

GENESIS TUTORIALS

Institute for CSIR-UGC-NET/JRF, GATE & IIT-JAM

MAGNETISM

Introduction:-

Electronic spectroscopy is a powerful method for investigating transition metal complexes. Additional and complementary information can be provided by magnetic measurement because complexes generally have partially filled metal d or f orbitals so a large range of magnetic properties can be expected depending on oxidation state, e^- configuration & co-ordination number of central atom.

DIAMAGNETISM

- When a substance is placed in an external or applied magnetic field, there is an induced circulation of e^- in substance, this induced circulation of e^- give rise to a magnetic moment or magnetic field and if this opposes the applied magnetic field then the substance is repelled by the magnetic field. This effect is called **Diamagnetic effect**.
- This effect is caused by the presence of paired electron.
- The diamagnetic effect exists only when a substance is placed in the magnetic field.
- The substances that have only paired electron exhibits a weak magnetic moment called Diamagnetism and such substances are called Diamagnetic Substance.

“If a substance has only paired e^- , the diamagnetic effect is dominated while if a substance has paired as well as unpaired electron, the paramagnetic effect is dominated”.

“Diamagnetism is a universal property of matter since all compound contains some paired electron”

PARAMAGNETISM:-

- Any substance that has one or more unpaired e^- exhibits stronger & permanent magnetic property known as paramagnetism
- Paramagnetism arises from spin and orbital motion of unpaired e^- in the absence of external magnetic field

When a paramagnetic substance is placed in an external magnetic field, the permanent magnetic moments tends to align themselves in the direction of external magnetic field and as a result they are attracted into the magnetic fields.

Since, paramagnetic effect is much larger than diamagnetic effect & opposite to diamagnetic effect, it cancels the diamagnetic effect.

- Thus even substances having only one unpaired electron per molecule will show a net attraction into a magnetic field.

The paramagnetic effect is observed only in the presence of an external field. When field is removed, individual molecular moments are randomised by thermal motion and bulk sample has no overall moment. When a field is present there is a competition between the thermal tendency towards randomness & field capacity to force alignment. As a result, paramagnetic effects decrease in magnitude as temperature is increased. It is due to the fact that increase in temperature, increase randomization and decreases paramagnetic effect

Now, When any substance is placed in a magnetic field, the field produced within the sample will either be greater than or less than applied field, depending on whether the material is paramagnetic or diamagnetic.

The difference between the two is expressed as:-

$$\Delta H = B - H_0$$

Where B is induced field inside the sample, H_0 is external field or free field value

- For. Diamagnetic substance, $B < H_0$ so, $\Delta H = \text{negative}$
- For paramagnetic substance, $B > H_0$ so, $\Delta H = \text{positive}$

More commonly, the difference between the applied and induced field in sample is expressed in terms of I (ie. intensity of magnetisation), which is magnetic moment per volume

i.e.

$$4\pi I = B - H_0$$

$$\frac{4\pi I}{H_0} = \frac{B}{H_0} - 1$$

Here, the ratios $\frac{I}{H_0}$ & $\frac{B}{H_0}$ are constant for given substance.

- Term $\frac{B}{H_0}$ is called magnetic permeability, it is the ratio of the density of magnetic force lines in the presence of same density with no sample & for vacuum, this ratio = 1
- $\frac{I}{H_0}$ is magnetic susceptibility per unit volume (k), which express the degree to which a material is subject to magnetization

$$4\pi K = \frac{B}{H_0} - 1$$

K → negative for diamagnetic substance,

K → positive for paramagnetic substance

The quantity that is most frequently obtained from experimental measurement for magnetism is **specific or mass susceptibility**.

It is related to volume susceptibility through density (d)

$$\chi = \frac{k}{d}$$

By multiplying the specific susceptibility of a compound by its molecular weight we obtain molar susceptibility

$$\chi_M = \chi \cdot Mw$$

➤ Methods in laboratory for the measurement of magnetic susceptibility

(a) Gouy Method

(b) Faraday Method

MORDERN TECHNIQUE:- SQUID (Super conductor quantum interference device)

- Once an experimental value of χ_M has been obtained for a paramagnetic substance it can be used to determine how many unpaired e^- are there per-molecule or ion.
- Next step is to connect the macroscopic susceptibility to individual molecular moment & finally to unpaired electron.
- From classical theory, the corrected or paramagnetic molar susceptibility is related to permanent magnetic moment of molecule (μ).

$$\chi_m = \frac{N^2 \mu^2}{3RT}$$

Where, N is Avagadro number
 R is ideal gas constant
 T is absolute temperature

μ is expressed in Bohr Magneton ($1BM = \frac{eh}{4\pi m}$)

Now, solving this expression for magnetic moment we get:-

$$\left(\frac{\chi_m 3RT}{N^2}\right)^{1/2} = \mu$$

$$\mu = 2.84 (\chi_m T)^{1/2} \text{B.M}$$

- Pierre curie has shown that the paramagnetic susceptibility is inversely proportional to absolute temperature.

$$\chi_m^P = \frac{C}{T} \quad \text{(This is curie's Law)}$$

Where, C is curie's constant $\left[C = \frac{N^2 \mu^2 \text{eff}}{3R}\right]$

This law is valid only for paramagnetic substances that are magnetically dilute (those in which paramagnetic centers are well separated from each other) by diamagnetic atoms.

- **NOTE:-** Magnetic susceptibility χ of a material is a measure of how easy it is to align electron spins with the applied field.

- A paramagnetic material has positive susceptibility.
- A Diamagnetic material has negative susceptibility.

Cooperative Mechanism

- The materials that are not magnetically dilute, unpaired spins on neighboring atoms may couple with each other, this phenomenon is called **Magnetic Exchange**.
- These substance may behave as either ferromagnetic or ferromagnetic or antiferromagnetic and they follow **Currie-Weirs Law** (modification of curie's Law) (This is called cooperative magnetism).

$$\chi_m = \frac{C}{T - \theta}$$

Where, θ is a constant with units of temperature.

- **NOTE-** When the paramagnetic species are very close together (as in bulk metal or are separated by species that can transmit interactions (as in many d-block metal oxides flourides & chlorides), the metal centers may interacts (couple) with one another, this give rise to ferro or anti-ferro.

Ferromagnetism:-

- If the interacting magnetic dipoles on neighboring atom tends to assume a parallel alignment, substance is said to be ferromagnetic.
- Ferromagnetism leads to greatly enhanced para magnetism as in iron metal at temperature of up to 1043 K above which thermal energy is sufficient to overcome the alignment and normal paramagnetic behavior prevails
- On cooling a sample, ferromagnetic ordering (change from paramagnetic to ferromagnetic occurs at curie temperature and curie's weirs law is written as:-

$$\left(\chi = \frac{C}{T - \theta} \right) \quad \begin{array}{l} \theta \rightarrow \text{weiss constant} \\ C \rightarrow \text{curie's constant} \end{array}$$

$$\chi = \frac{C}{T - T_C} \quad T_C \rightarrow \text{Curie temperature}$$

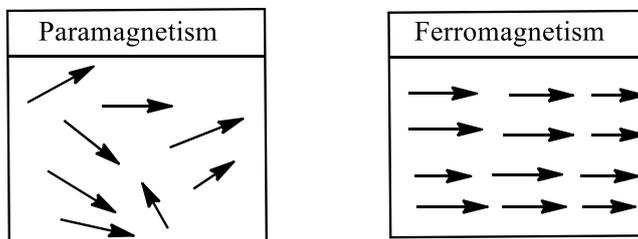
- If there is interaction between the magnetic moment on neighboring atoms of a paramagnetic substance, spontaneous ordering of magnetic moment occur below a particular temperature, called as critical temperature.

If alignment of all the magnetic moment of neighboring atoms is in same direction & produce a permanent magnetic moment substance is said to be ferromagnetic and critical temperature is called curie temperature (T_C) .

Above this temperature, the substance behaves as a normal paramagnetic substance below T_C , the ferromagnetic substance obeys **Curie Weiss law**,

$$\chi_M^P = \frac{C}{T - \theta}$$

For example Fe, Co, Ni & CrO₂ exhibit ferromagnetism below curies temperature (1043K, 1404K, 631K & 386K)



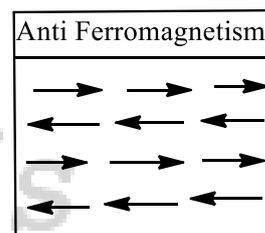
Antiferromagnetism

- If there is a tendency for anti-parallel arrangement of coupled spins, then the substance is said to be Antiferromagnetic
- If half of the magnetic moments are aligned in opposite direction to the other half resulting in a net zero magnetic moment, the substance is said to be anti-ferromagnetic and the critical temperature is called Neel Temperature

$$\chi = \frac{C}{T + T_N}$$

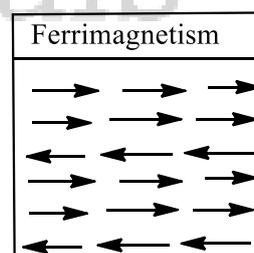
Where, T_N is Neel temperature

- An example of Antiferromagnetism is MnO which has NaCl type structure & has Neel temperature of 118K

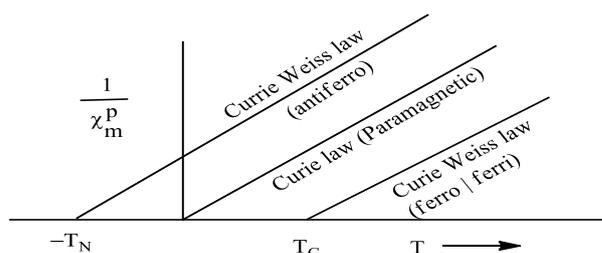


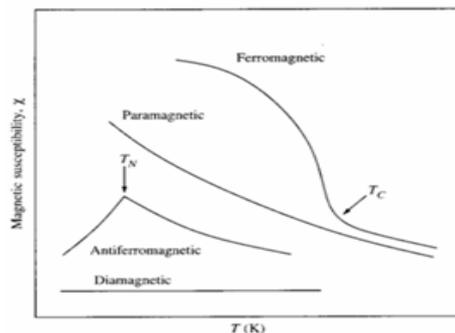
Ferrimagnetism

- If some of the magnetic moments are systematically aligned opposite to the others to give resultant magnetic moment and the critical temperature is called Curie temperature T_C.
- **Ex.** Magnetite (Fe₃O₄), In this substance, the magnetic moments of Fe(II) & Fe(III) are aligned in opposite directions and resultant magnetic moment is only from Fe(II) moment.



Plot of reciprocal of paramagnetic susceptibility v/s absolute temperature





Variation of magnetic susceptibility with temperature for diamagnetic, paramagnetic, ferromagnetic, and antiferromagnetic substances. Transition to paramagnetic behavior for ferromagnetic and antiferromagnetic substances occur at the Curie (T_c) and Neel (T_N) temperatures, respectively.

Super exchange:- When a bridging ligand facilitates the coupling of electron spins on adjacent metal centers, the mechanism is called super exchange.

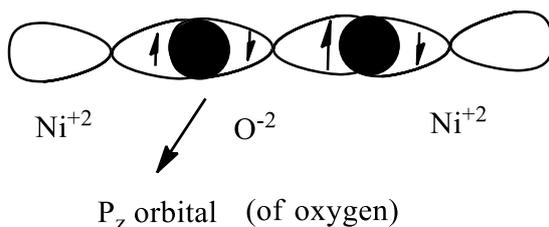
In super exchange pathway, the unpaired e^- on the first metal centre M_1 interacts with a spin-paired pair of e^- on bridging ligand with the result that unpaired e^- on M_2 is aligned in an antiparallel manner with respect to M_1 .

$$\text{Susceptibility}(\chi) = \frac{M}{H}$$

Where, M is magnetization produced, H is Field applied

Ex. MnO , NiO (in NiO where coupling of spins occurs to give rise to Anti ferromagnetism)

- Ni^{+2} is d^8 system and in octahedral environment i.e. (e_g^2) $\rightarrow d_{x^2-y^2}^1, d_{z^2}^1$. Here, the orbitals are oriented in such a way so that they point directly at adjacent oxide ions, the unpaired electron in e_g orbital of Ni^{+2} ions are able to couple magnetically with electron p orbitals of O^{-2} ions.
- The p orbital of O^{-2} ion contain $2e^-$ each which are also coupled antiparallel
- Ni^{+2} & O^{-2} ions are sufficiently close that coupling of their e^- is possible, a chain coupling effect occurs which passes through crystal structure
- The net effect is that neighboring Ni^{+2} ions separated by O^{-2} ions are coupled antiparallel.

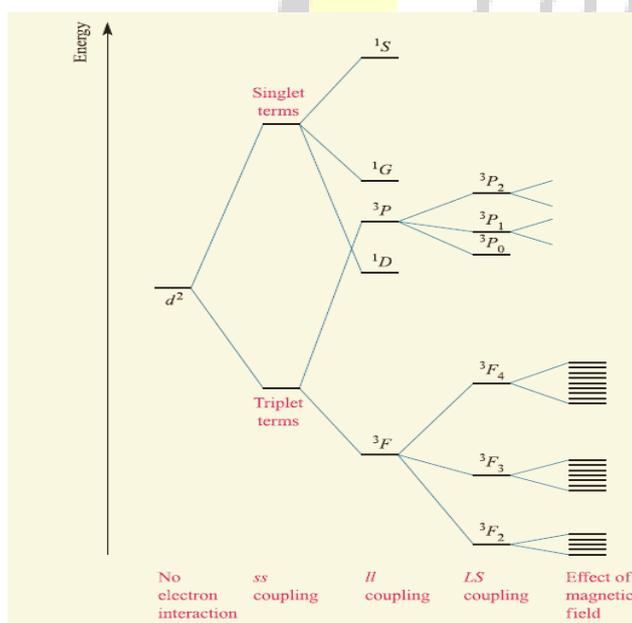


Magnetic Moments

- Spin-only values of μ_{eff} compared with approximate ranges of observed magnetic moments for high-spin complexes of first row d-block ions.

Metal	d^n	S	$\mu_{\text{eff}}(\text{spin-only})/\mu_B$	Observed values μ_{eff}/μ_B
Sc ³⁺ /Ti ⁴⁺	d^0	0	0	0
Ti ³⁺	d^1	1/2	1.73	1.7–1.8
V ³⁺	d^2	1	2.83	2.8–3.1
V ²⁺ /Cr ³⁺	d^3	3/2	3.87	3.7–3.9
Cr ²⁺ /Mn ³⁺	d^4	2	4.90	4.8–4.9
Mn ²⁺ /Fe ³⁺	d^5	5/2	5.92	5.7–6.0
Fe ²⁺ /Co ³⁺	d^6	2	4.90	5.0–5.6
Co ²⁺	d^7	3/2	3.87	4.3–5.2
Ni ²⁺	d^8	1	2.83	2.9–3.9
Cu ²⁺	d^9	1/2	1.73	1.9–2.1
Zn ²⁺	d^{10}	0	0	0

- It is often the case that moments arising from both the spin and orbital angular momenta contribute to the observed magnetic moment. The energy difference between adjacent states with J values of J' and $(J' + 1)$ is given by the expression $(J'+1)\lambda$ where λ is called the spin-orbit coupling constant. For the d^2 configuration, for example, the 3F term in an octahedral field is split into 3F_2 , 3F_3 and 3F_4 , the energy differences between successive pairs being 3λ and 4λ respectively. In a magnetic field, each state with a different J value splits again to give $(2J+1)$ different levels separated by $g_j\mu_B B_0$ where g_j is a constant called the Lande splitting factor and B_0 is the magnetic field. It is the very small energy differences between these levels with which EPR spectroscopy is concerned and g-values are measured using this technique. The overall splitting pattern for a d^2 ion is shown:-



Splitting of the terms for d^2 ions

- The value of λ varies from a fraction of a cm^{-1} for the very lightest atoms to a few thousand cm^{-1} for the heaviest ones. The extent to which states of different J values are populated at ambient temperature depends on how large their separation is compared with the thermal energy available, kT ; at 300 K, $kT \approx 200 \text{ cm}^{-1}$ or 2.6 kJ mol^{-1} . It can be shown theoretically that if the separation of energy levels is large, the magnetic moment is given by equation (1). Strictly, this applies only to free-ion energy levels, but it gives values for the magnetic moments of lanthanoid ions (for which λ is typically 1000 cm^{-1}) that are in good agreement with observed values

Where,

$$\mu_{\text{eff}} = g_J \sqrt{J(J+1)}$$

$$g_J = 1 + \left(\frac{S(S+1) - L(L+1) + J(J+1)}{2J(J+1)} \right) \quad \dots\dots (1)$$

- For d-block metal ions, eq. (1) gives results that correlate poorly with experimental data. For many (but not all) first row metal ions, λ is very small and the spin and orbital angular momenta of the electrons operate independently. For this case, the Van Vleck formula eq. (2) has been derived. Strictly, eq. (2) applies to free ions but, in a complex ion,

$$\mu_{\text{eff}} = \sqrt{4S(S+1) + L(L+1)} \quad \dots\dots (2)$$

- If there is no contribution from orbital motion, then eq. (2) reduces to eq. (3) which is the spin-only formula we met earlier. Any ion for which $L = 0$ (e.g. high-spin $d^5 \text{ Mn}^{2+}$ or Fe^{3+} in which each orbital with $m_l = +2, +1, 0, -1, -2$ is singly occupied, giving $L = 0$) should, therefore, obey eq. (3).

$$\mu_{\text{eff}} = \sqrt{4S(S+1)} = 2\sqrt{S(S+1)} \quad \dots\dots (3)$$

- The experimental magnetic moments for complexes of first row metal ions do not agree with those of calculated using eq(1) & (2). Though there is a good agreement between experimental magnetic moment calculated by spin only formula but in some cases, the experimental magnetic moment is higher than calculated by spin only formula, this is due to some orbital contribution
- In order for electron to have orbital angular momentum, it must be possible to transform the orbital it occupies into an entirely equivalent and degenerate orbital by rotation.
 - In octahedral complex, for ex. \rightarrow the three t_{2g} orbitals (d_{xy}, d_{yz} & d_{zx}) can be transformed into each other by rotating about an axis by 90° . Thus an electron in a t_{2g} orbital has orbital angular momentum.
 - The e_g orbitals ($d_{x^2-y^2}$ & d_{z^2}) cannot be transformed into one another because these have different shapes. Therefore these orbitals have no orbital contribution

- Another factor, that needs to be taken into account is:-
 - If all the t_{2g} orbitals are singly occupied, then it is not possible to transform an orbital say d_{xy} orbital into d_{yz} or d_{zx} orbital because they already contain an electron with same spin quantum number as the incoming electron
 - If all the t_{2g} orbitals are doubly occupied, electron transfer is also impossible
 - The configuration other than t_{2g}^3 & t_{2g}^6 make orbital contributions to the magnetic moments of octahedral complex.

Hence in octahedral complex following configuration make orbital contribution

	HS	LS
d^1	$t_{2g}^1 eg^0$ ✓	
d^2	$t_{2g}^2 eg^0$ ✓	
d^3	$t_{2g}^3 eg^0$	
d^4	$t_{2g}^3 eg^1$	$t_{2g}^4 eg^0$ ✓
d^5	$t_{2g}^4 eg^2$ ✓	$t_{2g}^5 eg^0$ ✓
d^6	$t_{2g}^5 eg^2$ ✓	$t_{2g}^6 eg^0$
d^7	$t_{2g}^6 eg^2$	$t_{2g}^6 eg^2$
d^8	$t_{2g}^6 eg^2$	
d^9	$t_{2g}^6 eg^3$	
d^{10}	$t_{2g}^6 eg^4$	

- For Td complexes, it is similarly show that the configurations that give rise to orbital contributions are $e^2 t_2^1, e^2 t_2^2, e^4 t_2^4, e^4 t_2^5$

- NOTE:- An oh high spin d^7 complex should have a magnetic moment greater than the spin only value of $3.87 \mu_B$ but a Td d^7 complex should not observed value of μ_{eff} for:-

$$[\text{Co}(\text{H}_2\text{O})_6]^{+2} = 5.0 \mu_B$$

$[\text{CoCl}_6]^{-2} = 4.4 \mu_B$. respectively i.e. in both complexes have magnetic moment greater than μ (spin only) The third factor involves is spin orbit coupling

- NOTE:- In general, orbital contribution is possible in complexes in which the ground state of metal ion is electronically triply degenerate (T), on the other hand, the orbital contribution is not possible in complexes in which ground state is electronically non-degenerate or doubly degenerate (A or E)
- NOTE:- A high spin octahedral complex of $d^7 (t_{2g}^5 eg^2)$ have calculated and experimental magnetic moments 3.87 & 5.2 BM . This higher value of experimental magnetic moments is expected because of orbital contribution.
- For Td complex $[\text{CoCl}_4]^{-2} (e^4 t_2^3)$, the calculated & experimental magnetic moments are 3.87 & 4.5 BM respectively. In this case higher value of experimental, magnetic moment is not due to orbital contribution.
- Although in most of the complexes with A or E ground state the quenching of the orbital contribution is expected to be complete & the experimental magnetic moment is very close to the spin only magnetic moment & is temperature independent.

- However, in some complexes there is the deviation of the experimental magnetic moment μ from spin only magnetic moment μ_s .

This is due to **Temperature independent paramagnetism (TIP)**

- In such cases, the first excited state T (of some spin-multiplicity of G.S mixes up with A or E ground state due to spin orbit coupling.
- The extent of spin-orbit coupling is given by constant λ
- For d^2 configuration:-

The energy difference between 3F_2 & 3F_3 levels & between 3F_3 & 3F_4 levels is 3λ & 4λ respectively

As a result, mixing of terms occurs

For ex:- The ${}^3A_{2g}$ ground term of an octahedral d^8 ion mixes with higher ${}^3T_{2g}$ terms. The extent of mixing is related to Δ_{oct} & to spin-orbit coupling constant.

$$\mu_{eff} = \mu (\text{spinonly}) \left(1 - \frac{\alpha \lambda}{\Delta_{oct}} \right)$$

This is the modification of the spin-only formula which takes into account the spin-orbit coupling

$$\mu_{eff} = \sqrt{n(n+2)} \left(1 - \frac{\alpha \lambda}{\Delta_{oct}} \right)$$

- Although the relationship depends on Δ_{oct} , it also applies to Td complexes
 - This equation applies only to ions having A or E ground terms. ie this approach is not applicable to ions with T ground terms
 λ is spin orbit coupling constant
 - Here, $\alpha = 4$ for A ground (3F & 4F)
 $\alpha = 2$ for E ground term (5D & 2D)
 $\alpha = 0$ for (6S)
- **NOTE:-** λ is positive for less than half filled shells & negative for shells that are more than half filled

Thus spin orbit coupling leads to: – $\mu_{eff} > \mu$ (spin – only) for d^6, d^7, d^8 & d^9 $\mu_{eff} < \mu$ (spin – only) for d^1, d^2, d^3 & d^4 ions

- **NOTE:-** High spin octahedral complex of $Mn^{+2} (d^5) [Mn (H_2O)_6]^{+2}$

Here, GST is ${}^6A_{1g}$ & has no excited state of same multiplicity as that of G.S, therefore mixing of GS with any of excited state due to spin-orbit coupling is not possible and thus there is no orbital contribution to μ_{eff} due to spin-orbit coupling

Therefore μ_{eff} is some as $\mu_{\text{s.o}}$

Spin-orbit coupling coefficients (λ)

Metal ion	Ti^{+3}	V^{+3}	Cr^{+3}	Mn^{+3}	Fe^{+2}	Co^{+2}	Ni^{+2}	Cu^{+2}
	↓	↓	↓	↓	↓	↓	↓	↓
d^n Conf	d^1	d^2	d^3	d^4	d^6	d^7	d^8	d^9
λ/cm^{-1}	155	105	90	88	-102	-177	-315	-830

Ques:- Calculate the value of μ_{eff} for $[\text{Ni}(\text{en})_3]^{+2}$ taking into account the spin-orbit coupling
 (given $\lambda = -315$ & $\Delta_{\text{oct}} = 11500 \text{ cm}^{-1}$)

Ans:- Octahedral Ni(II) d^8 had ${}^3A_{2g}$ ground state

$$\mu_{\text{eff}} = \mu(\text{spin only}) \left(1 - \frac{4\lambda}{\Delta_{\text{oct}}} \right)$$

$$\mu(\text{spin-only}) = \sqrt{n(n+2)} = \sqrt{2(4)} = \sqrt{8} = 2.83$$

$$\lambda = -315 \text{ (given)}$$

$$\Delta_{\text{oct}} = 11500 \text{ cm}^{-1} \text{ (given)}$$

$$\mu_{\text{eff}} = 2.83 \left(1 + \frac{4 \times 315}{11500} \right) = 3.14 \mu_B$$

Hence, value is significantly larger than $\mu(\text{spin only})$ as expected for a d^n conf. with more than half-full shell

➤ **NOTE:-** An important point is that spin-orbit coupling is generally large for second & third row d-block metal ions & they show large different between $\mu(\text{spin only})$ & observed values for μ_{eff} .

SPIN CROSSOVER

- Also known as Spin transition or spin equilibrium behaviour, that occurs in some metal complexes where spin state of complexes change due to external stimuli such as variation of temperature, pressure, light irradiation

High spin \longleftrightarrow low spin

- In case of Octahedral complex:-

For High spin complex $\Delta_0 < P$

For Low spin complex $\Delta_0 > P$

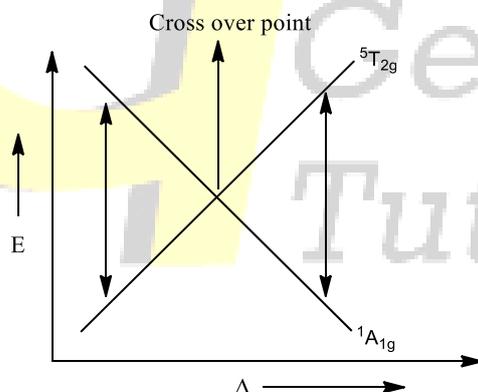
Now, When difference between Δ_0 & P is small then it is possible for two spin states to coexist in equilibrium with each other

Consider Fe^{+2} ion:-

$[\text{Fe}(\text{H}_2\text{O})_6]^{+2} \rightarrow$ (high spin) paramagnetic ($S = 2$) Ground state = ${}^5\text{T}_{2g}$

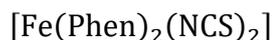
$[\text{Fe}(\text{CN})_6]^{-4} \rightarrow$ (low spin) diamagnetic ($S = 0$) Ground state = ${}^1\text{A}_{1g}$

- The Tanabe-Sugano diagram for d^6 show that near or at cross over point between weak & strong fields the difference in energy between spin-free (${}^5\text{A}_{2g}$) & spin paired (${}^1\text{A}_{1g}$) ground state becomes very small

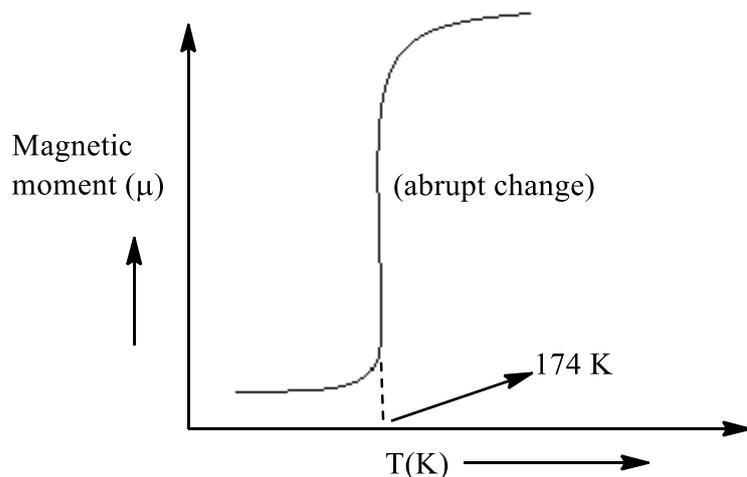


And with in this region, it is expected that both spin states may be present simultaneously and degree to which each is represented will depend on temperature ($\Delta_0 - P = KT$)

- **An important example of this compound showing this effect is**

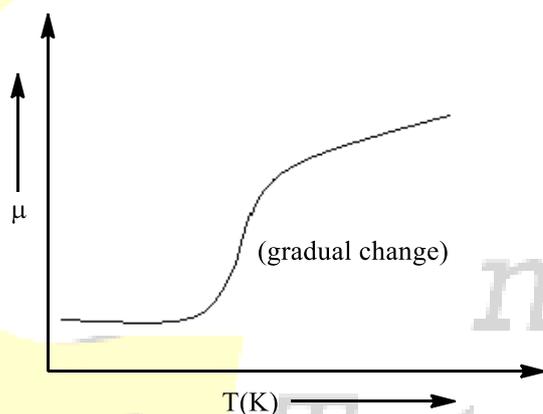


At high temperature, this complex exists as high spin with 4 unpaired e^- when the temperature is decreased, there is a sharp decrease in magnetic moment at 174K and the complex becomes low spin. This indicates that at 174K $[\text{Fe}(\text{Phen})_2(\text{NCS})_2]$ exists as both high spin & low spin

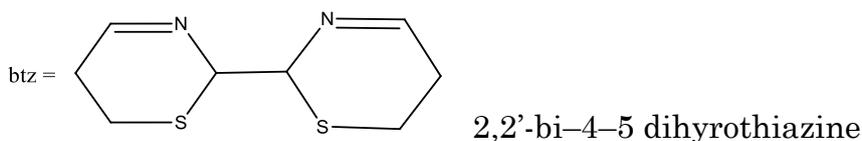


- **NOTE:-** The change in values of μ_{eff} which accompanies the spin cross-over may be gradual or abrupt or stepped

Ex:- $[\text{Fe}(\text{btz})_2(\text{NCS} - \text{N})_2]$



Where,

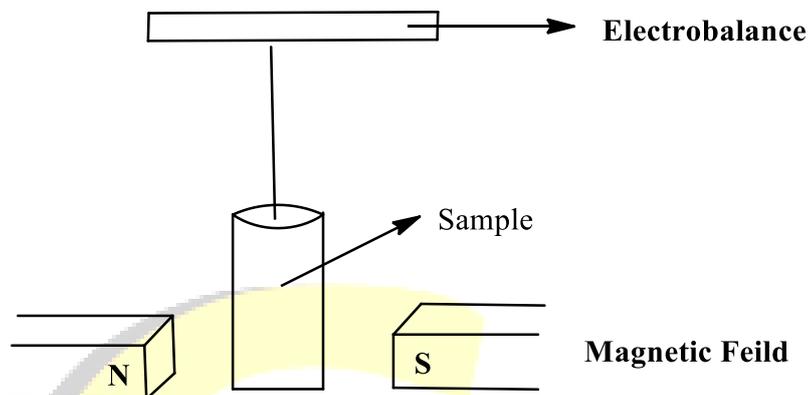


- At high pressure, low to high spin crossover for $[\text{Fe}(\text{CN})_5(\text{NH}_3)]^{-3}$ is observed.

In addition to magnetic measurements, Mossbauer spectroscopy can be used to study spin-cross over transition. (Isomer shifts of iron complexes are sensitive not only to oxidation state but also to spin state).

GOUY METHOD:- Makes the use of interaction between unpaired e^- & magnetic field

- ⇒ (a diamagnetic material is repelled by a magnetic field, where as a paramagnetic material is attracted to it)
- ⇒ The compound for study is placed in a glass tube, suspended from a balance on which weight of the sample is recorded.



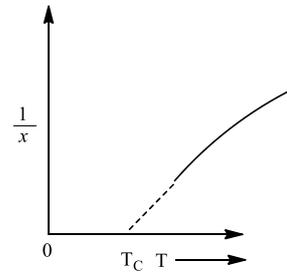
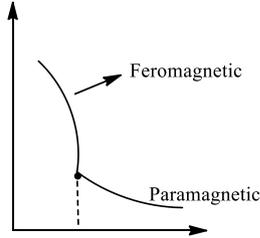
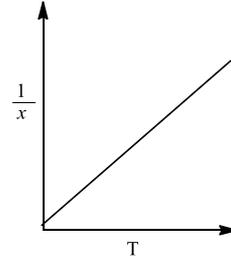
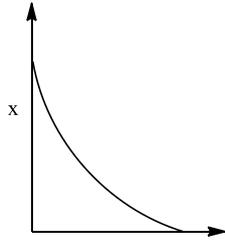
- ⇒ The tube is placed so that one end of sample lies at the point of maximum magnetic flux in an electromagnetic field while other end is at a point of low flux.
- ⇒ Initially the magnet is switched off, but on applying magnetic field, paramagnetic compound are drawn into it by an amount that depends on the number of unpaired e^-
- ⇒ The change in weight caused by the movement of sample into field is recorded & from associated force it is possible to calculate magnetic susceptibility of compound
- ⇒ Both methods are based on the determination of force exerted on a sample by inhomogeneous magnetic field and both of them involves measuring the weight of substance in presence & absence of field

Advantage of faraday method over Guoy Method

- (1) Regarding Sample Size:- Faraday's method require several Mg of material whereas Guoy method require approximately 1 gm
- (2) Faraday's method give magnetic susceptibility directly, while Guoy experimental gives volume susceptibility which must be converted to specific susceptibility. This conversion can be problematic because it requires an accurate value of density which can be difficult to obtain for solids because the value varies according to how material is packed.

* Dependence of $\frac{1}{\chi}$ on temperature

(a) Paramagnetic material



(b) Ferromagnetic Material

(c) Antiferromagnetic Material

