Rethinking the Fundamental Way Electrons Interact in Superconducting Quantum Materials

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Scientists have discovered a new twist to one of the fundamental interactions underpinning the physical world — the interplay of energy between electrons in a solid material.

It's the interaction between electrons that is at the heart of superconductivity, the ability of a material to move an electrical current with zero resistance. To achieve this, these superconductors must be cooled to very low temperatures — typically about minus 423 degrees Fahrenheit. Understanding electron interactions, scientists say, may help them create a new generation of superconducting quantum materials that function at higher, easier-to-manage temperatures.

"For decades the dream has been to make high-temperature superconductors that operate at as high as room temperature, but there is much we still don't understand about superconductivity," said Eduardo H. da Silva Neto, an assistant professor of physics at Yale and corresponding author of a new study that looked at how electrons interact in copper-based materials.

The study is published in the journal Nature Communications.

In examining electron interactions in copper oxides, the researchers paid close attention to a fundamental law of physics known as Coulomb's law, which holds that opposite charges attract and like charges repel.

What they discovered was surprising. Using a method called resonant inelastic X-ray scattering (RIXS), they found that electrons within copper oxides create fluctuating waves of electrical charge that emanate not just in two directions — something scientists have observed over the past decade — but in all directions.

“While charge density waves are usually oriented along the crystal axes — the lines we use to understand the arrangement of atoms in a crystal — we found that for a brief period of time they can rotate into another direction and come back, creating new structures from which novel properties can emerge,” said da Silva Neto, who is a faculty member of Yale’s Energy Sciences Institute at West Campus.

The implication, the researchers said, is that electrons in a solid material can interact in a way that bends Coulomb’s law. In some cases, the presence of the atoms in the solid could even cause electrons with the same electrical charge to attract rather than repel.

“Nobody saw this coming,” said co-author Alex Frano, an assistant professor of physics at the University of California-San Diego. “The Coulomb interaction governs most of the physical phenomena we have ever experienced.”

The researchers said this new information gives them a “fingerprint” of how Coulomb’s law works in solid quantum materials and higher-temperature superconductors. “Overall, we’re providing a new paradigm to think about charge order, superconductivity, and electron interactions in quantum materials,” da Silva Neto said.

Read the original article on Yale University.