Unified superconductors: A single theoretical model of superconductivity for many materials

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Superconductors are promising materials, with applications ranging from medicine to transport. Unfortunately, though, their use is for the time being limited to the very low temperatures (close to absolute zero) necessary for superconductivity to occur. Some materials, however, could be improved so as to obtain higher and energetically less “costly” critical temperatures. A team of researchers coordinated by SISSA investigated a class of conductors at high critical temperature, adding insight into the physics of these phenomena.

Leading-edge imaging and medical diagnostics, but also magnetic levitation trains: these are examples of technology relying on "superconductors". Superconductors are materials in which electrons flow without dissipation and which have very special properties such as expelling all magnetic fields. The physics underlying the phenomenon has only been explained for low-temperature superconductors, those exhibiting their properties at temperatures close to absolute zero.

The so-called high-temperature superconductors remain one of the major mysteries of the physics of matter, and scientists have recently been redoubling their efforts to understand the phenomenon and improve its yield. Among them are Massimo Capone and co-workers who have just published a paper in Physical Review Letters. The study was authored by Capone, ERC SUPERBAD project leader, Gianluca Giovannetti of CNR-IOM and SISSA, and Luca de' Medici of the European Synchrotron Radiation Facility in Grenoble.

"To be able to function, classical superconductors have to reach extremely low temperatures, very close to absolute zero. This makes their use very costly and uneconomical", explains Capone. "Almost 30 years ago scientists discovered some classes of materials that worked at temperatures that were substantially higher though still quite low – in the order of 200°C below zero. Several types of materials exist, with different characteristics and critical temperatures", continues Capone, "the most investigated family is based on copper, while another, slightly less efficient one is based on iron – and that's precisely the family we set out to investigate".

As Capone explains, there's no agreement on how the phenomenon originates in the different materials, and according to some scientists the explanations could be different for the various families. "We carried out a study based on theory and simulations that demonstrated that this is not the case: the theoretical explanation for copper and iron superconductors could be the same, and could even apply to other materials like carbon, for example carbon fullerenes, which have been
extensively studied at SISSA. In practice, there
could be a unified theory for these
superconductors”.

In their new paper, Capone and co-workers
demonstrate that the explanation is the same, and
they put forward some hypotheses as to the
theoretical framework for this explanation,
hypotheses which paradoxically liken
superconductivity and very high impedance
phenomena. "Clearly, we haven't yet explained the
physics of these superconductors, or we would
have won the Nobel prize”, he jokes. "However,
demonstrating that there is a single theoretical
framework explaining these phenomena could be
an important step forward”.

More information: Selective Mott Physics as a
Key to Iron Superconductors, Phys. Rev. Lett. 112,
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ABSTRACT
We show that electron- and hole-doped BaFe2As2
are strongly influenced by a Mott insulator that
would be realized for half-filled conduction bands.
Experiments show that weakly and strongly
correlated conduction electrons coexist in much of
the phase diagram, a differentiation which
increases with hole doping. This selective Mottness
is caused by the Hund’s coupling effect of
decoupling the charge excitations in different
orbitals. Each orbital then behaves as a single-
bond doped Mott insulator, where the correlation
degree mainly depends on how doped is each
orbital from half filling. Our scenario reconciles
contrasting evidences on the electronic correlation
strength, implies a strong asymmetry between hole
and electron doping, and establishes a deep
connection with the cuprates.

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