a guide to the length of answer expected; the mark in brackets tells you how many separate points the examiner is looking for.
- A **calculator** and a clean copy of the **IB Chemistry data booklet** are allowed. Mark your work with the markscheme at the end: each √ is one mark.

Command terms: what each one asks for

Command term	What earns the marks
State	A specific name, value or other brief answer, with no explanation.
Explain	A detailed account including the reasons or causes. Usually at least two marks: the observation, then the cause.
Deduce	Reach a conclusion from the information given, and show the link.
Determine / Calculate	Find the answer, showing the working. Give units and sensible significant figures.
Draw	A structure or diagram drawn accurately, with every bond and atom where the question requires it.

Three habits that separate a 6 from a 7 on Paper 2

- **One mark, one idea.** A three-mark 'explain' needs three separate creditworthy statements. Plan them before you write.
- **Name the particle.** 'The outer electron is further from the nucleus' scores; 'it is bigger' does not. Say which electron, which forces, which molecules.
- **Use the data you are given.** Quote the boiling point, the chemical shift, the wavenumber or the *m/z* value in your answer. Examiners reward the link between data and structure.

2 Questions

Question 1 Periodicity: selenium and its neighbours

Total 10 marks

Selenium, Se ($Z = 34$), is in the same group as oxygen and sulfur. Some data for these elements are given below.

	O	S	Se
First ionization energy / kJ mol^{-1}	1314	1000	941
Atomic radius / pm	66	103	120
Radius of X^{2-} ion / pm	140	184	198
Electronegativity	3.4	2.6	2.6

(a) (i) State the full electron configuration of a selenium atom. **[1]**

(ii) Explain how this electron configuration shows that selenium is in period 4 and group 16. **[1]**

(b) Explain why the first ionization energy decreases from sulfur to selenium. **[2]**

(c) Explain why the radius of the Se^{2-} ion is much larger than that of the Se atom. **[2]**

(d) The first electron affinity of selenium is −195 kJ mol^{-1}. Its second electron affinity is positive. Explain why the second electron affinity is positive. **[2]**

(e) (i) Define electronegativity. **[1]**

(ii) Suggest why the electronegativity of oxygen is much greater than that of sulfur. **[1]**

Question 2 Groups 1 and 17, oxides and oxidation states

Total 11 (SL) / 14 (HL) marks

(a) Rubidium reacts vigorously with cold water.

(i) Write an equation, with state symbols, for this reaction. **[1]**

(ii) Explain why rubidium reacts more vigorously with water than sodium does. **[2]**

(b) Household bleach is made by passing chlorine into cold aqueous sodium hydroxide:

$$Cl_2(g) + 2NaOH(aq) \rightarrow NaCl(aq) + NaClO(aq) + H_2O(l)$$

(i) Deduce the oxidation state of chlorine in Cl_2, NaCl and NaClO. **[1]**

(ii) Explain why this reaction is described as a disproportionation. **[1]**

(iii) Name NaClO using its oxidation number. **[1]**

(c) (i) Write an equation for the reaction of sulfur trioxide with water. **[1]**

(ii) Sodium oxide dissolves in water to form an alkaline solution, but sulfur trioxide forms an acidic solution. Explain this difference in terms of the bonding in the two oxides. **[2]**

(d) Outline, using equations, how increasing levels of carbon dioxide in the atmosphere lower the pH of the oceans. **[2]**

(e) Solutions containing $[Co(H_2O)_6]^{2+}$ ions are pink. They absorb light most strongly at 515 nm. HL

(i) State the electron configuration of the Co^{2+} ion. **[1]**

(ii) Calculate the energy, in J, of one photon of light of wavelength 515 nm. Use the data booklet. **[2]**

Question 3 The carboxylic acids

Total 11 marks

The carboxylic acids form a homologous series. The boiling points of the first four members are shown.

Acid	methanoic acid	ethanoic acid	propanoic acid	butanoic acid
Boiling point / °C	101	118	141	164

(a) For butanoic acid, draw:

(i) the full structural formula **[1]**

(ii) the skeletal formula. **[1]**

(iii) State the empirical formula of butanoic acid. **[1]**

(b) (i) State two features of a homologous series. **[2]**

(ii) State the general formula of the carboxylic acids. **[1]**

(c) Explain the trend in boiling point shown in the table. **[2]**

(d) Methyl methanoate, $HCOOCH_3$, is a structural isomer of ethanoic acid. Its boiling point is 32 °C.

(i) State the name of the functional group in methyl methanoate. **[1]**

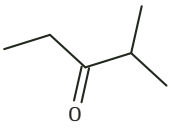
(ii) Explain why the boiling point of methyl methanoate is much lower than that of ethanoic acid. **[2]**

Question 4 Naming compounds and structural isomers

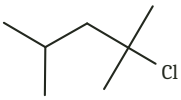
Total 12 marks

(a) State the IUPAC names of compounds **A**, **B** and **C**. **[3]**

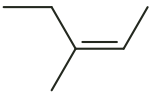
A



B



C



(b) Draw the skeletal formulas of: (i) 2,3-dimethylbutanal; (ii) 3-methylbutanoic acid. **[2]**

(i)

(ii)

(c) A student named the compound $CH_3CH{=}C(CH_3)CH_3$ as '3-methylbut-2-ene'. Explain why this name is incorrect, and state the correct name. **[2]**

(d) There are seven structural isomers with the molecular formula $C_4H_{10}O$: four alcohols and three ethers.

(i) Draw the structure of the isomer that is a tertiary alcohol, and state its IUPAC name. **[2]**

(ii) State the type of structural isomerism shown by butan-1-ol and butan-2-ol. **[1]**

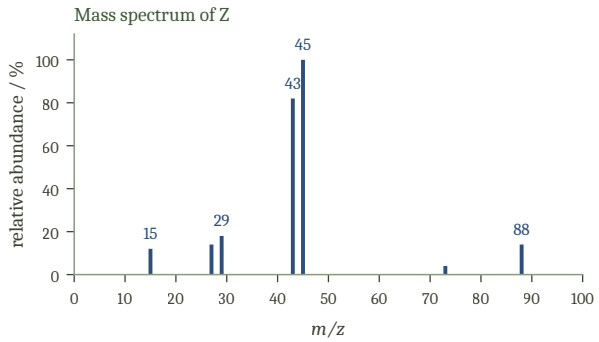
(iii) Ethoxyethane, $C_2H_5OC_2H_5$, is also an isomer of butan-1-ol. State the name of the functional group in ethoxyethane. **[1]**

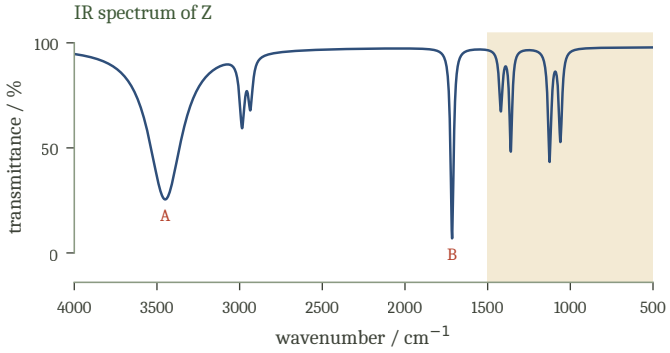
(iv) Classify butan-2-ol and 2-methylpropan-1-ol as primary, secondary or tertiary alcohols. **[1]**

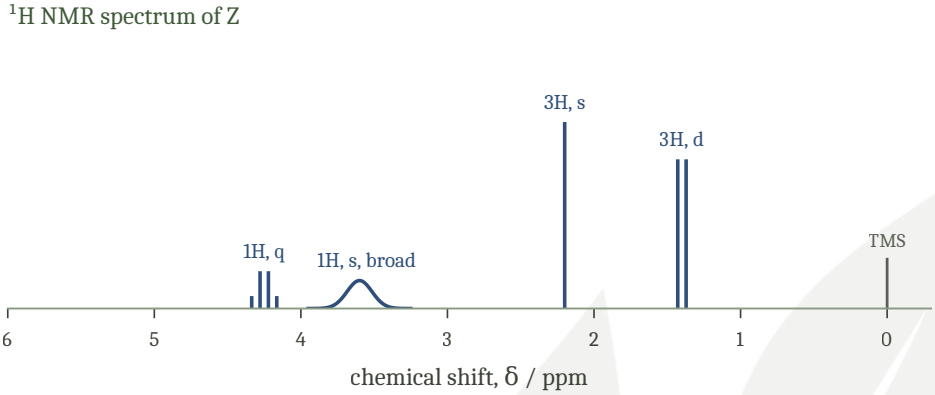
Question 5 Identifying an unknown compound HL

Total 11 marks

Compound **Z**, $C_4H_8O_2$, is a flavour compound found in butter. Its mass spectrum, infrared spectrum and ^{1}H NMR spectrum are shown. Use sections 20–22 of the data booklet.







(a) Identify the ions responsible for the peaks at $m/z = 43$ and $m/z = 45$. **[2]**

(b) Identify the bonds responsible for absorptions **A** and **B**, and explain how the spectrum shows that Z is **not** a carboxylic acid. **[2]**

(c) (i) State the number of different hydrogen environments in Z and the ratio of hydrogen atoms in them. **[1]**

(ii) Explain the splitting of the signals at $\delta = 4.25$ ppm and $\delta = 1.4$ ppm. **[2]**

(d) Deduce the structural formula of Z. **[1]**

(e) Z exists as two enantiomers. Draw three-dimensional formulas of both enantiomers. **[2]**

(f) State how a sample of one enantiomer could be distinguished from a sample of the other. **[1]**

END OF PAPER

3 Markscheme

Award one mark for each point marked √, up to the maximum for the part. Accept answers that are correct but expressed differently; **ECF** means error carried forward from an earlier part. Words in brackets are not needed for the mark; a slash (/) separates alternative acceptable answers; **OWTTE** means 'or words to that effect'.

Question 1 Periodicity: selenium and its neighbours (10 marks)

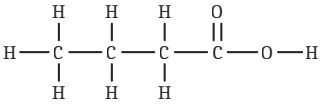
Part	Answer (one √ per mark)	Mk	Notes for markers
(a)(i)	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^4$ √	**1**	Accept $4s^2$ before $3d^{10}$. Do not accept [Ar] shorthand: 'full' is asked.
(a)(ii)	The highest occupied energy level is n = 4 (period 4) and there are 6 valence electrons, $4s^2\ 4p^4$ (group 10 + 6 = 16) √	**1**	Both points needed.
(b)	The outer electron of Se is in a higher energy level / further from the nucleus √ It is more shielded by inner electrons, which outweighs the increase in nuclear charge, so it is attracted less strongly √	**2**	Do not accept 'more shells' without reference to distance or shielding for M1.
(c)	Se^{2-} has two more electrons but the same nuclear charge (34 protons) √ Greater repulsion between the electrons / each electron is attracted less strongly, so the electron cloud expands √	**2**	Do not accept 'an extra shell is added'.
(d)	The electron is added to a negative ion, Se^- √ Energy is needed to overcome the repulsion between the ion and the incoming electron, so the process is endothermic √	**2**	
(e)(i)	The ability of an atom to attract a shared pair of electrons in a covalent bond √	**1**	Do not accept 'attract an electron' (that is electron affinity).
(e)(ii)	Oxygen atoms are much smaller, so the bonding pair is closer to the nucleus and less shielded (similar effective nuclear charge) √	**1**	Accept 'fewer occupied energy levels'.

Question 2 Groups 1 and 17, oxides and oxidation states (11 marks; HL 14)

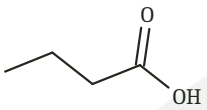
Part	Answer (one √ per mark)	Mk	Notes for markers
(a)(i)	$2Rb(s) + 2H_2O(l) \rightarrow 2RbOH(aq) + H_2(g)$ √	**1**	Balanced equation and correct state symbols.
(a)(ii)	The outer (5s) electron of Rb is further from the nucleus / more shielded than the outer (3s) electron of Na √ So it is attracted less strongly / Rb has a lower ionization energy, so it is lost more easily √	**2**	Do not accept 'Rb is bigger' alone for M1.
(b)(i)	0 in Cl_2, −1 in NaCl, +1 in NaClO √	**1**	All three needed. Signs required.
(b)(ii)	Chlorine is both oxidized (0 to +1) and reduced (0 to −1) in the same reaction √	**1**	ECF from (i).
(b)(iii)	Sodium chlorate(I) √	**1**	Accept 'sodium hypochlorite' as a common name only if 'chlorate(I)' is also given.
(c)(i)	$SO_3 + H_2O \rightarrow H_2SO_4$ √	**1**	

Part	Answer (one ✓ per mark)	Mk	Notes for markers
(c)(ii)	Na_2O is ionic; its oxide ions react with water to form hydroxide ions: $O^{2-} + H_2O \rightarrow 2OH^-$ ✓ SO_3 is covalent (molecular); it reacts with water to form an acid that releases H^+ ions ✓	2	Both bonding types needed across the two marks.
(d)	CO_2 dissolves in sea water and reacts: $CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$ ✓ Carbonic acid dissociates (partially): $H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$, so $[H^+]$ increases and the pH falls ✓	2	Accept the combined equation $CO_2 + H_2O \rightleftharpoons H^+ + HCO_3^-$ for M1 with the idea of increased $[H^+]$ for M2.
(e)(i) HL	[Ar] $3d^7$ / $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,3d^7$ ✓	1	Do not accept [Ar] $3d^5\,4s^2$.
(e)(ii) HL	$E = hc/\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^8) / (515 \times 10^{-9})$ ✓ $= 3.86 \times 10^{-19}$ J ✓	2	Award [1] for an answer out by a power of 10 (nm not converted). Or $f = c/\lambda = 5.83 \times 10^{14}\ s^{-1}$, then $E = hf$.

Question 3 The carboxylic acids (11 marks)



(a)(i) full structural formula

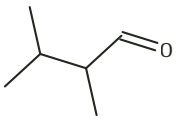


(a)(ii) skeletal formula

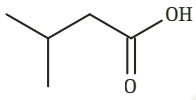
Part	Answer (one ✓ per mark)	Mk	Notes for markers
(a)(i)	Full structural formula with every atom and bond shown, including the O–H bond ✓	1	See the drawing. Do not accept –COOH or –OH condensed.
(a)(ii)	Skeletal formula: a zigzag of three lines with =O and –OH (or OH) on the end carbon ✓	1	Must show four carbons in total; C and H on the chain not shown.
(a)(iii)	C_2H_4O ✓	1	From $C_4H_8O_2$.
(b)(i)	Any two of: same general formula ✓; successive members differ by CH_2 ✓; similar chemical properties (same functional group) ✓; gradual change (trend) in physical properties ✓	2	
(b)(ii)	$C_nH_{2n}O_2$ / $C_nH_{2n+1}COOH$ ✓	1	Accept $C_nH_{2n+1}COOH$ with $n \geq 0$.
(c)	Boiling point increases as the chain length increases / by about 20 °C per CH_2 ✓ More electrons / larger surface area give stronger London (dispersion) forces, so more energy is needed to separate the molecules ✓	2	Do not award M2 for 'stronger hydrogen bonds'.
(d)(i)	Ester ✓	1	Do not accept 'ether' or 'carboxyl'.
(d)(ii)	Ethanoic acid molecules form hydrogen bonds between them (via the O–H group) ✓ Methyl methanoate has no O–H, so only (weaker) dipole–dipole and London forces act between its molecules ✓	2	Comparison required. Do not accept 'breaking O–H bonds'.

Question 4 Naming compounds and structural isomers (12 marks)

Part	Answer (one ✓ per mark)	Mk	Notes for markers
(a)	A: 2-methylpentan-3-one ✓ B: 2-chloro-2,4-dimethylpentane ✓ C: 3-methylpent-2-ene ✓	3	B: the locant set {2,2,4} beats {2,4,4}. Do not accept 4-chloro-2,4-dimethylpentane. Accept hyphens and commas used loosely.
(b)	(i) CC(C)C(C)C=O drawn as a skeletal formula ✓ (ii) CC(C)CC(=O)O drawn as a skeletal formula ✓	2	See the drawings below. The aldehyde H may be shown or omitted.
(c)	The chain must be numbered to give the lowest locants; both ends give the double bond the locant 2, so the branch takes the lower number, 2 (not 3) ✓ 2-methylbut-2-ene ✓	2	OWTTE.
(d)(i)	Correct structure of $(CH_3)_3C–OH$ drawn ✓ 2-methylpropan-2-ol ✓	2	Accept any clear structural or skeletal formula.
(d)(ii)	Position (positional) isomerism ✓	1	
(d)(iii)	Alkoxy / ether ✓	1	
(d)(iv)	Butan-2-ol: secondary; 2-methylpropan-1-ol: primary ✓	1	Both needed.



4(b)(i) 2,3-dimethylbutanal



4(b)(ii) 3-methylbutanoic acid

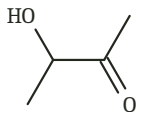


4(d)(i) 2-methylpropan-2-ol

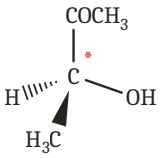
Question 5 Identifying an unknown compound (11 marks) HL

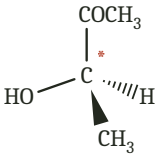
Part	Answer (one ✓ per mark)	Mk	Notes for markers
(a)	43: CH_3CO^+ ✓ 45: $CH_3CH(OH)^+$ / $C_2H_5O^+$ ✓	2	Positive charge needed on each ion (penalize once only). Accept $C_3H_7^+$ for 43 only with no ECF to (d).
(b)	A: O–H (in an alcohol, hydrogen bonded) and B: C=O ✓ No very broad absorption at 2500–3000 cm^{-1} (acid O–H); the O–H band is at 3200–3600 cm^{-1}, the alcohol range ✓	2	Both bonds needed for M1.
(c)(i)	Four environments in the ratio 1 : 1 : 3 : 3 ✓	1	Any order of the ratio.
(c)(ii)	4.25 ppm, quartet: this H has three H on the adjacent carbon (a CH_3), n + 1 = 4 ✓ 1.4 ppm, doublet: this CH_3 has one H on the adjacent carbon (a CH), n + 1 = 2 ✓	2	Award [1] max for 'n + 1 rule' with no reference to the neighbouring hydrogens.
(d)	$CH_3COCH(OH)CH_3$, 3-hydroxybutan-2-one ✓	1	Must be consistent with all the data: CH_3CO singlet at 2.2 (2.2–2.7, no H on the neighbouring C=O carbon); CH–O quartet at 4.25; OH singlet at 3.6; $M^+ = 88$.
(e)	Two tetrahedral 3D structures with H, OH, CH_3 and $COCH_3$ around the chiral carbon, using wedge and dash bonds ✓ Drawn as non-superimposable mirror images ✓	2	ECF from (d) if the structure in (d) has a chiral carbon. See the drawings below.

Part	Answer (one √ per mark)	Mk	Notes for markers
(f)	Pass plane-polarized light through each sample (a polarimeter): the enantiomers rotate the plane by the same angle in opposite directions √	1	Do not accept 'different boiling points'.



5(d) Z, 3-hydroxybutan-2-one





5(e) the two enantiomers (mirror images)

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