Developing ‘inducible-knockout’ mice, in which the expression of the α6 or δ subunits can be stopped quickly, might avoid the problems of compensatory alterations and may clarify the roles of tonic inhibition in brain function.

The next major advance in this field might not come from studies of genetically altered mice. The development of drugs that specifically block receptors containing the δ subunit, for example, would provide tools for unravelling the precise function of background inhibition, not just in the cerebellum but also in other brain areas where such receptors are expressed extrasynaptically. The task of understanding the function and importance of extrasynaptic $GABA_A$ receptors is an exciting one, and it is clear that neuroscientists have already lost their inhibition about listening to background noise. ■

Ivan Soltesz is in the Department of Anatomy and Neurobiology, University of California, Irvine, California 92697-1280, USA.
e-mail: isoltesz@uci.edu
Zoltan Nusser is in the Laboratory of Cellular Neurophysiology, Institute of Experimental Medicine, Hungarian Academy of Sciences, Szigony Street 43, 1083 Budapest, Hungary.
e-mail: nusser@koki.hu

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Quantum engineering

Squeezing entanglement

Nick Bigelow

Quantum entanglement between two particles is a spooky connection that means measuring one has an instant effect on the other. Connecting many atoms in this way would be the first step towards a quantum computer.

If a street magician with two identical coins told you he could predict which way up your coin would land — heads or tails — simply by tossing his coin first, you probably wouldn’t believe him. But what if he told you that, because of the laws of physics, your toss had to turn out the same as his toss? Not convinced, you try it and find that, yes, it is true. And it remains true, time after time, toss after toss. By some mechanism, there is a surprising correlation between the behaviour of the two coins. What’s going on? Well, it could be that these two coins have somehow been prepared in a remarkable quantum state known as an entangled state. On page 63 of this issue Sørensen *et al.*[1] provide physicists with an exciting new recipe for creating such entangled states from an unusual sample of atoms known as a Bose–Einstein condensate.

The concept of entanglement is one of the most fundamental features of quantum mechanics, yet it is one of the most puzzling, non-intuitive and ‘non-classical’ aspects of the theory. The consequences of entanglement are so disturbing that Albert Einstein called them “spooky action-at-a-distance”. But is entanglement real? Can we actually create entangled states? More importantly, can we observe the effects of entanglement? The answer to all of these questions is yes, at least on the rather remote and microscopic scale of a single pair of photons. More recently, entanglement has also been demonstrated using an ensemble of four carefully prepared atoms[2,3]. So far, though, entanglement has not been observed in any macroscopic (human-sized) system.

The physics of entangled states is also at the heart of a new generation of futuristic technologies, including recent plans for quantum computers and strategies for quantum teleportation. Making entanglement a tangible, exploitable phenomenon, however, requires the creation of entangled states of many particles — entanglement on a macroscopic scale. Moreover, it is important to achieve this with massive particles that can easily be stored and transported, rather than with photons, which have no mass. One of the exciting aspects of the work of Sørensen *et al.*[1] is that, by following their guidelines, researchers may soon be able to do just that — entangle the many particles within a Bose–Einstein condensate (BEC). A BEC is a large sample of particles (as many as 10 million ultracold atoms) that share exactly the same quantum state.

For the purposes of entanglement, theorists[1,4–6] are especially interested in a type of BEC in which the atoms have multiple internal states. This was first achieved experimentally for a ‘double condensate’ composed of two clouds of rubidium atoms,[7] each cloud having a different internal spin, which can be thought of as a tiny bar magnet. More recently, researchers have been able to transfer a BEC of sodium atoms from a magnetic trap into an optical trap formed from a focused laser beam[8]. Unlike a magnetic trap, this new laser-trapping technique is not sensitive to the spin state of the atoms, so physicists can vary the complex magnetic properties of these ‘spinor’ condensates[9,10].

In the quest to create entangled states for large collections of atoms, the ‘squeezed’ state is of particular interest. To appreciate the relationship between squeezing and entanglement, it is important to have a sense for quantum ‘noise’. At the heart of quantum theory is the idea that nature is inherently probabilistic. In classical physics you can predict the outcome of a coin toss if you know the exact starting conditions. But in quantum theory you can speak only of the probability of a certain outcome, no matter how much detail of the problem is known. Inherent in this picture is the idea that the measurable properties of a given state are accompanied by unavoidable fluctuations.

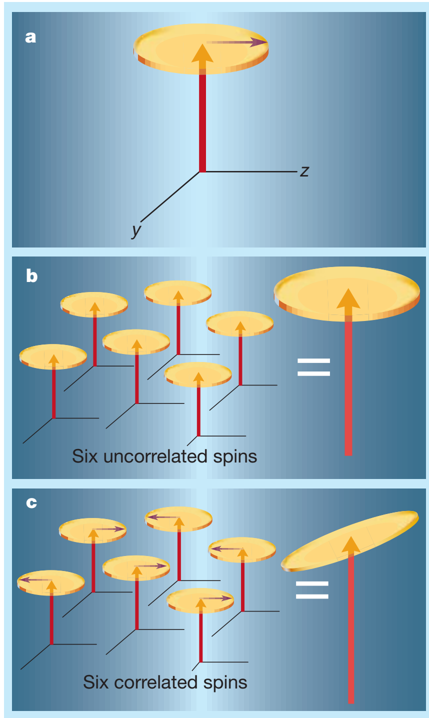

Figure 1 **Putting the squeeze on spin. Simple particles, such as electrons, have a quantum mechanical ‘spin’, which can be either up or down.** a, **This quantum spin is aligned mostly in the ‘up’ direction, but there is a quantum mechanical uncertainty in the component of the spin in the transverse direction, which is represented by a small circular disk.** b, **In a dilute gas of *N* atoms with uncorrelated spins, the collective uncertainty is a disk of diameter $\sqrt{N}$ times each individual uncertainty disk.** c, **In a gas of atoms with correlated spins, such as the Bose–Einstein condensate modelled by Sørensen *et al.*[1], the uncertainty disk becomes an ellipse, which is narrower along the *y*-axis than the *z*-axis. This means that measuring the left–right component of the spin is ‘noisier’ than the in–out component — it has been squeezed.**

These fluctuations are an expression of the Heisenberg uncertainty principle, and they set a quantum noise limit on the accuracy of any precision measurement. In a squeezed state, this quantum noise is 'squeezed', or redistributed in the system, so that some measurable properties become 'quieter', whereas other properties become 'noisier'.

The states studied by Sørensen *et al.*[1] are 'spin squeezed'[11,12]. In the quantum world we often represent an atomic spin by an arrow (Fig. 1a). For the simplest spins, like those of electrons, these arrows can point either up or down. Now, applying the uncertainty principle, we find that the transverse part of the spin (the part not exactly in the up–down direction) is uncertain by an amount represented by a small disc. In other words, if we try to find out whether the spin is angled left or right, or in or out of the page, we find that we cannot specify both the amount of left–rightness and in–outness at the same time. In the language of quantum noise, the transverse spin is 'noisy' in the left–right and in–out directions.

For a gas made up of many atoms, each with their own spin, the collective atomic spin is represented by one big arrow and one big uncertainty disc (Fig. 1b). A key idea exploited by Sørensen *et al.* is that if we entangle the individual atomic spin states, by introducing carefully tailored correlations between the individual atomic spins, then the collective spin state of the vapour can be squeezed. In Fig. 1c the transverse components of the individual atomic spins preferentially add up in the left–right direction, as opposed to the in–out direction, changing the uncertainty disc of the total spin from a circle into an ellipse — it is now squeezed.

One consequence of this spin-squeezing is that the quantum noise involved in measuring in–outness can be made smaller than that for measuring left–rightness. This entangled squeezed state provides a way to break what is known as the standard quantum limit for the measurement of one component of the collective spin (the standard quantum limit is the diameter of the unsqueezed uncertainty circle in Fig. 1b). The essence of Sørensen *et al.*'s idea is that by shining a judiciously tailored microwave field on a BEC and letting atoms in the condensate collide with each other, it is possible to achieve entanglement-induced squeezing.

This route to entanglement not only demonstrates the sort of large-scale quantum engineering needed for quantum-information applications, but also has potentially important consequences in other areas, such as precision atomic clocks[12,13]. The performance of sophisticated laser-cooled atomic clocks is already close to the limits set by quantum noise[14], a limitation that could be overcome if a spin-squeezed atomic BEC is used to run the clock.

Although recent experiments in our group and elsewhere have shown that a BEC is not absolutely required to create a spin-squeezed atomic vapour[15,16], the idea of marrying the power of entanglement with the remarkable properties of a BEC offers outstanding possibilities for creating a new generation of non-classical atomic states[1,4–6]. One day, we may even hear about entanglement of another macroscopic form of matter — the bulk sample of metal found in a simple pair of coins. ■

Nick Bigelow is in the Department of Physics and Astronomy and the Laboratory for Laser Energetics, PO Box 270171, University of Rochester, Rochester, New York 14627, USA.
e-mail: nbig@lle.rochester.edu

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Entomology

The alkaloid defence

W. E. CONNER

M. EISNER

The moth *Cosmosoma myrodora*, pictured left, is visually striking. And, as revealed by William E. Conner and colleagues in the *Proceedings of the National Academy of Sciences USA* (**97,** 14406–14411; 2000), its behaviour is also rather unusual. The male moths seem to have developed a chemical system to protect themselves, their female mates and their offspring from predation by spiders.

Conner *et al.* provide evidence that male — but few female — *C. myrodora* feed on the fluid secreted from certain plants (perhaps *Eupatorium capillifolium*). The alkaloid compounds thus ingested become particularly concentrated in a mass of filaments (pictured right) in the abdomen of the moths. The authors assume that this protects the males from spiders such as *Nephila clavipes* — when the moths were fed a similar alkaloid in the lab, the spider cut the moths free from its web rather than eat them.

Before mating, male *C. myrodora* release some of their filaments, covering their chosen female. This seems to protect the female from spiders, too. The females may also receive alkaloids from the males' sperm, and in turn pass on some of these protective chemicals to their eggs.

But questions remain. Do the females use receipt of alkaloids as a measure of a male's 'worth'? Females did seem to prefer males that had released filaments, but it is not certain if females could discern whether the filaments were laden with alkaloids. It is also not clear which plants the moths feed on in the wild, because the moths are rare and hard to spot. **Amanda Tromans**

Mammalian evolution

Relationships to chew over

Anne Weil

Did advanced mammals evolve on the southern continents and then move north? Not according to a new study, which concludes that such mammals evolved in both the south and the north.

There are three groups of living mammals — placentals, marsupials and the monotremes. The first two, along with some mammalian fossil relatives, have so-called 'tribosphenic' teeth, which provide a highly efficient way of chopping and grinding food. Monotreme ancestors are also thought to have possessed such teeth.

On page 53 of this issue, Luo *et al.*[1] argue that mammals with tribosphenic teeth evolved not once but twice, after the supercontinent of Pangaea pulled apart more than 160 million years ago. According to their hypothesis, one lineage radiated across the southern landmass of Gondwana but is represented today by only the platypus and