Properties of Transition Metals

A Level

Part A Characteristics of transition elements

Which of the following characteristics is **unique** to transition elements?

- In their compounds, they can exist in more than one oxidation state.
- They conduct electricity well.
- They form stable complexes with a variety of ligands.
- In at least one oxidation state they have an incomplete d shell.
- They can exist both as cations and in oxyanions.

Part B Copper or calcium?

The following data refer to copper as a typical transition element and to calcium as an s-block element.

For which property are the data under the correct element?

	property	copper	calcium
A	density/$\mathrm{g\,cm^{-3}}$	8.92	1.54
B	electrical conductivity/relative units	9.6	85
C	melting point/$^{\circ}\mathrm{C}$	810	1083
D	metallic radius/nm	0.197	0.117

- **A**
- **B**
- **C**
- **D**

Part A adapted with permission from OCSEB, A-Level Chemistry, June 1995, Paper 1, Question 22;
Part B adapted with permission from UCLES, A-Level Chemistry, June 1996, Paper 3, Question 16.

d-block Electronic Configurations

A Level

Part A Cr^{3+}

Chromium (atomic number 24) is a d-block element. Its compounds are useful reagents in the laboratory.

Using s, p and d notation for electron energy levels, write the electronic configuration of the Cr^{3+} ion.

Items:

[Ne] [Ar] [Kr] s p d 1 2 3 1 2 3 4 5 6

Part B V^{2+}

Which of the following electronic structures corresponds to the V^{2+} ion?

- $[Ar]\ 4s^1\ 4p^2$
- $[Ar]\ 3d^1\ 4s^2$
- $[Ar]\ 3d^2\ 4s^1$
- $[Ar]\ 3d^3$
- $[Ar]\ 4s^2\ 4p^1$

Part C Unpaired s electron in ground state

For which transition metal does its ground state atom have an unpaired electron in an s-orbital?

- Cobalt
- Chromium
- Manganese
- Iron

Part A adapted with permission from UCLES, A-Level Chemistry, June 1990, Paper 2, Question 3;
Part B adapted with permission from OCSEB, A-Level Chemistry, June 1994, Paper 1, Question 19 ;
Part C adapted with permission from UCLES, A-Level Chemistry, November 1996, Paper 4, Question 17.

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Ligands or Ligan'ts?

A Level

Part A Ligands

Which of the following species does *not* act as a ligand in the formation of transition metal complexes?

- NH_4^+
- CN^-
- OH^-
- Cl^-
- CH_3NH_2

Part B Bidentate ligands

Which of the following **cannot** act as a **bidentate ligand** towards transition metal ions?

- $^-OOC-COO^-$
- CH_3COO^-
- $H_2NCH_2CH_2NH_2$
- CN^-
- $H_2NCH_2COO^-$

Part A adapted with permission from UCLES, A-Level Chemistry, November 1991, Paper 1, Question 21;
Part B created for isaacphysics.org by R. Less

Shapes and Isomers

A Level

Passing air through an aqueous solution containing $\mathrm{CoCl_2}$, $\mathrm{H_2NCH_2CH_2NH_2}$ and HCl produces a green complex cation **Y** with formula:

$$[\mathrm{Co(NH_2CH_2CH_2NH_2)_2Cl_2}]^+$$

Y

Evaporation of an aqueous solution of **Y** at $90\,^\circ\mathrm{C}$ produces a red complex cation **Z**, with the same formula as that given for **Y** above. **Y** has no dipole moment, whereas **Z** does.

Part A Shapes with 4 ligands

State which two shapes are possible for transition metal complexes with **4 ligands** bonded to the central metal ion.

Give your answer in the format "**A**, **B**" (space after comma).

Part B Shape with 6 ligands

State which shape is possible for transition metal complexes with **6 ligands** bonded to the central metal ion.

Part C Y and Z isomerism

What kind of isomerism do **Y** and **Z** display with respect to each other?

Part D Isomerism in Z

Compound **Z** exists in two isomeric forms. What kind of isomerism does compound **Z** display?

Adapted with permission from UCLES A-Level Chemistry November 1991, Paper 4, Question 3.

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Colourful Complex Ions

A Level

Compounds containing complex ions of the transition metals are often coloured.

Part A Why coloured?

Which of the following statements help to explain why compounds containing complex ions of the transition metals are often coloured?

1. Ligands coordinated to the transition metal ion cause the d-orbitals to split into different energy levels.

2. Absorption of light causes metal electrons in d-orbitals to move to unoccupied s and p-orbitals.

3. Metal electrons move between different d-orbitals in the same subshell.

- **1**, **2** and **3** are correct
- **1** and **2** only are correct
- **1** and **3** only are correct
- **2** and **3** only are correct
- **1** only is correct
- **2** only is correct
- **3** only is correct

Part B Wavelength of absorption

Which of the following factors can influence the wavelength of light absorbed (and hence the colour observed)?

1. The oxidation number of the metal ion.

2. The type of ligand.

3. The coordination geometry.

- **1**, **2** and **3** are correct
- **1** and **2** only are correct
- **1** and **3** only are correct
- **2** and **3** only are correct
- **1** only is correct
- **2** only is correct
- **3** only is correct

Part C Colourless ions

Which of the following transition metal ions will **not** form coloured compounds?

- Cr^{3+}
- Fe^{3+}
- Co^{3+}
- Ni^{2+}
- Cu^{2+}
- Fe^{2+}
- Zn^{2+}

Stoichiometry and Isomerism

A Level

The potassium salt of the iron(III) ethanedioate complex has the following composition by mass:

$$\mathrm{K}\ 26.8\,\%,\ \mathrm{Fe}\ 12.8\,\%,\ \mathrm{C}\ 16.5\,\%,\ \mathrm{O}\ 43.9\,\%$$

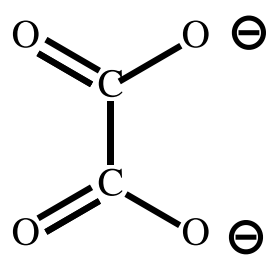

Figure 1: Structure of the ethanedioate (oxalate) anion.

Part A Metal : ligand stoichiometry

Calculate the stoichiometry of the complex formed between iron and ethanedioate ions.

How many ethanedioate ligands are there per iron?

Part B Overall charge on complex

What is the overall charge on the complex ion?

Part C Geometry of complex

Suggest the geometry of the above complex.

Part D Type of isomerism

What type of isomerism could this complex show?

Part E Addition of potassium thiocyanate

When aqueous potassium thiocyanate, $\mathrm{KSCN(aq)}$, is added to a solution of the above complex, a red colour is observed. By contrast, when aqueous potassium thiocyanate is added to aqueous potassium hexacyanoferrate(III), $\mathrm{K_3[Fe(CN)_6]}$ no such red colour is formed.

Suggest an explanation for this difference.

1. The thiocyanate ion displaces the ethanedioate ion in the above complex.

2. The cyanide ion ($\mathrm{CN^-}$) binds more strongly to $\mathrm{Fe^{3+}}$ than the thiocyanate ion.

3. Addition of the thiocyanate ion results in a change in geometry of the above complex.

- **1**, **2** and **3** are correct
- **1** and **2** only are correct
- **1** and **3** only are correct
- **2** and **3** only are correct
- **1** only is correct
- **2** only is correct
- **3** only is correct

Adapted with permission from UCLES A-Level Chemistry June 1994, Paper 2, Question 1.

$CoCl_3$-Ammonia Complexes

A Level

Four different complexes can be obtained by reacting aqueous cobalt (III) chloride with ammonia under various conditions. Different proportions of chloride are precipitated when each of the complexes is treated with aqueous silver nitrate.

Compound	Empirical formula	Colour of solid	Number of moles of $AgCl$ precipitated per complex	Does the complex have a dipole moment?
A	$CoCl_3(NH_3)_6$	orange	3	no
B	$CoCl_3(NH_3)_5$	violet	2	yes
C	$CoCl_3(NH_3)_4$	violet	1	yes
D	$CoCl_3(NH_3)_4$	green	1	no

For each compound give the formula and charge of the cobalt complex in the format $[CoCl_x(NH_3)_y]^{n+/-}$

Part A Compound A

Compound	Empirical formula	Colour of solid	Number of moles of $AgCl$ precipitated per complex	Does the complex have a dipole moment?
A	$CoCl_3(NH_3)_6$	orange	3	no

What is the formula (including charge) of the complex in compound **A**?

Part B Compound B

Compound	Empirical formula	Colour of solid	Number of moles of AgCl precipitated per complex	Does the complex have a dipole moment?
B	$\mathrm{CoCl_3(NH_3)_5}$	violet	2	yes

What is the formula (including charge) of the complex in compound **B**?

Part C Compound C

Compound	Empirical formula	Colour of solid	Number of moles of AgCl precipitated per complex	Does the complex have a dipole moment?
C	$\mathrm{CoCl_3(NH_3)_4}$	violet	1	yes

What is the formula (including charge) of the complex in compound **C**?

Part D Compound D

Compound	Empirical formula	Colour of solid	Number of moles of AgCl precipitated per complex	Does the complex have a dipole moment?
D	$\mathrm{CoCl_3(NH_3)_4}$	green	1	no

What is the formula (including charge) of the complex in compound **D**?

Part E Isomerism

Two of the above complexes are isomers. What kind of isomers are they with respect to each other?

Adapted with permission from UCLES A-Level Chemistry June 1990, Paper 4, Question 2.

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2-Hydroxybenzoate Complex

A Level

Mixtures of solutions containing $\mathrm{Fe}^{3+}(\mathrm{aq})$ and 2-hydroxybenzoate ions show light absorbancy as shown in the graph below.

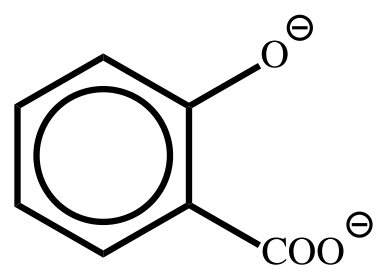

Figure 1: 2-Hydroxybenzoate ion

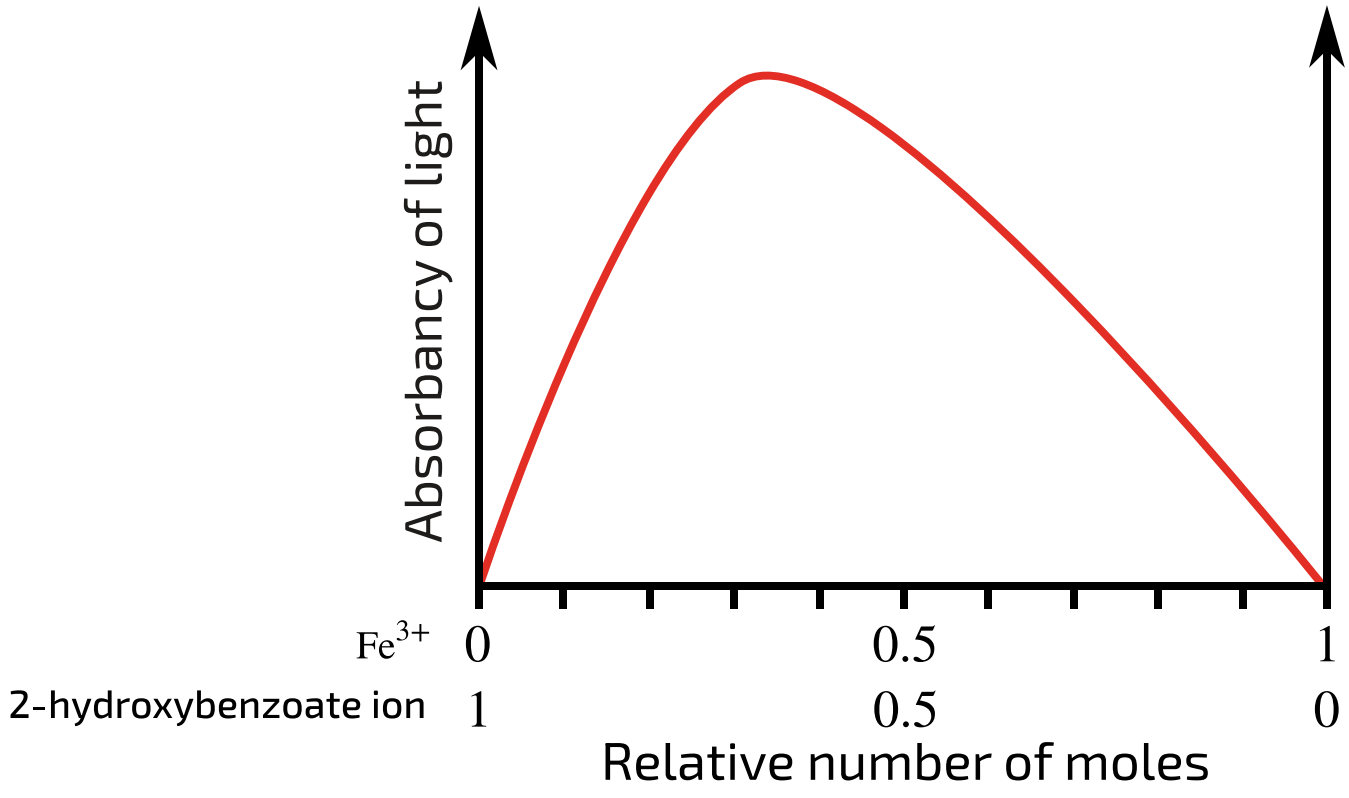

Figure 2: Variation of light absorbance with relative moles of Fe^{3+} and 2-hydroxybenzoate.

Part A Ratio

What is the ratio of these two species (Fe^{3+} : 2-hydroxybenzoate) in the complex ion?

- 4:1
- 1:2
- 1:1
- 3:1
- 1:3
- 1:4
- 2:1

Part B Coordination number

Suggest what is the likely coordination number of iron in this ion.

Part C Coordination geometry

Suggest a coordination geometry for the Fe^{3+}-2-hydroxybenzoate complex.

Part D Charge

What will be the overall charge on the complex ion?

Adapted with permission from UCLES A-Level Chemistry 1988, Paper 2, Question 7.

Transition Metal Isomerism

A Level

C C C

A compound of chromium with the general formula $\mathrm{CrCl_3 \cdot 6\,H_2O}$ forms an aqueous solution. When this solution is treated with an excess of aqueous silver nitrate, only one third of the total chloride present is precipitated as AgCl.

Part A Chromium ion

What represents the structure of the chromium ion present in the original solution?

- $[\mathrm{Cr(H_2O)_6}]^{3+}$
- $[\mathrm{Cr(H_2O)_4Cl_2}]^{+}$
- $\mathrm{Cr}^{3+}\,(\mathrm{aq})$
- $[\mathrm{Cr(H_2O)_3Cl_3}]$
- $[\mathrm{Cr(H_2O)_5Cl}]^{2+}$

Part B Number of isomers

How many isomers in total are possible for the correct ion in Part A?

Adapted with permission from UCLES A-Level Chemistry November 1995, Paper 4, Question 17.

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Analysis of Transition Metals

A Level C C C Further A C C C

A black oxide, **A**, which contains $76.5\,\%$ of chromium by mass, dissolves readily in dilute hydrobromic acid to form a sky-blue solution. When left in the air, the solution changes to a green solution from which it is possible to crystallise two hydrated isomeric salts, **B** and **C**, depending on the temperature. **B** and **C** each contain $13.0\,\%$ of chromium and $27.0\,\%$ of water, by mass.

B is violet; an aqueous solution of $0.400\,\mathrm{g}$ of **B** immediately gives $0.563\,\mathrm{g}$ of a cream precipitate when treated with aqueous silver nitrate.

C is green; an aqueous solution of $0.400\,\mathrm{g}$ of **C** immediately gives $0.188\,\mathrm{g}$ of a cream precipitate when treated with aqueous silver nitrate but on boiling for some time, a further $0.375\,\mathrm{g}$ of cream precipitate is formed.

Part A Oxide A

What is the empirical formula of oxide **A**?

Part B B and C

Compounds **B** and **C** each contain one chromium per formula unit. What is the formula of compounds **B** and **C**?

Give your answer in the format $\mathrm{Cr(H_2O)}_n$...

Part C Complex ion in B

What is the formula of the complex ion in compound **B**?

Give your answer in the format $[\mathrm{Cr(H_2O)}_x \ldots]^{n+/-}$

Part D Complex ion in C

What is the formula of the complex ion in compound **C**?

Give your answer in the format $[\mathrm{Cr(H_2O)}_x \ldots]^{n+/-}$

Adapted with permission from UCLES A-Level Chemistry June 1994, Special Paper, Question 4.