Magnetic Moment and Effective Magnetic Moment

This is a fundamental concept in magnetochemistry which shows correlation between the magnetic moment (μ) and the effective magnetic moment (μeff).

1. Magnetic Moment (μ)

The **magnetic moment** of a substance arises mainly due to the **unpaired electrons** present in its atoms or ions.

- Electrons have **spin** and **orbital** angular momentum.
- Both contribute to the total magnetic moment.

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2. Spin-Only Magnetic Moment (μ_s)

For most **transition metal ions**, especially those in complexes, the orbital contribution is often **quenched** (i.e., negligible).
Hence, the **spin-only** formula is used:

$$\mu_s = \sqrt{n(n+2)}\ \text{BM}$$

where:

- n= number of unpaired electrons
- BM = Bohr Magneton

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3. Effective Magnetic Moment (μ_eff)

The **effective magnetic moment** is the *experimentally observed* magnetic moment, which includes both spin and orbital contributions:

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

where:

- S= total spin quantum number (½ × number of unpaired electrons)
- L= total orbital angular momentum quantum number

In many coordination compounds (especially **octahedral and tetrahedral**), orbital contribution is small, so:

$$\mu_{\text{eff}} \approx \mu_s = \sqrt{n(n+2)}\ \mu_B$$

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4. Correlation Between μ and μ_eff

Case	Type of Ion	Dominant Contribution	Correlation
3d transition metal ions	Spin only (orbital quenched)	$\mu_{eff} \approx \mu_s = \sqrt{n(n+2)}$	
4d and 5d transition metal ions	Both spin and orbital	$\mu_{eff} > \mu_s$	
Lanthanides (4f elements)	Orbital contribution significant	$\mu_{eff} \neq \mu_s$ (must include L and S)	

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5. Example Calculations

Ion	Configuration	n	μ_{eff} (BM) (theoretical)
Ti^{3+} ($3d^1$)	$3d^1$	1	1.73
V^{3+} ($3d^2$)	$3d^2$	2	2.83
Cr^{3+} ($3d^3$)	$3d^3$	3	3.87
Mn^{2+} ($3d^5$)	$3d^5$	5	5.92
Fe^{2+} ($3d^6$)	$3d^6$	4	4.90

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6. Measure Magnetic Susceptibility (χ):

Using a device like a SQUID magnetometer or a Gouy balance, scientists measure how much a sample is magnetized in an applied magnetic field. This gives the molar magnetic susceptibility (χ_m).

7. Experimental Determination

The **effective magnetic moment (μ_{eff})** can be obtained experimentally from magnetic susceptibility (χ):

$$\mu_{\text{eff}} = 2.828\sqrt{\chi_M T}$$

where:

- χ_M= molar magnetic susceptibility
- T= temperature (K)

Summary of Correlation

If orbital contribution negligible:	$\mu_{\text{eff}} = \mu_s = \sqrt{n(n+2)}$ BM
If orbital contribution present:	$\mu_{\text{eff}} > \mu_s$