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Coordination Compounds — JEE (Main) Pattern Topic Test

FREE SAMPLE TEST · CHEMISTRY · PATTERN OF JEE (MAIN)

DURATION	MAXIMUM MARKS	QUESTIONS	NAME / ROLL NO.
60 minutes	100	25 (20 + 5)	

GENERAL INSTRUCTIONS

1. This question paper has two sections, A and B. All 25 questions are compulsory.
2. Section A has TWENTY (20) multiple-choice questions. Each has FOUR options, (1), (2), (3) and (4), of which ONLY ONE is correct.
3. Section B has FIVE (05) questions whose answer is a numerical value. Enter the value rounded off to the nearest integer.
4. Marking scheme for both sections: +4 for a correct answer, −1 for an incorrect answer, 0 if the question is not attempted.
5. Use of a calculator, log tables or any other aid is not allowed.
6. The answer key and worked solutions are at the end of this booklet. Attempt the paper in 60 minutes before you look at them.

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Topics covered: Werner's theory · Ligands and coordination number · Nomenclature · Isomerism · Valence bond theory · Crystal field theory · Bonding in metal carbonyls · Stability of complexes · Importance and applications

SECTION A (Q1–20) · Multiple choice · +4 / 0 / −1

Each question has FOUR options. ONLY ONE of them is correct.

1. Chromium(III) chloride hexahydrate, $CrCl_3 \cdot 6H_2O$, exists in several forms. A 0.01 mol sample of one form, treated at once with excess $AgNO_3$ solution, gives 2.87 g of AgCl (Ag = 108, Cl = 35.5). The form is

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

(2) $[Cr(H_2O)_5Cl]Cl_2 \cdot H_2O$

(3) $[Cr(H_2O)_4Cl_2]Cl \cdot 2H_2O$

(4) $[Cr(H_2O)_3Cl_3] \cdot 3H_2O$

2. The IUPAC name of $Na_2[Ni(CN)_4]$ is

(1) sodium tetracyanidonickel(II)

(2) sodium tetracyanidonickelate(III)

(3) sodium tetracyanidonickelate(II)

(4) sodium nickel(II) tetracyanide

3. The formula of pentaamminenitrito-O-cobalt(III) chloride is

(1) $[Co(NH_3)_5(ONO)]Cl_2$

(2) $[Co(NH_3)_5(NO_2)]Cl_2$

(3) $[Co(NH_3)_5(ONO)]Cl$

(4) $[Co(NH_3)_5(ONO)]Cl_3$

4. The number of geometrical isomers of the square planar complex $[Pt(NH_3)(py)ClBr]$ is

(1) 2

(2) 3

(3) 4

(4) 6

5. Which of the following complexes is optically active?

(1) $[Pt(en)Cl_2]$

(2) $[Co(NH_3)_5Cl]^{2+}$

(3) mer-$[Co(NH_3)_3Cl_3]$

(4) $[Cr(C_2O_4)_3]^{3-}$

6. $[Co(NH_3)_6][Cr(CN)_6]$ and $[Cr(NH_3)_6][Co(CN)_6]$ are

(1) linkage isomers

(2) ionisation isomers

(3) coordination isomers

(4) hydrate isomers

7. According to valence bond theory, the hybridisation of manganese and the number of unpaired electrons in $[Mn(CN)_6]^{4-}$ are, respectively,

(1) d^2sp^3 and 1

(2) sp^3d^2 and 5

(3) d^2sp^3 and 0

(4) sp^3d^2 and 1

8. Which of the following complexes is diamagnetic?

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

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

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

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

9. The crystal field stabilisation energy of a d^7 ion in a tetrahedral field is

(1) $-0.8\Delta_t$

(2) $-0.6\Delta_t$

(3) $-1.2\Delta_t$

(4) $-1.8\Delta_t$

10. For $[Co(NH_3)_6]^{3+}$, $\Delta_o = 22900\ cm^{-1}$ and the pairing energy $P = 21000\ cm^{-1}$. The configuration of the metal ion and the crystal field stabilisation energy, counting the pairing energy for electron pairs beyond those of the free ion, are

(1) $t_2g^6\ eg^0$ and $-12960\ cm^{-1}$

(2) $t_2g^4\ eg^2$ and $-9160\ cm^{-1}$

(3) $t_2g^6\ eg^0$ and $-54960\ cm^{-1}$

(4) $t_2g^6\ eg^0$ and $+12960\ cm^{-1}$

11. Which of the following cobalt(III) complexes absorbs light of the shortest wavelength?

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

(2) $[Co(H_2O)_6]^{3+}$

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

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

12. Which of the following pairs of a coordination compound and its central metal is INCORRECT?

(1) Chlorophyll: Mg

(2) Cisplatin: Pd

(3) Haemoglobin: Fe

(4) Vitamin B12: Co

13. Assertion A: The C–O bond in a metal carbonyl is longer than in free carbon monoxide.
Reason R: In metal carbonyls the metal donates electrons from a filled d orbital into the vacant antibonding π* orbital of CO.
In the light of the above statements, choose the correct answer from the options given below:

(1) Both A and R are true and R is the correct explanation of A

(2) Both A and R are true but R is NOT the correct explanation of A

(3) A is true but R is false

(4) A is false but R is true

14. The correct order of the molar conductivities of equimolar aqueous solutions of the following complexes is

(1) $[Co(NH_3)_3Cl_3] > [Co(NH_3)_4Cl_2]Cl > [Co(NH_3)_5Cl]Cl_2 > [Co(NH_3)_6]Cl_3$

(2) $[Co(NH_3)_5Cl]Cl_2 > [Co(NH_3)_6]Cl_3 > [Co(NH_3)_4Cl_2]Cl > [Co(NH_3)_3Cl_3]$

(3) $[Co(NH_3)_6]Cl_3 > [Co(NH_3)_5Cl]Cl_2 > [Co(NH_3)_4Cl_2]Cl > [Co(NH_3)_3Cl_3]$

(4) $[Co(NH_3)_6]Cl_3 > [Co(NH_3)_4Cl_2]Cl > [Co(NH_3)_5Cl]Cl_2 > [Co(NH_3)_3Cl_3]$

15. Which of the following complex ions has the largest overall stability constant?

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

(2) $[Ni(en)_3]^{2+}$

(3) $[Cu(NH_3)_4]^{2+}$

(4) $[Zn(NH_3)_4]^{2+}$

16. In which of the following compounds does the central metal ion have six d electrons?

(1) $K_3[Fe(CN)_6]$

(2) $[Cr(NH_3)_6]Cl_3$

(3) $[Cu(NH_3)_4]SO_4$

(4) $K_4[Fe(CN)_6]$

17. The denticity of the ethylenediaminetetraacetate ion ($EDTA^{4-}$) and the coordination number of calcium in $[Ca(EDTA)]^{2-}$ are, respectively,

(1) 6 and 6

(2) 4 and 6

(3) 6 and 4

(4) 4 and 4

18. The spin-only magnetic moment of $[Cr(CN)_6]^{4-}$ is about

(1) 4.90 BM

(2) 1.73 BM

(3) 2.83 BM

(4) 3.87 BM

19. The number of geometrical isomers of the octahedral ion $[Pt(NH_3)_2Cl_2(py)_2]^{2+}$ is

(1) 4

(2) 5

(3) 6

(4) 3

20. Statement I: In $[Co(NH_3)_5Cl]Cl_2$, the primary valency of cobalt is 3 and its secondary valency is 6.
Statement II: According to Werner, secondary valencies are non-directional.
In the light of the above statements, choose the correct answer from the options given below:

(1) Both Statement I and Statement II are true

(2) Statement I is true but Statement II is false

(3) Statement I is false but Statement II is true

(4) Both Statement I and Statement II are false

SECTION B (Q21–25) · Numerical value · +4 / 0 / −1

The answer to each question is a NUMERICAL VALUE. Enter it rounded off to the nearest integer.

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21. Counting both members of every pair of enantiomers, the number of distinct spatial arrangements of the ligands in the octahedral ion $[Co(en)(NH_3)_2Cl_2]^+$ is _____.

Answer: _____

22. The crystal field splitting energy of $[Cr(H_2O)_6]^{3+}$ is 210 kJ/mol. The wavelength (in nm) of light that it absorbs is _____ (to the nearest integer; $h = 6.626 \times 10^{-34}$ J s, $c = 3.0 \times 10^8$ m/s, $N_A = 6.022 \times 10^{23}$ mol^{-1}).

Answer: _____

23. For $[Ni(H_2O)_6]^{2+}$, $\Delta_o = 102$ kJ/mol. The magnitude of its crystal field stabilisation energy (in kJ/mol, to the nearest integer) is _____.

Answer: _____

24. The number of the following compounds whose freshly made aqueous solutions give a white precipitate with $AgNO_3$ solution at once is _____.
$[Co(NH_3)_6]Cl_3$, $[Co(NH_3)_3Cl_3]$, $[Pt(NH_3)_2Cl_2]$, $[Co(NH_3)_5Cl]SO_4$, $[Cr(H_2O)_6]Cl_3$, $K_2[PtCl_6]$, $[Pt(NH_3)_4]Cl_2$, $[Co(NH_3)_5(SO_4)]Cl$

Answer: _____

25. The number of bidentate ligands among the following is _____.
en, $C_2O_4^{2-}$, gly^-, $EDTA^{4-}$, NO_2^-, SCN^-, $acac^-$, dien, bipy, py, CO, phen

Answer: _____

END OF THE QUESTION PAPER

ANSWER KEY

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
(2)	(3)	(1)	(2)	(4)	(3)	(1)	(4)	(3)	(1)

Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
(4)	(2)	(1)	(3)	(2)	(4)	(1)	(3)	(2)	(2)

Q21	Q22	Q23	Q24	Q25
4	570	122	4	6

WORKED SOLUTIONS

Q1. Answer (2). 2.87 g AgCl = 2.87/143.5 = 0.02 mol, i.e. 2 mol of free Cl^- per mol of complex. Only chloride outside the coordination sphere is precipitated, so two Cl are ionic and one is a ligand: $[Cr(H_2O)_5Cl]Cl_2 \cdot H_2O$ (green).

Q2. Answer (3). The complex ion $[Ni(CN)_4]^{2-}$ is an anion, so the metal name ends in -ate: nickelate. Oxidation state: $x + 4(-1) = -2$, $x = +2$. Ligands come before the metal, and CN^- is named cyanido: sodium tetracyanidonickelate(II).

Q3. Answer (1). Five NH_3 and one nitrite bonded through O (written ONO; NO_2 would mean bonding through N). Charge on the complex ion: $+3 + 0 - 1 = +2$, so two Cl^- balance it: $[Co(NH_3)_5(ONO)]Cl_2$ (the red linkage isomer of the yellow nitro complex).

Q4. Answer (2). Fix NH_3 at one corner. The ligand trans to it can be py, Cl or Br, and each choice fixes the other two (which are mirror related only within the plane). So there are 3 geometrical isomers, none optically active.

Q5. Answer (4). Three bidentate oxalate ions wrap around Cr like a propeller, and the two propeller senses (Δ and Λ) are non-superimposable mirror images. Square planar $[Pt(en)Cl_2]$ lies in a mirror plane; $[Co(NH_3)_5Cl]^{2+}$ and the mer isomer also have mirror planes.

Q6. Answer (3). Both are salts of a complex cation and a complex anion with the same overall formula; the ligands are exchanged between the two metal ions. This is coordination isomerism.

Q7. Answer (1). Mn^{2+} is $3d^5$. CN^- is a strong-field ligand, so the five d electrons pair into three orbitals (one unpaired), leaving two 3d orbitals empty for d^2sp^3 (inner orbital) hybridisation. (With a weak-field ligand, as in $[Mn(H_2O)_6]^{2+}$, it would be sp^3d^2 with 5 unpaired.)

Q8. Answer (4). Co^{3+} in $[Co(CN)_6]^{3-}$ is $3d^6$ with strong-field CN^-: t_2g^6, no unpaired electrons. $[CoF_6]^{3-}$ ($3d^6$, weak field) has 4 unpaired; $[Ni(H_2O)_6]^{2+}$ ($3d^8$: $t_2g^6\ eg^2$) has 2 whatever the ligand; $[Cr(NH_3)_6]^{3+}$ ($3d^3$) has 3.

Q9. Answer (3). In a tetrahedral field the e set lies $0.6\Delta_t$ below and the t_2 set $0.4\Delta_t$ above the barycentre, and Δ_t is too small for pairing. d^7: $e^4\ t_2^3$, CFSE $= 4(-0.6) + 3(+0.4) = -1.2\Delta_t$.

Q10. Answer (1). Co^{3+} is d^6. Since $\Delta_o > P$ the electrons pair in t_2g: $t_2g^6\ eg^0$ (low spin). CFSE $= 6(-0.4\Delta_o) + 2P = -54960 + 42000 = -12960\ cm^{-1}$ (the free ion already has one pair; low spin has three).

Q11. Answer (4). Energy absorbed $= \Delta_o = hc/\lambda$, so the shortest wavelength goes with the largest splitting. In the spectrochemical series $F^- < H_2O < NH_3 < CN^-$, so $[Co(CN)_6]^{3-}$ absorbs at the shortest wavelength.

Q12. Answer (2). Cisplatin, the anticancer drug cis-$[PtCl_2(NH_3)_2]$, contains platinum, not palladium. Chlorophyll (Mg), haemoglobin (Fe) and vitamin B12 (Co) are correct.

Q13. Answer (1). The M–C bond has a σ part (CO lone pair to the metal) and a π part (metal d to CO π*). Electrons in π* lower the C–O bond order, so the C–O bond lengthens. Both are true and R explains A.

Q14. Answer (3). Conductivity follows the number of ions per formula unit: $[Co(NH_3)_6]Cl_3$ gives 4, $[Co(NH_3)_5Cl]Cl_2$ 3, $[Co(NH_3)_4Cl_2]Cl$ 2 and $[Co(NH_3)_3Cl_3]$ none.

Q15. Answer (2). log β: $[Ni(NH_3)_6]^{2+}$ 8.6, $[Ni(en)_3]^{2+}$ 18.3, $[Cu(NH_3)_4]^{2+}$ 13.1, $[Zn(NH_3)_4]^{2+}$ 9.5. The three chelate rings of ethane-1,2-diamine make $[Ni(en)_3]^{2+}$ far more stable than the hexaammine with the same six N donors (chelate effect).

Q16. Answer (4). Oxidation states from the charges: Fe +3 in $K_3[Fe(CN)_6]$ ($3d^5$), Cr +3 ($3d^3$), Cu +2 ($3d^9$) and Fe +2 in $K_4[Fe(CN)_6]$ ($3d^6$).

Q17. Answer (1). $EDTA^{4-}$ binds through two N atoms and four carboxylate O atoms: hexadentate. One $EDTA^{4-}$ occupies all six positions round Ca^{2+}, so the coordination number is 6 (this is why EDTA titrations measure the hardness of water).

Q18. Answer (3). In $[Cr(CN)_6]^{4-}$, x − 6 = −4, so Cr is +2: $3d^4$. Strong-field CN^- gives t_2g^4 (low spin), with 2 unpaired electrons. μ = √(2 × 4) = 2.83 BM. (High spin $t_2g^3\ eg^1$, as in $[Cr(H_2O)_6]^{2+}$, would give 4.90 BM.)

Q19. Answer (2). For $MA_2B_2C_2$: all three pairs trans (1); one pair trans and the other two cis (3, one for each pair chosen); all three pairs cis (1, which is chiral). 5 geometrical isomers, 6 stereoisomers in all.

Q20. Answer (2). Primary valency is the oxidation state (+3), satisfied by Cl^- ions; secondary valency is the coordination number (5 NH_3 + 1 Cl = 6): Statement I is true. Werner held that secondary valencies are directed in space, which gives complexes definite shapes and explains their isomers: Statement II is false.

Q21. Answer 4. With en spanning two cis positions: (i) both NH_3 trans, Cl cis (achiral); (ii) both Cl trans, NH_3 cis (achiral); (iii) NH_3 cis and Cl cis, which is chiral and exists as a pair of enantiomers. 3 geometrical isomers and 4 stereoisomers.

Q22. Answer 570. Energy per photon E = 210000/(6.022 × 10^{23}) = 3.487 × 10^{-19} J. λ = hc/E = (6.626 × 10^{-34} × 3.0 × 10^8)/(3.487 × 10^{-19}) = 5.70 × 10^{-7} m = 570 nm.

Q23. Answer 122. Ni^{2+} is d^8: $t_2g^6\ eg^2$ in any octahedral field (no extra pairing). CFSE = 6(−0.4Δ_o) + 2(+0.6Δ_o) = −1.2Δ_o = −122.4 kJ/mol. Magnitude 122.

Q24. Answer 4. Only chloride outside the coordination sphere is free to precipitate as AgCl: $[Co(NH_3)_6]Cl_3$, $[Cr(H_2O)_6]Cl_3$, $[Pt(NH_3)_4]Cl_2$ and $[Co(NH_3)_5(SO_4)]Cl$. In the other four all the chlorine is bound to the metal. Answer 4.

Q25. Answer 6. Bidentate: en (2 N), oxalate (2 O), glycinate (N and O), acetylacetonate (2 O), 2,2′-bipyridine (2 N) and 1,10-phenanthroline (2 N). $EDTA^{4-}$ is hexadentate and dien tridentate; NO_2^- and SCN^- are ambidentate but bind through one atom at a time; py and CO are monodentate. Answer 6.

All questions are original and © Master Testing Agency. Free to download and use for personal practice; not for resale. Every answer in this paper was checked independently by computer: isomers were counted by placing the ligands on the corners of an octahedron or square and removing arrangements related by a rotation (and, for geometrical isomers, a reflection); d-electron counts, unpaired electrons and CFSE from the oxidation state and the strong- or weak-field filling of t2g and eg; and the rest from the data given or tables typed in separately from the questions.