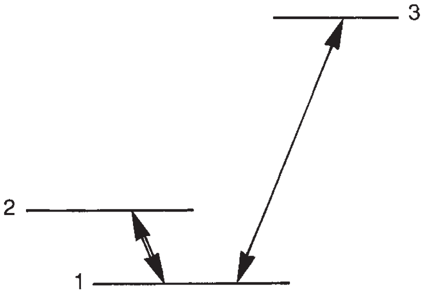
on whether t is greater than t_c. If it is, the survival probability is $(1-\gamma(T/N))$, after N such measurements the probability of survival is $(1-\gamma(T/N))^N$ which for large N is approximately the exponential decay law, $\exp(-\gamma T)$, seen in every undergraduate radioactivity text. But the survival prospects dramatically improve if we interrogate the system repeatedly so that the time elapsed between each measurement is much shorter than the internal coherence time. In this case the survival probability after N such measurements is $(1-a(T/N)^2)^N$, which for large N becomes unity: the repeated measurements collapse the state to its initial state and suppress the decay.



Level scheme used in the quantum Zeno experiment. Be^+ ions are prepared in level 1 by optical pumping. A radio-frequency field is then applied for a time T to drive transitions from state 1 to a nearby hyperfine level 2. Measurements of the survival in state 1 are made with pulses of laser light at 313 nm exciting transitions from the initial state 1 to the strongly fluorescing high-lying state 3.

Decay suppression, therefore, depends on the internal coherence time of the system, but this is usually so short that no practical measurement can be made in a time $(T/N) \ll t_c$. This has ruled out, so far, any experimental realization of decay inhibition through measurement. What Itano and co-workers have done is to settle for a simpler proposal: to inhibit not a decay but a coherent transition induced between two essentially stable atomic states driven by a radio-frequency field. Such a system does not decay and its internal coherence time is essentially infinite. Evolution is always coherent and governed by the quadratic survival probability $(1-at^2)$ for reasonably short times. Repeated interruption and the inhibition of coherent evolution is much more straightforward (although it lacks the concept of an irreversible decay characteristic of the theoretical Zeno effect).

The experiment uses laser-cooled Be^+ ions in a Penning ion trap, and drives a radio-frequency transition (at 320.7 megahertz) between ground-state hyperfine levels. Optical pumping prepares the ions in the level marked as 1 in the figure. A pulse of resonant radiofrequency radiation is applied for a time T whose amplitude and duration — 256 milliseconds — is chosen to drive all of the ions out of state 1 into the state 2. The measurement of survival in state 1 is done with a laser pulse at 313 nanometres wavelength which excites only transitions from the initial state 1 to a high-lying level 3 which strongly fluoresces. If at the time of application of the laser pulse, the ions survive in state 1, they can be driven into state 3 and the subsequent fluorescence observed. If, however, they have not survived, but have made the transition to state 2, they cannot be excited by the laser and no fluorescence is seen. The short laser pulse followed by photon counting of the fluorescence thus acts as a highly efficient measurement of the survival probability.

The number of measurements by the pulsed laser can be varied from one through to 64 within the 256 milliseconds of radio-frequency excitation. If only one is made, of course the survival probability is zero: the radio-frequency perturbation is chosen to excite all the probability out of state 1 into state 2. But if the system is interrogated by a short laser pulse half way through its coherent evolution as well the survival probability is seen to increases to one-half, in agreement with theory. As the number of measurements increase, the survival probability is seen to increase to nearly unity, indicating that the laser measurement repeatedly collapses the quantum evolution back to its initial state.

Whether the experiment tests the Zeno effect is a matter of taste: left to its own devices, the quantum system does not decay but coherently evolves. One could argue that inhibition of coherent evolution is rather less interesting and has been seen previously in laser excitation. For example, suppose the laser (the measurement apparatus) is left on continuously. Because the laser mixes into the initial state 1 some of the characteristics of the fluorescing level 3, the level 1 acquires an energy width Γ (which is the rate of stimulated transitions up to state 3 if the laser is not too strong). Then an elementary application of perturbation theory shows that the rate of radio-frequency transitions from a broadened state 1 to the state 2 is given by Ω^2/Γ where Ω is the Rabi frequency (the coherent evolution frequency) for the 1–2 radiofrequency transition. Increasing Γ reduces the radio-frequency transition rate. This is a well-known example of what is called power broadening. So the continuously observed coherent transition is well understood. But the repeatedly interrogated pulsed-excitation experiment tests a much more interesting feature of quantum dynamics: the destruction of coherent superpositions by measurement. This quantum watched pot is certainly prevented from boiling. □

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DAEDALUS

Play it again, Sam

LAST week Daedalus invented neuroseismology, a new way of reading the nerve traffic within the body. A nerve impulse produces a volume change moving along the nerve. This launches an ultrasonic disturbance into the tissues which, intercepted by an array of piezoelectric transducers on the skin, can be decoded to give the location, direction and velocity of the impulse. Proper electronic processing can even disentangle the very heavy impulse traffic in a multi-fibre nerve trunk, and can allocate every impulse to its originating fibre. Now Daedalus is taking the obvious next step. He is reversing the process, so as to induce pulses in the nerves.

The replay of a nerve recording back into the piezoelectric array would, of course, generate a zone of compression converging on the original nerve, and moving along it at the exact velocity and in the same direction as the original impulse. A nerve can be made to fire by squeezing it: this is what causes the 'pins and needles' sensation in awkwardly trapped or pressured limbs. So the replayed neuroseismogram should launch in the nerve a copy of the original impulse. An array that could spatially resolve the signals of the many fibres of a nerve trunk could also, in reverse, address them individually with the same resolution. The most complex original nerve traffic could be played back in full detail.

The obvious application of the new technology is the recording of human sensation. Why bother with videorecorders or tape machines when the nerve traffic of your own eyes and ears can be captured and replayed exactly? In principle, all the sensory delights of youth could be stored up and savoured into old age, a true *recherche du temps perdu*. In practice, however, the body grows and changes, the piezoelectric array could never be re-sited exactly, and the replay would hit the wrong nerves, giving a grotesque distortion of the original experience. Only an immediate replay could truly succeed.

The most immediate replay of all would give a neurological amplifier. A piezo-helmet that read the nerve traffic of the cranial nerves and spinal cord, and played it all back one or more times with a slight delay, would follow up every nerve impulse with one or more 'echoes'. Since the nervous system works by pulse-integration, this in effect would turn up its 'gain'. The ears would become sharper, the eyes more sensitive, taste and smell more vivid, the muscles more responsive. The user's whole world would be brighter and more dynamic. He could see in deep gloom, or lift astonishing weights, by increasing the relevant gain still further: until system noise, in the form of random sensory flicker or muscle tremor, stepped in to limit his powers.

David Jones