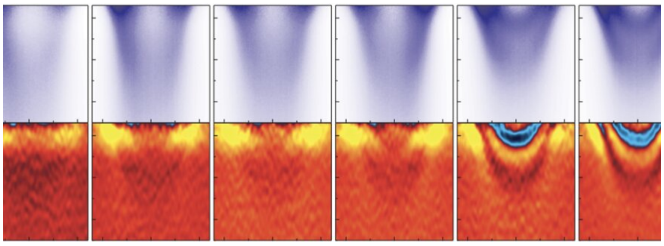
# Superconductivity theory under attack

29 November 2019, by Bruno Van Wayenburg



Credit: Leiden University

Measurements on a superconducting material show an abrupt transition between a normal metal and a "strange" metal. The really strange thing, however, is that this abruptness disappears when the temperature falls. "We don't have any theoretical machinery for this," says theoretical physicist Jan Zaanen, coauthor of a *Science* article, "this is something that only a quantum computer can calculate."

Superconductors have provided surprises for over a century. In 1911, Heike Kamerlingh Onnes in Leiden discovered that mercury will conduct electrical current without any resistance at 4.2 Kelvin (4.5 degrees above absolute zero, or -273.15 degrees Celsius).

The phenomenon was explained only in 1957, and in 1986, a new type of superconductivity was discovered in complex copper oxides. This high-temperature superconductivity even survives at balmy temperatures of 92 Kelvin.

If it could be extended toward room temperature, superconductivity would mean unprecedented technology applications, but so far, the phenomenon has dodged a complete explanation. This not for a lack of effort by physicists such as Jan Zaanen, co-author and house theoretician with a group of Stanford experimental physicists who published an article in *Science*.

## Strange Metal

"I suppose it will make an impression," Zaanen writes about the publication. "Even for *Science* standards, this is not a run-of-the-mill article."

Since 1957, it has been known that superconductivity is caused by electrons forming pairs, which can sail through a crystal unhindered. This only happens below a critical temperature, Tc. However, even above this temperature, high Tc-superconductors exhibit strange behavior. In this strange metal phase, electrons don't behave like largely independent particles, as they do in normal metals, but like collectives.

Sudi Chen and colleagues at Stanford University investigated the transition between normal and strange in the superconducting copper oxide Bi(2212), using the ARPES (Angle-Resolved Photoemission Spectroscopy) technique. In ARPES, intense UV light is aimed at the sample, carrying energy that can eject electrons from it. The energy and speed of such cast-out electrons betray the behavior of electrons within the sample.

## Boiling Water

Apart from the temperature, the doping parameter is crucial. By tweaking the exact chemistry of the material, the number of freely moving charge carriers can be varied, which influences the properties.

At relatively warm temperatures, just above the highest possible Tc, the transition between the normal and the strange metal takes place between a doping percentage of 19 and 20 percent. At this transition, Chen and colleagues show the energy distribution of the electrons changes abruptly. Such discontinuous transitions are common in physics. An example is boiling water: at the transition from liquid water into steam, the density makes a giant discontinuous jump.

But the odd thing is that in this case, the discontinuity disappears when the temperature is lowered into the superconducting realm: the abruptness smooths out, and the properties suddenly change continuously.

### Dustbin

"So which is the case? According to a general physical principle, discontinuous behavior at high temperatures would have to translate into a discontinuous transition at low temperatures," says Zaanen. "The fact that this doesn't happen is at odds with any calculation up to now. The complete theoretical machinery is failing us.'

This also means that the so-called quantum critical transition, a favorite among the explanations, can be chucked into the dustbin because it predicts a continuous behavior of the ARPES-signal when the doping varies.

According to Zaanen, all of this is a clear indication that the strange metal phase is a consequence of quantum entanglement. This is the entanglement of quantum mechanical properties of particles which is also an essential ingredient for quantum computers.

### Quantum computers

Hence, Zaanen thinks, this behavior can be calculated satisfactorily only using a quantum computer. Even more than breaking security codes or calculating molecules, the strange metal is the ideal test case, where quantum computers can show their advantages with respect to regular computers.

The moral of the story, says Zaanen, is that the origin of superconductivity itself is increasingly a side issue. "After thirty years, evidence is mounting that high Tc -superconductivity is pointing toward a radically new form of matter, which is governed by the consequences of quantum entanglement in the macroscopic world."

**More information:** Su-Di Chen et al. Incoherent strange metal sharply bounded by a critical doping in Bi2212, *Science* (2019). DOI: 10.1126/science.aaw8850

Provided by Leiden University

APA citation: Superconductivity theory under attack (2019, November 29) retrieved 8 May 2021 from https://phys.org/news/2019-11-superconductivity-theory.html