4

CHAPTER

d & *f* block Element

Level - 1 CORE SUBJECTIVE QUESTIONS

MULTIPLE CHOICE QUESTIONS (MCQs)

(1 Mark)

1. **Option (A) is correct.**

   Explanation: Actinoid having configuration [Rn] $5f_76d_17S_2$ is Cm-Curium

   Lanthanoid which has $4f^{14}$ electronic configuration in +3 oxidation state is Lutenium-Lu Lanthanoid which show + 4 oxidation state is Ce-Cerium

2. **Option (D) is correct.**

   Explanation: No. of unpaired electrons: Ti^{3+}(1), Cr^{3+}(3), Fe^{2+}(4) and Mn^{2+}(5)

   Paramagnetism depends on the number of unpaired electrons.

3. **Option (B) is correct.**

   Explanation: The value of third ionisation enthalpy will be the largest in the case of Manganese as the electrons in the orbitals are in half filled stable electronic configuration. To form Mn^{3+}, electron has to be taken away from a $3d^5$ configuration, which requires significant energy.

4. **Option (A) is correct.**

   Explanation: When small non-metallic atoms are trapped inside the crystal lattice of a transition metal, they form covalent bond with the metal atoms making the transition metal harder.

5. **Option (C) is correct.**

   Explanation: Mn show maximum oxidation state is +7. It shows oxidation states from +2 to +7.

6. **Option (A) is correct.**

   Explanation: Electronic configuration of *d*-block element is $(n-1)d^{1-10}\ ns^{1-2}$

7. **Option (D) is correct.**

   Explanation: Scandium always shows a +3 oxidation state.

8. **Option (B) is correct.**

   Explanation: When MnO_2 is fused with KOH in the presence of air, the product formed is K_2MnO_4 which is green in colour.

9. **Option (D) is correct.**

   Explanation: Variable oxidation states and the ability to form complexes with reactant molecules are characteristics of transition metals that are associated with their catalytic property.

10. **Option (C) is correct.**

    Explanation: Because their *d*-orbitals are full these metals do not behave like transition metals which typically have partially filled *d*-orbitals.

11. **Option (B) is correct.**

    Explanation: +3 is the most common oxidation state shown by lanthanides and actinides.

12. **Option (C) is correct.**

    Explanation: The outermost configuration of transition metals that shows the highest oxidation state is $3d^54s^2$ which shows an oxidation state of +7. It corresponds to Mn with maximum oxidation number +7.

13. **Option (B) is correct.**

    Explanatio: The dichromate ion Cr – O bonds are involved in resonance that's why it's 6 Cr – O bonds have same bond length.

14. **Option (C) is correct.**

    Explanation: Lanthanoid and Actinoids show +3 oxidation state.

15. **Option (C) is correct.**

    Explanation: In MnO_4^{2-}, Mn exhibit +6 oxidation state and it belongs to group 7.

ASSERTION-REASON QUESTIONS

(1 Mark)

1. **Option (A) is correct.**

   Explanation: Assertion is true. Zirconium and hafnium occur together in nature and have very similar chemical properties.

   Reason is also true. The filling of 4f orbitals in lanthanoids causes poor shielding, so Hf (in period 6) has nearly the same atomic and ionic radii as Zr (in period 5).

   Both assertion and reason are true and reason is the correct explanation of assertion as the similar sizes lead to nearly identical chemical behaviour, making separation by ordinary methods very difficult.

2. **Option (A) is correct.**

   Explanation: Assertion and reason are both correct statements and poor shielding effect of 4*f* electrons results in similar atomic radii in the Lanthanide contraction is right explanation.

3. **Option (A) is correct.**

   Explanation: Zn^{2+} ions are colourless in aqueous solution as it has completely filled *d*-orbital which prevents the transitions between *d-d* orbitals - the cause of colored ions.

4. **Option (A) is correct.**

   Explanation: Manganese exhibits the highest number of oxidation states among first-row transition metals as it has 5 unpaired electrons in its d-subshell.

5. **Option (C) is correct.**

   Explanation: Actinoids show a greater range of oxidation states than lanthanoids as the energy difference between their 5*f*, 6*d* and 7*f* orbitals is comparatively small allowing them to participate in bonding. Hence assertion is correct but reason is wrong.

6. **Option (A) is correct.**

   Explanation: Assertion is true. According to IUPAC, a transition element must have an incomplete *d*-subshell in its ground state or in any of its common oxidation states.

   Reason is also true. Zn has electronic configuration [Ar] $3d^1$ $4s^2$, and in Zn^{2+} it is [Ar] $3d^1$ (fully filled *d*-subshell).

   Both assertion and reason are true and reason is the correct explanation of assertion because Zn never has an incomplete *d*-subshell, it does not meet the definition of a transition element.

7. **Option (A) is correct.**

   Explanation: Assertion is true. These Group 12 elements have a fully filled d_{10} configuration in both their ground state and most common oxidation state (+2).

   Reason is also true. The IUPAC definition of a transition element requires the presence of a partially filled *d*-subshell in the ground state or in any common oxidation state. Since these three metals never have a partially filled *d*-orbital, they are excluded.

VERY SHORT ANSWER TYPE QUESTIONS (2 Marks)

1. (i) $2MnO_4^- + 5SO_3^{2-} + 6H^+ \longrightarrow 2Mn^{2+} + 5\,SO_4^{2-} + 3H_2O$

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

2. Transition metals have a large number of unpaired *d*-electrons which can form strong metal–metal bonds. The more unpaired electrons, the stronger the metallic bonding due to greater overlap of atomic orbitals. This strong bonding requires more energy to break, resulting in high enthalpy of atomisation.

   Zinc element in 3d-series has lowest enthalpy ofatomisation because it has a completely filled $3d^{10}4s^2$ configuration, meaning no unpaired *d*-electrons are available for metallic bonding, leading to weak metal–metal bonds and thus low enthalpy of atomisation.

3. Lanthanoid contraction is the gradual decrease in atomic and ionic radii of the lanthanoids (Z = 57 to Z = 71) with increase in atomic number, due to poor shielding of nuclear charge by 4*f*-electrons.

   In actinoids, 5*f*-electrons are even less effective at shielding than 4*f*-electrons and have greater penetration towards the nucleus, leading to a stronger nuclear attraction and hence greater contraction from element to element.

4. (a) $2MnO_4^- + 5NO_2^- + 6H^+ \longrightarrow 2Mn_2^+ + 5NO_3^- + 3H_2O$

   (b) $Cr_2O_7^{2-} + 14H^+ + 6^{e-} \longrightarrow 2Cr_3^+ + 7H_2O$

SHORT ANSWER TYPE QUESTIONS (3 Marks)

1. (i) In the case of a lower oxide of a transition metal, the metal atom has some electrons present in the valence shell of the metal atom that are not involved in bonding. As a result, it can donate electrons and behave as a base whereas in higher oxide of a transition metal, the metal atom does not have an electron in the valence shell for donation. As a result, it can accept electrons and behave as an acid.

   (ii) Chromium has unpaired electrons which result in strong metallic bonding which results in it being a hard solid and the absence of unpaired electrons in Hg results in it being a liquid.

   (iii) The increase in effective nuclear charge responsible for steady increase in ionisation energy is counterbalanced by shielding effect of (*n*–1)*d* electrons.

2. (i) It is evident from the crystal field splitting that the configuration of M changes from d^4 to ${t_{2g}}^3$ and ${e_g}^1$

   Since the half-filled ${t_{2g}}^3$ level is more stable, the M^{2+} ion will furnish one electron and will act as a reducing agent.

   (ii) Metal ion M has n = 4 and d^4 configuration. Its electronic configuration will be[Ar] $4s^0$ $3d^4$. As its oxidation state is +2, therefore, metal ion is likely to be Cr^{2+}.

3. (i) The formula of compound present in bottle A is $[Ag\,(NH_3)_2]\,NO_3$

Name of the compound is diammine silver nitrate or Tollen's reagent.

(ii) Compound present in test tube B containing Aldehyde functional group gives silver mirror formation.

(iii) $RCHO + [Ag(NH_3)_2]\,NO_3 + NaOH \xrightarrow{heat} RCOO^- + Ag_{(s)} + NH_3 + H_2O$

LONG ANSWER TYPE QUESTIONS (5 Marks)

1. (i) Ce(III) having configuration $4f^1\,3d^\circ\,6s^\circ$ can easily lose an electron to aquire the configuration $4f^\circ$ and form Ce(IV).

(ii) The E° values of Mn^{2+}/M is highly negative because of the stability of the half filled d^5 configuration in Mn^{2+}. This means that removing an electron from this configuration requires a large amount of energy resulting a highly negative E° value.

(iii) Zinc has lowest enthalpy of atomisation in 3*d* series because it has a completely filled 3*d* subshell and has no unpaired electrons.

(iv) When sodium chromate is acidified with sulphuric acid, the solution changes colour from yellow to orange.

$$\underset{\text{(yellow)}}{CrO_4^{2-}} \overset{H^+}{\rightleftharpoons} \underset{\text{(orange)}}{Cr_2O_7^{2-}}$$

(v) Zn, Cd and Hg are soft metal because they have weak metallic bonds which are caused by absence of unpaired electron in their *d*-orbital.

(vi) It is because the permaganate oxidises the HCl to chlorine gas which prevents the medium from becoming acidic. Titration requires an acidic medium So, HCl is not used.

(vii) The lower oxide of transition metal is basic because the metal atom has low oxidation state where as higher once are acidic due to high oxidation state.

2. (i) $CuCl_2$ is more stable than Cu_2Cl_2 in aqueous solution because copper has a higher oxidation state +2 in $CuCl_2$ as compared to Cu_2Cl_2 in which Cu is in +1 oxidation state, and Cu_2Cl_2 gives disproportionation reaction in Aqeous medium.

(ii) $(n-2)\,f^{1-14}\,(n-1)d^{0-1}\,ns^2$ is the general electronic configuration of f black elements.

(iii) $Sc^{3+} = [Ar]\,3d^0$ colourless

$Fe^{3+} = [Ar]3d^5$ Brown

$Zn^{2+} = [Ar]\,3d^{10}$ colourless

In Fe^{3+} unpaired electrons are present which show *d-d* transition.

(iv) Conversion of sodium chromate into potassium dichromate

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

$NaCr_2O_7 + 2KCl \rightarrow K_2Cr_2O_7 + 2NaCl$

(v) Transition metals and their compounds show catalytic activtities because of their ability to show vaxiable oxidation states and complex formation.

3. (i) (1) Zn, Cd and Hg have low meeting and boiling points because of the absence of unpaired electrons in their *d*-ordbitals resulting in weak bonding between the atoms.

(2) Cr^{2+} is reducing as its configuration changes from d^4 to d^3 a more stable half filled t_{2g} configuration while Mn^{3+} is oxidising as Mn^{3+} to Mn^{2+} results a more stable half filled d^5 configuration.

(3) E° value of Cu^{2+}/Cu is + 0.34V because of high ΔaH° and low $\Delta_{hyd}H^\circ$.

(ii) (1) $2KMnO_4 \xrightarrow{Heat} K_2MnO_4 + MnO_2 + O_2$

(2) $Cr_2O_7^{2-} + 14H^+ + 6I^- \rightarrow 2Cr^{3+} + 3I_2 + 7H_2O$

4. (i) The Cu^+ ion is unstable in aqueous solution because it disproportionates to form Cu^{2+} and Cu.

(ii) Cr^{2+} is a stronger reducing agent than Fe^{2+} in aqueous solution because Cr^{2+} is more likely to oxidise into Cr^{3+} which has a stable half filled $t_{2g}{}^3$ electronic configuration.

(iii) Actinoid contraction is greater than lanthanoid contraction because the shielding effect of 5*f* orbitals is poorer than the shielding effect of 4*f* orbitals.

(iv) $MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$

This equation shows that $KMnO_4$ act as an oxidising agent by accepting electrons and being reduced from MnO_4^- to Mn^{2+}.

(v) Copper (Cu)

(vi) Transition metals and their compounds are good catalysts because they show variable oxidation state, provide large surface area and form complex compounds.

(vii) Scandium is considered as a transition element because it has an incomplete *d*-subshell in its elemental form but it does not form coloured ions because it has no unpaired *d*-electrons in its most common oxidation state.

5. (i) Chemistry of actinoids is complicated as compared to lanthanoids because:

(1) Actinoid show a large number of oxidation state while lanthanoids primarily show only three oxidation states.

(2) Actinoids are radioactive in nature.

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

This a disproportionate reaction since the same element [Mn] is oxidising as well as reducing.

(iii) Chromium (Cr) has the greatest number of unpaired electrons in its valence shell i.e. $[Ar]\,3d^5 4s^1$. These unpaired electrons contribute to the creation of strong metallic bonds. As a result the elements of chromium group have extremely high melting points where as Manganese (Mn) has a half filled *d*-orbitals configuration which means that all of its electron spin in the same direction Mn has a lower melting point because it has fewer inter atomic forces of attraction which are easier to break.

6. (i) (1) Transition metals form complex compounds because of their small size, high ionic charge and partially filled *d*-orbitals.

(2) Mn^{2+} exist in half filled d^5 state which is very stable while Mn^{3+} is d^4 which is not so stable. Conversion from d^4 to d^5 will be quick and have negative ΔG value. Hence, because of the stability factor the E° value is high for this process.

(3) This is because although energy is required to remove one electron from Cu^+ and Cu^{2+} high hydration energy of Cu^{2+} compensates for it.

(ii) $2MnO_2 + 4KOH + O_2 \xrightarrow{\Delta} 2K_2\,MnO_4 + 2H_2O$

$3K_2MnO_4 + 4HCl \rightarrow 2KMnO_4 + MnO_2 + H_2O + 4KCl$

7. (i) (1) Zn^{2+} salts are colourless because the Zn^{2+} ion has a fully filled *d*-orbital and no unpaired electrons so it doesn't undergo electronic transition or absorb visible light. Whereas Ni^{2+} has unpaired e^- in *d*-orbitals so it can show electronic transition. Hence, salts of Ni^{2+} are coloured.

(2) Cr^{2+} has d^4 configuration while Cr^{3+} has more stable d^3 configuration. Thus, Cr^{2+} has tendency to aquire Cr^{3+} due to greater stability of +3 oxidation state Cr^{2+} act as a reducing agent.

(3) It is due to presence of vacant *d* orbitals they have ability to exhibit variable valencies and they have a tendency to form complex compounds.

(ii) (1) $2MnO_4^-\ 10\,I^- + 16H^+ \longrightarrow 2Mn^{2+} + 8H_2O + 5I_2$

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

8. (1) Positive value for Mn^{3+}/Mn^{2+} is much more positive than that for Cr^{3+}/Cr^{2+} because Mn^{3+} has the outer electronic configuration of $3d^4$ and Mn^{2+} has the outer electronic configuration of $3d^5$. Thus conversion of Mn^{3+} to Mn^{2+} is a very stable configuration as it is half filled configuration.

Cr^{3+} to Cr^{2+} undergoes a charge in outer configuration from $3d^3$ to $3d^4$, this configuration is not stable and hence have a lower value of E°.

(2) Sc^{3+} ($3d°$) is colourless because it does not have any unpaired electron whereas Ti^{3+} has outer electronic configuration $3d^1$ 4S° with one unpaired electron. Hence, it is coloured in aqueous solution.

(3) Actinoids show a wide range of oxidation states because the energy level of their 5*f*, 6*d* and 7*s* orbitals are comparable.

9. (i) (1) Scandium or Zinc

(2) Chromium

(ii) (1) $Cr_2O_7^{2-} + 6Fe^{2+} + 14H^+ \rightarrow 2Cr^{3+} + 6\,Fe^{3+} + 7H_2O$

(2) $2KMnO_4 \xrightarrow{\Delta} K_2MnO_4 + MnO_2 + O_2$

(iii) Misch metal is an alloy made up of about 95% lanthanoid meta, 5% iron and trace amounts of sulphur carbon. Calcium and aluminium. Misch metal is used to make lighter flints.

10. (i) In MnO_4, Mn has oxidation number and group number 7. In $Cr_2O_7^{2-}$ Cr has oxidation number and group number 6.

(ii) Increasing the pH of a potassium dichromate ($K_2Cr_2O_7$) solution causes the solution to change colour from orange to yellow.

(iii) The Cu^+ ion is not stable in an aqueous solution because it undergoes a disproportionation reaction where it break down into Cu^{2+} and Cu.

(iv) Cerium

(v) Chromium (Cr) and Copper (Cu).

11. (i) (1) Transition metals have very similar size. One metal can easily replace the other metal from its lattice to form alloy.

(2) Ce^{4+} is a strong oxidising agent because of its high oxidation state small size, and high positive charge.

(ii) **Similarity:** Both lanthanoids and actinoids typically exhibit a + 3 oxidation state.

Difference: Lanthanoid have a lesser tendency towards complex formation compared to actinoids.

(iii) $Cr_2O_7^{2-} + 2OH^- \rightarrow 2CrO_4^{2-} + H_2O$

12. (i) Mn exhibits the highest oxidation state because it has electronic configuration [Ar] $4s^2$, $3d^5$

(ii) Transition metals and their compounds are generally found to be good catalyst because they have tendency to show large number of oxidation states and the ability to form complexes which make them good catalyst.

(iii) Cr^{2+} is reducing as its configuration changes from d^4 to d^3 a more stable half filled $t_{2g}^{\,3}$ configuration while Mn^{3+} is oxidising as Mn^{3+} to Mn^{2+} result a more stable half filled d^5 configuration.

(iv) Zn has lowest enthalpy of atomisation due to absence of unpaired electrons.

(v) Cu^+ is unstable in an aqueous solution because it disproportionate to give Cu^{2+} and Cu.

13. (i) The chemistry of the actinoids is more complex as compared to lanthanoids because actinoids display a large number of oxidation states and are radioactive in nature.

(ii) It is because Mn^{3+} has the outer electronoic configuration of $3d^4$ and Mn^{2+} has the outer electronic configuration of $3d^5$. Thus, the conversion of Mn^{3+} to Mn^{2+} will be favourable reaction since $3d^5$ is a very stable configuration as it is half filled configuration. Hence, E° value for Mn^{3+}/Mn^{2+} couple is positive.

(iii) Transition metals form a large number of complex compounds. This is due to comparatively small size and of the metal ions, their high nuclear charges and the availability of vacant d orbitals for bond formation.

(iv) $MnO_4^- + 5Fe^{2+} + 8H^+ \rightarrow Mn^{2+} + 5\,Fe^{3+} + 4H_2O$

(v) The divalent ion in aqueous solution will have $3d^5$ configuration (five unpaired electrons) with atomic number 25. The magnetic moment (μ).

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

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

$$\mu = \sqrt{35}$$

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

14. The above given process is depicting the preparation of potassium dichromate.

The unknown compound 'C' is Potassium dichromate ($K_2Cr_2O_7$)

Stepwise chemical equations involved are as follows.

$$4FeCr_2O_4 + 16NaOH + 7O_2 \rightarrow 8Na_2CrO_4 + 2Fe_2O_3 + 8H_2O$$

Compound A is Na_2CrO_4

$2Na_2CrO_4 + H_2SO_4 \rightarrow Na_2Cr_2O_7 + Na_2SO_4 + H_2O$

Compound B is $Na_2Cr_2O_7$

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

Compound C is $K_2Cr_2O_7$

Level - 2 ADVANCED COMPETENCY FOCUSED QUESTIONS

MULTIPLE CHOICE QUESTIONS (MCQs)

(1 Marks)

1. Option (A) is correct.

Explanation: This is due to formation of dichromate ion in the presence of HCl.

2. Option (C) is correct

Explanation: The Mn^{2+} ion has the stable half-filled d^s configuration (electronic configuration: [Ar] $3d^s$). Half-filled subshells provide extra stability due to symmetrical distribution and exchange energy. Also, in aqueous medium, Mn^{2+} is relatively less prone to oxidation due to this stability.

3. Option (B) is correct

Explanation: Transition metals have partially filled *d*-orbitals. When these metal ions form complexes (especially in aqueous or ligand environments), the degenerate *d*-orbitals split into different energy levels due to the crystal field effect. Electrons absorb specific wavelengths of visible light to jump from a lower-energy *d*-orbital to a higher-energy *d*-orbital — this is known as a *d–d* transition. The remaining wavelengths (those not absorbed) are reflected or transmitted, giving the compound its characteristic colour.

4. Option (C) is correct

Explanation: Potassium dichromate ($K_2Cr_2O_7$) is a strong oxidising agent, especially in acidic medium. In breath analysers, it is used to detect alcohol (ethanol) in the breath of a person. It oxidises ethanol (C_2H_5OH) into acetic acid (CH_3COOH):

$$C_2H_5Oh + [O] \xrightarrow{K_2Cr_2O/H^+} CH_3COOH$$

During this reaction, the orange dichromate ion ($Cr_2O_7^{2-}$) is reduced to green Cr^{3+} ions, indicating the presence of alcohol.

5. Option (C) is correct

Explanation: Potassium permanganate ($KMnO_4$) contains the MnO_4^- ion, in which manganese is in the +7 oxidation state. This ion imparts a deep purple/violet colour to the solution. It is highly coloured due to charge transfer transitions, not typical *d–d* transitions.

6. Option (B) is correct

Explanation: In KMnO4, manganese is in the +7 oxidation state (MnO_4^-). In acidic medium, it acts as a strong oxidising agent, and Mn^{7+} is reduced to Mn^{2+}, which is very stable in aqueous solution.

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

So, the oxidation state of Mn changes from +7 to +2.

ASSERTION-REASON QUESTIONS

(1 Mark)

1. Option (A) is correct

Explanation: Assertion is true. Transition elements have a strong tendency to form complex compounds (coordination compounds) with ligands such as H_2O, NH_3, CN^-, etc. This is a key characteristic of *d*-block elements due to their electronic structure and bonding properties.

Reason is also true. Transition metal ions often have vacant low-energy d-orbitals that can accept lone pairs from ligands. They also have small size and high charge, resulting in high charge density, which attracts electron-rich ligands more effectively.

2. Option (A) is correct

Explanation: Assertion is true. Lanthanide contraction refers to the gradual decrease in atomic and ionic radii across the lanthanide series (Ce to Lu). This affects the chemical properties of the elements that follow, especially the 4*d* and 5*d* transition elements. For example, Zr and Hf (belonging to groups 4 of periods 5 and 6) have almost identical atomic radii, making their chemistry very similar.

Reason is also true. 4*f* electrons are poor at shielding the nuclear charge. As a result, electrons are pulled closer to the nucleus, leading to a gradual decrease in size across the series. This explains why atomic and ionic radii of the lanthanides decrease slightly but steadily, and why later elements show similar sizes.

3 Option (A) is correct

Explanation: Assertion is true. Zn^{2+} compounds in aqueous solution appear colourless.

This is because they do not absorb visible light due to the absence of *d–d* transitions.

Reason is also true. The electronic configuration of Zn^{2+} is [Ar] $3d^{10}$. Since all *d*-orbitals are completely filled, no *d–d* electronic transition is possible, which is responsible for colour in other transition metal ions.

4. Option (B) is correct

Explanation: Assertion is true. Manganese (Mn, atomic number 25) can show oxidation states from +2 to +7, making it the element with the widest range of oxidation states in the 3*d* series. This is due to the availability of both 3*d* and 4*s* electrons for bonding.

Reason is also true. Mn has the configuration [Ar] $3d^5$ $4s^2$, so the *d*-subshell ($3d^5$) has 5 unpaired electrons, which is the maximum possible in a *d*-subshell.

Both assertion and reason are true but the reason is not the correct explanation of assertion because the number of unpaired electrons contributes to magnetic behaviour, not directly to the number of oxidation states. Oxidation states depend on the number of electrons available for bonding, not just unpaired ones.

5. Option (C) is correct

Explanation: Assertion is true. Actinoids exhibit oxidation states ranging from +3 to +7 (e.g., uranium: +3 to +6), showing variable and higher oxidation states. This is because the 5*f*, 6*d*, and 7*s* orbitals have comparable energies, allowing more electrons to participate in bonding. In contrast, lanthanoids predominantly exhibit the +3 oxidation state with only a few showing +2 or +4.

Reason is false. In fact, 5*f* orbitals are less effectively shielded than 4*f* orbitals. As a result, 5*f* orbitals participate more in bonding, which contributes to the wide range of oxidation states—but not due to better shielding.

VERY SHORT ANSWER TYPE QUESTIONS (2 Marks)

1.

Properties	Actinoids	Lanthanoids
Magnetic properties	Lower	Higher
The action of boiling water	Gives a mixture of oxide and hydride	Gives a mixture of hydroxides and hydrogen gas

2. (i) The elements in decreasing order of atomic number are:

X > Z > Y

(ii) The overall decrease in atomic and ionic radii from lanthanum to lutetium (the lanthanoid contraction) is a unique feature in the chemistry of the lanthanoids. This is called Lanthanoid contraction.

3. Element J is expected to valence electrons in the 5*f* orbitals. The melting point of the element J is the highest among the three. So, it is expected to belong to the 3rd transition series with the valence electrons in 5*f* orbitals.

SHORT ANSWER TYPE QUESTIONS (3 Marks)

1. Potassium permanganate ($KMnO_4$) is used in water treatment because it is a strong oxidising agent, especially in acidic medium. It oxidises harmful organic and inorganic substances such as bacteria, iron, hydrogen sulphide (H_2S), and other pollutants present in water. During this oxidation process, Mn in $KMnO_4$ gets reduced from +7 oxidation state to +2.

Balanced Redox Reaction (in acidic medium):

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

If a reducing agent (e.g., Fe^{2+}) is present:

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

2. (i) Potassium dichromate acts as a strong oxidising agent in acidic medium. In a breath analyser, it oxidises ethanol (C_2H_5OH) present in the exhaled breath to acetic acid (CH_3OOH). This oxidation confirms the presence of alcohol.

(ii) The solution changes from orange to green. This is due to the reduction of Cr^{6+} (orange) in $Cr_2O_7^{2-}$ to Cr^{3+} (green).

(iii) Redox reaction involved:

$3C_2H_5OH + 2Cr_2O_7^{2-} + 16H^+ \rightarrow 3CH_3COOH + 4Cr^{3+} + 11H_2O$

3. (i) $KMnO_4$ has a deep purple colour, and it undergoes a colour change during the redox reaction. It does not require any external indicator, because at the endpoint, an extra drop of $KMnO_4$ gives a permanent pink colour in the solution. Hence, it acts as a self-indicator.

(ii) The colour of the solution changes from colourless (or very pale pink) to light/pale pink at the endpoint. This indicates that all Fe^{2+} ions have been oxidised, and the next drop of $KMnO_4$ remains unreacted.

(iii) Acidic medium (usually dilute H_2SO_4) is necessary for the complete reduction of MnO_4^- (Mn^{7+}) to Mn^{2+} (Mn^{2+} is colourless). Without acid, MnO_4^- may get reduced only to MnO_2 (brown precipitate) instead of Mn^{2+}, affecting the accuracy of the titration.

4. (i) Two examples of transition metal catalysts:

(1) Iron (Fe):Used as a catalyst in the Haber process for the synthesis of ammonia.

$$N_2 + 3H_2 \xrightarrow{Fe} 2NH_3$$

$$2SO_2 + O_2 \xrightarrow{Fe} 2SO_3$$

(2) Vanadium(V) oxide (V_2O_5): Used in the Contact process for the production of sulphur trioxide (SO_3), a key step in manufacturing sulphuric acid.

(ii) Transition metals have variable oxidation states and partially filled *d*-orbitals, which allow them to form unstable intermediate compounds with reactants. They also provide a large surface area for adsorption, lowering the activation energy of the reaction and increasing the reaction rate. These features enable them to speed up chemical reactions without undergoing permanent changes themselves.

CASE BASED QUESTIONS (4 Mark)

1. (i) Transition elements and their compounds are widely used as catalysts. One cause for this property of transition elements is that they are capable of exhibiting different oxidation state.

(ii) The cause of contraction in the atomic size of lanthanoid is due to poor shielding of the 4*f* electrons.

(iii) (a) Lanthanoid contraction is the gradual decrease in the atomic and ionic size of lanthanide elements as their atomic number increases.

Due to lanthanide contraction atomic radii of the third transition series and the second transition series are almost equal.

OR

(b) Cr^{2+} is a stronger reducing agent than Fe^{2+} in aqueous media because of its higher reduction potential and more favourable oxidation state.

2. (i) Crystal field spiliting energy (CFSE) is the energy difference between the two sets of *d*-orbitals in a transition metal complex when ligands approach the metal ion.

(ii) The complex $[Ti(H_2O)_6]^{3+}$ appears violet in colour due to *d-d* transition which is caused by the presence of an unpaired electron.

(iii) (a) Complex $[Cr(NH_3)_6]^{3+}$ is paramagnetic due to presence of three unpaired electrons whereas $[Ni(CN)_4]^{2-}$ is diamagnetic in nature due to absence of unpaired electron is *d*-subshell.

OR

(b) The complex ion $[Fe(CN)_6]^{3-}$ is an inner orbital complex because it uses the inner *d*-orbitals in complex while $[Fe(H_2O)_6]^{3+}$ is an outer orbital complex because it uses the outer *d*-orbitals in complex because it uses sp^3d^2 hybridisation.

3. (i) Copper has a partially filled *d*-orbital in its +2 oxidation state which is $3d^{9-}$ whereas zinc in its +2 oxidation state has $3d^{10}$ completely filled *d*-orbital.

(ii) Transition elements show variety of oxidation states because the energy difference between their $(n-1)d$ and ns orbitals is very small.

(iii) (a) (1) The value of $E^\circ_{M^{2+}/M}$ for transition metals are irregular because of the irregular variation of ionisation enthalpies heat of sublimation and enthalpy of hydration.

(2) In case of transition elements, the oxidation state can vary from +1 to the highest oxidation in transition elements the oxidation state differ by 1 whereas the oxidation state shown by non-transition elements differ by 2 units due to the inert pair effect.

OR

(b) (1) Cr^{2+} is reducing as its configuration changes from d^4 to d^3, the latter having a half filled t_{2g} level. On the other hand the change from Mn^{3+} to Mn^{2+} result has extra stability. That is why Cr^{2+} is reducing and Mn^{3+} is oxidising when both have d^4 configuration.

(2) $2MnO_4^- + H_2O + I^- \rightarrow 2MnO_2 + 2O\bar{H} + IO_3^-$

LONG ANSWER TYPE QUESTIONS (5 Marks)

1. (i) Potassium permanganate ($KMnO_4$) has a deep purple colour. During titration in acidic medium, it gets reduced to colourless Mn^{2+}. As it reacts, the purple colour disappears. The first permanent pink colour at the endpoint indicates that all Fe^{2+} has been oxidised. Hence, $KMnO_4$ acts as its own indicator, eliminating the need for an external one.

(ii) $MnO_4^- + 5Fe^{2+} + 8H^+ \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$

(iii) Potassium dichromate ($K_2Cr^2O_7$) is a strong oxidising agent in acidic medium. It oxidises ethanol (C_2H_5OH) present in the breath of an intoxicated person to acetic acid (CH_3COOH). During this redox reaction, $Cr_2O_7^{2-}$ (orange) is reduced to Cr^{3+} (green).This orange to green colour change indicates the presence of alcohol.

(iv) Transition metals have partially filled *d*-orbitals. When light falls on their compounds, electrons in lower-energy *d*-orbitals absorb specific wavelengths and jump to higher-energy *d*-orbitals—this is called a *d–d* transition. The remaining light is transmitted or reflected, giving the compound its characteristic colour. This is why most transition metal ions and complexes are coloured.

2. (i) Lanthanide oxides (e.g., CeO_2, EuO_3) are used in colour television screens and LEDs due to their phosphorescent properties. Alloys of lanthanides (like mischmetal containing Ce, La, Nd) are used in lighter flints, jet engine parts, and nuclear applications due to their heat resistance and magnetic properties.

(ii) **Cause:** As we move across the lanthanide series, the addition of electrons occurs in the 4*f* orbitals. These 4*f* electrons do not shield the nuclear charge effectively.

This leads to a gradual decrease in atomic and ionic radii, known as lanthanide contraction.

Effects of lanthanide contraction: Difficulty in separating lanthanides (they have very similar sizes). Causes similarity in size of elements in the 2nd and 3rd transition series (e.g., Zr and Hf).

(iii) Actinides have higher atomic numbers and larger nuclei, making their nuclei less stable.

Most actinides have unstable neutron-to-proton ratios, leading to radioactive decay.

Lanthanides, in contrast, are relatively more stable and only a few are radioactive.

(iv)

Lanthanides	Actinides
Show +3 oxidation state predominantly	Show variable oxidation states (+3 to +6)
Involve filling of 4*f* orbitals	Involve filling of 5*f* orbitals

3. (i) **Alloy formation:** Transition metals can form strong metallic bonds and have similar atomic sizes, allowing them to form solid solutions (alloys) with other metals. These alloys have high strength, toughness, and corrosion resistance (e.g., stainless steel, nichrome).

Electrical contacts: They have high electrical conductivity, thermal stability, and resistance to wear, making them suitable for electrical wires, relays, and switch contacts (e.g., Cu, Ag, Pt).

(ii) V_2O_5 (vanadium pentoxide) acts as a catalyst in the Contact process, which is used for manufacturing sulphuric acid (H_2SO_4).It catalyses the conversion of SO_2 to SO_3:

$$2SO_2 + O_2 \xrightarrow{V_2O_5} 2SO_3$$

V_2O_5 has variable oxidation states (+5 and +4), allowing it to accept and donate oxygen during the redox cycle.

(iii) **Reactivity:** Actinoids have larger atomic sizes and more shielded outer electrons, making them more electropositive and reactive.

Radioactivity: Due to their large, unstable nuclei and high neutron-to-proton ratios, most actinoids undergo radioactive decay. In contrast, only a few lanthanoids are radioactive.

(iv) *f*-Orbitals (especially 4*f* and 5*f*) have a very poor shielding effect. As electrons are added across the series, nuclear attraction increases more than the shielding. This causes a gradual decrease in atomic and ionic radii, known as Lanthanide contraction (in 4*f* series), and Actinide contraction (in 5*f* series).