Researchers discover new fundamental quantum mechanical property

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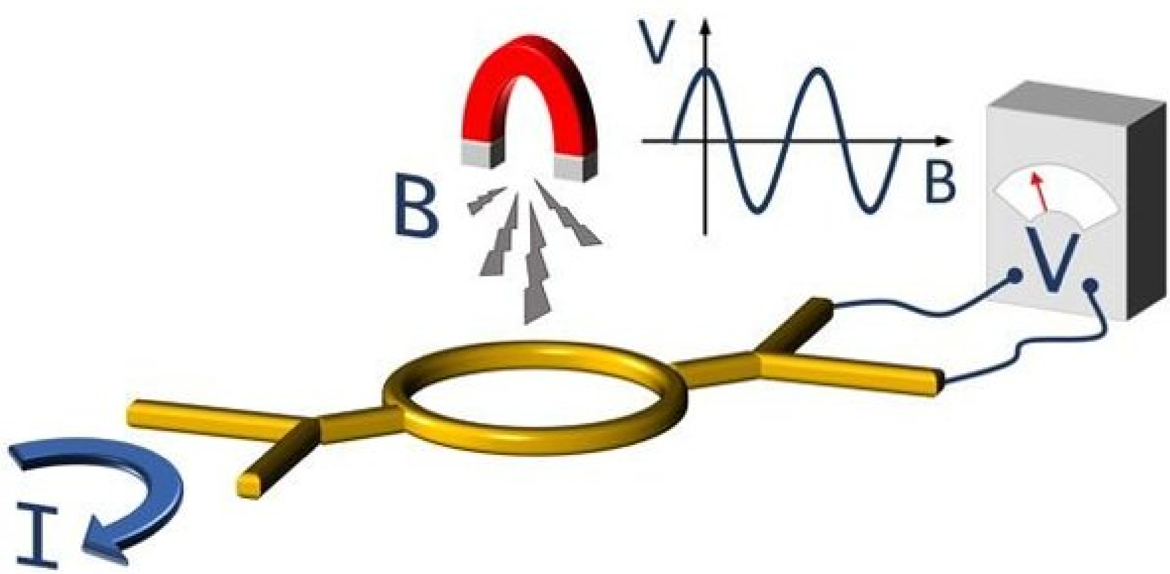

Schematic representation of the nonlocal electron interference experiment. A dc current is driven from the upper left to the lower left contact. A nonlocal, oscillating voltage is measured between the upper and lower right contacts due the magnetic-field induced single-electron interference in the 500 nanometer ring in the middle.

Nanotechnologists at the University of Twente research institute MESA+ have discovered a new fundamental property of electrical currents in very small metal circuits. They show how electrons can spread out over the circuit like waves and cause interference effects at places where no electrical current is driven. The geometry of the circuit plays a key role in this so called nonlocal effect. The interference is a direct consequence of the quantum mechanical wave character of electrons and the specific geometry of the circuit. For designers of quantum computers it is an effect to take account of. The results are published in the British journal *Scientific Reports*.

Interference is a common phenomenon in nature and occurs when one or more propagating waves interact coherently. Interference of sound, light or water waves is well known, but also the carriers of electrical current – electrons – can interfere. It shows that electrons need to be considered as waves as well, at least in nanoscale circuits at extremely low temperatures: a canonical example of the quantum mechanical wave-particle duality.

Gold ring

The researchers from the University of Twente have demonstrated electron interference in a gold ring with a diameter of only 500 nanometers (a nanometer is a million times smaller than a millimeter). One side of the ring was connected to a miniature wire through which an electrical current can be driven. On the other side, the ring was connected to a wire with a voltmeter attached to it. When a current was applied, and a varying magnetic field was sent through the ring, the researchers detected electron interference at the other side of the ring, even though no net current flowed through the ring.

This shows that the electron waves can "leak" into the ring, and change the electrical properties elsewhere in the circuit, even when classically one does not expect anything to happen. Although the gold ring is diffusive (meaning that the electron mean free path is much smaller than the ring), the effect was surprisingly pronounced.

Quantum information processing

The result is a direct consequence of the fact that the quantum equations of motion are nonlocal. That nature is nonlocal is also well-known from another kind of nonlocality: the counterintuitive ability of objects to instantaneously know about each other's state, even when separated by large distances. Einstein referred to it as: "spooky action at a distance". The Twente results help to further understand the first type of nonlocality, referred to as dynamical nonlocality, which plays a key role in all quantum interference experiments. It is very well known that quantum interference is affected by decoherence (where the physical environment causes loss of phase memory), and by performing a "which-path-measurement" (removing the dynamical nonlocality and hence destroying the interference pattern). Now the researchers from the University of Twente have discovered a new way to affect the dynamical noncality. Namely the geometry of the circuit. Understanding this fundamental effect is important for future quantum information processing. For example when creating a quantum computer.

More information: E. Strambini et al. Geometric reduction of dynamical nonlocality in nanoscale quantum circuits, *Scientific Reports* (2016). DOI: 10.1038/srep18827

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