Dr Clays A-level Chemistry

TRANSITION METALS
WEBINAR EXTRA
QUESTIONS & ANSWERS

Q1. Which one of the following electronic configurations is that of a transition element?

A [Ar] $4s^2 3d^{10}$

B [Ar] $4s^2 3d^9$

C [A] $4s^2 3d^0$

D [Ar] $4s^2 3d^{10} 4p^1$

(Total 1 mark)

Q2. In the table below, which one of the following complex ions has a correct shape, co-ordination number and oxidation state?

	Complex	Shape	Co-ordination number	Oxidation state of central cation
A	$[Ag(CN)_2]^-$	Linear	2	–1
B	$[CuCl_4]^{2-}$	Tetrahedral	4	–2
C	$[Cr(C_2O_4)_3]^{3-}$	Octahedral	3	+3
D	$[Cu(NH_3)_4(H_2O)_2]^{2+}$	Octahedral	6	+2

(Total 1 mark)

Q3. Which one of the following could **not** act as a ligand?

A F^-

B CH_3CH_3

C NH_2NH_2

D CH_3OCH_3

(Total 1 mark)

Q4. What forms when a solution of sodium carbonate is added to a solution of gallium(III) nitrate?

A A white precipitate of gallium(III) carbonate. ⬭

B A white precipitate of gallium(III) hydroxide. ⬭

C A white precipitate of gallium(III) carbonate and bubbles of carbon dioxide. ⬭

D A white precipitate of gallium(III) hydroxide and bubbles of carbon dioxide. ⬭

(Total 1 mark)

Q5. What is the final species produced when an excess of aqueous ammonia is added to aqueous aluminium chloride?

A $[Al(NH_3)_6]^{3+}$ ⬭

B $[Al(OH)_3(H_2O)_3]$ ⬭

C $[Al(OH)_4(H_2O)_2]^-$ ⬭

D $[Al(OH)(H_2O)_5]^{2+}$ ⬭

(Total 1 mark)

Q6. (a) State what is meant by the term *co-ordinate bond*.

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(2)

(b) Define the terms *Brønsted–Lowry acid* and *Lewis acid*.

Brønsted–Lowry acid .....

Lewis acid .....

(2)

(c) State what is meant by the term *bidentate ligand*.

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(2)

(d) State how the co-ordination number of cobalt(II) ions in aqueous solution changes when an excess of chloride ions is added. Give a reason for the change.

Change in co-ordination number .....

Reason for change .....

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(2)

(e) Suggest why the enthalpy change for the following reaction is close to zero.

$[Co(NH_3)_6]^{2+} + 3NH_2CH_2CH_2NH_2 \rightarrow Co(NH_2CH_2CH_2NH_2)_3]^{2+} + 6NH_3$

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(2)

(f) Deduce the formula of the compound formed when ethane-1,2-diamine is treated with an excess of hydrochloric acid.

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(1)

(Total 11 marks)

Q7. (a) Give **one** example of a bidentate ligand.

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(1)

(b) Give **one** example of a linear complex ion formed by a transition metal.

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(1)

(c) Write an equation for a substitution reaction in which the complete replacement of ligands in a complex ion occurs with a change in **both** the co-ordination number and the overall charge of the complex ion.

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(2)

(d) Write an equation for a substitution reaction in which the complete replacement of ligands in a complex ion occurs without a change in either the co-ordination number or the overall charge of the complex ion.

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(2)

(e) When a solution containing $[Co(H_2O)_6]^{2+}$ ions is treated with a solution containing $EDTA^{4-}$ ions, a more stable complex is formed. Write an equation for this reaction and explain why the complex is more stable.

Equation .....

Explanation .....

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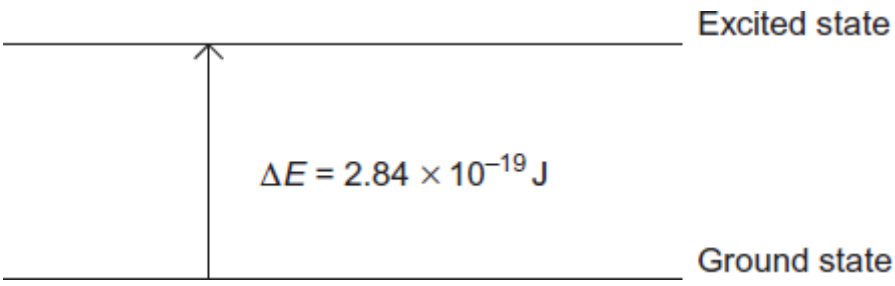
(3)
(Total 9 marks)

Q8. This diagram represents the energy change that occurs when a d electron in a transition metal ion is excited by visible light.



(a) Give the equation that relates the energy change ΔE to the Planck constant h and the frequency of the visible light v.

Use this equation and the information in the diagram to calculate a value for the frequency of the visible light, and state the units.
The Planck constant $h = 6.63 \times 10^{-34}$ J s.

Equation .....

Calculation .....

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(2)

(b) Explain why this electron transition causes a solution containing the transition metal ion to be coloured.

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(2)

(c) The energy change shown in the diagram represents the energy of red light and leads to a solution that appears blue.
Blue light has a higher frequency than red light.

Suggest whether the energy change ΔE will be bigger, smaller or the same for a transition metal ion that forms a red solution. Explain your answer.

Energy change .....

Explanation .....

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(2)

(d) State **three** different features of transition metal complexes that cause a change in

the value of ΔE, the energy change between the ground state and the excited state of the d electrons.

Feature 1 .....

Feature 2 .....

Feature 3 .....

(3)
(Total 9 marks)

Q9. A green solution, **X**, is thought to contain $[Fe(H_2O)_6]^{2+}$ ions.

(a) The presence of these ions can be confirmed by reacting separate samples of solution **X** with aqueous ammonia and with aqueous sodium carbonate.

Write equations for each of these reactions and describe what you would observe.

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(4)

(b) A 50.0 cm^3 sample of solution **X** was added to 50 cm^3 of dilute sulfuric acid and made up to 250 cm^3 of solution in a volumetric flask.

A 25.0 cm^3 sample of this solution from the volumetric flask was titrated with a 0.0205 mol dm^{-3} solution of $KMnO_4$
At the end point of the reaction, the volume of $KMnO_4$ solution added was 18.70 cm^3.

(i) State the colour change that occurs at the end point of this titration and give a reason for the colour change.

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(2)

(ii) Write an equation for the reaction between iron(II) ions and manganate(VII) ions.

Use this equation and the information given to calculate the concentration of iron(II) ions in the original solution **X**.

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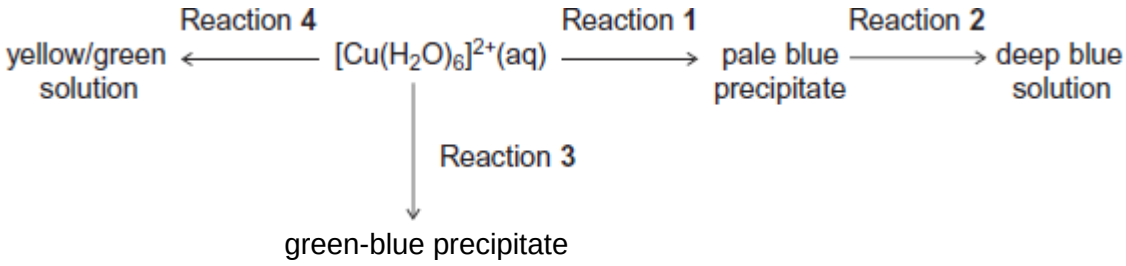
(5)
(Total 11 marks)

Q10. Consider the following reaction scheme that starts from aqueous $[Cu(H_2O)6]^{2+}$ ions.



For each of the reactions **1** to **4**, identify a suitable reagent, give the formula of the copper-containing species formed and write an equation for the reaction.

(a) Reaction **1**

Reagent .....

Copper-containing species .....

Equation .....

(3)

(b) Reaction **2**

Reagent .....

Copper-containing species .....

Equation .....

(3)

(c) Reaction **3**

Reagent .....

Copper-containing species .....

Equation .....

(3)

(d) Reaction **4**

Reagent .....

Copper-containing species .....

Equation .....

(3)
(Total 12 marks)

Q11.(a) A co-ordinate bond is formed when a transition metal ion reacts with a ligand.

Explain how this co-ordinate bond is formed.

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(2)

(b) Describe what you would observe when dilute aqueous ammonia is added dropwise, to excess, to an aqueous solution containing copper(II) ions. Write equations for the reactions that occur.

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(4)

(c) When the complex ion $[Cu(NH_3)_4(H_2O)_2]^{2+}$ reacts with 1,2-diaminoethane, the ammonia molecules but not the water molecules are replaced.

Write an equation for this reaction.

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(1)

(d) Suggest why the enthalpy change for the reaction in part **(c)** is approximately zero.

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(2)

(e) Explain why the reaction in part **(c)** occurs despite having an enthalpy change that is approximately zero.

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(2)

(Total 11 marks)

Q12. An excess of a given reagent is added to each of the following pairs of aqueous metal ions.

For each metal ion, state the initial colour of the solution and the final observation that you would make.

In each case, write an overall equation for the formation of the final product from the initial aqueous metal ion.

(a) An excess of aqueous sodium carbonate is added to separate aqueous solutions containing $[Fe(H_2O)_6]^{2+}$ and $[Fe(H_2O)_6]^{3+}$.

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(5)

(b) An excess of concentrated hydrochloric acid is added to separate aqueous solutions containing $[Cu(H_2O)_6]^{2+}$ and $[Co(H_2O)_6]^{2+}$.

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(4)

(c) An excess of dilute aqueous sodium hydroxide is added to separate aqueous solutions containing $[Fe(H_2O)_6]^{2+}$ and $[Cr(H_2O)_6]^{3+}$.

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(4)

(d) An excess of dilute aqueous ammonia is added to separate aqueous solutions containing $[Al(H_2O)_6]^{3+}$ and $[Ag(H_2O)_2]^{+}$

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(4)
(Total 17 marks)

Q13. The redox reaction, in aqueous solution, between acidified potassium manganate(VII) and sodium ethanedioate is autocatalysed.

(a) Write an equation for this redox reaction.

Identify the species that acts as the catalyst.

Explain how the properties of the species enable it to act as a catalyst in this reaction.

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(6)

(b) Sketch a graph to show how the concentration of MnO_4^- ions varies with time in this reaction.
Explain the shape of the graph.

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(4)
(Total 10 marks)

Q14. When iodine molecules are dissolved in aqueous solutions containing iodide ions, they react to form triiodide ions (I_3^-).

$$I_2 + I^- \longrightarrow I_3^-$$

The reaction above between I^- ions and $S_2O_8^{2-}$ ions has a high activation energy and $S_2O_8^{2-}$ ions are only reduced slowly to SO_4^{2-} ions.
The reaction is catalysed by Fe^{2+} ions.

(a) Explain why the reaction between I^- ions and $S_2O_8^{2-}$ ions is slow.

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(1)

(b) Other than having variable oxidation states, explain why Fe^{2+} ions are good catalysts for this reaction.

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(1)

(c) Write a half-equation for the reduction of $S_2O_8^{2-}$ ions to SO_4^{2-} ions.

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(1)

(d) Construct an overall equation for the reaction between $S_2O_8^{2-}$ ions and I^- ions.

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(1)
(Total 4 marks)

M1.B

[1]

M2.D

[1]

M3.B

[1]

M4.D

[1]

M5.B

[1]

M6. (a) A shared electron pair or a covalent bond **(1)**
Both electrons from one atom **(1)**

OR when a Lewis base reacts with a Lewis acid
Mark points separately

2

(b) *Brønsted-Lowry acid*: A proton or H^+ donor **(1)**
Not H_3O^+

Lewis acid: A lone or electron pair acceptor **(1)**

2

(c) Two atoms or two points of attachment **(1)**
Each donating a lone electron pair **(1)**

OR forms 2 (1) co-ordinate bonds (1)
OR donates two (1) pairs of electrons (1)

2

(d) *Change in co-ordination number*: 6 to 4 **(1)**

Reason for change: chloride ligands are larger than water ligands **(1)**

2

OR greater repulsion between chloride ligands
DO NOT allow chlorine or Cl

(e) Same number **(1)**, and same type of bonds **(1)**, broken and made

2

(f) $ClNH_3CH_2CH_2NH_3Cl$ **(1)**

OR $(NH_3CH_2CH_2NH_3)^{2+}$ $2Cl^-$
Allow $C_2H_{10}N_2Cl_2$ *and* $NH_3ClCH_2CH_2NH_3Cl$

1

[11]

M7. (a) $C_2O_4^{2-}$ or $H_2NCH_2CH_2NH_2$ **(1)**

1

(b) $[AgCl_2]^-$ or $[Ag(CN)_2]^-$ or $[Ag(NH_3)_2]^+$ **(1)**

1

(c) e.g. $[Co(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CoCl_4]^{2-} + 6H_2O$
Correct complex species **(1),** Balanced **(1),** Only allow if species correct

2

(d) e.g. $[Co(H_2O)_6]^{2+} + 6NH_3 \rightarrow [Co(NH_3)_6]^{2+} + 6H_2O$
Correct complex species **(1),** Balanced **(1),** Only allow if species correct

2

(e) *Equation:* $[Co(H_2O)_6]^{2+} + EDTA^{4-} \rightarrow [Co(EDTA)]^{2-} + 6H_2O$ **(1)**
Explanation: More molecules on right hand side **(1)**
Entropy increases **(1)**

3

[9]

M8.(a) $\Delta E = hv$

Allow = hf

1

$v = \Delta E / h = 2.84 \times 10^{-19} / 6.63 \times 10^{-34} = 4.28 \times 10^{14}\ s^{-1}$ / Hz

Allow $4.3 \times 10^{14}\ s^{-1}$ / Hz

Answer must be in the range:

$4.28 - 4.30 \times 10^{14}$

1

(b) (One colour of) light is absorbed (to excite the electron)

If light emitted, CE = 0

1

The remaining colour / frequency / wavelength / energy is transmitted (through the solution)

Allow light reflected is the colour that we see.

1

(c) Bigger

1

Blue light would be absorbed

OR light that has greater energy than red light would be absorbed
OR higher frequency (of light absorbed / blue light) leads to higher ΔE

Can only score M2 if M1 is correct.

1

(d) Any **three** from:
- (Identity of the) metal
- Charge (on the metal) / oxidation state / charge on complex
- (Identity of the) ligands
- Co-ordination number / number of ligands
- Shape

3 max

[9]

M9.(a) $[Fe(H_2O)_6]^{2+} + 2NH_3 \rightarrow Fe(H_2O)_4(OH)_2 + 2NH_4^+$

Allow equation with OH^- provided equation showing formation of OH^- from NH_3 given

1

Green precipitate

1

$[Fe(H_2O)_6]^{2+} + CO_3^{2-} \rightarrow FeCO_3 + 6H_2O$

1

Green precipitate

effervescence incorrect so loses M4

1

(b) (i) Colourless / (pale) green changes to pink / purple (solution)

Do not allow pale pink to purple

1

Just after the end−point MnO_4^- is in excess / present

1

(ii) $MnO_4^- + 8H^+ + 5Fe^{2+} \rightarrow Mn^{2+} + 4H_2O + 5Fe^{3+}$

1

Moles $KMnO_4 = 18.7 \times 0.0205 / 1000 = (3.8335 \times 10^{-4})$

Process mark

1

Moles $Fe^{2+} = 5 \times 3.8335 \times 10^{-4} = 1.91675 \times 10^{-3}$

Mark for M2 × 5

1

Moles Fe^{2+} in 250 $cm^3 = 10 \times 1.91675 \times 10^{-3} = 0.0191675$ moles in 50 cm^3

Process mark for moles of iron in titration (M3) × 10

1

Original conc Fe^{2+} = 0.0191675 × 1000 / 50 = 0.383 mol dm^{-3}

Answer for moles of iron (M4) × 1000 / 50

Answer must be to at least 2 sig. figs. (0.38)

1

[11]

M10.(a) **Reaction 1**

General principles in marking this question

Square brackets are not essential

Penalise charges on individual ligands rather than on the whole complex

Reagent and species can be extracted from the equation

Ignore conditions such as dilute, concentrated, excess

Reagent must be a compound NOT just an ion

Equations must start from $[Cu(H_2O)_6]^{2+}$ except in part (b)

Mark reagent, species and equation independently

ammonia (NH_3) (solution) / NaOH

1

$[Cu(H_2O)_6]^{2+} + 2NH_3 \rightarrow [Cu(H_2O)_4(OH)_2] + 2NH_4^+$ /

$[Cu(H_2O)_6]^{2+} + 2OH^- \rightarrow [Cu(H_2O)_4(OH)_2] + 2H_2O$

Do not allow OH^- for reagent

Product 1, balanced equation 1

Allow either equation for ammonia

2

(b) **Reaction 2**

Ammonia (conc / xs)

1

$[Cu(H_2O)_4(OH)_2] + 4NH_3 \rightarrow [Cu(H_2O)_2(NH_3)_4]^{2+} + 2H_2O + 2OH^-$

Product 1, balanced equation 1

Note that the equation must start from the hydroxide $[Cu(H_2O)_4(OH)_2]$

2

(c) **Reaction 3**

Na_2CO_3 / any identified soluble carbonate / $NaHCO_3$

Do not allow $NaCO_3$ or any insoluble carbonate but mark on

1

$[Cu(H_2O)_6]^{2+} + CO_3^{2-} \rightarrow CuCO_3 + 6H_2O$

OR $[Cu(H_2O)_6]^{2+} + Na_2CO_3 \rightarrow CuCO_3 + 6H_2O + 2Na^+$

OR $2[Cu(H_2O)_6]^{2+} + 2CO_3^{2-} \rightarrow Cu(OH)_2.CuCO_3 + 11H_2O + CO_2$

OR with $NaHCO_3$

$[Cu(H_2O)_6]^{2+} + HCO_3^- \rightarrow CuCO_3 + 6H_2O + H^+$

Product 1, balanced equation 1

2

(d) **Reaction 4**

HCl (conc / xs) / NaCl

Allow any identified soluble chloride

1

$[Cu(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CuCl_4]^{2-} + 6H_2O$

Product 1, balanced equation 1

2

[12]

M11.(a) An electron pair on the ligand

1

Is donated from the ligand to the central metal ion

1

(b) Blue precipitate

1

Dissolves to give a dark blue solution

1

$[Cu(H_2O)_6]^{2+} + 2NH_3 \longrightarrow Cu(H_2O)_4(OH)_2 + 2NH_4^+$

1

$Cu(H_2O)_4(OH)_2 + 4NH_3 \longrightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 2OH^- + 2H_2O$

1

(c) $[Cu(NH_3)_4(H_2O)_2]^{2+} + 2H_2NCH_2CH_2NH_2 \longrightarrow [Cu(H_2NCH_2CH_2NH_2)_2(H_2O)_2]^{2+} + 4NH_3$

1

(d) Cu–N bonds formed have similar enthalpy / energy to Cu–N bonds broken

1

And the same number of bonds broken and made

1

(e) 3 particles form 5 particles / disorder increases because more particles are formed / entropy change is positive

1

Therefore, the free-energy change is negative

M2 can only be awarded if M1 is correct

1

[11]

M12.(a) Iron(II): green (solution) gives a green precipitate

Apply list principle throughout if extra colours and / or extra observations given. Ignore state symbols in equations.

Not blue-green ppt.

1

$\underline{[Fe(H_2O)_6]^{2+}} + CO_3^{2-} \rightarrow FeCO_3 + 6H_2O$

Must start from $[Fe(H_2O)_6]^{2+}$

Allow equations with Na_2CO_3

1

Iron(III): yellow / purple / brown / lilac / violet (solution) gives a brown / rusty precipitate

1

Effervescence / gas / bubbles

Allow CO_2 evolved but not just CO_2

1

$\underline{2[Fe(H_2O)_6]^{3+}} + 3CO_3^{2-} \rightarrow 2[Fe(H_2O)_3(OH)_3] + 3CO_2 + 3H_2O$

1

(b) Copper(II): blue (solution) gives a green / yellow solution ***OR*** blue solution (turns) to green / yellow / olive green

Apply list principle throughout if extra colours and / or extra observations given. Ignore state symbols in equations.

1

$\underline{[Cu(H_2O)_6]^{2+}} + 4Cl^- \rightarrow [CuCl_4]^{2-} + 6H_2O$

Allow equations with HCl

1

Cobalt(II): pink (solution) gives a blue solution ***OR*** pink solution turns blue

1

$\underline{[Co(H_2O)_6]^{2+}} + 4Cl^- \rightarrow [CoCl_4]^{2-} + 6H_2O$

1

(c) Iron(II): green (solution) gives a green precipitate

Apply list principle throughout if extra colours and / or extra observations given. Ignore state symbols in equations.

1

$\underline{[Fe(H_2O)_6]^{2+}} + 2OH^- \rightarrow Fe(H_2O)_4(OH)_2 + 2H_2O$

Allow equations with NaOH

1

Chromium(III): green / ruby / purple / violet / red-violet (solution) gives a green solution ***OR*** green / ruby / purple / violet / red-violet solution turns green

Ignore green ppt.

1

$\underline{[Cr(H_2O)_6]^{3+}} + 6OH^- \rightarrow [Cr(OH)_6]^{3-} + 6H_2O$

Allow also with 4 or 5 OH balanced with 2 or 1 waters.

Also allow two correct equations showing $Cr(H_2O)_3(OH)_3$ as intermediate.

1

(d) Al: colourless (solution) gives a white ppt

Apply list principle throughout if extra colours and / or extra observations given. Ignore state symbols in equations.

1

$\underline{[Al(H_2O)_6]^{3+}} + 3NH_3 \rightarrow Al(H_2O)_3(OH)_3 + 3NH_4^+$

Allow + $3OH^- \rightarrow 3H_2O$ if

$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$ also

1

Ag: colourless (solution) remains a colourless solution / no visible change

Ignore brown ppt.

1

$\underline{[Ag(H_2O)_2]^+} + 2NH_3 \rightarrow [Ag(NH_3)_2]^+ + 2H_2O$

Allow 2 / 3 equations involving Ag_2O or $Ag(OH)_2$

1

[17]

M13.(a) $2MnO_4^- + 16H^+ + 5C_2O_4^{2-} \rightarrow 2Mn^{2+} + 8H_2O + 10CO_2$

1

Mn^{2+} OR Mn^{3+}

If catalyst incorrect can only score M1 and M3

1

(Possible because) <u>Mn</u> can exist in variable oxidation states

1

E_a lowered because oppositely charged ions attract

These marks can be gained in any order

1

Mn^{3+} (reduced) to Mn^{2+} by $C_2O_4^{2-}$ / equation

M5 may appear before M2

1

Mn^{2+} (oxidised (back)) to Mn^{3+} by MnO_4^- / equation

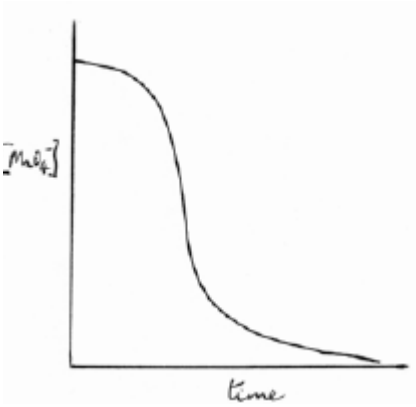
M5 and M6 can be scored in unbalanced equations or in words showing:

$Mn^{3+} + C_2O_4^{2-} \rightarrow Mn^{2+}$

$Mn^{2+} + MnO_4^- \rightarrow Mn^{3+}$

1

(b) **Graph marks**



S-shaped curve must not rise significantly and must not fall rapidly initially.

Starts on concentration axis **and** is levelling out (can level out on time axis or above but parallel to time axis)

Cannot score graph marks (M1 and M2) if no axes and / or no labels

1

1

Explanation marks

Slope / rate increases as catalyst (concentration) forms

1

Slope / rate decreases as (concentration) of MnO_4^- ions / reactant(s) decreases (OR reactants are being used up)

Explanation marks can be awarded independent of graph.

1

[10]

M14.(a) Negative ions repel one another

1

(b) Positive ions attract negative ions in catalysed process

Allow activation energy decreases.
Allow alternative route with lower E_a
Ignore references to heterogenous catalysis.

1

(c) $S_2O_8^{2-} + 2e^- \longrightarrow 2SO_4^{2-}$

Allow multiples including fractions.
Ignore state symbols.

1

(d) $S_2O_8^{2-} + 2I^- \longrightarrow 2SO_4^{2-} + I_2$

Allow multiples including fractions.
Ignore state symbols.
Allow the correct equation involving I_3^-
$S_2O_8^{2-} + 3I^- \longrightarrow 2SO_4^{2-} + I_3^-$

1

[4]