1 Hydrogen gas can be used as a fuel in car engines by being burnt in a combustion reaction or reacted with oxygen in a fuel cell to produce electricity.

(a) Write half-equations for the reaction of hydrogen gas at the anode and oxygen gas at the cathode in the fuel cell.

(2)

Anode

Cathode

(b) Describe one advantage of using hydrogen in fuel cells rather than burning the hydrogen directly.

(1)

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(c) Other fuels, such as ethanol, can also be used in fuel cells. By considering the possible sources of ethanol and hydrogen, explain why some scientists believe the use of such cells could provide a more sustainable source of energy for cars, compared with fossil fuels.

(3)

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(Total for Question   6 marks)

2 Brass is an alloy of copper, zinc and, in some cases, other metals too. There are over 30 varieties of brass for different applications.

The amount of copper in a brass can be found as follows:

- A weighed sample of brass is reacted with the minimum amount of concentrated nitric acid.

- The solution is neutralized, a portion of it pipetted into a conical flask, and excess potassium iodide solution is added.

- The iodine produced is titrated with a solution of sodium thiosulfate of known concentration.

(a) The ionic equation for the reaction between copper metal and concentrated nitric acid is shown below.

$$Cu(s) + 2NO_3^-(aq) + 4H^+ (aq) \rightarrow Cu^{2+}(aq) + 2NO_2(g) + 2H_2O(l)$$
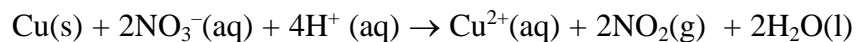
(i) Give the oxidation numbers of the copper and nitrogen in both the reactants and products.

(2)

Copper: from   **to**

Nitrogen: from   **to**

(ii) Write the two half-equations that can be combined to give the ionic equation shown above.

(2)

(iii) Explain why the standard electrode potentials for the two ionic half-equations that you have written give an incorrect value for E_{cell} for this reaction as described above.

(2)

(b) The solution produced contains a mixture of zinc ions and copper ions.

(i) State TWO observations that you would **see** if concentrated ammonia solution were to be added, drop by drop, to the solution until in excess.

(2)

(ii) Copper ions can be separated from the zinc ions in the solution by adding sodium hydroxide solution in excess, followed by filtration of the mixture.

Write equations, including state symbols, for the THREE reactions that occur.

(3)

Equation 1

Equation 2

Equation 3

*(iii) Give examples of amphoteric behaviour and ligand exchange, by reference to the reactions of zinc compounds.

(3)

(c) A sample of Admiralty Brass of mass 3.00 g was treated with nitric acid and made up to a neutral solution of volume 250 cm^3. Excess potassium iodide was added to 25.0 cm^3 portions of this solution, and the liberated iodine was titrated with sodium thiosulfate solution, concentration 0.100 mol dm^{-3}. The mean titre was 33.10 cm^3.

(i) Write the ionic equation for the reaction between thiosulfate ions and iodine.

(1)

*(ii) The equation for the reaction between copper(II) ions and iodide ions is shown below.

$$2Cu^{2+} + 4I^- \rightarrow 2CuI + I_2$$
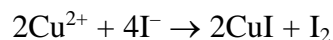
Hence calculate the percentage by mass of copper in Admiralty Brass. Give your answer to **three** significant figures.

(6)

(iii) When setting up the burette, a student failed to fill the jet of the burette. Explain the effect that this would have on the value of the first titre.

If this first titre was included in the calculation of the mean titre, what effect would this have on the value for the percentage of copper in the brass?

(2)

(Total for Question = 23 marks)

3 (a) Chromium is a typical transition metal, although its electronic configuration does **not** fit the general trend found in the first transition series.
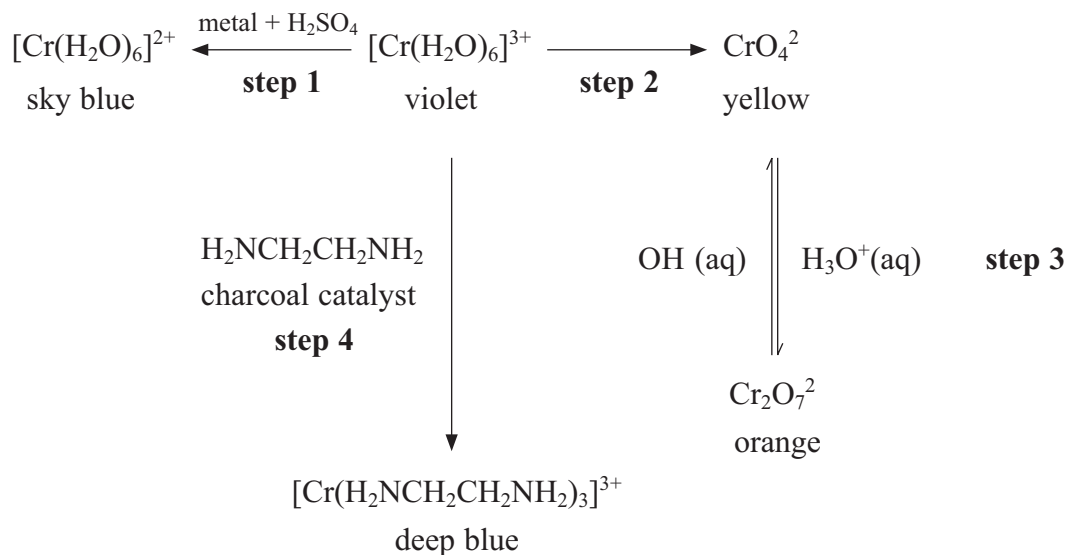
Complete the electronic configurations in *s,p,d* notation for vanadium and chromium.

(1)

Vanadium: [Ar] ....

Chromium: [Ar] ....

(b) Some interconversions found in the chemistry of chromium are shown below. Use this information to answer the questions that follow.

$[Cr(H_2O)_6]^{2+}$ $\xleftarrow{\text{metal + H}_2\text{SO}_4}$ $[Cr(H_2O)_6]^{3+}$ $\longrightarrow$ CrO_4^2

sky blue   **step 1**   violet   **step 2**   yellow

$H_2NCH_2CH_2NH_2$ OH (aq) ⇅ $H_3O^+(aq)$ **step 3**
charcoal catalyst
step 4

                                                          $Cr_2O_7^2$
                                                          orange

$[Cr(H_2NCH_2CH_2NH_2)_3]^{3+}$
deep blue

(i) State **two** typical properties of transition metals, other than the formation of coloured ions, which are shown in the diagram above.

(2)

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(ii) Use $E^{\ominus}$ values from your data booklet to suggest a metal that could be used for **step 1**. Justify your answer by calculating $E^{\ominus}$ for your cell.

(2)

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(iii) Explain, using oxidation numbers, whether or not the conversion in **step 3** is a redox reaction.

(2)

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(iv) The organic compound $H_2NCH_2CH_2NH_2$ that is used in **step 4** is 1,2-diaminoethane, often called ethylenediamine.
It is a **bidentate ligand**. Explain the meaning of this term.
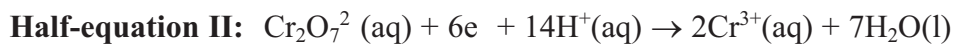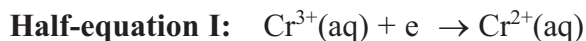
(1)

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(v) Explain, in terms of its structure, how $H_2NCH_2CH_2NH_2$ can act as a bidentate ligand whereas H_2NNH_2 cannot.

(2)

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(c) The half-equations relating the interconversion of the species $Cr^{2+}(aq)$, $Cr^{3+}(aq)$ and $Cr_2O_7{}^2{}^-$ (aq) are given below.

Half-equation I: $Cr^{3+}(aq) + e^- \rightarrow Cr^{2+}(aq)$

Half-equation II: $Cr_2O_7{}^2{}^-$ (aq) $+ 6e^- + 14H^+(aq) \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)$

(i) Use your data booklet to find $E^{\ominus}$ for each of the above half-equations.

(1)

Half-equation I .... Volts

Half-equation II .... Volts

*(ii)Write the overall equation for the disproportionation of Cr^{3+} into Cr^{2+} and $Cr_2O_7{}^2{}^-$.

Use the $E^{\ominus}$ values you have obtained in (c)(i) to show whether or not this disproportionation is feasible under standard conditions.

(4)

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(Total for Question   15 marks)