Quantum Phase Transition in Electron-doped High-Temperature Superconductors

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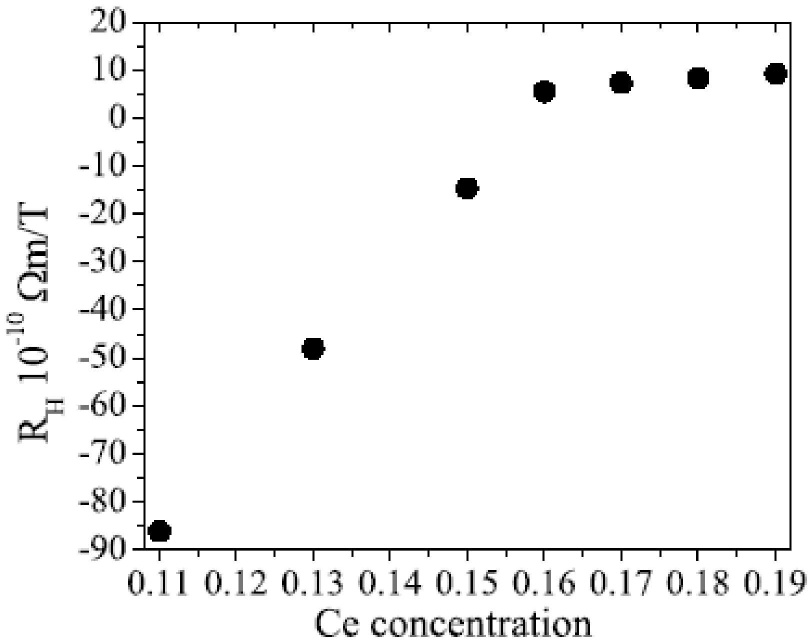
The origin of high-temperature superconductivity is one of the major unsolved problems in condensed matter physics. In one theoretical model the superconductivity competes with another phase ordering, which causes a T=0 transition between the two phases as a function of some control parameter, i.e. a quantum phase transition (QPT). Quantum fluctuations associated with this transition can affect many physical properties (including T_c) at finite temperatures. In our research we have found the first direct evidence that a QPT occurs in the electron-doped high T_c system $Pr_{2-x}Ce_xCuO_4$ (PCCO) as a function of doping (x). The figure shows an abrupt change in the Hall coefficient at a critical doping (x≈0.165). Other transport properties also show a dramatic change at that doping (1). The QPT occurs at a doping within the "superconducting dome", which suggests a strong connection between the superconductivity and the competing phase (most likely antiferromagnetism). Further work will be necessary to determine if a QPT is linked to superconductivity in all high-T_c superconductors.

1. Y. Dagan *et al.* Phys. Rev. Lett. **92**, 167001 (2004)



The Hall coefficient R_H at T=0.35K as a function of cerium doping, x. The abrupt change near x=0.165 is a strong evidence for a quantum phase transition.

The cause of high-temperature superconductivity (HTSC), which occurs just above the boiling point of liquid nitrogen (T=78K), is one of the major unsolved problems of condensed matter physics. If this problem can be solved then it is likely that even higher temperature superconductors might be found, perhaps working above room temperature (T=300K). This would be of great technological and economic importance. Many theories have been proposed to explain HTSC but there is no unambiguous experimental proof for any of them. In our research we have found experimental evidence for a quantum phase transition in one type of HTSC material. A quantum phase transition is a transition between two phases (e.g., between a ferromagnet and a superconductor) that occurs at T=0K. The existence of a quantum phase transition is a crucial feature of one of the leading theories for HTSC. Thus, our work gives strong support for this theory. However, more research is still required for an unambiguous proof of this theory and for the discovery of room temperature superconductivity.

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Education

Two undergraduates (Chris Hill and Matt Barr), one graduate student (Mumtaz Qazilbash) and one postdoc (Yoram Dagan) contributed to this work. Chris Hill has graduated and will be applying to graduate school next year. Matt Barr is a senior and will apply to graduate school this year. Mumtaz Qazilbash received his Ph.D. in 2004 and is presently searching for a postdoc position in the USA.

Societal Impact

An understanding of the mechanism causing high temperature superconductivity may enable the development of new materials that are superconducting above room temperature. This would have a large impact on electronic devices and electricity generation and distribution.