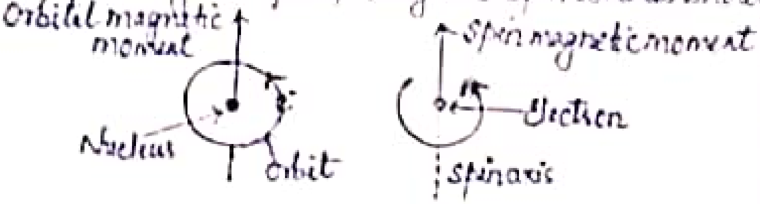
B.Sc. Part-I (Hons), Paper-IB (Inorganic chemistry)

Group-C, Unit-2 Elementary Magneto Chemistry (By Dr. Birendra Kumar, Maharaja College)

⇒ Magnetic Properties/Behaviours ?

Magnetic properties/behaviours of different materials or chemical substances are studied in terms of their magnetic moments. Magnetic moments arise due to the orbital motion and spining motion of the electrons. As electron is a charge (-ve) particle, its orbital motion produces a small magnetic field along the axis of rotation, and its spining motion produces a small magnetic field along the spin axis as shown in Fig. 1.



(Fig. 1)

Thus, each electron may be considered as a small magnet having a resultant permanent magnetic moment.

Magnetic moment may be defined as the moment of the couple (two opposite poles of magnet) when a magnet is suspended freely in a field of 1 oersted such that it makes an angle of 90° with the field direction. It is denoted by symbol 'μ' and expressed in Bohr Magneton (BM).

As magnetic moment is a vector quantity, the net magnetic moment of an electron may be represented by an arrow. Thus, a chemical substance may be considered to contain a number of magnetic dipoles (similar as bar magnet). The behaviour of materials/chemical substances in the external magnetic field is called their magnetic properties/magnetism.

⇒ **Types of magnetic properties:** On the basis of behaviour of chemical substances in external magnetic field, magnetic properties/magnetism are of following types:

1. Paramagnetism 2. Diamagnetism 3. Ferromagnetism 4. Anti-ferromagnetism 5. Ferrimagnetism

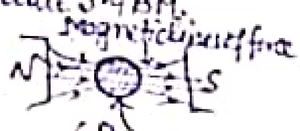
1. **Paramagnetism/Paramagnetic substances:** Substances that are freely magnetised in the direction of the magnetic field in which they are placed are called paramagnetic substances, and their property is called paramagnetism. Paramagnetic substances have the following characteristics:

* Paramagnetic substances contain one or more unpaired electrons. Paramagnetism is expressed in terms of magnetic moment (μ) which arises mainly from the spin of electrons.

Magnetic moment (μ_s) = $\sqrt{n(n+2)}$ BM; Paramagnetism $\propto \mu_s \propto n$ [where n = number of unpaired electron(s)]

e.g., Mn^{2+}, Cr^{3+}, V^{3+}, Fe^{2+} etc. are paramagnetic, out of which Mn^{2+} is most paramagnetic since it has maximum number of unpaired electrons (n=5), and has highest μ_s value 5.9 BM.

* When a paramagnetic substance is placed in a magnetic field, the magnetic lines of force prefer to pass through the substance. Thus, for paramagnetic substances $B > H$ or $B/H > 1$ (where B = magnetic flux density at any point in the substance & H = Strength of applied magnetic field). B/H is called permeability.



(Paramagnetic substance)

* When a paramagnetic is placed in an external magnetic field, the individual atoms/molecules of the substance behave as permanent magnets and allign themselves in the same direction as that of external magnetic field. Hence, the paramagnetic substances are attracted towards magnetic field.

Transition and inner transition metals, their ions and compounds are generally paramagnetic since they have incompletely filled d- or f- orbitals, and so they have one or more unpaired electrons.

Some other examples of paramagnetic substances: O_2; free radicals e.g. $(CH_3)_3C^{\bullet}$, $C_2H_5^{\bullet}$; Complex compounds, e.g. $[Cr(NH_3)_6]^{3+}$, $[Co(NO_2)_6]^{4-}$, $[NiCl_4]^{2-}$ etc.

2. Diamagnetism/Diamagnetic substances: Substances which are repelled away from the magnetic field, when placed in a magnetic field are called diamagnetic substances, and property exhibited by them is called diamagnetism.

Diamagnetism of a substance is produced due to the presence of paired electrons. Diamagnetic property increases with the increase of atomic number. Diamagnetic substances show following characteristics:

(Diamagnetic Substance)

* Diamagnetic substances are repelled by magnetic field. Diamagnetism is caused by the presence of paired electrons as the magnetic field produced by one electron is neutralised/cancelled by the other, because each of the two electrons has equal and opposite magnetic moment ($\mu_s = 0$).
* When they placed in a magnetic field, set themselves at right angles (90°) to the magnetic field. In non-uniform magnetic field, they accumulate towards the lowest part of the magnetic field.
* Diamagnetic substances allows a smaller number of lines of magnetic force to pass through as compared to that in vaccum, i.e., lines of magnetic force avoid diamagnetic substances hence the permeability of diamagnetic substances (B/H) is less than unity(1).
* The intensity of induced magnetisation is less in diamagnetic substances than the applied magnetic field in vaccum.

Some examples of diamagnetic substances are: elements/ions with vacant or completely filled suborbit/orbitals, e.g. Zn, Cu^+, Na^+, Mg, Ti^{4+}, Sc^{3+}, Hg etc; molecules with octet/duet confs. e.g. H_2, N_2, CO_2, NH_3, H_2O etc; complex compounds/ions, e.g. $[Ni(CO)_4]$, $K_4[Fe(CN)_6]$ etc.

3. Ferromagnetism/Ferromagnetic substances: Those substances which are strongly attracted by magnetic field or show permanent magnetism even in absence of magnetic field are called ferromagnetic substances, and property exhibited by them is called ferromagnetism.

In ferromagnetic substances strong magnetic interaction takes place between neighbouring paramagnetic centres when the paramagnetic centres are kept close enough, as the result an increment or enhancement in magnetic moment is found. It is special case of paramagnetism.

Some examples are: Fe, Co, Ni, their compounds/ions/alloys; magnetite (Fe_3O_4), CrO_2 etc.

Ferromagnetic substances show following characteristics:

* Ferromagnetic substances exhibit greater force of attraction in a magnetic field.
* The permeability of ferromagnetic substances is of the order 10^3.
* In absence of magnetic field, effective magnetic moment is zero because of random arrangement of domains/electrons. In magnetic field, they allign in parallel direction. $\uparrow\downarrow\uparrow \rightarrow \uparrow\uparrow\uparrow$
* On heating ferromagnetic substances, start loosing their magnetic property gradually. After Curie temperature, ferromagnetism is converted into normal paramagnetism.

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