ments with insulating barriers have been turning up these anomalies of raised conductance at low bias, which were difficult to explain (hence the vague, generic name). One explanation proposed is a magnetic interaction (the Kondo effect[10]) that involves the screening of a magnetic impurity by electron spins. In Gregory's experiment, the screening of a single magnetic atom apparently dominates the conductance, which can be made to change about tenfold. By shifting the wires, he can see discrete switching events that indicate sudden changes between different magnetic centres. (A change through many would be smooth.) The results of this experiment speak to a range of deep questions in physics of disordered materials, where magnetic interactions are at the heart of such problems as the transition from conductor to insulator[11].

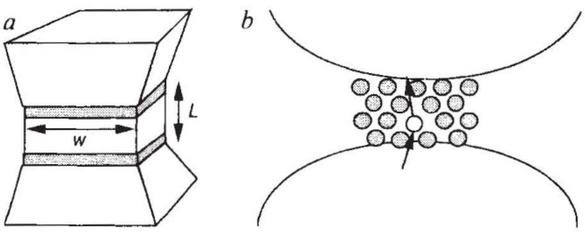

FIG. 2 The conduction path in a resonant tunnelling device can be restricted to a small port by (*a*) circuit lithography[1] or (*b*) tunnelling sensitivity[2] as in tunnelling microscopes. Impurities in the tunnelling regions almost wholly control the conductance if the port is small enough.

How might such devices be used in electronic circuits? Resonant tunnelling is a straightforward extension of the Esaki (or tunnel) diode. The peaks in the current–voltage curve provide regions of negative conductivity — where current is increased by *decreasing* the bias voltage. In the Esaki diode, this region is used in making high-precision oscillator circuits, and the single-atom resonant-tunnelling devices could be used to the same effect. Alternatively, the confined region could be biased independently with a third electrode, to create something more like a conventional transistor, with the conductance between the in and out connections controlled by the third. With Gregory's device, it is hard to see how a third connection could be made, but the applied magnetic field, tweaking the zero-bias anomaly, would achieve the same purpose. It is unlikely that the crossed-wire system would be used as it stands, but it is a powerful tool (because of its mechanical stability) for studying tunnelling processes. Resonant tunnelling, on the other hand, already has a demonstrated range of applications in transistors[12] and further applications in logic circuits are proposed[13].

In each of these experiments, the single atom governing the conductance is either a donor fortuitously situated near the tunnel barrier[1] or a magnetic asperity on the surface of a tungsten wire[2]. Although the experiments were carefully planned, the authors had to rely on luck for the placement of the impurities, which does not bode well for those who would like to make single-atom transistors. But several experiments have shown how one can use a scanning microscope probe to place atoms in specified positions on the surface of a semiconductor. Indeed, that was the basis of the atomic switch described by Eigler *et al.* last year[3], in which a single xenon atom was toggled between 'on' and 'off' positions.

The question for the practical use of atom-scale electronics becomes one of quality control. If the atom-scale circuitry can be made to do the work of a transistor, then this is a small step towards its use in practical circuits. The problem is repeating the process reliably: this is already forbidding in contemporary electronics, where keeping production facilities clean has become one of the main manufacturing tasks. To pack memory cells one thousand times more densely and do it reliably will require herculean efforts to keep the manufacturing environment controlled.

This still leaves untouched the question of connecting the transistors together. Interconnects now take up a large fraction of the area on the largest modern chips. Some new scheme will be required for the atomic-scale transistors — the simple isolated transistor connected by wires to others will become a thing of the past, to be replaced by functionally integrated circuits dedicated to particular operations. □

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DAEDALUS

Raising the roof

A BALLOON is an elegant flying machine, but its huge envelope wastes a lot of space. Daedalus once proposed a Zeppelin filled, not with pure helium, but with 80% helium and 20% oxygen. This lifting gas supports respiration. The whole vast envelope could then double as a spacious cabin for crew and passengers — a welcome change from the cramped fuselage of conventional aircraft. With its low density and inertia, the gas would be wonderfully light and easy to breathe, a boon to asthmatics and bronchial sufferers. Sadly, it would also raise their voices to an unintelligible duck-speak.

The envelope of a hot-air balloon, full of propane combustion gases, would be less welcoming. It would need some sort of heat-exchanger, ejecting the fumes of combustion while transferring their heat to the entrapped air. Daedalus was glumly concluding that a balloon so burdened would never get airborne, when he realized the advantages of simply leaving it on the ground. An anchored hot-air balloon would make an ideal tent.

The conventional pressure dome, kept inflated by a continuously running blower, has to be well sealed around the rim, and must be entered through an airlock. By contrast, Daedalus's hemispherical 'Hot-house' will be kept inflated by the hot air inside it, balloon-fashion. Its base will be at atmospheric pressure; it will need no rim seal and can be entered through normal doors.

Like all balloons, Hot-houses will get better as they get bigger. Really large ones could afford quite a thick, insulating fabric construction. They would then stay inflated on relatively little heat — perhaps that released naturally by the inhabitants and their equipment. Cheap, colourful and effective, Hot-houses will be ideal for exhibition halls, sports-centres and even factories, especially in cold climates. In sunnier regions, transparent Hot-houses could be kept inflated by pure sunlight. They could then serve as huge, elegant agricultural greenhouses. But even a solar Hot-house will need some sort of thermostatted emergency heating system to keep it inflated on cold nights or to melt any snow-load that threatens to collapse it. And every Hot-house will need to be firmly anchored against taking off — but not too firmly. Daedalus's design has strong but easily melted ground couplings. If fire breaks out in a Hot-house, its restraining ties will melt. The whole envelope will simply rise into the air, taking the smoke and fumes of the blaze with it. The inhabitants can walk away unimpeded, while the fire services tackle whatever contents are burning on the ground.

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