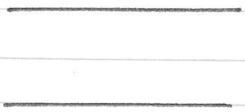
Chapter 31

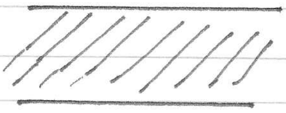
1. Review of Dielectrics
2. Magnetism in Matter
3. Orbital Magnetic Dipole Moment
4. Spin Magnetic Moment
5. Paramagnetism
6. Diamagnetism.
7. Ferromagnetism

Dielectrics

A non-conducting material, such as air, glass, paper, or wood is called a dielectric



$$C_0 = \frac{Q}{V_0}$$



$$C = \frac{Q}{V}$$

$$V_0 > V \Rightarrow C > C_0$$

$$C_0 = \frac{Q}{V} = \frac{Q}{Ed}$$

$\frac{C}{C_0} = \kappa$ characteristics

↳ dielectric

$$E = \frac{\sigma}{\epsilon_0} \qquad C_0 = \frac{\epsilon A}{d}$$

$$E = \frac{E_0}{\kappa}$$

$$C = C_0 k = k \frac{\epsilon_0 A}{d} = \epsilon \frac{A}{d}$$

$$\epsilon = \kappa \epsilon_0$$

↓

permittivity

$$U = \frac{1}{2} C V^2 =$$

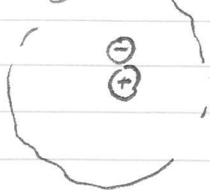
$$= \frac{1}{2} \left(\frac{\epsilon A}{d}\right) (E d^2) = \frac{1}{2} \epsilon E^2 (Ad)$$

$$u_e = \frac{1}{2} \epsilon E^2 = \frac{1}{2} k \epsilon_0 \left(\frac{E_0}{\kappa}\right)^2$$

$$= \underline{\frac{1}{2} \frac{1}{\kappa} (E_0)^2}$$

A dielectric weaken the electric field between the plates of capacitor decreases because the dielectric produce a field in a direction opposite to the field produced by the plates

The electric field is due to the electric dipole moment of the molecules in the dielectrics



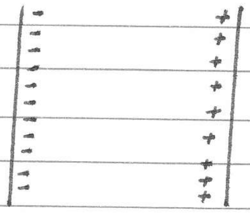
nonpolar

under external electrical field

↓

the molecules become polarized

Polar molecules ⇒ permanent electric dipole moment



Surface charge near the plate

$$E_b = \frac{\sigma_b}{\epsilon_0}$$

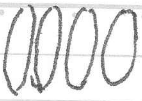
$$E_0 = \frac{\sigma_f}{\epsilon_0}$$

$$E = E_0 - E_b = \frac{E_0}{\kappa}$$

$$\underset{\displaystyle\frac{\sigma_b}{\epsilon_0}}{\underset{\shortparallel}{E_b}} = \left(\frac{\kappa-1}{\kappa}\right)E_0 = \left(\frac{\kappa-1}{\kappa}\right)\frac{\sigma_f}{\epsilon_0}$$

$$\Rightarrow \quad \underset{\text{bound}}{\underset{\downarrow}{\sigma_b}} = \left(1-\frac{1}{\kappa}\right)\underset{\text{free}}{\underset{\downarrow}{\sigma_f}}$$

Magnetism in Matter



current I

↓

inside : vacuum $\vec{B}_0$ along z direction

inside : medium $\vec{B}$ different from $\vec{B}_0$

↓ $\vec{M} \propto \vec{B}_M$

magnetic dipole moment

Orbital magnetic dipole moment

↓

loop model

$$\vec{\mu}_{orb} = -\frac{e}{2m}\vec{L}$$

start with $\vec{\mu}_{orb} = i\, A$

i ↓ current

A ↘ area

↓

See P. A of note.

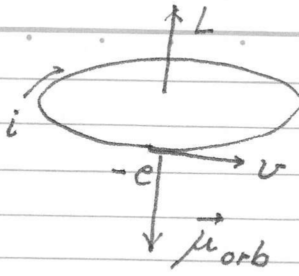
Spin magnetic moment

$$\vec{\mu}_s = -\frac{e}{m}\vec{S}$$

↓

See P. A. of the note.

Magnetism and Electrons



$$\vec{L} = \vec{r} \times \vec{p}$$

Orbital Magnetic Moment

$$|\vec{\mu}_{orbit}| = i A$$

$$A = \pi r^2$$

$$i = \frac{e}{T}$$

$$T = \frac{2\pi r}{v}$$

$$i = \frac{e}{\frac{2\pi r}{v}} = \frac{ev}{2\pi r}$$

$$\mu = \frac{ev}{2\pi r} \pi r^2 = \frac{evr}{2}$$

$$= \frac{emvr}{2m} = \frac{eL}{2m}$$

$$\vec{\mu}_{orb} = -\frac{e}{2m} \vec{L}_{orbit}$$

$$\mu_{orb,z} = -\frac{e}{2m} L_{orb,z}$$

$$L_{orb,z} = m_\ell \hbar$$

$$= m \frac{h}{2\pi}$$

$$= -\frac{e}{2m} m_\ell \frac{h}{2\pi}$$

$$= -\underbrace{\frac{eh}{4\pi m}}_{\mu_B} m_\ell$$

$\downarrow$

Bohr magneton.

Put a dipole in a $\vec{B}_{ext}$ field along z direction

$$U = -\mu_{orb,z} B_{ext}$$

$$\vec{S} \sim \vec{L}$$

$$\vec{\mu}_s = -\frac{e}{m} \vec{S}$$

$\downarrow$

similar to $\vec{L}$

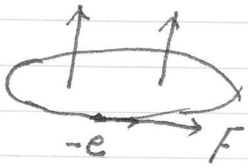
No external $\vec{B}$ field

unpolar molecule

polar molecule with random direction

⇒ average magnetic moment. $=0$

Induced dipole magnet moment → diamagnetism



B along z

$$\oint \vec{E}\cdot d\vec{l} = -\frac{d}{dt}\Phi_B$$

$$E\cdot 2\pi r = -\frac{d}{dt}(B\pi r^2)$$
$$\Downarrow$$
$$E = -\frac{r}{2}\frac{dB}{dt}$$

B → increase from $0 \to B$

EMf counterclockwise

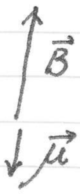
F on electron, see the graph

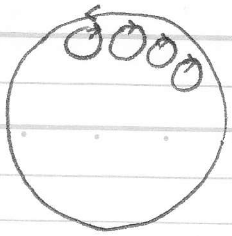
$$\begin{array}{ccc}\vec{\tau} & = & \vec{r}\times\vec{F} \\ \| & & \| \\ \frac{dL}{dt} & & \frac{er^2}{2}\frac{dB}{dt}\end{array}$$ along z direction

$$\Delta L \sim \frac{er^2}{2} B$$

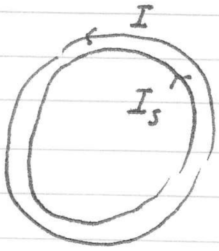
change of dipole moment

$$\underset{\substack{\downarrow \\ \text{due to the} \\ \text{external field}}}{\Delta\mu} = -\frac{e^2r^2}{2m}\Delta L = \underset{\substack{\downarrow \\ \text{along } -z \text{ direction}}}{-}\frac{e^2r^2}{4m}B$$





$\vec{B}$ outward → z direction



$\Rightarrow \quad \vec{B} < \vec{B}_0$

Diamagnetism.

$U = -\vec{\mu} \cdot \vec{B}$

$\mu < 0 \qquad U = |\mu||B|$

B smaller U smaller

larger U larger

⇒ Tend toward smaller energy
↓
smaller field
↓
See Fig. 32-9 → draw the graph.

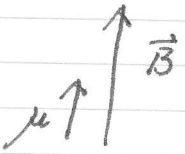
$d\vec{F} = i\, d\vec{l} \times \vec{B}$

Paramagnetism.

Alignment of the magnetic field

$$U = -\vec{\mu} \cdot \vec{B}$$

$\vec{\mu} \parallel \vec{B}$ is more favorable , energy wise



$\vec{B} > \vec{B}_0$

Toward field with greater strength.
when the magnetic field is not uniform.

usually the alignment is not complete.

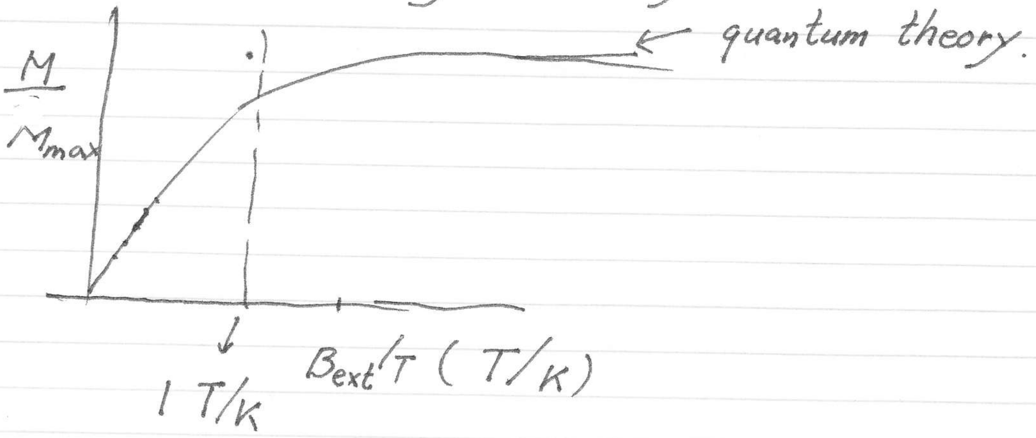
$$M = \frac{\text{measured magnetic moment}}{V}$$

$$M_{max} = \frac{N\mu}{V}$$ (all magnetic dipole moment are line out)

because K.E. $\gg U_B$

$\downarrow$

alignment may be



very high field , very low temperature

$$M = c\,\frac{B_{ext}}{T}$$ Curier law

Ferromagnetism.

$$\vec{B} = \vec{B}_0 + \vec{B}_M$$
$$\downarrow$$
$$\propto \vec{M}$$
↳ magnetization

strong coupling

↑ ↑ exchange coupling

spin spin

at higher temperature $T > T_c$

↳ Curie temperature

strong coupling cease to be effective

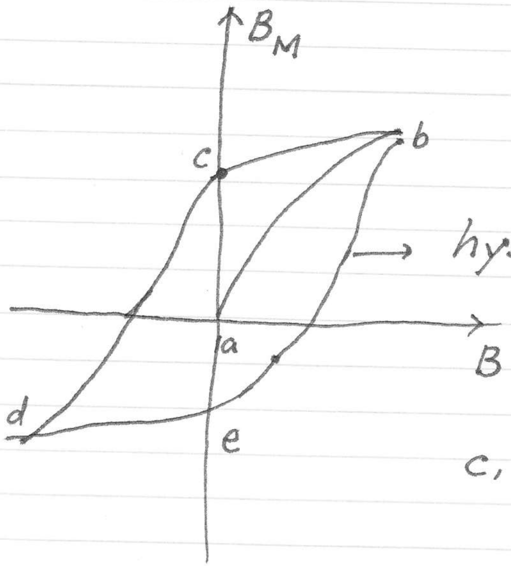
↓

paramagnetic

magnetic domain

↑ ↑ ↖↖

↗↗



→ hysteresis loop

c, e → permanent magnet.