EXAM PAPERS PRACTICE

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Detailed mark scheme

Suitable for all boards

Designed to test your ability and thoroughly prepare you

Level: CIE AS and A Level (9701)
Subject: Chemistry
Topic: CIE Chemistry
Type: Mark Scheme

Chemistry CIE AS & A Level
To be used for all exam preparation for 2025+

CHEMISTRY AS and A

This to be used by all students studying CIE AS and A level Chemistry (9701) But students of other boards may find it useful

Mark Scheme

Answer 1.

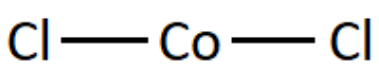
a) The electronic configurations of a Co atom and a Co^{2+} ion are:

- Co atom = $1s^2\ 2s^2\ 2p^6\ \mathbf{3s^2\ 3p^6\ 3d^7\ 4s^2}$
  OR
  Co atom = $1s^2\ 2s^2\ 2p^6\ \mathbf{3s^2\ 3p^6\ 4s^2\ 3d^7}$; [1 mark]
- Co^{2+} ion = $1s^2\ 2s^2\ 2p^6\ \mathbf{3s^2\ 3p^6\ 3d^7}$; [1 mark]

[Total: 2 marks]

- You should be aware that:
  - The Periodic Table makes it appear that electrons fill orbitals in the order 1s 2s 2p 3s 3p 4s 3d
  - However, electrons actually fill the orbitals in the order 1s 2s 2p 3s 3p 3d 4s
    - The 3d orbital comes before the 4s orbital because it is slightly lower in energy
  - s-orbitals can hold up to 2 electrons
  - p-orbitals can hold up to 6 electrons
  - d-orbitals can hold up to 10 electrons
- With 27 electrons, an atom cobalt will be $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^7\ 4s^2$
  - You can check this by just focussing on the numbers: 2 + 2 + 6 + 2 + 6 +7 + 2 = 27
- A Co^{2+} ion has lost 2 electrons, which means that it has 25 electrons
  - **Remember:** 4s electrons are lost before 3d electrons
  - Since the 4s shell electrons are lost first, this will give $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^7$

b) The structure of the linear complex formed by Co^{2+} ions and Cl^- ions is:



- Cl – Co – Cl; [1 mark]

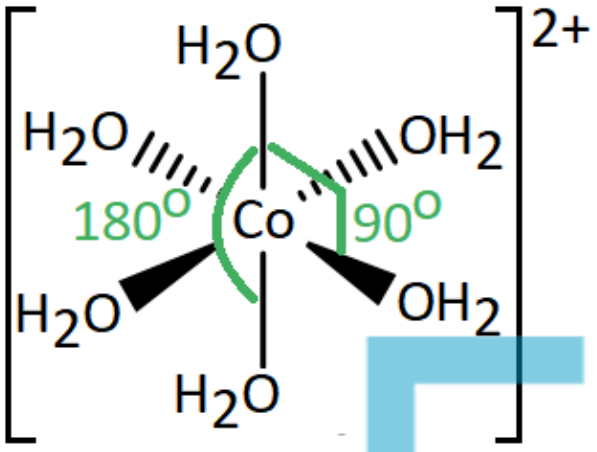
The overall charge of this complex is:

- Zero / 0 / no charge; [1 mark]

[Total: 2 marks]

- The question tells you that the complex is linear
- This means that the Co^{2+} in will have two of the monodentate chloride ligands / ions arranged in a linear fashion, i.e. with a 180^o bond angle
- One Co^{2+} ion with two Cl^- ions means that there will be no overall charge

c) The three-dimensional diagram of a $[Co(H_2O)_6]^{2+}$ complex ion including two bond angles is:



- Correct structure of the complex ion
  AND
  Correct 2+ charge; [1 mark]

The shape of the complex is:

- Octahedral; [1 mark]

The bond angles are:

- 90° correctly labelled on the diagram
  AND
  180° correctly labelled on the diagram; [1 mark]

[Total: 3 marks]

- Complexes with 6 ligands form an octahedral shape
- The bond angles within an octahedral structure are 90° for adjacent ligands and 180° for opposite ligands
- Since water is a neutral ligand, the complex will have an overall charge that is equal to the charge of the metal ion, i.e. 2+

d) The observations and equations for reactions 1 and 2 are:

Reaction 1

- Observation = blue / blue-green precipitate; [1 mark]
- Equation = $[Co(H_2O)_6]^{2+} + 2OH^- \rightleftharpoons Co(H_2O)_4(OH)_2 + 2H_2O$
  OR
  $Co(OH)_2 + 2OH^- \rightleftharpoons Co(OH)_2 + 2H_2O$; [1 mark]

Reaction 2

- Observation = (straw) yellow / brown solution; [1 mark]
- Equation = $Co(H_2O)_4(OH)_2 + 6NH_3 \leftrightharpoons [Co(NH_3)_6]^{2+} + 2H_2O + 2OH^-$
  OR
  $Co(OH)_2 + 6NH_3 \leftrightharpoons [Co(NH_3)_6]^{2+} + 2H_2O + 2OH^-$; [1 mark]

[Total: 4 marks]

- Cobalt(II) and copper(II) are the two transition metals that undergo ligand substitution with aqueous ammonia
- You need to be aware that cobalt(II) undergoes full substitution with 6 ligands being replaced by ammonia
  - Copper(II) undergoes partial ligand substitution with only four ligands being replaced by ammonia
- You also need to be aware of the colours / states associated with these complexes and reactions
- You could also be asked a follow on question about the $[Co(NH_3)_6]^{2+}$ as it will readily oxidise from a straw yellow / brown solution to form a blue solution of $[Co(NH_3)_6]^{3+}$

e)

i) A hexadentate ligand is:

- A ligand that can donate six lone pairs of electrons (to a central metal atom / ion); [1 mark]
- To form six dative (covalent) / coordinate bonds; [1 mark]

ii) The type of reaction is:

- Ligand exchange / displacement / replacement / substitution; [1 mark]

iii) The stability constant, K_{stab}, expression of $[CoEDTA]^{2-}$ in this reaction is:

- $K_{stab} = \frac{[[CuEDTA]^{2-}]}{[[Cu(H_2O)_6]^{2+}][[EDTA]^{4-}]}$; [1 mark]

iv) The numerical value of the K_{stab} tells us that the $[CoEDTA]^{2-}$ complex ion is:

- (Very) stable
  OR
  More stable than $[Co(H_2O)_6]^{2+}$; [1 mark]

[Total: 5 marks]

- The term ligand refers to a chemical that is able to donate lone pairs of electrons to a central metal atom / ion
  - You will most commonly be asked about mono- and bidentate ligands
- Since all of the water ligands are replaced by one EDTA ligand, this is a ligand exchange reaction
- The equation for the reaction is:
  - $[Co(H_2O)_6]^{2+} + EDTA^{4-} \rightleftharpoons [CoEDTA]^{2-} + 6H_2O$
- The reaction equation can be used (much like K_c) to deduce the K_{stab} expression
  - **Remember:** Water does not feature in K_{stab} expressions
  - $K_{stab} = = \frac{\text{products}}{\text{reactants}} = \frac{[[CuEDTA]^{2-}]}{[[Cu(H_2O)_6]^{2+}][[EDTA]^{4-}]}$
- **Remember:** The greater the value of K_{stab} the more stable the complex is

Answer 2.

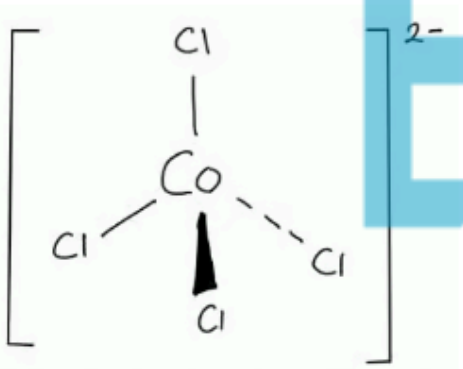
a)

i) The equation for the reaction when concentrated hydrochloric acid is added to $[Cu(H_2O)_6]^{2+}$:

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

- $[CoCl_4]^{2-}$ complex including correct charge; [1 mark]
- Rest of the equation fully correct; [1 mark]

ii) The three-dimensional diagram to show the complex formed in the reaction between $[Co(H_2O)_6]^{2+}(aq)$ and HCl is:



- Correct structure
  AND
  Correct charge; [1 mark]
- 3-D bonds used correctly
  AND
  Showing the tetrahedral shape of the complex; [1 mark]

[Total: 4 marks]

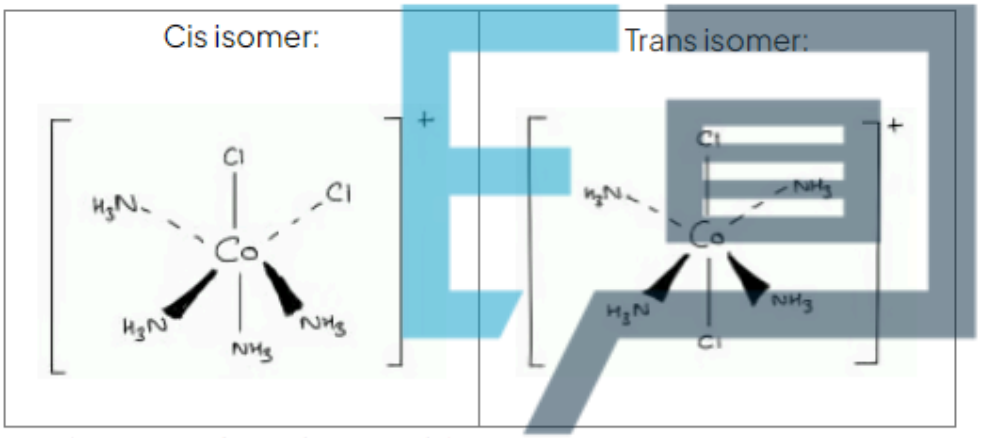
- In the ligand substitution reaction, the six water ligands are replaced by four chloride ions
- The shape of the complex formed is tetrahedral as it has four bonding pairs of electrons around the central metal ion
- As the chloride ion is larger than water a change in coordination number is observed

b)

i) The oxidation state of cobalt is:

- +3; [1 mark]
- The NH_3 ligands are neutral and the Cl- ligands each contribute -1
  OR
  The NH_3 ligands are neutral and the Cl- ligands overall contribute -2; [1 mark]

ii) The structures of each isomer are:



- Six correct ligands around Co
  AND
  Bonds are shown from the N of NH_3; [1 mark]
- 3-D bonds used correctly for an octahedral structure; [1 mark]
- cis and trans isomers correctly identified; [1 mark]

[Total: 5 marks]

- In the cis isomer, the two Cl^- ligands are at 90° to each other / next to each other
- In the trans isomer, the two Cl^- ligands are at 180° to each other / opposite or across from each other

c) Explanation of the origin of colour in a transition element complex such as $[Co(NH_3)_4Cl_2]^+$:

- Complexes have two sets of d orbital(s) of different energy
  OR
  d-orbitals split into two sets (of orbitals); [1 mark]
- Visible light absorbed (and complementary colour observed); [1 mark]
- Electron(s) are promoted / excited
  OR
  Electron(s) moves to higher (d–) orbital; [1 mark]

[Total: 3 marks]

- Questions about the origins of colour in transition metal complexes are typically for these same three marks
- So, it is worth taking the time to learn these points

Answer 3.

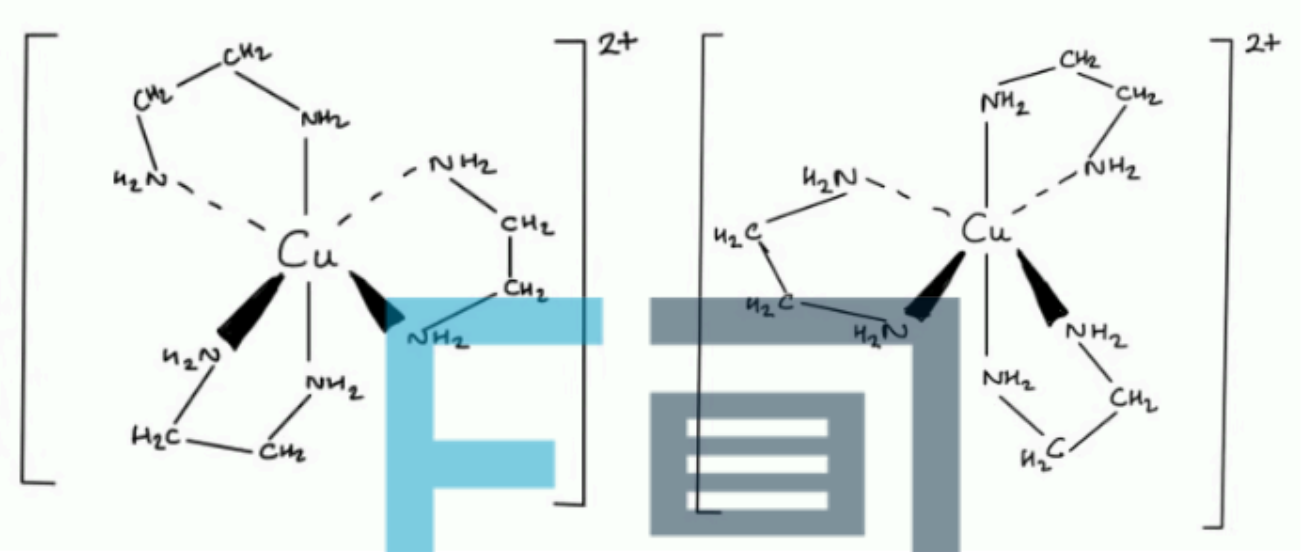
a) The meaning of bidentate ligand is:

- A ligand that donates 2 lone pairs to central metal atom / ion
  OR
  A ligand that forms 2 dative bonds to central metal atom / ion; [1 mark]

[Total: 1 mark]

- You need to able to describe what monodentate, bidentate and polydentate ligands are

c) The three-dimensional structures for the two optical isomers are:



- Three correct ligands around Cu
  AND
  Bonds are shown from the N of the 1,2–diaminoethane ligand; [1 mark]
- 3–D bonds used correctly to show an octahedral shape; [1 mark]
- Two mirror images to show optical isomerism; [1 mark]

[Total: 3 marks]

- The optical isomers are non-superimposable mirror images of each other
  - You must be confident in drawing these - questions asking for you to draw the isomers are common

b) The equation for the reaction of $[Cu(H_2O)_6]^{2+}$ with 1,2–diaminoethane is:

$$[Cu(H_2O)_6]^{2+} + 3H_2NCH_2CH_2NH_2 \rightarrow [Cu(H_2NCH_2CH_2NH_2)_3]^{2+} + 6H_2O$$

- $[Cu(H_2NCH_2CH_2NH_2)_3]^{2+}$ complex correct; [1 mark]
- Rest of the equation fully correct; [1 mark]

[Total: 2 marks]

- Each of the 1,2–diaminoethane ligands can form 2 coordinate bonds to the central metal ion, as they are bidentate ligands
  - So, only 3 molecules of 1,2–diaminoethane are required to replace all 6 of the water ligands

Answer 4.

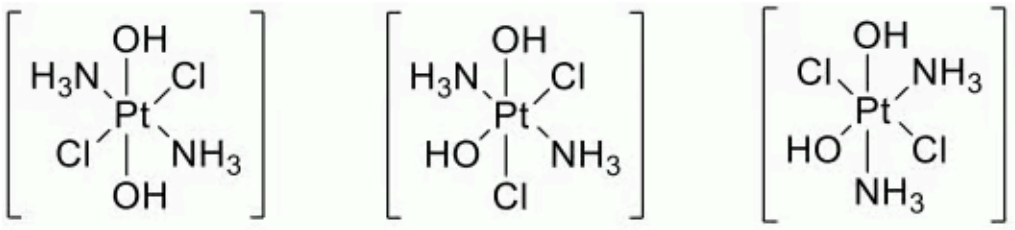
a) The correct information is:

- Oxidation number of the platinum ion = +4; [1 mark]
- Shape of the complexes = Octahedral; [1 mark]

[Total: 2 marks]

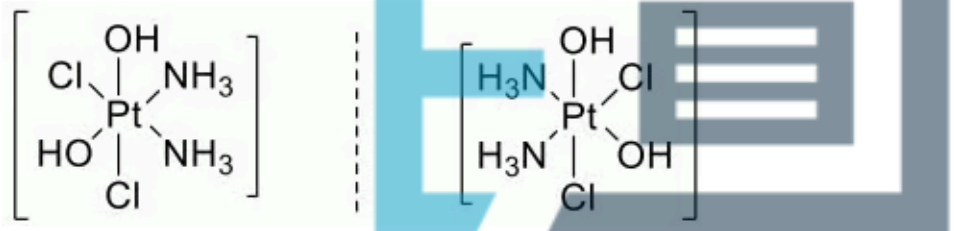
- You are told in the question that all four complexes have the same oxidation number for the platinum ion and the same shape
- Oxoplatin is the simplest of the four complexes as it contains familiar ligands that you should know the charges for:
  - OH = -1
  - Cl = -1
  - NH_3 = 0
- The overall charge on the complex is zero meaning, which means that:
  - Pt + (2 x OH) + (2 x Cl) + (2 x NH_3) = 0
  - Pt + (2 x –1) + (2 x –1) + (2 x 0) = 0
  - Pt + (–2) + (–2) = 0
  - Pt – 4 = 0
  - Pt = 4
- All of the complexes have 6 coordinate bonds, which means that the shape must be octahedral

b) The stereoisomers of oxoplatin are:



- Each correct structure; [1 mark]

The chiral isomers are:

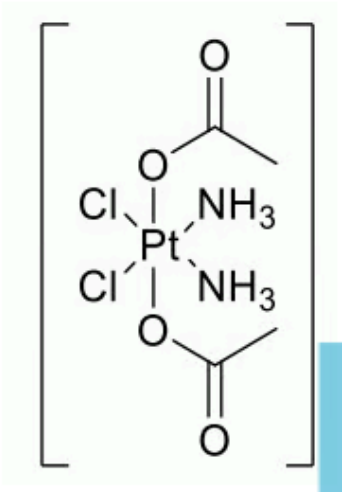


- Both enantiomer structures; [1 mark]

[Total: 4 marks]

- The stereoisomers can be identified by arranging the ligands in different positions relative to one another around the central Pt atom
- **Careful:**
  - Do not give the oxoplatin structure from Fig. 1.1 as an answer, this will not score a mark
  - When drawing these isomers, it can be easy to draw the same structure twice but from a different angle
- You can see none of the top three stereoisomers are chiral by drawing a dotted line and flipping the structure
  - For each of these, you will be able to rotate this flipped structure to align with the original isomer drawn
  - Therefore, they are not non-superimposable images

c) The structure of *cis*, *trans*, *cis*-$[PtCl_2(OCOCH_3)_2(NH_3)_2]$ is:

- 

; [1 mark]

[Total: 1 mark]

- There are three pairs of different ligands in this structure
  - Cl
  - $OCOCH_3$
  - NH_3
- The *cis*, *trans*, *cis* in the complex formula *cis*, *trans*, *cis*-$[PtCl_2(OCOCH_3)_2(NH_3)_2]$ refers, in order, to the three pairs of ligands
  - *Cis* - Cl
  - *Trans* - $OCOCH_3$
  - *Cis* – NH_3
- **Remember**
  - *Cis* means that the ligands are adjacent / next to each other
  - *Trans* means that the ligands are opposite one another