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Discover a new state of matter! Scientists find that electrons become "electronic liquids" under special conditions

English translation

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Quantum computers can compute much faster than conventional computers, but they have a big problem: They are prone to data storage and processing errors caused by disturbances from the environment, such as vibrations and radiation from warm objects. A discovery from a research project led by scientists in Singapore on how to control electrons at extremely low temperatures provides a way to solve the problem and develop more powerful and precise quantum computers.

Now, scientists have shown that under certain conditions, electrons can have strong interactions. These interactions, previously only predicted in theoretical models, are observed at the edge of an atomically thin and electrically insulating material at ultra-low temperatures approaching the frigid temperatures of outer space. The Singapore-led research team confirmed that the interactions at low temperatures cause electrons to flow like a liquid. This means that electrons tend to move collectively along a line, rather than individually or randomly in different directions. In the researchers' experiments, the atomic tips of a scanning tunnelling microscope detected ripples in the "electronic liquid."

Getting the electrons "aligned" to fit into this special state of matter, known as the helical Tomonaga-Luttinger liquid, is what physicists think is the one of the most important factors to getting the electrons to clump together to form a particle called a parafermion. In addition to this special state of matter, another key factor in the formation of parafermions is required, which works at lower temperatures: superconductivity. This property refers to the ability to conduct electricity without losing energy and can be found in certain materials.

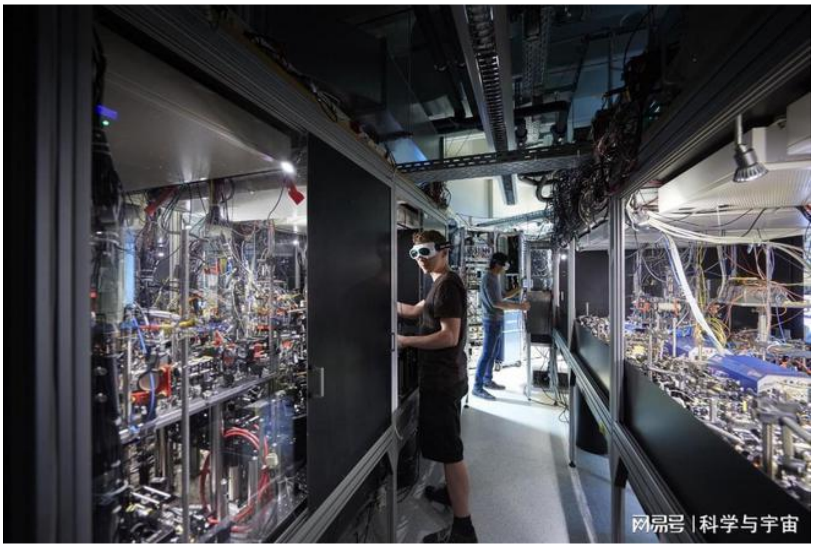
Creating parafermions is a highly sought-after goal by scientists, as these particles are predicted to help quantum computers store information in a way more powerful than they are today. A quantum computer can solve a complex mathematical problem in minutes, while the current state-of-the-art supercomputers take tens of thousands of years. Currently, quantum computers store information by manipulating electrons or light at ultra-low temperatures close to absolute zero, or -273 degrees Celsius. But data stored in quantum computers is vulnerable to environmental disturbances, including vibrations, radiation from warm objects, or changes in electric fields.

However, parafermions are thought to be more resistant to such perturbations because the interactions between the electrons that form parafermions and the way they move through the material make them more stable. If parafermions are used to store information in a quantum computer, the quantum computer will be less prone to errors. In this latest study, scientists observed the behaviour of electrons under a scanning tunnelling microscope. This is achieved by placing the edge of a special type of very thin electrically insulating material incredibly close to the microscope's extremely sharp metal tip. The distance between the two is a nanometre or less, even smaller than a cluster of DNA.

The insulating materials used by the scientists consisted of one-atom-thick crystals of the compound tungsten ditelluride grown on graphite or graphene substrates. Such materials appear almost two-dimensional and are classified as quantum spin Hall insulators, which are electrically insulating inside but have electrons along the edges of the material. The scientists then applied an electric current from the microscope and observed the electrons while maintaining the temperature of the experiment at around 4.5 Kelvin, or -269 degrees Celsius. This is the temperature close to absolute zero, at which particles slow to a near-total halt in motion. Typically, electrons repel each other because they are both negatively charged and tend to behave in a gas-like manner, rather than typically clumping together. But as the temperature drops, the electrons move more slowly.

At sufficiently low temperatures, the strong repulsion between electrons can cause the particles to behave like liquids. A measure of the strength of the interactions is a value called the Luttinger parameter. When this parameter is 1, the interaction between electrons are the weakest. "When the Luttinger parameter is less than 0.5, the interactions are strong and the electrons are forced to move collectively, which is the best way to predict the existence of parafermions." Using different substrates, such as graphene or graphite, and examining the different edges of the materials, the scientists were able to identify very low Luttinger parameters, which can be controlled in the range of 0.21 to 0.33.

"Scanning tunnelling spectroscopy was performed at a temperature of 4.5 Kelvin, and we needed to locate features in less than 30 nanometres. The edge of the quantum spin Hall insulator tested was only 2 nanometres thick." Probing the materials' surfaces at such distances with a microscope without losing track of the spot observed during temperature changes is very challenging. "In the future, one of our biggest challenges will be moving to lower temperatures, which are necessary to observe parafermions. For this, we need more advanced laboratories and equipment," explained the scientists from Singapore.



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