CHEMISTRY (CODE – 043)

Chapter-wise Test: Coordination Compounds

(NCERT Class XII Chemistry, Unit 5: Coordination Compounds)

SOLUTIONS AND MARKING SCHEME

CLASS XII (2026-27)

Time: 1½ hours **Max. Marks: 35**

Step-by-step solutions with the distribution of marks. Marks for each step are shown in square brackets [ ]. Any other correct method or answer should be given full credit.

Quick answer key – Section A

Q.	1	2	3	4	5	6	7	8
Ans.	B	D	A	C	B	D	A	C

SECTION A

Questions 1 to 8 are multiple choice questions. Only one of the choices is correct. Select and write the correct choice as well as the answer to these questions. Each question carries 1 mark.

1	**Answer: B** Ligands are named in alphabetical order (ammine before aqua) and the oxidation state of the metal is written in Roman numerals in brackets. Oxidation state of Cr: $x + 3(0) + 3(0) = +3$ (balanced by three Cl^-), so $x = +3$. The counter ion is named separately as *chloride* with no prefix. Hence: triamminetriaquachromium(III) chloride.	1
2	**Answer: D** Only the ionisable (primary valence) chloride ions are precipitated by Ag^+; chloride ions bonded to the metal (secondary valence) are not. The purple compound gives 2 mol AgCl, so it has two free Cl^- ions and one Cl^- inside the coordination sphere. With coordination number 6 (five NH_3 + one Cl^-) the formula is $[CoCl(NH_3)_5]Cl_2$. (A gives 3 mol AgCl, B gives 1 mol and C gives none.)	1
3	**Answer: A. $[Ni(CN)_4]^{2-}$** The figure shows Ni^{2+} ($3d^8$) with all eight d electrons paired in four 3d orbitals; the fifth 3d orbital, the 4s orbital and two 4p orbitals form four dsp^2 hybrid orbitals that accept the electron pairs of four ligands. This is the square planar, diamagnetic $[Ni(CN)_4]^{2-}$ (CN^- is a strong field ligand and forces pairing). $[NiCl_4]^{2-}$ is sp^3 (two unpaired electrons), $[Ni(H_2O)_6]^{2+}$ uses six orbitals, and in $[Ni(CO)_4]$ nickel is $3d^{10}$ (sp^3).	1
4	**Answer: C. 4.90** Co^{3+} is $3d^6$. F^- is a weak field ligand, so pairing does not occur: $t_{2g}^4 e_g^2$, with $n = 4$ unpaired electrons. $\mu = \sqrt{[n(n+2)]} = \sqrt{(4 \times 6)} = \sqrt{24} =$ **4.90 BM**.	1
5	**Answer: B** An ambidentate ligand has two different donor atoms but binds through only one of them at a time. SCN^- can bind through S (thiocyanato-S) or through N (isothiocyanato-N). en and $C_2O_4^{2-}$ are bidentate (two donor atoms of the same kind, both bind), and NH_3 is unidentate.	1
6	**Answer: D. CN^-** Spectrochemical series: $I^- < Br^- < SCN^- < Cl^- < F^- < OH^- < C_2O_4^{2-} < H_2O < NH_3 <$ en $< CN^- <$ CO. Among the options CN^- is the strongest field ligand and gives the largest Δ_o.	1
7	**Answer: A. $[Co(en)_3]^{3+}$** $[Co(en)_3]^{3+}$ is octahedral with three bidentate ligands; it has no plane or centre of symmetry, so its mirror images (*d* and *l*) are non-superimposable. $[Co(NH_3)_6]^{3+}$, square planar $[PtCl_2(NH_3)_2]$ and tetrahedral $[Ni(CO)_4]$ are symmetrical and optically inactive.	1

8	**Answer: C. A is true but R is false.** In a tetrahedral field the d orbitals do not point directly at the ligands and only four ligands are present, so $\Delta_t = (4/9)\Delta_o$, i.e. Δ_t is *smaller* than Δ_o. This small splitting is less than the pairing energy, so electrons occupy the higher orbitals singly: high spin. A is true; R is false.	1

SECTION B

Question Nos. 9 to 11 are very short answer questions carrying 2 marks each.

9	**(A)** (i) A: $[Pd(NH_3)_4]Cl_2$ (both Cl^- ionisable, 2 mol AgCl). B: $[CoCl_2(NH_3)_4]Cl$ (one ionisable Cl^-; two Cl^- are coordinated to make coordination number 6). C: $[PtCl_2(NH_3)_2]$ (no free Cl^-). [1: all three correct; ½ for any two] (ii) **C**, $[PtCl_2(NH_3)_2]$, is a neutral complex with no free ions, so it is a non-electrolyte. [1] **(B)** (i) Diamminechlorido(methanamine)platinum(II) chloride [1] (ii) Potassium hexacyanidoferrate(III) [1]	1 + 1
10	**(A)** **Ionisation isomerism:** isomers give different ions in solution because of the exchange of an ion between the coordination sphere and the counter ion. Example: $[Co(NH_3)_5SO_4]Br$ and $[Co(NH_3)_5Br]SO_4$. [1] **Coordination isomerism:** occurs in compounds having both cationic and anionic complex entities, when ligands are interchanged between the two entities. Example: $[Co(NH_3)_6][Cr(CN)_6]$ and $[Cr(NH_3)_6][Co(CN)_6]$. [1] **(B)** A double salt (e.g. carnallite $KCl·MgCl_2·6H_2O$, Mohr's salt $FeSO_4·(NH_4)_2SO_4·6H_2O$) dissociates completely into simple ions in water and loses its identity. [1] A coordination compound (e.g. $K_4[Fe(CN)_6]$) keeps its complex entity in solution; the complex ion $[Fe(CN)_6]^{4-}$ does not dissociate into Fe^{2+} and CN^-. [1]	1 + 1
11	**(A)** (i) Ni^{2+} is $3d^8$. Cl^- is a weak field ligand; the complex is sp^3 with two unpaired electrons. $\mu = \sqrt{[2(2+2)]} = \sqrt{8} =$ **2.83 BM**. [1] (ii) CN^- is a strong field ligand; the 3d electrons pair up, giving dsp^2 hybridisation and $n = 0$. $\mu =$ **0 BM** (diamagnetic). [1] **(B)** (i) $[Co(NH_3)_4(H_2O)Cl]Cl_2$ [1] (ii) $K_2[Zn(OH)_4]$ [1]	1 + 1

SECTION C

Question Nos. 12 to 15 are short answer questions carrying 3 marks each.

12	**(A)** (i) $[CoCl(NH_3)_5]^{2+} < [Co(NH_3)_6]^{3+} < [Co(CN)_6]^{3-}$. A stronger field ligand causes a larger Δ_o, so light of higher energy (shorter wavelength) is absorbed: 535 nm < 475 nm < 310 nm and $Cl^- < NH_3 < CN^-$ in the spectrochemical series ($E = hc/\lambda = \Delta_o$). [1] (ii) **Blue.** The d–d transition ($t_{2g} \rightarrow e_g$) absorbs red light (600 nm); the complementary colour, blue, is transmitted and seen. [1] (iii) CN^- is a very strong field ligand, so Δ_o is very large and the d–d absorption (310 nm) falls in the ultraviolet region. Very little visible light is absorbed, and the complex appears only pale yellow. [1] **(B)** (i) In anhydrous $CuSO_4$ there are no ligands (water) to split the d orbitals of Cu^{2+} ($3d^9$), so no d–d transition and it is white. In the hydrate, H_2O ligands split the d levels; the d–d transition absorbs red light and the transmitted colour is blue. [1] (ii) en is a stronger field ligand than H_2O. Replacing water by en increases Δ_o, so the wavelength absorbed shifts to a shorter value and the colour seen changes from green to pale blue, blue and violet. [1] (iii) The arrangement of ligands in increasing order of their crystal field splitting power (field strength) is called the spectrochemical series, e.g. $I^- < Cl^- < F^- < H_2O < NH_3 <$ en $< CN^- <$ CO. [1]	1 + 1 + 1
13	**(A)** (i) P = e_g ($d_{x^2-y^2}$, d_{z^2}), Q = t_{2g} (d_{xy}, d_{yz}, d_{zx}), R = t_2 (d_{xy}, d_{yz}, d_{zx}), S = e ($d_{x^2-y^2}$, d_{z^2}). [1: all four; ½ for two] (ii) $\Delta_2 = \Delta_t = (4/9)\Delta_1 = (4/9)\Delta_o$, i.e. Δ_t is smaller than Δ_o. [1] (iii) In a tetrahedral field the orbitals do not point directly at the ligands and only four ligands are present, so Δ_t is small and smaller than the pairing energy. Electrons therefore occupy the higher t_2 orbitals singly instead of pairing in the lower e orbitals; low spin configurations do not occur. [1] **(B)** (i) $[Co(NH_3)_6]^{3+}$: Co^{3+} is d^6; $\Delta_o > P$: $t_{2g}^6 e_g^0$; 0 unpaired electrons; diamagnetic; low spin (inner orbital) complex. [1½] (ii) $[CoF_6]^{3-}$: $\Delta_o < P$: $t_{2g}^4 e_g^2$; 4 unpaired electrons; paramagnetic (μ = 4.90 BM); high spin (outer orbital) complex. [1½]	1 + 1 + 1
14	**(A)** (i) Geometrical (*cis–trans*) isomerism. **I is cis** (the two Cl are at 90°, adjacent positions) and **II is trans** (the two Cl are at 180°, opposite positions). [1] (ii) **Isomer I (cis)** has a net dipole moment because the two Co–Cl dipoles do not cancel. In the trans isomer, the dipoles of the opposite Co–Cl (and Co–NH_3) bonds cancel, so the dipole moment is zero. [1] (iii) No. Both isomers have a plane of symmetry, so they are superimposable on their mirror images and are optically inactive. [1] **(B)** (i) Linkage isomerism occurs in coordination compounds containing an ambidentate ligand, which can bind to the metal through either of two different donor atoms, giving isomers that differ in the linking atom. [1] (ii) $[Co(NH_3)_5(NO_2)]Cl_2$ (nitrito-N, yellow) and $[Co(NH_3)_5(ONO)]Cl_2$ (nitrito-O, red). [1] (iii) The NO_2^- (nitrite) ion, which can bind through N or through O. [1]	1 + 1 + 1

15	**(A)** (i) Hardness is estimated by titration with Na_2EDTA. Ca^{2+} and Mg^{2+} form stable complexes with EDTA, and the two ions can be estimated selectively because their complexes have different stability constants. [1] (ii) Gold combines with cyanide in the presence of oxygen and water to form the soluble complex $[Au(CN)_2]^-$. Gold is recovered as metal by the addition of zinc, which displaces it. (Silver is extracted similarly.) [1] (iii) The developed film is fixed by washing with hypo (sodium thiosulphate) solution, which dissolves the undecomposed AgBr by forming the soluble complex ion $[Ag(S_2O_3)_2]^{3-}$. [1] **(B)** (i) The M–C σ bond is formed by donation of the lone pair on the carbonyl carbon into a vacant orbital of the metal. The M–C π bond is formed by donation of a pair of electrons from a filled d orbital of the metal into the vacant antibonding π* orbital of CO (back bonding). Each bond strengthens the other, hence the effect is called *synergic*, and the M–C bond is strengthened. [2] (ii) $Ni(CO)_4$: tetrahedral; $Fe(CO)_5$: trigonal bipyramidal; $Cr(CO)_6$: octahedral. [1]	1 + 1 + 1

SECTION D

Question No. 16 is a case-based/data-based question carrying 4 marks.

16	(i) $[NiCl_4]^{2-}$: $n = 2$, $\mu = \sqrt{(2 \times 4)} = \sqrt{8} =$ **2.83 BM**. $[CoF_6]^{3-}$: $n = 4$, $\mu = \sqrt{(4 \times 6)} = \sqrt{24} =$ **4.90 BM**. [½ + ½] (ii) $[Co(NH_3)_6]^{3+}$ is an **inner orbital** complex: NH_3 forces the 3d electrons to pair, leaving two 3d orbitals vacant, so (n−1)d orbitals take part in d^2sp^3 hybridisation. $[CoF_6]^{3-}$ is an **outer orbital** complex: no pairing occurs, so the outer 4d orbitals are used in sp^3d^2 hybridisation. [1] (iii) **(A)** CO is a strong field ligand. In the presence of CO the two 4s electrons of Ni shift to 3d, so Ni becomes $3d^{10}$ (all paired). The vacant 4s and three 4p orbitals undergo sp^3 hybridisation to accept four electron pairs from four CO, giving a tetrahedral complex with no unpaired electrons, hence diamagnetic. [2] **(B)** Fe^{3+} is $3d^5$. CN^- is a strong field ligand, so the electrons pair up leaving one unpaired electron (t_{2g}^5) and two vacant 3d orbitals. These two 3d, one 4s and three 4p orbitals form six d^2sp^3 hybrid orbitals (inner orbital, octahedral). $\mu = \sqrt{[1(1+2)]} = \sqrt{3} = 1.73$ BM. [2]	1 + 1 + 2

SECTION E

Question No. 17 is a long answer question carrying 5 marks.

17	**(A)** (i) Werner's postulates (any three, 1 mark each): • A metal exhibits two types of valence: **primary valence** (ionisable, satisfied by negative ions; equal to the oxidation state) and **secondary valence** (non-ionisable, satisfied by neutral molecules or negative ions; equal to the coordination number). [1] • Every metal tends to satisfy both its primary and secondary valences. [1] • The secondary valences are directed towards fixed positions in space, which gives the coordination entity a definite geometry (octahedral, tetrahedral, square planar). [1] (ii) The compounds show **ionisation isomerism**. [1] Test: with $BaCl_2$ solution, $[Co(NH_3)_5Br]SO_4$ gives a white precipitate of $BaSO_4$ (free SO_4^{2-}), while $[Co(NH_3)_5SO_4]Br$ gives none. Alternatively, with $AgNO_3$ solution $[Co(NH_3)_5SO_4]Br$ gives a pale yellow precipitate of AgBr, whereas $[Co(NH_3)_5Br]SO_4$ does not. [1] **(B)** (1 mark each; definition and example) (i) **Coordination entity:** a central metal atom/ion bonded to a fixed number of ions or molecules (ligands), e.g. $[CoCl_3(NH_3)_3]$. [1] (ii) **Ligand:** an ion or molecule bound to the central atom/ion in the coordination entity, e.g. Cl^-, NH_3, H_2O, en. [1] (iii) **Coordination number:** the number of ligand donor atoms directly bonded to the central metal, e.g. 6 in $[Co(NH_3)_6]^{3+}$. [1] (iv) **Coordination sphere:** the central atom/ion and the ligands attached to it, enclosed in square brackets, e.g. $[Ni(NH_3)_6]^{2+}$ in $[Ni(NH_3)_6]Cl_2$. [1] (v) **Homoleptic complex:** a complex in which a metal is bound to only one kind of donor group, e.g. $[Co(NH_3)_6]^{3+}$. [1]	5

Topic coverage of the paper

Topic (NCERT section)	Questions
Werner's theory, terminology, coordination number (5.1, 5.2)	Q2 (table), Q9 (table), Q17 (A), Q17 (B)
Nomenclature of coordination compounds (5.3)	Q1, Q9 (B), Q11 (B)
Isomerism: geometrical, optical, linkage, ionisation, coordination (5.4)	Q5, Q7, Q10 (A), Q14 (figure), Q14 (B)
Valence bond theory: hybridisation and magnetic behaviour (5.5.1–5.5.3)	Q3 (figure), Q4, Q11 (A), Q16 (table)
Crystal field theory, spectrochemical series and colour (5.5.4)	Q6, Q8, Q12 (table), Q13 (figure)
Metal carbonyls (5.6)	Q15 (B), Q16 (A)
Importance and applications of coordination compounds (5.7)	Q15 (A), Q10 (B)

Figure/table-based questions (7): Q2, Q3, Q9, Q12, Q13, Q14 and Q16.