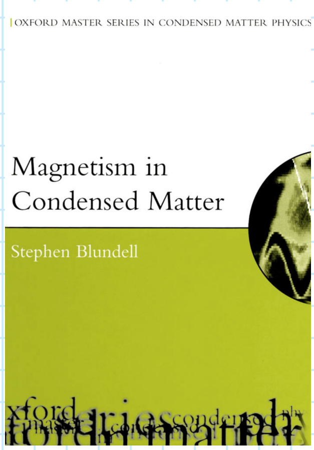
Magnetism in condenced matter systems

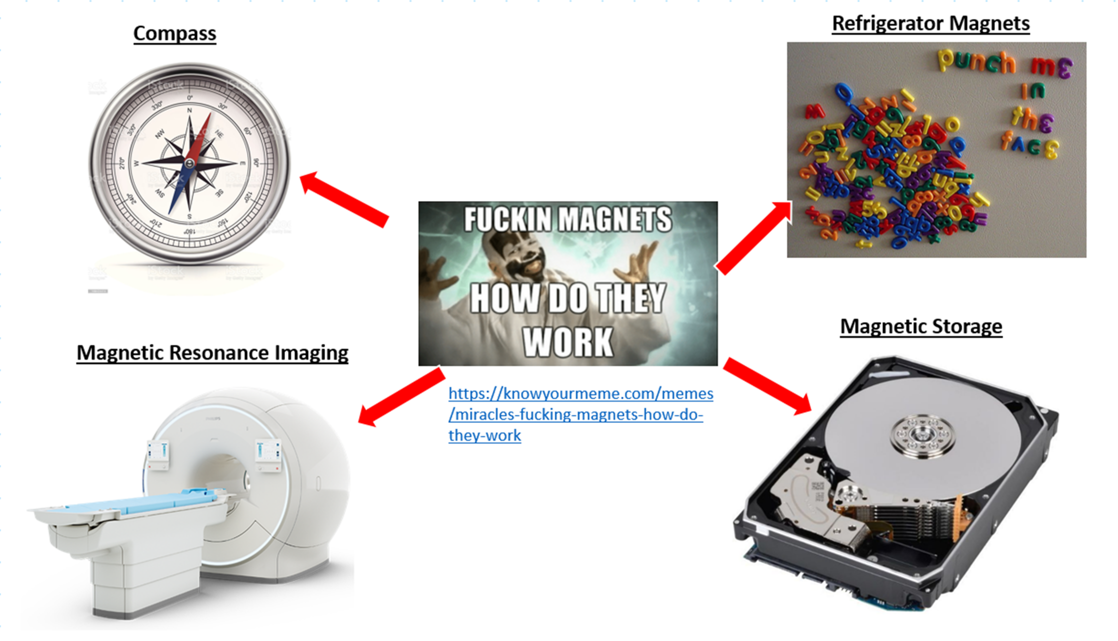
Friday, December 17, 2021 9:42 AM

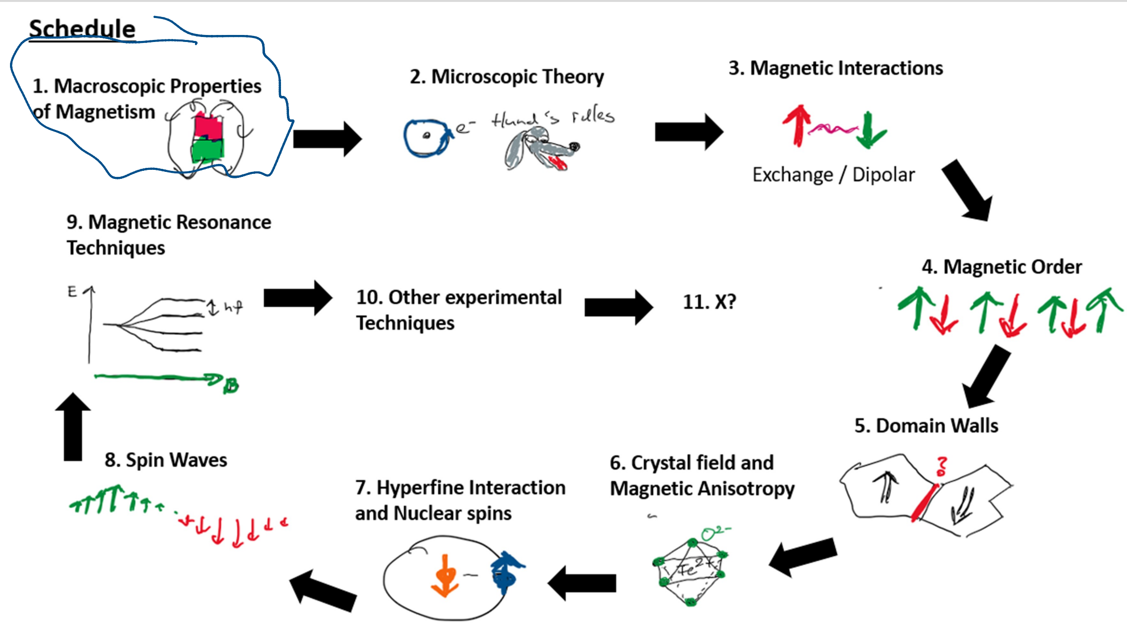
(Lecture 18)

- Gross/Marx, chapter 12
- Stephen Blundell



0. Motivation





1. Macroscopic Properties of Magnetism

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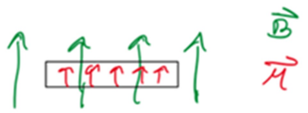

$B = \mu_0(H + M)$

$\mu_0 = 4\pi \cdot 10^{-7}\,\frac{H}{m}$ (vacuum permeability, magnetic field constant)

H: Magnetic field strength [A/m]
M: Magnetization [A/m]
B: Magnetic Flux Density [T]

$$M = \chi \cdot H = \frac{m}{V}$$

χ: magnetic susceptibility (how susceptible is my solid to H
e.g. $\chi = 0 \rightarrow$ no reaction to H)

→ Connects H and M
→ Could be written as a second order tensor (direction dependence)
→ Is unitless (can be given as molar susceptibility $\chi_m = \chi \cdot V_m\,[\frac{m^3}{mol}]$
Or mass susceptibility $\chi_\rho = \chi \cdot \rho\,[\frac{m^3}{kg}]$

$\chi < 0$: diamagnetism (dia = through; induced magnetic moments [Lenz law])
$\chi > 0$: paramagnetism (para = at, next; already existing moments which align)

Magnetic order

Ferromagnetism:

Antiferromagnetism:

Ferrimagnetism:

Important Questions to ask
- Do I have conducting e^- or not?
- Do I have filled or partially filled states?

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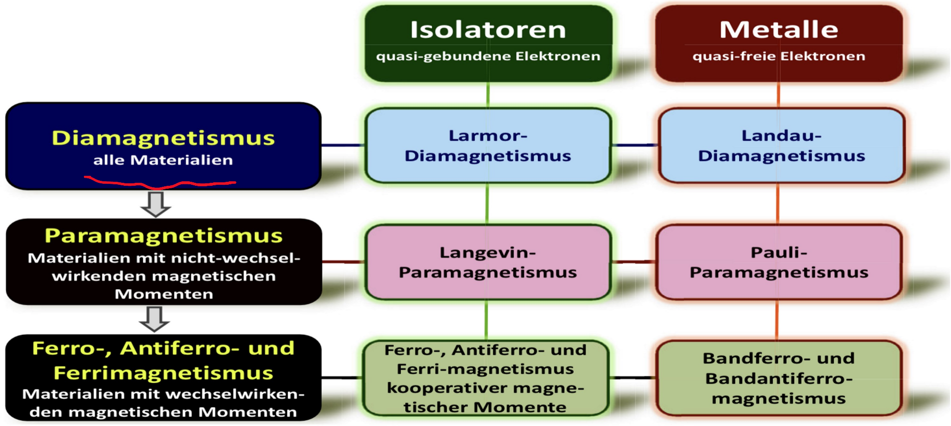
- Do I have filled or partially filled states?
- Exchange Interaction?



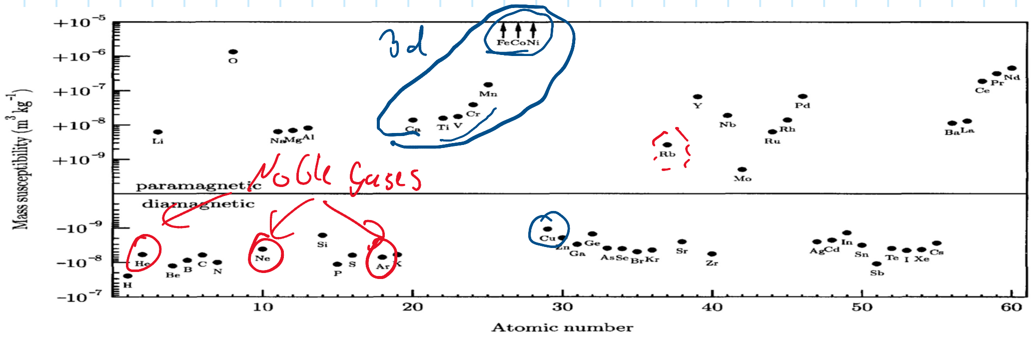


Fig. 2.1 The mass susceptibility of the first 60 elements in the periodic table at room temperature, plotted as a function of the atomic number. Fe, Co and Ni are ferromagnetic so that they have a spontaneous magnetization with no applied magnetic field.

2. Microscopic Origin of Magnetism

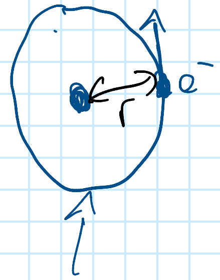
2.1 atomic units of magnetism

- Bohr magneton $\mu_B = \frac{e\hbar}{2m_e}$

$$\approx 9.27 \cdot 10^{-24} \frac{J}{T} = 58 \frac{\mu eV}{T}$$

- Nuclear magneton $\mu_N = \frac{e\hbar}{2m_p}$

Bohr magneton $\rightarrow$ semiclassical solution of an e^- with orbital momentum $1\hbar$



1. atomic current $I = \frac{-e}{T} = \frac{-e\,v}{2\pi r}$

2. angular momentum: $L = m_e v r = \hbar$

$$\underbrace{m}_{\text{magnetization}} = -\frac{e\hbar}{2m_e} := \mu_B$$

- Quantum mechanical description

Orbital angular momentum: $\hat{\mu}_l = -g_l \, \mu_B \frac{\hat{l}}{\hbar}$

Spin angular momentum: $\hat{\mu}_s = -g_s \, \mu_B \frac{\hat{s}}{\hbar}$

g-factors: g_l, g_s ; • $g_s \approx 2$ (2.0023 QED)

• g_l = depends on occupancy of the electronic states

↳ connection to macroscopic magnetism $\vec{m} = \sum_i \vec{\mu}_i = \sum_i g_i \mu_B \frac{\hat{l}_i}{\hbar}$ + spin...

2.2 Atoms in a homogeneous magnetic field

- Consider a system of atoms; non-interacting

$$H = \underbrace{\frac{1}{2m}\left[\vec{p} + eA\right]^2}_{\substack{\text{kinetic part} \\ T}} + V(\vec{r})$$

↳ electrostatic potential "crystal"

↳ $\vec{B} \parallel \hat{z} \rightarrow B = \begin{pmatrix} 0 \\ 0 \\ B_z \end{pmatrix}$ $\quad \vec{A} = -\frac{1}{2}\vec{r} \times \vec{B}$ (Coulomb-gauge)

$$T = \frac{1}{2m} \sum_{i} \left[\vec{p}_i - \frac{e}{2}\, \vec{r}_i \times \vec{B}\right]^2$$

scale

$$= \underbrace{\frac{1}{2m}\sum_i \vec{p}_i^{\,2}}_{T_0} + \underbrace{\frac{e\hbar}{2m}}_{\mu_B}\sum_i \underbrace{\frac{(\vec{r}_i \times \vec{p}_i)_z}{\hbar}}_{\frac{L_z}{\hbar}} \cdot B_z + \overbrace{\frac{e^2 B_z^2}{8m}\sum_i (x_i^2 + y_i^2)}^{u\,b^{2u}}$$