B.Sc Part II (Physics Hons)
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Q Discuss Langevin's theory of diamagnetism. Obtain an expression for the susceptibility of a diamagnetic material.?

Ans:→ **Langevin's theory of Diamagnetism:→**

A ~~diag~~ diamagnetic material is one which when placed in magnetic field, becomes weakly magnetised in a direction opposite to the field. It is thus characterised by a small negative susceptibility which is ~~sa~~ independent of temperature.

In 1905, Langevin explained diamagnetism from electron theory of matter. According to his theory, matter is atomic in structure and in each atom electrons revolves in closed orbits a positive nucleus. An electron revolving in orbit behaves as a current loop, and the value of the current 'i' equals the rate at which charge passes any given point of the loop. Thus $i = e\nu$ where e is the electronic charge and 'ν' is the angular frequency of the electron motion.

The magnetic Dipole moment associated with this current would be $P_m = iA = e\vec{\nu}A$ Put $\nu = \frac{\omega}{2\pi}$ where ω = angular velocity of electron and $A = \pi r^2$, where r = radius of orbit.

$$\therefore \quad P_m = e\left(\frac{\omega}{2\pi}\right)\cdot(\pi r^2) = \frac{1}{2} e r^2 \omega \quad \text{-------------} (1)$$

In a diamagnetic material the number and orientations of electron orbits in each atom are such that the net magnetic moment of the atom is zero. But when the material is placed in a magnetic field, three electronic currents in each atom are modified in such a way that a magnetic moment is induced whose direction is opposite to the applied field.

In the absence of magnetic field, the electrostatic force F excited on the electron by the atomic nucleus is the required centripetal force, that is $F_e = mr\omega_0^2$, where ω_0 = the angular velocity of electron of mass 'm' in its orbit.

When an external field $\vec{B}_F$ is applied $\perp$ to the plane of orbit, an additional magnetic force $\vec{F}_m$ acts on the electron, which is also radial. Hence the new centripetal force on the electron is $F_e \pm F_m$. The sign $\pm$ appear because F_m may be radially inward or outward. A change in the centripetal force requires a change in the angular velocity of ~~elel~~ electron.

Let ω be the new angular velocity, then

$F_e \pm F_m = mr\omega^2$. But $F_e = mr\omega_0^2$ & $F_m = eVB = e(r\omega)B$

Therefore $mr\omega_0^2 \pm e\omega rB = mr\omega^2$

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

The quantity $(\omega - \omega_0)$ is $\Delta\omega$ and may approximately be written as 2ω because ω differs only slightly from ω_0 even in the strongest external magnetic fields.

$\Rightarrow \pm eB\omega = m\Delta\omega(2\omega)$

$\therefore \Delta\omega = \pm \frac{eB}{2m}$

The change in angular velocity produces a change in magnetic moment whose magnitude is given as

$\Delta P_m = \frac{1}{2} er^2\Delta\omega$

or, $\Delta P_m = \frac{1}{2} er^2 \left(\frac{eB}{2m}\right)$

$\therefore \Delta P_m = \frac{e^2r^2B}{4m}$

By len's law, the magnetic moment will increase in a direction opposite to the applied field, or decrease in the direction of the field.

As an examples, suppose that an atom containing two electrons revolving in opposite ~~dir~~ directions in the same orbit. In the absence of an external field their magnetic moments are equal and opposite so that the net magnetic moment of the atom is zero. When a magnetic field is applied, the angular velocity and hence the magnetic moment of one electron is increased and that of the other is decreased by the same amount ΔP_m. Consequently, the magnetic moment in a direction opposite to the field $P_m + \Delta P_m$ and in the direction of the field $P_m - \Delta P_m$. Thus there is net induced magnetic moment of $2\Delta P_m$ in the direction opposite to the field.

for an atom containing i electrons, the total induced magnetic moment is given by

$$\sum_i \Delta P_m = Be^2 \sum r_i^2 / 4m$$

Let 'n' be the nos of atom per unit volume of the material, then the magnitude of the magnetisation is given by

$$I = n \sum_i \Delta P_m = \frac{ne^2 \sum_i r_i^2}{4m} B$$

We know that $B = \mu_0(I+H)$, since I is very small for diamagnetic, so by putting $B = \mu_0 H$

$$\therefore I = \frac{\mu_0 ne^2 \sum_i r_i^2}{4m} H$$

This equation in vector form is written as

$$\vec{I} = \frac{\mu_0 ne^2 \sum_i r_i^2}{4m} \vec{H}$$

Therefore, the magnetic susceptibility χ_m of diamagnetic material is given by

$$\chi_m = \frac{\vec{I}}{\vec{H}}$$

$$= -\frac{\mu_0 ne^2 \sum_i r_i^2}{4m}$$

But in practice $\chi_m = \frac{\vec{I}}{\vec{H}} = -\frac{\mu_0 ne^2 \sum_i r_i^2}{6m}$

because all the electrons are not be $\perp$ to applied field.

$\ominus$ Sign indicates that $\vec{I}$ & $\vec{H}$ are in opposite direction due to Lentz's law.