Past-paper walk-through

Stereoisomerism in transition element complexes ▪ 28.4

eXercise

Questions in this set

- 9701/41 N25 Q5 ▪ 14 marks
- 9701/42 N25 Q6 ▪ 7 marks
- 9701/44 N25 Q1 ▪ 19 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 5

9701/41 N25 ▪ Q5 ▪ 14 marks

5 **(a)** Copper shows typical properties of transition elements, including its behaviour as a catalyst.

Complete Table 5.1 to show the total number of **unpaired** electrons in the 3d and 4s orbitals of an isolated gaseous Cu atom and a Cu^{2+} ion.

Table 5.1

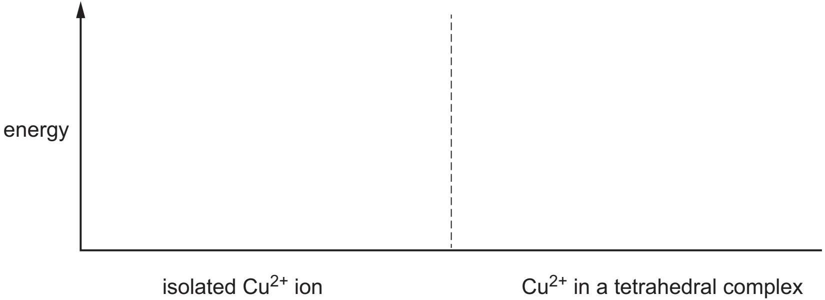
species	number of **unpaired** electrons	
	3d	4s
Cu		
Cu^{2+}		

[1]

(b) The 3d orbitals in an isolated Cu^{2+} ion are degenerate.

Question 5

Complete the diagram to show the relative energies of the 3d orbitals in an isolated Cu^{2+} ion and in Cu^{2+} in a tetrahedral complex.



[2]

(c) Explain why transition elements behave as catalysts.

Question 5

(d) CN^- is a monodentate ligand.

Table 5.2 shows information about two complex ions that contain only CN^- ions as ligands.

Complete Table 5.2.

Table 5.2

metal ion	coordination number	formula of complex ion	charge of complex ion
Ag^+	2		
Fe^{2+}			4–

[2]

(e) The complex ion $[Au(CN)_2Br_2]^-$ displays geometrical (cis / trans) isomerism.

Draw the structure of *trans*-$[Au(CN)_2Br_2]^-$. State its shape and the Br-Au-Br bond angle.

Question 5

Draw the structure of *trans*-$[Au(CN)_2Br_2]^-$. State its shape and the Br–Au–Br bond angle.

Question 5

Question 5

[2]

(f) An impure sample of a vanadium(V) compound of mass 0.250 g is dissolved in aqueous acid. This solution contains VO_3^- ions.

An excess of zinc is added to this solution. All the VO_3^- ions are reduced to V^{2+} ions and Zn atoms are oxidised to Zn^{2+} ions.

The unreacted zinc is removed and the resulting solution is titrated with acidified MnO_4^-.

The end-point is reached when 22.5 cm^3 of 0.0750 mol dm^{-3} MnO_4^- is added.

A redox reaction takes place and all the V^{2+} reacts forming VO_3^-.

$$3MnO_4^- + 5V^{2+} + 3H_2O \rightarrow 3Mn^{2+} + 5VO_3^- + 6H^+$$

(i) Calculate the percentage by mass of vanadium in the 0.250 g of impure sample.

Assume the impurities do not contain any vanadium ions.

Question 5

Question 5

Show your working.

Question 5

(ii) Complete the equation for the reaction between acidified VO_3^- ions and Zn metal.

Question 5

[2]

[Total: 14]

Solution 5

(a)

Mark scheme

- 1

Solution 5

(b) Mark scheme

- ▪
- five 3d orbitals (lines, boxes) in the isolated Cu2+ ion of the same energy
- ▪
- splitting: three higher and two lower d orbitals
- ▪
- energy of all five d orbitals in complex higher than all d orbitals in isolated ion
- any two [1], all three [2]
- 2

Solution 5

(c)

Mark scheme

- M1: more than one (stable) oxidation state / exist in variable oxidation states
- M2: vacant / empty (d) orbitals are energetically accessible
- OR vacant / empty (d) orbitals can form dative bonds with ligands
- 2

Solution 5

(d)

Mark scheme

- each row [1]
- 2
- 9701/41
- October/November 2025

Solution 5

(e)

Mark scheme

- M1:
- M2: (shape) square planar AND (bond angle) 180o
- 2

Solution 5

(f)(i)

Mark scheme

- M1: moles MnO4– $=$ 0.075 $\times$ 0.0225 $=$ 1.6875 $\times$ 10–3
- M2: moles V2+ $=$ 5 / 3 $\times$ 1.6875 $\times$ 10–3 $=$ 2.8125 $\times$ 10–3
- M3: mass V $=$ 50.9 $\times$ 2.8125 $\times$ 10–3 $=$ 0.143 g
- % of V $=$ 0.143 / 0.250 $\times$ 100 $=$ 57.3 min 2sf
- 3

Solution 5

(f)(ii)

Mark scheme

- $2VO3– + 3Zn + 12H+ \rightarrow 2V2+ + 3Zn2+ + 6H2O$
- M1: 2 : 3 ratio on both sides
- M2: rest of the equation correct
- 2

Question 6

9701/42 N25 ▪ Q6 ▪ 7 marks

6 **(a)** Nickel forms complexes.

(i) Give the formula and charge of the tetrahedral complex formed by Ni atoms with carbon monoxide molecules. Carbon monoxide is a monodentate ligand. This is complex **E**.

Question 6

(ii) Give the formula and charge of the octahedral complex formed by Ni^{2+} ions with ethanedioate ions. This is complex **F**.

Question 6

(iii) Identify which complex, **E** or **F**, exists as a mixture of two stereoisomers and the type of stereoisomerism involved.

Question 6

Question 6

[1]

(b) Cadmium forms complexes with methylamine, CH_3NH_2, and 1,2-diaminoethane, *en*. The values of the stability constants, K_{stab}, of these complex ions are given in Table 6.1.

Table 6.1

complex	K_{stab}
$[Cd(CH_3NH_2)_4]^{2+}$	3.5×10^6
$[Cd(en)_2]^{2+}$	4.0×10^{10}

(i) Explain, by reference to its structure, why CH_3NH_2 acts as a monodentate ligand.

Question 6

(ii) Some $Cd^{2+}(aq)$ is added to a solution containing equal concentrations of CH_3NH_2 and *en*.

Predict which of the two complexes in Table 6.1 forms at the higher concentration.

Explain your answer.

Question 6

[1]

(iii) Complete the expression for the K_{stab} of $[Cd(CH_3NH_2)_4]^{2+}$.

K_{stab} =

[1]

[Total: 7]

Solution 6

(a)(i)

Mark scheme

- Ni(CO)4
- 1

Solution 6

(a)(ii) Mark scheme

- ▪
- ethanedioate given as C2O4
- ▪
- formula shows one Ni and three ligands
- ▪
- charge = 4–
- any two [1], all three [2]
- Ni(C2O4)34– scores [2]

Solution 6

- 2
- 9701/42
- October/November 2025

Solution 6

(a)(iii)

Mark scheme

- F AND optical
- 1

Solution 6

(b)(i)

Mark scheme

- N atom can donate one lone pair of electrons
- 1

(b)(ii)

Mark scheme

Cd(en)2 2+ AND has a larger Kstab / is more stable

- 1

Solution 6

(b)(iii)

Mark scheme

(CH3NH2)4 2+]

Cd2+ [CH3NH2]4

- 1

Question 1

9701/44 N25 ▪ Q1 ▪ 19 marks

1 **(a)** Define a transition element.

Question 1

(b) The 3d orbitals in an isolated gaseous Cu^{2+} ion are degenerate.

(i) Define the term degenerate.

Question 1

(ii) Complete the electronic configuration of Cu^{2+}.

Question 1

(c) **(i)** State the colours of the aqueous solutions for the **two** copper(II) complex ions shown.

Question 1

Question 1

[1]

(ii) Explain why aqueous complex ions of transition elements are usually coloured.

Question 1

(d) (i) When an excess of NH_3(aq) is added to a solution of $[CuCl_4]^{2-}$(aq), $[Cu(NH_3)_4(H_2O)_2]^{2+}$(aq) is formed.

State the type of reaction.
Complete the equation for this reaction. State symbols are **not** required.

Question 1

equation

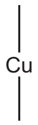
Question 1

[2]

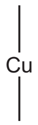
(ii) The $[Cu(NH_3)_4(H_2O)_2]^{2+}$ complex ion shows stereoisomerism.

Complete the three-dimensional diagrams in Fig. 1.1 to show the **two** different stereoisomers of $[Cu(NH_3)_4(H_2O)_2]^{2+}$.

isomer 1



isomer 2



Question 1

Fig. 1.1

Question 1

Fig. 1.1

[2]

(iii) Deduce which stereoisomer in **(d)(ii)** is polar.

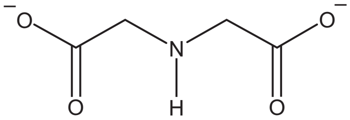
Explain your answer.

Question 1

[1]

(e) The dianion **P** can act as a tridentate ligand.

P



(i) Suggest how **P** can form **three** dative covalent bonds.

Question 1

(ii) 2 moles of dianion **P**, $C_4H_5NO_4^{2-}$, react with 1 mole of aqueous cobalt(III) ions, $[Co(H_2O)_6]^{3+}$ to form 1 mole of complex ion **Q**.

Deduce the formula and charge of **Q**.

Question 1

(f) Table 1.1 shows values for the stability constants, K_{stab}, of some silver(I) complexes.

Table 1.1

complex	value of K_{stab}
$[Ag(CN)_2]^-(aq)$	1.1×10^{18}
$[Ag(NH_3)_2]^+(aq)$	1.2×10^{7}
$[Ag(S_2O_3)_2]^{3-}(aq)$	2.9×10^{13}

(i) Define the stability constant of a complex.

Question 1

(ii) Use the information in Table 1.1 to identify the most stable silver(I) complex.

Explain your answer.

Question 1

Question 1

Question 1

[1]

(g) Sodium sulfite, Na_2SO_3, is used as a food preservative.

A 3.75 g sample of impure Na_2SO_3 is dissolved in distilled water and made up to 250 cm^3 in a volumetric flask.

10.0 cm^3 of this solution requires 18.70 cm^3 of acidified 0.0150 mol dm^{-3} $MnO_4^-(aq)$ to reach the end-point.

The equation for the reaction is shown.

$$2MnO_4^- + 5SO_3^{2-} + 6H^+ \rightarrow 2Mn^{2+} + 5SO_4^{2-} + 3H_2O$$

Calculate the percentage by mass of Na_2SO_3 in the sample.

Question 1

Question 1

[Total: 19]

Solution 1

(a)

Mark scheme

- forms (one or more) stable ions / compounds / oxidation states
- with incomplete / partially filled (3)d orbital(s) / d shell / d sub-shell
- 1

Solution 1

(b)(i)

Mark scheme

- (orbitals) are at the same energy
- 1

(b)(ii)

Mark scheme

- (1s2) 2s2 2p6 3s2 3p6 3d9
- 1

Solution 1

(c)(i)

Mark scheme

H3)4(H2O)2 2+(aq) deep / dark / royal blue

- AND

CuCl4 2–(aq)

- yellow
- 1

Solution 1

(c)(ii) Mark scheme

- M1:
- d orbital(s) of different energy / d-d splitting occurs / d sub-shell splits
- M2:
- electron(s) promoted / excited
- M3:
- light / wavelength / frequency / photon absorbed AND complementary colour seen
- 3

Solution 1

(d)(i)

Mark scheme

- M1: ligand exchange / replacement / substitution / displacement
- M2: $[CuCl_4]^{2-} + 4NH_3 + 2H_2O \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4Cl^-$
- 2

Solution 1

(d)(ii)

Mark scheme

- M1: one correct 3D structure of [Cu(H2O)2(NH3)4]2+
- M2: correct 3D stereoisomer structure of isomer 1/2

(d)(iii)

Mark scheme

- cis isomer AND dipoles do not cancel
- 1

Solution 1

(e)(i)

Mark scheme

- (two) oxygen and (one) nitrogen (can donate) three lone pair(s) of electrons (to the metal ion)
- 1
- 9701/44
- October/November 2025

Solution 1

(e)(ii)

Mark scheme

C4H5NO4)2 –

- 1

Solution 1

(f)(i)

Mark scheme

- equilibrium constant for the formation of the complex (ion)
- in a solvent / water / solution OR from its constituent ions or molecules
- 1

Solution 1

(f)(ii)

Mark scheme

Ag(CN)2 –(aq) AND largest (value of) Kstab

- 1

Solution 1

(g) Mark scheme

- M1 M2: any two [1], all four [2]
- ▪
- moles MnO4– = 0.015 ×18.70/1000 = 2.805 × 10–4
- ▪
- moles SO32– = 2.805 × 10–4 × 5/2 = 7.0125 × 10–4 (in 10 cm3)
- ▪
- moles SO32– = 1.753 × 10–2 (in 250 cm3)
- ▪

Solution 1

- mass Na2SO3 $= 1.753 \times 10–2 \times 126.1 = 2.21$ g
- M3: % purity $= 100 \times 2.21 / 3.75 = 58.9 - 59.0$ % min 2sf
- 3