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50 Years Ago

Charles Darwin's Orchid Bank at Downe in Kent has recently been acquired as a nature reserve by the Kent Naturalists' Trust. It is a site of great scientific interest which shows a wide range of vegetation types … and, as it is only sixteen miles from the centre of London, the need for conservation is urgent and considerable. It is also of unique historical importance, for Darwin is known to have carried out field studies there from his nearby home, Down House, where he lived for forty years … Eleven of the thirteen species of orchid mentioned by Darwin as occurring within a mile of his house can still be found in the reserve.
From *Nature* 21 April 1962

100 Years Ago

The Mind of Primitive Man. By Franz Boas — There is a popular fallacy that racial antipathy is based on physiological foundations. But in so far as such antipathy is real, there is nothing physiological in its causation … The author's discussion and explanation of the causes and results of variation within a race … supply the most convincing theory that has yet appeared … The ordinary view of the mental deficiencies of the "inferior races" is remorselessly criticised. The lowest savage *does* possess self-control. He is not improvident, but rather optimistic. He *can* concentrate his mind. He possesses originality. Savages who do not count beyond three or ten easily adapt their language and intellect to civilised methods of reckoning … The point is that these civilised methods are not needed in the primitive state, where each man on a war-expedition is known by name, though the number of the troop may not be reckoned. Both in mind and in body there is little to choose between the ordinary barbarian and the civilised man.
From *Nature* 18 April 1912

QUANTUM PHYSICS

Tunnelling across a nanowire

The observation of a phenomenon known as coherent quantum phase slip, across a nanowire in a superconducting system, paves the way for applications in quantum computing and metrology. SEE LETTER P.355

ALEXEY BEZRYADIN

Quantum mechanics is the most accurate theory of modern physics. It was originally formulated[1] in 1925 to describe microscopic particles such as electrons and atoms, but whether the theory is applicable to the macroscopic world of everyday objects has remained unclear. On page 355 of this issue, Astafiev *et al.*[2] demonstrate that quantum theory can describe the tunnelling of magnetic flux across a narrow segment of a superconducting loop. Taken as a whole, this device represents a macroscopic and complex system, involving — at the very least — probably many thousands of electrons.

Astafiev and colleagues[2] have created a type of superconducting quantum bit (qubit) that was first proposed by Mooij and Harmans[3]. The device's main element is a segment of a homogeneous nanowire within a closed superconducting loop (Fig. 1). The system operates by allowing quantum tunnelling of magnetic flux, into and out of the loop, across the nanowire. Such tunnelling preserves a form of quantum memory known as phase coherence and is called coherent quantum phase slip (CQPS). The device obeys the physics of macroscopic quantum systems and has implications for fundamental metrology and information technology.

The principle of quantum tunnelling[4] posits that any microscopic particle has some chance of penetrating any wall, no matter how high the wall's associated energy barrier. But does this effect apply to macroscopic objects? On the basis of one modern interpretation of quantum mechanics[5], quantum effects are applicable to any large system, even the Universe. But when applied to macroscopic objects, such a global theory would lead to paradoxical predictions — for example, Schrödinger's cat, which, according to the principle of quantum superposition, can be alive and dead at the same time.

However, another interpretation exists in which large Schrödinger's cats do not occur because of a phenomenon known as spontaneous wavefunction collapse[6,7]. Such a collapse destroys phase coherence and occurs spontaneously at a low rate. Therefore, experimental physicists are avidly testing the applicability of quantum theory to the macroscopic world[8]. To do this, they often start with tiny electronic devices, which display coherent quantum tunnelling between macroscopically distinct states[2,9,10]. Such small-scale but macroscopic quantum systems may be called artificial atoms, given the discrete nature of their energy states, and can be used as qubits, the building blocks of quantum computation.

The Mooij–Harmans qubit, which Astafiev *et al.* now demonstrate[2], can exist either in a state in which the superconducting current in the loop flows clockwise or in a state that has an anticlockwise current. It can also be in a symmetric quantum superposition of these two states, which is described mathematically by the sum of the clockwise and anticlockwise states. What's more, the symmetric superposition state has a twin state of higher energy, called the antisymmetric state. This state is obtained by subtracting the anticlockwise state from the clockwise state. In their study, the authors prepared the qubit in the symmetric superposition state and, by shining microwave photons on the qubit, were able to make it switch between the two superposition states. To detect these states, they connected the qubit to the centre conductor of a microwave resonator system, and showed that the two states slow down electromagnetic waves differently.

In a Mooij–Harmans qubit, the transition from the clockwise state to the anticlockwise state is accompanied by tunnelling of magnetic flux, or quantum phase slip, across the nanowire. If the qubit's wire is continuous, the magnetic flux enters the loop by creating what is known as a phase-slip core. Such a core is similar to the normal core of a vortex of magnetic flux in a superconductor. But CQPS, in which the quantum history of the tunnelling

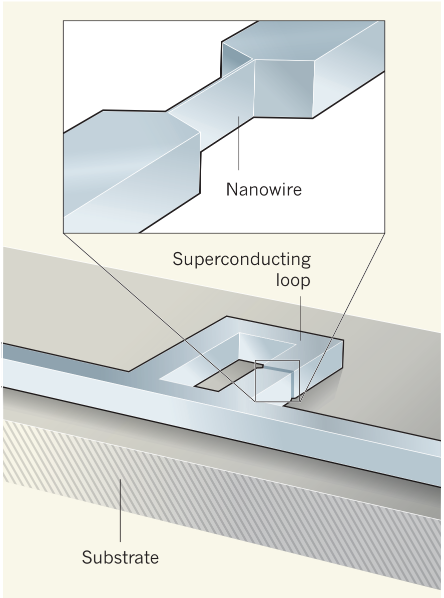

Figure 1 | The Mooij–Harmans qubit. The two-state quantum system, or qubit, demonstrated by Astafiev *et al.*[2] consists of a nanowire segment in a superconducting loop made of indium oxide and laid on a substrate. The strongly disordered electronic structure of indium oxide allows coherent quantum tunnelling of magnetic flux, known as coherent quantum phase slip, to occur across the nanowire. (Figure not drawn to scale.)

(the coherence) is preserved, is difficult to attain because the core dissipates energy, erases the quantum memory, causes decoherence and suppresses the tunnelling rate exponentially[11]. As a result, only incoherent quantum phase slips had thus far been detected in homogeneous nanowires[12,13].

Previous observations of CQPS have involved the use of superconducting qubits made of nanowires interrupted by thin insulating junctions. Such junctions create tunnel barriers for the superconducting current, but help the magnetic flux to cross the wire and enter the loop because superconductors expel the magnetic field from their interior whereas insulators do not. Also, CQPS in these interrupted wires has no core. Therefore, the tunnelling rate is not strongly influenced by dissipation effects[11]. Astafiev and colleagues' superconducting qubit[2] is the first of its kind in which CQPS is observed across an uninterrupted superconducting nanowire.

The observation of CQPS in a continuous nanowire was possible because the superconducting material from which the wire is made — indium oxide — has a strongly disordered electronic structure. Because of its oxygen atoms' tendency to bind or localize electrons, indium oxide is so disordered that it is not even described by the standard Bardeen–Cooper–Schrieffer (BCS) theory of superconductivity. In fact, the material is almost an insulator. In BCS-type superconductors, all free electrons participate in a single, collective bound state known as the BCS condensate. Such a state is like a huge superconducting 'molecule' of electrons, which moves without friction and so leads to superconductivity. In indium oxide, the BCS condensate is not one but many such molecules. The condensate is localized, meaning that it fractures into a system of BCS 'lakes' or 'droplets', which interact only very weakly with one another.

Astafiev and colleagues' work suggests that the presence of such lakes is crucial to the successful operation of the Mooij–Harmans qubit. In a superconducting wire that contains localized BCS-condensate lakes, the phase-slip core can pass between the lakes and thereby avoid any strong dissipation. Hence, instead of the conventional approach of making an insulating junction in the nanowire to observe CQPS, the researchers used a material (indium oxide) that is almost in an insulating state. This is a neat solution because, on the one hand, the wire has some phase-slip cores, but, on the other hand, dissipation effects are reduced.

The present study paves the way for testing theoretical predictions for nanowires supporting CQPS and for applications in fields such as quantum computing and quantum metrology. It has been proposed[14] that CQPS could be used to produce a fundamental standard of current. One issue that remains to be investigated is the possibility — or perhaps impossibility — of attaining CQPS in nanowires that are less disordered than indium oxide, and, in particular, in pure, single-crystal nanowires in which BCS theory is fully applicable and a well-developed phase-slip core exists[15]. Such systems should be compared with those that support coreless CQPS[16], to quantify the decoherence introduced by the phase-slip core. ■

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CIRCADIAN RHYTHMS

No lazing on sunny afternoons

In the laboratory, fruitflies rely on an internal clock to alternate activity with a midday nap and night-time sleep. Surprisingly, when outdoors, they follow temperature rather than the clock, and skip siestas. **See Letter p.371**

FRANÇOIS ROUYER

Circadian clocks are biological mechanisms that allow living organisms to adapt their physiology and behaviour to day–night cycles. In particular, a neuronal circadian clock controls rhythms of rest and activity in many animal species, including the fruitfly *Drosophila melanogaster*. In laboratory conditions, this insect shows a bimodal activity profile, with maximal activity concentrated in the morning and evening. However, the artificial light–dark cycles used in lab experiments only roughly mimic the complex environmental changes associated with alternating day and night. Vanin *et al.*[1] report on page 371 of this issue that fruitflies indeed behave very differently when exposed to more natural conditions. Moreover, the authors' results challenge the widely held idea that light and the known elements of the circadian clock are the main players that shape rest–activity rhythms.

Fruitflies show 24-hour sleep–wake rhythms that persist for weeks in laboratory conditions at constant room temperature, even in constant darkness. The insects' circadian clock relies on a feedback loop that involves four proteins — CLOCK, CYCLE, PERIOD and TIMELESS — that bind to specific regions of DNA and control the expression of many genes[2]. Mutant fruitflies devoid of any one these four proteins lack circadian rhythms. Obviously, though, the constant conditions used in the lab are not suited to understanding the adaptive role of the