

Reported successes and failures aid hot pursuit of superconductivity

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A collaboration of researchers in Japan report on four years of extensive research into superconductivity, including the materials that were found not to have superconducting properties, as well as those that were, and their potential for wires and devices.

Materials that superconduct at more practical temperatures than [liquid helium](#) are in high demand, both for the insights in fundamental physics they may reveal and their device potential. A review published in *Sci. Technol. Adv. Mater.* Vol. 16 (2015) p. 033503 by a collaboration of researchers in Japan now provides a detailed overview of the past four years extensive research on around 1000 materials, with detailed insights learnt from the new superconducting materials discovered. A unique feature of this review is incorporation of a lost of the roughly 700 studied materials that did not show superconductivity.

"This is probably the first such paper with opening of a list of experiments that failed," says Hideo Hosono, a researcher at Tokyo Institute of Technology and first author of the review. "It should be invaluable data for researchers in the field."

Existing theory offers little that helps identify high-temperature conductors, leaving a vast array of material possibilities. "We decided to not to waste the time and effort of other researchers, and wrote this paper with the results of samples that did not go superconducting," adds Hosono, who also led the research behind the first discovery of iron-based superconductors in 2006.

The research team members were also unique for a project in superconductivity since their research expertise emphasised solid-state chemistry over condensed-matter physics. They included researchers from Tokyo Institute of Technology, the International Superconductivity Research Center, the National Institute of Materials Science, Kyoto University, Hiroshima University, and Okayama University.

In the past, similar research projects have been strictly focused on finding [superconducting properties](#), resulting in an all or nothing outcome, and at the time the work in the review was carried out, funding for superconductivity research was in decline. Instead Hosono and his colleagues employed a flexible approach that led to valuable insights into other material properties, such as ammonia catalysis for fertiliser production, ambipolar oxide thin film transistors and metallic ferroelectricity.

Superconductivity

The conductivity of metals increases as temperatures drop due to the decrease in atomic vibrations thereby lowering the resistivity. In most metals the resistivity reaches a minimum at a certain temperature but for superconductors the resistivity drops to zero at the 'critical temperature'. Below the critical temperature the conductivity of a superconducting material is infinite and all magnetic field lines are expelled.

The potential applications of superconductivity range from fast digital circuits and powerful electromagnets for MRI, to quantum bits for next-generation computing. However the first observations of superconductivity required cooling with liquid helium, and such low temperatures greatly inhibit the development of new technologies using superconductivity.

High temperature superconductivity

In 1986 Georg Bednorz and K. Alex Müller observed superconducting properties in certain ceramic cuprates at much higher temperatures than ever before, a discovery for which they were awarded the Nobel Prize. In 2006 Hideo Hosono's group reported the first observations of superconductivity in the non-cuprate LaFePO, a discovery that initiated the field of iron-based superconductor research. The discovery of iron-based superconductivity was particularly surprising because iron atoms have a large magnetic moment and magnetism was thought to be incompatible with superconductivity.

Superconductivity theory

The BCS theory proposed by John Bardeen, Leon Cooper, and John Robert Schrieffer remains the primary explanation for the mechanism behind superconductivity. The theory describes the pairing of electrons to form a boson state.

Fermi particles such as electrons cannot occupy the same state, meaning there must be some characterising feature, such as spin or orbital, distinguishing them. This requirement leads to effects such as Fermi repulsion. In contrast bosons can occupy the same state, and the adoption of boson characteristics in electron Cooper pairs results in superconducting properties. The research summarised in the review provides several descriptions of the transport behaviour of the superconducting materials found in terms of interactions of electrons in 'd' and 'p' orbitals around the nucleus.

Despite the insights BCS theory can provide, it gives no quantitative prediction of the temperature at which a material becomes superconducting. This makes the search for [high temperature](#)

[superconductors](#) particularly challenging.

The project details

The project proposal was titled "the exploration for novel superconductors and relevant functional materials, and development of superconducting wires for industrial applications". The project proposal was one of just 30 selected from around 800 applications for a new research funding program launched in Japan in 2009: the Japan Society for the Promotion of Science (JSPS) FIRST (Funding Program for World-Leading Innovative R&D on Science and Technology) program initiated by the Council for Science and Technology Policy (CSTP).

At its outset the project proposed by Hosono in 2010 had 5 aims:

1. Discovery of a new superconductor above 77K (a significant temperature as it is the boiling point of liquid nitrogen)
2. Development of new superconductors with high performance
3. Development of related materials with outstanding functions
4. The development of a superconducting wire with a critical current density greater than 105 A/cm²
5. Production of a Josephson junction that allows the tunnelling of superconducting Cooper pairs, and a superconducting quantum interference device (SQUID) that uses similar tunnelling effects and can be used as a highly sensitive magnetometer

Bar the discovery of a superconductor with a [critical temperature](#) above 77 K the project has succeeded on all counts.

The expertise of the research team emphasised solid-state chemistry rather than condensed matter physics, the usual background for researchers in superconductivity. Hosono organised the team this way, believing that this distribution of skills would lead to research that

revealed interesting material properties regardless of its success specifically in superconductivity.

As well as the insights into [superconductivity](#) identified the research has led to a significant advance in ammonia catalysis where a hundred years on from the first development of the Haber process, iron-based catalysts were still being used. They also demonstrated the first ambipolar oxide thin-film transistors and ferroelectricity in metals.

More information: "Exploration of new superconductors and functional materials, and fabrication of superconducting tapes and wires of iron pnictides." *Sci. Technol. Adv. Mater.* 16 033503 [DOI: 10.1088/1468-6996/16/3/033503](#)

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