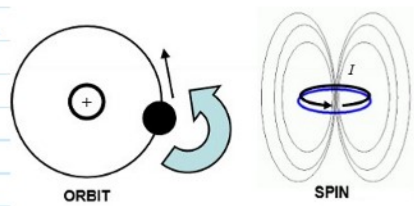
Magnetic Materials

Saturday, December 5, 2020 3:16 PM

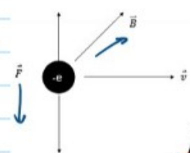
Magnetic Materials

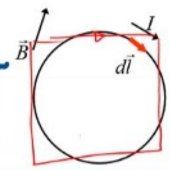
- Moving charge & Time changing $\vec{E}$ field → Magnetic Field B, produced by I
  - ↳ Dynamic: Maxwell's Eqns
  - ↳ Steady currents: Biot-Savart & Ampere's Law
- e^- in solids orbit nucleus & spin on own axis
  - ↳ Both generate magnetic current loops
  - ↳ dominant contribution = spin
  - ↳ atoms w/ even e^- → cancel
  - ↳ If odd e^- or shells not filled in order, can get non-zero magnetic current loops



Current Loop in Field

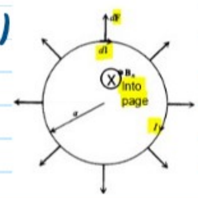
- Net force to displace loop, net torque
- Lorentz Force: $\vec{F} = q\vec{v} \times \vec{B}$ → RHR
- Net Force on loop: $\vec{F} = \oint I d\vec{l} \times \vec{B} = 0$
  - ↳ No net force to displace loop
- Force to deform loop: $\vec{B} = \vec{B}_n + \vec{B}_p$ → n normal, p perpendicular
- Field applied ⊥ loop → Force towards or away from loop axis → slow or speed up charge & change loop field in opp. dir. to applied field





Diamagnetism

- Normal component $\vec{B}$ slows orbital → Diamagnetism
  - ↳ local field reduced when field applied (materials w/ no net spin)
- Applying $\vec{B}$ field on orbiting e^- opposes applied field
- orbiting e^- slowed/sped up & create weak opposing field



Paramagnetism

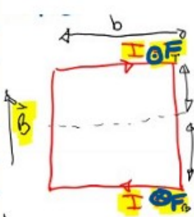
- Application of an external field leads to alignment of spins & increase in internal field

Ferromagnets

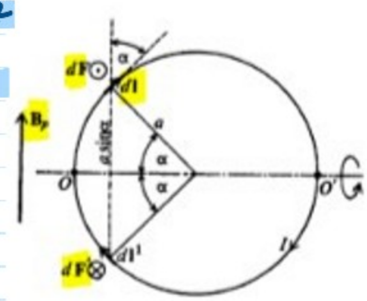
- Spontaneous alignment of spins → create magnetic domains
- aligned by application of external fields

Magnetic Moments

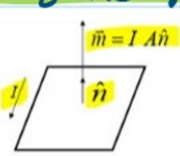
- Perpendicular Component: $T = a^2\pi I B_{parallel} = a^2\pi I B \sin\theta = mB\sin\theta$
  - ↳ θ = angle b/w B & loop, m = dipole moment $= IA = I\pi a^2$



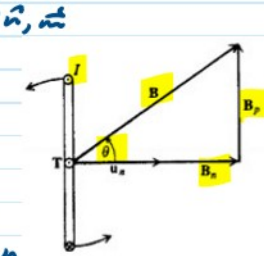
- Square loop: $F_{top} = IbB\hat{z}$, $F_{bottom} = -IbB\hat{z}$
  - $T = \frac{a}{2}F_{top} + (-\frac{a}{2})F_{bottom} = abIB$
- If θ = angle b/w B & loop: $T = abIB\sin\theta$
- RHR: Fingers $\vec{B}$ ↑
  - Thumb I →
  - Palm $\vec{F}$ ⊙



Magnetic Dipole moment



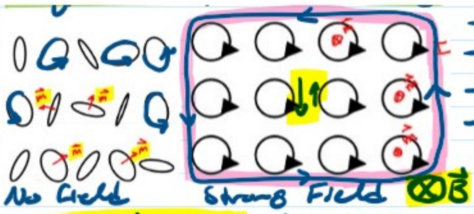
- $\vec{m} = IA\hat{n}$
- RHR: Thumb I ↙
  - Fingers curl in loop ↑ $\hat{n}$, $\vec{m}$



- Loop aligns w/ Field: $\vec{T} = \vec{m} \times \vec{B}$

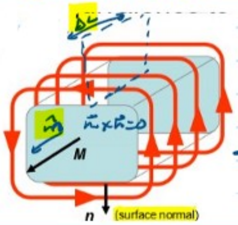
Magnetic Material in Field

- $\vec{m}$ align
- spins align
- current loops cancel

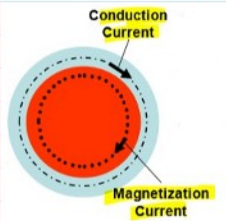


- $\vec{m}$ align
- spins align
- current loops cancel
- Surface currents

- **Magnetization:** - Avg magnetic moment / V $\vec{M} = \frac{\sum_k \vec{m}_k}{V}$
  - Alignment of dipoles → net dipole moment in material
- **Solenoid:**



- **Conduction & Magnetization Currents:** Alignment of many dipoles produce current around boundary of dipoles
- $\vec{K} = \vec{M}\times\hat{n}$, $B\Delta L = \mu_0 I_{enc} \rightarrow I_{enc} = K\Delta L = M\Delta L$
  - ↳ K = current @ surface / L
- **RHR:**



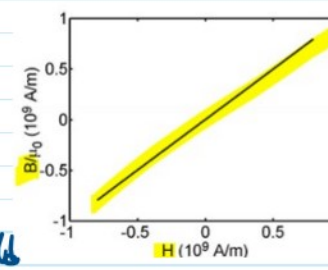
- Can use surface current to find field generated from circulating conducting current
  - $\oint_C \vec{B}\cdot d\vec{l} = \mu_0 I_{enc}$
  - $I_{enc} = I_{cond} + I_{magn}$
  - $\oint_C \vec{H}\cdot d\vec{l} = I_{cond}$

- **Solenoid w/o core:** Ampere's law: $\oint \vec{B}\cdot \mu = \mu_0 I_{enc} = \mu_r \mu_0 I_{cond}$.

- → No core: $\therefore \mu_r = 1$
  - $\oint \vec{B}\cdot d\vec{l} = B\Delta L = \mu_0 N I \cdot \frac{\Delta L}{L} = \mu_0 n I \Delta L$
  - ∴ Field inside coreless solenoid: $\vec{B} = \mu_0 n I \rightarrow n = \frac{N}{L}$

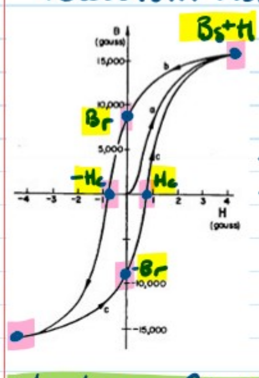
- **Solenoid w/ core:**

- Linear μ_r
- $\vec{B}_{total} = \mu_0 I_{cond} + \mu_0 M \rightarrow M = X_m I_{cond}$
  - $\vec{B}_{total} = \mu_0 I_{cond}(1+X_{cond}) = \mu_r \mu_0 I_{cond}$
  - ∴ $\vec{B}_{total} = \mu_r \mu_0 n I_{cond} = \mu_0 \mu_r H$
- $\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{m}$
- **Permeability:** - How strongly magnetic material is
  - $\vec{B} = \mu_r \mu_0 \vec{H}$
  - @ $\mu_r = 1$, linear relationship



Ferromagnets

- Unpaired spins create magnetic domains
- Can be aligned by application of external magnetic field
- When materials imperfect (impurities?), external field results in history dependent response → saturates B hysteretic



- Hysterisis: If magnetize, then return to $\vec{B}$ applied = 0, magnetization retained (no external field)
- $\vec{B} = \mu_0(\vec{H}+\vec{M}) \rightarrow$ @ $H=0$: $\vec{B} = \mu_0 \vec{M}$
  - $\vec{B}_r$ = Remnant magnetic field
- H_c = Coercive Field → H to apply to make $B=0$ (if saturated)
- B_{sat} = Saturation Magnetization: $B_{sat} = \mu_0(H(M_{sat}) + M_{sat})$
  - For $H > H(M_{sat})$, $\frac{dB}{dH} = \mu_0$

Hard vs Soft Magnetic Materials

- **Hard**: Coercivity $H_c \uparrow$, hard to demagnetize
- **Soft**: Coercivity $H_c \downarrow$, easy to demagnetize

Hard vs soft Magnetic Materials

- **Hard**: Coercivity $H_c \uparrow$, hard to demagnetize
- **Soft**: Coercivity $H_c \downarrow$, easy to demagnetize