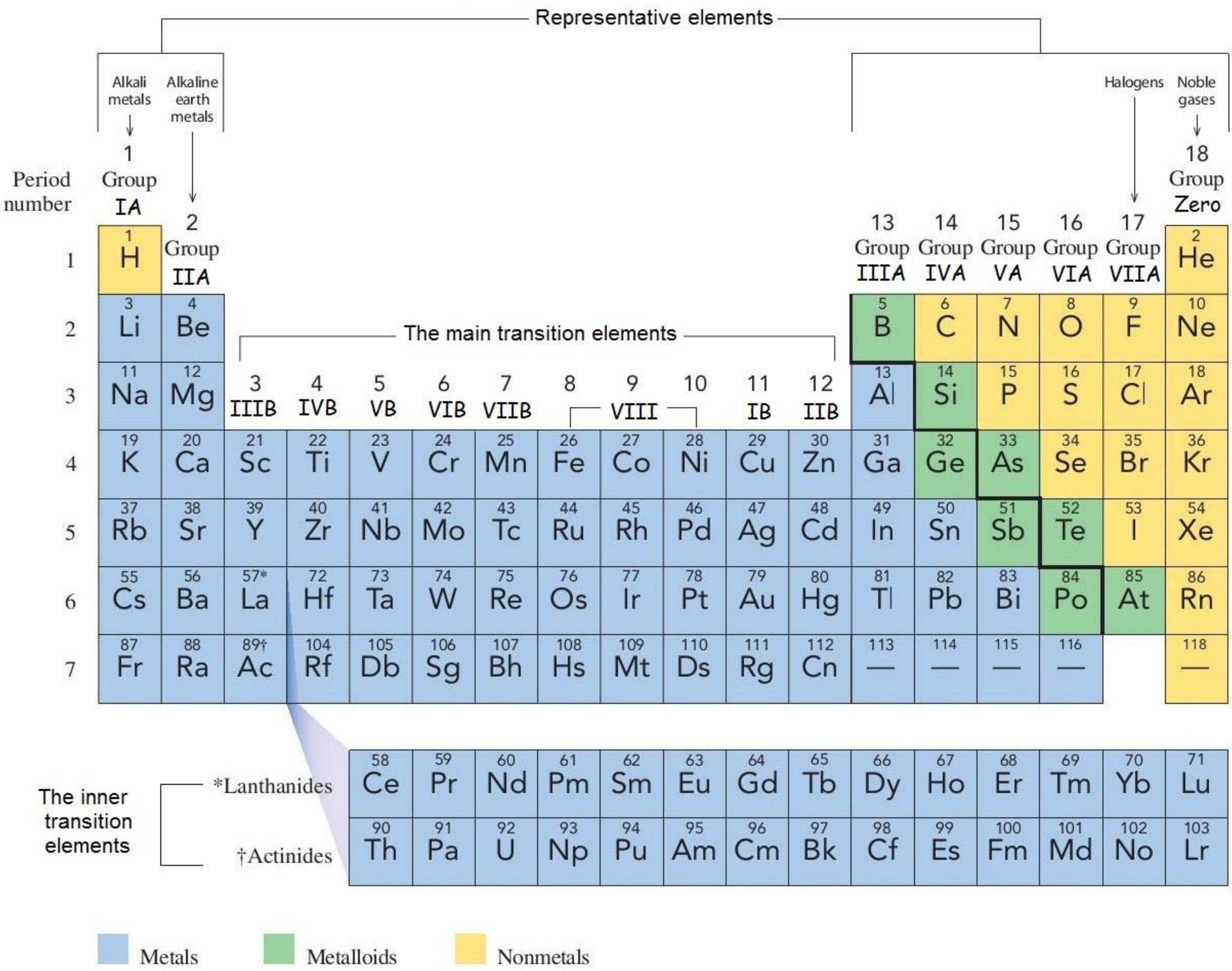
TRANSITION ELEMENTS

The periodic table consist of **4** blocks of elements **:**

- **(S & P) blocks :** they are called **" representative elements "** Which are found on both sides of the periodic table .
- **(d & f) blocks :** they are called **" Transition elements "** Which occupy the middle of periodic table between (**s**) and (**p**) blocks .



The Transition Elements in the periodic table :

- including more than 60 elements (more than half the number of elements in the periodic table)
- start appear from fourth period.

The Transition Elements divided into :

1- Main transition elements [elements of d-block] **(we will study it)**

2- Inner transition elements [elements of f-block]

The Main Transition Elements [elements of d-block]

- They occupy the middle block of the table which contains the elements with the outermost electrons occupying the (d) sublevel .

- they divided in the periodic table : **vertically** & **horizontally** :

Vertically

- the main transition elements contains **ten vertical columns** (G.R) as the d-sublevel can take up to ten electrons.

1- These columns starts from :

- The first columns which contains elements which are ended with ns^2 , $(n – 1)d^1$

Then the d-sublevel is filled gradually with electrons until reach to :

- The last columns which contains elements which are ended with ns^2 , $(n – 1)d^{10}$

2- These columns from left to right in the periodic table start with the Groups :

number of the Group	3B	4B	5B	6B	7B	8			1B	2B
	III B	IV B	V B	VI B	VII B	VIII			I B	II B
	3	4	5	6	7	8	9	10	11	12

3- Group (8) VIII : contain three vertical columns **8 , 9 , 10** which differing from other groups **B** (G.R)

bec. in these three groups , the similarity in properties between the horizontal elements is more than the vertical elements .

(or bec. their elements are similar horizontally more than vertically)

horizontally

The Main Transition Elements can be divided into **four series** which are :

1st transition series	2nd transition series	3rd transition series	4th transition series
placed in period 4	**Placed in period 5**	**Placed in period 6**	**Placed in period 7**
• elements in which the sublevel (**3d**) is filled successively.	• elements in which the sublevel (**4d**) is filled successively.	• elements in which the sublevel (**5d**) is filled successively.	• elements in which the sublevel (**6d**) is filled successively.
• **starts with :** **Scandium** $_{21}Sc$:[Ar] , $4s^2$, $3d^1$ • **ended with :** **Zinc** $_{30}Zn$:[Ar],$4s^2$,$3d^{10}$	• **starts with :** **Yttrium** $_{39}Y$:[Kr] , $5s^2$, $4d^1$ • **ended with :** **Cadmium** $_{48}Cd$:[Kr],$5s^2$,$4d^{10}$	• **starts with :** **Lanthanum** $_{57}La$:[Xe],$6s^2$, $5d^1$ • **ended with :** **Mercury** $_{80}Hg$:[Xe],$6s^2$,$4f^{14}$,$5d^{10}$	• **starts with :** **Actinium** $_{89}La$:[Rn],$7s^2$, $6d^1$ • **and in which the elements discovered gradually**
• consist of 10 elements	• consist of 10 elements	• consist of 10 elements	____

The first Transition Series

Group	III B	IV B	V B	VI B	VII B	VIII			I B	II B
Symbol	$_{21}Sc$	$_{22}Ti$	$_{23}V$	$_{24}Cr$	$_{25}Mn$	$_{26}Fe$	$_{27}Co$	$_{28}Ni$	$_{29}Cu$	$_{30}Zn$
Name	**Scandium**	**Titanium**	**Vanadium**	**Chromium**	**Manganese**	**Iron**	**Cobalt**	**Nickel**	**Copper**	**Zinc**
Wt %	**0.0026**	**0.66**	**0.02**	**0.014**	**0.11**	**5.1**	**0.003**	**0.0089**	**0.0068**	**0.0078**

NOTE

All of these elements form nearly **7 %** of the weight of earth's crust **,** but they have high economic importance **.**

Electronic configuration and oxidation states of the first transition series :

First :

Electronic configurations of the first transition series in atomic state

- elements of the first transition series are located in the 4th period after calcium $_{20}Ca$ whose electronic configuration is Ca_{20} : $[_{18}Ar]$, $4s^2$
- (3d) sublevel is filled with electrons in sequence by single electron in each orbital till manganese ($3d^5$) , after manganese the pairing of electrons takes place in each orbital till zinc ($3d^{10}$) [according to Hund's rule]

➲ **The general electronic configuration : $[_{18}Ar]$, $4s^2$, $3d^{1:10}$**

element	Electronic configuration	element	Electronic configuration
$_{21}Sc$	$[_{18}Ar]$, $4s^2$, $3d^1$	$_{26}Fe$	$[_{18}Ar]$, $4s^2$, $3d^6$
$_{22}Ti$	$[_{18}Ar]$, $4s^2$, $3d^2$	$_{27}Co$	$[_{18}Ar]$, $4s^2$, $3d^7$
$_{23}V$	$[_{18}Ar]$, $4s^2$, $3d^3$	$_{28}Ni$	$[_{18}Ar]$, $4s^2$, $3d^8$
$_{24}Cr^*$	$[_{18}Ar]$, $4s^1$, $3d^5$	$_{29}Cu^*$	$[_{18}Ar]$, $4s^1$, $3d^{10}$
$_{25}Mn$	$[_{18}Ar]$, $4s^2$, $3d^5$	$_{30}Zn$	$[_{18}Ar]$, $4s^2$, $3d^{10}$

<u>From the above table it is clear that</u> :

- the electron configuration of :

Cr_{24} is not [Ar] , $4s^2$, $3d^4$ ✗ but [Ar] , $4s^1$, $3d^5$ ✓

and

Cu_{29} is not [Ar] , $4s^1$, $3d^{10}$ ✗ but [Ar] , $4s^1$, $3d^{10}$ ✓

So Cr & Cu are anomalous from the expected electronic configuration (G.R)

in Cr atom 4s & 3d are half filled **but** in Cu atom 4s is half filled & 3d is completely filled :
That due to the atom has more stability (low energy) when 3d sublevel is half filled ($3d^5$) as in Cr atom **<u>or</u>** completely filled ($3d^{10}$) as in Cu atom.

NOTE

➲ the atom or ion becomes more stable (i.e. less energy) when (d) sublevel is :

- Empty (d^0)
- Half filled (d^5)
- Completely filled (d^{10})

➲ half or completely filling of a given sublevel is not the only factor that causes the stability of the atom.

Exercise 1 :

Explain : Why iron (II) ion Fe^{2+} is easily oxidized to iron (III) ion Fe^{3+}

While Mn (II) ion Mn^{2+} is difficult oxidized to Mn (III) ion Mn^{3+} ? (G.R)

Answer :

Fe : $[_{18}Ar]\ 4s^2, 3d^6$ $\xrightarrow[\text{oxidation}]{-2e^-}$ Fe^{2+} **:** $[_{18}Ar]\ , 3d^6$ $\xrightarrow[\text{oxidation}]{-e^-}$ $Fe^{3+} : [Ar]\ , 3d^5$

Fe^{2+}: [↑↓] [↑] [↑] [↑] [↑]

Fe^{3+}: [↑] [↑] [↑] [↑] [↑]

[half-filled (d^5)] more stable

Bec. Fe^{3+} ion is more stable as the 3d sublevel is half-filled ($3d^5$) **,**

so Fe^{2+} ion is easily oxidized to Fe^{3+} ion

as the reaction goes toward the formation of more stable compound.

While in case of manganese :

$_{25}$**Mn :** $[_{18}Ar]\ , 4s^2, 3d^5$ $\xrightarrow[\text{oxidation}]{-2e^-}$ Mn^{2+} **:** $[_{18}Ar]\ , 3d^5$ $\xrightarrow[\text{oxidation}]{-e^-}$ Mn^{3+} **:** $[_{18}Ar]\ , 3d^4$

Mn^{2+}: [↑] [↑] [↑] [↑] [↑]

Mn^{3+}: [↑] [↑] [↑] [↑] [ ]

[half-filled (d^5)] more stable

Bec. Mn^{2+} ion is more stable as the (3d) sublevel is half-filled ($3d^5$) **,**

so Mn^{2+} ion is difficult oxidized to Mn^{3+} ion

as the reaction goes toward the formation of more stable compound.

don't forget that :

Oxidation process	Reduction process
Process of losing electrons & increasing +ve charge	Process of gaining electrons & decreasing +ve charge

Second :

Oxidation state of the first transition series

Group no.	III B	IV B	V B	VI B	VII B	VIII			I B	II B
Element	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
Oxidation states	Sc^{3+}	Ti^{2+} Ti^{3+} Ti^{4+}	V^{2+} V^{3+} V^{4+} V^{5+}	Cr^{2+} Cr^{3+} Cr^{4+} Cr^{5+} Cr^{6+}	Mn^{2+} Mn^{3+} Mn^{4+} Mn^{5+} Mn^{6+} Mn^{7+}	Fe^{2+} Fe^{3+} Fe^{4+} Fe^{5+} Fe^{6+}	Co^{2+} Co^{3+} Co^{4+} Co^{5+}	Ni^{2+} Ni^{3+} Ni^{4+}	Cu^{1+} Cu^{2+}	Zn^{2+}

From the above table it is clear that :

[1] all elements of the first transition series have oxidation state (+2) by losing the two electrons of (4s) sublevel at the first (the farthest sublevel from the nucleus) while in the higher oxidation states they lose the electrons of (3d) gradually .

[2] scandium cannot give oxidation state (+2) but only (+3) (G.R)

$$_{21}Sc : [Ar] , 4s^2 , 3d^1 \xrightarrow[\text{oxidation}]{-3e^-} Sc^{3+} : [Ar]$$

due to it loses the 3 electrons of (4s & 3d) sublevels at once to reach empty (d) sublevel to be more stable .

[3] the oxidation states increases from scandium (3+) in group III B till reach a maximum (7+) in manganese in group VII B , after that the oxidation states decreases gradually till reach (+2) in zinc in group II B

NOTE

we find that the maximum oxidation state of any element not exceed the number of its group in periodic table except for the elements of group I B which contains [Cu , Ag & Au] they give the oxidation state (2+) .

Oxidation States

- **The transition metals** are characterized by variable oxidation states (G.R)

  bec. 4s and 3d subleves are very close in energy **,** so when atom of transition element oxidized **,** the atom loses the electrons from (4s) then (3d) in sequence

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Scientific evidence is : ionization potentials for the transition elements increases gradually.

Example :-

the graduation of the ionization potentials & oxidation states in $_{23}V$ & $_{21}Sc$.

V	$-e^-$	V^{1+}	$-e^-$	V^{2+}	$-e^-$	V^{3+}	$-e^-$	V^{4+}
[Ar] $4s^2,3d^3$	648 kj	[Ar] $4s^1,3d^3$	1364 kj	[Ar],$3d^3$	2858 kj	[Ar],$4s^0,3d^2$	4643 kj	[Ar] ,$4s^0,3d^1$

Sc	$-e^-$	Sc^{1+}	$-e^-$	Sc^{2+}	$-e^-$	Sc^{3+}	$-e^-$	Sc^{4+}
[Ar] $4s^2,3d^1$	631 kj	[Ar] $4s^1,3d^1$	1235 kj	[Ar],$3d^1$	2389 kj	[Ar]	7130 kj	$1s^2,2s^2,2p^6,3s^2,3p^5$

- **scandium cannot give oxidation state (+4) ?**
- **cannot obtained Sc^{4+} by chemical reaction under normal conditions ?** (G.R)

  Bec. that causes a breaking of energy level completely filled with electrons .

- While **The representative metals** (s-block & p-block) have only one oxidation state Like sodium that is Na^{+1} **,** magnesium Mg^{2+} **,** and aluminum Al^{3+} and it is difficult to obtain Na^{2+} , Mg^{3+} and Al^{4+}

Scientific evidence is : the increasing in the second ionization potential of sodium and the third of magnesium and the fourth of aluminum is very high.

Example :-

the graduation of the ionization potentials & oxidation state in $_{13}Al$.

Al	$-e^-$	Al^{1+}	$-e^-$	Al^{2+}	$-e^-$	Al^{3+}	$-e^-$	Al^{4+}
[Ne] $3s^2,3p^1$	578 kj	[Ne] $3s^2$	1811 kj	[Ne] $3s^1$	2745 kj	[Ne]	11540 kj	$1s^2,2s^2,2p^5$

- **Na^{2+} , Mg^{3+} or Al^{4+} cannot be obtained by the chemical reaction under normal conditions** (G.R)

  Bec. the increasing in the second ionization potential of Na and the third of Mg and the fourth of Al is very high **due to** that causes a breaking of energy level completely filled with electrons.

Now : Transition element can be defined as follows :

The transition element :

it is the element in which the orbitals of **d** or **f** sublevels occupied with (contain) electrons but incompletely filled in atomic state or in any one of its oxidation states .

Exercise 1 :

can we consider the coinage metals (element of group IB) as transition elements ?

Answer :

Yes , they are transition elements (G.R)

Because the (d) sublevel is completely filled with electrons (d^{10}) in their atomic state **,** but in the oxidation state (2+) or (3+) the sublevel (d) will be incompletely filled (d^9) or (d^8) .

Atomic state		Oxidation state
$_{29}Cu$: [Ar] $4s^1$, $3d^{10}$	$\xrightarrow{\text{Oxidation}(-2e^-)}$	Cu^{2+} : [Ar] $4s^0$, $3d^9$
$_{49}Ag$: [Ar] $5s^1$, $4d^{10}$	$\xrightarrow{\text{Oxidation}(-2e^-)}$	Ag^{2+} : [Kr] $5s^0$, $4d^9$
$_{79}Au$: [Ar] $6s^1$, $4f^{14}$, $5d^{10}$	$\xrightarrow{\text{Oxidation}(-2e^-)}$	Au^{2+} : [Xe] $6s^0$, $4f^{14}$, $5d^9$

Exercise 2 :

can we consider the metals zinc , cadmium and mercury (metals of group II B) as transition elements ?

Answer :

No , they aren't transition elements (G.R)

Because the (d) sublevel is completely filled with electrons (d^{10}) in both their atomic state and in oxidation state (+2) .

Atomic state		Oxidation state
$_{30}Zn$: [Ar] $4s^2$, $3d^{10}$	$\xrightarrow{\text{Oxidation}(-2e^-)}$	Zn^{2+} : [Ar] $4s^0$, $3d^{10}$
$_{48}Cd$: [Kr] $5s^2$, $4d^{10}$	$\xrightarrow{\text{Oxidation}(-2e^-)}$	Cd^{2+} : [Kr] $5s^0$, $4d^{10}$
$_{80}Hg$: [Xe] $6s^2$, $4f^{14}$, $5d^{10}$	$\xrightarrow{\text{Oxidation}(-2e^-)}$	Hg^{2+} : [Xe] $6s^0$, $4f^{14}$, $5d^{10}$