QUANTUM GRAVITY

A SQUID's loss of coherence

Ian Moss

QUANTUM cosmologists, accepting that the natural scale of events in quantum gravity is a mere 10^{-33} cm (the Planck length), have become accustomed to the idea that laboratory tests of their theories are unlikely to be forthcoming. Thus, the idea now put forward by Ellis, Mohanty and Nanopoulos[1] that SQUIDs, small superconducting magnetometers, might be noticeably affected by Planck-scale gravitational 'wormholes' is bound to be taken up with interest.

The special property of a SQUID — properly a superconducting quantum interference device — that is relevant here is that it displays coherent quantum phenomena despite its macroscopic size. A more familiar example of coherence is found when light is passed through a pair of slits and projected onto a screen: with low intensities, an interference pattern is seen, representing the relative phase of the light waves passing through each slit. Increase the intensity of the source and the pattern fades, because many bunches of photons arrive at the screen with random relative phases. This loss of phase coherence is typical of macroscopic systems in which the interactions between numerous particles obliterate the phase information.

For SQUIDs, in which the phase is that of the electrons passing through a resistive barrier, the low level of dissipation allows it to remain in a prepared coherent state on timescales of 10^{-4} s. Ellis and colleagues suggest that this time is sufficiently long for an additional mechanism that destroys coherence — quantum wormholes — to become apparent.

In any theory of quantum gravity, quantum fluctuations are expected to arise in both space and time. A theory of quantum wormholes has been developed to describe these fluctuations. A wormhole represents the creation of a 'baby universe', a self-contained piece of space that is disconnected from the rest of the Universe and owes its existence to a quantum fluctuation. Wormholes have another important property: they connect distant parts of space and time, rather like bridges in the geometry of space.

Any piece of space would be riddled with these wormholes, but their tiny size makes them far too small to be seen. Their only effect is to introduce many stochastic parameters into the world, which are the quantum numbers of the baby universes. These parameters modify all the fundamental constants of nature. They also give a means for losing coherence by scrambling of the quantum phases.

The strength of the effect that these wormholes can have on a macroscopic device is determined by a single parameter, λ. Unfortunately, the theory of quantum wormholes is too immature for us to calculate λ reliably. Stephen Hawking has pioneered calculations of the kind needed[2,3], and finds that λ should have a value of the order of either one or zero: one corresponds to a large effect, so that zero is the only reasonable value.

But Sidney Coleman[4] has improved on Hawking's methods by including the effects of not just one, but many wormholes. The result is that the baby-universe parameters are driven to definite values (see L. F. Abbott's News and Views article[5]). Coleman calls this the "big fix". If he is correct, the constants of nature are fixed and quantum wormholes cannot destroy coherence.

But if Coleman is wrong, as Ellis and colleagues assume for their calculations, the gravitational scrambling of phase may be possible. They suggest, somewhat arbitrarily, that the parameter λ is given by the ratio of the electron mass (10^{-31} g) to the scale mass, or Planck mass, for quantum gravity, 10^{-5} g — a value which is not unreasonable on dimensional grounds, but which has no firm physical basis. This value is sufficiently small for the wormholes not to influence most physical phenomena. But in the coherent state of the SQUID, its effect becomes multiplied by the number of electrons in the SQUID, around 10^{19}, so that there is a measurable effect: Ellis and colleagues suggest that coherence should be lost on a timescale of 1,000 s. To observe the loss of coherence, the authors suggest firing a beam of polarized neutrons through the centre of the SQUID (a ring-shaped device) and observing the decay of the oscillatory interference pattern they produce owing to the device's magnetic field. The difficulty would be to distinguish the weak wormhole effect from the stronger conventional effects.

It may be a little premature to be making such detailed predictions about wormholes, given the current state of theory. On the other hand, it is possible that the authors have made a lucky guess and we could be on the verge of measuring something truly astonishing. ☐

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FUEL CELLS

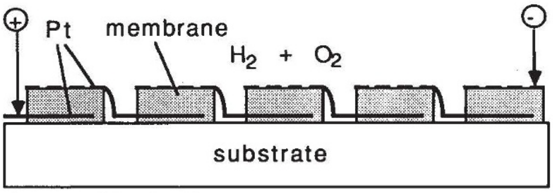
Miniaturized electrochemistry

Thomas E. Mallouk

OVER the past decade, electrochemists have turned their attention towards smaller and smaller devices. Electrochemical cells made with micrometre- and nanometre-size components have physical characteristics which differ from those of their macroscopic relatives, and they have been widely studied because of potential applications as chemical sensors and molecular electronic devices. On page 547 of this issue[1], C. K. Dyer describes a solid-state fuel cell, based on the oxygen–hydrogen reaction, that is less than a micrometre across. Although its current output is only low (around 100 μA cm^{-2}, compared with 100 mA cm^{-2} as available from conventional fuel cells under similar conditions[2]), its simple design and small size make it appropriate for use in series arrays to power microchips (see figure).

Conventional fuel cells, which were essential, for example, to the Apollo programme, use the combustion of hydrogen or methane to generate small voltages. To do this, they are constructed in the manner of an electrochemical battery, with the oxidation of hydrogen at one electrode releasing electrons and reduction of oxygen at the other mopping them up. The unexpected novelty of Dyer's cell is that it develops an unusually large voltage in *mixtures* of hydrogen and oxygen.

Both the magnitude and the polarity of the open-circuit voltage are hard to explain. If the two half-cell reactions (oxidation and reduction) are kinetically facile at both of the platinum electrodes that constitute the cell, it is hard to see how a voltage can be generated between the electrodes from gas mixtures. Unless one invokes Maxwell's demon to partition the reagents between the electrodes, one is forced to suppose that hydrogen gettering, or some similar mechanism, at the exposed outer electrode promotes hydro-



A series of thin-film fuel cells, after Dyer's design, operating in a mixture of hydrogen and oxygen.