Questions

Q1.

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

Under certain conditions, dichromate(VI) ions, $Cr_2O_7^{2-}$, can oxidise manganese(II) ions, Mn^{2+}.

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

$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O(l)$

In an experiment it was found that 20.0 cm^3 of 0.100 mol dm^{-3} potassium dichromate(VI) was required to oxidise 30.0 cm^3 of 0.200 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), $KMnO_4$, 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, $Na_2C_2O_4(aq)$, of concentration 0.200 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 $C_2O_4^{2-}$ ions from the sodium ethanedioate solution is shown.

$16H^+(aq) + 2MnO_4^-(aq) + 5C_2O_4^{2-}(aq) \rightarrow 2Mn^{2+}(aq) + 10CO_2(g) + 8H_2O(l)$

This redox reaction could be used in an electrochemical cell.

The cell half-equations are

$$2CO_2(g) + 2e^- \rightleftharpoons C_2O_4^{2-}(aq)$$

$$8H^+(aq) + MnO_4^-(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$$

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	$E^\ominus$ / V
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	−0.76
$Cr^{3+}(aq) + e^- \rightleftharpoons Cr^{2+}(aq)$	−0.41
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O(l)$	+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 $E^\ominus_{cell}$ 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, $[Cr(OH)_6]^{3-}$, 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 $E^\ominus_{cell}$ cell = + 0.65 V for which the cell diagram is

$$Pt(s)\,|\,H_2O_2(aq),\,[2H^+(aq)+O_2(g)]\,\vdots\vdots\,[Cr_2O_7^{2-}(aq)+14H^+(aq)],\,[2Cr^{3+}(aq)+7H_2O(l)]\,|\,Pt(s)$$

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 $Ag^{+}(aq)|Ag(s)$ 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

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

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

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

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

(3)

(Total for question = 3 marks)

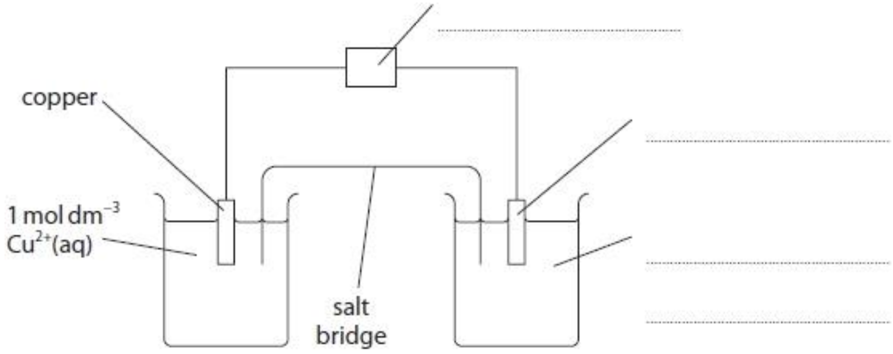
Q7.

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

$$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$$

$$Mn^{3+}(aq) + e^- \rightleftharpoons Mn^{2+}(aq)$$

The $E^\ominus_{cell}$ 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 $E^{\ominus}_{cell}$ = +1.15 V.

$$Cu^{2+}(aq) + 2e^{-} \rightleftharpoons Cu(s) \qquad E^{\ominus} = +0.34\ V$$

$$Mn^{3+}(aq) + e^{-} \rightleftharpoons Mn^{2+}(aq)$$

(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 Mn^{3+}(aq) I Mn^{2+}(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

$$\tfrac{1}{2}Cl_2(aq) + e^- \rightleftharpoons Cl^-(aq) \quad E^{\ominus}_{cell} = +1.36\,V$$

(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 $E^{\ominus}_{cell}$ 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.

$$MnO_4^-(aq) + 5Cl^-(aq) + 8H^+(aq) \rightleftharpoons Mn^{2+}(aq) + 2\tfrac{1}{2}Cl_2(g) + 4H_2O(l) \qquad E^{\ominus}_{cell} = +0.15\,V$$

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

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

$$\ln K = \frac{nE^{\ominus}_{cell}F}{RT}$$

where *n* is the number of electrons transferred in the overall equation,
F is the Faraday constant (96 500 C mol^{-1}) and
R is the gas constant (8.31 J mol^{-1} 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, 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)

(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

$$CH_3OH(g) + H_2O(l) \rightarrow HCOOH(aq) + 4H^+(aq) + 4e^-$$

Which reaction occurs at the other electrode?

(1)

☒ **A** $4H^+(aq) + O_2(g) + 4e^- \rightarrow 2H_2O(l)$

☒ **B** $2H_2(g) + 2O_2(g) + 4e^- \rightarrow 4OH^-(aq)$

☒ **C** $4OH^-(aq) \rightarrow 2H_2(g) + 2O_2(g) + 4e^-$

☒ **D** $2H_2O(l) \rightarrow 4H^+(aq) + O_2(g) + 4e^-$

(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.

$$Br_2(aq) + 2e^- \rightleftharpoons 2Br^-(aq) \qquad E^{\ominus} = +1.09\,V$$

$$2HOBr(aq) + 2H^+(aq) + 2e^- \rightleftharpoons Br_2(aq) + 2H_2O(l) \qquad E^{\ominus} = +1.57\,V$$

(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 $E^{\ominus}_{cell}$ 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)

Q13.

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

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 $E^\ominus_{cell}$ values. State symbols are not required.

(7)

Electrode system	$E^\ominus$ / V
$V^{2+}(aq) + 2e^- \rightleftharpoons V(s)$	−1.18
$V^{3+}(aq) + e^- \rightleftharpoons V^{2+}(aq)$	−0.26
$VO^{2+}(aq) + 2H^+(aq) + e^- \rightleftharpoons V^{3+}(aq) + H_2O(l)$	+0.34
$VO_3^-(aq) + 4H^+(aq) + e^- \rightleftharpoons VO^{2+}(aq) + 2H_2O(l)$	+1.00
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	−0.76

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(Total for question = 7 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, **X**SO_4(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, 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)

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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 $E^{\ominus}_{cell}$ 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

$$H_2(g) + ½O_2(g) \rightarrow H_2O(l)$$

In an alkaline fuel cell the oxidation half-equation is

$$H_2(g) + 2OH^-(aq) \rightarrow 2H_2O(l) + 2e^-$$

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 $Ag^+(aq)|Ag(s)$ half-cell.

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

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

(1)

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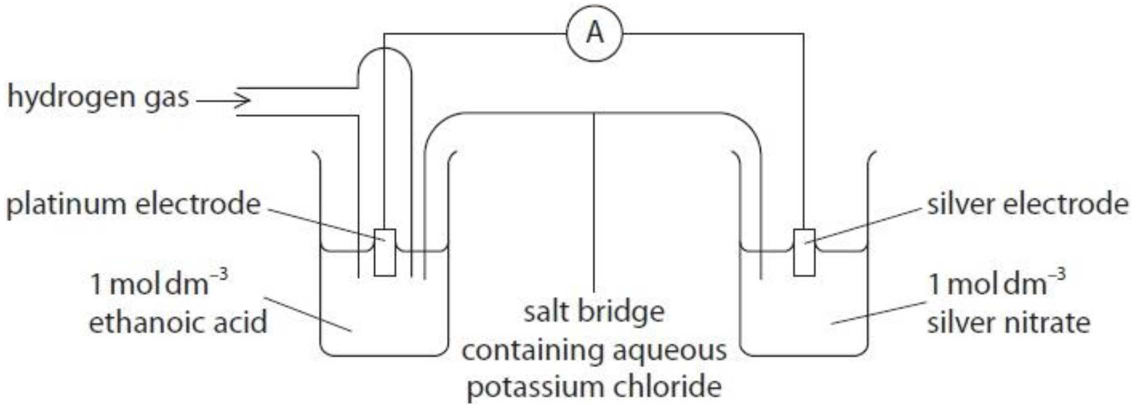
(ii) The student drew the diagram shown.



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), $KMnO_4$, 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, $Na_2C_2O_4(aq)$, of concentration 0.200 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 $C_2O_4^{2-}$ ions from the sodium ethanedioate solution is shown.

$$16H^+(aq) + 2MnO_4^-(aq) + 5C_2O_4^{2-}(aq) \rightarrow 2Mn^{2+}(aq) + 10CO_2(g) + 8H_2O(l)$$

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 $C_2O_4^{2-}$ ions from the sodium ethanedioate solution is shown.

$$16H^+(aq) + 2MnO_4^-(aq) + 5C_2O_4^{2-}(aq) \rightarrow 2Mn^{2+}(aq) + 10CO_2(g) + 8H_2O(l)$$

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)

(iii) A textbook suggested the conical flask should be heated during the titration, as the reaction between the MnO_4^- ions and the $C_2O_4^{2-}$ 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	$E^\ominus$ / V
$2CO_2(g) + 2e^- \rightleftharpoons C_2O_4^{2-}(aq)$	+0.64
$Mn^{3+}(aq) + e^- \rightleftharpoons Mn^{2+}(aq)$	+1.49
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$	+1.51

(4)

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(Total for question = 11 marks)

Mark Scheme

Q1.

Question Number	Acceptable Answers	Additional Guidance	Mark
	• calculation of moles of $Cr_2O_7^{2-}$ **(1)** • calculation of moles of Mn^{2+} **(1)** • deduction of whole number mole ratio of $Cr_2O_7^{2-}$: Mn^{2+} **(1)** • deduction of total number of electrons lost by 3 mol of Mn^{2+} **(1)** • deduction of final oxidation state of manganese **(1)**	Example of calculation • moles of $Cr_2O_7^{2-}$ $= \frac{0.100 \times 20.0}{1000}$ $= 2(.00) \times 10^{-3}$ (mol) • moles of Mn^{2+} $= \frac{0.200 \times 30.0}{1000}$ $= 6(.00) \times 10^{-3}$ (mol) • mole ratio $Cr_2O_7^{2-}$: Mn^{2+} = 1 : 3 • 3 mol Mn^{2+} lose a total of $6e^-$ • each Mn^{2+} loses $2e^-$, so final oxidation state of Mn is (+)4 / IV / Mn^{4+} MP3 and MP4 may be awarded via alternative methods e.g. use of oxidation numbers / moles of electrons correct final oxidation state with no working scores M5 only	**(5)**

Q2.

Question Number	Answer	Additional Guidance	Mark
	• both platinum symbols and salt bridge **(1)** • rest of diagram **(1)**	Pt(s) | $C_2O_4^{2-}$(aq) , $2CO_2$(g) ⋮⋮ [MnO_4^-(aq) + $8H^+$(aq)], [Mn^{2+}(aq) + $4H_2O$(l)] | Pt(s) Allow solid lines for salt bridge Allow half cells shown correctly on opposite side Ignore omission of square brackets / state symbols if neither marked scored allow 1 mark for all four 'redox' species in ROOR order, separated by commas or dashed lines, but not solid lines	**(2)**

Q3.

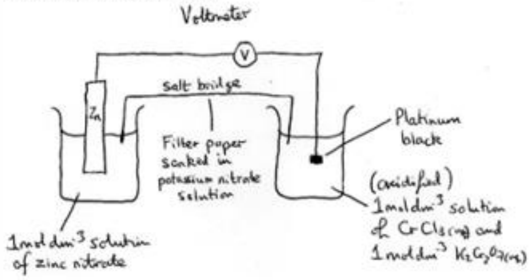
Question Number	Answer	Additional Guidance	Mark
(i)	• correct species**(1)** • balancing **(1)**	<u>Example of equation</u> $Cr_2O_7^{2-} + 14H^+ + 3Zn \rightarrow 2Cr^{3+} + 7H_2O + 3Zn^{2+}$ Allow multiples Allow ⇌ provided equation written in direction shown Ignore state symbols even if incorrect Do not award uncancelled electrons	**(2)**

Question Number	Answer	Additional Guidance	Mark
(ii)	• calculation of $E^{\ominus}_{cell}$	<u>Example of calculation</u> ($E^{\ominus}_{cell}$ = 1.33 – (−0.76)) = (+) 2.09 (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
(iii)	yes/zinc and acid will reduce chromium(III) ions to chromium(II) ions **and** because $E^{\ominus}_{cell}$ for the reaction between Zn and Cr^{3+} is (+) 0.35 (V) **or** Zn^{2+} / Zn electrode potential / SEP / $E^{\ominus}$ value is more negative / less positive / lower than the Cr^{3+} / Cr^{2+} value **or** Zn/ Zn^{2+} electrode potential / SEP / $E^{\ominus}$ value is less negative / more positive / higher than the Cr^{3+} / 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
(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 orbital**s** / d subshell **(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	**(2)**
	• 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)**	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	

Q4.

Question Number	Answer	Additional Guidance	Mark
	A diagram that includes	Example of diagram  	**(7)**
	• **(M1)** (high resistance) voltmeter/V **(1)**		
	• **(M2)** salt bridge to complete circuit **(1)**	Salt bridge must dip into the solutions	
	• **(M3)** filter paper soaked in (saturated) potassium nitrate/KNO_3 solution **(1)**	Allow sodium chloride/potassium chloride for potassium nitrate	
	(M4) zinc electrode of zinc metal and suitable zinc salt **(1)**	e.g. $ZnSO_4$	
	• **(M5)** platinum (black) electrode **(1)**		
	• **(M6)** suitable chromium salts **(1)**	e.g. $CrCl_3$ / $K_2Cr_2O_7$	
	• **(M7)** all solutions to be 1 mol dm^{-3} (wrt ions) **(1)**	if $Cr_2(SO_4)_3$ 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	

Q5.

Question Number	Answer	Additional Guidance	Mark
(i)	• four correct species **(1)** • balancing and the correct number of electrons **(1)**	<u>An example of equation</u> $[Cr(OH)_6]^{3-} + 2OH^- \rightarrow CrO_4^{2-} + 4H_2O + 3e^-$ Accept multiples	**(2)**

Question Number	Answer	Additional Guidance	Mark
(ii)	• equation	<u>An example of equation</u> $2CrO_4^{2-} + 2H^+ \rightarrow Cr_2O_7^{2-} + H_2O$ Accept $\rightleftharpoons$ / multiples	**(1)**

Question Number	Answer	Additional Guidance	Mark
(iii)	• oxidation half equation **(1)** • reduction half equation **(1)** • overall equation **(1)**	$H_2O_2 \rightarrow 2H^+ + O_2 + 2e^-$ $Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$ $Cr_2O_7^{2-} + 8H^+ + 3H_2O_2 \rightarrow 2Cr^{3+} + 7H_2O + 3O_2$ 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)**

Q6.

Question Number	Acceptable Answers	Additional Guidance	Mark
	• substitution of correct values into expression **(1)** • calculation of $\ln[Ag^+(aq)]$ **(1)** • calculation of $[Ag^+(aq)]$ **(1)**	<u>Example of calculation</u> $0.72 = 0.80 + \frac{8.31 \times 293}{96500} \times \ln[Ag^+(aq)]$ $\ln[Ag^+(aq)] = (0.72 - 0.80) \times \frac{96500}{8.31 \times 293} = -3.1707$ $[Ag^+(aq)] = e^{\ln[Ag+(aq)]}$ $= 0.041976$ / 4.1976×10^{-2} (mol dm^{-3}) TE on $\ln[Ag^+(aq)]$ Ignore SF except 1 SF Correct answer with no working scores full marks Expression can be rearranged before substitution of values	**(3)**

Q7.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)	• (high resistance) voltmeter **(1)** • platinum /Pt (electrode) **(1)** • manganese(II) **and** manganese(III) ions / Mn^{2+} **and** Mn^{3+} **(1)**	Allow potentiometer / Wheatstone bridge / just 'V' Ignore high voltage Do not award voltameter Ignore just 'inert metal' Do not award manganese / Mn Allow any named manganese(II) salt **and** manganese(III) salt Ignore concentration and units	**(3)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b) (i)	• potassium nitrate / KNO_3	If name and formula are given, both must be correct If more than one substance given, all must be correct Allow potassium chloride / KCl sodium nitrate / $NaNO_3$ sodium chloride / NaCl ammonium nitrate / NH_4NO_3 ammonium chloride / NH_4Cl Ignore concentration	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)(ii)	• wire does not allow the flow of ions **or** wire (only) allows flow of electrons **or** salt bridge allows flow of ions **or** salt bridge does not allow the flow of electrons **or** a flow of ions is needed to complete the circuit **or** ions (need to) flow between the half-cells / between the solutions	Allow any indication of movement for flow in all points Allow the salt bridge donates / removes ions (to balance the charges in the solution and the wire does not do this) Ignore just 'the circuit is not complete' Ignore references to changes in potential difference / E° / E°_{cell}	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
(c) (i)	• correct equation	<u>Example of equation</u> $2Mn^{3+} + Cu \rightarrow 2Mn^{2+} + Cu^{2+}$ Allow multiples Allow ⇌ provided equation is written in the direction shown Ignore state symbols, even if incorrect Ignore cancelled electrons e.g. $2Mn^{3+} + Cu \rightarrow 2Mn^{2+} + Cu^{2+} + 2e$ Do not award equation with uncancelled electrons	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
(c)(ii)	• $E^⦵$ = 1.15 − (−0.34) = (+)1.49 (V)	Stand alone mark Correct answer with no working scores the mark	(1)

Q8.

Question Number	Answer	Additional Guidance	Mark
(i)	• identification of oxidising agent	Either acidified (potassium) manganate(VII) / MnO_4^- and H^+ Or acidified hydrogen peroxide / H_2O_2 and H^+ Allow H^+ shown in equation in (i) or (ii) If the acid is specified it must be sulfuric acid	(1)

Question Number	Answer	Additional Guidance	Mark
(ii)	• value of $E^⦵_{cell}$	Either $E^⦵_{cell}$ = (+)0.15 (V) for acidified (potassium) manganate(VII) Or $E^⦵_{cell}$ = (+)0.41 (V) for acidified hydrogen peroxide No TE on any other reagent in (i)	(1)

Q9.

Question Number	Answer	Additional Guidance	Mark
	• 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) $K_c = 4.9289 \times 10^{12}$ $= 4.9 \times 10^{12}$ / 4.93×10^{12} TE on their value for $\ln K_c$ Ignore SF except 1SF Correct answer with no working scores (2)	(2)

Q10.

Question Number	Answer	Additional Guidance	Mark
	• one half-equation **(1)** • other half-equation **(1)** • state symbols **(1)**	<u>Examples of half-equations</u> $Pb(s) + SO_4^{2-}(aq) \rightleftharpoons PbSO_4(s) + 2e^-$ Allow $Pb(s) + H_2SO_4(aq) \rightleftharpoons PbSO_4(s) + 2H^+(aq) + 2e^-$ $PbO_2(s) + 4H^+(aq) + SO_4^{2-}(aq) + 2e^- \rightleftharpoons PbSO_4(s) + 2H_2O(l)$ Allow $PbO_2(s) + 2H^+(aq) + H_2SO_4(aq) + 2e^- \rightleftharpoons PbSO_4(s) + 2H_2O(l)$ Allow multiples Allow single headed arrows in the forward direction Ignore missing charge on electrons Conditional on correct species in one equation that has scored either M1or M2	**(3)**

Q11.

Question number	Answer	Mark
	The only correct answer is A ($4H^+(aq) + O_2(g) + 4e^- \rightarrow 2H_2O(l)$) ***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)**

Q12.

Question Number	Answer	Additional Guidance	Mark
(i)	An explanation that makes reference to the following points: • balanced equation **(1)** • calculation of $E^\ominus_{cell}$ value **(1)** • $E^\ominus_{cell}$ / answer is negative / <0 **and** the reaction is not (thermodynamically) feasible **(1)**	<u>Example of equation</u> $Br_2(aq) + H_2O(l) \rightarrow HOBr(aq) + HBr(aq)$ Allow multiples Allow $H^+(aq) + Br^-(aq)$ for HBr(aq) Allow reversible arrows Ignore state symbols even if incorrect $E^\ominus_{cell} = 1.09 - 1.57 = -0.48$ (V) Allow correct answer without calculation Allow 3 marks for reverse argument $HOBr(aq) + HBr(aq) \rightarrow Br_2(aq) + H_2O(aq)$ (1) $E^\ominus_{cell} = 1.57 - 1.09 = (+) 0.48$ (V) (1) $E^\ominus_{cell}$ is positive / >0 so the reverse of disproportionation is (thermodynamically) feasible (1)	**(3)**

Question Number	Answer	Additional Guidance	Mark
(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** HOBr undergoes further disproportionation	Ignore just 'non-standard conditions' Ignore references to activation energy / collision theory Ignore H^+ / ions from the water	**(1)**

Q13.

Question Number	Acceptable Answers	Additional Guidance	Mark
	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° values $Zn + 2VO_3^- + 8H^+ \rightarrow Zn^{2+} + 2VO^{2+} + 4H_2O$ **and** E° = (+)1.76 (V) **(1)** $Zn + 2VO^{2+} + 4H^+ \rightarrow Zn^{2+} + 2V^{3+} + 2H_2O$ **and** E° = (+)1.1(0) (V) **(1)** $Zn + 2V^{3+} \rightarrow Zn^{2+} + 2V^{2+}$ **and** E° = (+)0.5(0) (V) **(1)** **M7 – stops at V^{2+}** No (further) reduction (feasible) to V metal / V(0) **or** $Zn + V^{2+} \rightarrow Zn^{2+} + V$ not feasible **or** E° = −0.42 (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° scores 2 2 correct equations with incorrect E° scores 1 3 correct E° with incorrect equations scores 1	**(7)**

Q14.

Question Number	Acceptable Answers	Additional Guidance	Mark
	• calculation of moles of Cr **(1)** **MP2, 3 & 4 are only available for answers using a 3:2 mole ratio** • deduction of mole ratio of **X** to Cr^{3+} **(1)** • calculation of moles of **X** **(1)** • calculation of molar mass / A_r of **X** **and** identification of **X** accordingly **(1)**	<u>Example of calculation</u> Moles Cr = $\frac{1.456}{52(.0)}$ = 0.028(0) **3** mol **X** : **2** mol Cr^{3+} / Cr Allow $2Cr^{3+} + 3X \rightarrow 3X^{2+} + 2Cr$ Moles **X** = 0.028(0) x 1.5 = 0.042(0) Correctly multiplying by 1.5 for MP3 implies MP2 $M_r = \frac{1.021}{0.042(0)}$ = 24.3 (g mol^{-1}) **and** (so) **X** is magnesium/Mg COMMENT: If transpose 3:2 ratio, **X** has M_r = 54.7 (g mol^{-1}) and **X** = Mn so scores M1, then M3 and M4 by TE (i.e. **(3)** marks overall)	**(4)**

Q15.

Question Number	Acceptable Answers	Additional Guidance	Mark
	• Na / sodium	Do not award Na^+	**(1)**

Q16.

Question Number	Acceptable Answers	Additional Guidance	Mark
(i)	• MnO_2, MnO_4^-, OH^- and MnO_4^{2-} species correct in a single equation **(1)** • H_2O on right **and** balancing **(1)**	Example of equation $MnO_2 + 2MnO_4^- + 4OH^- \rightarrow 3MnO_4^{2-} + 2H_2O$ 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
(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)**

Q17.

Question Number	Answer	Mark
(i)	**The only correct answer is A** ***B*** *is not correct because Cl^- is not an oxidising agent* ***C*** *is not correct because I_2 is not a powerful enough oxidising agent* ***D*** *is not correct because* Mn^{2+} *is not an oxidising agent*	**(1)**

Question Number	Answer	Additional Guidance	Mark
(ii)	• all species on correct sides of equation **and** no electrons / electrons cancelled **(1)** • balancing correct species **(1)** • E°_{cell} value **(1)**	<u>Example of ionic equation</u> $2MnO_4^- + 16H^+ + 10Br^- \rightarrow 2Mn^{2+} + 8H_2O + 5Br_2$ Allow $\rightleftharpoons$ Allow correct species if shown in working with half-equations but slip made in final equation e.g. charge missing Ignore state symbols Allow multiples Allow M2 for almost correct species E°_{cell} (= 1.51 − 1.09) = (+)0.42 (V) No TE on incorrect equation	**(3)**

Q18.

Question Number	Answer	Additional Guidance	Mark
	• reduction half-equation	<u>Example of half equation</u> $\frac{1}{2}O_2 + H_2O + 2e^- \rightarrow 2OH^-$ Allow multiples Ignore state symbols even if incorrect	**(1)**

Q19.

Question Number	Acceptable Answers	Additional Guidance	Mark
(i)	• correct temperature **and** pressure	<u>Examples of values</u> Temperature: 298 K / 25°C Pressure: 1 atm / 1 bar 100 kPa/ 1 x 10^5 Pa / 101 kPa / 1.01 x 10^5 Pa / 1 x 10^5 Nm^{-2} / 1.01 x 10^5 Nm^{-2} Values **and** units are needed Ignore reference to concentration even if incorrect	**(1)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(ii)		The mistakes can be in any order Ignore any other errors Ignore reasons for replacements	(3)
	• ammeter / symbol for ammeter **and** replace with (high resistance) voltmeter / symbol for voltmeter **(1)**	Allow replace with potentiometer / Wheatstone bridge Do not award voltameter	
	• ethanoic acid **and** replace with solution that is 1.0 mol dm^{-3} with respect to $H^+(aq)$ **(1)**	Allow replace with (1.0 / 1.16-1.18 mol dm^{-3}) hydrochloric acid / HCl / nitric acid / HNO_3 **or** Allow 0.5 mol dm^{-3} sulfuric acid / H_2SO_4 Ignore just 'replace with a strong acid'	
	• potassium chloride / chemical in salt bridge **and** replace with potassium nitrate / KNO_3 / sodium nitrate / $NaNO_3$ **(1)**	Allow replace chloride with a nitrate anion Ignore replace with a different anion that will not react with Ag^+	

Q20.

Question Number	Answer	Additional Guidance	Mark
(i)	• titres calculated and both ticks correct **(1)** • mean calculated **(1)**	See table below. Both titres to 2 dp mean = (16.90+16.80)÷2 = 16.85 (cm^3) allow TE for M2 for mean of One, Two and Three = 16.97 (cm^3)	(2)

Run	Trial	One	Two	Three
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	16.**80**	17.20	16.**90**
Concordant titres (✓)		✓		✓
Mean titre / cm^3	**16.85**			

Question Number	Answer	Additional Guidance	Mark
(ii)	• calculation of moles of $Na_2C_2O_4(aq)$ **(1)** • calculation of moles of $KMnO_4$ in titre **(1)** • calculation of moles of $KMnO_4$ in 100 cm^3 **(1)** • calculation of M_r for $KMnO_4$ **(1)** • calculation of mass of 1 tablet in mg to 2 or 3SF **(1)**	Example of calculation (25.0÷1000) x 0.200 = 0.005 / 5.00 x 10^{-3} (mol) 5.00 x 10^{-3} x 2÷5 = 0.002 / 2.00 x 10^{-3} (mol) 2.00 x 10^{-3} x (100÷16.85) = 0.011869 (mol) 158 0.011869 x 158 = 1.8754 g (1.8754÷5) x 1000 = 375.07 mg = 380 / 375 (mg) Correct answer with or without working scores 5 marks 0.38 g scores 4 marks (M5 not awarded) TE at each stage and on mean titre 379 mg from 0.012 scores (5)	(5)

Question Number	Answer	Additional Guidance	Mark
(iii)	An explanation that makes reference to the following points • (reaction is slow initially) as MnO_4^- and $C_2O_4^{2-}$ are (both) negative (ions) so will repel (each other) **(1)** • when (sufficient) Mn^{2+} ions form they (auto) catalyse the reaction **(1)** • Mn^{2+} ions will reduce MnO_4^- ions (as $E^\ominus$ is more negative) forming Mn^{3+} ions OR $MnO_4^- + 8H^+ + 4Mn^{2+} \rightarrow 5Mn^{3+} + 4H_2O$ ($E^\ominus = +0.02V$) **(1)** • Mn^{3+} ions then oxidise $C_2O_4^{2-}$ ions (reforming Mn^{2+}) (as $E^\ominus$ is more positive) OR $C_2O_4^{2-} + 2Mn^{3+} \rightarrow 2Mn^{2+} + 2CO_2$ ($E^\ominus = +0.85V$) **(1)**	Allow 'heat is required to overcome high activation energy when catalyst is absent' Allow Mn^{2+} ions will react with MnO_4^- ions as $E^\ominus$ is more negative Allow Mn^{3+} ions then react with $C_2O_4^{2-}$ ions (reforming Mn^{2+}) as $E^\ominus$ is more positive May be shown in equations and / or by calculating $E^\ominus$	(4)