disease in developed countries — may result from the impaired actions of survival factors such as insulin, in addition to the deleterious effects of increased concentrations of glucose, angiotensin and other factors. This may provide the rationale for evaluating existing insulin-sensitizing drugs, as well as those under development, for their ability to improve insulin action in the kidney. It may also prove fruitful to develop insulin analogues that preferentially activate insulin-stimulated mechanisms in podocytes and other kidney cells. It is to be hoped that these strategies will provide further ways to decrease the risk of diabetic nephropathy. ■

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QUANTUM COMPUTING

Quantum RAM

Hybrid quantum systems have been suggested as a potential route to building a quantum computer. The latest research shows that they offer a robust solution to developing a form of random access memory for such a machine.

MILES BLENCOWE

Most of us have shared the frustration of a desktop computer grinding almost to a halt when running a data-intensive application — opening a high-resolution digital photograph, for example — or running one application too many at the same time. Some have also experienced the (usually short-lived) improvement in speed that comes from installing expensive additional memory called random access memory (RAM). Unlike that in the hard drive, data stored in RAM can be retrieved just as quickly in any order, making it well suited for its role as a temporary storage medium for the computer's central processing unit while executing a program. A quantum computer will also require a form of RAM for its proper function. Writing in *Physical Review B*[1] and in *Physical Review Letters*[2–4], four research groups report significant progress in demonstrating a proof-of-principle 'quantum RAM'.

As with a conventional computer, a quantum computer encodes the binary digits 0 and 1 — that is, a 'bit' of information — in the state of a physical system. But in contrast to its classical counterpart, it does not do so using the state of a classical system, such as the absence or presence of an electrical charge in a capacitor. The 0 and 1 will correspond instead to the two states of a two-level quantum system — for example, the spin 'down' and spin 'up' states of unpaired electrons of atomic or molecular defects in a crystal lattice, or the clockwise and anticlockwise electrical currents in a tiny superconducting ring. And because of quantum mechanics, both of these example quantum systems can be not only in either the 0 or 1 state, but also in a superposition state — a simultaneous combination of 0 and 1. As such, they act as a 'quantum bit', or qubit, to encode quantum information.

In their papers[1–4], the four teams describe work towards realizing a hybrid quantum-computer architecture that combines qubits of both types described above: superconducting qubits and spin qubits (Fig. 1). The superconducting qubits, which are typically a few hundred micrometres in size, are well suited to performing fast quantum logic-gate operations[5,6]. In addition, they are relatively straightforward to fabricate from materials such as aluminium using electron-beam lithography. The spin qubits, which are formed from a millimetre-to-centimetre-sized crystal containing upwards of 10^{12} electron-spin impurities, act as memory elements to store and retrieve data. The spin qubits considered by the authors include chromium(III) ions (Cr^{3+}) in aluminium oxide[2], nitrogen-vacancy defects in diamond[3], and rather exotic molecules consisting of single nitrogen atoms in fullerene (C_{60}) cages[4] (the fullerene cage prevents the normally chemically unstable nitrogen atoms from reacting). Such spin-qubit memories have the advantage of relatively long (millisecond) lifetimes, after which the stored information will typically have decayed away owing to unavoidable interactions with the uncontrolled environment of the spins. This lifetime is more than a thousand times longer than the microsecond or shorter lifetimes of the superconducting qubits.

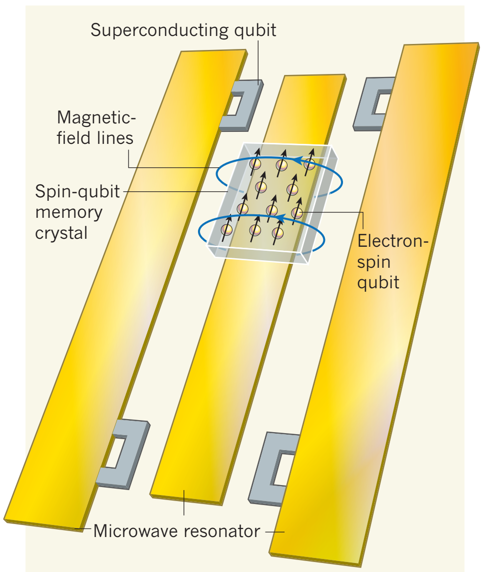

Figure 1 | Scheme for a hybrid quantum computer. The hybrid quantum-computer architecture envisaged in four papers[1–4] combines superconducting qubits and spin qubits. The superconducting-qubit states can be transferred to and retrieved from a spin-qubit memory crystal by microwave-resonator photons. The microwave resonator strongly couples to the crystal's ensemble of electron-spin memory qubits through the tightly confined oscillating magnetic field of the resonator photons. The resonator photons can also mediate couplings between the superconducting qubits to realize quantum logic gates[6].

In such hybrid schemes, the data buses that transport information between computer components can be fashioned from long, thin metallic strips of aluminium or some other suitable superconductor such as niobium. The strips can be carefully engineered to form microwave resonators that have resonant frequencies in the few-to-several gigahertz range, enabling the superconducting (logic) and spin (memory) qubits to emit and absorb resonant-frequency microwave photons and hence exchange information between one another.

The new studies[1–4] do not demonstrate such a hybrid quantum-computer architecture in its entirety. What the authors show is a strong coupling between the microwave resonator and the ensemble of electron-spin memory qubits in the crystal. To realize a quantum RAM, the coupling must be sufficiently strong for a microwave-resonator photon to be stored in the spin-qubit memory and retrieved on a timescale that is short compared with the photon lifetime in the resonator and the spin-qubit memory lifetime.

In their experiments, the authors[1–4] achieve strong coupling in two ways. First, the large cross-sectional aspect ratio (the ratio of width to height) of the wide but thin microwave resonator strip means that the photon's oscillating magnetic-field component, which interacts with the electron spins, is largely confined to a small volume above and below the strip, comparable to the thickness of the spin-qubit memory crystal. Second, the microwave photon's centimetre-scale wavelength along the strip length is comparable to the lateral dimensions of the crystal. Thus, with the crystal positioned on top of the strip, a significant portion of the photon's magnetic field will fill the crystal volume; a single photon therefore interacts simultaneously with a large number of the spins, with the result that the photon is stored non-locally throughout the crystal in the form of a many-spin superposition state. A strong coupling then depends simply on ensuring a high crystal spin density. But how is this coupling strength actually measured?

Consider two pendulums suspended from a ceiling with strings of identical length and bobs of identical mass. Suppose one of the pendulums represents the microwave resonator and the other the non-local spin 'mode'. If the two independent pendulums are set into equal, but small-amplitude motion, then they will oscillate at the same frequency — that is, in resonance. Now attach a spring between the two masses, coupling their motion. The spring represents the coupling between the microwave resonator and the spin mode. If we then initially displace one of the pendulums, it will gradually transfer all of its energy to the other pendulum and vice versa, resulting in a 'beat' frequency — this is similar to what is heard when two musical notes are played slightly out of tune with respect to each other. The beat frequency is directly related to the spring stiffness, and hence the coupling strength, between the pendulums. Analogously, the authors[1–4] measured the beat frequency of the microwave resonator when in resonance with the spin mode, and hence were able to extract their coupling strength.

Only one of the four experiments actually demonstrated[4] the RAM principle of multiple-state storage followed by arbitrary-order retrieval of the states. However, only classical microwave states involving a large, indeterminate number of photons were stored in and retrieved from the spin memory. To demonstrate the same at the single-photon level — as required for a quantum RAM — will require about an order-of-magnitude improvement in the resonator photon and spin-qubit memory lifetimes, together with the introduction of the superconducting qubits. Nevertheless, the current results represent a major step towards realizing a quantum RAM. ■

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MICROBIOLOGY

Slicer for DNA

Many bacteria and archaea protect themselves from viruses and other invasive genomes through a genetic interference pathway. The small RNAs that guide this defence specify the direct cleavage of foreign DNA. **SEE ARTICLE P.67**

ERIK J. SONTHEIMER & LUCIANO A. MARRAFFINI

All cells invest heavily in maintaining their genetic identities against invasion by foreign nucleic acids such as viral genomes. This problem is particularly acute for bacteria and archaea because of the pervasive presence of bacteriophages, plasmids and other mobile genetic elements in the biosphere. Genetic entities called clustered regularly interspaced short palindromic repeats (CRISPRs) have been revealed as adaptive, genomically encoded immune systems[1] that protect bacteria and archaea from phages[2], plasmids[3] and probably other forms of foreign DNA.

This system is sequence-directed, like the well-known RNA interference (RNAi) pathway[4] that operates in organisms such as plants and animals. If a portion of the CRISPR locus matches a sequence from the invasive genome, the invader is thwarted. This mechanism requires the action of CRISPR RNAs (crRNAs) that render the pathway addressable[5], presumably by delivering an interference machinery to target nucleic acids that are recognized by the

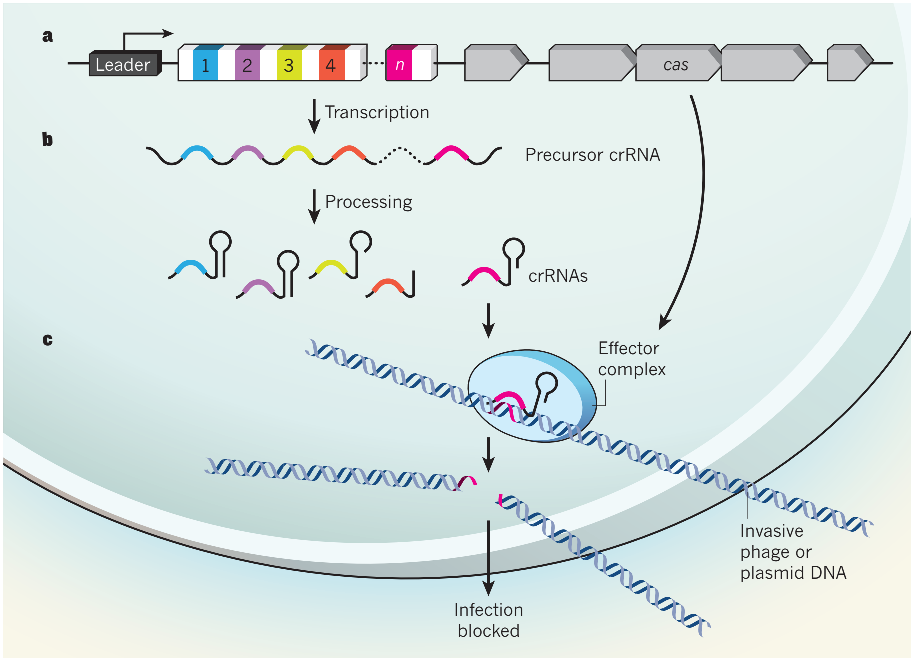

Figure 1 | RNA-guided DNA cleavage by the core CRISPR machinery. a, CRISPR loci include variable numbers of repeat and spacer sequences, with the latter derived from invasive DNAs previously encountered by the cell or its ancestors. The repeat/spacer region is flanked by a 'leader' sequence and by *cas* genes[1]. **b**, CRISPR transcription and processing of precursor crRNA yields mature crRNAs. **c**, These presumably associate with an effector complex that includes protein products of the *cas* genes. Garneau *et al.*[6] report that the CRISPR pathway in *Streptococcus thermophilus* induces double-strand breaks at cognate protospacers embedded within invasive DNAs, implying that the core effector complex achieves genetic interference, and so infection blockage, by crRNA-guided DNA cleavage.