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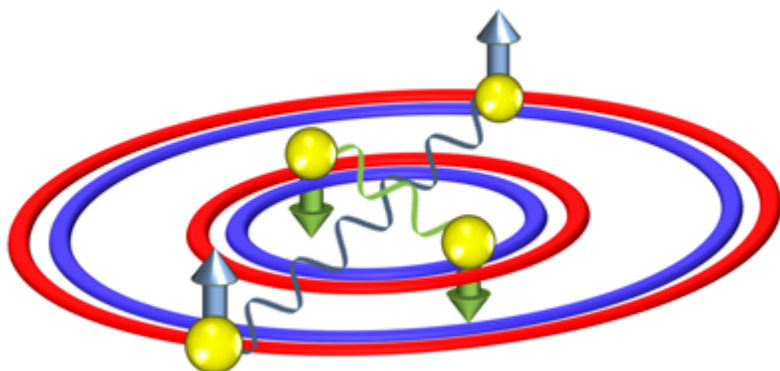
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## School of Physical Sciences

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# SPS Research into superconductivity highlighted in Physical Review Letters

Posted on 12th July 2016



Research conducted by Dr Jorge Quintanilla as part of an international collaboration has been chosen as an Editors' Suggestion on the [Physical Review Letters website](#) <sup>[1]</sup>. The full article can be accessed [here](#) <sup>[2]</sup>. Below is a summary from Dr Quintanilla about what the research was and how it is useful.

### A new form of superconductivity

Superconductors are remarkable materials which, when cooled below their "critical temperature", lose all electrical resistance. In addition, the electrons in a superconducting material all act in unison, which is called "quantum coherence". This leads to many special properties that are not displayed by ordinary matter, such as so-called "quantum levitation". There are many uses of superconductors, of which perhaps the most familiar are the Magnetic Resonance Imaging (MRI) machines found in all major hospitals. More futuristic applications currently in advanced stage of development include levitating trains capable of speeds exceeding 600 km/h and ultra-fast supercomputers. However, although the phenomenon was discovered more than a century ago and the theory that explains it dates from the 1950's, there are many so-called "unconventional superconductors" which do not fit that theory and are currently poorly understood. Now, in a paper written in collaboration with colleagues in Zhejiang University (Hangzhou, China), at the Max Planck Institute for Chemical Physics of Solids (Dresden, Germany) and at the University of Bristol, I have proposed a new class of unconventional superconductors.

At the heart of superconductivity is the phenomenon of "Cooper pairing". A Cooper pair is a pair of electrons that bind together. It is these Cooper pairs that act coherently as a single entity in a superconductor. Although an individual electron has electric charge and also a magnetic dipole moment (something like a tiny bar magnet), in the conventional theory of superconductivity the electrons in a Cooper pair combine their magnetic moments so that they cancel each other. Thus conventional superconductivity is antagonistic to magnetism: the superconducting state is not magnetic and magnets are not superconducting. Another important feature of the conventional theory is the energy gap: it takes a minimum amount of energy to unbind an electron from its partner. Many

unconventional superconductors feature Cooper pairs that have a magnetic moment, and usually this is associated with a lack of an energy gap: depending on the direction of travel of the electron, the energy necessary to kick it out of its Cooper pair may be quite low, or even zero. The reason for this is that in order to have a net magnetic moment the "wave function" of the two electrons, which is a quantity that describes their relative motion and depends on the direction and speed of motion of the electrons relative to each other, has to change sign as we vary the direction. For that to happen it has to vanish somewhere, and that leads to a vanishing energy.

Enter LaNiC<sub>2</sub> and LaNiGa<sub>2</sub>: these are superconductors whose Cooper pairs do have magnetic moments and where, moreover, these magnetic moments spontaneously align at the critical temperature, forming a magnetic superconducting state. On the other hand, in LaNiC<sub>2</sub> there seems to be a fully-formed energy gap protecting the Cooper pairs - just like in a conventional superconductor. In fact experiments showed that there are two distinct values of the gap in this system, but until now the reason was not understood. In the new paper, new experimental data on LaNiGa<sub>2</sub> obtained in Zhejiang and MPI Dresden is presented. Again, a fully-formed gap is found, and once more it has two distinct values. In the same paper, together with fellow theorist Annett (Bristol), I offer a novel explanation: the two values of the gap correspond to electrons whose magnetic moments point in one direction and its opposite, respectively. The magnetic nature of the superconducting state of these unusual superconductors means that electrons with differently-oriented magnetic moments behave differently, which makes the two different values of the gap possible. Moreover, this type of pairing involves two atomic "orbitals" so the wave function may change sign from one orbital to the other, without requiring a change of sign as a function of the electron's direction of motion - hence explaining the full energy gap.

The full energy gap in these materials may make them usable in applications where the less-protected Cooper pairs of other unconventional superconductors are a problem, for example when the atoms in the material are disordered. And the combination of quantum coherence and magnetism in the same system may offer new opportunities for example in information processing.

#### “Two-Gap Superconductivity in LaNiGa<sub>2</sub> with Nonunitary Triplet Pairing and Even Parity Gap Symmetry”

Z. F. Weng, J. L. Zhang, M. Smidman, T. Shang, J. Quintanilla, J. F. Annett, M. Nicklas, G. M. Pang, L. Jiao, W. B. Jiang, Y. Chen, F. Steglich, and H. Q. Yuan  
*Phys. Rev. Lett.* **117**, 027001 – Published 7 July 2016

DOI: <http://dx.doi.org/10.1103/PhysRevLett.117.027001> <sup>[3]</sup>

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#### Links

1. <http://prl.aps.org/>
2. <http://journals.aps.org/prl/abstract/10.1103/PhysRevLett.117.027001>
3. <http://dx.doi.org/10.1103/PhysRevLett.117.027001>

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