28.3 Colour of complexes

Name: _____ Class: _____ Date: _____ **Total: 28 marks**

KEY WORDS degenerate 简并 • non-degenerate 非简并 • complementary colour 互补色 • colour of complexes 配合物的颜色 • complex 配合物

Objective

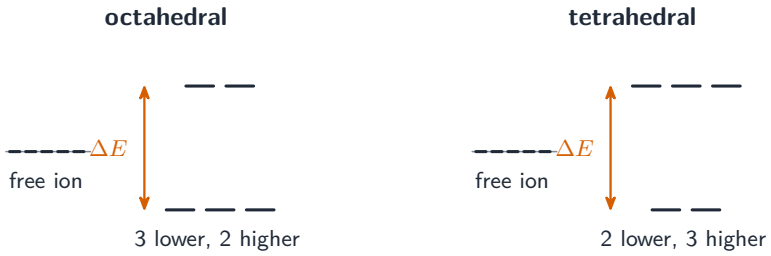
Build the skills to answer exam questions on the **colour of complexes** 配合物的颜色 — **d-orbital splitting** d 轨道分裂 and why transition complexes are coloured.

You must be able to:

- define degenerate and non-degenerate d orbitals
- describe the splitting in octahedral and tetrahedral complexes
- explain colour in terms of the frequency of light absorbed (ΔE)

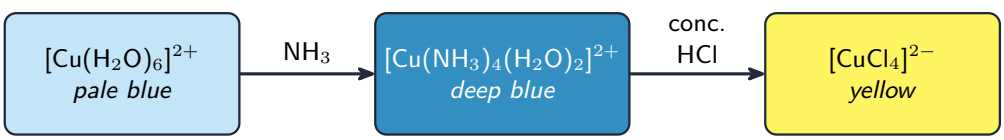
1 Worked examples

■ d-orbital splitting and colour



the complex absorbs light of energy ΔE, so we see the **complementary colour**

*Ligands split the five **degenerate** d orbitals into two **non-degenerate** sets separated by a gap ΔE*



Ligand exchange changes the complex colour

- **octahedral:** three lower + two higher.

- **tetrahedral:** two lower + three higher.

A complex absorbs light whose energy equals ΔE, promoting a d electron to the higher set. We **see** the **complementary colour** of the light absorbed. Different ligands give a different ΔE → different colour (why ligand exchange changes colour).

Why a complex is coloured, and what changes the colour

In a free gaseous ion the five 3d orbitals are **degenerate** — equal in energy. When **ligands** approach, their lone pairs repel the d electrons unequally: the orbitals pointing towards the ligands rise in energy and the others fall, so the set **splits** into two levels separated by ΔE.

The colour, in the order the marks are awarded:

1. The complex absorbs a photon whose energy equals ΔE.
2. That promotes an electron from the lower set to the higher — a **d–d transition**.
3. The frequency absorbed follows $\Delta E = h\nu$, so a larger ΔE means a higher frequency and a shorter wavelength absorbed.
4. The colour **seen** is the **complement** of the light absorbed: a complex absorbing red looks green; absorbing green, it looks red.

Why some ions are colourless. A d–d transition needs a **partially filled** d subshell. Sc^{3+} ($3d^0$), Cu^+ and Zn^{2+} ($3d^{10}$) have no vacancy to promote an electron into, absorb no visible light, and are colourless.

Three things change ΔE, and therefore the colour:

Change	Effect
the ligand	ligands have a fixed order of splitting power (the spectrochemical series): $I^- < Cl^- < F^- < OH^- < H_2O < NH_3 < CN^-$ — a stronger-field ligand gives a larger ΔE
the oxidation state	a higher charge pulls the ligands closer, increasing the repulsion and so ΔE
the coordination number / shape	octahedral and tetrahedral fields split the orbitals differently, so a change of geometry changes the colour

Worked example. Adding concentrated ammonia to pale blue $[Cu(H_2O)_6]^{2+}$ gives a deep blue solution. Explain. Ammonia replaces four of the water ligands by ligand exchange. Ammonia is higher in the spectrochemical series than water, so the splitting ΔE increases. A larger ΔE means light of a different (higher) frequency is absorbed, so the complementary colour transmitted changes, and the solution deepens to blue.

2 Practice

2.1 Define **degenerate** d orbitals. [1]

2.2 State how the five d orbitals split in an **octahedral** complex. [1]

2.3 Explain why Zn^{2+} complexes are colourless. [2]

2.4 State the relationship between the energy gap ΔE and the frequency of light absorbed. [1]

2.5 Name three factors that change the size of ΔE. [3]

3 Exam-style questions

3.1 A transition-metal complex is coloured because an electron is promoted: [1]

A | B
C | D

A out of the atom
B between two non-degenerate d orbitals
C into the nucleus
D between s orbitals

3.2 The colour we see is: [1]

A | B
C | D

A the colour of light absorbed
B the complementary colour of the light absorbed
C always green
D white

3.3 Explain, in terms of d orbitals, why $[Cu(H_2O)_6]^{2+}$ is coloured. [3]

3.4 Explain why changing the ligand around a transition-metal ion changes the colour of the complex. [2]

3.5 Aqueous cobalt(II) chloride is pink because of the complex $[Co(H_2O)_6]^{2+}$.

(a) Explain, in terms of d orbitals, why this complex is coloured. [4]

(b) The pink solution absorbs green light. State the relationship between the colour absorbed and the colour seen. [1]

(c) Concentrated hydrochloric acid is added and the solution turns blue, forming $[CoCl_4]^{2-}$. Explain the colour change, referring to both the ligand and the shape. [4]

(d) A solution of $[Sc(H_2O)_6]^{3+}$ is colourless. Explain why. [2]

(e) Predict, with a reason, whether $[Co(CN)_6]^{4-}$ would absorb light of a higher or lower frequency than $[Co(H_2O)_6]^{2+}$. [2]