Electronic Correlations in Solids

May 14 2007

The word “correlation” means “mutual dependence” or “interrelation” and the term “electronic correlation” summarises all effects arising from the mutual repulsion of negatively charged electrons. More precisely, it refers to how this repulsion influences the spatial and dynamical motion of the electrons. The concept can be likened to the behaviour of people in a crowded market place: people and electrons have to avoid each other so as not to bump into one other, something that greatly influences their motion.

At the EPL symposium, “Physics In Our Times” held on May, 9 at the Fondation Del Duca de l’Institut de France, Paris Dieter Vollhardt, professor of theoretical condensed matter physics at the University of Augsburg in Germany explained his team’s new theoretical method, dynamical mean-field theory, which can describe the whole range of materials from weakly interacting and strongly localised models within one framework.

Electronic correlations in solids may lead to spectacular effects, such as metal-to-insulator transitions, high-temperature superconductivity, and colossal magneto-resistance. These are not only interesting for fundamental research but also for technological applications in areas such as sensors, magnetic storage, switches and cables.

For technology to progress we need theoretical techniques that can help us understand and predict the behaviour of new materials. There are many examples of materials that show great promise for technological applications but which cannot be described by conventional theories.

For example, high-temperature superconducting materials and some high-density magnetic storage materials are still not well understood. This is because such theories either treat each electron in a material as weakly interacting with other electrons, or assume that electron-electron repulsion dominates, causing the electrons to be strongly localised to individual atoms.

Together with colleagues Antoine Georges, Walter Metzner and Gabriel Kotliar, one of Prof. Vollhardt's most recent successes has been to develop and apply a new theoretical method called dynamical mean-field theory. In combination with other techniques, this theory can, in principle, describe the whole range of materials from weakly interacting and strongly localised models within one framework. One of the steps in the theory imagines the material in a higher dimension space and then approximates an infinite number of dimensions.

Although this assumption sounds radical, it significantly simplifies the equations and leads to accurate predictions. Indeed, this theory - for which the physicists jointly received the Europhysics Prize in 2006 - has already been successfully applied to many correlated electron materials, in particular to transition metals and their oxides.

Prof. Vollhardt believes that future directions of research in his field will include such diverse topics as investigating electronic correlations in inhomogeneous materials and interfaces, complex ordering phenomena on frustrated structures, non-equilibrium physics and correlation effects in biological systems.

Source: Institute of Physics

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