Physics 489 S 04 Lecture 26
Magnetism II: Spontaneous Magnetic Order in Solids
Aschroft and Mermin, Ch. 33 and p 676-681 of 32; Kittel Ch. 15

1. Interactions between electrons lead to magnetism [brief summary of Chapt. 32]
   Hund's rules due to el.-el. interactions lead to net spin (magnetic moments) of atoms (previous lecture)
   Interactions between neighboring atoms lead to order with no external field
   (a) Bonding of wavefunctions from the two atoms favors antiparallel spins (A&M, 676-9)
   (b) Interaction between electrons in non-bonding states favors parallel spins (just like in Hund's rules)
   These effects are described by Heisenberg Hamiltonian
   $H = -J\mathbf{S}_1 \cdot \mathbf{S}_2$
   ($J > 0$ favors parallel, $J < 0$ favors antiparallel spins)

2. Magnetic order observed in solids – Ferromagnetism; Antiferromagnetism
   Long Range Order analogous to crystalline order in solids
   Observed by Magnetic Bragg Scattering using neutrons which have magnetic moments
   At high Temperature spins are disordered and there is no average magnetic moment vector on any atom (analogous to disordered liquid)
   Thermodynamic Phase Transition between states of different order

3. Curie-Weiss Law: mean field theory of transition to ordered state
   Interactions with spins of neighbors modifies Curie Law
   Mean field theory takes into account only the thermal average of the effects of the neighbors. Leads to Curie Law for each spin in an effective field that depends on the net spin of the neighbors
   Results of mean field theory for a ferromagnet:
   Disordered above $T_C \approx J/k_B$ times numerical factors
   Susceptibility diverges as T approaches T_C from above
   Better theories (beyond mean field) correct the form M(H,T) near T_C

4. Magnons
   Whenever there is long range order (crystal structure, magnetic order, ...), there must be excited states (lattice waves or phonons in crystals, spin waves or magnons in magnets, ...)
   These waves carry energy and contribute to the specific heat
   Spin waves have dispersion $\omega \approx sin^2(ka/2) \approx k^2$ at small k - different from phonons
   Simple derivation in Kittel

5. Magnetic Domains
   Due to long range magnetic dipolar forces, a magnet generally can lower its energy by forming domains
   Remnance, Hysterisis