Signature of long-sought particle that could revolutionize quantum computing

September 26 2012, by Elizabeth K. Gardner

A Purdue University physicist has observed evidence of long-sought Majorana fermions, special particles that could unleash the potential of fault-tolerant quantum computing.

Leonid Rokhinson, an associate professor of physics, led a team that is the first to successfully demonstrate the fractional a.c. Josephson effect, which is a signature of the particles.

"The search for this particle is for condensed-matter physicists what the Higgs boson search was for high-energy particle physicists," Rokhinson said. "It is a very peculiar object because it is a fermion yet it is its own antiparticle with zero mass and zero charge."

The pursuit of Majorana fermions is driven by their potential to encode quantum information in a way that solves a problem dogging quantum computing. The current carriers of quantum bits, the basic unit of information in quantum computing, are delicate and easily destroyed by small disturbances from the local environment. Information stored through Majorana fermions could be protected from such perturbances, resulting in a much more resilient quantum bit and 'fault-tolerant' quantum computing, he said.

"Information could be stored not in the individual particles, but in their relative configuration, so that if one particle is pushed a little by a local force, it doesn't matter," Rokhinson said. "As long as that local noise is not so strong that it alters the overall configuration of a group of particles, the information is retained. It offers an entirely new way of dealing with information."

Majorana fermions also have the unique ability to retain a history of their interactions that can be used to encode quantum information, he said.

"Other particles are interchangeable and if two electrons trade places, it is as if nothing had happened, but when you swap two Majorana fermions, it leaves a mark by altering their quantum mechanical state," Rokhinson said. "This change in state is like a passport book full of stamps and provides a record of exactly how the particle arrived at its current destination."

Rokhinson observed a variation of the Josephson effect that is a unique signature of Majorana fermions. The effect describes the way an electrical current traveling between two superconductors oscillates at a frequency that depends on the applied voltage. The reverse also is true; an oscillating current generates specific voltage, proportional to the frequency. In the presence of Majorana fermions the frequency-voltage relationship should change by a factor of two in what is called the fractional a.c. Josephson effect, he said.

Rokhinson used a one-dimensional semiconductor coupled to a superconductor to create a hybrid nanowire in which Majorana particles are predicted to form at the ends. When alternating current is applied through a set of two such wires, a specific voltage is generated across the device, which Rokhinson measured. As a magnetic field was applied and varied from weak to strong, the resulting steps in voltage became twice as tall, a signature of the formation of Majorana particles, he said.

Victor Yakovenko, a professor of physics at the University of Maryland, was one of the first theorists to predict the fractional a.c. Josephson effect.

The effect is very unusual and is specific to Majorana particles, which makes this observation more definitive than signatures obtained through other approaches, he said.

"Majorana particles are the only particle that can produce this effect, and experimental observation of it is a tremendous breakthrough," Yakovenko said. "Of course, it will take time and independent confirmation to firmly establish it, but this is very exciting."

The observation of this special state does not mean fault-tolerant quantum computing will happen any time soon, if at all, Yakovenko said.

"Whether or not these particles will work for quantum computing has yet to be seen, but in the process of trying we will learn a lot of unknown quantum physics," he said. "This could open the door to a whole new field of the topological effects of quantum mechanics."

A paper detailing the work will be published in the next issue of the journal *Nature Physics* and is currently available online. Co-authors include Xinyu Liu and Jacek Furdyna of the University of Notre Dame, who designed the material specifically for these experiments. Furdyna also has an honorary degree from Purdue. The work was partially supported by grants from the Army Research Office and the National Science Foundation.

Rokhinson next plans to perform follow-up experiments and to modify the system to probe different properties of the observed state.

More information: The Fractional ac Josephson Effect in a Semiconductor-Superconductor Nanowire as a Signature of Majorana Particles, *Nature Physics*, 2012.

ABSTRACT
Topological superconductors that support Majorana fermions have been predicted when one-dimensional semiconducting wires are coupled to a superconductor. Such excitations are expected to exhibit non-Abelian statistics and can be used to realize quantum gates that are topologically protected from local sources of decoherence. Here we report the observation of the fractional a.c. Josephson effect in a hybrid semiconductor-superconductor InSb/Nb nanowire junction, a hallmark of topological matter. When the junction is irradiated with a radio frequency f0 in the absence of an external magnetic field, quantized voltage steps (Shapiro steps) with a height ΔV=hf0/2e are observed, as is expected for conventional superconductor junctions, where the supercurrent is carried by charge-2e Cooper pairs. At high magnetic fields the height of the first Shapiro step is doubled to hf0/e, suggesting that the supercurrent is carried by charge-e quasiparticles. This is a unique signature of the Majorana fermions, predicted almost 80 years ago.

Provided by Purdue University