CIFAR quantum material summer school 2010

Abstracts

High-Temperature Superconductivity in Iron-Based Materials

Johnpierre Paglione - University of Maryland

The discovery of high-temperature superconductivity in iron-based pnictide compounds has sparked a flurry of activity in the condensed matter physics community. With transition temperatures reaching close to 60 K, this exciting and rapidly expanding field of research has caused a surge of experimental and theoretical activity devoted to understanding this new family of materials. In this set of lectures I will provide an overview of the basic components of this family of materials, including structural, magnetic, electronic and other physical properties, as well as unusual thermodynamic and magnetic relations that appear to be universal. In addition, I will discuss our efforts in growth and characterization of single crystals of iron-pnictide compounds, including Ni- and Pt-doped 122 superconductor series, as well as our ongoing study of the relation between magnetism and crystallographic structure in the solid solution series (Ba,Sr,Ca)Fe2As2.

Introduction to cold atoms

André Marie Tremblay - Université de Sherbrooke

Cold atoms are really cold! Nano-kelvin. In this brief introduction to the topic, I will first describe the Physics of the various tricks that allow one to reach such low temperatures. It is also remarkable that the effective interaction between cold atoms can be controlled. I will show how. We will then be in a position to survey (superficially I must admit) a few of the achievements of the field, such as Bose-Einstein condensation, the crossover between Bose-Einstein and BCS-type superconductivity and the simulation of neutron stars. Remarkably, one can also trap cold atoms in optical lattices to build an analog computer that simulates important models for condensed matter, such as the Hubbard model. Cold atoms are also cool for all sorts of reasons.

An Introduction to Superconducting Properties in the Cuprates

Jules Carbotte - University of McMaster

I will begin by placing the high Tc cuprates within an historical context. A first qualitative understanding of their properties is provided by an extension of BCS theory to include d-wave gap symmetry. While this is satisfactory for optimum and overdoped cases, the underdoped regime presents many striking anomalous properties which require further generalization. I will illustrate this for the specific heat, penetration depth, Raman scattering and angular-resolved photoemission (ARPES). I will also show that in all four cases a recent theory of the approach to the Mott insulator by Yang, Rice and Zhang, based on a resonating valence bond spin liquid which explicitly involves a new energy scale, namely the pseudogap scale, goes a very long way in providing a good understanding of these properties previously considered anomalous.

The Nature of Superconductivity in the Cuprates

Elisabeth Nicol - University of Guelph

Conventional superconductors are understood, through BCS theory, to be a condensation of pairs of electrons into a macroscopic quantum state. The pairs form a spin singlet with a pair wavefunction or order parameter symmetry which is k-independent and known as s-wave. The pairing mechanism is the electron-phonon interaction. How much of this applies to the cuprates? What is different? How can we answer such questions? In this lecture, I will give a pedagogical review of the experimental evidence for pairing in the cuprates, including the determination of the spin state and the symmetry, orientation and sign change of the order parameter. Examples will be drawn from tunneling, specific heat and flux quantization experiments. Several beautiful experiments have been developed to answer these questions. The final puzzle about the pairing mechanism will be left for the next lecture by Jules Carbotte.

Mechanism for Pairing in the Cuprates

Jules Carbotte - University of McMaster

To deal with mechanism, one needs to go beyond BCS theory. For conventional metals for which the pairing mechanism is provided by the electron-phonon interaction, Eliashberg theory coupled with experimental data has provided a detailed picture of the underlying electron-phonon spectral density sometimes referred to as the glue function. Similar methods with essential modifications can be applied to the cuprates. Results based on optics, ARPES and tunneling will be reviewed. The electron-boson spectral density which is extracted shows a great deal of consistency between the various methods but there remains considerable controversy as to the correct interpretation of the resulting spectral functions. Is the glue phonons or spin fluctuations or both? I will ask the audience to decide.

What can STM/STS do?

Christian Lupien - Univerisité de Sherbrooke

Scanning tunneling microscopy and spectroscopy (STM/STS) are very powerful techniques. They provide access to atomic scale electronic structures. The allow the study of a single atomic defect on its environment . I will describe the technique, discuss some of its theoretical underpinning and proceed to explore some of the more interesting uses and results such as atomic control, mirages, inelastic tunneling ...

Scattering and Pairing in Cuprate Superconductors

Louis Taillefer - Université de Sherbrooke

The origin of the exceptionally strong superconductivity of cuprates remains a subject of debate after more than two decades of investigation. Here we follow a new lead: The onset temperature for superconductivity scales with the strength of the anomalous normal-state scattering that makes the resistivity linear in temperature. The same correlation between linear resistivity and T_c is found in organic superconductors, for which pairing is known to come from fluctuations of a nearby antiferromagnetic phase, and in pnictide superconductors, for which an antiferromagnetic scenario is also likely. In the cuprates, the question is whether the pseudogap phase plays the corresponding role, with its fluctuations responsible for pairing and scattering. We review recent studies that shed light on this phase – its boundary, its quantum critical point, and its broken symmetries. The emerging picture is that of a phase with spindensity-wave order and fluctuations, in broad analogy with organic, pnictide, and heavyfermion superconductors.

BCS-BES crossover and the unitary Fermi gas

Mohit Randeria - The Ohio State University

I will begin this pedagogical lecture with a brief discussion of two-body interactions between atoms, introducing the scattering length and Feshbach resonance. I will then then describe the many-body physics of the BCS-BEC crossover, starting with Leggett's mean field approach, the role of thermal and quantum fluctuations, recent QMC results, and pairing pseudogap. I will introduce the ideas of scale-invariance and universality in the unitary gas, the most strongly interacting Fermi system at the center of the BCS-BEC crossover. Along the way, I will briefly mention some of the key experiments in the field probing condensates, RF spectroscopy, vortices, and critical velocity

Exotic Quantum and Classical Ground States in Geometrically Frustrated Magnets

Bruce Gaulin - University of McMaster

Geometrical frustration results from the incompatibility of the local geometry in solids and certain interactions and anisotropies. Combinations such as triangular coordination and antiferromagnetism preclude the formation of a conventional long range ordered state at low temperatures and open up possibilities for exotic, disordered phases, which include spin liquid, spin ice, and spin glass states. Quantum fluctuations add another dimension for disorder, and therefore more possibilities for exotica when combined with geometrical frustration. Neutron scattering is a particularly important probe of magnetism in solids, and I will survey some recent results on the quasi-two-dimensional Shastry-Sutherland system $SrCu_2(BO_3)_2$, as well as three dimensional pyrochlore magnets $Ho_2Ti_2O_7$ and $Tb_2Ti_2O_7$ which display spin ice and (maybe!) quantum spin ice ground states.

Theoretical introduction of quantum frustration

Yong-Baek Kim - University of Toronto

Visualizing the Hidden Broken Symmetries in both Copper-oxide and Ferrous-pnictide High-Tc Superconductors

Seamus Davis - Cornell University

We will review the similarities between Copper-oxides and Ferrous-pnictides to address the question of whether strong electronic correlations are required for high-Tc superconductivity. We then explore those issues by visualizing the electronic structure directly at atomic scale using spectroscopic imaging STM, and by comparing the observed broken electronic symmetries of Copper-oxides and Ferrous-pnictides.