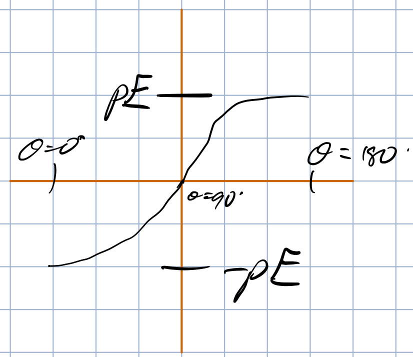
Torque on dipole → align dipole w/ field

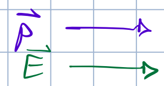
rotating back against forces gives dipole potential energy

define $U=0$ when dipole $\perp$ field

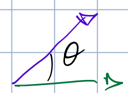
Electricity

$U = -\vec{p}\cdot\vec{E}$

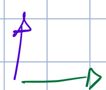




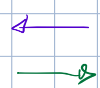
$U = -pE$



$U = -pE\cos\theta$



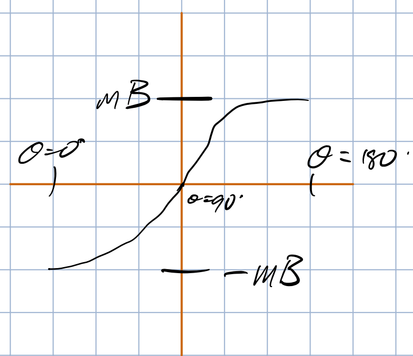
$U = 0$

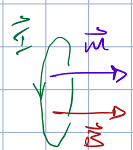


$U = pE$

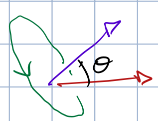
Magnetism

$U = -\vec{m}\vec{B}$

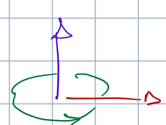




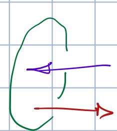
$U = -mB$



$U = -mB\cos\theta$



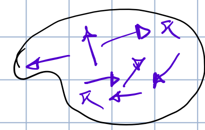
$U = 0$



$U = mB$

dipoles in magnetic materials

in absence of magnetic field

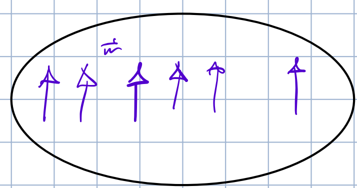


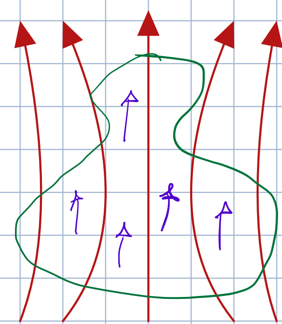
$\vec{M} = 0$

in magnetic field

- torque on dipoles
- dipoles aligned & Magnetized ($\vec{M} \neq 0$)
- remove $\vec{B}$ → demagnetized ($\vec{M} = 0$)

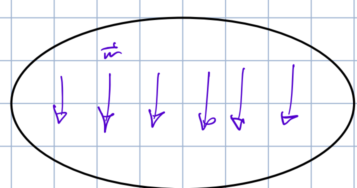
Paramagnetic

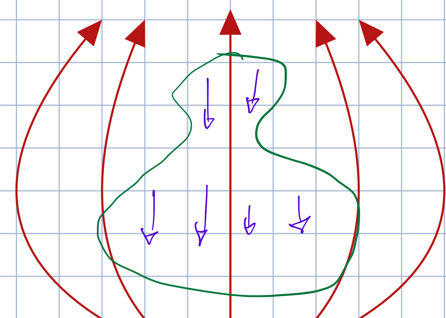




$\vec{B}$ stronger in than outside

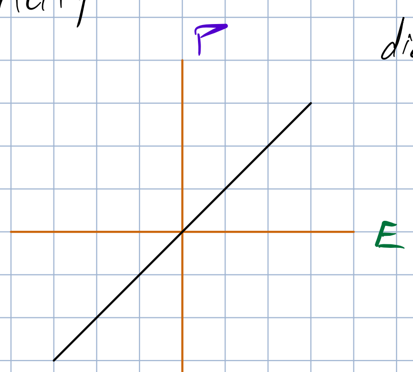
Diamagnetic



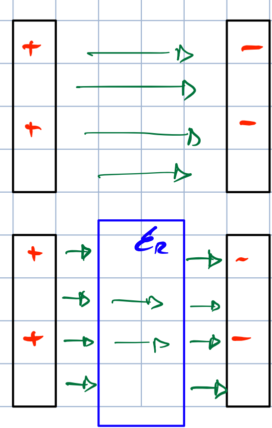


$\vec{B}$ weaker than outside

Electricity



dialectric $\vec{P} = 0$ if $\vec{E} = 0$



$$\vec{P} = \epsilon_0 \chi_e \vec{E}$$

$$\vec{D} = \epsilon_0 \vec{E} + \vec{P}$$

$$= \epsilon \cdot \vec{E}$$

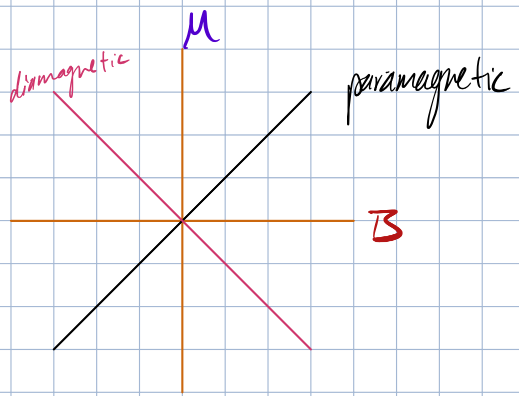
$\epsilon_R = 1 + \chi_e$

$\epsilon = \epsilon_0 \cdot \epsilon_R$

ϵ – permitivitty

χ_e – electric susceptibility $\chi_e > 0$

ϵ_R – relative permitivitty



$\vec{M} = 0$ if $\vec{B} = 0$

$\vec{M} = \chi_m \vec{H}$

$\vec{H} = \frac{1}{\mu_0}\vec{B} - \vec{M}$

$\vec{B} = \mu_0(\vec{H} + \vec{M}) = \mu H$

$\mu_R = 1 + \chi_m$
$\mu = \mu_0 \cdot \mu_R$

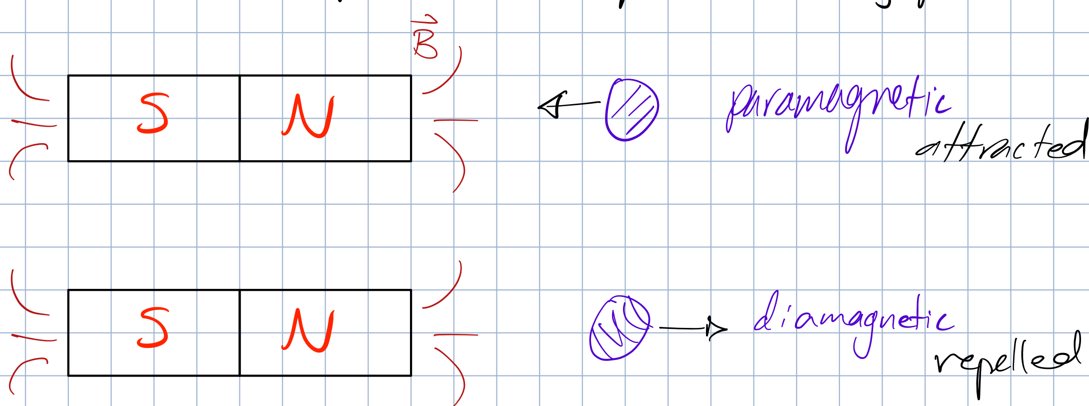
χ_m - magnetic susceptibility
μ - permeability
μ_R - relative permeability

$\chi_m > 0 \rightarrow$ paramagnetism

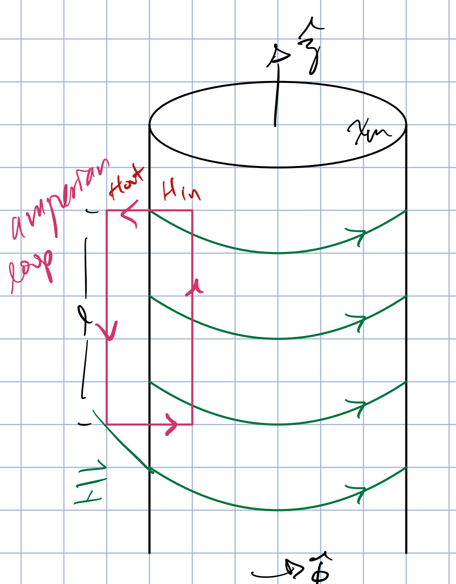
$\chi_m < 0 \rightarrow$ diamagnetism

susceptibility: lack of ability to rest

permeability: capability of being permeated



Griffiths ex. 6.3 infinite solenoid w/ material χ_m



$\vec{H}_{out} = 0$

$\vec{H}_{in} = H_{in}\hat{z}$

$\oint \vec{H}_{in} \cdot d\vec{l} = I_{encl}^{free} \rightarrow H_{in} \cdot l = n I \cdot l$

$\vec{H}_{in} = nI\hat{z}$

$\vec{B}_{in} = \mu_0(1+\chi_m)\vec{H} = \mu_0(1+\chi_m)nI\hat{z}$

paramagnetic: $\chi_m > 0$ increases B_{in}

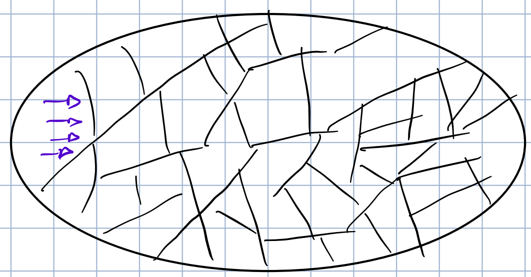
diamagnetic: $\chi_m < 0$ decreases B_{out}

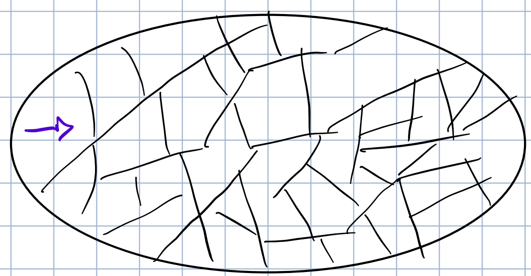
Ferromagnetism (non-linear materials)

materials can have $\vec{M}$ w/ $\vec{B} = 0$

$\vec{m}$ associated w/ spins of unpaired e^-'s

interactions between dipoles are large → each $\vec{m}$ likes to point in same direction as neighbors





$\uparrow\uparrow$ ferro

$\uparrow\downarrow$ antiferro

can add $\vec{B}_{ext}$ to "saturate" material

Hysteresis Loop – $\vec{M}$ depends on material history