

Exercise walk-through

28.1

General physical and chemical properties of the first row of transition elements, titanium to copper

A-Level Chemistry

Four key properties

variable oxidation state

– 3d & 4s close in energy

complex ions

– vacant d orbitals accept lone pairs

catalyst

– more than one stable state, vacant d orbitals

coloured

compounds – electrons jump split d orbitals

A **transition element**

forms ions with **incomplete d orbitals** (so Sc and Zn don't count).



Ruby

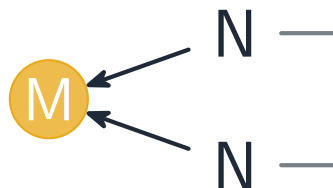
Ligands and denticity

A **ligand** donates a **lone pair** in a **dative bond** :

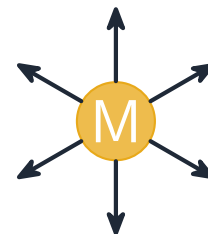
- **monodentate** – 1 bond (H_2O , NH_3)
- **bidentate** – 2 bonds (en)
- **polydentate** – many (EDTA: 6)



monodentate: 1 bond
(H_2O , NH_3 , Cl^-)



bidentate: 2 bonds
("en")



polydentate: many
(EDTA uses 6)

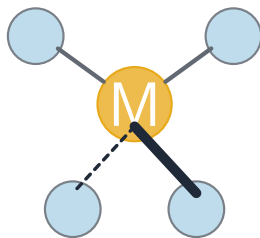
Complex shapes

The **coordination number** (dative bonds to the metal) sets the shape:

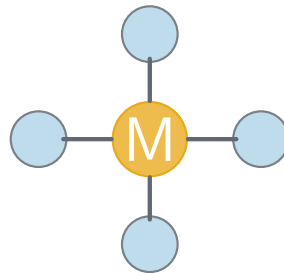
- 6 → **octahedral**
- 4 → tetrahedral or square planar
- 2 → linear



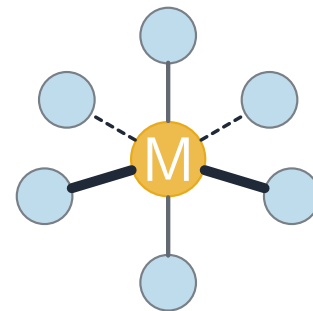
linear
CN 2



tetrahedral
CN 4



square planar
CN 4



octahedral
CN 6

The 3d orbitals, and the bond that makes a complex

the orbitals

the $3d_{xy}$ orbital has **four lobes pointing between** the axes; the $3d_{x^2-y^2}$ has four lobes pointing **along** them

why that matters

ligands approach along the axes, so those two sets are pushed up by **different amounts**

non-degenerate

the five 3d orbitals, equal in the free ion, split into two energy levels in a complex

a dative covalent bond

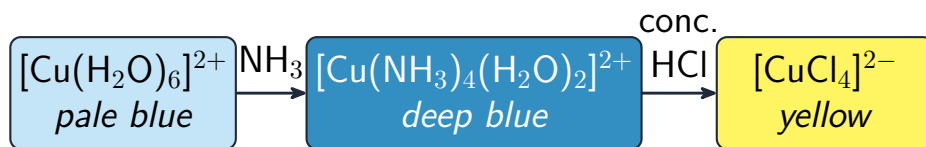
the ligand supplies **both** electrons to the bond with the metal ion

the colour

an electron absorbs light to jump the split, and the **complementary** colour is what we see

Change the ligand and you change the size of the split, so you change the colour. That is why ligand exchange is visible.

Ligand exchange



In **ligand exchange** one ligand replaces another, often with a colour change. Copper(II): pale blue (water) $\rightarrow$ deep blue (NH_3) $\rightarrow$ yellow ($[\text{CuCl}_4]^{2-}$).

Exercises 2.1-2.3

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]

Exercises 2.1-2.3

2.1 Define a **transition element**.

[2]

2.1

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

2.2 State the four characteristic properties of transition elements.

[2]

2.2

- variable oxidation state; catalytic behaviour; form complex ions; form coloured compounds

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

[2]

2.3

- Cr: $[\text{Ar}] 3d^5 4s^1$; Fe^{3+} : $[\text{Ar}] 3d^5$

Exercises 2.4·2.5

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]

Exercises 2.4·2.5

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]

2.4

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

2.5

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

Exercises 3.1·3.2

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

Exercises 3.1·3.2

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3.1 B

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

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

3.2 B

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

Exercises 3.3-3.4

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]

Exercises 3.3-3.4

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

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

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

Exercise 3.5 (a)

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]

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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]

(a)

- A d-block element that forms at least one stable ion with a partially filled d sub-shell

Exercise 3.5 (b)

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

(b) Complete the table of electronic configurations.

[4]

Species	Configuration
Cu atom	
Cu ²⁺ ion	
Zn atom	
Zn ²⁺ ion	

Exercise 3.5 (b)

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(b) Complete the table of electronic configurations.

[4]

Species	Configuration
Cu atom	
Cu ²⁺ ion	
Zn atom	
Zn ²⁺ ion	

(b)

- Cu atom [Ar] 3d¹⁰4s¹; Cu²⁺ [Ar] 3d⁹; Zn atom [Ar] 3d¹⁰4s²; Zn²⁺ [Ar] 3d¹⁰

Exercise 3.5 (c)

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

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

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

(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

Exercise 3.5 (d)

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

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

[4]

Exercise 3.5 (d)

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

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

(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

Exercise 3.5 (e)

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

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(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