1. This question is about compounds and ions of iron(II) and iron(III) that contain ethanedioate ions, $C_2O_4^{2-}$.

A student plans an investigation to find the number of waters of crystallisation, **x**, in a sample of hydrated iron(II) ethanedioate, $FeC_2O_4 \cdot xH_2O$.

The student decides to carry out a redox titration between solutions of iron(II) ethanedioate and potassium manganate(VII) in acidic conditions.

i.   In the titration, both iron(II) ions and ethanedioate, $C_2O_4^{2-}$, ions are oxidised.

Construct half-equations for the oxidation of iron(II) and ethanedioate ions.

Oxidation of iron(II) ions

_____

Oxidation of ethanedioate ions

_____**[2]**

ii.   The student prepares a 250.0 cm³ solution of iron(II) ethanedioate by dissolving 1.295 g of $FeC_2O_4 \cdot xH_2O$, in dilute sulfuric acid.

The student titrates 25.0 cm³ samples of this solution with 0.0200 mol dm⁻³ $KMnO_4$ in the burette. The student carries out a trial, followed by three further titrations.

The diagrams show the initial burette readings and the final burette readings for the student's three further titrations.

Titration 1		Titration 2		Titration 3	
Initial reading	Final reading	Initial reading	Final reading	Initial reading	Final reading

All burette readings are measured to the nearest 0.05 cm³.

Complete the titration table.

	1	2	3
Final reading/ cm^3			
Initial reading/ cm^3			
Titre / cm^3			

[3]

iii.   The uncertainty in each burette reading is ±0.05 cm^3.

Calculate the percentage uncertainty for the titre in **Titration 1**.

percentage uncertainty = ... %**[1]**

iv.   In the titration, 5 mol of iron(II) ethanedioate reacts with 3 mol of manganate(VII) ions.

Analyse the student's results to find the number of waters of crystallisation, **x**, in the hydrated iron(II) ethanedioate, $FeC_2O_4 \cdot \textbf{x}H_2O$.

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Extra answer space if required.

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_____**[6]**

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2. This question is about the chemistry of compounds containing phosphorus.

Phosphine, PH_3, is a poisonous gas.

    i.   Phosphine reacts with oxygen gas to form phosphorus(V) oxide and water.

           Write the equation for this reaction.

_____**[1]**

    ii.   Aqueous silver nitrate, $AgNO_3$, is reduced by PH_3.
           The unbalanced equation is shown below.

           Balance the equation and use oxidation numbers to explain why this is a redox reaction.

           .... $AgNO_3$ + ... PH_3 + ... H_2O .... Ag + ... H_3PO_3 +........ HNO_3

Explanation   _____

_____

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_____**[3]**
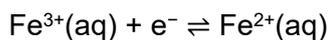
3(a). Standard electrode potentials are measured by comparison with a reference half-cell.

Draw a labelled diagram to show how the standard electrode potential could be measured for the redox system below.

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

Include details of the apparatus, solutions and the standard conditions needed when measuring this standard electrode potential.

Standard conditions

_____**[4]**

(b). Many electric vehicles are powered by lithium-ion cells.

Hydrogen-oxygen fuel cells can also be used to power vehicles.

Six redox systems are shown in the table. State symbols have been omitted.

Redox system	Half-equation	$E^{\ominus}/V$
1	$Li^+ + e^- \rightleftharpoons Li$	−3.04
2	$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^-$	−0.83
3	$2H^+ + 2e^- \rightleftharpoons H_2$	0.00
4	$O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^-$	+0.40
5	$Li^+ + CoO_2 + e^- \rightleftharpoons LiCoO_2$	+1.16
6	$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O$	+1.23

 i. A lithium-ion cell involves **redox systems 1 and 5**.

  Construct the overall cell equation for a lithium-ion cell.

_____**[1]**

ii.   Hydrogen-oxygen fuel cells can operate in acidic or in alkaline conditions.

Show that for acidic and alkaline hydrogen-oxygen fuel cells, the standard cell potentials, and the overall cell equations, are the same.

Acidic _____

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_____

Alkaline _____

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_____**[3]**

4(a). A mixture of concentrated nitric and hydrochloric acid is called 'aqua regia'. Aqua regia can dissolve gold.

The reaction of aqua regia with gold is a redox reaction which forms chlorauric acid, $HAuCl_4$.

i.   Balance the half-equation for the oxidation process in this reaction.

Au + ...HCl → ....H^+ + $AuCl_4^-$ + ...e^-

[1]

ii.   In the reduction process in this reaction, HNO_3 and H^+ react together to form 2 oxides:
        X (M_r = 30) and **Z** (M_r = 18).

Determine the formulae of **X** and **Z** and write the half-equation for this reduction.

X = ...

Z = ...

half-equation _____ **[3]**

(b). Three reactions involving sulfuric acid are shown below.

Reaction 1
Dilute sulfuric acid is reacted with nickel(II) hydroxide to form a green solution.

The solvent is allowed to evaporate leaving hydrated crystals of compound **D**, with the percentage composition by mass: Ni, 22.33%; S, 12.20%; O, 60.87%; H, 4.60%.

Reaction 2
Concentrated sulfuric acid is reacted with hydrogen bromide, HBr, to form three products:

- an element which exists as diatomic molecules
- a gaseous compound **E**
- a liquid.

At RTP, 1.00 dm^3 of compound **E** has a mass of 2.67 g.

Reaction 3
Concentrated sulfuric acid acts as a catalyst when 2-hydroxypropanoic acid reacts to form compound **F** (M_r = 144).

In this reaction, 2 mol of 2-hydroxypropanoic acid forms 1 mol of compound **F** and 2 mol of water.

Identify compounds **D**, **E** and **F** and construct equations for the reactions.

Show structures for any organic compounds.

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[6]


5(a). Some grass fertilisers contain compounds of iron.

During heavy rain, a fertiliser is washed into a nearby river causing the water to be polluted with a mixture of iron(II) and iron(III) ions.

A student determines the concentration of iron(II) ions in a sample of river water by titration with potassium manganate(VII).

25.0 cm^3 portions of river water are acidified with dilute sulfuric acid. Each portion is titrated with 0.00250 mol dm^{-3} potassium manganate(VII) until a colour change is seen.

$MnO_4^-(aq) + 8H^+(aq) + 5Fe^{2+}(aq) \rightarrow Mn^{2+}(aq) + 4H_2O(l) + 5Fe^{3+}(aq)$
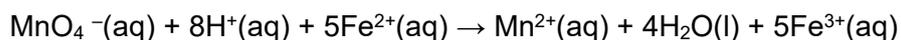
   i.   State the colour change seen at the end point of the titration.

       from .... to ....

[1]

   ii.   The student's titration results are shown in the table below.
       The trial titre has been omitted.

	1	2	3
Final volume / cm^3	12.65	25.60	38.35
Initial volume / cm^3	0.00	12.65	25.60
Titre volume / cm^3	....	....	....

Complete the table above and calculate the mean titre that the student should use to determine the concentration of iron(II) ions in the river water.

mean titre = ... cm^3 **[2]**

iii.   Determine the concentration, in mol dm^{-3}, of iron(II) ions in the river water.

concentration = ... mol dm^{-3} **[3]**

(b). The student modifies the experiment in **(a)** to determine the combined concentration of iron(II) and iron(III) ions in the river water.

The student's method is shown below.

Step 1   Add excess zinc to a 250.0 cm^3 sample of river water and warm gently.

Step 2   Cool the solution and remove excess zinc by filtration.

Step 3   Acidify 25.0 cm^3 portions of the filtrate from **Step 2**. Then titrate each portion with 0.00250 mol dm^{-3} potassium manganate(VII) until a colour change is seen.

The table below shows information about three redox systems.

Redox system	Half-equation	$E^{\ominus}$ / V
1	$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	−0.76
2	$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
3	$MnO_4^{-}(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$	+1.51

Use the information in the table above to explain the reasons for **Step 1** and **Step 2**.

Reason(s) for **Step 1**

_____

_____

_____

Reason(s) for **Step 2**

_____

_____

_____

[4]

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6. An acidified solution containing $Cr_2O_7{}^{2-}$ ions reacts with vanadium(III) ions in a redox reaction to form a solution containing Cr^{3+} ions and $VO_2{}^+$ ions.

Construct the overall equation for this reaction.

[2]

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7. The equations show the electrode potentials of the half-cells used in a lithium-ion cell.

|	$E^{\ominus}$ / V
$Li^+ + e^- \rightleftharpoons Li$	−3.04
$Li^+ + CoO_2 + e^- \rightleftharpoons LiCoO_2$	+1.16

Which statement is correct in a lithium-ion cell?

A   The cell potential is 2.88 V.
B   The reaction at the positive electrode is: $LiCoO_2$ $Li^+ + CoO_2 + e^-$
C   The overall cell reaction is: $Li + CoO_2 \rightarrow LiCoO_2$
D   The oxidation number of Co changes from +2 to +1.

Your answer [   ]   **[1]**

8. Chlorine trifluoride can be decomposed into its elements forming the equilibrium mixture below.

$2ClF_3(g)$ $\rightleftharpoons$ $Cl_2(g)$ + $3F_2(g)$ ΔH = +318 kJ mol^{-1}

colourless   green   yellow

gas   gas   gas
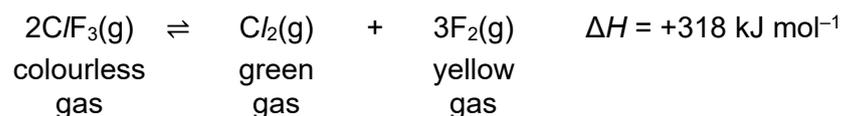
Which statement(s) is/are correct?

1	The decomposition is a redox reaction.
2	When the equilibrium mixture is cooled, the colour fades.
3	The decomposition has a negative entropy change.
A	1, 2 and 3
B	Only 1 and 2
C	Only 2 and 3
D	Only 1

Your answer ☐ **[1]**

9. This question is about the reactions of Group 2 metals and their compounds.

A student adds magnesium to dilute hydrochloric acid in one test tube.

The student adds calcium to dilute hydrochloric acid in a second test tube.

A redox reaction takes place in each test tube.

   i.   Suggest **two** observations from the student's experiment that would show that calcium is more reactive than magnesium.

      1 _____

      2 _____

[1]

   ii.   Write half-equations for the reaction of magnesium with hydrochloric acid.

      Oxidation half-equation: _____

      Reduction half-equation: _____

[2]

10. This question is about reactions of transition metal compounds.

Aqueous sodium hydroxide is added to an aqueous solution of iron(II) sulfate.

A pale green precipitate forms which turns brown when left to stand in air.

   i.   Write an ionic equation for the formation of the pale green precipitate.

--**[1]**

   ii.   Use the information below to explain why the pale green precipitate turns brown when left to stand in air and construct an equation for the reaction which occurs.

Redox System	Equation	E°/V
1	$Fe(OH)_3(s) + e^- \rightleftharpoons Fe(OH)_2(s) + OH^-(aq)$	$-0.56V$
2	$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	$+0.40V$

--**[4]**

11. Hydrogen peroxide, H_2O_2, can be oxidised by manganate(VII) ions under acid conditions as shown below.

$2MnO_4^-(aq) + 5H_2O_2(aq) + 6H^+(aq) \rightarrow 2Mn^{2+}(aq) + 5O_2(g) + 8H_2O(l)$
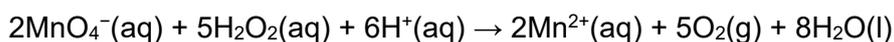
In a titration, 25.00 cm³ of a disinfectant containing hydrogen peroxide reacts with 22.00 cm³ of 0.125 mol dm⁻³ $KMnO_4(aq)$.

What is the concentration of H_2O_2, in mol dm⁻³, in the disinfectant?

Assume that KMnO4 only reacts with H_2O_2 in the disinfectant.

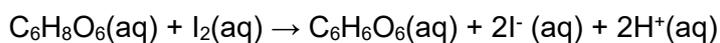|	
A	0.0440
B	0.110
C	0.275
D	0.550

Your answer ☐ **[1]**

12. A student carries out an investigation on vitamin C, $C_6H_8O_6$.

The label on a carton of orange juice lists the mass of vitamin C, in mg, in a typical serving of 150 cm³.

The student carries out an investigation to check the vitamin C content in the orange juice.

Vitamin C can be oxidised by iodine:

$C_6H_8O_6(aq) + I_2(aq) \rightarrow C_6H_6O_6(aq) + 2I^-(aq) + 2H^+(aq)$

The student dilutes 150 cm³ of the orange juice with water to 250.0 cm³ in a volumetric flask.

The student then titrates 25.0 cm³ volume of this solution with 9.60×10^{-4} mol dm⁻³ iodine solution, $I_2(aq)$.

The mean titre of $I_2(aq)$ is 22.50 cm³.

Determine the mass, in mg, of vitamin C in a 150 cm³ serving of the orange juice.

mass of vitamin C in the 150 cm³ serving of orange juice = ... mg **[4]**

13(a). This question is about redox reactions.

A student analyses the redox reactions shown below. State symbols have been omitted.

$CH_3CHO + 2H^+ + 2e^-$ $\rightleftharpoons$ C_2H_5OH $E^e = -0.197$ V

$Cr_2O_7{}^{2-} + 14H^+ + 6e^-$ $\rightleftharpoons$ $2Cr^{3+} + 7H_2O$ $E^e = +1.33$ V

$FeO_4{}^{2-} + 8H^+ + 3e^-$ $\rightleftharpoons$ $Fe^{3+} + 4H_2O$ $E^e = +2.20$ V

The student concludes that different ions containing chromium can act as oxidising or reducing agents.

Using the terms oxidising agent and reducing agent, and ideas about electrode potentials and equilibrium, explain how the student is correct.

Include overall equations.

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[5]

(b). A student bubbles hydrogen sulfide gas, $H_2S(g)$, through an acidified solution containing manganate(VII) ions, $MnO_4{}^-(aq)$.

A redox reaction takes place, forming aqueous manganese(II) ions, a yellow precipitate and one other product.

Construct the equation for this reaction. State symbols are not required.

[2]

END OF QUESTION PAPER