

stored bits determined its symmetry character — symmetric, antisymmetric or a superposition of both. The spin wavefunction also controlled the spatial wavefunction through the direct link between their symmetries, and so determined the collisional properties. Thus, the state of the quantum bits controlled the atoms' interactions.

To prepare, manipulate and detect the atomic states, Anderlini *et al.*² used a sophisticated technology developed by them and other groups in recent years. A large number (about 10,000) of isolated pairs of atoms are held in microscopic optical traps formed by interfering laser beams. The atoms in any given pair can be held separately, or brought together to interact.

The authors also developed a procedure to map out the quantum-bit content of each atom of a pair. By carefully switching off the optical trap, and with the help of magnetic-field gradients, the atoms can be distributed in space according to their quantum state. Projections of the quantum bits can then be read from a photographic image of this atomic distribution. The authors obtained a strong signal by simultaneously probing all of the pairs in the atomic ensemble, whose quantum states had undergone an identical evolution in parallel. By taking repeated measurements at different time intervals, they were able to map out this evolution.

In the first experiment with their system, Anderlini *et al.* tested an exchange of quantum information between two atoms. For this 'SWAP' operation, two atoms are initially held at separate sites and their individual quantum-bit states are set to 1 and 0 using radio-frequency radiation. The sites are then merged slowly enough that the two atoms end up in different trap states, but quickly enough that the wavefunction of the atoms is in a quantum superposition of the symmetric and antisymmetric states. These two states have different energies, so a quantum oscillation takes place in which the bit information is repeatedly exchanged between the atoms. To move from a SWAP operation to real quantum-computational operation is not, in principle, a big leap. By letting the atoms interact for only half of the time needed for a SWAP, one creates a quantum-mechanical correlation, known as entanglement, which is the basis for quantum computation.

There are many systems other than cold, colliding atoms that can make use of exchange symmetry for quantum computation: for example, coupled electron spins in a solid-state double quantum dot^{3,4}. Here, again, antisymmetric and symmetric wavefunctions lead to different effective interactions between the electrons. Equally, when two identical light particles, photons, arrive from different directions at a beamsplitter — a partially reflecting mirror at which an impinging photon can be either transmitted or reflected — they always end up travelling together as if

strongly attracted to one another. The photons respond to each other not because of interaction forces, but because of their symmetry of state. This effect, first described in 1987 by Hong, Ou and Mandel⁵, is now used in experiments on photon-based quantum computation^{6,7}.

What are the advantages of symmetry-based computation for atoms? Other schemes not involving exchange symmetry could do the job. But as Anderlini *et al.*² point out, these schemes place a number of requirements on the atoms that are more stringent than those of the exchange-symmetry scheme. Furthermore, these state-dependent schemes are more likely to suffer decoherence — loss of quantum information — through state-dependent coupling to the environment. In general, exchange-symmetry schemes should be less susceptible to the noise that plagues highly precise apparatus.

So, how far are we from a working quantum computer? A long way: there are still various issues to resolve, including efficiency, fidelity, decoherence and scalability. But scientists all over the world are closing in on this goal from many different directions. New ideas such as

making use of fundamental symmetries could ultimately provide new lines of attack. In view of all of the recent work in the field of quantum computation, we are perhaps experiencing a 'paradigm shift' for controlling the quantum-bit interactions, from schemes controlled by forces to schemes driven by symmetries. ■

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IMMUNOLOGY

Sensing the enemy within

Hongbo Chi and Richard A. Flavell

Damaged or foreign DNA stimulates immune responses by inducing the production of interferon proteins. New evidence indicates that this response is mediated by a cytosolic DNA sensor known as DAI.

On infection by a pathogen, the immune system rapidly mounts defence mechanisms, characterized by massive production of interferon proteins and other cytokines (immune mediators). This reaction, known as the innate immune response, is mediated by pattern-recognition receptors that detect conserved structures found in a broad range of pathogens. The best-studied receptors of this type are Toll-like receptors (TLRs) — a class of membrane receptor that senses microbes either in the extracellular space or intracellular compartments¹. So how do host cells fight pathogens that have entered their cytosol? Intracellular sensors that can detect microbial products, including viral RNA and bacterial cell-wall components, in the cytosol have been identified². Now, Takaoka *et al.*³ report on page 501 of this issue the identification of another cytosolic factor called DAI (also known as DLM-1 or ZBP1) as a DNA sensor.

Although host nucleic acids are normally sequestered in the nucleus and are therefore safe from recognition by cellular receptors, the immunostimulatory activity of DNA and RNA has long been recognized. In 1963, two groups^{4,5} — including one led by the discoverer of interferon, Alick Isaacs — reported

that DNA and RNA derived from pathogens or host cells can activate interferon production in chicken and mouse fibroblast cells. But the cellular receptors for nucleic acids remained unknown for almost four decades.

In the early 2000s, specific TLRs that detect immunostimulatory nucleic acids during infection or tissue damage were identified⁶. For example, TLR9 recognizes DNA sequences that contain specific motifs known as unmethylated CpG dinucleotides, features common to microbial, but not mammalian, DNA. In addition, TLR3 and TLR7/TLR8 sense double-stranded RNA (dsRNA) and single-stranded RNA (ssRNA), respectively⁷. Engagement of TLRs initiates a molecular signalling cascade that leads to the activation of essential gene transcription factors, including interferon-regulated factors (IRFs) and NF- κ B. This cascade ultimately leads to the production of type I interferon (interferon- α and - β) and proinflammatory cytokines to fight infectious organisms⁸ (Fig. 1, overleaf).

Despite the importance of TLRs in recognizing nucleic acids, alternative receptors must exist. This is because nucleic-acid-specific TLRs are localized in intracellular compartments such as endosomes, which

Sensing The Enemy

David Kirk



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