Tracking down nano-size current loops using polarized neutrons

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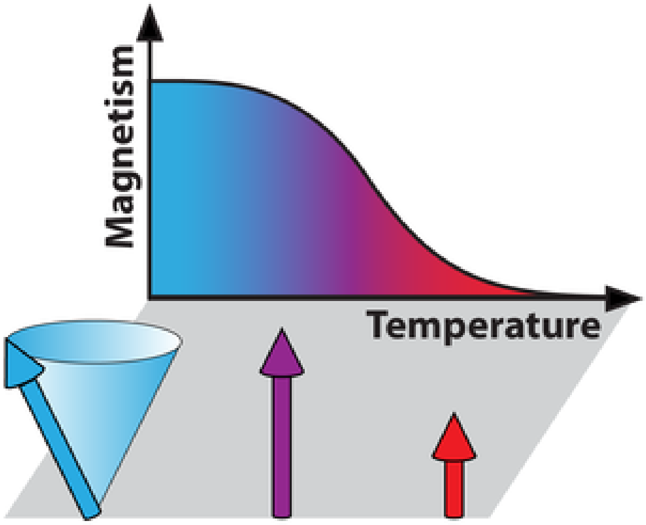

Determining the origin of high-temperature superconductivity is probably the single most important challenge faced today by solid-state physicists. This despite 30 years of extensive research efforts. High temperature superconductors are actually rather bad electrical conductors at room temperature. If they are cooled, they form a so-called "pseudogap phase" where electricity is conducted in a rather peculiar manner, with preferential directions. When cooled further, to temperatures easily reached using cheap and abundant liquid nitrogen, the electrical resistivity in the whole material falls to zero and the material becomes a superconductor.

There is a general consensus that the essential keys to unraveling superconductivity may be found in the pseudogap phase. The properties of this phase has been discussed in more than 100 000 scientific publications. A recent idea was put forward suggesting that small electrical current loops, travelling around tiny circuits of only three atoms each, are formed in the pseudogap phase and it is these current loops that give rise to the properties of the phase. The task for the experimentalist consists in tracking down features predicted by these intriguing models.

A high-school student attempting to determine the presence of a loop current might check for the magnetic field that the current must generate. The difficulty here is that the fields, and the size of the loop that generate them, are tiny. Measuring such fields is, however, exactly what neutrons are extremely good at. Like tiny compass needles, they explore the magnetic field on length scales going down to atomic dimensions. And indeed neutron diffraction measurements could show the presence of magnetic moments within the pseudogap state of high-temperature superconductors (B. Fauqué et al Physical Review Letters 2006). However, after the first positive evidence many questions remained concerning this magnetic order. What about the exact direction of the moments? If the moments are created by Loop Currents then they should be perpendicular to the areas enclosed by the loops. How big are the loops? Is there any correlation between the loops? What is the dependence on materials properties like disorder?

A team of researchers from the Laboratoire Léon Brillouin and ILL has now given a set of surprisingly complete answers to these important questions (Nature Communications 2015). Magnetic signals more than 3 orders of magnitude weaker than the dominant nuclear part could be measured on the instruments 4F1 (LLB) and D7 (ILL) using the method of polarized neutron diffraction. The measurements allowed not only to determine with precision the magnitude of the tiny moments but equally their direction and the extent to which they are correlated in space, Furthermore, they were able to follow all of this as a function of temperature. These results form an eagerly awaited stringent set of conditions on any model that tries to describe the physics of the pseudo-gap phase. They in particular provide us with a way better idea of the form that the postulated current loops may take.

These excellent results demonstrate the unique capabilities offered by polarized neutron scattering. They justify the prominent place that polarization plays in the ILL's modernization programme Endurance of which D7 is part. Once upgraded the new D7 will allow for a completely new quality of this kind of experiment.

More information: "Intra-unit-cell magnetic correlations near optimal doping in $YBa_2Cu_3O_{6.85}$." *Nature Communications* 6, Article number: 7705 DOI: 10.1038/ncomms8705

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