Physics 489 S 04 Lecture 27
Superconductivity – Aschroft and Mermin, Ch. 34; Kittel Ch. 12
Good Other text: P. deGennes, Superconductivity of Metals and Alloys
(now in reprinted hardback - not expensive!)

1. Experimental Survey. For $T < T_c$:
   Resistance R=0 at a *finite* temperature (K. Onnes, 1911)
   Linear specific heat becomes exponential → gap in the density of states
   Magnetism is *excluded* from superconductor - Meisner Effect (1934)
   Magnetic fields destroy superconductivity above a critical value
   Isotope effect → something to do with phonons

2. Phase Transition – *A different state of matter*
   Shown most clearly by experimental properties in magnetic field
   Superconductivity destroyed by applied magnetic field $H > H_c$ Phase boundary separates "normal" and "superconducting" phases
   Superconductivity vanishes for temperature $T > T_c$ Therefore, there *must* be an order parameter that describes the superconducting phase

3. Magnetic Effects
   Meissner Effect: complete exclusion of H field in Type I superconductors
   Superconducting state exists only for $H < H_{c1}(T)$
   Vortex State for Type II superconductors
   Exists for $H_{c1}(T) < H < H_{c2}(T)$

4. Sketch of ideas involved in Cooper pairs (1956), BCS theory (1957)
   Any attractive interaction between electrons causes Fermi surface to be unstable to formation of Cooper pairs
   Phonons provide a mechanism
   BCS theory: All electrons in the *same* pair state (like condensed bosons)
   BCS is a mean field theory, which described superconductors in great detail; e.g. the relation between the gap Δ and transition temperature T_c: $\Delta/k_B T_c = 1.76$
   The condensed state is the new state of matter
   The order parameter is the condensate wavefunction (two components since a wavefunction is complex)
   The order parameter is non-zero only for $T < T_c$, $H < H_c(T)$
   Maximum T_c before 1987: $\approx 30K$

5. Landau-Ginsberg Theory (1950, preceded BCS)
   Proposed Order Parameter - $\Psi(r) = (n_s)^{1/2} exp(i\phi(r))$
   $\Psi(r)$ obeys Shrödinger-like Eq. (later justified by BCS which shows $\Psi(r)$ is wavefunction describing center of mass $(r_1 + r_2)$ motion of pair)
   Variation of phase $\phi(r)$ describes current - just like ordinary Schr. Eq. but for pair states of charge -2e
   Just like other solutions of the Schr. Eq., $\phi(r)$ must be single valued - boundary conditions lead to quantization over macroscopic distances
   Leads to London Eq., Meissner Effect, flux quantization, etc.

6. Macroscopic Quantum Effects – Manifestations of the coherence of a single wavefunction over the entire superconductor
   Flux Quantization; Persistent Currents; Josephson Effect

7. High Temperature superconductors discovered starting in 1987
   CuO planar materials with T_c up to $\approx 150K$
   No agreed explanation for High T_c superconductivity!
   Fullerines (A_3C_{60}, A = Na,K,Cs) have T_c up to $\approx 50K$