Surname	StemUp Model Solution	Centre Number	Candidate Number
First name(s)			2

GCE A LEVEL

A410U10-1

S25-A410U10-1

TUESDAY, 10 JUNE 2025 – MORNING

CHEMISTRY – A level component 1

Physical and Inorganic Chemistry

2 hours 30 minutes

	For Examiner's use only		
	Question	**Maximum Mark**	**Mark Awarded**
Section A	**1. to 8.**	**15**	
Section B	**9.**	**21**	
	10.	**19**	
	11.	**19**	
	12.	**24**	
	13.	**22**	
	Total	**120**	

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ADDITIONAL MATERIALS

- A calculator, pencil and ruler
- **Data Booklet** supplied by WJEC

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen.
Do not use gel pen or correction fluid.

You may use a pencil for graphs and diagrams only.

Write your name, centre number and candidate number in the spaces at the top of this page.

Section A Answer **all** questions.
Section B Answer **all** questions.

Write your answers in the spaces provided in this booklet. If you run out of space, use the additional page(s) at the back of the booklet, taking care to number the question(s) correctly.

INFORMATION FOR CANDIDATES

The number of marks is given in brackets at the end of each question or part-question.

The maximum mark for this paper is 120.

Your answers must be relevant and must make full use of the information given to be awarded full marks for a question.

The assessment of the quality of extended response (QER) will take place in **Q9**(d) and **Q13**(c).

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SECTION A

Answer **all** questions.

1. State the colours observed in flame tests for compounds containing the following ions. [2]

Potassium ions lilac

Lithium ions red (crimson)

2. Write the equation for the enthalpy of formation of ethanol. [2]

Include state symbols.

$2C(s) + 3H_2(g) + \frac{1}{2}O_2(g) \rightarrow C_2H_5OH(l)$

3. Iron is used as a heterogeneous catalyst for the Haber process.

(a) State how catalysts act to increase the rate of a chemical reaction. [1]

Catalysts provide an alternative reaction pathway with a lower activation energy, so more collisions have energy $\geq E_a$.

(b) State what is meant by the term heterogeneous in this context. [1]

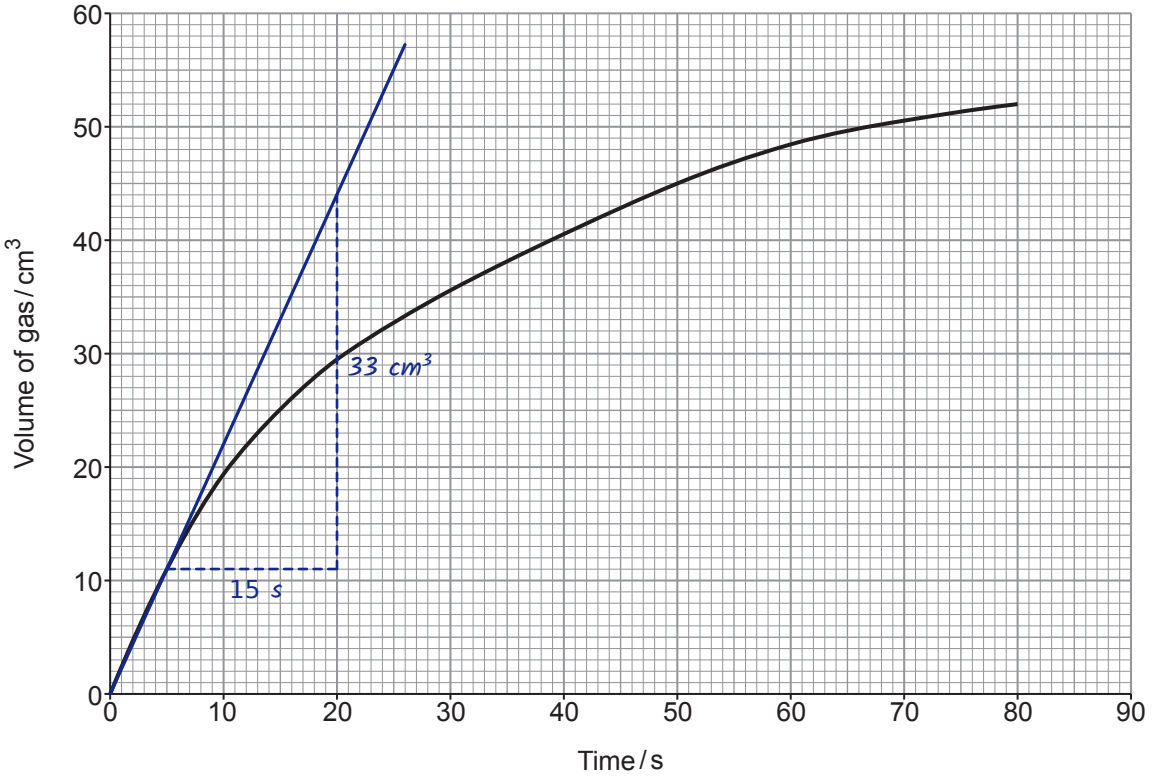
The catalyst is in a different physical state (phase) from the reactants: solid iron catalyst, gaseous N_2 and H_2.

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4. The graph below shows the volume of gas released during a chemical reaction.



Calculate the initial rate of the reaction. You **must** show your working. [2]

Tangent drawn at t = 0 (through the origin).

initial rate = gradient of tangent = 33 ÷ 15 = 2.20

Initial rate = *2.20* $cm^3 s^{-1}$

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5. Carbon dioxide is an acidic oxide and lead(II) oxide is an amphoteric oxide.

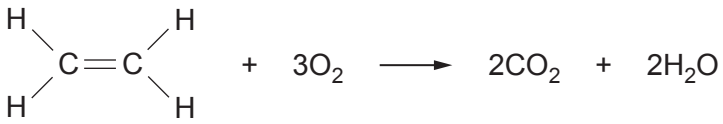
(a) Write an equation for a reaction that shows that carbon dioxide is an acidic oxide. [1]

$CO_2 + 2NaOH \rightarrow Na_2CO_3 + H_2O$

(b) State what is meant by the term amphoteric. [1]

An amphoteric oxide reacts with both acids and bases (alkalis).

6. Use the average bond enthalpies listed to calculate the enthalpy change of the reaction shown. [2]



Bond	C — H	C — C	C = C	O = O	C = O	O — H
Average bond enthalpy / kJ mol^{-1}	412	348	612	496	743	463

bonds broken: 4(C–H) + C=C + 3(O=O) = 4(412) + 612 + 3(496) = 3748 kJ

bonds made: 4(C=O) + 4(O–H) = 4(743) + 4(463) = 4824 kJ

ΔH = 3748 – 4824

Enthalpy change = −1076 kJ mol^{-1}

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7. State what is meant by the term dynamic equilibrium. [1]

A reversible reaction (in a closed system) where the forward and reverse reactions occur at the same rate, so concentrations stay constant.

8. Neptunium-237 decays into protactinium-233 by radioactive decay.

(a) Identify the type of particle emitted in this process. [1]

alpha (α) particle

(b) State how this particle would be affected by an electric field. [1]

It is deflected towards the negative plate (away from the positive plate).

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SECTION B

Answer **all** questions.

9. Hydrogen is the most abundant element in the universe, making up approximately 74% of the universe by mass.

(a) The light emitted by stars such as our own sun contains a wide range of frequencies but when the spectrum is studied, dark lines are seen due to the absorption of certain specific frequencies of light by the hydrogen in the outer layers of the stars.

(i) Explain how the dark lines form and why they get closer together. [2]

Electrons absorb specific frequencies and move from a lower to a higher energy level; each frequency matches the energy difference between two levels ($\Delta E = hf$), so it is missing and a dark line forms.

The lines get closer because the energy levels get closer together at higher energy, until they converge (ionisation).

(ii) The first ionisation energy of hydrogen is 1312 kJ mol^{-1}. Calculate the wavelength of the convergence limit of the Lyman series in the atomic spectrum of hydrogen. [3]

energy per atom, $E = 1312 \times 1000 \div 6.02 \times 10^{23} = 2.179 \times 10^{-18}$ J

$f = E \div h = 2.179 \times 10^{-18} \div 6.63 \times 10^{-34} = 3.287 \times 10^{15}$ Hz

$\lambda = c \div f = 3.00 \times 10^{8} \div 3.287 \times 10^{15} = 9.13 \times 10^{-8}$ m

Wavelength = *91.3* nm

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(b) The first ionisation energies of some of the first 13 elements are listed in the table.

Element	H	He	Li	Be	B	C	N	O	F	Ne	Na	Mg	Al
First ionisation energy / kJ mol^{-1}	1312	2372		900	801	1087	1402	1314	1681	2081	496		578

(i) Suggest a value for the first ionisation energy of lithium. Give your reasoning. [2]

About 520 kJ mol^{-1}. It must be greater than Na (496) because ionisation energy decreases down a group, and lower than Be (900) because ionisation energy increases across a period.

(ii) Suggest a value for the first ionisation energy of magnesium. Explain your answer. [3]

About 740 kJ mol^{-1}. It is lower than Be (900) as the 3s electron is further out with more shielding, so a lower effective nuclear charge. It is greater than Al (578): IE decreases from Group 2 to 3 as Al's electron is in a different (3p) subshell with increased shielding of the nuclear charge.

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(c) Acids are substances that donate hydrogen ions.

(i) Give the difference between strong and weak acids. [1]

Strong acids dissociate (ionise) completely in water, but weak acids only dissociate partially.

(ii) A weak acid can be used to make a buffer solution.

A student takes a certain volume of ethanoic acid of initial concentration 0.200 mol dm^{-3}. They add the same volume of aqueous sodium hydroxide to form a buffer of pH 5.0.

Calculate the concentration of the aqueous sodium hydroxide. [4]

K_a of ethanoic acid = 1.78×10^{-5} mol dm^{-3}

$pK_a = -\log(1.78 \times 10^{-5}) = 4.75$

$pH = pK_a + \log([salt]/[acid])$

$5.0 = 4.75 + \log([salt]/[acid])$, so $\log([salt]/[acid]) = 0.250$

$[salt]/[acid] = 10^{0.250} = 1.78$

NaOH turns some acid into salt, so the fraction of acid left = $1 \div 2.78$

acid left (from the initial 0.200) = $0.200 \div 2.78 = 0.072$ mol dm^{-3}

acid converted to salt = $0.200 - 0.072 = 0.128$ mol dm^{-3}

equal volumes mixed, so [NaOH] = 0.128 mol dm^{-3}

Concentration of NaOH = *0.128* mol dm^{-3}

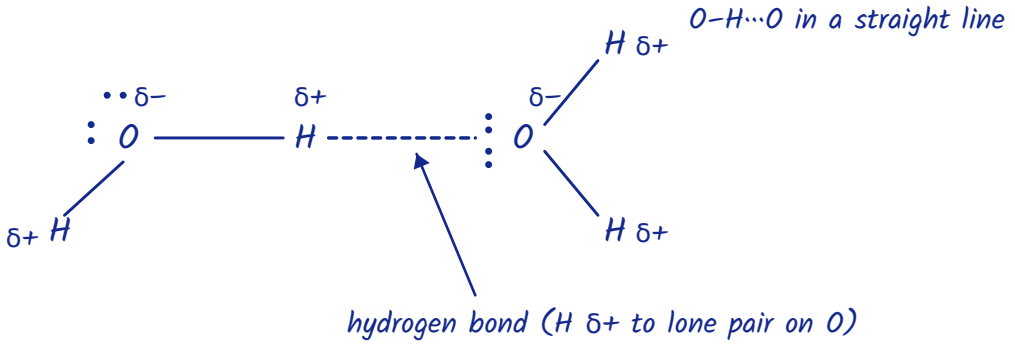
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(d) Hydrogen bonding is one type of intermolecular force. Explain what is meant by hydrogen bonding and how it affects the properties of water.

You may include diagram(s) to support your answer. [6 QER]



A hydrogen bond is the strongest type of intermolecular force (stronger than van der Waals and dipole-dipole forces), although it is much weaker than a covalent bond.

It forms when H is covalently bonded to N, O or F. These are the most electronegative elements, so the bond is very polar with a large dipole: H is δ+ and the N, O or F is δ−.

Electron density is pulled away from the H, so the hydrogen nucleus (a proton) is exposed, with very low electron density.

The hydrogen bond is the attraction between this δ+ hydrogen and a lone pair on an N, O or F atom in another molecule, as shown in the diagram.

Properties of water: water has a high boiling temperature for such a small molecule, because more energy is needed to overcome the hydrogen bonds

(continued on page 28)

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10. The following table contains a selection of *p*-block elements.

Group 4	Group 5	Group 6	Group 7
Si	P	S	Cl
Ge	As	Se	Br
Sn	Sb	Te	I
Pb	Bi	Po	At

(a) State why these elements are classed as part of the *p*-block. [1]

Their outermost (highest energy) electron is in a p-orbital (p subshell).

(b) Use elements from the table above to answer parts (i)-(iii).

(i) Identify the most electronegative element in the table. [1]

Cl (chlorine)

(ii) Give an element that forms an oxide of formula XO_2 and a hydride of formula H_2X.

S (sulfur) [1]

(iii) Identify the element that gives purple fumes when the solid is heated. [1]

I (iodine)

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(c) (i) Explain why silicon has the highest melting temperature of all these elements. [2]

Silicon is the only one with a giant covalent (macromolecular) structure; the others are simple molecular or metallic.

To melt silicon many strong covalent bonds must be broken, which needs a lot of energy.

(ii) State why lead is the only Group 4 element that is most stable in the +2 oxidation state in its compounds. [1]

The inert pair effect becomes greater down the group: lead's $6s^2$ electrons are not readily used in bonding, so +2 is the most stable oxidation state for lead.

(iii) Explain why addition of chlorine to a solution containing bromide ions causes a chemical reaction but addition of iodine to a solution containing bromide ions does not.

Include an equation for the reaction in your answer. [3]

Chlorine is a stronger oxidising agent than bromine, so it can oxidise bromide ions: $Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$

Iodine is a weaker oxidising agent than bromine, so it is not able to oxidise bromide ions.

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(d) Historically most of the tin and arsenic used in the United Kingdom was mined in Cornwall.

(i) The tin mined in Cornwall included the mineral cassiterite. Cassiterite is an oxide of tin that contains 78.8% tin by mass.

Find the formula of this oxide. You **must** show your working. [2]

% oxygen = 100 − 78.8 = 21.2%

Sn : O = 78.8 ÷ 118.7 : 21.2 ÷ 16.0

= 0.664 : 1.325 = 1 : 2

Formula SnO_2

(ii) Tin(II) compounds in solution oxidise slowly to form tin(IV).

The concentration of tin(II) ions remaining in solution can be found by titration against a solution containing iron(III) ions.

I. Write an equation for the reaction between Sn^{2+} ions and Fe^{3+} ions. [1]

$Sn^{2+} + 2Fe^{3+} \rightarrow Sn^{4+} + 2Fe^{2+}$

II. A standard solution containing 0.0210 mol dm^{-3} Fe^{3+} was used to titrate 25.0 cm^3 of a solution containing tin(II) ions. It needed 17.40 cm^3 of the Fe^{3+} solution for complete reaction.

Calculate the concentration of tin(II) ions in the solution. [3]

moles Fe^{3+} = 0.0210 × 17.40 ÷ 1000 = 3.654×10^{-4} mol

moles Sn^{2+} = $3.654 \times 10^{-4} \div 2 = 1.827 \times 10^{-4}$ mol

$[Sn^{2+}] = 1.827 \times 10^{-4} \div 0.0250 = 7.31 \times 10^{-3}$ mol dm^{-3}

Concentration = 7.31×10^{-3} mol dm^{-3}

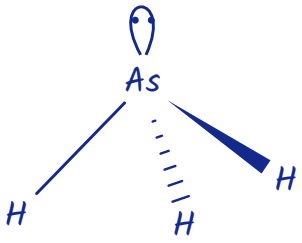
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(iii) Arsenic can form arsine, AsH_3. Use VSEPR theory to find the shape of this molecule.

Give your reasoning. [3]



pyramidal

As is in Group 5 so it has 5 outer electrons; three form As–H bonds, so there are three bonding pairs and one lone pair around the As.

Electron pairs repel to be as far apart as possible, and the lone pair repels more than the bonding pairs.

So the shape is (trigonal) pyramidal, with an H–As–H bond angle less than 109.5°.

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11. The chemistry of calcium is typical of the *s*-block elements.

(a) Calcium metal and calcium chloride can both conduct electricity under different conditions. State the conditions required and explain how these substances conduct electricity. [3]

Calcium conducts when solid, but calcium chloride only conducts when molten or dissolved.

In calcium, delocalised electrons can flow and carry the charge.

In calcium chloride, the ions can move and carry the charge.

(b) Calcium hydroxide forms when calcium metal is added to water.

(i) Write the equation for the reaction between calcium and water. [1]

$Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$

(ii) Heating calcium hydroxide can cause it to decompose and form calcium oxide.

$$Ca(OH)_2(s) \longrightarrow CaO(s) + H_2O(g)$$

I. The entropy change for this reaction is $153\,J\,K^{-1}\,mol^{-1}$. Explain why the entropy change value is positive. [2]

The entropy change is positive because a gas ($H_2O(g)$) is formed from a solid.

Gases have much higher entropies than solids as their particles are far more disordered.

II. The minimum temperature required for this decomposition is 446°C. Find the enthalpy change of the reaction. [3]

$T = 446 + 273 = 719\ K$

at the minimum temperature $\Delta G = 0$, so $\Delta H = T\Delta S$

$\Delta H = 719 \times 153 = 110\,007\ J\ mol^{-1}$

Enthalpy change = 110 $kJ\,mol^{-1}$

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(c) One mineral that contains calcium is gaylussite, $Ca_aM_b(CO_3)_c.dH_2O$. Metal M is another *s*-block element.

Strong heating of 2.50×10^{-2} mol of solid gaylussite decomposes the mineral in two stages, with the solid losing 30.4% of its initial mass in the first stage and then 29.7% of the initial mass in the second stage.

The gases released are passed through a U-tube surrounded by ice and 2.25 g of a colourless liquid condenses during the first stage of decomposition. The remaining gases are bubbled through limewater which turns milky during the second stage.

(i) Find the value of d. [2]

moles of water = 2.25 ÷ 18.02 = 0.125 mol

d = 0.125 ÷ 2.50×10^{-2} = 5

d = ... 5 .....

(ii) Find the relative formula mass, M_r, of gaylussite. [2]

2.25 g of water is 30.4% of the initial mass

mass of 2.50×10^{-2} mol = 2.25 ÷ 0.304 = 7.40 g

M_r = 7.40 ÷ 2.50×10^{-2} = 296

M_r = ... 296 .....

(iii) Find the value of c. [3]

second stage gas is CO_2 (turns limewater milky)

mass of CO_2 = 0.297 × 7.40 = 2.20 g

moles of CO_2 = 2.20 ÷ 44.0 = 0.0500 mol

c = 0.0500 ÷ 2.50×10^{-2} = 2

c = ... 2 .....

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(iv) Use your answers to parts (i), (ii) and (iii) to deduce the identity of metal M and hence write the formula of gaylussite. [3]

mass from Ca and M = 296 − 5(18.02) − 2(60.0) = 86

$2CO_3^{2-}$ give a charge of −4, so the metal ions total +4: only one Ca^{2+} (40.1)

remaining mass = 86 − 40 = 46 = 2 × 23, so b = 2 and M is Na^+

M is Na (sodium)

Formula of gaylussite $CaNa_2(CO_3)_2.5H_2O$

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12. Chromium and copper are both elements in the first row of the *d*-block.

(a) Write the electronic structure of a chromium atom. [1]

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5\ 4s^1$

(b) Acidified potassium dichromate solution is orange and changes colour when it reacts with other substances.

(i) State and explain the colour change that occurs when aqueous iron(II) sulfate is added to acidified potassium dichromate solution. [2]

The colour changes from orange to green.

Fe^{2+} reduces the dichromate(VI) ions to Cr^{3+} ions (green); Fe^{2+} is oxidised to Fe^{3+}.

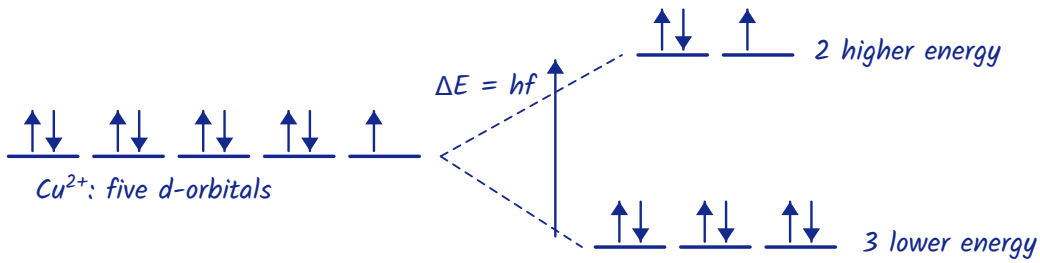
(ii) State and explain the colour change that occurs when excess aqueous sodium hydroxide is added to acidified potassium dichromate solution. [2]

The colour changes from orange to yellow.

In alkaline solution dichromate forms chromate ions, CrO_4^{2-}: $Cr_2O_7^{2-} + 2OH^- \rightleftharpoons 2CrO_4^{2-} + H_2O$

(c) Copper(II) ions in aqueous solution form a pale blue solution.

(i) Explain why the solution is pale blue. [3]



Water ligands split the d-orbitals into 3 lower and 2 higher energy orbitals. Electrons move from lower to higher orbitals by absorbing specific frequencies of light. The colour seen is the frequencies not absorbed: pale blue.

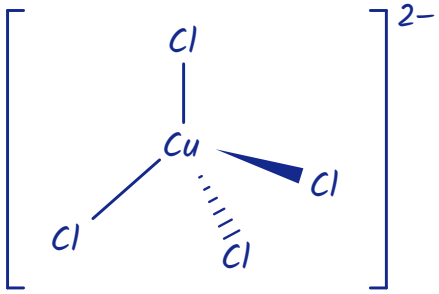
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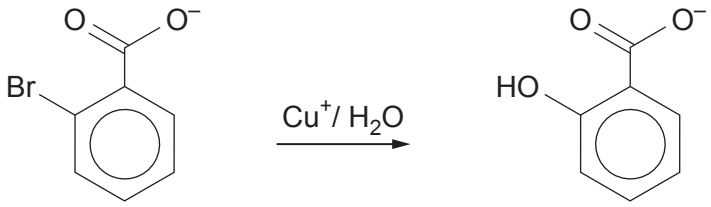
(ii) Addition of concentrated hydrochloric acid causes the solution to turn green.

Draw the structure of the copper-containing ion present in the solution. [1]



tetrahedral $[CuCl_4]^{2-}$

(d) Copper(I) compounds are used as catalysts in the Ullman reaction which converts 2-bromobenzoate into 2-hydroxybenzoate.



(i) Suggest why the reaction must be performed in the absence of air. [1]

Oxygen in the air would oxidise the Cu^+ (copper(I)) ions to Cu^{2+}, so the catalyst would be lost.

(ii) Suitable ligands must be chosen for the reaction to prevent the copper(I) ions precipitating as $Cu_2O(s)$ or undergoing disproportionation.

State what is meant by disproportionation. [1]

A reaction in which atoms of the same element are both oxidised and reduced, e.g. $2Cu^+ \rightarrow Cu + Cu^{2+}$.

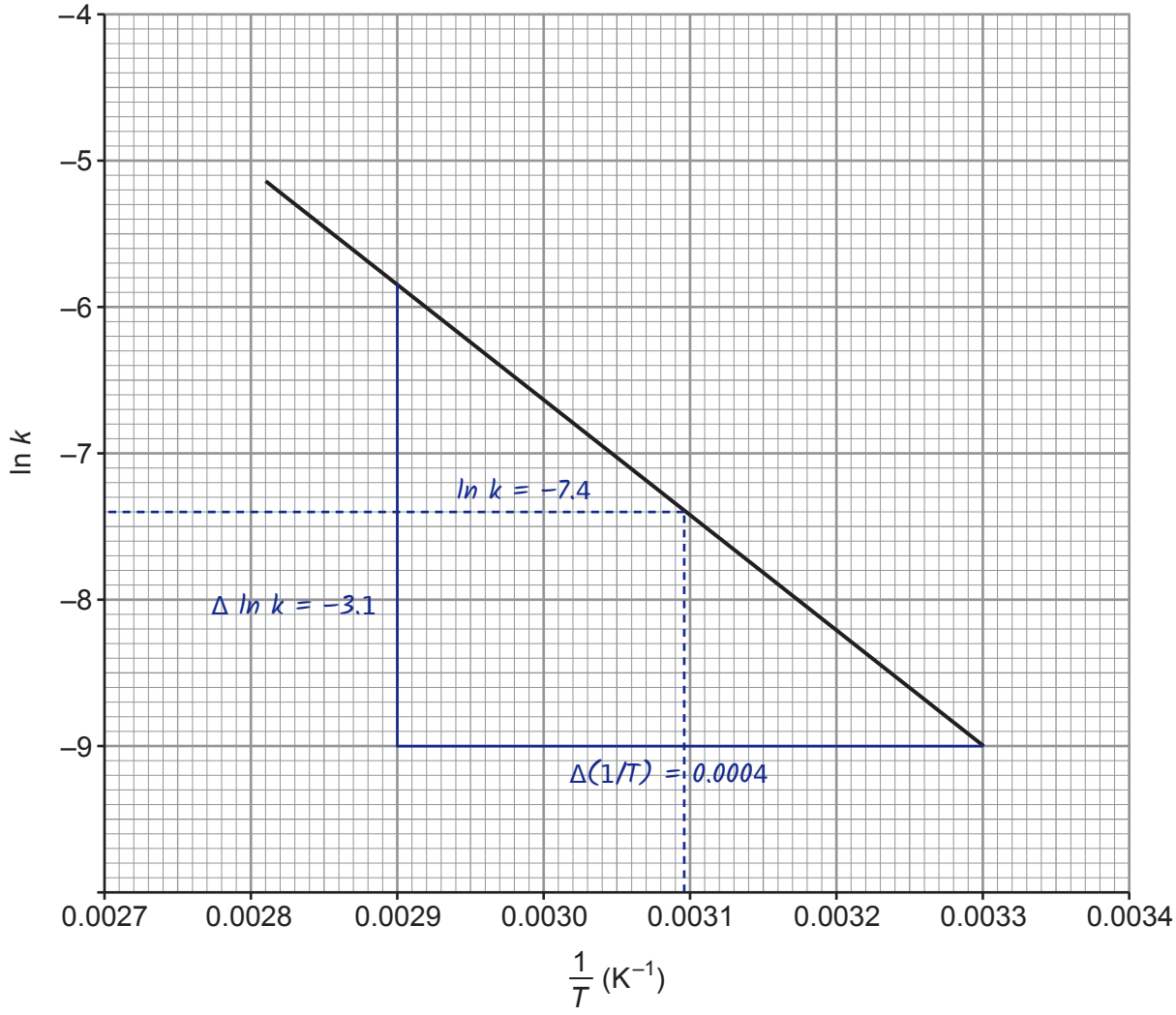
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(iii) The reaction is first order overall and the rate depends on the concentration of the copper complex only.

The rate constant for the reaction was found at four different temperatures with the initial concentration of the 2-bromobenzoic acid being $1.0 \times 10^{-3}\,\text{mol}\,\text{dm}^{-3}$ and the copper complex having a concentration of $2.5 \times 10^{-5}\,\text{mol}\,\text{dm}^{-3}$.

A plot of $\ln k$ against $\frac{1}{T}$ is shown below.



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I. Give the unit of the rate constant for this reaction. [1]

s^{-1}

II. Calculate the rate of the reaction at a temperature of 50°C. [4]

50 °C = 323 K, so $1/T = 1 \div 323 = 0.003096\ K^{-1}$

from the graph $\ln k = -7.4$, so $k = e^{-7.4} = 6.11 \times 10^{-4}\ s^{-1}$

rate = k[copper complex]

rate = $6.11 \times 10^{-4} \times 2.5 \times 10^{-5}$

Rate = 1.53×10^{-8} mol dm^{-3} s^{-1}

III. Calculate the activation energy of the reaction. [3]

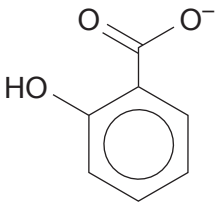
$\ln k = \ln A - (E_a/R)(1/T)$, so gradient = $-E_a/R$

gradient = $-3.1 \div 0.0004 = -7750$ K

$E_a = -(-7750) \times 8.31 = 64\,400$ J mol^{-1}

Activation energy = 64.4 kJ mol^{-1}

(iv) Under the conditions of the reaction, the ion below is formed. State what information this provides regarding the relative K_a values of the protons in 2-hydroxybenzoic acid. [1]



The K_a of the –COOH proton is greater than that of the –OH proton, so the carboxylic acid group loses H^+ first.

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(v) Copper(I) complexes such as $[Cu(CN)_2]^-$ can act as reducing agents for other metal ions.

	Standard electrode potential, E^θ/V
$Pr^{4+} + e^- \rightleftharpoons Pr^{3+}$	+3.21
$Mn^{3+} + e^- \rightleftharpoons Mn^{2+}$	+1.51
$MnO_2 + 4H^+ + e^- \rightleftharpoons Mn^{3+} + 2H_2O$	+1.23
$Cu^{2+} + 2CN^- + e^- \rightleftharpoons [Cu(CN)_2]^-$	+1.12
$VO^{2+} + 2H^+ + e^- \rightleftharpoons V^{3+} + H_2O$	+0.34
$V^{3+} + e^- \rightleftharpoons V^{2+}$	–0.26
$Pr^{3+} + e^- \rightleftharpoons Pr^{2+}$	–3.11

When $[Cu(CN)_2]^-$ is added to metal compounds in the +4 oxidation state the metal can be reduced to a lower oxidation state.

Identify which of the metals, manganese, vanadium and praseodymium in their +4 oxidation state, will form ions in their +3 oxidation state in the final product when excess $[Cu(CN)_2]^-$ is added. Explain your reasoning. [4]

Only praseodymium will end in the +3 oxidation state. To be reduced by $[Cu(CN)_2]^-$, the metal ion's $E^\ominus$ must be more positive than +1.12 V (EMF positive).

Mn: +1.23 V > +1.12 V so Mn(IV) is reduced to Mn^{3+}, but Mn^{3+}/Mn^{2+} is +1.51 V, so Mn^{3+} is then reduced further to Mn^{2+}.

Pr: +3.21 V > +1.12 V so Pr^{4+} is reduced to Pr^{3+}, but Pr^{3+}/Pr^{2+} is −3.11 V, so it is not reduced further to Pr^{2+}.

V: VO^{2+}/V^{3+} is +0.34 V < +1.12 V, so V(IV) cannot be reduced.

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13. A saturated solution of iodine in water has a concentration of 1.33×10^{-3} mol dm^{-3} at 298 K.

(a) Addition of iodide ions causes the following equilibrium to be established.

$$I_2(aq) + I^-(aq) \rightleftharpoons I_3^-(aq)$$

A solid sample of 0.100 g of potassium iodide is added to 1.00 dm^3 of a saturated solution of I_2(aq) at 298 K. At equilibrium the solution contains I_3^-(aq) of concentration 2.62×10^{-4} mol dm^{-3}.

Calculate the value of the equilibrium constant, K_c. [4]

$K_c = [I_3^-] \div ([I_2][I^-])$

initial $[I^-] = 0.100 \div 166.0 = 6.02 \times 10^{-4}$ mol dm^{-3}

$[I_2] = 1.33 \times 10^{-3} - 2.62 \times 10^{-4} = 1.068 \times 10^{-3}$ mol dm^{-3}

$[I^-] = 6.02 \times 10^{-4} - 2.62 \times 10^{-4} = 3.40 \times 10^{-4}$ mol dm^{-3}

$K_c = 2.62 \times 10^{-4} \div (1.068 \times 10^{-3} \times 3.40 \times 10^{-4})$

$K_c =$ 721.5 mol^{-1} dm^3

(b) Addition of bromide ions to a saturated solution of iodine causes interhalogen ions to form, $Br_nI_m^{x-}$.

(i) One interhalogen ion is crystallised as a potassium salt and the M_r of this compound is found to be 373. Identify the formula of this interhalogen salt. [2]

$M_r(KBrI) = 39.1 + 79.9 + 126.9 = 245.9 \approx 246$

373 − 246 = 127, which is one more iodine atom

Formula $KBrI_2$

(ii) The interhalogen ions have a negative charge so it is difficult to use a traditional mass spectrometer to measure their mass. Suggest **one** adaptation to a mass spectrometer so that it can measure the mass of these interhalogen ions. Give a reason for your suggestion. [1]

Reverse the direction of the magnetic field (reverse the current in the electromagnet), because negative ions are deflected in the opposite direction to positive ions.

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(iii) The spectrum of the interhalogen ion Br_2I^- contains three peaks with masses of 285, 287 and 289. Assume that all the iodine atoms present are iodine-127.

I. Show that the bromine isotopes present in these ions are bromine-79 and bromine-81. [2]

subtract the mass of iodine: 285 − 127 = 158, 287 − 127 = 160, 289 − 127 = 162

158 ÷ 2 = 79 and 162 ÷ 2 = 81 (160 = 79 + 81), so the isotopes are bromine-79 and bromine-81

II. Bromine-79 and bromine-81 are the only stable isotopes of bromine and the relative atomic mass (A_r) of bromine is 79.98.

Calculate the percentage of each isotope present in bromine. [3]

let x = percentage of bromine-81

79.98 = [79(100 − x) + 81x] ÷ 100

7998 = 7900 − 79x + 81x

2x = 98, so x = 49

Percentage bromine-79 = 51 %

Percentage bromine-81 = 49 %

(iv) The interhalogen compound ClF_3 is a gas at a particular temperature. The density of the gas is found to be 3.60 g dm^{-3} at a pressure of 1 atm.

Calculate the temperature. [4]

$M_r(ClF_3)$ = 35.5 + 3(19.0) = 92.5

molar volume = 92.5 ÷ 3.60 = 25.7 dm^3 = 0.0257 m^3

$pV = nRT$, so $T = pV \div nR$

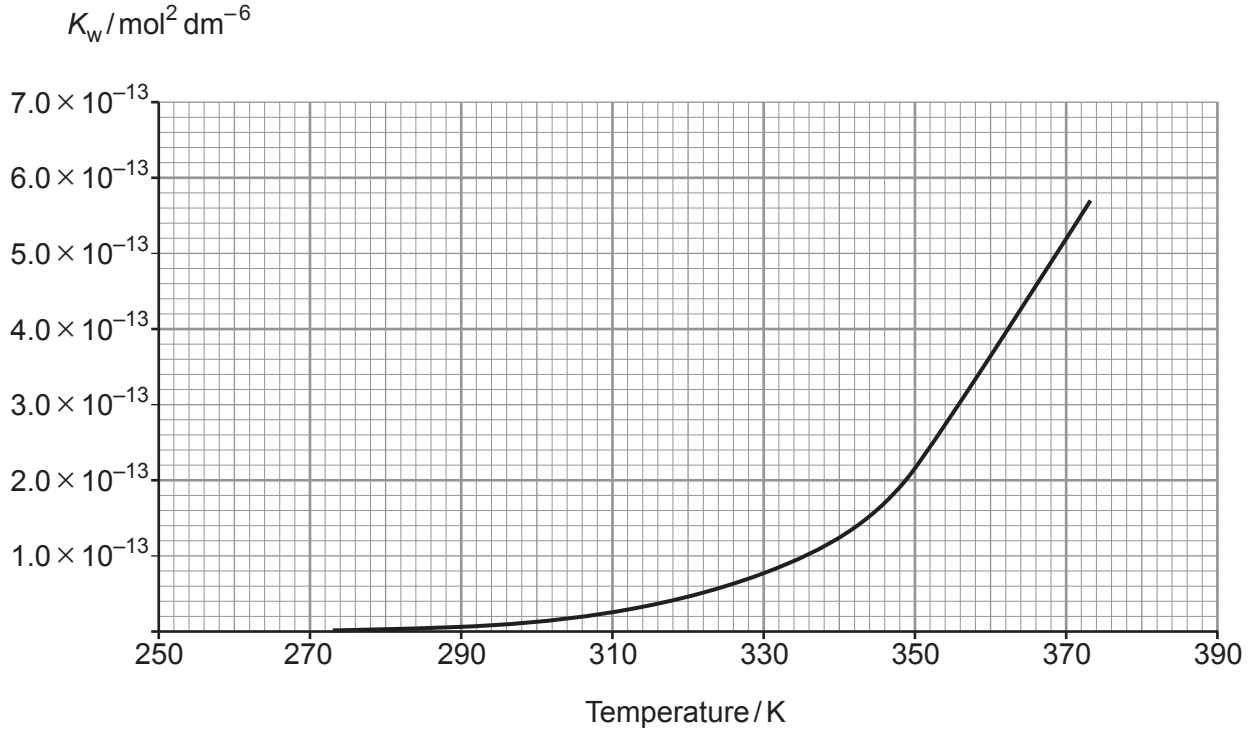
$T = (1.01 \times 10^5 \times 0.0257) \div (1 \times 8.31)$

Temperature = 312 K

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(c) The ionic product of water, K_w, varies with temperature as shown in the graph below.



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Discuss the ionic product of water and its temperature dependance.

Your answer should include:

- the meaning of K_w
- the information that can be obtained from the temperature dependance of K_w
- how K_w is used to find the pH of a strong alkali, and how the pH of a strong alkali changes with temperature

[6 QER]

K_w is the ionic product of water: $K_w = [H^+][OH^-]$. It is the equilibrium constant for the dissociation $H_2O \rightleftharpoons H^+ + OH^-$ (the $[H_2O]$ is constant). K_w is very small (1.0×10^{-14} mol^2 dm^{-6} at 298 K) because very little of the water has dissociated.

The graph shows that K_w increases with temperature, so there is much more dissociation at higher temperature: the equilibrium shifts to the right.

By Le Chatelier's principle a rise in temperature favours the endothermic direction, so the dissociation of water is endothermic (ΔH positive).

A strong alkali such as NaOH dissociates completely, releasing OH^-, so $[OH^-]$ = [alkali].

Then $[H^+] = K_w \div [OH^-]$ and $pH = -\log[H^+]$. E.g. 0.100 mol dm^{-3} NaOH at 298 K: $[H^+] = 1.0 \times 10^{-14} \div 0.100 = 1.0 \times 10^{-13}$ mol dm^{-3}, so pH = 13.0.

As temperature increases, K_w increases while $[OH^-]$ stays the same, so $[H^+]$ increases and the pH of the strong alkali decreases (e.g. at 370 K $K_w \approx 5 \times 10^{-13}$, so the pH of 0.100 mol dm^{-3} NaOH is about 11.3).

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END OF PAPER

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Question number	Additional page, if required. Write the question number(s) in the left-hand margin.
9(d)	between the molecules before the water can boil. Ice is less dense than liquid water (water expands when it freezes). Hydrogen bonds are directional, so in ice each molecule is held in an open, tetrahedral lattice with a lot of empty space; when ice melts this collapses and the molecules pack closer together. Water is a good solvent for many substances because it can form hydrogen bonds with molecules that contain oxygen or nitrogen atoms, e.g. ethanol, ammonia and sugars.

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