Physics 489 S 04 Lecture 24
Magnetism I: Diamagnetism and Paramagnetism
"Local moments" in solids - due to electron-electron interactions
Aschroft and Mermin, Ch. 31; Kittel Ch. 14

1. Magnetism: Purely quantum phenomenon. Bohr-van Leeuwen Theorem
    $B = H + 4\pi M$ in cgs units
    Magnetization $M = -\frac{1}{V}\frac{dF}{dH}$, F = free energy
    Magnetic susceptibility $\chi = dM/dH = -\frac{1}{V}\frac{d^2F}{dH^2}$

2. Interaction of electrons with magnetic field
    Orbital motion: $\mathbf{p} \rightarrow \mathbf{p} - (-e/c)\mathbf{A}$
    Spin: $g_0\mu_B(\mathbf{H} \cdot \mathbf{s})$

3. Pauli spin paramagnetism (plus Landau current diamagnetism) in metals
    $\chi_{Pauli} = \mu_B^2 g(\epsilon_F) \approx 3(N/V)(\mu_B^2/2\epsilon_F)$
    In independent electron approximation $C_V/T = (\pi^2/3)k_B^2 g(\epsilon_F)$
    Landau current diamagnetism: $\chi_{Landau} = -(1/3)\chi_{Pauli}$
    Can measure χ_{Pauli} separately by NMR, Knight Shift
    Applies to "simple" metals: Na, Al, . . .

4. Localized systems, e.g. atoms
   Consider effect of constant H field on electrons orbits around a center (the nucleus)
    $\nabla \times \mathbf{A} = \mathbf{H}$; can choose $A = -\frac{1}{2}\mathbf{r} \times \mathbf{H}$
    Leads to diamagnetic + paramagnetic terms (see text)

   Diamagnetism in closed shell system - Larmor (Langevin) Diamagnetism
    $\chi = -(N/V)Z(e^2/6mc^2) < r^2 >$

   Paramagnetic moments in open-shell systems
    Curie Law: Statistical Mechanics of independent moments in a magnetic field
    $\chi \approx (1/3)(N/V)(\mu_B^2/k_BT)p^2$, where $p \approx gJ(J+1)$
    Brillouin function - see text

5. Origin of Paramagnetic moments: Electron-electron interactions - beyond independent electron approximation
   Hund's rules in atoms - due to electron-electron interactions
   Three rules: 1. Max S; 2. Max L consistent with 1; 3. J = L-S or L+S

6. Beyond independent electron models in solids: Atomic-like "local moments" in solids
    Rare Earth atoms - localized 4f states
    Transition metals - 3d states often act localized
    Next lectures:
        Kondo Effect in metals
        Interactions between different atoms leads to magnetic order

7. Extra - include in there is time
    Van Vleck paramagnetism
    The nuclear spin adiabatic refrigerator