



## Questions

Q1.

This question is about the chemistry of elements in the *d*-block of the Periodic Table.

Under certain conditions, dichromate(VI) ions,  $\text{Cr}_2\text{O}_7^{2-}$ , can oxidise manganese(II) ions,  $\text{Mn}^{2+}$ .

In this reaction, dichromate(VI) ions are reduced to chromium(III) ions, in acidic conditions, according to the half-equation



In an experiment it was found that  $20.0 \text{ cm}^3$  of  $0.100 \text{ mol dm}^{-3}$  potassium dichromate(VI) was required to oxidise  $30.0 \text{ cm}^3$  of  $0.200 \text{ mol dm}^{-3}$  manganese(II) sulfate solution.

Use these data to calculate the final oxidation state of the manganese.

(5)

(Total for question = 5 marks)



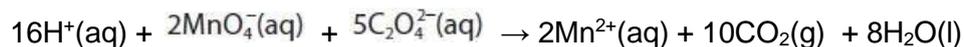
## Q2.

Tablets containing potassium manganate(VII),  $\text{KMnO}_4$ , are dissolved in water forming an antiseptic solution to treat skin conditions. The manufacturers claim that each tablet contains 400 mg of  $\text{KMnO}_4$ .

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

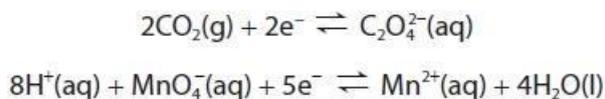
- Five tablets were dissolved in distilled water to make  $100.0 \text{ cm}^3$  of solution.
- Some of the  $\text{KMnO}_4$  solution was used to fill a burette.
- $25.0 \text{ cm}^3$  of sodium ethanedioate solution,  $\text{Na}_2\text{C}_2\text{O}_4(\text{aq})$ , of concentration  $0.200 \text{ mol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

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



This redox reaction could be used in an electrochemical cell.

The cell half-equations are



Write a cell diagram for this cell using the conventional representation.

(2)

(Total for question = 2 marks)



Q3.

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	$E^{\ominus} / \text{V}$
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^{-} \rightleftharpoons \text{Zn}(\text{s})$	-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 (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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**(Total for question = 6 marks)**



Q4.

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

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 = 7 marks)**

**Q5.**

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,  $\text{CrO}_4^{2-}$ , 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)

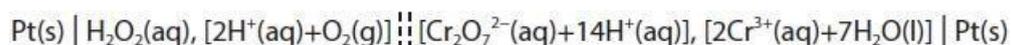
(ii) If the solution of chromate(VI) ions is then acidified, the colour of the solution changes to orange as dichromate(VI) ions form.

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  $E^\ominus_{\text{cell}}$  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)**



Q6.

The standard electrode potential,  $E^\ominus$ , of the  $\text{Ag}^+(\text{aq})|\text{Ag}(\text{s})$  half-cell is +0.80 V.

The effect of changing the concentration of the ions on the value of the electrode potential,  $E$ , in this half-cell is calculated using the equation

$$E = E^\ominus + \frac{RT}{96500} \times \ln[\text{Ag}^+(\text{aq})]$$

where  $T$  is the temperature in kelvin and  $R$  is the gas constant.

The electrode potential of a  $\text{Ag}^+(\text{aq})|\text{Ag}(\text{s})$  half-cell was measured at 20 °C and found to be +0.72 V.

Calculate the concentration of silver ions, in  $\text{mol dm}^{-3}$ , in this half-cell.

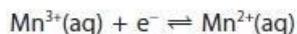
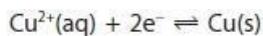
(3)

(Total for question = 3 marks)

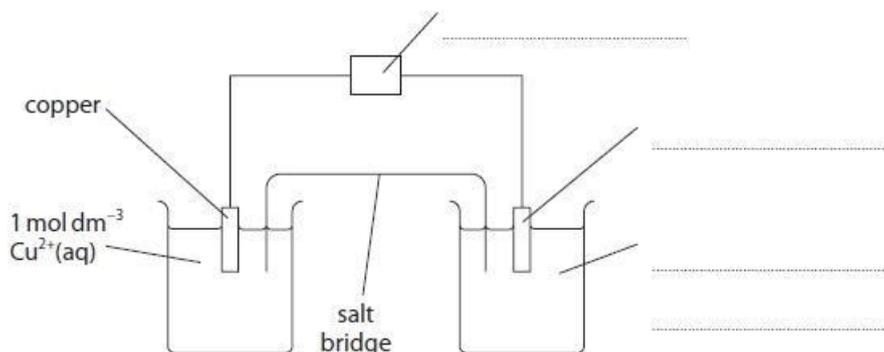


Q7.

An electrochemical cell is made from the electrode systems represented by these half-equations.



The  $E_{\text{cell}}^{\ominus}$  value is measured using the apparatus shown.



(a) Complete the diagram by adding labels on the dotted lines provided.

(3)

(b) A salt bridge is used to connect the two half-cells.

(i) State what chemical is contained in the salt bridge.

(1)

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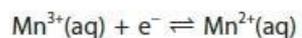
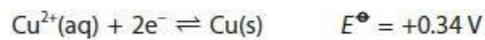
(ii) Give a possible reason why the salt bridge cannot be replaced by an unreactive metal wire.

(1)

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(c) In this cell, the copper is oxidised and  $E_{\text{cell}}^{\ominus} = +1.15 \text{ V}$ .



(i) Write the overall ionic equation for the reaction taking place.  
State symbols are not required.

(1)

(ii) Calculate the value of the standard electrode potential for the  $\text{Mn}^{3+}(\text{aq}) \mid \text{Mn}^{2+}(\text{aq})$  half-cell.

(1)

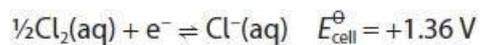
**(Total for question = 7 marks)**



**Q8.**

This question is about chlorine.

The standard electrode potential for the chlorine / chloride ion half-cell is



(i) Identify an oxidising agent from the Data Booklet that will convert chloride ions into chlorine under standard conditions.

(1)

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

(1)

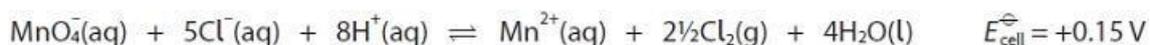
**(Total for question = 2 marks)**



Q9.

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

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)

(Total for question = 2 marks)



**Q10.**

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

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,  $\text{PbO}_2$ .

As the cell discharges, the lead and the lead(IV) oxide are both converted to solid lead(II) sulfate,  $\text{PbSO}_4$ , 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)

**(Total for question = 3 marks)**



Q11.

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

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?

- 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  $2\text{H}_2\text{O}(\text{l}) \rightarrow 4\text{H}^+(\text{aq}) + \text{O}_2(\text{g}) + 4\text{e}^-$

(1)

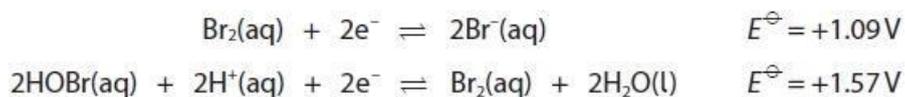
(Total for question = 1 mark)



## Q12.

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

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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**(Total for question = 4 marks)**





**Q14.**

This question is about the chemistry of elements in the *d*-block of the Periodic Table.

A student constructed an electrochemical cell as follows:

- a half-cell was made from a strip of chromium metal and a solution of aqueous chromium(III) sulfate
- a second half-cell was made from a piece of metal, **X**, and a solution of its sulfate,  $\text{XSO}_4(\text{aq})$
- the two half-cells were connected and a current allowed to pass for some time.

**Results**

- the chromium electrode increased in mass by 1.456 g
- the electrode made of metal **X** decreased in mass by 1.021 g.

Use these data to determine the identity of the metal, **X**.

(4)

**(Total for question = 4 marks)**



**Q15.**

This question is about redox reactions.

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

(1)

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**(Total for question = 1 mark)**



**Q16.**

This question is about redox reactions.

Manganese(IV) oxide,  $\text{MnO}_2$ , and manganate(VII) ions,  $\text{MnO}_4^-$ , react in alkaline solution to form manganate(VI) ions,  $\text{MnO}_4^{2-}$ .

(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)

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**(Total for question = 3 marks)**



Q17.

This question is about halogens and redox reactions.

Use these electrode potentials to answer the following questions.

Electrode reaction	$E^\ominus / V$
$I_2(aq) + 2e^- \rightleftharpoons 2I^-(aq)$	+0.54
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$Br_2(aq) + 2e^- \rightleftharpoons 2Br^-(aq)$	+1.09
$MnO_2(s) + 4H^+(aq) + 2e^- \rightleftharpoons Mn^{2+}(aq) + 2H_2O(l)$	+1.23
$Cl_2(aq) + 2e^- \rightleftharpoons 2Cl^-(aq)$	+1.36
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$	+1.51

(i) Which species will oxidise  $Fe^{2+}(aq)$  to  $Fe^{3+}(aq)$ ?

(1)

- A  $Br_2(aq)$
- B  $Cl^-(aq)$
- C  $I_2(aq)$
- D  $Mn^{2+}(aq)$

(ii) Write the ionic equation and calculate the  $E_{cell}^\ominus$  for the reaction between  $MnO_4^-$  ions and  $Br^-$  ions in acidic solution. State symbols are not required.

(3)

(Total for question = 4 marks)

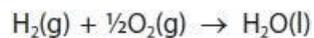


**Q18.**

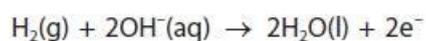
Sodium hydride, NaH, can be used to generate hydrogen for fuel cells.

The sodium hydride is crushed in the presence of water to release the hydrogen gas for a fuel cell.

The overall equation for the reaction occurring in the fuel cell is



In an alkaline fuel cell the oxidation half-equation is



Deduce the reduction half-equation for the alkaline fuel cell.

State symbols are not required.

(1)

**(Total for question = 1 mark)**



Q19.

This question is about the  $\text{Ag}^+(\text{aq})|\text{Ag}(\text{s})$  half-cell.

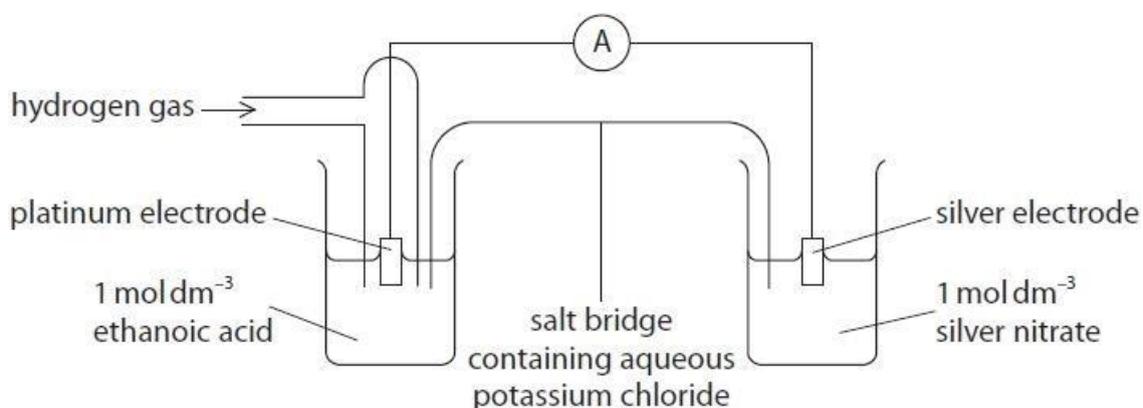
A student was asked to plan an experiment to measure the standard electrode potential of the  $\text{Ag}^+(\text{aq})|\text{Ag}(\text{s})$  half-cell.

(i) State the conditions of temperature and pressure under which standard electrode potentials are measured.

(1)

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(ii) The student drew the diagram shown.



Identify **three** mistakes in this diagram and the modifications that should be made to correct them.

(3)

Mistake in diagram	Modification needed to correct mistake

(Total for question = 4 marks)



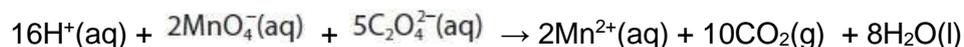
## Q20.

Tablets containing potassium manganate(VII),  $\text{KMnO}_4$ , are dissolved in water forming an antiseptic solution to treat skin conditions. The manufacturers claim that each tablet contains 400 mg of  $\text{KMnO}_4$ .

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

- Five tablets were dissolved in distilled water to make  $100.0 \text{ cm}^3$  of solution.
- Some of the  $\text{KMnO}_4$  solution was used to fill a burette.
- $25.0 \text{ cm}^3$  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  $2 \text{ mol dm}^{-3}$ , was also added to the conical flask.
- The  $\text{KMnO}_4$  solution was added to the flask from the burette, until the end-point.

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



The results of the titration are shown.

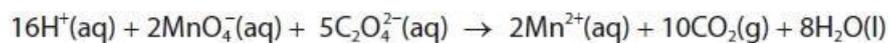
Run	Trial	1	2	3
Final volume / $\text{cm}^3$	17.50	34.10	17.20	34.10
Initial volume / $\text{cm}^3$	0.00	17.30	0.00	17.20
Titre / $\text{cm}^3$	17.50		17.20	
Concordant titres (✓)				
Mean titre / $\text{cm}^3$				

(i) Complete the table.

(2)



(ii) The equation for the reaction between  $\text{MnO}_4^-$  ions from the  $\text{KMnO}_4$  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  $\text{KMnO}_4$  in **one** tablet.

Give your answer to an appropriate number of significant figures.

(5)



(iii) A textbook suggested the conical flask should be heated during the titration, as the reaction between the  $\text{MnO}_4^-$  ions and the  $\text{C}_2\text{O}_4^{2-}$  ions is slow.

Use these electrode potentials and your knowledge of homogeneous catalysis to deduce why the heating is very important at the start of the titration, but less important as the titration proceeds. Justify your answer.

You may include equations in your justification.

Electrode system	$E^\ominus / \text{V}$
$2\text{CO}_2(\text{g}) + 2\text{e}^- \rightleftharpoons \text{C}_2\text{O}_4^{2-}(\text{aq})$	+0.64
$\text{Mn}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{Mn}^{2+}(\text{aq})$	+1.49
$\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^- \rightleftharpoons \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$	+1.51

(4)

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(Total for question = 11 marks)