The transition elements

We studded in the second year elements of (s) and (p) blocks which are found on both sides of the long form of periodic table, now we'll study the transition elements which occupy the middle of the periodic table between(s) and (p) blocks. Including more than 60 elements

i.e. more than half the number of known elements.

These elements can be classified into:

1. Main transition elements.

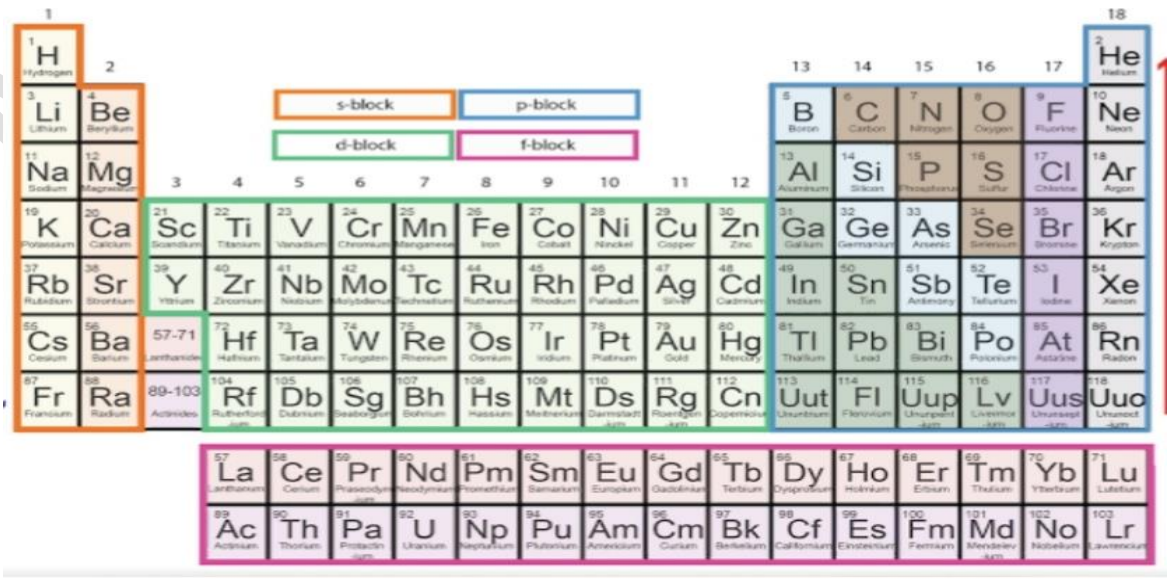
2. Inner transition elements.

But we'll study the main transition elements only.

- The Main transition elements (elements of d-block):

In the main transition elements electrons occupy the d sublevel in sequence Since the d-sublevel can take up to ten electrons, it contains ten vertical columns. These columns starts from The first column which contains all elements that have electronic configuration end with $ns^2,(n-1)d^1$ to the last column which ends with $ns^2,(n-1)d^{10}$ in which the d sublevel is filled in sequence.

These columns from left to right of the periodic table starts with the groups (3) IIIB. (4) IVB. (5)VB. (6)VIB. (7)VIIB and (8)VIII which contain three vertical column (8),(9),(10) which are different from the other transition elements of (B) groups in their properties, in which these elements are similar **horizontally** more than the elements below in the same column. Then followed by 1B (11) and 2B (12) that is not considered from one point of view as transition elements.



These elements can be classified to four horizontal series which are:

1-The first transition series:

It includes the elements in which the sublevel (3d) is filled successively. They are found in the fourth period after calcium and consists of ten elements start from scandium Sc ($4s^2$, $3d^1$) and ended with zinc Zn ($4s^2$,$3d^{10}$).

2-The second transition series

It includes the elements in which the sublevel (4d) is filled successively. They are found in the fifth period and consist of ten elements start with yttrium,Y ($5s^2$,$4d^1$) and ended with cadmium Cd ($5s^2$,$4d^{10}$).

3-The third transition series:

It includes the elements in which the sublevel (5d) is filled successively. They are found in the sixth period and consist of ten elements start with lanthanum ($6s^2$,$5d^1$)and ended with Mercury Hg ($6s^2$,$4f^{14}$,$5d^{10}$).

4. The fourth transition series :

It includes the elements in which the sublevel (6d) is filled successively. They are found in seventh period..

The First Transition Series

This series contains ten elements which are scandium (Sc), titanium (Ti) ,vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu) and zinc (Zn).

The following table represents the percent of each transition element in the earth's crust

element	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
weight%	0.0026	0.66	0.02	0.014	0.11	5	0.003	0.0089	0.0068	0.0078

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

1-Scandium

- It is found in very small amount spread on a large area in the earth's crust.
- On adding a little amount of scandium to aluminum it gives light and very hard alloy used in manufacture of Mig fighter jets.

- It is added to Mercury-vapour lamps to produce light with high quality looks like sun light, so it is used in TV Photography at night.

2- Titanium

- Strong element of rigidity as steel but it is less denser than steel.
- Its alloys with Aluminum are used in the manufacture of aircraft and space shuttle because it maintains its durability at high temperatures while the hardness of aluminum decreases.
- It is used in the dental implants and artificial joints, because it is inert substance so the body does not eject it and does not cause any type of poisoning.
- From the famous Titanium compound: Titanium dioxide (TiO_2) that is used in Sun protection cosmetics, where minute nanoparticles prevent effect of the UV on the skin.

3-Vanadium

- When we add a small portion of it to the steel, a high hardness alloy is formed and has great ability to resist corrosion so it is used in the manufacture of car springs.
- From the important compounds of vanadium:
  - Vanadium penta oxide (V_2O_5) used in manufacture of dyes used in ceramics and glass industry also is used as a catalyst and manufacture of strong magnetic conductors.

4-Chromium

- It is chemically active metal but it resist the effect of the atmospheric air due to the formation of a larger metal oxide on its surface in which the molecular volume of the produced oxide is larger than that of the metal atoms which forms a nonporous layer of metal oxide that prevent the continued interaction with oxygen of air ***(passivity)***.
- It is used in metal plating and leather tanning.
- From the important compounds of chromium:
  - Chromium III oxide (Cr_2O_3) that used in manufacture of dyes.
  - Potassium dichromate ($K_2Cr_2O_7$) that used as oxidizing agent.

5-Manganese

- Manganese is not used as a pure metal because it is brittle metal so always used as alloys or compounds.
- Ferromanganese alloy is used in railway track, because it is harder than steel.
- Aluminum and manganese alloys are used in manufacture of Soft drinks vessels (cans) because it resists corrosion.
- The important compounds of manganese:

- Manganese dioxide (MnO_2) which acts as strong oxidizing agent used in dry cells
- Potassium permanganate ($KMnO_4$) that is used as antiseptic substance.
- Manganese II sulphate ($MnSO_4$) that is used as a fungicide.

6-Iron

- Used in manufacture of reinforced concrete.
- Electricity pylons.
- Knifes.
- Gun and cannons pipes.
- Surgical tools.
- Also used as a catalyst in the manufacture of ammonia by Haber-Bosch method.
- The conversion of water gas (mixture of hydrogen and carbon monoxide) to a fuel by Fischer-Tropsch method.

7-Cobalt

- It is similar to iron in which both of them can be magnetized so they are used in the manufacture of magnets.
- Cobalt is used in manufacture of modern dry batteries that used in cars.
- Cobalt has twelve radioactive isotopes, cobalt 60 is very important one because it produces gamma rays which have high penetrating power so it is used in food preserving processes.
- Used for the detection of the quality of the industrial products, and to detects cracks and welding connections.
- In medicine used for diagnosis and treatment tumors.

8- Nickel

- It is used in the manufacture of nickel - cadmium battery which can be recharged.
- It forms with steel alloys which are hard and resist rust and the effect of acids.
- Nickel chromium alloys are used in heating coils and electric furnaces because they resist corrosion at high temperature.
- It is used for panting the other metals to protect them from oxidation and rust and give these metals beautiful appearance.
- Divided nickel is used as a catalyst like in hydrogenation processes of oil.

9-Copper

- Copper is the first discovered metal.
- Copper tin alloys are known as bronze alloy.
- Copper is good conductor of electricity so it is used in electric cables and coins industry.

- Copper II sulphate ($CuSO_4$) is used as insecticide and fungicide in the purification of water.
- Fehling solution (one of copper compounds)is used to detect glucose in which its blue colour changes to orange.

10-Zinc

- It is used in the galvanizing other metals to protect them from rusting.
- From its compounds:
  - Zinc oxide (ZnO) is used in the manufacture of paints , rubber and cosmetics.
  - zinc sulphide (ZnS) is used in manufacture of illuminating paints and X-ray screens

Electronic Configurations and Oxidation states

The following table represents the electron configuration of the elements of the first transition series and their common oxidation states.(for illustration only)

The element	The group	The electron configuration	oxidation states	Some of the compounds
$_{21}Sc$	IIIB	$[Ar],4s^2,3d^1$	3	Sc_2O_3
$_{22}Ti$	IVB	$[Ar],4s^2,3d^2$	2 ,3 ,4	TiO_2, Ti_2O_3, TiO
$_{23}V$	VB	$[Ar],4s^2,3d^3$	2,3,4,5	V_2O_5 , VO_2 , V_2O_3 , VO
$_{24}Cr$	VIB	$[Ar],4s^1,3d^5$	2 ,3 ,6	CrO_3 , Cr_2O_3 , CrO
$_{25}Mn$	VIIB	$[Ar],4s^2,3d^5$	2,3,4,6,7	MnO_2 , Mn_2O_3 , MnO $KMnO_4$, K_2MnO_4
$_{26}Fe$	VIII	$[Ar],4s^2,3d^6$	2 ,3, 6	Fe_2O_3 , FeO
$_{27}Co$	VIII	$[Ar],4s^2,3d^7$	2,3,4	, $CoCl_3$, $CoCl_2$
$_{28}Ni$	VIII	$[Ar],4s^2,3d^8$	2, 3, 4	NiO_2 ,Ni_2O_3 ,NiO
$_{29}Cu$	IB	$[Ar],4s^1,3d^{10}$	1, 2	CuO ,Cu_2O
$_{30}Zn$	IIB	$[Ar],4s^2,3d^{10}$	2	ZnO

N.B. The oxidation state underline is the most stable one

1- The elements of the first transition series is located in the fourth period after calcium Ca its electronic configuration is $[Ar_{18}],4s^2$. After that there is a gradual filling of the five orbitals of (3d) sublevel by single electron in each orbital in sequence till manganese ($3d^5$). After manganese pairing of electrons takes place in each orbital till zinc ($3d^{10}$) (**Hund's rule**).

2- Chromium and copper are different from the expected electronic configuration as their configurations are ,Cr (Ar_{18}), $3d^5$, $4s^1$ and copper Cu (Ar_{18}), $3d^{10}$, $4s^1$, in these elements we find that their outer most sublevel 4s and 3d in chromium atom are half

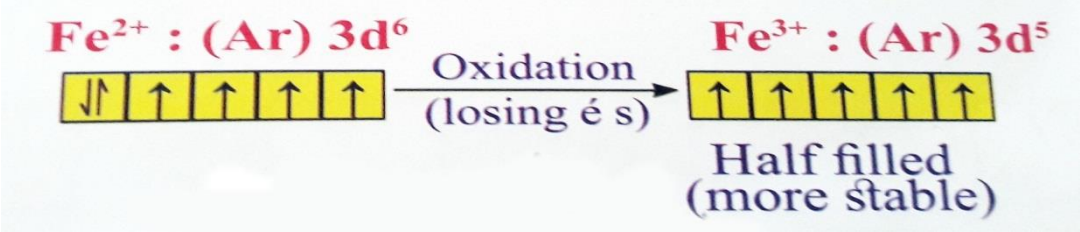
filled while in copper 4s is half filled but 3d is filled, this explain that the atom has low energy this means that it has extra stability when the outer most sublevel half filled(d) or filled (d) but this is not the only main factor that causes the stability of the atom.

Exereise:

Explain why iron (II) is easily oxidized to iron (III) whereas Mn (II) is not readily oxidized to Mn (III) ?

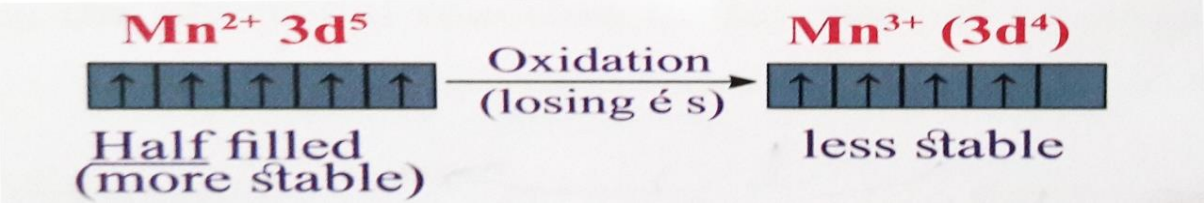
Solution :

The electronic configuration of an iron atom is :Fe_{26}: [Ar],$3d^6$, $4s^2$



Iron (III) ion is more stable as the 3d sublevel is half-filled $3d^5$ it is more stable so the reaction goes toward the formation of the more stable compound.

But in case of manganese atom the electronic configuration is Mn_{25}: -[Ar],$3d^5$,$4s^2$



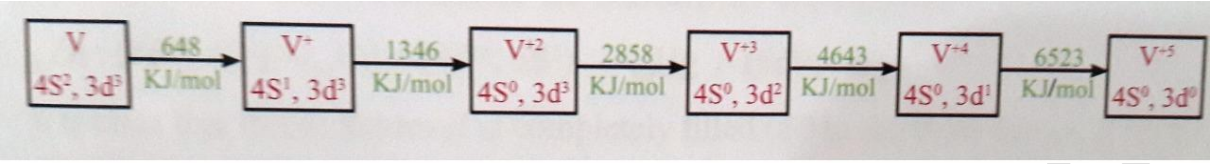
We find that the 3d sublevel is half-filled $3d^5$ in Mn^{+2} ion so it is more stable than Mn (III) ion then Mn^{+2} ion is not readily oxidized to Mn^{+3} ion.

3- All elements of the first transition series have oxidation state (+2) after losing the electrons of (4S) sublevel at first(**except for scandium**).while in the higher oxidation states they lose the electrons of (3d) in sequence.

4- The oxidation states increase from scandium to manganese which has the highest oxidation state (+7) in group VIIB, after that the oxidation states decreases gradually to be (+2) in zinc in group IIB, from the previous we find that the maximum oxidation state not exceed its group number except for the group **IB** that contains copper, silver and gold.

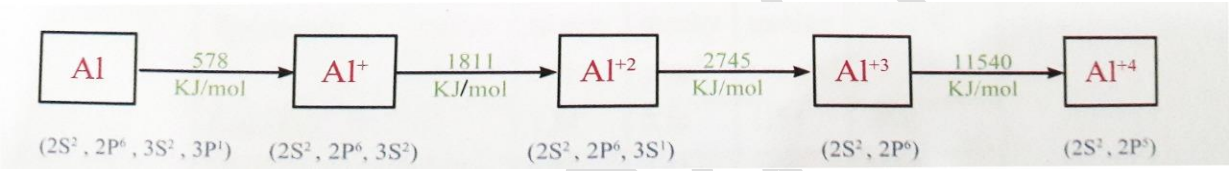
5- **G.R**: The main transition elements are characterized by several oxidation state (*while in the representative metals have one oxidation state*)?

Ans when the atom of the main transition elements oxidized by losing electrons from 4s and 3d sublevels in sequence(which are close in energy) therefore the ionization potentials for the transition element increases gradually as its shown in ionization potential in kilojoule/mole



successive of oxidation states in vanadium.

While in the representative metals like sodium, magnesium and aluminum, the increasing in the second ionization potential of sodium and the third of magnesium and the fourth of aluminum is very high due to breaking a complete energy level so it is difficult to obtain Na^{+2} or Mg^{+3} or Al^{+4} during the chemical reaction under normal conditions.



6- From the previous a general definition for the transition element can be obtained as follows: The transition element it is the element in which the orbitals of **d** or **f** occupied with electrons but **not completely filled** either in its atomic state or in one of its oxidation states.

Exercise: 1

Can **coinage metals** which are Cu (3^{10} 4s'), Ag ($4d^{10}$ $5s^1$) and Au ($5d^{10}$ 6s') be considered as transition elements?

Solution :

It is clear that the(d) sublevel is completely filled (d^{10}) in the three metals in the atomic state, but in the oxidation state (+2) or (+3) the sublevel (d) will be **partially filled** (d^9) or (d^8) ,so they are transition elements..

Exercise:2

Are the metals zinc, cadmium and mercury be consider as transition elements?

Zn ($4s^2$, $3d^{10}$) - Ca ($5s^2$, $4d^{10}$) - Hg ($6s^2$, $5d^{10}$)

Solution:

It is clear that the (d) sublevel is completely filled (d^{10}) in the three metals in **both** atomic state and oxidation state (+2 ion) so they are not transition elements.

The general properties of the first transition elements

The following table shows some spatial data for elements of this group which indicates their general properties by which these elements are characterized as following:

(the table for illustration only)

The element	The atomic mass	The atomic radius	The density g/cm^3	The melting point ^oC	The boiling point ^oC
Scandium Sc	45	1.44	3.10	1397	3900
Titanium Ti	47.9	1.32	4.42	1680	3130
Vanadium V	51	1.22	6.07	1710	3530
Chromium Cr	52	1.17	7.19	1890	2480
Manganese Mn	54.9	1.17	7.21	1247	2087
Iron Fe	55.9	1.16	7.87	1538	2800
Cobalt Co	58.9	1.16	8.70	1490	3520
Nickel Ni	58.7	1.15	8.90	1492	2800
Copper Cu	63.5	1.17	8.92	1083	2582

1. **The atomic mass:**

   It increases gradually with increasing their atomic number**.** *but nickel is abnormal because it has five stable isotopes with average mass 58.7 u*

3- **Atomic radius:**

Its noticed that there is a little change in atomic radii as we move through first transition series, Its also noticed that atomic radius is *nearly constant from (Cr) to (Cu) this is due to two opposite factors:*

a- The first factor causes decreasing in the atomic radius with increasing atomic number: where the effective nuclear charge for these elements increases and also number of electrons in the atom increases from (Sc) to (Cr) so the nuclear attraction to electrons increases which cause decrease the atomic radius.

b- The second factor causes increasing the atomic radius: The increasing in the number of the electron in 3d sublevel will increase the repulsion force between them.

As a result of these two **opposite factors**, atomic radii of these elements are relatively **constant** which explains using them in making alloys.

4- **The Metallic property:**

a- All of them are solid, having metallic luster and good conductivity of heat and electricity.

b- They have high melting and boiling points, due to the strong metallic bond which is formed due to the sharing of both 4s and 3d electrons in the formation of this bond.

c- Most of them have high density which increases with the increasing in the atomic number because the atomic size is relatively constant with increase atomic mass.

d- There is variation in their activity of these elements - as copper has limited chemical activity, and some are moderate like iron that goes rusty if it exposed to air and some are highly active like scandium which replaces hydrogen of water strongly.

5- **The Magnetic properties** :

a-Paramagnetic property, which appear in the ions or atoms or molecules that have unpaired electrons in their orbitals (↑), which forms a magnetic field due to its spinning. Attracting external magnetic field.

The paramagnetic substance is known as the substance that attracts to the external magnetic field, due to the presence of unpaired electrons, the magnetic moment of the paramagnetic substances increases with the increasing in the number of the unpaired electrons.

(most of compounds of the transition elements are paramagnetic.)

b- Diamagnetic property which appear in the substances having all orbitals are paired with electrons (so their magnetic moment equal zero due to opposite spin motion of every paired electrons

Diamagnetic substance is the substance that repel the external magnetic field, due to Pairing of all its electrons

Exercise:

Which of the following substances is paramagnetic and which is diamagnetic?

$Zn(d^{10})$, Cu (II) ion (d^9), iron (II) chloride (d^6).

Write the order of the moment of these substances.

Answer:

Electronic configuration of (d) sublevel	number of unpaired electron	Magnetic property
$Zn(d^{10})$	0	diamagnetic
$Cu^{+2}(d^9)$	1	paramagnetic
$Fe^{+2}(d^6)$	4	paramagnetic

*The magnetic moments of the substance can be measured by the number of unpaired electrons. the measure of magnetic moments of the substance indicate the number of unpaired electrons and the electronic configuration of the metal ion:

Exercise:

Re arrange the following cations in ascending order according to their magnetic moment: $FeCl_3$, CrO_2,$CuCl_2$, TiO_2. Answer: check the answer in the video .

6- Catalytic activity :

Transition elements are considered as ideal catalyst.

- Finally divided Nickel is used as catalyst like in the hydrogenation process.
- divided iron is used as a catalyst in the preparation of ammonia gas by Haber - Bosh method.

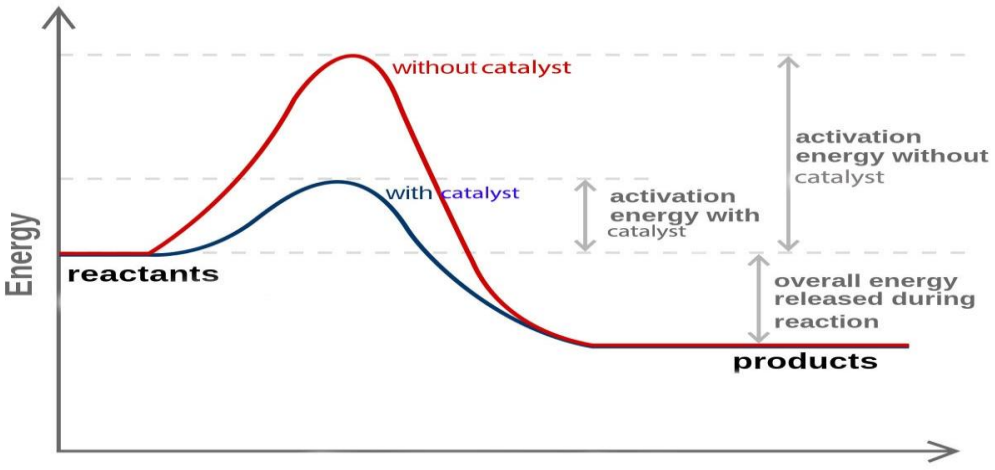
$$N_2(g) + 3H_2 \xrightarrow[Fe]{500^\circ C / 200\ atm} 2NH_3$$

Vanadium pent oxide V_2O_5 is used as a catalyst during the preparation of sulphuric acid by the contact method.

$$2SO_2(g) + O_2(g) \xrightarrow[450^\circ C]{V_2O_5} 2SO_3(s)$$

$$SO_3(s) + H_2O(L) \longrightarrow H_2SO_4(aq)$$

(Effect of MnO_2 as a catalyst in decomposition of H_2O_2)



$$2H_2O_2 \xrightarrow{MnO2\ (catalyst)} 2H_2O + O_2$$

-The catalytic activity of the metals of the first transition series refers to presence of the 4S and 3d-electrons

-which can be used in the formation of bonds between the atoms of the surface of metal and the reacting molecules

-leading to the increase of concentration of these molecules on the surface of the catalyst weaken the bond in the reactant molecules

-and so decreases the activation energy which help to increase speed of reaction.

6- Coloured ions:

Most of the compound of transition elements and their aqueous solutions are coloured,

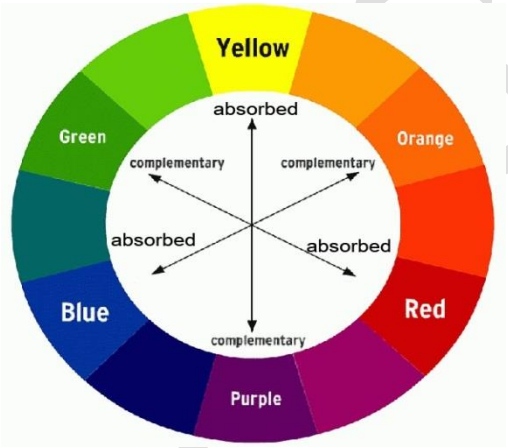
Explanation of the colour in materials: The colour is formed due to the absorption of some photons in the area of visible light.Eye see only the remained colour (reflected) which is a mixture of some colours,

if the substance absorb no light colour it appears white.

If the substance absorb all visible light colour it appears black to eye

If the substance absorbs certain colour its colour appears by the complementary colour.

The following figre shows the absorbed colour and its complementary (the reflected colour) Ex. **Chromium (III)** compounds absorb red colour so it appears green.



As in the vedio:

R ⟷ G

O ⟷ B

Y ⟷ ؟V

The relation between colours of transition elements ion and their electronic configuration some are colourless if the non-transition elements contain orbitals of d empty (d^0) or completely filled (d^{10}).

Then we can conclude that the colour in the transition elements ions is due to partially filling of the orbitals of d sublevel (1 - 9 electrons) i e, due to the presence of the **unpaired electrons in d sublevel**.