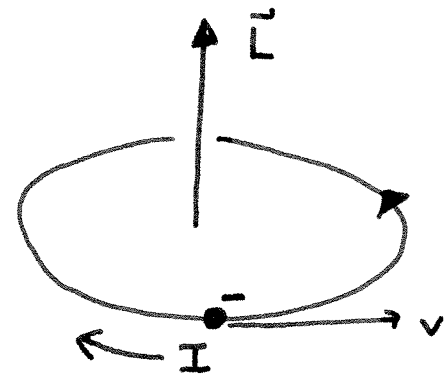
L17 Magnetic Materials + Displacement Current

In any practical application of electromagnetism one has to deal with the magnetic properties of the material. There are three classes of behavior – paramagnetism, diamagnetism & ferromagnetism.

BOHR MAGNETON



"Atom of magnetism"

$$I = \frac{e}{T} = \frac{ev}{2\pi r}$$

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

$$L = mvr$$

$$\mu = \frac{e}{2m} L$$

Quantum mechanics $\Longrightarrow$ angular momentum is quantized in units of $\hbar$

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

$h = 6.626 \times 10^{-34}$ Js

$\hbar = 1.05 \times 10^{-34}$ Js

$$L = \hbar \Rightarrow \boxed{\mu_B = \frac{e\hbar}{2m} = \frac{eh}{4\pi m}}$$

MAGNETIC MOMENT OF ELECTRON

$\mu_B = 9.27 \times 10^{-24}$ Am^2

BOHR MAGNETON

Magnetization

$$\vec{M} = \frac{\vec{\mu}_{TOT}}{V} = \text{magnetization} \quad (\text{magnetic mom/unit vol.})$$

The magnetization <u>enhances</u> the magnetic field in a medium

$$\vec{B} = \vec{B}_0 + \mu_0 \vec{M}$$

$\uparrow$ internal $\quad \uparrow$ external

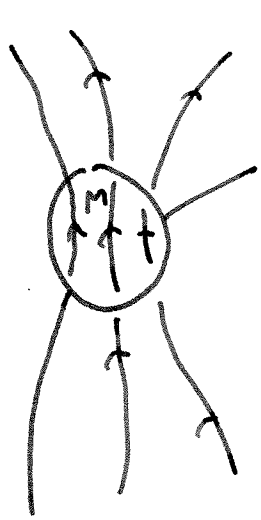
[often write $\vec{B} = \mu_0(\vec{H} + \vec{M})$]

We write

$$\vec{B} = K_m \vec{B}_0$$

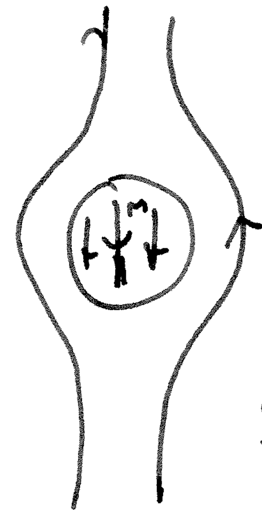
In paramagnetic materials $\quad M/B > 0$

In diamagnetic materials $\quad M/B < 0$.



B enhanced

Field enhanced



Field partially excluded.

Paramagnetic $\chi > 0$

$\boxed{\text{PRODUCED BY SPIN ALIGNMENT}}$

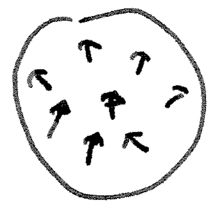
Diamagnetic. $\chi < 0$

$\boxed{\text{PRODUCED BY ORBITAL CURRENTS}}$

$$\mu_0 M = \chi B$$

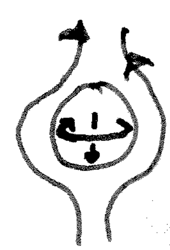
$$k_m = 1 + \chi .$$

- Curie paramagnet : $\chi = \dfrac{C}{T}$



Spins polarized in a field.

- Superconductor : perfect diamagnet. $\chi = -1$



e.g. A) $\chi_{Pt} = 26$ calculate magnetic moment of

1 cm³ in one tesla.

$$\left.\begin{aligned} \mu &= MV \\ \mu_0 M &= \chi B \end{aligned}\right\} \quad \mu = \frac{V \chi B}{\mu_0}$$

$$= \frac{10^{-6}\,m^3 \times 26 \times 1\ \text{Tesla}}{4\pi \times 10^{-7}}$$

$$= \frac{260}{4\pi} = \underline{20.7\ A\,m^2}$$

B) Calculate the energy per unit volume of a paramagnet in a field

$$M = \frac{\chi B}{\mu_0} \qquad dU = -VM\,dB = -\frac{\chi B\,dB\,V}{\mu_0}$$

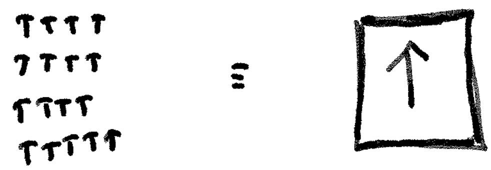
$$U = -\int M\,dB = -\frac{\chi B^2 V}{2\mu_0}.$$

$$\boxed{\text{THIS ENERGY "ATTRACTS" PARAMAGNETS TO REGIONS OF HIGH FIELD.}}$$

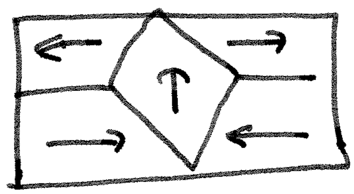
Ferromagnetism

Fe, Co, Ni many alloys.

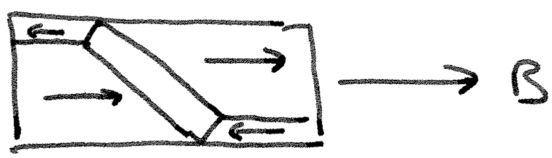
One domain



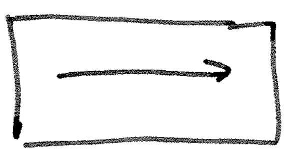
Multidomain

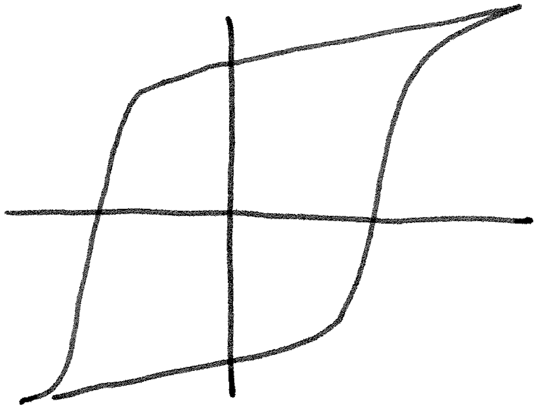


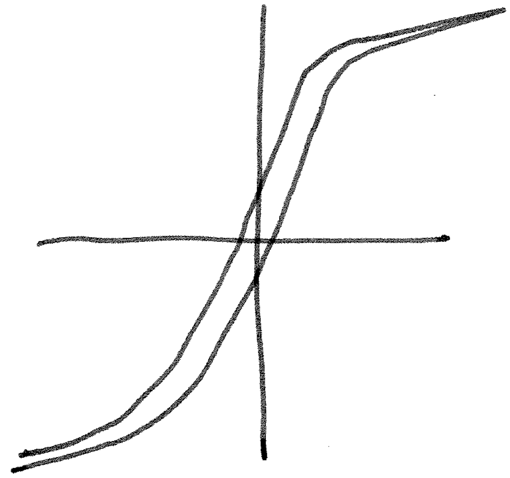
In a field:



Beyond the saturation field







"Hard"

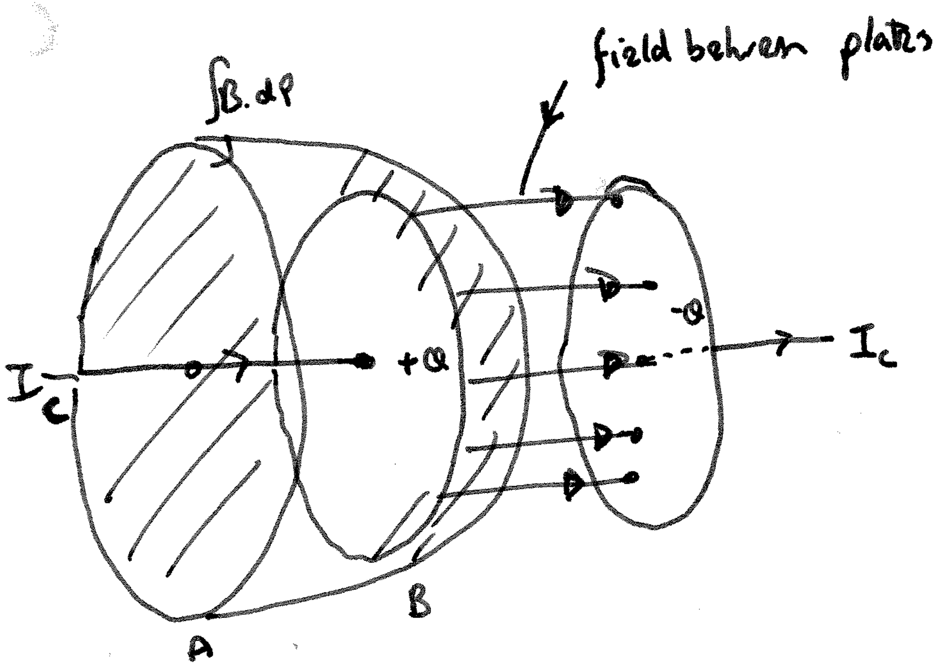
- difficult to magnetize or demagnetize
- good for magnets

"Soft"

- easy to magnetize demagnetize.
- good for A.C devices like transformers.

29.7 Displacement Current

$$\oint \vec{B} \cdot d\vec{\ell} = \mu_0 I_{encl}$$ Ampères law.



When we calculate I_{encl}, we get a different answer for surface A than for surface B.

Resolution — correct Ampères law!

$$q = CV = \left(\frac{\epsilon_0 A}{d}\right)(Ed) = \epsilon_0 EA = \epsilon_0 \Phi_E$$

$$I_C = \frac{dq}{dt} = \epsilon_0 \frac{d\Phi_E}{dt}$$

In between the Capacitor plates there is no current of charge, but the ~~mag~~ electric flux is increasing. If we combine the charge current &

$$I_D = \epsilon_0 \frac{d\Phi_E}{dt} \qquad \text{"displacement current"}$$

then

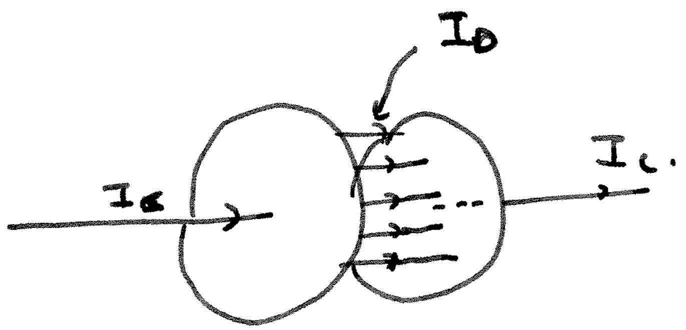
$$I = I_C + I_D$$

is the same for both surface A & B.

The generalized version of Ampère's law is then.

$$\oint \vec{B} \cdot d\ell = \mu_0 (I_c + I_D) = \mu_0 \left(I_c + \epsilon_0 \frac{d\Phi_E}{dt} \right)$$

e.g



$$2\pi r B = \mu_0 \frac{r^2}{R^2} I_c$$

$$B = \frac{\mu_0 I_c}{2\pi R} \left(\frac{r}{R} \right).$$

$$I_D = \epsilon_0 A \frac{\partial E}{\partial t} = I_c \qquad \boxed{\frac{\partial E}{\partial t} = \frac{I_c}{\epsilon_0 \pi R^2}}$$