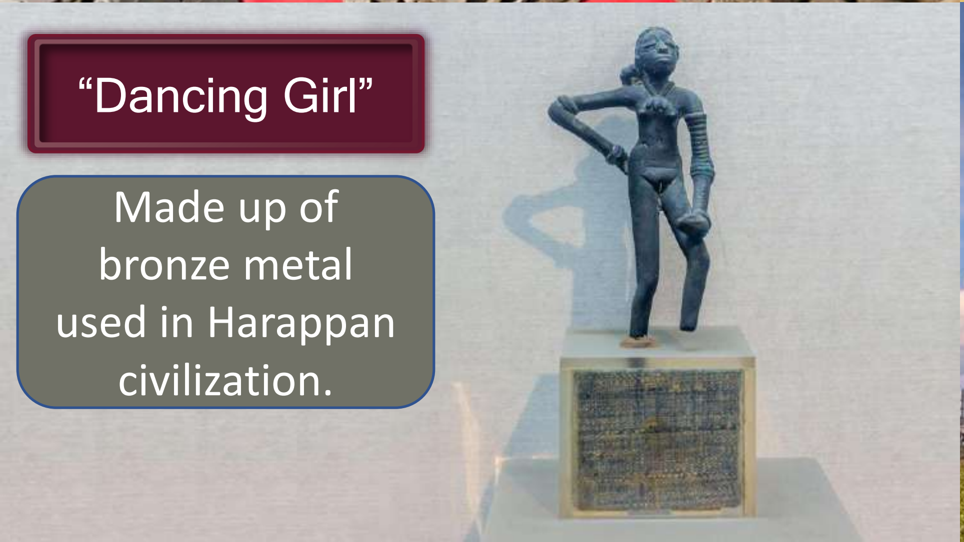
Welcome to

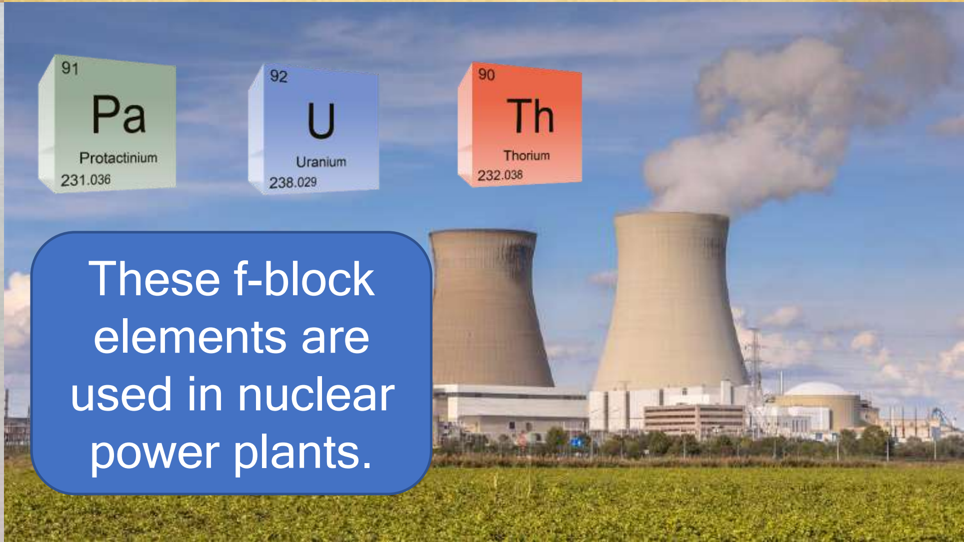
Aakash + BYJU'S LIVE

The d and f-Block Elements

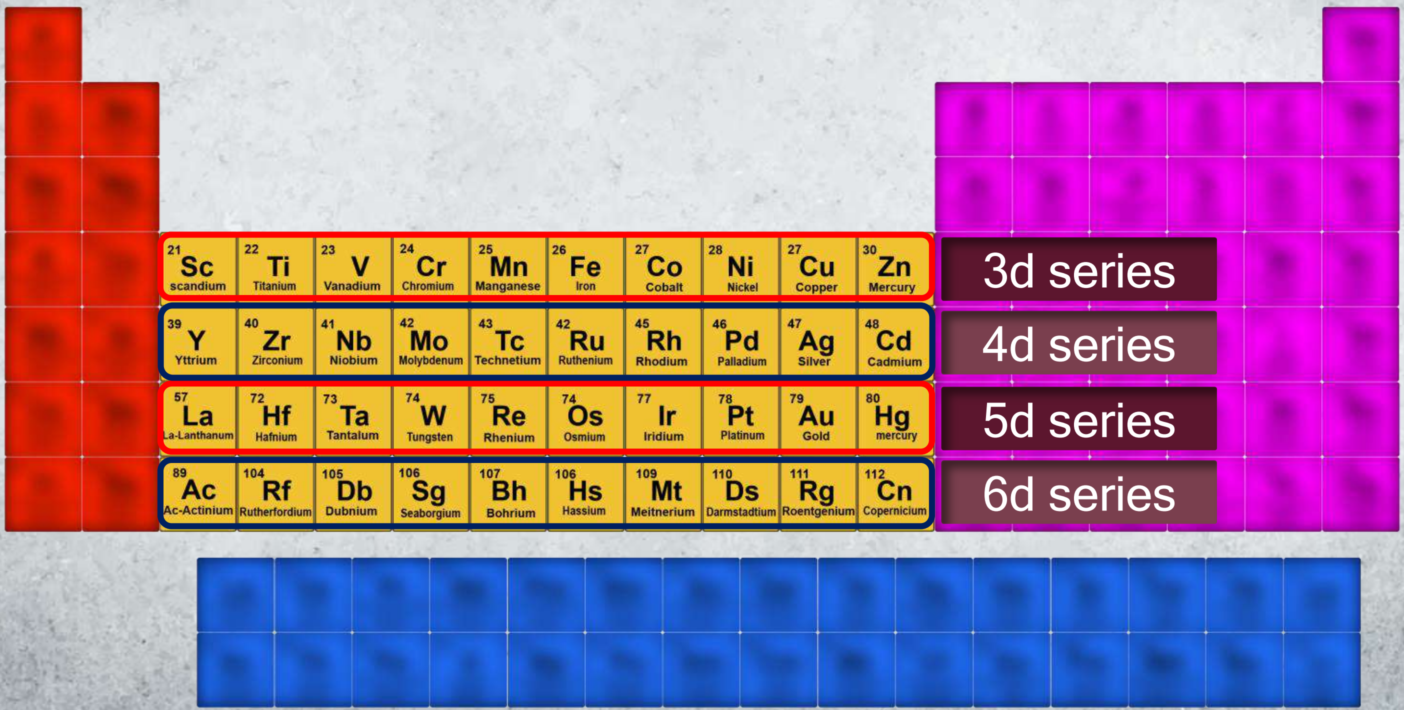

Coinage Metals
(Cu, Ag, Au)


Some ancient
metal artifacts
Copper,
iron used
to make
weapons.


“Dancing Girl”
Made up of
bronze metal
used in Harappan
civilization.


91
Pa
Protactinium
231.036
92
U
Uranium
238.029
90
Th
Thorium
232.038
These f-block
elements are
used in nuclear
power plants.

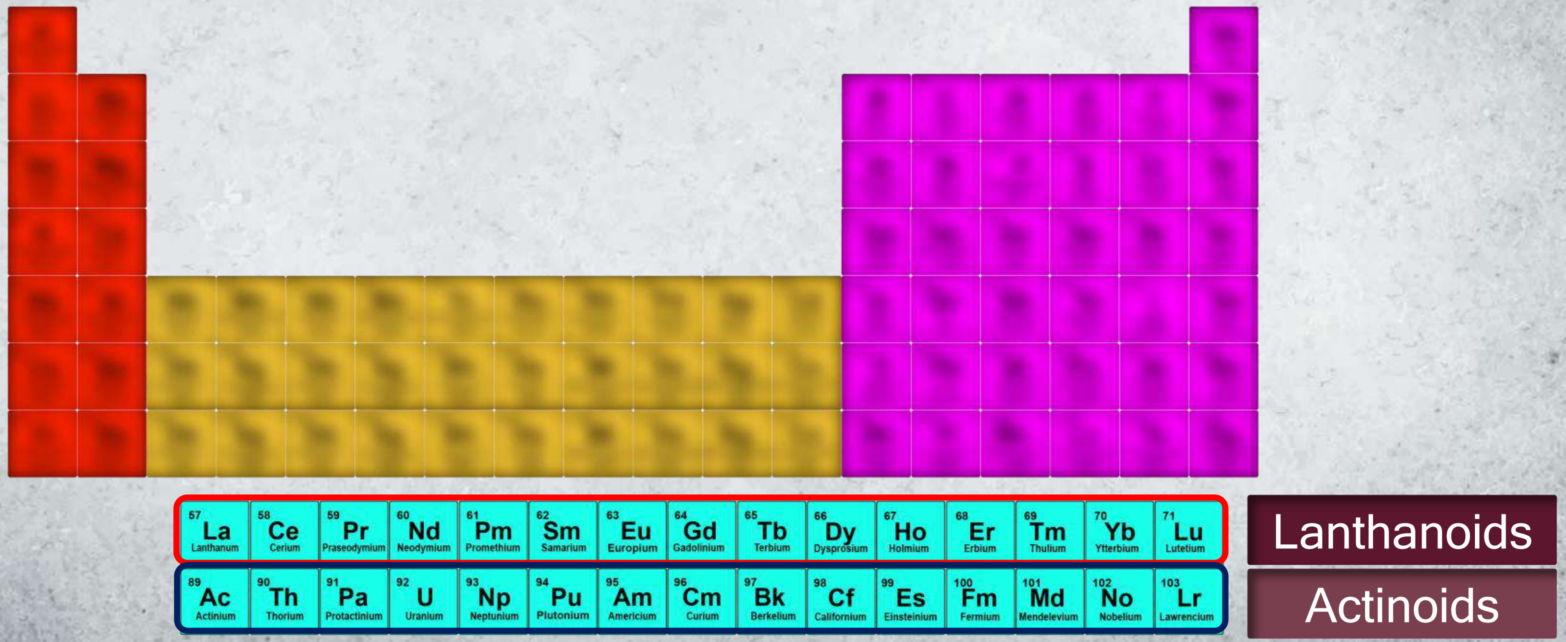
d-Block elements



Pneumonic for d-Series

Sc	Sachin	Y	Yes	La	Larry
Ti	Tendulkar	Zr	Zebras	Hf	Have fun
V	Very	Nb	Never but	Ta	Travelling
Cr	Crazy	Mo	Most	W	World and
Mn	Man	Tc	Technicians	Re	Reach
Fe	Free	Ru	Run	Os	Out
Co	Coaching to	Rh	Rhymes	Ir	Ireland and
Ni	Nitin’s	Pd	Purely sweet	Pt	Please
Cu	Cou	Ag	And	Au	Ask
Zn	Zin	Cd	Cute	Hg	Her

f-Block elements



d-Block Elements

d-Block & f-block elements are known as transition and inner transition elements, respectively

Generally, d-block elements are called transition elements

Because their chemical properties are transitional between those of s- & p-block elements

Known as transition metals

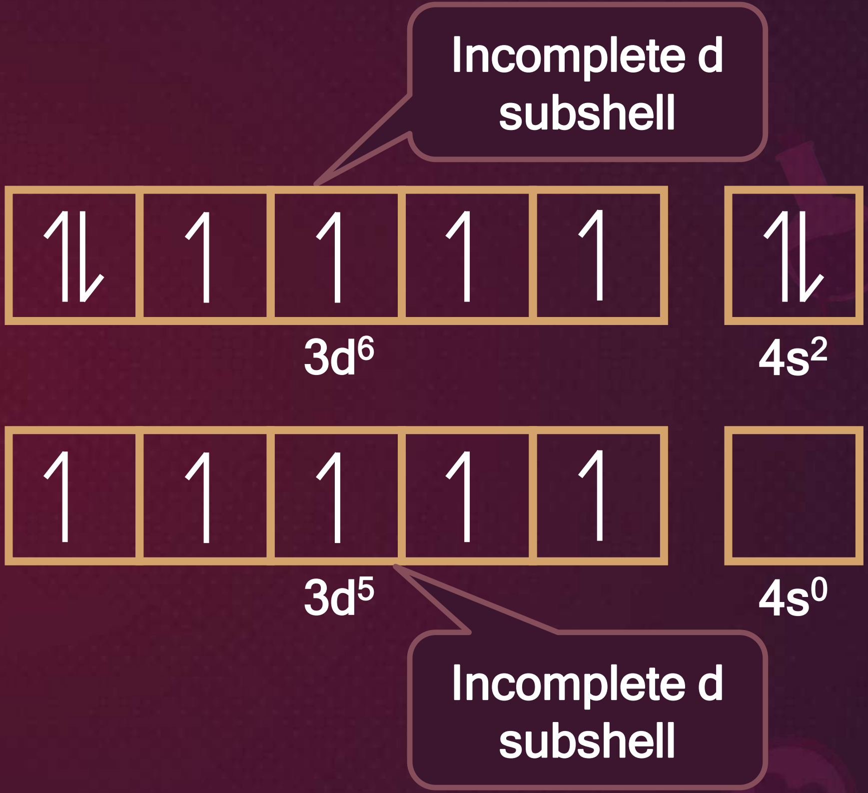
Metals that have incomplete d subshell either in neutral atom or in their ions.

Transition Elements

EXAMPLE

Fe : [Ar] — Neutral

Fe^{3+} : [Ar] — Ion



Inner Transition Elements

f-Block elements are called **inner transition** elements

Because their valence shell electrons lie in **anti-penultimate energy level**

Example: Cerium (58)
[Xe] $4f^1\ 5d^1\ 6s^2$

Non-transition d-Block Elements

Zn (30) : [Ar] $3d^{10}$ $4s^2$

Zn^{2+} : [Ar] $3d^{10}$ $4s^0$

Cd (48) : [Kr] $4d^{10}$ $5s^2$

Cd^{2+} : [Kr] $4d^{10}$ $5s^0$

Hg (80) : [Xe] $4f^{14}$ $5d^{10}$ $6s^2$

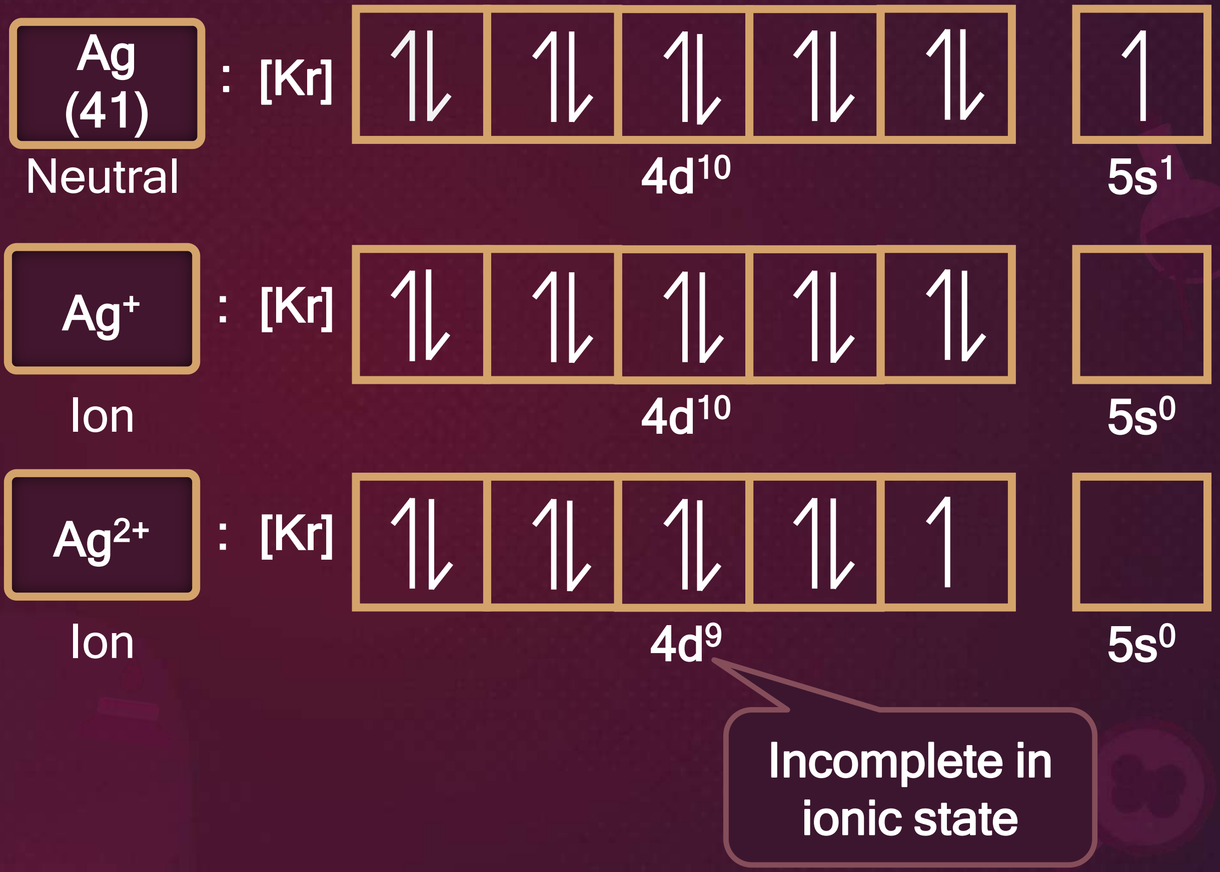
Hg^{2+} : [Xe] $4f^{14}$ $5d^{10}$ $6s^0$

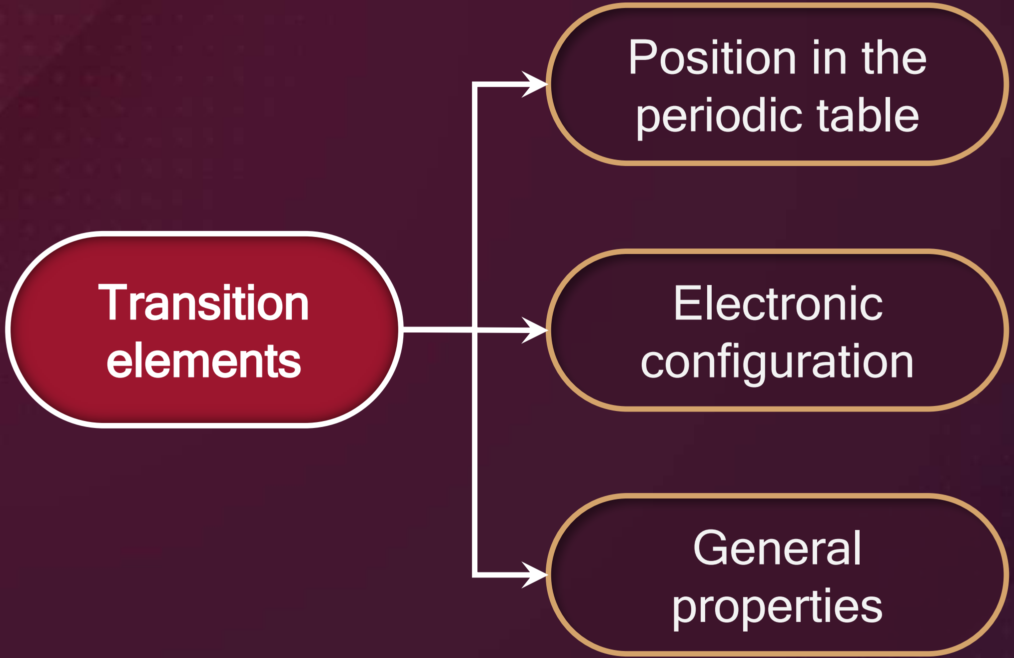
Zn, Cd, Hg of group 12 have **full d^{10}** configuration in their **ground state** as well as in their **common oxidation states**.

Known as **non-transition metals**

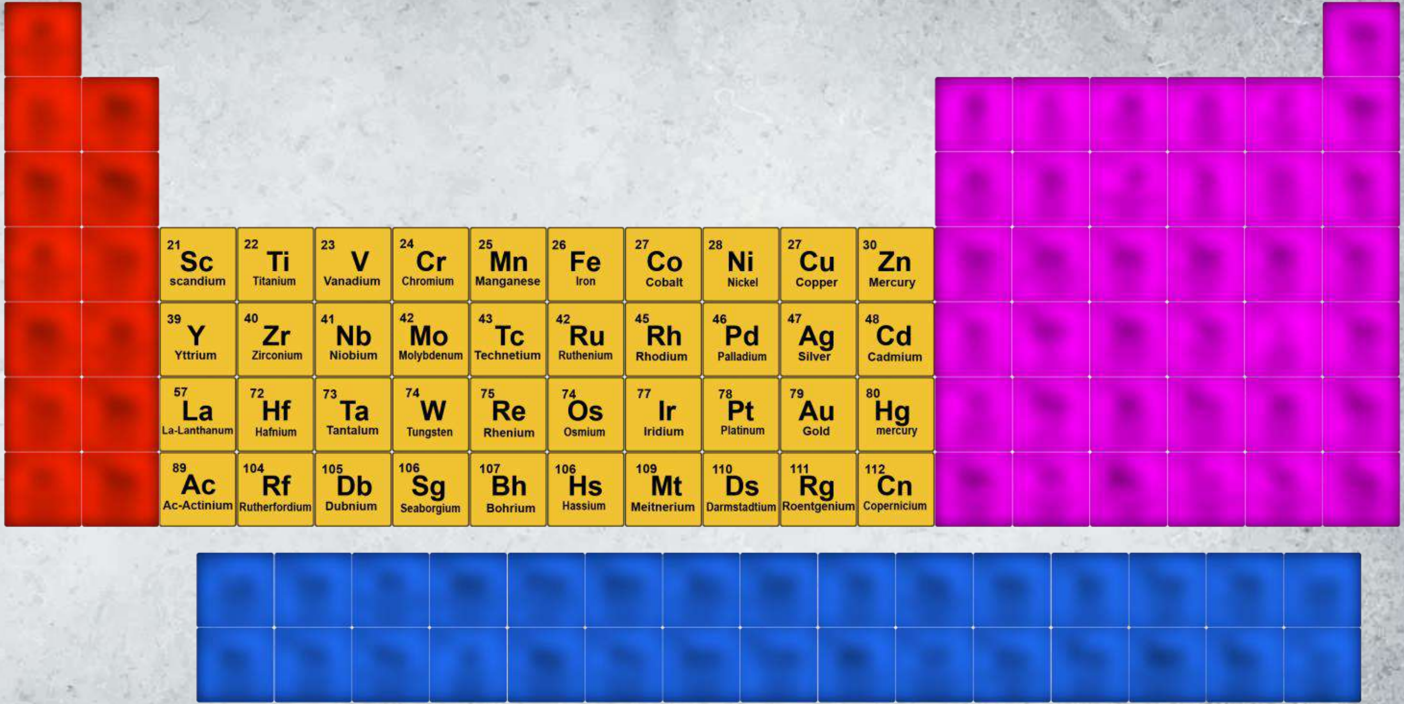
Transition d-Block Elements

Silver is a **transition element** as it has incomplete d-orbital in its +2 oxidation state.




Transition elements
Position in the periodic table
Electronic configuration
General properties

Position of d-Block elements



Electronic Configuration of d-Block Elements

General configuration

$(n-1)d^{1-10}\ ns^{1-2}$

Inner d-orbital

Last electron enters in the d-orbital

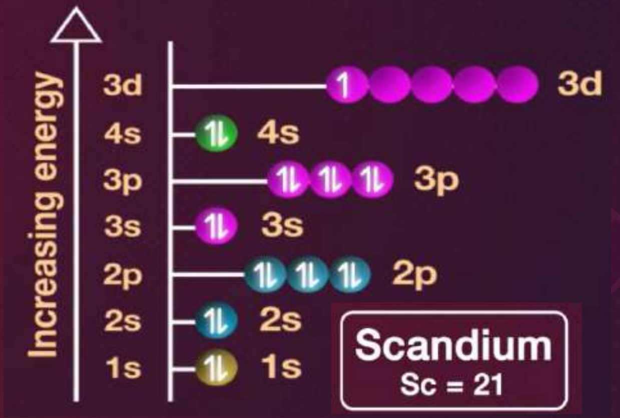
Example

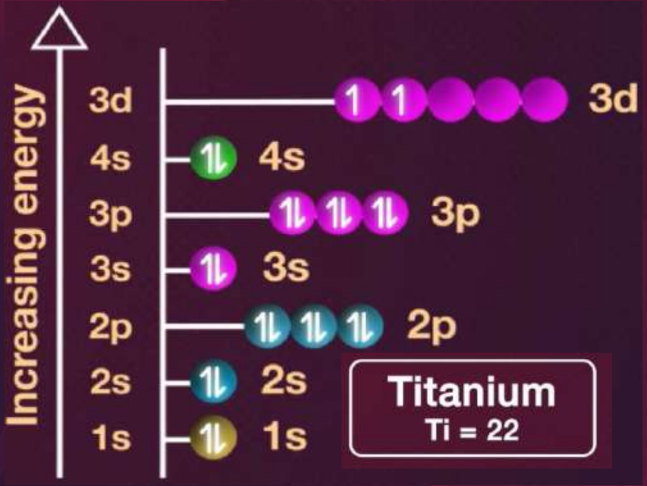
Sc(21) → $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^1\ 4s^2$

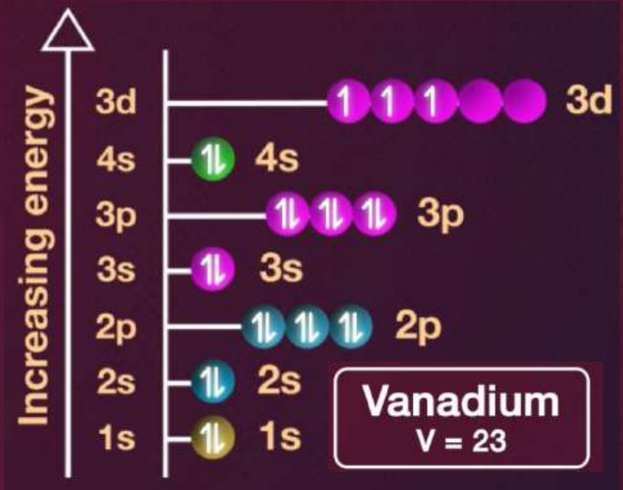
Co(27) → $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^7\ 4s^2$

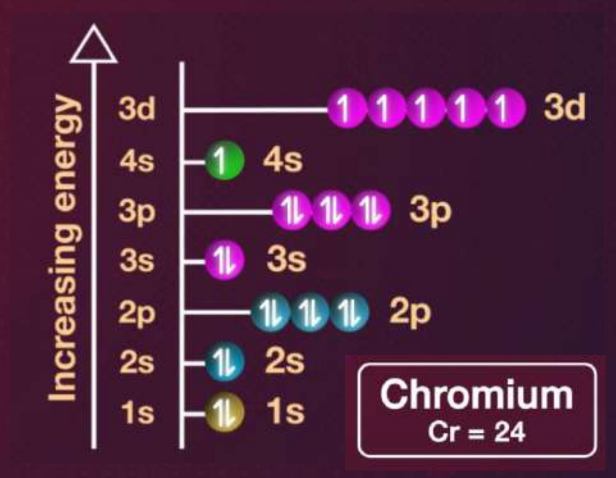
Electrons filling in 3d elements

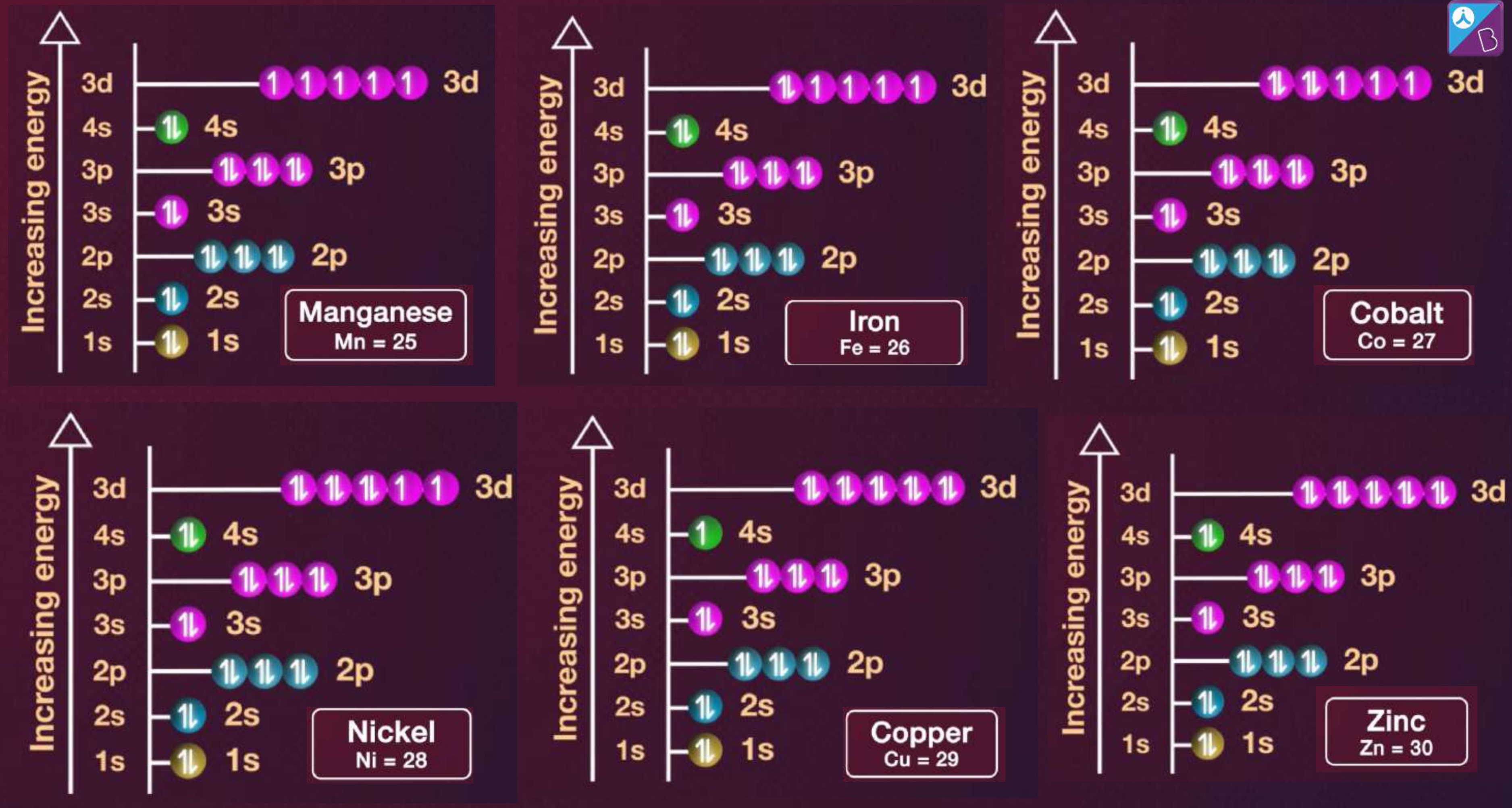
For 3d-series elements, electrons enters in 3d orbitals which is occupied generally after 4s orbital.











Increasing energy
3d
4s
3p
3s
2p
2s
1s
Manganese
Mn = 25
Increasing energy
3d
4s
3p
3s
2p
2s
1s
Iron
Fe = 26
Increasing energy
3d
4s
3p
3s
2p
2s
1s
Cobalt
Co = 27
Increasing energy
3d
4s
3p
3s
2p
2s
1s
Nickel
Ni = 28
Increasing energy
3d
4s
3p
3s
2p
2s
1s
Copper
Cu = 29
Increasing energy
3d
4s
3p
3s
2p
2s
1s
Zinc
Zn = 30

Examples

The electronic configuration has several exceptions because of very little difference in energy of (n-1)d and ns electrons. This can be reflected in electronic configuration of Cr (half filled) and Cu (fully filled) in 3d series.

Cr(24)	→	[Ar] $3d^4\ 4s^2$	✗
Cr(24)	→	**[Ar] $3d^5\ 4s^1$**	✓
Mo(42)	→	[Kr] $4d^4\ 5s^2$	✗
Mo(42)	→	**[Kr] $4d^5\ 5s^1$**	✓
Ag(47)	→	[Kr] $4d^9\ 5s^2$	✗
Ag(47)	→	**[Kr] $4d^{10}\ 5s^1$**	✓
Cu(29)	→	[Ar] $3d^9\ 4s^2$	✗
Cu(29)	→	**[Ar] $3d^{10}\ 4s^1$**	✓

Examples

Au(79)	[Xe] $4f^{14}\,5d^{9}\,6s^{2}$	✗
Au(79)	**[Xe] $4f^{14}\,5d^{10}\,6s^{1}$**	✓
Pd(46)	[Kr] $4d^{8}\,5s^{2}$	✗
Pd(46)	**[Kr] $4d^{10}\,5s^{0}$**	✓
Pt(78)	[Xe] $4f^{14}\,5d^{8}\,6s^{2}$	✗
Pt(78)	**[Xe] $4f^{14}\,5d^{9}\,6s^{1}$**	✓

Transition elements exhibit certain **characteristic properties** due to **partially filled** d-orbitals.

General properties

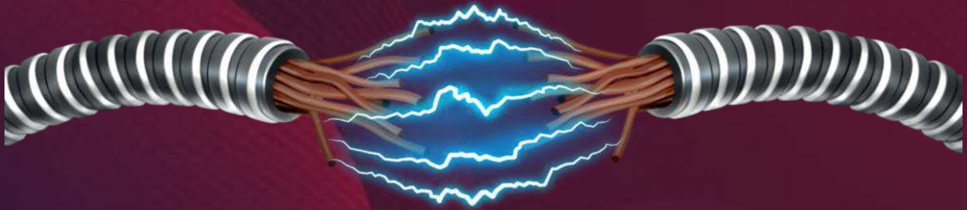
- Physical properties
- Atomic properties
- Chemical properties

Physical Properties

All the transition elements display typical metallic properties

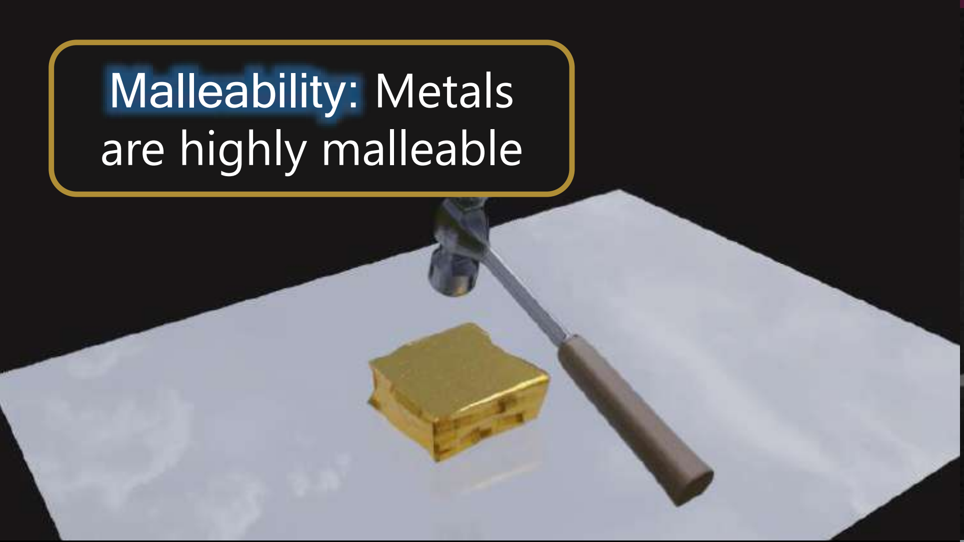
- High tensile strength
- High thermal and electrical conductivity
- Malleability
- Ductility
- Metallic lustre
- Hard and less volatile
- High melting and boiling points

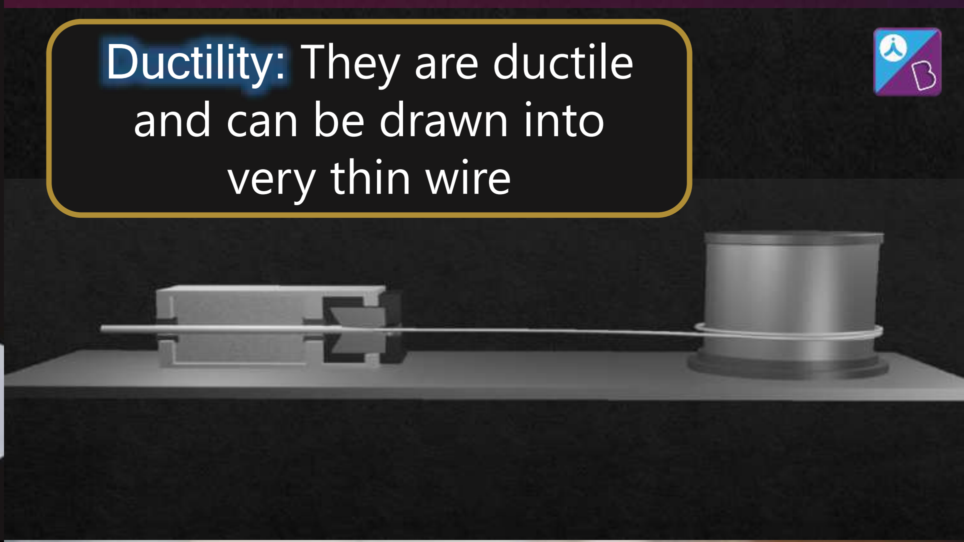
High tensile strength



High electrical conductivity

High thermal conductivity

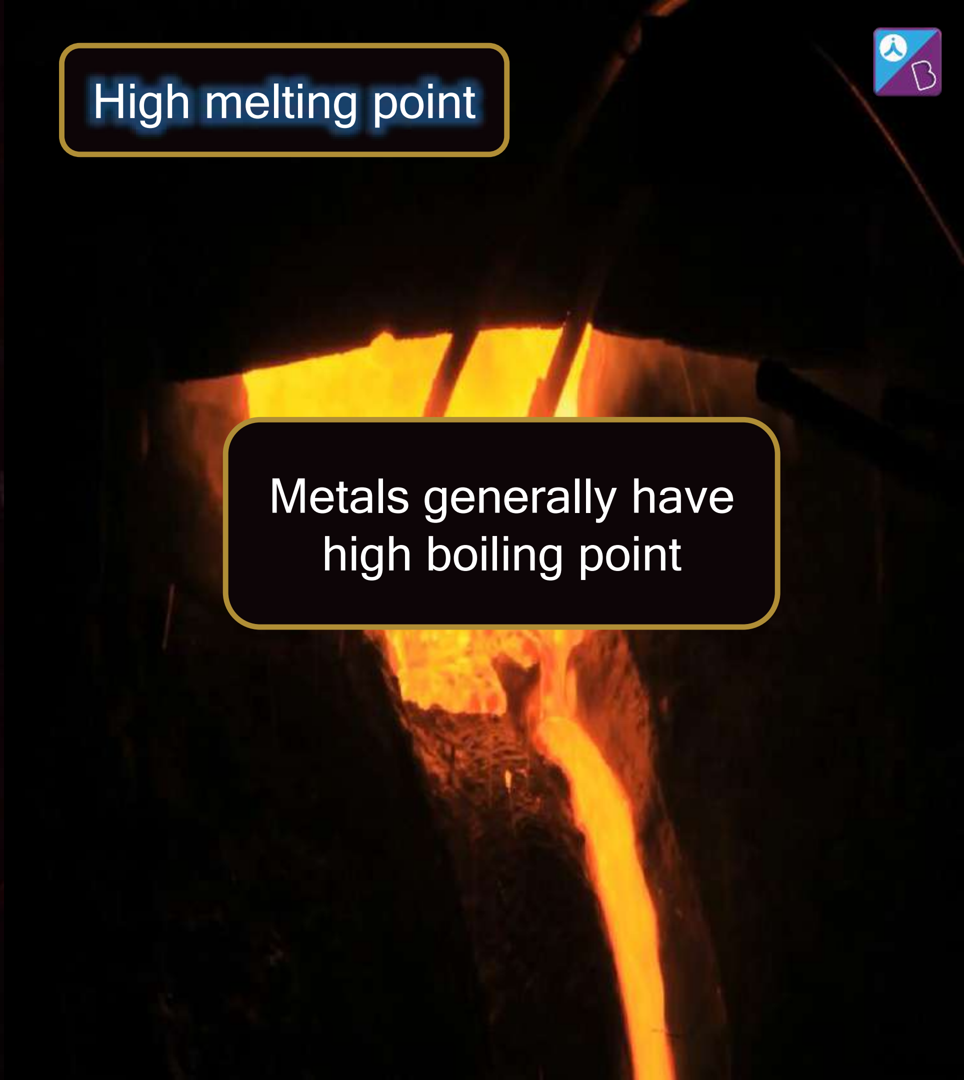

Malleability: Metals are highly malleable


Ductility: They are ductile and can be drawn into very thin wire


Metallic lustre: Metals are lusturous in nature


Volatility: Metals are non-volatile in nature


High boiling point
Metals generally have high melting point


High melting point
Metals generally have high boiling point

Melting Point of Transition Elements

Melting point of transition metal is high because of the involvement of greater number of electrons from (n-1)d in addition to the ns electrons in the interatomic metallic bonding.

Melting Point of Transition Elements

General rule

Greater the number of unpaired electrons

↓

Higher will be the melting point

In any row,

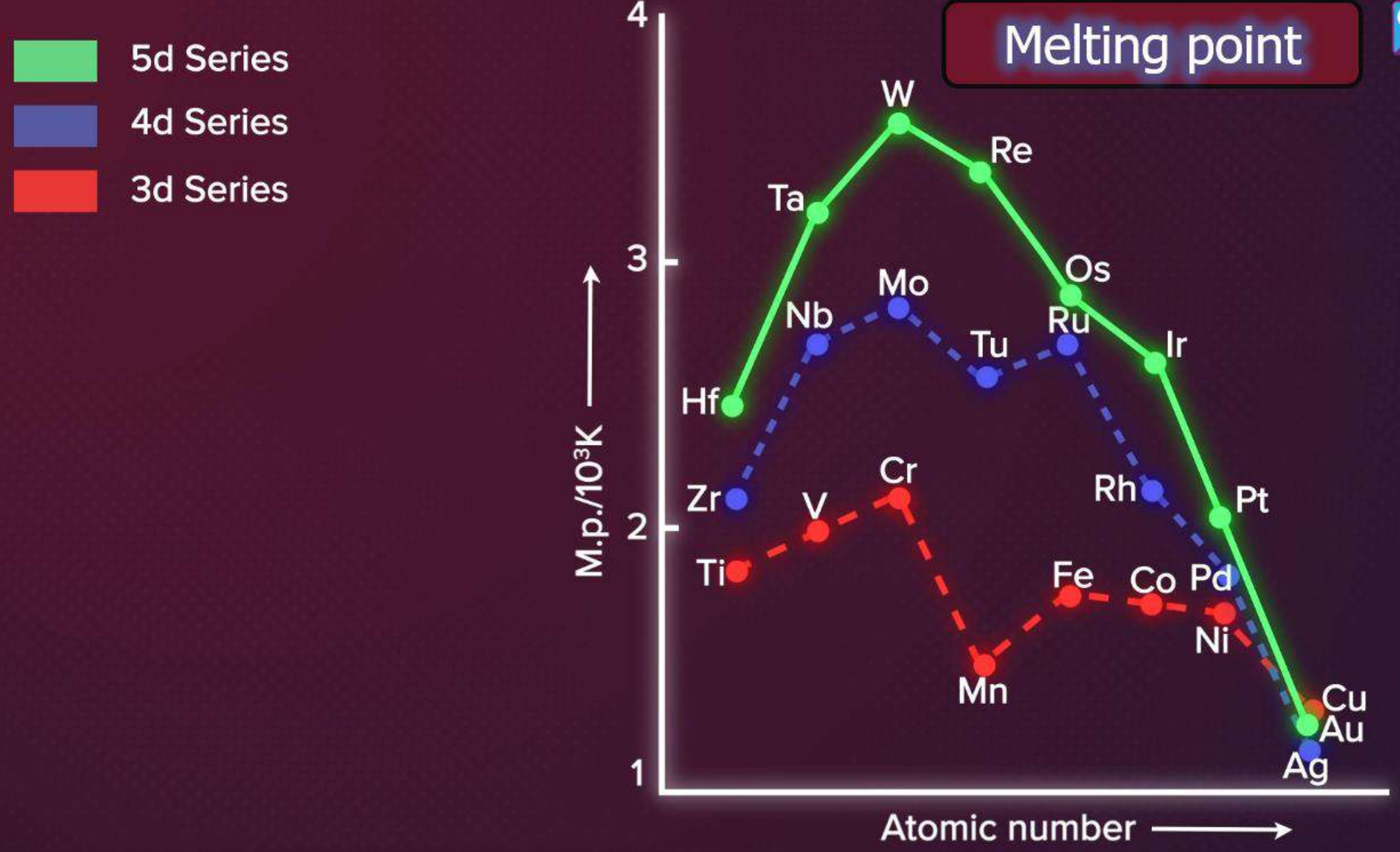
3d metals rise to a maximum at d^5

Except for anomalous values of Mn and Tc

↓

Then, fall regularly as the atomic number increases

Melting point



Boiling Point of Transition Elements

Transition elements have high boiling point due to high enthalpy of atomisation

Enthalpy of Atomisation

It is the enthalpy change on **breaking one mole** of bonds completely to obtain atoms in the **gaseous phase.**

$$A_2(g) \longrightarrow 2A(g)$$

Transition elements exhibit higher enthalpies of atomization due to high effective nuclear charge and large number of valence electrons.

↓

Form very strong metallic bonds.

↓

Arise due to unpaired electrons in the (n−1)d subshell.

Boiling Point of Transition Elements

General rule

Greater the number of valence electrons

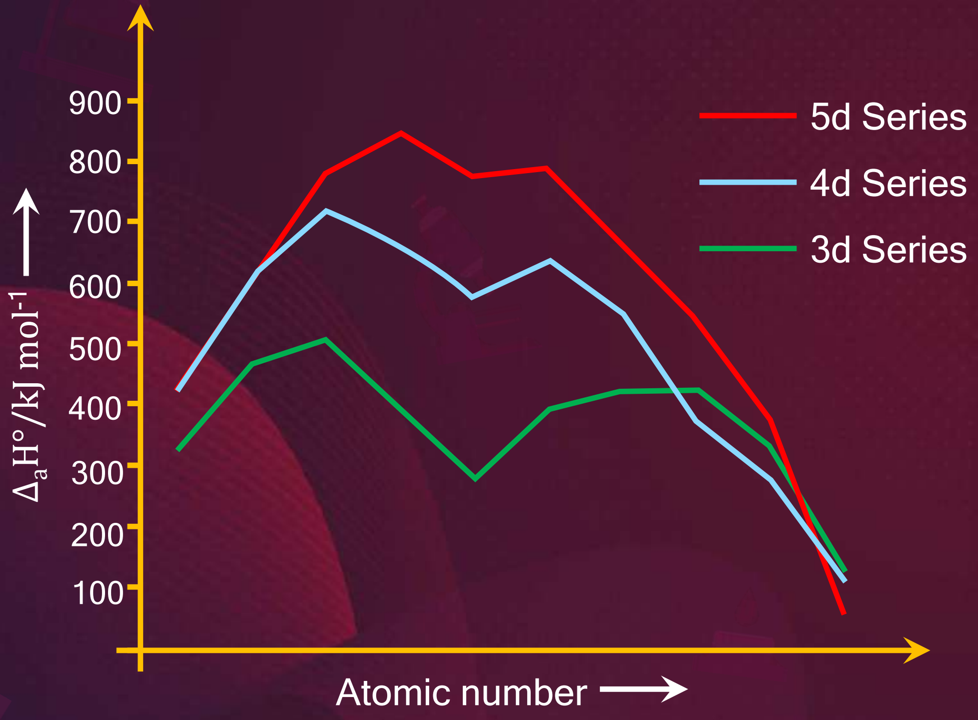
↓

Stronger is the resultant bonding

↓

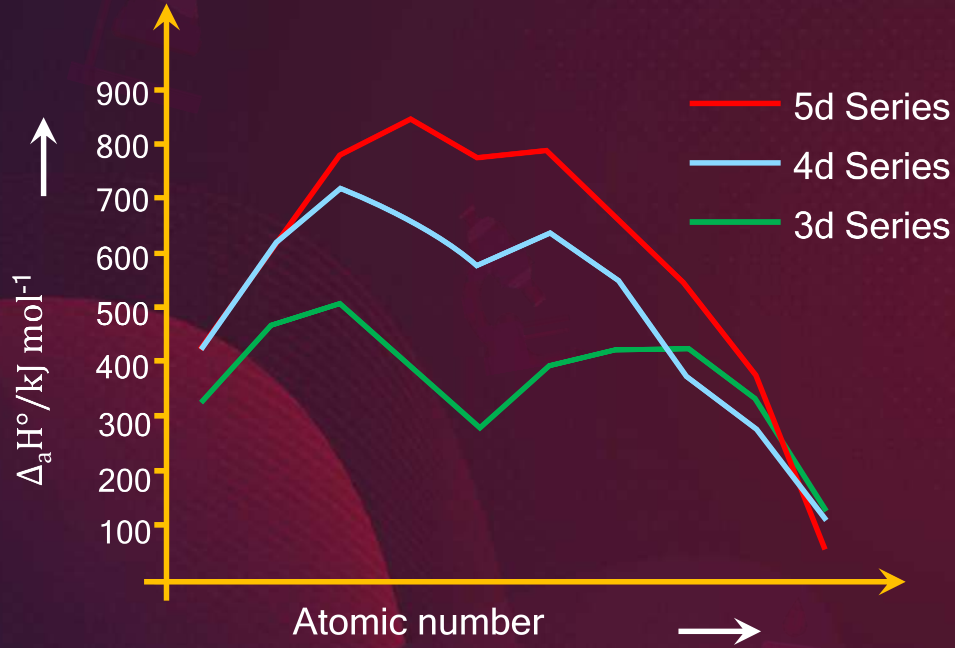
Higher will be the boiling point.

Enthalpy of Atomisation



The maxima at about the middle of each series indicate that one unpaired electron per d orbital is particularly favourable for strong interatomic interaction.

Enthalpy of Atomisation



Boiling point of transition elements **increases** down the group.

Boiling Point of Transition Elements

Zn, Cd and Hg have low boiling point

- Zn
- Cd
- Hg

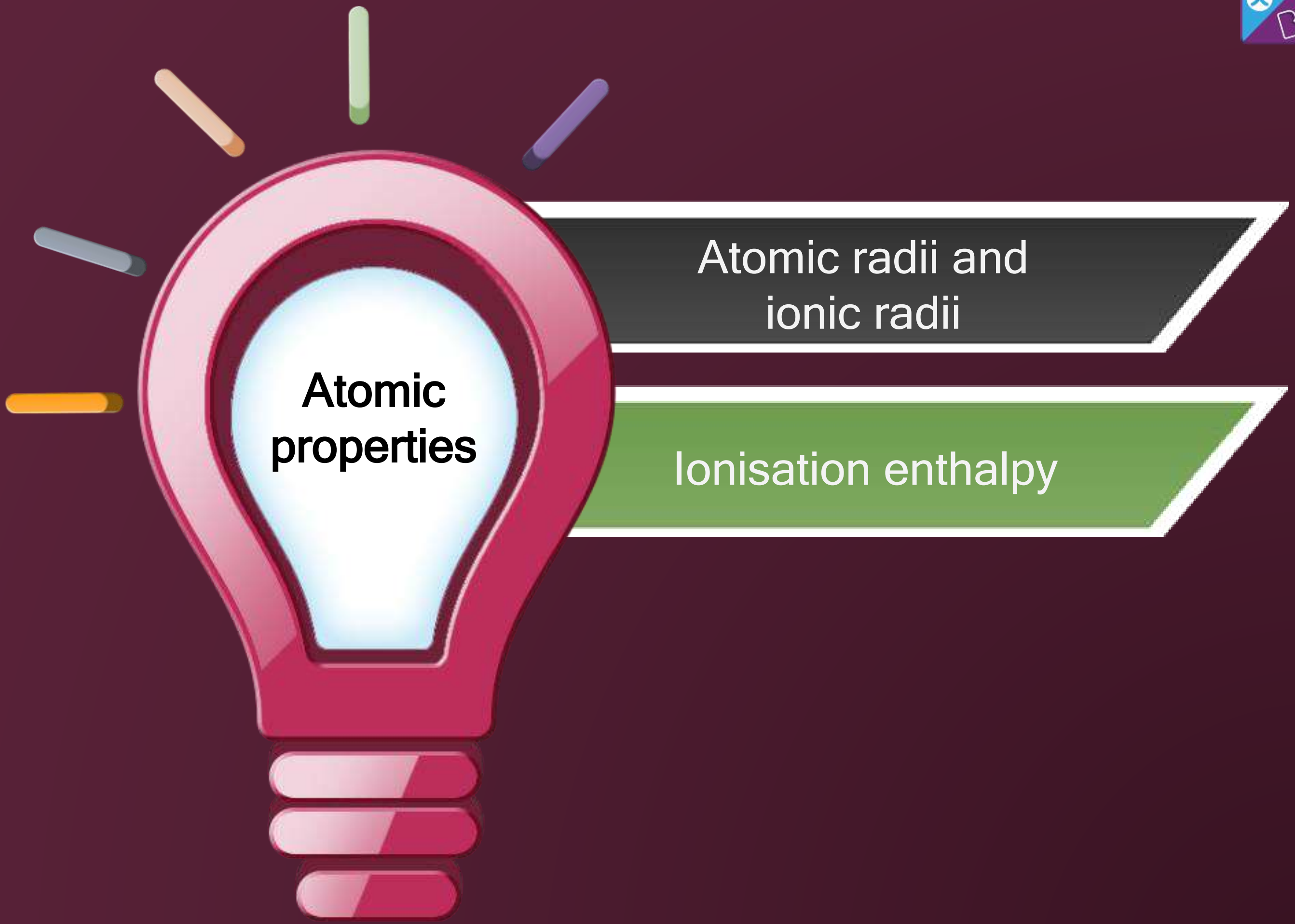
Zero unpaired electrons

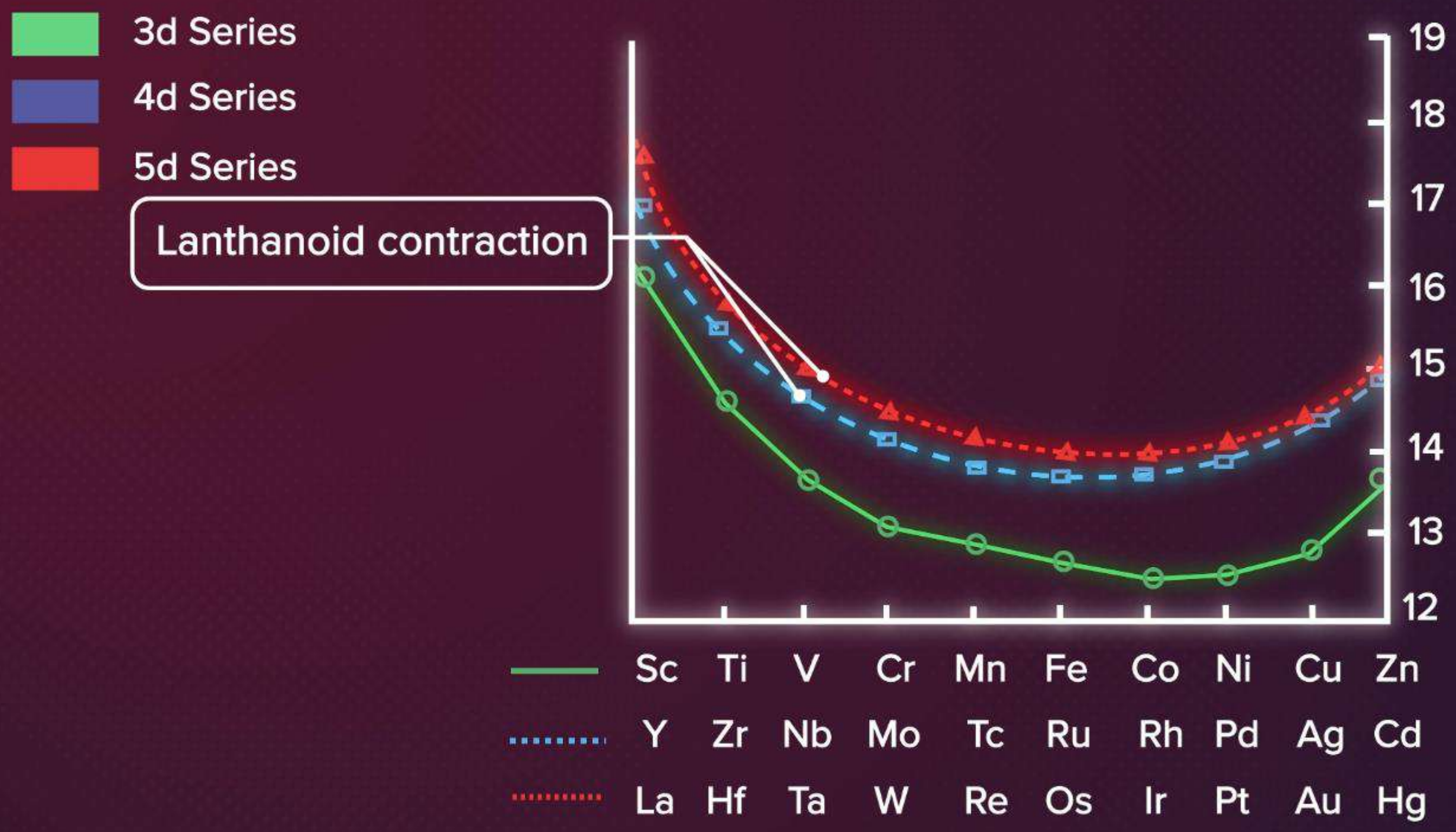
↓

Weak metallic bonding

↓

Lowest boiling and melting point


Atomic properties
Atomic radii and ionic radii
Ionisation enthalpy


3d Series
4d Series
5d Series
Lanthanoid contraction
19
18
17
16
15
14
13
12
Radius / nm
Sc Ti V Cr Mn Fe Co Ni Cu Zn
Y Zr Nb Mo Tc Ru Rh Pd Ag Cd
La Hf Ta W Re Os Ir Pt Au Hg

Atomic Radii – 3d Series

Sc > Ti > V > Cr > Mn ≈ Fe ≈ Co ≈ Ni < Cu < Zn

Sc to Mn: Decreases gradually

Due to poor shielding by d electrons, attraction increases more than repulsion

Mn to Ni: Nearly constant

Repulsion almost balances out attraction

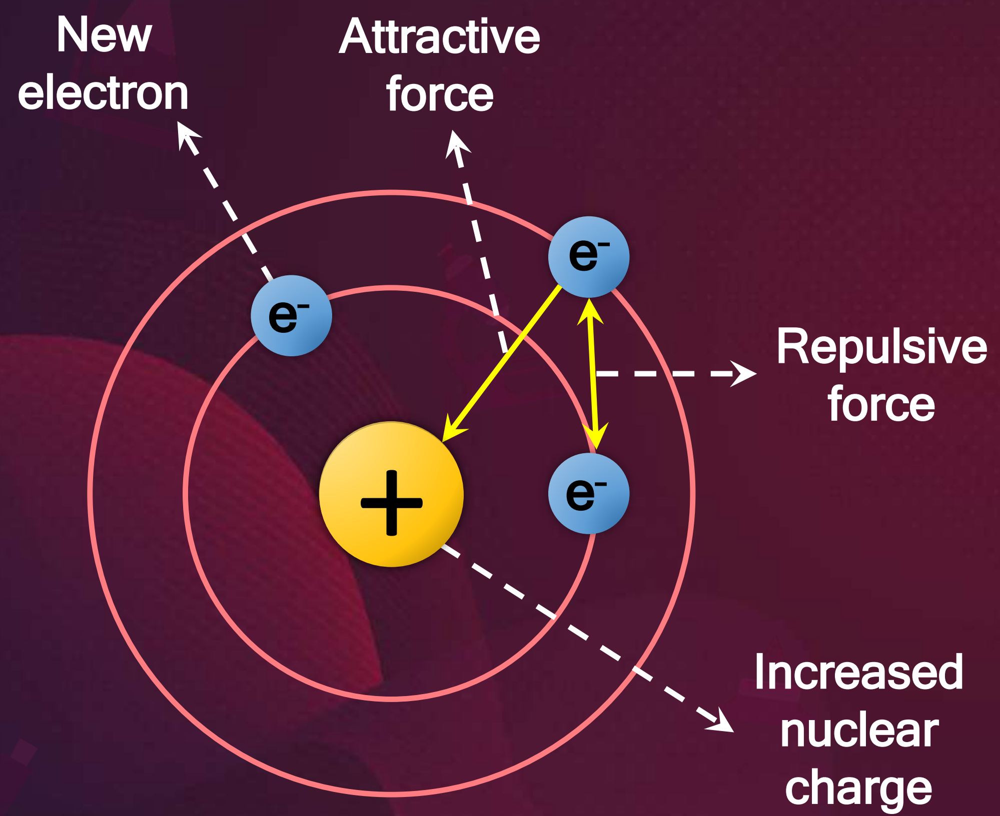
Ni to Zn: Increases

Repulsion dominates attraction

↓

No. of (n-1)d electrons are very high

Atomic Radii of Transition Elements



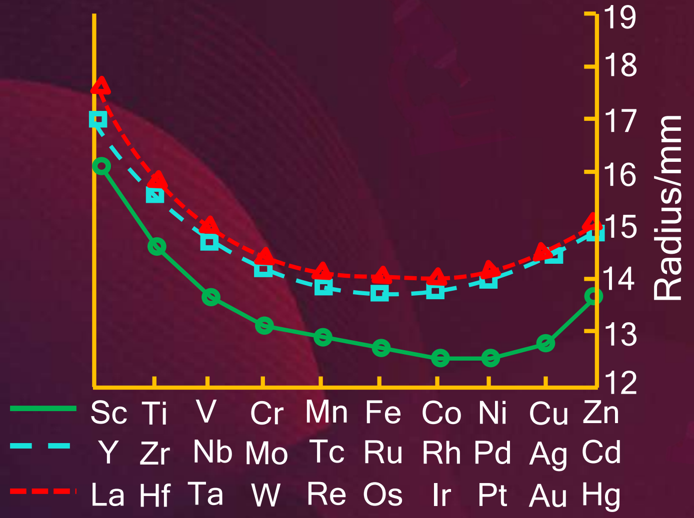
Left to right

- Nuclear charge increases
- Attraction on outermost e^- increases
- electron in (n-1)d subshell
- Repulsion between electrons increases

Atomic Radii of 3d, 4d and 5d Series

Due to lanthanoid contraction

Radius of 4d series is similar to radius of 5d series



The filling of 4f before 5d orbital results in a regular decrease in atomic radii.

The **imperfect shielding** of one electron by another in the same set of orbitals.

Lanthanoid Contraction

The filling of 4f before 5d orbital results in a **regular decrease** in atomic radii.

Lanthanoid Contraction (Effect on Radii)

Down the group

Titanium (Ti)	$4s^2\,3d^2$	147 pm
Zirconium (Zr)	$5s^2\,4d^2$	160 pm
Hafnium (Hf)	$4f^{14}\,6s^2\,5d^2$	159 pm

$Ti < Zr \approx Hf$

Lanthanoid Contraction

Reason 1

Shielding power of orbitals → s > p > d > f

↓

Nuclear attraction on outermost e^- increases → Size decreases

Lanthanoid Contraction

Reason 2

- Titanium (Ti, 22)
- Zirconium (Zr, 40)
- Hafnium (Hf, 72)

Titanium → Zirconium: +18 increase in positive charge

Zirconium → Hafnium: +32 increase in positive charge

Drastic increment in charge

↓

Increase in attraction

↓

Decrease in radii

Lanthanoid Contraction

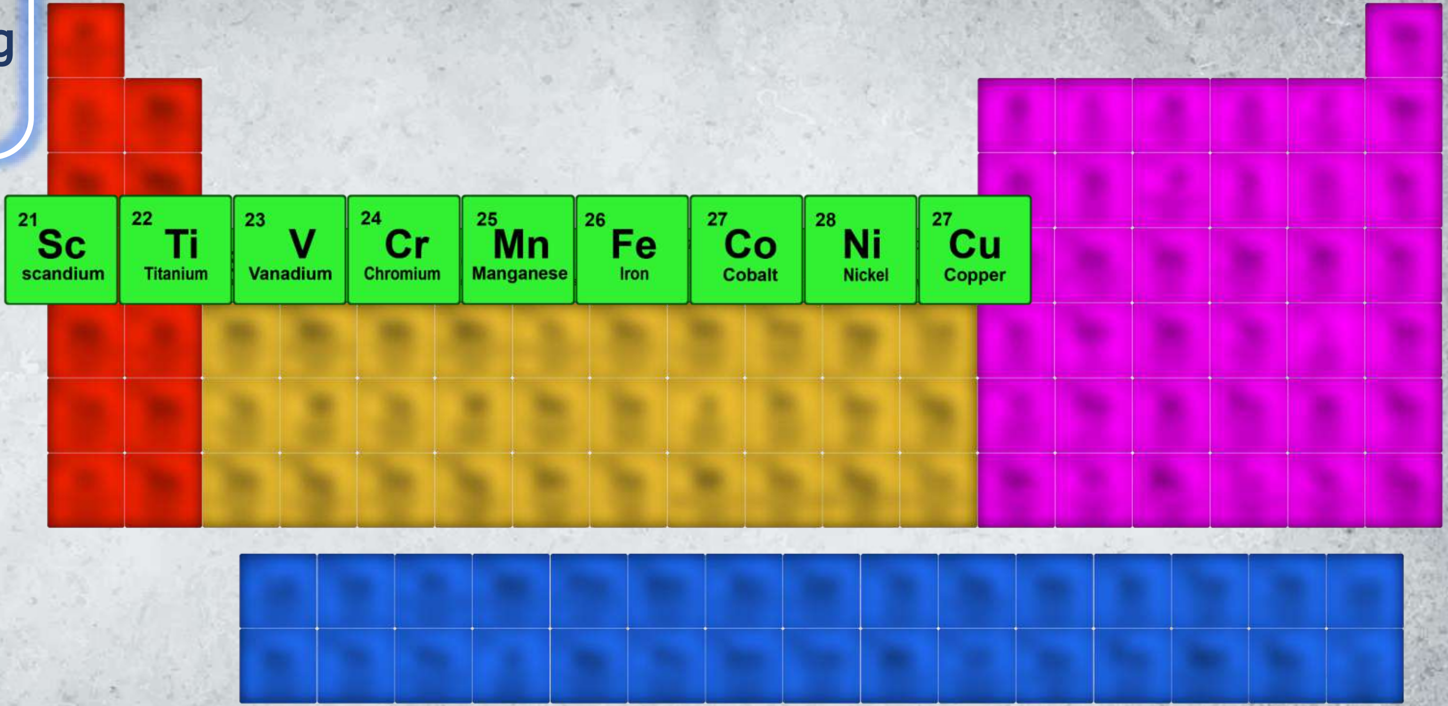
Lanthanoid contraction essentially compensates for the expected increase in atomic size with increasing atomic number.

Due to lanthanoid contraction, 4d and 5d elements have very similar physical and chemical properties.

Due to decrease in radii and increase in atomic mass, density of transition elements is generally high.

Density increases down the group

Density increases from Sc to Cu along the period



Trends in Ionisation Enthalpy

In general, from left to right ionization enthalpy **increases** Gradually.

Reason

Due to an increase in nuclear charge

↓

Accompanied by the filling of the inner d-orbitals

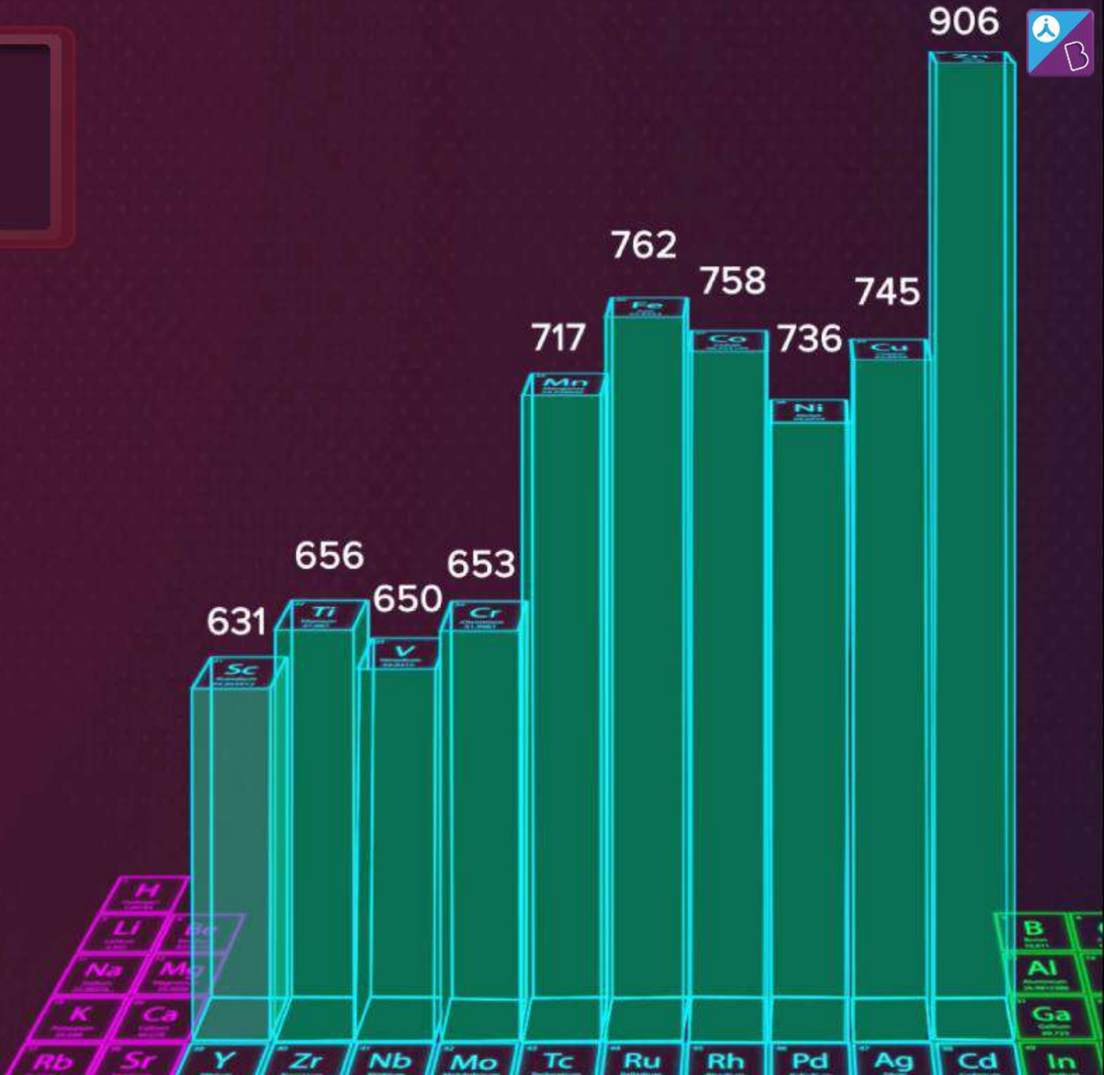
↓

Ionisation enthalpy increases

Ionisation Enthalpy Values For 3d Series

3d series	$I.E_1$ ($kJmol^{-1}$)	$I.E_2$ ($kJmol^{-1}$)	$I.E_3$ ($kJmol^{-1}$)
Sc	631	1235	2393
Ti	656	1309	2657
V	650	1414	2833
Cr	653	1592	2990
Mn	717	1509	3260
Fe	762	1561	2962
Co	758	1644	3243
Ni	736	1752	3402
Cu	745	1958	3556
Zn	906	1734	3837

Ionisation enthalpy (kJ/mol)



Ionisation Enthalpy Values For 3d Series

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Ionisation Enthalpy

Zinc have significantly **higher ionisation enthalpy** than copper

Due to completely filled d and s electrons in Zn, its first ionisation energy is more than Cu.

r_{Zn} > r_{Cu}

$I.E._{Zn}$ > $I.E._{Cu}$

First ionisation enthalpy

$3d^{10}\ 4s^{2}$

$3d^{10}\ 4s^{1}$

Fully filled → More stable → High I.E.

Ionisation Enthalpy Values For 3d Series

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Ionisation Enthalpy

Manganese have abnormally **high ionisation enthalpy** compared to chromium

r_{Cr} > r_{Mn}

$I.E._{Cr}$ < $I.E._{Mn}$ (First ionisation enthalpy)

$3d^5\ 4s^1$ | $3d^5\ 4s^2$

Fully filled → More stable → High I.E.

Trends in Ionisation Enthalpy

Down the group

5d > 4d

Lanthanoid contraction

Poor shielding of f-orbitals

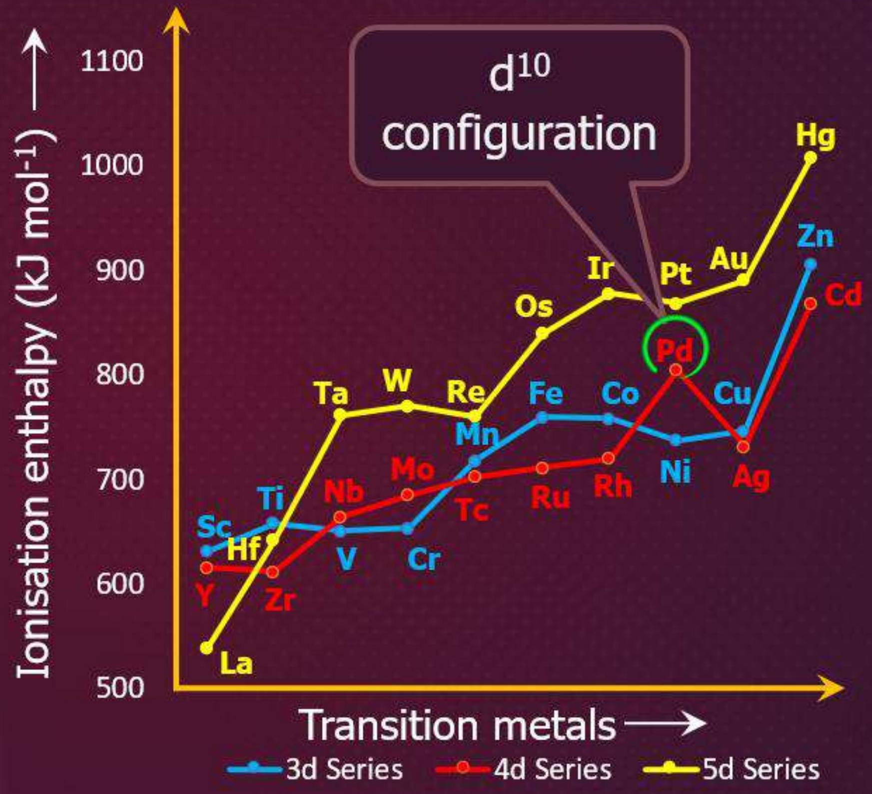
Radius increases

But, nuclear charge also increases

Irregular trend in ionisation energy is observed for 3d & 4d series

Trends in Ionisation Enthalpy

Down the group



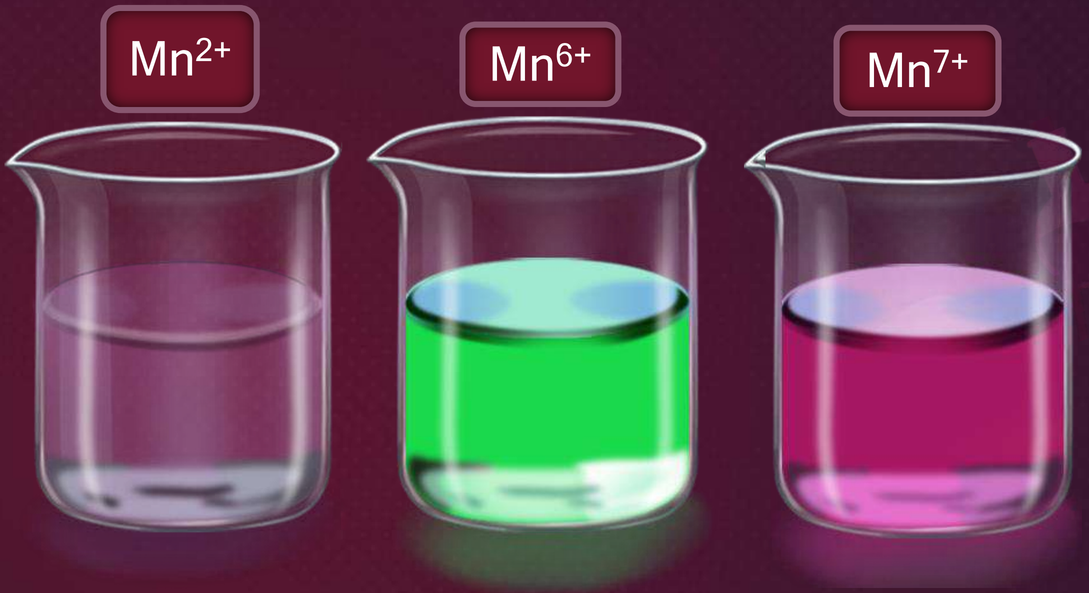
Chemical Properties

- Oxidation state
- Standard electrode potential and reactivity
- Magnetic properties
- Colour
- Formation of complex compounds
- Catalytic properties
- Formation of interstitial compounds
- Alloy formation

Oxidation State of Transition Elements

Due to incomplete filling of d-orbitals

Transition elements show a great variety of oxidation states



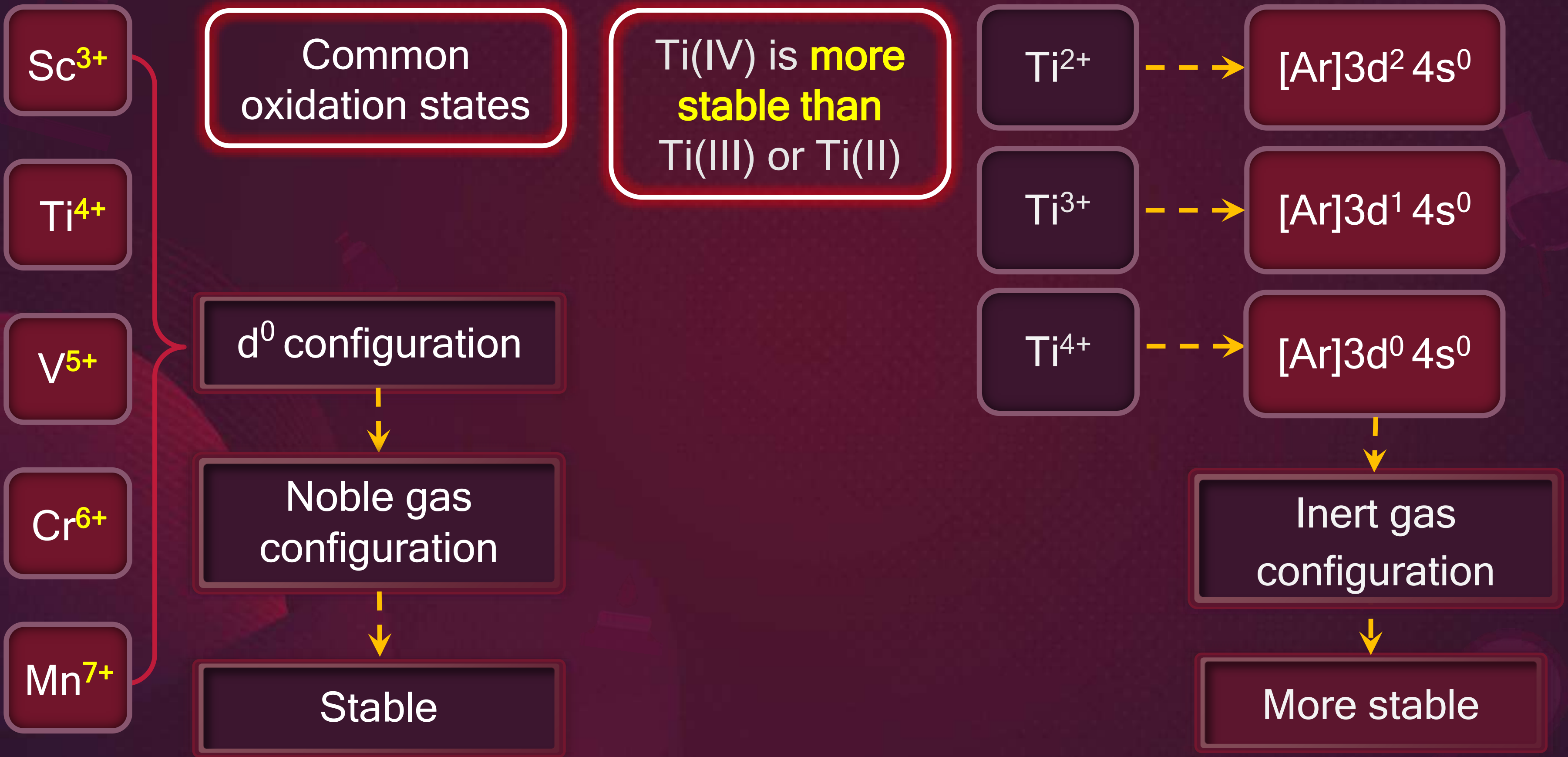
Manganese in different oxidation states

Oxidation States of 3d Series Elements

Oxidation states form regular pyramid

Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
								+1	
	+2	+2	+2	+2	+2	+2	+2	+2	+2
+3	+3	+3	+3	+3	+3	+3	+3		
	+4	+4	+4	+4	+4	+4	+4		
		+5	+5	+5					
			+6	+6	+6				
				+7					

Oxidation State of 3d Transition Elements



Oxidation State of 3d Transition Elements

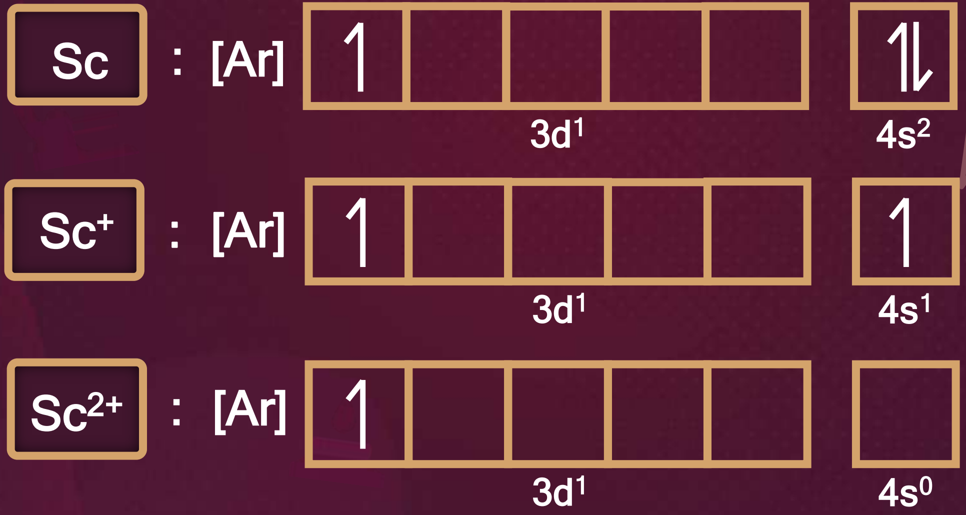
Common oxidation states

Mn^{2+}(25), Fe^{3+}(26) → $3d^5 4s^0$ → Half-filled orbital → Stable

Zn^{2+} → $3d^{10} 4s^0$ → Fully filled → More stable

Oxidation State of 3d Transition Elements

Requires high energy for removing electron



Oxidation State Stability - Down the Group

Inert pair effect

p-block

Lower oxidation states are favoured by heavier elements

Higher oxidation states are favoured by the heavier elements

d-block

Easier to remove valence electrons

Oxidation State Stability - Down the Group

Example

Stability order

Mo (VI) & W (VI) > Cr (VI)

- Mo (VI) & W (VI): MoO_3 and WO_3 are not oxidising agents
- Cr (VI): Dichromate ion ($Cr_2O_7^{2-}$) in acidic medium is a strong oxidising agent

Inert pair effect

p-block

Oxidation state normally differ by unit of 2.

Oxidation state normally differ by unity

d-block

Successive removal of electrons from d-orbital

Oxidation State in d-block Elements

Fe and Ni in $Fe(CO)_5$ and $Ni(CO)_4$ have **zero oxidation states** despite the d block elements favouring higher oxidation states

Low oxidation state is favoured by metals when a complex compound has ligands

Which are not just strong **σ-donors** but also **π-acceptors** like in $Ni(CO)_4$ and $Fe(CO)_5$, etc.

Halides of 3d metals

X : F → I
X^{I} : F → Br
X^{II} : F, Cl
X^{III} : Cl → I

Oxidation Number ↓ / Group →	3	4	5	6	7	8	9	10	11	12
+6				CrF_6						
+5			VF_5	CrF_5						
+4		TiX_4	VX_4^{I}	CrX_4	MnF_4					
+3		TiX_3	VX_3	CrX_3	MnF_3	FeX_3^{I}	CoF_3			
+2		TiX_2^{III}	VX_2	CrX_2	MnX_2	FeX_2	CoX_2	NiX_2	CuX_2^{II}	ZnX_2
+1									CuX^{III}	

Stability of Higher Oxidation States

Fluorine stabilizes the highest oxidation state

Stability through

Higher lattice energy

Example: CoF_3

Higher bond enthalpy (higher covalent compound)

Example: VF_5, CrF_6

Halides of 3d metals

X : F → I
X^{I} : F → Br
X^{II} : F, Cl
X^{III} : Cl → I

Oxidation Number ↓ / Group →	3	4	5	6	7	8	9	10	11	12
+6				CrF_6						
+5			VF_5	CrF_5						
+4		TiX_4	VX_4^{I}	CrX_4	MnF_4					
+3		TiX_3	VX_3	CrX_3	MnF_3	FeX_3^{I}	CoF_3			
+2		TiX_2^{III}	VX_2	CrX_2	MnX_2	FeX_2	CoX_2	NiX_2	CuX_2^{II}	ZnX_2
+1									CuX^{III}	

X: Cl, Br or I

All halides are known except iodide

Note

1

V(+5) is represented only by VF_5.

The other halides, however, undergo hydrolysis to give **oxohalides**, VOX_3.

2

In lower oxidation states, fluorides are **unstable**.
Example: VX_2 (X = Cl, Br or I)

↓

On the other hand, all Cu(II) halides are known including CuF_2 except the iodide.

↓

In this case, Cu^{2+} oxidises I^- to I_2.

Instability of Cu^{II} Iodides

Cu^{2+} oxidises I^- to I_2

$$2Cu^{2+} + 4I^- \longrightarrow Cu_2I_2\,(s) + I_2$$

Oxides of 3d Metals

* : Mixed oxides

Oxidation number ↓ / Group →	3	4	5	6	7	8	9	10	11	12
+7					Mn_2O_7					
+6				CrO_3						
+5			V_2O_5							
+4		TiO_2	V_2O_4	CrO_2	MnO_2					
+3	Sc_2O_3	Ti_2O_3	V_2O_3	Cr_2O_3	Mn_2O_3	Fe_2O_3				
					$Mn_3O_4^*$	$Fe_3O_4^*$	$Co_3O_4^*$			
+2		TiO	VO	(CrO)	MnO	FeO	CoO	NiO	CuO	ZnO
+1									Cu_2O	

Oxides of 3d Metals

The ability of oxygen to stabilise these high oxidation states exceeds that of fluorine.

MnF_4 — Highest Mn fluoride

Mn_2O_7 — Highest Mn oxide

Oxides are more stable than halides due to ability of oxygen to form **multiple bonds** with metals.

Reactivity of Transition Metals

Transition metals vary widely in their chemical reactivity.

The study of **standard electrode potential** is important to understand the

- Reactivity of transition elements
- Stability of various oxidation states

Standard electrode potentials are measurements of the equilibrium potentials.

$M^{n+} + ne^- \rightleftharpoons M, E^0_{M^{n+}/M}$

Standard reduction potential

Trends in standard electrode potentials

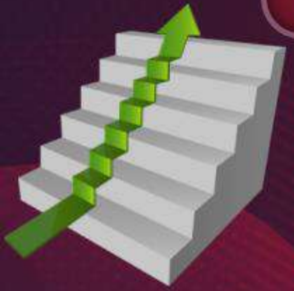
$M^{2+} \longrightarrow M$
$(E^0_{M^{2+}/M})$

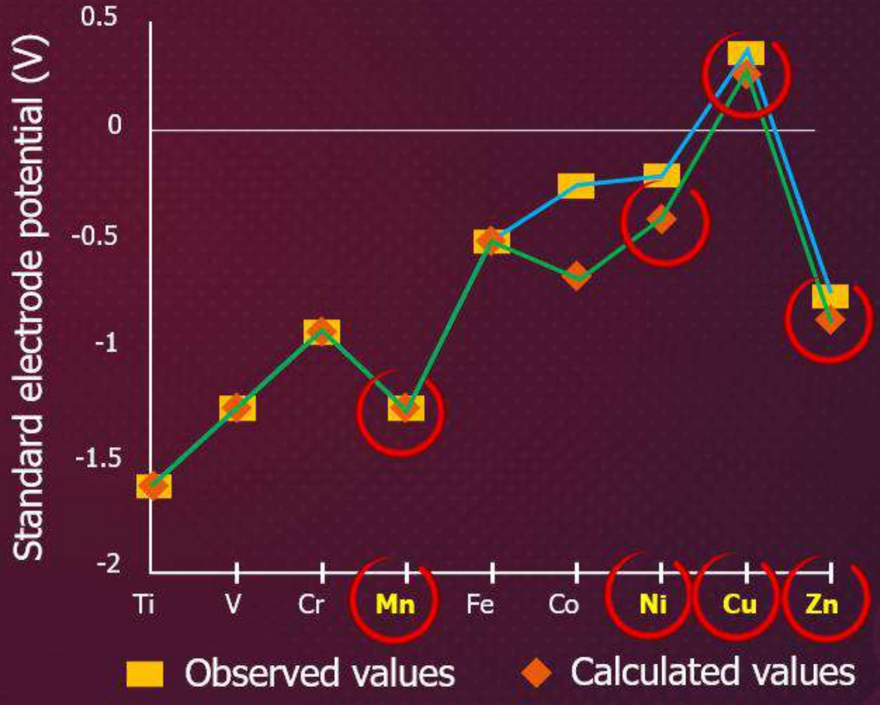
$M^{3+} \longrightarrow M^{2+}$
$(E^0_{M^{3+}/M^{2+}})$

Trends of Standard Electrode Potential

Generally,

The value of $E^0_{M^{2+}/M}$ **increases** from left to right





Cu shows positive standard electrode potential

Enthalpy of atomisation & ionisation energies

The high energy required to transform Cu (s) to Cu^{2+} (g)

Not balanced by its hydration energy

Sublimation enthalpy(+ve)

$Cu (s) \longrightarrow Cu (g); \Delta_s H$

+

$Cu (g) \longrightarrow Cu^{2+} (g); \Delta_i H$

High

Ionisation enthalpy ($I.E._1 + I.E._2$), +ve

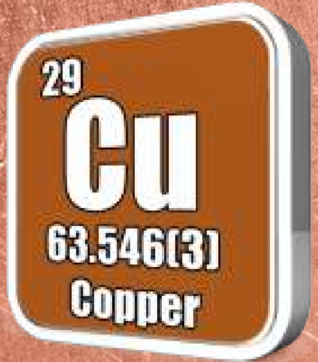
$Cu^{2+} (g) \longrightarrow Cu^{2+} (aq); \Delta_{Hyd} H$

Low

Hydration enthalpy(-ve)

Result

Inability to liberate H_2 from acid



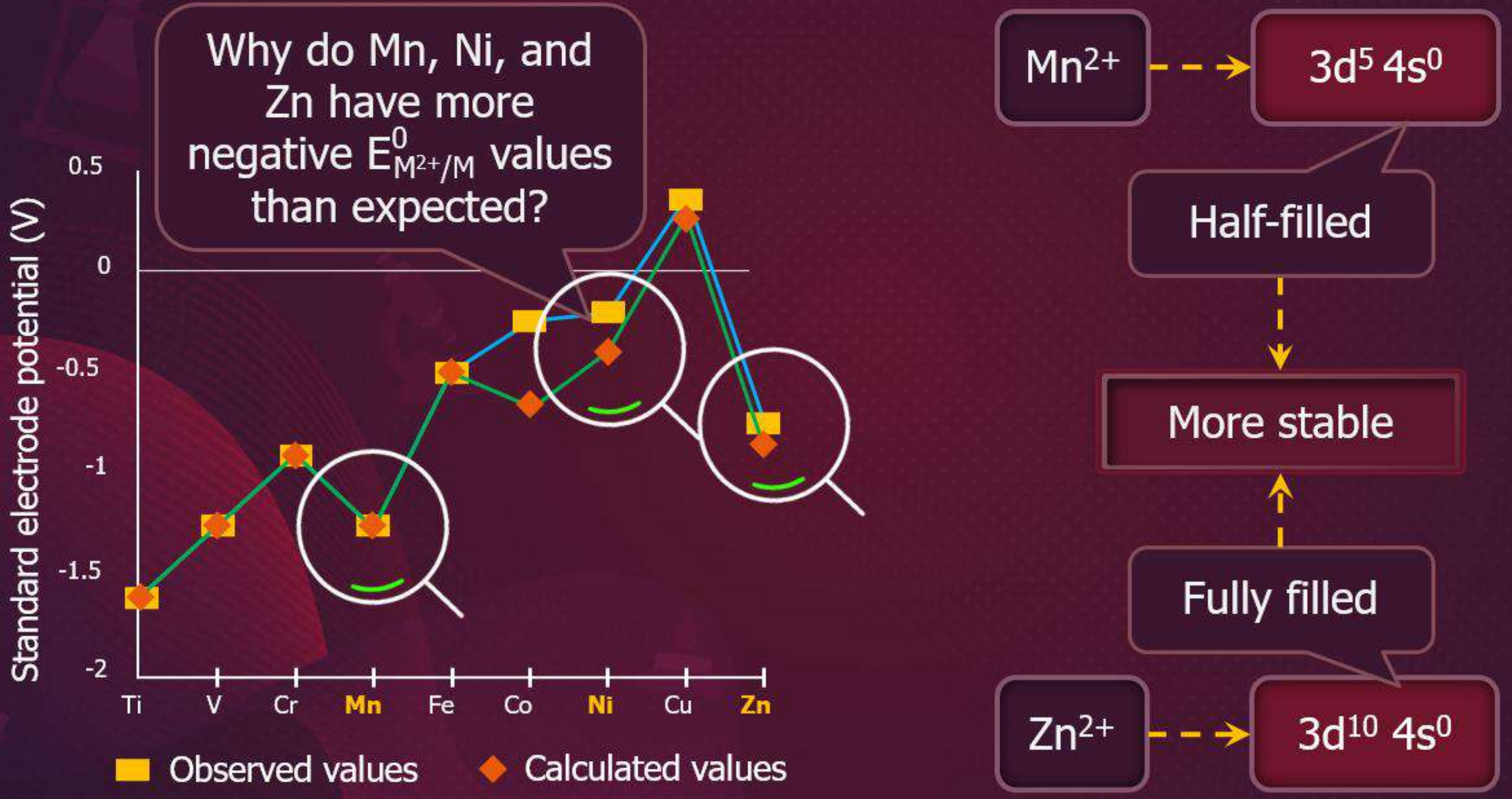
Only oxidising acids (HNO_3, hot conc. H_2SO_4) react with Cu to liberate NO_2 and SO_2 and oxidise Cu to Cu^{2+}

$$Cu\ (s) + 2HCl\ (aq) \not\longrightarrow CuCl_2\ (aq) + H_2\ (g)$$

Whereas,

$$Zn\ (s) + 2HCl\ (aq) \longrightarrow ZnCl_2\ (aq) + H_2\ (g)$$

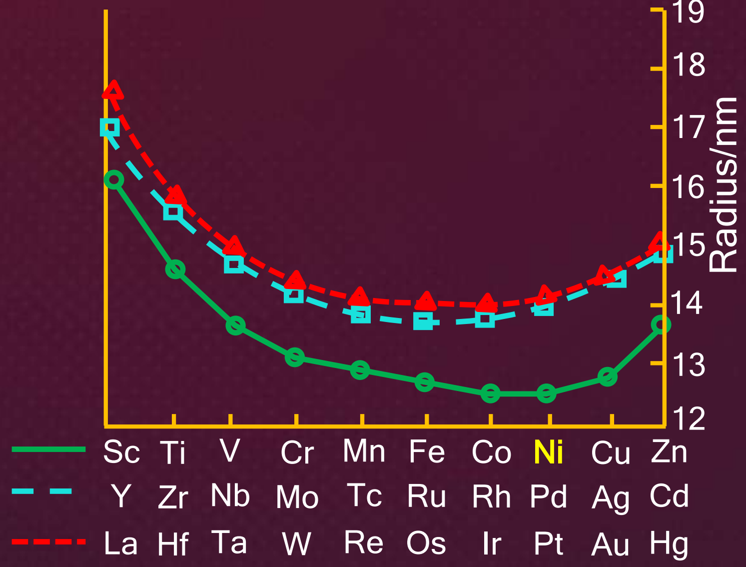
Trends in the $E^0_{M^{2+}/M}$ Standard Electrode Potential



Trends in the $E^0_{M^{2+}/M}$

In +2 state, Mn shows d^5, Ni with d^8 has completely filled t_{2g} and Zn has completely filled d^{10}). So, they show more negative E^0 values than expected

Hydration Energy



Due to high charge density

Ni^{2+} ion has the **highest negative enthalpy** of hydration among the elements of 3d series.

Standard Electrode Potential $E^0_{M^{3+}/M^{2+}}$ of 3d Elements

Metal	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
$E^0_{M^{3+}/M^{2+}}$	-2.10	-0.37	-0.26	-0.41	+1.57	+0.77	+1.97	-	-	-

Lower value for Sc^{3+} due to stable d^0 configuration

Lower value for Fe^{3+} due to stable d^5 configuration

Standard Electrode Potential $E^0_{M^{3+}/M^{2+}}$ of 3d Elements

Metal	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
$E^0_{M^{3+}/M^{2+}}$	-2.10	-0.37	-0.26	-0.41	+1.57	+0.77	+1.97	-	-	-

Higher value for Mn^{2+} due to stable d^5 configuration

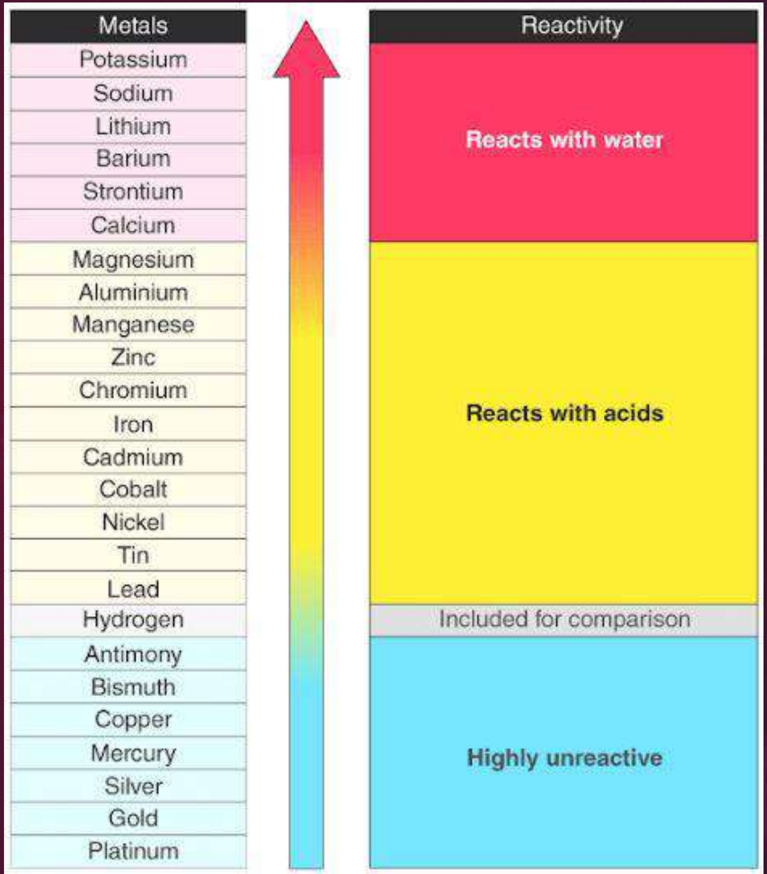
Highest value for Zn^{2+} due to stable d^{10} configuration

Chemical Reactivity

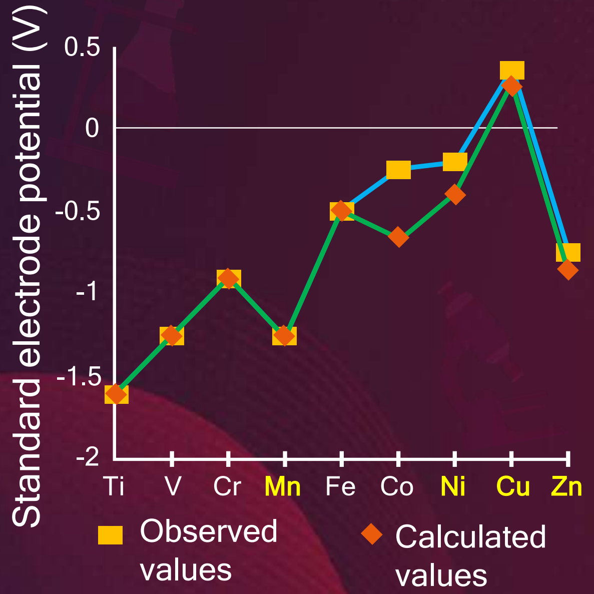
Transition metals vary widely in their chemical reactivity.

Many are electropositive and dissolve in mineral acids.

A few metals are **noble** or remain unreactive towards single acids.



Chemical Reactivity



Across the series

Less negative E^0 values

The $E^0_{M^{2+}/M}$ values indicate decreasing tendency to form divalent cation

Due to **increase** in the sum of **first two ionisation enthalpies**

Standard Electrode Potential $E^0_{M^{3+}/M^{2+}}$ of 3d Elements

Metal	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
$E^0_{M^{3+}/M^{2+}}$	-2.10	-0.37	-0.26	-0.41	+1.57	+0.77	+1.97	-	-	-

Mn^{3+} and **Co^{3+}** ions are **strong oxidising agents**

Standard Electrode Potential $E^0_{M^{3+}/M^{2+}}$ of 3d Elements

Metal	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
$E^0_{M^{3+}/M^{2+}}$	-2.10	-0.37	-0.26	-0.41	+1.57	+0.77	+1.97	-	-	-

Ti, V, Cr → **Strong reducing agents**

↓

Liberate **H_2** from dil. acid

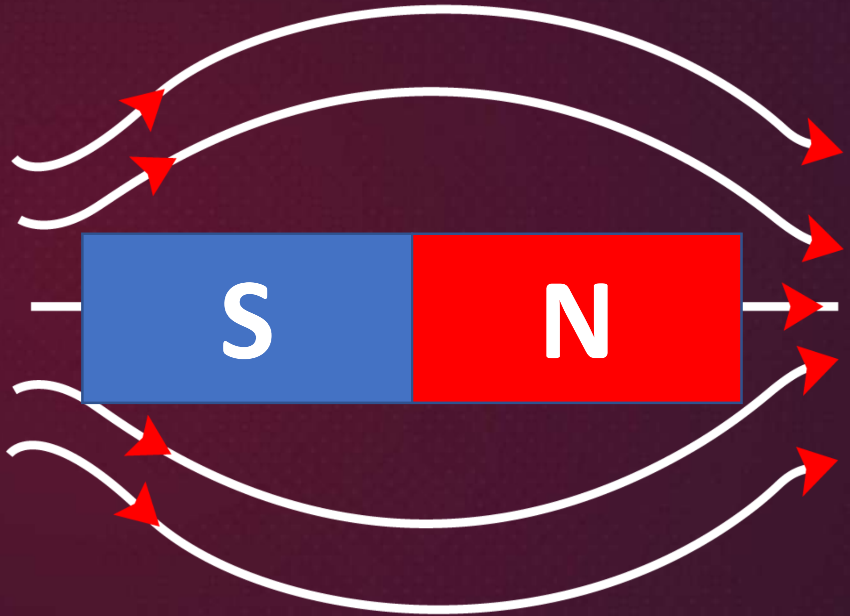
$$2Cr^{2+}(aq) + 2H^+(aq) \longrightarrow 2Cr^{3+}(aq) + H_2(g)$$

When a magnetic field is applied to substances, mainly two types of magnetic behaviours are observed.

- Diamagnetism
- Paramagnetism

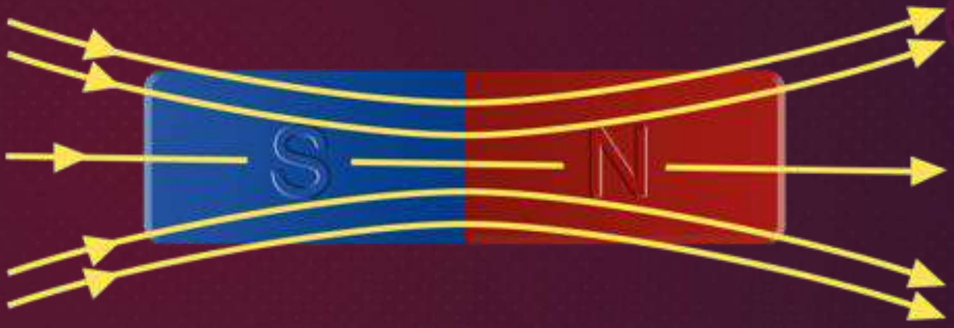
Diamagnetic Nature

Diamagnetic substances are **repelled** by the applied field.



Paramagnetic Nature

Paramagnetic substances are **attracted** by the applied field.

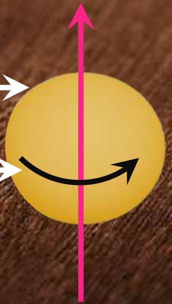


Magnetic Properties

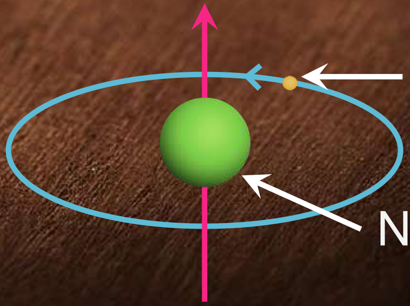
Transition elements are paramagnetic in nature.

Each electron has an associated magnetic moment, due to

Spin angular momentum



Orbital angular momentum



Magnetic moment

Spin-only magnetic moment (in BM)

$$\mu = \sqrt{n(n+2)}$$

Where,

n = No. of unpaired electron(s)

Magnetic Moments of Mn^{2+} Ion

EXAMPLE

Mn^{2+} → $[Ar]\ 3d^5 4s^0$

↓

5 unpaired electrons

$$\mu = \sqrt{5(5+2)}$$

$$= 5.92\ \text{BM}$$

Calculated and Observed Magnetic Moments (BM)

Magnetic moment increases with number of unpaired electrons.

Ion	Configuration	Unpaired electron(s)	Magnetic moment	
			Calculated	Observed
Sc^{3+}	$3d^0$	0	0	0
Ti^{3+}	$3d^1$	1	1.73	1.75
TI^{2+}	$3d^2$	2	2.84	2.76
V^{2+}	$3d^3$	3	3.87	3.86
Cr^{2+}	$3d^4$	4	4.90	4.80
Mn^{2+}	$3d^5$	5	5.92	5.96
Fe^{2+}	$3d^6$	4	4.90	5.3-5.5
Co^{2+}	$3d^7$	3	3.87	4.4-5.2
Ni^{2+}	$3d^8$	2	2.84	2.9-3.4
Cu^{2+}	$3d^9$	1	1.73	1.8-2.2
Zn^{2+}	$3d^{10}$	0	0	

Formation of Coloured Ions: 3d Metal Ions

Ti^{3+} : Purple
Cr^{3+} : Green
Mn^{2+} : Light pink
Fe^{3+} : yellow
Co^{2+} : pink
Ni^{2+} : green
Cu^{2+} : blue

Formation of Coloured Ions

When an electron from a lower energy d orbital is excited to a higher energy d-orbital

Due to this excitation, the compounds shows a **color.**

Color of Transition Elements

This frequency generally lies in the visible region.

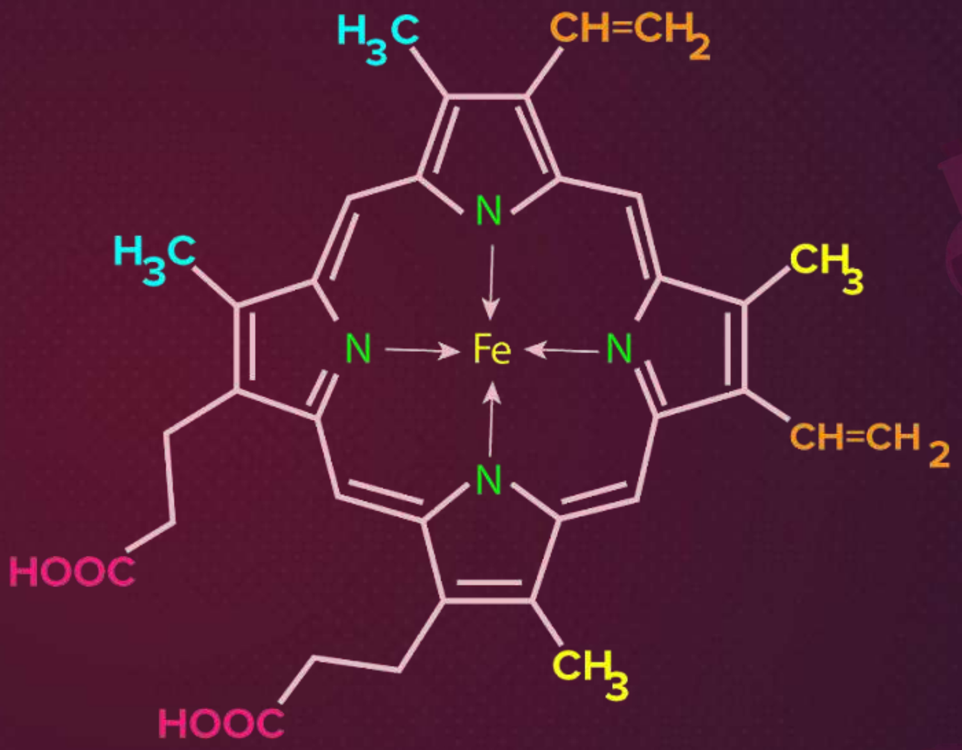
The colour observed corresponds to the complementary colour of the light absorbed.

Complex Compounds

Compounds in which the metal atoms/ions bind to a number of anions/neutral molecules, by sharing of electrons and forming complex species with characteristic properties.

Example: $[Fe(CN)_6]^{3-}$, $[PtCl_4]^{2-}$, etc.

Haemoglobin



Formation of Complex Compounds

Reasons for complex formation

- Comparatively smaller sizes
- High ionic charges
- Availability of d-orbitals for bond formation

Catalytic Property of Transition Metals

Transition metals show catalytic property due to the ability to

- Adopt multiple oxidation states
- Form complexes

Catalytic Property of Transition Metals

EXAMPLE

Iron(III) catalyses the reaction between iodide and persulphate ions.

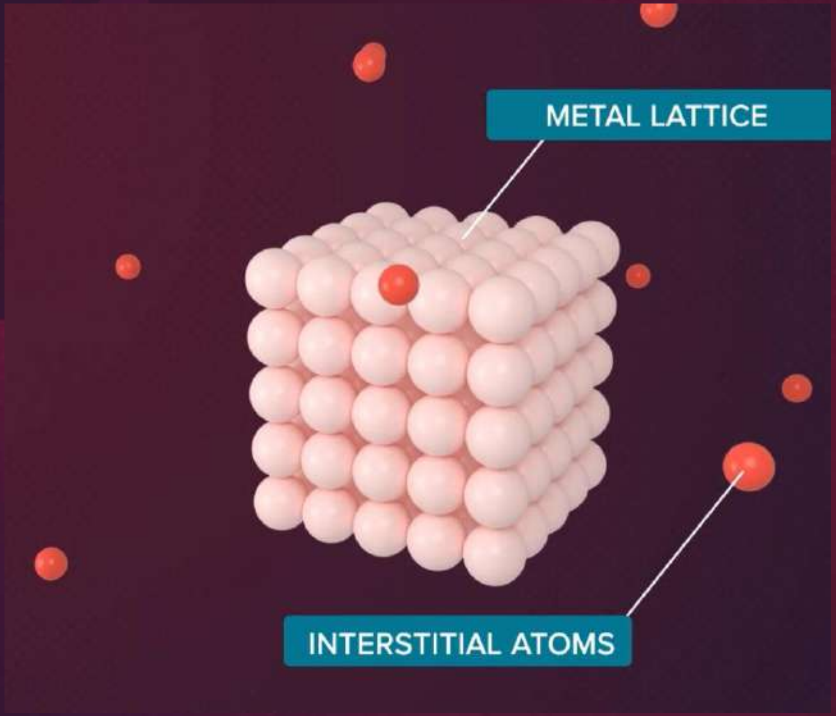
$$2I^- + S_2O_8^{2-} \longrightarrow I_2 + 2SO_4^{2-}$$

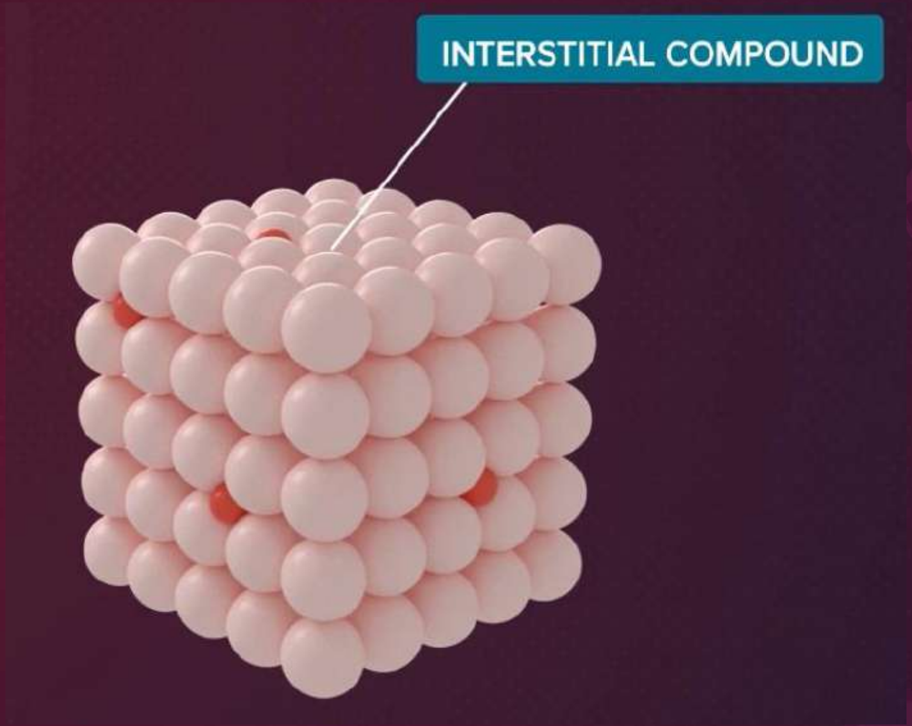
Catalytic action,

$$2Fe^{3+} + 2I^- \longrightarrow 2Fe^{2+} + I_2$$

$$2Fe^{2+} + S_2O_8^{2-} \longrightarrow 2SO_4^{2-} + 2Fe^{3+}$$

Formation of Interstitial Compounds





Formation of Interstitial Compounds

Interstitial compounds are formed when small atoms like H, C, or N are trapped inside the crystal lattices of metals.

- TiC
- Mn_4N
- Fe_3H
- $VH_{0.56}$
- $TiH_{1.7}$

Usually, non-stoichiometric compounds are neither typically ionic nor covalent.

Characteristics of Interstitial Compounds

Higher than those of pure metals

Some borides approach diamond in hardness.

i. High melting points.

ii. Very hard.

iii. Retain metallic conductivity.

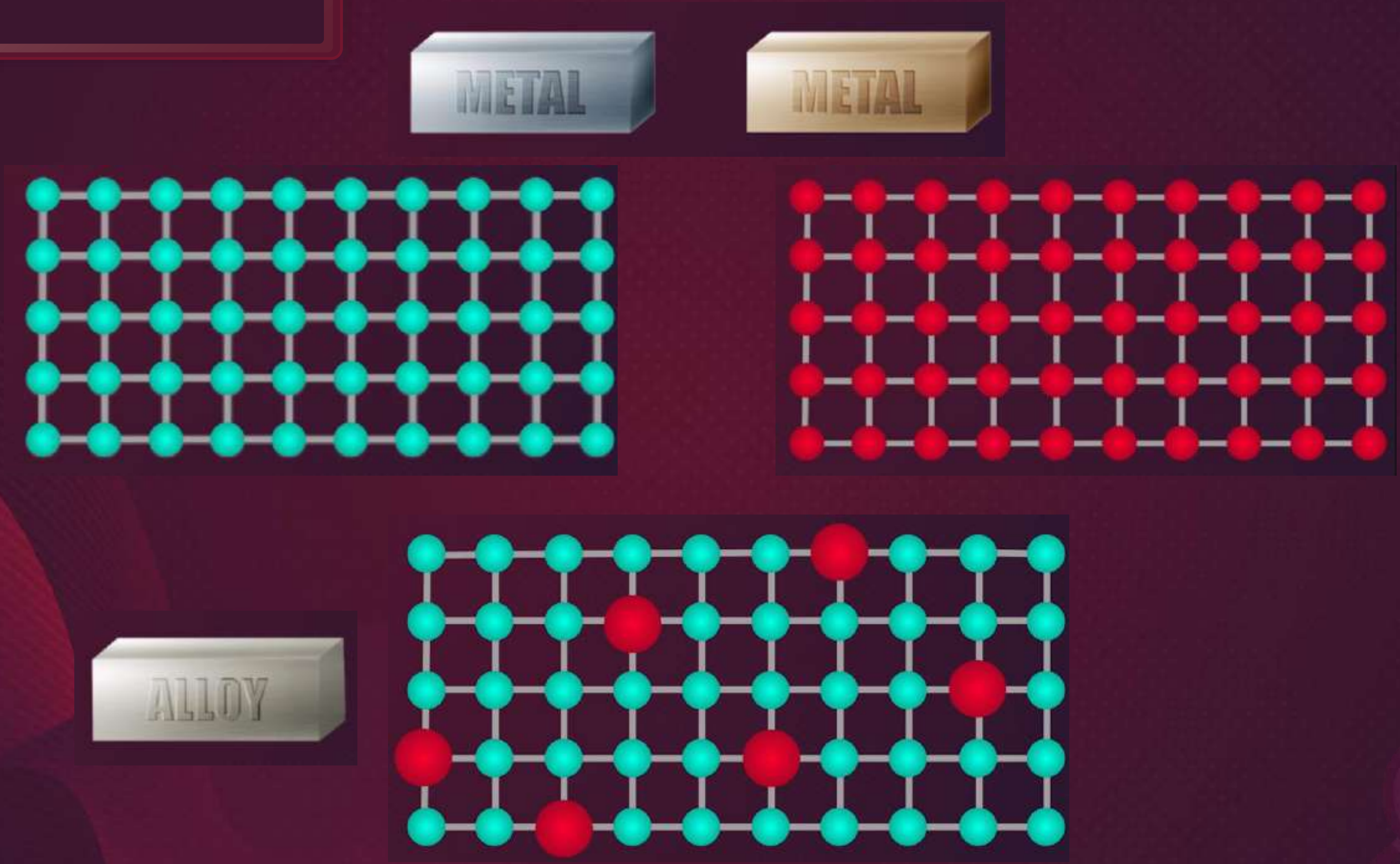
iv. Chemically inert.

Alloy

An alloy is a blend of metals prepared by mixing the components.

Alloys may be homogeneous solid solutions in which the atoms of one metal are distributed randomly among the atoms of the other.

Alloy Formation



Alloy Formation

Transition metals form alloys due to **similar radii** along with the other characteristics

Within about 15% of each other

Properties of alloys:

a. Are hard

b. Often have high melting points

c. Show better conductivity

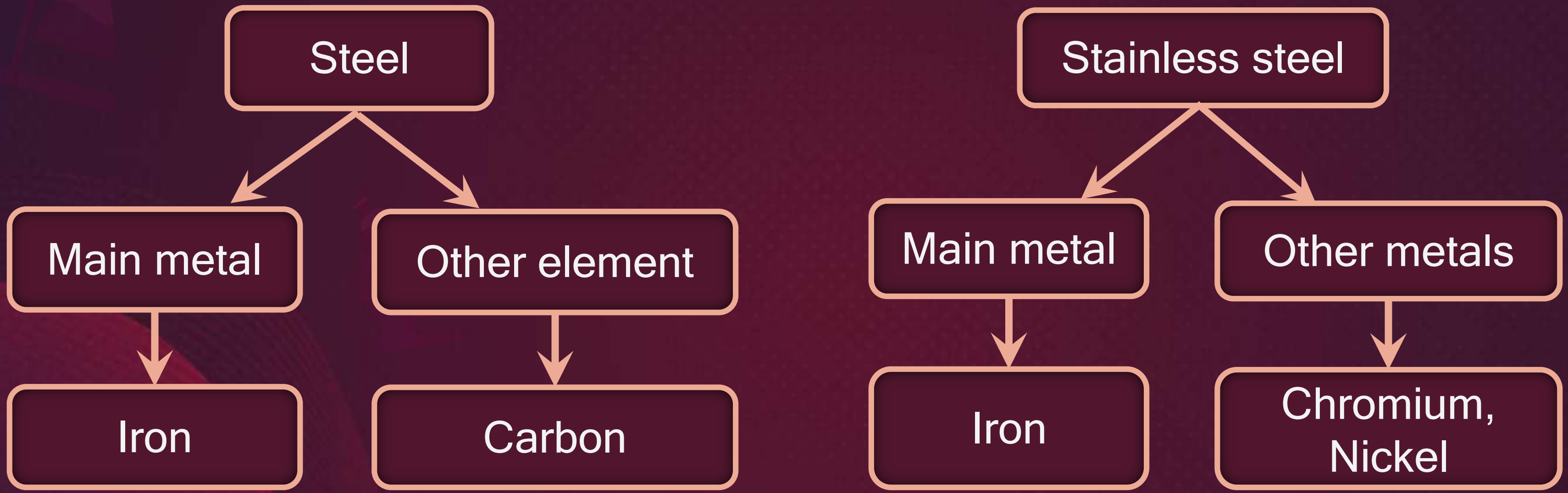
Alloy Formation

EXAMPLE

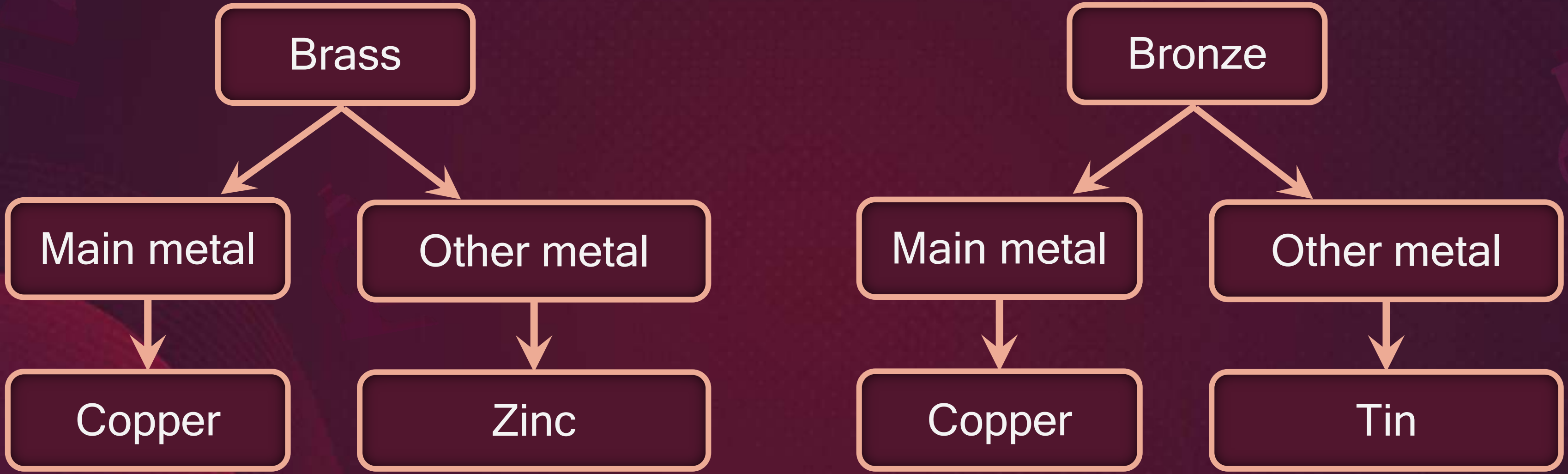
- Ferrous alloys
  - Steel
  - Stainless Steel

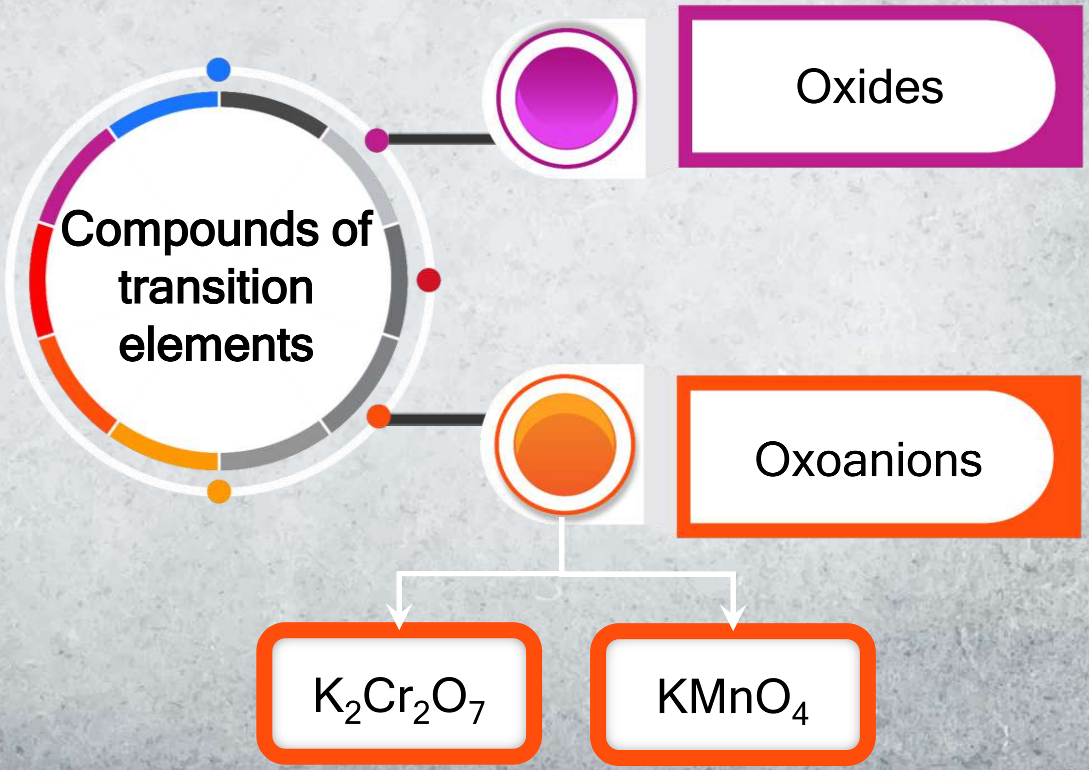
Cr, V, W, Mo, and Mn are used to produce various varieties.

Alloy Formation



Alloy Formation





Compounds of transition elements
Oxides
Oxoanions
$K_2Cr_2O_7$
$KMnO_4$

Metal Oxides

Metal oxides are formed by reaction of metals with oxygen at high temperature.

Oxidation Number ↓ Group →	3	4	5	6	7	8	9	10	11	12
+7					Mn_2O_7					
+6				CrO_3						
+5			V_2O_5							
+4		TiO_2	V_2O_4	CrO_2	MnO_2					
+3	Sc_2O_3	Ti_2O_3	V_2O_3	Cr_2O_3	Mn_2O_3	Fe_2O_3				
					Mn_3O_4	Fe_3O_4	Co_3O_4			
+2		TiO	VO	(CrO)	MnO	FeO	CoO	NiO	CuO	ZnO
+1									Cu_2O	

Properties of Transition Metal Oxides

Properties of metal oxides

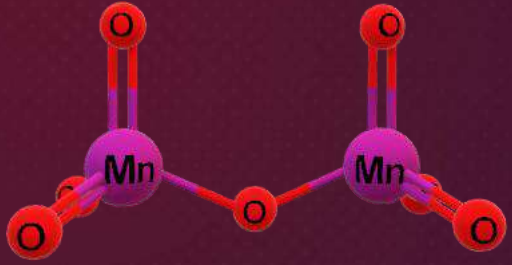
- Ionic character
- Melting point
- Acidic or basic nature

Ionic Character of Transition Metal Oxides

Oxidation number of a metal in metal oxide increases

Ionic character of the oxide decreases.

Mn_2O_7 ⟶ Covalent green oil



Transition Metal Oxides: Melting Points

$$\text{Oxidation number} \propto \frac{1}{\text{Ionic character}}$$

Ionic character ∝ Melting point

Hence, CrO_3 and V_2O_5 have low melting points

Oxidation number of a metal in metal oxide increases

Acidic character of the oxide increases.

Important Oxides of Transition Metals

EXAMPLE

$$Mn_2O_7 + H_2O \longrightarrow 2HMnO_4$$

Strong acid

$$3CrO_3 + 2H_2O \longrightarrow H_2CrO_4 + H_2Cr_2O_7$$

Strong acid

Important Oxides of Transition Metals

Oxides of Vanadium

Oxidation state	Oxide	Nature
+3	V_2O_3	More basic
+4	V_2O_4	Less basic
+5	V_2O_5	Amphoteric

Oxides of Chromium

Oxidation state	Oxide	Nature
+2	CrO	Basic
+3	Cr_2O_3	Amphoteric
+6	CrO_3	Acidic

Potassium Dichromate
($K_2Cr_2O_7$)

Potassium Dichromate

$K_2Cr_2O_7$

- Preparation
- Properties
- Structure
- Uses

Preparation of $K_2Cr_2O_7$

i Fusion of chromite ore with Na_2CO_3

$$4FeCr_2O_4 + 2Na_2CO_3 + 7O_2 \longrightarrow 8Na_2CrO_4 + 2Fe_2O_3 + 8CO_2$$

Filtered

Yellow solution

ii Reaction with H_2SO_4

$$2Na_2CrO_4 + 2H^+ \longrightarrow Na_2Cr_2O_7 + 2Na^+ + H_2O$$

Orange solution

Preparation of $K_2Cr_2O_7$

iii

Reaction with KCl

More soluble than $K_2Cr_2O_7$

Crystallised

$$Na_2Cr_2O_7 + 2KCl \longrightarrow K_2Cr_2O_7 + 2NaCl$$

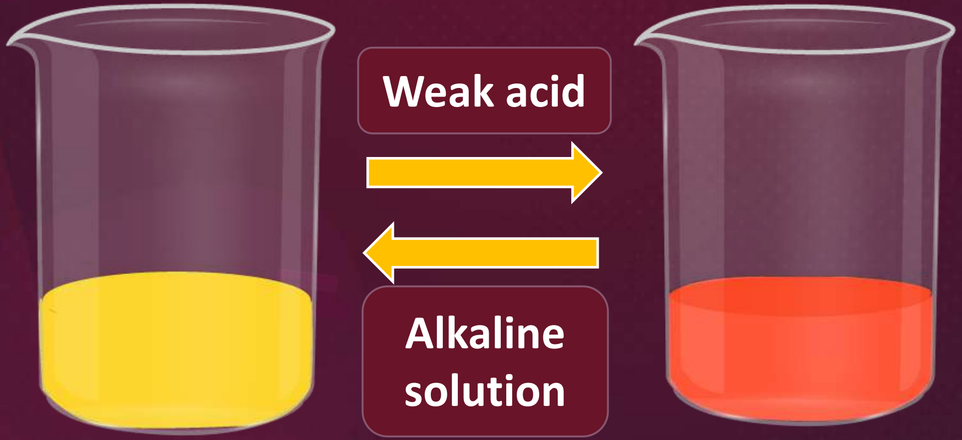
Orange Crystals

Properties of $K_2Cr_2O_7$

$$CrO_4^{2-} \underset{+OH^-}{\overset{+H^+}{\rightleftharpoons}} Cr_2O_7^{2-}$$

Chromate

Dichromate



Properties of $K_2Cr_2O_7$

Oxidising nature

Strong oxidising agent

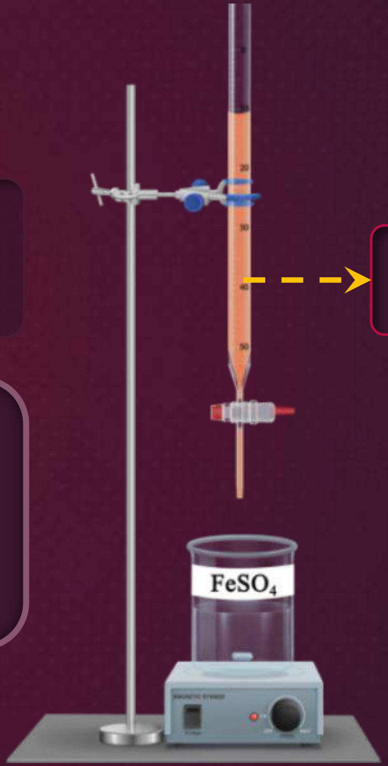
$Na_2Cr_2O_7$

In organic chemistry

Also **greater solubility** in the polar solvent like **CH_3COOH**

$K_2Cr_2O_7$

As a primary standard in **volumetric analysis**



$K_2Cr_2O_7$

Properties of $K_2Cr_2O_7$

In acidic medium

Oxidising action

$$\overset{+6}{Cr}{}_2O_7^{2-} + 14H^+ + 6e^- \longrightarrow 2Cr^{3+} + 7H_2O$$

Standard electrode potential

$E^0 = 1.33\ V$

Properties of $K_2Cr_2O_7$

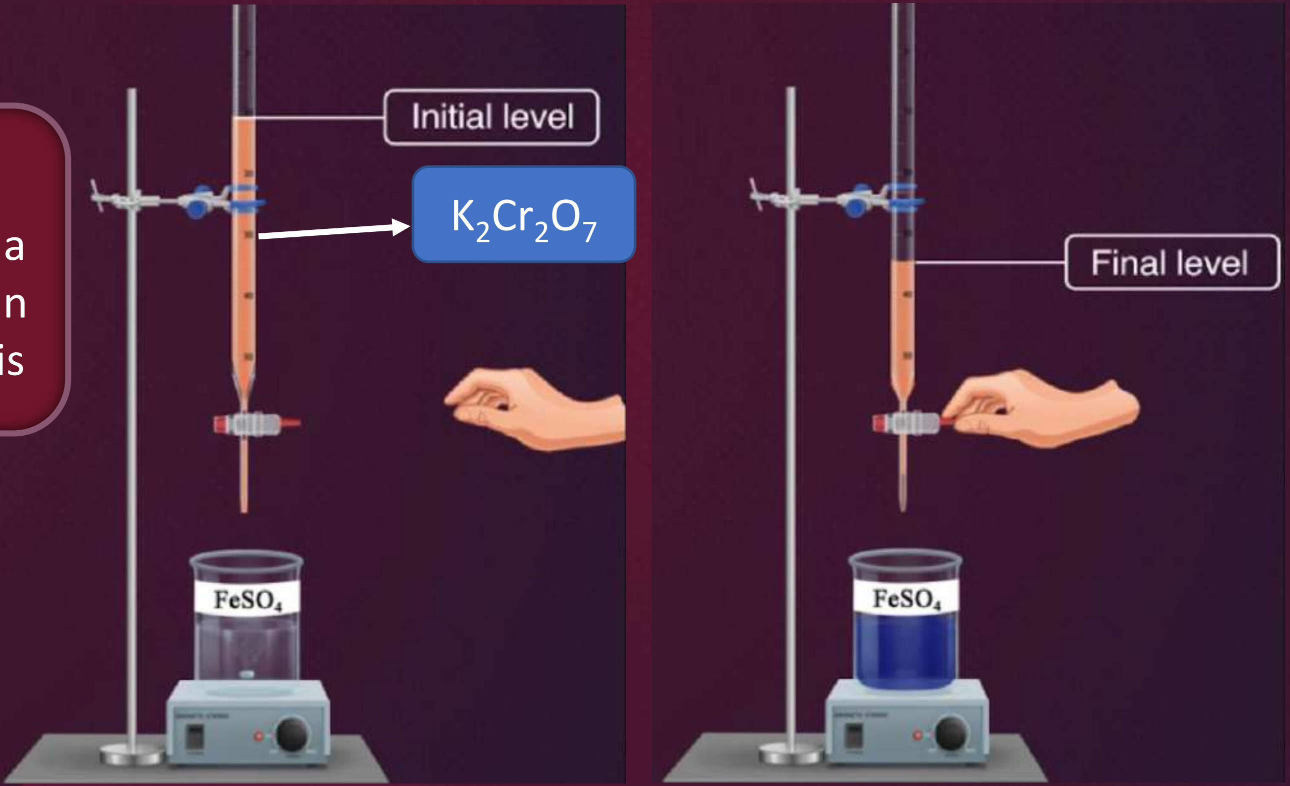
EXAMPLE

Oxidation by acidified $K_2Cr_2O_7$	Half reactions
Iodides to Iodine	$6I^- \rightarrow 3I_2 + 6e^-$
Sulphides to Sulphur	$3H_2S \rightarrow 6H^+ + 3S + 6e^-$
Tin (II) to Tin (IV)	$3Sn^{2+} \rightarrow 3Sn^{4+} + 6e^-$
Fe (II) to Fe (III)	$6Fe^{2+} \rightarrow 6Fe^{3+} + 6e^-$

$$K_2Cr_2O_7 + 6FeSO_4 + 7H_2SO_4 \longrightarrow Cr_2(SO_4)_3 + 3Fe_2(SO_4)_3 + K_2SO_4 + 7H_2O$$

Uses:

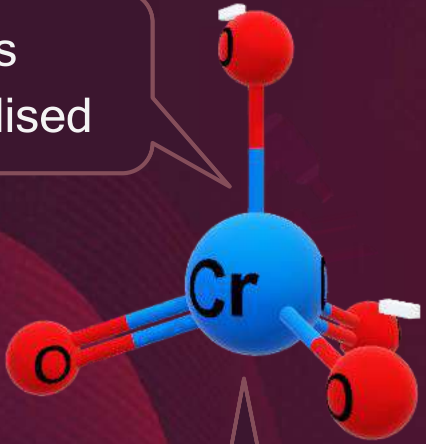
$K_2Cr_2O_7$ is used as a primary standard in Volumetric analysis



Chromate: Structure

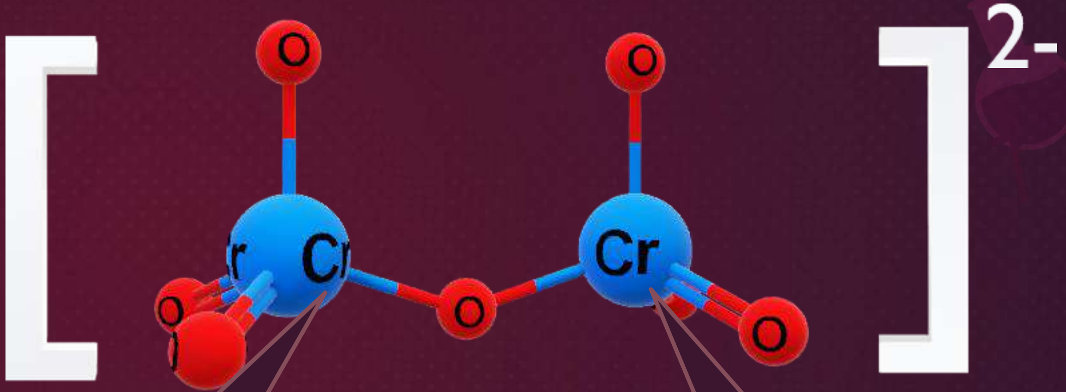
Chromate ion

d^3s hybridised



Tetrahedral

Dichromate ion

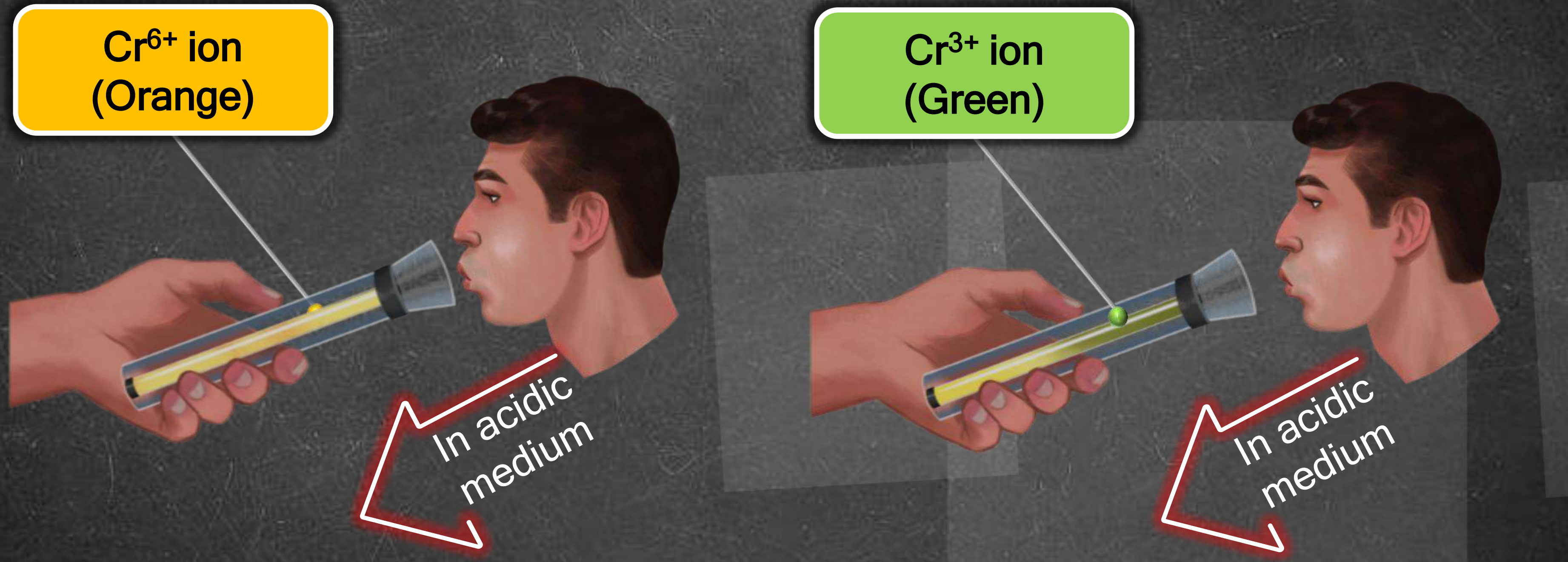


Tetrahedral

Tetrahedral

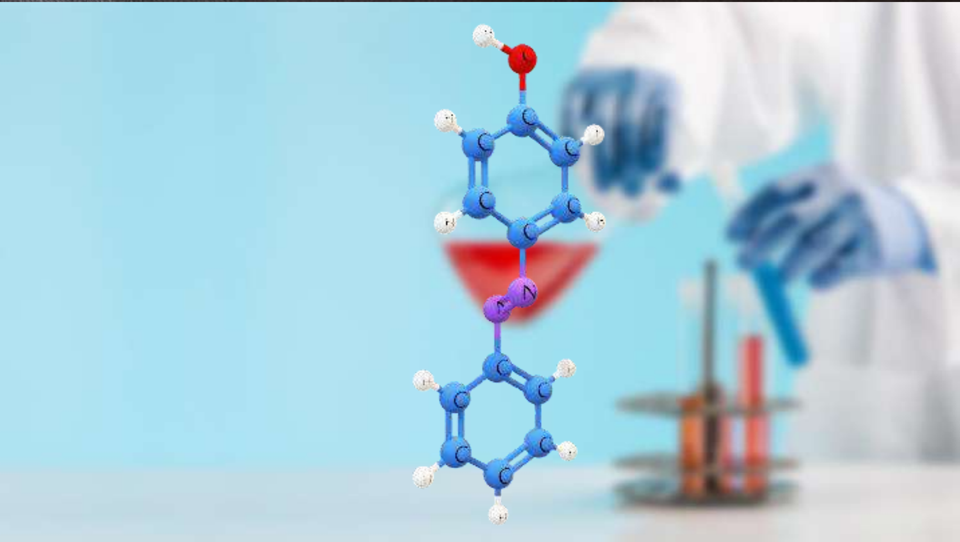
BREATHE ANALYSER

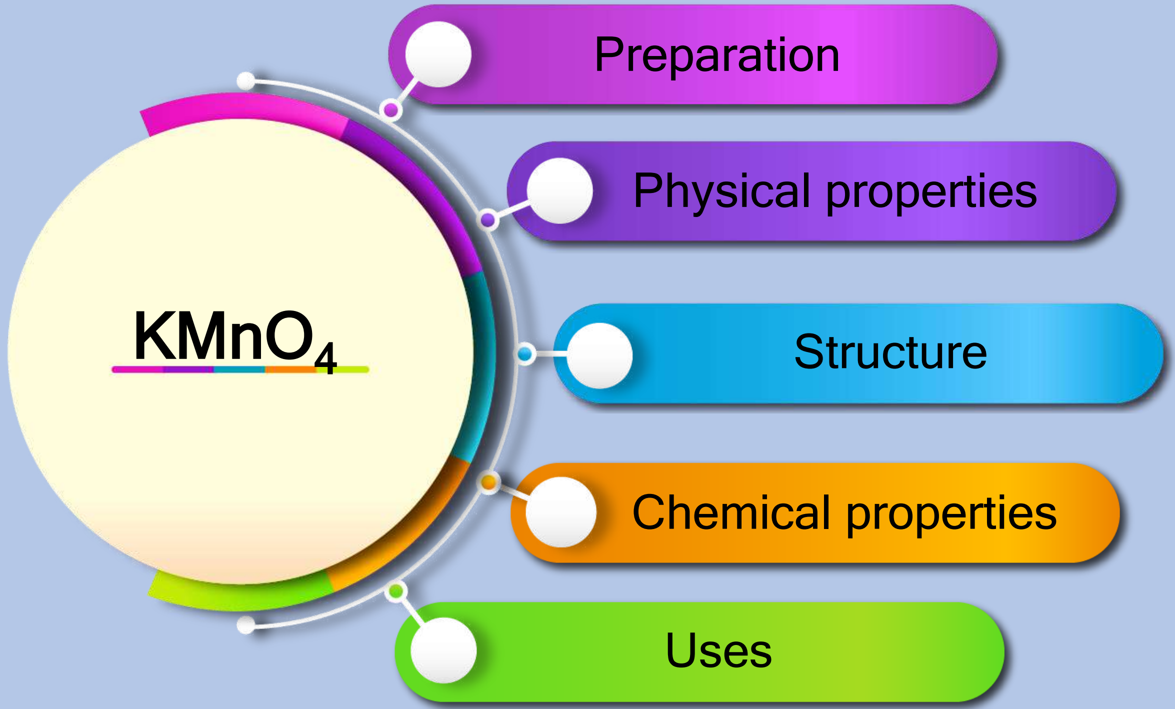
When orange $K_2Cr_2O_7$ reacts with alcohol, it converts into green solution containing chromium sulfate.



USED IN LEATHER INDUSTRY

TO PREPARE AZO COMPOUNDS





$KMnO_4$
Preparation
Physical properties
Structure
Chemical properties
Uses

Potassium Permanganate: Preparation

i Fusion of pyrolusite (MnO_2)

$$2MnO_2 + 4KOH + O_2 \longrightarrow 2K_2MnO_4 + 2H_2O$$

Black solid

Dark green

ii Disproportionation of manganate (MnO_4^{2-})

Disproportionation reaction in presence of an oxidising agent(KNO_3 or $KClO_3$)

$$3MnO_4^{2-} + 4H^+ \longrightarrow 2MnO_4^- + MnO_2 + 2H_2O$$

Dark purple

Potassium Permanganate: Preparation

Commercial method

Step-1

$$MnO_2 \xrightarrow[\text{oxidised with air or } KNO_3]{\text{Fused with KOH,}} MnO_4^{2-}$$

Step-2

$$MnO_4^{2-} \xrightarrow[\text{in alkaline solution}]{\text{Electrolytic oxidation}} MnO_4^{-}$$

Laboratory method

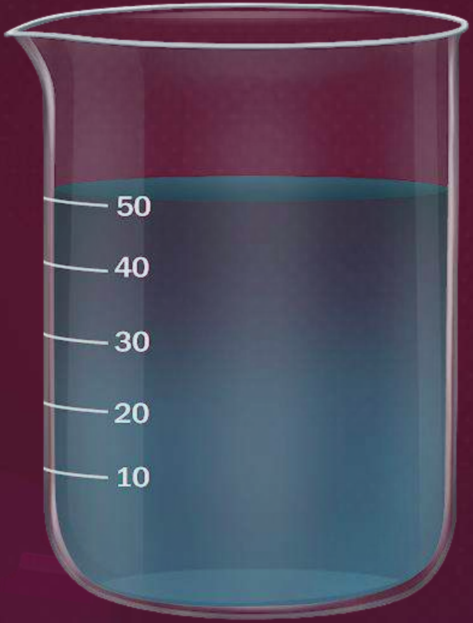
Oxidation of manganese(II) ion

$$2Mn^{2+} + 5S_2O_8^{2-} + 8H_2O \longrightarrow 2MnO_4^{-} + 10SO_4^{2-} + 16H^{+}$$

Colour of MnO_4^{2-} and MnO_4^- Ions

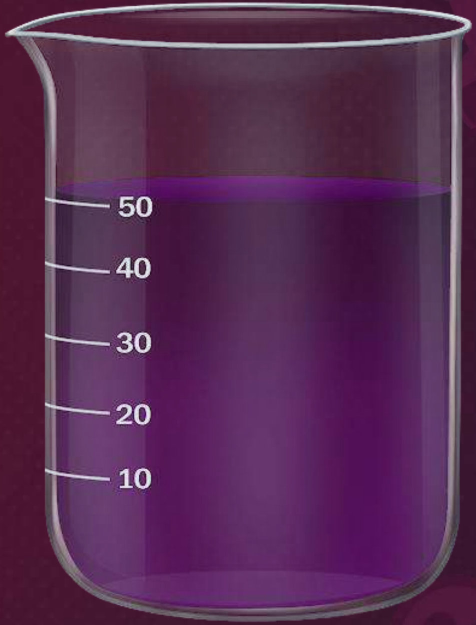
Intense color (dark purple)

Manganate ion



Green

Permanganate ion



Purple

Magnetic Property of $KMnO_4$

Heating effect

Diamagnetic (no unpaired electron)

Paramagnetic (one unpaired electron)

$$2KMnO_4 \xrightarrow[513\ K]{\Delta} K_2MnO_4 + MnO_2 + O_2$$

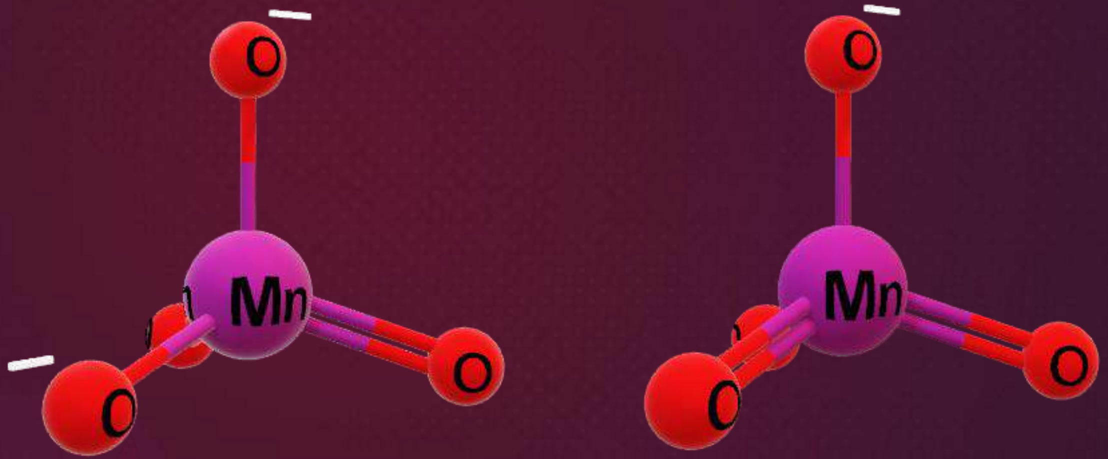
Dark purple

Green

Black

Potassium Permanganate: Structure

Tetrahedral



Manganate ion

Permanganate ion

Potassium Permanganate: Chemical Properties

Oxidising nature

Oxidising properties of $KMnO_4$ in

- Acidic medium
- Neutral or faintly alkaline medium
- Alkaline medium

In acidic medium

$$\overset{+7}{MnO_4^-} + 8H^+ + 5e^- \longrightarrow Mn^{2+} + 4H_2O$$

$E^0 = 1.52\ V$

Oxidising nature of $KMnO_4$ in acidic medium

$$6HCl + 2KMnO_4 + 5NaHSO_3 \rightarrow 3H_2O + 2KCl + 2MnCl_2 + 5NaHSO_4$$

Potassium Permanganate: Chemical Properties

EXAMPLE

Oxidising nature of $KMnO_4$ in acidic medium

Liberation of I_2 from I^- solution:

$$10I^- + 2MnO_4^- + 16H^+ \longrightarrow 2Mn^{2+} + 8H_2O + 5I_2$$

Conversion of Fe(II) to Fe(III):

$$5Fe^{2+} + MnO_4^- + 8H^+ \longrightarrow Mn^{2+} + 4H_2O + 5Fe^{3+}$$

Green

Yellow

Potassium Permanganate: Chemical Properties

EXAMPLE

Oxidation of oxalate ion:

$$5C_2O_4^{2-} + 2MnO_4^- + 16H^+ \longrightarrow 2Mn^{2+} + 8H_2O + 10CO_2$$

Oxidation of Nitrite ion:

$$5NO_2^- + 2MnO_4^- + 6H^+ \longrightarrow 2Mn^{2+} + 5NO_3^- + 3H_2O$$

NOTE

$$2KMnO_4(aq) + 16HCl(aq) \longrightarrow 2KCl(aq) + 2MnCl_2(aq) + 8H_2O(l) + 5Cl_2(g) \uparrow$$

Endpoint ✕

Permanganate titration is not carried out in the presence of hydrochloric acid because some of the hydrochloric acid gets oxidised to chlorine gas. Hence, we do not get the correct endpoint for the given titration.

Potassium Permanganate: Chemical Properties

In neutral medium

$$\overset{+7}{MnO_4^-} + 4H^+ + 3e^- \longrightarrow \overset{+4}{MnO_2} + 2H_2O$$

$E^0 = 1.69\ V$

Potassium Permanganate: Chemical Properties

Oxidising nature of $KMnO_4$ in neutral medium

Thiosulphate is oxidised to sulphate:

$$8MnO_4^- + 3S_2O_3^{2-} + H_2O \longrightarrow 8MnO_2 + 6SO_4^{2-} + 2OH^-$$

Oxidation of iodide to iodate:

$$2MnO_4^- + I^- + H_2O \longrightarrow 2MnO_2 + 2OH^- + IO_3^-$$

Potassium Permanganate: Chemical Properties

The oxidation of manganous salt to MnO_2

$$2MnO_4^- + 3Mn^{2+} + 2H_2O \longrightarrow 5MnO_2 + 4H^+$$

$ZnSO_4$ or ZnO catalyst

Potassium Permanganate: Chemical Properties

In alkaline medium

$$\overset{+7}{MnO_4^-} + e^- \longrightarrow \overset{+6}{MnO_4^{2-}}$$

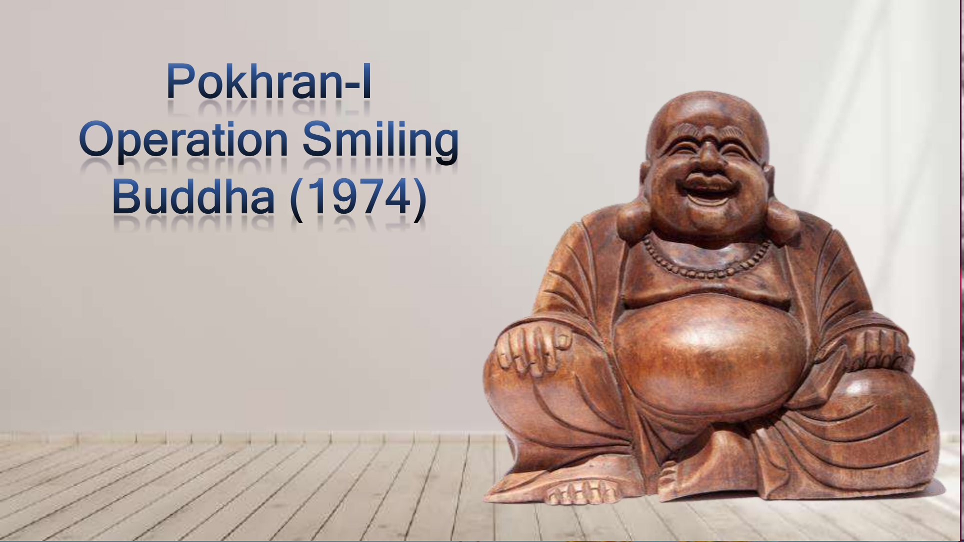
$E^0 = 0.56\ V$

Uses of $KMnO_4$

Periodic Table

d-Block elements

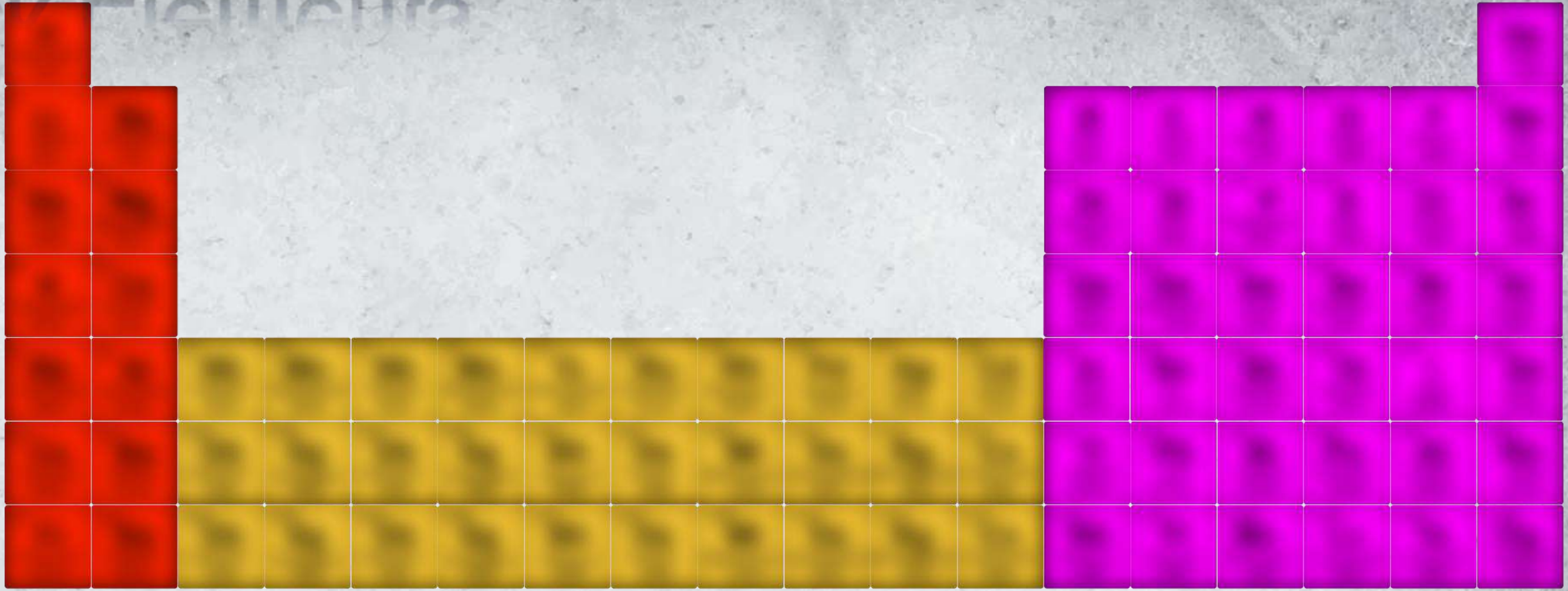
f-Block elements


Pokhran-I
Operation Smiling
Buddha (1974)


Pokhran-II
Operation Shakti
(1998)


POKARAN MILITARY STATION

f-Block Elements



57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

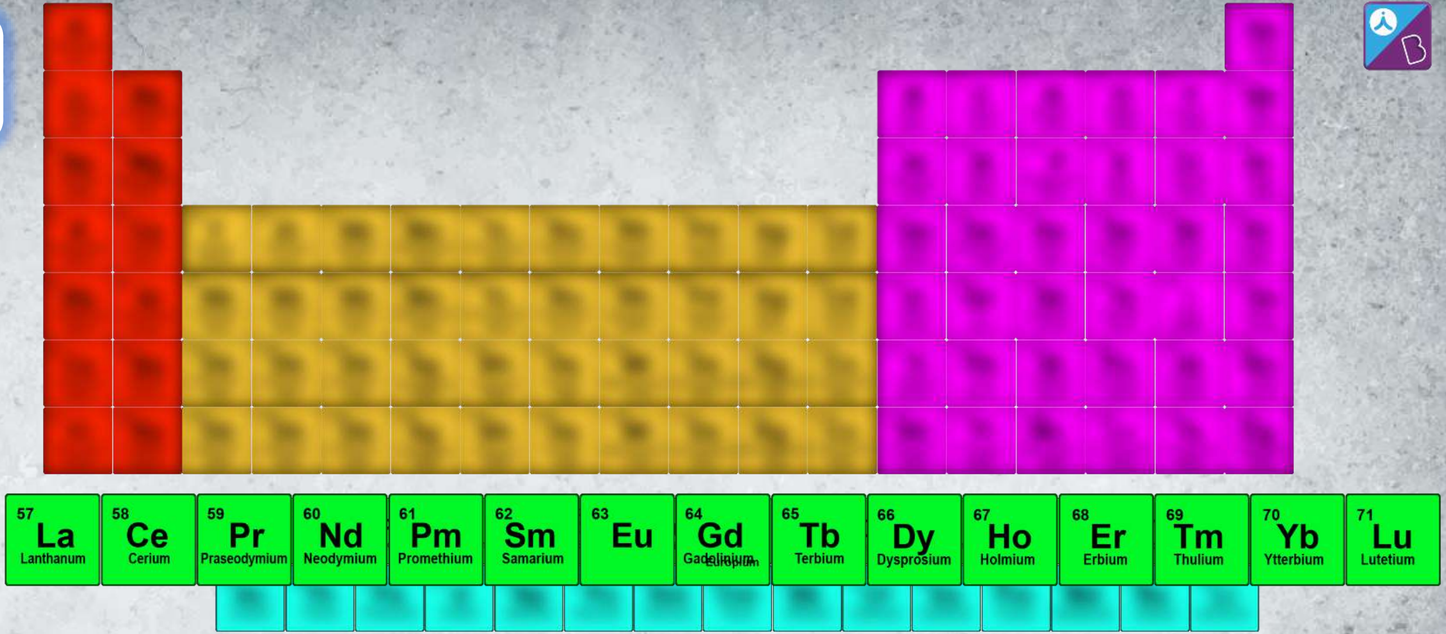
Point to Remember

La and Ac closely resemble the lanthanoids and actinoids, respectively.

↓

Included in discussion of the respective series besides the 14 elements.

Lanthanoids



Lanthanoids (Ln)

- Electronic configurations
- Atomic and ionic size
- Oxidation states
- Physical properties
- Chemical properties
- Uses

Lanthanoids: Electronic Configuration

General configuration

Variable occupancy

$4f^{1-14}\ 5d^{0-1}\ 6s^2$

- d^1 → Ce, Gd, Lu
- d^0 → All other elements

Lanthanoids: Electronic Configuration

Electronic configurations of lanthanum and lanthanoids

Atomic number	Name	Symbol	Electronic configuration Ln
57	Lanthanum	La	$5d^1\ 6s^2$
58	Cerium	Ce	$4f^1\ 5d^1\ 6s^2$
59	Praseodymium	Pr	$4f^3\ 6s^2$
60	Neodymium	Nd	$4f^4\ 6s^2$
61	Promethium	Pm	$4f^5\ 6s^2$
62	Samarium	Sm	$4f^6\ 6s^2$
63	Europium	Eu	$4f^7\ 6s^2$
64	Gadolinium	Gd	$4f^7\ 5d^1\ 6s^2$

Lanthanoids: Electronic Configuration

Electronic configurations of lanthanum and lanthanoids

Atomic number	Name	Symbol	Electronic configuration Ln
65	Terbium	Tb	$4f^9 6s^2$
66	Dysprosium	Dy	$4f^{10} 6s^2$
67	Holmium	Ho	$4f^{11} 6s^2$
68	Erbium	Er	$4f^{12} 6s^2$
69	Thulium	Tm	$4f^{13} 6s^2$
70	Ytterbium	Yb	$4f^{14} 6s^2$
71	Lutetium	Lu	$4f^{14} 5d^1 6s^2$

Lanthanoids: Atomic and Ionic Size

Lanthanoids
(left to right)

57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu	64 Gd Gadolinium Europium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium

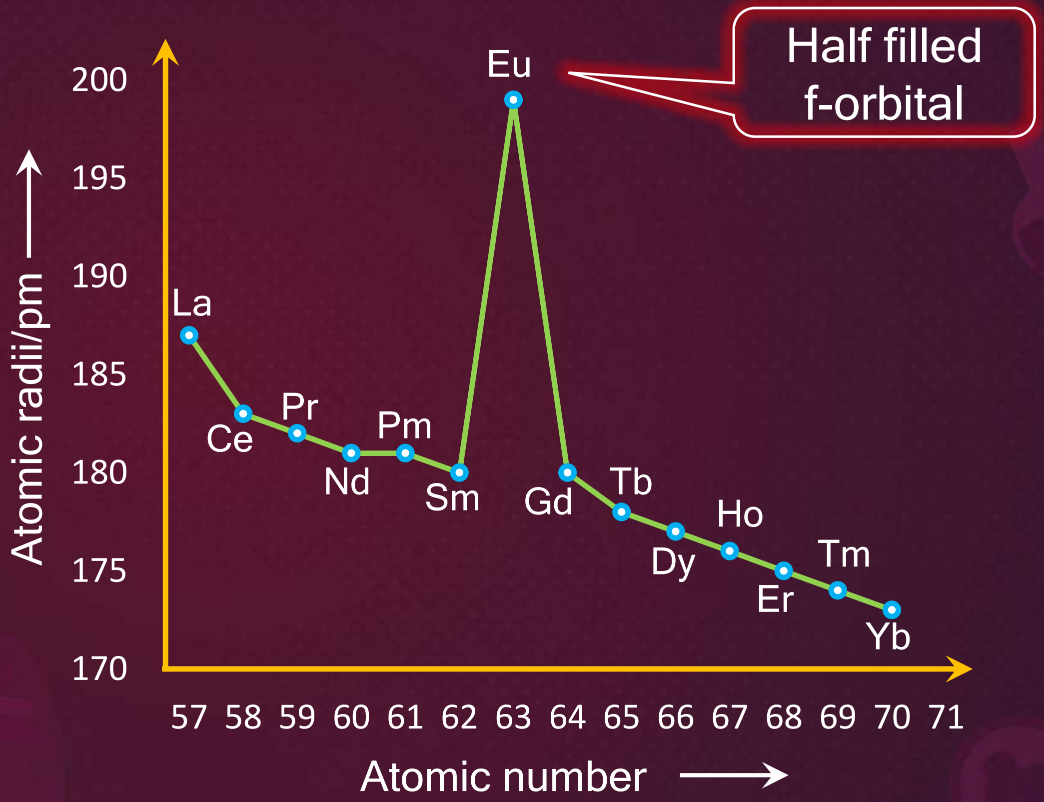
La → Lu

Due to **lanthanoid contraction**

Overall decrease in atomic and ionic radii

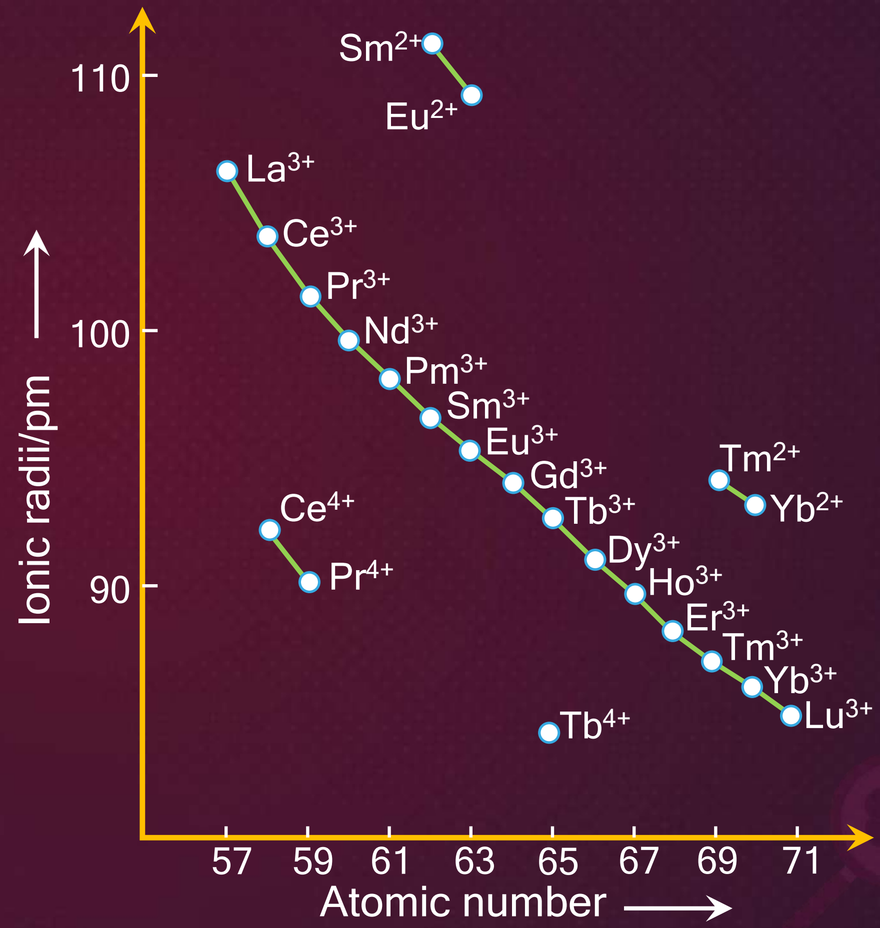
Lanthanoids: Atomic Sizes

Overall decrease in atomic size



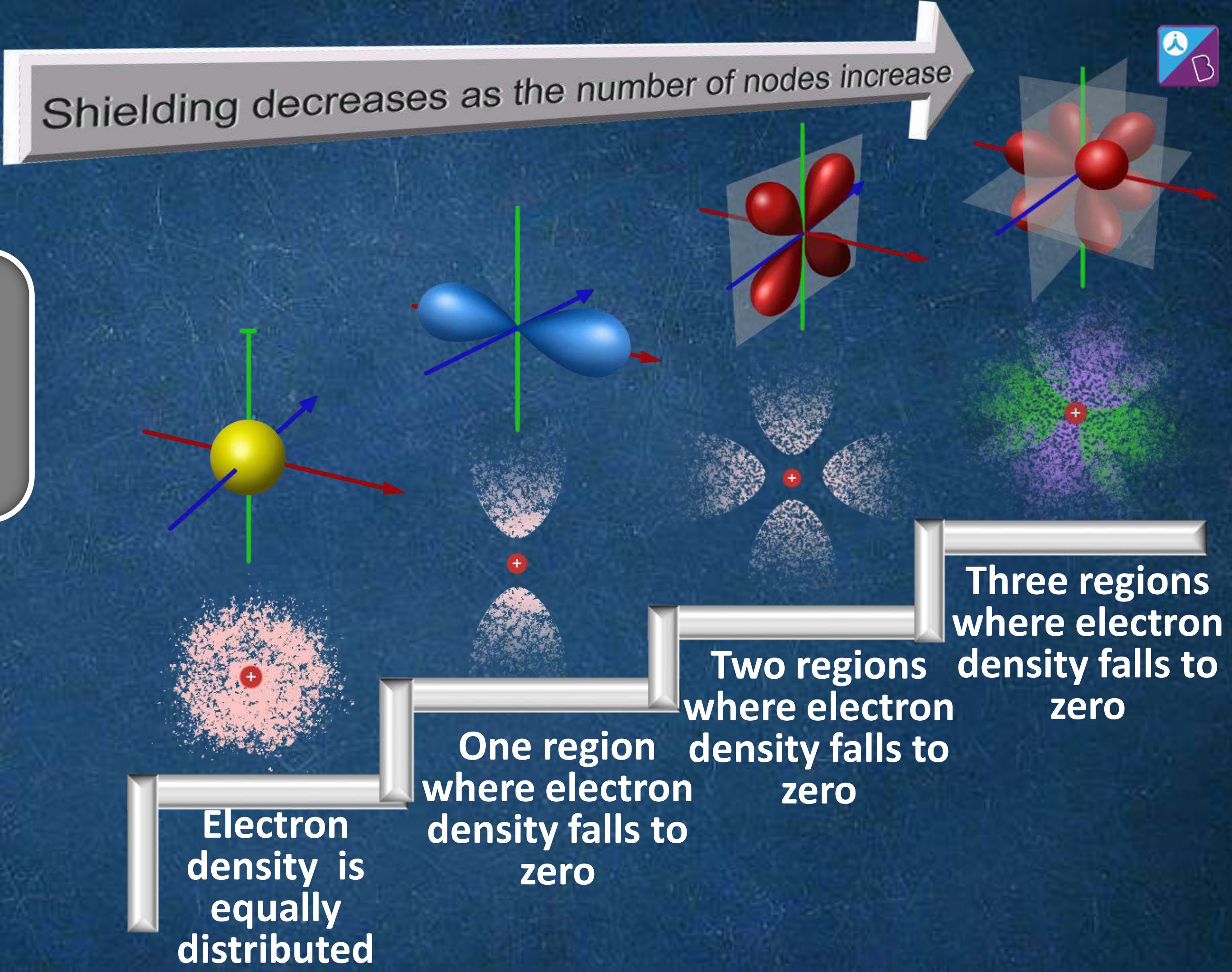
Lanthanoids: Ionic Sizes

Overall decrease in ionic size



Lanthanoid Contraction

Decrease in sizes fairly regular for Ln as compared to transition elements



Lanthanoids: Oxidation States

Common oxidation state

Common oxidation state is Ln(III)

Easy removal of two 6s and one 5d (or 4f) electrons except Eu and Yb

Occasionally +2 and +4 oxidation states are also obtained

Extra stability of empty, half-filled and fully filled f subshell

Lanthanoids: Oxidation States

$Ce^{4+} \longrightarrow Ce^{3+}$ $E^{o} = +1.74\ V$

- Ce^{4+}: $[Xe]\ 4f^{0}$
- Ce^{3+}: $[Xe]\ 4f^{1}$

$Eu^{2+} \longrightarrow Eu^{3+}$

- Eu^{2+}: $[Xe]\ 4f^{7}$
- Eu^{3+}: $[Xe]\ 4f^{6}$

$Tb^{4+} \longrightarrow Tb^{3+}$

- Tb^{4+}: $[Xe]\ 4f^{7}$
- Tb^{3+}: $[Xe]\ 4f^{8}$

$Yb^{2+} \longrightarrow Yb^{3+}$

- Yb^{2+}: $[Xe]\ 4f^{14}$
- Yb^{3+}: $[Xe]\ 4f^{13}$

All these ions shift back to **+3** state hence they act as **reducing** or **oxidising agents.**

Lanthanoids are silvery white soft metals and tarnish rapidly in air.

Samarium (Steel Hard)

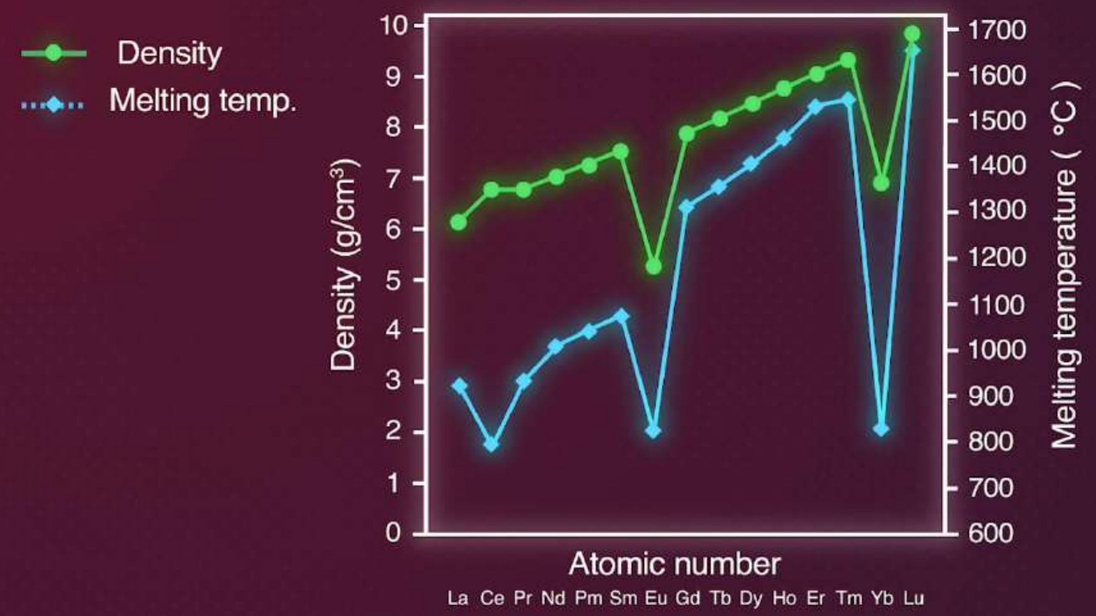
The **hardness** increases with increasing atomic number, samarium being steel hard.

High melting points

Their **melting points** range between 1000 to 1200 K but samarium melts at 1623 K.

Density

Density and other properties change smoothly except for Eu and Yb and occasionally for Sm and Tm.



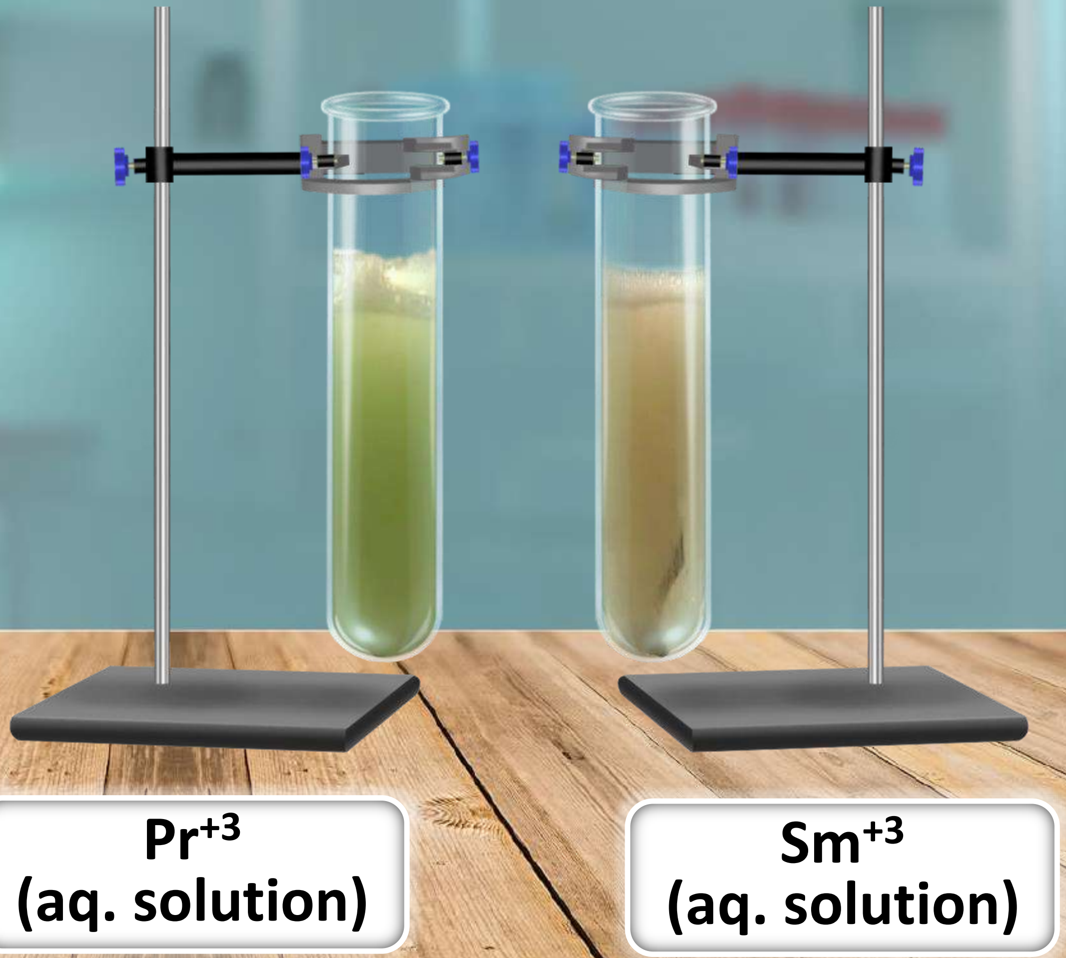
High electrical conductivity

High thermal conductivity

They are good conductors of heat and electricity.

Trivalent lanthanoid ions

Many trivalent lanthanoid ions are coloured both in the solid state and in aqueous solutions due to incomplete filling of f-orbitals except La^{3+} and Lu^{3+}



Colour of Lanthanoid Ions

NOTE

La^{3+} → $[Xe]\ 4f^0$

Lu^{3+} → $[Xe]\ 4f^{14}$

No unpaired electron

↓

Colourless

Magnetic Properties

f^0 type → La^{3+} & Ce^{4+}

f^{14} type → Yb^{2+} & Lu^{3+}

Other than these, all other ions are **paramagnetic.**

Point to Remember

Ionisation enthalpies are **fairly low** and comparable to alkaline earth metals.

Hence, they are **good reducing agents**.

La^{3+}, Gd^{3+} and Lu^{3+} have abnormally low third ionisation enthalpy values.

Extra stability of f^0, f^7 and f^{14} orbitals

Lanthanoids: Ionisation Enthalpy

$La^{2+} \longrightarrow La^{3+}$
[Xe] $4f^0\ 5d^1$ → [Xe] $4f^0$

$Gd^{2+} \longrightarrow Gd^{3+}$
[Xe] $4f^7\ 5d^1$ → [Xe] $4f^7$

$Lu^{2+} \longrightarrow Lu^{3+}$
[Xe] $4f^{14}\ 5d^1$ → [Xe] $4f^{14}$

Low values of ionization enthalpy (III)

Good reducing agents due to low IE values

E^o values

$Ln^{3+}(aq) + 3e^- \longrightarrow Ln(s)$

$E^o \approx$ -2.2 to -2.4 v

Except Eu = -2.0 V

Lanthanoids : Chemical Properties

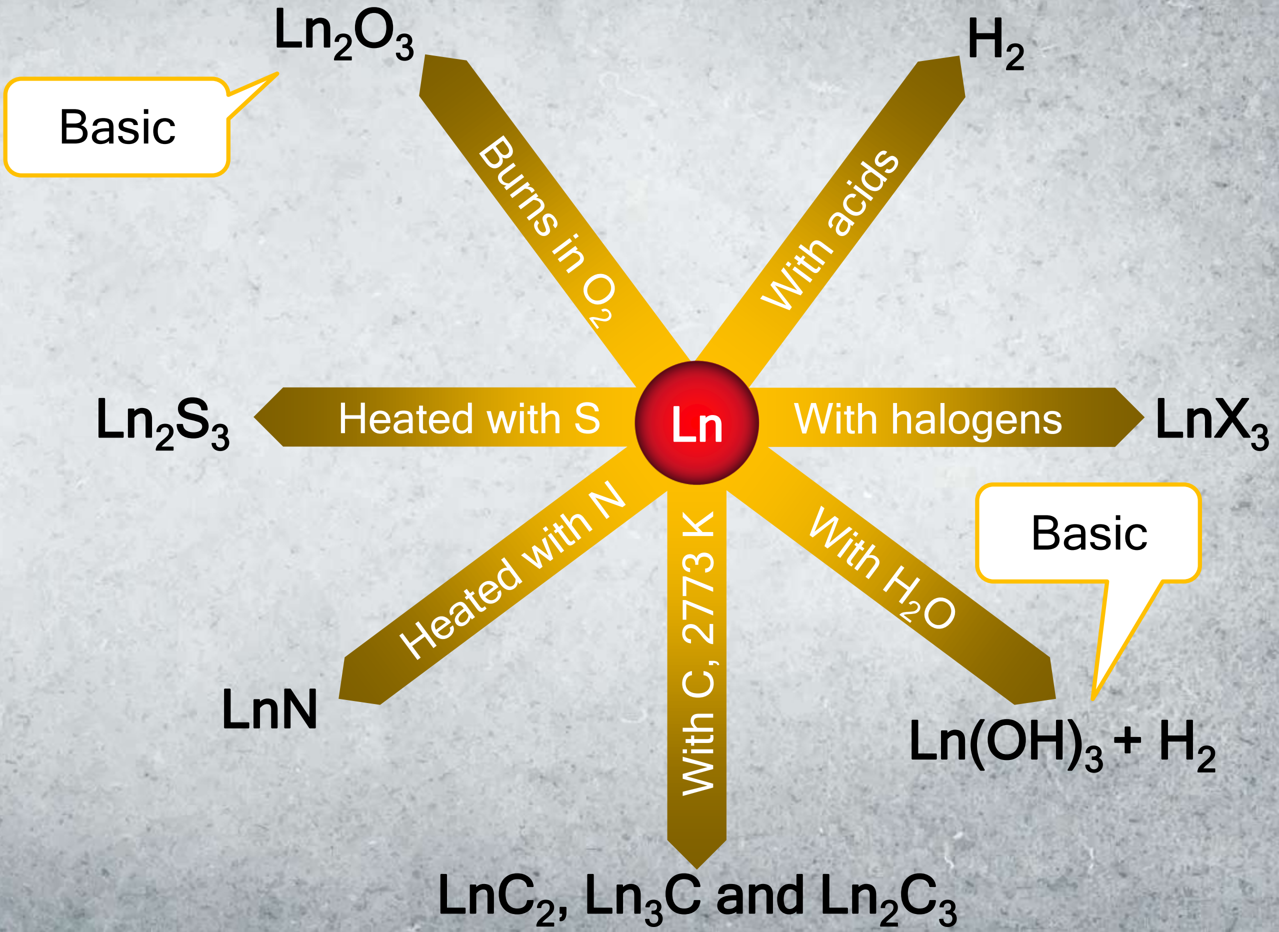
The earlier members of the series are **quite reactive**

Like **calcium**

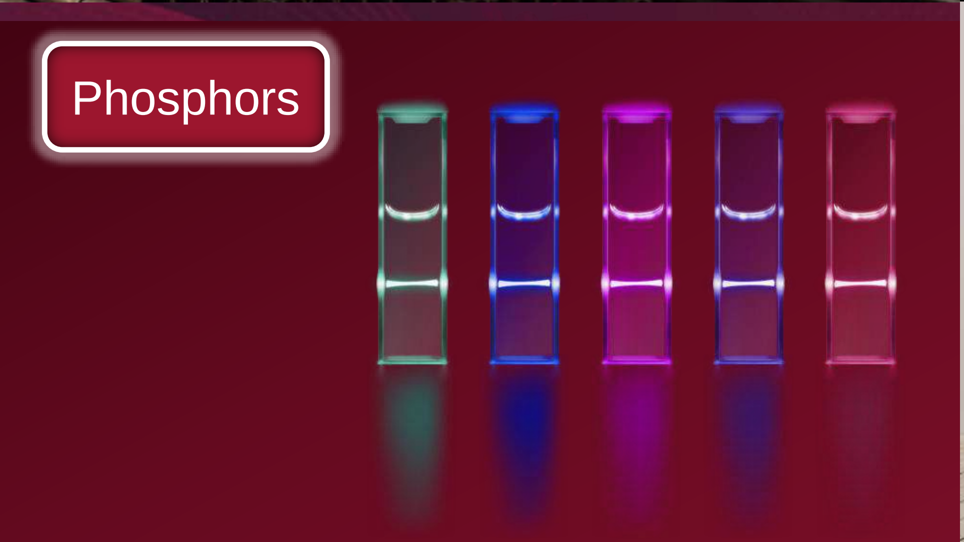
However, with **increasing atomic number,** they behave more like **aluminium.**

Typically form compounds which are ionic and trivalent(Ln^{3+})

Chemical Reaction of Lanthanoids



Uses of Inner Transition Metals

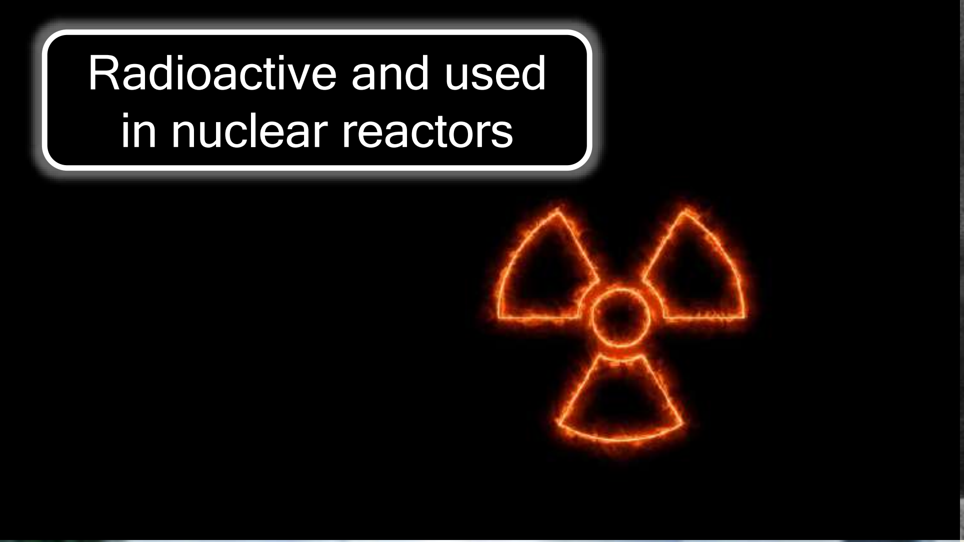


Mischmetall

It consists of a lanthanoid metal (~ 95%), iron (~ 5%) and traces of S, C, Ca and Al.

Mischmetal bullets and shells

Mischmetal in lighter flint

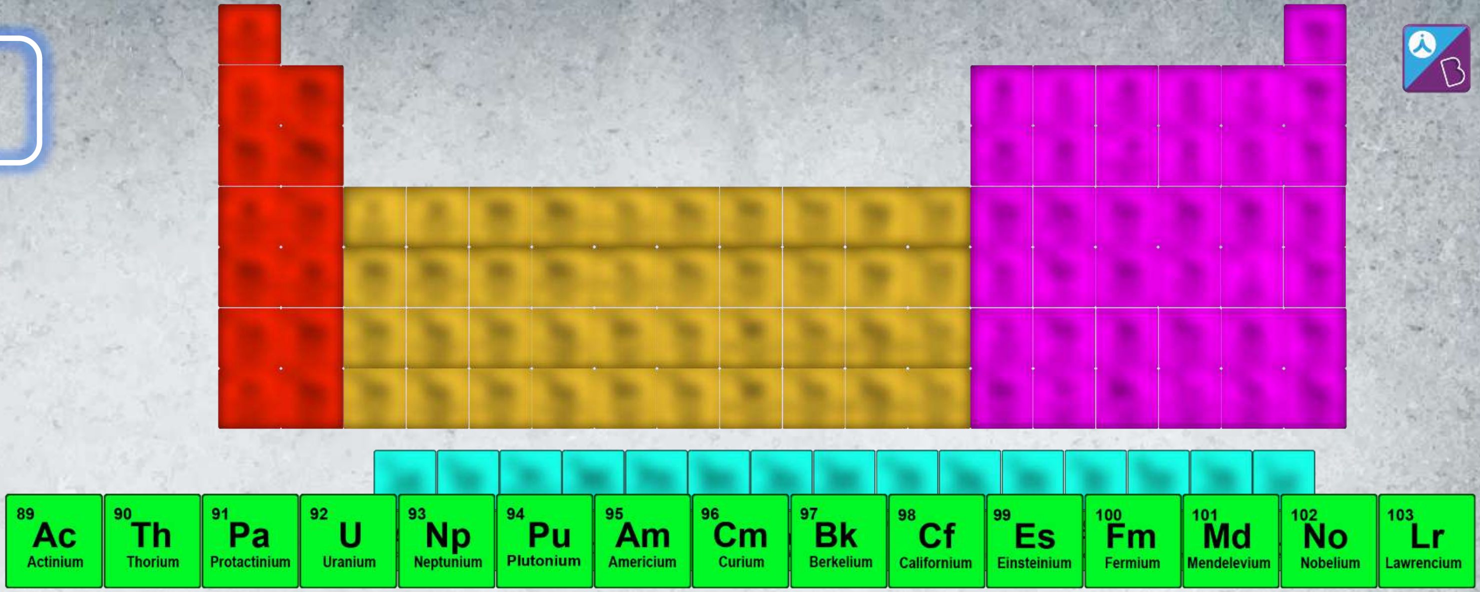

Radioactive and used
in nuclear reactors


Hiroshima and
Nagasaki bomb attack


Chernobyl
disaster


Radiotherapy

Actinoids



89 Ac Actinium
90 Th Thorium
91 Pa Protactinium
92 U Uranium
93 Np Neptunium
94 Pu Plutonium
95 Am Americium
96 Cm Curium
97 Bk Berkelium
98 Cf Californium
99 Es Einsteinium
100 Fm Fermium
101 Md Mendelevium
102 No Nobelium
103 Lr Lawrencium

Uranium is the heaviest naturally occurring element.

After uranium, 12 more elements has been artificial synthesized (atomic number more than 92) and are called the **transuranium elements**

Actinoids are radioactive elements

Earlier members

Relatively, long half-lives

Latter members

Half-life: A day to **3 minutes**

Lr (lawrencium)

Prepared only in **nanogram** quantities

Actinoids (An)

- Electronic configurations
- Atomic and ionic size
- Oxidation states
- General characteristics

Actinoids: Electronic Configuration

General configuration →

89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

Variable occupancy: $5f^{0-14}$ $6d^{0-2}$

$5f^{0-14}\ 6d^{0-2}\ 6s^2$

- d^2 → Th
- d^1 → Ac, Pa, U, Np, Cm, Lr
- d^0 → All other elements

NOTE

The difference between the energy levels of 5f and 6d orbitals are small

Thus in **Ac, Th, Pa, U** and **Np** electrons may occupy either 5d or 6f orbitals.

5f orbital extend in space, comparatively more than 4f orbital, hence 5f electrons participate in bonding to a greater extent

Actinoids: Atomic and Ionic sizes

Due to **actinoid contraction**

Gradual decrease in the size of atoms or An^{3+} ions across the series

Oxidation States of Actinium and Actinoids

Oxidation states form regular pyramid

The actinoids resemble the lanthanoids in having more compounds in +3 state than in the +4 state.

Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
+3		+3	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3
	+4	+4	+4	+4	+4	+4	+4	+4						
		+5	+5	+5	+5	+5								
			+6	+6	+6	+6								
				+7	+7									

Actinoids : General Characteristics

Physical properties

Actinoid metals are all silvery in appearance but display a **variety of structures.**

Due to irregularities in metallic radii which are far greater than in lanthanoids

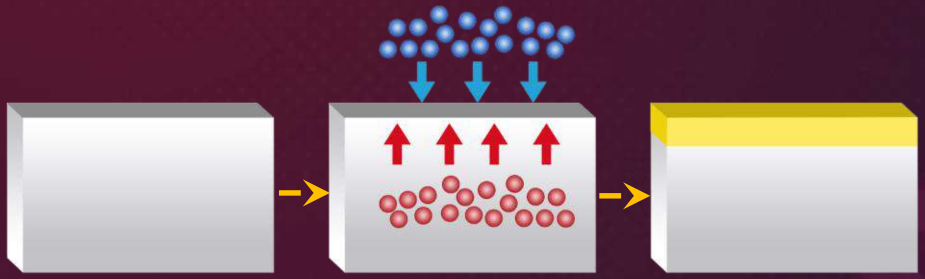
Actinoids : Chemical Properties

Actinoids are **highly reactive** metals

1	H_2O (Boil)	✓
2	Most non-metals	✓
3	HCl	✓
4	HNO_3	✗

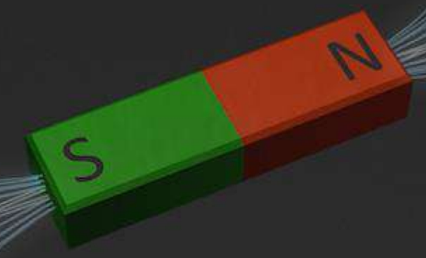
Hydrochloric acid attacks all metals but most metals are less affected by **nitric acid.**

Due to formation of **protective oxide layer**.



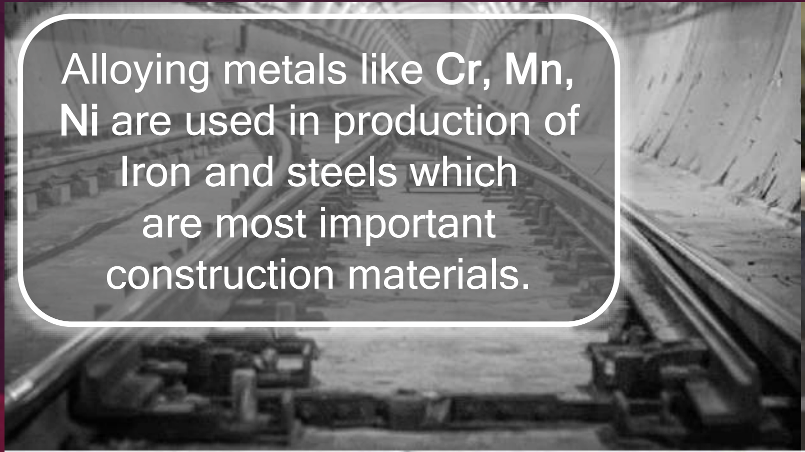
Actinoids : General Characteristics

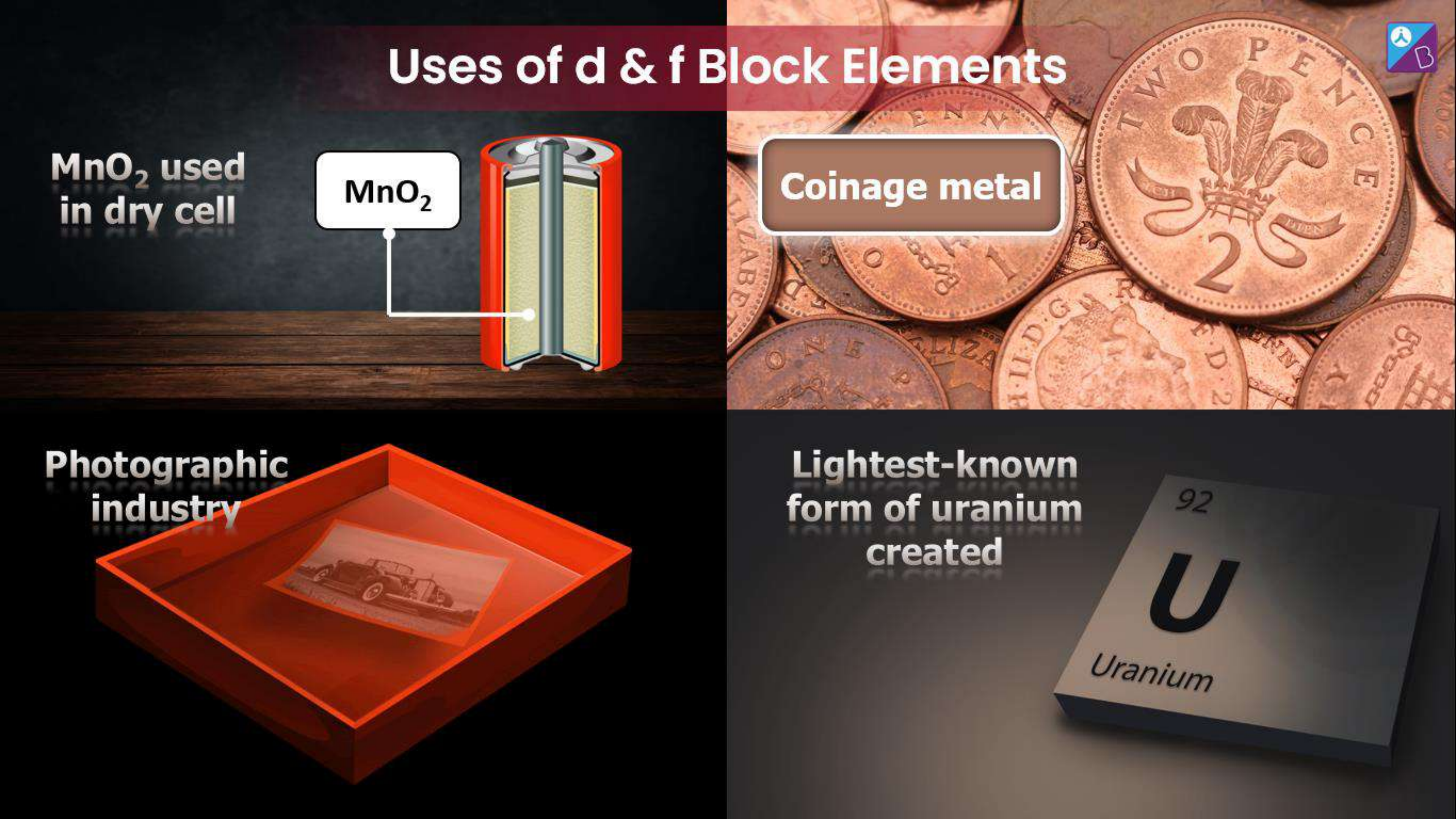
Magnetic properties



Ions are paramagnetic or diamagnetic depending upon the number of unpaired 5f electrons.

Uses of d & f Block Elements




Uses of d & f Block Elements
MnO2 used in dry cell
MnO2
Coinage metal
TWO PENCE
2
Photographic industry
Lightest-known form of uranium created
92
U
Uranium

Application as Catalysts

Important

Catalyst	Process
V_2O_5	Contact process
Ziegler catalyst [$TiCl_4$ with $Al(CH_3)_3$]	Polythene manufacturing
Iron	Haber process
Nickel	Hydrogenation of fats
$PdCl_2$	Wacker process
Nickel complex	Polymerisation of alkynes and benzene