

28.3 COLOUR OF COMPLEXES

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Degenerate and non-degenerate orbitals

1. The 4d orbitals in an isolated Ag^+ ion are degenerate.

Define degenerate d orbitals.

.....
..... [1]

2. Define the term non-degenerate d-orbitals.

.....
..... [1]

In an isolated Cu^{2+} ion, the d-orbitals are all degenerate. In a complex ion such as $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$, the d-orbitals are non-degenerate.

Define degenerate and non-degenerate in this context.

degenerate

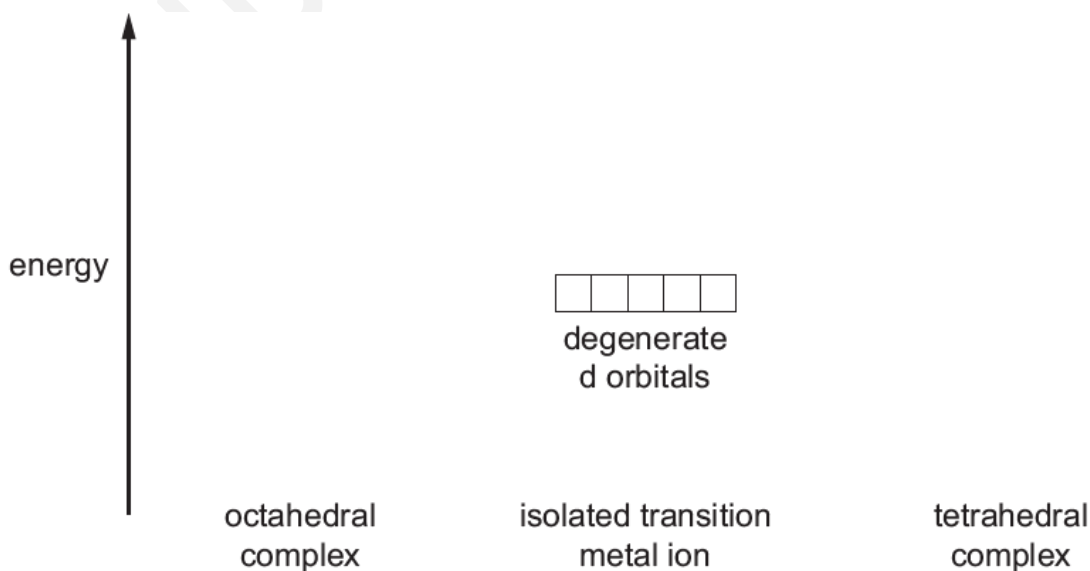
non-degenerate [1]

Splitting of degenerate orbitals

3. The transition elements can form stable complexes with a wide range of molecules and ions.

The d orbitals in an isolated transition metal ion are degenerate. In complexes, the d orbitals occupy two energy levels.

Complete the diagram to show the arrangement of d orbital energy levels in octahedral and in tetrahedral complexes. [1]



4. The complex ion $[\text{CoCl}_4]^{2-}$ has tetrahedral geometry.
 The 3d orbitals in an isolated Co^{2+} ion are degenerate.
 Complete Fig. 2.2 to show the relative energies of the 3d orbitals in an isolated Co^{2+} ion and in Co^{2+} in a tetrahedral complex.

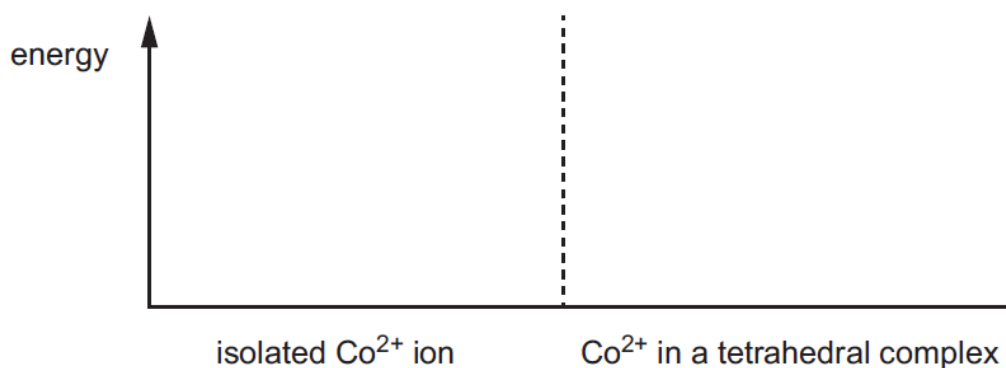
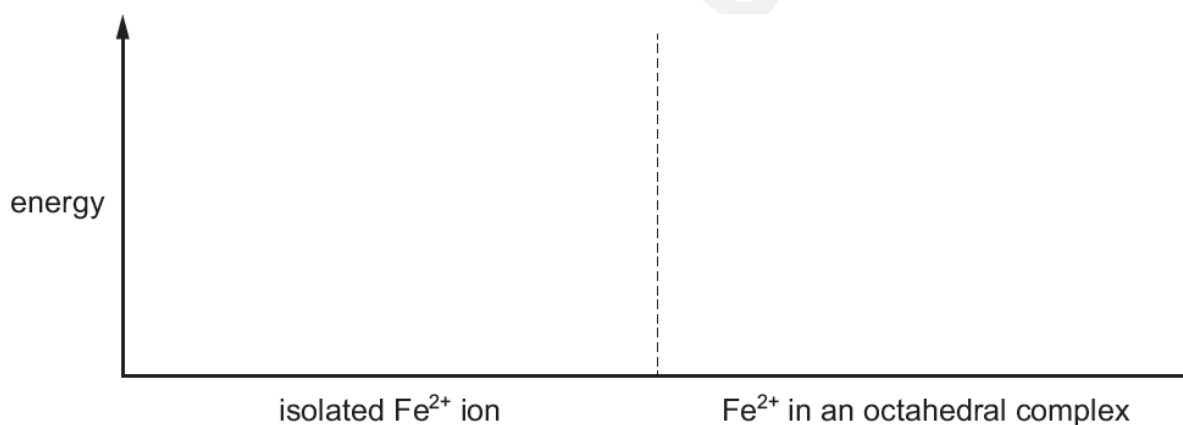
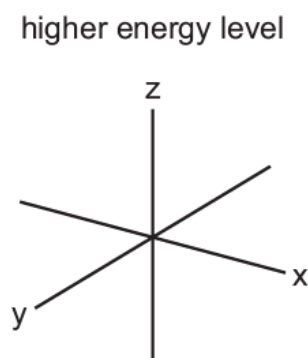
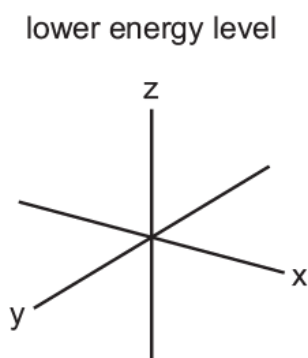


Fig. 2.2

5. The 3d orbitals in an isolated Fe^{2+} ion are degenerate.
 Complete the diagram to show the splitting of the 3d orbital energy levels in an isolated Fe^{2+} ion and when Fe^{2+} forms an octahedral complex. [2]



6. Sketch the shape of **two** d orbitals:
 • one d orbital from the lower energy level in an octahedral complex
 • one d orbital from the higher energy level in an octahedral complex.
 Use the axes below. [2]



7. Fe^{2+} and Fe^{3+} ions can form a variety of complexes with different species.

(i) Table 3.1 gives some details of different complexes of Fe^{2+} and of Fe^{3+} .

Complete the following table.

complex	ion	ligand	coordination number	formula and charge of complex
E	Fe^{2+}	NH_3	6	
F				$[\text{FeCl}_4]^{2-}$
G		en		$[\text{Fe}(\text{en})_3]^{3+}$

(ii) Complete Fig. 3.1 to show the splitting of the d-orbitals in a tetrahedral complex.

[1]

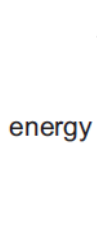


Fig. 3.1

8. L is an uncharged tridentate ligand. L donates three lone pairs to a metal atom or ion.

Cobalt forms an octahedral complex ion, E, with L. Complex ion E has a 2+ charge.

(i) Give the formula of E.

..... [1]

(ii) Identify the oxidation state of cobalt in E.

..... [1]

(iii) The d-orbitals of the cobalt atom or ion present in E are split in energy.

State the number of d-orbitals that are at a higher energy level and the number of d-orbitals that are at a lower energy level.

number of d-orbitals at a higher energy level

number of d-orbitals at a lower energy level

[1]

9. Potassium iron(III) ethanedioate, $\text{K}_3[\text{Fe}(\text{C}_2\text{O}_4)_3]$, dissolves in water to form a green solution.

Explain why transition elements form coloured compounds.

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 [3]

Explain why iron complexes are coloured.

10. Explain the origin of colour in copper(II) complexes.

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..... [4]

11. Explain why $\text{BaCrO}_4(\text{s})$ is coloured.

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..... [3]

12. The TiO^{2+} ion forms when TiO_2 reacts with an excess of sulfuric acid.

TiO^{2+} can be reduced by zinc metal in acidic conditions to form a purple solution containing $\text{Ti}^{3+}(\text{aq})$.

$\text{TiO}^{2+}(\text{aq})$ is a colourless ion.

Suggest why.

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..... [2]

13. Suggest why a solution of Cu^{2+} is coloured but solid CuI is white.

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..... [2]

14. Iron forms complex ions with the monodentate ligand, CN^- .

(i) Complex ion A contains one Fe^{3+} ion and six CN^- ligands.

Complex ion B contains one Fe^{2+} ion and six CN^- ligands.

State the formulae of these two complex ions. Include the overall charge of each complex ion.

complex ion A

complex ion B

[1]

(ii) Explain why a solution containing complex ion A and a solution containing complex ion B are different colours.

.....
.....
..... [2]

15. $[\text{Cr}(\text{H}_2\text{O})_6]^{2+}$ and $[\text{Cr}_2(\text{O}_2\text{CCH}_3)_4(\text{H}_2\text{O})_2]$ are both complexes of chromium(II) and have different colours. Explain why the colours of these complexes are different.

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..... [2]

16. A solution of $\text{Cr}^{3+}(\text{aq})$ and a solution of $\text{Fe}^{3+}(\text{aq})$ have different colours. Explain why the two complexes have different colours.

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..... [2]

17. Aqueous solutions of complexes $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ and $[\text{Fe}(\text{H}_2\text{O})_5\text{SCN}]^{2+}$ are different colours. Explain why these complexes are different colours.

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..... [2]

18. The two complex ions $[\text{Fe}(\text{CN})_6]^{4-}$ and $[\text{Fe}(\text{CN})_5\text{NO}]^{2-}$ are different colours. Explain why the colours of the two complex ions are different. [2]

19. An excess of sodium iodide is added to a solution of copper(II) sulfate. Iodine and a white precipitate of copper(I) iodide are formed.

(a) Write an equation for the reaction that occurs.

..... [1]

(b) (i) Explain why the copper(II) sulfate solution is coloured.

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..... [4]

(ii) Suggest why the precipitate of copper(I) iodide is white.

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..... [1]

20. An excess of concentrated hydrochloric acid is added to the dark blue solution of $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$. A new complex, **Z**, is formed. The colour of the solution changes.

(i) Write an equation for the formation of **Z** from the solution of $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$. Include the formula and charge of **Z**.

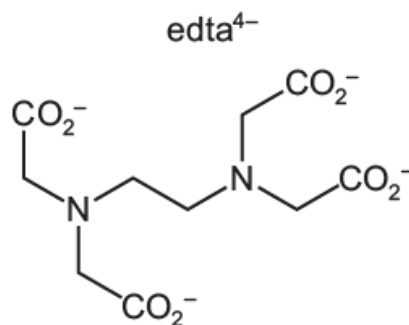
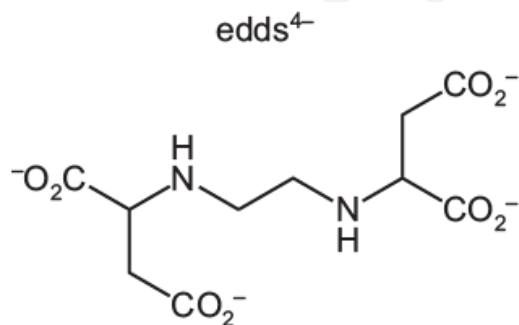
..... [2]

(v) Explain why the colour of a solution of $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ is different from the colour of a solution of **Z**. You should refer to the energies of the orbitals involved in your answer.

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..... [1]

21. The formulae of the complexes are $[\text{Fe}(\text{edds})]^-$ and $[\text{Fe}(\text{edta})]^-$ respectively. edds^{4-} and edta^{4-} are polydentate ligands that form octahedral complexes with $\text{Fe}^{3+}(\text{aq})$.



(i) $[\text{Fe}(\text{edds})]^-$ is red and $[\text{Fe}(\text{edta})]^-$ is yellow.

Explain why the two complexes have different colours.

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..... [2]

22. The solution of $[\text{Cu}(\text{NH}_3)_4]^{2+}$ is heated gently in a fume cupboard so that NH_3 is released. Some NH_3 remains in solution and some forms NH_3 gas. The colour of the solution changes; a precipitate of $\text{Cu}(\text{OH})_2$ forms and is collected.

A sample of $\text{Cu}(\text{OH})_2$ is added to concentrated hydrochloric acid. A reaction takes place, forming a coloured copper complex, Y.

A sample of $\text{Cu}(\text{OH})_2$ is added to dilute sulfuric acid. A reaction takes place, forming a coloured copper complex, Z.

$[\text{Cu}(\text{NH}_3)_4]^{2+}$, Y and Z are different colours.

Explain why complexes Y and Z are coloured and why their colours are different.

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..... [5]

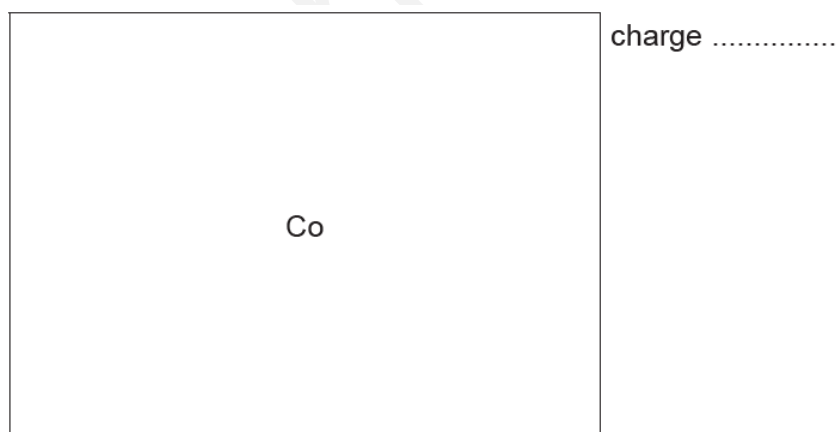
Ligand exchange

23. Cobalt(II) sulfate is added to water to form a pink solution containing complex ion P. An excess of concentrated hydrochloric acid is added to this solution to form a blue solution containing complex ion Q.

(i) Complete the diagram to show the three-dimensional structure of Q.

State the charge on this complex ion.

[2]



(ii) Name the type of reaction in which P forms Q.

..... [1]

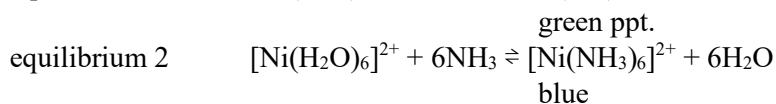
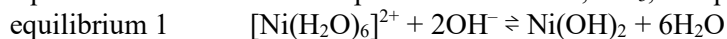
(iv) Explain why the colours of P and Q are different.

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..... [2]

24. Hexaaquanickel(II) ions are green. They form a green precipitate with hydroxide ions, OH^- , in equilibrium 1 and a blue complex with ammonia, NH_3 , in equilibrium 2.



Use Le Chatelier's principle to suggest explanations for the following observations.

- (i) Explain why when aqueous NH_3 is added dropwise to $[\text{Ni}(\text{H}_2\text{O})_6]^{2+}$ a green precipitate is formed.

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..... [1]

- (ii) Explain why when a large excess of aqueous NH_3 is added to $[\text{Ni}(\text{H}_2\text{O})_6]^{2+}$, the green precipitate dissolves and a blue solution is formed.

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..... [1]

25. Hydrated cobalt(II) nitrate, $\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, is a red solid that behaves like hydrated magnesium nitrate, $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, when heated.

Describe in detail what you would expect to observe when crystals of $\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ are heated in a boiling tube, gently at first and then more strongly.

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..... [2]

- (b) Co^{2+} ions form complex ion G.

Each G ion contains two Co^{2+} ions, both of which are octahedrally coordinated.

Each G ion contains one O_2 molecule, which donates one pair of electrons to each Co^{2+} ion, and one NH_2^- ion, which donates one pair of electrons to each Co^{2+} ion.

The remaining ligands are NH_3 molecules.

- (i) Deduce the formula of complex ion G. Include its overall charge.

formula of G [2]

- (ii) The d-orbitals of the Co^{2+} ions present in complex ion G are split. State the number of d-orbitals that are at a higher energy level and the number of d-orbitals that are at a lower energy level in each Co^{2+} ion.

number of d-orbitals at a higher energy level:

number of d-orbitals at a lower energy level: [1]

- (iii) Co^{2+} ions form a different complex ion, M.

Each M ion contains two Co^{2+} ions, both of which are octahedrally coordinated, but the ligands are different from the ligands in G.

Explain why G and M have different colours. [2]