Magnetisation: The term magnetisation may be defined as the process of converting a non magnetic bar into a magnetic bar. The term is almost analogous to the polarisation in dielectric materials. The flux density,

$$B = \mu H \qquad \mu_0 = \frac{\mu}{\mu_r}$$

$$\therefore \quad B = \mu_0 \mu_r H$$

μ_0 = absolute permeability in vacuum.

$$B = \mu_0 H + \mu_0 \mu_r H - \mu_0 H$$

$\mu_r = \frac{\mu}{\mu_0}$, relative permeability

$$B = \mu_0 H + \mu_0 H(\mu_r - 1)$$

$$\boxed{B = \mu_0 [H + M]}$$

H = magnetic field strength

μ = absolute permeability

Where $M = H(\mu_r - 1)$ known as Magnetisation.

The magnetic induction B_0 inside a long solenoid which have a core of vacuum of air is $\mu_0 n i$. If the core is replaced by any other magnetic material and the value of B in the material is experimentally measured, one of the following results is obtained for any material.

$$B < B_0$$

$$B > B_0$$

$$B >> B_0$$

On the basis of these ~~et~~ observations, magnetic material can be classified into three categories: Diamagnetic, paramagnetic and ferromagnetic respectively.

Othe classes of materials which in structure close to ferromagnetic material but posses different magnetic effects are antiferromagnetic and ferrimagnetic

Origin of Magnetic Momement:

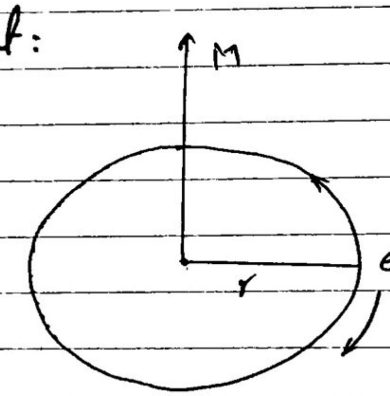


fig: electron revolving arround the nucleus.

The moment of particle is associated with its circular or rotational motion. In the case of an atom, an electron posses an inharent spin motion in addition to its orbital motion about the nucleus. These motion together constitute the magnetic moment.

Suppose an eletron is revolving around the nucleus having charge e and radius is r, of the orbit. The revolving election is making a loop to the current Thus current can be define as

$$I = \frac{Charge}{time} = \frac{e}{T} \quad \text{—— (1)}$$

Where T is the time period, if v is the linear velocity then we can write

$$T = \frac{2\pi r}{v} \quad \text{—— (2)}$$

The area enclosed by the orbit

$$A = \pi r^2 \quad \text{--- } ③$$

The magnetic moment M associated with current is given by

$$M = IA$$

$$M = \frac{e}{T} \cdot \pi r^2 \Rightarrow \frac{ev}{2\pi r} \cdot \pi r^2$$

$$\boxed{M = \frac{evr}{2}}$$

The magnetic dipole moment of a revolving electron is thus half the product of its charge, linear velocity, and the radius of it's orbit.

⇒ In terms of magnetic succeptibility χ_m, M is given by as follows:

$$M = \chi_m H$$

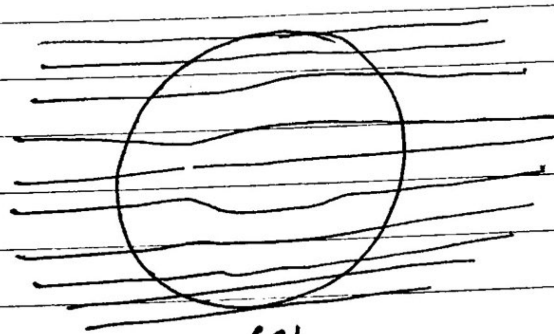
⇒ (i) for free space $M = 0$

(ii) $B = \mu_0 H \Rightarrow H = B/\mu_0$

⇒ Diamagnetism: Diamagnetism is very small and very weak effect in many materials caused by the reaction of orbiting electrons to an applied magnetic field in accordance with Lenz's law, so that the magnetisation and hence

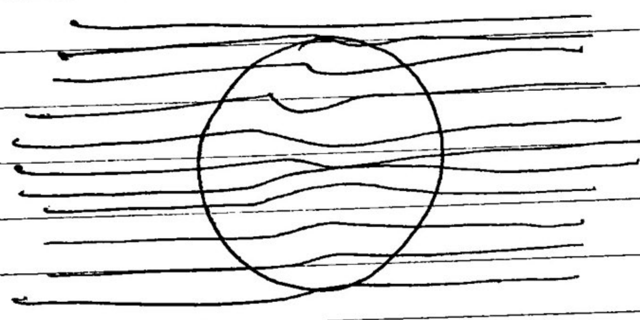
The succeptibility are both negative.
Antimony, Bismuth, mercury, gold, and copper are some examples

If a magnetic material is placed in magnetic field, it can increase or decrease the flux density.



(a)

Diamagnetic materials reduce the ~~line~~ density of lines of forces as shown in fig (a), while para-magnetic materials increase the flux density as shown in fig (b).



(b)

for diamagnetic substance $\chi < 0$, and it is independent of temperature.

Classical Theory of Diamagnetism:
(Langevin Theory of Diamagnetism):-

Consider a circular ~~loop~~ orbit of radius r in which an electron revolves with angular velocity ω_0 around the nucleus of charge Ze. Then

$$f_0 = \frac{mv^2}{r} = \frac{mr^2\omega_0^2}{r} = mr\omega_0^2 \quad \text{— (1)}$$

and also $$f_0 = \frac{1}{4\pi\epsilon_0}\frac{(Ze).e}{r^2} = \frac{Ze^2}{4\pi\epsilon_0 r^2} \quad \text{— (2)}$$

from equation (1) & (2), we get

$$\omega_0^2 = \frac{Ze^2}{4\pi m\epsilon_0 r^3}$$

$$\omega_0 = \sqrt{\frac{Ze^2}{4\pi m\epsilon_0 r^3}} \quad \text{— (3)}$$

The magnetic moment of the electron is

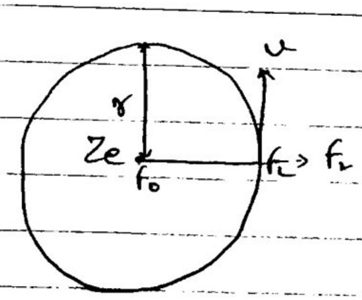
$$M = iA = \frac{e}{T}\pi r^2 = \frac{e\omega_0 r^2}{2} \qquad \left|\ M = \frac{evr}{2},\ v = r\omega_0\right.$$

The Lorentz force acting on the electron is

$$f_L = -Bev = -Berw$$

Now the equation for motion is

$$f_m = f_0 - f_L = \frac{Ze^2}{4\pi\epsilon_0 r^2} - Be\omega r$$



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$$\frac{m\omega^2}{r} = \frac{Ze^2}{4\pi\epsilon_0 r^2} - eB\omega r$$

$$mr\omega^2 = \frac{Ze^2}{4\pi\epsilon_0 r^2} - eB\omega r$$

$$\omega^2 + \frac{eB\omega}{m} - \frac{Ze^2}{4\pi m\epsilon_0 r^3} = 0$$

$$\omega = \left(-\frac{eB}{m} \pm \sqrt{\frac{e^2B^2}{m^2} + \frac{4Ze^2}{4\pi\epsilon_0 m r^3}} \right) \frac{1}{2}$$

$$\omega = -\frac{eB}{2m} \pm \frac{1}{2}\sqrt{\frac{Ze^2}{\pi m\epsilon_0 r^3} + \frac{e^2B^2}{m^2}}$$

$$\omega = -\frac{eB}{2m} \pm \sqrt{\omega_0^2 + \frac{e^2B^2}{4m^2}}$$

if $\frac{eB}{2B} << \omega_0$ then

$$\boxed{\omega = \pm\omega_0 - \frac{eB}{2m}} \quad \text{—— (4)}$$

Now change in the frequency

$$\omega = 2\pi\nu \quad , \quad \Delta\nu = -\frac{eB}{4\pi m}$$

$$\Delta M = iA = \frac{e}{T} 2\pi r^2$$

$$\Delta M = e(\Delta\nu)\pi r^2$$

$$\Delta M = \frac{e\pi r^2 eB}{4\pi m}$$

$$\Delta M = -\frac{e^2 r^2 B}{4m} \quad \text{--- } (5)$$

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Summing over all

$$\Delta M = -\frac{e^2 B \Sigma r^2}{4m} \quad \text{--- } (6)$$

$$\Sigma r^2 = Z\langle r^2 \rangle$$

$$\langle r^2 \rangle = \langle x^2 \rangle + \langle y^2 \rangle$$

If $\langle r_0^2 \rangle$ represents average distance of the electron from the nucleus

$$\langle r_0 \rangle^2 = \langle x \rangle^2 + \langle y^2 \rangle + \langle z^2 \rangle$$

When the atom has spherical symmetry

$$\langle x^2 \rangle = \langle y^2 \rangle = \langle z^2 \rangle$$

$$\langle r^2 \rangle = 2\langle x^2 \rangle$$

$$\& \quad \langle r_0^2 \rangle = 3\langle x^2 \rangle$$

$$\frac{\langle r^2 \rangle}{\langle r_0^2 \rangle} = \frac{2}{3} \Rightarrow \langle r^2 \rangle = \frac{2}{3}\langle r_0^2 \rangle$$

Thus equation (6) becomes:

$$\Delta M = -\frac{e^2 B Z}{4m}\left[\frac{2}{3}\langle r_0^2 \rangle\right]$$

If N is the number of atoms/m³, then magnetisation

$$\Delta M = -\frac{N e^2 \mu_0 H Z}{4m}\left[\frac{2}{3}\langle r_0^2 \rangle\right] = -\frac{N e^2 \mu_0 H Z}{6m}\langle r_0^2 \rangle$$

$$\chi = \frac{M}{H} = -\frac{\mu_0 Z e^2 N}{6m}\langle r_0^2 \rangle$$

This is the Langevins formula for the volume succeptibility.

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