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1 a) i) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4s^2$ [1]

ii) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$ [1]

iii) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^9$ [1]

b) In d-block elements, the last electron added enters a d sub-shell [1]; which applies to both Sc and Cu.

Transition elements have at least one stable ion [1]; with a partially filled d sub-shell. [1]

c) i) Tetraamminediaquacopper(II) [1]

ii) Octahedral [1]

d) In the Cu^{2+} ion, the energy levels of the five d-orbitals are split [1] by ligands. Electrons in the slightly lower 3d level can absorb energy from certain wavelengths in the visible spectrum [1] and jump to the slightly higher 3d level. [1]

The light transmitted is therefore richer in certain wavelengths than others in the visible spectrum, so it appears coloured [1].

2 a) i) A transition metal is an element with at least one stable ion [1] with a partially filled d sub-shell. [1]

Example: electron configuration of a transition metal ion with the 3d orbitals shown between d^1 and d^9. [1]

ii) An oxidation number is a number assigned to an atom or ion [1] to describe its relative state of oxidation or reduction. [1]

Example: oxidation number of Fe in any iron(II) compound is +2. [1]

iii) A complex ion is an ion in which a number of molecules and/or anions (ligands) [1] are bound to a central metal ion by co-ordinate bonds. [1]

Example: $Cu(H_2O)_6^{2+}$ [1]

b) This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully sustained line of reasoning. Assess the quality of the answer taking into account both the key points made (*up to 4 marks*) and the logic and coherence of the discussion (*up to 2 marks*).

Points to make in the answer:

- Precipitation reactions – example with equation and colour of precipitate.
- Complexing (ligand substitution) – example with equation and colours of complex ions.
- Redox reactions – example with equation (half-equations) and colour change.
- Catalytic action – example with equation(s) and evidence of catalytic activity.

3 a) +6 [1]

b) Yellow [1]; to orange [1]

$2CrO_4^{2-}(aq) + 2H^+(aq) \rightarrow Cr_2O_7^{2-}(aq) + H_2O(l)$ [1]

c) Green [1]; Cr^{3+} [1]

d) i) $Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)$ [1]

ii) $\frac{20}{1000}\ dm^3 \times 0.100\ mol\ dm^{-3} = 0.002\ mol$ [1]

iii) $0.002 \times 6 = 0.012$ mol [1]

iv) 0.012 mol of $VOCl_x$ gives up 0.012 mol of electrons. Therefore 1 mol of $VOCl_x$ gives up 1 mol of electrons. So, vanadium changes its oxidation state by +1. [1]

v) Oxidation state of vanadium in $VOCl_x$ is +4. So the formula of the oxochloride is $VOCl_2$. [1]

4 a) i) Heterogeneous [1]

ii) Homogeneous [1]

iii) Heterogeneous [1]

iv) Heterogeneous [1]

b) In the presence of a catalyst, the reaction pathway has an activation energy which is much lower than when there is no catalyst. [1] Tungsten metal adsorbs hydrogen onto the crystal structure as single atoms. [1] So the catalyst breaks the bonds between the atoms in one of the reactants. [1] The pathway with a lower activation energy allows the reaction to proceed much faster. [1]

5 a) A contains $[Cu(H_2O)_6]^{2+}$ [1]

B contains $Cu(OH)_2(H_2O)_4$ [1] (accept $Cu(OH)_2$)

C contains $[CuCl_4]^{2-}$ [1]

D contains $[Cu(NH_3)_4(H_2O)_2]^{2+}$ [1] (accept $Cu(NH_3)_4^{2+}$)

b) The yellow/green solution changes colour through green [1] to blue. [1]

When conc. HCl is added to the blue copper(II) sulfate solution (A), the following equilibrium [1] is set up:

$$\underset{\text{blue}}{Cu(H_2O)_6^{2+}(aq)} + 4Cl^-(aq) \rightleftharpoons \underset{\text{yellow}}{CuCl_4^{2-}(aq)} + 6H_2O(l) \quad [2]$$

In excess HCl, the equilibrium lies to the right so the solution appears yellow/green. [1] As excess water is added, the equilibrium shifts to the left [1]; and the solution becomes blue. (*maximum 6 marks*)

c) $Cu(H_2O)_6^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(H_2O)_4(OH)_2(s) + 2H_2O(l)$ [1]

(accept $Cu^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s)$)

$EDTA^{4-}$ is a very powerful [1]; hexadentate [1]; ligand. [1]

It forms a chelated complex/chelate [1]; with copper(II) ions and prevents them from reacting with OH^- ions. [1] (*maximum 5 marks*)

6 a) Homogeneous catalysis involves catalysis in which the catalyst and the reactants are in the same phase. [1]

The most important feature of transition metal ions in homogeneous catalysis is that they can change their oxidation state. [1]

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

[1] for balanced equation, [1] for state symbols

ii) Either – the reactants are both negative ions which will repel each other;

or – there are bonds to break in the $S_2O_8^{2-}$ to form SO_4^{2-}. [1]

iii) $2Fe^{3+}(aq) + 2I^-(aq) \rightarrow 2Fe^{2+}(aq) + I_2(aq)$ [1]

$2Fe^{2+}(aq) + S_2O_8^{2-}(aq) \rightarrow 2Fe^{3+}(aq) + 2SO_4^{2-}(aq)$ [1]

c) i) Adsorption of gases on the metal surface is so strong that reactions cannot occur [1]; adsorption of gases on the metal surface is so poor that there are insufficient atoms for the reaction to occur at a useful rate. [1]

ii) Adsorption is neither too strong nor too weak [1]; reactants can be adsorbed in sufficient numbers, react and then get desorbed from the metal surface at a good rate. [1]

d) Pt alloy or Pt or Pt/Rh [1]; the reducing agent is CO/carbon monoxide [1];

$2CO(g) + 2NO(g) \rightarrow 2CO_2(g) + N_2(g)$ [1]

7 a) $H_2NNH_2(aq) + 4OH^-(aq) \rightarrow N_2(g) + 4H_2O(l) + 4e^-$ [2]

b) Its $E^\ominus$ value is more positive than +0.66 V [1] but less positive than +1.32 V. [1]

c) The two half-equations are:

$H_2NNH_2(aq) + 4OH^-(aq) \rightarrow N_2(g) + 4H_2O(l) + 4e^-$ and

$(VO_2^+(aq) + H_2O(l) + e^- \rightarrow VO^{2+}(aq) + 2OH^-(aq)) \times 4$ [1]

Overall: $H_2NNH_2(aq) + 4VO_2^+(aq) \rightarrow N_2(g) + 4VO^{2+}(aq) + 4OH^-(aq)$ [1]

d) i) Disproportionation is the simultaneous oxidation and reduction of atoms or ions of the same element. [1]

For example, Cu^+ ions can disproportionate to Cu^{2+} and Cu. [1]

ii) Disproportionation requires the oxidation state of an element to both rise to a higher state and fall to a lower state. [1]

iii) $2VO^{2+}(aq) \rightarrow V^{3+}(aq) + VO_2^+(aq)$ [1]

iv) $VO^{2+}(aq) + H_2O(l) + e^- \rightarrow V^{3+}(aq) + 2OH^-(aq)$ $E^\ominus = -1.32$ V

$VO_2^+(aq) + 2OH^-(aq) \rightarrow VO_2^+(aq) + H_2O(l) + e^-$ $E^\ominus = +0.66$ V

This disproportionation will not occur under standard conditions in alkaline solution, because $VO_2^+(aq)$ (the oxidised form of the more positive electrode system) [1] tends to oxidise $V^{3+}(aq)$ (the reduced form of the less positive electrode system) to $VO^{2+}(aq)$. [1]

So vanadium(V) and vanadium(III) tend to react to give vanadium(IV), which is the reverse of disproportionation. [1]

8 a) A complex is a molecule or ion in which ligands [1] are attached to a central metal cation by co-ordinate bonds. [1]

A stereoisomer is one of two or more molecules or ions with the same molecular/ionic formula and the same structural formula [1], but different stereo formulae (different positions of the atoms in space). [1]

b) i) +2 [1]

ii) +3 [1]

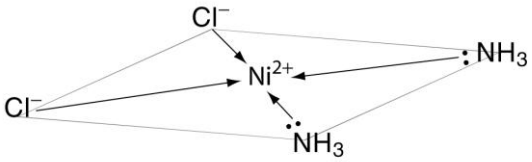
c) i) 4 [1]

ii) 6 [1]

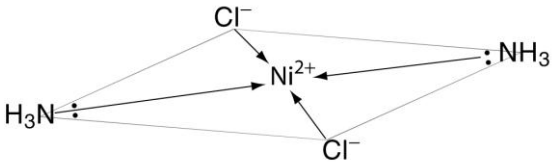
d) i) Diamminedichloronickel(II) [1]

ii) Tetraamminedichlorocobalt(III) [1]

e)



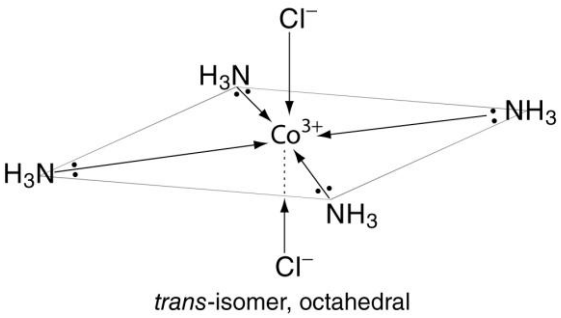
cis-isomer, planar



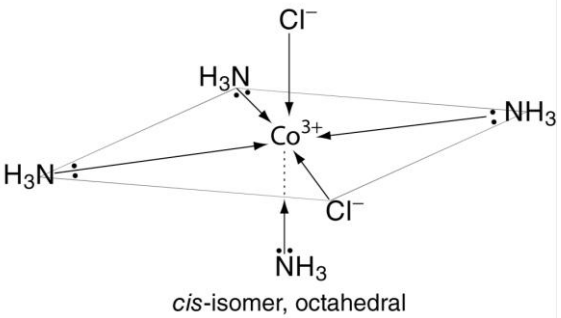
trans-isomer, planar

2 marks for each diagram: [1] for lone pairs on N; [1] for correct shape.

f)



trans-isomer, octahedral



cis-isomer, octahedral

2 marks for each diagram: [1] for lone pairs on N; [1] for correct shape.