# 'Cooper pairs' can be found in insulators as well superconductors

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Nearly a century ago, Dutch physicist Kamerlingh Onnes discovered that some metals transform into perfect electrical conductors when cooled to temperatures near absolute zero. Once started, their currents of electrons can flow perpetually.

How electrons reorganize to produce this behavior remained mysterious until 1957, when theoretical physicists John Bardeen, Leon Cooper and Robert Schrieffer unveiled their BCS (Bardeen, Cooper, Schrieffer) theory of superconductivity. The theory shows that superconducting electrons form pairs, now known as Cooper pairs, that correlate their motion with other electron pairs to smoothly and infinitely flow. Cooper, currently the Thomas J. Watson, Sr. Professor of Science at Brown University, went on with his colleagues to win a Nobel Prize for this work.

Now, in the 50th anniversary year of BCS theory, Brown physicists are making a surprising addi-tion to the scientific canon created by their famous colleague. In new work appearing in *Science*, the team shows that Cooper pairs not only form in superconductors, but can also form their opposite – electrical insulators.

“Our finding is quite counterintuitive,” said James Valles, a Brown professor of physics who led the research. “Cooper pairing is not only responsible for conducting electricity with zero resis-tance, but it can also be responsible for blocking the flow of electricity altogether.”

Michael Stewart is a physics graduate student at Brown and the lead author of the Science article. Stewart started the research as a skeptic. He'd seen scientific papers suggesting that Cooper pairs might exist in electrical insulators under certain conditions. Stewart decided to test this unorthodox idea. "I'd would've put my money down," he said, "that the answer was 'no'."

To create an insulator for his experiments, Stewart chose bismuth, a rare metal that, when thick, serves as an excellent superconductor and, when thin, serves as an exceptional insulator. Stewart turned to Jimmy Xu, a Brown professor of engineering and physics and a pioneering nanotechnology researcher, to create a template for the special experimental film.

Xu supplied a template honeycombed with holes measuring only 50 nanometers in diameter. When coated with an ultra-thin coating of bismuth just four atoms thick, and cooled to super-low temperatures, the material could be transformed into either a superconductor to insulator. When the material was behaving as an insulator, and the researchers applied a magnetic field, they detected a telltale change in electrical current, which announced the presence of Cooper pairs.

While the team found that Cooper pairs are present in both superconductors and insulators, they believe that they behave differently in each instance. In superconductors, pairs link up with other pairs and move in a linear way to create a continuous stream of electric current. Think of a conga line. But in the insulating film, researchers believe the pairs spin solo. Think of couples twirling on a ballroom dance floor.

The holes in their test material were the clincher, Valles and Stewart said, allowing them to detect the electron pairs. "Cooper pairs formed, but stayed segregated in these whirlpools," Stewart said. "Because of that, the pairs can't make a continuous line of current."

The findings could help researchers understand the limits of superconductivity and, perhaps, push them to create insulated wires that conduct electricity without heating up. Cooper said the work sheds important and intriguing new light on quantum effects.

“This very interesting result reminds us that unexpected, important discoveries await if we continue to look," Cooper said.

Source: Brown University

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