

Questions**Q1.**

Transition metals form complex ions.

Hydrated chromium(III) chloride, $\text{CrCl}_3 \cdot 6\text{H}_2\text{O}$, dissolves in water to form a number of different complex ions containing both chloride and water ligands.

The general formula of these complex ions is $[\text{Cr}(\text{H}_2\text{O})_x(\text{Cl})_y]^{(3-y)+}$

In an experiment, 0.10 mol of a complex reacted with excess silver nitrate solution to produce 0.20 mol of silver chloride.

Chloride ions which are ligands within the complex do not react with silver nitrate.

Deduce the formula of this chromium(III) complex ion. Justify your answer.

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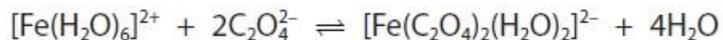
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(Total for question = 2 marks)

Q2.

Iron and zinc are in the d-block of the Periodic Table.

Hydrated iron(II) ions react with ethanedioate ions, $\text{C}_2\text{O}_4^{2-}$, to form a complex ion.



(i) Draw a structure of the $[\text{Fe}(\text{C}_2\text{O}_4)_2(\text{H}_2\text{O})_2]^{2-}$ ion, showing **all** of the bonds.

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(ii) Explain, in terms of entropy, why this reaction is feasible.

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(Total for question = 4 marks)

Q3.

Transition metals form complex ions.

Complex ions have a central metal ion surrounded by ligands.

(i) Give a reason why the ammonium ion cannot act as a ligand.

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(ii) Explain why the complex ions $[\text{Co}(\text{NH}_3)_6]^{2+}$ and $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ are coloured and have different colours.

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(Total for question = 5 marks)

Q4.

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

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.

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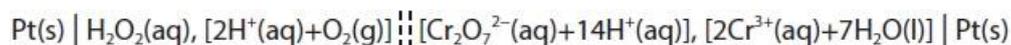
(ii) If the solution of chromate(VI) ions is then acidified, the colour of the solution changes to orange as dichromate(VI) ions form.

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_{cell} cell = + 0.65 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)

(Total for question = 6 marks)

Q5.

This question is about transition metal chemistry.

Dilute aqueous ammonia is added, drop by drop, to an aqueous solution of copper(II) sulfate until the aqueous ammonia is in excess.

(i) Describe what you would **see** during this experiment.

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(ii) The reaction between aqueous copper(II) sulfate and **excess** aqueous ammonia is an example of a **ligand substitution** reaction.

Write an equation for the ligand substitution reaction that occurs, showing the formulae of the complex ions involved. State symbols are not required.

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(Total for question = 4 marks)

Q6.

This question is about catalytic converters.

A catalytic converter decreases the emissions of gases, such as carbon monoxide and nitrogen monoxide, from an internal combustion engine.

Describe the stages in a catalytic converter that result in this decrease.
No equations are required.

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(Total for question = 3 marks)

Q7.

This question is about chromium and some of its compounds.

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.

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(Total for question = 1 mark)

Q8.

This question is about chromium and some of its compounds.

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 / 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_{cell}^\ominus for the reaction in (i).

(1)

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

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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.

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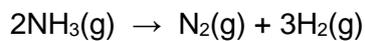
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(Total for question = 6 marks)

Q9.

This question is about transition metals and their ions.

Tungsten wire catalyses the decomposition of ammonia.

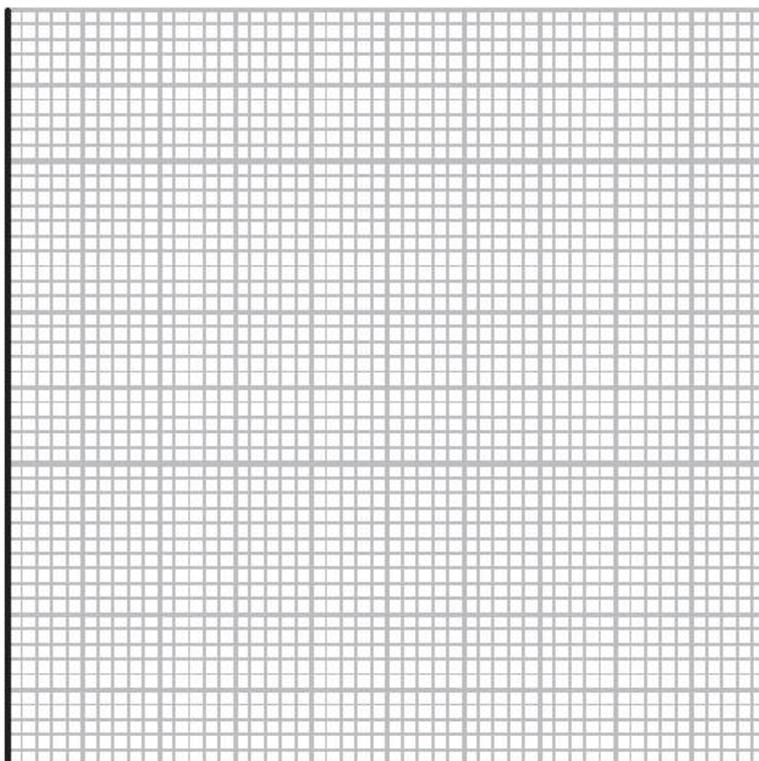


In an experiment, the following results were obtained.

Time /s	Partial pressure of ammonia / kPa
0	0.350
100	0.335
200	0.319
300	0.303
400	0.287
500	0.271

(i) Plot a graph of partial pressure of ammonia against time.

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(ii) Deduce the rate equation for this reaction by using your graph in (i).

Justify your answer.

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(iii) Use the graph to calculate the rate constant. Include units in your answer.

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(iv) Describe the stages in the catalytic decomposition of ammonia by tungsten.

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(Total for question = 9 marks)

Q10.

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

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

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(Total for question = 2 marks)

Q12.

This is a question about catalysis.

The trend in the strength of gaseous adsorption by three transition elements is

tungsten > platinum > silver

Silver is not suitable as a replacement for platinum in a catalytic converter because the adsorption of gases is too weak to allow significant chemical reaction.

Give a possible reason why tungsten would also **not** be a suitable replacement for platinum in a catalytic converter. Refer to the mechanism of heterogenous catalysis in your answer.

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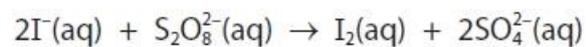
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(Total for question = 1 mark)

Q13.

Iron and zinc are in the d-block of the Periodic Table.

Iodide ions, I^- , react with peroxodisulfate(VI) ions, $\text{S}_2\text{O}_8^{2-}$



This reaction is catalysed by iron(II) ions, $\text{Fe}^{2+}(\text{aq})$.

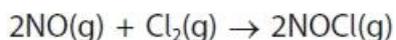
Write **two** ionic equations to show how iron(II) ions act as a catalyst in this reaction.
State symbols are not required.

(2)

(Total for question = 2 marks)

Q14.

Nitrogen monoxide and chlorine react together to form nitrosyl chloride.



The rate equation for the formation of nitrosyl chloride is

$$\text{Rate} = k[\text{NO}]^2[\text{Cl}_2]$$

(i) Complete the table by adding the missing values.

Experiment	[NO] / mol dm ⁻³	[Cl ₂] / mol dm ⁻³	Rate / mol dm ⁻³ s ⁻¹
1	0.122	0.241	1.09×10^{-2}
2		0.482	8.72×10^{-2}
3	0.366		4.91×10^{-2}

(2)

(ii) Calculate the rate constant, k , using data from Experiment 1.

Include units with your answer.

(3)

(iii) Explain how using a catalyst increases the rate constant, k .

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(iv) The heterogeneous catalyst palladium was suggested for use in this reaction.

Explain how impurities in the gaseous reactants could make the catalyst less effective.

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(Total for question = 10 marks)

Q15.

This is a question about catalytic converters in car exhaust systems.

When petrol is burnt in a car engine, pollutant gases including carbon monoxide and nitrogen monoxide are formed.

(i) Write the equation for the reaction between these two polluting gases that takes place on the surface of a catalytic converter. State symbols are not required.

(1)

(ii) Describe the stages by which the reaction in (i) occurs in a catalytic converter.

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(Total for question = 4 marks)

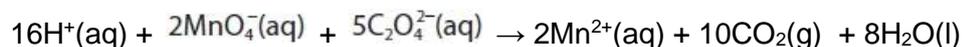
Q17.

Tablets containing potassium manganate(VII), KMnO_4 , are dissolved in water forming an antiseptic solution to treat skin conditions. The manufacturers claim that each tablet contains 400 mg of KMnO_4 .

To check the claim, the titration procedure outlined was carried out.

- Five tablets were dissolved in distilled water to make 100.0 cm^3 of solution.
- Some of the KMnO_4 solution was used to fill a burette.
- 25.0 cm^3 of sodium ethanedioate solution, $\text{Na}_2\text{C}_2\text{O}_4(\text{aq})$, of concentration $0.200 \text{ mol dm}^{-3}$, was added to a conical flask and warmed.
- Sulfuric acid, of concentration 2 mol dm^{-3} , was also added to the conical flask.
- The KMnO_4 solution was added to the flask from the burette, until the end-point.

The equation for the reaction between MnO_4^- ions from the KMnO_4 and $\text{C}_2\text{O}_4^{2-}$ ions from the sodium ethanedioate solution is shown.



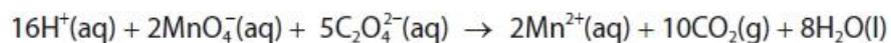
The results of the titration are shown.

Run	Trial	1	2	3
Final volume / cm^3	17.50	34.10	17.20	34.10
Initial volume / cm^3	0.00	17.30	0.00	17.20
Titre / cm^3	17.50		17.20	
Concordant titres (✓)				
Mean titre / cm^3				

(i) Complete the table.

(2)

(ii) The equation for the reaction between MnO_4^- ions from the KMnO_4 and $\text{C}_2\text{O}_4^{2-}$ ions from the sodium ethanedioate solution is shown.



Use this equation and your mean titre from (i) to calculate the mass, in mg, of KMnO_4 in **one** tablet.

Give your answer to an appropriate number of significant figures.

(5)

Q18.

This question is about transition metals and transition metal complexes.

Aqueous vanadium(II) chloride, $\text{VCl}_2(\text{aq})$, can be oxidised by bubbling gaseous chlorine, $\text{Cl}_2(\text{g})$, through the solution in the absence of air.

40.0 cm^3 of $0.100 \text{ mol dm}^{-3}$ VCl_2 solution was oxidised by 144 cm^3 of chlorine gas, at room temperature and pressure (r.t.p.).

The chlorine was reduced to chloride ions, according to the half-equation



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

- (i) Use these data to calculate the final oxidation state of vanadium.
You **must** show your working.

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- (ii) State the initial and final colours you would see as the chlorine bubbles through the aqueous vanadium(II) chloride, $\text{VCl}_2(\text{aq})$.

(2)

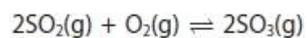
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(Total for question = 7 marks)

Q19.

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

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

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(Total for question = 2 marks)

Q20.

This question is about transition metal chemistry.

The **amphoteric** character of solid chromium(III) hydroxide is shown by the fact that it reacts separately with both dilute hydrochloric acid and dilute sodium hydroxide solution.

(i) Write an **ionic** equation for the reaction of solid chromium(III) hydroxide with dilute hydrochloric acid, showing the formula of the complex ion formed. Include state symbols in your answer.

(2)

(ii) Describe the changes you would **see** when the reaction in (i) is carried out.

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(iii) Write an **ionic** equation for the reaction of solid chromium(III) hydroxide with dilute sodium hydroxide solution, showing the formula of the complex ion formed. Include state symbols in your answer.

(2)

(iv) State the final appearance of the reaction mixture in (iii).

(1)

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(Total for question = 7 marks)