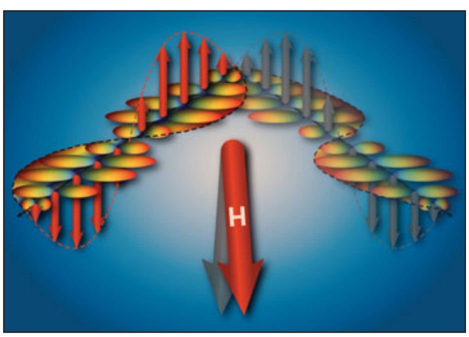
Superconductivity switched on by magnetic field

Superconductivity and magnetic fields are normally seen as rivals—very strong magnetic fields normally destroy the superconducting state. Now Simon Gerber and Michel Kenzelmann at the Paul Scherrer Institute (PSI) and their international research group from three other institutions have demonstrated that in the material $CeCoIn_5$, a novel superconducting state is only created when accompanied by strong external magnetic fields. They report their findings in the December 22, 2013 online edition of *Nature Physics* (DOI: 10.1038/NPHYS2833).



Depending on the orientation of the magnetic field (H), the triggered spin density wave (red arrows or gray arrows) can move in different directions. The superconductivity, which is generated at the same time, is modulated by the spin density wave. Illustration: Paul Scherrer Institute/Simon Gerber.

This novel state can be manipulated by modifying the field direction. The material is already superconducting in weaker fields, too. In strong fields, however, an additional second superconducting state is created, which means that two different superconducting states exist at the same time in the same material. The new state is coupled with an antiferromagnetic order that appears simultaneously with the field.

Superconductivity occurs when electrons come together in Cooper pairs, which can then move unimpeded through the material. While the symmetry properties of the movement of the Cooper pairs are similar in many superconductors, $CeCoIn_5$ is extremely unusual in that the initial *d*-wave superconductivity is joined in the exotic state by *p*-wave superconductivity.

The antiferromagnetic order in the material was detected in neutron scattering experiments. In this case, an additional direction emerged in which many neutrons were diffracted at high magnetic fields. This corresponded to the antiferromagnetic order, that is, the spin density wave.

In $CeCoIn_5$, spin density waves can only run in two directions that are perpendicular to one another, that is, they can appear in two different domains. The direction in which the spin density wave moves depends on the direction of the external magnetic field. When the direction of the magnetic field is altered, then for a specific direction, the orientation of the spin density wave also changes abruptly.

"The observed behavior of the material was completely unexpected and is certainly not a purely magnetic effect," said Kenzelmann, head of the PSI research team. "This is a clear indication that in the material the new superconducting state occurs together with the spin density wave, as is also expected from symmetry arguments." The special feature of this state is that it is very closely linked to the magnetic order. This means that they both become stronger when the strength of the outer magnetic field is increased. Hence, one can directly control the quantum state, which is linked to superconductivity by means of an external magnetic field. The possibility of directly controlling quantum states may be important for possible future quantum computers.

"Even if this particular material is not used due to the low temperatures and strong magnetic domains required, our experiments show what this kind of control could, in principle, look like," said Gerber, first author of the publication.

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