InkChemistry

ANSWER BOOK

Transition metal characteristics and complex formation

Transition metals · Unit C14

AQA 3.2.5.1, 3.2.5.2 · OCR A 5.3.1

15 questions · 53 marks

NAVY EDITION

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SECTION A · Short, 1 to 2 marks

A1 TMC-Q18

B1 3dxy has four lobes in the plane of the x and y axes, pointing between the axes. **B1** $3dz^2$ has two lobes along the z axis with a ring of electron density round the middle in the xy plane. [2]

SECTION B · Standard, 3 to 5 marks

B1 TMC-Q5

B1 they form complexes and they form coloured ions; allow coloured compounds. **B1** they show variable oxidation states, and they and their compounds act as catalysts; ignore high density or melting point. **B1** the 3d and 4s electrons are similar in energy. **B1** so the successive ionisation energies rise gradually, with no large jump after the 4s electrons are removed. **B1** the energy needed to form a more highly charged ion can be repaid by its larger lattice or hydration enthalpy, so several ions are stable. [5]

B2 TMC-Q1

B1 an element that forms at least one stable ion with an incomplete (partly filled) d subshell; ignore any reference to the d block. **B1** Ti^{4+} is [Ar] $3d^0$: the two 4s and the two 3d electrons have all been removed, so it has no d electrons. **B1** Ti^{3+} is [Ar] $3d^1$ and Ti^{2+} is [Ar] $3d^2$, each with an incomplete d subshell. **B1** the definition needs only one such stable ion, so titanium qualifies; a definition in terms of the atom is not accepted. [4]

B3 TMC-Q2

B1 Cr is [Ar] $3d^5$ $4s^1$; reject [Ar] $3d^4$ $4s^2$. **B1** Cr^{3+} is [Ar] $3d^3$; allow the full form $1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$ $3d^3$. **B1** once the 3d orbitals are occupied, the 3d subshell is lower in energy than the 4s subshell. **B1** so the 4s electron is the outermost and is removed first, followed by two 3d electrons. [4]

B4 TMC-Q6

B1 the oxygen atom of each water molecule has a lone pair of electrons. **B1** the lone pair is donated to the Cu^{2+} ion, forming a coordinate (dative covalent) bond in which both electrons come from the oxygen. **B1** water is therefore a ligand, a molecule that donates a lone pair of electrons to the metal ion. **B1** the coordination number is 6, the number of coordinate bonds to the copper; accept 'six coordinate bonds'. [4]

B5 TMC-Q15

B1 water is monodentate, forming one coordinate bond through a lone pair on its oxygen atom. **B1** ethane-1,2-diamine is bidentate, forming two coordinate bonds through a lone pair on each nitrogen atom. **B1** $EDTA^{4-}$ is multidentate, forming six coordinate bonds through two nitrogen and four oxygen atoms. **B1** so six water molecules, three ethane-1,2-diamine molecules or one $EDTA^{4-}$ ion give a coordination number of 6. [4]

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B6 TMC-Q3 **B1** zinc's highest-energy electrons are in the 3d subshell, so it is in the d block. **B1** zinc forms only one ion, Zn^{2+}, with the configuration [Ar] $3d^{10}$. **B1** the 3d subshell of Zn^{2+} is full, so zinc forms no stable ion with an incomplete d subshell. [3]

B7 TMC-Q9 **B1** $EDTA^{4-}$ is a multidentate (hexadentate) ligand with six donor atoms. **B1** it forms coordinate bonds through two nitrogen atoms and four oxygen atoms, filling all six positions round the ion. **B1** one $EDTA^{4-}$ binds one Cu^{2+}, giving the complex $[Cu(EDTA)]^{2-}$. [3]

B8 TMC-Q11 **M1** moles of $EDTA^{4-}$ = 0.0100 × 12.40 ÷ 1000 = 1.24×10^{-4} mol, equal to the moles of Ca^{2+}. **M1** concentration = moles ÷ volume in dm^3 = $1.24 \times 10^{-4} \div 0.0250$; allow error carried forward from M1. **A1** 4.96×10^{-3} mol dm^{-3}, to three significant figures. [3]

B9 TMC-Q12 **M1** Mr = 63.5 + 32.1 + 4(16.0) + 5(18.0) = 249.6. **M1** percentage = 63.5 ÷ 249.6 × 100. **A1** 25.4%, to three significant figures. [3]

B10 TMC-Q14 **B1** $EDTA^{4-}$ forms complexes with the Fe^{3+} and Cu^{2+} ions. **B1** the complexes are very stable (chelate effect), so the metal ions are held and cannot take part in the oxidation as catalysts. **B1** the fats are oxidised more slowly, so the mayonnaise keeps for longer. [3]

B11 TMC-Q19 **B1** in $[Co(NH_3)_6]Cl_3$ all three chloride ions are outside the complex, free in solution, and all react with Ag^+. **B1** in $[Co(NH_3)_5Cl]Cl_2$ one chloride is a ligand, held to the cobalt by a coordinate bond. **B1** the ligand chloride is not free to react with Ag^+, so only the two chloride ions outside the brackets precipitate. [3]

B12 TMC-Q20 **B1** only one chloride ion is free, so two of the three chloride ions are ligands. **B1** four water ligands complete the coordination number of 6, giving the complex ion $[Cr(H_2O)_4Cl_2]^+$. **B1** the formula is $[Cr(H_2O)_4Cl_2]Cl{\cdot}2H_2O$, with two water molecules as water of crystallisation. [3]

B13 TMC-Q21 **B1** a transition metal forms at least one stable ion with a partly filled d subshell; the definition needs one such ion, not every ion. **B1** Cu^{2+} is [Ar] $3d^9$, with one d orbital partly filled, and copper(II) compounds are common and stable, so copper qualifies. **B1** Cu^+, [Ar] $3d^{10}$, has no partly filled d orbital, which is why copper(I) compounds such as CuCl are white while copper(II) compounds are coloured; allow zinc, whose only ion is Zn^{2+} $3d^{10}$, as the contrast. [3]

SECTION C · Long, 6 marks or more

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C1 TMC-Q10 **Indicative content** [6]

B1 haem contains an Fe^{2+} ion at the centre of a flat porphyrin ring, which bonds to the iron through four nitrogen atoms arranged in a square. **B1** a nitrogen atom from the protein chain bonds from below, so five of the six octahedral positions are filled and the sixth, above the ring, is free. **B1** in the lungs an oxygen molecule forms a coordinate bond to the Fe^{2+} at that sixth position, replacing a water molecule by ligand substitution. **B1** the bond to oxygen is weak and reversible, so the oxygen is released in respiring tissues where its concentration is low. **B1** carbon monoxide bonds to the same position through its carbon atom, and its coordinate bond to Fe^{2+} is much stronger than the bond to oxygen. **B1** carbon monoxide replaces the oxygen and is released only very slowly, so that haem cannot carry oxygen and less oxygen reaches the cells.

Levels

Level 3 (5–6 marks) both parts are fully answered: the haem structure is described with the four nitrogen atoms of the ring, the protein nitrogen below and the free sixth position, the reversible coordinate bond to oxygen is explained with its release in the tissues, and the toxicity of carbon monoxide is explained through its much stronger bond at the same position, released only very slowly.

Level 2 (3–4 marks) the Fe^{2+} in the ring and the coordinate bond to oxygen are described and carbon monoxide is said to bind more strongly; the free sixth position, the reversibility of the oxygen bond, or the ligand substitution is not mentioned.

Level 1 (1–2 marks) iron is said to bond to oxygen; carbon monoxide is often said to react with the oxygen in the blood, and the structure of haem is largely absent.

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