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Quantum Computing May be Bolstered by Liquid-Like Electrons

By Francisco Pires

Another day, another exciting advancement for quantum computing.

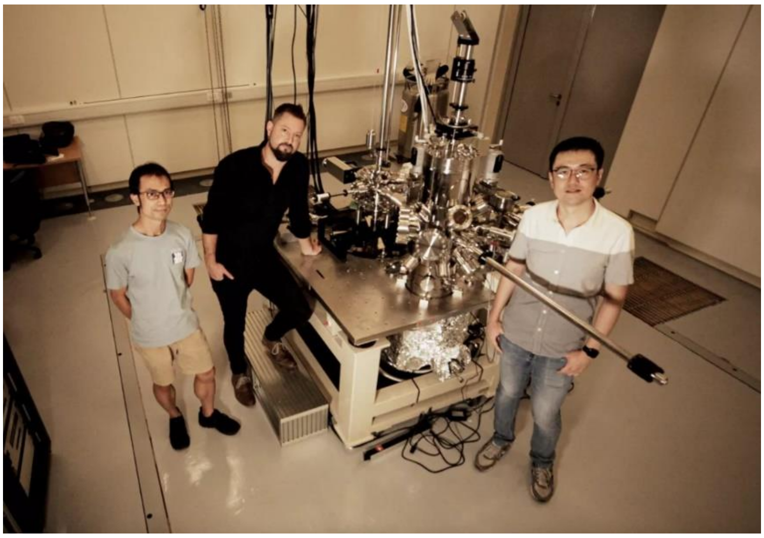

(Image credit: Shutterstock)

The quantum computing field may have just received a coherence and error-prevention boost in the form of parafermions: grouped electrons that behave as liquids in a special state of matter. Scientists with the Nanyang Technological University in Singapore have demonstrated experimental results they expect to lead to parafermions when electrons maintain temperatures close to absolute zero (-273 degrees Celsius). The research achieved a breakthrough by demonstrating that there are conditions in which electrons can have strong interactions – something that scientists merely theorized until now.

The ordered movement of electrons results in what we know as electricity. However, even when electrons are moving in this "ordered" pattern, they're actually not. Because they're negatively charged, electrons repel one another, tending to move individually and haphazardly in different directions (like a gas) instead of as a cohesive whole. They're akin to impaired drivers: they may reach their destination with a few "bumps" along the way. But when electrons behave like a liquid, it's akin to swapping the impaired drivers with orderly ones; drivers that know and respect each other's boundaries, speed and direction to reduce conflicts and better reach their destination.

Of course, drivers such as these are the subject of much theoretical thought, but the strong electron interactions at least have now been experimentally proven to exist.

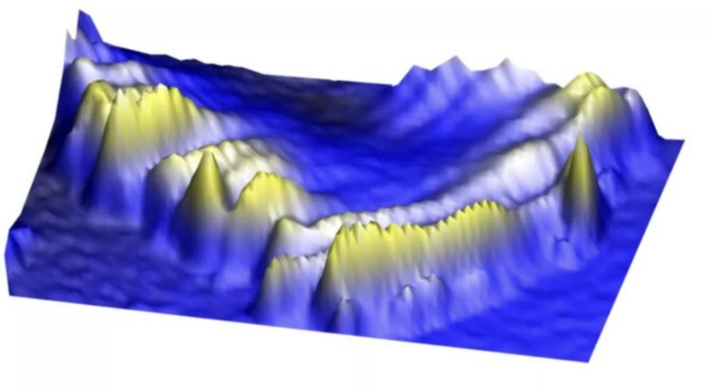
When electrons are made to act in what's known as a "helical Tomonaga-Luttinger liquid," there are fewer particle interactions and energy exchange between them and the system. This, in turn, decreases the amount of systemic and environmental interference that's so often the cause of errors and collapsed quantum states in quantum systems. The electrons being previously cooled to near absolute zero is also an essential element, as it allows certain materials to achieve the state of a superconductor, where electrons traverse its surface absent of any electrical resistance, further reducing the possible elements of environmental interference. The system being cooled to absolute zero (in the experiment, down to 4.5 Kelvin or -269 degrees Celsius) forces particles to slow down so that they almost become immobile.



Left to Right: Dr. Que Yande, a senior research fellow from Nanyang Technological Universit; Asst. Prof. Bent Weber who led the research; and PhD student Jia Junxiang, the first author of the study, with a scanning tunnelling microscope at the university. (Image credit: SPMS/NTU Singapore)

Electrons (and their spin property) have been used as quantum-programmable particles for a while now. As such, improvements in electron control that lead to fewer disturbances mean fewer errors and improved coherence, which means longer life for the actual qubits that can store or process information. In fact, certain quantum systems (such as IBM's Quantum One and Quantum Two) already make use of superconducting qubits.

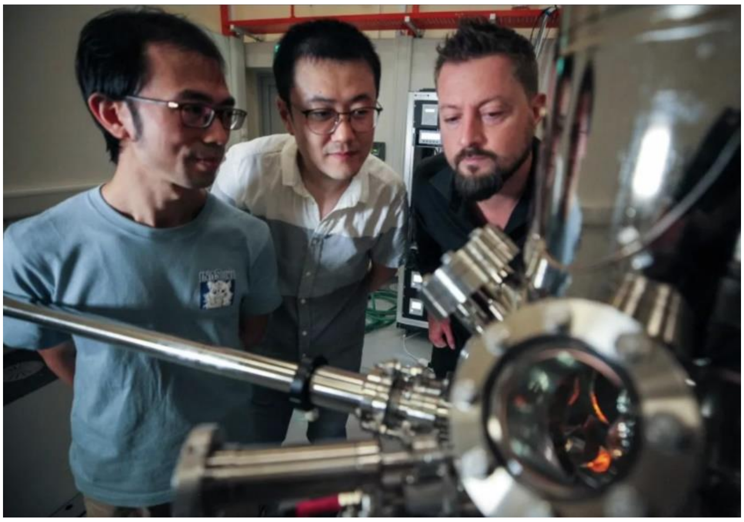
In this case, scientists used an atom-thick graphene substrate where they deposited atom-thick crystals of tungsten ditelluride: an almost two-dimensional material known as a "quantum spin Hall insulator," which insulates gravity on its inside but features electrons on the outside. After putting together the graphene/tungsten ditelluride substrate and cooling it towards absolute zero, the research team put it under a scanning tunneling microscope that lay just one nanometer from its surface: smaller than a DNA strand and smaller than any transistor ever manufactured (even when looking at the ones powering the latest best graphics cards).



The ripples in the "electronic liquid" were probed by the atomically sharp tip of a scanning tunnelling microscope. It could also be a topographic image of the sea. (Image credit: SPMS/NTU Singapore)

When put under the scanning tunneling microscope and cooled to absolute zero, the researchers noticed the electrons in the graphene/tungsten substrate increased their repulsion. Their repulsion was so strong that the electrons were forced to move collectively due to the interaction between each electron's repulsion field. The researchers registered a Luttinger parameter within a range of 0.21 to 0.33. This parameter represents the strength of the interactions between particles; when it reaches 1, the interactions are at their weakest.

"When the Luttinger parameter is less than 0.5, the interactions are strong and the electrons are forced into collective motion. This is the realm where parafermions are predicted to exist," said Assistant Prof Weber. "This is a truly remarkable range of variation, since the Luttinger parameter can only range between 0 and 1," he continued. "Control of the Luttinger parameter at such low values has never been observed before in any helical Tomonaga-Luttinger liquid."



Left to Right: Dr Que Yande, a senior research fellow from NTU Singapore's SPMS; PhD student Jia Junxiang, the first author of the study; and Asst Prof Bent Weber from the school who led the research, with a scanning tunnelling microscope at the university. (Image credit: SPMS/NTU Singapore)

The team is now planning to reduce temperatures even further by leveraging NTU Singapore's new Ultra-Low Vibration Laboratory, which was built earlier this year. The laboratory will allow experiments to be done at even lower temperatures of 150 millikelvins (mK) – even closer to absolute zero, which should enable the researchers to see stronger repulsion amongst electrons and the actual witnessing of parafermion groupings.

Interestingly, it seems that the researchers' approach is somewhat connected with Microsoft's own race to implement so-called topological qubits and their required (and still missing in action) Majorana modes.

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