

salts — the charged material causes the reduction of  $\text{Cu}^{2+}$  ions to Cu metal and the latter is deposited on the electrode (Fig. 1b). By analysis of the product, the charge density is estimated to be similar to that found in the previous experiment, around  $7 \times 10^{14} \text{ cm}^{-2}$ . Further electrochemical reactions were possible — including the reduction of  $\text{Fe}(\text{CN})_6^{3-}$  to  $\text{Fe}(\text{CN})_6^{4-}$  and the generation of chemiluminescence — all of which indicate the electron is the charge carrier for the single-electrode system.

As is the case with any new process in science, single-electrode electrochemistry raises new questions. For instance, is there a spatial distribution of electrons on the surface chains, or does a certain electronic distribution exist inside the dielectric material? And, is it possible to use electronic conduction on the dielectric to produce cooperative electrodeposition, nucleation and growth of metals or gases?

In future studies, the technique could be applied to other dielectric materials of various sizes and shapes, and different media including solutions, gases, gels and protoplasm. Both negative and positive electrodes should be possible by contacting

two insulators and then using them as individual electrodes in different cells. Also, by rubbing together different materials, it may be possible to obtain a wide range of electrode potentials. This could culminate in a list of electrode potentials — similar to normal electrode potentials and the triboelectric series<sup>1</sup> — for electrostatically charged insulators. This would allow a scientist to choose, at a glance, the most suitable dielectric material to generate chemicals, collect and identify pollutants from soil and water, obtain metallic patterns of dielectric materials and stimulate biological processes in living cells.

Further questions remain about the dielectric nature of individual polymeric chains, and whether the storage of electrons followed by reduction in solution induce, as in the case of conducting polymers<sup>6</sup>, conformational movements of the chains. The system requires deeper study to determine the potential gradient across the electrical double layer at the dielectric–solution interface. In addition, evolution of hydrogen eliminates protons from the solution and induces solution basification ( $\text{OH}^-$  concentration increases);

if the single-electrode discharges other cations, for example,  $\text{Cu}^{2+}$  in the copper electrodeposition experiment, an equivalent number of anions (for example,  $\text{SO}_4^{2-}$ ) should remain in solution — how these surplus charges are balanced requires clarification. Finally, the efficiency of the process and the possibility of deterioration of the single dielectric electrodes, as is observed with the long-term use of metallic electrodes, need to be investigated.

Its practical simplicity makes this one-electrode experiment attractive in the clarification of any complex electrochemical concept. As a result, this single-electrode technique is not limited to electrochemists — biologists, clinicians, physicists and engineers could easily use it to develop products and understand biological processes.

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## MATERIAL WITNESS

### Quantum writ large



The standard journalistic shorthand for quantum theory calls it ‘the theory that describes very small objects such as atoms’. It’s convenient, generally pertinent, and historically reasonable, but sadly that doesn’t stop it from being wrong. (Whether it will stop

me from using it is another matter.)

The notion most students of quantum theory are given is that its limits are a matter of spatial scale: quantized energy levels get ever more closely spaced as the system size increases, until eventually they blur into a continuum. There is some truth in that, but it’s not the end of the matter. For one thing, it doesn’t explain the most striking distinction between classical and quantum physics, which is not discreteness of energies but the fact that superpositions of states — being in two places at once, say — make perfect sense in the quantum world but perfect nonsense in the classical. The usual explanation for classicality now invokes decoherence, a dispersal of quantum behaviour as a quantum object interacts with its environment.

The fundamental problem of quantum superpositions at macroscopic scales was made clear in Schrödinger’s *gedanken* experiment with a cat, a box, and a bottle of poison opened by the decay of an atom. Again, students are often given a handwaving argument for why the cat cannot be in a superposition of live and dead states: the quantum weirdness is somehow washed out by decoherence in the chain of interactions leading from the atom to the many-particle animal and its environment.

It’s sobering, then, to realize that the cat’s fate is still disputed. Wojciech Zurek of the Los Alamos National Laboratory, a former student of the late John Wheeler, remembers a talk on these issues at a condensed-matter conference some time ago. “At one point the speaker asked the audience, ‘So do you really believe that the cat in the box, assuming perfect isolation, is in a dead/alive superposition?’”, he says. “The vote was an overwhelming disbelief in the suspension of the cat between life and death.”

But when Zurek saw the same question raised at another meeting around 2005 involving researchers in the burgeoning

new field of quantum information, “people had no problem with the cat in a superposition.” This younger audience seemingly embraced quantumness, however classically paradoxical.

Surely materials scientists needn’t worry about such foundational issues, but can take the pragmatic ‘shut up and calculate’ view that quantum theory is just a handy tool for deducing the properties of condensed matter? Not necessarily. For instance, nanoelectromechanical systems such as nanoscale resonating arms, potential high-precision force and displacement sensors, now operate at scales where quantum effects could remain evident even in structures containing billions of atoms. One must work incredibly hard to see them, cooling the devices to millikelvin temperatures. But in principle these structures could reveal the haziness in position imposed by the uncertainty principle, and the strange prospect of microscopically visible objects (‘Schrödinger’s kittens’) being effectively in two places at once, showing that quantum mechanics is not sizeist after all.

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