Part I
Cuprate (High Tc) Superconductors

\[ \text{La}_{2-x}\text{Sr}_x\text{CuO}_4 \quad \text{YBa}_2\text{Cu}_3\text{O}_7 \]

\[ \text{Tc} = 40^0 \quad \text{Tc} = 90^0 \]

Bednorz & Muller ‘86
Wu et.al. ‘87

What is the Mechanism? (Non BCS?)
Conduction planes

P.W. Anderson: "One Band Hubbard Model".
"Resonating Valence Bonds" Jan '87

Bangalore, India 1/87

\( \text{Cu}^{2+} \) S=1/2 d-hole \( \text{CuO}_2 \) planes

(\( \text{La, Sr} \))

LSCO

YBCO
Parents Compounds
Antiferromagnet Mott Insulators

Antiferromagnetism in La$_2$CuO$_4$ – $\gamma$


Research Laboratories, Exxon Research and Engineering Company, Annandale, New J
(Received 4 May 1987)

\[ T_N = \rho_s / \log(J / J_\perp) \]

Magnetic moment

1/correlation length

\[ e^{-\pi \rho_s / T} \]
Hole Doping

example: $La_{2-x}Sr_xCuO_4$

Non-Fermi liquid?

Optimally doped

Spin glass/stripes

Underdoped

Overdoped

Parent compound

Antiferromagnet

Superconducting phase

$La_{2}CuO_4$

$T^*$

$T_c$
Low energy spin fluctuations

A. Remnant local moments in underdoped superconducting phase.

\[(Ca_xLa_{1-x})(Ba_{1.75-x}La_{0.25+x})Cu_3O_y\]

Kanigel & Keren, Technion

B. Low energy antiferromagnetic spin fluctuations
The Antiferromagnetic resonance

$S(\mathbf{q}, \omega)$

neutron scattering

Very sharp paramagnons? Why: $\mathbf{q} = (\pi, \pi)$?
d-wave Superconductivity

Tricrystal SQUID experiment

 FIG. 1. Schematic diagram for the tricrystal (100) SrTiO$_3$ substrate, with four epitaxial YBa$_2$Cu$_3$O$_{7-\delta}$ rings.

ARPES

$\Delta_k \propto \cos(k_x) - \cos(k_y)$

Shen, Campuzano
Unconventional Superconductivity cont’d

Low Superfluid Density

Uemura’s Plot (89)

\[ \rho_c \propto \frac{1}{\lambda^2} \]

\[ \rho_c \approx T_c \propto x \]

unconventional relation

BCS (conventional)

\[ \rho_c \approx \hbar^2 n / m \approx \epsilon_F \gg T_c \]

weakly doping dependent
Unconventional Superconductivity cont’d

Short Coherence Length

Tunneling Microscopy

Howald et.al (Stanford)

Pan et.al (Berkeley)

Hoogenboom et.al

$\xi \approx 20 \text{ Å}$

Image of vortex cores at 6 T (field
Abnormal “Normal State”

“Fermi surface” above Tc: Fuzzy Notion

(0, π)

Studying the behavior of materials above the transition temperature (Tc) is crucial for understanding the properties of these substances. The diagram illustrates the transition from a non-Fermi liquid to a Fermi liquid, indicating the presence of a pseudogap regime. This concept is central in the study of high-temperature superconductors and other quantum materials.

The term “Fermi surface” refers to the shape of the boundary of the occupied electronic states in a solid. In the context of high-temperature superconductors, the Fermi surface can undergo significant changes near the transition temperature, leading to a fuzzy or less defined structure, as indicated by the term “Fuzzy Notion.”

The diagram shows the carrier concentration on the x-axis and temperature on the y-axis, with regions labeled as “non-Fermi liquid” regime and “Fermi liquid?” highlighting the uncertainty in the transition region.

The tight binding representation of the Fermi surface is also depicted, with specific points labeled (0, π) and (π, 0), which are critical for understanding the electronic structure of these materials.
Mysteries of ARPES

- Very diffuse spectral peaks
- Spin/charge separation?

Optimally doped
- Underdoped

Abnormal “Normal State” cont’d

Damaselli, Lu & Shen

Putative electron dispersion

“Pseudogap”
Weird Transport

More: Nernst Effect, Hall angle, (Ong)
Pseudogap temperature

Tunneling gap above $T_c$

ARPES gap above $T_c$

$T > T_c$

$T^*$

Opt. doped

Resistivity

Knight shift

Temperature ($K$)

Opt. doped

Underdoped $T^*$
"pseudogap phase"

What's going on?

- Gauge field fluctuations (Lee, Wen)?
- $Z_2$ symmetry breaking (Senthil, Fisher)?
- DDW (Nayak, Chakravarty, Laughlin)?
- Fluctuating stripes (Zachar, Emery, Kivelson)?
High Tc Phenomenology: Summary of Problems

IN NEED OF A MODEL & ITS SOLUTION

- Spin fluctuations
- "Hi Tc"
- D-wave superconductivity
- Low Superfluid Density
- Short Coherence Length
- Abnormal "Normal State"
- Mysteries of ARPES
- Weird Transport
- Pseudogap temperature
- T* versus doping

Non Fermi Liquid

unconventional SC
Part II: Microscopic Theory