# 08

# Transition and inner transition elements

**Syllabus**

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| 8.2 | Trends in atomic properties of the first transition series | 8.5 | Metallurgy |
| 8.3 | Compounds of Mn and Cr ($KMnO_4$ and $K_2Cr_2O_7$) | 8.6 | Inner transition (f block) elements |

**+1. Do you know?**
**In which block of the modern periodic table are the transition and inner transition elements placed?**

**Ans:** Transition and inner transition elements are placed in the d-block and f-block of the modern periodic table respectively.

## 8.1 Introduction

**Q.2 According to IUPAC how are atoms classified as transition metal?**

**Ans:** As per IUPAC convention the transition metal atom has an incomplete d-subshell or it give cations with incomplete d subshell.

*Note-*

They exhibit properties between S and p block elements.

**Q.3 Explain the four transition series elements.**

**Ans:**

i. The 3d series is comprised of elements from scandium (Z=21) to zinc (Z=30), 4d series has elements from yttrium (Z=39) to cadmium (Z=48).

ii. 5d series from lanthanum (Z=57) to mercury (Z=80) without those from cerium to lutecium, and 6d series has actinium to curium without those from thorium to lawrentium.

**Q.4 What is the general electronic configuration of transition elements.**

**Ans:** The general electronic configuration of transition elements is $(n-1)d^{1-10}\ ns^{1-2}$.

## 8.2 Position in the periodic table

**Q.5 Explain the position of transiton elements in the modern periodic table.**

**Ans:**

i. The transition elements are placed in the periods 4 to 7 and groups 3 to 12 those constitute 3d, 4d, 5d and 6d series.

ii. They are placed at the centre with s block on one side and p on the other.

iii. The electropositivity, reactivity and other properties show a gradual change from s block to p block through those of the d block elements.

## 8.3 Electronic configuraion

**Q.6 Give the electronic configuration of scandium.**

**Ans:** Electronic configuration of Sc is written as $1s^2\ 2s^2\ 2p^6\ 3s^2 3p^6\ 3d^1 4s^2$ or also can be represented as $[Ar]\ 3d^1 4s^2$.

**Q.7 Give the expected and observed electronic configuration of elements of 3d series of d-block elements.**

**Ans:**

| Elements | Symbol | At.No. | Expected electronic configuration | Observesed electronic configuration |
|---|---|---|---|---|
| Scandium | Sc | 21 | [Ar] $3d^1\ 4s^2$ | [Ar] $3d^1\ 4s^2$ |
| Titanium | Ti | 22 | [Ar] $3d^2\ 4s^2$ | [Ar] $3d^2 4s^2$ |
| Vanadium | V | 23 | [Ar] $3d^3$ 4s2 | [Ar]$3d^3 4s^2$ |
| Chromium | Cr | 24 | [Ar] $3d^4\ 4s^2$ | [Ar] $3d^5\ 4s^1$ |
| Manganese | Mn | 25 | [Ar] $3d^5$ 4s2 | [Ar] $3d^5\ 4s^2$ |
| Iron | Fe | 26 | [Ar] $3d^6\ 4s^2$ | [Ar] $3d^6\ 4s^2$ |
| Coblat | Co | 27 | [Ar] $3d^7\ 4s^2$ | [Ar] $3d^7$ 4s2 |
| Nickel | Ni | 28 | [Ar] $3d^8\ 4s^2$ | [Ar] $3d^8\ 4s^2$ |
| Copper | Cu | 29 | [Ar] $3d^9\ 4s^2$ | [Ar] $3d^{10}\ 4s^2$ |
| Zinc | Zn | 30 | [Ar] $3d^{10}\ 4s^2$ | [Ar] $3d^{10}\ 4s^2$ |

**Q.8 Why Zinc, cadium and mercury are not considered as transition elements?**

**Ans:** Since zinc has completely filled (n – 1)d orbital in the ground state ($3d^{10}$,$4s^2$) and ($3d^{10}$) in its common oxidation state +2, it is not regarded as transition element. On the same ground, cadmium and mercury from 4d and 5d series are not considered as transition elements.

**Q.9 Copper in its elementary state has completely filled 3 d orbital yet it is considered as transition element. Explain.**

**Ans:** Copper in the elementary state ($3d^{10}4s^1$) contains filled 3d orbitals but in the +2 oxidation state it has partly filled 3d orbital ($3d^9$), hence copper is a transition element.

**Q.10 Give the general electronic configuration of four series of d-block elements?**

**Ans:** General electronic configuration of four series of d-block elements of periodic table can be represented as given below:

i. 3d series : [Ar] $3d^{1-10}\ 4s^2$
ii. 4d series : [Kr] $4d^{1-10}\ 5s^{0-2}$
iii. 5d series : [Xe] $5d^{1-10}\ 6s^2$
iv. 6d series : [Rn] $6d^{1-10}\ 7s^2$

**Q.11 Write probable electronic configurations of chromium and copper.**

**Ans:**

i. The probable electronic configuration of chromium is $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^4\ 4s^2$ or [Ar] $3d^4\ 4s^2$.
ii. The probable electronic configuration of copper is $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^9\ 4s^2$ or [Ar]$3d^9\ 4s^2$.

**Q.12 Give reason: The expected electronic configuration of chromium and copper differ from the observed configuration.**

**Ans:**

i. This can be explained on the basis of the concept of additional stability associated with the completely filled and half filled subshells.
ii. The general electronic configuration of the elements of the 3d series is $3d^{(1-10)}\ 4s^2$ with the exceptions of Cr and Cu.
iii. The 3d and 4s orbitals are close in energy and in order to gain extra stability the last electron instead of occupying 4s orbital occupies the 3d orbital that assigns Cr the $3d^5$, $4s^1$and Cu $3d^{10}$, $4s^1$configuration.

**Remember-**

Any subshell having a half filled or completely filled electronic configuration has extra stability.

**Remember-**

Electronic configuration of Cr is [Ar] $3d^5$ $4s^1$ andCu is : [Ar]$3d^{10}$, $4s^1$.

**Q.13 Describe the oxidation states of first transition series.**

**Ans:**

i. One of the notable features of transition elements is the great variety of oxidation states they show in their compounds.

ii. Loss of 4s and 3d electrons progressively leads to formation of ions.

iii. The transition elements display a variety of oxidation states in their compounds.

iv. Loss of one 4s electron leads to the formation of $M^+$ ion, loss of two 4s electrons gives a $M^{2+}$ ion while loss of unpaired 3d and 4s electrons gives $M^{3+}$, $M^{4+}$ions and so on.

| Elements | Outer elecronic configuration | Oxidation states | Elements | Outer electronic configuration | Oxidation states |
|---|---|---|---|---|---|
| Sc | $3d^1$ $4s^2$ | +2, +3 | Fe | $3d^6$ $4s^2$ | +2, +3, +4, +5, +6 |
| Ti | $3d^2$ $4s^2$ | +2, +3, +4 | Co | $3d^7$ $4s^2$ | +2, +3, +4, +5 |
| V | $3d^3$ $4s^2$ | +2, +3, +4, +5 | Ni | $3d^{10}$ $4s^2$ | +2, +3, +4 |
| Cr | $3d^5$ $4s^1$ | +2, +3, +4, +5, +6 | Cu | $3d^{10}$ $4s^1$ | +1, +2 |
| Mn | $3d^5$ $4s^2$ | +2, +3, +4, +5, +6, +7 | Zn | $3d^{10}$ $4s^2$ | +2 |

**Q.14 Iron exhibits +2 and +3 oxidation states. Write their electronic configuration. Which will be more stable? Why?**

**Ans:**

i. Electronic configuration of $Fe^{2+}$ : $1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$ $3d^6$

ii. Electronic configuration of $Fe^{3+}$ : $1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$ $3d^5$

iii. $Fe^{3+}$ is mor stable than $Fe^{2+}$. This is due to the presence of half filled 'd' orbital in $Fe^{3+}$

**+Q.15 Can you tell?**

**i. Which of the first transition series elements shows the maximum number of oxidation state and why?**

**Ans:**

i. Among the first transition series manganese shows the maximum number of oxidation state.

ii. Manganese has the highest oxidation state because the number of unpaired electrons in the outermost shell is more i.e. $3d^5$ $4s^2$ .

**ii. Which element in the 4d and 5d series show maximum number of oxidation states?**

**Ans:** In 4d and 5d series, molybdenum (MO) and Rhenium (Re) shows maximum number of oxidation states respectively.

**Q.16 What is the oxidation state of manganese in**

**i. $MnO_4^{2-}$**

**ii. $MnO_4^-$**

**Ans:**

**i. $MnO_4^{2-}$ :**

Net charge = – 2

∴ (O.S. of Mn) + 4(O.S. of O) = Net charge

(O.S. of Mn) + 4 (–2) = –2

(O.S. of Mn) – 8 = –2

∴ (O.S. of Mn) = + 16

**ii.** $MnO_4^-$ :

Net charge = – 1
(O.S of Mn) + 4 (O.S. of O) = –1
(O.S. of Mn) +4 ( –2) = –1
(O.S. of Mn) – 8 = –1
∴ (O.S. of Mn) = +7

**Q.17 Try This**
**Write the electronic configurations of $Mn^{6+}$, $Mn^{4+}$, $Fe^{4+}$, $Co^{5+}$, $Ni^{2+}$**

**Ans:**

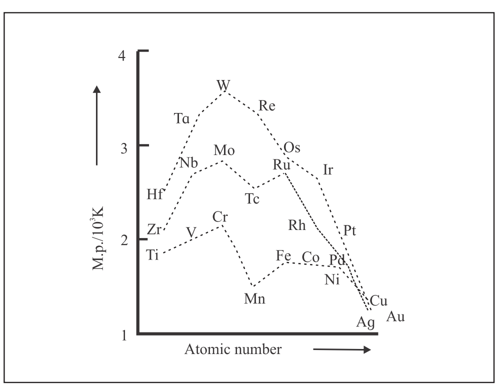
| Ion | Electronic configuration |
|---|---|
| $Mn^{6+}$ | $[Ar]3d^1$ |
| $Mn^{4+}$ | $[Ar]3d^3$ |
| $Fe^{4+}$ | $[Ar]3d^4$ |
| $Co^{5+}$ | $[Ar]3d^4$ |
| $Ni^{2+}$ | $[Ar]3d^8$ |

## 8.5 Physical properties of first transition elements

**Q.18 Explain the physical properties of first transition elements.**

**Ans:**

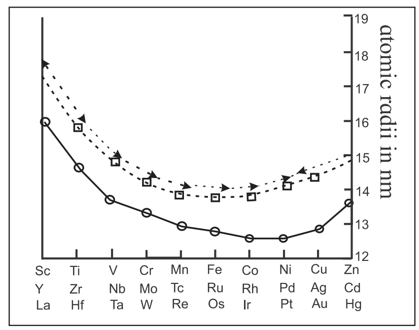
i. All transition elements are metals and show properties that are characteristic of metals.
ii. They are hard, lustrous, malleable, ductile and form alloys with other metals.
iii. They are good conductors of heat and electricity. Except Zn, Cd, Hg and Mn, all the other transition elements have one or more typical metallic structures at ambient temperature.
iv. These transition metals (with the exception of Zn, Cd and Hg) are very hard and have low volatility.
v. They possess high melting and boiling points.




**Q.19 Explain the trends in atomic radii of d block elements.**

**Ans:**

i. Atomic radii of the elements of the transition series decrease gradually from left to right.
ii. As we move across a transition series from left to right the nuclear charge increases by one unit at a time.
iii. The last filled electron enters a penultimate (n-1)d subshell.
iv. However, d orbitals in an atom are less penetrating or more diffused and, therefore d electrons offer smaller screening effect.
v. The result is that effective nuclear charge also increases as the atomi number increases along a transition series.
vi. Hence the atomic radii decrease gradually across a transition series from left to right.




Trends in atomic radii of a block elements.

**Q.20 Explain the trends in ionic radii of d block elements.**

**Ans:**

i. Ionic radii of transition elements show the same trend as of the atomic radii.
ii. The elements of first transition series show variable oxidation states.
iii. The trends in ionic radii, thus, can be studied with
   a. elements having same oxidation state or
   b. considering various oxidation states of the same element.
iv. For the same oxidation state, with an increase of nuclear charge a gradual decrease in ionic radii was observed.
v. The trend is pronounced for the divalent ions of the first transition series ($Cr^{2+}$ – 82 pm, $Cu^{2+}$ – 72 pm).
vi. The oxidation states of the same element shows difference of one unit such as $M^+$, $M^{2+}$, $M^{3+}$, $M^{4+}$ and so on.

vii. With higher oxidation state the effective nuclear charge also increases and hence, decrease of ionic radii can be observed from $M^{2+}$ to $M^{3+}$.

ix. Ionic radii of transition elements are smaller than ionic radii of representative elements of the same period.

| Element (M) | Atomic numbr (Z) | Density ($g/cm^3$) | Atomic/ionic radius (pm) | | | Ionisation enthalpy (kJ/mol) |
|---|---|---|---|---|---|---|
| | | | M | $M^{2+}$ | $M^{3+}$ | |
| Sc | 21 | 3.43 | 164 | - | 73 | 631 |
| Ti | 22 | 4.1 | 147 | - | 67 | 656 |
| V | 23 | 6.07 | 135 | 79 | 64 | 650 |
| Cr | 24 | 7.19 | 129 | 82 | 62 | 653 |
| Mn | 25 | 7.21 | 127 | 82 | 65 | 717 |
| Fe | 26 | 7.8 | 126 | 77 | 65 | 762 |
| Co | 27 | 8.7 | 125 | 74 | 61 | 758 |
| Ni | 28 | 8.9 | 125 | 70 | 60 | 736 |
| Cu | 29 | 8.9 | 128 | 73 | - | 745 |
| Zn | 30 | 7.1 | 137 | 75 | - | 906 |

**Q.21 Explain the trends in ionization enthalpy of transition elements.**

**Ans:**

i. The ionisation enthalpies of transition elements are intermediate between those of s-block or p-block elements.

ii. This suggests that transition elements are less electropositive than elements of group 1 and 2.

iii. Depending on the conditions, they form ionic or covalent bonds. Generally in the lower oxidation states these elements form ionic compounds while in the higher oxidation states they form covalent compounds.

iv. There is substantial increase from the first ionisation enthalpy $IE_1$ to the third ionisation enthalpy $IE_3$.

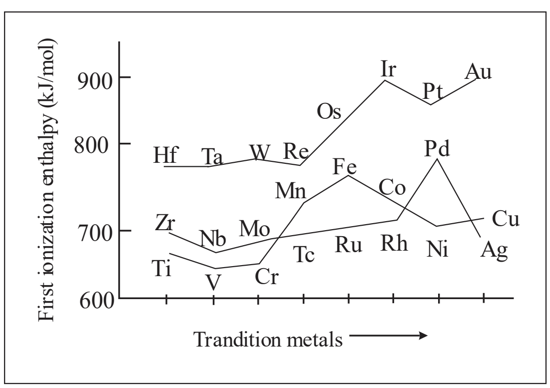
v. As we move across the transition series, slight variation is observed in the successive enthalpies $IE_1$, $IE_2$, $IE_3$ of these elements.

vi. The atoms of elements of third transition series possess filled 4f- orbitals. 4f orbitals show poor shielding effect on account of their peculiar diffused shape.

vii. As a result, the valence electrons experience greater nuclear attraction.

ix. A greater amount of energy is required to ionize elements of the third transition series.

x. The ionisation enthalpies of the elements of the third transition series are, therefore much higher than the first and second series.



| Element / IE | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn |
|---|---|---|---|---|---|---|---|---|---|---|
| $IE_1$ | 632 | 659 | 650 | 652 | 717 | 762 | 756 | 736 | 744 | 906 |
| $IE_2$ | 1245 | 1320 | 1376 | 1635 | 1513 | 1563 | 1647 | 1756 | 1961 | 1736 |
| $IE_3$ | 2450 | 2721 | 2873 | 2994 | 3258 | 2963 | 3237 | 3400 | 3560 | 3838 |

**Q.22 Write a short note on the metallic character of transiton elements.**

**Ans:**

i. Low ionization enthalpies and vacant d orbitals in the outermost shell are responsible for the metallic character of the transition elements.

ii. These favour the formation of metallic bonds and thus these elements show typical metallic properties.

iii. The hard nature of these elements suggests the formation of covalent bonds in them.

iv. This is possible due to the presence of unpaired (n-1)d electrons in these elements.

v. Nearly all transition metals have simple hexagonal closed packed (hcp), cubic closed packed (ccp) or body centered cubic (bcc) lattices which are characteristic of true metals.

**Q.23 Explain the observed trend in the melting of d-block elements.**

**Ans:**

i. In all the transition series the melting points steadily increase upto $d^5$ configuration.Cr, Mo and W show highest melting points in their respective series.

ii. Mn and Tc display anomalous values of melting points.

iii. After this with increasing atomic number the melting point decreases regularly.

**Remember-**

Hardness, high melting points and metallic properties of the transition elements indicate that the metal atoms are held strongly by metallic bonds with covalent character.

**+Q.24 Can you recall?**

**i. What happens when magnetic field is applied to substances ?**

**Ans:** When a magnetic field is applied, substances which are attracted towards the applied magnetic field are called paramagnetic, while the ones which are repelled are called diamagnetic.

**ii. What is meant by the terms paramagnetism and diamagnetism ?**

**Ans:** If all electrons in the particle are paired. Then the substance made of this particle is diamagnetic; if is has unpaired electrons, then the substance is paramagnetic.

**Q.25 Explain in brief the magnetic properties of transition metals.**

**Ans:**

i. The compounds of transition metals exhibit magnetic properties due to the unpaired electrons present in their atoms or ions.

ii. Among transition metals Fe, Co, Ni are ferromagnetic. When magnetic field is applied externally all the unpaired electrons in these metals and their compounds align in the direction of the applied magnetic field.

iii. Due to this the magnetic susceptibility is enhanced. These metals can be magnetized, i.e. , they aquire permanent magnetic moment.

iv. Each unpaired electron gives rise to a small magnetic field (magnetic moment) due to its spin angular momentum and orbital angular momentum.

v. In case of the first row transition elements, the contribution from the orbital angular momentum is quenched and hence, can be neglected.

vi. The spin-only formula for magnetic moment is :

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

vii. where n is the number of unpaired electrons and $\mu$ is the magnetic moment expressed in Bohr Magneton (BM).

viii. A single unpaired electron has magnetic moment $\mu = 1.73$ BM.

ix. From the magnetic moment ($\mu$) measurements of the metal complexes of the first row transition elements, the number of unpaired electrons can be calculated, with the use of spin-only formula.

x. As magnetic moment is directly related to number of unpaired electrons, value of $\mu$ will vary directly with the number of unpaired electrons.

xi. Magnetic moments are determined experimentally in solution or in solid state where the central metal is hydrated or bound to ligands.

xii. A slight difference in the calculated and observed values of magetic moments thus can be noticed.

xiii. In second and third transition series, orbital angular moment is significant. Therefore, the simple spin only formula is not useful and more complicated equations have to be employed to determine magnetic moments.

xiv. The magnetic moments further are found to be temperature dependent.

**Remember-**

Paramagnetism and ferromagnetism arises due to presence of unpaired electrons in a species.

When all electron spins are paired, the compound becomes diamagnetic.

**Try this.**

**+Q.26 What will be the magnetic moment of transition metal having 3 unpaired electrons?**

**i. equal to 1.73 BM**

**ii. less than 1.73 BM or**

**iii. more than 1.73 BM**

**Ans:** A single unpaired electron has magnetic moment $\mu$ = 1.73 BM. Hence, 3 unpaired electrons will have magnetic moment more than 1.73 BM.

**+Q.27 Use your brain.**

**A metal ion from the first transition series has two unpaired electrons. Calculate the magnetic moment.**

**Ans:** Magnetic moment $(\mu) = \sqrt{n(n+2)}$

n = no. of unpaired electrons

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

$\mu = \sqrt{2(4)}$

$\mu = \sqrt{8}$

$\mu = 2.82\,\text{BM}$

**+Q.28 Calculate the spin only magnetic moment of divalent cation of a transition metal with atomic number 25.**

**Solution :**

For element with atomic number 25, electronic configuration for its divalent cation will be

[Ar] 3d: ↑ ↑ ↑ ↑ ↑ 4s: □

There are 5 unpaired electrons, so n = 5.

∴ $\mu = 5(5 + 2) = 5.92$ BM

**Try this.**

**+Q.29 Calculate the spin only magnetic moment of divalent cation of element having atomic number 27.**

**Ans:**

For element with atomic number 27, electronic configuration for its divalent cation will be

[Ar] 3d: ↑↓ ↑↓ ↑ ↑ ↑ 4s: □

$$\mu = \frac{\sqrt{n(n+2)}}{\sqrt{3(3+2)}} = \sqrt{15}$$

= 3.87 BM.

**Can you tell?**

**+Q.30 Compounds of s and p block elements are almost white. What could be the absorbed radiation : uv or visible ?**

**Ans:** The compounds of s and p-block are generally colourless. High energy is required to promote electrons to an outer shell and falls in UV region.

**Q.31 Explain: Why most of the transition metals are coloured.**

**Ans:**

i. A substance appears coloured if it absorbs a portion of visible light.

ii. The colour depends upon the wavelength of absorption in the visible region of electromagnetic radiation.

iii. The ionic and covalent compounds formed by the transition elements are coloured. Transition elements contain unpaired electrons in their d orbitals.

iv. When the atoms are free or isolated, the five d orbitals are degenerate; or have the same energy.

v. In complexes, the metal ion is surrounded by solvent molecules or ligands. The surrounding molecules affect the energy of d orbitals and their energies are no longer the same.

vi. As the principal quantum number of 'd' orbitals is the same, the amount of energy required for transition of electron from one d orbital to another is quite small.

vii. The small energy required for this transition is available by absorption of radiation having certain wavelength from the visible region. Remaining light is transmitted and the observed colour of the compound corresponds to the complimentary colour of light absorbed.

viii. That means, if red light is absorbed then the transmitted light contains excess of other colours in the spectrum, in particular blue, so the compound appears blue. The ions having no unpaired electrons are colorless for example $Cu^{+}(3d^{10})$; $Ti^{4+}(3d^{0})$. of 3d transition metal ions.

ix. The how colour of the transition metal ion depends upon ligand and geometry of the complex formed by metal ion. When cobalt chloride ($CoCl_2$) is dissolved in water, it forms a pink solution of the complex $[Co(H_2O)_6]^{2+}$ which has octahedral geometry.

x. But when this solution is treated with concentrated hydrochloric acid, it turns deep blue.

xi. This change is due to the formation of another complex $[CoCl_4]^{2-}$ which has a tetrahedral structure.

$$[Co(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CoCl_4]^{2-} + 6H_2O$$

xii. Thus the colour of a transition metal ion relates to

a. presence of unpaired d electrons

b. d - d transitions

c. nature of ligands attached to the metal ion

d. geometry of the complex formed by the metal ion.

| Ion | Outer electronic configuration | Number of unpaired electrons | Colour |
|---|---|---|---|
| $Sc^{3+}$ | $3d^0$ | 0 | Colourless |
| $Ti^{3+}$ | $3d^1$ | 1 | Purple |
| $Ti^{4+}$ | $3d^0$ | 0 | Colourless |
| $V^{3+}$ | $3d^2$ | 2 | Green |
| $Cr^{3+}$ | $3d^3$ | 3 | violet |
| $Mn^{2+}$ | $3d^5$ | 5 | Light pink |
| $Mn^{3+}$ | $3d^4$ | 4 | Violet |
| $Fe^{2+}$ | $3d^6$ | 4 | Pale green |
| $Fe^{3+}$ | $3d^5$ | 5 | Yellow |
| $Co^{2+}$ | $3d^7$ | 3 | Pink |
| $Ni^{2+}$ | $3d^8$ | 2 | Green |
| $Cu^{2+}$ | $3d^9$ | 1 | Blue |
| $Cu^{+}$ | $3d^{10}$ | 0 | Colourless |
| $Zn^{2+}$ | $3d^{10}$ | 0 | Colourless |

**Q.32 Give the factors that are responsible for the colour of a transition metal ion.**

**Ans:**

i. Thus the colour of a transition metal ion relates to

a. presence of unpaired d electrons
b. d - d transitions
c. nature of ligands attached to the metal ion
d. geometry of the complex formed by the metal ion.

**Q.33 Explain: Colour of transition metal ions may arise due to a charge transfer.**

**Ans:**

Colour of transition metal ions may arise due to a charge transfer. For example, $MnO_4^-$ ion has an intense purple colour in solution. In $MnO_4^-$, an electron is momentarily transferred from oxygen (O) to metal, thus momentarily changing $O^{2-}$ to $O^-$ and reducing the oxidation state of manganese from +7 to +6. For charge transfer transition to take place, the energy levels of the two different atoms involved should be fairly close. Colours of $Cr_2O_7^{2-}$ , $CrO_4^-$ , $Cu_2O$ and Ni-DMG (where DMG = dimethyl glyoxime) complex thus can be explained through charge transfer transitions.

**Q.34 Why salts of $Sc^{3+}$, $Ti^{4+}$, $V^{5+}$ are colourless?**

**Ans:**

i The outer electronic configuration of $Sc^{3+}$, $Ti^{4+}$, $V^{5+}$ are $Sc^{3+} - 3d^0$, $Ti^{4+} - 3d^0$ and $V^{5+} - 3d^0$

ii. The ions $Sc^{3+}$, $Ti^{4+}$ and $V^{5+}$ have no unpaired electrons.

iii. As d-d transition are not possible, Their salts are colourless.

**Q.35 Write a short note on catalytic properties of transiton elements.**

**Ans:**

i. Transition metals and their compounds exhibit good catalytic properties.

ii. They have proven to be good homogeneous and heterogeneous catalysts.

iii. Partly because of their ability to participate in different oxidation-reduction steps of catalytic reactions.

iv. These steps involve changes in the oxidation states of these metal ions. Compounds of Fe, Co, Ni, Pd, Pt, Cr, etc. are used as catalysts in a number of reactions.

v. Their compounds enhance the rate of the chemical reactions.In homogeneous catalysis reactions, the metal ions participate by forming unstable intermediates.

vi. In heterogeneous catalysis reactions on the other hand, the metal provides a surface for the reactants to react.

**Q.36 Give the examples of chemical reactions that are catalysed by transition metals/ transition metal compounds.**

**Ans:**

i. $MnO_2$ acts as a catalyst for decomposition of $KClO_3$.

ii. In manufacture of ammonia by Haber's process Mo/Fe is used as a catalyst.

iii. Co-Th alloy is used in Fischer Tropsch process in the synthesis of gasoline.

iv. Finely divided Ni, formed by reduction of the heated oxide in hydrogen is an extremely efficient catalyst in hydrogenation of ethene to ethane at 140 $^0$C.

$$H_2C=CH_2 + H-H \xrightarrow[Ni,140^0C]{\Delta} H_3C-CH_3$$

Commercially, hydrogenation with nickel as catalyst is used to convert inedible oils into solid fat for the production of margarine.

v. In the contact process of industrial production of sulfuric acid; sulphur dioxide and oxygen from the air react reversibly over a solid catalyst of platinised asbestos.

$$2SO_2 + O_2 \underset{asbestos}{\overset{platinised}{\rightleftharpoons}} 2SO_3$$

vi. Carbon dioxide and hydrogen are formed by reaction of the carbon monoxide and steam at about 500 $^0$C with an Fe – Cr catalyst.

$$CO + \underset{(steam)}{H_2O} \underset{catalyst}{\overset{Fe-Cr}{\rightleftharpoons}} CO_2 + H_2$$

**Q.37 Explain the formation of interstitial compounds.**

**Ans:**

i. When small atoms like hydrogen, carbon or nitrogen are trapped in the interstitial spaces within the crystal lattice, the compounds formed are called interstitial compounds.

ii. Sometimes sulphides and oxides are also trapped in the crystal lattice of transition elements.

iii. Steel and cast iron are examples of interstitial compounds of carbon and iron.

iv. Due to presence of carbon, the malleability and ductility of iron is reduced while its tenacity increases.

**Q.38 Give the properties of interstitial compounds.**

**Ans:** Some properties of interstitial compounds:

i. They are hard and good conductors of heat and electricity.

ii. Their chemical properties are similar to the parent metal.

iii. Their melting points are higher than the pure metals.

iv. Their densities are less than the parent metal.

v. The metallic carbides are chemically inert and extremely hard as diamond.

vi. Hydrides of transition metals are used as powerful reducing agents.

**Remeber-**

- Tungsten carbide is used for cutting tools.
- Iron carbide is used in manufacture of steel.

**+Q.39 Can you recall?**

**i. What is an alloy?**

**Ans:** A metal alloy is a substance that combines more than one metal or mixes a metal with other non-metallic elements.

**ii. Do atomic radii of 3d transition elements differ largely ?**

**Ans:** As we move from left to right the atomic radii decreasesl. In the 3d transition series, the atomic radii from chromium to copper is nearly same. Thus, 3d, transition elements do not differ largely in atomic radii.

**Q.40 What are alloys of transition elements?**

**Ans:** Transition metals form alloys where atoms of one metal are distributed randomly in the lattice of another metal. The metals with similar radii and similar properties readily form alloys.

**Q.41 Give the classification of alloys.**

**Ans:**

i. Alloys are classified into ferrous and non-ferrous.

ii. Ferrous alloys have atoms of other elements distributed randomly in atoms of iron in the mixture.

iii. As percentage of iron is more, they are termed ferrous alloys eg. nickel steel, chromium steel, stainless steel etc. All steels have 2% carbon.

iv. Non-ferrous alloys are formed by mixing atoms of transition metal other than iron with a non transition element.

v. Example. brass, which is an alloy of copper and zinc. Ferrous and non-ferrous alloys are of industrial importance.

**Q.42 Give the uses of alloy along with the examples.**

**Ans:**

i. Bronze, an alloy of copper and tin is tough, strong and corrosion resistant. It is used for making statues, medals and trophies.

ii. Cupra-nickel, an alloy of copper and nickel is used for making machinary parts of marine ships, boats. For example, marine condenser tubes.

iii. Stainless steels are used in the construction of the outer fuselage of ultra-high speed air craft.

iv. Nichrome an alloy of nickel and chromium in the ratio 80 : 20 has been developed specifically for gas turbine engines.

v. Titanium alloys withstand stress up to high temperatures and are used for ultra high speed flight, fire proof bulkheads and exhaust shrouds.

## 8.7 Compounds of Mn and Cr ($KMnO_4$ and $K_2Cr_2O_7$)

**Q.43 Explain how potassium permanganate is prepared by**
**i. Chemical oxidation and**
**ii. Electrolytic oxidation.**

**Ans:**

**i. Chemical oxidation:**

a. When a finely divided manganese dioxide ($MnO_2$) is heated strongly with fused mass of caustic potash (KOH) and an oxidising agent, potassium chlorate ($KClO_3$), dark green potassium manganate, $K_2MnO_4$ is formed.

$$3MnO_2 + 6KOH + KClO_3 \xrightarrow{\Delta} 3K_2MnO_4 + KCl + 3H_2O$$

b. In neutral or acidic medium the green potassium manganate disproportionates to $KMnO_4$ and $MnO_2$.

$$3K_2MnO_4 + 4CO_2 \rightarrow 2KMnO_4 + MnO_2 + 4KHCO_3$$

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

c. The liquid is filtered through glass wool or sintered glass and evaporated until crystallisation occurs.

d. Potassium permanganate forms small crystals which are almost black in appearance.

**ii. Electrolytic oxidation:**

a. In electrolytic oxidation, alkaline solution of manganate ion is electrolysed between iron electrodes separated by a diaphragm.

b. Overall reaction is as follows :

$$2K_2MnO_4 + H_2O + [O] \rightarrow 2KMnO_4 + 2KOH$$

c. The oxygen evolved at the anode converts manganate to permanganate.

d. The solution is filtered and evaporated to get deep purple black coloured crystals of $KMnO_4$.

**Q.44 Write the chemical reactions showing oxidising property of $KMnO_4$ in acidic medium.**

**Ans:** The oxidizing reactions of $KMnO_4$ in acidic medium.

i. Oxidation of iodide to iodine: $2MnO_4^- + 10\ I^- + 16H^+ \rightarrow 2Mn^{2+} + 8H_2O + I_2$

ii. Oxidation of $Fe^{2+}$ to $Fe^{3+}$ $MnO_4^- + 5Fe^{2+} + 8H^+ \rightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$

iii. Oxidation of $H_2S$ : $H_2S \rightarrow 2H^+ + S^{2-}$ $5S^{2-} + 2MnO_4^- + 16H^+ \rightarrow 2Mn^{2+} + 5S + 8H_2O$

iv. Oxidation of oxalic acid: $2MnO_4^- + 5H_2C_2O_4 + 6H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$

**Q.45 Write the chemical reactions show oxidation property of $KMnO_4$ in neutral or alkaline medium.**

**Ans:**

i. Oxidation of iodide $I^-$ to iodate $IO_3^-$. $2MnO_4^- + H_2O + I^- \rightarrow 2MnO_2 + 2OH^- + IO_3^-$

ii. Thiosulphate $(S_2O_3^{2-})$ is oxidised to sulphate $(SO_4^{2-})$.

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

iii. Mananous salt is oxidised to $MnO_2$. $2MnO_4^- + 3Mn^{2+} + 2H_2O \rightarrow 5MnO_2 + 4H^+$

**Q.46 Give uses of $KMnO_4$.**

**Ans:**

i. An antiseptic.
ii. For unsaturation test in laboratory.
iii. In volumetric analysis of reducing agents.
iv. For detecting halides in qualitative analysis.
v. Powerful oxidising agent in laboratory and industry.

**Q.47 Which steps are involved in manufacture of potassium dichromate from chromate ore.**

**Ans:**

i. In the industrial production, finely powdered chromite ore ($FeOCr_2O_3$) is heated with anhydrous sodium carbonate ($Na_2CO_3$) and a flux of lime in air in a reverbatory furnace.

$$4(FeO.Cr_2O_3) + 8Na_2CO_3 + 7O_2 \xrightarrow{\Delta} 8Na_2CrO_4 + 2Fe_2O_3 + 8CO_2.$$

ii. Sodium chromate ($Na_2CrO_4$) formed in this reaction is then extracted with water and treated with concentrated sulphuric acid to get sodium dichromate and hydrated sodium sulphate :

$$2Na_2CrO_4 + H_2SO_4 \rightarrow Na_2Cr_2O_7 + 2NaCl + Na_2Cr_2O_7.H_2O$$

iii. Addition of potassium chloride to concentrated solution of sodium dichromate precipitates less soluble orange-red coloured potassium dichromate, $K_2Cr_2O_7$.

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

**Q.48 Explain the chemical properties of $K_2Cr_2O_7$.**

**Ans:**

i. a. Oxidation of $I^-$ from aq. solution of KI by acidified $K_2Cr_2O_7$ gives $I_2$.
b. Potassium dichromate is reduced to chromic sulphate. Liberated $I_2$ turns the solution brown.

$$K_2Cr_2O_7 + 6KI + 7H_2SO_4 \rightarrow 4K_2SO_4 + Cr_2(SO_4)_3 + 7H_2O + 3I_2$$

ii. a. When $H_2S$ gas is passed through acidified $K_2Cr_2O_7$ solution, $H_2S$ is oxidised to pale yellow precipitate of sulphur.
b. Simultaneously potassium dichromate is reduced to chromic sulphate, which is reflected as colour change of solution from orange to green.

$$K_2Cr_2O_7 + 4H_2SO_4 3H_2S \rightarrow K_2SO_4 + Cr_2(SO_4)_3 + 7H_2O + 3S$$

## 8.8 Common properties of d block elements

**Q.49 Give the physical properties of d-block elements.**

**Ans:**

i. All d block elements are lustrous and shining.
ii. They are hard and have high density.
iii. Have high melting and boiling points.
iv. Are good electrical and thermal conductors.
v. Have high tensile strength and malleability.
vi. Can form alloys with transition and non transition elements.
vii. Many metals and their compounds are paramagnetic.
viii. Most of the metals are efficient catalysts.

**Q.50 Mention some chemical properties of d-block elements.**

**Ans:**

i. All d block elements are electropositive metals.
ii. They exhibit variable valencies and form colored salts and complexes.
iii. They are good reducing agents.
iv. They form insoluble oxides and hydroxides.
v. Iron, cobalt, copper, molybdenum and zinc are biologically important metals
vi. Catalyse biological reactions.

**Q.51 Give the difference in elements of 3d, 4d, and 5d series.**

**Ans:**

i. Although most properties exhibited by d block elements are similar, the elements of first row differ from second and third rows in stabilization of higher oxidation states in their compounds.
ii. For example, Mo(V) and W (VI) compounds are more stable than Cr(VI) and Mn (VIII).
iii. Highest oxidation state for elements of first row is +7, and in the case of 3rd row +8 oxidation state as in ($RuO_4$) and ($OsO_4$).

**Q.52 Give the similarities and differences in elemencts of 3d, 4d, and 5d series.**

**Ans:**

i. similarities in physical properties: *Refer Q.49*

ii. similarities in chemical properties: *Refer Q.50*

iii. Differences: *Refer Q.51 (i)*

## 8.5 Metallurgy

**+Q.53 Can you recall?**

**i. How are metals found in nature?**

**Ans:** Most metals are found in the earth's crust in the form of their salts, such as carbonates, sulphates, sulphides and oxides.

**ii. Name the two salts of metals that are found in nature.**

**Ans:** NaCl and KCl are two salts of metal that are found in nature.

**Q.54 How are noble metals occur in the nature?**

**Ans:** A few metals are non reactive and occur in the free state in the earth's crust, for example, silver, gold, and platinum.

**Q.55 What are minerals?**

**Ans:** A naturally occuring substance found in the earth's crust containing inorganic salts, solids, siliceous matter etc, is called a mineral.

**Q.56 What is an ore?**

**Ans:** The mineral which contains high percentage of the metal and from which the metal can be extracted economically is called an ore.

| Metal | Mineral | Ore |
|---|---|---|
| Iron | Haematite $Fe_2O_3$<br>Magnetite $Fe_3O_4$<br>Limonite $2Fe_2O_3, 3H_2O$<br>Iron pyrites $Fes_2$<br>Siderite $FeCO_3$ | Haematite |
| Copper | Chalcopyrite $CuFeS_2$<br>Chalcocite Cuprite $Cu_2O$ | Chalcopyrite<br>Chalcocite |
| Zinc | Zinc blende ZnS<br>Zinccite ZnO<br>Calamine $ZnCO_3$ | Zinc blende |

**Q.57 Define metallurgy give its classification.**

**Ans:**

i. Commercial extraction of metals from their ores is called metallurgy. Different methods are used for their extraction depending on the nature of a metal and its ore.

ii. Metallurgy
- Pyrometallurgy
- Hydrometallurgy
- Electro–metallurgy

**Q.58 Define the following**

**i. Pyrometallrgy**

**ii. Hydrometallurgy**

**iii. Electrometallurgy**

**Ans:**

**i. Pyrometallurgy:**

A process in which the ore is reduced to metal at high temperature using reducing agents like carbon, hydrogen, aluminium, etc. is called pyrometallurgy.

**ii. Hydrometallurgy :**

The process of extracting metals from the aqueous solution of their salts using suitable reducing agent is called hydrometallurgy.

**iii. Electrometallurgy :**

A process in which metal is extracted by electrolytic reduction of molten (fused) metallic compound is called electrometallurgy.

**Q.59 Write steps involved in metallurgical process.**

**Ans:** The various steps involved in their extraction of pure metals from their ores are as follows.

i. Concentration of ores

ii. Conversion of ores into oxides or other desired compounds

iii. Reduction of ores to form crude metals

iv. Refining of metals.

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