Researchers take first look into the 'eye' of majoranas

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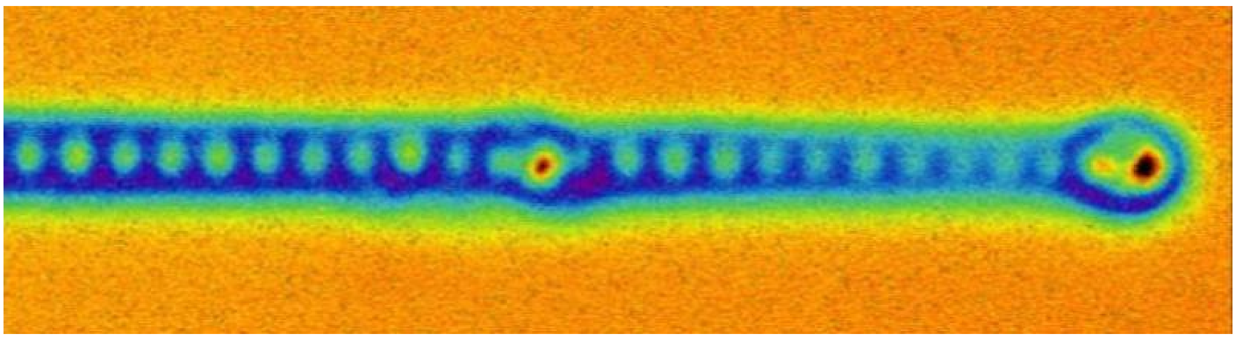

Atomic force microscopy image of the end of a mono-atomic iron wire. The individual iron atoms are clear to see, as well as the “eye” of the Majorana fermions on the end. Credit: University of Basel, Department of Physics

Majorana fermions are particles that could potentially be used as information units for a quantum computer. An experiment by physicists at the Swiss Nanoscience Institute and the University of Basel's Department of Physics has confirmed their theory that Majorana fermions can be generated and measured on a superconductor at the end of wires made from single iron atoms. The researchers also succeeded in observing the wave properties of Majoranas and, therefore, in making the interior of a Majorana visible for the first time. The results were published in the journal *npj Quantum Information*.

Around 75 years ago, Italian physicist Ettore Majorana hypothesized the existence of exotic particles that are their own antiparticles. Since then, interest in these particles, known as Majorana fermions, has grown enormously given that they could play a role in creating a quantum computer. Majoranas have already been described very well in theory. However, examining them and obtaining experimental evidence is difficult because they have to occur in pairs but are then usually bound to form one normal electron. Ingenious combinations and arrangements of various materials are therefore required to generate two Majoranas and keep them apart.

Collaboration between theory and practice

The group led by Professor Ernst Meyer has now used predictions and calculations by theoretical physicists Professor Jelena Klinovaja and Professor Daniel Loss (from the Swiss Nanoscience Institute and the University of Basel's Department of Physics) to experimentally measure states that correspond to Majoranas. On a superconductor, the researchers evaporated single iron atoms with spin that, due to the row structure of the lead atoms, arrange themselves into a minute wire comprising one row of single atoms. The wires reached an astounding length of up to 70 nanometers.

Single Majoranas on the ends

The researchers examined these mono-atomic chains with the aid of scanning tunneling microscopy and, for the first time, with an atomic force microscope as well. Using the images and measurements, they found clear indications of the existence of single Majorana fermions on the ends of the wires under certain conditions and from a specific wire length on.

Despite the distance between them, the two Majoranas on the ends of the wires are still connected. Together, they form a new state extended across the whole wire that can either be occupied ("1") or not occupied ("0") by an electron. This binary property can then serve as the basis for a quantum bit (Qubit) and means that Majoranas, which are also very robust against a number of environmental influences, are promising candidates for creating a future quantum computer.

Predicted wavefunction measured

The researchers from Basel have not only shown that single Majoranas can be generated and measured at the ends of an iron wire, they also performed the first experiment to show that Majoranas are extended quantum objects with an inner structure, as predicted by their theory colleagues. Over an area of several nanometers, the measurements showed the expected wavefunction with characteristic oscillations and twofold decay lengths, which have now been made visible for the first time.

More information: Rémy Pawlak et al. Probing atomic structure and Majorana wavefunctions in mono-atomic Fe chains on superconducting Pb surface, *npj Quantum Information* (2016). DOI: 10.1038/npjqi.2016.35

Provided by University of Basel