InkChemistry

ANSWER BOOK

Colour in transition metal complexes and colorimetry

Transition metals · Unit C14

AQA 3.2.5.4 · OCR A 5.3.1 (colour as a property only)

17 questions · 54 marks

NAVY EDITION

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SECTION A · Short, 1 to 2 marks

A1 CTM-Q10
B1 a green filter should be used. **B1** green is the complementary colour of pink, the colour the solution absorbs most strongly, so the absorbance changes most with concentration. [2]

A2 CTM-Q14
B1 Cu^{+} is [Ar] $3d^{10}$, a full d subshell, so no d electron can be promoted and no visible light is absorbed. **B1** Cu^{2+} is [Ar] $3d^{9}$, with a vacancy in the upper d orbitals, so a d electron can absorb visible light and be promoted. [2]

A3 CTM-Q19
B1 manganese in MnO_4^{-} is +7, [Ar] $3d^{0}$, so it has no d electrons to promote. **B1** the colour must come from another process, an electron moving from oxygen to the metal (charge transfer). [2]

SECTION B · Standard, 3 to 5 marks

B1 CTM-Q1
B1 the d electron is promoted from its ground state to an excited state, a higher-energy d orbital. **B1** the energy absorbed equals ΔE, the gap between the split d orbitals. **B1** the equation is $\Delta E = h\nu$; allow $\Delta E = hc/\lambda$ with λ defined. **B1** h is the Planck constant and ν the frequency of the light absorbed, in Hz or s^{-1}. [4]

B2 CTM-Q2
B1 the water ligands split the 3d orbitals of the Cu^{2+} ion into two groups of different energy. **B1** light of energy ΔE is absorbed as a d electron is promoted to the higher group. **B1** the light absorbed is at the orange and red end of the visible spectrum. **B1** the remaining light, which appears blue, is transmitted. [4]

B3 CTM-Q4
M1 $\nu = \Delta E \div h = 2.6 \times 10^{-19} \div 6.63 \times 10^{-34}$. **A1** $\nu = 3.9 \times 10^{14}$ Hz, to two significant figures. **M1** energy per mole $= 2.6 \times 10^{-19} \times 6.022 \times 10^{23} = 1.57 \times 10^{5}$ J, divided by 1000. **A1** 1.6×10^{2} kJ mol^{-1}, to two significant figures. [4]

B4 CTM-Q3
M1 $\lambda = 500 \times 10^{-9}$ m $= 5.00 \times 10^{-7}$ m. **M1** $\Delta E = hc/\lambda = 6.63 \times 10^{-34} \times 3.00 \times 10^{8} \div 5.00 \times 10^{-7}$. **A1** $\Delta E = 3.98 \times 10^{-19}$ J, to three significant figures. [3]

B5 CTM-Q5
B1 Zn^{2+} has the configuration [Ar] $3d^{10}$. **B1** the 3d subshell is full, so there is no vacancy in the upper d orbitals and no d electron can be promoted. **B1** no visible light is absorbed, so all wavelengths are transmitted and the solution is colourless. [3]

B6 CTM-Q6
B1 a change of oxidation state of the metal, as in $[Fe(H_2O)_6]^{2+}$ to $[Fe(H_2O)_6]^{3+}$. **B1** a change of ligand, as in $[Cu(H_2O)_6]^{2+}$ to $[Cu(NH_3)_4(H_2O)_2]^{2+}$. **B1** a change of coordination number and shape, as in $[Co(H_2O)_6]^{2+}$ to $[CoCl_4]^{2-}$. [3]

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B7 CTM-Q7 **B1** ammonia replaces four of the water ligands, giving $[Cu(NH_3)_4(H_2O)_2]^{2+}$. **B1** the new ligand splits the d orbitals by a different (larger) amount, so ΔE changes. **B1** light of a different frequency is absorbed, so a different colour is transmitted. [3]

B8 CTM-Q11 **B1** the unknown lies outside the range of the standards, so its concentration can only be found by extrapolation. **B1** the line may not stay straight at high absorbance, so the extrapolated value may be wrong. **B1** dilute the unknown by a known factor until its absorbance lies within the standards, then multiply the concentration read off by that factor. [3]

B9 CTM-Q13 **B1** $[Co(H_2O)_6]^{2+}$ is octahedral with coordination number 6, while $[CoCl_4]^{2-}$ is tetrahedral with coordination number 4. **B1** the different ligand and shape give a smaller ΔE in $[CoCl_4]^{2-}$, so it absorbs light of longer wavelength. **B1** $[Co(H_2O)_6]^{2+}$ is a pink solution and $[CoCl_4]^{2-}$ a blue solution. [3]

B10 CTM-Q15 **B1** 300 nm is in the ultraviolet, outside the visible range. **B1** so ΔE is too large to correspond to any visible wavelength and no visible light is absorbed. **B1** all visible wavelengths are transmitted, so the solution appears colourless. [3]

B11 CTM-Q17 **B1** the number of d electrons is the same, but the metal and its charge are different (+3 iron against +2 manganese). **B1** a different nuclear charge and ion charge change how strongly the ligands interact, so ΔE is different. **B1** different wavelengths are absorbed, so the colours differ and the conclusion is wrong. [3]

B12 CTM-Q18 **B1** the six ligands approach the metal ion along the x, y and z axes. **B1** the lobes of $3dz^2$ and $3dx^2-y^2$ lie along the axes, pointing at the ligands' lone pairs, so they are repelled more strongly. **B1** the lobes of 3dxy, 3dxz and 3dyz lie between the axes, away from the ligands, so they are repelled less and lie lower. [3]

B13 CTM-Q20 **M1** ΔE for one ion = $1.86 \times 10^5 \div 6.022 \times 10^{23} = 3.089 \times 10^{-19}$ J. **M1** $\lambda = hc \div \Delta E = 6.63 \times 10^{-34} \times 3.00 \times 10^8 \div 3.089 \times 10^{-19} = 6.44 \times 10^{-7}$ m. **A1** λ = 644 nm, to three significant figures. [3]

SECTION C · Long, 6 marks or more

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C1 CTM-Q8 **Indicative content** [6]

B1 make a series of standard solutions of known Cu^{2+} concentration by diluting a stock solution, each with the same excess of ammonia. **B1** choose a filter of the complementary colour, orange or red, the light that the deep blue complex absorbs most strongly. **B1** zero the colorimeter with a cuvette of the solvent alone, so that the cuvette and solvent contribute no absorbance. **B1** measure the absorbance of each standard and plot a calibration curve of absorbance against concentration, with a line of best fit. **B1** measure the unknown with the same filter and cuvette, and read its concentration from the curve, within the range of the standards. **B1** ammonia forms deep blue $[Cu(NH_3)_4(H_2O)_2]^{2+}$, which absorbs far more strongly than the aqua ion, so absorbances are larger and percentage uncertainties smaller.

Levels

Level 3 (5–6 marks) the standards with the same excess of ammonia, the complementary filter, zeroing with the solvent, the calibration curve and reading the unknown within its range are all present, and the ammonia is explained through the much stronger absorbance of the deep blue complex and the smaller percentage uncertainty.

Level 2 (3–4 marks) the calibration curve from standards, the filter and the reading of the unknown are described; zeroing, keeping the unknown inside the range of the standards, or the reason for the ammonia is left out.

Level 1 (1–2 marks) absorbance is compared with known solutions; the ammonia is typically said to be there to precipitate the copper, and calibration and filter are largely missing.

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