International Baccalaureate®
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Chemistry

Higher and Standard level

Specimen papers 1A, 1B and 2

For first examinations in 2025

CONTENTS

Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 1A

Specimen paper

2 hours [Paper 1A and Paper 1B]

Instructions to candidates

- Do not open this examination paper until instructed to do so.
- Answer all questions.
- For each question, choose the answer you consider to be the best and indicate your choice on the answer sheet provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for paper 1A is **[40 marks]**.
- The maximum mark for paper 1A and paper 1B is **[75 marks]**.

0000–6101

Section A

1. What is thin-layer chromatography best used for separating?

A. molecules of varying polarity

B. molecules of similar polarity

C. metals in an alloy

D. water of crystallization from hydrated salts

2. Ice containing only the isotope ^2H sinks and does not melt when dropped into ordinary distilled water maintained at 3 °C.

Which statement is correct?

A. The isotope ^2H has a high natural abundance.

B. $^2H_2O(s)$ has a higher melting point than normal ice.

C. $^2H_2O(s)$ has a lower density than normal ice-cold water.

D. ^2H_2O has different chemical properties from normal water.

3. The table lists successive ionization energies of an element **Z**.

Ionization number	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**
Ionization energy / kJ mol^{-1}	577.54	1816.68	2744.78	11 577.5	14 841.9	18 379.0

Which is the formula of the stable oxide of the element **Z**?

A. Z_2O

B. ZO

C. Z_2O_3

D. ZO_2

4. A container holds 30 g of argon and 60 g of neon.

What is the ratio of number of atoms of argon to number of atoms of neon in the container?

A. 0.25

B. 0.50

C. 2.0

D. 4.0

5. A gas storage tank of fixed volume V contains N molecules of an ideal gas at 300 K with a pressure of 40 kPa. $\frac{N}{4}$ molecules are removed, and the temperature is changed to 450 K.

What is the new pressure of the gas in kPa?

A. 15

B. 30

C. 45

D. 60

6. What is the formula of the compound formed between magnesium ions and hydrogencarbonate ions?

A. $MgHCO_3$

B. $Mg(HCO_3)_2$

C. $Mg(HCO_3)_3$

D. $Mg_3(HCO_3)_2$

7. In which group of ions and molecules are electrons delocalized in all species?

A. CH_3COOH, O_3, C_{60}

B. CH_3COO^-, NO_2^-, C(graphite)

C. C_2H_2, $(COOH)_2$, C(diamond)

D. C_2H_4, NO_2^+, SiO_2

8. What is the molecular geometry of the central atom in SF_4Cl_2?

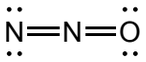
A. linear

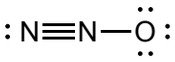
B. tetrahedral

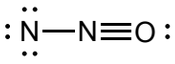
C. hexagonal

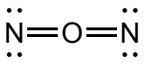
D. octahedral

9. Which is the preferred Lewis formula of nitrous oxide, N_2O, as deduced by formal charges?

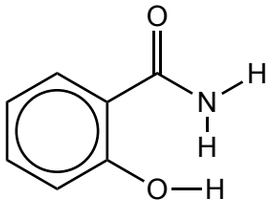
A. 

B. 

C. 

D. 

10. Which pair of statements about electrons in this molecule is correct?



	Number of non-bonding pairs of electrons	Number of electrons in π bonds
A.	3	6
B.	3	8
C.	5	6
D.	5	8

11. What is the explanation for the malleability of metals?

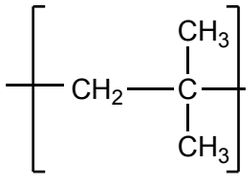
A. The bonds are strong.

B. The bonds are weak.

C. The bonds involve free electrons.

D. The bonds do not have a specific direction.

12. The structure shows the repeating unit of a polymer found in some plastics.



Which monomer is used to form this plastic?

A. $H_2C{=}C(CH_3)_2$

B. $CH_3CH(CH_3)_2$

C. $(H_3C)_2C{=}C(CH_3)_2$

D. $(H_3C)_2C{=}CHCH(CH_3)_2$

13. Why is copper(II) sulfate blue?

A. Red light is absorbed when electrons are promoted between the orbitals in the split d-sublevels.

B. Blue light is emitted when electrons fall between the orbitals in the split d-sublevels.

C. Red light is absorbed when electrons fall between the orbitals in the split d-sublevels.

D. Blue light is emitted when electrons are promoted between the orbitals in the split d-sublevels.

14. Which molecule has a carbonyl functional group?

A. CH_3OCH_3

B. CH_3COCH_3

C. CH_3CH_2OH

D. $CH_3CH_2NH_2$

15. The block structure of the periodic table groups elements according to which characteristic?

A. atomic number

B. atomic mass

C. electron configuration

D. reactivity

16. Which d block element has the highest number of different oxidation states?

A. Ti

B. Mn

C. Cu

D. Zn

17. What do all greenhouse gases have in common?

A. They are emitted by the burning of fossil fuels.

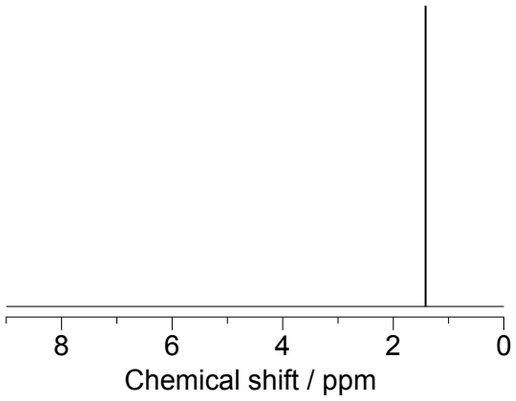
B. They absorb ultraviolet radiation.

C. They are symmetrical molecules with no polar bonds.

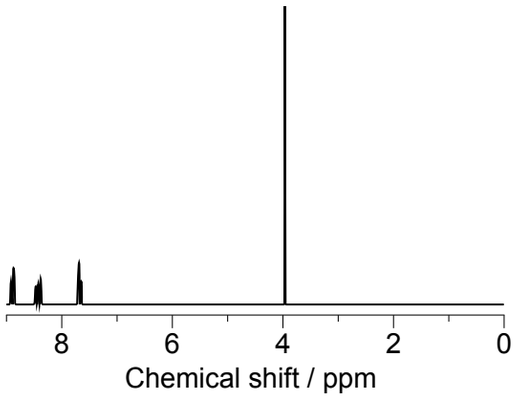
D. They absorb infrared radiation.

18. Which is the ^{1}H NMR spectrum of cyclohexane?

A.



C.



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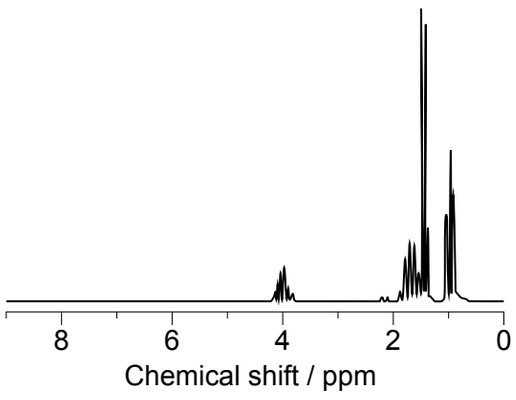

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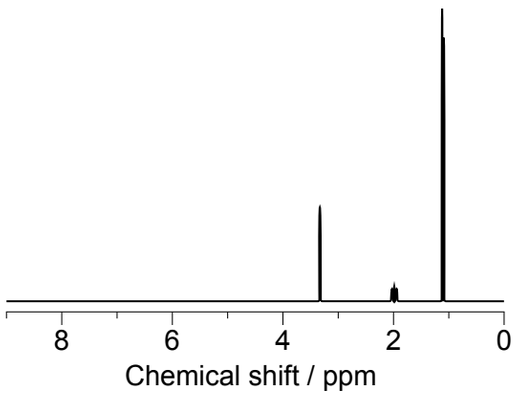
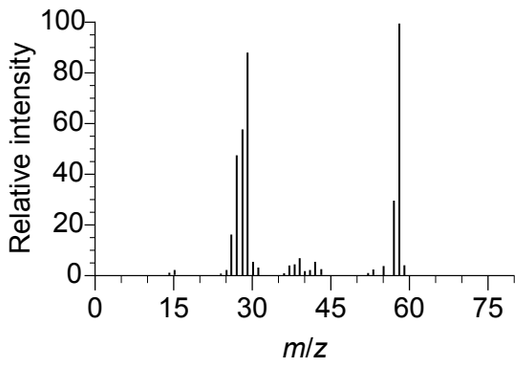


19. Which is the mass spectrum of butanal?

A.



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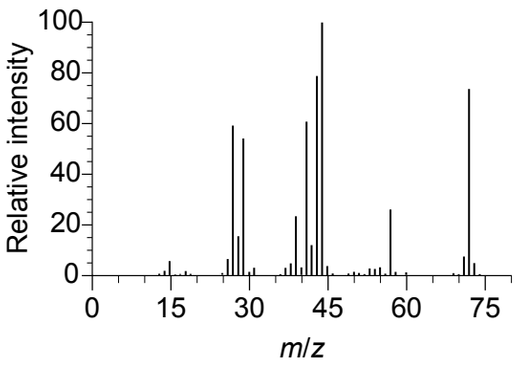

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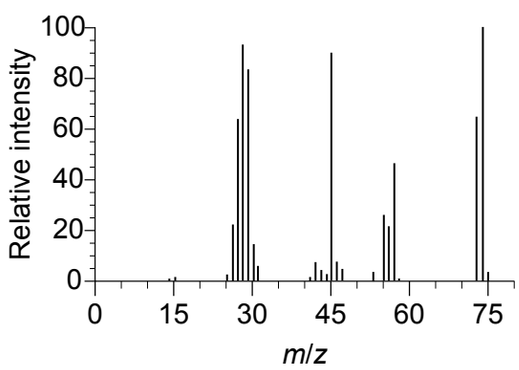
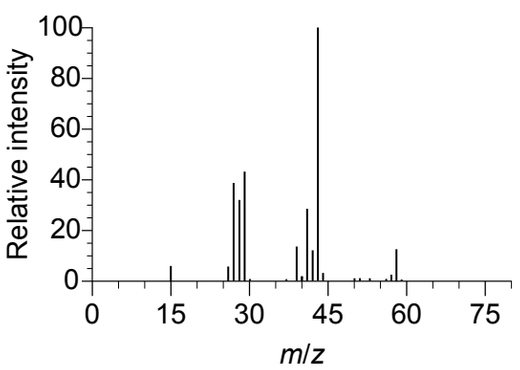
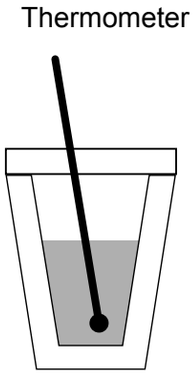


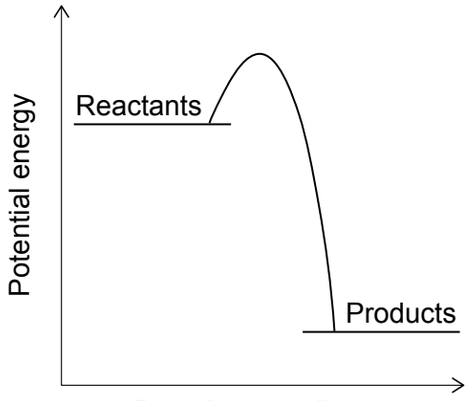
D.



20. The potential energy profile for a “coffee cup” calorimetry experiment is shown.



Coffee cup calorimeter



What is the correct interpretation of this reaction?

	Temperature	Type of reaction
A.	increases	exothermic
B.	increases	endothermic
C.	decreases	exothermic
D.	decreases	endothermic

21. What is the enthalpy change for the reaction in $kJ\,mol^{-1}$?

$$CO_2(g) + H_2(g) \rightarrow CO(g) + H_2O(g)$$

$2CO(g) + O_2(g) \rightarrow 2CO_2(g) \qquad \Delta H = -566\,kJ\,mol^{-1}$

$2H_2(g) + O_2(g) \rightarrow 2H_2O(l) \qquad \Delta H = -572\,kJ\,mol^{-1}$

$H_2O(g) \rightarrow H_2O(l) \qquad \Delta H = -44\,kJ\,mol^{-1}$

A. −1182

B. −899

C. −41

D. +41

22. Which is a renewable energy source?

A. natural gas

B. uranium

C. coal

D. wood

23. Which are endothermic processes in a Born–Haber cycle for the formation of an ionic compound?

I. Enthalpy of atomization

II. First electron affinity

III. First ionization energy

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

24. What is correct as a system approaches equilibrium?

A. Q remains constant.

B. K_c increases.

C. $\Delta G^{\ominus}$ becomes more negative.

D. ΔG approaches zero.

25. The complete combustion of 20.0 cm^3 of a gaseous hydrocarbon, C_xH_y, produces 80.0 cm^3 of gaseous products. This volume reduces to 40.0 cm^3 when the water vapour present condenses. All volumes are measured at the same temperature and pressure.

What is the molecular formula of the hydrocarbon?

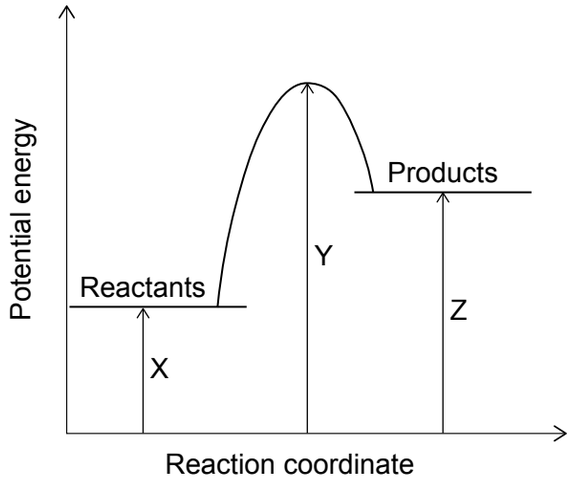
A. CH_4

B. C_2H_2

C. C_2H_4

D. C_3H_6

26. The diagram shows the energy profile of a reaction.



Which combination is correct?

	Activation energy of forward reaction	Activation energy of reverse reaction
A.	X	Z
B.	Y – X	Y – Z
C.	Y	Y
D.	Y – X	Z – X

27. What is the main reason for an increase in rate of reaction when the temperature is raised?

A. A greater proportion of collisions are successful.

B. Particles collide more frequently.

C. The bonds in the reactants are weakened.

D. The activation energy of the reaction decreases.

28. What is the equilibrium constant expression for the following reaction?

$$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$$

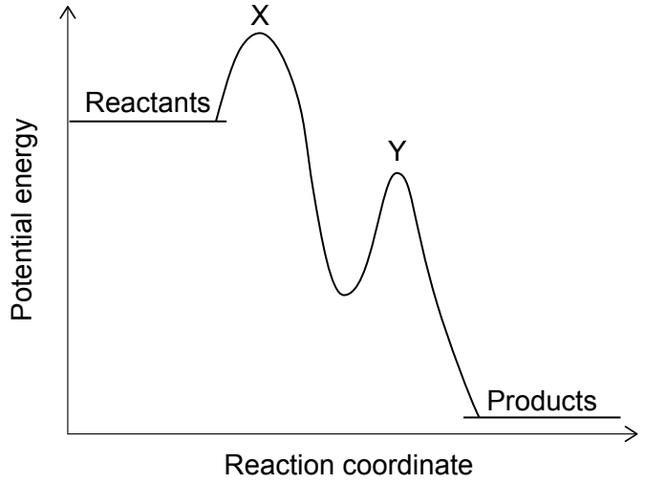
A. $\frac{[SO_2]^2[O_2]}{[SO_3]^2}$

B. $\frac{[SO_2]^2 + [O_2]}{[SO_3]^2}$

C. $\frac{[SO_3]^2}{[SO_2]^2[O_2]}$

D. $\frac{2[SO_2][O_2]}{2[SO_3]}$

29. Which statement is correct about points X and Y on the energy profile diagram?



A. X is a transition state and Y is an intermediate.

B. X is an intermediate and Y is a transition state.

C. X and Y are transition states.

D. X and Y are intermediates.

30. The equation for the reaction between two gases, A and B, is:

$$A(g) + 2B(g) \rightleftharpoons 2C(g)$$

When the reaction is at equilibrium at 600 K, the concentrations of A, B, and C are 2, 1, and 2 mol dm^{-3} respectively. What is the value of the equilibrium constant at 600 K?

A. 0.25

B. 1

C. 2

D. 4

31. Which reaction would be expected to have the largest Arrhenius (pre-exponential) factor, *A,* at constant temperature?

A. $H(g) + I(g) \rightarrow HI(g)$

B. $H_2(g) + I_2(g) \rightarrow 2HI(g)$

C. $2HCl(g) \rightarrow H_2(g) + Cl_2(g)$

D. $H_2 + C_2H_4 \rightarrow C_2H_6$

32. Which reactions involve the transfer of a proton?

I. $2HCl(aq) + Mg(s) \rightarrow MgCl_2(aq) + H_2(g)$

II. $2HCl(aq) + MgO(s) \rightarrow MgCl_2(aq) + H_2O(l)$

III. $2HCl(aq) + MgCO_3(s) \rightarrow MgCl_2(aq) + H_2O(l) + CO_2(g)$

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

33. The indicator, HInd, is used in an acid–base titration.

$$HInd(aq) \rightleftharpoons H^+(aq) + Ind^-(aq)$$

colour A colour B

Which statements are correct?

I. In a strongly alkaline solution, colour B is observed.

II. Colour A is observed when $[HInd] < [Ind^-]$.

III. $[Ind^-]$ approximately equals [HInd] at the end point.

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

34. The overall reaction occurring at the electrodes of a rechargeable metal hydride battery can be summarized as:

$$MH + NiO(OH) \rightleftharpoons M + Ni(OH)_2$$

Which statement is correct?

A. The oxidation state of Ni does not change.

B. M is oxidized by loss of hydrogen.

C. The oxidation state of one H atom changes from -1 to $+1$.

D. The oxidation state of one O atom changes from -1 to -2.

35. In a redox titration, manganate(VII) ions are reduced to manganese(II) ions and iron(II) ions are oxidized to iron(III) ions.

$MnO_4^-(aq)$ reduced to $Mn^{2+}(aq)$

$Fe^{2+}(aq)$ oxidized to $Fe^{3+}(aq)$

What volume, in cm^3, of $0.1\,mol\,dm^{-3}$ $MnO_4^-(aq)$ is required to reach the equivalence point in the titration of $20.00\,cm^3$ of $0.1\,mol\,dm^{-3}$ $Fe^{2+}(aq)$?

A. 2.00

B. 4.00

C. 20.00

D. 100.00

36. Which statements explain the following reactions occurring in the upper atmosphere?

	Chlorofluorocarbon (CFC) compounds break down to produce chlorine radicals but usually not fluorine radicals.	**A single chlorine radical breaks down many ozone, O_3, molecules.**
A.	C–Cl bond is stronger than C–F bond	chain propagation steps produce more radicals
B.	C–F bond is stronger than C–Cl bond	chain termination steps cause chlorine radicals to reform chlorine molecules
C.	C–Cl bond is stronger than C–F bond	chain termination steps cause chlorine radicals to reform chlorine molecules
D.	C–F bond is stronger than C–Cl bond	chain propagation steps produce more radicals

37. Which term cannot characterize ammonia, NH_3?

A. Lewis acid

B. Brønsted–Lowry acid

C. ligand

D. nucleophile

38. Which ion is a better leaving group in nucleophilic substitutions?

A. bromide ion

B. chloride ion

C. fluoride ion

D. iodide ion

39. Which statement is correct when 2-chloro-2-methylpentane reacts with water to form 2-methylpentan-2-ol?

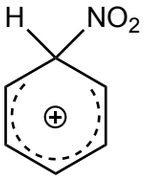
A. Water acts as a nucleophile and attacks the chlorine atom.

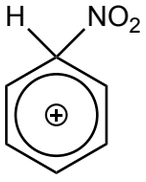
B. The reaction occurs in a single step.

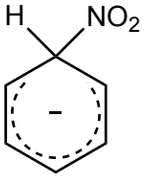
C. A carbocation intermediate is formed.

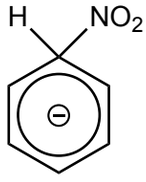
D. Homolytic bond fission occurs.

40. Which illustrates the correct intermediate formed in the nitration of benzene by NO_2^+?

A. 

C. 

B. 

D. 

Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

Specimen paper

Chemistry

Higher level

Paper 1 – Section A

2 pages

1.	A	16.	B	31.	A	46.	–
2.	B	17.	D	32.	C	47.	–
3.	C	18.	A	33.	B	48.	–
4.	A	19.	C	34.	C	49.	–
5.	C	20.	A	35.	B	50.	–
6.	B	21.	D	36.	D	51.	–
7.	B	22.	D	37.	A	52.	–
8.	D	23.	B	38.	D	53.	–
9.	B	24.	D	39.	C	54.	–
10.	D	25.	C	40.	A	55.	–
11.	D	26.	B	41.	–	56.	–
12.	A	27.	A	42.	–	57.	–
13.	A	28.	A	43.	–	58.	–
14.	B	29.	C	44.	–	59.	–
15.	C	30.	C	45.	–	60.	–

Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 1B

Specimen paper

Candidate session number

2 hours [Paper 1A and Paper 1B]

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for paper 1B is **[35 marks]**.
- The maximum mark for paper 1A and paper 1B is **[75 marks]**.

0000–6102

Please **do not** write on this page.

Answers written on this page
will not be marked.

Section B

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Hypochlorous acid, HOCl, is a sterilizing agent used in swimming pools and is produced when chlorine reacts with water.

$$Cl_2(aq) + H_2O(l) \rightleftharpoons HOCl(aq) + HCl(aq)$$

(a) Deduce the oxidation states of chlorine in the reactants and products. [2]

Reactant: Cl_2:

. . . . . .

Products: HOCl:

. . . . . .

HCl:

. . . . . .

(b) Explain why more chlorine reacts with water when NaOH (aq) is added. [1]

. . . . . .

. . . . . .

(c) Researchers studying the solubility of chlorine in pure water at different temperatures compile the following data from different sources.

Source	Temperature / °C	Solubility of chlorine
A	0	1.46 g per 100 cm^3
B	10	310 cm^3 per 100 cm^3
C	20	0.70 g per 100 cm^3
D	25	6300 mg per 1000 cm^3
E	30	177 cm^3 per 100 cm^3
F	30	0.57 g per 100 cm^3

(This question continues on the following page)

(Question 1 continued)

(i) Identify a problem in comparing the data from different sources. [1]

. . . . . .

. . . . . .

(ii) The units of solubility are converted to mol dm^{-3}.

Source	Temperature / °C	Solubility of chlorine	Solubility of chlorine / mol dm^{-3}
A	0	1.46 g per 100 cm^3	0.206
B	10	310 cm^3 per 100 cm^3	0.13
C	20	0.70 g per 100 cm^3	0.099
D	25	6300 mg per 1000 cm^3	0.089
E	30	177 cm^3 per 100 cm^3	
F	30	0.57 g per 100 cm^3	0.080

Complete the table by calculating the value for source E.

Assume the density of chlorine is 2.86 g dm^{-3} at 30 °C. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(iii) Suggest an explanation for the effect of temperature on solubility. [1]

. . . . . .

. . . . . .

(d) Suggest why chlorine is not often added to swimming pools directly. [1]

. . . . . .

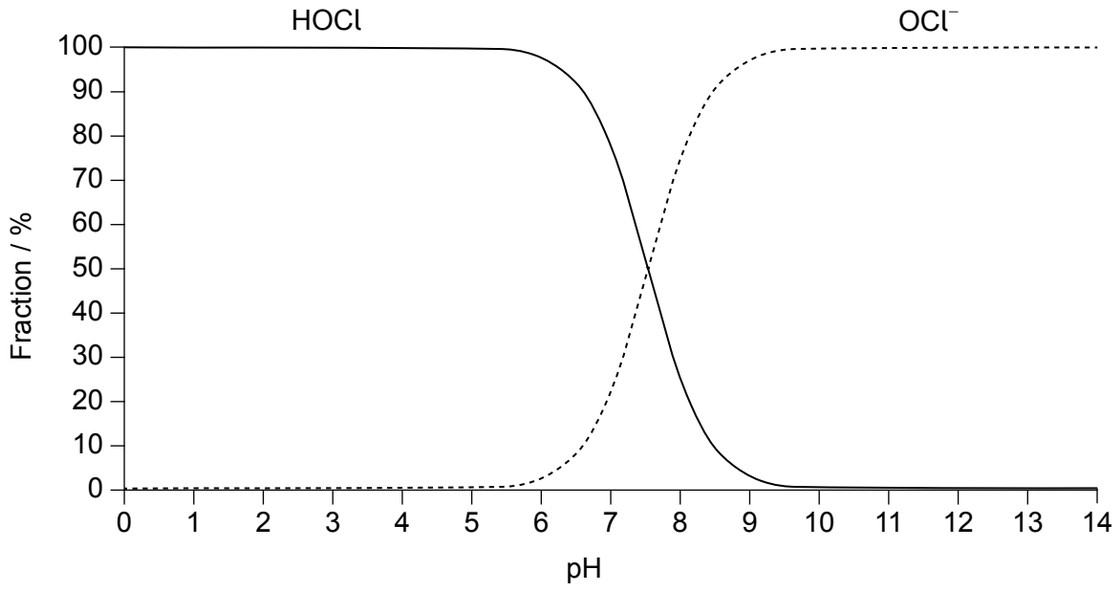
. . . . . .

(This question continues on the following page)

(Question 1 continued)

(e) HOCl ionizes to form the hypochlorite ion, OCl^-, which is a less effective disinfectant than the undissociated acid.

The graph shows the concentrations of HOCl (aq) and OCl^- (aq) at different pH values at 25 °C.



(i) Deduce the pH range where the water is most effectively sterilized. [1]

. . . . . .

. . . . . .

(ii) Determine, with reference to the graph in (e), the pK_a of HOCl. [2]

. . . . . .

. . . . . .

. . . . . .

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(This question continues on the following page)

(Question 1 continued)

(f) Ammonia released from sweat and urine reacts with HOCl to form a range of compounds including chloramines.

(i) Deduce an equation for the formation of dichloramine, $NHCl_2(aq)$, from ammonia and $HOCl(aq)$. [1]

. . . . . .

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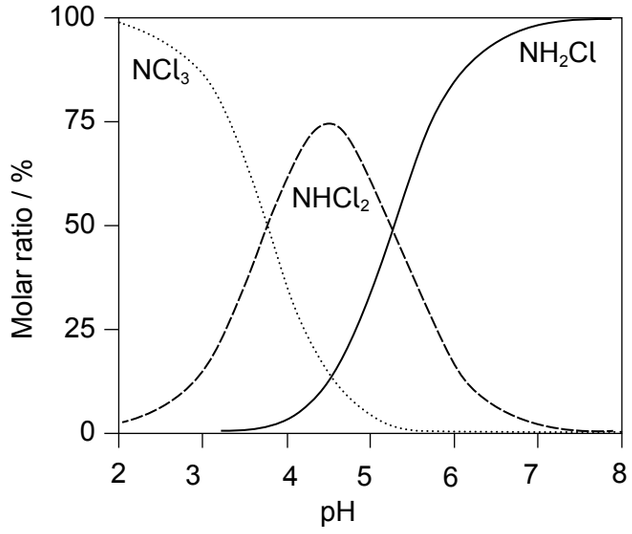
(ii) The graph shows the molar ratio of chloramines formed at different pH values at 25 °C. Trichloramine, NCl_3, causes pool water to smell bad.



State **two** conditions needed to prevent the bad smell. [2]

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(g) Suggest **two** reasons why operating a swimming pool at a lower temperature is favourable for the environment. [2]

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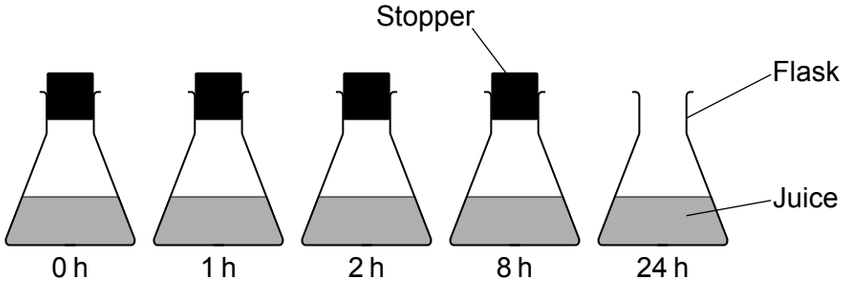
2. A student investigates the effect of exposure to the air on the ascorbic acid (vitamin C) concentration in a specific orange juice. Equal volumes of orange juice are sealed into identical flasks and placed in a refrigerator for two weeks. The samples in the refrigerator are exposed to the air by removing the stopper for a different number of hours each day as shown.



(a) Identify **two** variables that are controlled. [1]

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(b) The concentration of ascorbic acid is determined by titration with a standard iodine solution. Every few days, 10.00 cm^3 of orange juice is removed from each sample, diluted to 100.0 cm^3, and titrated.

(i) Suggest why the juice is diluted before titration. [1]

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(ii) Identify a possible systematic error with this method regarding the sample that is exposed for zero hours. [1]

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(iii) Suggest how an additional flask could be set up to verify whether the systematic error in (ii) has occurred. [1]

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(This question continues on the following page)

(Question 2 continued)

(c) The following data are collected during a titration.

Final burette reading = $16.10 \pm 0.05\,cm^3$

Initial burette reading = $1.10 \pm 0.05\,cm^3$

Calculate the percentage uncertainty of the titre. [1]

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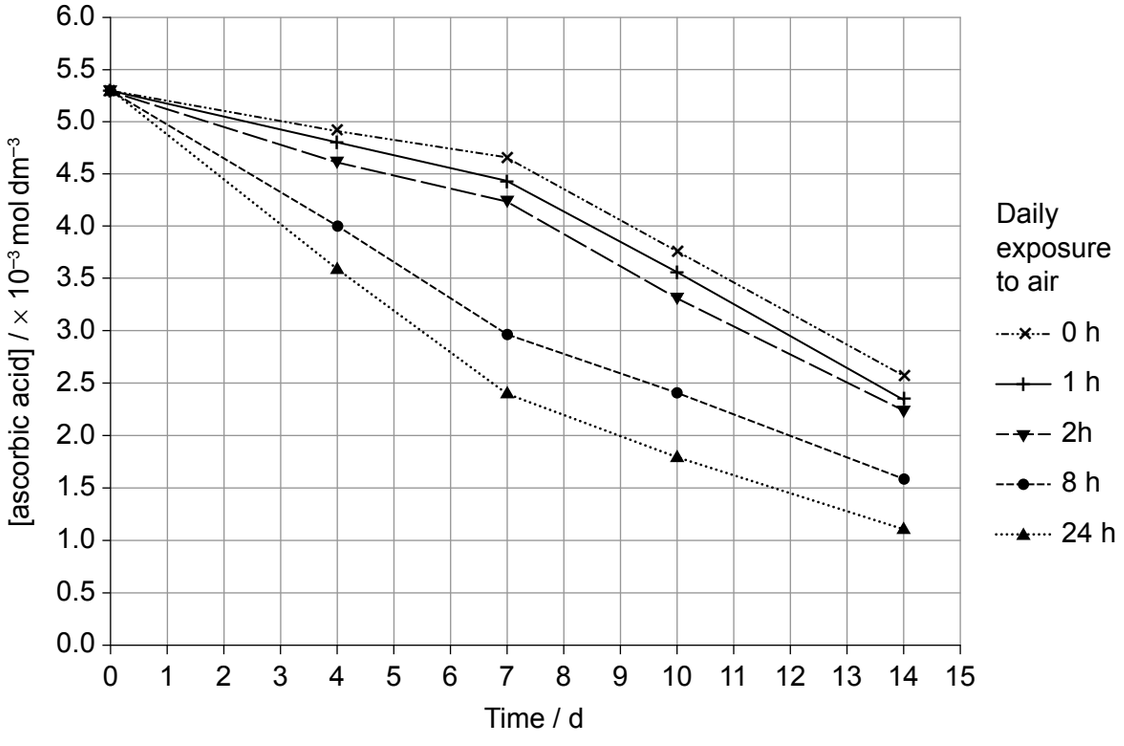
(d) The following graph shows the student's results.



(i) Calculate the average rate of decrease in ascorbic acid concentration for the 24 h sample over the period of 14 days, including units. [2]

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(This question continues on the following page)

(Question 2 continued)

(ii) The student's hypothesis is: "A lower ascorbic acid concentration will be found in juice exposed to the air for longer, due to oxidation of ascorbic acid by oxygen."

Discuss whether or not the data support the hypothesis. [2]

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(iii) State the implications of the results of the experiment for avoiding loss of vitamin C in the storage of orange juice. [1]

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(e) Suggest an extension to the investigation that would generate further recommendations for the storage of orange juice. [1]

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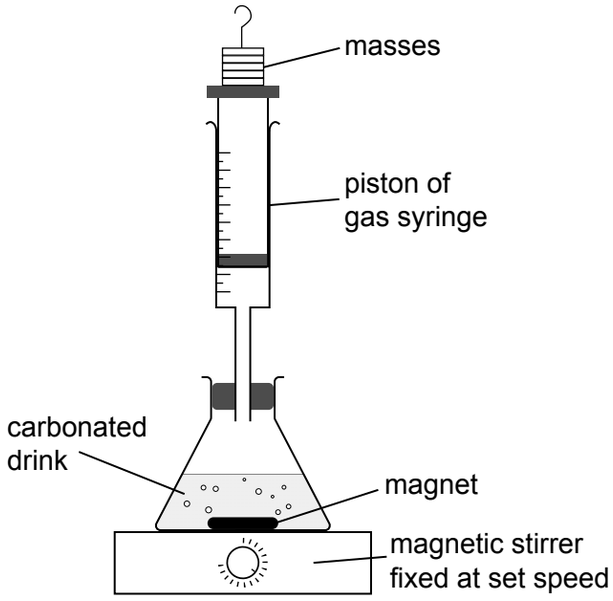
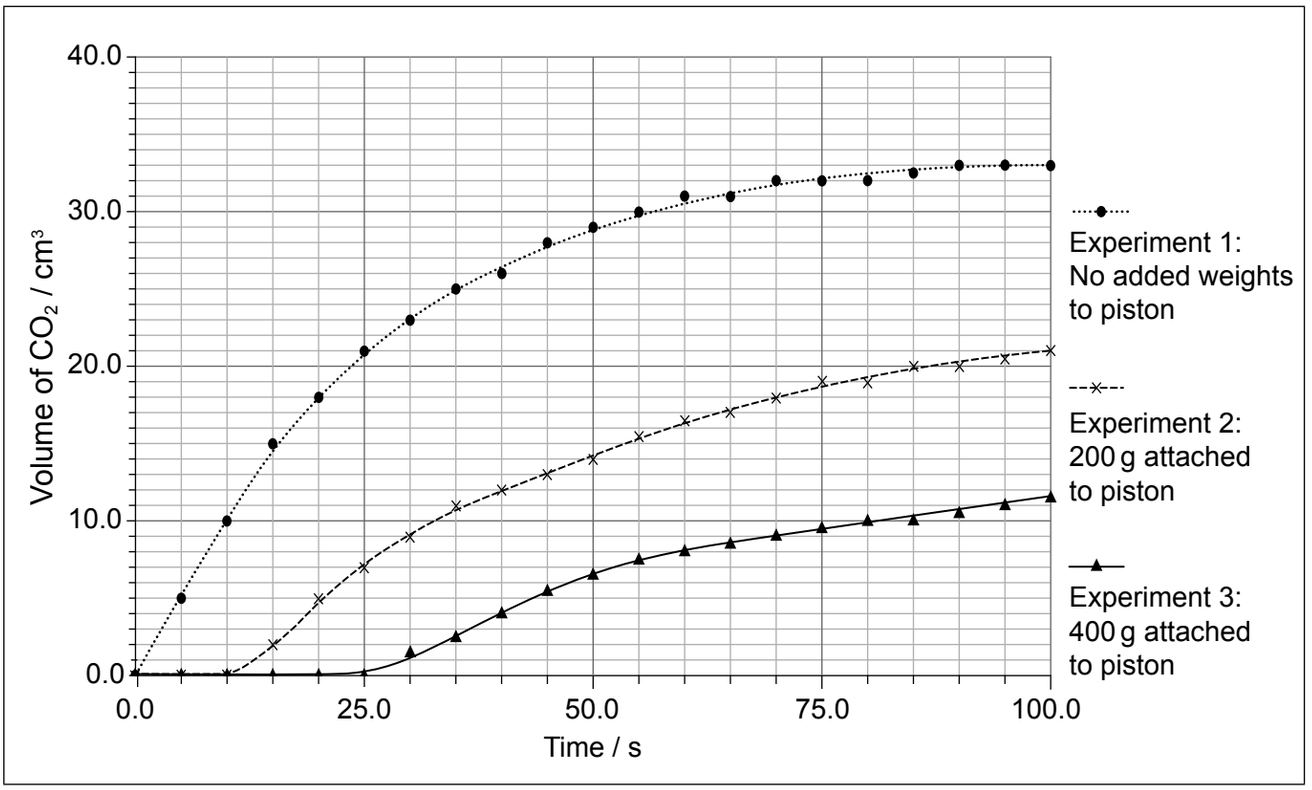
3. A student investigates the effect of pressure on the volume of carbon dioxide gas released from a carbonated drink poured into a flask.

To alter the pressure on the carbonated drink, masses are placed on top of the piston of the gas syringe as shown.



The graph shows some of the data collected.



(a) Determine, by annotating the graph, the initial rate of release of CO_2 in Experiment 1 in $cm^3 s^{-1}$. [2]

(This question continues on the following page)

(Question 3 continued)

(b) Estimate the time at which the piston would begin to move if a 600 g mass is used. [1]

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(c) Suggest **two** reasons why the volume of CO_2 collected in the gas syringe is smaller when more masses are placed on top of the piston. [2]

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(d) Calculate the percentage decrease in the final volume of CO_2 per 100 g mass placed on the piston, using the results of Experiment 1 and Experiment 3 at 100 s. [1]

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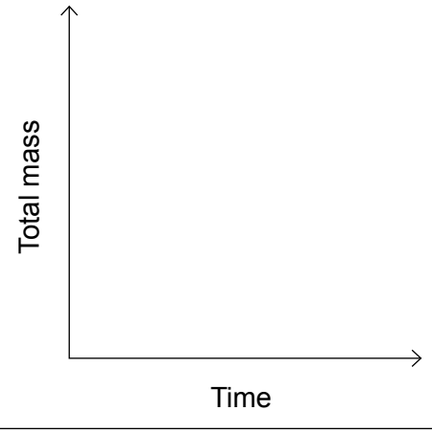
(e) Sketch and give a reason for a graph of the total mass of the apparatus in Experiment 1 against time. [2]



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References:

1(c) National Center for Biotechnology Information, 2020. *PubChem Compound Summary for CID 24526, Chlorine* [online] Available at: <https://pubchem.ncbi.nlm.nih.gov/compound/Chlorine> [Accessed 23 September 2020].

1(e) Norlex, 2020. *Chlorine for water disinfection.* [online] Available at: <https://norlexpoolspa.com/guidance/about-the-right-water-balance/safe> [Accessed 23 September 2020].

1(f)(ii) ResearchGate, 2015. *Distributions of chloramines as a function of pH.* [image online] Available at: <https://www.researchgate.net/figure/Distribution-of-chloramines-as-a-function-of-pH_fig8_273449675> [Accessed 23 September 2020].

Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

Specimen paper

Chemistry

Higher level

Paper 1 – Section B

7 pages

Question			Answers	Notes	Total
1.	(a)		*Reactant:* Cl_2 0 *Products:* *HOCl* +1 *HCl* -1 ✓ ✓	*Award **[2]** for three correct.* *Award **[1]** for any two correct.*	**2**
1.	(b)		equilibrium shifts to the right/product ***AND*** HCl/HOCl/H^+ removed/neutralized «by NaOH» ✓	*Accept any suitable equation to illustrate the neutralization reaction.*	**1**
1.	(c)	i	*Any one of:* pressure not given ✓ use of different units ***OR*** different ways of measuring ✓ different precisions/significant figures ***OR*** uncertainties not given ✓		**1 max**
1.	(c)	ii	0.177 «dm^3» × 2.86 «g dm^{-3}» / 0.506 «g» ***OR*** $\frac{0.506\text{«g»}}{70.9\text{«g mol}^{-1}\text{»} \times 0.100\text{«dm}^3\text{»}}$ ✓ 0.0714 «mol dm^{-3}» ✓	*Award **[2]** for correct final answer.* *Accept use of PV = nRT to calculate the solubility. Using P = 100 kPa gives a solubility of 0.0703 «mol dm^{-3}».*	**2**
1.	(c)	iii	«as temperature increases solubility decreases» dissolution is exothermic «hence equilibrium shifts to reactants side at higher temperatures» ***OR*** thermal energy overcomes intermolecular forces between chlorine and water ***OR*** negative entropy change «of dissolution» becomes more dominant at higher temperatures ✓	*Accept "kinetic energy increases with temperature «so more gas molecules escape»".*	**1**

1.	**(d)**		*Any one of:* toxic ✓ gas ✓ difficult to handle/store ✓		**1 max**
1.	**(e)**	**i**	0 – 6 ✓	*Accept any number or range below pH 6.5.*	**1**
1.	**(e)**	**ii**	7.5 ✓ $[OCl^-] = [HOCl]$ ***OR*** $[H^+] = K_a$ ✓		**2**
1.	**(f)**	**i**	$NH_3(aq) + 2HOCl(aq) \rightarrow NHCl_2(aq) + 2H_2O(l)$ ✓		**1**
1.	**(f)**	**ii**	pH > 5/high ✓ low concentration of Cl_2/HOCl/NH_3 ✓	*Do **not** accept general statements such as "less urination in the pool".*	**2**
1.	**(g)**		*Any two of* lower water evaporation ✓ reduce energy consumption/less energy needed to heat the water ✓ higher solubility of chlorine «so less chlorine lost»✓	*Accept "less chlorine needed **AND** fewer bacteria".*	**2 max**

Question			Answers	Notes	Total
2.	(a)		*Any two for [1 max]* type of orange juice temperature light intensity «initial» surface area ***OR*** «initial» volume ***AND*** flask ✓		**1 max**
2.	(b)	i	*Any one of:* to perform multiple titrations ✓ too concentrated «so using too much iodine solution» ✓ end-point colour easier to see ✓		**1 max**
2.	(b)	ii	flask has to be opened to withdraw samples «so not 0 h» ***OR*** air was present in the flask at the start «so the ascorbic acid was exposed to air» ✓		**1**
2.	(b)	iii	titrate only once after two weeks ***OR*** fill flask with nitrogen/argon/inert gas ***OR*** withdraw samples with syringe «without opening flask» ✓		**1**
2.	(c)		$\text{«}\frac{0.1\ \text{cm}^3}{15.0\ \text{cm}^3}\times 100 = \text{»}\ 0.7\ \text{«\%»}$ ✓		**1**
2.	(d)	i	$\text{«}\frac{(5.3\times10^{-3}\text{mol dm}^{-3} - 1.1\times10^{-3}\text{mol dm}^{-3})}{14\text{d}} = \text{»}3.0\times10^{-4}$ ✓ mol dm^{-3} d^{-1} ✓	*Accept values in the range 2.9 × 10^{-4} – 3.1 × 10^{-4}.* *Accept values converted to other units, such as* *3.4 × 10^{-9} – 3.6 × 10^{-9}* *mol dm^{-3} s^{-1}* *or 0.29–0.31 mmol dm^{-3} d^{-1}.*	**2**

2.	**(d)**	**ii**	«support» longer daily exposure leads to lower concentration of ascorbic acid ***OR*** 0 h decreases the least ✓ «doesn't support» no direct evidence of oxidation by oxygen ✓		**2**
2.	**(d)**	**iii**	should be stored in sealed container ***OR*** should be consumed in a few days after opening ✓		**1**
2.	**(e)**		*Any one of:* effect of temperature/light ***AND*** would show the value of refrigeration/darkness ✓ effect of preservative ✓ compare types of orange juice «e.g. fresh, from concentrate, etc.» ✓		**1 max**

Question			Answers	Notes	Total
3.	**(a)**		tangent drawn at t = 0 ✓ « $\frac{40.0\ \text{cm}^3}{35.0\ \text{s}}$ =» 1.14 «$\text{cm}^3\ \text{s}^{-1}$» ✓	*Accept values in the range 1.04 – 1.24 $cm^3\ s^{-1}$.*	**2**
3.	**(b)**		any value between 35 and 50 s ✓	*Only a simple estimation is required.*	**1**
3.	**(c)**		*Any two:* drink releases gas more slowly at higher pressure ✓ gas occupies lower volume at higher pressure ✓ gas is more soluble «in carbonated drink» at higher pressure ✓		**2 max**
3.	**(d)**		« $\frac{33.0\ \text{cm}^3 - 11.5\ \text{cm}^3}{33.0\ \text{cm}^3} \times \frac{100}{4} =$ » 16.3 «% per 100 g» ✓	*Accept values in the range 15.8 – 16.7 «% per 100 g».*	**1**
3.	**(e)**		horizontal line ✓ closed system ✓		**2**

Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

Specimen paper

Candidate session number

2 hours 30 minutes

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[90 marks]**.

0000–6103

Answer **all** questions. Answers must be written within the answer boxes provided.

1. A monoprotic acid, HX, is found to have the following composition by mass:

C = 39.99 % H = 6.73 % O = 53.28 %

(a) Determine the empirical formula of the compound HX. [2]

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(b) 25.00 cm^3 of a solution, containing 1.51 g of HX is titrated with a 0.750 mol dm^{-3} solution of NaOH (aq). The HX (aq) solution is exactly neutralized by 22.30 cm^3 of the NaOH (aq) solution. Determine the molar mass (*M*) of HX. [2]

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(c) State the molecular formula of HX. [1]

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(d) HX reacts with aqueous sodium hydroxide according to the equation:

$$HX(aq) + NaOH(aq) \rightarrow NaX(aq) + H_2O(l)$$

Identify a functional group present in HX. [1]

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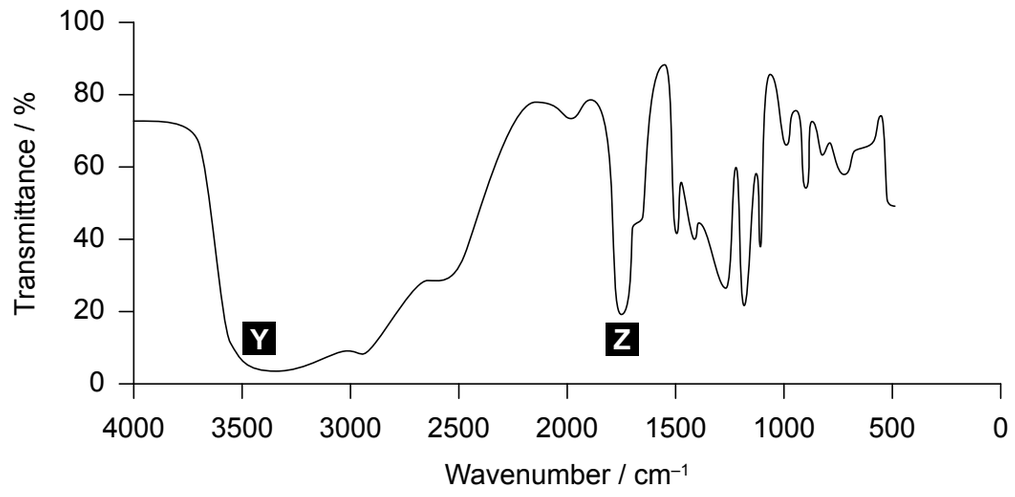
(Question 1 continued)

(e) The IR spectrum of HX is shown.

IR spectrum



(i) Identify the functional groups responsible for the absorption bands shown at **Y** and **Z** using section 20 of the data booklet. [1]

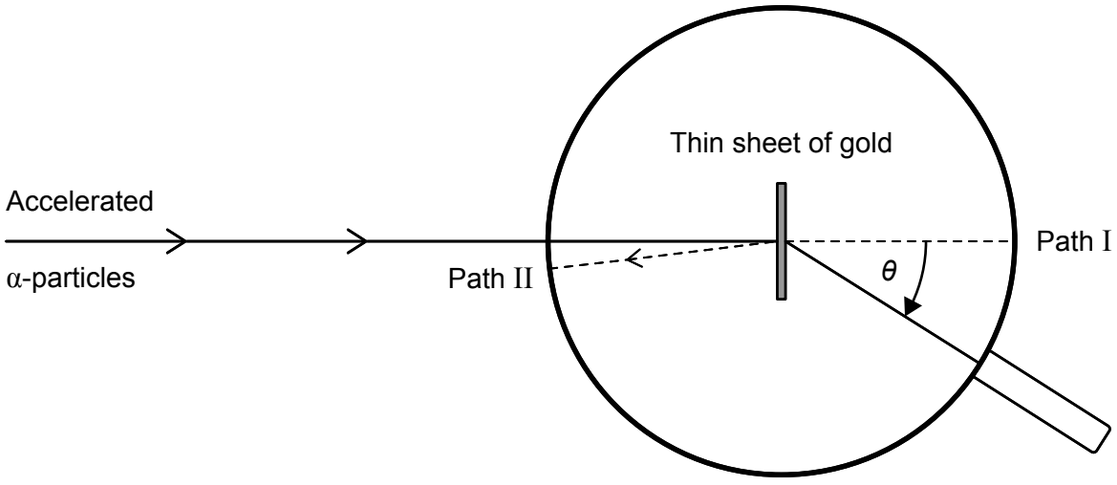
Y: . . . . . .

Z: . . . . . .

(ii) Draw a structural formula of HX that is consistent with all the evidence. [1]

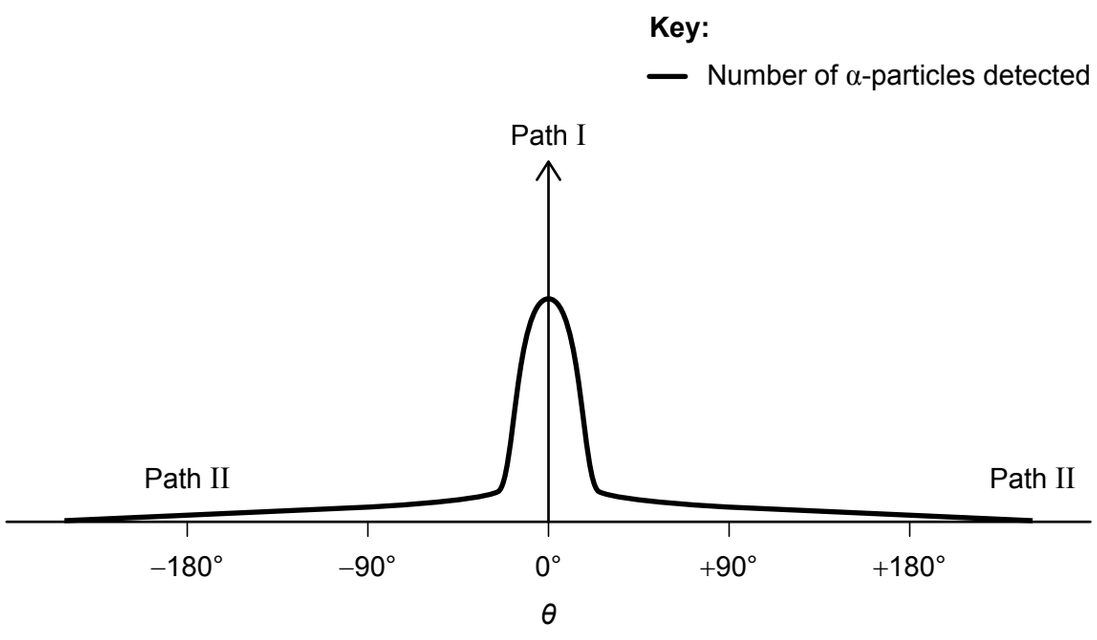
2. Scientific models are used to explain the structure of matter.

(a) An α-particle is a helium-4 nucleus. In an experiment, α-particles are accelerated towards a thin sheet of gold and their resulting paths are detected, giving evidence of the positive charge of the nucleus.



Angle of detection θ increase from 0° to 180°

The number of α-particles detected at different angles of deflection θ are shown.



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(Question 2 continued)

(i) Explain why some α-particles follow path II, rebounding from the gold sheet. [1]

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(ii) Most of the α-particles follow path I and pass straight through undeflected ($\theta = 0°$). Suggest a conclusion that can be made about the structure of the atom based on this evidence. [1]

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(This question continues on the following page)

(Question 2 continued)

(b) Helium was first identified by analysing spectra of solar radiation.

(i) Outline the appearance of the emission spectrum of helium. [1]

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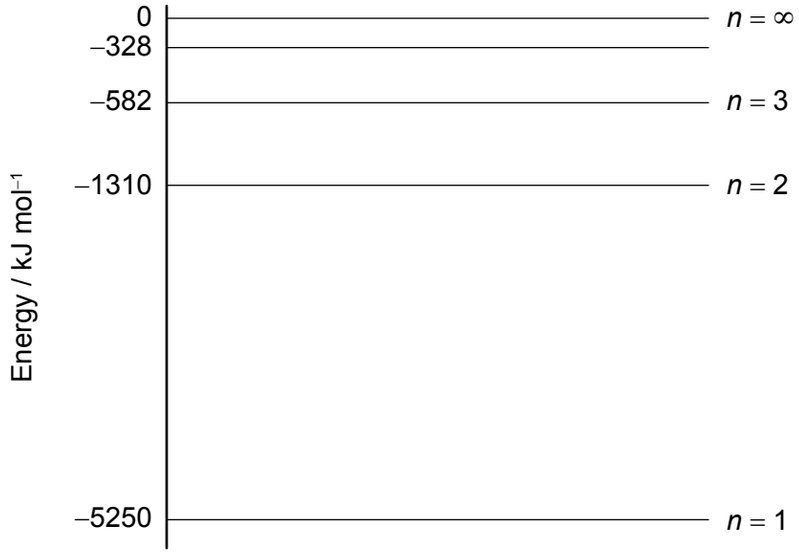
Emission spectra of one-electron systems can be explained using a model with the electron attracted to the nucleus by an electrostatic force.

This model predicts that the electron occupies discrete energy levels. Some energy levels for the He^+ ion are shown.



(ii) Explain how the frequencies observed in emission spectra support the idea of the electron occupying discrete energy levels. [2]

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(This question continues on the following page)

(Question 2 continued)

(iii) Deduce the ionization energy of the He^+ ion from the energy levels shown. [1]

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(iv) Suggest **two** reasons why the ionization energy of the hydrogen atom is significantly smaller than the ionization energy of the He^+ ion. [2]

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(v) Suggest why the model outlined in (b)(ii) can predict the emission spectrum of He^+ but not He. [1]

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(c) Outline why models of the atom have evolved over time. [1]

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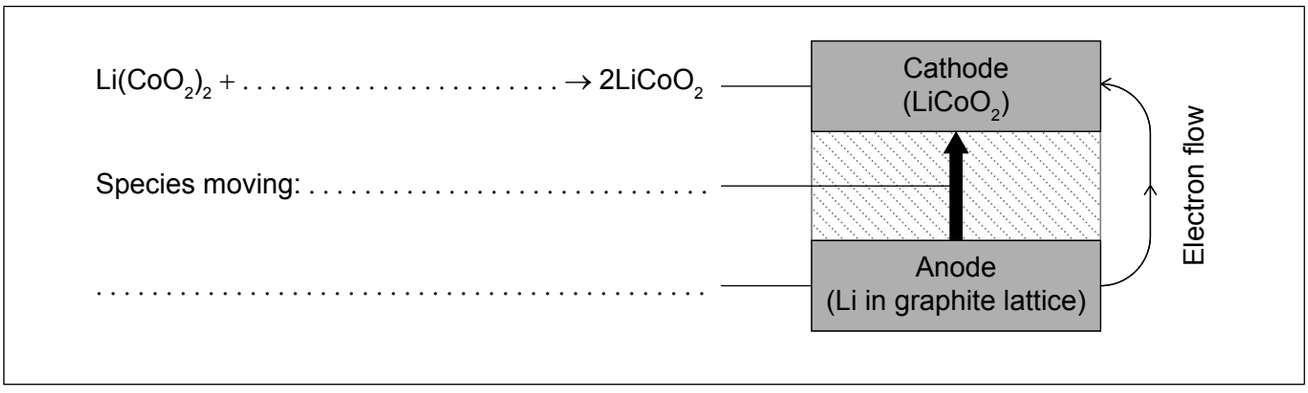
3. The development of the lithium-ion battery won the 2019 chemistry Nobel Prize.

(a) The diagram represents a cell in such a battery delivering a current. Complete the half-equations on the diagram and identify the species moving between the electrodes. [3]



(b) The discharge of the lithium-ion battery is a spontaneous chemical reaction producing a potential difference and an increase in temperature.

(i) Deduce the signs of the following: [1]

$\Delta H_{discharge}$: . . . . . .

E_{cell}: . . . . . .

$\Delta G_{discharge}$: . . . . . .

(ii) The lithium-ion battery can be recharged by reversing the reactions at each electrode. Compare the absolute value of $\Delta G_{recharge}$ and $\Delta G_{discharge}$. [1]

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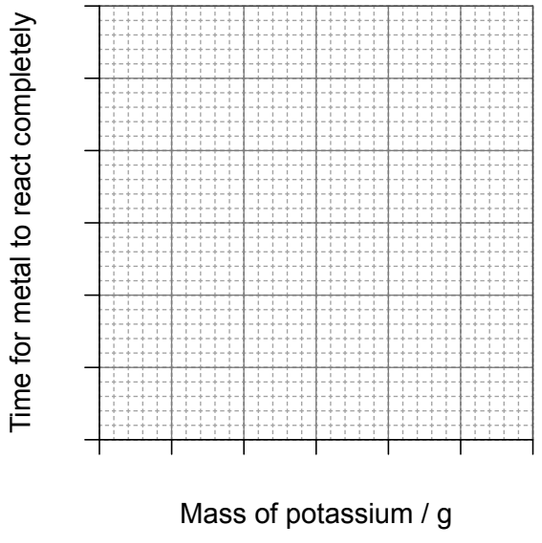
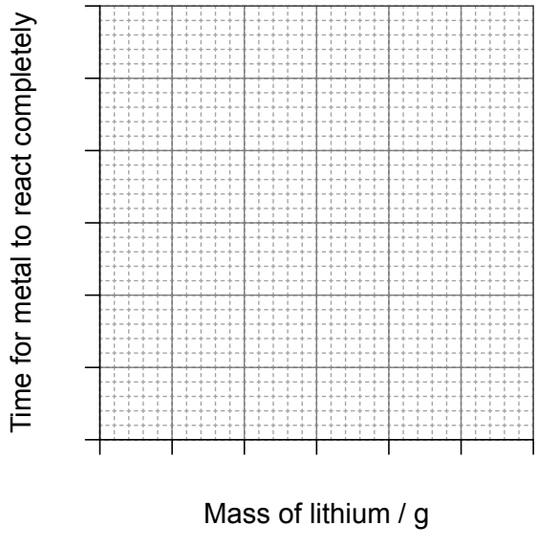
(This question continues on the following page)

(Question 3 continued)

(c) In a simulation, equal masses of potassium and lithium are added to water and the time taken for the metals to fully react is recorded. Five different increasing masses of each metal are used, and the reaction is timed.

(i) Sketch the graphs on the axes to show the expected results of this experiment. [2]





(ii) Suggest a reason why comparing the time for complete reaction of equal masses is not a valid measure of reactivity. [1]

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(iii) Lithium carbide, Li_2C_2, is one of many compounds of lithium and carbon. Determine the percentage covalent character and bonding type in this compound by using sections 9 and 17 of the data booklet. [2]

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Answers written on this page
will not be marked.

(Question 3 continued)

(iv) Calculate the Gibbs energy of formation, $\Delta G_f^{\ominus}$, in kJ mol^{-1}, for Li_2C_2 at 298.15 K. Use the data provided and section 1 of the data booklet. [1]

$$\Delta H_f^{\ominus} \, Li_2C_{2\,solid} = -62 \, kJ \, mol^{-1}$$

$$\Delta S_f^{\ominus} \, Li_2C_{2\,solid} = -11 \, J \, mol^{-1} \, K^{-1}$$

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(v) Draw the Lewis formula of the anion in the salt Li_2C_2. [2]

(vi) State the type of hybridization shown by the carbon atoms in the anion. [1]

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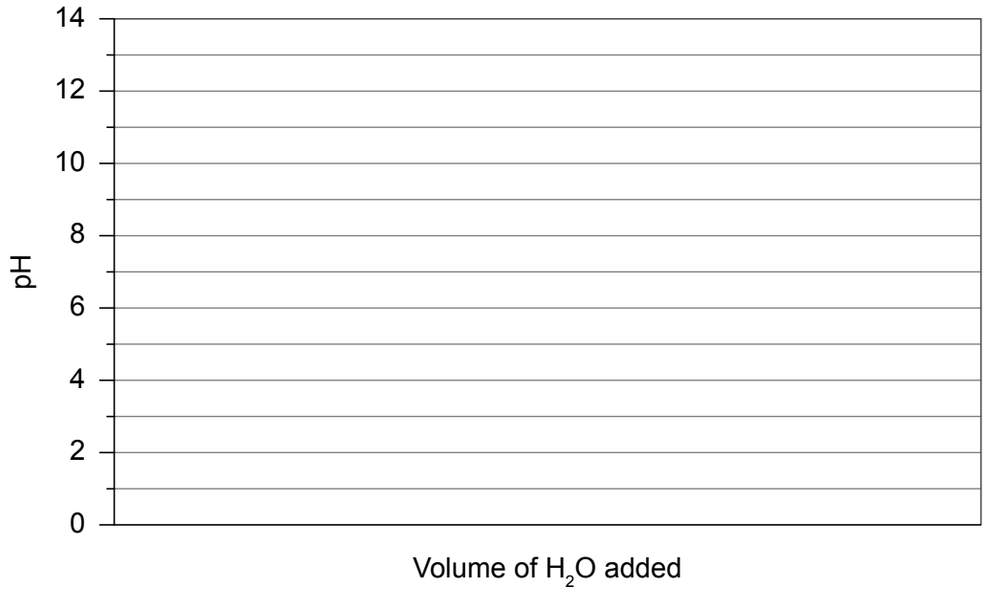
will not be marked.

4. Hydrochloric acid is an important chemical reactant and industrial chemical.

(a) A pH probe is placed in a small volume of 0.10 mol dm^{-3} solution of hydrochloric acid. The pH is recorded while a steady stream of distilled water is added to the acid at constant temperature.

(i) On the axes, sketch the graph of pH against volume of water added. [3]



(ii) The experiment is repeated using 0.10 mol dm^{-3} ethanoic acid at the same temperature. Calculate the initial pH of the ethanoic acid. [2]

pK_a ethanoic acid = 4.76

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(This question continues on the following page)

(Question 4 continued)

(b) Chloride ions can form complex ions with some transition metals. The formulas and colours of three compounds of cobalt are:

Compound	Colour
$[Co(NH_3)_6]Cl_3$	orange–yellow
$[Co(NH_3)_5Cl]Cl_2$	purple
$[Co(NH_3)_4Cl_2]Cl$	green

(i) Deduce the oxidation state of cobalt in $[Co(NH_3)_5Cl]Cl_2$ and the charge of the complex ion. [2]

Oxidation state: . . . . . .

Charge of complex ion: . . . . . .

(ii) Describe the bonding of chloride ions in $[Co(NH_3)_4Cl_2]Cl$. [2]

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(iii) Explain why these complex ions are coloured. [3]

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(This question continues on the following page)

(Question 4 continued)

(iv) State and explain, in which of the complex ions, the electron transitions responsible for the colour require the highest energy. Use the colour wheel and the electromagnetic spectrum in sections 5 and 15 of the data booklet. [2]

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Answers written on this page
will not be marked.

5. Heptadecane, $C_{17}H_{36}$, can be extracted from crude oil or cactus plants.

(a) Write an equation for the complete combustion of $C_{17}H_{36}$. [1]

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. . . . . .

(b) The enthalpy of combustion of $C_{17}H_{36}$ is $-11\,350\,kJ\,mol^{-1}$.

(i) Calculate the maximum energy produced when 2.00 g of $C_{17}H_{36}$ is combusted. [2]

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(ii) Determine the maximum temperature change when 500.0 cm^3 of water is heated by a 2.00 g sample of $C_{17}H_{36}$. [2]

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(iii) Outline **two** assumptions made in the calculation in (b)(ii). [2]

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(This question continues on the following page)

(Question 5 continued)

(c) Explain why biofuels contribute less to climate change than fossil fuels. [1]

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(d) Heptadecane can be broken down into smaller molecules. Consider the reaction:

$$C_{17}H_{36}(g) \rightarrow 2\ C_2H_4(g) + C_{13}H_{28}(g)$$

(i) Determine the standard enthalpy change, $\Delta H^{\ominus}$, for the reaction stated, using section 12 of the data booklet. [3]

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(ii) Determine the enthalpy change of reaction. Use the data provided and section 13 of the data booklet. [2]

$$\Delta H_f\ (C_{17}H_{36}) = -393.9\,\text{kJ mol}^{-1}$$

$$\Delta H_f\ (C_{13}H_{28}) = -311.5\,\text{kJ mol}^{-1}$$

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(This question continues on the following page)

(Question 5 continued)

(iii) Comment on the difference between the two values calculated in (d)(i) and (d)(ii). [1]

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(iv) Predict the sign of the entropy change of the reaction, giving a reason. [1]

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(v) Discuss, with reference to (d)(ii) and (d)(iv), how temperature affects the spontaneity of the reaction. [2]

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(e) Ethene can be converted to ethanol in one reaction. State the equation for this reaction. [1]

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(This question continues on the following page)

(Question 5 continued)

(f) Ethanol reacts with oleic acid to produce ethyl oleate.

$$C_{17}H_{33}COOH(l) + CH_3CH_2OH(l) \rightleftharpoons C_{17}H_{33}COOCH_2CH_3(l) + \mathbf{X}(l)$$

(i) Identify the type of reaction and the side product **X**(l). [1]

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(ii) Calculate the atom economy of the reaction. [1]

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(iii) Discuss why the atom economy of a reaction is an important consideration when evaluating the impact of a reaction in an industrial process. [2]

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(iv) Deduce the equilibrium constant expression, K_c, for the reaction. Assume that the reaction is homogeneous. [1]

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(This question continues on the following page)

(Question 5 continued)

(g) The equilibrium constant, K_c, is 9.3×10^{-5} at 75 °C.

(i) Determine the amount of ethyl oleate present in the reaction mixture at equilibrium when 0.10 mol dm^{-3} of oleic acid reacts with 0.10 mol dm^{-3} of ethanol at 75 °C and state any assumptions you have made in your calculation. [2]

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(ii) State **one** method of increasing the yield. [1]

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Please **do not** write on this page.

Answers written on this page
will not be marked.

6. Halogens are important reactants in the laboratory and in the environment.

(a) (i) Write an equation for the homolytic fission of chlorine under UV light, showing the movement of electrons. [2]

. . . . . .

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(ii) Under different conditions, chlorine molecules can break down by heterolytic fission. Write an equation showing the movement of electrons. [1]

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(iii) Identify, giving a reason, which one of the three species produced in (a)(i) and (a)(ii) is an electrophile. [1]

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(iv) Draw the full structural formula of the most stable carbocation formed in the reaction between hydrogen chloride and propene. [1]

(v) Outline why this intermediate is the most stable. [1]

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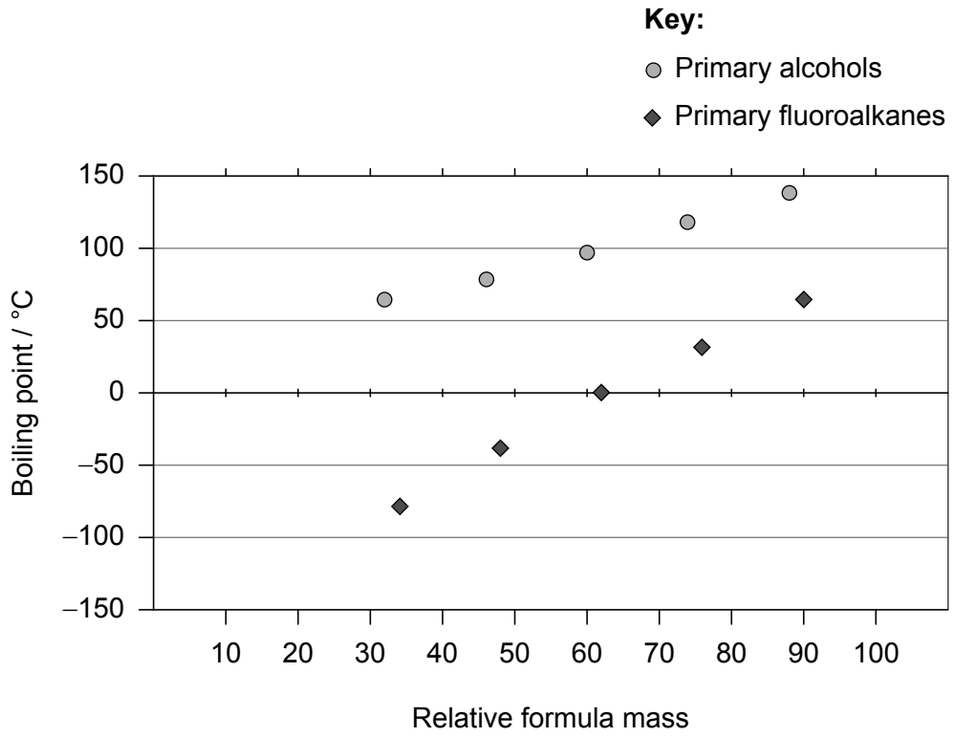
(This question continues on the following page)

(Question 6 continued)

(b) The graph shows the boiling points of the first five straight-chain primary alcohols and fluoroalkanes.



(i) Outline why the alcohols have higher boiling points than fluoroalkanes of similar relative formula mass. [1]

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(ii) Explain the general trend in the boiling points shown for the alcohols. [2]

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(Question 6 continued)

(iii) Predict, giving a reason, how the boiling points of branched fluoroalkanes compare to their straight-chain isomers. [1]

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(iv) Explain why primary bromoalkanes have higher boiling points compared to the corresponding fluoroalkanes. [1]

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(c) (i) Draw the structures of 2-bromobutane and its tertiary isomer. [2]

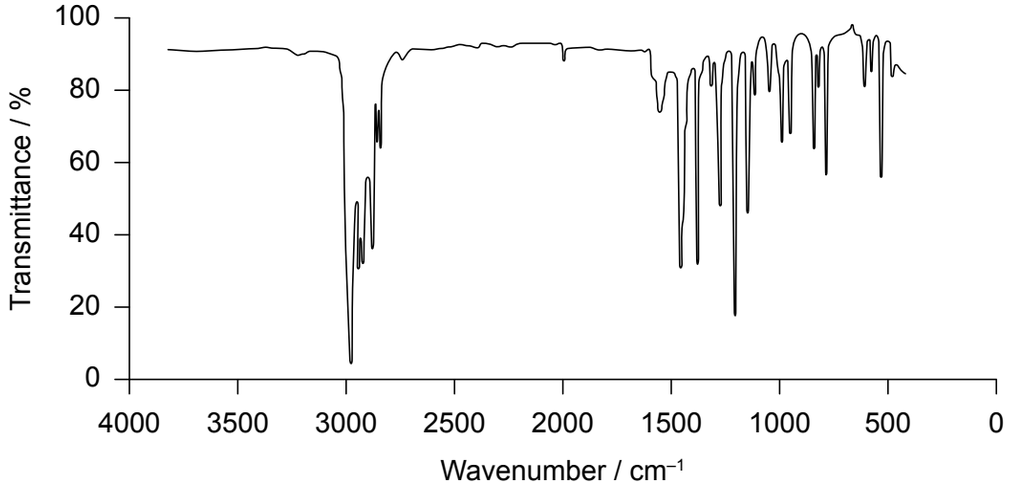
(ii) One of the isomers in (c)(i) exists as enantiomers. Draw their stereochemical formulas. [1]

(This question continues on the following page)

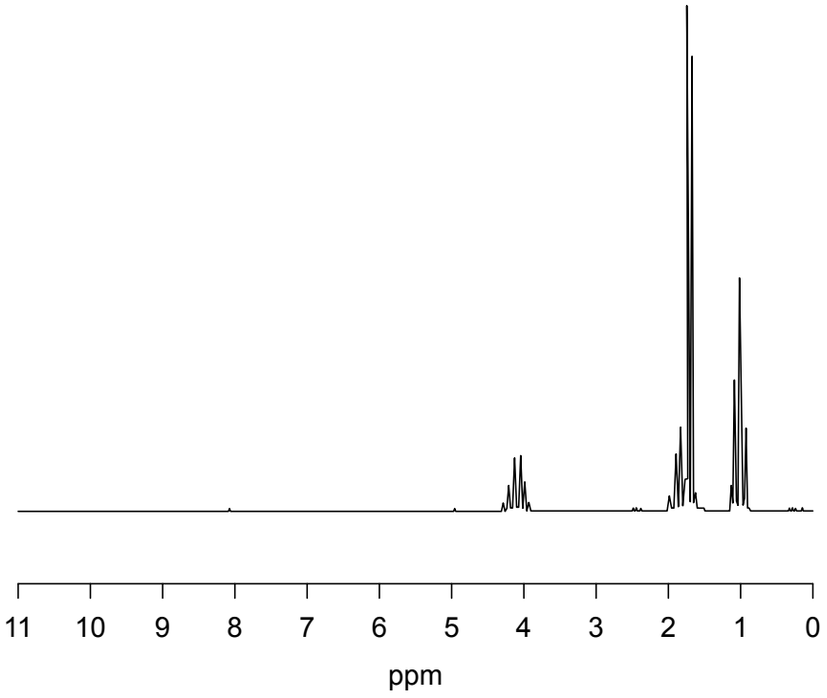
(Question 6 continued)

(iii) The IR and ^{1}H NMR spectra of 2-bromobutane are shown. Circle the regions which indicate the presence of the bromine atoms. Use sections 20 and 21 of the data booklet. [2]

2-Bromobutane infrared spectrum



^{1}H NMR spectrum



(This question continues on the following page)

(Question 6 continued)

(iv) Explain whether the IR and ^{1}H NMR spectra can be used to distinguish the tertiary isomer from 2-bromobutane. [2]

IR: . . . . . .

^{1}H NMR: . . . . . .

Disclaimer:

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References:

6. (c)(iii) [2-Bromobutane infrared spectrum] NIST, 1960. Butane, 2-bromo-. *NIST Chemistry WebBook*. [online] Available at: <https://webbook.nist.gov/cgi/cbook.cgi?ID=C78762&Units=SI&Type=IR-SPEC&Index=1#IR-SPEC> [Accessed 1 February 2021].

[^{1}H NMR spectrum] ChemicalBook, n.d. *2-Bromobutane (78-76-2) 1H NMR*. [CAS DataBase List>78-76-2More Spectrum> 2-Bromobutane (78-76-2) 1H NMR] ChemicalBook [online] Available through: <https://www.chemicalbook.com/SpectrumEN_78-76-2_1HNMR.htm> [Accessed 1 February 2021].

Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

Specimen paper

Chemistry

Higher level

Paper 2

17 pages

International Baccalaureate®
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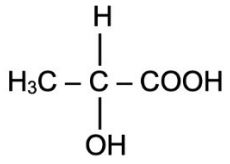
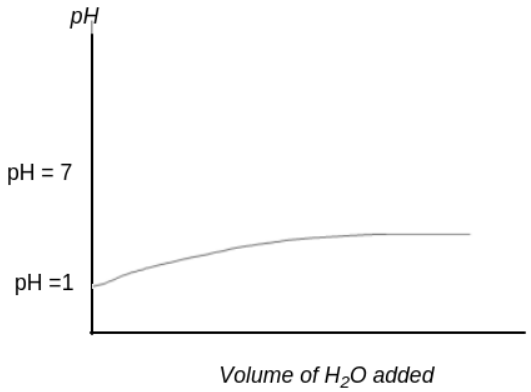
Question			Answers	Notes	Total
1.	(a)		n_C = «$\frac{39.99\,g}{12.01\,g\,mol^{-1}}$ =» 3.33 «mol» n_H = «$\frac{6.73\,g}{1.01\,g\,mol^{-1}}$ =» 6.66 «mol» n_O= «$\frac{53.28\,g}{16.00\,g\,mol^{-1}}$ ==» 3.33 «mol» ✓ CH_2O ✓		2
1.	(b)		n_{HX} (= nNaOH =) 0.750 «mol dm^{-3}» × 0.02230 «dm^3» / 0.0167 «mol» ✓ M_{HX} = ($\frac{1.51\ g}{0.0167 mol}$ =) 90.4 g mol^{-1} ✓	*Accept 90.3 «g mol^{-1}».*	2
1.	(c)		$C_3H_6O_3$ ✓	*Accept consistent feasible structural formula.*	1
1.	(d)		carboxyl/COOH ✓	*Do **not** accept "carbonyl/C=O".*	1
1.	(e)	(i)	Y: O-H/hydroxyl «with hydrogen bonding» ***AND*** Z: C=O/carbonyl «in carboxylic acid» ✓		1
1.	(e)	(ii)	 ***OR*** $HO–CH_2–CH_2–COOH$ ✓		1

Question			Answers	Notes	Total
2.	**(a)**	**(i)**	repelled by «hitting/close contact with» gold nucleus ✓		**1**
2.	**(a)**	**(ii)**	atom is mainly empty space/vacuum ***OR*** nucleus is very small «compared to the size of the atom» ✓		**1**
2.	**(b)**	**(i)**	discrete/series of lines of different frequency/wavelength ✓		**1**
2.	**(b)**	**(ii)**	energy of photon relates to a frequency «in the spectrum» ✓ energy of photon depends on difference in energy levels ✓		**2**
2.	**(b)**	**(iii)**	5250 «kJ mol^{-1}» ✓		**1**
2.	**(b)**	**(iv)**	H half/lower nuclear charge/number of protons ✓ H larger/double radius ✓		**2**
2.	**(b)**	**(v)**	electron-electron interactions «need to be taken in account» ✓		**1**
2.	**(c)**		*Any one of:* new evidence new technology developments in related models models incomplete/failed to account for all observations ✓		**1**

Question			Answers	Notes	Total
3.	(a)		$Li(CoO_2)_2 + \quad Li^+ + e^- \rightarrow 2LiCoO_2$ ✓ Species moving: Lithium ions/Li^+ ✓ $Li \rightarrow Li^+ + e^-$ ✓		3
3.	(b)	(i)	$\Delta H_{discharge}$: negative ***AND*** E_{cell}: positive ***AND*** $\Delta G_{discharge}$: negative ✓		1
3.	(b)	(ii)	$\Delta G_{recharge} > \Delta G_{discharge}$ ✓		1
3.	(c)	(i)	separate curves/lines for Li and K sketched ***AND*** both increasing ✓ steeper gradient for Li ***OR*** curve/line for Li higher ✓		2
3.	(c)	(ii)	equal masses «of different substances» do not contain equal amounts/moles ✓		1
3.	(c)	(iii)	«Avg electronegativity = 1.8 Δ electronegativity = 1.6» % covalent character = 45-55 ✓ ionic ✓		2
3.	(c)	(iv)	«$\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$ = -62 – 298 × -0.011 =» -59 «kJ mol^{-1}» ✓		1

Question			Answers	Notes	Total
3.	**(c)**	**(v)**	$[:C\equiv C:]^{2-}$ 2- charge ✓ $:C\equiv C:$ ✓		**2**
3.	**(c)**	**(vi)**	sp ✓		**1**

Question			Answers	Notes	Total
4.	(a)	(i)	 start at pH = 1 ✓ curve with decreasing gradient ✓ must finish below pH = 7 ✓		3
4.	(a)	(ii)	$K_a = \frac{[H^+][CH_3COO^-]}{[CH_3COOH]}$ ***OR*** $K_a = \frac{[H^+]^2}{[CH_3COOH]}$ ***OR*** $pK_a = 2pH - 1$ ***OR*** $pH = \frac{pK_a + 1}{2} =$ ✓ 2.88 ✓		2

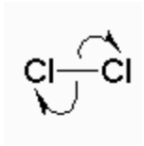
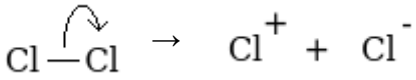
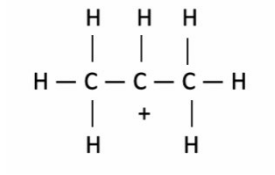
Question			Answers	Notes	Total
4.	**(b)**	**(i)**	*Oxidation state:* +3 ✓ *Charge of complex ion:* 2+ ✓		**2**
4.	**(b)**	**(ii)**	two chlorides covalently bonded/coordination bond to cobalt ion ✓ one chloride ionically bonded to complex ion ✓		**2**
4.	**(b)**	**(iii)**	3d sub-level split in presence of ligands ✓ light is absorbed when electrons promoted between split-levels ✓ colour seen is complementary to the light absorbed ✓		**3**
4.	**(b)**	**(iv)**	complex $[Co(NH_3)_6]\ Cl_3$ ✓ absorbs blue-purple light/wavelength 424 nm/shortest wavelength/highest energy ✓		**2**

Question			Answers	Notes	Total
5.	**(a)**		$C_{17}H_{36}(l) + 26O_2(g) \rightarrow 17CO_2(g) + 18H_2O(l)$ ✓		**1**
5.	**(b)**	**(i)**	$nC_{17}H_{36}$ = « $\frac{2.00\text{ g}}{[(17 \times 12.01\text{ g mol}^{-1}) + (36 \times 1.01\text{ g mol}^{-1})]} = \frac{2.00\text{ g}}{240.53\text{ g mol}^{-1}} =$ » 0.008315/0.00831 «mol» ✓ « energy = 11350 kJ mol^{-1} × 0.008315 mol = » 94.4 «kJ» ✓		**2**
5.	**(b)**	**(ii)**	94 400 = 500.0 g × 4.18 J g^{-1} K^{-1} × ΔT ✓ ΔT = 45.2«K» ✓		**2**
5.	**(b)**	**(iii)**	*Any two:* water does not evaporate ✓ heat is not lost to the surroundings ***OR*** all heat is transferred to the water ✓ density of water is 1 g cm^{-3} ✓ water is pure ✓ complete combustion ✓		**2 max**

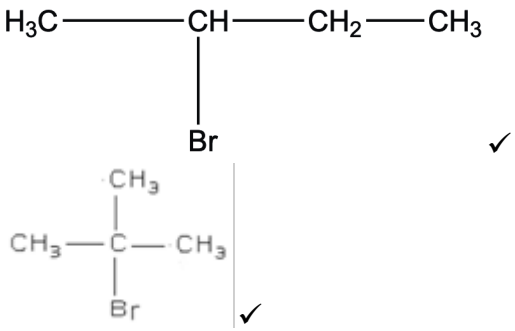
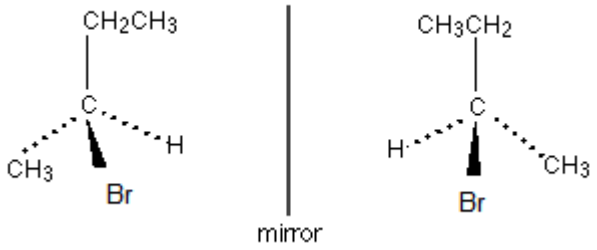
Question			Answers	Notes	Total
5.	**(c)**		CO_2 consumed while plant is growing «and later released when biofuel is combusted» ***OR*** photosynthesis uses up CO_2 «later released when biofuel is combusted» ✓		**1**
5.	**(d)**	**(i)**	bonds broken: 4(C – C) / 4 × 346 ✓ bonds formed: 2(C=C) / 2 × 614 ✓ $\Delta H^{\ominus}$ = «4 × 346 kJ – 2 × 614 kJ / 1384 kJ – 1228 kJ =» $\Delta H^{\ominus}$ = «+»156 «kJ» ✓	*Award **[3]** for correct final answer.*	**3**
5.	**(d)**	**(ii)**	«$\Delta H = \Sigma \Delta H_f$ (products) - $\Sigma \Delta H_f$(reactants)» ΔH = (-311.5 + 2(52.0)) – (-393.9) ✓ ΔH = «+»186.4 «kJ mol^{-1}» ✓		**2**
5.	**(d)**	**(iii)**	(d)(ii) more accurate than (d)(i) as bond energies are average values ***OR*** (d)(ii) more accurate than (d)(i) as not specific to bonds in the reaction ✓		**1**
5.	**(d)**	**(iv)**	positive ***AND*** increase in number of moles/molecules «of gas» ✓		**1**
5.	**(d)**	**(v)**	$\Delta H > 0$ «*and* $\Delta S > 0$» ***AND*** reaction spontaneous if ΔG «= $\Delta H - T\Delta S$» < 0 ✓ at high«er» T reaction «more» spontaneous/ΔG «more» negative ✓		**2**

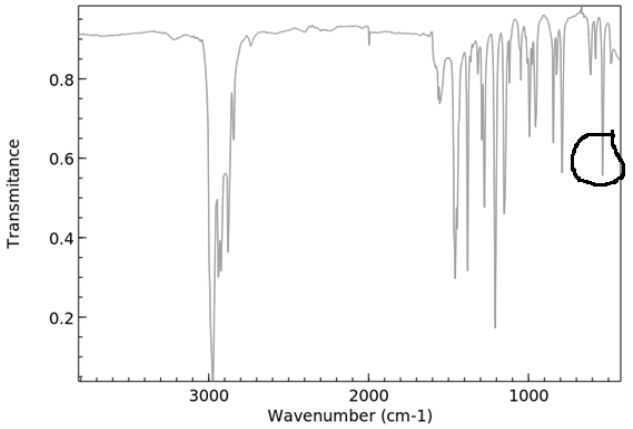
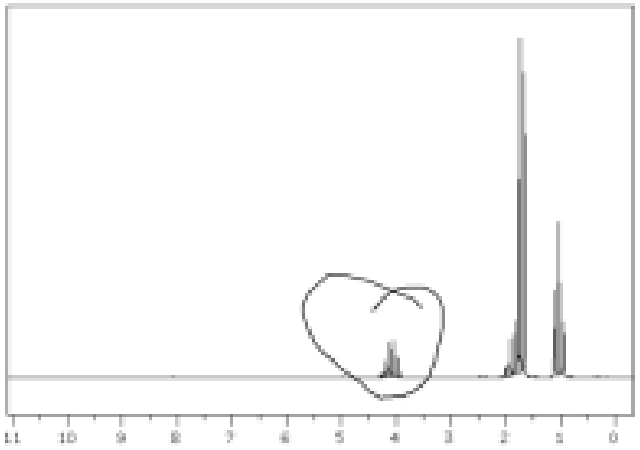
Question			Answers	Notes	Total
5.	**(e)**		$C_2H_4(g) + H_2O(g) \rightarrow C_2H_5OH(g)$ ✓		**1**
5.	**(f)**	**(i)**	condensation/esterification ***AND*** H_2O / water ✓		**1**
5.	**(f)**	**(ii)**	«20(12.01) + 38(1.01) + 2(16.00) = 310.58 $\frac{100 \times 310.58}{(310.58 + 18.02)} =$ » 94.5 % ✓		**1**
5.	**(f)**	**(iii)**	*Any two of:* sustainable development ✓ more economical/efficient ✓ better use of natural resources ✓ reduces waste ✓		**2 max**
5.	**(f)**	**(iv)**	$K = \frac{[C_{17}H_{33}COOCH_2CH_3][H_2O]}{[C_{17}H_{33}COOH][CH_3CH_2OH]}$	*Accept expressions with [X(l)] instead of [H_2O].*	**1**

Question			Answers	Notes	Total
5.	**(g)**	**(i)**	*K* small ***AND*** $[\text{reactants}]_{eqm} = [\text{reactants}]_0 / 0.10$ ✓ $n_{oleate} = « (0.10 \times 0.10 \times 9.3\times10^{-5})^{½} =» 9.6\times10^{-4}$ «mol» ✓		**2**
5.	**(g)**	**(ii)**	remove water ***OR*** add more oleic acid ***OR*** add more ethanol ✓		**1**

Question			Answers	Notes	Total
6.	**(a)**	**(i)**	 → 2 Cl• 2 Cl• ✓ single-barbed/fish-hooks ✓	*Accept chlorine atoms.*	**2**
6.	**(a)**	**(ii)**	 *full/double-barbed arrow **AND** charges on both ions are required for mark.* ✓		**1**
6.	**(a)**	**(iii)**	Cl^+ ***AND*** can accept a pair of electrons to form a new bond ✓		**1**
6.	**(a)**	**(iv)**	 ✓		**1**
6.	**(a)**	**(v)**	positive inductive effects from two $-CH_3$ /methyl groups ✓		**1**

Question			Answers	Notes	Total
6.	**(b)**	**(i)**	hydrogen bonding stronger than dipole-dipole ✓		**1**
6.	**(b)**	**(ii)**	«increase because» stronger London/dispersion forces ✓ more electrons ***OR*** surface contact ✓		**2**
6.	**(b)**	**(iii)**	lower ***AND*** more compact shape reduces contact area/London/ dispersion forces ✓		**1**
6.	**(b)**	**(iv)**	more electrons increase London/dispersion forces ✓		**1**

Question			Answers	Notes	Total
6.	(c)	(i)	 ✓ ✓		2
6.	(c)	(ii)	 ✓		1

Question			Answers	Notes	Total
6.	(c)	(iii)	 ✓  ✓		2

Question			Answers	Notes	Total
6.	**(c)**	**(iv)**	*IR:* no ***AND*** same bonds ✓ ^{1}*H NMR:* yes ***AND*** tertiary «isomer» one signal ✓	*Accept "yes **AND** difference in "fingerprint" region/1500–500 cm^{-1}/fewer peaks in tertiary isomer «due to more symmetrical molecule»*.	**2**

Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Standard level
Paper 1A

Specimen paper

1 hour 30 minutes [Paper 1A and Paper 1B]

Instructions to candidates

- Do not open this examination paper until instructed to do so.
- Answer all questions.
- For each question, choose the answer you consider to be the best and indicate your choice on the answer sheet provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for paper 1A is **[30 marks]**.
- The maximum mark for paper 1A and paper 1B is **[55 marks]**.

0000–6104

Section A

1. Which technique is used to purify a solid obtained from a chemical reaction?

A. distillation

B. evaporation

C. recrystallization

D. filtration

2. Ice containing only the isotope ^{2}H sinks and does not melt when dropped into ordinary distilled water maintained at 3 °C.

Which statement is correct?

A. The isotope ^{2}H has a high natural abundance.

B. $^{2}H_2O$ (s) has a higher melting point than normal ice.

C. $^{2}H_2O$ (s) has a lower density than normal ice-cold water.

D. $^{2}H_2O$ has different chemical properties from normal water.

3. Which electron transition in the hydrogen atom emits radiation with the highest energy?

A. $n = 1$ to $n = 2$

B. $n = 2$ to $n = 3$

C. $n = 2$ to $n = 1$

D. $n = 3$ to $n = 2$

4. A container holds 30 g of argon and 60 g of neon.

What is the ratio of number of atoms of argon to number of atoms of neon in the container?

A. 0.25

B. 0.50

C. 2.0

D. 4.0

5. A gas storage tank of fixed volume V contains N molecules of an ideal gas at 300 K with a pressure of 40 kPa. $\frac{N}{4}$ molecules are removed, and the temperature is changed to 450 K.

What is the new pressure of the gas in kPa?

A. 15

B. 30

C. 45

D. 60

6. What is the formula of the compound formed between magnesium ions and hydrogencarbonate ions?

A. $MgHCO_3$

B. $Mg(HCO_3)_2$

C. $Mg(HCO_3)_3$

D. $Mg_3(HCO_3)_2$

7. Which species contains a coordination bond?

A. CO_2

B. HCN

C. NO_2^+

D. NO_3^-

8. Which properties depend on the movement of the delocalized electrons in a metal?

I. Electrical conductivity

II. Thermal conductivity

III. Density

A. I and II only

B. I and III only

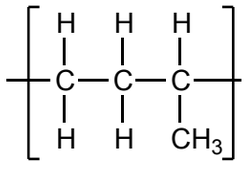
C. II and III only

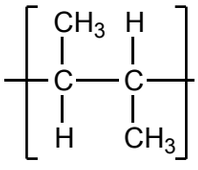
D. I, II and III

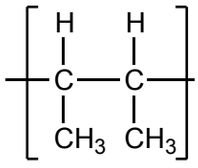
9. Which substance, made from two elements with electronegativities E_X and E_Y, is an alloy?

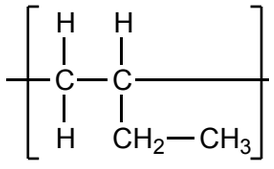
	Average electronegativity $\frac{E_X + E_Y}{2}$	**Electronegativity difference** $E_X - E_Y$
A.	2.5	2.5
B.	2.5	1.0
C.	3.5	0.2
D.	1.2	0.2

10. Which structure shows the repeating unit of the polymer formed by but-1-ene?

A. 

C. 

B. 

D. 

11. What is the explanation for the malleability of metals?

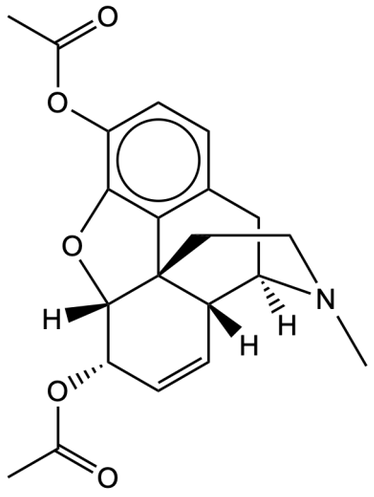
A. The bonds are strong.

B. The bonds are weak.

C. The bonds involve free electrons.

D. The bonds do not have a specific direction.

12. Which functional groups are present in this molecule?



A. amino, alkoxy, ester

B. ether, carboxyl, amino

C. carboxyl, alkoxy, ester

D. ester, amino, carboxyl

13. In which block of the periodic table would element 119 be placed, if it is found in the future?

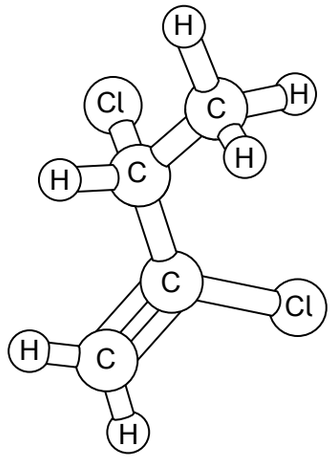
A. s

B. p

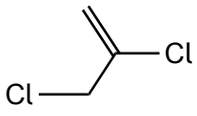
C. d

D. f

14. Which is a correct alternative representation of this molecule?



A. $C_3H_6Cl_2$

B. 

C. 2,2-dichlorobut-1-ene

D. $CH_3CHClC(Cl)=CH_2$

15. The block structure of the periodic table groups elements according to which characteristic?

A. atomic number

B. atomic mass

C. electron configuration

D. reactivity

16. Which set of conditions describe a reaction in which the reactants are more stable than the products?

A. endothermic and ΔH negative

B. endothermic and ΔH positive

C. exothermic and ΔH negative

D. exothermic and ΔH positive

17. Which enthalpy changes can be calculated using only bond enthalpy data?

I. $N_2(g) + 2H_2(g) \rightarrow N_2H_4(g)$

II. $CH_4(g) + 2O_2(g) \rightarrow 2H_2O(l) + CO_2(g)$

III. $H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

18. Which is a renewable energy source?

A. natural gas

B. uranium

C. coal

D. wood

19. What is the amount, in mol, of H_2O produced for a reaction between 10.0 mol of C_2H_3Cl and 10.0 mol of O_2 if the yield is 90 %?

$$2C_2H_3Cl(g) + 5O_2(g) \rightarrow 4CO_2(g) + 2H_2O(g) + 2HCl(g)$$

A. 3.60

B. 4.00

C. 9.00

D. 10.00

20. The complete combustion of 20.0 cm^3 of a gaseous hydrocarbon, C_xH_y, produces 80.0 cm^3 of gaseous products. This volume reduces to 40.0 cm^3 when the water vapour present condenses. All volumes are measured at the same temperature and pressure.

What is the molecular formula of the hydrocarbon?

A. CH_4

B. C_2H_2

C. C_2H_4

D. C_3H_6

21. Large deposits of methane hydrate, $CH_4 \cdot 6H_2O$ ($M_r = 124$), have been discovered under the ocean floor. What mass of carbon dioxide would be produced by the complete combustion of 12.4 g of the methane hydrate?

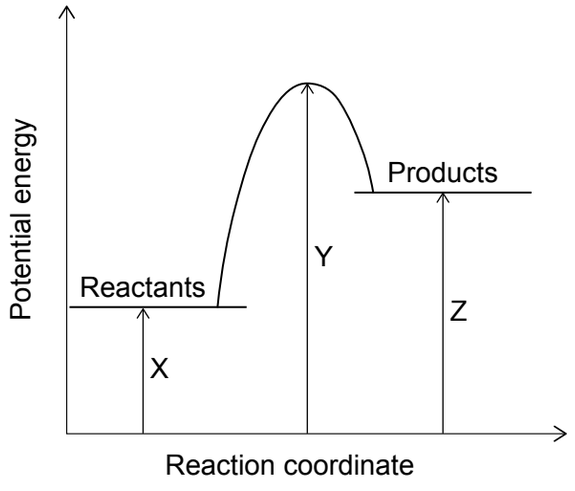
A. 4.40 g

B. 26.4 g

C. 34.1 g

D. 44.0 g

22. The diagram shows the energy profile of a reaction.



Which combination is correct?

	Activation energy of forward reaction	Activation energy of reverse reaction
A.	X	Z
B.	Y – X	Y – Z
C.	Y	Y
D.	Y – X	Z – X

23. What is the main reason for an increase in rate of reaction when the temperature is raised?

A. A greater proportion of collisions are successful.

B. Particles collide more frequently.

C. The bonds in the reactants are weakened.

D. The activation energy of the reaction decreases.

24. What is the equilibrium constant expression for the following reaction?

$$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$$

A. $\frac{[SO_2]^2[O_2]}{[SO_3]^2}$

B. $\frac{[SO_2]^2 + [O_2]}{[SO_3]^2}$

C. $\frac{[SO_3]^2}{[SO_2]^2[O_2]}$

D. $\frac{2[SO_2][O_2]}{2[SO_3]}$

25. Which reactions involve the transfer of a proton?

I. $2HCl(aq) + Mg(s) \rightarrow MgCl_2(aq) + H_2(g)$

II. $2HCl(aq) + MgO(s) \rightarrow MgCl_2(aq) + H_2O(l)$

III. $2HCl(aq) + MgCO_3(s) \rightarrow MgCl_2(aq) + H_2O(l) + CO_2(g)$

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

26. The overall reaction occurring at the electrodes of a rechargeable metal hydride battery can be summarized as:

$$MH + NiO(OH) \rightleftharpoons M + Ni(OH)_2$$

Which statement is correct?

A. The oxidation state of Ni does not change.

B. M is oxidized by loss of hydrogen.

C. The oxidation state of one H atom changes from -1 to $+1$.

D. The oxidation state of one O atom changes from -1 to -2.

27. In a redox titration, manganate(VII) ions are reduced to manganese(II) ions and iron(II) ions are oxidized to iron(III) ions.

$$MnO_4^-(aq) \text{ reduced to } Mn^{2+}(aq)$$

$$Fe^{2+}(aq) \text{ oxidized to } Fe^{3+}(aq)$$

What volume, in cm^3, of $0.1\,mol\,dm^{-3}$ $MnO_4^-(aq)$ is required to reach the equivalence point in the titration of $20.00\,cm^3$ of $0.1\,mol\,dm^{-3}$ $Fe^{2+}(aq)$?

A. 2.00

B. 4.00

C. 20.00

D. 100.00

28. What is the organic product of the reaction of 1-chloropentane with aqueous sodium hydroxide?

A. pentan-1-ol

B. 1-chloropentan-1-ol

C. 1-chloropent-1-ene

D. 1-chloropent-2-ene

29. Which statements explain the following reactions occurring in the upper atmosphere?

	Chlorofluorocarbon (CFC) compounds break down to produce chlorine radicals but usually not fluorine radicals.	**A single chlorine radical breaks down many ozone, O_3, molecules.**
A.	C–Cl bond is stronger than C–F bond	chain propagation steps produce more radicals
B.	C–F bond is stronger than C–Cl bond	chain termination steps cause chlorine radicals to reform chlorine molecules
C.	C–Cl bond is stronger than C–F bond	chain termination steps cause chlorine radicals to reform chlorine molecules
D.	C–F bond is stronger than C–Cl bond	chain propagation steps produce more radicals

30. Which species can act as an electrophile?

A. CH_4

B. Cl_2

C. Cl^-

D. OH^-

Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

Specimen paper

Chemistry

Standard level

Paper 1 – Section A

2 pages

1.	C	16.	B	31.	–	46.	–
2.	B	17.	B	32.	–	47.	–
3.	C	18.	D	33.	–	48.	–
4.	A	19.	A	34.	–	49.	–
5.	C	20.	C	35.	–	50.	–
6.	B	21.	A	36.	–	51.	–
7.	D	22.	B	37.	–	52.	–
8.	A	23.	A	38.	–	53.	–
9.	D	24.	A	39.	–	54.	–
10.	D	25.	C	40.	–	55.	–
11.	D	26.	C	41.	–	56.	–
12.	A	27.	B	42.	–	57.	–
13.	A	28.	A	43.	–	58.	–
14.	D	29.	D	44.	–	59.	–
15.	C	30.	B	45.	–	60.	–

Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Standard level
Paper 1B

Specimen paper

Candidate session number

1 hour 30 minutes [Paper 1A and Paper 1B]

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for paper 1B is **[25 marks]**.
- The maximum mark for paper 1A and paper 1B is **[55 marks]**.

0000–6105

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Answers written on this page
will not be marked.

Section B

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Hypochlorous acid, HOCl, is a sterilizing agent used in swimming pools and is produced when chlorine reacts with water.

$$Cl_2(aq) + H_2O(l) \rightleftharpoons HOCl(aq) + HCl(aq)$$

(a) Deduce the oxidation states of chlorine in the reactants and products. [2]

Reactant: Cl_2:

. . . . . .

Products: HOCl:

. . . . . .

HCl:

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(b) Explain why more chlorine reacts with water when NaOH (aq) is added. [1]

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(c) Researchers studying the solubility of chlorine in pure water at different temperatures compile the following data from different sources.

Source	Temperature / °C	Solubility of chlorine
A	0	1.46 g per 100 cm^3
B	10	310 cm^3 per 100 cm^3
C	20	0.70 g per 100 cm^3
D	25	6300 mg per 1000 cm^3
E	30	177 cm^3 per 100 cm^3
F	30	0.57 g per 100 cm^3

(This question continues on the following page)

(Question 1 continued)

(i) Identify a problem in comparing the data from different sources. [1]

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(ii) The units of solubility are converted to mol dm^{-3}.

Source	Temperature / °C	Solubility of chlorine	Solubility of chlorine / mol dm^{-3}
A	0	1.46 g per 100 cm^3	0.206
B	10	310 cm^3 per 100 cm^3	0.13
C	20	0.70 g per 100 cm^3	0.099
D	25	6300 mg per 1000 cm^3	0.089
E	30	177 cm^3 per 100 cm^3	
F	30	0.57 g per 100 cm^3	0.080

Complete the table by calculating the value for source E.

Assume the density of chlorine is 2.86 g dm^{-3} at 30 °C. [2]

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(iii) Suggest an explanation for the effect of temperature on solubility. [1]

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(d) Suggest why chlorine is not often added to swimming pools directly. [1]

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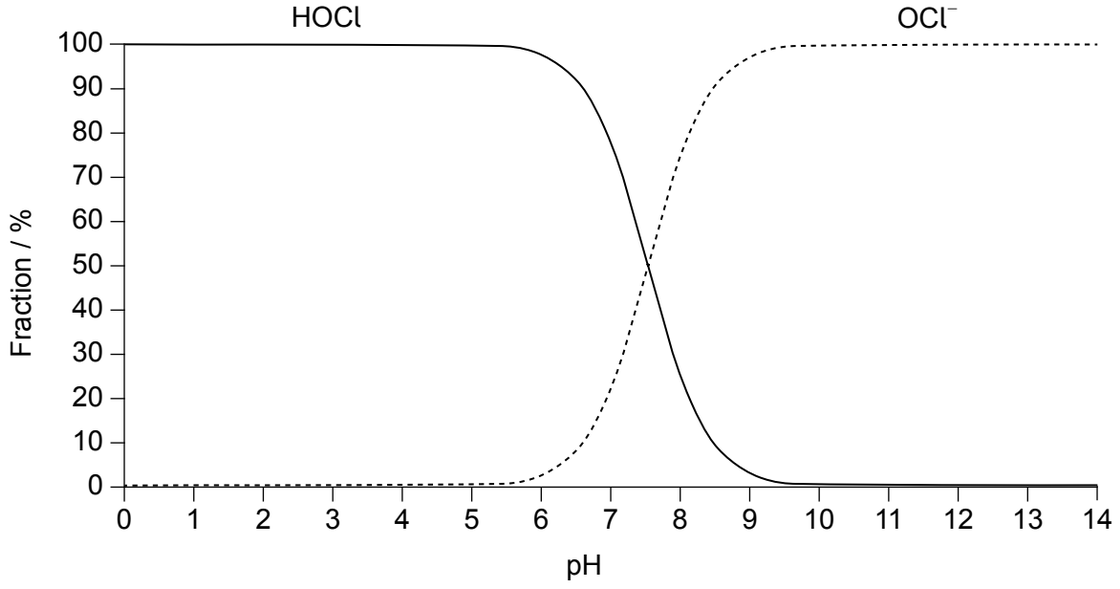
(This question continues on the following page)

(Question 1 continued)

(e) HOCl ionizes to form the hypochlorite ion, OCl^-, which is a less effective disinfectant than the undissociated acid.

The graph shows the concentrations of HOCl (aq) and OCl^- (aq) at different pH values at 25 °C.



Deduce the pH range where the water is most effectively sterilized. [1]

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(f) Ammonia released from sweat and urine reacts with HOCl to form a range of compounds including chloramines.

(i) Deduce an equation for the formation of dichloramine, $NHCl_2$ (aq), from ammonia and HOCl (aq). [1]

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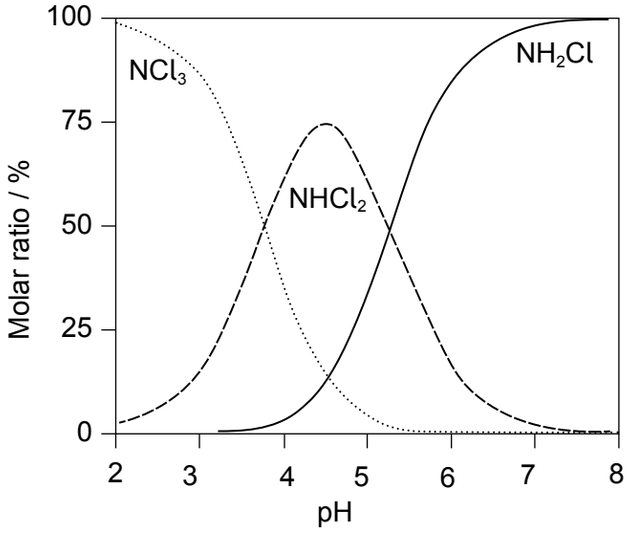
(This question continues on the following page)

(Question 1 continued)

(ii) The graph shows the molar ratio of chloramines formed at different pH values at 25 °C. Trichloramine, NCl_3, causes pool water to smell bad.



State **two** conditions needed to prevent the bad smell. [2]

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(g) Suggest **two** reasons why operating a swimming pool at a lower temperature is favourable for the environment. [2]

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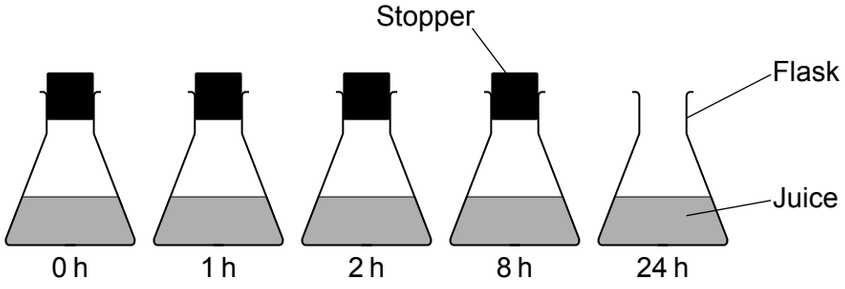
2. A student investigates the effect of exposure to the air on the ascorbic acid (vitamin C) concentration in a specific orange juice. Equal volumes of orange juice are sealed into identical flasks and placed in a refrigerator for two weeks. The samples in the refrigerator are exposed to the air by removing the stopper for a different number of hours each day as shown.



(a) Identify **two** variables that are controlled. [1]

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(b) The concentration of ascorbic acid is determined by titration with a standard iodine solution. Every few days, 10.00 cm^3 of orange juice is removed from each sample, diluted to 100.0 cm^3, and titrated.

(i) Suggest why the juice is diluted before titration. [1]

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(ii) Identify a possible systematic error with this method regarding the sample that is exposed for zero hours. [1]

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(iii) Suggest how an additional flask could be set up to verify whether the systematic error in (ii) has occurred. [1]

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(This question continues on the following page)

(Question 2 continued)

(c) The following data are collected during a titration.

Final burette reading = $16.10 \pm 0.05\,cm^3$

Initial burette reading = $1.10 \pm 0.05\,cm^3$

Calculate the percentage uncertainty of the titre. [1]

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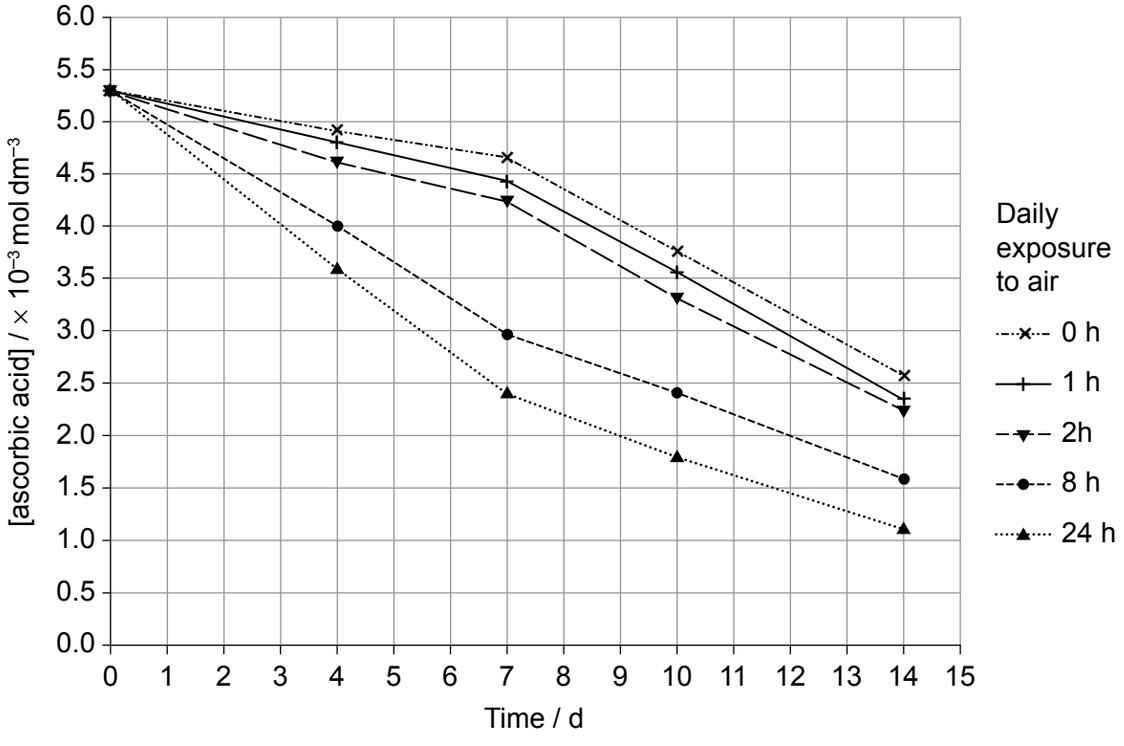
(d) The following graph shows the student's results.



(i) Calculate the average rate of decrease in ascorbic acid concentration for the 24 h sample over the period of 14 days, including units. [2]

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(This question continues on the following page)

(Question 2 continued)

(ii) The student's hypothesis is: "A lower ascorbic acid concentration will be found in juice exposed to the air for longer, due to oxidation of ascorbic acid by oxygen."

Discuss whether or not the data support the hypothesis. [2]

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(iii) State the implications of the results of the experiment for avoiding loss of vitamin C in the storage of orange juice. [1]

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(e) Suggest an extension to the investigation that would generate further recommendations for the storage of orange juice. [1]

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References:

1(c) National Center for Biotechnology Information, 2020. *PubChem Compound Summary for CID 24526, Chlorine* [online] Available at: <https://pubchem.ncbi.nlm.nih.gov/compound/Chlorine> [Accessed 23 September 2020].

1(e) Norlex, 2020. *Chlorine for water disinfection.* [online] Available at: <https://norlexpoolspa.com/guidance/about-the-right-water-balance/safe> [Accessed 23 September 2020]

1(f)(ii) ResearchGate, 2015. *Distributions of chloramines as a function of pH.* [image online] Available at: <https://www.researchgate.net/figure/Distribution-of-chloramines-as-a-function-of-pH_fig8_273449675> [Accessed 23 September 2020]

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Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

Specimen paper

Chemistry

Standard level

Paper 1 – Section B

6 pages

International Baccalaureate®
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Bachillerato Internacional

Question			Answers	Notes	Total
1.	(a)		*Reactant:* Cl_2 0 *Products:* *HOCl* +1 *HCl* -1 ✓ ✓	*Award **[2]** for three correct.* *Award **[1]** for any two correct.*	**2**
1.	(b)		equilibrium shifts to the right/product ***AND*** HCl/HOCl/H^+ removed/neutralized «by NaOH» ✓	*Accept any suitable equation to illustrate the neutralization reaction.*	**1**
1.	(c)	i	*Any one of:* pressure not given ✓ use of different units ***OR*** different ways of measuring ✓ different precisions/significant figures ***OR*** uncertainties not given ✓		**1 max**
1.	(c)	ii	0.177 «dm^3» × 2.86 «g dm^{-3}» / 0.506 «g» ***OR*** $\frac{0.506\text{«g»}}{70.9\text{«g mol}^{-1}\text{»} \times 0.100\text{«dm}^3\text{»}}$ ✓ 0.0714 «mol dm^{-3}» ✓	*Award **[2]** for correct final answer.* *Accept use of PV = nRT to calculate the solubility. Using P = 100 kPa gives a solubility of 0.0703 «mol dm^{-3}».*	**2**

1.	**(c)**	**iii**	«as temperature increases solubility decreases» dissolution is exothermic «hence equilibrium shifts to reactants side at higher temperatures» ***OR*** thermal energy overcomes intermolecular forces between chlorine and water ***OR*** negative entropy change «of dissolution» becomes more dominant at higher temperatures ✓	*Accept "kinetic energy increases with temperature «so more gas molecules escape»".*	**1**
1.	**(d)**		*Any one of:* toxic ✓ gas ✓ difficult to handle/store ✓		**1 max**
1.	**(e)**		0 - 6 ✓	*Accept any number or range below pH 6.5.*	**1**
1.	**(f)**	**i**	$NH_3(aq) + 2HOCl(aq) \rightarrow NHCl_2(aq) + 2H_2O(l)$ ✓		**1**
1.	**(f)**	**ii**	pH > 5/high ✓ low concentration of Cl_2/HOCl/NH_3 ✓	*Do not accept general statements such as "less urination in the pool".*	**2**
1.	**(g)**		*Any two of* lower water evaporation ✓ reduce energy consumption/less energy needed to heat the water ✓ higher solubility of chlorine «so less chlorine lost»✓	*Accept "less chlorine needed **AND** fewer bacteria".*	**2 max**

Question			Answers	Notes	Total
2.	**(a)**		*Any two for [1 max]* type of orange juice temperature light intensity «initial» surface area ***OR*** «initial» volume ***AND*** flask ✓		**1**
2.	**(b)**	**i**	*Any one of:* to perform multiple titrations ✓ too concentrated «so using too much iodine solution» ✓ end-point colour easier to see ✓		**1**
2.	**(b)**	**ii**	flask has to be opened to withdraw samples «so not 0 h» ***OR*** air was present in the flask at the start «so the ascorbic acid was exposed to air» ✓		**1**
2.	**(b)**	**iii**	titrate only once after two weeks ***OR*** fill flask with nitrogen/argon/inert gas ***OR*** withdraw samples with syringe «without opening flask» ✓		**1**
2.	**(c)**		$\text{«}\frac{0.1\ \text{cm}^3}{15.0\ \text{cm}^3}\times 100 = \text{»}\ 0.7\ \text{«\%»}$ ✓		**1**
2.	**(d)**	**i**	$\text{«}\frac{(5.3\times10^{-3}\text{mol dm}^{-3} - 1.1\times10^{-3}\text{mol dm}^{-3})}{14\text{d}} = \text{»}3.0\times10^{-4}$ ✓ mol dm^{-3} d^{-1} ✓	*Accept values in the range 2.9 × 10^{-4} - 3.1 × 10^{-4}.* *Accept values converted to other units, such as 3.4 × 10^{-9} - 3.6 × 10^{-9}* *mol dm^{-3} s^{-1} or 0.29 - 0.31 mmol dm^{-3} d^{-1}.*	**2**

2.	**(d)**	**ii**	«support» longer daily exposure leads to lower concentration of ascorbic acid ***OR*** 0 h decreases the least ✓ «doesn't support» no direct evidence of oxidation by oxygen ✓		**2**
2.	**(d)**	**iii**	should be stored in sealed container ***OR*** should be consumed in a few days after opening ✓		**1**
2.	**(e)**		*Any one of:* effect of temperature/light ***AND*** would show the value of refrigeration/darkness ✓ effect of preservative ✓ compare types of orange juice «e.g. fresh, from concentrate, etc.» ✓		**1**

Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Standard level
Paper 2

Specimen paper

Candidate session number

1 hour 30 minutes

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[50 marks]**.

0000 – 6106

16 pages

Please **do not** write on this page.

Answers written on this page
will not be marked.

Answer **all** questions. Answers must be written within the answer boxes provided.

1. A monoprotic acid, HX, is found to have the following composition by mass:

C = 39.99 % H = 6.73 % O = 53.28 %

(a) Determine the empirical formula of the compound HX. [2]

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(b) 25.00 cm^3 of a solution, containing 1.51 g of HX is titrated with a 0.750 mol dm^{-3} solution of NaOH (aq). The HX (aq) solution is exactly neutralized by 22.30 cm^3 of the NaOH (aq) solution. Determine the molar mass (*M*) of HX. [2]

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(c) State the molecular formula of HX. [1]

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. . . . . .

(d) HX reacts with aqueous sodium hydroxide according to the equation:

$$HX(aq) + NaOH(aq) \rightarrow NaX(aq) + H_2O(l)$$

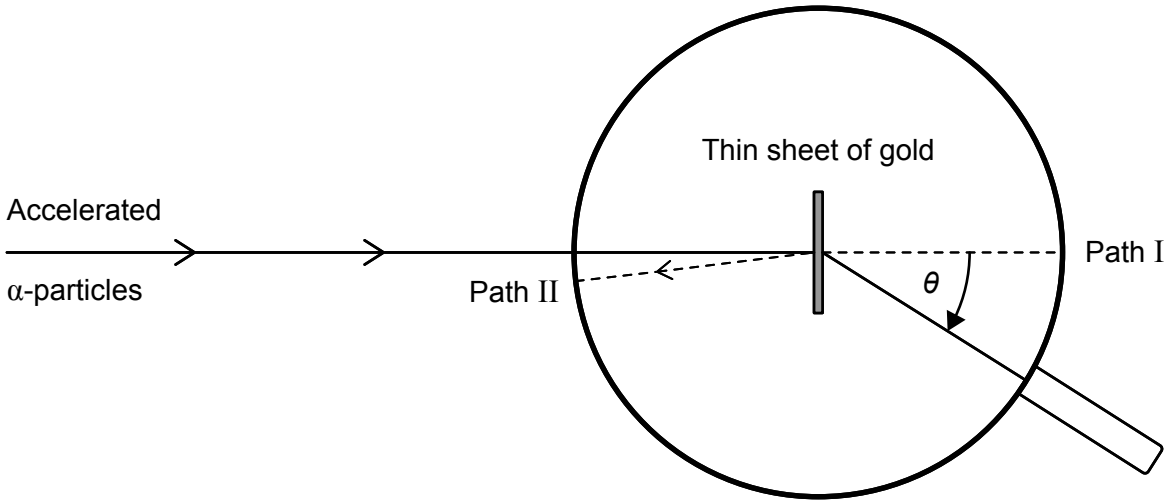
Identify a functional group present in HX. [1]

. . . . . .

. . . . . .

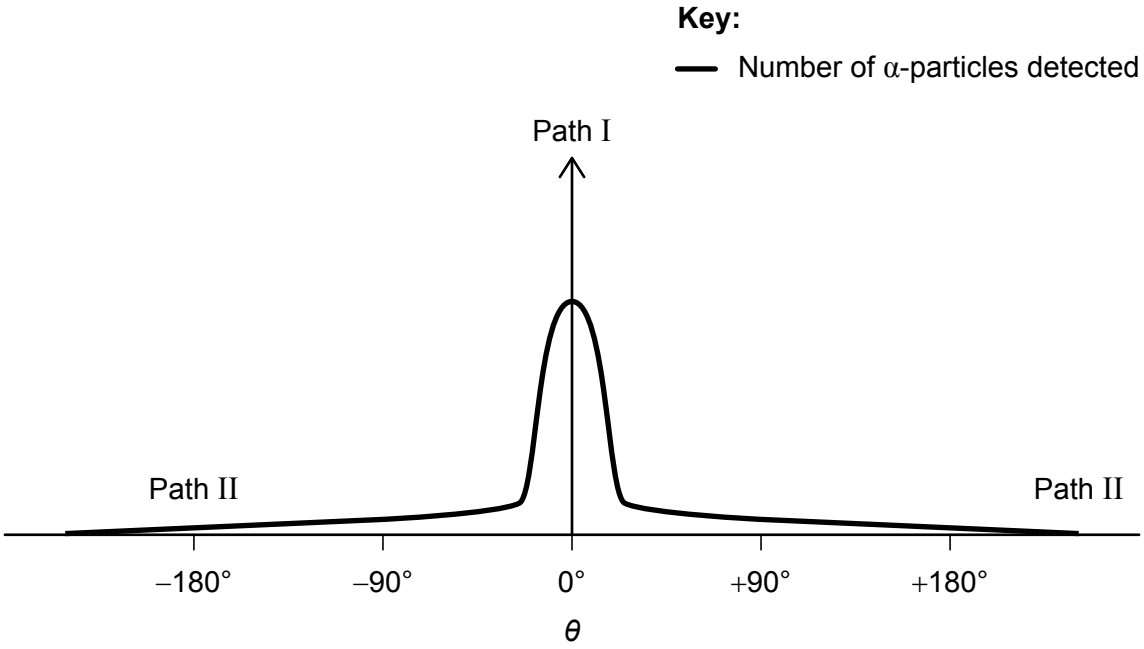
2. Scientific models are used to explain the structure of matter.

(a) An α-particle is a helium-4 nucleus. In an experiment, α-particles are accelerated towards a thin sheet of gold and their resulting paths are detected, giving evidence of the positive charge of the nucleus.



Angle of detection θ increase from 0° to 180°

The number of α-particles detected at different angles of deflection θ are shown.



(This question continues on the following page)

(Question 2 continued)

(i) State the nuclear charges of gold and helium. [1]

Gold: . . . . . .

Helium: . . . . . .

(ii) Explain why some α-particles follow path II, rebounding from the gold sheet. [1]

. . . . . .

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(iii) Most of the α-particles follow path I and pass straight through undeflected ($\theta = 0°$). Suggest a conclusion that can be made about the structure of the atom based on this evidence. [1]

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(This question continues on the following page)

(Question 2 continued)

(b) Helium was first identified by analysing spectra of solar radiation.

(i) Outline the appearance of the emission spectrum of helium. [1]

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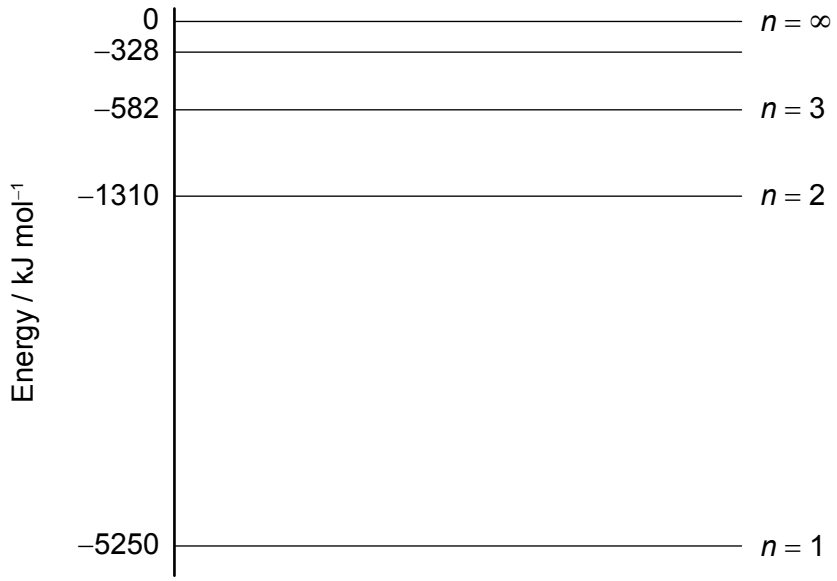
Emission spectra of one-electron systems can be explained using a model with the electron attracted to the nucleus by an electrostatic force.

This model predicts that the electron occupies discrete energy levels. Some energy levels for the He^+ ion are shown.



(ii) Explain how the frequencies observed in emission spectra support the idea of the electron occupying discrete energy levels. [2]

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(This question continues on the following page)

(Question 2 continued)

The ionization energy of the He^+ ion is 5250 kJ mol^{-1} and the ionisation energy of hydrogen is 1312 kJ mol^{-1}.

(iii) Suggest **two** reasons why the ionization energy of the hydrogen atom is significantly smaller than the ionization energy of the He^+ ion. [2]

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(iv) Suggest why the model outlined in (b)(ii) can predict the emission spectrum of He^+ but not He. [1]

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(c) Outline why models of the atom have evolved over time. [1]

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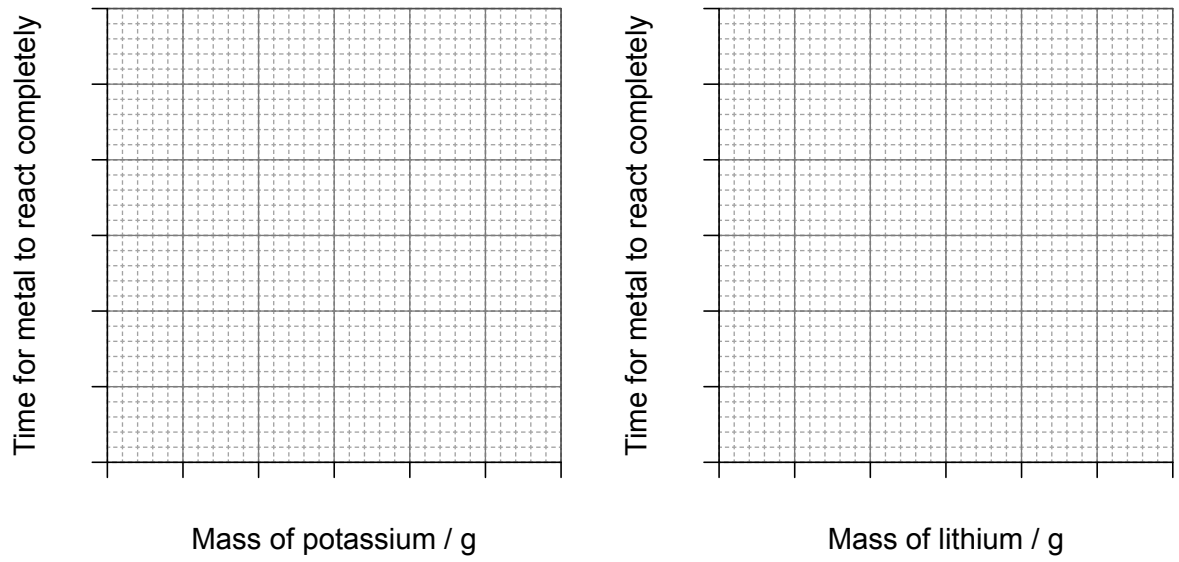
3. In a simulation, equal masses of potassium and lithium are added to water and the time taken for the metals to fully react is recorded. Five different increasing masses of each metal are used, and the reaction is timed.

(a) Sketch the graphs on the axes to show the expected results of this experiment. [2]



(b) Suggest a reason why comparing the time for complete reaction of equal masses is not a valid measure of reactivity. [1]

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(c) Lithium carbide, Li_2C_2, is one of many compounds of lithium and carbon. Determine the percentage covalent character and bonding type in this compound by using sections 9 and 17 of the data booklet. [2]

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(This question continues on the following page)

(Question 3 continued)

(d) Draw the Lewis formula of the anion in the salt Li_2C_2. [2]

Please **do not** write on this page.

Answers written on this page
will not be marked.

4. Heptadecane, $C_{17}H_{36}$, can be extracted from crude oil or cactus plants.

(a) Write an equation for the complete combustion of $C_{17}H_{36}$. [1]

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(b) The enthalpy of combustion of $C_{17}H_{36}$ is $-11\,350\,kJ\,mol^{-1}$.

(i) Calculate the maximum energy produced when 2.00 g of $C_{17}H_{36}$ is combusted. [2]

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(ii) Determine the maximum temperature change when 500.0 cm^3 of water is heated by a 2.00 g sample of $C_{17}H_{36}$. [2]

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(iii) Outline **two** assumptions made in the calculation in (b)(ii). [2]

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(This question continues on the following page)

(Question 4 continued)

(c) Explain why biofuels contribute less to climate change than fossil fuels. [1]

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(d) Heptadecane can be broken down into smaller molecules. Consider the reaction:

$$C_{17}H_{36}(g) \rightarrow 2\ C_2H_4(g) + C_{13}H_{28}(g)$$

Determine the standard enthalpy change, $\Delta H^{\ominus}$, for the reaction stated, using section 12 of the data booklet. [3]

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(e) Ethene can be converted to ethanol in one reaction. State the equation for this reaction. [1]

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(This question continues on the following page)

(Question 4 continued)

(f) Ethanol reacts with oleic acid to produce ethyl oleate.

$$C_{17}H_{33}COOH(l) + CH_3CH_2OH(l) \rightleftharpoons C_{17}H_{33}COOCH_2CH_3(l) + \mathbf{X}(l)$$

(i) Identify the side product **X**(l). [1]

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(ii) Calculate the atom economy of the reaction. [1]

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(iii) Discuss why the atom economy of a reaction is an important consideration when evaluating the impact of a reaction in an industrial process. [2]

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5. Halogens are important reactants in the laboratory and in the environment.

(a) (i) Write an equation for the homolytic fission of chlorine under UV light, showing the movement of electrons. [2]

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(ii) Under different conditions, chlorine molecules can break down by heterolytic fission. Write an equation showing the movement of electrons. [1]

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(iii) Identify, giving a reason, which one of the three species produced in (a)(i) and (a)(ii) is an electrophile. [1]

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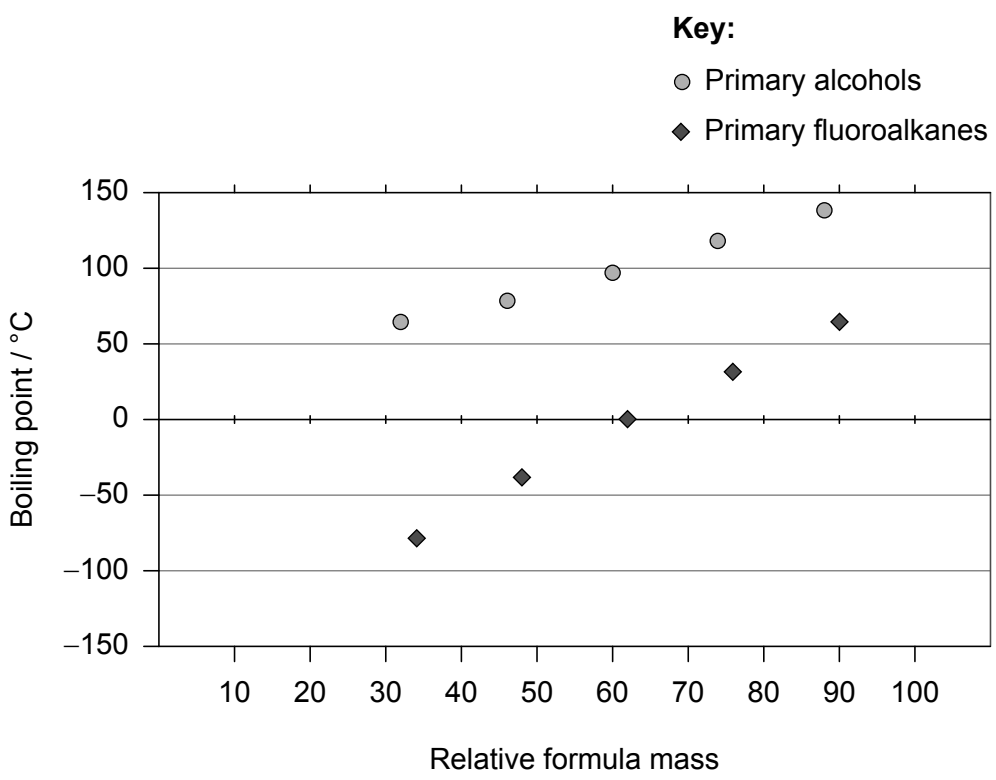
(Question 5 continued)

(b) The graph shows the boiling points of the first five straight-chain primary alcohols and fluoroalkanes.



(i) Outline why the alcohols have higher boiling points than fluoroalkanes of similar relative formula mass. [1]

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(ii) Explain the general trend in the boiling points shown for the alcohols. [2]

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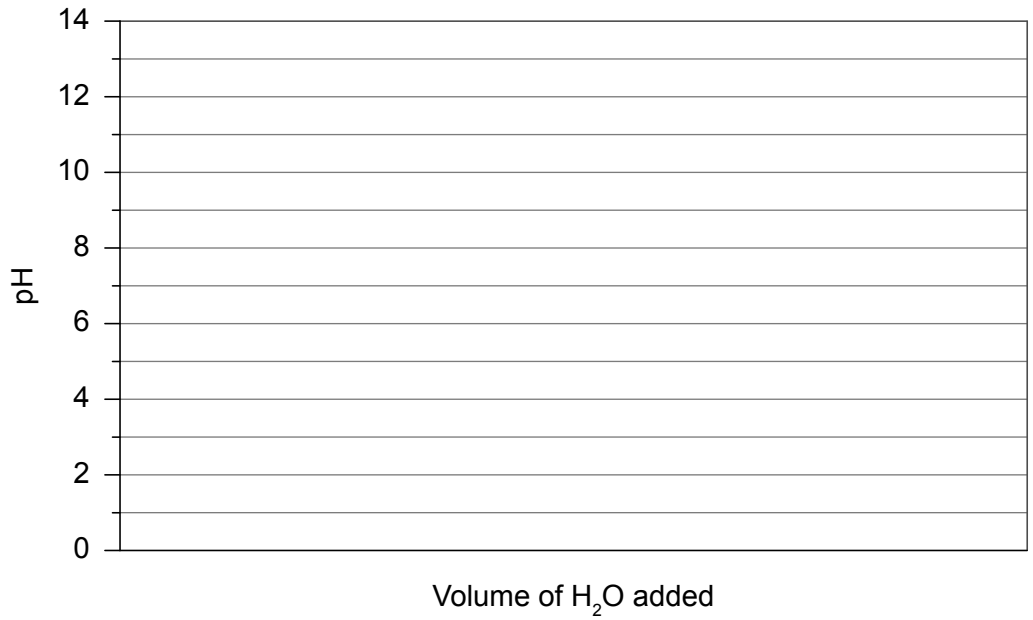
(This question continues on the following page)

(Question 5 continued)

(c) Hydrochloric acid is an important chemical reactant and industrial chemical.

A pH probe is placed in a small volume of 0.10 mol dm^{-3} solution of hydrochloric acid. The pH is recorded while a steady stream of distilled water is added to the acid at constant temperature.

(i) On the axes, sketch the graph of pH against volume of water added. [3]



(ii) The experiment is repeated using 0.010 mol dm^{-3} NaOH (aq) at the same temperature. State the initial pH of the sodium hydroxide solution. [1]

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Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

Specimen paper

Chemistry

Standard level

Paper 2

10 pages

General Marking Instructions

Assistant Examiners (AEs) will be contacted by their team leader (TL) through RM™ Assessor, by e-mail or telephone—if through RM™ Assessor or by email, please reply to confirm that you have downloaded the markscheme from IBIS. The purpose of this initial contact is to allow AEs to raise any queries they have regarding the markscheme and its interpretation. AEs should contact their team leader through RM™ Assessor or by e-mail at any time if they have any problems/queries regarding marking. For any queries regarding the use of RM™ Assessor, please contact emarking@ibo.org.

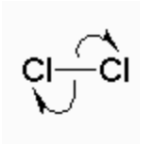
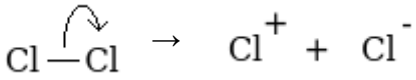
Question			Answers	Notes	Total
1.	(a)		n_C = «$\frac{39.99\,g}{12.01\,g\,mol^{-1}}$ =» 3.33 «mol» n_H = «$\frac{6.73\,g}{1.01\,g\,mol^{-1}}$ =» 6.66 «mol» n_O= «$\frac{53.28\,g}{16.00\,g\,mol^{-1}}$ ==» 3.33 «mol» ✓ CH_2O ✓		2
1.	(b)		n_{HX} (= nNaOH =) 0.750 «mol dm^{-3}» × 0.02230 «dm^3» / 0.0167 «mol» ✓ M_{HX} = ($\frac{1.51\ g}{0.0167 mol}$ =) 90.4 g mol^{-1} ✓	*Accept 90.3 «g mol^{-1}».*	2
1.	(c)		$C_3H_6O_3$ ✓	*Accept consistent feasible structural formula.*	1
1.	(d)		carboxyl/COOH ✓	*Do **not** accept "carbonyl/C=O".*	1

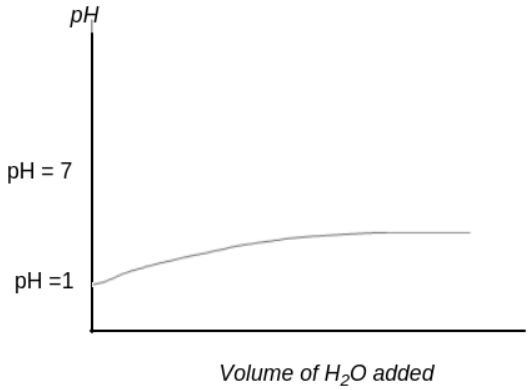
Question			Answers	Notes	Total
2.	**(a)**	**(i)**	*Gold:* +79 ***AND*** *Helium:* +2 ✓		**1**
2.	**(a)**	**(ii)**	repelled by «hitting/close contact with» gold nucleus ✓		**1**
2.	**(a)**	**(iii)**	atom is mainly empty space/vacuum ***OR*** nucleus is very small «compared to the size of the atom» ✓		**1**
2.	**(b)**	**(i)**	discrete/series of lines of different frequency/wavelength ✓		**1**
2.	**(b)**	**(ii)**	energy of photon relates to a frequency «in the spectrum» ✓ energy of photon depends on difference in energy levels ✓		**2**
2.	**(b)**	**(iii)**	H half/lower nuclear charge/number of protons ✓ H larger/double radius ✓		**2**
2.	**(b)**	**(iv)**	electron-electron interactions «need to be taken in account» ✓		**1**
2.	**(c)**		*Any one of:* new evidence new technology developments in related models models incomplete/failed to account for all observations ✓		**1**

Question			Answers	Notes	Total
3.	**(a)**		separate curves/lines for Li and K sketched ***AND*** both increasing ✓ steeper gradient for Li ***OR*** curve/line for Li higher ✓		**2**
3.	**(b)**		equal masses «of different substances» do not contain equal amounts/moles ✓		**1**
3.	**(c)**		«Avg electronegativity = 1.8 Δ electronegativity = 1.6» % covalent character = 45-55 ✓ ionic ✓		**2**
3.	**(d)**		$[:C\equiv C:]^{2-}$ 2- charge ✓ $:C\equiv C:$ ✓		**2**

Question			Answers	Notes	Total
4.	(a)		$C_{17}H_{36}(l) + 26O_2(g) \rightarrow 17CO_2(g) + 18H_2O(l)$ ✓		1
4.	(b)	(i)	$nC_{17}H_{36} = « \frac{2.00\ g}{[(17 \times 12.01\ g\ mol^{-1}) + (36 \times 1.01\ g\ mol^{-1})]} = \frac{2.00\ g}{240.53\ g\ mol^{-1}} = »$ 0.008315/0.00831 «mol» ✓ « energy = 11350 kJ mol^{-1} × 0.008315 mol = » 94.4 «kJ» ✓		2
4.	(b)	(ii)	$94\ 400 = 500.0 \times 4.18 \times \Delta T$ ✓ ΔT = 45.2«K» ✓		2
4.	(b)	(iii)	*Any two:* water does not evaporate ✓ heat is not lost to the surroundings ***OR*** all heat is transferred to the water ✓ density of water is 1 g cm^{-3} ✓ water is pure ✓ complete combustion ✓		2 max

Question			Answers	Notes	Total
4.	**(c)**		CO_2 consumed while plant is growing «and later released when biofuel is combusted» ***OR*** photosynthesis uses up CO_2 «later released when biofuel is combusted» ✓		**1**
4.	**(d)**		bonds broken: 4(C – C) / 4 × 346 ✓ bonds formed: 2(C=C) / 2 × 614 ✓ $\Delta H^{\ominus}$ = «4 × 346 – 2 × 614 / 1384 – 1228 =» «+»156 **«**kJ**»** ✓	*Award **[3]** for correct final answer.*	**3**
4.	**(e)**		$C_2H_4(g) + H_2O(g) \rightarrow C_2H_5OH(g)$ ✓		**1**
4.	**(f)**	**(i)**	H_2O / water ✓		**1**
4.	**(f)**	**(ii)**	«20(12.01) + 38(1.01) + 2(16.00) = 310.58 $\frac{100 \times 310.58}{(310.58 + 18.02)} =$ » 94.5 % ✓		**1**
4.	**(f)**	**(iii)**	*Any two of:* sustainable development ✓ more economical/efficient ✓ better use of natural resources ✓ reduces waste ✓		**2 max**

Question			Answers	Notes	Total
5.	**(a)**	**(i)**	 → 2 Cl• 2 Cl• ✓ single-barbed/fish-hooks ✓	*Accept chlorine atoms.*	**2**
5.	**(a)**	**(ii)**	 *full/double-barbed arrow **AND** charges on both ions are required for mark.* ✓		**1**
5.	**(a)**	**(iii)**	Cl^+ ***AND*** can accept a pair of electrons to form a new bond ✓		**1**

Question			Answers	Notes	Total
5.	**(b)**	**(i)**	hydrogen bonding stronger than dipole-dipole ✓		**1**
5.	**(b)**	**(ii)**	«increase because» stronger London/dispersion forces ✓ more electrons ***OR*** surface contact ✓		**2**
5.	**(c)**	**(i)**	 start at pH = 1 ✓ curve with decreasing gradient ✓ must finish below pH = 7 ✓		**3**
5.	**(c)**	**(ii)**	12 ✓		**1**