

Colour, complexes and catalysis in the d-block

Chemistry grades 11-12 (A Level · IB · Class 11-12) · Worksheet answers

Each answer shows the reasoning and the result in bold. Check configurations and charges first, then ratios in titrations, and finally significant figures and units.

Level: Chemistry grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** A Level 3.2.5

Problem 1 Electron configurations

1. **[Ar] 3d⁶ 4s².**
2. Fe²⁺: **[Ar] 3d⁶**; Fe³⁺: **[Ar] 3d⁵** (4s electrons leave first).
3. Cu: **[Ar] 3d¹⁰ 4s¹.**

Problem 2 Is it a transition element?

Sc: no, Sc³⁺ is 3d⁰. **Ti: yes**, Ti³⁺ is 3d¹. **Zn: no**, Zn²⁺ is 3d¹⁰ (full). **Cu: yes**, Cu²⁺ is 3d⁹ (partly filled).

Problem 3 Match the colours

[Cu(H₂O)₆]²⁺ **pale blue**; [Fe(H₂O)₆]²⁺ **pale green**; [Co(H₂O)₆]²⁺ **pink**; MnO₄⁻ **purple**.

Problem 4 Oxidation state and coordination number

[Fe(CN)₆]⁴⁻: **+2, 6**; [Cr(H₂O)₆]³⁺: **+3, 6**; [CuCl₄]²⁻: **+2, 4**; [Ag(NH₃)₂]⁺: **+1, 2**.

Problem 5 Classify the ligands

H₂O, Cl⁻ and NH₃ are **monodentate**; ethanedioate is **bidentate** (two O donors); EDTA⁴⁻ is **hexadentate**.

Problem 6 Writing complex formulae

1. **[Ni(en)₃]²⁺**; each en forms 2 bonds so the coordination number is 6.
2. **[Cr(NH₃)₄Cl₂]⁺**: +3 + 2(-1) = +1.
3. **[Cr(NH₃)₄Cl₂]Cl**.

Problem 7 Colour and energy gap

1. $\lambda = hc \div \Delta E = (6.63 \times 10^{-34} \times 3.00 \times 10^8) \div (3.98 \times 10^{-19}) = \mathbf{5.00 \times 10^{-7} \text{ m} = 500 \text{ nm}}$.
2. Blue-green is absorbed, so the solution looks **pink-red**.
3. A 3d electron is promoted from the lower to the higher set of d orbitals.

Problem 8 Dichromate titration

1. $n = 0.01860 \times 0.0150 = \mathbf{2.79 \times 10^{-4} \text{ mol}}$.
2. $n(\text{Fe}^{2+}) = 6 \times 2.79 \times 10^{-4} = 1.674 \times 10^{-3} \text{ mol}$; $c = 1.674 \times 10^{-3} \div 0.0250 = \mathbf{0.0670 \text{ mol dm}^{-3}}$.

Problem 9 A homogeneous catalyst

1. $2\text{Fe}^{3+} + 2\text{I}^- \rightarrow 2\text{Fe}^{2+} + \text{I}_2$ and $2\text{Fe}^{2+} + \text{S}_2\text{O}_8^{2-} \rightarrow 2\text{Fe}^{3+} + 2\text{SO}_4^{2-}$.
2. Adding and cancelling 2Fe^{3+} and 2Fe^{2+} gives $\mathbf{\text{S}_2\text{O}_8^{2-} + 2\text{I}^- \rightarrow 2\text{SO}_4^{2-} + \text{I}_2}$.
3. Two negative ions repel one another, so collisions are rarely successful; the $\text{Fe}^{2+}/\text{Fe}^{3+}$ steps involve oppositely charged ions.

Problem 10 Contact process

1. $\text{SO}_2 + \text{V}_2\text{O}_5 \rightarrow \text{SO}_3 + \text{V}_2\text{O}_4$; $\mathbf{2\text{V}_2\text{O}_4 + \text{O}_2 \rightarrow 2\text{V}_2\text{O}_5}$.
2. Vanadium goes $\mathbf{+5 \rightarrow +4}$.
3. V_2O_5 is regenerated in the second step, so it appears on both sides and is unchanged overall.

Problem 11 Copper and ammonia

1. A **pale blue precipitate** forms first, which then dissolves in excess ammonia to give a **deep blue solution**.
2. $\text{Cu}^{2+}(\text{aq}) + 2\text{OH}^-(\text{aq}) \rightarrow \text{Cu}(\text{OH})_2(\text{s})$; $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{NH}_3 \rightarrow [\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+} + 4\text{H}_2\text{O}$.

Problem 12 Copper and chloride

1. Left: $+2 + 4(-1) = -2$; right: -2 .
2. Chloride ions are larger than water molecules, so only four fit around Cu^{2+} : $6 \rightarrow 4$.
3. Adding water shifts the equilibrium left, so the solution turns **blue** again.

Problem 13 Manganese oxidation states

MnO_4^- **+7** (purple); MnO_4^{2-} **+6** (green); MnO_2 **+4** (brown solid); Mn^{2+} **+2** (pale pink).

Problem 14 Trends across the first row

1. Highest vanadium (1910 °C); lowest zinc (420 °C).
2. $1910 - 420 = \mathbf{1490 \text{ °C}}$.
3. Many delocalised 3d and 4s electrons give strong metallic bonding, except zinc whose 3d is full and does not contribute.

Problem 15 Spot the errors

1. Chromium is **[Ar] 3d⁵ 4s¹**, a half-filled d subshell is stable.
2. Zinc is **not** a transition metal: Zn²⁺ is 3d¹⁰.
3. Iron loses its **4s electrons** first, giving [Ar] 3d⁶.

Problem 16 Chromium chemistry

1. Cr in [Cr(OH)₆]³⁻ is **+3**; in CrO₄²⁻ and Cr₂O₇²⁻ **+6**.
2. Chromium stays +6 in both, so there is no electron transfer.
3. OH⁻ removes H⁺, shifting the equilibrium left, so the orange solution turns **yellow**.

Problem 17 Cisplatin

1. Ligands are neutral NH₃ and two Cl⁻, so platinum is **+2**.
2. **cis-trans (geometric) isomerism**.
3. In the cis form the two Cl⁻ are adjacent, so the new bonds can form close together; in the trans form they are on opposite sides, too far apart to bind to the same DNA site.

Problem 18 Tablet analysis

1. $n(\text{MnO}_4^-) = 0.02160 \times 0.0100 = 2.16 \times 10^{-4} \text{ mol}$; $n(\text{Fe}^{2+}) = 5 \times 2.16 \times 10^{-4} = \mathbf{1.08 \times 10^{-3} \text{ mol}}$.
2. $\times 10 = \mathbf{1.08 \times 10^{-2} \text{ mol}}$.
3. Mass = $1.08 \times 10^{-2} \times 151.9 = 1.640 \text{ g}$; % = $1.640 \div 2.00 \times 100 = \mathbf{82.0 \%}$.

Problem 19 The chelate effect

1. 4 particles on the left become 7 on the right, so disorder increases: ΔS is positive.
2. $\Delta G = -12 - (298 \times 0.120) = -12 - 35.8 = \mathbf{-47.8 \text{ kJ mol}^{-1}}$.
3. ΔG is negative, so the substitution is **feasible**.

Problem 20 Identify solution P

1. **Fe²⁺** (pale green, green hydroxide that oxidises) and **sulfate** (white BaSO₄).
2. **Fe²⁺(aq) + 2OH⁻(aq) → Fe(OH)₂(s)**.
3. **4Fe(OH)₂ + O₂ + 2H₂O → 4Fe(OH)₃**.