Condensed Matter Physics II
SS 2015

Wednesday 9:30-12:30

Seminar Room Physics 2

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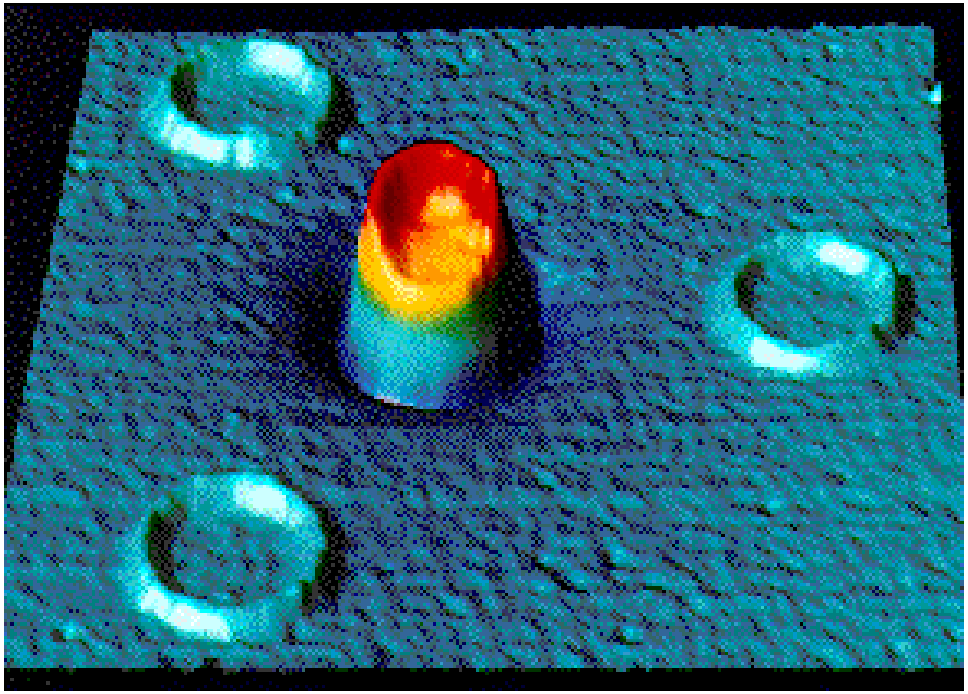
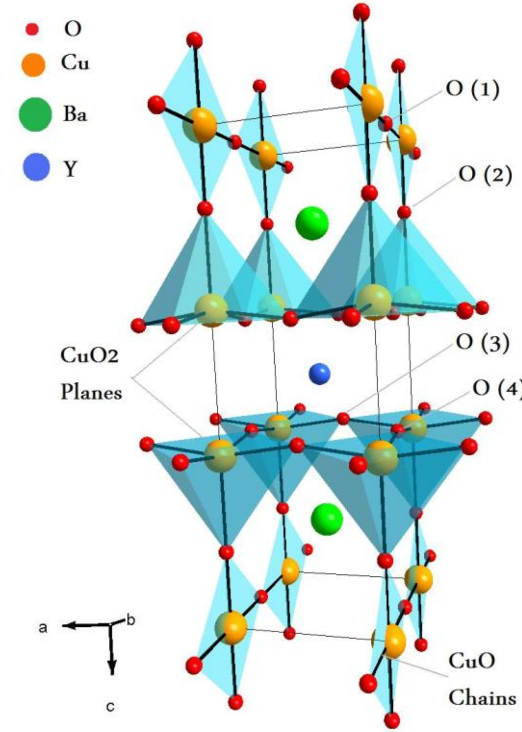
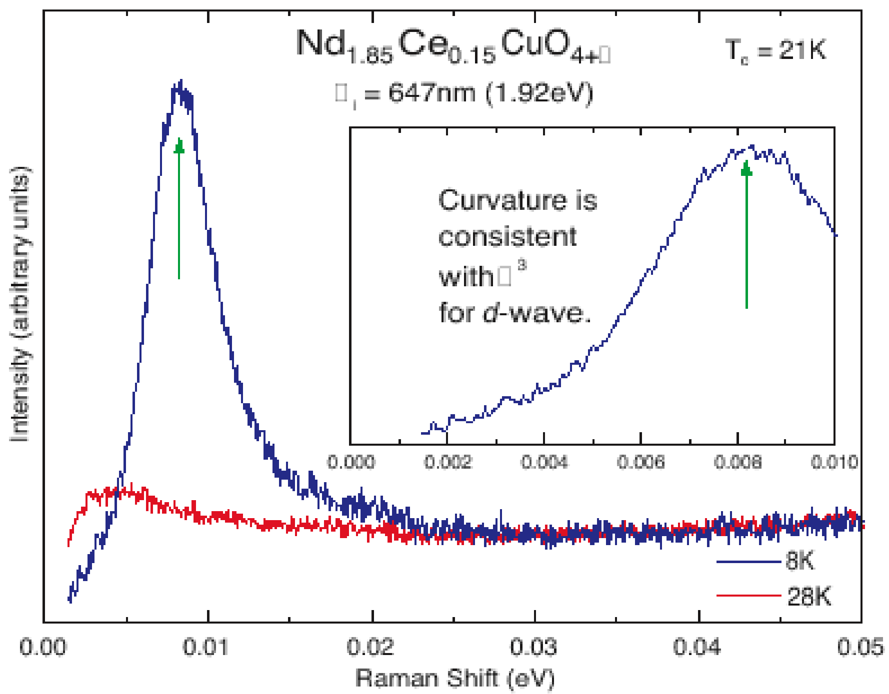




False color scanning SQUID image (red=high B, blue=low B) from John Kirtley, Chang Tsuei and Mark Ketchen of IBM showing the magnetic field in four split YBCO rings. Only the central ring is composed of three junctions, such that in a d-wave superconductor, the three crystal interfaces would lead to a net phase shift of 180 degrees around the ring. This leads to spontaneous currents creating a 1/2 quantum of flux in the ring, as observed.

J.R. Kirtley et al., Nature 373, 225 (1995).



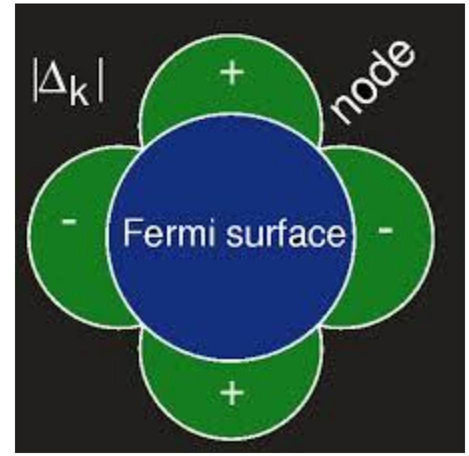


FIGURE 8

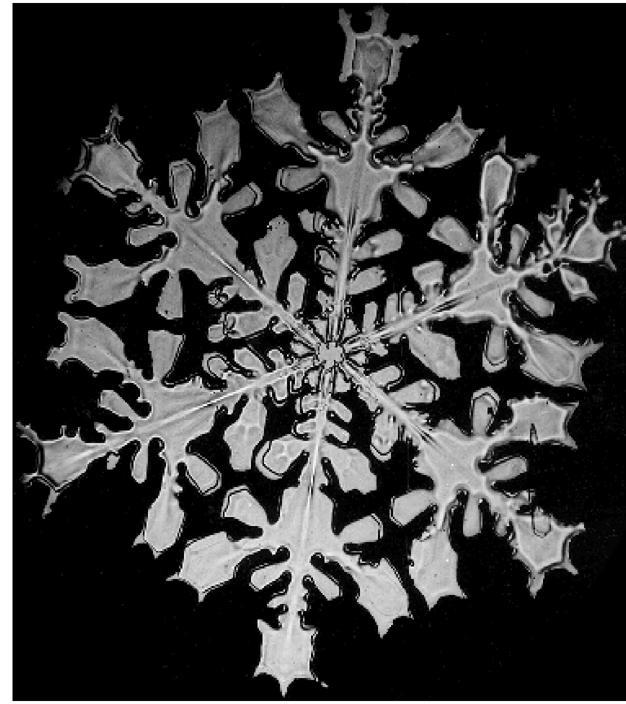
The Raman spectrum of Nd1.85Ce0.15CuO4+d measured above and below the T_c of 21K. The incident laser energy of 1.92 *e*V is defined as zero, and only the downward 'red' shift is plotted. The inset expands the low-frequency scale for the 8 K data to accentuate the curvature.

C. Kendziora

Symmetry

BROKEN SYMMETRY

- Phase transitions (critical behavior, 1st/2nd order)
- Rigidity (crystals don't bend, permanent M)
- Excitations (spectral changes, soft mode, order parameter)
- Defects (order parameter discontinuity)



What is the difference between phases ?

Density, correlations, symmetry

color, magnetization, charge state, etc

Symmetry breaking transitions (solid-liquid)

Liquid: High symmetry

Solid: Few symm. elements kept.

Non-breaking transitions (gas-liquid)

Density

Universality classes depending on

- d, dimension of space
- D, dimension of order parameter
- short/long range order

Some examples

Liquid:

Each positions in space occupied (t-average)

High symmetry (all rotations & translations)

Solid:

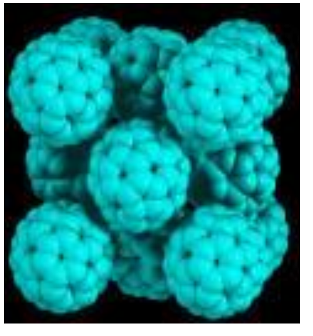
Few positions occupied

Low symmetry (few rotations & translations)

C_{60}:

High T: FCC

Low T: SC



Magnetic:

High T: No preferred spin direction

Low T : Alignment

Landau theory

ORDER PARAMETER:

Density, Position, Dipole moment, Magnetization, Occupation number, Orientation, …

FREE ENERGY

$F = E - T \cdot S$

E: energy, S: entropy ($S = k_b \ln(\# \text{ states})$)

LANDAU THEORY

- Free energy order parameter expansion
- Linearize near T_c
- Minimize free energy
- Mean field approach:
  correlations or fluctuations not included

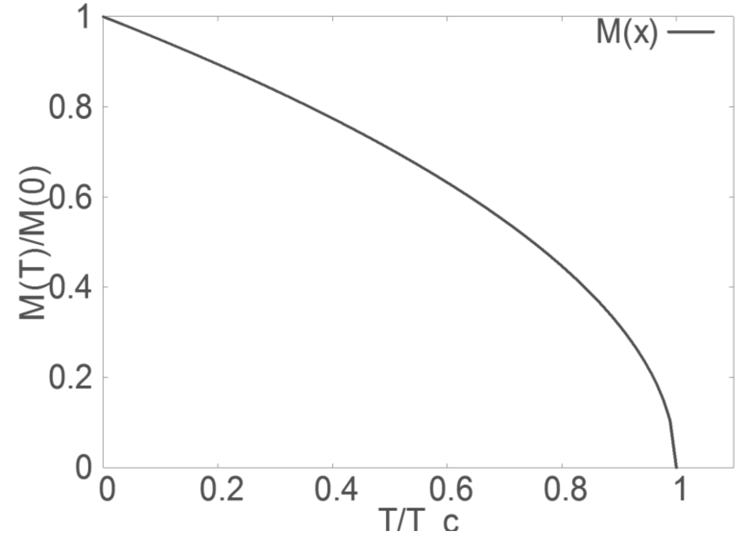
Example: Ferromagnet, order parameter: M

Landau theory

$$F(M) = F_0 + a_0(T - T_c)M^2 + bM^4$$

$$T < T_c : M = \pm\sqrt{\frac{a_0(T_c - T)}{2b}}$$

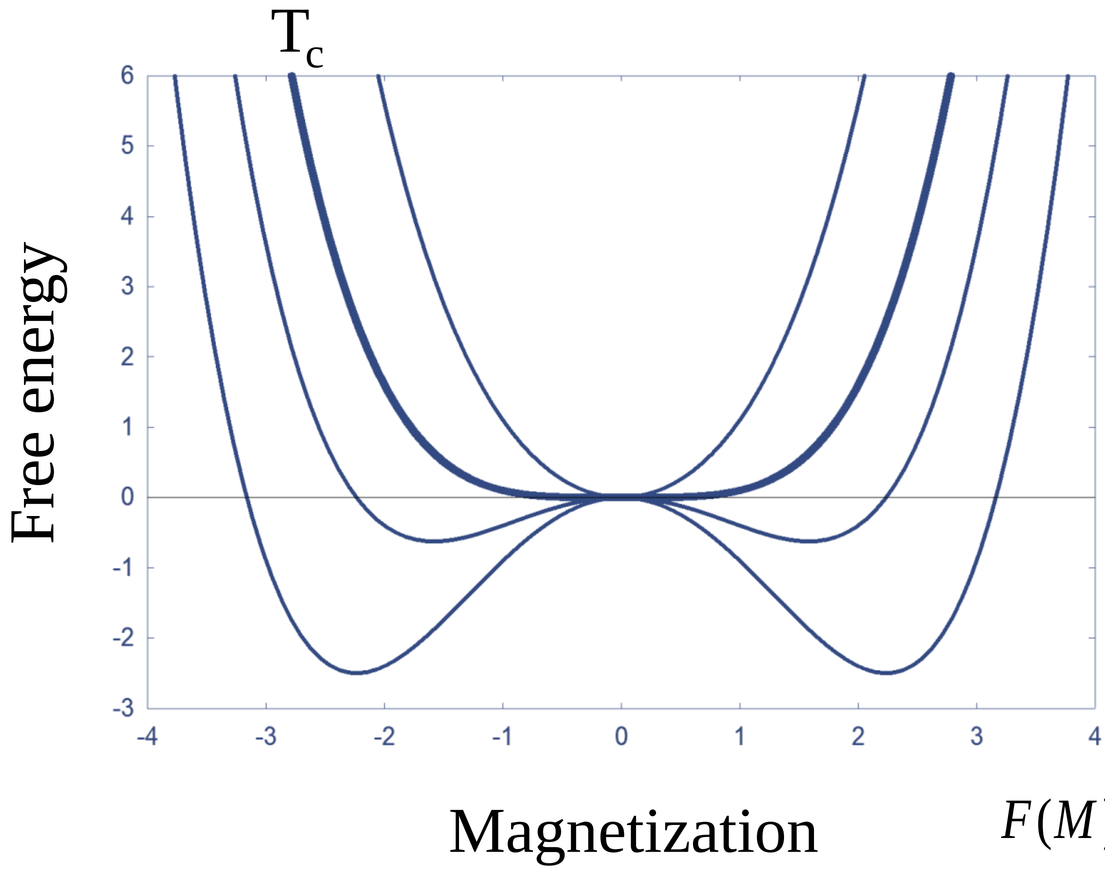
$$T_c = \frac{2b}{a_0} M_{\max}^2$$



Landau theory

Degenerate ground state

Two metastable states



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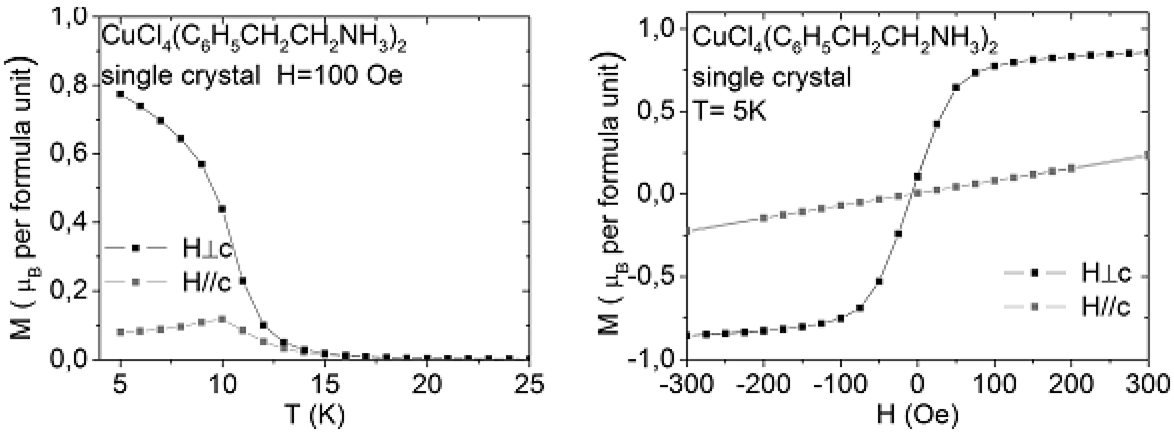


Figure 2. Magnetic susceptibility versus temperature (left) measured in a field of 100 Oe applied parallel and perpendicular to the *c*-axis, showing ferromagnetic ordering below 13 K. Magnetization versus applied magnetic field at 5 K (right).

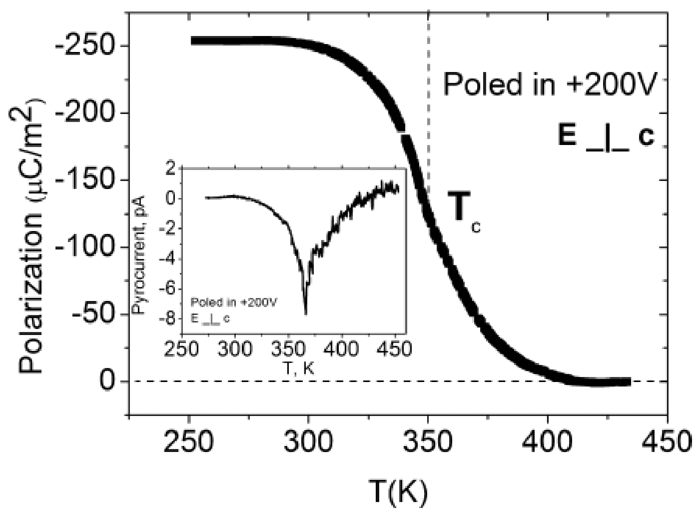
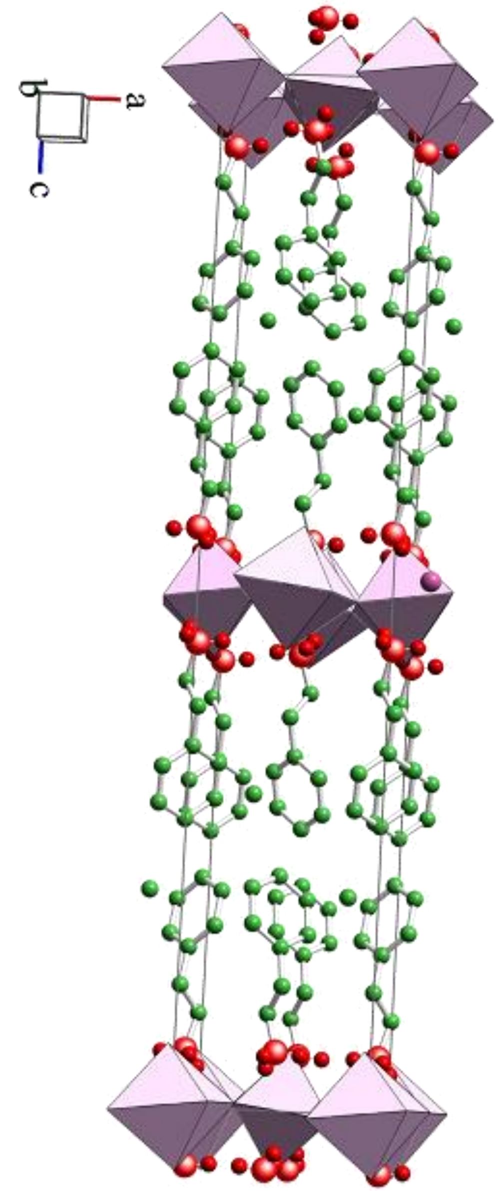


Figure 4. Temperature dependence of the pyroelectric current (inset) and the polarization perpendicular to the *c*-axis.



Polyakov et al. Chem. Mat. 2011

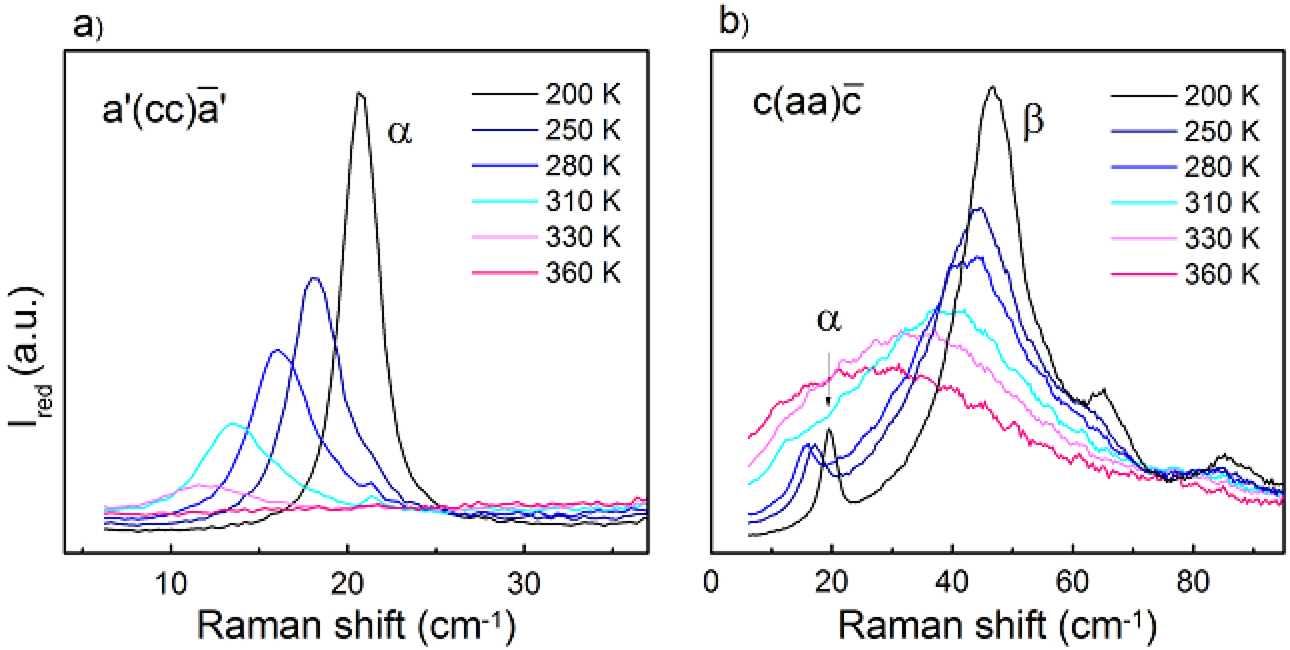


Figure 2.3: Temperature evolution of low energy phonons α, at $\sim$15 cm^{-1} ($a'(cc)\overline{a'}$, a), and β, at $\sim$40 cm^{-1} ($c(aa)\bar{c}$, b). On heating, the modes continuously soften and broaden. The intensity of α decreases to zero at T_C, indicating a change of symmetry in the system. In contrast, β is still Raman active above T_C. The measured intensity I_{meas} is scaled as I_{red} = I_{meas} /(1+n(ω,T).

Caretta et al. Phys. Rev. B, 2014