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Solving a cryptic puzzle with a little help from a hologram

NEW WORLDS

• By JUDY SIEGEL-ITZKOVICH

Scientists from Bar-Ilan University and Harvard University have cracked the code of several enigmatic experiments – performed over the past 15 years on superconductors – by developing a mathematical tool to find the shape of the electrons in these materials

A recent discovery published in *Nature Physics* provides an innovative technique for calculating the shapes of electrons. This finding will help scientists gain a better and faster understanding of the properties of complex materials, said Dr. Emanuele Dalla Torre of the physics department at Bar-Ilan University in Ramat Gan, who worked together with Dr. Yang He and Prof. Eugene Demler of Harvard University.

They used holographic logic to compile an algorithm for visualizing the shape of an electron in a superconducting material. This successful collaboration clarified the puzzling results of a series of experiments performed in the past 15 years, resolving a mysterious scientific enigma.

Dalla Torre said that according to quantum mechanics, electrons can possess wave-like properties.

"The wave shape, however, is not always apparent, and tends to vary depending on the conditions of the material that hosts the electron," he said. "The invention in the early 1980s of the STM – a remarkably high-resolution microscope – provided the ability for the first time to view individual atoms in materials. Nevertheless until now, scientists had viewed the shape of an electron only in isolated atoms – in a vacuum – but not within a complex material containing a vast array of atoms, where the outline of each electron is indistinguishable," he explained.

"We developed a mathematical algorithm that helped us analyze high-precision STM measurements of cuprates – copper-oxygen compounds known to maintain the best superconductive properties. By identifying recurring correlations between previously unnoticed experimental data points, we were able to reconstruct the shape of the electrons in these wondrous materials," he added.

"The shape that we found contains positive (blue) and negative (red) regions. The electrons are suspended within an ordered structure of atoms: The blue circles indicate oxygen atoms, while the pink circles indicate copper atoms. For the first time ever, we isolated and confirmed a unique shape of an electron within a complex material," explained Torre.

Over the years, numerous researchers offered interpretations for these findings and for other related ambiguous observations, but until now, there was no satisfactory explanation for the mysteriously recurring signals. Dalla Torre suspected it had to do with the shape of the electrons, and, once they mapped these shapes in cuprates, they were able to offer a simple explanation for the observation.

"Superconductors are materials that at room temperature, barely conduct electricity. However, when cooled below a certain temperature – the critical temperature – they morph into superheroes and conduct electric currents without any resistance, and without heating up or melting. These materials, are, therefore, highly sought after for their potential use in a variety of next-generation technologies," explained Dalla Torre.

"The highest critical temperature of superconductors discovered until now is that of cuprates, which require cooling to as low as -135° C to become superconductive. The costs involved in cooling down to these temperatures are prohibitively high, which explains the ongoing search for the Holy Grail – the highest possible critical temperature that provides economic viability," Dalla Torre said.

"In the absence of an effective methodology on their quest for new superconducting materials, labs worldwide resort to testing elements randomly, in the hope to discover the perfect candidate," he says. "It's like baking a cake with no recipe: You hope it comes out fluffy, but have no idea as to which ingredients may affect stiffness."

A hologram is not an actual image, but rather an encoded pattern based on a special characteristic of light.

"We are looking at a 2D image, which our eyes convert into 3D. We applied the logic of a hologram in order to attain information about a 3D object from measurements of a 2D surface. By extracting all the information encoded in a 2D STM measurement of cuprate, they visualized the shape of an electron.

Some consider electrons to be the "soul" of a material – determining its color, its conductivity, and its entire chemical activity. Dalla Torre expects that this innovative technique for decoding shapes of electrons will enable the design of smarter materials suitable for ever-changing future technologies.

"By gaining a better understanding of the behavior of materials, scientists may be on the path to finding the next superconductor," he said