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EDEXCEL A LEVEL CHEMISTRY: QUESTIONS BY TOPIC

Redox I (3)

A Level Chemistry Topic 3

19 questions · 203 marks · Mark schemes included

Pearson Edexcel A Level Chemistry (9CH0), June 2017 - June 2025

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HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic; within each sub-topic they run from the lowest mark tariff to the highest.

Click any sub-topic heading or question row below to jump straight to it.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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QUESTIONS

19 questions · 203 marks · grouped by sub-topic



SUB-TOPIC 3(a)

OXIDATION NUMBERS

3 questions in this sub-topic · 30 marks · lowest tariff first



2 Magnesium nitrate decomposes on heating as shown by the equation.



(a) Explain, in terms of all the relevant oxidation numbers, why this is a redox reaction.

(3)

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(b) Calcium nitrate decomposes in a similar way to magnesium nitrate, but requires a higher temperature for decomposition.

Explain this observation in terms of the charge and size of the cations.

(3)

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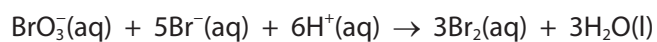
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(Total for Question 2 = 6 marks)



3 This question is about the compound potassium bromate, KBrO_3 .

(a) These bromate ions react with bromide ions in acidic solution.



(i) Explain, in terms of oxidation numbers, whether or not this is a disproportionation reaction.

(2)

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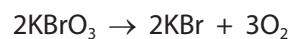
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(ii) What is the overall order of this reaction?

(1)

- ☐ **A** 3
- ☐ **B** 6
- ☐ **C** 12
- ☐ **D** cannot tell from this information

(b) Potassium bromate decomposes on heating.



Calculate the maximum volume of oxygen, in dm^3 , measured at room temperature and pressure (r.t.p.), that could be produced from the complete decomposition of 5.20 g of potassium bromate.

[Molar volume of gas at r.t.p. = $24.0 \text{ dm}^3 \text{ mol}^{-1}$]

(3)

(Total for Question 3 = 6 marks)

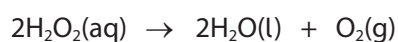


3 This question is about hydrogen peroxide, H_2O_2 .

(a) Draw a dot-and-cross diagram of a molecule of hydrogen peroxide.

(1)

(b) Hydrogen peroxide decomposes to form water and oxygen.



Explain, using oxidation numbers, why the decomposition of hydrogen peroxide is classified as a disproportionation reaction.

(3)

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(c) The decomposition of hydrogen peroxide is catalysed by iodide ions, $\text{I}^-(\text{aq})$.

The kinetics of this reaction were investigated using different concentrations of hydrogen peroxide and iodide ions.

The results are shown in the table.

Experiment	$[\text{H}_2\text{O}_2(\text{aq})] / \text{mol dm}^{-3}$	$[\text{I}^-(\text{aq})] / \text{mol dm}^{-3}$	Rate / $\text{mol dm}^{-3} \text{s}^{-1}$
1	0.100	0.0500	8.90×10^{-7}
2	0.400	0.0500	3.56×10^{-6}
3	0.200	0.100	3.56×10^{-6}

(i) Deduce the order of reaction with respect to hydrogen peroxide and to iodide ions.

(2)

Order with respect to hydrogen peroxide

Order with respect to iodide ions

(ii) Write the rate equation for the reaction using your answer to (c)(i).

(1)

(iii) Calculate the rate constant, k , using data from Experiment 3.
Include units in your answer.

(2)



- (d) The breakdown of hydrogen peroxide with iodide ions as a catalyst is the basis of the demonstration 'Elephant's Toothpaste'.

The presence of a detergent results in a rapid eruption of foam as the oxygen gas is released.

- (i) Describe the test and the positive result that confirms the gas produced is oxygen.

(1)

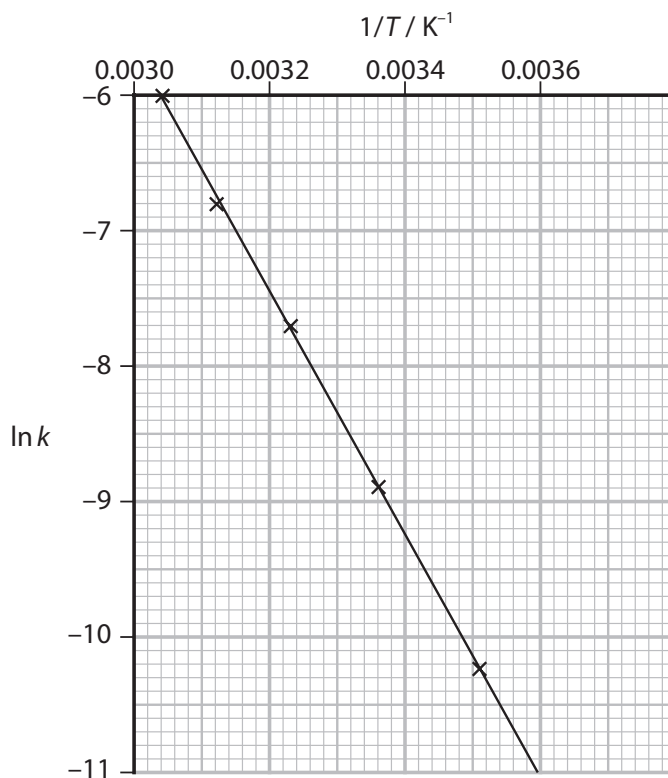
- (ii) The foam produced often has a slight yellow / brown colour.

Explain what causes this colour, which is **not** caused by the detergent.

(2)



- (e) The effect of temperature on the rate of the decomposition of hydrogen peroxide without a catalyst was also investigated.
A graph of $\ln k$ against $1/T$ was plotted.



- (i) Determine the gradient of the graph.
Include units in your answer. You must show your working on the graph.

(3)



- (ii) Calculate the activation energy, E_a , of the reaction, in kJ mol^{-1} , using your answer to (e)(i) and the Arrhenius equation shown.

$$\ln k = -\frac{E_a}{R} \times \frac{1}{T} + \text{constant}$$

[Gas constant (R) = $8.31 \text{ J mol}^{-1} \text{ K}^{-1}$]

(1)

- (f) Another way to write the Arrhenius equation is shown.

$$k = Ae^{-E_a/RT}$$

The constant A is often called the collision factor as it is linked to the orientation of the particles colliding in a reaction.

The decomposition of hydrogen peroxide is also catalysed by aluminium.

Calculate a value for A at 370 K , for the catalysed decomposition of hydrogen peroxide with an activation energy, E_a , of $5.02 \times 10^4 \text{ J mol}^{-1}$ and a numerical value for the rate constant of 1.60×10^{-3} .

Units are **not** required.

(2)

(Total for Question 3 = 18 marks)



SUB-TOPIC 3(b)

REDOX REACTIONS AND HALF-EQUATIONS

11 questions in this sub-topic · 120 marks · lowest tariff first



- *8** Compare and contrast the mechanisms of the catalysts in the table.
Illustrate your answer with equations that demonstrate the redox reactions involved.

(6)

Catalyst	Catalysed reaction
$\text{V}_2\text{O}_5(\text{s})$	$\text{SO}_2(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}) \rightarrow \text{SO}_3(\text{g})$
$\text{Fe}^{2+}(\text{aq})$	$\text{S}_2\text{O}_8^{2-}(\text{aq}) + 2\text{I}^-(\text{aq}) \rightarrow \text{I}_2(\text{aq}) + 2\text{SO}_4^{2-}(\text{aq})$



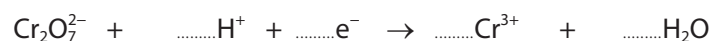
(Total for Question 8 = 6 marks)



5 Some alcohols can be oxidised by acidified sodium dichromate(VI), $\text{Na}_2\text{Cr}_2\text{O}_7$.

- (a) Balance the ionic half-equation for the reduction of the dichromate(VI) ion.
Give the colours of all of the species involved, or state colourless if appropriate.

(2)

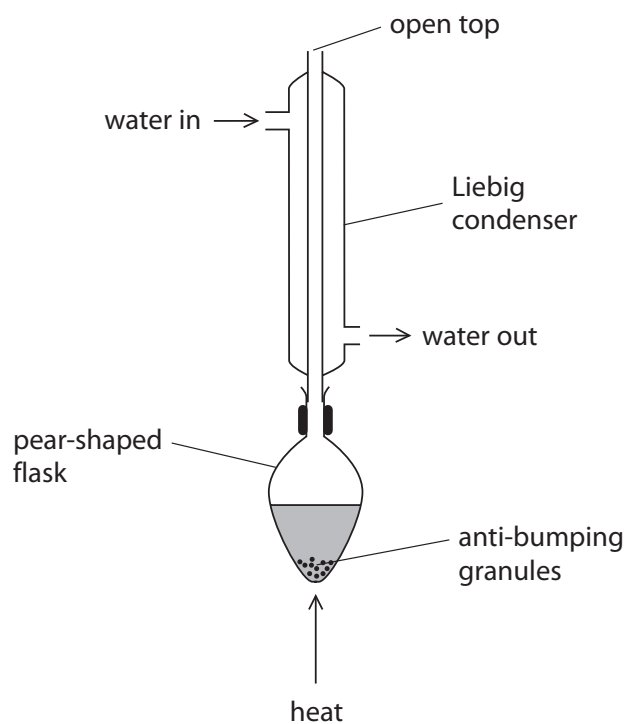


Colour

- (b) Reflux apparatus can be used to carry out the oxidation of alcohols.

- (i) This Liebig condenser has been set up incorrectly. Add shading to the diagram to show the water in the condenser, illustrating the effect of the incorrect water flow.

(1)



- (ii) State how the granules prevent bumping.

(1)

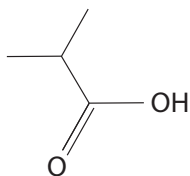
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(c) The carboxylic acid shown can be produced by oxidation of an alcohol under reflux.



Which alcohol would be oxidised under reflux to produce this carboxylic acid?

(1)

- ☒ A 1,1-dimethylethanol
- ☒ B 2-methylpropan-1-ol
- ☒ C 2-methylbutan-1-ol
- ☒ D propan-2-ol

(d) Using the apparatus for distillation instead of reflux is not an efficient way to produce ethanoic acid from ethanol. Explain why.

(2)

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(Total for Question 5 = 7 marks)

2 This question is about some redox reactions of chlorine, bromine and iodine.

(a) An **excess** of aqueous potassium bromide was added to chlorine water and the solution turned orange.

(i) Write an equation for this reaction. State symbols are not required.

(1)

(ii) Silver nitrate solution was added to the mixture in (a) and excess dilute ammonia solution was then added to the precipitate formed. Only some of the precipitate dissolved.

Deduce why only **some** of the precipitate dissolved.

(3)

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(iii) Aqueous potassium bromide was added to aqueous iodine, instead of chlorine water. There was no reaction.

Give a reason why no reaction occurred.

(1)

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(b) Chlorine undergoes disproportionation when it reacts with **hot** aqueous sodium hydroxide solution.

- (i) Complete the ionic equation for this reaction.
State symbols are not required.

(1)



- (ii) Explain, in terms of oxidation numbers, why this is a disproportionation reaction.

(2)

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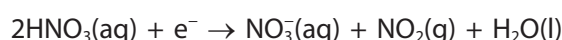
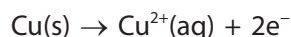
(Total for Question 2 = 8 marks)



- 10** Yellow gold is used to make jewellery. It is an alloy of copper, gold and silver. The purity of gold is measured in carats. The higher the carat, the higher the percentage of gold in the alloy. Pure gold is 24 carat.

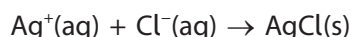
A sample of yellow gold is analysed using the steps below.

- Step 1** Excess concentrated nitric acid is reacted with 1.250 g of the alloy. The gold does **not** react but the copper and silver do react. The half-equations are



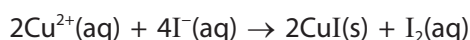
- Step 2** The mixture is diluted with distilled water and the gold is filtered off.

- Step 3** Excess hydrochloric acid is added to the filtrate. It reacts with the silver ions to form a precipitate of silver chloride.

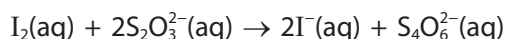


- Step 4** The silver chloride precipitate is filtered off, washed, dried and weighed. The mass of silver chloride formed is 0.706 g.

- Step 5** Excess potassium iodide is added to the remaining solution. A precipitate of copper(I) iodide and a solution of iodine forms.



- Step 6** The resulting mixture is titrated with $0.100 \text{ mol dm}^{-3}$ sodium thiosulfate solution.



The titre is 39.40 cm^3 .

- (a) Write the equation for the reaction of copper with concentrated nitric acid, using the half-equations given in Step 1. State symbols are not required.

(1)

- (b) State the indicator used and its colour change at the end-point in the titration in Step 6.

(2)



(c) The table shows the percentage by mass of gold in four different carats of yellow gold.

Carat	Percentage by mass of gold
9	37.5
10	41.7
14	58.3
18	75.0

Determine, using the experimental data, the carat of the sample of yellow gold that was analysed.

(6)

(Total for Question 10 = 9 marks)



3 This question is about the elements in Group 7 of the Periodic Table and some of their compounds.

(a) What is the colour of iodine in the solid and gas states?

(1)

	Colour of iodine solid	Colour of iodine gas
☐ A	purple	brown
☐ B	purple	purple
☐ C	grey/black	brown
☐ D	grey/black	purple

(b) Which of these reactions occurs?

(1)

- ☐ **A** $\text{Br}_2(\text{aq}) + 2\text{NaCl}(\text{aq}) \rightarrow 2\text{NaBr}(\text{aq}) + \text{Cl}_2(\text{aq})$
- ☐ **B** $\text{Br}_2(\text{aq}) + 2\text{NaF}(\text{aq}) \rightarrow 2\text{NaBr}(\text{aq}) + \text{F}_2(\text{aq})$
- ☐ **C** $\text{Cl}_2(\text{aq}) + 2\text{NaBr}(\text{aq}) \rightarrow 2\text{NaCl}(\text{aq}) + \text{Br}_2(\text{aq})$
- ☐ **D** $\text{Cl}_2(\text{aq}) + 2\text{NaF}(\text{aq}) \rightarrow 2\text{NaCl}(\text{aq}) + \text{F}_2(\text{aq})$

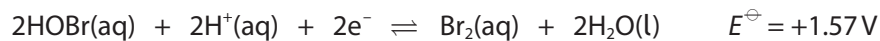
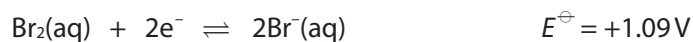
(c) The halogens can form halide ions during reactions.

Complete the electronic configuration of the chloride ion.

(1)

$1s^2$

- (d) The standard electrode potentials for two half-equations involving bromine are given.



- (i) Explain why the disproportionation of bromine in water is **not** thermodynamically feasible under standard conditions.
Include the overall equation for the disproportionation and its $E_{\text{cell}}^\ominus$ value.

(3)

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- (ii) Bromine disproportionates in water to a small extent at 298 K.

Give a possible reason why this reaction occurs.

(1)

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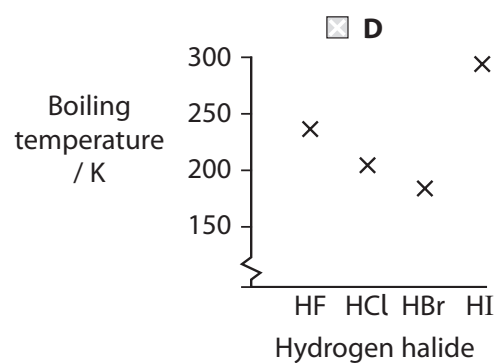
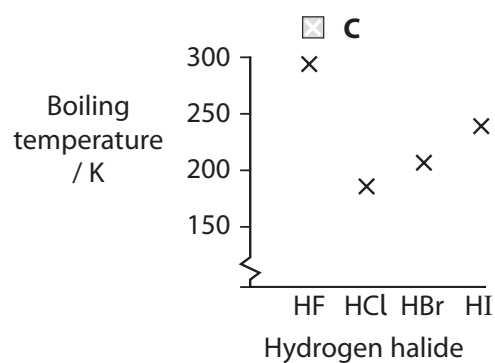
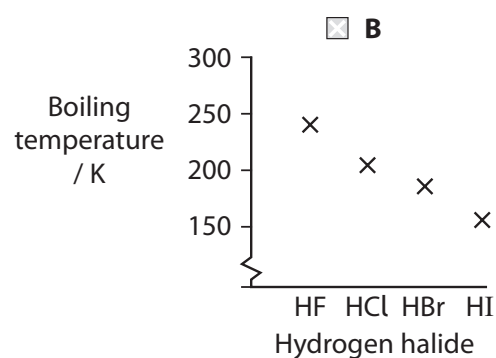
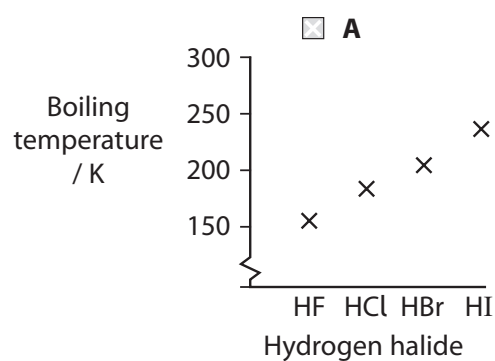
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(e) The hydrogen halides have the general formula HX, where X represents the symbol of the halogen.

(i) Which diagram shows the trend in the boiling temperatures of the hydrogen halides?

(1)



(ii) What type of reaction occurs when ammonia gas reacts with hydrogen chloride gas?

(1)

- ☒ **A** acid-base
- ☒ **B** displacement
- ☒ **C** redox
- ☒ **D** substitution

(Total for Question 3 = 9 marks)

5 This question is about redox reactions.

(a) Name the ion with formula PO_3^{3-} . Include the relevant oxidation number.

(1)

(b) State what happens to a reducing agent during a reaction, in terms of oxidation number **and** electrons.

(1)

(c) Identify the species that is the strongest reducing agent from the list of standard electrode potentials in the Data Booklet.

(1)

(d) Manganese(IV) oxide, MnO_2 , and manganate(VII) ions, MnO_4^- , react in alkaline solution to form manganate(VI) ions, MnO_4^{2-} .

(i) Write the **ionic** equation for this reaction.
State symbols are not required.

(2)

(ii) Give a reason why this reaction is **not** disproportionation.

(1)



(e) Sodium tetrahydridoborate(III), NaBH_4 , is used in organic chemistry. It is an alternative reagent to lithium tetrahydridoaluminate(III) for the reduction of carbonyl compounds.

(i) Draw a dot-and-cross diagram of the BH_4^- ion.

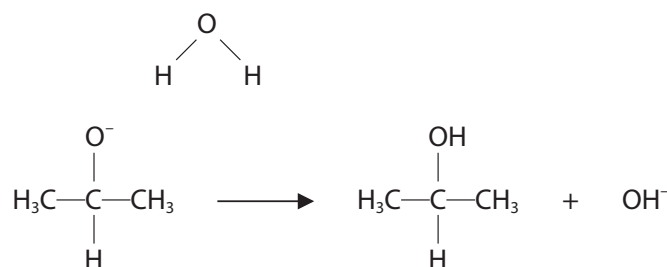
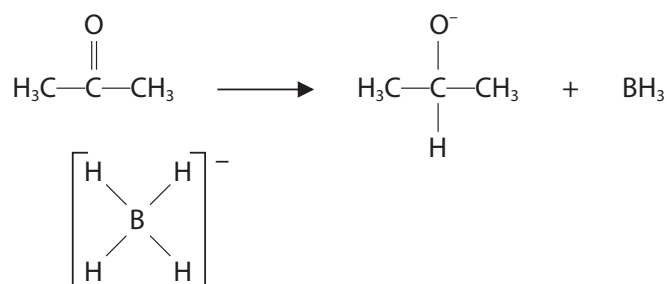
Use crosses (x) for the boron electrons, dots (•) for the hydrogen electrons and triangles (Δ) for the additional electron forming the negative ion.

(1)

(ii) The BH_4^- ions reduce carbonyl compounds to alcohols in aqueous solution.

Complete the mechanism for the reduction of propanone to propan-2-ol by adding curly arrows, and any relevant lone pairs and dipoles.

(4)



(Total for Question 5 = 11 marks)



4 Many vehicles are fitted with airbags which provide a gas-filled safety cushion to protect the occupant of the vehicle if there is a crash.

(a) The first reaction in airbags is the thermal decomposition of sodium azide, NaN_3 , to form sodium and nitrogen gas.

(i) Write the equation for this decomposition of sodium azide.
State symbols are not required.

(1)

(ii) In the reaction in (a)(i), a typical airbag is inflated by about 67 dm^3 of gas. Calculate the **minimum mass** of sodium azide, in grams, needed to produce this volume of gas. Use the Ideal Gas Equation and give your answer to an appropriate number of significant figures.

For the purpose of this calculation, assume that the temperature is 300°C and the pressure is $140\,000 \text{ Pa}$.

(4)



- (b) The second reaction in the airbag is between the sodium produced in the reaction (a)(i) and potassium nitrate.



Balance the above equation, justifying your answer in terms of the changes in oxidation numbers.

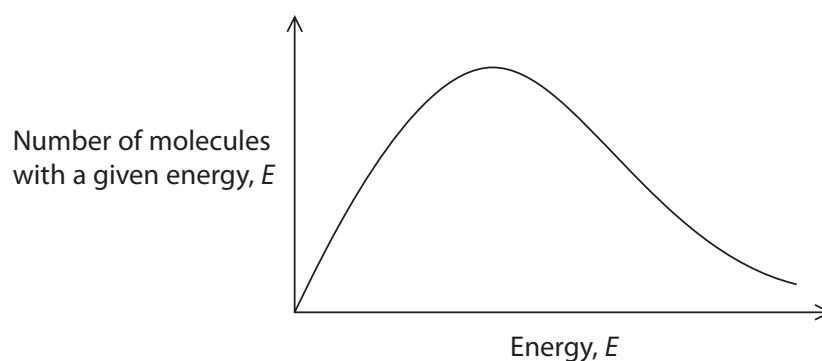
(3)

- (c) The third reaction in the airbag is between the metal oxides and silicon dioxide.

State the type of reaction taking place and justify why this reaction is necessary.

(3)

- (d) The Maxwell-Boltzmann distribution diagram shows the molecular energies for the gaseous system immediately after the airbag has been deployed.



What is the change in shape of the curve when the airbag **cools**?

(1)

- ☒ **A** the peak would shift to the left and be higher
- ☒ **B** the peak would shift to the left and be lower
- ☒ **C** the peak would shift to the right and be higher
- ☒ **D** the peak would shift to the right and be lower

(Total for Question 4 = 12 marks)

8 This question is about electrode potentials, cells and equilibrium constants.

- (a) Chlorine gas can be prepared by the oxidation of chloride ions with manganate(VII) ions in acid solution.



During this reaction, each manganate(VII) ion accepts five electrons.

Calculate the equilibrium constant, K , for this reaction at 298 K using the expression

$$\ln K = \frac{nE_{\text{cell}}^\ominus F}{RT}$$

where n is the number of electrons transferred in the overall equation,
 F is the Faraday constant ($96\,500 \text{ C mol}^{-1}$) and
 R is the gas constant ($8.31 \text{ J mol}^{-1} \text{ K}^{-1}$).
 Units of K are not required.

(2)



(b) A fuel cell produces a voltage from the reaction between a fuel and oxygen.

The reaction occurring at one electrode in a methanol fuel cell is



Which reaction occurs at the other electrode?

(1)

- ☐ **A** $4\text{H}^+(\text{aq}) + \text{O}_2(\text{g}) + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}(\text{l})$
- ☐ **B** $2\text{H}_2(\text{g}) + 2\text{O}_2(\text{g}) + 4\text{e}^- \rightarrow 4\text{OH}^-(\text{aq})$
- ☐ **C** $4\text{OH}^-(\text{aq}) \rightarrow 2\text{H}_2(\text{g}) + 2\text{O}_2(\text{g}) + 4\text{e}^-$
- ☐ **D** $2\text{H}_2\text{O}(\text{l}) \rightarrow 4\text{H}^+(\text{aq}) + \text{O}_2(\text{g}) + 4\text{e}^-$

(c) Lead-acid batteries are used as storage cells in some cars.

The electrolyte is sulfuric acid, one electrode is lead and the other is lead(IV) oxide, PbO_2 .

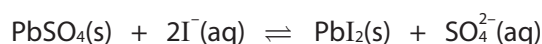
As the cell discharges, the lead and the lead(IV) oxide are both converted to solid lead(II) sulfate, PbSO_4 , and the concentration of the sulfuric acid decreases.

Deduce, using the information given, the two half-equations occurring in the lead-acid battery.

State symbols **are** required.

(3)

- (d) When solid lead(II) sulfate is added to aqueous sodium iodide, an equilibrium is established.



The expression for the equilibrium constant, K_c , for this reaction is

$$K_c = \frac{[\text{SO}_4^{2-}(\text{aq})]}{[\text{I}^-(\text{aq})]^2}$$

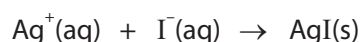
In an experiment, K_c may be determined by adding excess lead(II) sulfate to 25.0 cm^3 of $0.100 \text{ mol dm}^{-3}$ sodium iodide.

The volume remains constant at 25.0 cm^3 .

The mixture is left to reach equilibrium at room temperature.

Ice-cold water is added to freeze the position of equilibrium and the mixture is then titrated with standard silver nitrate solution.

The whole mixture requires 12.20 cm^3 of $0.0500 \text{ mol dm}^{-3}$ silver nitrate solution to react with the aqueous iodide ions at equilibrium.



Calculate the equilibrium concentrations of the sulfate ions and the iodide ions, and hence the value of K_c at room temperature.

Give your answer to an appropriate number of significant figures and include units for K_c , if any.

(7)



(Total for Question 8 = 13 marks)



7 This question is about chromium and some of its compounds.

(a) The common oxidation numbers of chromium are +2, +3 and +6.

Give a reason, in terms of ionisation energies, why chromium can show variable oxidation numbers.

(1)

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(b) The bonding in chromate(VI) ions, CrO_4^{2-} , is similar to that in sulfate(VI) ions, SO_4^{2-} .

Draw a possible dot-and-cross diagram for a chromate(VI) ion.

(2)



- (c) A student added some pieces of zinc to an acidified solution of potassium dichromate(VI).

Some standard electrode potentials are given in the table.

Right-hand electrode system	$E^{\ominus} / \text{V}$
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^{-} \rightleftharpoons \text{Zn}(\text{s})$	-0.76
$\text{Cr}^{3+}(\text{aq}) + \text{e}^{-} \rightleftharpoons \text{Cr}^{2+}(\text{aq})$	-0.41
$\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^{+}(\text{aq}) + 6\text{e}^{-} \rightleftharpoons 2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l})$	+1.33

- (i) Write the overall equation for the reduction of dichromate(VI) ions to chromium(III) ions by zinc in acid conditions.
State symbols are not required.

(2)

- (ii) Calculate $E_{\text{cell}}^{\ominus}$ for the reaction in (c)(i).

(1)

- (iii) Predict whether or not a further reduction of chromium(III) ions to chromium(II) ions will occur. Justify your answer.

(1)

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(iv) Aqueous solutions containing chromium(III) ions and chromium(II) ions have different colours.

Explain why these solutions **differ** in colour.

An explanation of the origin of the colours is not required.

(2)

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(d) An iron nail was analysed using the following outline procedure.

- An iron nail was placed in a beaker and excess dilute sulfuric acid was added.
- After all the iron had reacted to form iron(II) ions, the solution was made up to 1.00 dm^3 in a volumetric flask.
- 25.0 cm^3 portions of the solution were acidified and titrated with potassium dichromate(VI) solution of concentration $0.0167 \text{ mol dm}^{-3}$.

Results

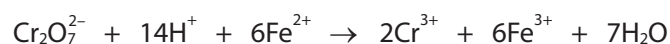
mass of iron nail = 3.54 g

mean titre = 15.50 cm^3

The table shows the percentage by mass of iron in four different brands of nail.

Brand of nail	Percentage by mass of iron
A	92
B	94
C	96
D	98

Potassium dichromate(VI) in acid solution oxidises iron(II) ions as shown in the equation



Determine, using the experimental data, the brand of nail that was analysed.

(5)



(Total for Question 7 = 14 marks)



8 This is a question about chromium(III) and chromium(VI) compounds.

- (a) Describe the observations when aqueous sodium hydroxide is added drop by drop until in excess to a solution of chromium(III) ions.

(2)

- (b) The chromium(III) complex, $[\text{Cr}(\text{OH})_6]^{3-}$, can be oxidised to chromate(VI) ions, CrO_4^{2-} , by hydrogen peroxide solution.

- (i) Deduce the oxidation half-equation for this reaction, which takes place in alkaline conditions. State symbols are not required.

(2)

- (ii) If the solution of chromate(VI) ions is then acidified, the colour of the solution changes to orange as dichromate(VI) ions form.

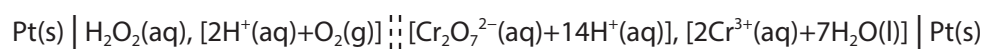
Write the equation for this change. State symbols are not required.

(1)



(iii) In acidic conditions, dichromate(VI) ions can also be reduced to chromium(III) ions using hydrogen peroxide.

The value of $E^{\ominus}_{\text{cell}} = + 0.65 \text{ V}$ for which the cell diagram is



Deduce from the cell diagram the oxidation and the reduction half-equations, and thus the overall equation for this reaction.

State symbols are not required.

(3)

- (c) Draw a labelled diagram of the apparatus that you would use to measure the standard emf of a cell with a zinc-zinc(II) electrode system and a chromium(III)-dichromate(VI) electrode system.

Include the **formulae** of all the compounds required and the concentrations of the solutions.

(7)

(Total for Question 8 = 15 marks)



5 This question is about the properties of transition elements, their ions and their complexes.

(a) Give the oxidation state of vanadium in the compound NH_4VO_3 .

(1)

(b) Excess zinc powder is added to an acidified solution of the compound NH_4VO_3 . Using the data in the table, explain the sequence of reactions that takes place.

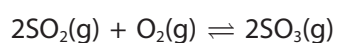
In your answer, include a description of what you would **see**, and the relevant ionic equations with their calculated $E^\ominus_{\text{cell}}$ values. State symbols are not required.

(7)

Electrode system	$E^\ominus / \text{V}$
$\text{V}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{V}(\text{s})$	-1.18
$\text{V}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{V}^{2+}(\text{aq})$	-0.26
$\text{VO}^{2+}(\text{aq}) + 2\text{H}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{V}^{3+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$	+0.34
$\text{VO}_3^-(\text{aq}) + 4\text{H}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{VO}^{2+}(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$	+1.00
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76



(c) Explain how vanadium(V) oxide acts as a catalyst in one step of the contact process. The equation for this step is



(2)



*(d) Describe the reactions of separate portions of aqueous copper(II) ions with aqueous sodium hydroxide solution, with excess aqueous ammonia solution and with concentrated hydrochloric acid.

In your answer you should link observations with equations which include the formulae of any copper-containing complex ions. Include state symbols.

(6)



Handwriting practice area with 25 horizontal dotted lines.

(Total for Question 5 = 16 marks)

TOPIC 3

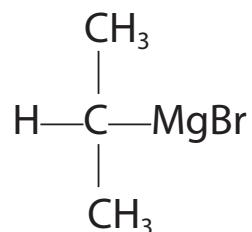
SYNOPTIC AND MIXED QUESTIONS

5 questions in this sub-topic · 53 marks · lowest tariff first



5 Grignard reagents are used in organic synthesis as a way of increasing the length of the carbon chain in a molecule.

(a) The structure of the Grignard reagent formed by the reaction between 2-bromopropane and magnesium is



On the diagram, draw the permanent dipole involving the central carbon atom.

(1)

(b) The Grignard reagent in part (a) reacts with propanal.

(i) Draw the **fully displayed** formula of the final organic product of this reaction.

(1)

(ii) Name the organic product in (b)(i).

(1)



- (c) Identify, by using ticks, **two** boxes in the table to select appropriate terms that describe a Grignard reagent.

(2)

acid	
electrophile	
nucleophile	
oxidising agent	
reducing agent	

- (d) The solvent used for Grignard reagents has to be completely **dry**.

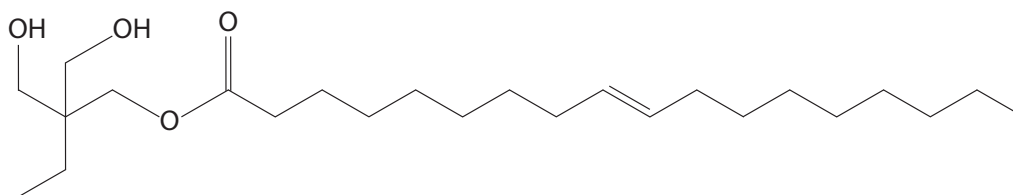
By considering the dipole on the O—H bonds in water, predict the identity of the organic product that forms if water is added to the Grignard compound in part (a).

(1)

(Total for Question 5 = 6 marks)



- 5 Compound **X** is a component of synthetic oils used as lubricants, for instance in the gearboxes of ships.



compound **X**

- (a) Name the **three** functional groups present in compound **X**.

(2)

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- (b) The effectiveness of this synthetic oil is much reduced if it is contaminated with water.

Give, in terms of a chemical reaction, a possible reason for this.

(1)

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.....

(c) An alternative to synthetic oil is known as mineral oil and consists solely of hydrocarbons separated from crude oil.

(i) What is the name of the process used to separate different hydrocarbons from crude oil?

(1)

- ☐ A cracking
- ☐ B reforming
- ☐ C fractional distillation
- ☐ D heating under reflux

(ii) Explain why compound **X** is likely to have a higher boiling temperature than hydrocarbons of a similar molecular mass and shape.

A detailed description of how the intermolecular forces arise is not required.

(2)

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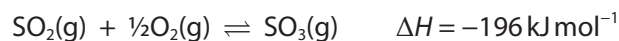
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(Total for Question 5 = 6 marks)

7 This question is about vanadium.

The contact process is used in the manufacture of sulfuric acid. In the second stage, sulfur dioxide is converted into sulfur trioxide by passing sulfur dioxide and air over a solid V_2O_5 catalyst.

The equation for the second stage is shown.



(a) (i) What are the expression and the units for the equilibrium constant (K_p) for this reaction?

(1)

	Expression	Units
☐ A	$\frac{p(SO_3)}{p(SO_2)p(O_2)^{1/2}}$	atm^2
☐ B	$\frac{p(SO_2)p(O_2)^{1/2}}{p(SO_3)}$	$\text{atm}^{1/2}$
☐ C	$\frac{p(SO_2)p(O_2)^{1/2}}{p(SO_3)}$	$\text{atm}^{-1/2}$
☐ D	$\frac{p(SO_3)}{p(SO_2)p(O_2)^{1/2}}$	$\text{atm}^{-1/2}$

(ii) Which variable affects the value of K_p ?

(1)

- ☐ A pressure
- ☐ B temperature
- ☐ C surface area of the catalyst
- ☐ D concentration of $O_2(g)$

- (b) Write **two** equations that show the conversion of SO_2 and O_2 into SO_3 by using V_2O_5 as the catalyst.
State symbols are not required.

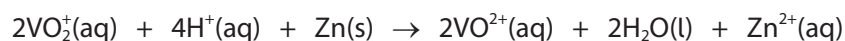
(2)

- (c) Which row of the table shows the correct colour of the solution and oxidation number of vanadium in the aqueous ions shown?

(1)

	Aqueous ion	Colour of solution	Oxidation number of vanadium
☐ A	VO_2^+	yellow	+3
☐ B	VO^{2+}	green	+4
☐ C	VO_2^+	yellow	+5
☐ D	VO^{2+}	blue	+5

- (d) What is the value of the cell potential for the reaction of Zn and VO_2^+ ?
Use your Data Booklet.



(1)

- ☐ **A** +1.76V
☐ **B** +0.24V
☐ **C** -0.24V
☐ **D** -1.76V

(Total for Question 7 = 6 marks)

- 5 This question is about extracting benzoic acid from a mixture of benzoic acid, $\text{C}_6\text{H}_5\text{COOH}$, and phenol, $\text{C}_6\text{H}_5\text{OH}$.

The following steps were carried out.

- Step 1 A suitable mass of the mixture was placed in a separating funnel and some ether added. The funnel was shaken to dissolve the mixture.
- Step 2 Aqueous sodium hydrogencarbonate was added to the separating funnel, and the contents shaken.
- Step 3 Once the reaction was complete, the two layers were allowed to separate.
- Step 4 The lower aqueous layer was removed and placed in a beaker.
- Step 5 The ether layer in the separating funnel was washed with deionised water and the washings added to the beaker.
- Step 6 Hydrochloric acid was added to the aqueous solution in the beaker to precipitate the benzoic acid.
- Step 7 The impure benzoic acid was filtered under reduced pressure.
- Step 8 The impure benzoic acid was purified by recrystallisation.
- Step 9 The melting temperature of the purified benzoic acid was measured and compared with the literature value of 122°C .

- (a) Complete the equation for the reaction between benzoic acid and sodium hydrogencarbonate.

(2)



- (b) In Step 2 there is a pressure build-up in the separating funnel.

Describe how you would lower the pressure.

(1)

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(c) State why, in Step **4**, the aqueous layer was the lower of the two layers.

(1)

(d) Give a reason why, in Step **5**, the ether layer was washed with deionised water.

(1)

(e) Explain why the addition of hydrochloric acid in Step **6** results in the precipitation of benzoic acid.

(2)

(f) Draw a diagram of the apparatus used in Step **7** to filter under reduced pressure.

(2)



- (g) Benzoic acid can be purified in Step 8 because of its high solubility in hot water and low solubility in cold water.

Calculate the maximum number of benzoic acid molecules that can dissolve in 50.0 cm^3 of cold water if the solubility is $1.70 \text{ g per } 1000 \text{ cm}^3$.

(3)

- (h) The melting temperature range of the purified benzoic acid in Step 9 was $116\text{--}121^\circ\text{C}$.

Compare this result with the literature value, giving a reason for any differences.

(2)

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(Total for Question 5 = 14 marks)

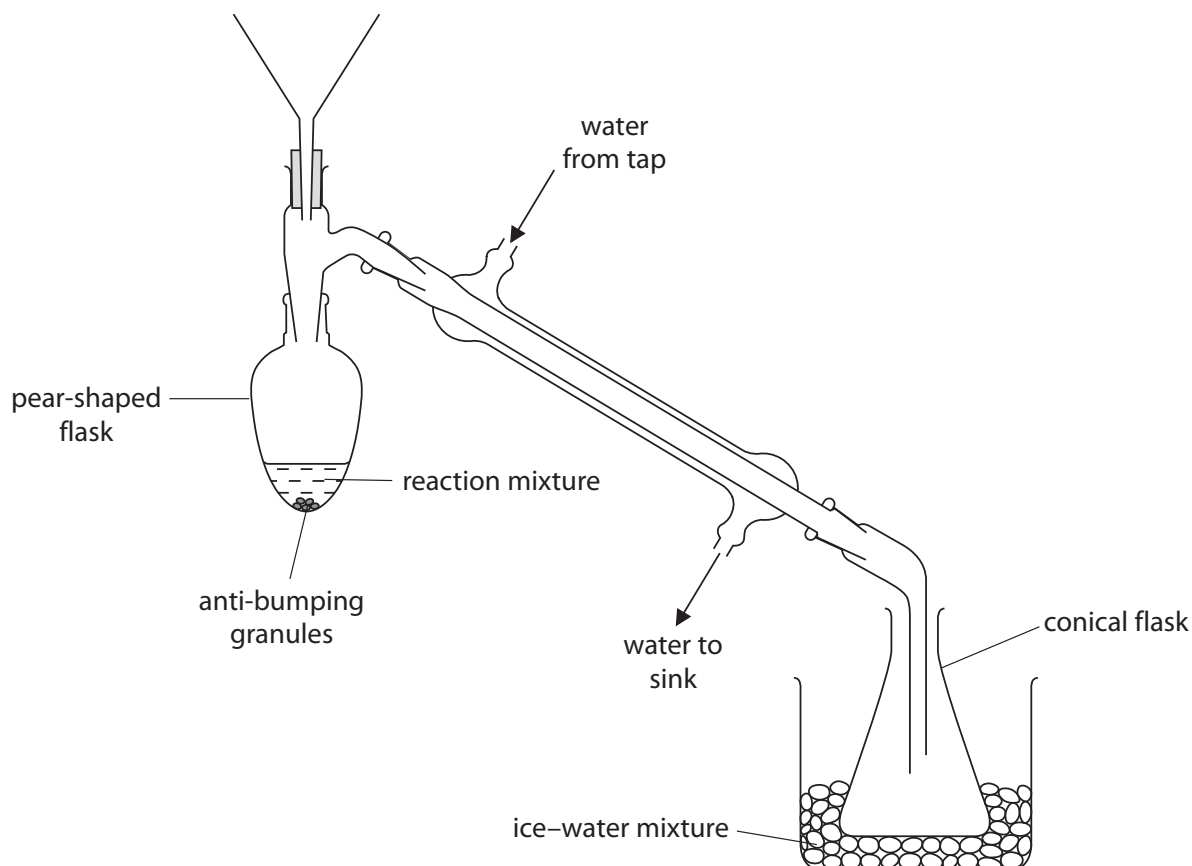


- 2 This question is about the preparation of a sample of the ketone, 3-methylbutan-2-one.

A student's research suggested that 3-methylbutan-2-one may be prepared by oxidising 3-methylbutan-2-ol with acidified potassium dichromate(VI) solution.

The student sets up the apparatus as shown in the diagram. You may assume that all the equipment is suitably clamped.

The student adds dilute sulfuric acid to the pear-shaped flask. A mixture of potassium dichromate(VI) and 3-methylbutan-2-ol is then added slowly to the dilute sulfuric acid in the flask.



- (a) Identify the **two** changes that must be made to the apparatus before heating the pear-shaped flask, giving a reason for each change.

(4)

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- (b) Draw the **skeletal** formulae for 3-methylbutan-2-ol and 3-methylbutan-2-one.

(2)

3-methylbutan-2-ol

3-methylbutan-2-one



- (c) Once the essential changes are made to the apparatus, the pear-shaped flask is heated. The distillate formed is collected in the conical flask.

On testing the distillate with pH paper, it is found that its pH is 2.

The student suggests that this pH is due to the formation of 3-methylbutanoic acid.

- (i) Give a reason why 3-methylbutanoic acid cannot be formed in the reaction.

(1)

- (ii) Deduce the **formula** of the compound that could cause the distillate to have a pH value of 2.

(1)

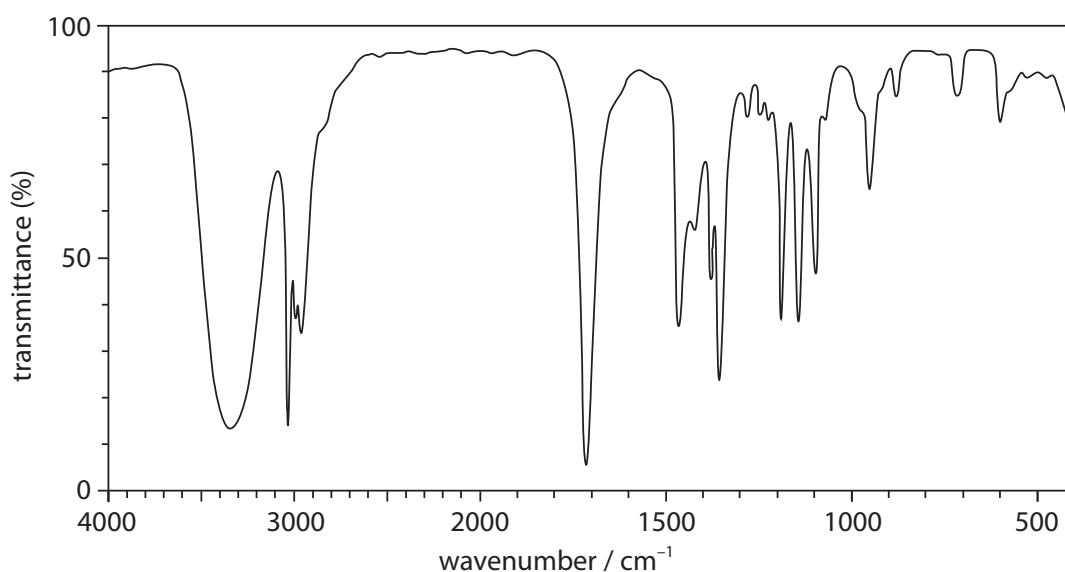
- (iii) Solid sodium carbonate is added to the distillate. The sodium carbonate disappears and fizzing occurs.

Write an equation, including state symbols, for the reaction that occurs between sodium carbonate and the compound you have identified in (c)(ii).

(2)



- (d) The organic mixture was separated from the aqueous layer and dried.
The infrared spectrum of the organic mixture is shown.



- (i) By reference to any relevant peak(s), deduce how the infrared spectrum shows that the mixture contains 3-methylbutan-2-one.

(2)

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- (ii) From the infrared spectrum, the student concludes that the mixture contains another organic compound.

The mixture is redistilled and the fraction that boils in the range 93–95°C is collected.
The boiling temperature of 3-methylbutan-2-one is 94°C.

Predict any change(s) you would see in the infrared spectrum after redistillation, justifying your answer.

(2)

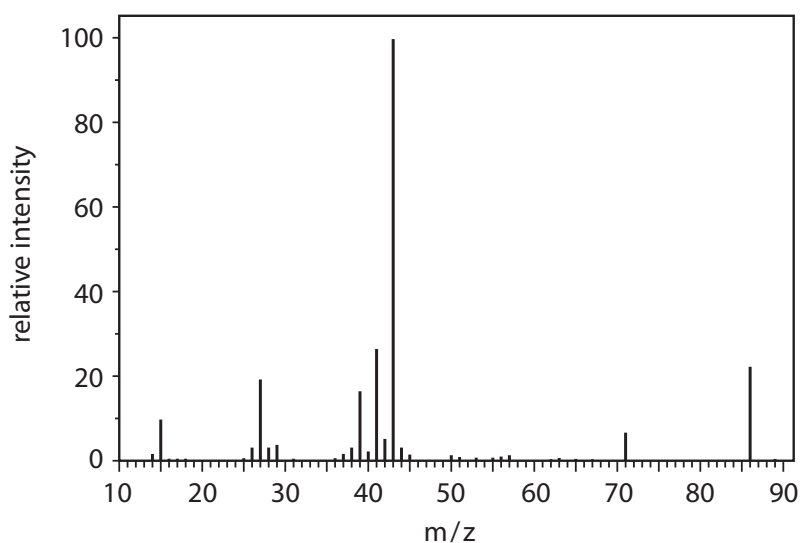
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(e) The mass spectrum of pure 3-methylbutan-2-one is shown.



(i) State how you would find the molar mass of 3-methylbutan-2-one from the mass spectrum.

(1)

(ii) The mass spectrum shows a peak at $m/z = 43$.

Draw the **displayed** formulae of two fragment **ions** that might be responsible for this peak.

(2)

(f) The sample of purified 3-methylbutan-2-one is found to have a mass of 2.15 g. This mass of 3-methylbutan-2-one represents a yield of 62.5% by mass.

- (i) Write an equation, using **molecular** formulae, for the oxidation of 3-methylbutan-2-ol to 3-methylbutan-2-one. Use [O] to represent the oxidising agent.

(2)

- (ii) Calculate the mass of 3-methylbutan-2-ol that the student uses at the start of the preparation.

(2)

(Total for Question 2 = 21 marks)



MARK SCHEMES

official Pearson Edexcel mark schemes



Question Number	Answer	Additional Guidance	Mark
2(a)	An explanation that makes reference to the following points: - N changes from (+)5 to (+)4 (1) - O changes from -2 to 0 (in O₂) (1) so nitrogen / N is reduced (as the oxidation number has decreased) and oxygen / O (in forming O₂) is oxidised (as the oxidation number has increased) (1)	These numbers may be written under the formulae in the equation Allow oxidation numbers written as 5+, 4+, 2- Ignore unchanged oxidation numbers of magnesium and oxygen Allow this mark if incorrect / missing oxidation numbers in M1 and M2 Ignore general statement about redox Ignore redox explained in terms of electron gain or loss	(3)



Question Number	Answer	Additional Guidance	Mark
2(b)	An explanation that makes reference to the following points: Size calcium ion / Ca^{2+} has larger (ionic) radius / is larger than magnesium ion or magnesium ion / Mg^{2+} has smaller (ionic) radius / is smaller than calcium ion (1) Polarising power so calcium ion/ Ca^{2+} causes less polarisation/ distortion or magnesium ion/ Mg^{2+} causes more polarisation/ distortion (1) What is polarised of the nitrate (ion / electron cloud) / NO_3^- / anion / negative ion / N—O bonds / N=O bonds / NO bonds (1)	Penalise omission of 'ion' or just 'calcium / Ca / magnesium / Mg' without charge, or reference to atom or molecule once only Ignore general references to ionic / covalent character Allow ionic radius increases down the group / decreases up the group Allow magnesium ions have a higher charge density (than calcium ions) Ignore atomic radius Ignore effective nuclear charge Allow the cation causes less / more polarisation if it is clear from M1 which cation is involved Do not allow this mark for carbonate / C-O bonds Do not allow mention of bond between cation and anion Note Nitrate ions are less polarised by Ca^{2+} / more polarised by Mg^{2+} scores M2 and M3	(3)

(Total for Question 2 = 6 marks)



Question Number	Answer	Additional Guidance	Mark
3(a)(i)	An explanation that makes reference to the following points: - oxidation numbers of Br identified as (+)5 for BrO_3^-, -1 for Br^- and 0 for Br_2 (1) - this is not disproportionation because: two different species of bromine / reactants are oxidised and reduced / not one species oxidised and reduced or only one species containing bromine is produced / two different species containing bromine in two different oxidation states are not produced (1)	These may be shown in the equation Allow 5+ / V / 1- / -I Do not award any change in oxidation numbers of oxygen and or hydrogen Allow bromine is oxidised and reduced in the reverse reaction Allow this is reverse disproportionation / comproportionation	(2)

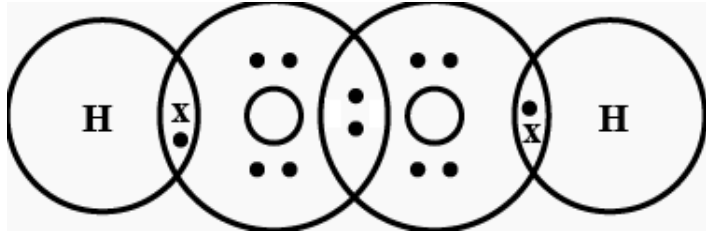
Question number	Answer	Mark
3(a)(ii)	The only correct answer is D (cannot tell from this information) <i>A is incorrect because there are 3 reactant species but the overall order of a reaction can only be determined by experiment</i> <i>B is incorrect because there is 1 bromate ion and 5 bromide ions but the overall order of a reaction can only be determined by experiment</i> <i>C is incorrect because there are 12 reactant particles but the overall order of a reaction can only be determined by experiment</i>	(1)



Question Number	Answer	Additional Guidance	Mark
3(b)	- calculation of moles of KBrO_3 - calculation of moles of O_2 - calculation of volume of O_2	<u>Example of calculation</u> moles of $\text{KBrO}_3 = \frac{5.20}{(39.1 + 79.9 + (3 \times 16.0))} = \frac{5.20}{167(.0)} = 0.031138 / 3.1138 \times 10^{-2} \text{ (mol)}$ moles of $\text{O}_2 = \frac{0.031138 \times 3}{2} = 0.046707 / 4.6707 \times 10^{-2} \text{ (mol)}$ TE on moles of KBrO_3 volume of $\text{O}_2 = 0.046707 \times 24 = 1.12096 \text{ (dm}^3\text{)}$ TE on moles of O_2 Do not award incorrect unit e.g. dm^{-3} Correct answer with no working scores (3) Ignore SF except 1 SF Ignore use of $pV = nRT$	(3)

(Total for Question 3 = 6 marks)



Question Number	Answer	Additional Guidance	Mark
3(a)		Ignore omission of circles Ignore line to show covalent bonds Allow reversal of dots and crosses Allow all dots or all crosses	(1)

Question Number	Answer	Additional Guidance	Mark
3(b)	An explanation that makes reference to the following points: - oxidation number of oxygen has changed from -1 (in H_2O_2) - to -2 in water, so reduced - and 0 in (elemental) oxygen, so is oxidised	Oxidation numbers may be shown above / below species in equation Allow Roman numerals to show oxidation numbers Allow 1 rescue mark for correct oxidation numbers of oxygen in both products if references to oxidation and reduction incorrect or omitted or not linked to a specific reaction in M2 and M3 Allow 1 rescue mark for correct oxidation numbers and references to oxidation and reduction if products omitted in M2 and M3	(3)

Question Number	Answer	Additional Guidance	Mark
3(c)(i)	An answer that makes reference to the following points: (order with respect to hydrogen peroxide =) 1 / first (1) (order with respect to iodide ions =) 1 / first (1)		(2)

Question Number	Answer	Additional Guidance	Mark
3(c)(ii)	An answer that makes reference to the following point: rate / $r = k[\text{H}_2\text{O}_2][\text{I}^-]$	Rate equation must be consistent on orders from (i) Allow use of correct names Allow TE from 3(c)(i) Do not award round brackets Do not award omission of rate / r	(1)



Question Number	Answer	Additional Guidance	Mark
3(c)(iii)	- calculation of k - units of k	<u>Example of calculation</u> Calculation must be consistent on rate equation from (ii) (1) $k = \text{rate} \div [\text{H}_2\text{O}_2][\text{I}^-]$ $3.56 \times 10^{-6} \div (0.200 \times 0.100) = 1.78 \times 10^{-4}$ (1) $\text{dm}^3 \text{mol}^{-1} \text{s}^{-1}$ Allow $\text{dm}^3/\text{mol/s}$ Allow $\text{dm}^3 \text{mol}^{-1} \text{s}^{-}$ Allow units in any order Ignore SF except 1 SF Allow TE from incorrect rate equation in 3(c)(ii) Allow calculation based on data from experiments 1 or 2 NOTE – with TE on incorrect order, calculation and units require checking as different experiments give different values	(2)

Question Number	Answer	Additional Guidance	Mark
3(d)(i)	An answer that makes reference to the following points: put glowing splint (into bubbles of gas / presence of gas) and splint relights	Ignore ‘a splint that has (just) been blown out relights’ Do not award ‘relights a burnt splint’ Do not award squeaky pop	(1)

Question Number	Answer	Additional Guidance	Mark
3(d)(ii)	An explanation that makes reference to the following points: (colour caused by aqueous solution of) iodine (1) (formed as excess hydrogen) peroxide oxidises iodide (ions) / converts iodide (ions) / reacts with iodide (ions) (1)	Accept (colour caused by) aqueous (solution of) I_3^- Ignore iodide ions are yellow in solution Do not award iodine ions Allow oxygen oxidises / converts / reacts with the iodide (ions) / iodide reduces (hydrogen) peroxide Allow correct equation $2H^+ + H_2O_2 + 2I^- \rightarrow I_2 + 2H_2O$ Ignore incomplete equations (as considered part of the working out process)	(2)



Question Number	Answer	Additional Guidance	Mark
3(e)(i)	- triangle or similar shown on graph to indicate changes in x and y (1) - calculation of gradient (1) - units of gradient (1)	<u>Example of calculation</u> Allow circling of points / marking of points on line For example $-11 - -6 = -5$ $0.003588 - 0.003038 = 0.00055$ $-5 \div 0.00055 = -9090.9$ Allow gradient in range -8500 to -9500, consistent with correctly determined y and x values, though gradient must be checked for calculator errors Allow TE on incorrectly determined y and x values from M1 Allow negative gradient even if values used in $\Delta y / \Delta x$ would give a positive value Ignore SF Ignore rounding errors in final value of gradient K No TE for units based on inverted axes	(3)

Question Number	Answer	Additional Guidance	Mark
3(e)(ii)	calculation of E_a	<u>Example of calculation</u> $-9090.9 \times 8.31 = -E_a$ $E_a = (+) 75.545 \text{ (kJ mol}^{-1}\text{)}$ Allow (+) 75545 J mol⁻¹ Ignore SF except 1 SF Allow TE from (e)(i) Do not award negative activation energies. Note : if answer is in J mol⁻¹ units must be given	(1)

Question Number	Answer	Additional Guidance	Mark
3(f)	- expression for, using numbers, or calculation of $e^{-E_a/RT}$ (1) - calculation of A (1)	<u>Example of calculation</u> $e^{-50200 \div (8.31 \times 370)} / 8.1164 \times 10^{-8}$ $1.60 \times 10^{-3} \div 8.1164 \times 10^{-8} = 1.9713 \times 10^4$ Ignore SF Ignore units TE from M1 to M2 Correct answer with no working scores 2 Note – use of rounded values of $e^{-E_a/RT}$ is acceptable and final answer may need checking as it will make a difference to the numerical value M1 can be subsumed in M2	(2)

(Total for Question 3 = 18 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark																				
*8	This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr><tr><td>6</td><td>4</td></tr><tr><td>5–4</td><td>3</td></tr><tr><td>3–2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table> The following table shows how the marks should be awarded for structure and lines of reasoning. <table><tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr><tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout.</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning.</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured.</td><td>0</td></tr></table>	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	6	4	5–4	3	3–2	2	1	1	0	0		Number of marks awarded for structure of answer and sustained line of reasoning	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout.	2	Answer is partially structured with some linkages and lines of reasoning.	1	Answer has no linkages between points and is unstructured.	0	Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points, which is partially structured with some linkages and lines of reasoning, scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages). In general it would be expected that 5 or 6 indicative points would get 2 reasoning marks, and 3 or 4 indicative points would get 1 mark for reasoning, and 0, 1 or 2 indicative points would score zero marks for reasoning. If there is any incorrect chemistry, deduct mark(s) from the reasoning. If no reasoning mark(s) awarded do not deduct mark(s).	(6)
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points																						
6	4																						
5–4	3																						
3–2	2																						
1	1																						
0	0																						
	Number of marks awarded for structure of answer and sustained line of reasoning																						
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout.	2																						
Answer is partially structured with some linkages and lines of reasoning.	1																						
Answer has no linkages between points and is unstructured.	0																						

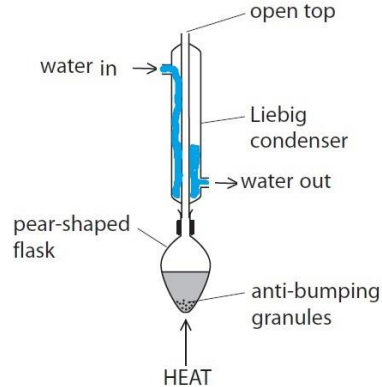


*8	Indicative content • IP1 (similarity: mechanism of action) both (increase the rate of a reaction) by lowering the activation energy by providing an alternative pathway / route for the reaction • IP2 (similarity: oxidation number changes) both involve the change of oxidation numbers and then the return to the original oxidation number • IP3 (V₂O₅ mechanism) reactants / SO₂ and O₂ adsorb(s), (reactant bonds weaken / break) and product / SO₃ desorb(s) or (Fe²⁺ mechanism) (the) positive Fe²⁺ ions attract the negative S₂O₈²⁻ ions • IP4 (difference: homogeneous / heterogeneous) V₂O₅ is heterogeneous / different phase / state (as reactants) and Fe²⁺ is homogeneous / same phase / state (as reactants) • IP5 (Equation 1) V₂O₅(s) + SO₂(g) → V₂O₄(s) + SO₃(g) and V₂O₄(s) + ½O₂(g) → V₂O₅(s) • IP6 (Equation 2) S₂O₈²⁻(aq) + 2Fe²⁺(aq) → 2Fe³⁺(aq) + 2SO₄²⁻(aq) and 2Fe³⁺(aq) + 2I⁻(aq) → I₂(aq) + 2Fe²⁺(aq)	Ignore any references to colours of species in reactions Allow via illustration of correct changes in oxidation state Allow V₂O₅ is reduced to V₂O₄, which is then oxidised to V₂O₅ and Fe²⁺ is oxidised to Fe³⁺ which is then reduced to Fe²⁺ Ignore catalyst is reformed / regenerated Ignore sulfur/ iodine oxidation numbers Do not award autocatalysis Allow S₂O₈²⁻ and I⁻ repel (so the reaction starts slowly) Allow specific states mentioned – V₂O₅ is a solid and the reactants are gases and Fe²⁺ and the reactants are all in aqueous solution Allow multiples Ignore state symbols for IP5 and IP6 If IP5 and IP6 not given allow 1IP for any two correct equations	(6)
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(Total for Question 8 = 6 marks)



Question Number	Acceptable Answer	Additional guidance	Mark
5(a)	- Balanced equation (1) - Appropriate colours (1)	Example of equation: $\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^- \rightarrow 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$ Allow multiples Orange colourless green colourless Allow 'No colour' for colourless Do not award 'blue' for 'green' Do not award 'clear' for colourless Do not award if any spaces left blank Ignore any colour given for electrons Ignore any shades of colour	(2)

Question Number	Acceptable Answer	Additional guidance	Mark
5(b)(i)	A diagram with any shading that is not 100%	An example of a suitable diagram:  Allow shaded area to show 'air pockets'	(1)

Question Number	Acceptable Answer	Additional guidance	Mark
5(b)(ii)	An answer that makes reference to the following prevention of uncontrolled boiling by: - distributing the heat more evenly or - providing a surface for bubbles to form/allow smaller bubbles to form/provides nucleation sites for bubbles	Do not award provide surface area for reaction Ignore reference to mixing the reagents/provide smooth boiling	(1)

Question Number	Acceptable Answer	Mark
5(c)	The only correct answer is B <i>A is incorrect because not a systematic name</i> <i>C is incorrect because it has five carbons</i> <i>D is incorrect because it has only three carbons</i>	(1)

Question Number	Acceptable Answer	Additional guidance	Mark
5(d)	An explanation that makes reference to the following - ethanol would be oxidised to ethanal (1) - because ethanal has a low boiling temperature (1) or ethanal will distil before ethanoic acid can be formed	Allow aldehyde for ethanal Allow ethanal will be formed Allow ethanal is (more) volatile Accept reverse argument in terms of reflux condensing ethanal for oxidation to ethanoic acid	(2)

(Total for Question 5 = 7 marks)



Question Number	Answer	Additional Guidance	Mark
2(a)(i)	equation	<u>Example of equation</u> $\text{Cl}_2 + 2\text{KBr} \rightarrow \text{Br}_2 + 2\text{KCl}$ Accept ionic equation $\text{Cl}_2 + 2\text{Br}^- \rightarrow \text{Br}_2 + 2\text{Cl}^-$ Allow multiples Ignore state symbols even if incorrect	(1)

Question Number	Answer	Additional Guidance	Mark
2(a)(ii)	An answer that makes reference to the following points: (M1) the precipitate is a mixture of silver chloride and bromide silver - or - not all of the bromide ions were oxidised (1) (M2) silver chloride/AgCl dissolves in dilute ammonia (1) (M3) silver bromide/AgBr does not dissolve in dilute ammonia (1)	Allow Some bromide ions are still present/bromide ions were in excess/both chloride and bromide ions are present Do not award references to Cl^- dissolving Silver bromide only dissolves in concentrated ammonia	(3)

Question Number	Answer	Additional Guidance	Mark
2(a)(iii)	An answer that makes reference to the following point: iodine is a weaker oxidising agent than chlorine or iodine cannot oxidise bromide ions or iodine is a stronger reducing agent	Accept reverse arguments Ignore Just references to reactivity/displacement e.g. iodine is less reactive/cannot displace	(1)

Question Number	Answer	Additional Guidance	Mark
2(b)(i)	balanced equation	<u>Example of equation</u> $3\text{Cl}_2 + 6\text{OH}^- \rightarrow 5\text{Cl}^- + \text{ClO}_3^- + 3\text{H}_2\text{O}$ Allow multiples Ignore state symbols even if incorrect	(1)

Question Number	Answer	Additional Guidance	Mark
2(b)(ii) Clip with 2(b)(i)	An explanation that makes reference to the following points: - oxidation number for chlorine changes from 0 to -1 so it is reduced (1) - oxidation number for chlorine changes from 0 to +5 so it is oxidised (1)	Ignore general definitions of disproportionation Accept oxidation numbers and their changes shown with equation Allow 1 out of 2 marks for three correct oxidation numbers of the chlorine	(2)

(Total Question 2 = 8 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
10(a)	correct equation	<u>Examples of equations</u> $\text{Cu} + 4\text{HNO}_3 \rightarrow \text{Cu}^{2+} + 2\text{NO}_3^- + 2\text{NO}_2 + 2\text{H}_2\text{O}$ or $\text{Cu} + 4\text{HNO}_3 \rightarrow \text{Cu}(\text{NO}_3)_2 + 2\text{NO}_2 + 2\text{H}_2\text{O}$ Allow multiples Allow $\rightleftharpoons$ provided equation is written in the direction shown Ignore state symbols, even if incorrect Ignore cancelled electrons Ignore Ag or Au on both sides	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
10(b)	- Indicator: starch (1) - Colour change: Starting colour: blue/black or blue or black Final colour: colourless (1)	M2 is conditional on starch or no indicator Ignore mention of precipitate Ignore other words to describe colour e.g. deep / dark Ignore clear	(2)



Question Number	Answer	Additional Guidance	Mark
10(c)	- calculation of moles of silver chloride (1) - calculation of mass of silver (1) - calculation of moles of Cu^{2+} (1) - calculation of mass of copper (1) - calculation of percentage of gold (1)	<u>Example of calculation</u> moles $\text{AgCl} = 0.706 / (107.9 + 35.5)$ $= 0.00492329 / 4.92329 \times 10^{-3}$ mass $\text{Ag} = 0.00492329 \times 107.9 = 0.531223 \text{ (g)}$ moles $\text{S}_2\text{O}_3^{2-}$ or moles $\text{Cu}^{2+} = 39.40 \times 0.100 / 1000$ $= 0.00394 / 3.94 \times 10^{-3}$ mass $\text{Cu} = 0.00394 \times 63.5 = 0.25019 \text{ (g)}$ mass $\text{Au} = 1.250 - (0.531223 + 0.25019)$ $= 0.468587 \text{ (g)}$ percentage of gold $= 0.468587 / 1.250 \times 100$ $= 37.5 \text{ (\%)}$ or percentage of silver $= 0.531223 / 1.250 \times 100$ $= 42.4978 / 42.5 \text{ (\%)}$ percentage of copper $= 0.25019 / 1.250 \times 100$ $= 20.0151 / 20 \text{ (\%)}$ percentage of gold $= 100 - (42.5 + 20) = 37.5 \text{ (\%)}$ Allow TE for each step Allow final answer based on correct rounding at each stage (36.3 to 37.9%) Ignore SF except 1 SF in final answer Correct answer without working scores (5) Continued on next page	(6)

	deduction that alloy is 9 carat gold (1)	Conditional on some correct working to show the percentage of gold If calculated % is not 37.5, allow: calculated value of carat ($24 \times \text{their percentage}/100$) or 'less than 9 carat gold' if calculated % is less than 37.5% or nearest carat value from table or a (rough) interpolated carat value or between the two relevant carat values	
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(Total for Question 10 = 9 marks)



Question number	Answer	Mark
3(a)	The only correct answer is D (grey/black solid, purple gas) <i>A is incorrect because iodine solid is not purple and iodine gas is not brown</i> <i>B is incorrect because iodine solid is not purple</i> <i>C is incorrect because iodine gas is not brown</i>	(1)

Question number	Answer	Mark
3(b)	The only correct answer is C ($\text{Cl}_2(\text{aq}) + 2\text{NaBr}(\text{aq}) \rightarrow 2\text{NaCl}(\text{aq}) + \text{Br}_2(\text{aq})$) <i>A is incorrect because bromine is less reactive than chlorine so no reaction occurs</i> <i>B is incorrect because bromine is less reactive than fluorine so no reaction occurs</i> <i>D is incorrect because chlorine is less reactive than fluorine so no reaction occurs</i>	(1)

Question Number	Answer	Additional Guidance	Mark
3(c)	electronic configuration of chloride ion	<u>Example of electronic configuration</u> $(1s^2)2s^22p^63s^23p^6$ Allow $2p^6 / 3p^6$ shown as e.g. $2p_x^22p_y^22p_z^2$ Ignore $1s^2$ repeated Ignore working Do not award correct answer if one or more incorrect answers are given	(1)



Question Number	Answer	Additional Guidance	Mark
3(d)(i)	An explanation that makes reference to the following points: - balanced equation (1) - calculation of $E^\ominus_{\text{cell}}$ value (1) $E^\ominus_{\text{cell}}$ / answer is negative / <0 and the reaction is not (thermodynamically) feasible (1)	<u>Example of equation</u> $\text{Br}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{HOBr}(\text{aq}) + \text{HBr}(\text{aq})$ Allow multiples Allow $\text{H}^+(\text{aq}) + \text{Br}^-(\text{aq})$ for $\text{HBr}(\text{aq})$ Allow reversible arrows Ignore state symbols even if incorrect $E^\ominus_{\text{cell}} = 1.09 - 1.57 = -0.48 \text{ (V)}$ Allow correct answer without calculation Allow 3 marks for reverse argument $\text{HOBr}(\text{aq}) + \text{HBr}(\text{aq}) \rightarrow \text{Br}_2(\text{aq}) + \text{H}_2\text{O}(\text{aq})$ (1) $E^\ominus_{\text{cell}} = 1.57 - 1.09 = (+) 0.48 \text{ (V)}$ (1) $E^\ominus_{\text{cell}}$ is positive / >0 so the reverse of disproportionation is (thermodynamically) feasible (1)	(3)



Question Number	Answer	Additional Guidance	Mark
3(d)(ii)	An answer that makes reference to the following point: disproportionation is an equilibrium system (and although K is very small, there is still a small concentration of disproportionation products) or excess water is used or concentration is not 1 mol dm^{-3} or HBr undergoes further disproportionation	Ignore just 'non-standard conditions' Ignore references to activation energy / collision theory Ignore H^+ / ions from the water	(1)

Question number	Answer	Mark
3(e)(i)	The only correct answer is C (graph C) A is incorrect because HF has a much higher boiling temperature than expected due to hydrogen bonding B is incorrect because there is an increase in boiling temperature from HCl to HI as the number of electrons in the molecules increases so the London forces increase in strength D is incorrect because HBr has a higher boiling temperature than HCl as there are more electrons in the molecules	(1)



Question number	Answer	Mark
3(e)(ii)	The only correct answer is A (acid-base) B is incorrect there is no displacement taking place C is incorrect because neither substance is oxidised or reduced D is incorrect because there is no substitution taking place	(1)

(Total for Question 3 = 9 marks)



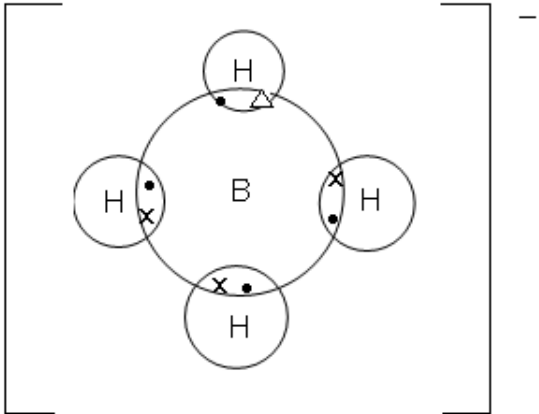
Question Number	Acceptable Answers	Additional Guidance	Mark
5(a)	phosphate(III) (ion)	Name and oxidation number are required Allow gap between name and oxidation number Allow phosphate and +3 Ignore missing brackets around oxidation number Do not award phosphorus / trioxide / phosphite(III)	(1)

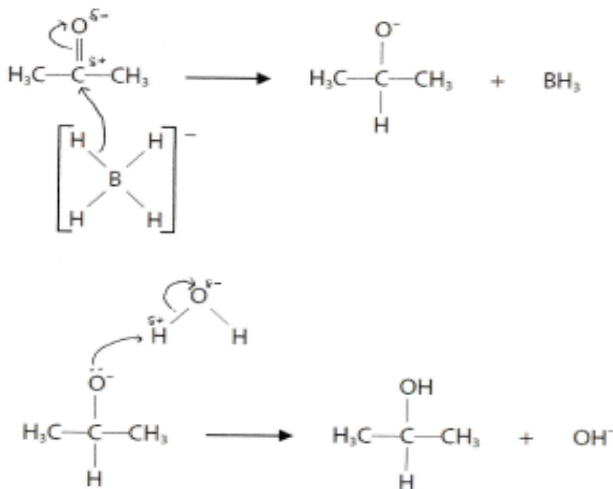
Question Number	Acceptable Answers	Additional Guidance	Mark
5(b)	(a reducing agent) increases in oxidation number and loses electron(s)	Allow oxidation number becomes more positive / gets larger Allow donates / gives electrons / number of electrons decreases Ignore a reducing agent decreases the oxidation number of another substance	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
5(c)	Na / sodium	Do not award Na ⁺	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
5(d)(i)	MnO_2, MnO_4^-, OH^- and MnO_4^{2-} species correct in a single equation (1) H_2O on right and balancing (1)	<u>Example of equation</u> $\text{MnO}_2 + 2\text{MnO}_4^- + 4\text{OH}^- \rightarrow 3\text{MnO}_4^{2-} + 2\text{H}_2\text{O}$ Ignore state symbols, even if incorrect Do not award M1 if H^+ is on the left Allow cancelled electrons Allow multiples	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
5(d)(ii)	An answer that makes reference to: 2 different species are oxidised and reduced (to form the same species) or there is not 1 species that is being oxidised and reduced or 2 different oxidation states are not produced from one oxidation state or only 1 oxidation state / +6 is formed as a product or Mn changes from +4 and +7 to +6 (only)	This mark can be awarded even if (i) is incorrect Allow manganate(VI) / MnO_4^{2-} is oxidised and reduced in the reverse reaction Allow Mn in the same species is not being oxidised and reduced Ignore just 'Mn is not simultaneously oxidised and reduced' Ignore this is reverse disproportionation / comproportionation Do not award O / H is oxidised / reduced Do not award molecules / compounds for species	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
5(e)(i)	dot-and-cross diagram	<u>Example of diagram</u>  Electrons must have the correct symbols i.e. 3 bonds with • and x and 1 bond with • and Δ Circles do not need to be shown Allow missing brackets but charge needs to be shown Allow charge anywhere on or close to diagram Ignore lines representing covalent bonds e.g. $\begin{array}{c} \times \\ \bullet \end{array}$ Ignore missing atom labels / inner shell of 2 electrons on B	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
5(e)(ii)	- curly arrow from B-H bond to C of C=O Allow curly arrow from B-H bond to H and curly arrow from H to C (1) - dipole on C=O and curly arrow from C=O bond to or just beyond O (1) - lone pair on O⁻ and curly arrow from lone pair to H of H₂O (1) - curly arrow from O-H bond to O and dipole on H-O bond (1)	<u>Example of mechanism</u>  Allow curly arrow from any B-H bond Ignore lone pair on O in H₂O Penalise half-headed curly arrow once only	(4)

(Total for Question 5 = 11 marks)

Question Number	Acceptable Answer	Additional guidance	Mark
4(a)(i)	correct equation	<u>Example of equation:</u> $2\text{NaN}_3 \rightarrow 2\text{Na} + 3\text{N}_2$ Allow multiples Ignore state symbols even if incorrect	(1)

Question Number	Acceptable Answer	Additional guidance	Mark
4(a)(ii)	- conversion of volume and temperature to correct units (1) - rearrangement of ideal gas equation so $n = pV \div RT$ and calculation of $n(\text{N}_2)$ in moles (1) - evaluation of $n(\text{NaN}_3)$ (1) - answer converted into mass to 2/3 SF (1) Allow TE at each stage	<u>Example of calculation:</u> $67 \text{ dm}^3 = 0.067 \text{ m}^3$, $300^\circ\text{C} = 573 \text{ K}$ $n(\text{N}_2) = \frac{140\,000 \times 0.067}{8.31 \times 573} = 1.9699\ldots(\text{mol})$ $n(\text{NaN}_3) = (2/3 \times 1.9699\ldots) = 1.313\ldots (\text{mol})$ $m = (1.313 \ldots \times 65 = 85.3629\ldots) = 85.4 / 85 (\text{g})$ Correct answer without working scores (4)	(4)



Question Number	Acceptable Answer	Additional guidance	Mark
4(b)	An answer that makes reference to the following points: - Nitrogen (is reduced) from +5 to 0 (1) - Sodium (is oxidised) from 0 to +1 (1) - Balanced equation (1)	Look for oxidation numbers annotated on the equation Do not award potassium oxidised Penalise omission of "+" sign, once only Example of balanced equation: $10\text{Na} + 2\text{KNO}_3 \rightarrow \text{K}_2\text{O} + 5\text{Na}_2\text{O} + \text{N}_2$ Allow multiples	(3)

Question Number	Acceptable Answer	Additional guidance	Mark
4(c)	An answer that makes reference to the following points: - Neutralisation reaction / acid base reaction (1) - Sodium and/or potassium oxides are caustic / corrosive (1) - Salts (silicates) formed are inert / unreactive (1)	Allow salt formation Allow "metal oxides" Ignore "harmful" / "alkaline" Allow "not harmful" / "not caustic" Ignore "neutral"	(3)

Question Number	Acceptable Answer	Mark
4(d)	The only correct answer is A <i>B is incorrect because the peak would shift to the left and be higher</i> <i>C is incorrect because the peak would shift to the left not to the right</i> <i>D is incorrect because the peak would be shift to the left not to the right</i>	(1)

(Total for Question 4 = 12 marks)



Question Number	Answer	Additional Guidance	Mark
8(a)	- substitution of values into the equation (1) - calculation of K_c (1)	Example of calculation $\ln K_c = \frac{5 \times 0.15 \times 96\,500}{8.31 \times 298}$ ($\ln K_c = 29.226$) $K_c = 4.9289 \times 10^{12}$ $= 4.9 \times 10^{12} / 4.93 \times 10^{12}$ TE on their value for $\ln K_c$ Ignore SF except 1SF Correct answer with no working scores (2)	(2)

Question number	Answer	Mark
8(b)	The only correct answer is A $(4\text{H}^+(\text{aq}) + \text{O}_2(\text{g}) + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}(\text{l}))$ B is incorrect because methanol does not react with hydrogen C is incorrect because this reaction shows an oxidation D is incorrect because this reaction shows an oxidation	(1)

Question Number	Answer	Additional Guidance	Mark
8(c)	- one half-equation - other half-equation - state symbols	(1) <u>Examples of half-equations</u> $\text{Pb(s)} + \text{SO}_4^{2-}(\text{aq}) \rightleftharpoons \text{PbSO}_4(\text{s}) + 2\text{e}^-$ Allow $\text{Pb(s)} + \text{H}_2\text{SO}_4(\text{aq}) \rightleftharpoons \text{PbSO}_4(\text{s}) + 2\text{H}^+(\text{aq}) + 2\text{e}^-$ (1) $\text{PbO}_2(\text{s}) + 4\text{H}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{PbSO}_4(\text{s}) + 2\text{H}_2\text{O}(\text{l})$ Allow $\text{PbO}_2(\text{s}) + 2\text{H}^+(\text{aq}) + \text{H}_2\text{SO}_4(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{PbSO}_4(\text{s}) + 2\text{H}_2\text{O}(\text{l})$ Allow multiples Allow single headed arrows in the forward direction Ignore missing charge on electrons (1) Conditional on correct species in one equation that has scored either M1 or M2	(3)



Question Number	Answer	Additional Guidance	Mark
8(d)	- calculation of initial mol I^- (1) - calculation of eqm mol I^- (1) - calculation of mol I^- reacted (1) - calculation of eqm mol SO_4^{2-} (1) - calculation of eqm $[SO_4^{2-}(aq)]$ and calculation of eqm $[I^-(aq)]$ (1) - calculation of K_c and answer to 2 / 3 SF (1) - units (1)	<u>Example of calculation</u> initial mol $I^- = (25.0 \times 0.100) \div 1000 = 2.5 \times 10^{-3} / 0.0025$ (mol) eqm mol $I^- (= \text{mol } Ag^+) = (12.20 \times 0.0500) \div 1000 = 6.1 \times 10^{-4} / 0.00061$ (mol) mol I^- reacted $= 2.5 \times 10^{-3} - 6.1 \times 10^{-4} = 1.89 \times 10^{-3} / 0.00189$ (mol) eqm mol $SO_4^{2-} = \text{mol } I^- \text{ reacted} / 2 = 1.89 \times 10^{-3} \div 2 = 9.45 \times 10^{-4} / 0.000945$ eqm $[SO_4^{2-}] = (9.45 \times 10^{-4} \times 1000) \div 25 = 0.0378$ (mol dm^{-3}) and eqm $[I^-] = (6.1 \times 10^{-4} \times 1000) \div 25.0 = 2.44 \times 10^{-2} / 0.0244$ (mol dm^{-3}) $K_c = 0.0378 \div 0.0244^2 = (63.49) = 63 / 63.5$ Do not award unless their numbers are correct or are TE. Allow TE throughout. Correct answer with working gains 7 marks dm^3 mol^{-1} (standalone mark) Allow dm^3 mol^{-1} / mol^{-1} dm^3 / mol^{-1} dm^3	(7)

(Total for Question 8 = 13 mark)



Question Number	Answer	Additional Guidance	Mark
7(a)	An answer that makes reference to the following point: there is only a gradual / steady increase in (successive ionisation energies)	Allow they / the (successive) ionisation energies are close in value / similar Allow the extra ionisation energy to increase oxidation state is similar to the increase in hydration enthalpy / lattice energy Ignore chromium is a transition element Ignore 3d (and 4s) orbitals have similar energy Ignore Cr is $[\text{Ar}]3d^54s^1$ so can lose 6 electrons Ignore reference to electrons being removed from the d-orbital	(1)

Question Number	Answer	Additional Guidance	Mark
7(b)	2 double bonds and 2 single bonds shown as dots and crosses (1) - Another 4 electrons around each oxygen involved in the double bond and another 6 electrons around each oxygen involved in the single bond with one different symbol on each of two oxygens to indicate the extra electrons in the ion (1) Or 2 single bonds shown as dots and crosses 2 dative bonds with the electrons being donated from the chromium (1) - another 6 electrons around each oxygen with one different symbol on two of the oxygens to indicate the extra electrons (1)	Examples of diagrams Penalise extra electrons on chromium In both examples, M2 is conditional on M1 Allow overlapping circles with electrons in correct places Ignore missing brackets and charge / shape Ignore lines representing covalent bonds	(2)

Question Number	Answer	Additional Guidance	Mark
7(c)(i)	- correct species (1) - balancing (1)	<u>Example of equation</u> $\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 3\text{Zn} \rightarrow 2\text{Cr}^{3+} + 7\text{H}_2\text{O} + 3\text{Zn}^{2+}$ Allow multiples Allow $\rightleftharpoons$ provided equation written in direction shown Ignore state symbols even if incorrect Do not award uncanceled electrons	(2)

Question Number	Answer	Additional Guidance	Mark
7(c)(ii)	calculation of $E^\ominus_{\text{cell}}$	<u>Example of calculation</u> $(E^\ominus_{\text{cell}} = 1.33 - (-0.76))$ $= (+) 2.09 \text{ (V)}$ Allow -2.09 (V) if equation written in reverse in (c) (i) Correct answer with no working scores (1)	(1)



Question Number	Answer	Additional Guidance	Mark
7(c)(iii)	yes/zinc and acid will reduce chromium(III) ions to chromium(II) ions and because $E^\ominus_{\text{cell}}$ for the reaction between Zn and Cr^{3+} is (+) 0.35 (V) or $\text{Zn}^{2+} / \text{Zn}$ electrode potential / SEP / $E^\ominus$ value is more negative / less positive / lower than the $\text{Cr}^{3+} / \text{Cr}^{2+}$ value or Zn/ Zn^{2+} electrode potential / SEP / $E^\ominus$ value is less negative / more positive / higher than the $\text{Cr}^{3+} / \text{Cr}^{2+}$	Allow positive or >0 if not calculated Allow explanations in terms of the anti-clockwise rule	(1)



Question Number	Answer	Additional Guidance	Mark
7(c)(iv)	An explanation that makes reference to the following points: - the energy difference between the two sets of d orbitals is different in the two ions / Cr^{3+} and Cr^{2+} or there is different splitting of the d orbitals / d subshell (1) - electrons undergo different d-d transitions/ are promoted to a higher d-orbital absorbing/requiring a different amount of energy or a different amount of energy is absorbed the frequency / wavelength/colour of (visible) light absorbed is different (1)	Allow the d orbital energies are different Allow different charges / oxidation numbers alter the d orbital energies differently Do not award reference to a single d orbital splitting/ d orbital splitting Ignore references to charges/charge density/oxidation numbers/electron configurations of the ions Do not award references to electrons being excited and falling back to the ground state (or words to that effect) Allow the frequency / wavelength of (visible) light transmitted / reflected is different Do not award emitted instead of absorbed Ignore reference to different ligands	(2)



Question Number	Answer	Additional Guidance	Mark
7(d)	- calculation of mol of $\text{Cr}_2\text{O}_7^{2-}$ (1) - calculation of mol Fe^{2+} in 25.0 cm^3 (1) - calculation of mol Fe^{2+} in 1.00 dm^3 (1) - calculation of mass of Fe in 1 nail (1) - calculation of percentage of iron and brand of nail (1)	<u>Example of calculation</u> mol $\text{Cr}_2\text{O}_7^{2-}$ used = $(15.50 \times 0.0167) \div 1000$ $= 2.5885 \times 10^{-4} / 0.00025885 \text{ (mol)}$ mol Fe^{2+} in $25.0 \text{ cm}^3 = 6 \times 2.5885 \times 10^{-4}$ $= 1.5531 \times 10^{-3} = 0.0015531 \text{ (mol)}$ mol Fe^{2+} in $1.00 \text{ dm}^3 = (1.5531 \times 10^{-3} \times 1000) / 25$ $= 6.2124 \times 10^{-2} / 0.062124 \text{ (mol)}$ mass of Fe = $6.2124 \times 10^{-2} \times 55.8 = 3.4665 \text{ (g)}$ Allow 3.4789 (g) from A_r of 56 Percentage of iron = $(3.4665/3.54) \times 100 (=97.924)= 98 / 97.9 \text{ (%)}$ Allow 98 / 98.3 from A_r of 56 and Brand D Do not award for a percentage of 84% or below Ignore SF except 1 SF Correct answer with some relevant working scores 5 Correct percentage (98%) and brand (D) with no working scores (1) Any other percentage and brand with no working scores (0)	(5)

(Total for Question 7 = 14 marks)



Question Number	Answer	Additional Guidance	Mark
8(a)	A description that makes reference to - green ppt. (1) - ppt dissolves (in excess NaOH) to give a green solution (1)	Accept 'green solid' Allow 'grey-green ppt' Do not award blue-green Ignore shades M2 dependent upon M1 or near-miss	(2)

Question Number	Answer	Additional Guidance	Mark
8(b)(i)	- four correct species (1) - balancing and the correct number of electrons (1)	<u>An example of equation</u> $[\text{Cr}(\text{OH})_6]^{3-} + 2\text{OH}^- \rightarrow \text{CrO}_4^{2-} + 4\text{H}_2\text{O} + 3\text{e}^-$ Accept multiples	(2)

Question Number	Answer	Additional Guidance	Mark
8(b)(ii)	equation	<u>An example of equation</u> $2\text{CrO}_4^{2-} + 2\text{H}^+ \rightarrow \text{Cr}_2\text{O}_7^{2-} + \text{H}_2\text{O}$ Accept $\rightleftharpoons$ / multiples	(1)



Question Number	Answer	Additional Guidance	Mark
8(b)(iii)	- oxidation half equation - reduction half equation - overall equation	(1) $\text{H}_2\text{O}_2 \rightarrow 2\text{H}^+ + \text{O}_2 + 2\text{e}^-$ (1) $\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^- \rightarrow 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$ (1) $\text{Cr}_2\text{O}_7^{2-} + 8\text{H}^+ + 3\text{H}_2\text{O}_2 \rightarrow 2\text{Cr}^{3+} + 7\text{H}_2\text{O} + 3\text{O}_2$ for M3 do not award if H^+ / e^- left on both sides Accept multiples Allow $\rightleftharpoons$ Ignore state symbols even if incorrect Oxidation and reduction half equations scores (2) if not identified but in correct order Award (1) only for M1 and M2 if half equations are not in correct order No TE on incorrect half equations	(3)



Question Number	Answer	Additional Guidance	Mark
8(c)	A diagram that includes (M1) (high resistance) voltmeter/V (1) (M2) salt bridge to complete circuit (1) (M3) filter paper soaked in (saturated) potassium nitrate/KNO_3 solution (1) (M4) zinc electrode of zinc metal and suitable zinc salt (1) (M5) platinum (black) electrode (1) (M6) suitable chromium salts (1) (M7) all solutions to be 1 mol dm^{-3} (wrt ions) (1)	Example of diagram Salt bridge must dip into the solutions Allow sodium chloride/potassium chloride for potassium nitrate e.g. ZnSO_4 e.g. $\text{CrCl}_3 / \text{K}_2\text{Cr}_2\text{O}_7$ if $\text{Cr}_2(\text{SO}_4)_3$ is used then M7 can only be awarded if its concentration is 0.5 mol dm^{-3} Allow electrodes drawn the other way round Ignore temperature is 298 K Penalise use of just names once only	(7)

(Total Question 8 = 15 marks)

Question Number	Acceptable Answers	Additional Guidance	Mark
5(a)	+5	Allow 5+ / +V / V+ / (V) / 5 Do not award V ⁺	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
5(b)	A description that makes reference to the following points: M1 and M2 –colours Yellow → blue → green → violet / lavender / purple / mauve 2 or 3 colours linked to correct species / oxidation states / reactions (1) 4 colours linked to correct species / oxidation states / reactions (1) M3 - statement Statement that sequence is from +5 to +4 to +3 to +2 or (step-wise) reduction / zinc is a reducing agent (1) M4, M5 and M6 - equations These three equations, with appropriate $E^\ominus$ values $\text{Zn} + 2\text{VO}_3^- + 8\text{H}^+ \rightarrow \text{Zn}^{2+} + 2\text{VO}^{2+} + 4\text{H}_2\text{O}$ and $E^\ominus = (+)1.76 \text{ (V)}$ (1) $\text{Zn} + 2\text{VO}^{2+} + 4\text{H}^+ \rightarrow \text{Zn}^{2+} + 2\text{V}^{3+} + 2\text{H}_2\text{O}$ and $E^\ominus = (+)1.1(0) \text{ (V)}$ (1) $\text{Zn} + 2\text{V}^{3+} \rightarrow \text{Zn}^{2+} + 2\text{V}^{2+}$ and $E^\ominus = (+)0.5(0) \text{ (V)}$ (1) M7 – stops at V²⁺ No (further) reduction (feasible) to V metal / V(0) or $\text{Zn} + \text{V}^{2+} \rightarrow \text{Zn}^{2+} + \text{V}$ not feasible or $E^\ominus = -0.42 \text{ (V)}$ (1)	M3 can be implied from species in explanation or equations Allow multiples Ignore state symbols even if incorrect 3 correct equations with incorrect $E^\ominus$ scores 2 2 correct equations with incorrect $E^\ominus$ scores 1 3 correct $E^\ominus$ with incorrect equations scores 1	(7)



Question Number	Acceptable Answers	Additional Guidance	Mark
5(c)	A explanation that makes reference to the following points: M1 V changes (its oxidation state / oxidation number) from +5 to +4 (as it oxidises the sulfur dioxide) OR The oxidation number of V decreases in the reaction OR Vanadium is reduced in the reaction with SO₂ OR V₂O₅ oxidises the SO₂ / S OR $V_2O_5 + SO_2 \rightarrow V_2O_4 + SO_3$ (1) M2 (Then) returns to +5 (oxidation state / oxidation number) by reacting with oxygen OR $2 V_2O_4 + O_2 \rightarrow 2 V_2O_5$ (1)	Ignore any references to heterogeneous catalysis Allow Forms V₂O₄ / VO₂ (as an intermediate) Do not award VO²⁺ or VO₃⁻ or VO₂⁺ Allow (re-) forms V₂O₅	(2)



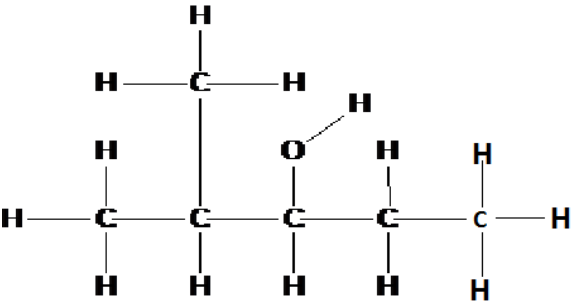
Question Number	Acceptable Answers	Additional Guidance	Mark												
*5(d)	This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr><tr><td>6</td><td>4</td></tr><tr><td>5–4</td><td>3</td></tr><tr><td>3–2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table> The following table shows how the marks should be awarded for structure and lines of reasoning.	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	6	4	5–4	3	3–2	2	1	1	0	0	Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages). In general it would be expected that 5 or 6 indicative points would score 2 reasoning marks, and 3 or 4 indicative points would score 1 reasoning mark. A total of 2, 1 or 0 indicative points would score 0 marks for reasoning. If there is any incorrect chemistry, deduct mark(s) from the reasoning. If no reasoning mark(s) awarded do not deduct mark(s).	(6)
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points														
6	4														
5–4	3														
3–2	2														
1	1														
0	0														



Indicative content (IPs) IP1: $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq}) \rightarrow [\text{Cu}(\text{OH})_2(\text{H}_2\text{O})_4](\text{s}) + 2\text{H}_2\text{O}(\text{l})$ IP2: - blue ppt / blue solid (when $[\text{Cu}(\text{OH})_2(\text{H}_2\text{O})_4](\text{s})$ is formed) IP3: $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq}) + 4\text{NH}_3(\text{aq}) \rightarrow [\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$ IP4: - Deep blue solution / dark blue solution (when $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}(\text{aq})$ is formed) IP5: $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq}) + 4\text{Cl}^{-}(\text{aq}) \rightarrow [\text{CuCl}_4]^{2-}(\text{aq}) + 6\text{H}_2\text{O}(\text{l})$ IP6: - Yellow / green (solution when $[\text{CuCl}_4]^{2-}(\text{aq})$ is formed)	Allow omission of square brackets throughout Allow for IP1 $\text{Cu}^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq}) \rightarrow \text{Cu}(\text{OH})_2(\text{s})$ Only penalise incorrect or missing state symbols in this equation (IP1) Allow for IP3 $\text{Cu}^{2+}(\text{aq}) + 4\text{NH}_3(\text{aq}) \rightarrow [\text{Cu}(\text{NH}_3)_4]^{2+}(\text{aq})$ $[\text{Cu}(\text{OH})_2(\text{H}_2\text{O})_4](\text{s}) + 4\text{NH}_3(\text{aq}) \rightarrow [\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}(\text{aq}) + 2\text{H}_2\text{O}(\text{l}) + 2\text{OH}^{-}(\text{aq})$ $[\text{Cu}(\text{OH})_2(\text{H}_2\text{O})_4](\text{s}) + 6\text{NH}_3(\text{aq}) \rightarrow [\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}(\text{aq}) + 2\text{NH}_4^{+}(\text{aq}) + 2\text{H}_2\text{O}(\text{l}) + 2\text{OH}^{-}(\text{aq})$ Ignore formation of initial precipitate $\text{Cu}(\text{OH})_2(\text{s})$ Do not award $[\text{Cu}(\text{NH}_3)_6]^{2+}(\text{aq})$ Do not award 'yellow precipitate' Allow equilibrium sign $\rightleftharpoons$ in any reaction Ignore any initial colours, even if incorrect
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(Total for Question 5 = 16 marks)

5(a)	C atom of C–Mg bond labelled as δ^- and Mg labelled as δ^+	Do not award full + or – charge Ignore δ^- on Br	(1)
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Question Number	Acceptable Answers	Additional Guidance	Mark
5(b)(i)		Ignore other structures Allow non-displayed formula	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
5(b)(ii)	2-methylpentan-3-ol	Allow 2-methyl-3-pentanol No TE on incorrect formula from 5(b)(i)	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
5(c)	✓ next to nucleophile (1) ✓ next to reducing agent (1)	If more than two boxes ticked scores (0)	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
5(d)	propane / C₃H₈	Accept name or formula or structural / skeletal / displayed formula Ignore additional inorganic products Do not award just 'alkane' If name and formula given then they both must be correct	(1)

(Total for Question 5 = 6 marks)



Question Number	Answer	Additional Guidance	Mark
5(a)	Name of the three functional groups (2)	Alcohol / diol, ester and alkene Allow hydroxy / hydroxyl (group) for alcohol Ignore primary Do not award incorrect structures of functional groups in conjunction with correct name Do not award secondary or tertiary alcohol Three correct functional groups scores (2) Two correct functional groups scores (1) One or zero correct functional groups (0) Four groups named with three correct scores (1)	(2)

Question Number	Answer	Additional Guidance	Mark
5(b)	An answer that makes reference to the following point the ester (functional group) will react (with the water) in a hydrolysis reaction	Ignore reference to H-bonds between water and OH groups Allow 'hydrolysis reaction' if equation showing break up of ester group also shown	(1)



Question Number	Answer	Mark
5(c)(i)	The only correct answer is C (fractional distillation) <i>A is incorrect because the process is used to produce smaller hydrocarbons</i> <i>B is incorrect because the process is used to produce branched and cyclic hydrocarbons</i> <i>D is incorrect because the process is used to heat reaction mixtures</i>	(1)

Question Number	Answer	Additional Guidance	Mark
5(c)(ii)	An explanation that makes reference to one of the following pairs of points Either - the OH groups (in compound X) can form hydrogen bonds (1) - so more energy is needed to vaporise compound X / break intermolecular forces in compound X (1) Or - hydrocarbons have only London forces, but compound X has hydrogen bonds (as well) (1) - hydrogen bonds are stronger (than London forces) (1)	Ignore references to dipole-dipole interactions Allow ‘the oxygen (in compound X) can form hydrogen bonds’) Allow ‘more energy is needed to break bonds in compound X’ if H bonds discussed Any reference to the breaking of covalent bonds loses M2 only	(2)

(Total Question 5 = 6 marks)



Question Number	Answer	Mark
7(a)(i)	The only correct answer is D ($\frac{p(\text{SO}_3)}{p(\text{SO}_2) p(\text{O}_2)^{1/2}}$, $\text{atm}^{-1/2}$) <i>A is not correct because the expression is correct but the units are incorrect</i> <i>B is not correct because both the expression and the units are incorrect</i> <i>C is not correct because the expression is not correct</i>	(1)

Question Number	Answer	Mark
7(a)(ii)	The only correct answer is B (temperature) <i>A is not correct because this would affect the rate of the reaction but not the value of K_p</i> <i>C is not correct because this would affect the rate of the reaction but not the value of K_p</i> <i>D is not correct because this would affect the rate of the forward reaction temporarily but not the value of K_p</i>	(1)



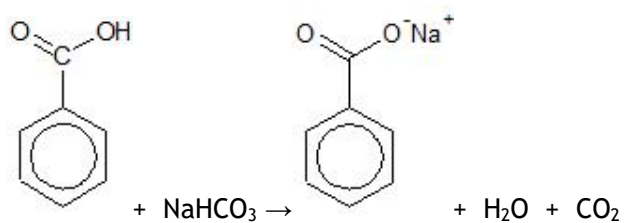
Question Number	Acceptable Answer	Additional Guidance	Mark
7(b)	An answer that makes reference to the following points: • $\text{SO}_2 + \text{V}_2\text{O}_5 \rightarrow \text{SO}_3 + \text{V}_2\text{O}_4$ • $\text{V}_2\text{O}_4 + \frac{1}{2} \text{O}_2 \rightarrow \text{V}_2\text{O}_5$	(1) (1) Allow multiples Allow reversible arrows Ignore state symbols even if incorrect Do not award equations with electrons Allow for 2 marks any balanced equations showing formation of a lower oxidation state oxide by reaction with SO_2 and a higher oxidation state by reaction with O_2 Example $2\text{SO}_2 + \text{V}_2\text{O}_5 \rightarrow 2\text{SO}_3 + \text{V}_2\text{O}_3$ $\text{V}_2\text{O}_3 + \text{O}_2 \rightarrow \text{V}_2\text{O}_5$ Allow use of 2VO_2 instead of V_2O_4 in both equations	(2)

Question Number	Answer	Mark
7(c)	The only correct answer is C (VO_2^+ yellow +5) <i>A is not correct as although the colour is correct for VO_2^+ the oxidation number is incorrect</i> <i>B is not correct as although the oxidation number of vanadium is correct, VO^{2+} is blue</i> <i>D is not correct as VO^{2+} as although the colour of the solution is blue, the oxidation number of vanadium in VO^{2+} is +4</i>	(1)

Question Number	Answer	Mark
7(d)	The only correct answer is A (+1.76 V) <i>B is not correct because the E° values have been added</i> <i>C is not correct because the E° values have been added and the sign reversed</i> <i>D is not correct because this is the value for the reverse reaction</i>	(1)

(Total for Question 7 = 6 marks)



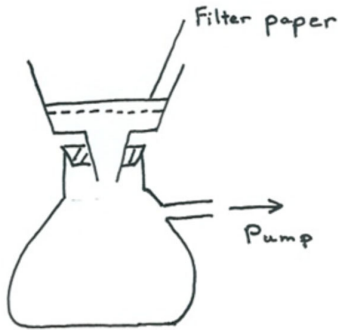
Question Number	Answer	Additional Guidance	Mark
5(a)	- formula of sodium benzoate - remainder of equation	<u>Example of equation</u>  + NaHCO₃ → + H₂O + CO₂ (1) Accept C₆H₅COONa and/or C₆H₅COO⁽⁻⁾Na⁽⁺⁾ Allow omission of charges Allow Kekulé structures Do not award O–Na (1) Ignore state symbols even if incorrect Standalone mark	(2)
Question Number	Answer	Additional Guidance	Mark
5(b)	An answer that makes reference to: invert the funnel and then open the tap	Allow Just removal of stopper/bung/lid/top Ignore shaking	(1)

Question Number	Answer	Additional Guidance	Mark
5(c)	An answer that makes reference to (Water is) more dense (than ether/than the organic layer)	Accept reverse argument Ignore references to immiscibility Do not award references to water being insoluble	(1)

Question Number	Answer	Additional Guidance	Mark
5(d)	An answer that makes reference to: some sodium benzoate has dissolved in the ether (instead of the aqueous sodium carbonate)	Ignore to increase the yield of sodium benzoate Ignore to remove the product from the ether	(1)

Question Number	Answer	Additional Guidance	Mark
5(e)	An explanation that makes reference to: - The benzoate ion is protonated by the hydrochloric acid (1) - benzoic acid is less soluble (in water) than the sodium salt (1)	Allow HCl/acid reacts to form benzoic acid Allow benzoic acid is insoluble	(2)



Question Number	Answer	Additional Guidance	Mark
5(f)	A labelled diagram that includes • Buchner/side-armed flask connected to vacuum/ pump/ water aspirator (1) • funnel with flat filter paper (1)	<u>Example of diagram</u>  Do not award fluted filter paper Do not award water flow into the flask	(2)

Question Number	Answer	Additional Guidance	Mark
5(g)	Method 1 • (M1) mass of benzoic acid in 50 cm³ (1) • (M2) no. of moles of benzoic acid in 50 cm³ (1) OR Method 2 • (M1) moles of benzoic acid in 1000 cm³ (1) • (M2) no. of moles of benzoic acid in 50 cm³ (1) then • (M3) evaluation of the number of molecules of benzoic acid in 50 cm³ (1)	<u>Example of calculation</u> $m = (1.70 \times 0.05) = 0.0850 \text{ (g)}$ $n = (0.0850 \div 122) = 6.967 \dots \times 10^{-4} \text{ (mol)}$ $n = (1.70 \div 122) = 0.01393\dots \text{ (mol)}$ $n = (0.01393\dots \times 0.05) = 6.967 \dots \times 10^{-4} \text{ (mol)}$ $N = (6.967 \dots \times 10^{-4} \times 6.02 \times 10^{23}) = 4.19 \times 10^{20} / 4.2 \times 10^{20}$ Ignore sf except 1sf Penalise excessive (6+) SF Allow use of 6.0×10^{23} to give 4.18×10^{20} for (3) Correct final answer without working scores (3) TE throughout	(3)

Question Number	Answer	Additional Guidance	Mark
5(h)	A comparison that makes reference to • (melting temperature) is a (wide) range/ not sharp (1) • (it is lower) because impurities are present (1)	Ignore just lower for M1 Allow water/phenol is present Allow 'it is not pure'	(2)

(Total Question 5 = 14 marks)



2(a)	An answer that makes reference to the following points: (First change) Adjust so that the flow of water goes in at the bottom of the condenser and out at the top of the condenser (1) (Reason) Keeps condenser full of water / water removes (any) air in the condenser / allows more efficient / better cooling / prevents 'air-lock' (1) (Second change) (Replace funnel and) seal with a thermometer or a stopper (1) (Reason) Prevents vapour / gas / product / reactants escaping (1)	First and second change can be in either order Ignore prior refluxing Ignore water bath Allow just "water should enter the condenser at the bottom" OR Just "water should leave at the top" OR Just "swap the tubes around" Allow replacing the funnel with a tap / dropping funnel Ignore thermometers used to measure boiling temperatures	(4)
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Question Number	Acceptable Answers	Additional Guidance	Mark
2(c)(i)	3-methylbutan-2-ol / secondary alcohols cannot be oxidised to a carboxylic acid OR 3-methylbutanone / the product / ketones cannot be (further) oxidised	Allow only primary alcohols can be oxidised to carboxylic acids	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
2(c)(ii)	H₂SO₄	Ignore 'sulfuric acid'	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
2(c)(iii)	- all formulae correct (1) - all state symbols correct (1)	Example of equation: $\text{Na}_2\text{CO}_3(\text{s}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{Na}_2\text{SO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$ OR $\text{Na}_2\text{CO}_3(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow 2\text{Na}^+(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$ OR $\text{Na}_2\text{CO}_3(\text{s}) + 2\text{H}_2\text{SO}_4(\text{aq}) \rightarrow 2\text{NaHSO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$ Use of NaCO_3 or H_2CO_3 scores zero Allow any acid. M2 consequential on M1 being awarded, or a 'near-miss'	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
2(d)(i)	An explanation that makes reference to the following points: - peak at 1720 cm^{-1} (1) - shows presence of a C=O bond / carbonyl (1)	Allow any absorbance between 1720 to 1700 cm^{-1} Marks cannot be awarded if ANY incorrect other peaks are identified e.g. peak due to C=C / peak due to O-H Ignore references to alkane C-H bonds / fingerprint region Do not award just 'ketone' for MP2	(2)



Question Number	Acceptable Answers	Additional Guidance	Mark
2(d)(ii)	An answer that makes reference to the following points: - peak between 3750 and 3200 (cm^{-1}) will disappear / will be absent from the spectrum OR Peak(s) above 3000(cm^{-1}) will disappear / will be absent from the spectrum (1) (because) 3-methylbutan-2-ol / the alcohol / O-H has now been removed (1)	Allow any absorbance between 3750 to 3200 (cm^{-1}) Ignore references to fingerprint region	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
2(e)(i)	(identify the peak at the) highest/largest m/z value	Allow Peak (furthest) to the right/last peak on the spectrum Do not award the mark for "largest peak" / "highest peak" Ignore "parent ion" / molecular ion peak / References to $m/z = 86$	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
2(e)(ii)	$\begin{array}{c} \text{H} & \text{H} & \text{H} \\ & & \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\ & + & \\ \text{H} & & \text{H} \end{array}$ (1) $\begin{array}{c} \text{H} & \text{O} \\ & \\ \text{H}-\text{C}-\text{C}^+ \\ \\ \text{H} \end{array}$ (1)	Allow positive charge anywhere on structure Ignore open bonds Penalise non-displayed formulae once only Ignore brackets around the structure Penalise missing charge once only	(2)
2(f)(i)	$\text{C}_5\text{H}_{12}\text{O} + [\text{O}] \rightarrow \text{C}_5\text{H}_{10}\text{O} + \text{H}_2\text{O}$ • left-hand side of equation correct • right-hand side of equation correct (1) (1)	Molecular formulae must be used throughout Allow [O] above the arrow Do not award for $\text{C}_5\text{H}_{11}\text{OH}$ as the alcohol Ignore state symbols if incorrect or conditions mentioned	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
2(f)(ii)	- calculation of moles of both of $C_5H_{10}O$ and $C_5H_{12}O$ (1) - calculation of mass of $C_5H_{12}O$ (1) OR - calculation of theoretical mass of $C_5H_{10}O$ and moles of $C_5H_{10}O$ (1) - calculation of mass of $C_5H_{12}O$ (1)	<u>Example of calculation</u> Moles $C_5H_{10}O = \frac{2.15}{86.0} = 0.025(0)$ (mol) and moles $C_5H_{12}O = \frac{0.025(0)}{62.5} \times 100 = 0.04(00)$ (So) mass of $C_5H_{12}O = 0.04(00) \times 88 = 3.52$ g Theoretical mass $C_5H_{10}O = \frac{2.15}{62.5} \times 100 = 3.44$ g and moles $C_5H_{10}O = \frac{3.44}{86.0} = 0.04(00) = \text{mol } C_5H_{12}O$ (So) mass of $C_5H_{12}O = 0.04(00) \times 88 = 3.52$ g Correct answer with no working scores (2) Allow TE from MP1 Award 1 mark for 3.36 g, 1.375 g or 2.2 g	(2)

(Total for Question 2 = 21 marks)