

Transition Elements

Topical - Paper 4

Chembridge

Faizan Saleem

+92 331 5000262

1. Fe^{2+} and Fe^{3+} ions are able to form a variety of complexes with different species.

Define complex.

.....

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..... [1]

2. Define transition element.

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..... [1]

3. Define degenerate d orbitals.

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..... [1]

4. An aqueous solution of $\text{Fe}(\text{NO}_3)_3$ contains the complex $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$.

When solutions of $\text{KSCN}(\text{aq})$ and $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$ are mixed, a colour change is observed. The red complex $[\text{Fe}(\text{H}_2\text{O})_5\text{SCN}]^{2+}$ forms.

Define complex.

.....

..... [1]

5. Define stability constant.

.....

..... [1]

6. Phosphine, $:\text{PH}_3$, and carbon monoxide, $:\text{CO}$, are monodentate ligands found in some transition element complexes.

Define monodentate ligand.

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..... [1]

7. Define transition element complex.

.....
..... [1]

8. Explain what is meant by a polydentate ligand.

.....
.....
..... [2]

9. The calcium ions in $[\text{Ca}(\text{H}_2\text{O})_6]^{2+}$ and $[\text{CaEDTA}]^{2-}$ have a coordination number of 6.

Explain what is meant by coordination number.

.....
..... [1]

10. Define complex ion.

.....
..... [1]

11. Explain what is meant by a bidentate ligand.

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..... [2]

12. Define stability constant.

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..... [1]

13. Copper is a transition element. It forms a wide variety of compounds.

(a) Define transition element.

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..... [1]

(b) In an isolated Cu^{2+} ion the d-orbitals are all degenerate. In a complex ion such as $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ the d-orbitals are non-degenerate.

Define degenerate and non-degenerate in this context.

degenerate

non-degenerate [1]

14. Cu^{2+} forms a complex ion containing water molecules and ethanedioate ions, $\text{C}_2\text{O}_4^{2-}$, as ligands. The formula of the complex is $[\text{Cu}(\text{C}_2\text{O}_4)_2(\text{H}_2\text{O})_2]^{2-}$. The ethanedioate ion is a bidentate ligand.

Explain what is meant by bidentate.

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..... [1]

15. Define stability constant.

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..... [1]

16. (a) Define transition element.

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..... [1]

(b) Manganese(IV) oxide, MnO_2 , acts as a heterogeneous catalyst in the decomposition of hydrogen peroxide, H_2O_2 .

(i) Explain what is meant by a heterogeneous catalyst.

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..... [1]

(ii) Describe the mode of action of a heterogeneous catalyst in a reaction.

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..... [2]

17. Explain what is meant by bidentate ligand.

.....

18. Define stability constant, K_{stab} .

[2]

19. Titanium is a transition element in Period 4.

It is commonly found as TiO_2 in minerals.

(a) Define transition element.

[1]

[2]

(b) Identify two typical properties of transition elements.

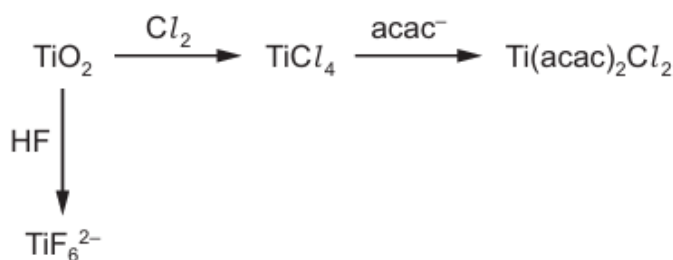
1

2 [1]

(c) Some reactions of TiO_2 are shown in Fig. 3.1.

The anion, acac^- , is a bidentate ligand.

Fig. 3.1



(i) The titanium ions in TiF_6^{2-} and $\text{Ti}(\text{acac})_2\text{Cl}_2$ have a coordination number of 6.

State what is meant by coordination number.

[1]

(ii) Write an equation for the formation of TiF_6^{2-} from TiO_2 .

..... [1]

(iii) State what is meant by bidentate ligand.

.....

 [2]

20. Vanadium is a transition element in Period 4 of the Periodic Table.

(a) Define transition element.

.....
 [1]

(b) Vanadium shows typical chemical properties of transition elements, including variable oxidation states.

(i) State two other typical chemical properties of transition elements.

1
 2 [1]

(ii) Explain why transition elements have variable oxidation states.

.....
 [1]

21. Methylamine, CH_3NH_2 , is another primary amine. CH_3NH_2 can act as a monodentate ligand.

Define monodentate ligand.

.....

 [2]

22. Cobalt forms the complex ion $[\text{Co}(\text{NH}_3)_2(\text{en})_2]^{2+}$. The abbreviation *en* is used for the bidentate ligand 1,2-diaminoethane, $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$. The complex ion shows both geometrical and optical isomerism.

Define the term bidentate ligand.

.....
 [2]

23. Transition elements form complexes.

Molybdenum, Mo, forms an octahedral complex consisting of one Mo atom surrounded by carbon monoxide, CO, molecules. CO is a monodentate ligand. Iron forms an octahedral complex consisting of one Fe^{3+} and a number of cyanide, CN^- , ions. CN^- is a monodentate ligand.

Define the term monodentate ligand.

.....
 [1]

24. Define the term bidentate ligand.

.....
 [2]

25. Define the term *transition element*.

.....
 [1]

26. An aqueous solution of chromium(III) contains the green $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ complex ion.

(a) Complete the electronic configuration of an isolated, gaseous Cr^{3+} ion.

$1s^2$ [1]

(b) Define the term *complex ion*.

.....
 [1]

27. Define the term *ligand*.

.....
 [1]

28. The transition elements are able to form stable complexes with a wide range of molecules and ions.

State the meaning of *transition element*.

.....
 [1]

29. When $1.0 \text{ mol dm}^{-3} \text{ Na}_2\text{S}_2\text{O}_3$ (aq) is added to a solution containing Ag^+ (aq) ions, a linear complex, **P**, is formed. $\text{S}_2\text{O}_3^{2-}$ ions are present in **P** as monodentate ligands.

(a) Define the term monodentate ligand.

.....

..... [2]

(b) Give the formula of **P**, including its charge.

..... [1]

30. EDTA^{4-} , is a polydentate ligand.

Explain what is meant by the term *polydentate ligand*.

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..... [2]

31. (a) Iron is a transition element in the fourth period. Iron forms compounds containing the ions Fe^{2+} and Fe^{3+} .

Define the term *transition element*.

.....

.....

..... [1]

(b) Define the term monodentate ligand.

.....

..... [2]

(c) **E** is a complex ion, $[\text{Fe}(\text{C}_2\text{O}_4)_2\text{Cl}_2]^{4-}$, containing Fe^{2+} with a coordination number of 6.

Define the term *coordination number*.

.....

..... [1]

32. Copper is a transition element.

(a) Complete the electronic configurations of a Cu^+ ion & a Cu^{2+} ion.

Cu^+ ion: $[\text{Ar}]$

Cu^{2+} ion: $[\text{Ar}]$

[1]

(b) Explain why transition elements have variable oxidation states.

.....

..... [1]

33. Silver, Ag, is a metal in the d-block of the periodic table.

Silver can form compounds containing either Ag^+ or Ag^{2+} ions.

Explain why silver is a transition element.

.....

..... [1]

34. Fe^{2+} ions can be oxidised to Fe^{3+} ions under alkaline conditions by suitable oxidising agents.

Iron is a transition element. Explain why iron forms stable compounds in both the +2 and the +3 oxidation states.

..... [1]

35. Transition metals atoms and transition metals ions form complexes by combining with ligands.

Explain why transition elements form complex ions.

.....

..... [1]

36. Potassium iron(III) ethanedioate, $\text{K}_3[\text{Fe}(\text{C}_2\text{O}_4)_3]$, dissolves in water to form a green solution.

Explain why transition elements can form coloured complexes.

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..... [3]

37. Explain why transition elements have variable oxidation states.

.....
..... [1]

38. Iron is a transition metal in Group 8 of the Periodic Table.

Explain why iron has variable oxidation states.

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.....
..... [1]

39. Complete the shorthand electronic configurations of Fe and Fe³⁺.

Fe [Ar]

Fe³⁺ [Ar] [1]

40. (a) The molecule H₂NCH₂CH₂NHCH₂CH₂NH₂ is a tridentate ligand.

Suggest the meaning of tridentate ligand.

.....
..... [1]

(b) Suggest how H₂NCH₂CH₂NHCH₂CH₂NH₂ acts as a tridentate ligand.

.....
..... [1]

41. State **two** typical chemical properties of a transition element.

1

2 [1]

42. Explain why transition elements have variable oxidation states.

.....
..... [1]

43. The complex ion $[\text{CoCl}_4]^{2-}$ has a tetrahedral geometry.

The 3d orbitals in an isolated Co^{2+} ion are degenerate.

(a) Complete Fig. 2.2 to show the relative energies of the 3d orbitals in an isolated Co^{2+} ion and in Co^{2+} in a tetrahedral complex.

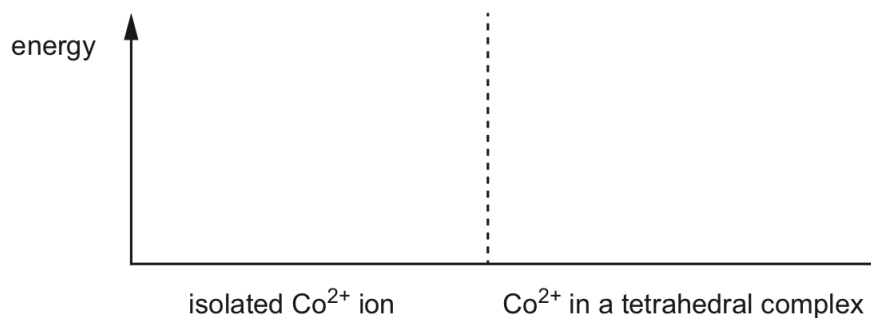
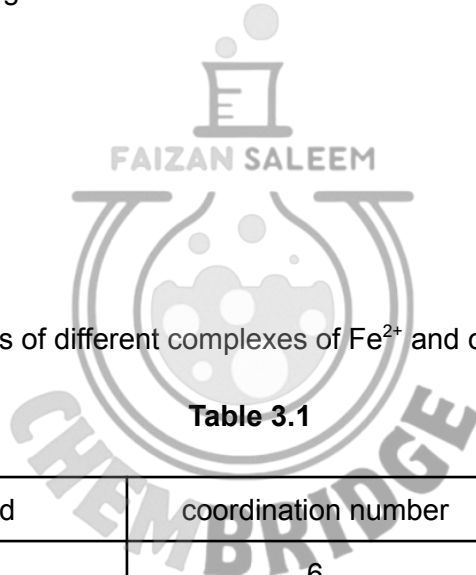


Fig. 2.2

[2]

(b) Draw the three-dimensional diagram to show the structure of the complex ion $[\text{CoCl}_4]^{2-}$.



[1]

44. (a) Table 3.1 gives some details of different complexes of Fe^{2+} and of Fe^{3+} . Complete Table 3.1.

Table 3.1

complex	ion	ligand	coordination number	formula & charge of complex
E	Fe^{2+}	NH_3	6	
F				$[\text{FeCl}_4]^{2-}$
G		en		$[\text{Fe}(\text{en})_3]^{3+}$

[3]

(b) Complete Fig. 3.1 to show the splitting of the d-orbitals in a tetrahedral complex.

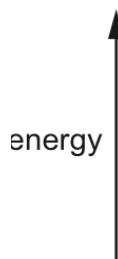


Fig. 3.1

[1]

45. (a) The 3d orbitals in an isolated Ag^+ ion are degenerate.

Sketch the shape of a $3d_{xy}$ orbital in Fig. 2.1.

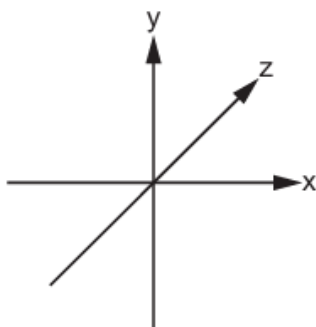


Fig. 2.1

[1]

(b) Name the shape of the complex ion $[\text{Ag}(\text{NH}_3)_2]^+$.

State the bond angle for H-N-Ag and for N-Ag-N.

shape

bond angle for H-N-Ag = ... °

bond angle for N-Ag-N = ... °

[2]

(c) Coordination polymers are made when a bidentate ligand acts as a bridge between different metal ions. Under certain conditions $\text{Ru}^{3+}(\text{aq})$ and the bidentate ligand *dps* can form a coordination polymer containing $[\text{Ru}(\text{dps})\text{Cl}_4]^-$ chains.

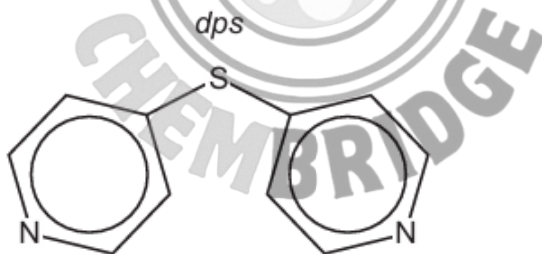


Fig. 2.2

The bidentate ligand *dps* uses each of the nitrogen atoms to bond to a different Ru^{3+} .

Complete Fig. 2.3 by drawing the structure for the coordination polymer $[\text{Ru}(\text{dps})\text{Cl}_4]^-$. Show **two** repeat

units. The *dps* ligand can be represented using .

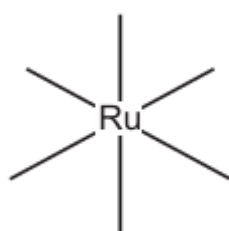


Fig. 2.3

[2]

46. Transition elements behave as catalysts and can form complex ions.

(a) Explain why transition elements behave as catalysts.

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.....

..... [2]

(b) Silver forms the linear complex ion $[\text{Ag}(\text{CN})_2]^-$.

Copper forms the tetrahedral complex ion $[\text{Cu}(\text{CN})_4]^{3-}$.

Titanium forms the complex $[\text{TiCl}_4(\text{diars})_2]$, where diars is a neutral bidentate ligand.

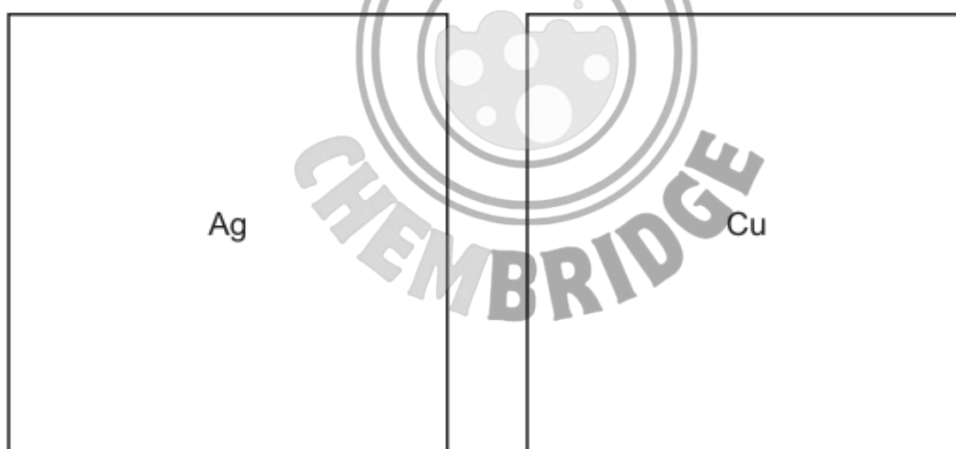
(i) State the oxidation state and the coordination number of titanium in $[\text{TiCl}_4(\text{diars})_2]$.

oxidation state

coordination number

[1]

(ii) Draw three-dimensional diagrams to show the shapes of $[\text{Ag}(\text{CN})_2]^-$ and $[\text{Cu}(\text{CN})_4]^{3-}$, in the boxes. Label one bond angle on each diagram.



[2]

47. Five ligands are listed in Table 6.1.

Table 6.1

ligand	type of ligand
NH_3	
EDTA^{4-}	
CN^-	
$\text{H}_2\text{NCH}_2\text{CH}_2\text{NHCH}_2\text{CH}_2\text{NH}_2$	tridentate
$\text{C}_2\text{O}_4^{2-}$	

Complete Table 6.1 using the words monodentate, bidentate and polydentate only.

Each of these three words may be used once, more than once, or not at all.

[2]

48. The formulae of six complexes are given in Table 6.1.

The abbreviation *en* is used for 1,2-diaminoethane.

The abbreviation *dien* is used for the tridentate ligand $\text{H}_2\text{NCH}_2\text{CH}_2\text{NHCH}_2\text{CH}_2\text{NH}_2$.

The *dien* ligand forms three bonds to the gold ion in $[\text{Au}(\textit{dien})(\text{H}_2\text{O})_2\text{Cl}]^{2+}$ and $\text{Au}(\textit{dien})\text{Cl}_3$.

These three bonds all lie in the same plane.

The CO ligand coordinates through the carbon atom in $[\text{Rh}(\text{CO})_2\text{Cl}_2]^+$.

Table 6.1

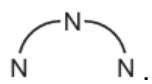
formula	isomerism shown	geometry
$[\text{Rh}(\textit{en})_2\text{Cl}_2]^+$	yes	
$[\text{Rh}(\text{CO})_2\text{Cl}_2]^+$	yes	
$[\text{Au}(\textit{dien})(\text{H}_2\text{O})_2\text{Cl}]^{2+}$		
$\text{Au}(\textit{dien})\text{Cl}_3$	no	octahedral
$\text{Ni}(\text{PH}_3)_2\text{Cl}_2$	no	
$[\text{Ni}(\text{H}_2\text{O})_2(\text{NH}_3)_4]^{2+}$	yes	

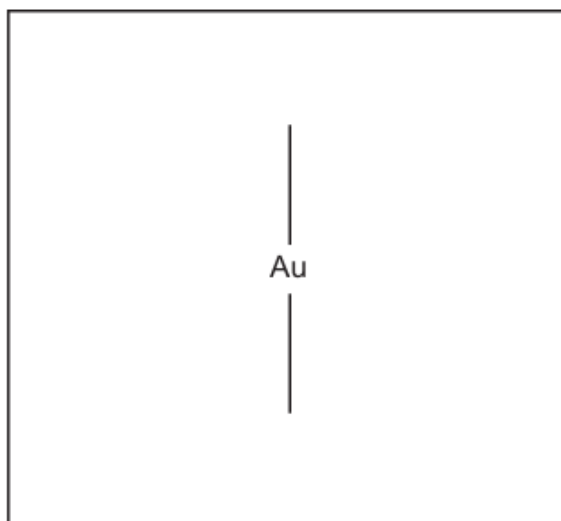
(a) Complete Table 6.1 to state the geometry of the first three complexes. Each complex is either square planar, tetrahedral or octahedral. [1]

(b) Use complexes $[\text{Au}(\textit{dien})(\text{H}_2\text{O})_2\text{Cl}]^{2+}$ and $\text{Au}(\textit{dien})\text{Cl}_3$ to write an equation showing ligand exchange.

..... [1]

(c) Draw the three-dimensional structure of $\text{Au}(\textit{dien})\text{Cl}_3$ in the box.

The *dien* ligand can be drawn as .



[1]

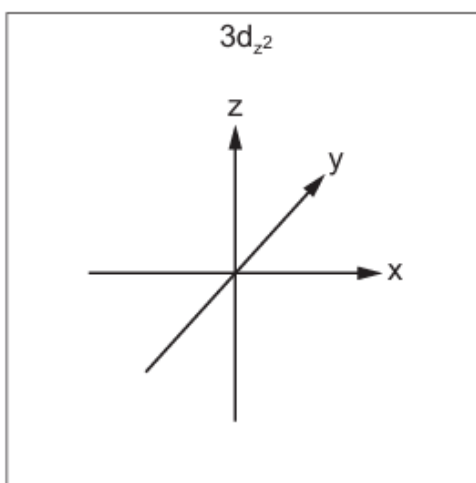
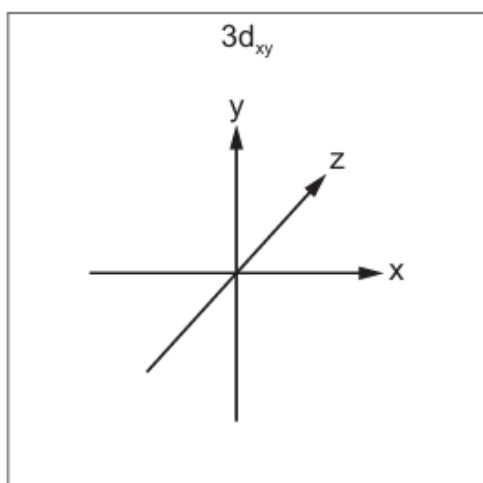
(d) Draw the three-dimensional structure of $\text{Ni}(\text{PH}_3)_2\text{Cl}_2$ in the box.



[1]

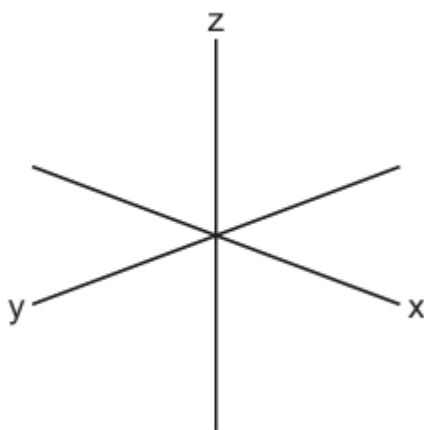
49. A transition element is a d-block element which forms one or more stable ions with incomplete d-orbitals.

Two of the 3d orbitals are the $3d_{xy}$ orbital and the $3d_{z^2}$ orbital. Sketch the shapes of these two orbitals.



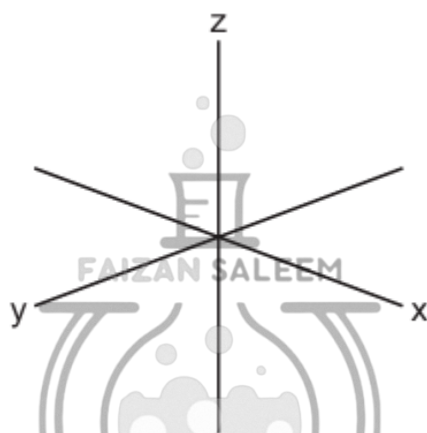
[1]

50. Sketch the shape of a $3d_{z^2}$ orbital.



[1]

51. Sketch the shape of a $3d_{xy}$ orbital. [1]



52. Vanadium is a transition element in Period 4 of the Periodic Table.

An excess of $\text{C}_2\text{O}_4^{2-}$ reacts with VO_2^+ to form a mixture of two octahedral complex ions. The complex ions are stereoisomers of each other.

Each complex ion contains a V^{2+} cation and three $\text{C}_2\text{O}_4^{2-}$ ions.

Complete the diagram to show the three-dimensional structure of one of the complex ions.

Include the charge of the complex ion.

Use  to represent a $\text{C}_2\text{O}_4^{2-}$ ion. [2]



53. $[\text{MnCl}_4]^{2-}$ is a complex ion.

(a) Deduce the oxidation state of manganese in $[\text{MnCl}_4]^{2-}$.

oxidation state = ... [1]

(b) The $[\text{MnCl}_4]^{2-}$ complex does not contain any 180° bond angles.

Draw a three-dimensional diagram to show the shape of the $[\text{MnCl}_4]^{2-}$ complex.

State one bond angle on your diagram. [2]



54. Transition elements form complexes.

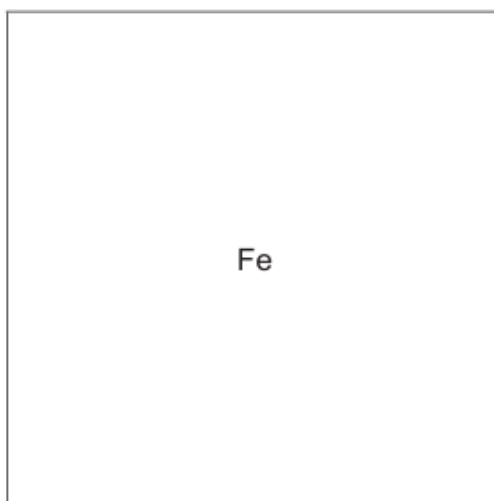
Molybdenum, Mo, forms an octahedral complex consisting of one Mo atom surrounded by carbon monoxide, CO, molecules. CO is a monodentate ligand. Iron forms an octahedral complex consisting of one Fe^{3+} and a number of cyanide, CN^- , ions. CN^- is a monodentate ligand.

(a) Complete the table by stating the formulae and charges of the complexes described. [2]

	formula	charge
molybdenum complex		
iron(III) complex		

(b) Draw a three-dimensional diagram to show the shape of this iron(III) complex.

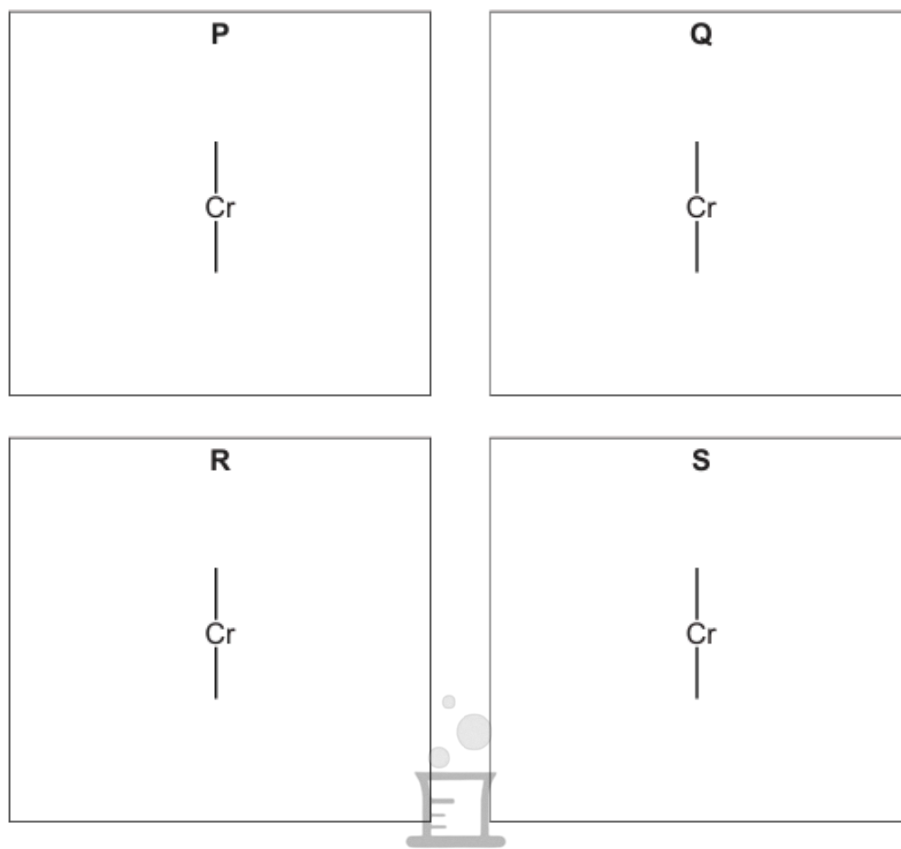
Label one 180° bond angle on your diagram. [1]



55. (a) Four different compounds can be obtained when anhydrous chromium(III) chloride reacts with water under various conditions. When samples of each compound are reacted separately with aqueous silver nitrate, different amounts of silver chloride are precipitated. The precipitation leaves the complex ions **P**, **Q**, **R** and **S** in solution.

formula of compound	moles of AgCl precipitated per mole of complex ion	complex ion	property of complex ion
$\text{CrCl}_3(\text{H}_2\text{O})_6$	3	P	non-polar
$\text{CrCl}_3(\text{H}_2\text{O})_5$	2	Q	polar
$\text{CrCl}_3(\text{H}_2\text{O})_4$	1	R	polar
$\text{CrCl}_3(\text{H}_2\text{O})_4$	1	S	non-polar

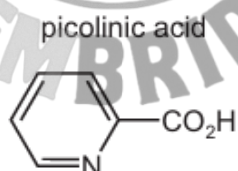
(i) Draw three-dimensional diagrams for the structures of complex ions **P**, **Q**, **R** and **S**. Include the charges for each complex ion. **[4]**



(ii) Suggest why complex ion **S** is non-polar.

.....
 [1]

(b) The structure of picolinic acid is shown.



The conjugate base of picolinic acid is a bidentate ligand, **Z**.

(i) Draw the structure of **Z**.

[1]

(ii) **Z** reacts with aqueous chromium(III) ions, $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$, in a 3 : 1 ratio to form a new neutral complex.

State the coordination number and the geometry of the chromium(III) centre in the complex.

coordination number geometry

[1]

(c) $(\text{NH}_4)_2\text{Cr}_2\text{O}_7$ decomposes readily on heating to form Cr_2O_3 , steam and an inert colourless gas.

(i) Deduce the oxidation numbers of chromium in $(\text{NH}_4)_2\text{Cr}_2\text{O}_7$ and in Cr_2O_3 .

$(\text{NH}_4)_2\text{Cr}_2\text{O}_7$ Cr_2O_3

[1]

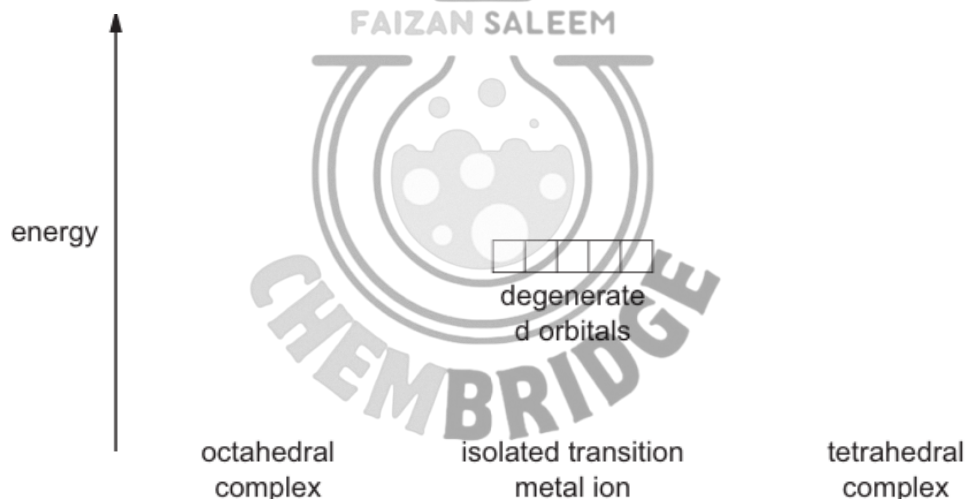
(ii) Construct an equation for the thermal decomposition of $(\text{NH}_4)_2\text{Cr}_2\text{O}_7$.

..... [1]

56. The transition elements are able to form stable complexes with a wide range of molecules and ions.

The d orbitals in an isolated transition metal ion are degenerate. In complexes, the d orbitals occupy two energy levels.

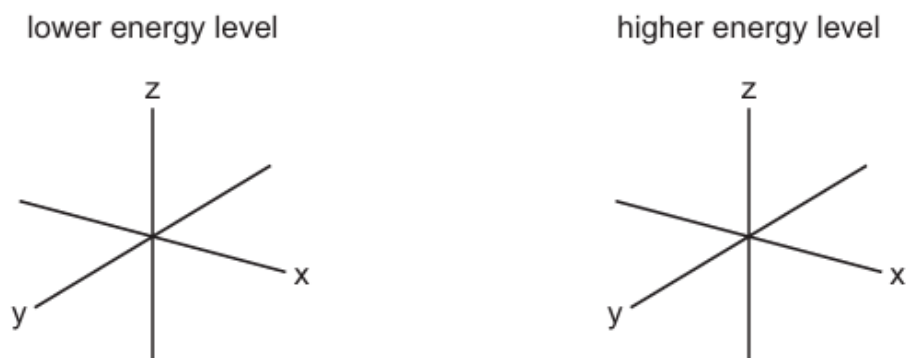
(a) Complete the diagram to show the arrangement of d orbital energy levels in octahedral and in tetrahedral complexes. [1]



(b) Sketch the shape of **two** d orbitals:

- one d orbital from the lower energy level in an octahedral complex
- one d orbital from the higher energy level in an octahedral complex.

Use the axes below. [2]



57. (a) The electronic configuration of transition element **Q** is $[\text{Ar}] 3d^2 4s^2$.
Predict the likely oxidation states of element **Q** in compounds.

[1]

(b) Suggest why transition elements often show variable oxidation states in their compounds, but typical s-block elements such as calcium do not.

[1]

58. When Cobalt (II) Sulfate, CoSO_4 , is dissolved in water, solution **A** is formed.
The reaction scheme in Fig. 2.1 shows some reaction of solution **A**.

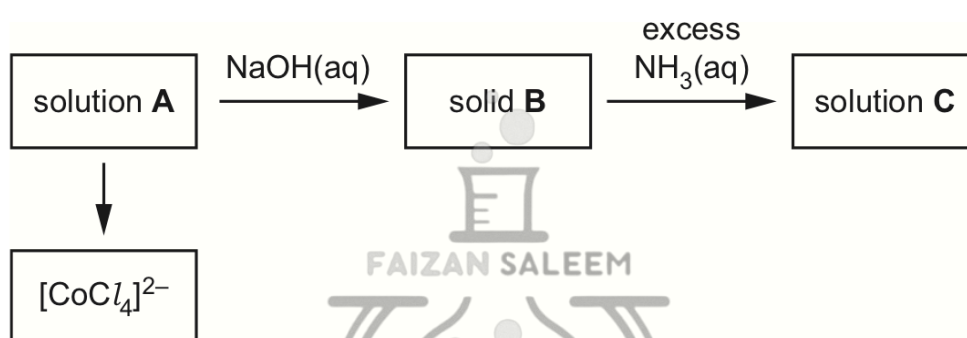


Fig. 2.1

(a) Complete Table 2.1 to show the formula & colour of each of the cobalt-containing species present in **A**, **B** and **C**. Identify the type of reaction forming each of **B** and **C**.

Table 2.1

	formula of cobalt-containing species	colour of cobalt-containing species	type of reaction
A			—
B			
C			

[4]

(b) Suggest a suitable reagent for the forms of $[\text{CoCl}_4]^{2-}$ from solution **A**.

[1]

59. Transition metals atoms and transition metals ions form complexes by combining with ligands.

Co^{2+} ions form complex ion **G**.

Each **G** contains **two** Co^{2+} ions, both of which are octahedrally coordinated.

Each **G** ion contains one O_2 molecule, which donates one pair of electrons to **each** Co^{2+} ion, & one NH_2^- ion, which donates one pair of electrons to **each** Co^{2+} ion.

(a) Deduce the formula of complex ion **G**. Include its overall charge.

formula of **G** [2]

(b) The d-orbitals of the Co^{2+} ions present in complex ion **G** are split. State the number of d-orbitals that are at a higher energy level & the number of d-orbitals that are at a lower energy level in **each** Co^{2+} ion.

number of d-orbitals at a higher energy level	
number of d-orbitals at a lower energy level	

[1]

(c) Co^{2+} ions form a different complex ion, **M**.

Each **M** ion contains **two** Co^{2+} ions, both of which are octahedrally coordinated, but the ligands are different from the ligands in **G**.

Explain why **G** and **M** have different colours.

.....

.....

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[2]

60. Solutions containing the $[\text{Ag}(\text{NH}_3)_2]^+$ complex are colourless.

Explain why this complex is colourless.

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[2]

61. Iron is a transition metal in Group 8 of the Periodic Table.

An aqueous solution of $\text{Fe}(\text{NO}_3)_3$ contains the complex $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$.

When solutions of KSCN(aq) and $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$ are mixed, a colour change is observed. The red complex $[\text{Fe}(\text{H}_2\text{O})_5\text{SCN}]^{2+}$ forms.

(a) State the coordination number of Fe in $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$.

..... [1]

(b) The H—O—H bond angle in water is 104.5° . Suggest the H—O—H bond angle in $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$. Explain your answer.

.....

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..... [1]

(c) Explain why iron complexes are coloured.

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..... [3]

(d) Aqueous solutions of complexes $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ and $[\text{Fe}(\text{H}_2\text{O})_5\text{SCN}]^{2+}$ are different colours.

Explain why these complexes are different colours.

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.....

..... [2]

62. Suggest why a solution of Cu^{2+} is coloured but solid Cu/ is white.

.....

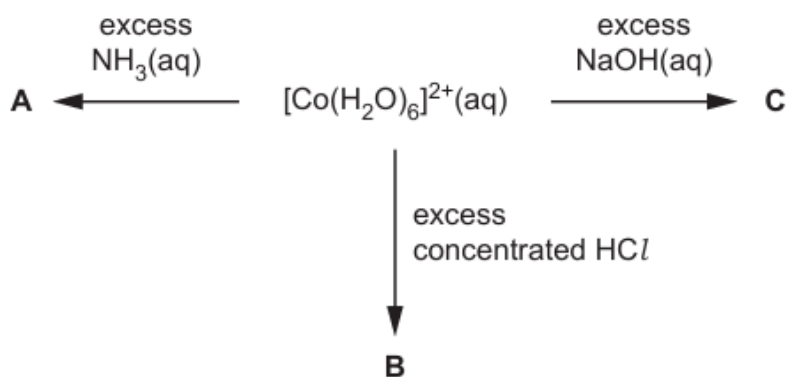
.....

..... [2]

63. Aqueous solutions of cobalt(II) salts contain the complex ion $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$.

Samples of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ are reacted separately with an excess of aqueous ammonia, with an excess of concentrated HCl and with an excess of aqueous sodium hydroxide, as shown in Fig. 2.1.

Fig. 2.1



Complete Table 2.1 about the reactions shown by $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$.

Table 2.1

reagent added to $[\text{Co}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$	formula of cobalt species formed	colour and state of cobalt species formed	type of reaction
an excess of $\text{NH}_3(\text{aq})$	A =		
an excess of concentrated HCl	B =		
an excess of $\text{NaOH}(\text{aq})$	C =		

[4]

64. Copper is a transition element. It forms a wide variety of compounds.

An aqueous solution of copper(II) sulfate, CuSO_4 , contains $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ complex ions. If an excess of concentrated hydrochloric acid is added to this solution a ligand exchange reaction occurs and $[\text{CuCl}_4]^{2-}$ complex ions are formed.

(a) Complete Table 5.1 to state the geometry, the coordination number of copper, and one bond angle in each of the two complex ions.

Table 5.1

complex ion	geometry	coordination number	bond angle
$[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$			
$[\text{CuCl}_4]^{2-}$			

[3]

(b) Explain why the solutions of the two complex ions in Table 5.1 are **different** colours.

.....

..... [1]

65. Titanium is a transition element in Period 4.

It is commonly found as TiO_2 in minerals.

(a) The TiO^{2+} ion forms when TiO_2 reacts with an excess of sulfuric acid.

TiO^{2+} can be reduced by zinc metal in acidic conditions to form a purple solution containing $\text{Ti}^{3+}(\text{aq})$.

(i) $\text{TiO}^{2+}(\text{aq})$ is a colourless ion.

Suggest why.

.....

 [2]

(ii) Give the electronic configuration of an isolated Ti^{3+} ion.

$1s^2$ [1]

(iii) Write an ionic equation for the reduction of TiO^{2+} by zinc metal in acidic conditions.

..... [1]

(b) When aqueous citrate ions, $\text{C}_6\text{H}_5\text{O}_7^{3-}$, are added to $\text{Ti}^{3+}(\text{aq})$, the $[\text{Ti}(\text{C}_6\text{H}_5\text{O}_7)_2]^{3-}(\text{aq})$ complex forms.

Explain, in terms of d-orbitals, why Ti^{3+} is able to form complex ions.

.....
 [1]

66. (a) An excess of aqueous ammonia is added to dilute copper(II) sulfate solution. A dark blue complex, $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$, is formed.

(i) Write an ionic equation for this reaction.

..... [1]

(ii) Explain the origin of colour in copper(II) complexes.

.....

[4]

(b) An excess of concentrated hydrochloric acid is added to the dark blue solution of $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$. A new complex, **Z**, is formed. The colour of the solution changes.

(i) Write an equation for the formation of **Z** from the solution of $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$. Include the formula and charge of **Z**.

[2]

(ii) Name the type of reaction when **Z** forms from $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$.

[1]

(iii) State the geometry of **Z**.

[1]

(iv) State the colour of a solution of **Z**.

[1]

(v) Explain why the colour of a solution of $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ is different from the colour of a solution of **Z**. You should refer to the energies of the orbitals involved in your answer.

[1]

67. Explain why chromium complexes are coloured.

[4]

68. An aqueous solution of chromium(III) contains the green $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ complex ion.

(a) $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$ shows some similar chemical properties to $[\text{Co}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$.

Samples of $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ are reacted separately with either $\text{NaOH}(\text{aq})$, $\text{H}_2\text{O}_2(\text{aq})$, or excess $\text{NH}_3(\text{aq})$.

Use this information and the *Data Booklet* to suggest the formula of the chromium species formed. State the type of reaction taking place in each case. [5]

reagent added to $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$	formula of chromium species formed	type of reaction
$\text{NaOH}(\text{aq})$		
$\text{H}_2\text{O}_2(\text{aq})$		
an excess of $\text{NH}_3(\text{aq})$		

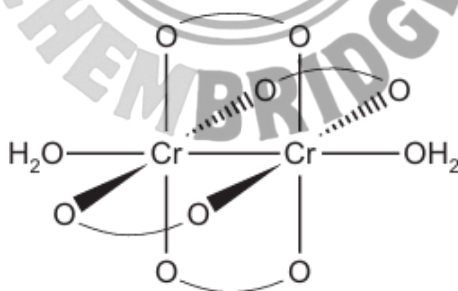
(b) $[\text{Cr}(\text{H}_2\text{O})_6]^{2+}$ and $[\text{Cr}_2(\text{O}_2\text{CCH}_3)_4(\text{H}_2\text{O})_2]$ are both complexes of chromium(II) and have different colours.

Explain why the colours of these complexes are different.

.....

 [2]

(c) The structure of $[\text{Cr}_2(\text{O}_2\text{CCH}_3)_4(\text{H}_2\text{O})_2]$ is shown. Ethanoate ions act as ligands in this complex. The ethanoate ligand, CH_3CO_2^- , is shown as



(i) Water and ethanoate ions behave as different types of ligand in this complex.

Suggest an explanation for this statement.

.....
 [1]

(ii) Deduce the coordination number of Cr and the geometry around each Cr atom in this structure.

coordination number

geometry around Cr atom

[1]

[4]

(b) When an excess of $\text{CN}^-(\text{aq})$ ions is added to green $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$ ions, yellow $[\text{Fe}(\text{CN})_6]^{4-}$ complex ions are formed.

Heating $[\text{Fe}(\text{CN})_6]^{4-}$ with dilute nitric acid and then neutralising the product with $\text{Na}_2\text{CO}_3(\text{aq})$ produces red crystals, containing the $[\text{Fe}(\text{CN})_5\text{NO}]^{2-}$ complex ion. NO is a neutral, monodentate ligand.

(i) State the shape of the $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$ complex ion.

[1]

(ii) Write the equation for the reaction between $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$ ions and an excess of $\text{CN}^-(\text{aq})$ ions.

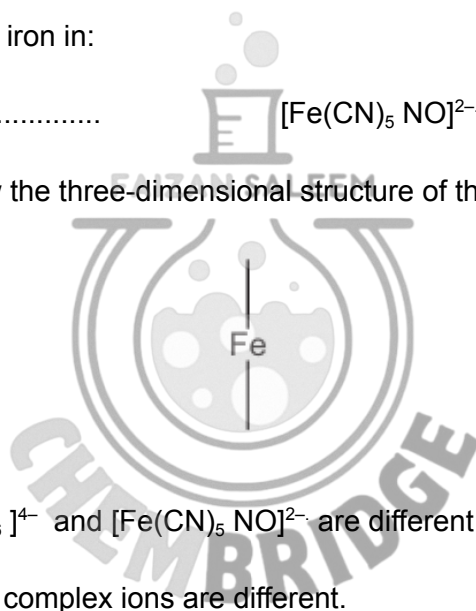
[1]

(iii) Deduce the oxidation states of iron in:

$[\text{Fe}(\text{CN})_6]^{4-}$

$[\text{Fe}(\text{CN})_5\text{NO}]^{2-}$ [1]

(iv) Complete the diagram to show the three-dimensional structure of the $[\text{Fe}(\text{CN})_5\text{NO}]^{2-}$ complex ion. [1]



(v) The two complex ions $[\text{Fe}(\text{CN})_6]^{4-}$ and $[\text{Fe}(\text{CN})_5\text{NO}]^{2-}$ are different colours.

Explain why the colours of the two complex ions are different.

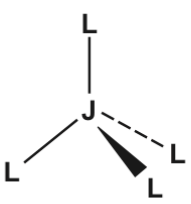
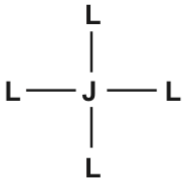
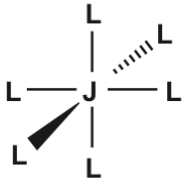
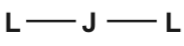
[2]

71. The shapes of four different complexes, **P**, **Q**, **R** and **S**, are shown in Table 5.1.

The symbol **J** represents an atom or ion of a transition element.

The symbol **L** is used to represent a monodentate ligand.

Table 5.1

P 	Q 
R 	S 

(a) Label **one** bond angle on **each** of the complexes **P**, **Q**, **R** and **S**, and identify the size of the angle in degrees. [2]

(b) Identify the shapes of complexes **P**, **Q**, **R** and **S**.

P

Q

R

S [2]

(c) Two **L** ligands are exchanged with two **different** monodentate ligands **X** and **Y** in each of complexes **P**, **Q**, **R** and **S**.

Identify all the complexes which form new complexes that show geometrical isomerism.

..... [1]

(d) Three **L** ligands are exchanged with three **different** monodentate ligands **X**, **Y** and **Z** in each of complexes **P**, **Q** and **R**.

Identify all the complexes which form new complexes that show optical isomerism.

..... [1]

72. Potassium iron(III) ethanedioate, $K_3[Fe(C_2O_4)_3]$, dissolves in water to form a green solution.

The $[Fe(C_2O_4)_3]^{3-}$ complex ion shows stereoisomerism.

Complete the three-dimensional diagrams in Fig. 3.1 to show the two stereoisomers of $[Fe(C_2O_4)_3]^{3-}$.

The $C_2O_4^{2-}$ ligand can be represented using .

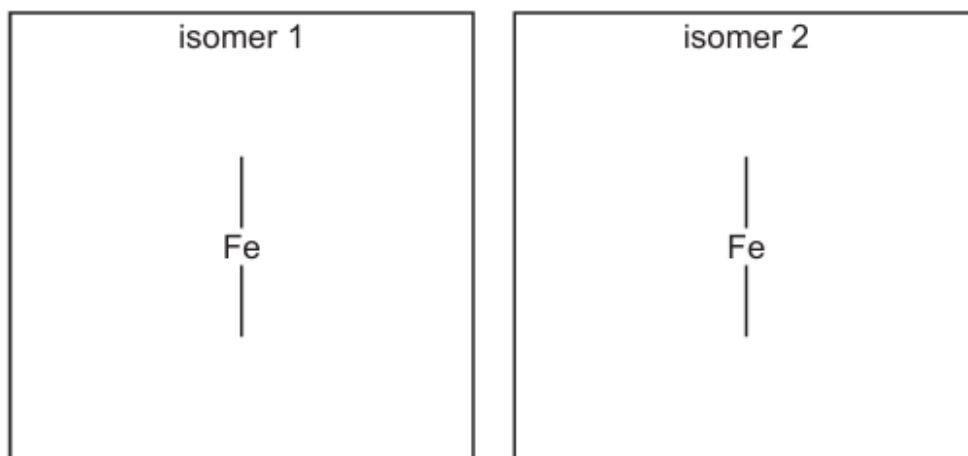


Fig. 3.1

[2]

73. Two bidentate ligands are shown in Fig. 4.2.



Fig. 4.2

Ruthenium(III) ions, Ru^{3+} , form an octahedral complex, $[\text{Ru}(\text{dpys})_2\text{Cl}_2]^+$, with the ligands *dpys* and chloride ions.

This complex shows the same kind of stereoisomerism as $[\text{Ru}(\text{NH}_3)_4\text{Cl}_2]^+$ but also shows a different type of stereoisomerism.

(a) Complete the three-dimensional diagrams in Fig. 4.3 to show the **three** different stereoisomers of

$[\text{Ru}(\text{dpys})_2\text{Cl}_2]^+$. The *dpys* ligand can be represented using . [3]

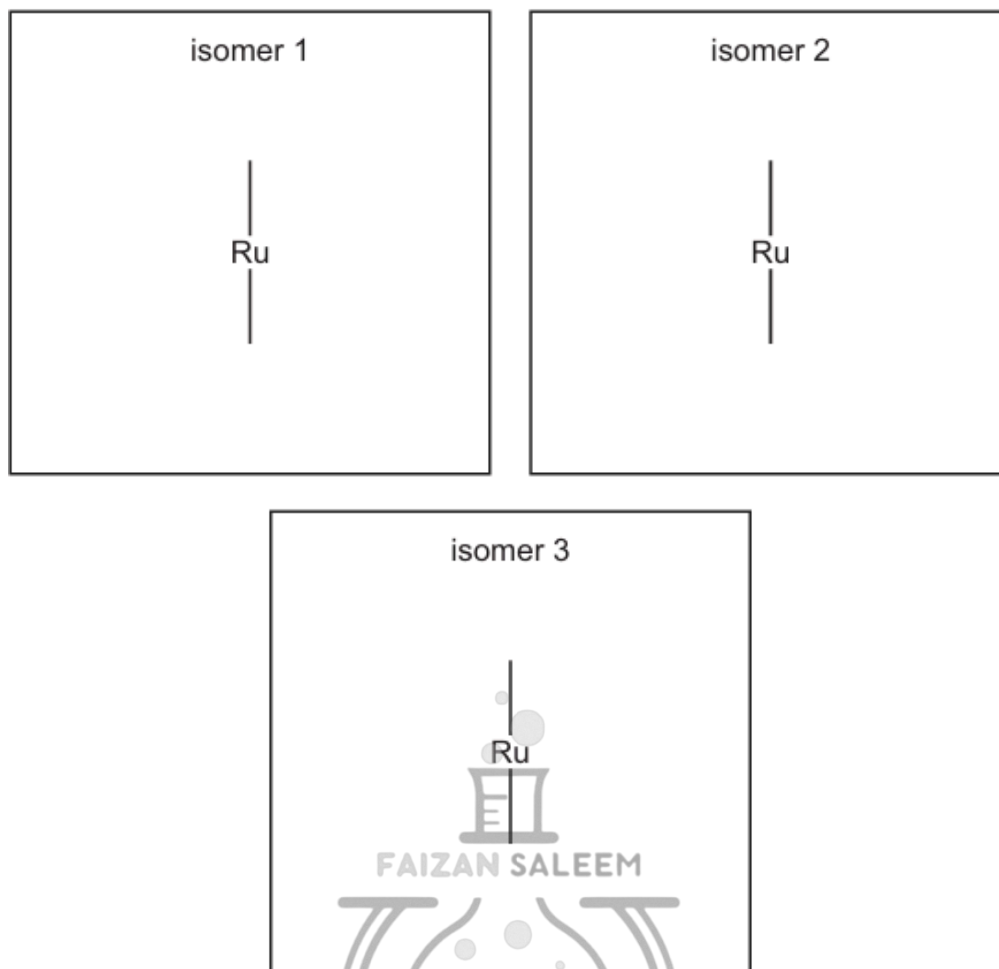


Fig. 4.3

(b) State the different types of stereoisomerism shown by $[\text{Ru}(\text{dpys})_2\text{Cl}_2]^+$.

[1]

(c) Deduce which stereoisomers in (e)(i) are non-polar. Explain your answer.

[1]

74. Nickel forms the octahedral complex $[\text{Ni}(\text{en})_2(\text{H}_2\text{O})_2]^{2+}$. This complex can exist in three isomeric forms, listed in Table 6.2. One of these forms is a trans isomer, the other forms are two different cis isomers.

Table 6.2

isomer	polarity
trans isomer	
cis isomer 1	
cis isomer 2	

(a) Complete Table 6.2 using the terms polar or non-polar. Each term may be used once, more than once, or not at all. [1]

(b) Describe the difference between cis isomer 1 and cis isomer 2.

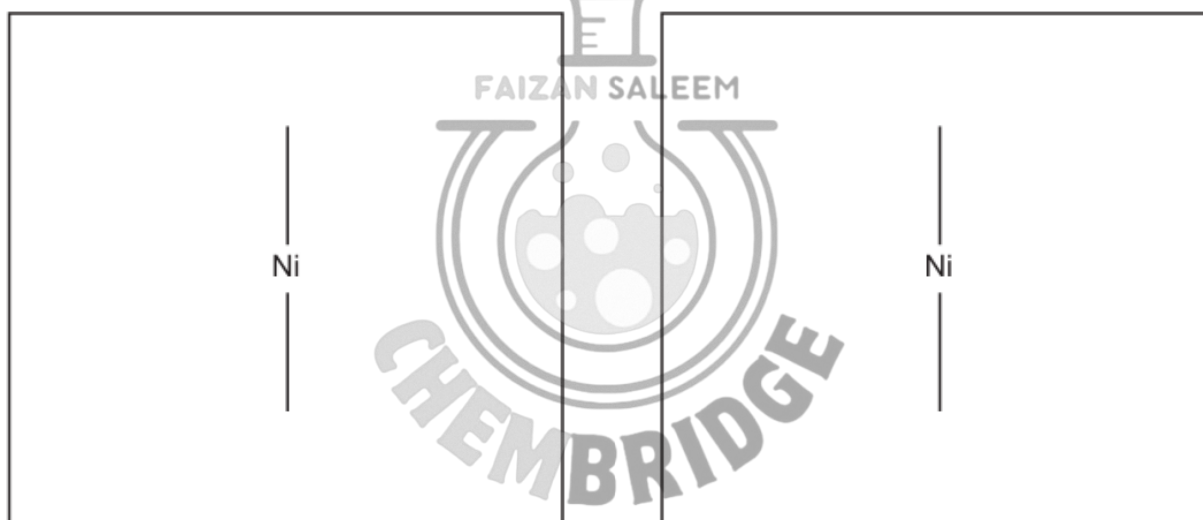
.....
 [1]

75. (a) One of the complexes, $[\text{Rh}(\text{en})_2\text{Cl}_2]^+$ or $[\text{Rh}(\text{CO})_2\text{Cl}_2]^+$, can exist in three isomeric forms.

Identify this complex and the types of isomerism shown.

.....
 [1]

(b) Draw the three-dimensional structures of the two isomers of $[\text{Ni}(\text{H}_2\text{O})_2(\text{NH}_3)_4]^{2+}$ in the boxes and identify the type of isomerism shown.



type of isomerism shown [2]

76. (a) Some transition element complexes can show stereoisomerism.

State **two** types of stereoisomerism shown by transition element complexes.

1
 2 [1]

(b) The complexes $[\text{Pt}(\text{NH}_3)_2\text{Cl}_2]$ and $[\text{Pt}(\text{en})_2]^{2+}$ have the same geometry (shape) around the metal ion.

$[\text{Pt}(\text{NH}_3)_2\text{Cl}_2]$ exists as two stereoisomers whereas $[\text{Pt}(\text{en})_2]^{2+}$ only has one possible structure.

State the geometry around the metal ion.

(c) The complex $[\text{Cr}(\text{en})_3]^{2+}$ exists as two stereoisomers whereas the complex $[\text{Cr}(\text{OCH}_2\text{CH}_2\text{NH}_2)_3]^-$ exists as four stereoisomers.

Complete the three-dimensional diagrams in Fig. 2.1 to show the four stereoisomers of $[\text{Cr}(\text{OCH}_2\text{CH}_2\text{NH}_2)_3]^-$.

Represent the ligand $-\text{OCH}_2\text{CH}_2\text{NH}_2$ by using .

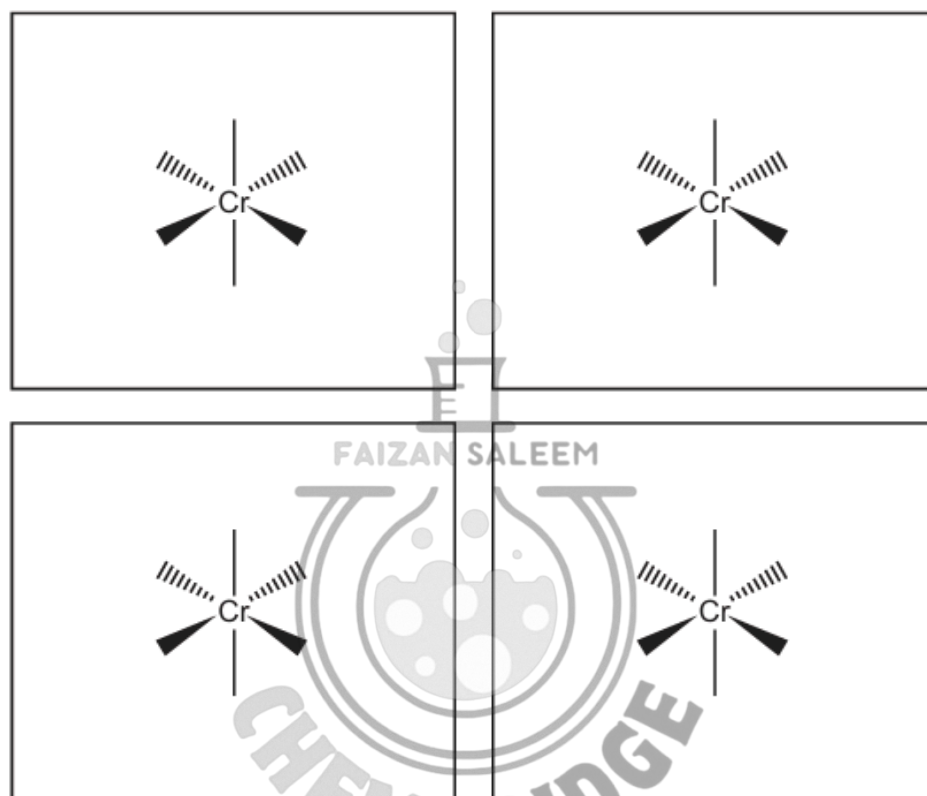


Fig. 2.1

[3]

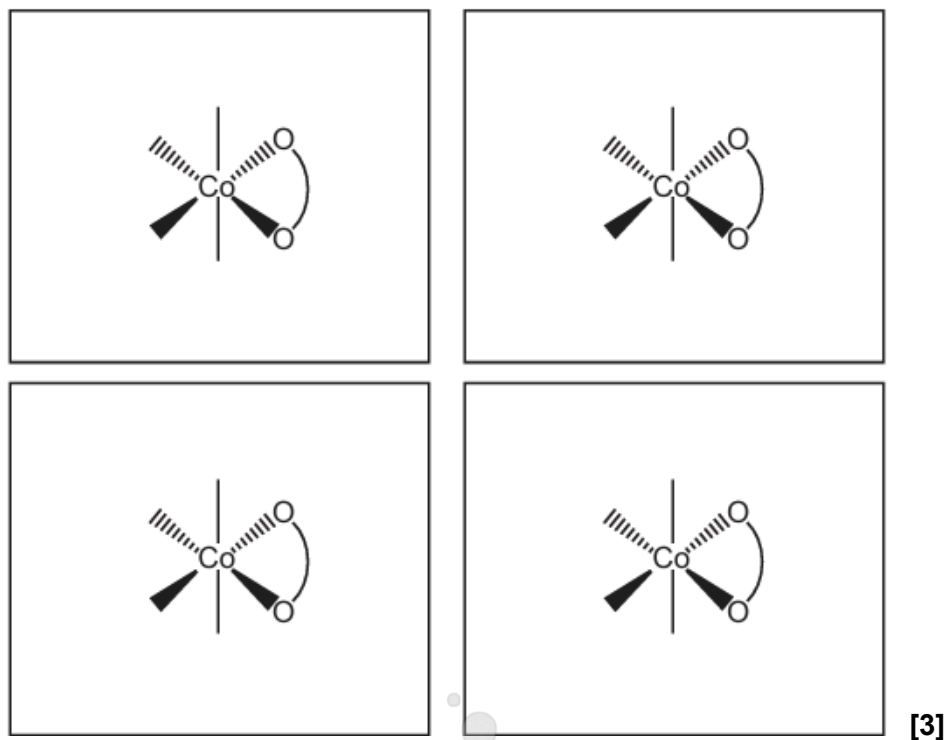
77. The ethanedioate ion, $\text{C}_2\text{O}_4^{2-}$, can act as a bidentate ligand.

(a) The complex $[\text{Co}(\text{H}_2\text{O})_2(\text{C}_2\text{O}_4)\text{BrCl}]^-$ exists as stereoisomers.

Complete the three-dimensional diagrams in Fig. 2.2 to show **four** stereoisomers of $[\text{Co}(\text{H}_2\text{O})_2(\text{C}_2\text{O}_4)\text{BrCl}]^-$.

The $\text{C}_2\text{O}_4^{2-}$ ligand is represented using .

Fig. 2.2



(b) State the oxidation state of cobalt in this complex and a type of stereoisomerism shown.

oxidation state of cobalt

type of stereoisomerism [1]

78. The Ni^{2+} ion forms many different complexes. A solution containing the $[\text{Ni}(\text{H}_2\text{O})_6]^{2+}$ complex ion is green. When an excess of 1,2-diaminoethane, *en*, $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$, is added, the colour of the solution changes to blue. This is due to the formation of the $[\text{Ni}(\text{en})_3]^{2+}$ complex ion.

(a) Explain why the two solutions are coloured, and why the colours are different.

.....

.....

.....

.....

.....

.....

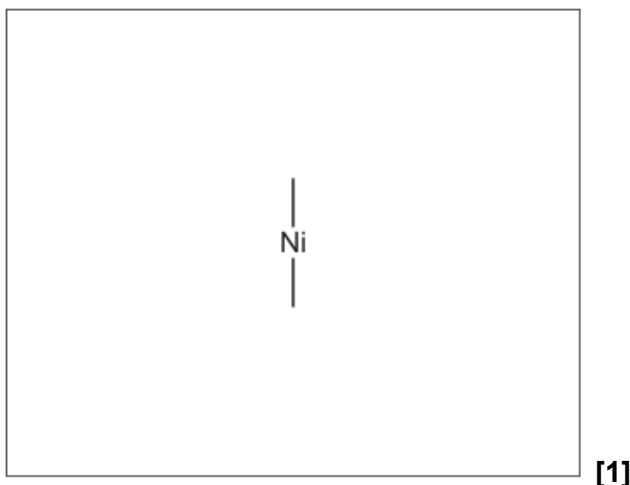
.....

..... [4]

(b) The $[\text{Ni}(\text{en})_3]^{2+}$ complex can exist as a mixture of two stereoisomers.

Complete the three-dimensional diagram to show one of the stereoisomers. Each *en* ligand can be

represented using .



[1]

(c) Name the geometry of the complex ion drawn in (b)(ii) and the type of stereoisomerism shown by $[\text{Ni}(\text{en})_3]^{2+}$.

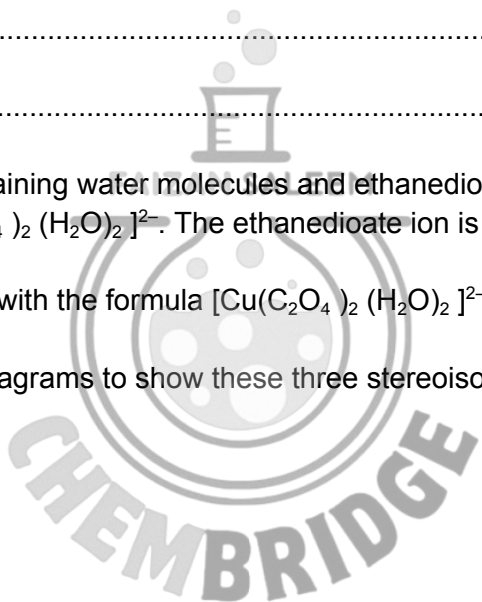
geometry

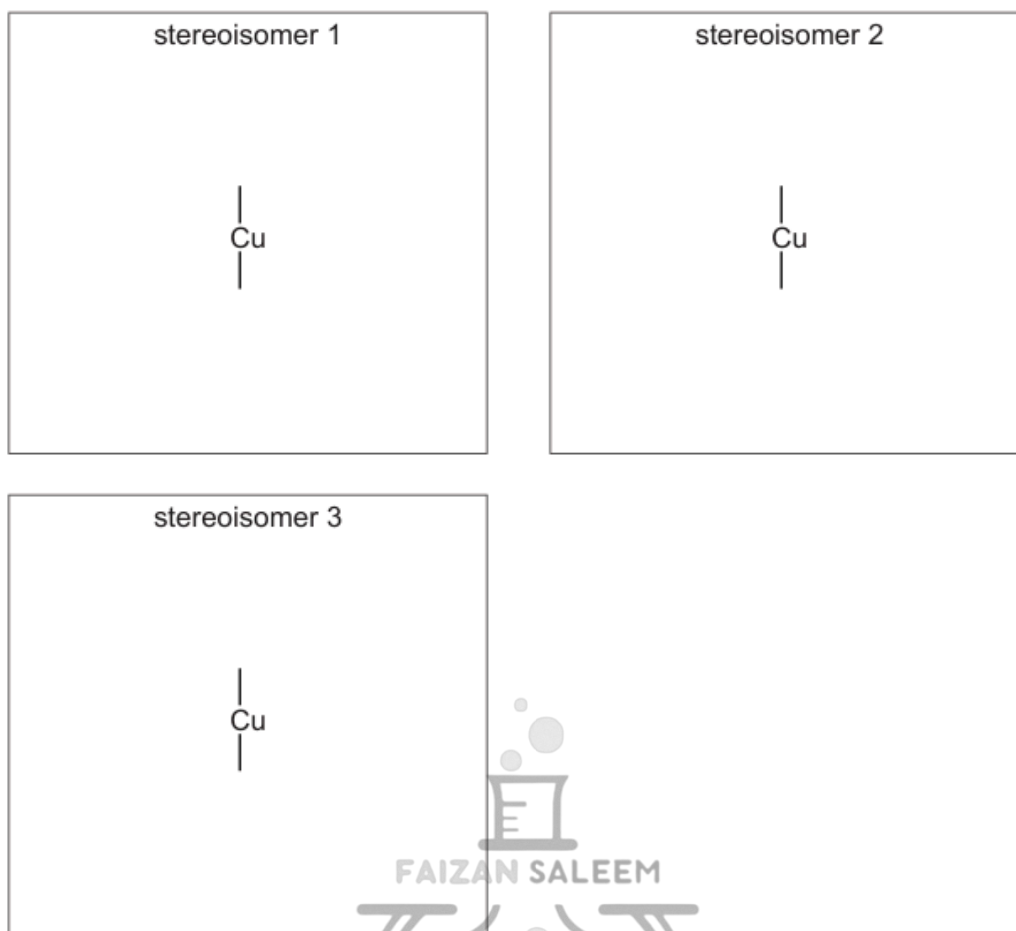
stereoisomerism shown [1]

79. Cu^{2+} forms a complex ion containing water molecules and ethanedioate ions, $\text{C}_2\text{O}_4^{2-}$, as ligands. The formula of the complex is $[\text{Cu}(\text{C}_2\text{O}_4)_2(\text{H}_2\text{O})_2]^{2-}$. The ethanedioate ion is a bidentate ligand.

(a) There are three stereoisomers with the formula $[\text{Cu}(\text{C}_2\text{O}_4)_2(\text{H}_2\text{O})_2]^{2-}$.

Complete the three-dimensional diagrams to show these three stereoisomers.





[2]

(b) Use your answer to (c)(ii) to answer this question.

Stereoisomers 1, 2 and 3 show two different types of isomerism.

Name these two types of isomerism.

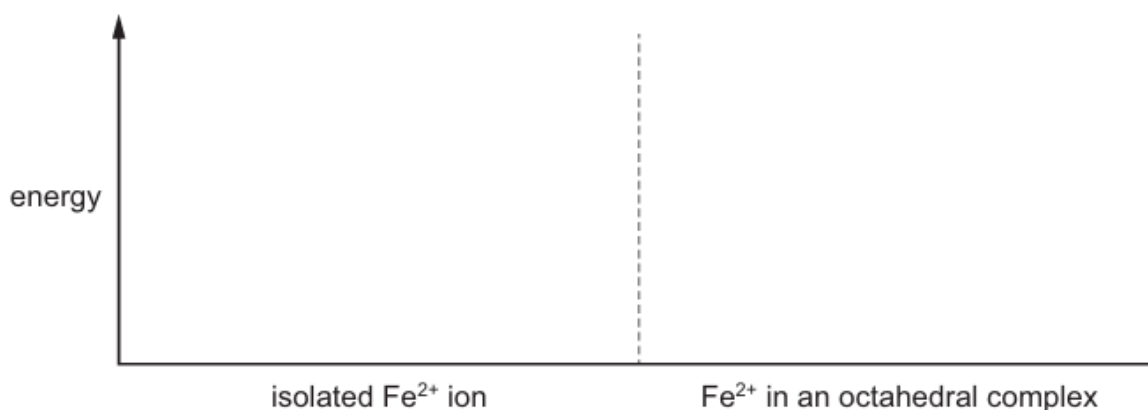
For each type of isomerism identify the pair of stereoisomers that demonstrate this isomerism.

type of isomerism	pair of stereoisomers
	and
	and

[2]

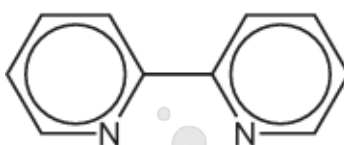
80. (a) The 3d orbitals in an isolated Fe^{2+} ion are degenerate.

Complete the diagram to show the splitting of the 3d orbital energy levels in an isolated Fe^{2+} ion and when Fe^{2+} forms an octahedral complex. [2]



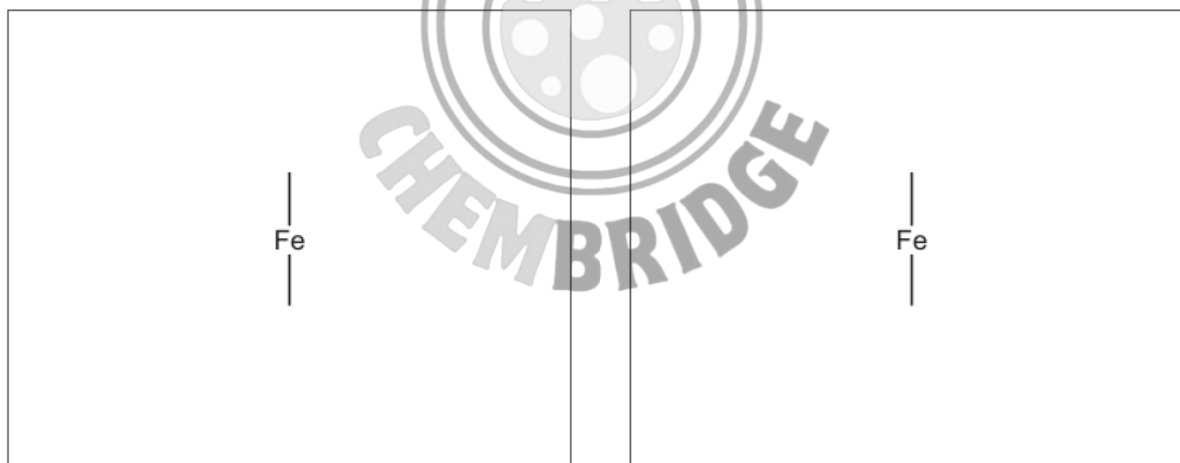
(b) Bipyridine, bipy, is a bidentate ligand.

Fig. 4.1
bipy



The complex $[\text{Fe}(\text{bipy})_3]^{2+}$ exists as two stereoisomers. Complete the three-dimensional diagrams to show the two stereoisomers of $[\text{Fe}(\text{bipy})_3]^{2+}$. State the type of stereoisomerism shown.

Use  to represent bipy in your diagrams.



type of stereoisomerism [3]

81. Complete Table 1.1 to show the coordination number of each metal ion, and the shapes and overall polarities of the complex ions listed. [2]

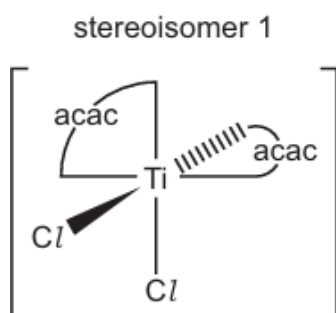
Table 1.1

complex ion	shape	coordination number	polar or non-polar
<i>cis</i> - $[\text{Pt}(\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2)\text{Cl}_2]$	square planar		
$[\text{Ag}(\text{NH}_3)_2]^+$			non-polar
$[\text{Fe}(\text{C}_2\text{O}_4)_3]^{3-}$		6	

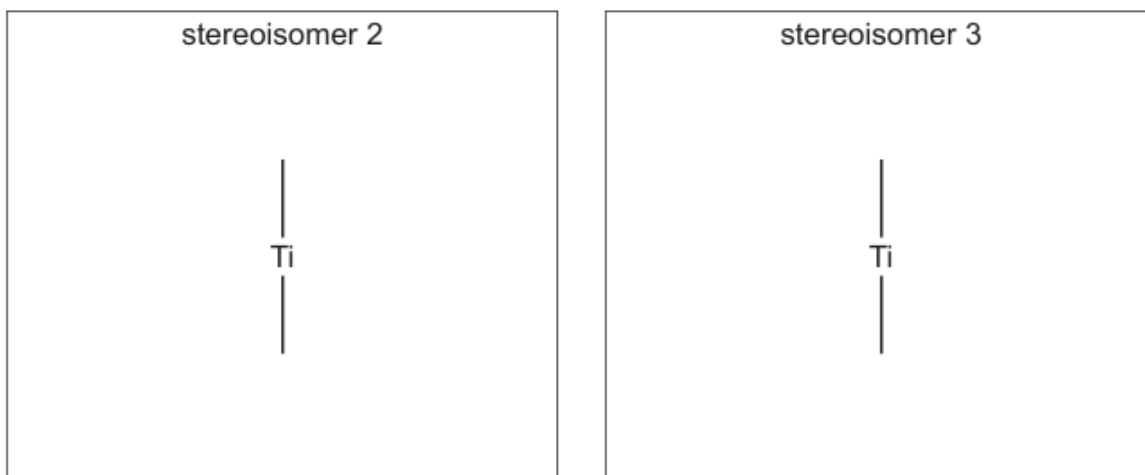
[3]

The structure of one stereoisomer of $\text{Ti}(\text{acac})_2\text{Cl}_2$ is shown in Fig. 3.2.

Fig. 3.2



Complete the structures of the other two stereoisomers of $\text{Ti}(\text{acac})_2\text{Cl}_2$. [2]



(b) The acac^- anion is symmetrical.

Deduce which, if any, of stereoisomers 1, 2 and 3 in (a) are polar.
Explain your answer.

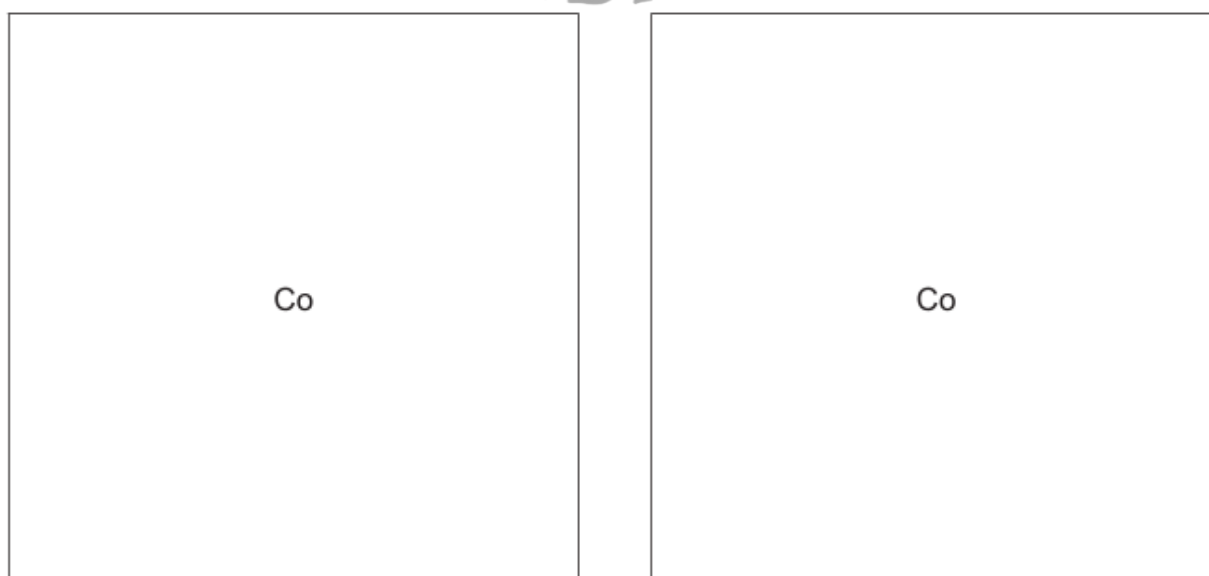
.....

 [2]

84. Cobalt forms the complex ion $[\text{Co}(\text{NH}_3)_2(\text{en})_2]^{2+}$. The abbreviation *en* is used for the bidentate ligand 1,2-diaminoethane, $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$. The complex ion shows both geometrical and optical isomerism.

Draw three-dimensional diagrams for the two optical isomers of $[\text{Co}(\text{NH}_3)_2(\text{en})_2]^{2+}$. Each *en* ligand can be

represented using . [2]

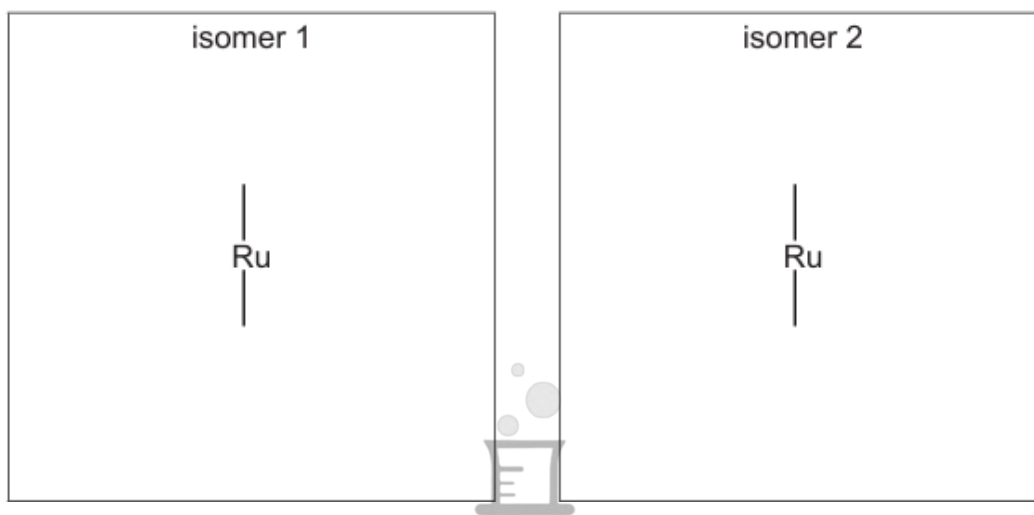


85. The complex $[\text{Ru}(\text{en})_3]^{3+}$ shows stereoisomerism. The ligand *en* is bidentate.

Draw three-dimensional diagrams to show the two isomers of $[\text{Ru}(\text{en})_3]^{3+}$. Represent the ligand *en* by using



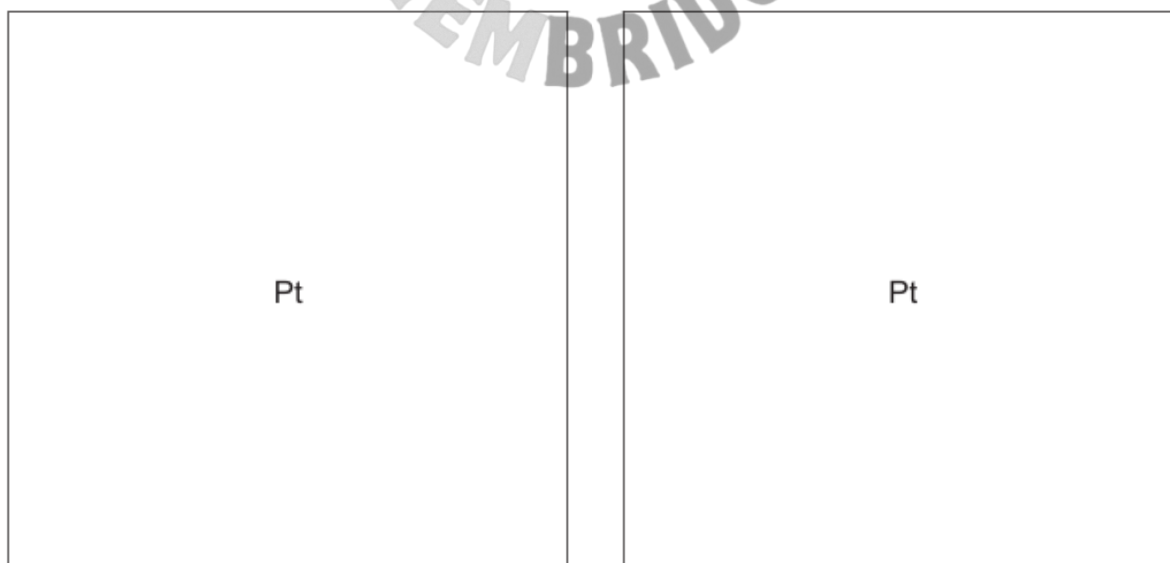
Name the type of stereoisomerism.



type of stereoisomerism **[3]**

86. Platinum forms a complex ion with the formula $[\text{Pt}(\text{CN})_2\text{Cl}_2]^{2-}$. In this complex ion the carbon atom of each CN^- ligand bonds to the platinum ion. This complex shows stereoisomerism.

(a) There are only two isomers of this complex. Draw structures of these two isomers in the boxes below. **[1]**



(b) Describe the geometry of $[\text{Pt}(\text{CN})_2\text{Cl}_2]^{2-}$.

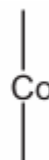
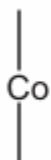
..... **[1]**

(c) Name the type of stereoisomerism shown by $[\text{Pt}(\text{CN})_2\text{Cl}_2]^{2-}$.

[1]

87. The $[\text{Co}(\text{NH}_3)_3\text{Cl}_3]$ complex shows stereoisomerism.

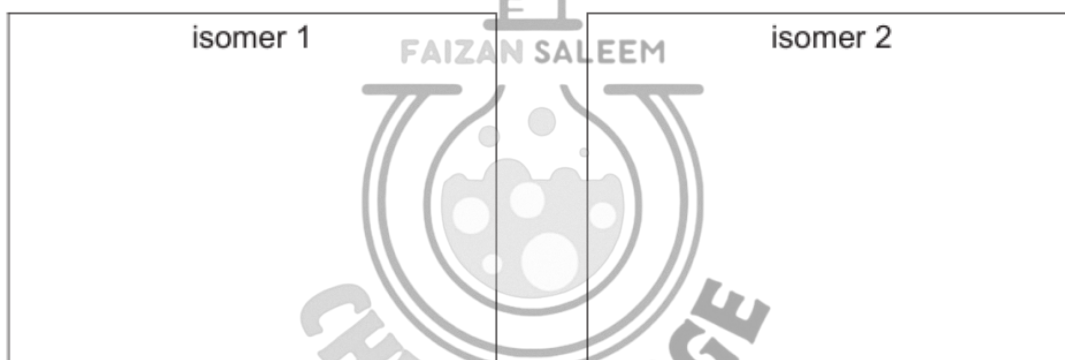
Complete the three-dimensional diagrams to show the two isomers of $[\text{Co}(\text{NH}_3)_3\text{Cl}_3]$.
Suggest the type of stereoisomerism.



type of stereoisomerism

[2]

88. The complex ion $[\text{NiBr}_2(\text{CN})_2]^{2-}$ shows stereoisomerism. Draw diagrams to show the two isomers of $[\text{NiBr}_2(\text{CN})_2]^{2-}$. Name the type of stereoisomerism.

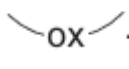


type of stereoisomerism

[2]

89. **E** is a complex ion, $[\text{Fe}(\text{C}_2\text{O}_4)_2\text{Cl}_2]^{4-}$, containing Fe^{2+} with a coordination number of 6.

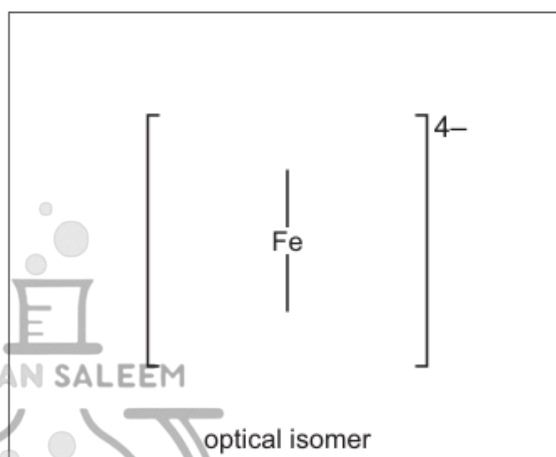
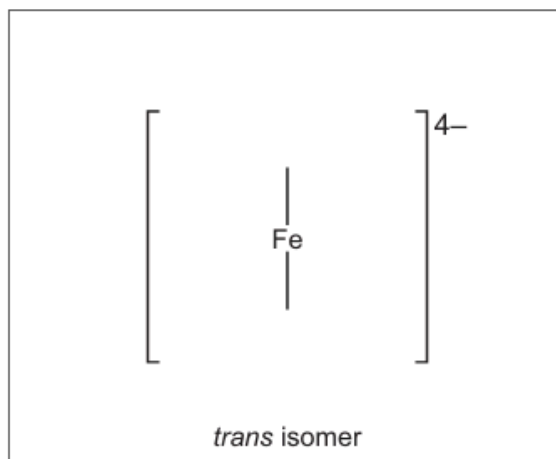
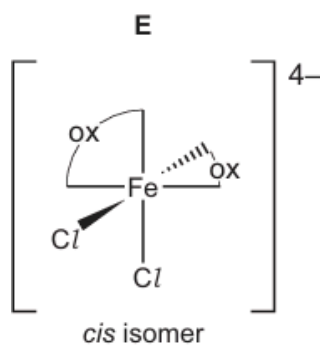
(a) **E** shows both optical isomerism and cis-trans isomerism.

One isomer of **E** is shown. The $\text{C}_2\text{O}_4^{2-}$ ion is represented as .

In the boxes, draw three-dimensional diagrams to show:

- the *trans* isomer of **E**
- the optical isomer of **E**.

[2]



(b) $[\text{Fe}(\text{C}_2\text{O}_4)_2\text{Cl}_2]^{4-}$ contains ligands which are anions of ethanedioic acid, $\text{HO}_2\text{CCO}_2\text{H}$.

Complete the table to show any observations for the reactions of $\text{HO}_2\text{CCO}_2\text{H}$ with the named reagents.

Where no change is observed, write 'none'. **[2]**

reagent	observations with $\text{HO}_2\text{CCO}_2\text{H}$
warm acidified manganate(VII)	
2,4-dinitrophenylhydrazine	
warm Tollens' reagent	

90. Cadmium forms complex ion **X**, $[\text{Cd}(\text{NH}_3)_4]^{2+}$.

When a solution containing CN^- ions is added to an aqueous solution of **X**, a ligand exchange reaction takes place, forming complex ion **Y**. **Y** contains no NH_3 ligands and no H_2O ligands.

Y is in a much higher concentration in the mixture than **X**.

The oxidation state and coordination number of cadmium do **not** change in this reaction.

(a) Write an ionic equation for this reaction, using the formulae of the complex ions.

[2]

(b) Cadmium forms complex ion **Z** in the same oxidation state and with the same coordination number as in **X**. All the ligands in **Z** are Cl^- ions.

When NaCl (aq) is added to a solution of **X**, very little **Z** forms.

Write the **three** cadmium complexes, **X**, **Y** and **Z**, in order of increasing stability constant, K_{stab} .

.....
smallest values of K_{stab}

.....
largest value of K_{stab}

[1]

91. Table 3.1 gives values for the stability constants, K_{stab} , of different complexes of iron.

Table 3.1

complex	stability constant, K_{stab}
$[\text{Fe}(\text{H}_2\text{O})_5(\text{H}_2\text{PO}_4)]^{2+}$	5.90×10^1
$[\text{Fe}(\text{H}_2\text{O})_5\text{SCN}]^{2+}$	1.30×10^2

(a) $[\text{Fe}(\text{H}_2\text{O})_5(\text{H}_2\text{PO}_4)]^{2+}$ can form when H_3PO_4 reacts with $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$.

Write an equation for this reaction.

[1]

(b) Write an expression for K_{stab} of $[\text{Fe}(\text{H}_2\text{O})_5\text{SCN}]^{2+}$ and give its units.

$K_{\text{stab}} =$

units = ... [2]

92. The numerical value of the stability constant, K_{stab} , of the copper(I) complex $[\text{Cu}(\text{CN})_4]^{3-}$ is 2.0×10^{27} .

(a) Write an expression for the K_{stab} of $[\text{Cu}(\text{CN})_4]^{3-}$.

$K_{\text{stab}} =$

[1]

(b) In a solution the concentrations of CN^- and $[\text{Cu}(\text{CN})_4]^{3-}$ are both $0.0010 \text{ mol dm}^{-3}$.

Use your expression from (c)(i) and the value of K_{stab} to calculate the concentration of $\text{Cu}^+(\text{aq})$ in this solution.

concentration of $\text{Cu}^+(\text{aq}) = \dots\dots\dots \text{mol dm}^{-3}$ [1]

93. The structure of the polydentate ligand, EDTA^{4-} , is shown in Fig. 4.1.

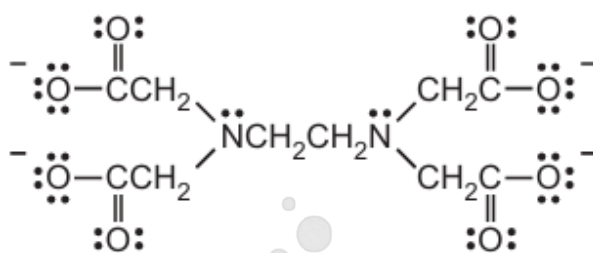


Fig 4.1

The stability constants, at 298 K, of five octahedral complexes are given in Table 4.1.

Table 4.1

complex	K_{stab}
$[\text{Cu}(\text{EDTA})]^{2-}$	6.31×10^{19}
$[\text{Cr}(\text{EDTA})]^{2-}$	1.00×10^{13}
$[\text{Cr}(\text{EDTA})]^{-}$	1.00×10^{24}
$[\text{Fe}(\text{EDTA})]^{2-}$	2.00×10^{14}
$[\text{Fe}(\text{EDTA})]^{-}$	1.26×10^{25}

(a) Calculate the oxidation states of Cu in $[\text{Cu}(\text{EDTA})]^{2-}$ and Cr in $[\text{Cr}(\text{EDTA})]^{-}$.

Cu

Cr

[1]

(b) Deduce the number of lone pairs donated by each EDTA^{4-} ligand in a single $[\text{Fe}(\text{EDTA})]^{2-}$ complex ion.

..... [1]

(c) Identify the most stable complex in Table 4.1. Explain your choice.

.....

(d) In a solution at equilibrium at 298 K, $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} = 3.00 \times 10^{-10} \text{ mol dm}^{-3}$ and $[\text{EDTA}^{4-}] = 5.00 \times 10^{-12} \text{ mol dm}^{-3}$.

Use the expression for K_{stab} to calculate the concentration of $[\text{Cu}(\text{EDTA})]^{2-}$ in this solution.
Show your working.

$$[[\text{Cu}(\text{EDTA})]^{2-}] = \dots\dots\dots \text{mol dm}^{-3} \quad [2]$$

(e) A solution of $[\text{Cu}(\text{EDTA})]^{2-}$ ions is pale blue while a solution of $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ ions is deep blue.

Explain this difference in colour.

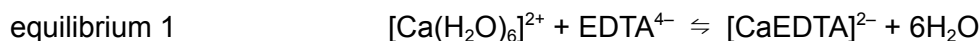
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[2]

94. EDTA^{4-} is a polydentate ligand.

(a) (i) Group 2 metal ions can form complexes similar to those of transition elements.

A solution of EDTA^{4-} is added to water containing $[\text{Ca}(\text{H}_2\text{O})_6]^{2+}$ to form a new complex, $[\text{CaEDTA}]^{2-}$, as shown.



Circle on the structure of EDTA^{4-} in Fig. 1.2 the **six** atoms that form bonds with the metal ion. [1]

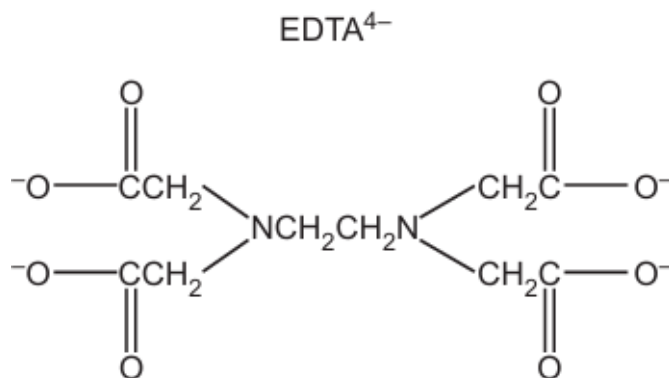


Fig. 1.2

(ii) The complex $[\text{CaEDTA}]^{2-}$ can be used to remove toxic metals from the body.

Table 1.2 shows the numerical values for the stability constants, K_{stab} , for some metal ions with EDTA^{4-} .

Table 1.2

complex	K_{stab}
$[\text{CaEDTA}]^{2-}$	5.0×10^{10}
$[\text{CrEDTA}]^{-}$	2.5×10^{23}
$[\text{FeEDTA}]^{-}$	1.3×10^{25}
$[\text{PbEDTA}]^{2-}$	1.1×10^{18}

An aqueous solution containing $[\text{CaEDTA}]^{2-}$ is added to a solution containing equal concentrations of $\text{Cr}^{3+}(\text{aq})$, $\text{Fe}^{3+}(\text{aq})$ and $\text{Pb}^{2+}(\text{aq})$. The resulting mixture is left to reach a state of equilibrium.

State the type of reaction when $[\text{CaEDTA}]^{2-}$ reacts with $\text{Cr}^{3+}(\text{aq})$, $\text{Fe}^{3+}(\text{aq})$ and $\text{Pb}^{2+}(\text{aq})$.

..... [1]

(b) A solution of $\text{Cr}^{3+}(\text{aq})$ and a solution of $\text{Fe}^{3+}(\text{aq})$ have different colours.

Explain why the two complexes have different colours.

..... [2]

95. An aqueous solution of copper(II) sulfate is a blue colour due to the presence of $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ complex ions.

(a) (i) Write an equation for the reaction between $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ ions and $\text{NaOH}(\text{aq})$.

..... [1]

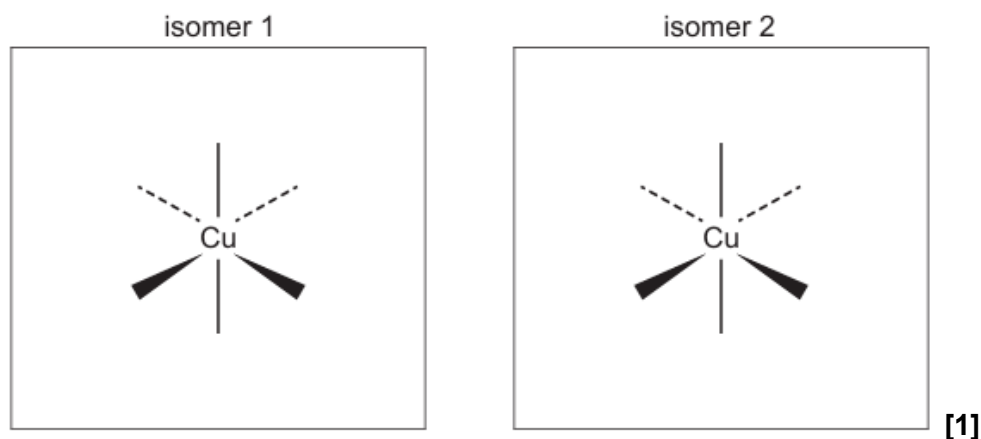
(ii) Write an equation for the reaction between $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ ions and an excess of conc. HCl .

..... [1]

(b) If an excess of ammonia is added to a solution of $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ a deep blue solution containing $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ complex ions is formed.

(i) There are two possible stereoisomers with the formula $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$.

Complete the diagrams to show the two stereoisomers in the boxes below.



(ii) Use your answer in (b)(i) to deduce whether each of these isomers is polar or non-polar.

polarity of isomer 1

polarity of isomer 2 [1]

(c) (i) Compare the stabilities of the $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ and $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ complex ions. Explain your answer.

.....

..... [1]

(ii) Write an expression for the stability constant, K_{stab} , of the $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ complex ion. State the units of the stability constant.

$K_{\text{stab}} =$

units = ... [2]

(iii) In a particular solution the concentration of the $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ complex ion is $0.0074 \text{ mol dm}^{-3}$ and the concentration of NH_3 is 0.57 mol dm^{-3} .

Use your expression in (c)(ii) and the K_{stab} value of 1.40×10^{13} to calculate the concentration of the $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ complex ion in this solution.

concentration of $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} = \dots \text{ mol dm}^{-3}$ [1]

(d) Phenanthroline, $\text{C}_{12}\text{H}_8\text{N}_2$, and ethanedioate ions, $\text{C}_2\text{O}_4^{2-}$, are bidentate ligands.

Ruthenium(III) ions, Ru^{3+} , form an octahedral complex with phenanthroline and chloride ions. The complex ion contains two phenanthroline molecules.

Iron(III) ions, Fe^{3+} , form an octahedral complex with ethanedioate ions only.

Deduce the formula and charge of each of these complex ions.

Ru^{3+} complex

Fe^{3+} complex [2]

96. An aqueous solution of cobalt(II) chloride is a pink colour due to the presence of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ complex ions.

(a) (i) Complete Table 6.1 to describe what is observed when the named reagent is added to an aqueous solution of cobalt(II) chloride.

Table 6.1

reagent	colour of cobalt-containing product	state of cobalt-containing product
$\text{NaOH}(\text{aq})$		
an excess of conc. HCl		

[2]

(ii) Write an equation for the reaction between $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ ions and $\text{NaOH}(\text{aq})$.

..... [1]

(iii) Write an equation for the reaction between $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ ions and an excess of conc. HCl .

..... [1]

(b) (i) Write an expression for the stability constant, K_{stab} , of the $[\text{Co}(\text{NH}_3)_6]^{2+}$ complex ion.

$K_{\text{stab}} =$

[1]

(ii) Give the units of the stability constant, K_{stab} , of the $[\text{Co}(\text{NH}_3)_6]^{2+}$ complex ion.

units = ... [1]

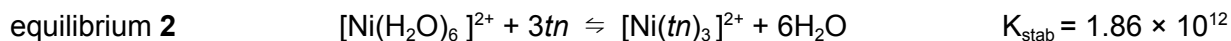
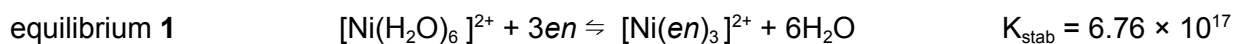
(iii) The numerical value of the stability constant, K_{stab} , of the $[\text{Co}(\text{NH}_3)_6]^{2+}$ complex ion is 7.7×10^4 .

In an aqueous solution the concentration of the $[\text{Co}(\text{NH}_3)_6]^{2+}$ complex ion is $0.0740 \text{ mol dm}^{-3}$ and the concentration of NH_3 is $0.480 \text{ mol dm}^{-3}$ at equilibrium.

Calculate the concentration of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ in this solution.

concentration = ... mol dm^{-3} [1]

97. (a) Nickel can form complexes with the ligands *en*, $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$, and *tn*, $\text{H}_2\text{NCH}_2\text{CH}_2\text{CH}_2\text{NH}_2$, as shown.



Construct an expression for the stability constant, K_{stab} , for equilibrium 1.

State the units for K_{stab} .

$K_{\text{stab}} =$

units = ... [2]

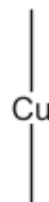
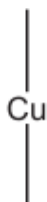
(b) Describe what the K_{stab} values indicate about the position of equilibrium for equilibrium 1 and 2. Use the K_{stab} values to deduce which complex, $[\text{Ni}(\text{en})_3]^{2+}$ or $[\text{Ni}(\text{tn})_3]^{2+}$, is more stable.

.....

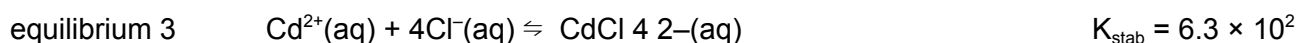
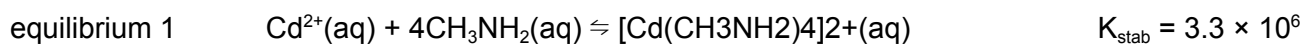
..... [1]

98. (a) Methylamine, CH_3NH_2 , is another primary amine. CH_3NH_2 can act as a monodentate ligand.

$\text{Cu}^{2+}(\text{aq})$ reacts with CH_3NH_2 to form $[\text{Cu}(\text{CH}_3\text{NH}_2)_2(\text{H}_2\text{O})_4]^{2+}$. Draw three-dimensional diagrams to show the two geometrical isomers of $[\text{Cu}(\text{CH}_3\text{NH}_2)_2(\text{H}_2\text{O})_4]^{2+}$. [2]



(b) $\text{Cd}^{2+}(\text{aq})$ ions form tetrahedral complexes with CH_3NH_2 , OH^- and Cl^- ions, as shown in equilibria 1, 2 and 3.



(i) Give the units of K_{stab} for equilibrium 1.

..... [1]

(ii) Write an expression for K_{stab} for equilibrium 3.

$$K_{\text{stab}} =$$

[1]

(iii) A solution of $\text{Cl}^-(\text{aq})$ is added to $\text{Cd}^{2+}(\text{aq})$ and allowed to reach equilibrium. The equilibrium concentrations are given.

$$[\text{Cd}^{2+}(\text{aq})] = 0.043 \text{ mol dm}^{-3}$$

$$[\text{Cl}^-(\text{aq})] = 0.072 \text{ mol dm}^{-3}$$

Use your expression in (b)(ii) to calculate the concentration of $\text{CdCl}_4^{2-}(\text{aq})$ in the equilibrium mixture.

$$[\text{CdCl}_4^{2-}(\text{aq})] = \dots\dots\dots \text{mol dm}^{-3} \quad [1]$$

(iv) When $\text{CH}_3\text{NH}_2(\text{aq})$ is added to $\text{Cd}^{2+}(\text{aq})$, a mixture of $[\text{Cd}(\text{CH}_3\text{NH}_2)_4]^{2+}(\text{aq})$ and $[\text{Cd}(\text{OH})_4]^{2-}(\text{aq})$ forms.

Suggest how the $[\text{Cd}(\text{OH})_4]^{2-}(\text{aq})$ is formed.

.....
 [1]

(v) $\text{Cd}^{2+}(\text{aq})$ exists as a complex ion, $[\text{Cd}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$.

Identify the most stable and the least stable of the complexes in Table 4.1 by placing **one** tick in each column.

Explain your answer.

Table 4.1

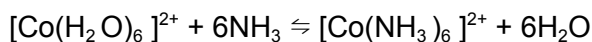
complex	most stable	least stable
$[\text{Cd}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$		
$[\text{Cd}(\text{OH})_4]^{2-}(\text{aq})$		
$[\text{Cd}(\text{CH}_3\text{NH}_2)_4]^{2+}(\text{aq})$		
$[\text{CdCl}_4]^{2-}(\text{aq})$		

explanation

.....

[2]

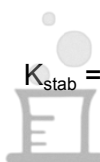
99. An excess of aqueous ammonia is added to a solution containing the complex ion $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$.



(a) Complete the sentence to describe the colour change that will be seen during this reaction.

The colour changes from to [1]

(b) Write an expression for the stability constant, K_{stab} , of $[\text{Co}(\text{NH}_3)_6]^{2+}$.



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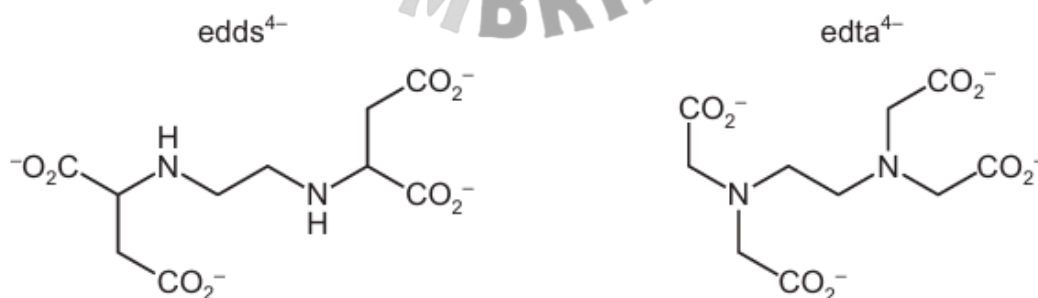
[1]

(c) The numerical value of K_{stab} of $[\text{Co}(\text{NH}_3)_6]^{2+}$ is 7.7×10^4 .

What deduction about the properties of $[\text{Co}(\text{NH}_3)_6]^{2+}$ and $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ can be made from this K_{stab} value?

[1]

100. Edds^{4-} and edta^{4-} are polydentate ligands that form octahedral complexes with $\text{Fe}^{3+}(\text{aq})$.



The formulae of the complexes are $[\text{Fe}(\text{edds})]^-$ and $[\text{Fe}(\text{edta})]^-$ respectively.

(a) On the diagram of edds^{4-} , circle each atom that forms a bond to the Fe^{3+} ion in $[\text{Fe}(\text{edds})]^-$. [1]

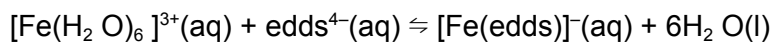
(b) $[\text{Fe}(\text{edds})]^-$ is red and $[\text{Fe}(\text{edta})]^-$ is yellow.

Explain why the two complexes have different colours.

.....

[2]

(c) When $\text{edds}^{4-}(\text{aq})$ is added to $\text{Fe}^{3+}(\text{aq})$, the following reaction occurs.



State the type of reaction that occurs.

[1]

(d) Write an expression for the stability constant, K_{stab} , of $[\text{Fe}(\text{edds})]^{-}(\text{aq})$.

$$K_{\text{stab}} =$$

[1]

(e) The table shows the values for the stability constants, K_{stab} , of both complexes.

complex	$K_{\text{stab}} / \text{mol}^{-1} \text{dm}^3$
$[\text{Fe}(\text{edds})]^{-}$	3.98×10^{20}
$[\text{Fe}(\text{edta})]^{-}$	1.26×10^{25}

Predict which of the $[\text{Fe}(\text{edds})]^{-}$ and $[\text{Fe}(\text{edta})]^{-}$ complexes is more stable.

Explain your answer with reference to the K_{stab} value for each complex.

[1]

101. A solution is made by dissolving $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ in an excess of aqueous ammonia. This solution contains the copper complex $[\text{Cu}(\text{NH}_3)_4]^{2+}$.

(a) (i) Write an expression for the K_{stab} of $[\text{Cu}(\text{NH}_3)_4]^{2+}$.

$$K_{\text{stab}} =$$

(ii) State the colour of the solution of $[\text{Cu}(\text{NH}_3)_4]^{2+}$.

[1]

The solution of $[\text{Cu}(\text{NH}_3)_4]^{2+}$ is heated gently in a fume cupboard so that NH_3 is released. Some NH_3 remains in solution and some forms NH_3 gas. The colour of the solution changes; a precipitate of $\text{Cu}(\text{OH})_2$ forms and is collected.

A sample of $\text{Cu}(\text{OH})_2$ is added to concentrated hydrochloric acid. A reaction takes place forming a coloured copper complex, **Y**.

A sample of $\text{Cu}(\text{OH})_2$ is added to dilute sulfuric acid. A reaction takes place forming a coloured copper complex, **Z**.

$[\text{Cu}(\text{NH}_3)_4]^{2+}$, **Y** and **Z** are different colours.

(b) Suggest an equation for the reaction of $[\text{Cu}(\text{NH}_3)_4]^{2+}$ to form $\text{Cu}(\text{OH})_2$ as the aqueous solution of $[\text{Cu}(\text{NH}_3)_4]^{2+}$ is heated.

[1]

(c) Suggest an equation for the reaction of $\text{Cu}(\text{OH})_2$ with concentrated hydrochloric acid, forming **Y**.

[2]

(d) Complete the table with the colour and geometry of complex **Y** and the colour, geometry and formula of complex **Z**. [2]

	Y	Z
colour of complex		
geometry of complex		
formula of complex		

(e) Explain why complexes **Y** and **Z** are coloured and why their colours are different.

.....

.....

.....

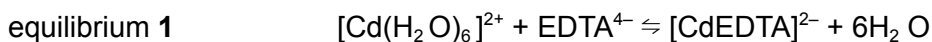
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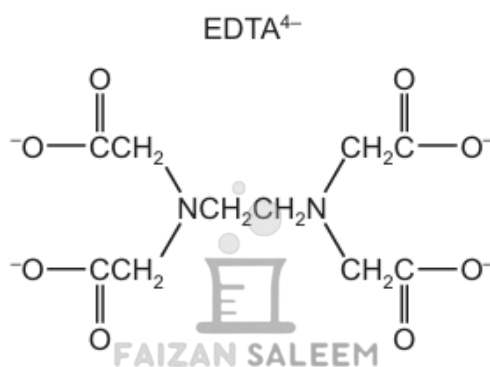
[5]

102. EDTA^{4-} , is a polydentate ligand.

(a) When a solution containing EDTA^{4-} is added to a solution containing $[\text{Cd}(\text{H}_2\text{O})_6]^{2+}$ a new complex is formed, $[\text{CdEDTA}]^{2-}$.



Circle, on the structure of EDTA^{4-} , the **six** atoms that form bonds with the metal ion. [1]



(b) Write an expression for the stability constant, K_{stab1} , for equilibrium 1, and state its units.

$K_{\text{stab1}} =$

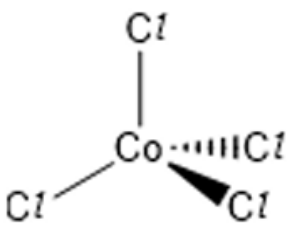
units = ... [2]

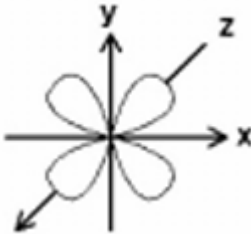
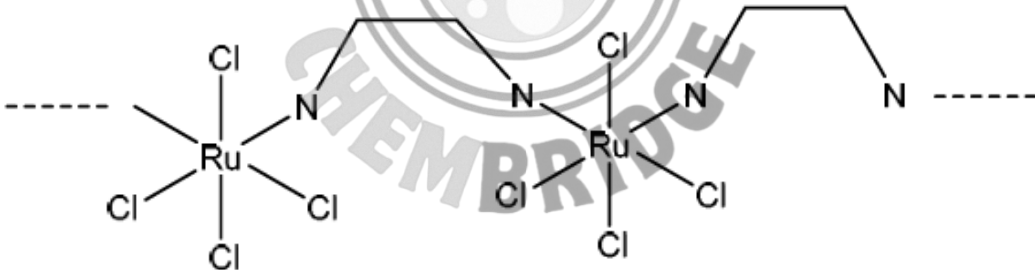
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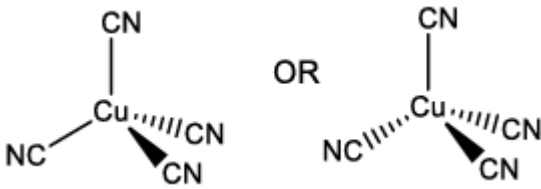
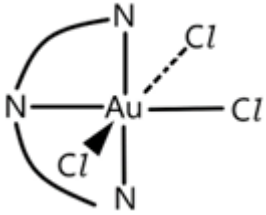
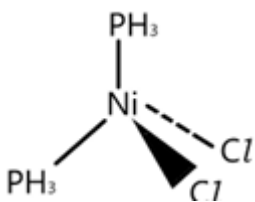
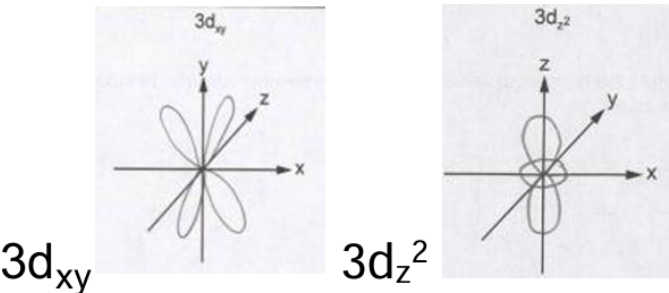
Question	Answers	Marks
1	(central) metal / transition element atom / ion AND surrounded by / bonded to ligands	1
2	element which forms one or more stable ion with incomplete d orbitals	1
3	orbitals of the same energy	1
4	(a molecule or ion formed by a central) metal atom / ion surrounded / bonded by one or more ligands	1
5	equilibrium constant for the formation of a complex in a solvent / from its constituents	1
6	donates one lp to metal atom or ion	1

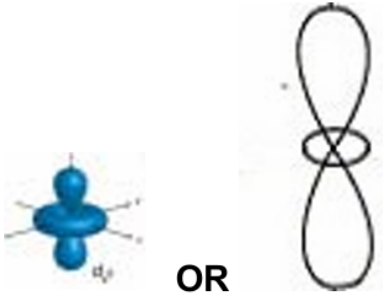
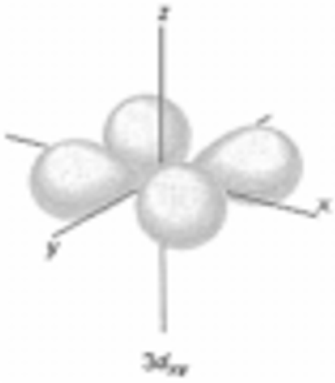
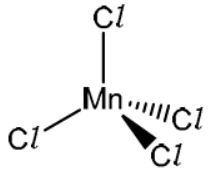
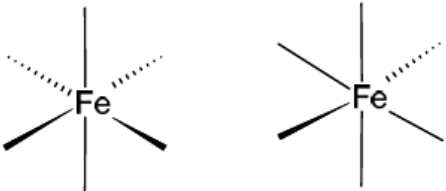
7	metal atom or ion bonded to one or more ligands	1
8	M1 (a species) that donates more than two lone pairs M2 to form dative / coordinate bonds to a metal atom or ion	2
9	the number of co-ordinate bonds being formed by the metal ion	1
10	(is a molecule or ion formed by a central) metal atom / metal ion bonded / surrounded by (one or more) ligands	1
11	M1 (a species) that donates / uses two lone pairs M2 to form a two dative / coordinate bond to a metal atom / metal ion	2
12	the equilibrium (constant) for the formation of the complex ion in a solvent from its constituent ions or molecules	1
13 (a)	a d-block element that forms one or more stable ions with incomplete d-orbitals	1
(b)	degenerate – of the same energy non-degenerate – not of the same energy / different energy	1
14	forms 2 dative / coordinate bonds	1
15	the equilibrium constant for the formation of a complex ion in a solvent OR the equilibrium constant for the formation of a complex ion from its constituent ions	1
16 (a)	forms one or more stable ions / compounds / oxidation states with incomplete / partially filled (3)d-orbital(s) / d-shell / d-subshell	1
(b) (i)	the catalyst and the reactants are in a different state / phase	1
(ii)	M1 adsorption of reactants to the surface of the catalyst M2 bonds in the reactants weaken (lowering the activation energy) M3 reaction occurs and the products are desorbed	2
17	M1 (a species) that donates / uses two lone pairs M2 to form dative / coordinate bonds to a metal atom / metal ion / TM / TE / metal	2
18	the equilibrium constant for the formation of the complex ion in a solvent (from its constituent ions or molecules)	1
19 (a)	(d-block) element that forms one or more stable ions with incomplete d subshell / incomplete d orbitals	2
(b)	• variable oxidation states • behave as catalysts • form complex ions / complexes • form coloured compounds / ions Any two for one mark	1
(c) (i)	the number of co-ordinate bonds being formed by the metal atom/ion	1
(ii)	$\text{TiO}_2 + 6\text{HF} \rightarrow \text{TiF}_6^{2-} + 2\text{H}_2\text{O} + 2\text{H}^+$ OR $\text{TiO}_2 + 6\text{HF} \rightarrow \text{TiF}_6^{2-} + 2\text{H}_3\text{O}^+$	1
(iii)	species with two lone pairs (of electrons) [1] that form dative covalent / co-ordinate bonds to a central metal atom/ion [1]	2

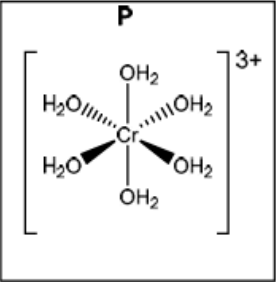
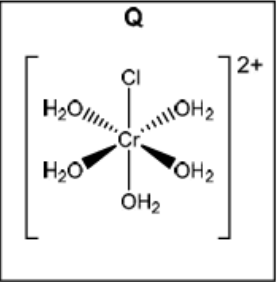
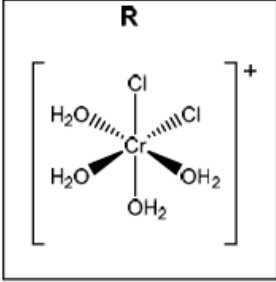
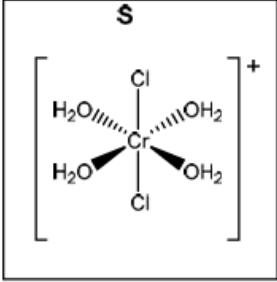
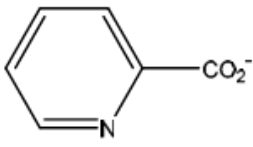
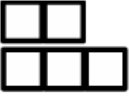
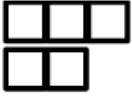
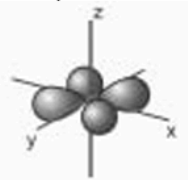
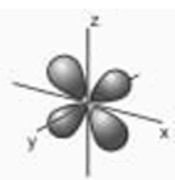
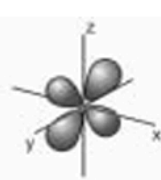
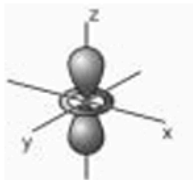
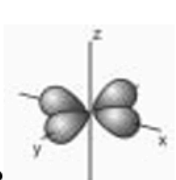
20 (a)	(a d-block element forms one or more) stable ions with incomplete filled d-subshell	1
(b) (i)	• they behave as catalysts • they form complex ions / complexes • they form coloured compounds / salts / ions any two	1
(ii)	the d and s sub-shells/orbitals are close/similar in energy	1
21	species that uses one lone pair of electrons that forms a single dative covalent bond to a central metal atom / ion	2
22	(a species) that donates two lone pairs to form two dative bonds [1] to a (transition) metal atom / metal ion [1]	2
23	donates one lone pair / forms one dative bond AND to metal atom / to metal ion [1]	1
24	M1: (a species) that donates two lone pairs / forms two coordinate bonds / two dative bonds M2: to a metal atom / metal ion	2
25	(an element) forming stable ion / ions / compound(s) / oxidation state(s) AND with partially filled / incomplete AND d orbitals / d subshell / d shell	1
26 (a)	$[1s^2] 2s^2 2p^6 3s^2 3p^6 3d^3$	1
(b)	(a molecule or ion formed by a central) metal atom/ion surrounded by / bonded to one or more ligands	1
27	(a species) that uses / shares a lone pair of electrons to form a coordinate bond to a metal atom / ion	1
28	(element that forms one or more stable) ions with incomplete/ partially filled 3d-orbitals/d-subshell	1
29 (a)	(a species) that donates one lone pair [1] to form a dative / coordinate to a central metal atom / metal ion [1]	2
(b)	$[Ag(S_2O_3)_2]^{3-}$ [1]	1
30	M1 (a species) that donates/uses a many lone pairs/more than one lone pair M2 to form a dative/coordinate to a metal atom/metal ion/TM/TE/metal OR M1 (a species) that donates/uses lone pairs to form many/more than one M2 dative/coordinate bond to a metal atom/metal ion/TM/TE/metal	2
31 (a)	forms (one or more stable) ions with partially filled (3)d-subshell	1
(b)	M1 forms a single / one dative bond to a (central) metal atom / ion M2 with lone pair (of electrons)	2
(c)	the number of dative bonds formed with/by the (central) metal atom / ion OR number of bonds between the ligands and the (central) metal atom / ion	1
32 (a)	(Ar) $3d^{10}$ AND (Ar) $3d^9$	1

(b)	similar energy of 3d and 4s subshells	1
33	(Ag ⁽²⁺⁾ is a) forms stable ion(s) with incomplete d orbitals / an incomplete d subshell	1
34	similar energy of the (3)d and (4)s subshells / orbitals	1
35	empty (d) orbitals are energetically accessible OR empty (d) orbitals can form dative bonds with ligands OR empty (d) orbitals can accept a lone pair from ligands	1
36	M1 d orbital(s) of different energy / d-d splitting occurs M2 electron(s) promoted / excited M3 light is absorbed AND colour seen is complementary	3
37	the (3)d and (4)s (sub-shells/orbitals) are close/similar in energy	1
38	energies / energy levels of the 3d and the 4s (sub-shells / orbitals) are similar OR the difference between the 3d and the 4s is small	1
39	Fe = [Ar] 3d ⁶ 4s ² AND Fe ³⁺ = [Ar] 3d ⁵	1
40 (a)	(ligand that) donates 3 lone pairs to central metal atom / ion OR (ligand that) forms 3 dative bonds to central metal atom / ion [1]	1
(b)	ref to using the electrons / lone pair on (each) N / amine group [1]	1
41	Any two from: • they have variable / multiple oxidation states OWTTE • they behave as catalysts • they form complex ions / complexes • they form coloured compounds/ions	1
42	the d and s sub-shells / orbitals are close / similar in energy	1
43 (a)	• five (3d) orbitals (lines, boxes) in the isolated Co²⁺ ion of same energy • splitting three higher and two lower d orbitals • energy of all d orbitals in the complex clearly higher than all d orbitals in isolated ion any two [1] all three [2]	2
(b)		1

44 (a)	<table><tr><th>complex</th><th>ion</th><th>ligand</th><th>coordination number</th><th>formula and charge of complex</th></tr><tr><td>E</td><td>Fe²⁺</td><td>NH₃</td><td>6</td><td>[Fe(NH₃)₆]²⁺</td></tr><tr><td>F</td><td>Fe²⁺</td><td>Cl⁻</td><td>4</td><td>[FeCl₄]²⁻</td></tr><tr><td>G</td><td>Fe³⁺</td><td>en</td><td>6</td><td>[Fe(en)₃]³⁺</td></tr></table> any two [1] any four [2] all six [3]	complex	ion	ligand	coordination number	formula and charge of complex	E	Fe ²⁺	NH ₃	6	[Fe(NH ₃) ₆] ²⁺	F	Fe ²⁺	Cl ⁻	4	[FeCl ₄] ²⁻	G	Fe ³⁺	en	6	[Fe(en) ₃] ³⁺	3
complex	ion	ligand	coordination number	formula and charge of complex																		
E	Fe ²⁺	NH ₃	6	[Fe(NH ₃) ₆] ²⁺																		
F	Fe ²⁺	Cl ⁻	4	[FeCl ₄] ²⁻																		
G	Fe ³⁺	en	6	[Fe(en) ₃] ³⁺																		
(b)	three(3) higher AND two(2) lower boxes / energy levels 	1																				
45 (a)		1																				
(b)	M1 bond angle H–N–Ag is 109.5° M2 shape is linear AND bond angle for N–Ag–N is 180°	2																				
(c)	For example:  M1 presence of <i>dps</i> ligand bonded to two Ru M2 the rest of the structure correct	2																				
46 (a)	more than one (stable) oxidation state [1] empty / vacant (d) orbitals are energetically accessible OR empty / vacant (d) orbitals can form dative bonds with ligands [1]	2																				
(b) (i)	oxid. no. = + 4 AND coord. no. = 8 [1]	1																				
(ii)	bond angle must go from bond to bond OR CN group to CN group diagram • for Ag: NC—Ag—CN • angle = labelled 180°	2																				

	 • for Cu: • angle = labelled 109–110° any two [1] all four [2]	
47	NH₃ = monodentate EDTA⁴⁻ = polydentate / hexadentate CN⁻ = monodentate C₂O₄²⁻ = bidentate any two [1] all four [2]	2
48 (a)	octahedral square planar octahedral [1]	1
(b)	[Au(dien)(H₂O)₂Cl]²⁺ + 2Cl⁻ → [Au(dien)Cl₃] + 2H₂O [1] OR [Au(dien)Cl₃] + 2H₂O → [Au(dien)(H₂O)₂Cl]²⁺ + 2Cl⁻	1
(c)		1
(d)		1
49	 3d_{xy} 3d_{z²}	1

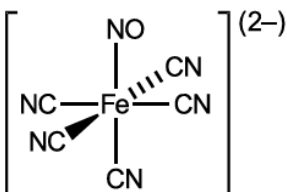
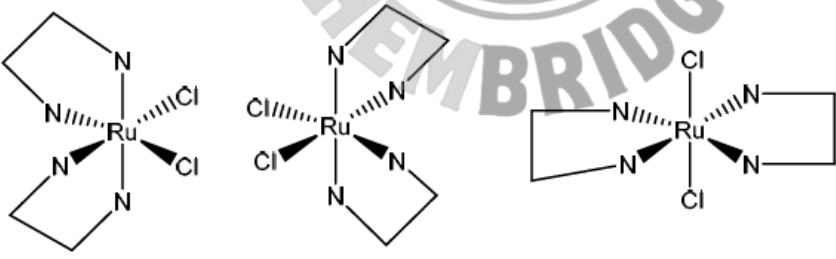
50		1
51		1
52	(a d-block element forms one or more) stable ions with incomplete filled d-subshell	2
53 (a)	+ 2	1
(b)	 [1] bond angle labelled 109.5° [1]	2
54 (a)	Mo(CO)₆ 0 / no charge / neutral / zero Fe(CN)₆ 3– both formulae [1] both charges [1]	2
(b)	either of these renditions, with a CN on each bond  AND 180° bond angle between two opposite bonds [1]	1

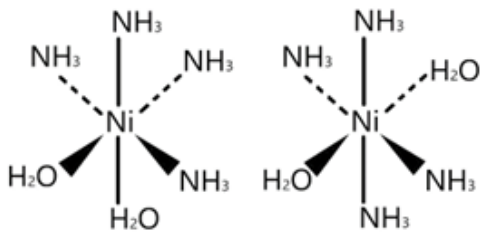
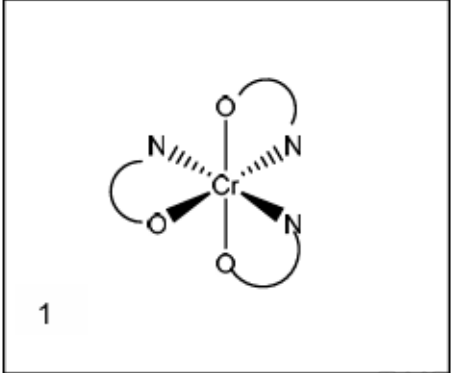
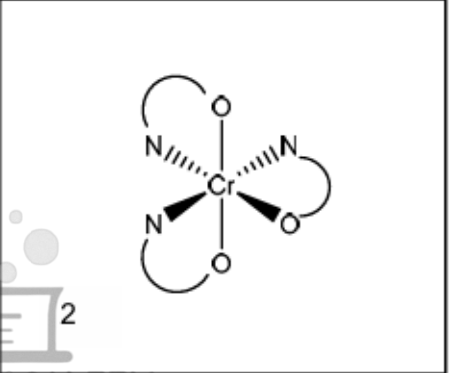
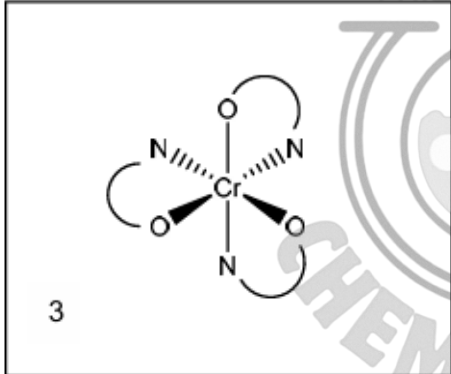
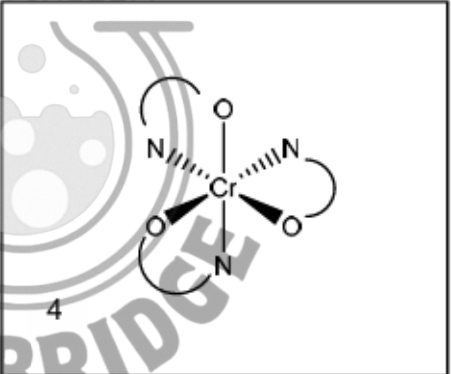
55 (a) (i)	P  Q  R  S  M1: All charges M2: One octahedral with correct 3D M3: All formulae M4: R is cis, S is trans	4
(ii)	dipoles cancel	1
(b) (i)	 structure of the picolinate anion ligand	1
(ii)	(coordination number) six AND (geometry around Cr) octahedral	1
(c) (i)	$(\text{NH}_4)_2\text{Cr}_2\text{O}_7$ +6 Cr_2O_3 +3	1
(ii)	$(\text{NH}_4)_2\text{Cr}_2\text{O}_7 \rightarrow \text{N}_2 + \text{Cr}_2\text{O}_3 + 4\text{H}_2\text{O}$	1
56 (a)	O_h  AND T_d 	1
(b)	M1: lower energy level (in between axes)  OR  OR  M2: higher energy level (on the axes)  OR 	2

57 (a)	+4 and any of +1, +2, +3	1
(b)	close similarity of energy of the 4s and 3d sub-shells	1
58 (a)	$A = [\text{Co}(\text{H}_2\text{O})_6]^{2+}$ pink $B = [\text{Co}(\text{H}_2\text{O})_4(\text{OH})_2] / \text{Co}(\text{OH})_2$ blue $C = [\text{Co}(\text{NH}_3)_6]^{2+}$ straw / yellow-brown B = precipitation / deprotonation / acid-base C = ligand exchange Any two [1] any four [2] any six [3] all eight [4]	4
(b)	concentrated HCl	1
59 (a)	$[\text{Co}_2\text{O}_2\text{NH}_2(\text{NH}_3)_8]^{3+}$ scores [2] must have Co_2 • $\text{Co}_2\text{O}_2\text{NH}_2$ • 8 ammonia so both Co are octahedral (ecf bullet 1) • correct charge based on ligands present (ecf Co and NH_2) any two [1] all three [2]	2
(b)	2 3	1
(c)	ΔE different OR (d–d) energy gap different [1] different frequency/wavelength/energy from visible light absorbed [1]	2
60	M1 (Ag^+) d-subshell is full / complete OR d10 OR d-orbitals are full M2 no d-d(*) transition OR no d electrons promoted/excited	2
61 (a)	6/ six	1
(b)	bond angle 106–108° AND lone pair from O is donated (in a bond) OR one more of O's electron pairs is now a bond/bonding pair (so repels less)	1
(c)	M1 (degenerate) d orbitals split (into two energy levels) OR (degenerate) d orbitals become non-degenerate M2 as an electron moves up / to a higher energy level M3 absorption of light energy / energy in the visible region AND colour seen is complementary (to colour absorbed)	3
(d)	(d–d) energy gap / ΔE / Δ_{oct} is different different frequency / wavelength (of light) absorbed / transmitted / reflected	2
62	Cu^{2+} is d^9 / d shell / sub-shell / orbitals is / are not full AND Cu^+ is d^{10} / d shell / sub-shell / orbitals is / are full [1] d-d* transitions / d electron promotion not possible / possible (linked correctly) [1]	2

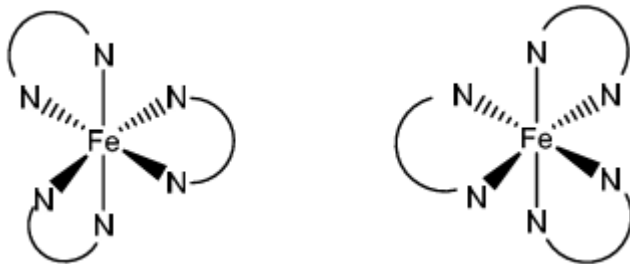
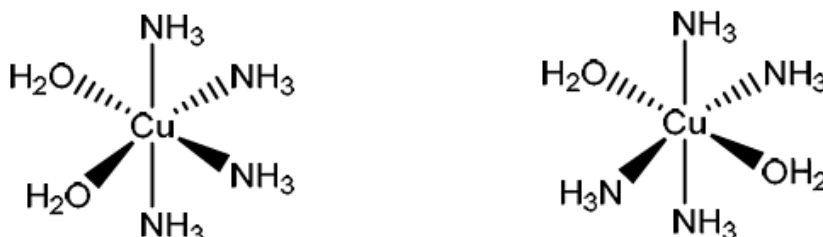
63	<table><tr><td>reagent added</td><td>formula of species formed</td><td>colour / state of species formed</td><td>type of reaction</td></tr><tr><td>an excess of $\text{NH}_3(\text{aq})$</td><td>$[\text{Co}(\text{NH}_3)_6]^{2+}$</td><td>brown solution ALLOW yellow-brown solution</td><td>ligand exchange</td></tr><tr><td>an excess of concentrated HCl</td><td>$[\text{CoCl}_4]^{2-}$</td><td>blue solution</td><td>ligand exchange</td></tr><tr><td>$\text{NaOH}(\text{aq})$</td><td>$\text{Co}(\text{OH})_2$ OR $\text{Co}(\text{OH})_2(\text{H}_2\text{O})_4$</td><td>blue ppt. ALLOW pink ppt</td><td>precipitation</td></tr></table> formula and colour / state: any two [1], any four [2], all six [3] type of reaction: all three correct [1]	reagent added	formula of species formed	colour / state of species formed	type of reaction	an excess of $\text{NH}_3(\text{aq})$	$[\text{Co}(\text{NH}_3)_6]^{2+}$	brown solution ALLOW yellow-brown solution	ligand exchange	an excess of concentrated HCl	$[\text{CoCl}_4]^{2-}$	blue solution	ligand exchange	$\text{NaOH}(\text{aq})$	$\text{Co}(\text{OH})_2$ OR $\text{Co}(\text{OH})_2(\text{H}_2\text{O})_4$	blue ppt. ALLOW pink ppt	precipitation	4
reagent added	formula of species formed	colour / state of species formed	type of reaction															
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64 (a)	<table><tr><td></td><td>geometry</td><td>CN</td><td>bond angle</td></tr><tr><td>$[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$</td><td>octahedral</td><td>6</td><td>90 or 180</td></tr><tr><td>$[\text{CuCl}_4]^{2-}$</td><td>tetrahedral</td><td>4</td><td>109 to 110</td></tr></table>		geometry	CN	bond angle	$[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$	octahedral	6	90 or 180	$[\text{CuCl}_4]^{2-}$	tetrahedral	4	109 to 110	3				
	geometry	CN	bond angle															
$[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$	octahedral	6	90 or 180															
$[\text{CuCl}_4]^{2-}$	tetrahedral	4	109 to 110															
(b)	different frequency / wavelength / photon absorbed	1																
65 (a) (i)	Ti is in +4 oxidation state so no d electrons / d^0 OR Ti in TiO^{2+} has no d electrons / d^0 [1] cannot absorb photons / light in visible spectrum OR no wavelength / frequency absorbed in visible spectrum [1]	2																
(ii)	$(1s^2) 2s^2 2p^6 3s^2 3p^6 3d^1 (4s^0)$	1																
(iii)	$2\text{TiO}^{2+} + 4\text{H}^+ + \text{Zn} \rightarrow 2\text{Ti}^{3+} + 2\text{H}_2\text{O} + \text{Zn}^{2+}$	1																
(b)	Ti^{3+} empty / vacant d orbitals can form dative bonds / accept a lone pair from a ligand OR Ti^{3+} has vacant d-orbitals which are energetically accessible	1																
66 (a) (i)	$[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{NH}_3 \rightarrow [\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+} + 4\text{H}_2\text{O}$ OR $\text{Cu}^{2+} + 2\text{H}_2\text{O} + 4\text{NH}_3 \rightarrow [\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ [1]	1																
(ii)	M1 d-orbitals split (could be in diagram) [1] M2 electrons transition to higher orbital / electrons promoted or excited [1] M3 wavelength / frequency / light / photon / hf / hn absorbed [1] M4 colour seen / reflected / transmitted is complement of colour absorbed [1]	4																
(b) (i)	$[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+} + 4\text{HCl} \rightarrow \text{CuCl}_4^{2-} + 2\text{H}_2\text{O} + 4\text{NH}_4^+$ OR $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+} + 4\text{Cl}^- (+ 4\text{H}^+) \rightarrow \text{CuCl}_4^{2-} + 2\text{H}_2\text{O} + 4\text{NH}_3 (+ 4\text{H}^+)$ M1 formula and charge of CuCl_4^{2-} [1] M2 rest of equation [1]	2																
(ii)	ligand exchange / substitution / replacement / displacement [1]	1																
(iii)	tetrahedral [1]	1																

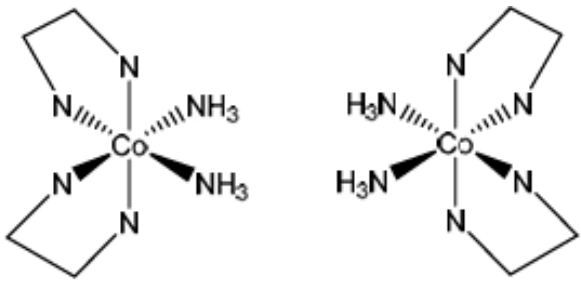
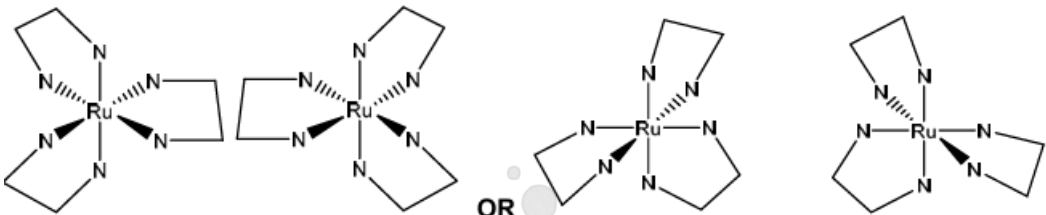
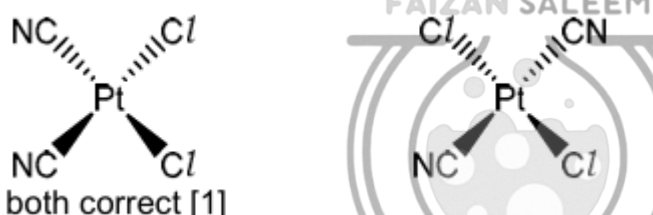
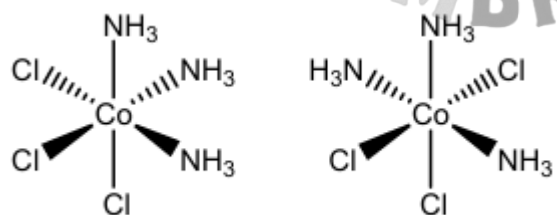
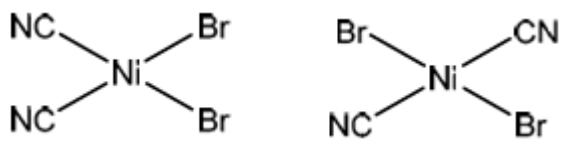
(iv)	Yellow [1]	1												
(v)	b-orbital splitting changes / ΔE changes	1												
67	forms one or more stable ions / compounds / oxidation states with incomplete / partially filled (3)d-orbital(s) / d-shell / d-subshell	4												
68 (a)	<table border="1"><thead><tr><th>$[\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$</th><th>formula of chromium species formed</th><th>type of reaction</th></tr></thead><tbody><tr><td>+ NaOH(aq)</td><td>$\text{Cr}(\text{OH})_3$ or $\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3$</td><td>precipitation</td></tr><tr><td>+ $\text{H}_2\text{O}_2(\text{aq})$</td><td>$\text{Cr}_2\text{O}_7^{2-}$ / CrO_4^{2-}</td><td>redox / oxidation</td></tr><tr><td>+ excess $\text{NH}_3(\text{aq})$</td><td>$\text{Cr}(\text{NH}_3)_6^{3+}$</td><td>ligand substitution</td></tr></tbody></table> chromium species: one mark for each correct species type of reaction: two correct for one mark and three correct for two marks	$[\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$	formula of chromium species formed	type of reaction	+ NaOH(aq)	$\text{Cr}(\text{OH})_3$ or $\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3$	precipitation	+ $\text{H}_2\text{O}_2(\text{aq})$	$\text{Cr}_2\text{O}_7^{2-}$ / CrO_4^{2-}	redox / oxidation	+ excess $\text{NH}_3(\text{aq})$	$\text{Cr}(\text{NH}_3)_6^{3+}$	ligand substitution	5
$[\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$	formula of chromium species formed	type of reaction												
+ NaOH(aq)	$\text{Cr}(\text{OH})_3$ or $\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3$	precipitation												
+ $\text{H}_2\text{O}_2(\text{aq})$	$\text{Cr}_2\text{O}_7^{2-}$ / CrO_4^{2-}	redox / oxidation												
+ excess $\text{NH}_3(\text{aq})$	$\text{Cr}(\text{NH}_3)_6^{3+}$	ligand substitution												
(b)	M1: ΔE is different OR energy gap between d-orbitals is different M2: different frequency / wavelength is absorbed OR different energy / light in visible region is absorbed	2												
(c) (i)	ethanoate ions are bidentate whereas H_2O are monodentate OR ethanoate ions form two dative bonds whereas H_2O forms one (dative) bond OR ethanoate ions donate two lone pairs whereas H_2O donates one (lone) pair	1												
(ii)	(coordination number) six AND (geometry around Cr) octahedral	1												
(iii)	coordinate / (dative) covalent	1												
69 (a)	3d <table border="1"><tr><td>(Ni^{2+})</td><td>$\uparrow\downarrow$</td><td>$\uparrow\downarrow$</td><td>$\uparrow\downarrow$</td><td>$\uparrow$</td><td>$\uparrow$</td></tr></table>	(Ni^{2+})	$\uparrow\downarrow$	$\uparrow\downarrow$	$\uparrow\downarrow$	$\uparrow$	$\uparrow$	1						
(Ni^{2+})	$\uparrow\downarrow$	$\uparrow\downarrow$	$\uparrow\downarrow$	$\uparrow$	$\uparrow$									
(b)	M1 d orbitals split into two levels / lower and upper orbitals M2 electron(s) promoted / excited to a higher d-orbital M3 frequency of light absorbed M4 observed colour is complement of light absorbed	4												
70 (a) (i)	(Iron) has a higher (melting point) AND is denser/higher (density) (than calcium)	1												
(ii)	$(1s^2) 2s^2 2p^6 3s^2 3p^6 3d^6 (4s^0)$	1												
(iii)	M1 d sub-shell splits into two sets of d orbitals of different energy M2 wavelength / frequency of light absorbed M3 electron(s) promoted / excited M4 colour seen is complementary (to colour absorbed)	4												
(b) (i)	octahedral	1												
(ii)	$[\text{Fe}(\text{H}_2\text{O})_6]^{2+} + 6\text{CN}^- \rightarrow [\text{Fe}(\text{CN})_6]^{4-} + 6\text{H}_2\text{O}$	1												
(iii)	$[\text{Fe}(\text{CN})_6]^{4-}$ is (+)2 $[\text{Fe}(\text{CN})_5\text{NO}]^{2-}$ is (+)3	1												

(iv)		1
(v)	M1 d-d energy gap / ΔE is different M2 different frequency / wavelength of light <u>absorbed</u>	2
71 (a)	bond angle must go from bond to bond P 109 OR 109.5° Q 90° (or 180° if different angle labelled) R 90° (or 180° if different angle labelled) S 180°	2
(b)	P tetrahedral Q square planar R octahedral S linear	2
(c)	Q AND R	1
(d)	P AND R	1
72		2
73 (a)		3
(b)	optical AND cis-trans / geometrical	1
(c)	trans isomer / trans isomer correctly identified AND dipoles cancel / partial charges cancel / ion dipoles cancel	1
74 (a)	trans = non-polar cis isomer 1 = polar cis isomer 2 = polar ALL [1]	1
(b)	optical isomers / non-superimposable mirror images [1] ALLOW enantiomers / they rotate polarised light differently	1
75 (a)	$[\text{Rh}(\text{en})_2\text{Cl}_2]^+$ AND optical AND cis / trans OR geometric [1]	1

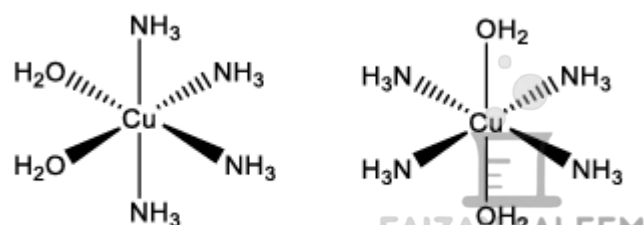
(b)	 cis/trans OR geometric [1]	2
76 (a)	geometrical / cis-trans AND optical	1
(b)	Square planar	1
(c)	 1  2  3  4 Two correct for one mark, three correct for two marks, four correct for three marks.	3
77 (a)	Any four from:	3

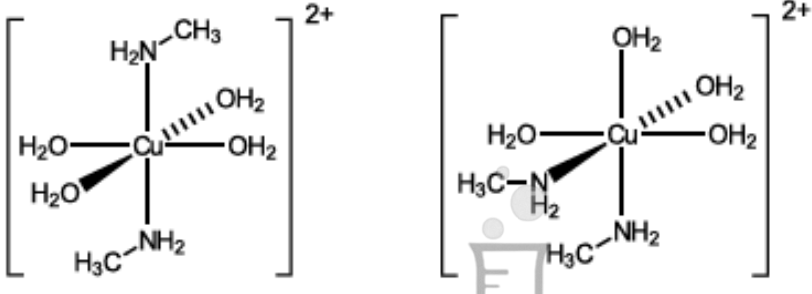
	isomer 1 isomer 2 isomer 3 isomer 4 isomer 5 isomer 6 Any two [1], any three [2], all four [3]	
(b)	oxidation state of cobalt (+)3 AND type of stereoisomerism cis-trans OR geometric(al) OR optical	1
78 (a)	• d orbital(s) of different energy / d-d splitting occurs • electron(s) promoted / excited • wavelength of visible light absorbed AND complementary colour seen • different energy gap / different ΔE OR different frequency/wavelength of light is absorbed	4
(b)		1
(c)	octahedral AND optical isomerism	1
79 (a)	one isomer correct with correct 3D [1] three isomers different with correct 3D [1]	2

(b)	e.g. 1 and 2 optical [1] e.g. 1 or 2 and 3 cis-trans / geometric [1]	2																
80 (a)	five 3d orbitals in the isolated Fe ²⁺ ion of same energy splitting two higher and three lower d orbitals energy of non-degenerate d orbitals in the complex more than degenerate d orbitals in isolated ion two for one mark, three for two marks	2																
(b)	 M1 one correct 3D diagram with three bipy ligands M2 both diagrams correct M3 optical isomerism	3																
81	<table border="1"><thead><tr><th>complex ion</th><th>shape</th><th>coordination number</th><th>polarity</th></tr></thead><tbody><tr><td>cis-[Pt(en)Cl₂]</td><td>square planar</td><td>4</td><td>polar</td></tr><tr><td>[Ag(NH₃)₂]⁺</td><td>linear</td><td>2</td><td>non-polar</td></tr><tr><td>[Fe(C₂O₄)₃]³⁻</td><td>octahedral</td><td>6</td><td>non-polar</td></tr></tbody></table> three for one mark, six for two marks	complex ion	shape	coordination number	polarity	cis-[Pt(en)Cl ₂]	square planar	4	polar	[Ag(NH ₃) ₂] ⁺	linear	2	non-polar	[Fe(C ₂ O ₄) ₃] ³⁻	octahedral	6	non-polar	2
complex ion	shape	coordination number	polarity															
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[Fe(C ₂ O ₄) ₃] ³⁻	octahedral	6	non-polar															
82 (a)	M1 (in a complex / in the presence of ligands) the d-orbitals are split into two sets of orbitals M2 as an electron is excited / promoted M3 visible light is absorbed AND colour seen is complementary	3																
(b)	 M1 one correct 3D diagram with the six correct ligands M2 both 3D diagrams correct	2																
83 (a)	mirror image of isomer I  trans isomer 	2																

(b)	isomer I AND cis isomer drawn by candidate ecf [1] dipoles do not cancel / partial charges do not cancel [1]	2
84	 M1 one correct 3D structure – trans or cis [1] M2 a correct optical isomer of M1 [must 3D] [1]	2
85	 M1 / M2: two 3D isomers of $[\text{Ru}(\text{en})_3]^{3+}$ M3: optical / enantiomerism	3
86 (a)	 both correct [1]	1
(b)	square planar	1
(c)	cis-trans OR geometric(al)	1
87	 geometric ALLOW cis-trans Two correct responses = 1 mark Three correct responses = 2 marks	2
88	M1 two correct structures cis & trans for $[\text{NiBr}_2(\text{CN})_2]^{2-}$  M2 type of stereoisomerism: cis-trans/geometric	2

89 (a)	$\left[\begin{array}{c} \text{ox} \\ \diagup \\ \text{Fe} \\ \diagdown \\ \text{Cl} \end{array} \begin{array}{c} \diagdown \\ \text{Cl} \\ \diagup \\ \text{ox} \end{array} \right]^{4-}$ trans $\left[\begin{array}{c} \text{ox} \\ \diagup \\ \text{Fe} \\ \diagdown \\ \text{Cl} \end{array} \begin{array}{c} \diagdown \\ \text{Cl} \\ \diagup \\ \text{ox} \end{array} \right]^{4-}$ optical	2								
(b)	<table><tr><th>reactant</th><th>observation with (CO₂H)₂</th></tr><tr><td>warm H⁺/MnO₄⁻</td><td>decolourised OR effervescence / bubbling / fizzing</td></tr><tr><td>2,4-DNPH</td><td>none / no reaction</td></tr><tr><td>warm Tollens' reagent</td><td>none / no reaction</td></tr></table>	reactant	observation with (CO ₂ H) ₂	warm H ⁺ /MnO ₄ ⁻	decolourised OR effervescence / bubbling / fizzing	2,4-DNPH	none / no reaction	warm Tollens' reagent	none / no reaction	2
reactant	observation with (CO ₂ H) ₂									
warm H ⁺ /MnO ₄ ⁻	decolourised OR effervescence / bubbling / fizzing									
2,4-DNPH	none / no reaction									
warm Tollens' reagent	none / no reaction									
90 (a)	$[\text{Cd}(\text{NH}_3)_4]^{2+} + 4\text{CN}^- \rightarrow [\text{Cd}(\text{CN})_4]^{2-} + 4\text{NH}_3$ X Y complex formed is [Cd(CN)₄]²⁻ / Na₂[Cd(CN)₄] [1] equation fully correct [1] ECF	2								
(b)	$[\text{Cd}(\text{Cl})_4]^{2-} \quad [\text{Cd}(\text{NH}_3)_4]^{2+} \quad [\text{Cd}(\text{CN})_4]^{2-}$ OR Z X Y	1								
91 (a)	$[\text{Fe}(\text{H}_2\text{O})_6]^{3+} + \text{H}_3\text{PO}_4 \rightarrow [\text{Fe}(\text{H}_2\text{O})_5(\text{H}_2\text{PO}_4)]^{2+} + \text{H}_3\text{O}^+$	1								
(b)	$K_{\text{stab}} = \frac{[[\text{Fe}(\text{H}_2\text{O})_5(\text{SCN})]^{2+}]}{[[\text{Fe}(\text{H}_2\text{O})_6]^{3+}][\text{SCN}^-]}$ mol⁻¹ dm³ u/c	2								
92 (a)	$K_{\text{stab}} = \frac{[[\text{Cu}(\text{CN})_4]^{3-}]}{[\text{Cu}^+][\text{CN}^-]^4}$ [1] ALLOW use of [[Cu(H ₂ O) ₆] ⁺]	1								
(b)	[Cu ⁺] = 5.0 × 10 ⁻¹⁹ (mol dm ⁻³) [1] min 1sf ECF from reversed ratio 5(c)(i)	1								
93 (a)	+2 AND + 3 [1]	1								
(b)	six	1								
(c)	[Fe(EDTA)] ⁻ AND largest K _{stab} [1]	1								
(d)	$\frac{[[\text{CuEDTA}]^{2-}]}{([[\text{Cu}(\text{H}_2\text{O})_6]^{2+}][\text{EDTA}^{2-}])} = 6.31 \times 10^{19}$ [1] 0.095 [1]	2								
(e)	different ΔE OR different energy gap between d-orbitals [1]	2								

	absorption of different wavelength OR absorption of different frequency [1]					
94 (a) (i)	six atoms circled, 2N and 4O from different CO_3^{2-}	1				
(ii)	ligand exchange	1				
(b)	M1 ΔE is different M2 different frequency (of light) is absorbed	2				
95 (a) (i)	$[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 2\text{OH}^- \rightarrow [\text{Cu}(\text{OH})_2(\text{H}_2\text{O})_4] + 2\text{H}_2\text{O}$ OR $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 2\text{NaOH} \rightarrow [\text{Cu}(\text{OH})_2(\text{H}_2\text{O})_4] + 2\text{H}_2\text{O} + 2\text{Na}^+$	1				
(ii)	$[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{Cl}^- \rightarrow [\text{CuCl}_4]^{2-} + 6\text{H}_2\text{O}$ OR $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{HCl} \rightarrow [\text{CuCl}_4]^{2-} + 6\text{H}_2\text{O} + 4\text{H}^+$	1				
(b) (i)	 cis and trans drawn	1				
(ii)	cis identified as polar AND trans identified as non-polar conditional on diagram	1				
(c) (i)	$[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ AND as K_{stab} is large OWTTE	1				
(ii)	$K_{\text{stab}} = \frac{[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}}{[\text{Cu}(\text{H}_2\text{O})_6]^{2+} [\text{NH}_3]^4}$ [1] mol ⁻⁴ dm ¹² [1] ecf M1	2				
(iii)	$[\text{Cu}(\text{H}_2\text{O})_6]^{2+} = (0.0074) \div (1.4 \times 10^{13} \times 0.57^4)$ $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} = 5.01 \times 10^{-15}$ min 2sf ecf 6(c)(iii)	1				
(d)	$[\text{Ru}(\text{C}_{12}\text{H}_8\text{N}_2)_2\text{Cl}_2]^+$ [1] $[\text{Fe}(\text{C}_2\text{O}_4)_3]^{3-}$ [1]	2				
96 (a) (i)	<table border="1" data-bbox="277 1599 724 1733"><tr><td>blue or pink</td><td>s / solid</td></tr><tr><td>blue</td><td>aq / aqueous</td></tr></table> two cells correct [1] two more cells correct [1]	blue or pink	s / solid	blue	aq / aqueous	2
blue or pink	s / solid					
blue	aq / aqueous					
(ii)	$[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 2\text{OH}^- \rightarrow \text{Co}(\text{OH})_2 + 6\text{H}_2\text{O}$ or $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 2\text{OH}^- \rightarrow \text{Co}(\text{H}_2\text{O})_4(\text{OH})_2 + 2\text{H}_2\text{O}$	1				
(iii)	$[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 4\text{Cl}^- \rightarrow [\text{CoCl}_4]^{2-} + 6\text{H}_2\text{O}$	1				

(b) (i)	$K_{\text{stab}} = \frac{[\text{Co}(\text{NH}_3)_6]^{2+}}{[\text{Co}(\text{H}_2\text{O})_6]^{2+}[\text{NH}_3]^6}$ or $\frac{[\text{Co}(\text{NH}_3)_6]^{2+}}{[\text{Co}^{2+}][\text{NH}_3]^6}$	1
(ii)	$\text{mol}^{-6} \text{ dm}^{18}$	1
(iii)	7.86×10^{-5}	1
97 (a)	M1 $K_{\text{stab}} = \frac{[\text{Ni}(\text{en})_3]^{2+}}{[\text{Ni}(\text{H}_2\text{O})_6]^{2+}[\text{en}]^3}$ M1 units = $\text{mol}^{-3} \text{ dm}^9 \text{ ecf}$	2
(b)	the equilibria lie to the right / product side OR equilibrium 1 lies more to the right AND en complex is more stable / $[\text{Ni}(\text{en})_3]^{2+}$ is more stable	1
98 (a)	 correct 3D cis isomer correct 3D trans isomer	2
(b) (i)	units = $\text{mol}^{-4} \text{ dm}^{12}$	1
(ii)	$(K_{\text{stab}} =) \frac{[\text{CdCl}_4]^{2-}}{[\text{Cd}^{2+}][\text{Cl}^-]^4}$	1
(iii)	$[\text{CdCl}_4]^{2-} = K_{\text{stab}} \times 0.043 \times 0.072^4 = 7.28 / 7.3 \times 10^{-4} (\text{mol dm}^{-3}) \text{ min 2sf}$	1
(iv)	CH_3NH_2 (is basic so) reacts with water to produce OH^- that reacts with Cd^{2+} OR CH_3NH_2 acts as a base and accepts a proton from $[\text{Cd}(\text{H}_2\text{O})_6]^{2+}$ / water OR $[\text{Cd}(\text{H}_2\text{O})_6]^{2+} + 4\text{CH}_3\text{NH}_2 \rightarrow [\text{Cd}(\text{OH})_4(\text{H}_2\text{O})_2]^{2-} + 4\text{CH}_3\text{NH}_3^+$ OWTTE	1
(v)	$\text{Cd}(\text{OH})_4^{2-}$ = most stable (2nd box) AND $[\text{Cd}(\text{H}_2\text{O})_6]^{2+}$ = least stable (first box) $\text{Cd}(\text{OH})_4^{2-}$ has highest K_{stab} (and all K_{stab} values given > 1)	2
99 (a)	red or pink to yellow / straw / brown / orange	1
(b)	$\frac{[\text{Co}(\text{NH}_3)_6]^{2+}}{[\text{Co}(\text{H}_2\text{O})_6]^{2+}[\text{NH}_3]^6}$	1
(c)	$[\text{Co}(\text{NH}_3)_6]^{2+}$ is more stable (than $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$)	1
100 (a)	Circles round both N atoms and all four O^-	1
(b)	M1: (d-d) energy gap / ΔE is different M2: different frequency / wavelength (of light) absorbed	2
(c)	ligand exchange / substitution / displacement / replacement	1

(d)	$K_{\text{stab}} = \frac{[\text{Fe}(\text{edds})^-]}{[\text{Fe}(\text{H}_2\text{O})_6^{3+}][\text{edds}^{4-}]}$	1												
(e)	$[\text{Fe}(\text{edta})]^-$ is more stable as it has the higher K_{stab}	1												
101 (a)(i)	$K_{\text{stab}} = \frac{[(\text{Cu}(\text{NH}_3)_4)^{2+}]}{[(\text{Cu}(\text{H}_2\text{O})_6)^{2+}][\text{NH}_3]^4}$	1												
(ii)	deep / dark / royal blue	1												
(b)	$[\text{Cu}(\text{NH}_3)_4]^{2+} + 2\text{H}_2\text{O} \rightarrow \text{Cu}(\text{OH})_2 + 2\text{NH}_4^+ + 2\text{NH}_3$ [1] OR $[\text{Cu}(\text{NH}_3)_4]^{2+} + 2\text{H}_2\text{O} \rightarrow \text{Cu}(\text{OH})_2 + 2\text{H}^+ + 4\text{NH}_3$	1												
(c)	$\text{Cu}(\text{OH})_2 + 4\text{HCl} \rightarrow [\text{CuCl}_4]^{2-} + 2\text{H}_2\text{O} + 2\text{H}^+$ OR $\text{Cu}(\text{OH})_2 + 4\text{Cl}^- + 2\text{H}^+ \rightarrow [\text{CuCl}_4]^{2-} + 2\text{H}_2\text{O}$ $[\text{CuCl}_4]^{2-}$ complex including charge [1] rest of equation fully correct [1]	2												
(d)	<table border="1" data-bbox="596 902 1326 1122"> <thead> <tr> <th></th><th>Y</th><th>Z</th></tr> </thead> <tbody> <tr> <td>colour of complex</td><td>yellow</td><td>blue / pale blue</td></tr> <tr> <td>geometry of complex</td><td>tetrahedral</td><td>octahedral</td></tr> <tr> <td>formula of complex</td><td></td><td>$[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$</td></tr> </tbody> </table> one mark for any three cells [1] two marks for all five cells [2]		Y	Z	colour of complex	yellow	blue / pale blue	geometry of complex	tetrahedral	octahedral	formula of complex		$[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$	2
	Y	Z												
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(e)	M1: d orbitals splits into two sets of energy levels of different energy [1] M2: wavelength / frequency / light / photon / $h\nu$ absorbed [1] M3: electron(s) promoted / excited [1] M4: colour seen is complementary (to colour absorbed) [1] M5: d–d energy gap / ΔE is different for Y and Z AND so different frequency / wavelength of light <u>absorbed</u> [1]	5												
102 (a)	structure of EDTA any six atoms circled of 2 N & 4 O	1												
(b)	M1 $K_{\text{stab1}} = \frac{[\text{CdEDTA}^{2-}]}{[\text{Cd}(\text{H}_2\text{O})_6^{2+}][\text{EDTA}^{4-}]}$ M2 units = $\text{mol}^{-1} \text{dm}^3$	2												

