PEARSON EDEXCEL A-LEVEL CHEMISTRY · 9CH0

CHEMISTRY



EXAM QUESTION PACK

TOPIC 15: TRANSITION METALS

SCORE	PERCENTAGE
/394	%

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Q1.

A **heterogeneous** catalyst is often preferred to a **homogenous** catalyst for an industrial process because

☒ **A** it is easily separated from the products.

☒ **B** it has empty d-orbitals.

☒ **C** it has more than one oxidation state.

☒ **D** it cannot be poisoned.

(Total for question = 1 mark)

Q2.

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.

(2)

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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.

(2)

(Total for question = 4 marks)

Q3. The ligands that form complex ions are either neutral, like NH_3, or negatively charged, like CN^-. Nickel(II) ions, Ni^{2+}, form complexes with both these ligands. The bonding between Ni^{2+} and the ligands in these complexes is

	NH_3	CN^-
☐ **A**	dative covalent	dative covalent
☐ **B**	ionic	dative covalent
☐ **C**	dative covalent	ionic
☐ **D**	ionic	ionic

(Total for Question = 1 mark)

Q4.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

This is a question about catalysis.

The rate of oxidation of ethanedioate ions by manganate(VII) ions starts slowly and then rapidly increases.

$$2MnO_4^- + 16H^+ + 5C_2O_4^{2-} \rightarrow 2Mn^{2+} + 8H_2O + 10CO_2$$

What is the catalyst in this reaction?

(1)

☐ **A** CO_2

☐ **B** H^+

☐ **C** Mn^{2+}

☐ **D** MnO_4^-

(Total for question = 1 mark)

Q5.

This is a question about catalysis.

The oxidation of sulfate(IV) ions to sulfate(VI) ions is catalysed by cobalt(II) ions in **acidic** solution. The role of cobalt(II) ions is similar to that of iron(II) ions in (a).

$$SO_3^{2-} + \tfrac{1}{2}O_2 \xrightarrow{Co^{2+}} SO_4^{2-}$$

Deduce two ionic equations to show how cobalt(II) ions catalyse the reaction in **acidic**solution. State symbols are not required.

(2)

(Total for question = 2 marks)

Q6.

This is a question about catalysis.

The reaction between iodide ions and peroxodisulfate ions is catalysed by iron(II) ions.

$$2I^- + S_2O_8^{2-} \xrightarrow{Fe^{2+}} I_2 + 2SO_4^{2-}$$

(i) Give a reason why the reaction between iodide ions and peroxodisulfate ions has a high activation energy and is therefore very slow without a catalyst.

(1)

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(ii) Explain, with the aid of two equations, how the iron(II) ions catalyse this reaction. State symbols are not required.

(3)

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(Total for question = 4 marks)

Q7. In the manufacture of sulfuric acid, sulfur dioxide is converted to sulfur trioxide using a catalyst of vanadium(V) oxide:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

The electronic configuration of vanadium is [Ar] $3d^3\ 4s^2$, so the mechanism for this reaction is most likely to involve a sequence in which vanadium(V) is converted to

☒ **A** vanadium(VI) by oxygen then back to vanadium(V) by sulfur dioxide.

☒ **B** vanadium(VI) by sulfur dioxide then back to vanadium(V) by oxygen.

☒ **C** vanadium(IV) by oxygen then back to vanadium(V) by sulfur dioxide.

☒ **D** vanadium(IV) by sulfur dioxide then back to vanadium(V) by oxygen.

(Total for Question = 1 mark)

Q8.

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.

(3)

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(Total for question = 3 marks)

Q9.

This question is about transition metals and their ions.

Tungsten wire catalyses the decomposition of ammonia.

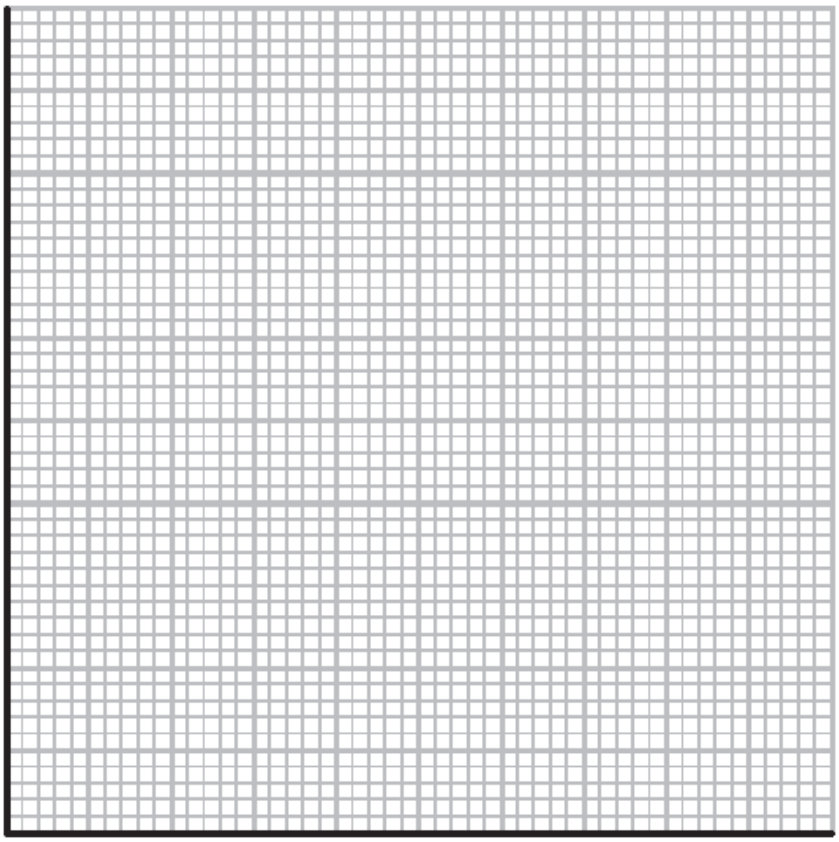
$$2NH_3(g) \rightarrow N_2(g) + 3H_2(g)$$

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.

(2)



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

Justify your answer.

(2)

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

(2)

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

(3)

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(Total for question = 9 marks)

Q10.

A student stated that 'the elements scandium and zinc are d-block elements but are not transition metals'.

Discuss this statement, using appropriate electronic configurations to support your answer.

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(Total for question = 4 marks)

Q11.

Compound **A** is a green solid containing one cation and one anion. It dissolves in water to form a green solution.

(a) Give the formulae of **two** cations which could be responsible for the green colour in the solid.

(2)

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(b) A student adds dilute sodium hydroxide solution, drop by drop, to an aqueous solution of **A**. A green precipitate forms, which dissolves in excess sodium hydroxide solution to form a dark green solution.

(i) Give the formula of the cation in **A**.

(1)

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(ii) Give a formula for the green precipitate.

(1)

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(iii) Give a formula for the species present in the dark green solution.

(1)

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(c) The student adds a few drops of acidified potassium manganate(VII) solution to another sample of a solution of **A** in a test tube.

State the colour change that occurs.

(1)

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(d) The student acidifies 2 cm^3 of a solution of **A** with dilute nitric acid in a test tube and then adds a few drops of aqueous silver nitrate. A white precipitate is formed.

(i) Give the formula of the anion in **A**.

(1)

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(ii) This test is usually followed by the addition of ammonia solution to test the solubility of the precipitate.

Explain why this procedure in not suitable to confirm the identity of the anion in **A**.

(2)

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Q12.

This question is about equilibrium systems.

An equilibrium exists in aqueous solution between the chromate(VI) ions and the dichromate(VI) ions.

$$2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(l)$$

Explain any change in the position of equilibrium if a few drops of sodium hydroxide solution are added to this equilibrium system.

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(Total for question = 2 marks)

Q13.

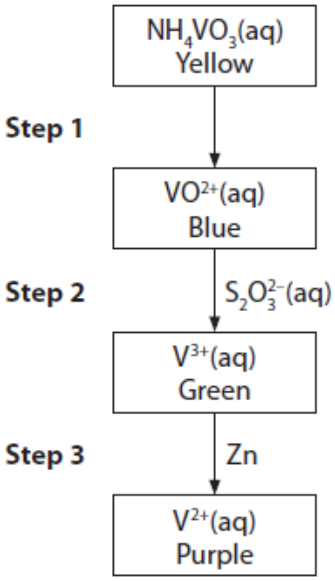
The element vanadium exists in a variety of oxidation numbers in its compounds.

(a) Calculate the oxidation number of vanadium in the compound NH_4VO_3.

(1)

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(b) NH_4VO_3 forms VO_2^+ in solution and can be reduced stepwise to form the ion, $V^{2+}(aq)$.



(i) Use the Data Booklet to give a suitable reducing agent for **Step 1** in order to only produce the blue solution.

(1)

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(ii) Give a possible reason why the reducing agent you choose may not be suitable.

(1)

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(iii) Explain what you would see during **Step 1**.

(2)

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(iv) Justify the choice of reducing agent for **Step 2**.
Write an equation for the reaction. State symbols are not required.

(2)

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Q14.

Titanium is the seventh most abundant metal in the Earth's crust and occurs principally as rutile (impure titanium(IV) oxide, TiO_2).

Early attempts to extract the metal from its oxide by reduction with heated carbon failed because the compound titanium carbide is formed. In 1910, however, pure titanium was made by heating titanium(IV) chloride with sodium.

Titanium has a high melting temperature and a density of 4.50 g cm^{-3}. Titanium is as strong as steel, but is about 40% less dense and is therefore suitable for use in the aircraft industry. Titanium metal resists corrosion as it has an impervious coating of titanium(IV) oxide. The metal adheres well to bone, is not rejected by the body and is in demand for the manufacture of replacement joints.

Titanium has two common oxidation states, +3 and +4. Solutions containing the $[Ti(H_2O)_6]^{3+}(aq)$ ion, such as titanium(III) chloride, are purple in colour and are readily oxidized by the oxygen in air to colourless titanium(IV) ions. An aqueous solution of titanium(III) chloride is a strong reducing agent. Titanium(IV) chloride, $TiCl_4$, is a colourless liquid with a boiling temperature of 136°C. This compound is used, in conjunction with organic compounds of aluminium, as a catalyst for the polymerization of propene to poly(propene). Titanium(IV) chloride is hydrolysed by water to give titanium(IV) oxide, TiO_2 and hydrogen chloride gas.

Titanium(IV) oxide is a white, non-toxic solid at room temperature. It is used as a white pigment in paint, largely replacing toxic lead compounds which were used previously. Titanium(IV) oxide reacts with concentrated sulfuric acid to form a salt and water. Titanium(IV) oxide also reacts with aqueous potassium hydroxide solution, under suitable conditions, to form a compound with formula $K_2Ti(OH)_6$.

(a) (i) Write the equation for the reaction which occurs during the manufacture of titanium from titanium(IV) chloride as described in the article above. State symbols are not required.

(1)

(ii) Explain, by stating the changes of oxidation numbers, why the reaction in (i) is classified as a redox reaction.

(2)

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(b) Complete the electronic configurations of

(2)

Ti [Ar] .....

Ti^{3+} [Ar] .....

Ti^{4+} [Ar] .....

(c) Use your answer to (b) to explain why titanium is

(i) a *d*-block element

(1)

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(ii) a transition element

(1)

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*(d) (i) Explain why the hexaaquatitanium(III) ion, $[Ti(H_2O)_6]^{3+}$, is coloured.

(3)

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(ii) Explain briefly why titanium(IV) compounds are colourless.

(1)

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*(e) (i) Titanium(IV) oxide has a melting temperature of 1830 °C. Use this data, plus information in the article at the start of the question, to compare the structure and bonding in titanium(IV) oxide with that in titanium(IV) chloride. Hence explain why these two compounds change state at very different temperatures.

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(ii) Give the term used to describe an oxide, such as titanium(IV) oxide, which can react with both acids and bases.

(1)

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(iii) Using information in the article, write the equation for the reaction between titanium(IV) oxide and aqueous potassium hydroxide solution. State symbols are not required.

(1)

(iv) Titanium(IV) chloride is one of the catalysts used in the polymerization of propene to form poly(propene).

Give the displayed formula of the repeat unit of poly(propene).

(1)

(f) The concentration of a solution of titanium(III) chloride can be determined by titration with a solution of hydrogen peroxide, H_2O_2, in acidic conditions. The end-point of the reaction is when the solution of titanium(III) chloride in the flask goes colourless.

(i) Complete the ionic half-equation to show the reduction of hydrogen peroxide.

(1)

$$H_2O_2 + 2H^+ + \text{.....} \rightarrow \text{.....}$$

*(ii) One mole of hydrogen peroxide reacts with two moles of titanium(III) chloride.

In an experiment, 5.00 cm^3 of a sample of titanium(III) chloride solution was transferred to a volumetric flask and made up to 250 cm^3 of an aqueous solution. A 25.0 cm^3 portion of this diluted solution was acidified and titrated with a 0.0200 mol dm^{-3} solution of hydrogen peroxide, H_2O_2. The mean titre was 22.50 cm^3.

Calculate the concentration of the **original** titanium(III) chloride solution, in mol dm^{-3}.

(3)

(iii) Use information in the article to suggest why this titration gives a value that is lower than the true value for the concentration of titanium(III) chloride solutions.

(1)

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(Total for Question = 23 marks)

Q15.

This question is about transition metals and transition metal complexes.

When chromium(III) sulfate dissolves in water, a green solution containing the $[Cr(H_2O)_6]^{3+}$ ion forms.

(i) Give the shape of this complex ion.

(1)

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(ii) Explain why the chromium complex ion is coloured.

(3)

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(Total for question = 4 marks)

Q16.

Platinum forms a complex with the formula $Pt(NH_3)_2Cl_2$ and chromium forms a complex ion with the formula $CrCl_4^-$.

(a) Considering the shapes of these complexes,

(1)

☒ **A** both complexes are square planar.

☒ **B** both complexes are tetrahedral.

☒ **C** $Pt(NH_3)_2Cl_2$ is tetrahedral and $CrCl_4^-$ is square planar.

☒ **D** $Pt(NH_3)_2Cl_2$ is square planar and $CrCl_4^-$ is tetrahedral.

(b) Considering the structures of these complexes,

(1)

☒ **A** both complexes form stereoisomers.

☒ **B** neither complex forms a stereoisomer.

☒ **C** $Pt(NH_3)_2Cl_2$ forms a stereoisomer but $CrCl_4^-$ does not.

☒ **D** $CrCl_4^-$ forms a stereoisomer but $Pt(NH_3)_2Cl_2$ does not.

(c) Considering the bonding between the central atom and the ligands in these complexes

(1)

☒ **A** the bonding in both complexes is dative covalent.

☒ **B** the bonding in both complexes is ionic.

☒ **C** the bonding in $Pt(NH_3)_2Cl_2$ is dative covalent and in $CrCl_4^-$ is ionic.

☒ **D** the bonding in $Pt(NH_3)_2Cl_2$ is ionic and in $CrCl_4^-$ is dative covalent.

(Total for question = 3 marks)

Q17.

Chromium has the electronic configuration $[Ar]3d^54s^1$. Which of the following compounds is **unlikely** to exist?

☒ **A** K_3CrO_4

☒ **B** CrO_2Cl_2

☒ **C** $KCrO_2Cl$

☒ **D** $KCrO_4$

(Total for question = 1 mark)

Q18. All metal hydroxides dissolve in acid. When aqueous solutions of sodium hydroxide and ammonia are added separately to samples of chromium(III) hydroxide, in both cases the solid dissolves to form a green solution. How should these reactions be classified?

	sodium hydroxide	ammonia
☒ **A**	amphoteric	amphoteric
☒ **B**	amphoteric	ligand exchange
☒ **C**	ligand exchange	amphoteric
☒ **D**	ligand exchange	ligand exchange

(Total for Question = 1 mark)

Q19.

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

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

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)

Q20.

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.

(2)

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(Total for question = 2 marks)

Q21.

When concentrated ammonia solution is added to a green solution of chromium(III) sulfate, a green precipitate is formed which slowly dissolves in excess of the concentrated ammonia solution.

The chromium-containing species formed in these reactions are

	Green precipitate	Resulting solution
☒ **A**	$Cr(OH)_3$	$[Cr(OH)_6]^{3-}$
☒ **B**	$Cr(OH)_3$	$[Cr(NH_3)_6]^{3+}$
☒ **C**	$(NH_4)_2CrO_4$	$[Cr(OH)_6]^{3-}$
☒ **D**	$(NH_4)_2CrO_4$	$[Cr(NH_3)_6]^{3+}$

(Total for question = 1 mark)

Q22. When excess aqueous ammonia is added to a solution containing $Zn^{2+}(aq)$ ions, a colourless solution is formed. This solution is colourless because

☒ **A** zinc does not form complex ions.

☒ **B** the d orbitals of Zn^{2+} in the complex formed are not split into different energy levels.

☒ **C** the energy difference between the d orbitals of Zn^{2+} in the complex formed does not correspond to the visible region of the spectrum.

☒ **D** the d orbitals of Zn^{2+} in the complex formed are full.

(Total for Question = 1 mark)

Q23.

This question is about transition metals.

Which **best** explains why $[Cu(NH_3)_2]^+$ ions are colourless?

(1)

☒ **A** all complex ions having a metal ion with a +1 charge are colourless

☒ **B** no electronic transitions can take place between *d*-orbitals

☒ **C** the *d*-orbitals cannot split in energy

☒ **D** there are no electrons in the *d*-subshell

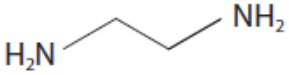
(Total for question = 1 mark)

Q24.

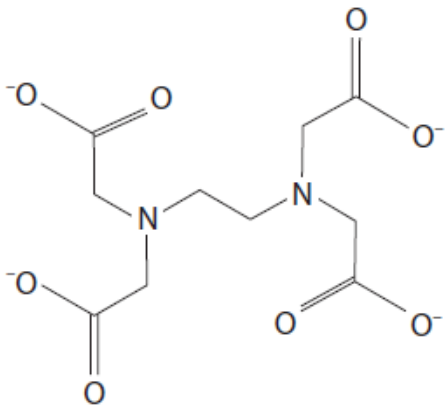
Transition metals form complex ions.

Compare and contrast the complex ions formed by cobalt(III) ions with the ligand ethane-1,2-diamine and with the ligand $EDTA^{4-}$.

Ignore any difference in colour.



ethane-1,2-diamine



$EDTA^{4-}$

(4)

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(Total for question = 4 marks)

Q25.

Prussian Blue, $[Fe_4[Fe(CN)_6]_3]$, is a dark blue pigment used in painting and dyeing.

It was discovered around 1700 AD in the German state of Prussia.

Prussian Blue is formed when an iron(III) salt is added to a solution containing the complex ion $[Fe(CN)_6]^{4-}$.

The cyanide ion has the formula CN^-.

(a) (i) The oxidation number of Fe in the $[Fe(CN)_6]^{4-}$ ion is

(1)

☒ **A** +2

☒ **B** +3

☒ **C** +4

☒ **D** +6

(ii) Draw a diagram to show the shape of a $[Fe(CN)_6]^{4-}$ ion, using the structure CN^- to represent a cyanide ligand and showing how the cyanide ligands bond to the central iron ion.

(2)

(b) A solution containing $[Fe(CN)_6]^{3-}$ ions can be made from $[Fe(H_2O)_6]^{2+}$ ions in two steps as shown:

Step 1 $[Fe(H_2O)_6]^{2+}(aq) + 6CN^-(aq) \rightleftharpoons [Fe(CN)_6]^{4-}(aq) + 6H_2O(l)$

Step 2 $2[Fe(CN)_6]^{4-}(aq) + Cl_2(aq) \rightarrow 2[Fe(CN)_6]^{3-}(aq) + 2Cl^-(aq)$

Name the type of reaction taking place in each of Steps 1 and 2.

(2)

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(c) In a separate reaction, aqueous sodium hydroxide was added to a solution containing iron(II) sulfate. A green precipitate formed that turned brown on standing in air.

Identify the green precipitate and explain why it turns brown on standing in air.

(3)

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Q26.

*"Cobalt(II) ions combine with substances in solution to form complex ions with different coordination numbers."

Discuss this statement by referring to **two** complex ions containing cobalt(II).

Include

- reference to any difference in colour
- a definition of any terms used
- an explanation of the different shapes

(Total for question = 6 marks)

Q27.

Compound **C** is a pink crystalline solid containing two cations and one anion.

Three tests were carried out on **C**. The observation made for each test was recorded in the table.

Test	Observation	Inference
Test 1 Aqueous sodium hydroxide was added to solid **C** and the mixture warmed The gas evolved was tested with damp red litmus paper	The red litmus paper turned blue	The gas evolved was ..... One of the cations in **C** is .....
Test 2 Concentrated hydrochloric acid was added to an aqueous solution of **C**	The pink solution turned blue	The other cation in **C** is ..... The formula of the complex ion in the blue solution is .....
Test 3 Dilute hydrochloric acid and aqueous barium chloride were added to an aqueous solution of **C**	A white precipitate formed	The white precipitate is ..... The anion in **C** is .....

State the type of reaction occurring in **Test 2**.

(1)

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(Total for question = 1 mark)

Q28.

Copper(II) sulfate solution is blue. This is because

☒ **A** excited electrons emit light in the blue region of the spectrum as they drop back to the ground state.

☒ **B** excited electrons emit light in the red region of the spectrum as they drop back to the ground state.

☒ **C** electrons absorb light in the red region of the spectrum and the residual frequencies are observed.

☒ **D** electrons absorb light in the blue region of the spectrum and the residual frequencies are observed.

(Total for question = 1 mark)

Q29.

One method of manufacturing hydrazine (N_2H_4) involves the action of sodium chlorate(I) on excess ammonia at 443 K and 50 atm. The yield is normally around 80% but, if just 1 part per million of copper(II) ions is present, the yield drops to 30%.

The most likely explanation for this is the ability of copper(II) ions to

☒ **A** form complex ions with ammonia.

☒ **B** catalyse reactions producing other nitrogen compounds.

☒ **C** reduce the hydrazine as it is formed.

☒ **D** reduce the sodium chlorate(I).

(Total for question = 1 mark)

Q30.

Transition metals form complex ions.

Hydrated chromium(III) chloride, $CrCl_3 \cdot 6H_2O$, 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 $[Cr(H_2O)_x(Cl)_y]^{(3-y)+}$

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.

(2)

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(Total for question = 2 marks)

Q31.

Aqueous copper(II) sulfate reacts with an excess of aqueous ammonia to give a dark blue solution.

The dark blue solution contains the octahedral complex ion, $[Cu(NH_3)_x(H_2O)_y]^{2+}$.

The formula of this complex ion is determined by colorimetry, using this method:

- Make up six different mixtures of 1.00 mol dm^{-3} aqueous ammonia and 0.500 mol dm^{-3} aqueous copper(II) sulfate and water.
- Filter the mixtures to remove any precipitate that forms.
- The filtrate is a dark blue solution that contains the complex ion, $[Cu(NH_3)_x(H_2O)_y]^{2+}$.
- Place the dark blue solution into a colorimeter and measure the absorbance of the solution.

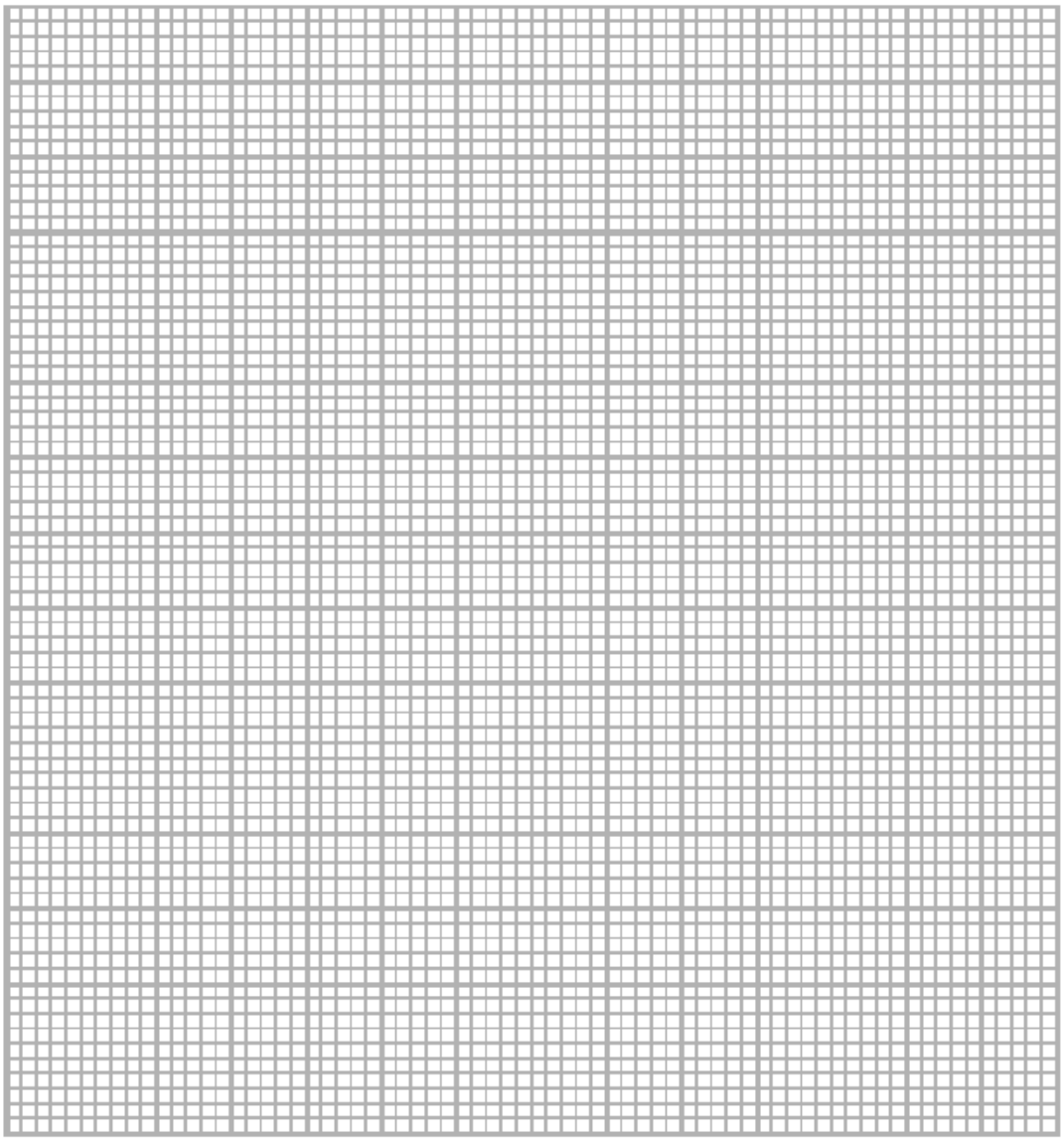
The table shows the absorbance of each mixture.

	Mixture					
	1	2	3	4	5	6
Volume of 0.500 mol dm^{-3} $CuSO_4(aq)$ / cm^3	5.00	5.00	5.00	5.00	5.00	5.00
Volume of 1.00 mol dm^{-3} $NH_3(aq)$ / cm^3	3.00	6.00	9.00	12.00	15.00	18.00
Volume of $H_2O(l)$ / cm^3	17.00	14.00	11.00	8.00	5.00	2.00
Absorbance	0.25	0.50	0.76	0.84	0.84	0.84

(a) Plot a graph of absorbance against volume of $NH_3(aq)$ on the grid opposite.

Draw a straight line of best fit through the first three points and another straight line of best fit through the last three points. Extend both lines so that they cross.

(2)



(b) (i) Use the graph to determine the smallest volume of 1.00 mol dm^{-3} $NH_3(aq)$ required to completely react with 5.00 cm^3 of 0.500 mol dm^{-3} of $CuSO_4$ solution

(1)

(ii) Calculate the amount, in moles, of $CuSO_4$ in 5.00 cm^3 of 0.500 mol dm^{-3} solution.

(1)

(iii) Calculate the amount of NH_3, in moles, present in the volume of $NH_3(aq)$ in (b)(ii).

(1)

(iv) Deduce the values of x and y in the formula of the complex ion $[Cu(NH_3)_x(H_2O)_y]^{2+}$.

(1)

x = ... y = ...

(c) The precipitate formed is copper (II) hydroxide.

Write an ionic equation to show the formation of copper(II) hydroxide from its ions. Include state symbols.

(2)

Q32.

(i) $Cu^+(aq)$ ions are not stable in solution and undergo a disproportionation reaction.

Suggest an equation for this reaction, including state symbols.

(1)

(ii) Suggest in what way the **appearance** of CuI is similar to that of ZnI_2.

Give a reason for this similarity.

(2)

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Q33.

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

Hydrated iron(II) ions react with ethanedioate ions, $C_2O_4^{2-}$, to form a complex ion.

$$[Fe(H_2O)_6]^{2+} + 2C_2O_4^{2-} \rightleftharpoons [Fe(C_2O_4)_2(H_2O)_2]^{2-} + 4H_2O$$

(i) Draw a structure of the $[Fe(C_2O_4)_2(H_2O)_2]^{2-}$ ion, showing **all** of the bonds.

(2)

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

(2)

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(Total for question = 4 marks)

Q34.

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

Which of these is the electronic configuration of an iron(II) ion, Fe^{2+}?

(1)

		3d					4s
☒ **A**	[Ar]	↑↓	↑↓	↑↓			
☒ **B**	[Ar]	↑↓	↑	↑	↑	↑	
☒ **C**	[Ar]	↑↓	↑↓				↑↓
☒ **D**	[Ar]	↑	↑	↑	↑		↑↓

(Total for question = 1 mark)

Q35.

What is the electronic configuration of the stable scandium ion?

- ☒ **A** [Ar] $3d^0$ $4s^2$
- ☒ **B** [Ar] $3d^1$ $4s^1$
- ☒ **C** [Ar] $3d^0$ $4s^1$
- ☒ **D** [Ar] $3d^0$ $4s^0$

(Total for question = 1 mark)

Q36.

This question is about transition metals.

Which of these ions has the electronic configuration [Ar]$3d^5$?

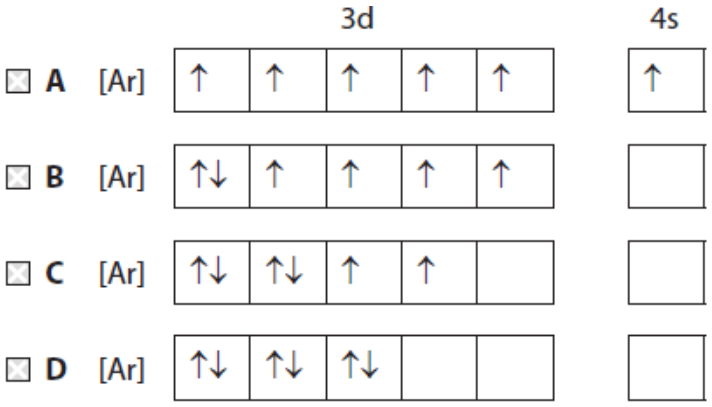
(1)

- ☒ **A** Cr^{3+}
- ☒ **B** Fe^{2+}
- ☒ **C** Mn^{2+}
- ☒ **D** Mn^{3+}

(Total for question = 1 mark)

Q37.

The electronic configuration of iron is [Ar]$3d^6 4s^2$. What is the electronic configuration of the iron(II) ion, Fe^{2+}?



(Total for question = 1 mark)

Q38.

Vanadium is a transition metal that forms ions with several oxidation numbers. Four of these ions are shown in the table.

Formula of ion	Oxidation number of vanadium	Colour of ion
V^{2+}	+2	violet
V^{3+}	+3	green
VO^{2+}	+4	blue
VO_2^+	+5	yellow

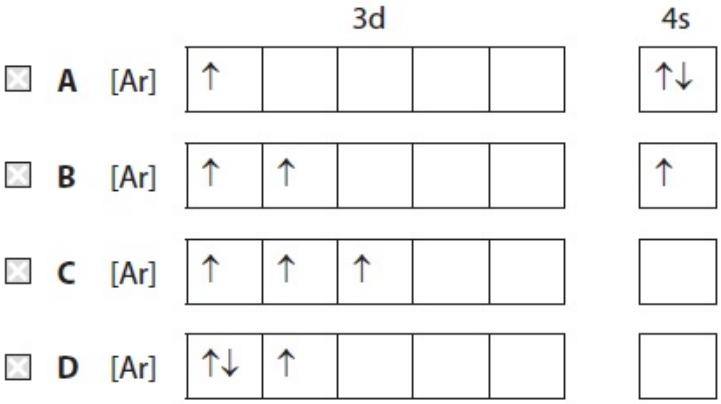
Complete the electronic configuration for the vanadium atom and the V^{3+} ion.

(2)

V $1s^2\ 2s^2\ 2p^6$
$3s^2$.....

V^{3+} $1s^2\ 2s^2\ 2p^6$
$3s^2$.....

Q39. The electronic structure of the chromium(III) ion, Cr^{3+}, is

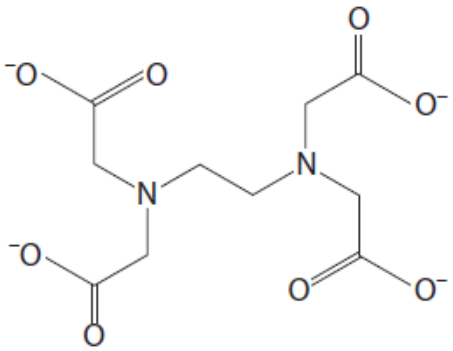


(Total for Question = 1 mark)

Q40.

This question is about transition metals and transition metal complexes.

The ligand ethylenediaminetetraacetate, $EDTA^{4-}$, has the structure shown.



When a solution of $EDTA^{4-}$ is added to a solution of $[Cr(H_2O)_6]^{3+}$ ions, a new complex ion is formed.

$$[Cr(H_2O)_6]^{3+} + EDTA^{4-} \rightleftharpoons [Cr(EDTA)]^{-} + 6H_2O$$

The equilibrium constant for this equilibrium is 2.51×10^{23} dm^3 mol^{-1}.

By considering the equilibrium for this reaction and changes in entropy, comment on the value of the equilibrium constant. No calculations are required.

(3)

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(Total for question = 3 marks)

Q41.

This question is about transition metals.

Which type or types of bonding exist **within** the complex ion $[Cr(H_2O)_6]^{3+}$?

(1)

☒ **A** dative covalent only

☒ **B** dative covalent and covalent only

☒ **C** dative covalent and ionic only

☒ **D** dative covalent, covalent and ionic

(Total for question = 1 mark)

Q42.

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

* Many of the *d*-block elements are also classified as transition metals.

Explain why two of the *d*-block elements within Period 4 (scandium to zinc) are **not** classified as transition metals.

You should include **full** electronic configurations where relevant.

(6)

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(Total for question = 6 marks)

Q43.

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

Iron(II) ions, $[Fe(H_2O)_6]^{2+}$, form a pale green solution but zinc ions, $[Zn(H_2O)_6]^{2+}$, form a colourless solution.

Explain why zinc ions are colourless.

(2)

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(Total for question = 2 marks)

Q44.

Explain why zinc is **not** classified as a transition element.

(1)

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Q45.

The solid compound V_2O_5 is used as a heterogenous catalyst in industry to speed up the reaction between oxygen and sulfur dioxide gas.

The reaction has two stages:

Stage 1 $SO_2(g) + V_2O_5(s) \rightarrow SO_3(g) + 2VO_2(s)$

Stage 2 $2VO_2(s) + ½O_2(g) \rightarrow V_2O_5(s)$

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

(1)

*(ii) Explain the catalytic behaviour of V_2O_5 in this reaction.

(6)

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Q46.

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)

Q47.

This question is about transition metals and their ions.

The complex ions of transition metals have different colours in aqueous solution.

Two factors that affect the colour of the solution are the oxidation number of the central metal ion, and the ligands present.

Give examples to illustrate these factors by referring to complex ions of iron and/or copper. Include the formula and colour of each complex.

An explanation of why transition metal ions are coloured is **not** required.

(3)

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(Total for question = 3 marks)

Q48.

This question is about how catalysts work.

Gaseous reactants attach to the catalytic surface by the process of

(1)

☒ **A** absorption

☒ **B** activation

☒ **C** adsorption

☒ **D** desorption

(Total for question = 1 mark)

Q49.

The table shows the standard electrode (redox) potentials, $E^{\ominus}$, for some half-cell reactions.

Redox system	Half-cell reaction	$E^{\ominus}$ / V
1	$V^{2+}(aq) + 2e^- \rightleftharpoons V(s)$	−1.20
2	$V^{3+}(aq) + e^- \rightleftharpoons V^{2+}(aq)$	−0.26
3	$VO^{2+}(aq) + 2H^+(aq) + e^- \rightleftharpoons V^{3+}(aq) + H_2O(l)$	+0.34
4	$VO_2^+(aq) + 2H^+(aq) + e^- \rightleftharpoons VO^{2+}(aq) + H_2O(l)$	+1.00
5	$SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \rightleftharpoons SO_2(g) + 2H_2O(l)$	+0.17

(i) Explain, using information from the table, the colour changes that take place when SO_2 gas is bubbled slowly through an acidified solution containing VO_2^+ ions.

Equations are not required.

(3)

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(ii) Explain, using information in the table, whether the disproportionation of $V^{2+}(aq)$ into $V^{3+}(aq)$ and V(s) is feasible under standard conditions.

(2)

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Q50. Transition metals are often used as heterogeneous catalysts. Which of the following processes does **not** occur during such a catalysed reaction?

☒ **A** Adsorption of reactant molecules on the surface of the metal.

☒ **B** Bond breaking in the reactant molecules.

☒ **C** Desorption of product molecules from the surface of the metal.

☒ **D** An overall change in the oxidation number of the metal.

(Total for Question = 1 mark)

Q51.

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.

(1)

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(Total for question = 1 mark)

Q52. The hydrolysis of a transition metal cation can be represented by the following equation

$$[M(H_2O)_6]^{n+}(aq) + H_2O(l) \rightleftharpoons [M(H_2O)_5OH]^{(n-1)+}(aq) + H_3O^+(aq)$$

In this reaction

☒ **A** the solvent H_2O is acting as an acid by donating a proton to the metal cation.

☒ **B** the pH of the solution will be lower if the value of n is 2 instead of 3.

☒ **C** the equilibrium position lies further to the right if the value of n is 3 instead of 2.

☒ **D** the oxidation state of the metal in the cation has decreased from n to (n − 1).

(Total for Question = 1 mark)

Q53.

Answer the question with a cross in the box you think is correct ☒ . If you change

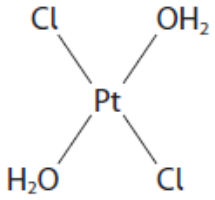
your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒ .

Transition metals form complex ions.

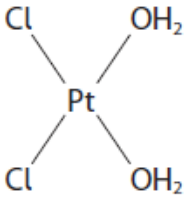
Which of these complexes is used in the treatment of cancer?

(1)

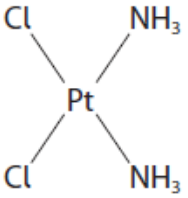
☒ **A**



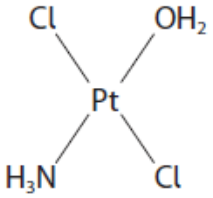
☒ **B**



☒ **C**



☒ **D**



(Total for question = 1 mark)

Q54.

Hydrated crystals of a compound have the formula $CrCl_3(H_2O)_6$.
A solution containing one mole of the compound reacts with two moles of silver nitrate to form two moles of silver chloride.
The complex chromium ion in the compound is most likely to be

☒ **A** $[Cr(H_2O)_3Cl_3]^{3+}$

☒ **B** $[Cr(H_2O)_4Cl_2]^{+}$

☒ **C** $[Cr(H_2O)_5Cl]^{2+}$

☒ **D** $[Cr(H_2O)_6]^{3+}$

(Total for question = 1 mark)

Q55.

The reaction

$$[Fe(H_2O)_6]^{2+} + H_2O \rightarrow [Fe(H_2O)_5(OH)]^{+} + H_3O^{+}$$

is an example of

☒ **A** oxidation.

☒ **B** reduction.

☒ **C** ligand exchange.

☒ **D** acid-base behaviour.

(Total for question = 1 mark)

Q56.

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

Iodide ions, I^-, react with peroxodisulfate(VI) ions, $S_2O_8^{2-}$

$$2I^-(aq) + S_2O_8^{2-}(aq) \rightarrow I_2(aq) + 2SO_4^{2-}(aq)$$

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

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)

Q57.

Tests are carried out on aqueous solutions of two salts, **X** and **Y**.

X contains one cation and one anion.

The observations for each test are recorded in the table.

(i) Complete the table by writing the names or formulae of the species.

(2)

Test	Observation	Inference
Test 1 Add aqueous sodium hydroxide to an aqueous solution of **X**	A green precipitate forms The precipitate turns brown on the top after a few minutes	The cation in **X** is .....
Test 2 To an aqueous solution of **X**, add dilute hydrochloric acid followed by aqueous barium chloride	A white precipitate forms	The anion in **X** is .....

(ii) Write the ionic equation for the reaction between the cation in **X** and aqueous sodium hydroxide in **Test 1**. Include state symbols.

(2)

(iii) Give a reason why the green precipitate turns brown on the top after a few minutes.

(1)

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(iv) Give a reason why dilute hydrochloric acid is needed in **Test 2**.

(1)

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(Total for question = 6 marks)

Q58.

A complex ion contains one Fe^{3+} ion, four ammonia molecules and two chloride ions.

(i) Give the formula of this ion.

(1)

(ii) This complex ion exhibits *cis* -*trans* isomerism.
Draw diagrams to show the structure of both the *cis*- and the *trans*-isomer.
Label each isomer.

(2)

Q59. Consider the equation below.

$$[Cu(H_2O)_6]^{2+}(aq) + 4NH_3(aq) \rightleftharpoons [Cu(NH_3)_4]^{2+}(aq) + 6H_2O(l)$$

This reaction is best described as

☒ **A** acid-base.

☒ **B** redox.

☒ **C** addition.

☒ **D** ligand exchange.

(Total for Question = 1 mark)

Q60.

When EDTA is added to $[Cu(NH_3)_4]^{2+}$ in aqueous solution, the copper(II)-EDTA complex, $[Cu(EDTA)]^{2-}$, predominates in the resulting solution.

This is **best** explained by the fact that when $[Cu(EDTA)]^{2-}$ is formed from $[Cu(NH_3)_4]^{2+}$

☒ **A** there are much stronger bonds between the ligands and the copper(II) ion.

☒ **B** the reaction has a low activation energy.

☒ **C** the reaction is exothermic.

☒ **D** the total number of particles on the right-hand side of the equation is greater than on the left.

(Total for question = 1 mark)

Q61.

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.

(1)

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(ii) Explain why the complex ions $[Co(NH_3)_6]^{2+}$ and $[Co(H_2O)_6]^{2+}$ are coloured and have different colours.

(4)

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(Total for question = 5 marks)

Q62.

This question is about transition metals.

Manganate(VII) ions, MnO_4^-, react with ethanedioate ions in acid solution.

$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$

The reaction starts slowly, the rate of reaction then increases, before it decreases again.

Explain this sequence.

(3)

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(Total for question = 3 marks)

Q63.

Complexes involve ligands forming dative covalent bonds with a central cation; the number of dative covalent bonds is the coordination number of the cation in the complex. Complexes may be positive, negative or neutral. The ligands may be neutral or negatively charged, but are never positively charged. The ligands must have a lone pair of electrons. In some complexes the central atom is neutral, as is the case with nickel carbonyl which is used in the Mond process for the purification of nickel:

$$Ni(s) + 4CO(g) \rightleftharpoons Ni(CO)_4(g)$$

The formation of complexes is typical of transition metals but other elements also form complexes. Zinc, which is a d block element but not a transition metal, and aluminium, which is

a Group 3 element, both form complexes. Transition metal complexes are usually coloured, but if the interaction between the ligand and the central ion is very strong, then the resulting complex may well be colourless. This is the case with the complex $[FeF_6]^{3-}$.

The ligand in a complex affects its redox properties and this is apparent from considering the relevant standard electrode potentials. For example, with copper(II) species:

$$[Cu(H_2O)_6]^{2+}(aq) + 2e^- \rightleftharpoons Cu(s) + 6H_2O(l) \quad E^{\ominus} = +0.34\,V$$

$$[Cu(H_2O)_2(NH_3)_4]^{2+}(aq) + 2e^- \rightleftharpoons Cu(s) + 2H_2O(l) + 4NH_3(aq) \quad E^{\ominus} = -0.05\,V$$

Complexes are industrially important, for example in the purification of nickel mentioned above and in the extraction of gold which involves the complex $[Au(CN)_2]^-$.

Complex formation is used in estimating the concentrations of metal ions in solution. Examples of this are the use of EDTA in titration and dimethylglyoxime in gravimetric analysis. Complexes are also used in qualitative analysis, for example, in Tollens' reagent. This reagent is usually prepared by the addition of sodium hydroxide solution to an aqueous solution of silver nitrate followed by aqueous ammonia. The resulting solution contains diamminesilver(I) ions.

(a) The hydrated copper(II) ion is classed as a complex but the hydrated sodium ion is not. By considering the interaction between the water molecules and the sodium ion, explain why the hydrated sodium ion is **not** considered to be a complex.

(2)

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(b) Suggest how the aluminium ion is able to form dative covalent bonds in its complexes such as $[AlF_6]^{3-}$.

(1)

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*(c) (i) Transition metal complexes are usually coloured. Explain how the colours occur.

(4)

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(ii) Why are zinc complexes such as $[Zn(NH_3)_4]^{2+}$ colourless?

(1)

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(iii) Suggest why the strong interactions between the F^- ligands and Fe^{3+} ion result in the complex $[FeF_6]^{3-}$ being colourless.

(2)

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(d) Use the standard electrode potentials given in the passage to predict whether it is feasible for thiosulfate ions, $S_2O_3^{2-}$, to reduce copper(II) ions to copper. Consider the case when the copper(II) ions are dissolved in water, and when they are dissolved in aqueous ammonia. Give chemical equations to support your answer.

(3)

The relevant redox reaction for thiosulfate ions is

$$S_4O_6^{2-}(aq) + 2e^- \rightleftharpoons 2S_2O_3^{2-}(aq) \quad E^{\ominus} = +0.09\,V$$

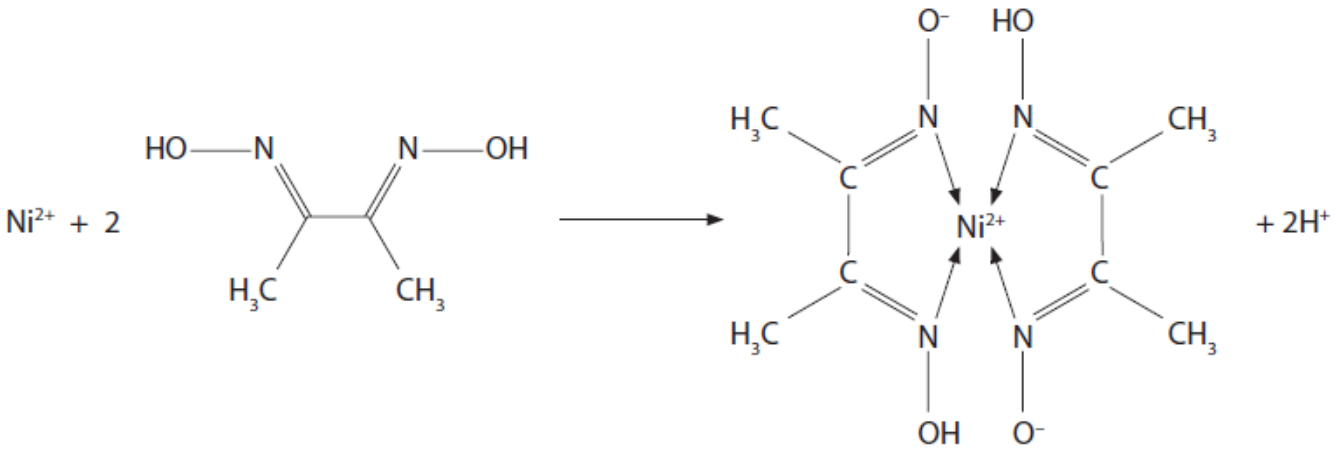
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(e) The proportion of nickel in nisil, an alloy of nickel and silicon used in thermocouples, may be determined by the following gravimetric analysis.

Finely ground nisil is dissolved in concentrated hydrochloric acid and, after neutralization, excess dimethylglyoxime dissolved in ethanol is added to the solution formed. The resulting red precipitate is filtered, washed, dried and weighed. The equation for the formation of the precipitate is



(i) State the coordination number of the nickel in the complex ion.

(1)

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(ii) In an experiment, 1.02 g of nisil formed 4.82 g of the complex. Calculate the percentage by mass of nickel in the alloy. The molar mass of the complex is 288.7 g mol^{-1}.

(2)

(Total for question = 16 marks)

Q64.

Compound **C** is a pink crystalline solid containing two cations and one anion.

Three tests were carried out on **C**. The observation made for each test was recorded in the table.

(i) Complete the statements in the inference column by writing the names or formulae of the species.

(6)

Test	Observation	Inference
Test 1 Aqueous sodium hydroxide was added to solid **C** and the mixture warmed The gas evolved was tested with damp red litmus paper	The red litmus paper turned blue	The gas evolved was ..... One of the cations in **C** is .....
Test 2 Concentrated hydrochloric acid was added to an aqueous solution of **C**	The pink solution turned blue	The other cation in **C** is ..... The formula of the complex ion in the blue solution is .....
Test 3 Dilute hydrochloric acid and aqueous barium chloride were added to an aqueous solution of **C**	A white precipitate formed	The white precipitate is ..... The anion in **C** is .....

(ii) Use the results of the tests in (i) to give a formula of **C**.

Do not include water of crystallisation.

(1)

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(Total for question = 7 marks)

Q65.

Nitrogen monoxide and chlorine react together to form nitrosyl chloride.

$$2NO(g) + Cl_2(g) \rightarrow 2NOCl(g)$$

The rate equation for the formation of nitrosyl chloride is

Rate = $k[NO]^2[Cl_2]$

(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*.

(2)

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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.

(3)

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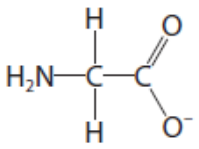
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(Total for question = 10 marks)

Q66.

Some organic compounds contain metals.

Glycinate ions are formed from the amino acid glycine.



glycinate ion

(i) Explain the effect, if any, of an aqueous solution containing glycinate ions on

plane-polarised monochromatic light.

(2)

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(ii) A hot aqueous solution of glycine is added to a hot solution of copper(II) ethanoate.

When the mixture is cooled, crystals of copper(II) glycinate are formed.

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

(2)

(iii) In an experiment, the crystals are filtered, weighed and the percentage yield calculated.

Student **1** obtained a yield of 102.6%.

Student **2** obtained a yield of 56.4%.

The expected yield is 82% and the students carried out the calculation correctly.

Discuss possible reasons for the yields obtained by these students.

(4)

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(Total for question = 8 marks)

Q67.

Iron is a transition element that forms a number of ions with the iron in different oxidation states.

(a) What is the electronic configuration of the iron cation that can form the complex ion $[Fe(CN)_6]^{4-}$?

(1)

☒ **A** [Ar] $3d^4 4s^2$

☒ **B** [Ar] $3d^5 4s^0$

☒ **C** [Ar] $3d^6 4s^0$

☒ **D** [Ar] $3d^6 4s^2$

(b) Iron forms a ferrate ion of formula FeO_4^{2-}.

(i) What is the oxidation number of the iron in FeO_4^{2-}?

(1)

☒ **A** + 2

☒ **B** + 3

☒ **C** + 4

☒ **D** + 6

(ii) Deduce, using the data shown, whether ferrate ions are stable in acidic conditions.

Write an overall ionic equation for any reaction that takes place. State symbols are not required.

$$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l) \qquad E^\ominus = +1.23\,V$$

$$FeO_4^{2-}(aq) + 8H^+(aq) + 3e^- \rightleftharpoons Fe^{3+}(aq) + 4H_2O(l) \qquad E^\ominus = +2.20\,V$$

(4)

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(c) The salt $K_3Fe(CN)_6$ can be prepared by oxidising $K_4Fe(CN)_6$.
The relevant standard electrode (redox) potential is:

$$[Fe(CN)_6]^{3-}(aq) + e^- \rightleftharpoons [Fe(CN)_6]^{4-}(aq) \qquad E^\ominus = +0.36\,V$$

Which species will oxidise $K_4Fe(CN)_6$ to $K_3Fe(CN)_6$?
You may find it helpful to refer to the Data booklet.

(1)

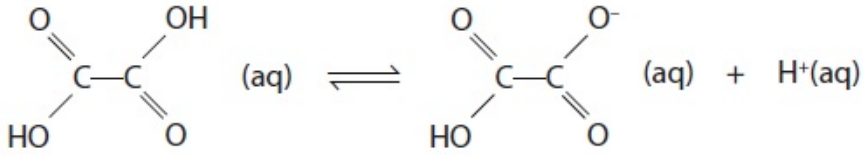
☒ **A** Ag(s)

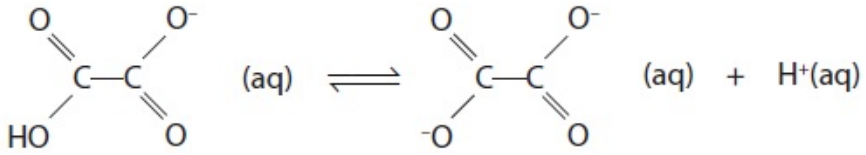
☒ **B** $Cl_2(g)$

☒ **C** $Cu^{2+}(aq)$

☒ **D** $Fe^{2+}(aq)$

Q68. Ethanedioic acid (also known as oxalic acid) is a dicarboxylic acid. Like sulfuric acid, it has two replaceable hydrogen atoms so it dissociates in two stages which are shown below. Acids like these are called 'dibasic'.





As is always the case with dibasic acids, the first dissociation occurs to a far greater extent than the second. Ethanedioic acid is a carboxylic acid but, because there are two carboxyl groups, it is a much stronger acid than ethanoic acid.

Ethanedioic acid is toxic, mainly due to the precipitation of calcium ethanedioate in the kidneys. As it occurs in many plants, the toxicity of ethanedioic acid has caused a number of deaths notably during the First World War when people in England used rhubarb leaves, which contain significant concentrations of the compound, as a vegetable substitute. As it is a reducing agent, the concentration of ethanedioic acid is usually determined by titration with a solution of potassium manganate(VII) of known concentration.

The ethanedioate ion, which is formed when ethanedioic acid dissociates fully, is a bidentate ligand. The ethanedioate ion together with 1,2-diaminocyclohexane, another bidentate ligand, forms a complex with platinum(II) called oxaliplatin which has the same geometry as cisplatin. Oxaliplatin is an anti-cancer drug, which has been used to treat cancers that have become resistant to cisplatin.

Ethanedioic acid has numerous uses, from cleaning and rust removal to the purification of metals. Although it can be prepared from ethene in a two stage process, it is usually manufactured by the oxidation of carbohydrates or glucose using nitric acid, or air, in the presence of vanadium(V) oxide.

(a) (i) Suggest why the presence of the second carboxylic acid group increases the extent of the **first** dissociation of ethanedioic acid compared with the dissociation of ethanoic acid.

(2)

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(ii) Explain, by referring to the equilibria in the passage, why the second dissociation of a dibasic acid occurs to a lesser extent than the first.

(1)

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(b) In an experiment to determine the proportion of ethanedioic acid in rhubarb leaves, 250 g of leaves was crushed and boiled in a solution of sodium carbonate. The resulting mixture was filtered and the filtrate transferred, along with washings from the mixture, to a 250 cm^3 volumetric flask. The solution was acidified with sulfuric acid, made up to the mark and mixed thoroughly. 25.0 cm^3 portions of the solution were pipetted into a conical flask, about 25 cm^3 of sulfuric acid added and the mixture titrated against a solution of potassium manganate(VII) of concentration 0.0200 mol dm^{-3}. The mean titre was 28.55 cm^3. The relevant ionic half equations for the reaction are

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

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

(i) State the colour change that occurs at the end-point of the titration.

(1)

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*(ii) Calculate the percentage by mass of ethanedioic acid in rhubarb leaves.

(5)

(c) (i) Explain the term 'bidentate'.

(1)

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(ii) Draw a diagram of the oxaliplatin(II) complex, showing clearly the geometry and charge of the complex and how the ligands are attached to the central ion.

(3)

(d) (i) Suggest a two step **laboratory** synthesis of ethanedioic acid from ethene. Indicate the intermediate compound formed and the reagents required.

(3)

(ii) Suggest why it is preferable from an environmental perspective that ethanedioic acid is manufactured from carbohydrates and glucose rather than from ethene.

(1)

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(iii) A sample of ethanedioic acid, manufactured from glucose, was contaminated with a small amount of propanoic acid.

High resolution nmr may be used to distinguish propanoic acid from ethanedioic acid.

Describe the high resolution nmr spectra of both propanoic acid and ethanedioic acid. Do **not** include chemical shift data in your answer.

(4)

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(Total for Question = 21 marks)

Q69.

Brass is an alloy of copper and zinc.

(i) Explain why copper is classified as a transition element but zinc is not.

(2)

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(ii) Brass has a structure similar to that of metallic copper, but with zinc ions replacing some copper ions in the lattice.

Explain why brass is malleable whereas a crystal of sodium chloride is not.

(3)

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Q70.

Tests are carried out on aqueous solutions of two salts, **X** and **Y**.

Y contains one cation and one anion.

The observations for each test are recorded in the table.

(i) Complete the table by writing the names or formulae of the species.

(2)

Test	Observation	Inference
Test 3 Add dilute aqueous ammonia to an aqueous solution of **Y** until it is present in excess	A pale blue precipitate forms The precipitate dissolves in excess ammonia to form a deep blue solution	The cation in **Y** is .....
Test 4 To an aqueous solution of **Y**, add dilute nitric acid followed by aqueous silver nitrate	A white precipitate forms	The anion in **Y** is .....

(ii) Give the formula of the complex ion present in the deep blue solution at the end of **Test 3**.

(1)

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(iii) Give a reagent that could be added to the mixture at the end of **Test 4** to confirm the identity of the anion in **Y**.

Include the observation when this reagent is added.

(2)

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(Total for question = 5 marks)

Q71.

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.

(3)

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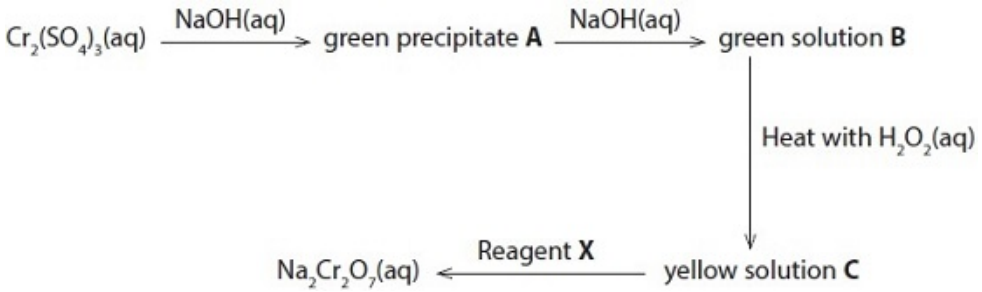
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(Total for question = 4 marks)

Q72. Sodium dichromate(VI) may be prepared from chromium(III) sulfate using the

sequence outlined below.



(a) (i) Complete the table below, giving the **formula** of the chromium containing species.

(4)

Substance	Formula of chromium containing species
$Cr_2(SO_4)_3(aq)$	
Green precipitate **A**	
Green solution **B**	
Yellow solution **C**	

(ii) Complete the half equation for the reduction of hydrogen peroxide, $H_2O_2(aq)$.

(1)

$$H_2O_2 + \text{.....} \rightarrow \text{.....} OH^-$$

(iii) Identify reagent **X**

(1)

.....

(iv) Write an **ionic** equation for the conversion of solution **C** to $Na_2Cr_2O_7$. State symbols are not required.

(1)

(b) Chromium also exists in a +2 oxidation state. Use the Data booklet to determine the feasibility of the disproportionation of chromium(III) in aqueous solution into chromium(II) and dichromate(VI).

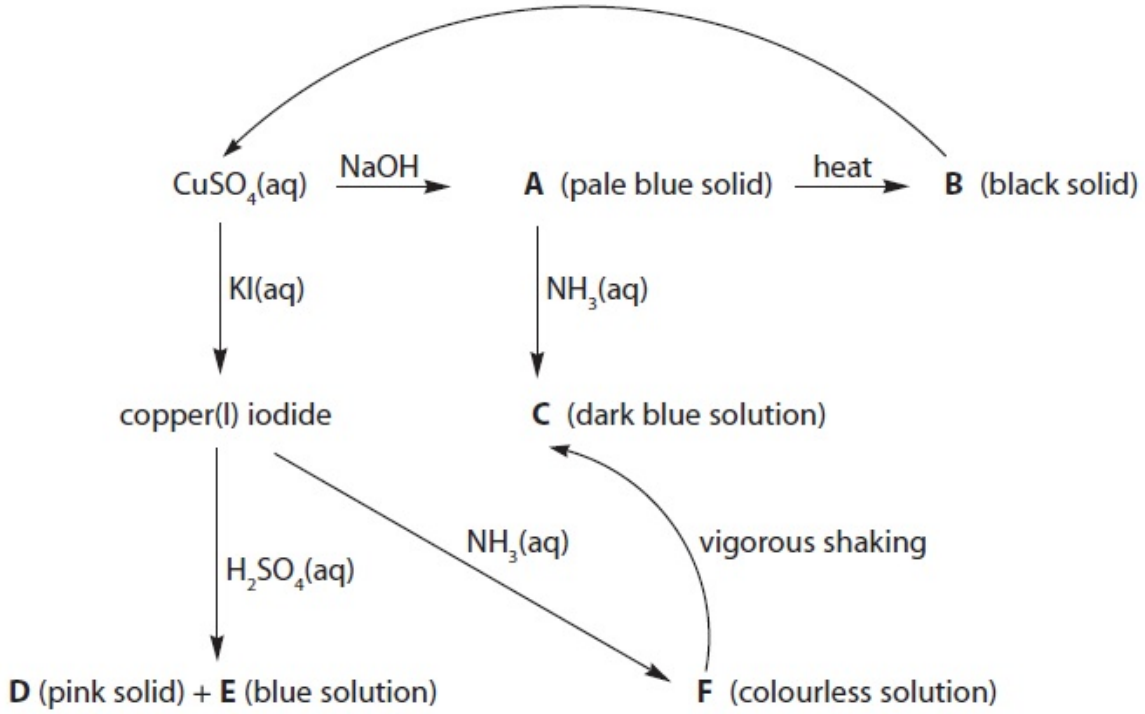
In your answer, show both half equations and the overall equation for the proposed disproportionation. Calculate $E^{\ominus}_{cell}$ for this reaction and use this value to predict the feasibility of this reaction.

(4)

(Total for Question = 11 marks)

Q73.

This question concerns the chemistry of copper. In the sequence below, **A**, **B**, **C**, **D**, **E** and **F** all contain copper in various oxidation states.



(a) Identify, by name (including the oxidation state where appropriate) or formula, the copper-containing species in the sequence.

(6)

A

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B

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C

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D

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E

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F

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(b) Identify, by name or formula, the reagent that would be used to convert **B** into $CuSO_4(aq)$.

(1)

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(c)

(i) **C** and **F** are the same type of chemical species. Name this type.

(1)

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(ii) Explain why **C** is coloured but **F** is colourless.

(3)

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*(iii) Explain why **F** changes into **C** on shaking.

(2)

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(b) The reaction of copper(I) iodide to form **D** and **E** is a disproportionation.

(i) Explain the term disproportionation.

(2)

(ii) Write an ionic equation for this reaction. State symbols are **not** required.

(1)

(iii) Use the relevant standard reduction (electrode) potentials, from the table on page 17 of your data booklet, to calculate the $E^{\ominus}_{cell}$ value for this reaction, giving your answer with the appropriate sign.

(2)

*(iv) If copper(I) iodide is treated with nitric acid, rather than sulfuric acid, a blue solution is still formed but no pink solid. Use the standard electrode potentials on page 15 of your data booklet to explain this. Quote any data that you use.

(4)

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(Total for question = 22 marks)

Q74.

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

* Describe the reactions of separate portions of aqueous copper(II) ions with aqueous sodium hydroxide solution, with excess aqueous ammonia solution and with concentrated hydrochloric acid.

In your answer you should link observations with equations which include the formulae of any copper-containing complex ions. Include state symbols.

(6)

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(Total for question = 6 marks)

Q75.

When aqueous sodium hydroxide is added to an aqueous solution of a transition metal compound, a green precipitate is formed which dissolves in excess sodium hydroxide forming a green solution. The transition metal ion present in the original solution is

☒ **A** Cr^{3+}

☒ **B** Fe^{3+}

☒ **C** Fe^{2+}

☒ **D** Ni^{2+}

(Total for question = 1 mark)

Q76.

Chromium is a typical transition metal: it forms complexes, coloured compounds and exists in a range of stable oxidation states. Chromium and some of its compounds also show catalytic properties.

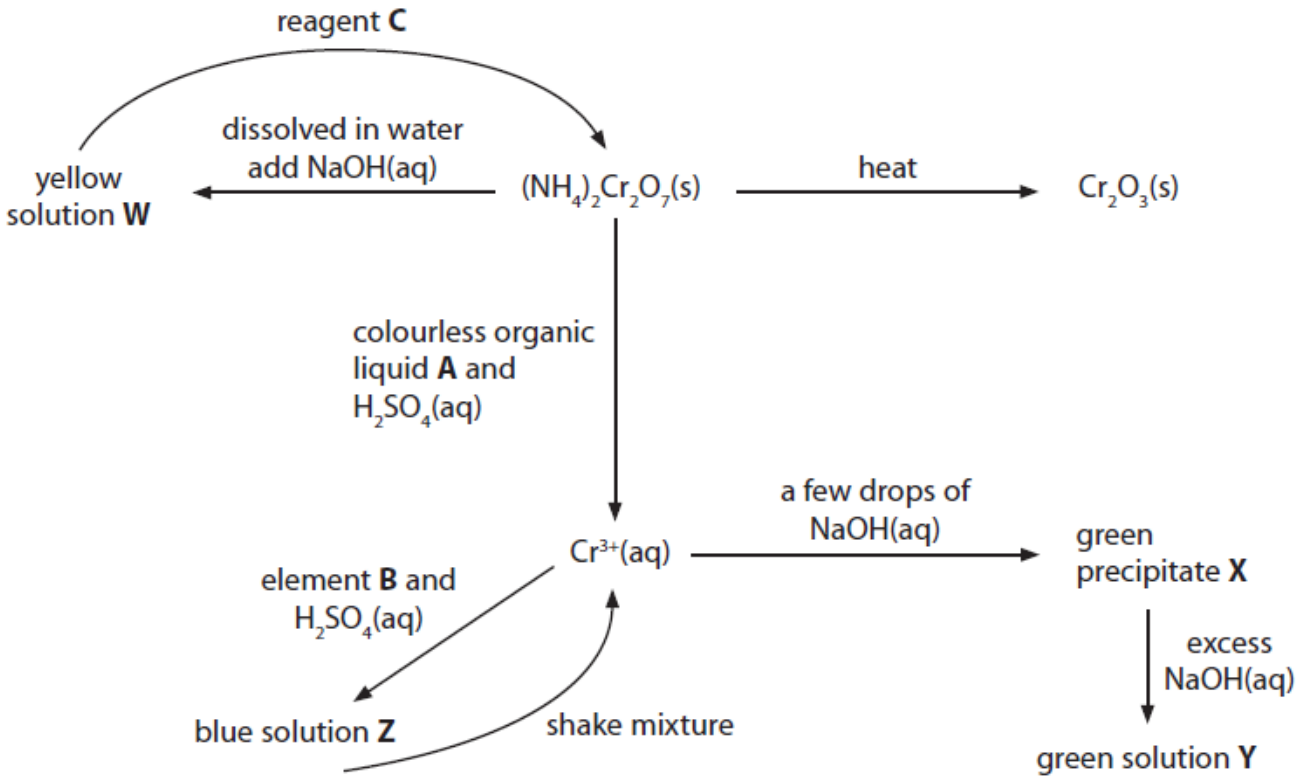
(a) Define the term **transition metal**.

(1)

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(b) The diagram below summarises some reactions of chromium compounds.



(i) Identify, by name (including the oxidation state where appropriate) or formula, the species containing **chromium** in the sequence.

(4)

W.....

X.....

Y.....

Z.....

(ii) Identify, by name or formula, suitable reagents for the sequence.

(3)

A.....

B.....

C.....

(iii) Write the ionic equation for the reaction between $(NH_4)_2Cr_2O_7$ and NaOH to form the yellow solution. State symbols are not required.

(1)

(iv) When $(NH_4)2Cr_2O_7$ is heated, steam and nitrogen are formed as well as Cr_2O_3. Write the equation for this reaction. State symbols are not required.

Explain why this is a redox reaction, stating any changes in oxidation numbers that occur.

(3)

Equation

Explanation

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(v) Explain how shaking solution **Z** re-forms $Cr^{3+}(aq)$.

(1)

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(c) If excess aqueous ammonia is added to $Cr^{3+}(aq)$, the ammonia acts as a ligand and the resulting green solution contains a chromium species which is different from the one found in **Y**.

(i) Explain the term 'ligand'.

(2)

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(ii) Write an equation for the reaction that occurs, showing **all** the ligands involved for both the chromium species in the reaction. State symbols are not required.

(2)

(Total for question = 17 marks)

Q77.

The shapes of the complexes $[CrCl_4]^-$ and $[CuCl_2]^-$ are

	$[CrCl_4]^-$	$[CuCl_2]^-$
☒ **A**	tetrahedral	linear
☒ **B**	square planar	linear
☒ **C**	tetrahedral	V-shaped
☒ **D**	square planar	V-shaped

(Total for question = 1 mark)

Q78.

The shapes of the complexes $[CrCl_4]^-$ and $[Pt(NH_3)_2Cl_2]$ are

	$[CrCl_4]^-$	$[Pt(NH_3)_2Cl_2]$
☐ **A**	square planar	square planar
☐ **B**	tetrahedral	tetrahedral
☐ **C**	square planar	tetrahedral
☐ **D**	tetrahedral	square planar

(Total for question = 1 mark)

Q79. EDTA ions form a complex with aqueous nickel(II) ions as shown by the equation

$$[Ni(H_2O)_6]^{2+}(aq) + (EDTA)^{4-}(aq) \rightleftharpoons Ni(EDTA)^{2-}(aq) + 6H_2O(l)$$

Aqueous nickel(II) ions also form a complex ion with ammonia as shown by the equation

$$[Ni(H_2O)_6]^{2+}(aq) + 6NH_3(aq) \rightleftharpoons [Ni(NH_3)_6]^{2+}(aq) + 6H_2O(l)$$

Aqueous nickel(II) ions form a more stable complex with EDTA ions than with ammonia because

☒ **A** six ammonia ligands cause steric hindrance around the central nickel(II) ion.

☒ **B** EDTA ions carry a negative charge whereas ammonia molecules do not.

☒ **C** there is a large increase in entropy when aqueous nickel(II) ions react with EDTA ions, but not when aqueous nickel(II) ions react with ammonia.

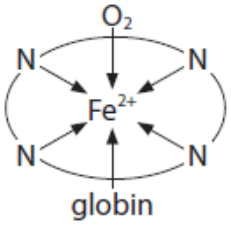
☒ **D** ammonia molecules tend to evaporate from the solution of the complex whereas EDTA ions do not.

(Total for Question = 1 mark)

Q80.

Some organic compounds contain metals.

Haemoglobin is an iron(II) complex. It carries oxygen around the body.
Part of the structure of haemoglobin is shown.



The four nitrogen atoms are part of a multidentate ligand in the haem group.

Explain why inhaling carbon monoxide can be fatal.

(2)

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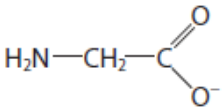
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(Total for question = 2 marks)

Q81.

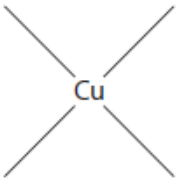
This question is about transition metals.

Glycinate ions are bidentate ligands and can be represented by the structure



Complete the diagram below to show the structure of the $[Cu(NH_2CH_2COO)_2]$ complex, which is square planar.

(2)



(Total for question = 2 marks)

Q82. Titanium has the electronic structure $1s^2 2s^2 2p^6 3s^2 3p^6 3d^2 4s^2$. Which of the following compounds is **unlikely** to exist?

☒ **A** K_3TiF_6

☒ **B** K_2TiF_6

☒ **C** $K_2Ti_2O_5$

☒ **D** K_2TiO_4

(Total for Question = 1 mark)

Q83.

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)

Q84.

Brass is an alloy of copper and zinc.

A sample of brass was weighed on a balance, reading to two decimal places. The mass of the sample was recorded as 5.00 g.

This sample of brass was reacted with excess concentrated nitric acid and the resulting solution was made up to 250 ^{3} in a volumetric flask using distilled water.

25.0 cm^3 portions were taken from this solution using a pipette. Each portion was neutralised by adding sodium carbonate solution; and excess potassium iodide solution was then added. The liberated iodine was titrated with 0.250 mol dm^{-3} sodium thiosulfate solution, using a freshly prepared solution of starch as indicator.

The mean titre was 22.70 cm^3.

(i) Use the equation for the reaction to give two observations when nitric acid reacts with copper.

$$Cu(s) + 2NO_3^-(aq) + 4H^+(aq) \rightarrow Cu^{2+}(aq) + 2NO_2(g) + 2H_2O(l)$$

(2)

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(ii) Complete the equation for the reaction between iodine and thiosulfate ions. Include state symbols.

(1)

$I_2(aq) + 2S_2O_3^{2-}(aq) \rightarrow$

(iii) Copper(II) ions react with iodide ions to form iodine.

$$2Cu^{2+}(aq) + 4I^-(aq) \rightarrow 2CuI(s) + I_2(aq)$$

Calculate the percentage by mass of copper in the brass. Give your answer to an appropriate number of significant figures.

(5)

(iv) A student wants to identify the piece of apparatus that contributes most to measurement

uncertainties in this experiment, so that the procedure can be modified.

The percentage measurement uncertainty is marked on the pipette as ±0.24%, and on the volumetric flask as ±0.08%.

By using appropriate calculations for the other apparatus used, deduce the **most** significant source of measurement uncertainty in this procedure.

(2)

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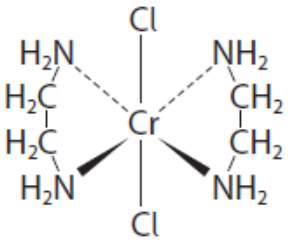
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Q85.

This question is about transition metals and their ions.

The **shape** of a complex ion formed from Cr^{3+} ions is shown.



(i) State the coordination number of Cr^{3+} in this complex ion.

(1)

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(ii) State the overall charge on this complex ion.

(1)

.....

(Total for question = 2 marks)

Q86.

This question is about transition metals and transition metal complexes.

Aqueous vanadium(II) chloride, $VCl_2(aq)$, can be oxidised by bubbling gaseous chlorine, $Cl_2(g)$, through the solution in the absence of air.

40.0 cm^3 of 0.100 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

$$Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$$

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

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

(5)

(ii) State the initial and final colours you would see as the chlorine bubbles through the aqueous vanadium(II) chloride, $VCl_2(aq)$.

(2)

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(Total for question = 7 marks)

Q87.

Which of the following does **not** have a central metal ion having six bonds and an oxidation state of +2?

☒ **A** $[Cu(C_2O_4)_3]^{4-}$

☒ **B** $[Co(CN)_5(H_2O)]^{3-}$

☒ **C** $[Fe(CN)_6]^{3-}$

☒ **D** $[Zn(OH)_4(H_2O)_2]^{2-}$

(Total for question = 1 mark)

Q88.

The reaction below can be catalysed by either Fe^{2+} ions or Fe^{3+} ions.

$$S_2O_8^{2-}(aq) + 2I^-(aq) \rightarrow 2SO_4^{2-}(aq) + I_2(aq)$$

This is because

☒ **A** both reactants can react with Fe^{2+} ions.

☒ **B** both reactants can react with Fe^{3+} ions.

☒ **C** $S_2O_8^{2-}$ ions can be oxidized by Fe^{3+} ions and I^- ions can be reduced by Fe^{2+} ions.

☒ **D** $S_2O_8^{2-}$ ions can be reduced by Fe^{2+} ions and I^- ions can be oxidized by Fe^{3+} ions.

(Total for question = 1 mark)

Q89.

The table below shows the first and second ionization energies of nickel, copper and zinc.

Element	1st ionization energy / kJ mol^{-1}	2nd ionization energy / kJ mol^{-1}
Ni	737	1753
Cu	746	1958
Zn	906	1733

(i) Complete the electronic configurations for an atom of nickel and an atom of copper.

(2)

Ni: $1s^2\ 2s^2\ 2p^6$

.....

Cu: $1s^2\ 2s^2\ 2p^6$

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*(ii) The values for the first ionization energies of copper and nickel are similar, but the values of the second ionization energies are significantly different.

Explain how these data give evidence for the electronic configuration of a copper atom.

(2)

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(iii) Suggest why you might expect the **third** ionization energies of the three elements to increase from nickel to zinc.

(1)

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Q90.

The compound 1,2-diaminoethane, $H_2NCH_2CH_2NH_2$, is a bidentate ligand; in formulae, it is usually abbreviated to 'en'.

When 1,2-diaminoethane is added to $[Co(NH_3)_6]^{2+}$ in aqueous solution, $[Co(en)_3]^{2+}$ is formed. What is the **best** explanation for this?

☒ **A** There are much stronger bonds between the ligands and the cobalt(II) ion in $[Co(en)_3]^{2+}$ than in $[Co(NH_3)_6]^{2+}$.

☒ **B** When $[Co(en)_3]^{2+}$ is formed from $[Co(NH_3)_6]^{2+}$ the reaction is exothermic.

☒ **C** When $[Co(en)_3]^{2+}$ is formed from $[Co(NH_3)_6]^{2+}$ the total entropy change is positive.

☒ **D** When $[Co(en)_3]^{2+}$ is formed from $[Co(NH_3)_6]^{2+}$ the reaction has a low activation energy.

(Total for question = 1 mark)

Q91.

Colour is often used in chemistry to identify substances.

Compare and contrast the origin of the colour of a copper(II) complex with the origin of the colour of the copper(II) ion in a flame test.

You do not need to state any specific colours.

(6)

(Total for question = 6 marks)

Q92.

Vanadium is classified as a transition metal. This is because vanadium

☒ **A** is a d-block element.

☒ **B** has incompletely filled d orbitals.

☒ **C** forms stable ions with incompletely filled d orbitals.

☒ **D** forms stable ions in which it has different oxidation states.

(Total for question = 1 mark)

Q93.

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

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

(2)

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(Total for question = 2 marks)

Q94.

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.

(2)

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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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