Unit 9

COORDINATION COMPOUNDS

I. Multiple Choice Questions (Type-I)

1. Which of the following complexes formed by Cu^{2+} ions is most stable?

(i) $Cu^{2+} + 4NH_3 \rightleftharpoons [Cu(NH_3)_4]^{2+}$, logK = 11.6

(ii) $Cu^{2+} + 4CN^- \rightleftharpoons [Cu(CN)_4]^{2-}$, logK = 27.3

(iii) $Cu^{2+} + 2en \rightleftharpoons [Cu(en)_2]^{2+}$, logK = 15.4

(iv) $Cu^{2+} + 4H_2O \rightleftharpoons [Cu(H_2O)_4]^{2+}$, logK = 8.9

2. The colour of the coordination compounds depends on the crystal field splitting. What will be the correct order of absorption of wavelength of light in the visible region, for the complexes, $[Co(NH_3)_6]^{3+}$, $[Co(CN)_6]^{3-}$, $[Co(H_2O)_6]^{3+}$

(i) $[Co(CN)_6]^{3-} > [Co(NH_3)_6]^{3+} > [Co(H_2O)_6]^{3+}$

(ii) $[Co(NH_3)_6]^{3+} > [Co(H_2O)_6]^{3+} > [Co(CN)_6]^{3-}$

(iii) $[Co(H_2O)_6]^{3+} > [Co(NH_3)_6]^{3+} > [Co(CN)_6]^{3-}$

(iv) $[Co(CN)_6]^{3-} > [Co(NH_3)_6]^{3+} > [Co(H_2O)_6]^{3+}$

3. When 0.1 mol $CoCl_3(NH_3)_5$ is treated with excess of $AgNO_3$, 0.2 mol of AgCl are obtained. The conductivity of solution will correspond to

(i) 1:3 electrolyte

(ii) 1:2 electrolyte

(iii) 1:1 electrolyte

(iv) 3:1 electrolyte

4. When 1 mol $CrCl_3{\cdot}6H_2O$ is treated with excess of $AgNO_3$, 3 mol of AgCl are obtained. The formula of the complex is :

(i) $[CrCl_3\,(H_2O)_3]{\cdot}3H_2O$

(ii) $[CrCl_2(H_2O)_4]Cl{\cdot}2H_2O$

(iii) $[CrCl(H_2O)_5]Cl_2{\cdot}H_2O$

(iv) $[Cr(H_2O)_6]Cl_3$

5. The correct IUPAC name of $[Pt(NH_3)_2Cl_2]$ is

(i) Diamminedichloridoplatinum (II)

(ii) Diamminedichloridoplatinum (IV)

(iii) Diamminedichloridoplatinum (0)

(iv) Dichloridodiammineplatinum (IV)

6. The stabilisation of coordination compounds due to chelation is called the chelate effect. Which of the following is the most stable complex species?

(i) $[Fe(CO)_5]$

(ii) $[Fe(CN)_6]^{3-}$

(iii) $[Fe(C_2O_4)_3]^{3-}$

(iv) $[Fe(H_2O)_6]^{3+}$

7. Indicate the complex ion which shows geometrical isomerism.

(i) $[Cr(H_2O)_4Cl_2]^+$

(ii) $[Pt(NH_3)_3\,Cl]$

(iii) $[Co(NH_3)_6]^{3+}$

(iv) $[Co(CN)_5(NC)]^{3-}$

8. The CFSE for octahedral $[CoCl_6]^{4-}$ is 18,000 cm^{-1}. The CFSE for tetrahedral $[CoCl_4]^{2-}$ will be

(i) 18,000 cm^{-1}

(ii) 16,000 cm^{-1}

(iii) 8,000 cm^{-1}

(iv) 20,000 cm^{-1}

9. Due to the presence of ambidentate ligands coordination compounds show isomerism. Palladium complexes of the type $[Pd(C_6H_5)_2(SCN)_2]$ and $[Pd(C_6H_5)_2(NCS)_2]$ are

(i) linkage isomers

(ii) coordination isomers

(iii) ionisation isomers

(iv) geometrical isomers

10. The compounds $[Co(SO_4)(NH_3)_5]Br$ and $[Co(SO_4)(NH_3)_5]Cl$ represent

(i) linkage isomerism

(ii) ionisation isomerism

(iii) coordination isomerism
(iv) no isomerism

11. A chelating agent has two or more than two donor atoms to bind to a single metal ion. Which of the following is **not** a chelating agent?

(i) thiosulphato
(ii) oxalato
(iii) glycinato
(iv) ethane-1,2-diamine

12. Which of the following species is **not** expected to be a ligand?

(i) NO
(ii) NH_4^+
(iii) $NH_2CH_2CH_2NH_2$
(iv) CO

13. What kind of isomerism exists between $[Cr(H_2O)_6]Cl_3$ (violet) and $[Cr(H_2O)_5Cl]Cl_2 \cdot H_2O$ (greyish-green)?

(i) linkage isomerism
(ii) solvate isomerism
(iii) ionisation isomerism
(iv) coordination isomerism

14. IUPAC name of $[Pt(NH_3)_2Cl(NO_2)]$ is :

(i) Platinum diaminechloronitrite
(ii) Chloronitrito-N-ammineplatinum (II)
(iii) Diamminechloridonitrito-N-platinum (II)
(iv) Diamminechloronitrito-N-platinate (II)

II. Multiple Choice Questions (Type-II)

Note : In the following questions two or more options may be correct.

15. Atomic number of Mn, Fe and Co are 25, 26 and 27 respectively. Which of the following inner orbital octahedral complex ions are diamagnetic?

(i) $[Co(NH_3)_6]^{3+}$
(ii) $[Mn(CN)_6]^{3-}$
(iii) $[Fe(CN)_6]^{4-}$
(iv) $[Fe(CN)_6]^{3-}$

16. Atomic number of Mn, Fe, Co and Ni are 25, 26 27 and 28 respectively. Which of the following outer orbital octahedral complexes have same number of unpaired electrons?

(i) $[MnCl_6]^{3-}$

(ii) $[FeF_6]^{3-}$

(iii) $[CoF_6]^{3-}$

(iv) $[Ni(NH_3)_6]^{2+}$

17. Which of the following options are correct for $[Fe(CN)_6]^{3-}$ complex?

(i) d^2sp^3 hybridisation

(ii) sp^3d^2 hybridisation

(iii) paramagnetic

(iv) diamagnetic

18. An aqueous pink solution of cobalt(II) chloride changes to deep blue on addition of excess of HCl. This is because____________.

(i) $[Co(H_2O)_6]^{2+}$ is transformed into $[CoCl_6]^{4-}$

(ii) $[Co(H_2O)_6]^{2+}$ is transformed into $[CoCl_4]^{2-}$

(iii) tetrahedral complexes have smaller crystal field splitting than octahedral complexes.

(iv) tetrahedral complexes have larger crystal field splitting than octahedral complex.

19. Which of the following complexes are homoleptic?

(i) $[Co(NH_3)_6]^{3+}$

(ii) $[Co(NH_3)_4 Cl_2]^+$

(iii) $[Ni(CN)_4]^{2-}$

(iv) $[Ni(NH_3)_4Cl_2]$

20. Which of the following complexes are heteroleptic?

(i) $[Cr(NH_3)_6]^{3+}$

(ii) $[Fe(NH_3)_4 Cl_2]^+$

(iii) $[Mn(CN)_6]^{4-}$

(iv) $[Co(NH_3)_4Cl_2]$

21. Identify the optically active compounds from the following :

(i) $[Co(en)_3]^{3+}$

(ii) *trans*– $[Co(en)_2 Cl_2]^+$

(iii) *cis*– $[Co(en)_2 Cl_2]^+$

(iv) $[Cr (NH_3)_5Cl]$

22. Identify the correct statements for the behaviour of ethane-1, 2-diamine as a ligand.

(i) It is a neutral ligand.

(ii) It is a didentate ligand.

(iii) It is a chelating ligand.
(iv) It is a unidentate ligand.

23. Which of the following complexes show linkage isomerism?

(i) $[Co(NH_3)_5(NO_2)]^{2+}$
(ii) $[Co(H_2O)_5CO]^{3+}$
(iii) $[Cr(NH_3)_5SCN]^{2+}$
(iv) $[Fe(en)_2Cl_2]^{+}$

III. Short Answer Type

24. Arrange the following complexes in the increasing order of conductivity of their solution: $[Co(NH_3)_3Cl_3]$, $[Co(NH_3)_4Cl_2]Cl$, $[Co(NH_3)_6]Cl_3$, $[Cr(NH_3)_5Cl]Cl_2$

25. A coordination compound $CrCl_3{\cdot}4H_2O$ precipitates silver chloride when treated with silver nitrate. The molar conductance of its solution corresponds to a total of two ions. Write structural formula of the compound and name it.

26. A complex of the type $[M(AA)_2X_2]^{n+}$ is known to be optically active. What does this indicate about the structure of the complex? Give one example of such complex.

27. Magnetic moment of $[MnCl_4]^{2-}$ is 5.92 BM. Explain giving reason.

28. On the basis of crystal field theory explain why Co(III) forms paramagnetic octahedral complex with weak field ligands whereas it forms diamagnetic octahedral complex with strong field ligands.

29. Why are low spin tetrahedral complexes not formed?

30. Give the electronic configuration of the following complexes on the basis of Crystal Field Splitting theory.

$[CoF_6]^{3-}$, $[Fe(CN)_6]^{4-}$ and $[Cu(NH_3)_6]^{2+}$.

31. Explain why $[Fe(H_2O)_6]^{3+}$ has magnetic moment value of 5.92 BM whereas $[Fe(CN)_6]^{3-}$ has a value of only 1.74 BM.

32. Arrange following complex ions in increasing order of crystal field splitting energy (Δ_O) :

$[Cr(Cl)_6]^{3-}$, $[Cr(CN)_6]^{3-}$, $[Cr(NH_3)_6]^{3+}$.

33. Why do compounds having similar geometry have different magnetic moment?

34. $CuSO_4.5H_2O$ is blue in colour while $CuSO_4$ is colourless. Why?

35. Name the type of isomerism when ambidentate ligands are attached to central metal ion. Give two examples of ambidentate ligands.

IV. Matching Type

Note : In the following questions match the items given in Columns I and II.

36. Match the complex ions given in Column I with the colours given in Column II and assign the correct code :

Column I (Complex ion)	**Column II (Colour)**
A. $[Co(NH_3)_6]^{3+}$	1. Violet
B. $[Ti(H_2O)_6]^{3+}$	2. Green
C. $[Ni(H_2O)_6]^{2+}$	3. Pale blue
D. $(Ni\ (H_2O)_4\ (en)]^{2+}$ (aq)	4. Yellowish orange
	5. Blue

Code :

(i)	A (1)	B (2)	C (4)	D (5)
(ii)	A (4)	B (3)	C (2)	D (1)
(iii)	A (3)	B (2)	C (4)	D (1)
(iv)	A (4)	B (1)	C (2)	D (3)

37. Match the coordination compounds given in Column I with the central metal atoms given in Column II and assign the correct code :

Column I (Coordination Compound)	**Column II (Central metal atom)**
A. Chlorophyll	1. rhodium
B. Blood pigment	2. cobalt
C. Wilkinson catalyst	3. calcium
D. Vitamin B_{12}	4. iron
	5. magnesium

Code :

(i)	A (5)	B (4)	C (1)	D (2)
(ii)	A (3)	B (4)	C (5)	D (1)
(iii)	A (4)	B (3)	C (2)	D (1)
(iv)	A (3)	B (4)	C (1)	D (2)

38. Match the complex ions given in Column I with the hybridisation and number of unpaired electrons given in Column II and assign the correct code :

Column I (Complex ion)	**Column II (Hybridisation, number of unpaired electrons)**
A. $[Cr(H_2O)_6]^{3+}$	1. dsp^2, 1
B. $[Co(CN)_4]^{2-}$	2. sp^3d^2, 5
C. $[Ni(NH_3)_6]^{2+}$	3. d^2sp^3, 3
D. $[MnF_6]^{4-}$	4. sp^3, 4
	5. sp^3d^2, 2

Code :

(i)	A (3)	B (1)	C (5)	D (2)

(ii)	A (4)	B (3)	C (2)	D (1)
(iii)	A (3)	B (2)	C (4)	D (1)
(iv)	A (4)	B (1)	C (2)	D (3)

39. Match the complex species given in Column I with the possible isomerism given in Column II and assign the correct code :

Column I (Complex species)	**Column II (Isomerism)**
A. $[Co(NH_3)_4Cl_2]^+$	1. optical
B. *cis*-$[Co(en)_2Cl_2]^+$	2. ionisation
C. $[Co(NH_3)_5(NO_2)]Cl_2$	3. coordination
D. $[Co(NH_3)_6][Cr(CN)_6]$	4. geometrical
	5. linkage

Code :

(i)	A (1)	B (2)	C (4)	D (5)
(ii)	A (4)	B (3)	C (2)	D (1)
(iii)	A (4)	B (1)	C (5)	D (3)
(iv)	A (4)	B (1)	C (2)	D (3)

40. Match the compounds given in Column I with the oxidation state of cobalt present in it (given in Column II) and assign the correct code.

Column I (Compound)	**Column II (Oxidation state of Co)**
A. $[Co(NCS)(NH_3)_5](SO_3)$	1. + 4
B. $[Co(NH_3)_4Cl_2]SO_4$	2. 0
C. $Na_4[Co(S_2O_3)_3]$	3. + 1
D. $[Co_2(CO)_8]$	4. + 2
	5. + 3

Code :

(i)	A (1)	B (2)	C (4)	D (5)
(ii)	A (4)	B (3)	C (2)	D (1)
(iii)	A (5)	B (1)	C (4)	D (2)
(iv)	A (4)	B (1)	C (2)	D (3)

V. Assertion and Reason Type

Note : In the following questions a statement of assertion followed by a statement of reason is given. Choose the correct answer out of the following choices.

(i) Assertion and reason both are true, reason is correct explanation of assertion.

(ii) Assertion and reason both are true but reason is not the correct explanation of assertion.

(iii) Assertion is true, reason is false.

(iv) Assertion is false, reason is true.

41. Assertion : Toxic metal ions are removed by the chelating ligands.
Reason : Chelate complexes tend to be more stable.

42. Assertion : $[Cr(H_2O)_6]Cl_2$ and $[Fe(H_2O)_6]Cl_2$ are reducing in nature.
Reason : Unpaired electrons are present in their *d*-orbitals.

43. Assertion : Linkage isomerism arises in coordination compounds containing ambidentate ligand.
Reason : Ambidentate ligand has two different donor atoms.

44. Assertion : Complexes of MX_6 and MX_5L type (X and L are unidentate) do not show geometrical isomerism.
Reason : Geometrical isomerism is not shown by complexes of coordination number 6.

45. Assertion : ($[Fe(CN)_6]^{3-}$ ion shows magnetic moment corresponding to two unpaired electrons.
Reason : Because it has d^2sp^3 type hybridisation.

VI. Long Answer Type

46. Using crystal field theory, draw energy level diagram, write electronic configuration of the central metal atom/ion and determine the magnetic moment value in the following :
(i) $[CoF_6]^{3-}$, $[Co(H_2O)_6]^{2+}$, $[Co(CN)_6]^{3-}$
(ii) $[FeF_6]^{3-}$, $[Fe(H_2O)_6]^{2+}$, $[Fe(CN)_6]^{4-}$

47. Using valence bond theory, explain the following in relation to the complexes given below:
$[Mn(CN)_6]^{3-}$, $[Co(NH_3)_6]^{3+}$, $[Cr(H_2O)_6]^{3+}$, $[FeCl_6]^{4-}$
(i) Type of hybridisation.
(ii) Inner or outer orbital complex.
(iii) Magnetic behaviour.
(iv) Spin only magnetic moment value.

48. $CoSO_4Cl.5NH_3$ exists in two isomeric forms 'A' and 'B'. Isomer 'A' reacts with $AgNO_3$ to give white precipitate, but does not react with $BaCl_2$. Isomer 'B' gives white precipitate with $BaCl_2$ but does not react with $AgNO_3$. Answer the following questions.
(i) Identify 'A' and 'B' and write their structural formulas.
(ii) Name the type of isomerism involved.
(iii) Give the IUPAC name of 'A' and 'B'.

49. What is the relationship between observed colour of the complex and the wavelength of light absorbed by the complex?

50. Why are different colours observed in octahedral and tetrahedral complexes for the same metal and same ligands?

ANSWERS

I. Multiple Choice Questions (Type-I)

1. (ii) 2. (iii) 3. (ii) 4. (iv) 5. (i) 6. (iii)
7. (i) 8. (iii) 9. (i) 10. (iv) 11. (i) 12. (ii)
13. (ii) 14. (iii)

II. Multiple Choice Questions (Type-II)

15. (i), (iii) 16. (i), (iii) 17. (i), (iii) 18. (ii), (iii)

19. (i), (iii) 20. (ii), (iv) 21. (i), (iii) 22. (i), (ii), (iii)

23. (i), (iii)

III. Short Answer Type

24. $[Co(NH_3)_3Cl_3] < [Cr(NH_3)_5Cl]Cl < [Co(NH_3)_5Cl]Cl_2 < [Co(NH_3)_6]Cl_3$

25. $[Co(H_2O)_4Cl_2]Cl$ (tetraaquadichloridocobalt(III) chloride)

26. An optically active complex of the type $[M(AA)_2X_2]^{n+}$ indicates *cis*-octahedral structure, e.g. *cis*-$[Pt(en)_2Cl_2]^{2+}$ or *cis*-$[Cr(en)_2Cl_2]^+$

27. The magnetic moment of 5.92 BM corresponds to the presence of five unpaired electrons in the *d*-orbitals of Mn^{2+} ion. As a result the hybridisation involved is sp^3 rather than dsp^2. Thus tetrahedral structure of $[MnCl_4]^{2-}$ complex will show 5.92 BM magnetic moment value.

28. With weak field ligands; $\Delta_O < p$, the electronic configuration of Co (III) will be $t^4_{2g}\ e^2_g$ and it has 4 unpaired electrons and is paramagnetic. With strong field ligands, $\Delta_0 > p$, the electronic configuration will be $t^6_{2g}\ e^0_g$. It has no unpaired electrons and is diamagnetic.

29. Because for tetrahedral complexes, the crystal field stabilisation energy is lower than pairing energy.

30. $[CoF_6]^{3-}$, $Co^{3+}(d^6)\ t_{2g}^4\ e_g^2$,
$[Fe(CN)_6]^{4-}$, $Fe^{2+}(d^6)\ t_{2g}^6\ e_g^0$,
$[Cu(NH_3)_6]^{2+}$, $Cu^{2+}(d^9)\ t_{2g}^6\ e_g^3$,

31. $[Fe(CN)_6]^{3-}$ involves d^2sp^3 hybridisation with one unpaired electron and $[Fe(H_2O)_6]^{3+}$ involves sp^3d^2 hybridisation with five unpaired electrons. This difference is due to the presence of strong ligand CN^- and weak ligand H_2O in these complexes.

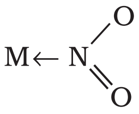
32. Crystal field splitting energy increases in the order $[Cr(Cl)_6]^{3-} < [Cr(NH_3)_6]^{3+} < [Cr(CN)_6]^{3-}$

33. It is due to the presence of weak and strong ligands in complexes, if CFSE is high, the complex will show low value of magnetic moment and vice versa, e.g. $[CoF_6]^{3-}$ and $[Co(NH_3)_6]^{3+}$, the former is paramagnetic and the latter is diamagnetic.

34. In $CuSO_4.5H_2O$, water acts as ligand as a result it causes crystal field splitting. Hence d—d transition is possible in $CuSO_4.5H_2O$ and shows colour. In the anhydrous $CuSO_4$ due to the absence of water (ligand), crystal field splitting is not possible and hence no colour.

35. Linkage isomerism

Examples : (i)



nitrito-N

$M \leftarrow O—N{=}O$

nitrito — O

(ii) $M \leftarrow SCN$ thiocyanato $M \leftarrow NCS$ isothiocyanato

IV. Matching Type

36. (ii) 37. (i) 38. (ii) 39. (iv) 40. (i)

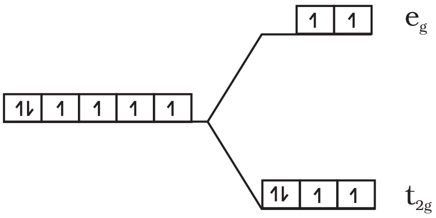
$\sqrt{n(n+2)}$

V. Assertion and Reason Type

41. (i) 42. (ii) 43. (i) 44. (ii) 45. (iv)

VI. Long Answer Type

46. (i) $[CoF_6]^{3-}$



i.e. $t_{2g}^4 e_g^2$

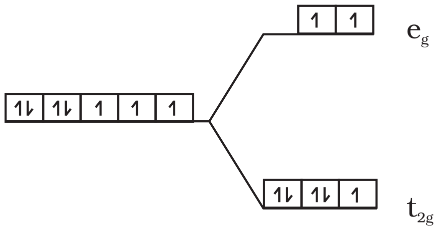
$Co^{3+} = 3d^6$

Number of unpaired electrons = 4

$$= \sqrt{4(4+2)} = \sqrt{24} = 4.9 \text{ BM}$$

$[Co(H_2O)_6]^{2+}$

$Co^{2+} = 3d^7$



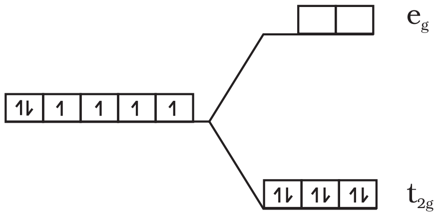
i.e. $t_{2g}^5 e_g^2$

Number of unpaired electrons = 3

$\sqrt{3(3+2)} = \sqrt{15} = 3.87$ BM

$[Co(CN)_6]^{3-}$

$Co^{3+} = 3d^6$

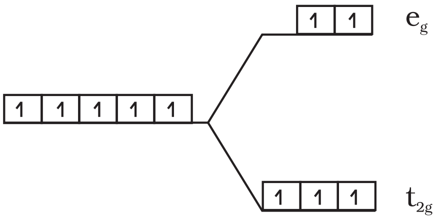


i.e. $t_{2g}^6 e_g^0$

No unpaired electrons so diamagnetic

(ii) FeF_6^{3-}

$Fe^{3+} = 3d^5$



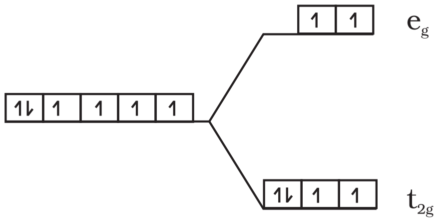
i.e. $t_{2g}^3 e_g^2$

Number of unpaired electrons = 5

$\sqrt{5(5+2)} = \sqrt{35} = 5.92$ BM

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

$Fe^{2+} = 3d^6$

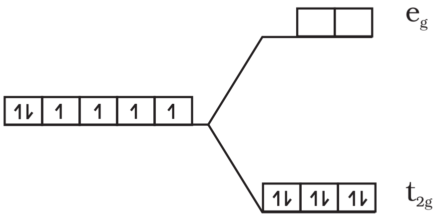


i.e. $t_{2g}^4 e_g^2$

Number of unpaired electrons = 4

$\sqrt{4(4+2)} = \sqrt{24} = 4.9$ BM

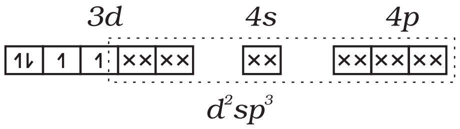
$[Fe(CN)_6]^{4-}$
$Fe^{2+} = 3d^6$
Since CN^- is strong field ligand all the electrons get paired.



i.e. $t_{2g}^6 e_g^0$

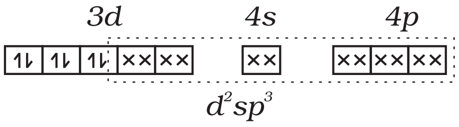
No unpaired electrons so diamagnetic

47. $[Mn(CN)_6]^{3-}$
$Mn^{3+} = 3d^4$



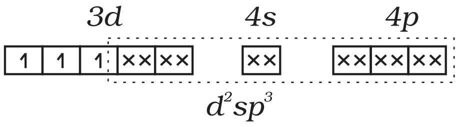
(i) d^2sp^3
(ii) Inner orbital complex
(iii) Paramagnetic
(iv) $\sqrt{2(2+2)} = \sqrt{8} = 2.87$ BM

$[Co(NH_3)_6]^{3+}$
$Co^{3+} = 3d^6$



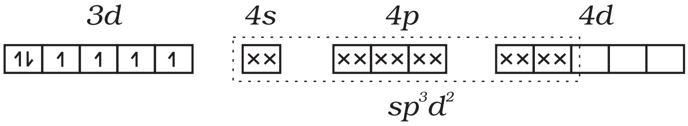
(i) d^2sp^3
(ii) Inner orbital complex
(iii) Diamagnetic
(iv) Zero

$[Cr(H_2O)_6]^{3+}$
$Cr^{3+} = 3d^3$



(i) d^2sp^3
(ii) Inner orbital complex
(iii) Paramagnetic
(iv) 3.87 BM

$[Fe(Cl)_6]^{4-}$
$Fe^{2+} = 3d^6$



- (i) sp^3d^2
- (ii) Outer orbital complex
- (iii) Paramagnetic
- (iv) 4.9 BM

48. (i) A - $[Co(NH_3)_5SO_4]Cl$
    B - $[Co(NH_3)_5Cl]SO_4$
    (ii) Ionisation isomerism
    (iii) (A), Pentaamminesulphatocobalt (III) chloride
    (B), Pentaamminechlorocobalt (III) sulphate.

49. When white light falls on the complex, some part of it is absorbed. Higher the crystal field splitting, lower will be the wavelength absorbed by the complex. The observed colour of complex is the colour generated from the wavelength left over.

50. $\Delta_t = \frac{4}{9}\Delta_0$. So higher wavelength is absorbed in octahedral complex than tetrahedral complex for same metal and ligands.