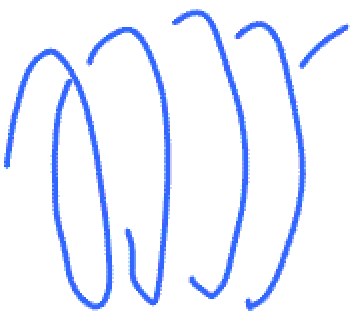
Physics 114 — March 25, 2010

Last Time

Inductance

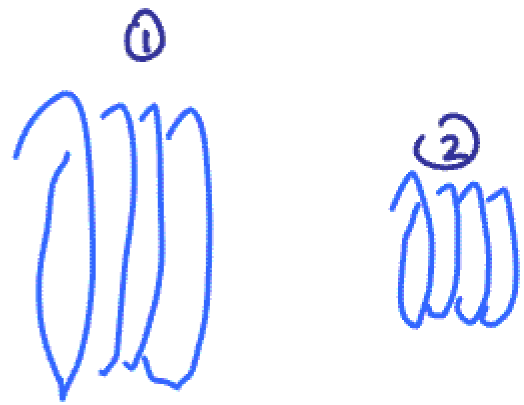
Self inductance



$\Phi_M = L i$

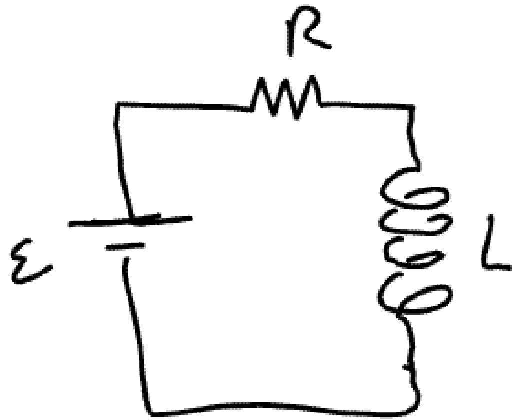
$\mathcal{E} = -L\, di/dt$

Mutual inductance



$\Phi_{M_2} = M i_1$

$\mathcal{E}_2 = -M \dfrac{di_1}{dt}$

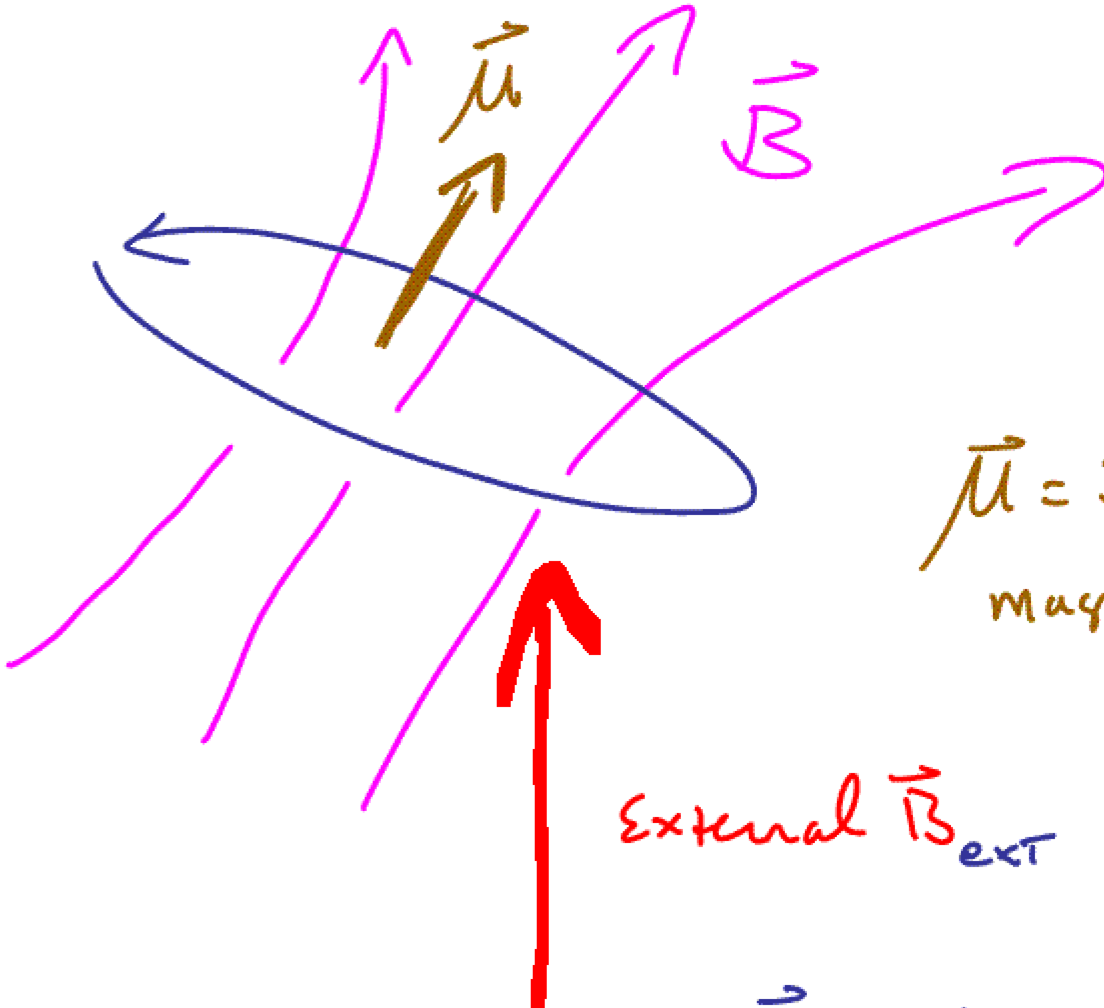


$$\underbrace{\mathcal{E} i}_{\text{Power output of Battery}} = \underbrace{i^2 R}_{\text{Power dissipated in Resistor}} + \underbrace{L i \frac{di}{dt}}_{\text{Power going into the inductor}}$$

$$L i \, di/dt \longrightarrow \underbrace{U_B}_{\text{energy stored in B field in inductor}} = \tfrac{1}{2} L i^2$$

solenoid

$$u_B = \frac{|\vec{B}|^2}{2\mu_0}$$ Energy Density in B field



$\vec{\mu} = \vec{B}A$

magnetic Moment

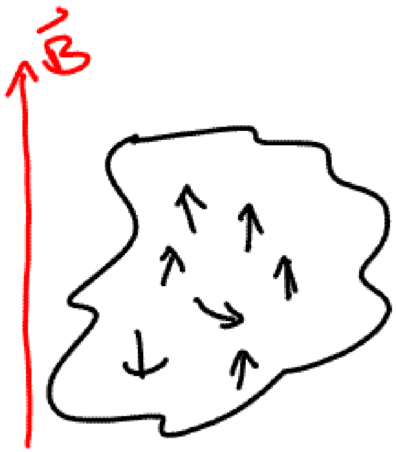
$\vec{\tau} = \vec{\mu} \times \vec{B}_{ext}$

Aligns $\vec{\mu}$ with $\vec{B}_{ext}$

Magnetism in Materials

Paramagnetic

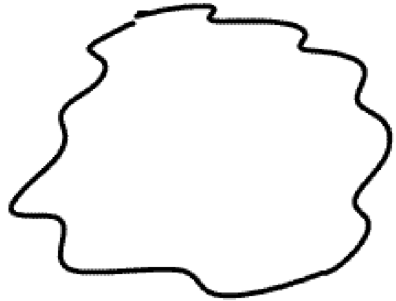
Natural Dipoles



Torque from $\vec{B}$
Aligns more Dipoles along $\vec{B}$

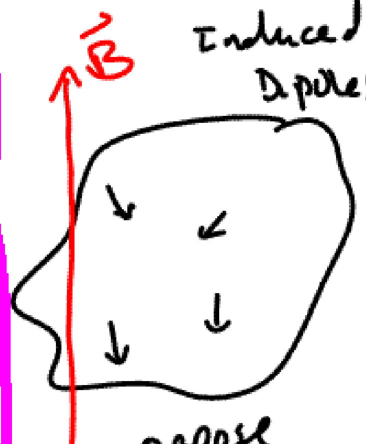
$\rightarrow$ $\vec{B}$ increased

Diamagnetic



No Dipole

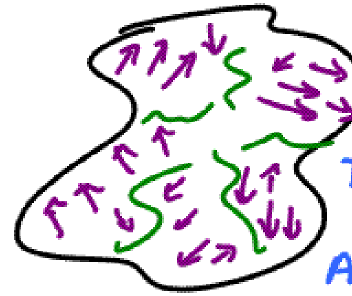
Induced Dipoles



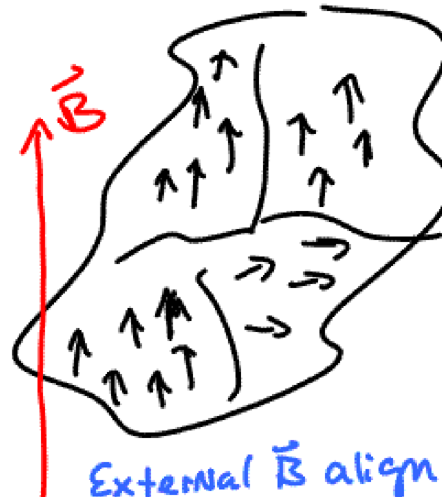
oppose External $\vec{B}$

$\rightarrow$ $\vec{B}$ weakened

Ferromagnetic



Strong Dipoles in Domains of local Alignment



External $\vec{B}$ aligns more Domains along $\vec{B}$

$\rightarrow$ $\vec{B}$ increased

$$B = \mu_0 \left(\boxed{1+\chi_M}\right) B_{free}$$

Magnetic Susceptibility K_M

External B field

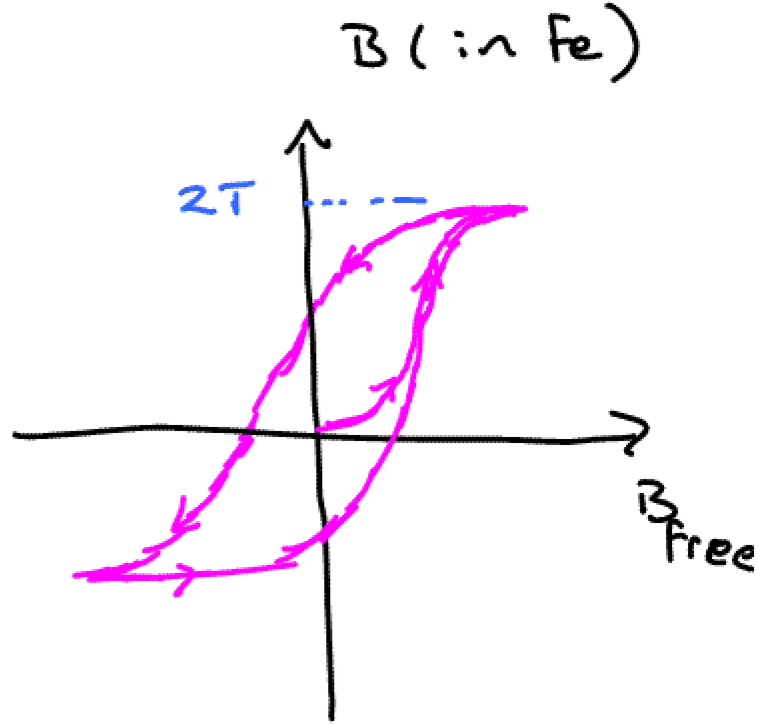
relative permeability

$\mu_0 K_M \sim$ permeability $\to \mu$

$\chi_M \gtrsim 1$ Paramagnetism

$\cdot \quad \gg 1$ Ferromagnetism

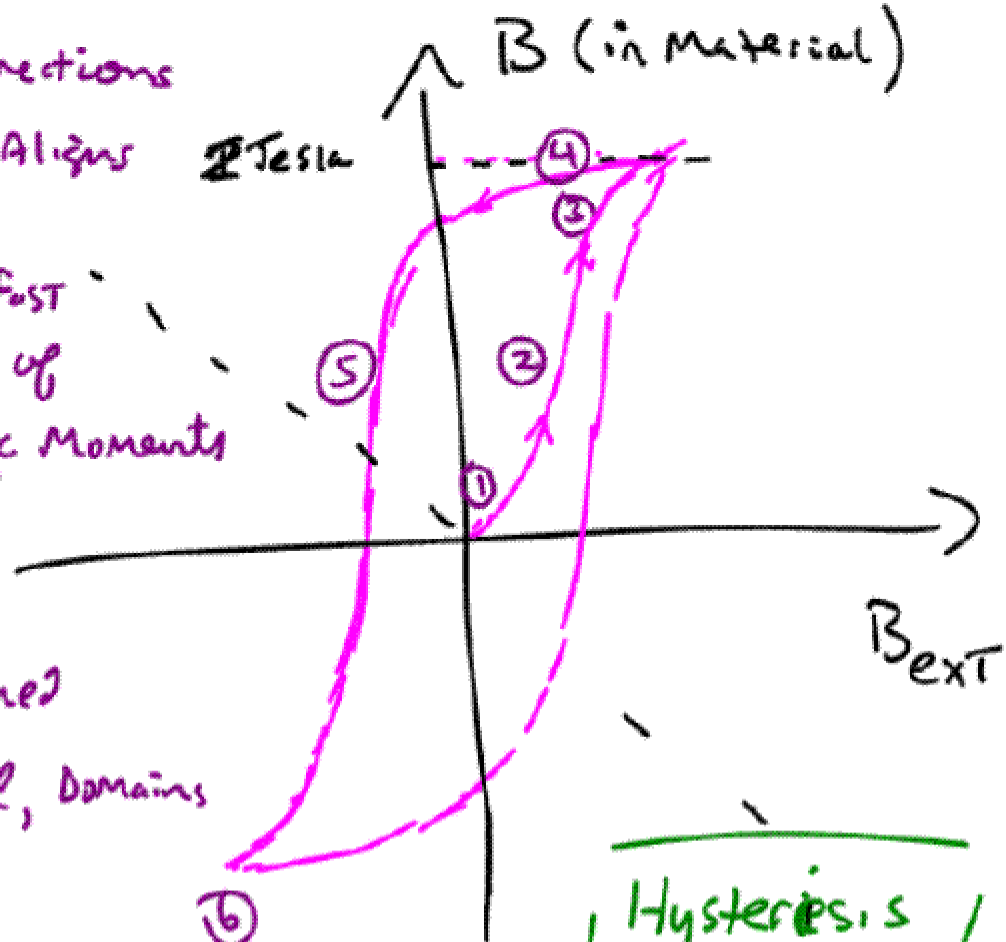
$\chi_M < 1$ Diamagnetism



Hysteresis loop

① Domains oriented
in random directions

② provide Bext, Aligns
domains,
B internal grows fast
due to addition of
Domain magnetic Moments
to external field



③ saturation
All domains Aligned

④ reduce Bexternal, Domains
stay aligned

Hysteresis
Loop

⑤ Binternal drops
quickly when Bexternal changes
direction and causes domains to orient in other direction

⑥ saturation with domains pointed opposite the
direction at position ③-④

Maxwell's Equations

1873

James Clerk Maxwell

1831 - 1879 (Edinburgh)

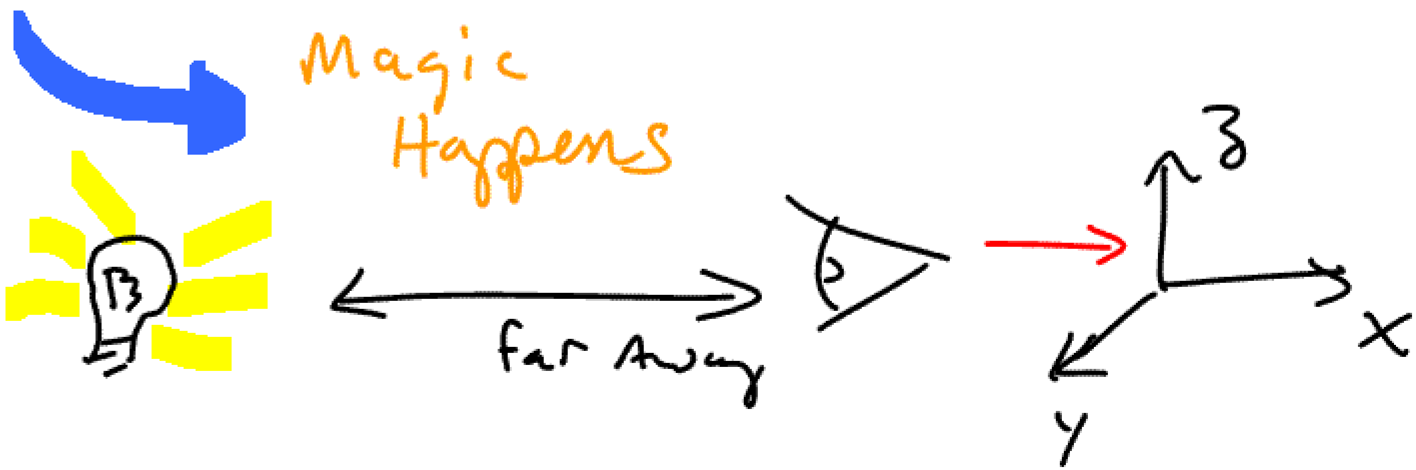
$$\oint_S \vec{E}\cdot d\vec{A} = \frac{Q_{encl}}{\epsilon_0}$$ Gauss' law

$$\oint_S \vec{B}\cdot d\vec{A} = 0$$ No Magnetic Monopoles

$$\oint_c B\cdot dl = \mu_0 I_{encl}$$ Ampere's law

$$\oint_c \vec{E}\cdot d\vec{l} = -\frac{d\Phi_M}{dt} = -\frac{d}{dt}\oint_S \vec{B}\cdot d\vec{A}$$ Faraday's law

$$\oint_c \vec{B}\cdot d\vec{l} = \mu_0 I_{encl} + \underbrace{\mu_0\epsilon_0 \frac{d}{dt}\oint_S \vec{E}\cdot d\vec{A}}_{\text{Maxwell's displacement current}}$$



phase

speed of prop

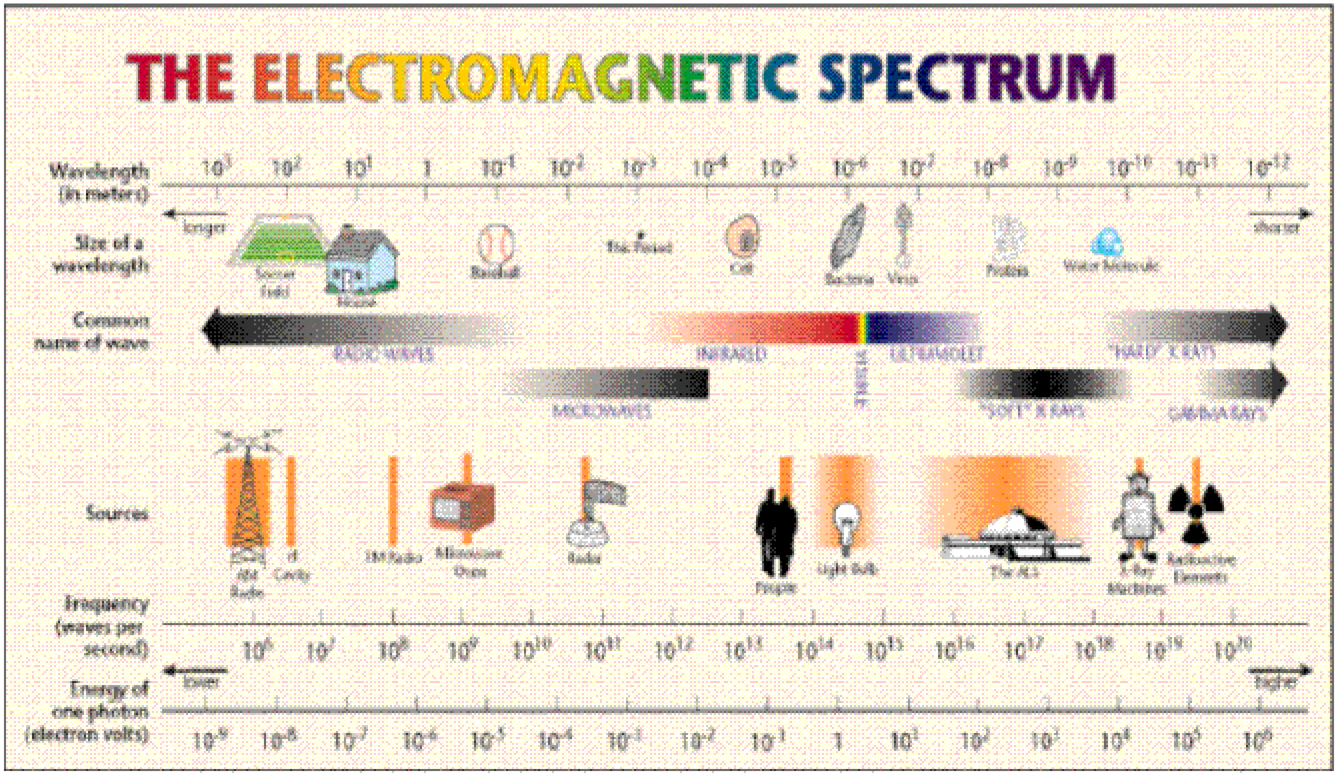
$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

$$E_y(x,t) = E_{0y} \cos(kx - \omega t + \varphi)$$

$\frac{2\pi}{\lambda}$ $\quad$ $2\pi/T$

$$B_z(x,t) = \frac{k}{\omega} E_{0y} \cos(kx - \omega t + \varphi)$$

$$= \frac{1}{c} E_y$$



-figure from www.lbl.gov
LBNL