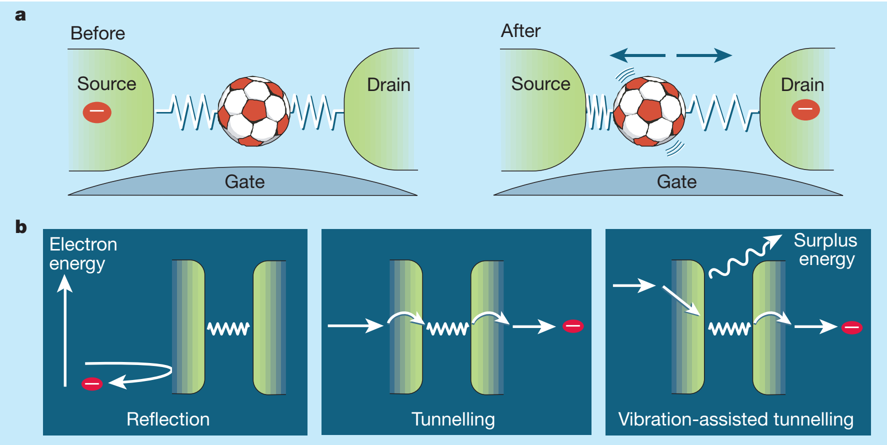

Figure 1 **How to build a transistor from a single C_{60} molecule.** a, **The C_{60} transistor can be viewed as a soccer ball bound by two springs to the gold electrodes. First the C_{60} ball is at rest and one electron is at the source electrode. After the electron has tunnelled via the C_{60} ball to the drain electrode, it has excited the C_{60} enough to bounce the molecular ball back and forth between the two electrodes.** b, **Possible electron tunnelling processes through the transistor, depending on the energy of the incoming electron. The energy of the electron has to be just right for electron tunnelling: if the energy is too high or too low it will be reflected. But if the C_{60} ball can be made to vibrate it can assist in tunnelling, as Park *et al.*[1] show in their device.**

coupling we need to consider the energies that are involved in the different tunnelling processes (Fig. 1b).

To hop on the molecule, an electron has to have the correct energy to occupy a discrete molecular state. Too little energy leads to the electron being reflected, in which case it will not contribute to the current. If the electron has precisely the right amount of energy to occupy the lowest unoccupied molecular state, it can hop on and off, giving rise to electrical current. Too much energy usually also leads to reflection. But in quantum mechanics there exists an extra process by which an electron can tunnel across the molecule, owing to the unavoidable existence of fluctuations even at zero temperature. If the electron has a surplus energy precisely equal to the vibrational energy of C_{60}, then by spontaneous emission of this surplus energy, which starts the C_{60} ball bouncing, it can still hop on and off the molecule. In Park and co-workers' C_{60} device, the applied voltage controls the surplus electron energy. So a sudden current rise at a particular voltage indicates that the C_{60} ball is being made to oscillate.

When bouncing a ball on the ground with your hands, the amplitude and frequency of the bounces are determined mostly by the elasticity of the ball and the forces from gravity and your hands. A similar situation is experienced by the C_{60} ball. The force that makes the molecule stick to the surface of the gold electrodes is the van der Waals interaction. This sticking is not completely rigid. Electrons hopping on the C_{60} ball play the role of the hands, bringing the molecule into motion. But the bounces occur only at particular frequencies, owing to the quantization imposed by quantum mechanics. When the shape of the C_{60} ball does not deform, the bouncing frequency is about 1 terahertz. If the electrons hit the ball with more energy thereby denting the shape, the bouncing occurs about ten times faster. Park *et al.* found evidence for both types of motion.

In basketball, for regular bounces, the motion of the hand needs to be in phase with the ball's motion. The new experiment by Park *et al.* does not measure or control the phase between the motions of the electrons and the C_{60} molecule. But it has been predicted that, under specific circumstances, every time the C_{60} ball is close to the source electrode an electron might hop on, and when it reaches the drain electrode it would hop off[4]. If during each cycle of the C_{60} oscillation an electron is transferred across, then, because the frequency of the C_{60} bounces is quantized, the electric current also becomes quantized. Electronic devices in which the electro-mechanical motion is strictly coupled in this way could function as 'electron turnstiles' that allow electrons to pass one at a time. Devices in which electrons are under such tight control are being sought to provide a means for measuring electrical current with extreme accuracy[5]. ■

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Daedalus

Cleaning the cleaner

The traditional cleaning cloth or wiping rag is a universal accessory in every kitchen, workshop and laboratory. But it is ecologically very unsound. The cloth either has to be cleaned in its turn, or must be thrown away, adding to the growing pile of organic waste. Seeking a better technology, Daedalus has been inspired by a kitchen household hint. To clean a dirty kitchen table, wipe it down with a kitten; then hand the kitten back to its mother for grooming.

This primitive biological 'disposal at source' can clearly be improved. DREADCO's biologists are devising a cleaning-rag bearing a carefully formulated mixed bacterial ecology. Some of the organisms degrade hydrocarbons, some hydrolyse proteins, and others split fats. The DREADCO 'Dirt Eater' will be made by dipping a thick inert fabric impregnated with polymerization catalyst into a bacterial culture containing suitable monomers. It will acquire a thin polymer coating loaded with trapped bacteria. A lightly crosslinked alkyd resin should resist bacterial attack while allowing water and organic molecules to diffuse readily through it. Bacteria are immortal, but trapped in the polymer they will have no room to divide. They will also be unable to escape to contaminate objects cleaned by the cloth. After each use, the Dirt Eater will slowly 'digest' the dirt it has picked up, turning it to gases or simple water-soluble molecules. A hygroscopic component in the cloth will prevent it drying out during its digestion period. An active kitchen or workshop would use a set of Dirt Eaters in rotation.

Dirt Eaters will rapidly replace traditional kitchen rags, domestic mops and bathroom flannels. They could even transform medical practice. A self-cleaning wound dressing would save the repeated work and distress of changing such dressings. For this service, however, even a small escape of bacteria could not be tolerated. Daedalus may have to devise a sterile Dirt Eater containing not trapped bacteria, but supported enzymes from them.

Yet even the most voracious bacterial or enzyme system will be unable to digest all possible contaminants. The Dirt Eater may also need a layer of that powerful photo-oxidation catalyst titanium dioxide. When it shows signs of indigestion, it could be laid out in the daylight for a while. Biologically resistant contamination would be mineralized, freeing the Dirt Eater for re-use. **David Jones**