A-LEVEL CHEMISTRY • EXERCISE SHEET

28.1 General properties of the transition elements

Name: _____ Class: _____ Date: _____ **Total: 32 marks**

KEY WORDS transition element 过渡元素 • complex 配合物 • complex ion 配离子 • oxidation state 氧化态 • catalyst 催化剂

Objective

Build the skills to answer exam questions on **transition elements** 过渡元素 — the definition and the four characteristic properties.

You must be able to:

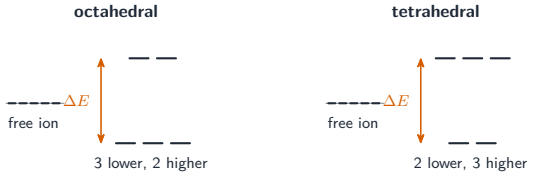
- define a transition element and explain why Sc and Zn are excluded
- state the four key properties (variable oxidation state, catalysis, complexes, colour) and why

1 Worked examples

What a transition element is

A **transition element** is a d-block element that forms one or more stable ions with **incomplete d orbitals**. (Sc and Zn are excluded: their stable ions have empty or full d orbitals.)

Coloured compounds are one of the four characteristic properties of transition elements



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

d-orbital splitting explains colour and variable oxidation states

property	reason
variable **oxidation state**	the 3d and 4s sub-shells are close in energy
act as a **catalyst**	more than one oxidation state; vacant d orbitals form dative bonds
form **complex ions**	vacant d orbitals accept lone pairs
coloured compounds	electrons move between split d orbitals

The definition, and the four properties that follow from it

A **transition element** 过渡元素 is a d-block element that forms **one or more stable ions with a partially filled d sub-shell**. The definition matters because it is what excludes **scandium** (its only stable ion, Sc^{3+}, is $3d^0$) and **zinc** (its only stable ion, Zn^{2+}, is $3d^{10}$) — both are d-block, neither is a transition element.

The electronic configurations, with the two exceptions the exam always asks for:

- Fill 4s before 3d: Fe is $[Ar]\,3d^6 4s^2$.
- **Chromium** is $[Ar]\,3d^5 4s^1$ and **copper** is $[Ar]\,3d^{10} 4s^1$ — a half-filled or filled d sub-shell is more stable than the expected arrangement.
- △ When an ion forms, the **4s electrons are lost FIRST**: Fe^{2+} is $3d^6$, not $3d^4 4s^2$.

The four characteristic properties, each with its reason — the reason is always the mark:

Property	Why
variable oxidation states	the 4s and 3d sub-shells are close in energy, so different numbers of electrons can be lost for a similar energy cost
coloured compounds	ligands split the d orbitals into two energy levels; an electron absorbs a photon of visible light to jump the gap, and the colour seen is the complement of the light absorbed
catalytic activity	variable oxidation states let the metal accept and donate electrons in a redox cycle (homogeneous), or its d orbitals adsorb reactants onto a surface at the right strength (heterogeneous)
complex ion formation	the ion is small and highly charged with vacant d orbitals, so it accepts lone pairs from ligands into dative bonds

Worked example. Explain why a solution of $[Cu(H_2O)_6]^{2+}$ is blue but $[Zn(H_2O)_6]^{2+}$ is colourless. In the copper complex the ligands split the 3d orbitals and the Cu^{2+} ion has a partially filled d sub-shell ($3d^9$), so an electron can be promoted across the gap by absorbing visible light; the complementary colour is transmitted, and the solution looks blue. Zn^{2+} is $3d^{10}$ — the sub-shell is full, there is no vacancy to promote an electron into, no visible light is absorbed, and the solution is colourless.

2 Practice

2.1 Define a **transition element**. [2]

2.2 State the four characteristic properties of transition elements. [2]

2.3 Give the electronic configuration of a Cr atom and of a Fe^{3+} ion. [2]

2.4 Iron forms stable Fe^{2+} and Fe^{3+} ions, but calcium forms only Ca^{2+}. Explain this difference in terms of the sub-shells involved. [2]

2.5 State why scandium is not classed as a transition element. [2]

3 Exam-style questions

3.1 Why is zinc **not** classed as a transition element? [1]

- **A** it is not in the d-block
- **B** its stable ion (Zn^{2+}) has a full d sub-shell ($3d^{10}$)
- **C** it is colourless
- **D** it has no electrons

3.2 Transition elements show variable oxidation states because: [1]

- **A** their atoms are large
- **B** the 3d and 4s sub-shells are close in energy
- **C** they are coloured
- **D** they are catalysts

3.3 Explain why transition metals can act as catalysts. [2]

3.4 Explain why scandium is not classed as a transition element, with reference to its ion. [2]

3.5 Copper and zinc are adjacent in the d block, but only copper is a transition element.

(a) Define the term transition element. [2]

(b) Complete the table of electronic configurations. [4]

Species	Configuration
Cu atom	
Cu^{2+} ion	
Zn atom	
Zn^{2+} ion	

(c) Use your answers to (b) to explain why zinc is not a transition element. [2]

(d) Explain, in terms of d orbitals, why aqueous copper(II) sulfate is blue while aqueous zinc sulfate is colourless. [4]

(e) State two other characteristic properties of transition elements, and give the reason for each. [4]

Solutions

2.1 a d-block element that forms one or more stable ions with incomplete (partly filled) d orbitals.

2.2 variable oxidation state; catalytic behaviour; form complex ions; form coloured compounds.

2.3 Cr: $[Ar]\,3d^5 4s^1$; Fe^{3+}: $[Ar]\,3d^5$.

2.4 In iron the 4s and 3d sub-shells are very close in energy, so electrons can be removed from either for a similar energy cost, giving more than one stable ion; calcium has only 4s electrons available above a noble-gas core, and removing a third electron would break into that core, which costs far too much energy.

2.5 Its only stable ion is Sc^{3+}, which has an empty d sub-shell ($3d^0$) rather than a partially filled one.

3.1 B. Zn^{2+} is $3d^{10}$ (a full d sub-shell), so it is not a transition element.

3.2 B. The close energies of 3d and 4s allow different numbers of electrons to be removed.

3.3 they have more than one stable oxidation state; and vacant d orbitals that can form dative bonds with reactants, providing a surface/intermediate.

3.4 scandium's only stable ion is Sc^{3+}, which has an empty d sub-shell ($3d^0$), so it has no incomplete d orbitals.

3.5 (a) A d-block element that forms at least one stable ion with a partially filled d sub-shell.
(b) Cu atom $[Ar]\,3d^{10}4s^1$; Cu^{2+} $[Ar]\,3d^9$; Zn atom $[Ar]\,3d^{10}4s^2$; Zn^{2+} $[Ar]\,3d^{10}$.
(c) The only stable zinc ion, Zn^{2+}, has a FULL d sub-shell; the definition requires a partially filled one, so zinc is excluded.
(d) In the copper complex the ligands split the 3d orbitals into two energy levels; Cu^{2+} is $3d^9$, so there is a vacancy and an electron can absorb a photon of visible light to jump the gap; the transmitted light is the complementary colour, which is blue. Zn^{2+} is $3d^{10}$, so the sub-shell is full, no electron can be promoted, no visible light is absorbed and the solution is colourless.
(e) Any two, each with its reason: catalytic activity, because variable oxidation states allow electrons to be accepted and donated in a redox cycle; complex ion formation, because the small, highly charged ion has vacant d orbitals that accept lone pairs from ligands.