Figure 1 Method used by Julsgaard and colleagues¹ to entangle two atomic samples. The same laser light is sent through both atomic samples. Its frequency and polarization are carefully selected so that after the interaction the spin of the atoms in both samples becomes entangled with the laser beam. A suitable measurement of the polarization of the light then changes the atomic state in such a way that it becomes a superposition of states that are compatible with the outcome of the measurement. These states are symmetric with respect to the quantum properties of the atoms in each sample — practically half the atoms are spin up and the other half spin down — which protects the entangled state against destructive interactions with the environment.

properties of an object are not necessarily well defined if we do not look at them. Suppose I have a coin in my hand and then, when I look at it, I see that it lies tails up. This does not necessarily mean that the property of being heads up or tails up was defined before my observation. As long as we do not 'observe', there exist intermediate situations between being tails and heads up (something like being part heads up and part tails up at the same time), which are called quantum superpositions. Of course, we cannot directly see these superpositions because, as soon as we look at the coin, the property is defined and the superposition disappears.

The situation gets even more intriguing if we have two or more objects. In that case quantum mechanics predicts the existence of the type of superpositions known as entangled states. For example, we could have two coins (in two closed hands) which are in a superposition of two states — one in which both coins lie heads up, and one with both tails up. Because the coins are entangled, opening one hand defines the property of both coins, because if one lies heads up, the other must also be heads up. The reason is that having one coin heads up and the other tails up is not compatible with the states that create the superposition. The effect of observing one coin has an instantaneous consequence for the second — a strange phenomenon that is the basis of teleportation and other applications of entangled states.

In practice, we cannot do these experiments with coins, but physicists can use microscopic objects, such as atoms or photons. For an atom, for example, heads and tails equate to the quantum-mechanical property of spin — in other words, spin up and spin down. Up to four individual atoms have been entangled in this way in experiments carried out in Boulder⁶ and Paris⁷. Entangling more atoms would appear to be an even greater challenge because entangled states are easily destroyed. The reason for this is that the observations that destroy quantum superpositions do not necessarily require a human observer; they can result from any physical object (even the molecules of the air surrounding the object). So, to perform experiments with entangled atoms, the atoms must be isolated in such a way that

nothing can tell which state the superposition is in. The situation gets more difficult if the entangled objects are bigger and composed of more atoms, because then the interaction of a single atom with the environment may reveal the state of the superposition, destroying the entangled state.

How, then, have Julsgaard *et al.*¹ been able to entangle objects containing trillions of atoms? The trick is to have a superposition of two states: one in which slightly more than half of the atoms in each sample are spin up and another one in which slightly more than half are spin down. If the environment interacts with one (or more) atom and 'observes' that it is spin up, this is compatible with both states, so the superposition is not destroyed but slightly damaged. As a result, trillions of atoms must interact with the environment before the entanglement disappears.

The entangled state generated by Julsgaard *et al.* was created following a proposal made by Duan *et al.*⁸, in which a single light pulse interacts with the atoms of both samples and entangles them (Fig. 1). This is the first time two different atomic samples have been entangled in this way — using light — even though the samples are separated by some distance. Now that the experiment has been done, it should be relatively simple to entangle more than two atomic samples, or to teleport states of atomic samples. The work of Julsgaard and colleagues shows that in certain situations it may be more practical, and robust, to weakly entangle many atoms rather than strongly entangle a few of them. I expect that many new experiments will follow this one and help us better understand this strange theory. At the same time, they may well revolutionize the field of quantum information. ■

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Daedalus

Ardent spirits

The fundamental laws of science, says Daedalus, must apply both to the material and spiritual worlds. These, he reckons, occupy the same space but are very weakly coupled, which is why ghosts are seldom observed and spiritual experience is rare too. The most fundamental scientific law is probably the 'zeroth law of thermodynamics': that any two objects in contact reach thermal equilibrium.

Over the age of the Universe, 18 gigayears or so, the material and spirit worlds must have equilibrated. The cosmic microwave background is 2.7 K; allowing for dark matter, the average temperature of the material world should be 10 or 15 K. The spirit world must have this temperature too, making it chilly indeed. Even the stars don't raise the average much.

Our nearest star is the Sun. The Michelson–Morley experiment found that the speed of light is the same in every solar season, making the Earth almost static with respect to the Sun. Spiritual experience and ghost observation are also independent of season, suggesting that the spirit world also moves slowly with respect to the Sun. This could be checked by flying a group of monks or nuns on Concorde or the Space Shuttle, looking to see whether spiritual insight is reduced as the velocity of the group rises with respect to the Sun.

All this leads up to a Daedalian theory of spiritual survival. To free itself for further adventures, a soul released from a body must try to warm itself, and will therefore head for the interior of the nearest star. A temperature of 16 million K will warm it usefully even with the weakest coupling, assuming that spiritual space moves slowly with respect to the solar interior. (By contrast, souls that 'go the wrong way' and head for the Earth's interior at a mere 6,000 K, will find themselves trapped in a local 'Hell'.) Furthermore, intelligent life on Earth over the years has released many souls, most of whom will have reached the Sun. They should perturb its internal reactions slightly, perhaps reducing its output of neutrinos, or setting them oscillating.

This novel theory of the solar neutrino deficit suggests a new way of seeking intelligent life around other stars. Rather than looking for the tiny librations caused by a circling planet, it would be easier to search directly for low neutrino emission by its primary star. Daedalus's recent directional neutrino telescope could prove vital.

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