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IB DIPLOMA CHEMISTRY · FIRST ASSESSMENT 2025

Structure 3
Paper 1 Practice

Paper 1A (multiple choice) and Paper 1B (data-based) · Structure 3.1 and 3.2

A full exam-style workout on classification of matter: the periodic table and its trends, and the functional groups, names, isomers and spectra of organic compounds

Exam practice with a full answer key, worked reasons and markscheme · Standard Level & Higher Level

How the level tags work in this paper

SL + HL **Questions for every student.** Section A questions 1–24 and Section B questions B1–B3 test the common core: 3.1.1–3.1.6 and 3.2.1–3.2.6.

HL **Higher level only.** Section A questions 25–32 and Section B question B4 test the additional higher level material: 3.1.7–3.1.10 (ionization energy dips, transition elements and colour) and 3.2.7–3.2.12 (stereoisomers, MS, IR and ^{1}H NMR). SL students leave these out.

Section A	32 multiple-choice questions, 1 mark each (HL-only: 25–32)
Section B	4 data-based questions on experimental work (HL-only: B4)
Marks and time	SL 46 marks, about 75 minutes · HL 60 marks, about 95 minutes
Allowed	Calculator and the IB Chemistry data booklet

Inside this paper

1. How to use this paper
2. Section A — multiple choice
3. Section B — data-based questions
4. Answer key
5. Worked reasons for every option
6. Section B 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). It follows the format of **Paper 1** of the IB Diploma Chemistry course (first assessment 2025): **Section A** is in the style of Paper 1A (multiple choice) and **Section B** in the style of Paper 1B (data-based questions on experimental work).

	Questions	Standard Level	Higher Level
Section A	1–24 (SL and HL)	24 marks	24 marks
	25–32 HL	—	8 marks
Section B	B1–B3 (SL and HL)	22 marks	22 marks
	B4 HL	—	6 marks
Total		**46 marks · about 75 minutes**	**60 marks · about 95 minutes**

- **Timing.** The real papers run at about 1.6 minutes per mark (HL Paper 1: 75 marks in 2 hours; SL Paper 1: 55 marks in 1 hour 30 minutes). This paper is set at the same pace. Allow roughly a minute for each multiple-choice question, and the rest of the time for Section B.
- **Section A.** Write A, B, C or D in the answer grid below. One mark per question; no marks are deducted for wrong answers, so answer every question.
- **Section B.** Write your answers in the spaces provided. Show your working in calculations, and give units.
- A **calculator** and a clean copy of the **IB Chemistry data booklet** are allowed in both sections, as in the real examination (from 2025 a calculator is permitted in Paper 1A).
- When you have finished, mark your work with the answer key and markscheme at the end. The worked reasons explain why each wrong option is wrong, which is where most of the learning happens.

Answer grid — Section A

Questions on a gold background are HL only.

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

Section A: _____ / 24 (SL) or _____ / 32 (HL) · Section B: _____ / 22 (SL) or _____ / 28 (HL) · **Total: _____ / 46 (SL) or _____ / 60 (HL)**

Three habits that earn marks in Paper 1

- **Answer before you look.** Decide what the answer should be, then find it among the options. The wrong options are written to match the errors students actually make.
- **Use the data booklet actively.** Section 9 (electronegativity, ionization energy, electron affinity), Section 10 (radii), the colour wheel, and Sections 20–22 (IR wavenumbers, ^{1}H NMR shifts, MS fragments) turn many questions into look-ups.
- **In Section B, read the data first.** Most marks are for using the numbers or observations given, not for reciting the notes. Quote the data in your answer.

What each question tests

Understanding	Section A	Section B	Level
3.1.1–3.1.2 Periodic table, configuration and position	1, 2		SL + HL
3.1.3 Periodicity (radius, ionization energy, electron affinity, electronegativity)	3, 4, 5		SL + HL
3.1.4 Group 1 and group 17 trends	6, 7, 8	B2	SL + HL
3.1.5 Metallic and non-metallic oxides	9, 10	B1	SL + HL
3.1.6 Oxidation states and naming	11, 12, 13, 14	B1	SL + HL
3.2.1–3.2.3 Formulas, functional groups, homologous series	15, 16, 18		SL + HL
3.2.4 Trends in physical properties	19, 20	B3	SL + HL
3.2.5–3.2.6 IUPAC names and structural isomers	17, 21, 22, 23, 24	B3	SL + HL
3.1.7 Discontinuities in first ionization energy	25		HL
3.1.8–3.1.10 Transition elements, oxidation states and colour	26, 27	B4	HL
3.2.7 Stereoisomers	28, 29		HL
3.2.8–3.2.12 MS, IR, ^{1}H NMR and combined techniques	30, 31, 32		HL

2 Section A — multiple choice

Questions 1–24: all candidates
Structure 3.1.1–3.1.6 and 3.2.1–3.2.6 · 24 marks · about 25 minutes

1. An atom of element X has the ground-state electron configuration $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^3$. Where is X in the periodic table?

A period 3, group 15
B period 4, group 15
C period 4, group 5
D period 4, group 13

2. Element Q forms an ion, Q^{2-}, that has the same electron configuration as argon. Where is Q in the periodic table?

A period 4, group 2, s block
B period 3, group 18, p block
C period 3, group 16, p block
D period 3, group 14, p block

3. Which shows the ions in order of **increasing** ionic radius?

A $S^{2-} < Cl^- < K^+ < Ca^{2+}$
B $K^+ < Ca^{2+} < Cl^- < S^{2-}$
C $Ca^{2+} < K^+ < S^{2-} < Cl^-$
D $Ca^{2+} < K^+ < Cl^- < S^{2-}$

4. The atomic radius decreases across period 3 from sodium to chlorine. Which statement explains this?

A The nuclear charge increases while electrons are added to the same outer energy level, so shielding stays almost constant.
B The number of occupied energy levels decreases.
C Shielding by the inner electrons increases across the period.
D Repulsion between the outer electrons decreases as more electrons are added.

5. Which equation represents the first electron affinity of chlorine?

A $\frac{1}{2}Cl_2(g) + e^- \rightarrow Cl^-(g)$
B $Cl(g) + e^- \rightarrow Cl^-(g)$
C $Cl(g) \rightarrow Cl^+(g) + e^-$
D $Cl^-(g) \rightarrow Cl(g) + e^-$

6. Which property **decreases** going down both group 1 and group 17?

A atomic radius
B melting point
C first ionization energy
D chemical reactivity

7. A small piece of potassium is added to water containing a few drops of phenolphthalein indicator. Which observations are expected?

I. A lilac flame may be seen.
II. The gas given off relights a glowing splint.
III. The solution turns pink.

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

8. Aqueous chlorine is added to aqueous potassium bromide. Cyclohexane is then added and the mixture is shaken. What colour is the cyclohexane layer?

A pale green
B purple
C colourless
D orange

9. Which pair of oxides **both** react with aqueous sodium hydroxide?

A Al_2O_3 and SO_2
B MgO and SO_2
C Na_2O and Al_2O_3
D MgO and P_4O_{10}

10. Which statement explains why the pH of the oceans is falling as the concentration of carbon dioxide in the atmosphere rises?

A Carbon dioxide is a basic oxide, so it removes H^+ ions from sea water.

B Carbon dioxide reacts with water to form a strong acid that dissociates completely.

C Carbon dioxide reacts with calcium carbonate in shells, releasing OH^- ions.

D Carbon dioxide dissolves and reacts with water to form carbonic acid, H_2CO_3, which partially dissociates to release H^+ ions.

11. What is the oxidation state of sulfur in the tetrathionate ion, $S_4O_6^{2-}$, if all four sulfur atoms are treated as equivalent?

A +2 **B** +2.5 **C** +5 **D** +6

12. In which option does the stated element have an oxidation state of −1 in **both** compounds?

A H in HCl; O in Na_2O_2
B H in NaH; O in Na_2O
C Cl in Cl_2O; O in H_2O_2
D H in CaH_2; O in BaO_2

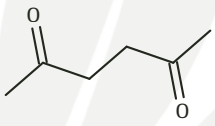
13. Which name is correct?

A Cu_2O, copper(II) oxide
B $NaNO_2$, sodium nitrate(V)
C $KClO_3$, potassium chlorate(V)
D $FeSO_4$, iron(III) sulfate

14. Which reaction is a disproportionation?

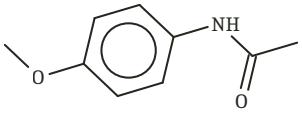
A $2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$
B $Cl_2(aq) + 2KBr(aq) \rightarrow 2KCl(aq) + Br_2(aq)$
C $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$
D $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$

15. What are the molecular formula and the empirical formula of the compound shown?



	Molecular formula	Empirical formula
A	$C_6H_{12}O_2$	C_3H_6O
B	$C_4H_6O_2$	C_2H_3O
C	$C_6H_{10}O_2$	C_3H_5O
D	$C_6H_{10}O_2$	$C_6H_{10}O_2$

16. Which functional groups are present in the molecule shown?



A ester, phenyl and amino
B alkoxy, phenyl and amido
C hydroxyl, phenyl and amido
D alkoxy, phenyl, amino and carbonyl

17. Which pair of compounds are functional group isomers?

A propan-1-ol and propan-2-ol
B butane and methylpropane
C ethanol and ethanal
D propanal and propanone

18. Which general formula describes both the aldehydes and the ketones (non-cyclic and saturated)?

A $C_nH_{2n+2}O$ **B** $C_nH_{2n}O$ **C** $C_nH_{2n}O_2$ **D** $C_nH_{2n-2}O$

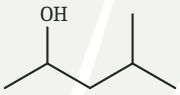
19. The four compounds below have similar molar masses. Which shows them in order of **increasing** boiling point?

A butane < propanal < propan-1-ol < ethanoic acid
B propanal < butane < ethanoic acid < propan-1-ol
C butane < propan-1-ol < propanal < ethanoic acid
D butane < propanal < ethanoic acid < propan-1-ol

20. Pentane (boiling point 36 °C) and 2,2-dimethylpropane (boiling point 10 °C) are structural isomers. Why is the boiling point of pentane higher?

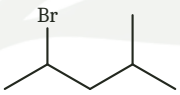
A Pentane has a greater molar mass.
B Pentane molecules are polar.
C More energy is needed to break the C–C bonds in pentane.
D Pentane molecules have a larger surface area of contact, so the London (dispersion) forces between them are stronger.

21. What is the IUPAC name of this compound?



A 2-methylpentan-4-ol
B hexan-2-ol
C 4-methylpentan-2-ol
D 1,3-dimethylbutan-1-ol

22. What is the IUPAC name of this compound?



A 4-bromo-2-methylpentane
B 2-bromo-4-methylpentane
C 2-methyl-4-bromopentane
D 1-bromo-1,3-dimethylbutane

23. How many structural isomers have the molecular formula C_4H_9Br?

A 2 **B** 3 **C** 4 **D** 5

24. Which compound is a **tertiary** alcohol?

A 3-methylbutan-2-ol
B 2-methylbutan-1-ol
C pentan-3-ol
D 2-methylbutan-2-ol

Questions 25–32: Higher Level candidates only

Structure 3.1.7–3.1.10 and 3.2.7–3.2.12 · 8 marks · about 10 minutes

25. The first ionization energy **decreases** from magnesium to aluminium, and from phosphorus to sulfur. Which explanations are correct? HL

	Mg → Al	P → S
A	The electron removed from Al is in a 3p orbital, which is higher in energy than 3s.	The electron removed from S is in a 3p orbital that already holds an electron, so it is repelled.
B	Al has a greater nuclear charge than Mg.	P has a half-filled 3p sublevel, which is especially stable.
C	The electron removed from Al comes from a doubly occupied 3p orbital.	The electron removed from S is in a higher-energy sublevel than in P.
D	The 3p electron in Al is in a new, outer energy level.	S has a greater nuclear charge than P.

26. Which ion has the same electron configuration as Mn^{2+}? HL

A Cr^{2+} **B** Fe^{2+} **C** Fe^{3+} **D** Co^{3+}

27. An aqueous solution of a transition element complex appears **yellow**. Using the colour wheel in the data booklet, which wavelength is the complex most likely to absorb most strongly? HL

A 410 nm **B** 480 nm **C** 580 nm **D** 650 nm

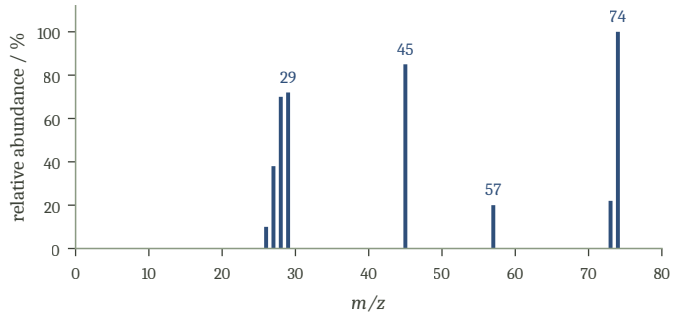
28. Which compound shows **both** cis–trans isomerism and optical isomerism? HL

A $CH_2{=}CHCH(OH)CH_3$
B $CH_3CH{=}CHCH_2OH$
C $CH_3CH{=}CHCH(OH)CH_3$
D $(CH_3)_2C{=}CHCH(OH)CH_3$

29. Which statement about the two enantiomers of butan-2-ol is correct? HL

A They rotate the plane of plane-polarized light by the same angle in opposite directions.
B They have different boiling points.
C An equimolar (racemic) mixture of them rotates plane-polarized light clockwise.
D They are structural isomers with different connectivities.

30. The mass spectrum of an organic compound is shown. Which compound produced this spectrum? HL



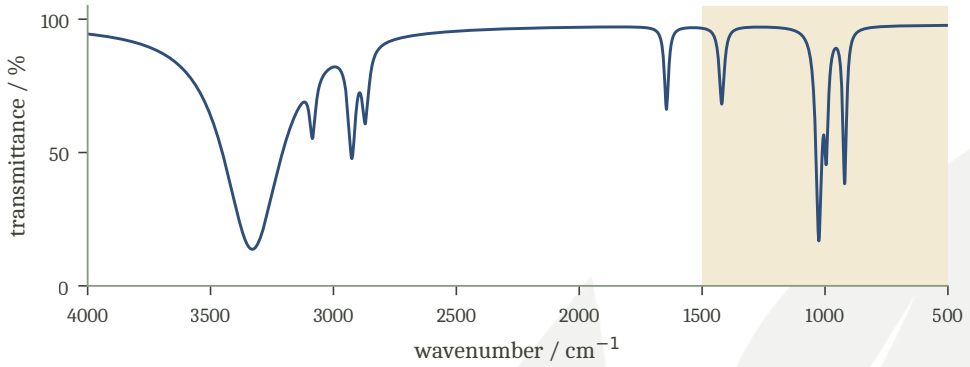
A methyl ethanoate, CH_3COOCH_3

B butan-1-ol, $CH_3CH_2CH_2CH_2OH$

C butanal, $CH_3CH_2CH_2CHO$

D propanoic acid, CH_3CH_2COOH

31. The infrared spectrum of an organic compound is shown. Which compound could produce this spectrum? HL



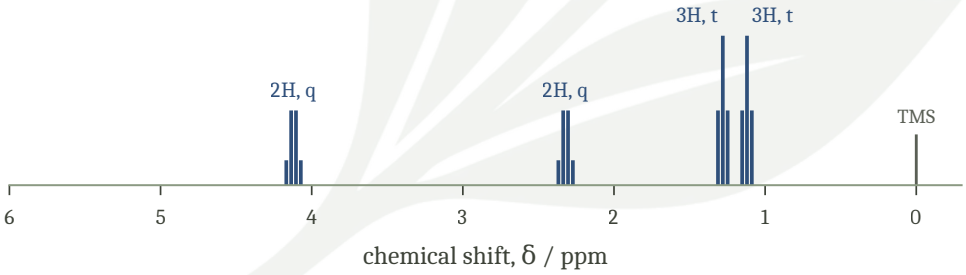
A propan-1-ol, $CH_3CH_2CH_2OH$

B prop-2-en-1-ol, $CH_2{=}CHCH_2OH$

C propanal, CH_3CH_2CHO

D propanoic acid, CH_3CH_2COOH

32. The ^1H NMR spectrum of a compound with molecular formula $C_5H_{10}O_2$ is shown. The relative number of hydrogen atoms and the splitting pattern are given above each signal. Which compound is it? HL



A ethyl propanoate, $CH_3CH_2COOCH_2CH_3$

B propyl ethanoate, $CH_3COOCH_2CH_2CH_3$

C pentanoic acid, $CH_3CH_2CH_2CH_2COOH$

D methyl butanoate, $CH_3CH_2CH_2COOCH_3$

END OF SECTION A

3 Section B — data-based questions

Questions B1–B3: all candidates · B4: Higher Level only
Answer in the spaces provided · SL 22 marks, about 45 minutes · HL 28 marks, about 55 minutes

B1 The oxides of period 3

Total 8 marks

A student added a small spatula of each period 3 oxide to 25 cm^3 of distilled water, stirred, and measured the pH with a calibrated pH probe. Separate samples of each oxide were then tested with dilute hydrochloric acid and with aqueous sodium hydroxide. Sulfur dioxide was bubbled through the solutions as a gas. The results are shown below.

	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO_2
Appearance of mixture with water	colourless solution	cloudy white suspension	white solid, no change	white solid, no change	colourless solution	colourless solution
pH	13.8	9.6	7.0	7.0	1.6	2.9
Reacts with HCl(aq)?	yes	yes	yes	no	no	no
Reacts with NaOH(aq)?	no	no	yes	yes (hot, concentrated)	yes	yes

(a) Write an equation for the reaction of sodium oxide with water. **[1]**

(b) Magnesium oxide is a basic oxide, yet its mixture with water has a much lower pH than that of sodium oxide. Suggest a reason, using the appearance of the mixture. **[1]**

(c) Both aluminium oxide and silicon dioxide give a pH of 7.0. Using the data, classify **each** oxide as basic, amphoteric or acidic, and explain why both give a pH of 7.0. **[2]**

(d) Phosphorus(V) oxide, P_4O_{10}, reacts with water to form phosphoric acid. Write an equation for this reaction, and deduce the oxidation state of phosphorus in the product. **[2]**

(e) Sulfur dioxide is released when fuels containing sulfur are burned, and contributes to acid rain. Write an equation for the reaction of sulfur dioxide with water. **[1]**

(f) State one advantage of using a pH probe rather than universal indicator paper in this investigation. **[1]**

B2 Displacement reactions of the halogens

Total 6 marks

A student added a few drops of each aqueous halogen to aqueous solutions of three potassium halides. A little cyclohexane was then added to each tube, and the tube was stoppered and shaken. The cyclohexane forms an upper layer. The table shows the colour of the cyclohexane layer. For comparison, the colours of the halogens themselves in cyclohexane are: chlorine, very pale green; bromine, orange; iodine, purple.

Halogen added	KCl(aq)	KBr(aq)	KI(aq)
Cl_2(aq)	—	orange	purple
Br_2(aq)	orange	—	**W**
I_2(aq)	purple	purple	—

(a) State the colour of the cyclohexane layer in the tube marked **W**. **[1]**

(b) Write an ionic equation for the reaction between aqueous chlorine and aqueous potassium iodide. **[1]**

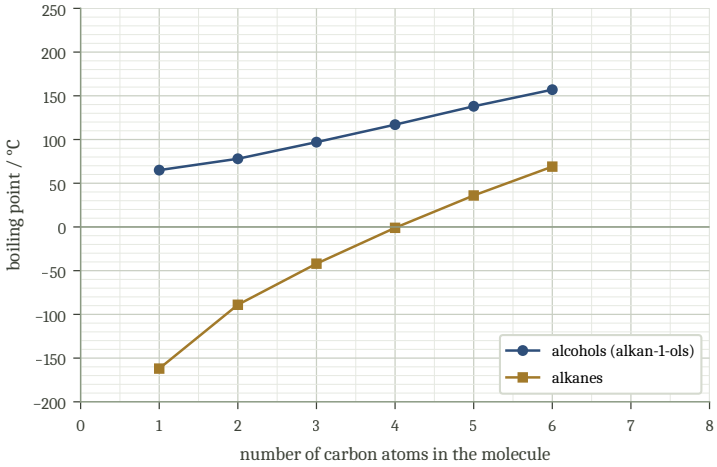
(c) Deduce the order of oxidizing strength of chlorine, bromine and iodine from the results, and explain this order in terms of the structure of the halogen atoms. **[3]**

(d) Explain why cyclohexane was added to each tube. **[1]**

B3 Boiling points of two homologous series

Total 8 marks

The graph shows the boiling points of the first six straight-chain alcohols (alkan-1-ols) and the first six alkanes.



Boiling points of alkan-1-ols and alkanes with 1 to 6 carbon atoms.

(a) Use the graph to estimate the boiling point of heptan-1-ol. **[1]**

(b) Explain why the boiling points of the alcohols increase as the chain length increases. **[2]**

(c) The difference between the boiling point of an alcohol and that of the alkane with the same number of carbon atoms becomes smaller as the chain gets longer. Explain this. **[2]**

(d) A student measured the boiling point of propan-1-ol as 95.5 ± 0.5 °C. The literature value is 97.2 °C. Calculate the percentage error. **[1]**

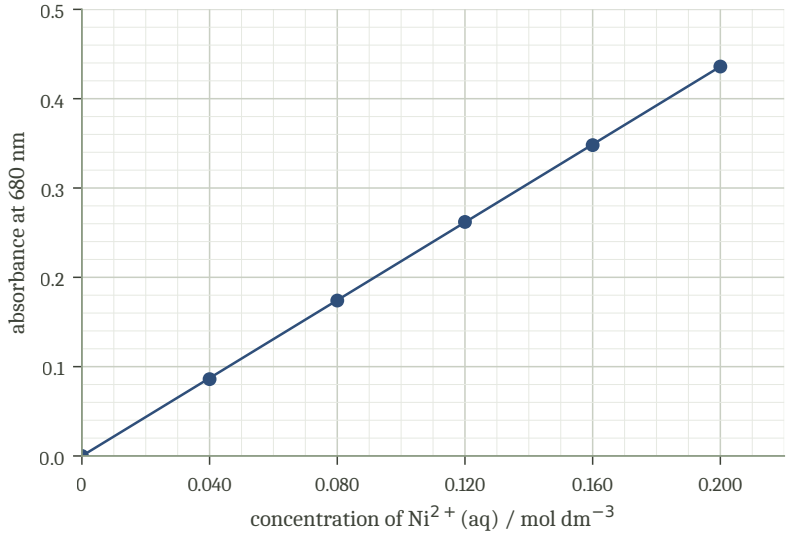
(e) State, with a reason, whether the difference in (d) is due to random uncertainty alone, and suggest one possible cause of it. **[1]**

(f) Butan-2-ol (boiling point 99.5 °C) is a structural isomer of butan-1-ol (boiling point 117.7 °C). State the class of alcohol to which butan-2-ol belongs, and suggest why its boiling point is lower than that of butan-1-ol. **[1]**

B4 Finding the concentration of nickel(II) ions by colorimetry HL

Total 6 marks

Aqueous solutions containing $[Ni(H_2O)_6]^{2+}$ ions are green. A student prepared standard solutions of nickel(II) sulfate and measured their absorbance at 680 nm in a colorimeter, using the same 1 cm cuvette each time. The results were used to draw the calibration graph below. A solution of unknown concentration, made by dissolving a nickel-plated alloy in acid, gave an absorbance of 0.300 under the same conditions.



Calibration graph for $[Ni(H_2O)_6]^{2+}$ at 680 nm.

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

(b) Explain why solutions containing $[Ni(H_2O)_6]^{2+}$ are coloured. **[2]**

(c) Use the colour wheel in the data booklet to explain why 680 nm is a suitable wavelength for this measurement. **[1]**

(d) Determine the concentration of Ni^{2+} ions in the unknown solution. **[1]**

(e) Explain why this method could not be used to find the concentration of a solution of zinc sulfate. **[1]**

END OF PAPER

4 Answer key — Section A

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

Each letter is the answer to eight questions. Questions 25–32 (gold) are HL only. SL: score out of 24 · HL: score out of 32.

Worked reasons for every option

1. **B.** The highest occupied level is n = 4, so period 4. There are 2 + 3 = 5 electrons in the outer shell, and a p-block element with 5 valence electrons is in group 10 + 5 = 15 (it is arsenic). A counts the 3d electrons as if they set the period. C uses the old 'group V' label as a group number: group 5 is a d-block group (vanadium). D is the group for $4s^2\,4p^1$.

2. **C.** Q^{2-} has 18 electrons, so the Q atom has 16: sulfur, $1s^2\,2s^2\,2p^6\,3s^2\,3p^4$, period 3, group 16, p block. A describes calcium (Ca^{2+} is also isoelectronic with Ar, but it is a 2+ ion). B is argon itself. D is silicon.

3. **D.** All four ions have 18 electrons. The more protons, the stronger the pull on the same electron cloud: Ca^{2+} (20 protons, 100 pm) < K^+ (19, 138 pm) < Cl^- (17, 181 pm) < S^{2-} (16, 184 pm), data booklet Section 10. A is the reverse order; B and C each swap one pair.

4. **A.** Across a period the electrons go into the same shell, which inner electrons shield about equally, while each step adds a proton: the effective nuclear charge rises and pulls the outer shell in. B is false (all have three occupied levels); C is false (the inner shells are the same); D is false and would not explain a contraction anyway.

5. **B.** First electron affinity: one mole of electrons added to one mole of gaseous **atoms** to form gaseous 1− ions. A starts from the element, so it includes atomisation. C is the first ionization energy. D is the reverse of the electron affinity.

6. **C.** Down both groups the outer electron is further from the nucleus and better shielded, so it is removed more easily. A increases in both groups. B decreases down group 1 but increases down group 17 (stronger London forces between larger halogen molecules). D increases down group 1 but decreases down group 17.

7. **B.** $2K + 2H_2O \rightarrow 2KOH + H_2$. The reaction is vigorous enough to ignite the hydrogen, which burns with a lilac flame coloured by potassium (I), and KOH makes the solution alkaline, so phenolphthalein turns pink (III). The gas is hydrogen, which gives a squeaky pop, not oxygen (II).

8. **D.** Chlorine is the stronger oxidizing agent: $Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$. Bromine dissolves in cyclohexane to give an orange layer. A is the colour of chlorine itself (it has reacted). B is iodine, which needs iodide ions. C would mean no halogen in the layer.

9. **A.** Aluminium oxide is amphoteric (reacts with acids and bases) and sulfur dioxide is acidic: both react with NaOH. MgO and Na_2O are basic and do not react with NaOH, which rules out B, C and D.

10. **D.** $CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$: carbonic acid is weak, and the extra H^+ lowers the pH. CO_2 is an acidic (non-metal) oxide, so A is wrong; carbonic acid is weak, so B is wrong; C would raise the pH, not lower it.

11. **B.** $4x + 6(-2) = -2$, so $4x = +10$ and $x = +2.5$. A fractional oxidation state is an average over atoms that are in fact different. C and D come from using the charge of the ion wrongly or from assuming the oxidation state of S in sulfate.

12. **D.** H in a metal hydride is −1 (Ca is +2, so 2H = −2), and O in a peroxide is −1 (Ba is +2, O_2^{2-}). In A, H in HCl is +1. In B, O in Na_2O is −2. In C, Cl in Cl_2O is +1 (O is more electronegative).

13. **C.** In $KClO_3$, K = +1 and 3O = −6, so Cl = +5: potassium chlorate(V). In Cu_2O, Cu = +1: copper(I) oxide. In $NaNO_2$, N = +3: sodium nitrate(III), commonly sodium nitrite. In $FeSO_4$, Fe = +2: iron(II) sulfate.

14. **A.** In disproportionation one element is both oxidized and reduced. O in H_2O_2 is −1; it becomes −2 in H_2O (reduced) and 0 in O_2 (oxidized). B is redox but not disproportionation (Cl is reduced, Br oxidized). C is not redox. D is redox between two different elements.

15. **C.** Six carbons (each end of a line and each vertex), two C=O groups and 10 H: $C_6H_{10}O_2$ (hexane-2,5-dione). Dividing by 2 gives C_3H_5O. A forgets that each C=O carbon carries no H. B misses the two terminal CH_3 groups. D does not simplify the ratio.

16. **B.** CH_3O– on a ring is an **alkoxy** group (an ether), the ring is **phenyl**, and –NH–C(=O)– is an **amido** group. A misreads the ether O as an ester and the amide N as an amine. C mistakes O–CH_3 for O–H. D splits the amide into two separate groups.

17. **D.** Propanal (an aldehyde) and propanone (a ketone) are both C_3H_6O with different functional groups. A are position isomers; B are chain (branched) isomers; C are not isomers at all (C_2H_6O and C_2H_4O).

18. **B.** Ethanal C_2H_4O, propanone C_3H_6O: $C_nH_{2n}O$. A fits alcohols and ethers, C fits carboxylic acids and esters, D has one more degree of unsaturation than a single C=O provides.

19. **A.** Butane has London forces only; propanal adds dipole–dipole forces; propan-1-ol forms hydrogen bonds; ethanoic acid forms more hydrogen bonds (two O atoms and an O–H, often as dimers). Measured values: −1, 49, 97 and 118 °C. D is the common error of ranking propan-1-ol above the acid.

20. **D.** The straight chain can line up along neighbouring chains; the near-spherical 2,2-dimethylpropane touches its neighbours over a smaller area, so the London forces are weaker. A is false (same formula). B is false (both are essentially non-polar). C confuses boiling with breaking covalent bonds.

21. **C.** The longest chain has five carbons; numbering from the end nearer the OH gives the OH locant 2 and the methyl branch 4: 4-methylpentan-2-ol. A numbers from the wrong end (the functional group takes priority for the lowest locant). B counts all six carbons as one chain. D chooses a four-carbon chain.

22. **B.** Both directions give the locant set {2, 4}, a tie. The tie is broken alphabetically: bromo before methyl, so bromo gets 2. A gives the lower number to methyl. C lists the substituents out of alphabetical order. D does not use the longest chain.

23. **C.** 1-bromobutane, 2-bromobutane, 1-bromo-2-methylpropane and 2-bromo-2-methylpropane. There are two carbon skeletons (straight and branched) and two different positions on each. 2-Bromobutane is chiral, but its enantiomers are stereoisomers, not extra structural isomers, so D is wrong.

24. **D.** In 2-methylbutan-2-ol the C bearing the OH is bonded to three other carbons. 3-Methylbutan-2-ol and pentan-3-ol are secondary (two C on the C–OH carbon); 2-methylbutan-1-ol is primary.

25. **A.** Explanations must be based on the energy of the electron removed. Al's electron is removed from 3p, which is higher in energy (and slightly further out) than Mg's 3s. In S the fourth 3p electron pairs up in an orbital, and the repulsion between the paired electrons makes one easier to remove. B uses the nuclear charge (which would *raise* the IE) and 'half-filled stability', which the IB guide does not accept. C swaps the two reasons. D is wrong: 3p is in the same energy level (n = 3) as 3s.

26. **C.** Mn (Z = 25) is [Ar] $3d^5\ 4s^2$; Mn^{2+} loses the 4s electrons: [Ar] $3d^5$. Fe^{3+} (26 − 3 = 23 electrons) is also [Ar] $3d^5$. Cr^{2+} is $3d^4$; Fe^{2+} and Co^{3+} are $3d^6$.

27. **A.** The colour seen is complementary to the colour absorbed. Yellow is opposite violet on the colour wheel, and violet light is 400–424 nm, so 410 nm. C (580 nm) is yellow light itself, the colour that is transmitted. B is blue (complementary to orange); D is red (complementary to green).

28. **C.** In pent-3-en-2-ol each C=C carbon carries two different groups (H and CH_3; H and $CH(OH)CH_3$), so cis and trans forms exist, and C2 carries H, OH, CH_3 and $CH{=}CHCH_3$, so it is chiral. A and D are chiral, but one C=C carbon carries two identical groups ($=CH_2$; $=C(CH_3)_2$). B shows cis–trans isomerism, but no carbon has four different groups.

29. **A.** Enantiomers have identical physical properties except their effect on plane-polarized light: equal rotation in opposite directions. B is false. In a racemic mixture the rotations cancel, so C is false. D is false: enantiomers have the same connectivity and differ only in the 3D arrangement.

30. **D.** M^+ = 74 fits $C_3H_6O_2$. The peak at 57 is M − 17 (loss of OH), at 45 is $COOH^+$ (M − 29, loss of C_2H_5), and 29 is $C_2H_5^+$: propanoic acid. Methyl ethanoate (A) also has M = 74, but would lose CH_3O (31) to give a strong peak at 43, CH_3CO^+. Butan-1-ol (B) has M = 74 but loses water (M − 18 = 56) and gives CH_2OH^+ at 31. Butanal (C) has M = 72.

31. **B.** A broad absorption at about 3200–3600 cm^{-1} shows an alcohol O–H, a weak band at 1620–1680 cm^{-1} shows C=C, and there is no C=O band at 1700–1750 cm^{-1}: an unsaturated alcohol. A has no C=C band. C and D would both show a strong C=O band, and D a very broad O–H at 2500–3000 cm^{-1}.

32. **A.** Two quartet–triplet pairs (2H q + 3H t, twice) mean two separate ethyl groups. One CH_2 at 4.1 ppm is on the ester oxygen (R–COO–CH_2–, 3.7–4.8 ppm); the other at 2.3 ppm is next to the C=O (2.0–2.5 ppm): $CH_3CH_2COOCH_2CH_3$. B and D each contain a CH_3 singlet and a CH_2 with five neighbouring H (a sextet). C would show a 1H signal at 9.0–13.0 ppm.

5 Section B — 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.

B1 The oxides of period 3 (8 marks)

Part	Answer (one ✓ per mark)	Mk	Notes for markers
(a)	$Na_2O(s) + H_2O(l) \rightarrow 2NaOH(aq)$ ✓	**1**	State symbols not required. Accept the ionic equation $O^{2-} + H_2O \rightarrow 2OH^-$.
(b)	MgO is only sparingly soluble / most of it does not dissolve (cloudy suspension), so the concentration of $OH^-(aq)$ is much lower ✓	**1**	Do not accept 'MgO is a weaker base' without reference to solubility.
(c)	Al_2O_3 amphoteric (reacts with both HCl and NaOH) and SiO_2 acidic (reacts with NaOH only) ✓ Both are insoluble in water, so they do not change the pH ✓	**2**	Both classifications needed for the first mark.
(d)	$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$ ✓ +5 ✓	**2**	Accept '+V'. Do not accept '5' or '5+'.
(e)	$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$ ✓	**1**	Accept ⇌. Do not accept H_2SO_4 as the product.
(f)	Gives a numerical / more precise reading (to 0.1 pH unit) / not subjective, unlike judging a colour ✓	**1**	Accept: can be used with cloudy or coloured mixtures.

B2 Displacement reactions of the halogens (6 marks)

Part	Answer (one ✓ per mark)	Mk	Notes for markers
(a)	Purple ✓	**1**	Accept violet / pink-purple.
(b)	$Cl_2(aq) + 2I^-(aq) \rightarrow 2Cl^-(aq) + I_2(aq)$ ✓	**1**	Accept the full equation with KI and KCl. Must be balanced.
(c)	$Cl_2 > Br_2 > I_2$ (chlorine displaces Br and I; bromine displaces I only) ✓ Down the group the atoms are larger / have more occupied energy levels, so the incoming electron is further from the nucleus and more shielded ✓ Weaker attraction for the electron, so the halogen gains electrons (is reduced) less readily ✓	**3**	The order must be supported by the results for M1. Do not accept 'more reactive' alone for M3.
(d)	Halogens are more soluble in the non-polar solvent, and their colours there are distinct (bromine orange, iodine purple), whereas in water bromine and iodine can both look yellow-brown ✓	**1**	Idea of distinguishing the colours needed.

B3 Boiling points of two homologous series (8 marks)

Part	Answer (one ✓ per mark)	Mk	Notes for markers
(a)	174–178 °C ✓	**1**	Literature value 176 °C. Extrapolation of the trend of about +19 to +20 °C per CH_2.

Part	Answer (one ✓ per mark)	Mk	Notes for markers
(b)	Longer chains have more electrons / a larger surface area, so the London (dispersion) forces between molecules are stronger ✓ More energy is needed to separate the molecules ✓	2	Do not accept 'bonds break' or any reference to breaking covalent bonds.
(c)	Alcohols have hydrogen bonding from the OH group in addition to London forces; the OH contributes a roughly constant amount ✓ As the chain grows, London forces make up a larger share of the total intermolecular attraction / the OH is a smaller part of the molecule ✓	2	Accept the idea that the hydrocarbon chain increasingly dominates the properties.
(d)	(97.2 − 95.5) / 97.2 × 100 = 1.7 % ✓	1	Accept 1.75 % or 2 %.
(e)	No: the error (1.7 °C) is larger than the uncertainty of ±0.5 °C, so a systematic error is present; e.g. thermometer bulb not level with the side arm / heat loss / atmospheric pressure below 100 kPa / thermometer calibration / impure sample ✓	1	Both the judgement with reason and a plausible cause needed.
(f)	Secondary; the more compact / branched shape gives a smaller contact area, so weaker London forces (and the OH is less exposed for hydrogen bonding) ✓	1	Both the class and a valid reason needed.

B4 Colorimetry of nickel(II) (6 marks) HL

Part	Answer (one ✓ per mark)	Mk	Notes for markers
(a)	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^8$ / [Ar] $3d^8$ ✓	1	Do not accept [Ar] $3d^6\ 4s^2$: the 4s electrons are lost first.
(b)	The water ligands split the 3d sublevel into two levels of different energy ✓ An electron absorbs a photon of visible light and is promoted to the higher level; the colour seen is the complementary colour of the light transmitted ✓	2	Accept 'd–d transition' for promotion. Do not accept 'emits light' for M2.
(c)	The solution is green, so it absorbs the complementary colour, red, and 680 nm is in the red region (647–700 nm) ✓	1	Idea of choosing the wavelength most strongly absorbed.
(d)	0.137–0.139 mol dm^{-3} ✓	1	From the graph: 0.300 ÷ 2.18 = 0.138 mol dm^{-3}. Units needed.
(e)	Zn^{2+} has a full 3d sublevel ($3d^{10}$), so no d–d transition is possible; the solution absorbs no visible light / is colourless ✓	1	

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