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B.Sc. 3rd Year

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Chapter-3rd

Magnetism In Transition Metal Compounds



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Magnetism In Transition Metal Compounds

In transition metal compounds or complexes generally following five type of magnetism are found.

1. Paramagnetism 2. Diamagnetism

3. Ferromagnetism 4. Antiferromagnetism 5. Ferrimagnetism

1. Paramagnetism- When a substances placed in magnetic field of strength H. If the field in substance is greater than H, the substance is paramagnetic. It is easier for magnetic line of force to travel through paramagnetic material than through a vacuum. Thus paramagnetic material attract line of forces and if it is free to move a paramagnetic material will move from weaker to stronger part of magnetic field. Paramagnetism arises as a result of unpaired electrons in atoms, molecules or ions. Unpaired electrons are the main source of paramagnetism. For example- Ti³⁺, Mn²⁺, Cu²⁺,Au³⁺,etc.

Origin of paramagnetism - **We know from** elementary physics any moving charge particle create magnetic field . **The** electron has two type of motion and produces two type magnetic moment. One is orbital motion due to motion of electron round the nucleus in own orbit create orbital moment. Another is spin motion due to spin of electron in own axis produce spin moment. The effective magnetic moment is obtained by adding the magnetic moment due to orbital motion i.e. orbital magnetic moment, μ_l and due to spin motion i.e. spin magnetic moment, μ_s of electrons given as :

$\mu_{eff} = \mu_{L} + \mu_{S} = \sqrt{L(L+1)} + \sqrt{4S(S+1)}$

Orbital magnetic moment, $\mu_L = g_L VL(L+1)$ and spin magnetic moment $\mu_s = g_s VS(S+1)$

Dia magnetism is much weaker than paramanetism i.e. 10-100 time weaker.

2. Diamagnetism- If the field in the substance is less than H, and then the substance is diamagnetic. Diamagnetic material tends to repel line of force. It is harder for magnetic lie of force to travel through diamagnetic material than through vacuum ad such material tends to

move from a stronger to a weaker part of magnetic field. In diamagmetic compound, al the electron spis are paired that is in d-subshell, all electrons are completely filled or completely vacant (d¹⁰, d⁰). Ex. Sc³⁺, Ti⁺, Zn²⁺, Cd²⁺, etc.

3. Ferromagnetism- It should be noted that Fe, Co, Ni is ferromagnetic. Ferromagetic material may be regarded as special case of paramagnetism in which the moment on individual atom becomes aligned and all points in the same direction. When this happens, magnetic property is greatly enhanced. These substances show permanent magnetism even after magnetic field is removed. Such substances are called ferromagnetic substances. In case of ferromagnetic substances, the alignments of all magnetic moments are in same direction (parallel direction) $\uparrow \uparrow \uparrow \uparrow \uparrow \uparrow$ and such substances have definite value of their magnetic moments. This is only difference from paramagnetic substances. Thus a ferromagnetic substances can be defined as that substance in which alignment of all magnetic moments are in same direction that is parallel. Ferromagnetism like paramagnetism is also due to the presence of unpaired electrons but ferromagnetic substances are very important in technology. For example- Cr₂O₃ is used as ferromagnetic tapes in cassette recorder.

4.Antiferromagntism- Antiferromagetic substance is that in which number of magnetic moment vector aligned in one direction is equal to magnetic moment vectors aligned in opposite direction $\uparrow \downarrow \uparrow \downarrow \uparrow \downarrow \uparrow \downarrow$ and hence such substances have zero value for resultant magnetic moment. In other words we can say that in an antiferromagnetic substance, half of the magnetic moment vectors are aliged in one direction while the remaining half magnetic moment vector aligned in opposite direction. Transition metal oxide namely, V₂O₃, Cr₂O₃, MnO, Mn₂O₃, FeO,Fe₂O₃, CoO, Co₃O₄ and NiO show antiferromagnetic character. Cupric acetate monohydrate is also example of antiferromagnetic substances.

5.Ferrimagnetism- A ferrimagnetic substance is that in which number of magnetic moment vectors aligned in parallel and antiparallel direction is unequal $\uparrow \uparrow \uparrow \downarrow \uparrow \downarrow$ and hence such substances have some value of net magnetic moment. Example of substances which show ferrimagnetic behavior are Fe₃O₄ and ferrites having general formula M²⁺Fe³⁺₂O₄ (M²⁺ = Mg²⁺, Cu²⁺, Zn²⁺, etc).

Effect of temperature on ferromagnetic, ferrimagnetic and antiferromagnetic substances:

By the increase of temperature the order of alignment of magnetic moment vector in ferromagnetic, antiferromagnetic and ferrimagnetic substances get changed and hence the substances become paramagnetic. For example-

 Fe₃O₄ which is ferrimagnetic at ordinary temperature show paramgnetic character at 850K.

- 2. V_2O_5 transform from antiferromagnetic to paramagmetic at 150K.
- 3. NiO transforms from atiferromagnetic state to paramagnetic state at 395K.
- 4. CrO₂ transform from ferromagnetic state to paramagnetic state at 395K.

Magnetic susceptibility-

When a substance is placed in magnetic field of strength H, the flux of magnetic induction B within the substance is given by

B=H+4πI(1)

Where I is termed as intensity of magnetization. Dividing both side of equation by H,

B/H = H/H +
$$4\pi$$
I/H = 1+ 4π I/H = 1 + $4\pi\chi$ (χ -Chi)

Or, B/H = $4\pi \chi$ (2)

Where the ratio B/H is called magnetic permeability of substances and χ is magnetic susceptibility per unit volume. Susceptibility per unit volume, χ is given by $\chi = I/H$ and the extent to which the material is susceptible to the external magnetic field or susceptible to magnetization. It may be noted that I and H are in the same unit, χ become dimensionless quantity. By placing B/H = P and I/H = χ in the equation 2, we get P = 1+4 $\pi\chi$.

Gram Susceptibility

In the practice, susceptibility is usually expressed in per unit mass that is gram specific or weight susceptibility (χ_g) rather than per unit volume. X_g is given by

 χ_g = volume susceptibility/density = χ/d

The molar susceptibility χ_M is given as

X_m = Gram susceptibility x Molecular weight

$$X_m = (\chi/d) \times M$$

Curie Law:

Pierre Curie found that the major magnetic susceptibility χ is inversely proportional to absolute temperature and this is called Curie Law.

 $X_{M} \alpha 1/T \text{ or } \chi_{M} = C/T$ where C = constant which is equal to $N\mu_{eff}^{2}/3k$.

This constant is characteristic of substance and is called Curie constant and the expression is called Curie expression. From this equation it is evident that the plot of χ_M values against 1/T will give us straight line of slope C which intercepts the origin. Although, many paramagnetic substances obeys Curie's Law.

Curie-Weiss Law

It is determined by $\chi^{corr}_{M} = C/T \cdot \theta$ where θ is the temperature at which line cuts the T axis and is called **Weiss constant**. If the value of θ is positive i.e. above OK, the substance is said to be ferromagnetic and if θ is negative, that is below OK, the substance is said to be antiferromagetic.

Method for determining magnetic susceptibility- The method for determining magnetic susceptibility can be divided into two groups .

1. Uniform magnetic field type 2. Nonuniform magnetic field type.

Most of the balances are used for the measurement of magnetic susceptibility are of uniform type. Example-Guoy method, Bhatnagar-Mathur method, Quincke method, etc while the method used in non uniform method magnetic field method are Curie method, Curie-Cheneveau's method, NMR method etc.

1.Guoy method- This method was suggested by Gouy 1889. This is used to measure magnetic susceptibility of various substances. In this method about 0.5 -1.0g sample in form of powdered solid, \liquid or solution of moderate concentration are used.

Principle- This method is based on the fact that the magnetic field exerted on the sample is directly proportional to difference in masses when the field is switched on and off.

Method- The Gouy method is more often used. Here the sample may be presented as a long rod of material. A solution, or glass tube packed with powder. One end of sample is placed in uniform magnetic field and other end in very low or zero field. The forces observed here are much larger and can be measured using a modified laboratory balance.

F= ½ A. χ H²1

Where A is the cross sectional area of the tube and H is the intensity of magnetic field and χ is volume susceptibility. This expression is valid only if the measurement done in vacuum. However if the sample is surrounded by air then the susceptibility of air much be substracted from the measured susceptibility. In the case we shall use this equation.

F= $\frac{1}{2}$ A.H² (χ - χ').....2 where, χ' is volume susceptibility of air.

Now the Gouy tube itself develops a force which is always present. Therefore to calculate the actual force acting on the sample, the force acting on the Gouy tube is subtracted from the observed force. This force is negative because of the diamagnetic material of the tube. It is denoted by δ . The equation 2 becomes-

$F = \frac{1}{2} A.H^2 (\chi - \chi') + \delta$3

For the sample of constant length and cross sectional area the factor, AH² is constant. Now if the density of sample is introduced the above equation may be written as

 $10^{6}\chi = (\alpha + \beta F')/W$ where α =constant allowing the displaced air and is equal to 0.029

W= weight of sample expressed in gram.F['] = Force on the sample and is equal to F- δ but F and δ are given in milligrams. β = tube calibration constant.

The apparatus is calibrated by making measurement on a substance whose susceptibility is accurately known.

The standard substance commonly used for calibration is **mercury tetrathiocyanatocobalt (II)** Hg[Co(SCN)₄]. Its susceptibility is 16.44×10^{-6} at 20° C.

2. Bhatnagar-Mathur Method:

Bhatnagar and Mathur in 1928 modified the Gouy balance such a way that it may measure susceptibility of liquid. This method is based on the fact that the force acting on the sample is directly proportional to magnetic pull producing a displacement of pointer when the magnetic field is on. Bhatnagar and Mathur used a balance in this method contains a **silver spiral S**' which is suspended from a brass hook at the top and the sample A is suspended from the lower end of the spiral in such a way that the lower end of the sample lies in the region of strong and uniform magnetic field. P is the thin pointer attached to the spiral. The displacement of pointer P is measured with the microscope provided with a scale.

Theory and calculation

When the sample is placed between two poles of strong magnetic field the vertical magnetic pull on the sample is given by the following relation.

 $F_x=1/2(\chi_1-\chi_2)AH^2$ 1 A= area of cross section of the sample

In this balance the strong magnetic field pulls the sample which pulls the spiral producing a displacement of pointer. Reading is taken when the magnetic field is on and off. Thus the force is given by

F_x= (L/s)g2

Where L is the displacement of pointer and s is the displacement of pointer produced by 1 gram of the sample. From equation 1 and 2 we get

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1/2(\chi_1-\chi_2)AH^2 = (I/s)g or \chi_1=\chi_2+(2Ig/sAH^2)
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where χ_1 and χ_2 are the volume susceptibility of sample and surrounding medium.



3. Quincke's method

This method was suggested by G. Quincke in 1885. It was suitable for liquid, aqueous solution and some gases. This method is based upon the principle of the fact that when magnetic fiels is applied on the liquid placed in capillary tube the **meniscus** fall if the liquid is diamagnetic and rises if it is paramagnetic. The apparatus in this method is shown in figure it consists of **U-tube** (ABCDE) in which CD is a capillary tube placed in **uniform magnetic field of strength 25000** oerested. The field **near C is 50-100 oerested** which is negligible. When the field is applied the liquid rises and fall in the capillary tube, the liquid is paramagnetic and diamagnetic in nature, respectively.

Theory

When a strong and uniform magnetic field is applied at upper end of capillary tube the liquid rises if it is paramagnetic or fall if it is diamagnetic in nature. Letus Δh is the change in the height of the liquid then the corresponding hydrostatic pressure will be given by following relation

P = Δhdg1 Force = Pressure x Area $F = \Delta hdg \times A$ 2 where A = area of cross section of tube

Equation- 2 represents the vertical force ΔF_x . Hence, $F_x = \Delta hdg \times A$. The vertical force due to change in hydrostatic pressure will be balanced by magnetic pull i.e.

F = Δhdg x A = $\frac{1}{2} (\chi_1 - \chi_2)AH^2$ or $\chi_1 - \chi_2 = (2dg\Delta h)/H^2$ 3

Every step of the equation divided by d

 $\chi_1/d - \chi_2/d = (2dg\Delta h)/dH^2$ or $\chi - \chi_0 = (2dg\Delta h)/H^2$ 4 Since, $\chi = \chi/d$ is the gram susceptibility.

Thus the magnetic susceptibility of a liquid can be measured with help of this equation where χ and χ_0 are the mass susceptibility of the liquid of density d and gas and vapour of density d₀ above the liquid.

If the tube AB is sufficiently larger diameter and the susceptibility of vapour χ_0 above the liquid is negligible. Then the equation 4 becomes $\chi = (2dg\Delta h)/H^2$



4. Curie Method- This method is based on non uniform magnetic field type. Curie devised magnetic balance known as Curie balance to study the variation of susceptibility with temperature. This gives a clear knowledge among paramagnetic, diamagnetic and ferromagnetic substances. The principle of this method is based on the fact that if a sample is placed in non uniform magnetic field, a force is exerted on the sample giving a displacement which is measured in terms of Torque required to bring the sample back to its original position. Let us consider a small volume dv of the sampe, the force exerted on the sample dF_x is given by equation

 $dF_x = (\chi_1 - \chi_2) dv H_y \partial H_y / \partial x \dots 1$

The total forceexerted on the sample may becalculated by integrating equation 1

$\int dF_x = \int (\chi_1 - \chi_2) dv H_y \partial H_y / \partial x$

 $F_x = (\chi_1 - \chi_2) dv H_y \partial H_y / \partial x \dots 2 \quad \text{but } w = v x d \text{ or } v = w/d \qquad \dots 3 \quad \chi = \chi_1 / d \text{ and } \chi_0 = \chi_2 / d \dots 4$

Substituting the value from equation 3 and 4 in equation 2.

$F_x = (\chi - \chi_0) W H_y \partial H_y / \partial x$5

 χ and χ_0 are gram susceptibility of sample and surrounding medium respectively.

W is the weight of the sample. In equation 5, all quantity except $\partial H_y/\partial x$ can be known easily. To measure this quantity a test coil and ballistic galvanometer is used.

5. **Cheneveau Method-** In 1910, Cheneveau modified the Curie balance as shown in the figure.

It consists of **torsion of AB** suspended by fine wire from torsion head C. The end B of the arm AB support the sample which move freely between the poles of permanent magnet. The magnet may move forward or backward with respect to sample due to its magnetic susceptibility sample is either repelled or attracted. The magnet is slowly turned so as to recede from the sample till the deflection is maximum. This reading is noted for both side of zero. For calibration distilled water is used as a standard substance. The observations are recorded first for the empty tube and then with the samples in it. The susceptibility is calculated from the following relations

$\chi/\chi_1 = (m_1 x \pm x_2)/(m x_1 \pm x_2)$

Where, χ_1 is the susceptibility of known substance of known susceptibility, m_1 is mass of known substance, m is mass of sample of unknown susceptibility (χ), x is deflection from unknown substance, x_1 deflection of reference substance and x_2 is deflection from empty tube. The positive sign for x_2 is used when the empty tube have susceptibility opposite to that of test substance.



6. NMR Method

This is useful method to measure magnetic susceptibility. The dissolved paramagnetic substance causes a shift (Δ H) in the resonance line of inert reference molecule. Thus,

 $\Delta H/H = (2\pi/3)\Delta \chi$ 1

Where, $\Delta \chi$ is the change in volume susceptibility. Actually a paramagnetic substance is dissolved in water containing 2% tertiary butanol which acts as reference standard. For external reference and aqueous solution of 2% tertiary butanol is used in capillary tube. Methyl proton of tertiary butanol in two solutions would resonate at two places due to difference in volume susceptibility of two solution the resonance line of paramagnetic substance is observed at high field. The gram susceptibility χ_g of the solute is given by the following equation

$$X_{g} = \Delta H/H(3/2\pi c) + \chi_{0} + d_{0}-d_{s}/c$$
2

Where, χ_0 is the gram susceptibility of solvent, c is concentration of solute in g/mL of solution, d_0 is the density of the solvent and d_s is the density of solution.

Spin only Formula and correlation of μ_s and $\mu_{eff}.$

The effective magnetic moment is obtained by adding the magnetic moment due to orbital motion i.e. orbital magnetic moment, μ_l and due to spin motion i.e. spins magnetic moment, μ_s of electrons given as

Orbital magnetic moment, $\mu_L = g_L VL(L+1)$ and spin magnetic moment $\mu_s = g_s VS(S+1)$

Here, g_L and g_S are the Lande splitting factors for orbital and spin magnetic moments. Since the $\mu_L g_L = 1$ for $\mu_S g_S = 2$, then μ_L and μ_S are given by

The μ_{eff} is given by the addition of equation 1 and equation 2

$\mu_{eff} = \mu_{L} + \mu_{S} = \sqrt{L(L+1)} + \sqrt{4S(S+1)}$3

This equation is generally used to calculate the value of μ_{eff} of the ions of metal of first transition series. For the ions with S term symbol example Mg²⁺ and Fe³⁺ ions. L = 0 i.e. L = 0 for S term symbol. There is no contribution of orbital magnetic moment to μ_{eff} for the ions which containing S term symbol. For the ions which have L = 0, the equation 3 giving the value of μ_{eff} becomes as

 $\mu_{eff} = \sqrt{4S(S+1)}$ BM......4 Now, $S = \frac{1}{2} \times n = n/2$ Here, n = number of unpaired electrons. Putting the valu of S in equation 4, then

$$\mu_{eff} = \sqrt{4n/2(n/2+1)} = \sqrt{n(n+2)} BM$$
5

Since the value of μ_{eff} given by equation 4 and 5 is that which contains only contribution made by spin magnetic moment resulting from the spin motion of the electrons, it is called spin only magnetic moment i.e. μ_{spin} only whose value thus given as

μ_{spin} only = $\sqrt{4S(S+1)}$ BM = $\sqrt{n(n+2)}$ BM6

This formula represented by equation is called spin only formula and the value of magnetic moment calculated from this formula is called spin only value. The magnetic moment due to spin magnetic moment, the orbital magnetic moment is largely suppressed or quenched. Due to the electrostatic field of other atoms, ions or molecules surrounding metal ions. The metal ions restrict the motion of electrons around the nucleus.

Orbital contribution to magnetic moment:

For f-block elements especially in Lanthanides, the unpaired electrons in n-2 f orbital are quite deeply seated and hence are well shielded by 5s and 5p electrons from the effect of other atoms in their compounds (crystal field effect) consequently the effective magnetic moment Ln³⁺ ions with the exception of Sm³⁺ ions are given by following equation provided that ground state symbol of Ln³⁺ ions as

 $\mu_{eff} = \mu_J = g \sqrt{J(J+1)} BM$ where g = Lande splitting factor are

given as

$$g = 1 + \frac{J(J+1) + S(S+1) - L(L+1)}{2J(J+1)}$$
 S =

= resultant spin quantum number

L = resultant orbital quantum number and J = resultant inner quantum number which is obtained by coupling of L and S. In lanthanide, the spin contribution S and orbital contribution L couple together to give new quantum number, J.

J = L-S, when the shell is less than half field and J = L+ S, when the shell is more than half field.

L-S coupling: It is also known as Russel-Saunder's coupling. According to this coupling

1. All the l vectors (angular momentum quantum number) of the electron couples together electro statically to give the resultant vector, L called resultant orbital angular momentum quantum number. Different values of I (small) $\mu_{eff} = \mu_L + \mu_S = \sqrt{L(L+1)} + \sqrt{4S(S+1)}$ defines the state of electron only while those of L defines the state of free atom or ion as a whole. L is always an integer including 0. Different values of I are represented by capital letters known as Mulliken's notation as shown here

Values of L = 0 1 2 3 4 5.....

 Mulliken notation
 = S P D F G H.....
 L = +1+1, 0 0, -1-1 = 0 when the

p orbital is fulfilled

2. Similarly, all s vectors (spin angular momentum quantum number)

Also combined to give the resultant spin angular momentum quantum number S which is an integer or half integer depending on the number of electrons involved and the direction of the spin vectors, s = half of the number of unpaired electrons n i.e. s = n/2. The value of S for electrons in other completely filled s, p, d or f orbital is zero. For completely filled p-orbital for which L =1, S =0. The value of S = +1/2-1/2, +1/2-1/2, +1/2-1/2 = 0.

3. 2S+1 is known as multiplicity of L state. This quantity gives the permitted value of J for a given value of L and J is called resultant inner quantum number obtained by coupling of L and S where L and S vectors couple together, they give the the resultant vector J which is known as resultant inner quantum number or total angular momentum number of the atom. The process of L-S coupling may be representing as

s₁ + s₂ + s₃ +..... + l₁ + l₂ + l₃.... = S+L=J

The value of J are 2S+1 when L≥S and 2L+1 when L≤ S

When L=0, J can have only one value J = S .The value of J always positive never negative.

Magnetic moment from magnetic susceptibility:

Paramagnetic susceptibility, χ_p is given by $\chi_p = \frac{N0\mu 2\mu 0}{3kT}$ 1 where N₀ is Avogadro Number, μ = magnetic moment, k = Boltzmann constant, μ_0 = permeability, T = absolute temperature.

The value of χ_M calculated from the experimental value of χ_g . It is an algebraic sum of χ_p , χ_{TIP} (Temperature independent paramagnetism) and χ_{dia} (diamagnetic susceptibility).

$$X_{M} = \chi_{p} + \chi_{TIP} + \chi_{dia}$$
2

Generally we do not usually know the value of χ_{TIP} . Corrected molar susceptibility, χ_M ^{corr} which is equal to $\chi_M - \chi_{dia}$ is also used in place of χ_P in equation 1. The value of magnetic moment obtained by putting χ_M ^{corr} in place of χ_P in equation 1 is called effective magnetic moment and hence is represented by μ_{eff} , the equation 1 becomes

$$\chi_{M} \operatorname{corr} = \frac{N_{0} \mu_{eff}^{2} 2 \mu_{0}}{3kT} \quad \text{or } \mu_{eff} = \sqrt{\frac{3kT \chi_{M}^{corr}}{N_{0} \mu_{0}}}$$

On substituting the value of k and N, we get

 $\mu_{\rm eff} = 2.83 \, \sqrt{\chi_M^{corr} T}$ 3

magnetic moments are expressed in Bohr Magneton (BM)

1BM = h/4\pi mc = 9.27 x 10⁻²¹ erg/Gauss where h= Planck's constant, e = electronic charge, v = velocity of light and m = mass of electron.

Uses of magnetic moment values:

The **number of unpaired electron** present in d-orbital of central metal ion of given complex compound can be determined with the help of experimental magnetic moment values of complex compounds. The number of unpaired electrons thus determined can be used to predict

- Whether a given four coordinated complex is square planar (dsp² hybridized) or tetrahedral (sp³). To make it clear let us consider the geometry of [Ni(CN)₄]²⁻ ion has n=0 diamagnetic and is square planar due to dsp² hybridization while [NiCl₄]²⁻ has n=2, paramagnetic and is tetrahedral due to sp³ hybridisation.
- 2. Whether the given six coordinated compound is inner orbital complex i.e d²sp³ hybridized or outer orbital complex i.e. sp³d² hybridized. To make it clear, consider the number of unpaired electrons in d-orbital. For example in Fe(CN)₆³⁻ ion has n=1 paramagnetic and is inner orbital octahedral complex due to d²sp³ hybridization while FeF₆³⁻ ion has n=5 i.e number of unpaired electrons = 5 and is outer orbital octahedral complex due to sp³d² hybridisation.

Questions.

Explain the following

- a. L-S coupling.
- b. $[FeF_6]^{3-}$ has much higher magnetic properties than $[Fe(CN)_6]^{3-}$.
- c. [Ni(CN)₄]²⁻ is diamagnetic and square planar while [NiCl₄]²⁻ is paramagnetic and tetrahedral.]
- d. Quenching of orbiotal angular momentum
- e. Lande splitting factor.

2. a. Describe the method of Gouy's for the measurement of magnetic susceptibilities of substance.

b. What are the origin of paramagnetism and diamagnetism?

3. a. What are μ_s and μ_{L+S} values? Explain why are μ_{eff} values close to μ_s values for majority of 3d metal complexes?

b. What is Curie's-Weiss Law? Give significance of Weiss constant.

4. How is magnetic susceptibility measured by Bhatnagar-Mathur method?

5. Describe the method of Quincke's for the measurement of magnetic susceptibilities of substance.

6. Describe the Curie's method of the measurement of magnetic susceptibilities of substance.

7. Describe the Cheneveau and NMR method for the measurement of magnetic susceptibilities of substance.

Multiple Choice Questions

- 1. The spin only magnetic moment for Mn²⁺ is
 - a. 5.91 BM b. 4.89 BM c. 3.87 BM d.1.73 BM
- 2. Which of the following has maximum magnetic moment values
 - a. Mn^{3+} b. Fe^{3+} c. Co^{2+} d. Cu^{2+}
- 3. The number of unpaired electrons in $[Co(NH_3)_6]Br_3$ is
- a. 1 b.2 c.3 d.0

Answers

1. a, 2. b, 3. d

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