Introduction to Strongly Correlated Electrons in New Materials

2003 J. Phys. A: Math. Gen. 36

(http://iopscience.iop.org/0305-4470/36/35/000)

PREFACE

Introduction to Strongly Correlated Electrons in New Materials

The discovery of new natural and artificial materials has revolutionized condensed matter physics and our views on the role of correlations between electrons. Novel properties such as high-temperature superconductivity and colossal magnetoresistance discovered in these materials have overturned our conventional representations of condensed matter physics and pushed us to reconsider many well-established concepts. For example, we must treat the Coulomb interaction between electrons far beyond perturbation theory; we must recall long-forgotten ideas of electronic phase separation introduced originally by Nagaev in the 1960s; we must reconsider the role of electron–phonon and electron–magnon interactions, orbital degrees of freedom, the Rashba effect and many other aspects of condensed matter physics that are becoming increasingly important.

In many novel materials, such as the two-dimensional electron gas, the energy associated with the Coulomb interaction is typically of the order of (or even larger than) the kinetic energy of electrons or the Fermi energy. Therefore perturbation theory and associated renormalization group methods are not applicable to these situations and we may expect to find a novel state of matter associated with correlation effects. It is worth mentioning the known examples of these states proposed recently, such as marginal Fermi liquids, novel metal–insulator phase transitions in the two-dimensional electron gas associated with new metallic and insulating states, structured liquids, microscopic electronic phase separations, stripes, strings, polarons and others. The discussion of these states is now on the frontier of modern condensed matter physics and is partially covered in this special issue.

The demand to treat the Coulomb interaction properly has stimulated a development of many-body theory, which considers correlations as fully as possible. Strong correlations may play an important role in the dynamics of the electronic system. In a two-dimensional electron gas subjected to a transverse magnetic field, correlations associated with the Coulomb interaction transform normal electrons into composite fermions consisting of electrons with integer magnetic fluxes attached to them. The quasiparticle excitations, such as holes, arising in these systems may have fractional statistics (the so-called anyons).

Thus, a strong Coulomb interaction in novel materials may change the face of electrons, transforming their statistical properties. Such a phenomenon has already been established in quasi-one-dimensional materials, where an arbitrarily weak interaction transforms the Fermi liquid state associated with fermions into a bosonic Luttinger liquid. Will this effect happen in other types of novel materials? Future studies will answer this question. Many-body correlations may change the nature of the Coulomb interaction between electrons, leading to screening and over-screening effects. In the latter case the Coulomb repulsion between electrons will be transformed into a mutual attraction at certain distances. At some critical electron density, when the average distance between electrons is within this attractive region, this over-screening effect will obviously lead to the formation of electronic clusters and eventually to the formation of a clustered liquid or stripes. A similar effect may also arise through lattice distortions or electron–phonon interaction.

In many new materials there exists an insulating antiferromagnetic state, which is transformed under doping, eventually leading to a metallic state. The evolution of the antiferromagnetic state under doping has been a central issue in scientific discussions for decades. How the metal–insulator transition arises and the nature of the eventual metallic state are still not clear, although many interesting ideas are competing. The motion of a single doped hole leaves a trace behind, a piece of a single domain wall. Such pieces of domain walls arising from the motion of holes may be self-organized into a network of channels or a network of string and stripes. Such a network serves as a roadmap for hole motion and may be responsible for anomalies in physical properties of novel materials.

The Department of Physics at Loughborough University held an international workshop on Strongly Correlated Electrons in New Materials (SCENM02) which took place in conjunction with the annual meeting of the Condensed Matter Theory Group of the Institute of Physics on 14–17 December 2002. There were about 40 invited speakers and many poster presenters from a total of 12 countries, covering many aspects of the physics of colossal magnetoresistance manganites, high-temperature superconductors, two-dimensional electron gases displaying metal–insulator transition, electron–hole liquids, hydrogen at high pressures, semiconductor superlattices, magnetic multilayers and other novel materials. The abstract book is available on the physics department website at http://www.lboro.ac.uk/departments/ph/events/Abstracts.pdf. In this special issue we have collected papers covering these and many other important aspects of correlated electrons in new materials presented at the international workshop. We hope that this issue will stimulate further development in the physics of correlated electrons and lead to many new phenomena still waiting to be discovered.

Feo V Kusmartsev

Guest editor