see fewer start-up companies in the plant biotechnology sector." Oxford's Leaver adds that "recruiting top-quality workers for plant research at the postgraduate and postdoctoral level is a major problem in the U.K.," where concerns about GM foods run particularly deep. And in Germany, plant geneticist Heinz Saeidler of the Max Planck Institute for plant propagation research in Cologne says he is getting fewer students, who see poor career prospects in such an unpopular field.

Most researchers believe the public will come to embrace transgenic crops, especially after future varieties show traits that genuinely benefit consumers, such as increased nutritional value or the elimination of natural allergens. But by then it may be too late for European researchers. "The worst case scenario is Europe taking a break to think about things," warns Nielsen. "By not concentrating on this research now we risk having to import the future products of plant biotechnology from elsewhere." —**LONE FRANK**

Lone Frank writes from Copenhagen, Denmark.

NEUROSCIENCE

Cold Numbers Unmake the Quantum Mind

Calculations show that collapsing wave functions in the scaffolding of the brain can't explain the mystery of consciousness

Sir Roger Penrose is incoherent, and Max Tegmark says he can prove it. According to Tegmark's calculations, the neurons in Penrose's brain are too warm to be performing quantum computations—a key requirement for Penrose's favorite theory of consciousness.

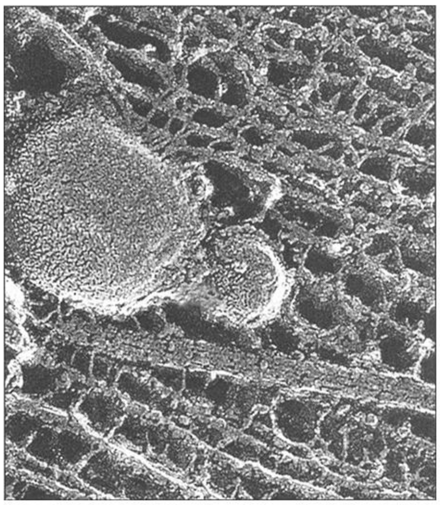
Penrose, the Oxford mathematician famous for his work on tiling the plane with various shapes, is one of a handful of scientists who believe that the ephemeral nature of consciousness suggests a quantum process. In the realm of the extremely small, an object with a property such as polarization or spin may exist in any of a number of quantum states. Or, bizarrely, it may inhabit several quantum states at once, a property called superposition. A quantum superposition is extremely fragile. If an atom in such a state interacts with its environment—by being bumped or prodded by nearby atoms, for instance—its waveform can "collapse," ending the superposition by forcing the atom to commit to one of its possible states.

To some investigators, this process of coherence and collapse seems strikingly similar to what goes on in the mind. Multiple ideas flit around below the threshold of awareness, then somehow solidify and wind up at the front of our consciousness. Quantum consciousness aficionados suspect that the analogy might be more than a coincidence. Eleven years ago, Penrose publicly joined their number, speculating in a popular book called *The Emperor's New Mind* that the brain might be acting like a quantum computer.

"Between the preconscious and conscious transition, there's no obvious threshold," says Penrose's sometime collaborator Stuart Hameroff, an anesthesiologist at the University of Arizona in Tucson. Ideas start out in superposition in the preconscious and then wind up in the conscious mind as the superposition ends and the waveform collapses. "The collapse is where consciousness comes in," says Hameroff.

But what exactly is collapsing? From his studies of neurophysiology, Hameroff knew of a possible seat for the quantum nature: "microtubules," tiny tubes constructed out of a protein called tubulin that make up the skeletons of our cells, including neurons. Tubulin proteins can take at least two different shapes—extended and contracted—so, in theory, they might be able to take both states at once. If so, then an individual tubulin protein might affect its neighbors' quantum states, which in turn affect their neighbors'—and so forth, throughout the brain. In the 1990s, Penrose and Hameroff showed how such a tubulin-based quantum messaging system could act like a huge quantum computer that might be the seat of our conscious experience.

The idea attracted a few physicists, some consciousness researchers, and a large number of mystics. Quantum physicists, however, largely ignored it as too speculative to be worth testing with numerical calculations. Now Tegmark, a physicist at the University of Pennsylvania, has done the numbers. In the February issue of *Physical Review E*, Tegmark presents calculations showing just what a terrible environment the brain is for quantum computation.



Broken thread. Microtubules decohere too fast to generate our thought patterns.

CREDIT: N. HIROKAWA

Combining data about the brain's temperature, the sizes of various proposed quantum objects, and disturbances caused by such things as nearby ions, Tegmark calculated how long microtubules and other possible quantum computers within the brain might remain in superposition before they decohere. His answer: The superpositions disappear in 10^{-13} to 10^{-20} seconds. Because the fastest neurons tend to operate on a time scale of 10^{-3} seconds or so, Tegmark concludes that whatever the brain's quantum nature is, it decoheres far too rapidly for the neurons to take advantage of it.

"If our neurons have anything at all to do with our thinking, if all these electrical firings correspond in any way to our thought patterns, we are not quantum computers," says Tegmark. The problem is that the matter inside our skulls is warm and ever-changing on an atomic scale, an environment that dooms any nascent quantum computation before it can affect our thought patterns. For quantum effects to become important, the brain would have to be a tiny fraction of a degree above absolute zero.

Hameroff is unconvinced. "It's obvious that thermal decoherence is going to be a problem, but I think biology has ways around it," he says. Water molecules in the brain tissue, for instance, might keep tubulin coherent by shielding the microtubules from their environment. "In back-of-the-envelope calculations, I made up those 13 orders of magnitude pretty easily."

Some members of the quantum-consciousness community, however, concede that Tegmark has landed a body blow on Penrose-Hameroff–type views of the brain. "Those models are severely impacted by these results," says physicist Henry Stapp of Lawrence Berkeley National Laboratory in California. (Stapp's own theory of quantum consciousness, he says, is unaffected by Tegmark's arguments.)

Physicists outside the fray, such as IBM's John Smolin, say the calculations confirm what they had suspected all along. "We're not working with a brain that's near absolute zero. It's reasonably unlikely that the brain evolved quantum behavior," he says. Smolin adds: "I'm conscientiously staying away" from the debate. —**CHARLES SEIFE**