



Trends in
**Applied Sciences
Research**

ISSN 1819-3579



Academic
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Electron 'Pairing': Triplet Superconductivity Proven Experimentally for First Time

Researchers at Ruhr-Universität Bochum (RUB), Christian-Albrechts-Universität zu Kiel (CAU) and Santa Barbara (USA) have made the first experimental breakthrough in quantum physics: Their studies on the "pairing behavior" of electrons have proven for the first time the existence of electron pairs, so-called Cooper pairs, with parallel spin direction. Cooper pairs cause superconductivity -- this is a particular state of material, in which the electrical resistance disappears. Until now the existence of triplet Cooper pairs has only been predicted theoretically. The results achieved by this research team headed by Prof. Kurt Westerholt and Prof. Hartmut Zabel (Department of Physics and Astronomy at RUB) could contribute to new, power saving components in the future.

The researchers reported on their findings in the American Physical Society's journal *Physical Review B*.

If, it were possible to eliminate electrical resistance, we could reduce our electric bill significantly and make a significant contribution to solving the energy problem, if it were not for a few other problems. Many metals as well as oxides demonstrate a superconductive state, however only at low temperatures. The superconductive effect results from Cooper pairs that migrate through the metal together "without resistance." The electrons in each Cooper pair are arranged so that their composite angular momentum is zero. Each electron has an angular momentum, the so-called spin, with a value of $1/2$. When one electron spins counter-clockwise ($-1/2$) and the other clockwise ($+1/2$), the total of the two spin values is zero. This effect, found only in superconductors, is called the singlet state.

If, a superconductor is brought into contact with a ferromagnetic material, the Cooper pairs are broken up along the shortest path and the superconductor becomes a normal conductor. Cooper pairs cannot continue to exist in a singlet state in a ferromagnetic material. Researches at RUB (Prof. Konstantin Efetov, Solid State Physics) among others have, however, theoretically predicted a new type of Cooper pair, which has a better chance of survival in ferromagnetic materials. In such Cooper pairs the electrons spin in parallel with one another so that they have a finite spin with a value of 1. Since this angular momentum can have three orientations in space, it is also known as the triplet state. "Obviously there can also be only one certain, small fraction of Cooper pairs in a triplet state, which then quickly revert to the singlet state" explained Prof. Kurt Westerholt. "The challenge was to verify these triplets Cooper pairs experimentally."

Superconductors allow us to produce highly sensitive detectors for magnetic fields, which even allow detection of magnetic fields resulting from brain waves. These detectors

are called SQUID's (superconducting quantum interference devices) -- components which use the superconductive quantum properties. The central feature in these components consists of so-called tunnel barriers with a series of layers made up of a superconductor, insulator and another superconductor. Quantum mechanics allows a Cooper pair to be "tunneled" through a very thin insulating layer. Tunneling of a large number of Cooper pair's results in a tunnel current. "Naturally the barrier cannot be too thick, otherwise the tunnel current subsides. A thickness of one to two nanometers is ideal," according to Prof. Hermann Kohlstedt (CAU).

If part of the tunnel barrier is replaced by a ferromagnetic layer, the Cooper pairs are broken up while they are still in the barrier and do not reach the superconductor on the other side. The tunnel current decreases drastically. "Triplet Cooper pairs can, however, be tunneled much better through such a ferromagnetic barrier," says Dirk Sprungmann, who was involved as Ph.D. student. If we are successful in converting a portion of the singlet Cooper pairs to triplet Cooper pairs, the tunnel current should be significantly stronger and be able to pass through a thicker ferromagnetic layer. This is precisely what the physicists in Bochum and Kiel tested. They allowed the Cooper pairs to pass through ferromagnetic barriers with thicknesses of up to 10 nanometers. With this attempt the physicists achieved a double success. On the one hand they were able to experimentally verify the existence of triplet Cooper pairs, and, on the other, they demonstrated that the tunnel current is greater than for singlet Cooper pairs in conventional tunnel contacts. "These new ferromagnetic tunnel barriers may possibly be used for new types of components," states Dr. Martin Weides (Santa Barbara). With their research findings the scientists confirmed, among other things, the theoretical work of a Norwegian research team published only a few weeks before.