Chapter # 2

CHEMISTRY OF OUTER TRANSITION ELEMENTS

INTRODUCTION

- The elements that possess partially occupied d-orbitals, either in their atomic state or any of their ionic states, are commonly referred as outer transition elements or d-block elements.
- These elements are positioned in the middle section of the periodic table and are recognized for their intermediate characteristics between s-block and p-block elements.
- The elements are called d-block elements because they possess partially filled d-electrons in their valence shell.
- These elements hold considerable significance across numerous domains of chemistry and industries due to their versatile oxidation states, catalytic activity, alloy forming ability, colour, complex forming ability, magnetic behavior and electrical conductivity.
- The unique electronic structure and broad range of oxidation states exhibited by these elements make significant contributions to the advancement of technology in industry and various scientific fields.
- There are total four series of d-block elements found in the 4th, 5th, 6th and 7th periods.

3d- series:

- ✓ This ten elements series is located in the 4th period. It includes elements from scandium (Sc) to zinc (Zn).

4d - series:

- ✓ This series is placed in 5th period and consists of elements from yttrium(Y) to cadmium (Cd).

5d– series:

- ✓ This series is situated in the sixth period and consists of elements from lanthanum (La) to mercury (Hg).

6d- series:

- ✓ This series consists of elements from actinium (Ac) to copernicium (Cn).

Elements	Sc	T	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
Atomic No. (z)	21	22	23	24	25	26	27	28	29	30
Atomic size (pm)	144	132	122	117	117	117	116	115	117	125
1st ionization potential (KJ/mol)	632	661	648	653	716	762	757	736	745	908
Melting Point (°C)	1539	1668	1760	1875	1245	1535	1480	1452	1083	419
Boiling point (°C)	3900	3130	3000	2480	2087	2450	2900	2900	2310	907
Electronegativity	1.3	1.5	1.6	1.6	1.5	1.8	1.8	1.8	1.9	1.6

Electronic Structure

d-block elements have valence electrons both in outer most and second outer most shells (penultimate) therefore the general valence electronic configuration of these elements is represented by **ns^2, $(n-1)d^1$ till ns^2, $(n-1)d^{10}$**, where "n" is the outermost shell and n-1 is the penultimate shell.

Binding Energy

The amount of energy required to separate the constituents of a bound system, such as atoms, nuclei, or particles.

- It represents the strength of the attractive forces holding the system together.
- The d-block elements have partially filed d orbitals, which contribute to their unique properties.
- Their binding energy is higher than that of other elements due to the strong attraction to their outermost d electrons.
- The binding energy increases across a period from left to right in the d-block elements due to increasing nuclear charge and decreasing atomic radius.
- The stronger positive charge attracts the d electrons more, requiring more energy to remove them.
- Down a group, the binding energy tends to decrease in the d-block elements.
- This is because the increasing atomic size and shielding effect reduce the effective nuclear charge felt by the outermost d electrons, making them easier to remove.

Variable Oxidation States

- The variable oxidation states displayed by transition elements are recognized as one of their distinctive properties.
- The oxidation states of transition metal ions are in the range of +1 to +7.
- This variation is due to very small energy difference between 3d and 4s orbitals".

Elements	Outer Electronic Configuration	Oxidation States
Scandium (Sc)	$1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 3d^1, 4s^2$	+2, +3
Titanium (Ti)	$1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 3d^2, 4s^2$	+2, +3, +4
Vanadium (V)	$1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 3d^3, 4s^2$	+2, +3, +t4, +5
Chromium (Cr)	$1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 3d^5, 4s^1$	+1, +2, +3, +4, +5, t6
Manganese (Mn)	$1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 3d^5, 4s^2$	+2, +3, t4, +5, +6, +7
Iron (Fe) [Ar	$1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 3d^6, 4s^2$	+2, +3, +4, +5, +6
Cobalt (Co)	$1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 3d^7, 4s^2$	+2, +3, +4
Nickel (Ni)	$1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 3d^8, 4s^2$	+2, +3, +4
Copper (Cu)	$1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 3d^{10}, 4s^1$	+1, +2

Zinc (Zn)	$1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 3d^{10}, 4s^2$		+2

Catalytic Activity

Most of the transition elements and their compounds serve as catalysts in numerous chemical splitting reactions

The property of transition metals to serve as catalyst can be explained by the following factors.

(i) Transition elements have variable oxidation states. They can easily withdraw or lend electrons from the reagent to form unstable intermediate which then changes into the final product.

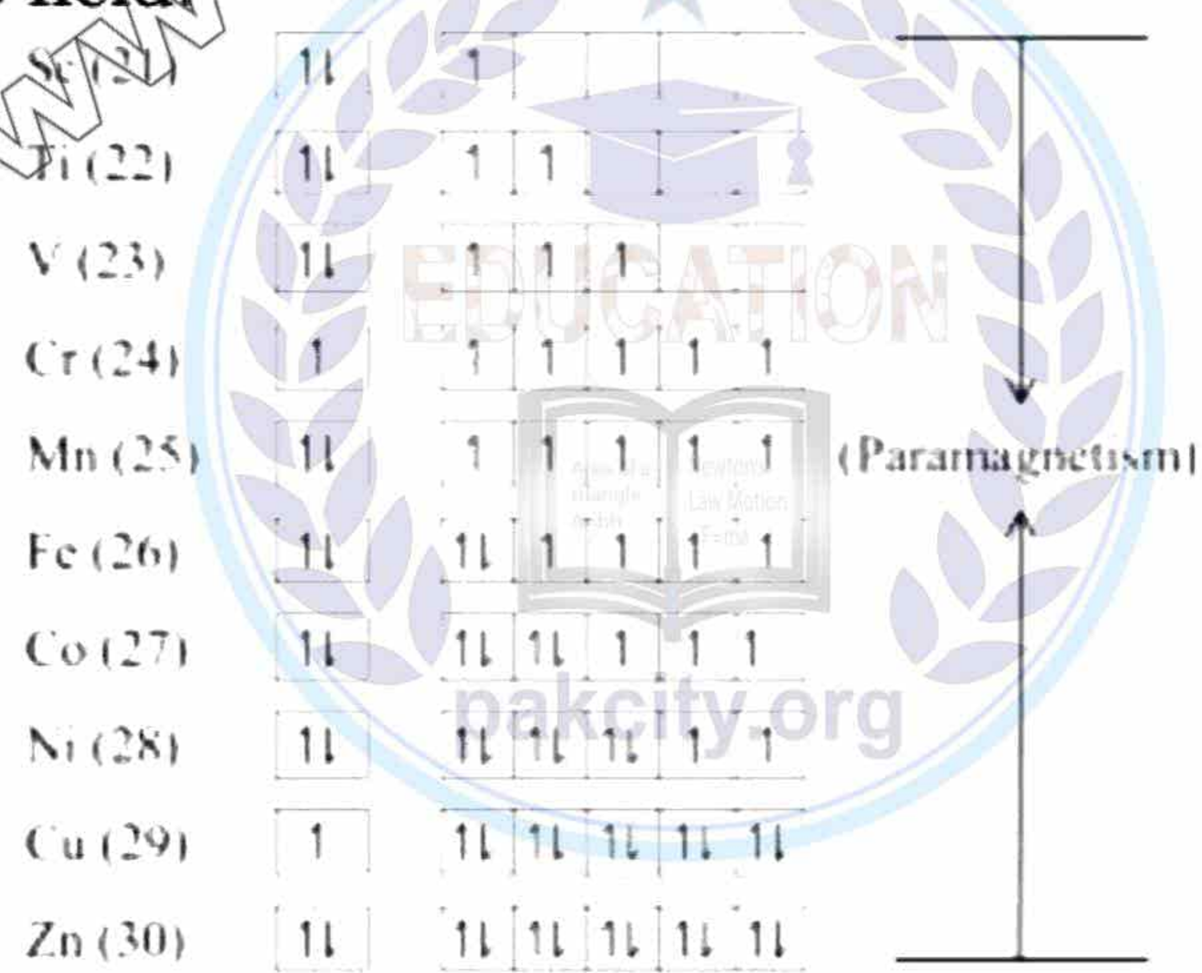
(ii) The surfaces of transition metals offer many active sites where reactant molecules can adsorb.

Magnetic Behavior

Atoms, ions or molecules when exposed to a strong external magnetic field, exhibit two distinct behaviors, either they are weakly attracted or repelled by the magnetic field.

The substances that are attracted by the magnetic field are called paramagnetic substances and those which are repelled by magnetic field are known as diamagnetic substances".

Most of the transition elements and their ions show paramagnetic behavior. This is due to the fact that d-orbitals of these elements possess one or more unpaired electrons and the spinning of unpaired electrons generates a magnetic moment. This magnetic moment causes the ion to interact with the external magnetic field.



The paramagnetic behavior is more pronounced in the middle of 3d series due to the maximum spin of electrons.

However, zinc is diamagnetic since it lacks unpaired electrons in its d-orbitals.

Alloy Formation

"Alloy is a homogenous mixture of two or more elements with at least one of them being a metal".

- Transition elements have the tendency to form alloys because of their similarities in atomic size which enable them to mix easily with one another.
- Alloys of transition metals exhibit greater rigidity, strength, light weight and shine compared to pure metals.
- Moreover, they possess enhanced resistance against corrosion. The composition and uses of some alloys are given below.
- Compositions and important uses of some alloys of transition-elements

Alloy	Stainless steel
Compositions	Iron, Chromium and Nickel.
Important Uses	In making cutlery, and surgical instruments
Alloys	Duralumin
Compositions	Aluminum, Copper Magnesium and Manganese
Important Uses	In making utensils, aero plane etc.
Alloys	Brass
Compositions	Copper and Zinc
Important Uses	In plumbing and automotive parts etc
Alloys	Bronze
Compositions	Copper and Aluminum
Important Uses	In making medals, statues, coins etc

Colour of Complexes

When a transition metal cation interacts with ligand, its five degenerate d-orbitals split into two sets of energy levels known as t_2g (lower energy level) and eg (higher energy level)"

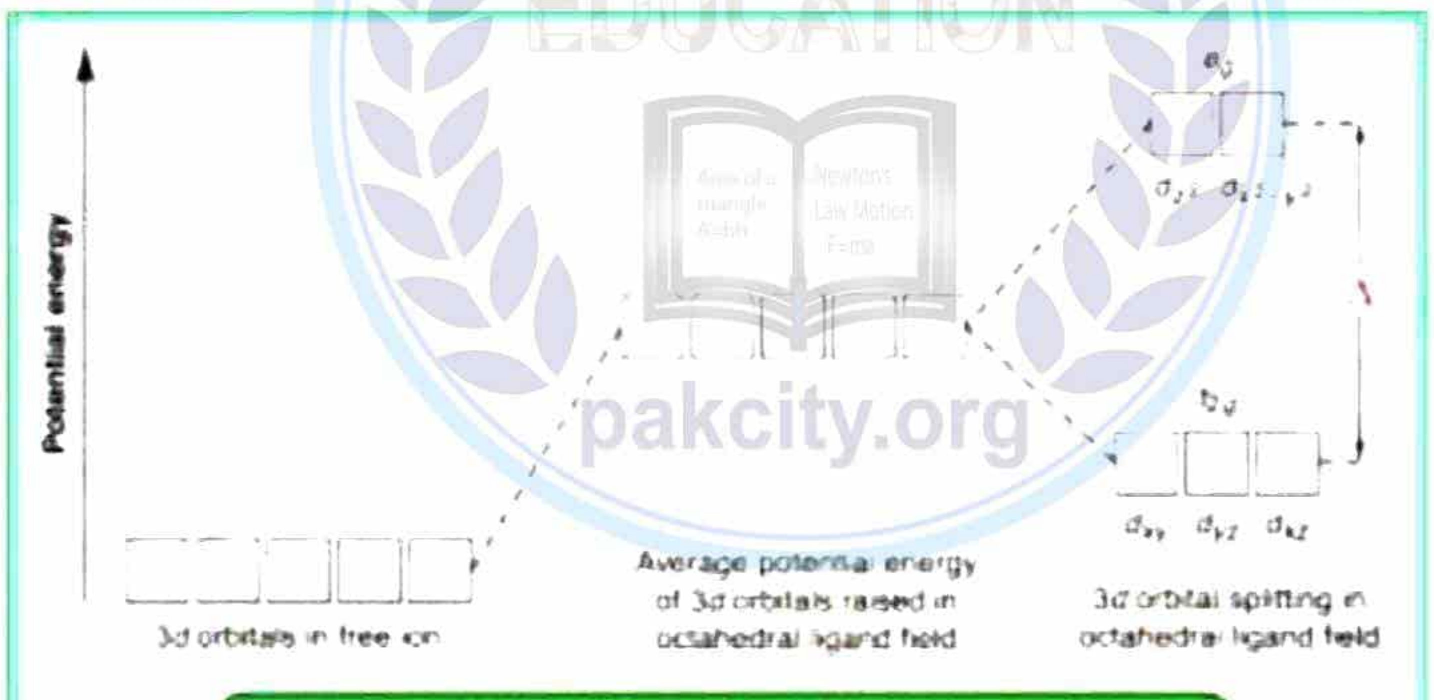
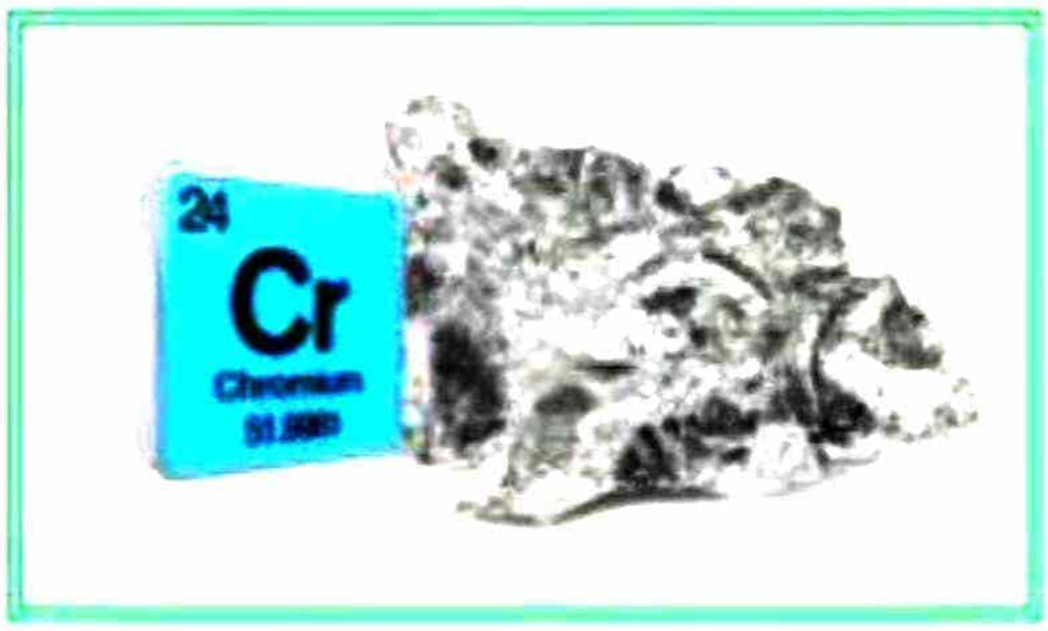


Fig 2.1: Splitting of five degenerate d-orbitals into t_{2g} and eg energy level

CHEMISTRY OF SOME IMPORTANT TRANSITION ELEMENTS

Chromium



- Chromium is the fourth member of 3d series of transition elements.
- It is characterized by its silvery grey colour and metallic luster.
- It is widely used as Cr protective coating on metal surfaces to prevent them from corrosion.
- Chromium exhibits various Oxidation states (+2, +3, +4, +5, +6) due to the electronic configuration of its atom (3d, 4s).
- The multiple oxidation states of chromium allow it to play a versatile role in redox reactions.
- In lower oxidation states, it serves as a reducing agent while in higher oxidation state works as an oxidizing agent.
- Chromium reacts with dilute hydrochloric acid to liberate hydrogen gas.

$$2Cr + 6HCl \longrightarrow 2CrCl_3 + 3H_2$$

Chromium reacts with oxygen to form chromium oxide

$$4Cr + 3O_2 \xrightarrow{Heat} + 2Cr_2O_3$$

Chromium reacts with steam at high temperatures to form chromium oxide with the liberation of hydrogen.

$$2Cr + 3H_2O \xrightarrow{Heat} Cr_2O_3\ t + 3H_2$$

Chromium is used in the production of stainless steel, chrome plating, pigments and as a catalyst in certain chemical reactions.

Chemistry of Potassium dichromate

Potassium dichromate is a red crystalline solid that is highly soluble in water. If it dissolves in water at neutral pH, a chromate and dichromate equilibrium is formed which shows an orange red colour.

$$\underset{\text{(red)}}{Cr_2O_7^{-2} + H_2O} \xrightarrow{} \underset{\text{(yellow)}}{} 2CrO_2 + 2H^+$$

The preparation of Potassium dichromate is commonly done by using chromates and these chromates are formed by the reaction of chromite ore with sodium or potassium carbonate.

Potassium dichromate is used as an oxidizing agent in various chemical reactions since it possesses the highest oxidation state of chromium (+6). The redox titration of potassium dichromate with oxalic acid ($H_2C_2O_4$) and Mohr's salt (Fe(NH,),(So)2.6H,0) is commonly carried out in the laboratories for determining the concentration of analyte. The end point of this titration is indicated by the colour change from orange (Cr^{+6}) to green (Cr^{+3}).

$$\underset{\text{(orange)}}{2Cr_2O_7^{-2} + 3H_2C_2O_4 + 8H^+} \longrightarrow \underset{\text{(green)}}{4Cr^{+3} + 6CO_2 + 7H_2O}$$

$$\underset{\text{(orange)}}{Cr_2O_7^{-2} + 6Fe^{+2} + 14H^+} \longrightarrow \underset{\text{(green)}}{2Cr^{+3} + 6Fe^{+3} + 7H_2O}$$

Manganese

Manganese is a greyish white, hard and brittle metal. It ranks as the twelfth most prevalent element within the Earth crust.
It exists in various oxidation states.
For example the oxidation state of manganese in potassium permanganate

($KMn0_4$) is +7 and in manganese dioxide ($Mn0_2$) it is +4, where as in manganese chloride ($MnCl_2$) it is +2.

Manganese reacts with air to form manganese oxide Mn_20_4.

$$3Mn + 20_2 \longrightarrow Mn_20_4$$

Manganese reacts with chlorine to form manganese chloride.

$$Mn + Cl_2 \longrightarrow MnCl_2$$

Manganese when dissolves in dilute sulphuric acid, it liberates hydrogen gas.

$$Mn + H_2SO_4 \longrightarrow MnSO_4 + H_2$$

Manganese is used in the production of steel, alloys, batteries, ceramics and glasses etc. It is an essential nutrient and play vital role in metabolism, bone development and enzyme function.

Chemistry of Potassium Permanganate

Potassium permanganate is a deep purple crystalline solid. Commercially, potassium permanganate ($KMnO_4$) is prepared by mixing a solution of potassium hydroxide (KOH) with powdered manganese dioxide (MnO_4) along with an oxidizing agent such as potassium chlorate ($KClO_3$). It is highly soluble in water, forming a pink solution, potassium permanganate is a powerful oxidizing agent. It works cither in acidic, alkaline or neutral medium.

In acidic solutions permanganate ion accept five electrons and change from $Mn0_4^-$ to Mn^{+2}

$$Mn0_4^- + 8H^+ + 5e^- \longrightarrow Mn^{+2} + 4H_20$$

In basic or neutral medium it accepts three electrons and changes from $Mn0_4^-$ to $Mn0_2$

$$Mn0_4^- + 2H_20 + 3e^- \longrightarrow Mn0_2 \text{ t } 40H^-$$

The reaction of potassium permanganate with ferrous sulphate and Mohr's salt is given as;

$$Mn0_4^- + 5Fe^{+2} + 8H^+ \longrightarrow Mn^{+2} + 5Fe^{+3} + 4H_20$$

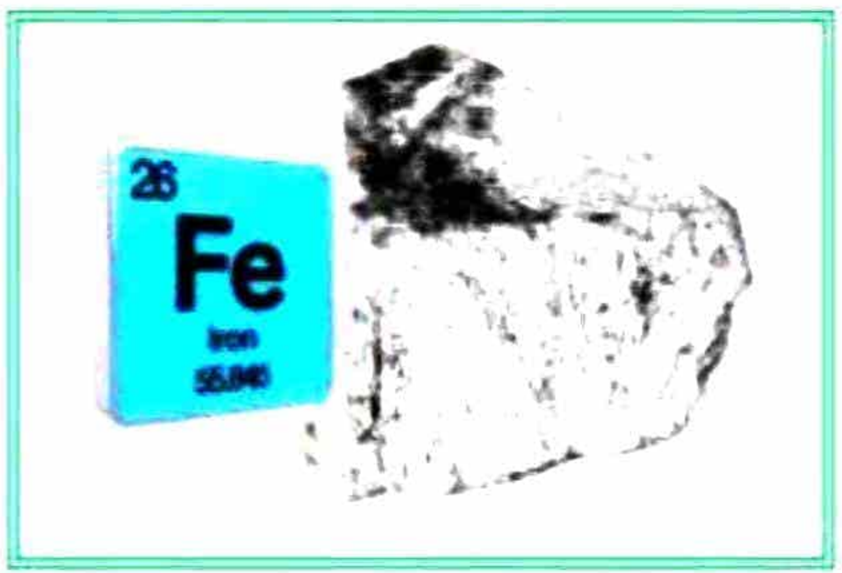
The reaction of potassium permanganate with oxalic acid is given as

$$2\ Mn0_4^- + 5C_20_4^{-2} + 16H^+ \longrightarrow 2Mn^{+2} + 10C02 + 8H20$$

Potassium permanganate is used as a powerful Oxidizing agent in various applications, including water treatment for purification and disinfection, and as a chemical reagent in organic synthesis and laboratory experiments.

Iron

Iron is the fourth most abundant element in the Earth crust. Its strength and magnetic properties make it valuable in industries such as Construction and manufacturing.



Furthermore, iron is an indispensable Component of hemoglobin, emphasizing its critical role in the biological system.

When iron is exposed to air, it oxidizes and forms an oxide film on its surface which is rusting of iron.

$$4Fe + 3O_2 \longrightarrow 2Fe_2O_3$$

When it reacts with excess of chlorine, it forms ferric chloride.

$$2Fe + 3Cl_2 \longrightarrow 2FeCl_3$$

Iron is mainly used in the construction of buildings and flyovers. It is used in industries for making tools, weapons, appliances, rail tracks, trains, automobiles etc.

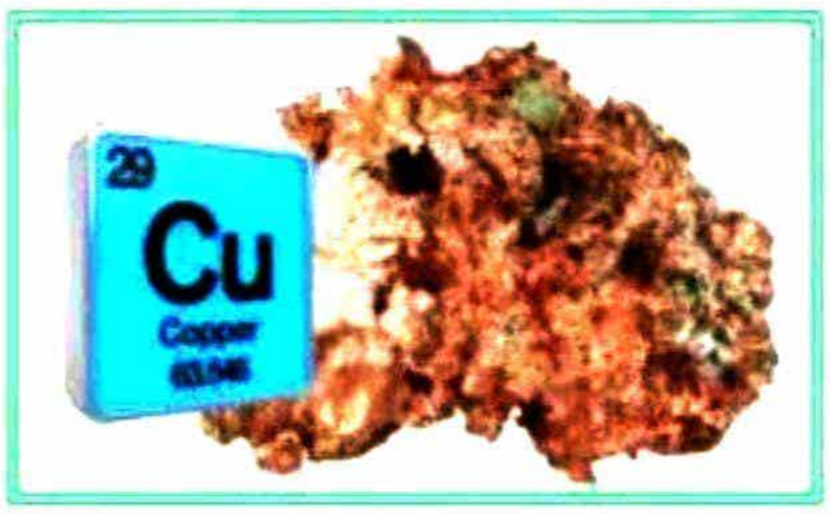
Steel Types and Applications

Steel is a widely used alloy comprised primarily of iron combined with some other elements. By the inclusion of carbon and other alloying elements in steel enhances its mechanical, thermal and chemical properties compared with simple iron.

There are several types of steel each characterized by unique compositions and properties suited for specific applications.

Type of Steel	Applications
Carbon Steel	Construction tools, machinery, pipes, tubes, automotive etc.
Stainless Steel	Kitchen appliances, Cutlery and Medical equipment
Tool Steel	Cutting and drilling equipment
Alloy Steel	Fry pan, Toaster etc

Copper



- ✓ Copper is a dense metal with a reddish brown colour.
- ✓ It is malleable and ductile, allowing it to be easily shaped and wired.
- ✓ Copper is known for its excellent electrical conductivity and it ranks as second highest (after silver) electrical conductor among pure metals.

Copper reacts with conc. sulphuric acid to form copper sulphate and sulphur dioxide.

$$Cu + 2H_2SO_{4(conc)} \longrightarrow CuSO_4 + SO_2 + 2H_2O$$

Copper reacts with conc. nitric acid to form copper nitrate and nitrogen dioxide.

$$Cu + 4HNO_{3(conc.)} \longrightarrow Cu(NO_3)_2 + 2NO_2 + 2H_2O$$

Copper is primarily used in making electric wires, cables, motors and other electrical equipment's. It is also used in plumbing, piping, telecommunication, coinage and alloy formation.

Metallurgy of Copper

Copper is present in Earth's crust in the combined form referred to as ore. The most abundant ore of copper is chalcopyrite ($CuFeS_2$). The process of extracting metal like copper from its ore is called metallurgy. The metallurgical operations associated with chalcopyrite ore include series of steps: such as crushing, grinding, Concentration, roasting, smelting and refining.

Concentration

In this stage, the objective is to eliminate gangue impurities from the powdered chalcopyrite ore. This is accomplished through a froth floating process, where the ore is blended with water that has pine oil added to it. Subsequently, air is introduced into the water, causing the ore particles to become coated with froth, while the gange particles settle to the bottom as shown in figure

Roasting

This process involves the heating of ore in the presence of excess air at an elevated temperature in a roasted kiln. As a result, the impurities oxidizes and the ore undergoes decomposition, leading to the formation of cupreous sulphide and ferrous oxide while sulphur dioxide is simultaneously eliminated.

$$2CuFeS_2 + 4O_2 \longrightarrow Cu_2S + 2FeO + 3SO_2$$

Smelting

Roasted ore along with silica and coal is charged into a blast furnace. The combustion of coal elevates the furnace temperature to approximately 1200°C to 1500°C. Within this environment, ferrous oxide (FeO) present in the ore reacts with silica, resulting in the formation of iron silicate ($FeSiO_3$) commonly referred to as slag. The slag floats on the surface of the molten matte while the matte (consisting of Cu,S and some impurities) is separately collected from the slag.

$$FeO + SiO_2 \xrightarrow{1200^\circ C - 1500^\circ C} FeSiO_3$$

(Iron oxide) (Silica) (Slag)

Bessemerization

The matte is subsequently fed into a pear shaped Bessemer converter, where hot gases are introduced from the mid lower portion. Within this converter, cupreous sulphide (Cu_2S) is partly converted into cupreous oxide (Cu_2O), which then reacts with the remaining cupreous sulphide, resulting in the production of molten metallic copper.

$$2Cu_2S + 3O_2 \longrightarrow 2Cu_2O + 2SO_2$$

$$2Cu_2O + Cu_2S \longrightarrow 6Cu + SO_2$$

The copper thus produced is called blister copper because as it solidifies hidden Sulphur dioxide gas escapes producing blisters on its surface. It is about 99% pure. The blister copper contains impurities mainly iron but small amount of arsenic, zinc, lead, silver and gold. Blister copper is not suitable especially for electrical purposes; therefore, it undergoes a refining process to remove all remaining impurities as shown in figure.

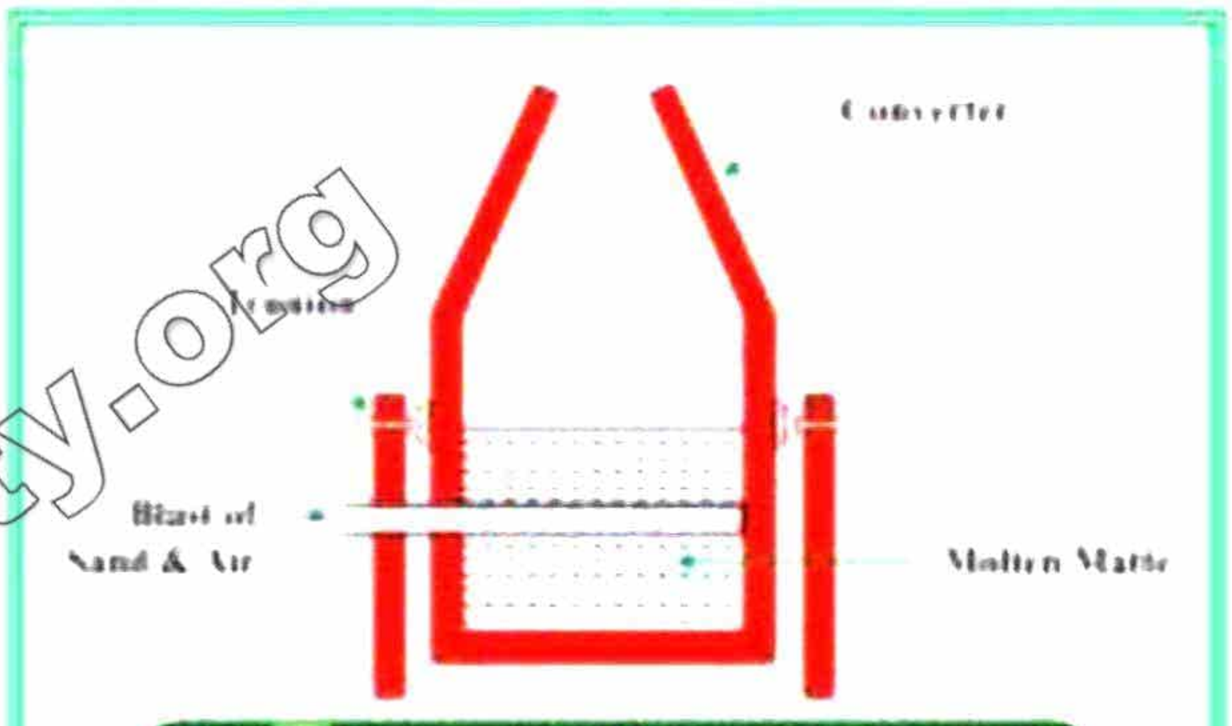


Fig. : Structure of Bessemer Converter

Refining of Copper

Copper is refined by electrolysis in an electrolytic tank. The blocks of blister copper are used as anodes and thin sheets of pure copper act as cathodes as shown in figure. The electrolyte is copper sulphate which is acidified with sulphuric acid. By passing electricity through the electrolytic solution, the blister copper undergoes oxidation and the Cu^{+2} ions produced in this oxidation process are then deposited onto cathode. The impurities are left behind which fall to the bottom of the cell as anode mud.

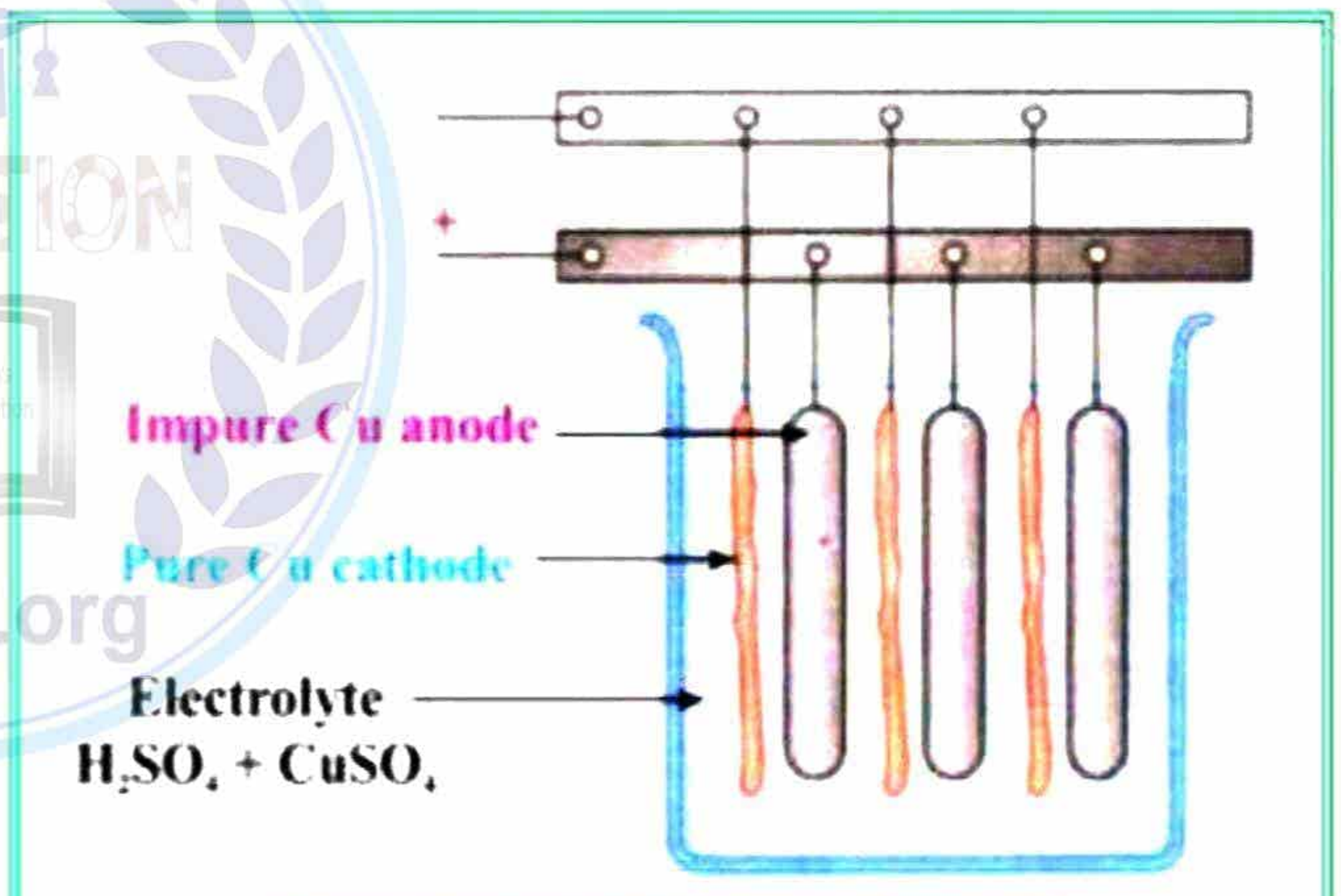


Fig : Electrolytic refining of blister copper

$$Cu \longrightarrow Cu^{+2} + 2e^- \text{ (oxidation at anode)}$$

(Blister copper)

$$Cu^{+2} + 2e^- \longrightarrow Cu \text{ (reduction at cathode)}$$

Copper obtained after electrolytic refining is 99.99% pure.

Commercial applications of some common transition elements

Transition	Elements Commercial Applications
Titanium	In making artificial joints, bone plates, screws and dental implants.
Vanadium	Use in batteries, as a catalyst and as a pigment in glass making
Iron	Building and bridge construction and tool making.
Copper	In making copper wires, alloys and sanitary works.
Zinc	Galvanizing, alloying and also use in batteries
Platinum	In making jewellery and also serves as a catalyst.
Mercury	Use in thermometers, B.P. apparatus, and amalgam formation

Short Questions

1. Write the IUPAC names of the following:

(i) $Na_2[Pt(OH)_4]$	Sodium tetra hydroxo platinate (II)
(ii) $K_2[Fe(CN)_5 NO]$	Potassium penta cyano nitrosyl ferrate (II)
(ii) $(Zn(NH_3)_4]^{+2}$	Tetra ammine zinc (II) ion
(iv) $[Ni(SCN)_4]^{-2}$	Tetra thio cyanato nickelate (II) ion

2. Give reasons for the following:

i) Why do transition elements show variable oxidation states?

Transition elements show variable oxidation states because their valence electrons are in two different sets of orbitals, i.e. in (n - 1) d and ns orbitals. The energy difference between these orbitals is very less. This means that transition metals can lose electrons from either the (n - 1) d or ns orbitals, or from both, depending on the conditions.

(ii) Why transition elements have ability to form alloys?

Transition elements have the ability to form alloys because their atoms have similar sizes and similar electronic configurations. This allows them to mix together and form solid solutions. Alloys are often stronger and more durable than pure metals, and they can also have other desirable properties, such as resistance to corrosion or high melting points.

(iii) Why Cu^{+2} ion is blue but Zn+2 is colourless?

Copper(II) ion (Cu^{+2}) is blue in color because it can absorb visible light of the orange-red wavelength. This absorption is due to a phenomenon called d-d transition. In a d-d transition, an electron is excited from one d orbital to another d orbital of higher energy.

Zinc(II) ion (Zn^{+2}), on the other hand, is colorless because it does not have any d orbitals. All of its valence electrons are in s orbitals. This means that there are no d-d transitions possible, and therefore Zn^{+2} does not absorb visible light.

(iv) Why chromium exists in $4s^1$, $3d^5$ configuration but not in $4s^2$, $3d^4$?

Chromium exists in the $4s^1$,$3d^5$ configuration because it is more stable than the $4s^2$, $3d^4$ configuration. This is due to the phenomenon of Hund's rule, which states that electrons will occupy different orbitals of the same energy level before they pair up. In the $4s^1$, $3d^5$ configuration, all of the electrons in the 3d orbital have unpaired spins. This is more stable than the $4s^2$, $3d^4$ configuration, in which two of the electrons in the 3d orbital would have to pair up.

(v) Why binding energy of zinc is least in 3d series?

The binding energy of zinc is the least in the 3d series because it has the smallest atomic radius. Atomic radius is the distance from the nucleus of an atom to its outermost valence electrons. The smaller the atomic radius, the more tightly the valence electrons are held to the nucleus. This means that it takes more energy to remove an electron from a zinc atom than from any other atom in the 3d series.

In addition, zinc has a filled 3d subshell. Filled subshells are more stable than incomplete subshells. This also contributes to the high binding energy of zinc.

However, it is important to note that the binding energy of zinc is still relatively low. This is because the energy difference between the 4s and 3d orbitals in zinc is very small. This allows zinc to lose electrons from either the 4s or 3d orbital, or from both, depending on the conditions.

(i) Reaction of conc. nitric acid with copper

$$Cu_{(s)} + 4HNO_{3(conc.)} \longrightarrow Cu(NO_3)_{2(aq)} + 2NO_{2(g)} + 2H_2O_{(l)}$$

(ii) Reaction of conc. sulphuric acid with copper

$$Cu_{(s)} + 2H_2SO_{4(conc.)} \longrightarrow CuSO_{4(aq)} + SO_{2(g)} + 2H_2O_{(l)}$$

(iii) Reaction of permanganate with oxalic acid

$$5H_2C_2O_4 + 2KMnO_4 + 3H_2SO_4 \longrightarrow 2KHSO_4 + 5CO_2 + 2MnSO_4 + 8H_2O$$

(iv) Reaction of dichromate with ferrous sulphate

$$2Cr_2O_7^{2-} + 6Fe^{2+} + 14H_{+} \longrightarrow 2Cr^{3+} + 6Fe^{3+} + 7H_2O$$

(v) Reaction of manganese with dilute sulphuric acid

$$Mn_{(s)} + H_2SO_{4(aq)} \longrightarrow MnSO_{4(aq)} + H_{2(g)}$$

(vi) Reaction of iron with chlorine

$$Fe_{(s)} + Cl_{2(g)} \longrightarrow FeCl_{2(s)}$$

4. Why d-block elements are called outer transition elements?

The d-block elements are called outer transition elements because they are located in the middle of the periodic table, between the s-block and p-block elements. They are also called transition elements because their properties show a gradual transition from the properties of the s-block elements to the properties of the p-block elements.

5. Write down the effect of pH changes on dichromate equilibrium in water.

The equilibrium between dichromate (Cr2O72−) and chromate (CrO42−) ions in water is pH-dependent. At low pH, the dichromate ion is the predominant species. As the pH increases, the equilibrium shifts to the right, and the chromate ion becomes the predominant species. This is because the chromate ion is more stable at higher pH values.

The following equation shows the equilibrium between dichromate and chromate ions in water:

$$2Cr_2O_7^{2-} + 2H_2O \longrightarrow CrO_4^{2-} + 2H^{+} + 2CrO_4^{2-}$$

6. Melting point of d-block elements increase up to middle of the series and then decrease why?

The melting point of d-block elements increases up to the middle of the series and then decreases because of the increasing number of d electrons. The d electrons can participate in metallic bonding, which strengthens the metal and increases its melting point. However, as the number of d electrons increases, the electrons become more delocalized and less involved in metallic bonding. This leads to a decrease in the melting point.

Another factor that contributes to the decrease in melting point after the middle of the series is the increasing size of the atoms. The larger atoms have more space between them, which makes it easier for them to slide past each other and melt.

7. Give the composition and applications of stainless steel, brass and bronze.

Stainless steel is a type of steel that is resistant to corrosion. It is typically made up of iron, chromium, and nickel. Stainless steel is used in a wide variety of applications, including:

- Food processing equipment
- Medical devices
- Chemical processing equipment
- Automotive parts
- Architectural components

Brass is an alloy of copper and zinc. It is typically made up of 60-70% copper and 30-40% zinc. Brass is a strong and durable material that is also resistant to corrosion. It is used in a wide variety of applications, including:

- Plumbing hardware
- Electrical connectors
- Musical instruments
- Decorative items

Bronze is an alloy of copper and tin. It is typically made up of 80-90% copper and 10-20% tin. Bronze is a strong and durable material that is also resistant to corrosion. It has been used for centuries to make a variety of items, including:

- Sculptures
- Statues
- Bells
- Coins
- Bearings

Note: The composition and applications of stainless steel, brass, and bronze can vary depending on the specific alloy.

Descriptive Questions

1. Explain the trend of following properties of 3d-series of transition elements.
(a) Paramagnetic behavior (b) Variable oxidation state (c) Colour formation.

(a) Paramagnetic behavior

Paramagnetism is a type of magnetism in which materials are attracted to magnetic fields. It is caused by the presence of unpaired electrons.

Transition elements are paramagnetic because they have unpaired electrons in their d orbitals. The number of unpaired electrons in a transition element depends on its oxidation state. For example, scandium (Sc) has no unpaired electrons in its +3 oxidation state, so it is diamagnetic (not attracted to magnetic fields). However, titanium (Ti) has one unpaired electron in its +3 oxidation state, so it is paramagnetic.

The trend of paramagnetic behavior in the 3d series of transition elements is as follows:

- The maximum number of unpaired electrons is five, and this occurs at the middle of the series (from chromium (Cr) to manganese (Mn)).
- The number of unpaired electrons decreases on either side of the series.

- Elements at the end of the series (from nickel (Ni) to zinc (Zn)) have no unpaired electrons, so they are diamagnetic.

(b) Variable oxidation state

Transition elements show variable oxidation states because they have unpaired electrons in their d orbitals. These unpaired electrons can be lost or gained to form different oxidation states.

The trend of variable oxidation state in the 3d series of transition elements is as follows:

- The maximum number of oxidation states is seven, and this occurs at the middle of the series (from manganese (Mn) to chromium (Cr)).
- The number of oxidation states decreases on either side of the series.
- Elements at the beginning of the series (from scandium (Sc) to titanium (Ti)) have only one or two oxidation states. Elements at the end of the series (from nickel (Ni) to zinc (Zn)) have only one oxidation state.

(c) Colour formation

Transition elements are colored because they can absorb visible light. This absorption is due to a phenomenon called d-d transition. In a d-d transition, an electron is excited from one d orbital to another d orbital of higher energy.

The energy of the absorbed light depends on the energy difference between the two d orbitals. The greater the energy difference, the shorter the wavelength of the absorbed light.

The trend of colour formation in the 3d series of transition elements is as follows:

- Elements at the beginning of the series (from scandium (Sc) to titanium (Ti)) are colorless because their d-d transitions are too high in energy to be absorbed in the visible region of the spectrum.
- Elements at the middle of the series (from chromium (Cr) to manganese (Mn)) are colored because their d-d transitions are in the visible region of the spectrum.
- Elements at the end of the series (from nickel (Ni) to zinc (Zn)) are colorless because their d orbitals are filled, so there are no d-d transitions possible.

Conclusion

The paramagnetic behaviour, variable oxidation state, and colour formation of transition elements are all due to the presence of unpaired electrons in their d orbitals. The trends in these properties can be explained by the energy levels of the d orbitals and the energy of the absorbed light.

2. How can you define a coordination complex and a chelating ligand? Explain various types of ligands with examples.

Coordination complex

A coordination complex is a chemical compound consisting of a central atom or ion, which is usually metallic and is called the coordination centre, and a surrounding array of bound molecules or ions, that are in turn known as ligands or complexing agents. Many metal-containing compounds, especially those that include transition metals (elements like titanium that belong to the periodic table's d-block), are coordination complexes.

Examples of coordination complexes include:

- Haemoglobin, which contains an iron atom coordinated to four nitrogen atoms in a porphyrin ring, and two oxygen molecules.
- Chlorophyll, which contains a magnesium atom coordinated to four nitrogen atoms in a porphyrin ring.
- Cisplatin, a cancer drug that contains a platinum atom coordinated to two chloride ions and two ammonia molecules.

Chelating ligand

A chelating ligand is a ligand that can bond to a central metal atom through two or more donor atoms. This forms a ring structure called a chelate ring. Chelating ligands are typically more stable than monodentate ligands, which can only bond to a central metal atom through one donor atom.

Examples of chelating ligands include:

- Ethylenediamine (en)
- Bidentate (bipy)
- Triphenylphosphine (PPh3)
- Oxalate (ox)
- Glycinate (gly)

Types of ligands

Ligands can be classified into two main types: monodentate and polydentate.

- Monodentate ligands can only bond to a central metal atom through one donor atom. Examples of monodentate ligands include water (H_2O), ammonia (NH_3), chloride (Cl^-), and fluoride (F^-).
- Polydentate ligands can bond to a central metal atom through two or more donor atoms. Examples of polydentate ligands include ethylenediamine (en), bidentate (bipy), triphenylphosphine (PPh3), oxalate (ox), and glycinate (gly).

3. Describe how 99.99% pure copper is obtained from its chalcopyrite ore.

Notes Pg no

4. Explain why transition elements and their compounds serve as catalysts in many chemical reactions

Transition elements and their compounds serve as catalysts in many chemical reactions because of the following reasons:

- **Variable oxidation state:** Transition elements can exist in a variety of oxidation states, which allows them to act as electron donors or acceptors in chemical reactions. This can help to lower the activation energy of the reaction and speed it up.
- **Formation of coordination complexes:** Transition elements can form coordination complexes with other molecules, which can change the reactivity of the transition metal. For example, the coordination complex cisplatin is a cancer drug that is much more effective than platinum metal alone.

- **Presence of d orbitals:** Transition elements have d orbitals, which can overlap with the orbitals of other molecules to form bonds. This can help to activate reactants and speed up reactions.

5. What is meant by binding energy? Write down the trend of binding energy in 3d series of transition elements.

Binding energy

Binding energy is the energy required to break a bond between two atoms. It is a measure of the strength of the bond. The higher the binding energy, the stronger the bond.

The binding energy of a transition metal atom is the energy required to remove an electron from the outermost shell of the atom. The binding energy of a transition metal atom depends on the number of protons in the nucleus, the number of electrons in the outermost shell, and the shielding effect of the inner electrons.

The trend of binding energy in the 3d series of transition elements is as follows:

- The binding energy increases up to the middle of the series, and then decreases.
- The maximum binding energy occurs at chromium (Cr).
- The minimum binding energy occurs at zinc (Zn).