An introduction to superconductivity

At very low temperatures, some solids conduct electricity without any resistance, so that once a current of electrons is started, it continues without any voltage applied. This is called superconductivity and it was discovered in 1911. An explanation was provided in the 1950s, based on the quantum theory of solids. It is known as the BCS theory.

In quantum theory only certain configurations are allowed; particles cannot be in an arbitrary state. Moreover, particles are either fermions or bosons. Fermions cannot occupy the same quantum state, but bosons can. If electrons were bosons then they could all be in the lowest energy state at sufficiently low temperature – and this state would not ‘see’ the lattice of atomic nuclei, so that the electrons could move free of resistance, as in superconductivity. Electrons are fermions, however. Fortunately, at low temperatures, two electrons can couple and act like a single boson. Electrons have half-integer spin (an intrinsic quantum property) whereas bosons have integer spin, so that a coupled electron pair has integer spin. These are known as Cooper pairs.

Magnetic fields cannot penetrate superconductors. This, the Meissner effect, is predicted by BCS theory. If an increasing magnetic field is applied to a superconductor, the field eventually becomes strong enough to penetrate the material and destroy superconductivity.

In 1986 a new class of materials was discovered which superconduct at temperatures higher than BCS theory predicts (above about 40 K). The record for these high-temperature superconductors is currently around 135 K.

In high-temperature superconductivity, electrons still form pairs which condense into a superconducting bosonic ground state, but the BCS pairing mechanism of electrons, via interaction with the atomic lattice, does not occur. The new pairing mechanism is not known, but must arise from features common to the atomic structure of high-temperature superconductors. Their lattices have a layered structure, and also typically constitute a distortion, due to substituted ‘alien’ atoms, of a more highly symmetrical lattice structure.

Most cited paper - superconductivity

The most cited paper in this collection is ‘Superconductivity and phase diagram in iron-based arsenic-oxides ReFeAsO$_{1−δ}$ (Re = rare-earth metal) without fluorine doping’ by Ren et al.

This paper reports and studies a new class of high-temperature superconductors having the formula ReFeAsO$_{1−δ}$, where δ is small and Re is a rare earth metal. This class was inspired by the discovery of the superconductor LaFeAsO$_{1−x}$F$_x$; Ren et al. dispensed with the fluorine dopant, so that vacancies exist at a fraction δ of the oxygen positions in the undistorted lattice. As well as lanthanum (La) they looked at other rare earths, and measured the resistivities and magnetic susceptibilities of these compounds as the temperature varied across the superconducting transition, to determine the transition temperature. Samarium, with the largest atomic number of the rare earths studied, was superconducting at the highest temperature, 55 K. The structures of these compounds were determined by powder X-ray diffraction.

Referenced paper

Superconductivity and phase diagram in iron-based arsenic-oxides ReFeAsO$_{1−δ}$ (Re = rare-earth metal) without fluorine doping

Ren et al 2008 EPL 83 17002

Anton Garrett is a physicist who runs the online scientific editing business Scitext Cambridge.