

28.1 GENERAL PHYSICAL AND CHEMICAL PROPERTIES OF TRANSITION ELEMENTS

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Learning outcomes

Candidates should be able to:

1. define a transition element as a d-block element which forms one or more stable ions with incomplete d orbitals
2. sketch the shape of a $3d_{xy}$ orbital and a $3d_{z^2}$ orbital
3. understand that transition elements have the following properties:
 - (a) they have variable oxidation states
 - (b) they behave as catalysts
 - (c) they form complex ions
 - (d) they form coloured compounds
4. explain why transition elements have variable oxidation states in terms of the similarity in energy of the 3d and the 4s sub-shells
5. explain why transition elements behave as catalysts in terms of having more than one stable oxidation state, and vacant d orbitals that are energetically accessible and can form dative bonds with ligands
6. explain why transition elements form complex ions in terms of vacant d orbitals that are energetically accessible

Initial assessment

1. List the full electron configurations for each of the elements titanium to copper

Introduction

The elements from scandium to zinc inclusive comprise the 3d block. The 3d sub-shell contains five orbitals, each able to accommodate two electrons, and so this block contains ten elements.

 The electronic configuration of scandium is $[\text{Ar}]3d^14s^2$, and that of zinc is $[\text{Ar}]3d^{10}4s^2$.

Apart from scandium and zinc, the other eight elements are known as the transition elements because some of their properties show a gradual change (transition) from those of the reactive metal calcium in Group 2 to the much less reactive metal gallium in Group 13.

Transition elements are d-block elements that form one or more stable ions with incomplete d orbitals.

✗ Sc: $\text{Sc}^{3+} = [\text{Ar}] 3d^0 \rightarrow$ not a transition element

✗ Zn: $\text{Zn}^{2+} = [\text{Ar}] 3d^{10} \rightarrow$ not a transition element

When transition elements form ions, their atoms lose electrons from the 4s sub-shell first, followed by 3d electrons.

 Remember

Cr: $[\text{Ar}] 3d^54s^1$

Cu: $[\text{Ar}] 3d^{10}4s^1$

Properties of the transition elements

They form some compounds containing ions with an incomplete d sub-shell.

They have variable oxidation states.

They can behave as catalysts.

They form complex ions.

They form coloured compounds.

The transition elements commonly have physical properties that are typical of most metals:

they have high melting points

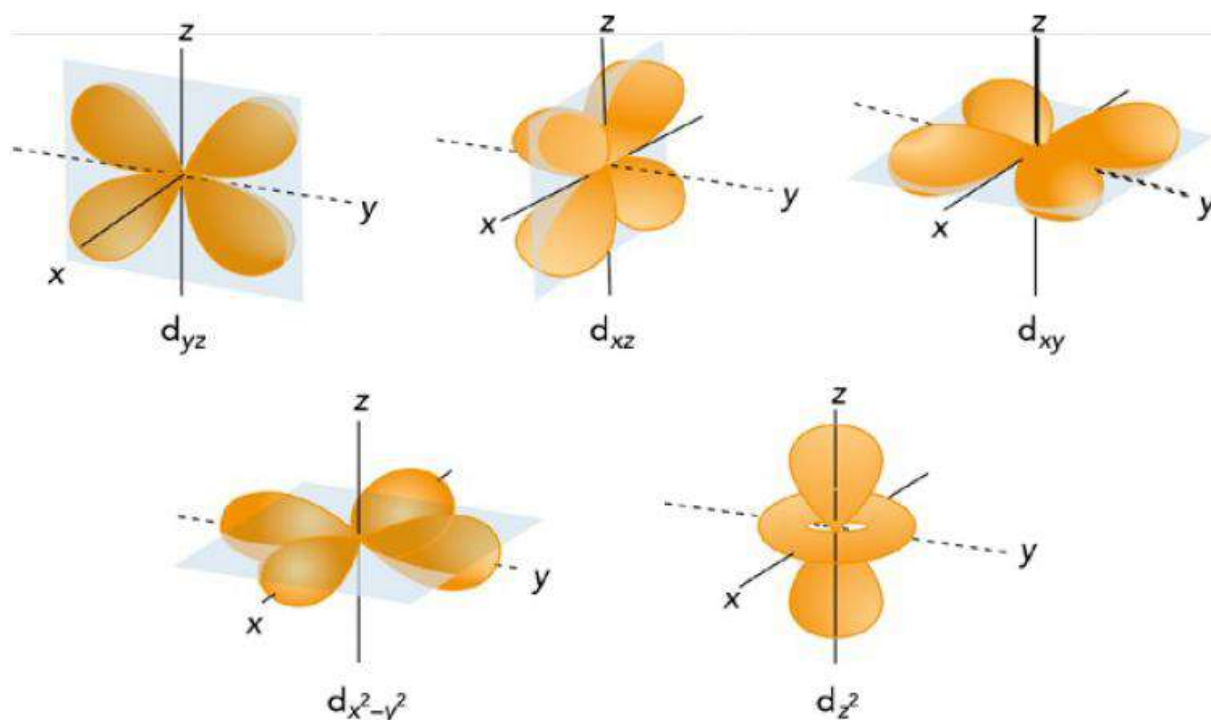
they have high densities

they are hard and rigid, and so are useful as construction materials

they are good conductors of electricity and heat

- The melting and boiling points of the transition elements are generally much higher than those of the s- and p-block elements.
- This indicates that not only the 4s electrons but also the 3d electrons are involved in the metallic bonding.
- Transition elements are good conductors of heat and electricity. Copper has particularly high electrical conductivity.
- The metallic radii tend to decrease across the block as the increasing nuclear charge attracts the outer electrons more strongly. There are minor variations to this trend.
- There is no obvious trend in the M^{2+} ionic radii, but the M^{3+} ionic radii tend to decrease across the block as the nuclear charge increases and attracts the electrons more strongly.

shape of a $3d_{xy}$ orbital and $3d_{z^2}$ orbital



d_{xy} : four lobes between the x- and y-axes.

d_{z^2} : two lobes along the z-axis with a ring around the centre.

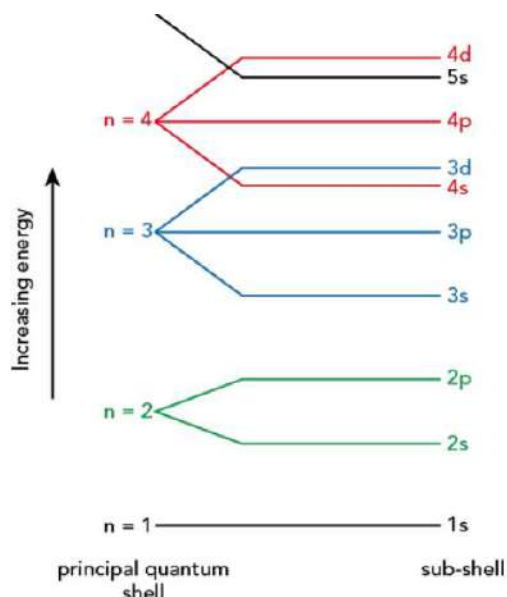
Variable oxidation states

Note down compounds of various common first-row transition elements, and the oxidation states in these compounds.

Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
	+2	+2	+2	+2	+2	+2	+2	+2	+2
+3	+3	+3	+3	+3	+3	+3	+3	+3	
	+4	+4	+4	+4	+4	+4	+4		
	+5	+5	+5	+5	+5	+5			
			+6	+6	+6				
				+7					

The 3d and 4s electrons have similar energies. Therefore, different numbers of these electrons can be removed or used in bonding.

As a result, transition elements can form ions with different oxidation states.



Formation of complex ions

Transition-metal ions can form complex ions by accepting lone pairs of electrons from ligands into vacant d orbitals.

A **ligand** is a species that donates a lone pair of electrons to a central metal ion to form a **dative covalent bond**.

For example: $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$

Why do transition metals form complex ions?

Vacant d orbitals that are energetically accessible and can form dative bonds with ligands

Transition elements as catalysts

Transition elements can act as catalysts because they can:

- change between different oxidation states, and
- provide vacant d orbitals that can form dative bonds with reactant molecules.

These features provide an alternative reaction pathway with lower activation energy

Examples

Haber process:	$\text{N}_2 + 3\text{H}_2 \rightleftharpoons 2\text{NH}_3$	Fe catalyst
Contact process:	$2\text{SO}_2 + \text{O}_2 \rightleftharpoons 2\text{SO}_3$	V₂O₅ catalyst
Hydrogenation of alkenes:	$\text{alkene} + \text{H}_2 \rightarrow \text{alkane}$	Ni catalyst

★ Remember

Transition elements are associated with four important properties:

 Variable oxidation states

 Catalytic activity

 Complex-ion formation

 Coloured compounds

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