LANGEVIN THEORY OF DIAMAGNETISM

1. Diamagnetic substances are those for which magnetic moment of each atom/molecule is zero. For such a substance it may be assumed that the atom/molecule is equivalent to a pair of electrons moving in same orbit in opposite directions

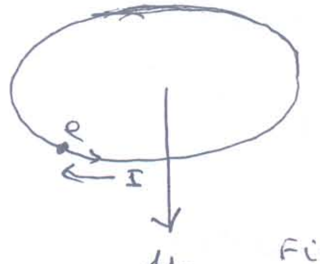


Fig i)

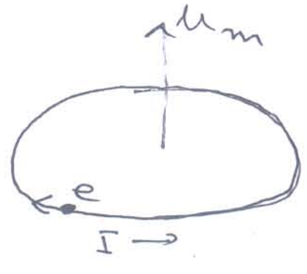


Fig ii)

Magnetic moment of a current loop is given by

$$\mu_m = IA = \frac{q}{t}A = \frac{e}{\frac{2\pi r}{v}} \times \pi r^2$$

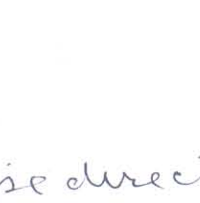
$$\mu_m = \frac{evr}{2} = \frac{er^2\omega}{2} \quad \text{—(1)}$$

For electron moving in clockwise direction μ_m is downward & for electron moving anticlockwise μ_m is upward as shown in field

In the absence of external magnetic field it is only electrical force F_e which provides necessary centripetal force to moving electrons such that

$$F_e = m r \omega_0^2 \quad \text{—(2)}$$

However, as soon as a magnetic field is applied the electron experiences a magnetic force



$$F_m = |evB| = er\omega B \quad [\vec{F} = q(\vec{v} \times \vec{B})]$$

radially outward for clockwise & radially inward for anticlockwise electron

This decreases and increases the centripetal force on electrons moving clockwise and anticlockwise direction respectively and hence decreases & increases velocity of electrons correspondingly.

$$F_e \pm F_m = m r \omega^2 \quad \text{—(3)} \quad (\omega = \text{angular freq in presence of field})$$

$$m r \omega_0^2 \pm e r \omega B = m r \omega^2$$

$$\Rightarrow \quad m\omega_0^2 \pm e\omega B = m\omega^2$$

$$\pm e\omega B = m(\omega^2 - \omega_0^2) = m(\omega+\omega_0)(\omega-\omega_0)$$

$$\Rightarrow \quad \pm e\omega B = m\, 2\omega \cdot \Delta\omega$$

$$\Rightarrow \quad \Delta\omega = \pm \frac{eB}{2m} \quad \text{——— (4)}$$

From (1) $\Delta\mu_m = \frac{er^2}{2}\Delta\omega$

$$= \pm \frac{er^2}{2} \cdot \frac{eB}{2m}$$

$$\Delta\mu_m = \pm \frac{e^2 r^2 B}{4m} \quad \text{——— (5)}$$

For electron in clockwise motion

$$\mu_m \rightarrow \mu + \Delta\mu_m \quad \text{opposite to } \vec{B}.$$

& For electron in anticlockwise motion

$$\mu_m \rightarrow \mu - \Delta\mu_m \quad \text{along } \vec{B}.$$

∴ Net change in magnetic moment is

$$= (\mu + \Delta\mu_m) - (\mu - \Delta\mu_m)$$

$$= 2\Delta\mu_m$$

$$= \frac{2e^2 r^2 B}{4m} \quad \text{opposite to } \vec{B}$$

∴ Net change in μ $= \frac{e^2 r^2 B}{2m}$ opposite to B

This explains diamagnetism.

Also from (5) change in magnetic moment of <u>one</u> electron is

$$|\Delta\mu_m| = \frac{e^2 r^2 B}{4m}$$

If there are N electrons in an atom then dipole moment of one atom

$$\mu_i = \sum_{i=1}^{N} \Delta\mu_i = \frac{e^2 B}{4m}\sum r_i^2 \quad \text{——— (6)}$$

If n = No of atoms per unit volume then

$$M = n\mu_i = n\frac{e^2 B}{4m}\sum r_i^2$$

$$M = \frac{ne^2 B}{4m}\sum r_i^2 \qquad (7)$$

$$\Rightarrow \quad M = \frac{ne^2\mu_0 H}{4m}\sum_{i=1}^{N} r_i^2$$

$$\frac{M}{H} = \frac{ne^2\mu_0}{4m}\sum_{i=1}^{N} r_i^2$$

$$\chi_m = \frac{ne^2\mu_0}{4m}\sum_{i=1}^{N} r_i^2. \quad \text{——— (8)} \qquad \left[\frac{M}{H} = \chi\right]$$

Since $\vec{M}$ & $\vec{H}$ are opposite to each other a -ve sign appears in eqn

$$\therefore \quad \chi_m = -\frac{ne^2\mu_0}{4m}\sum_{i=1}^{N} r_i^2$$

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