Using magnetic fields to understand high-temperature superconductivity
26 March 2015

Los Alamos National Laboratory scientist Brad Ramshaw conducts an experiment at the Pulsed Field Facility of the National High Magnetic Field Lab, exposing high-temperature superconductors to very high magnetic fields, changing the temperature at which the materials become perfectly conducting and revealing unique properties of these substances. Credit: Los Alamos National Laboratory

High-temperature superconductors have been a thriving field of research for almost 30 years, not just because they can conduct electricity with no losses—one hundred degrees higher than any other material—but also because they represent a very difficult and interesting "correlated-electron" physics problem in their own right.

The theory of traditional, low-temperature superconductors was constructed by Bardeen, Cooper, and Schrieffer in 1957, winning them the Nobel prize; this theory (known as the BCS theory) had a far-reaching impact, laying the foundation for the Higgs mechanism in particle physics, and it represents one of the greatest triumphs of 20th century physics.

On the other hand, high-temperature superconductors, such as yttrium barium copper oxide (YBa2Cu3O6+x), cannot be explained with...
BCS theory, and so researchers need a new theory for these materials. One particularly interesting aspect of high-temperature superconductors, such as YBa2Cu3O6+x, is that one can change the superconducting transition temperature (Tc, where the material becomes perfectly conducting) by "doping" it, i.e., changing the number of electrons that participate in superconductivity.

The Los Alamos team's research in the 100-T magnet found that if one dopes YBa2Cu3O6+x to the point where Tc is highest ("optimal doping"), the electrons become very heavy and move around in a correlated way.

"This tells us that the electrons are interacting very strongly when the material is an optimal superconductor," said Ramshaw. "This is a vital piece of information for building the next theory of superconductivity."

"An outstanding problem in the field of high-transition-temperature (high-Tc) superconductivity has been the issue as to whether a quantum critical point—a special doping value where quantum fluctuations lead to strong electron-electron interactions—is driving the remarkably high Tc's in these materials," he said.

Proof of its existence has previously not been found due to the robust nature of the superconductivity in the copper oxide materials, yet if scientists can show that there is a quantum critical point, it would constitute a significant milestone toward resolving the superconducting pairing mechanism, Ramshaw explained.

"Assembling the pieces of this complex superconductivity puzzle is a daunting task that has involved scientists from around the world for decades," said Charles H. Mielke, NHMFL-Pulsed Field Facility director at Los Alamos. "Though the puzzle is unfinished, this essential piece links unquestionable experimental results to fundamental condensed matter physics—a connection made possible by an exceptional team, strong partner support and unsurpassed capabilities."

In a paper this week in the journal Science, the team addresses this longstanding problem by measuring magnetic quantum oscillations as a function of hole doping in very strong magnetic fields in excess of 90 tesla.

By accessing a very broad range of dopings, the authors show that there is a strong enhancement of the effective mass at optimal doping. A strong enhancement of the effective mass is the signature of increasing electron interaction strength, and the signature of a quantum critical point. The broken symmetry responsible for this point has yet to be pinned down, although a connection with charge ordering appears to be likely, Ramshaw notes.

More information: "Quasiparticle mass enhancement approaching optimal doping in a high-Tc superconductor"

Provided by Los Alamos National Laboratory