Electronic Cooperation

The goal of the condensed-matter physicist is to understand the electronic, magnetic, and structural properties of matter—a daunting task, given that one 1 cm^3 of material contains around 10^{23} atoms. The standard model for metals, the Landau-Fermi liquid theory, allows the problem to be simplified greatly: Each atom's conduction electrons are free to move around, but instead of having to describe all the interactions separately, Coulomb repulsion between the electrons can be ignored through a process called renormalization. The transport properties of the system can then be effectively described as weak interactions between independent quasiparticles; that is, electrons and holes with a modified mass.

In strongly correlated electron systems, the interaction between neighboring, and often next-neighboring, electrons is so strong that they can no longer be considered separately. The collective behavior of the microscopic properties of the electrons are then scaled up to a macroscopic, strongly interacting ensemble, which is quite different from the free electron picture of the standard model. The challenge then is to understand and describe these complex interactions.

This special issue of *Science* looks at recent developments in some systems in which there is a strong correlation between the electrons. Tokura and Nagaosa (p. 462) review the role of orbital physics—the spin, charge, and orbital coupling between neighboring electrons and the lattice—in determining how magnetic systems organize themselves into various magnetically ordered phases.

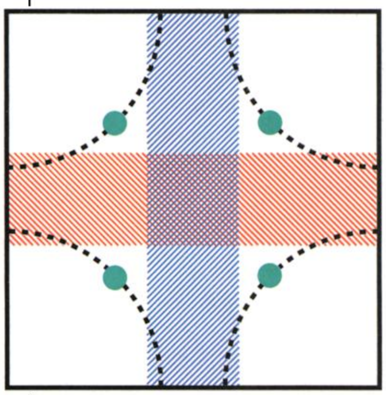
Superconductivity was first reported in doped perovskite materials at temperatures well above those seen in conventional superconductors 14 years ago, and many different theories have been proposed to explain their behavior. With the growing body of experimental evidence, some models have naturally floundered while others have shown hardy resilience. Orenstein and Millis (p. 468) review recent experimental and theoretical developments that have led us to our present understanding of these materials.

With strong correlation, even a small change in an external parameter can have a dramatic effect on the system's ground state, changing the electronic and/or magnetic phase of the material from one ground state to another. This phase transition is a quantum-mechanical effect, and can therefore be induced at zero temperature, with the point separating the two ground states a quantum-critical point. Sachdev (p. 475) describes the dynamics of low-dimensional, quantum-critical systems and discusses how these may describe the essential features of high-transition-temperature (high-T_c) materials.

In an accompanying Viewpoint, Anderson (p. 480) introduces the ideas of Laughlin and Pines about "quantum protectorates," in which the robustness of some systems to defects suggests that there must be a many-bodied, quantum mechanical cooperative effect that drives the ordering of a system into a particular state. Anderson argues that high-T_c cuprates are such a quantum protectorate.

The field is also seeing the emergence of a coordinated effort to understand the properties of these materials. The Institute for Correlated Electron Technology in Tsukuba, Japan, opens this month. The Newton Institute at Cambridge University, in the United Kingdom, is presently hosting a 6-month program of workshops and seminars in collaboration with the European Science Foundation's program on Fermi-Liquid Instabilities in Correlated Metals (FERLIN). And at Boulder, Colorado, in the United States, an annual summer school on correlated electron systems will start this July, with funding from the National Science Foundation. Correlated electron systems require the combined efforts of experimental innovation, theoretical rigor, and materials science to unravel the complexities of these systems. The foundations of this field are now beginning to take shape.

–IAN S. OSBORNE



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