equivalent of a diode, a pressure-sensitive valve (see Fig. 1b). At low liquid pressures, such a valve strongly limits the flow of liquid. But as the pressure is increased, the valve opens up, allowing the liquid to flow more freely. The importance of this element is evident when you consider the response of a resistor, capacitor and pressure-sensitive valve connected in series. The frequency-dependent resistor and capacitor establish a narrow range of frequencies with large enough pressures to maintain the valve open and generate a net flow.

Leslie *et al.* demonstrate this approach by constructing two different channels, built with two sets of resistors, capacitors and diodes; the two branches have different characteristic frequencies, are filled with two different coloured liquids and are fed into a single output channel (see Fig. 1c). Driving the two channels with a single oscillatory pressure source, they show that as the driving frequency ω is varied, the liquid flowing to the output channel changes from one predominant colour to another, which demonstrates that the flow has switched from one input channel to the other.

Although it is certainly a promising development, there is still much to be done. The switching from one channel to another is not perfect, which is probably because of the relatively large bandwidth of each channel's resonant response. The authors note that this is one of the first issues that they hope to address in future research. Looking forward, it is interesting to imagine how this concept will scale up to manipulate the flow through many more channels or perhaps in three-dimensional networks[6]. Alternatively, the integration of CMOS technologies with microfluidic networks[7] allows ready manipulation of materials using electric and magnetic fields without extensive hardware. It might then be possible to use embedded magnets in elastic materials to actively manipulate the resonant characteristics of different parts of a microfluidic circuit and thus allow even greater control over the properties and behaviour of the system as a whole. ❐

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NANOTECHNOLOGY

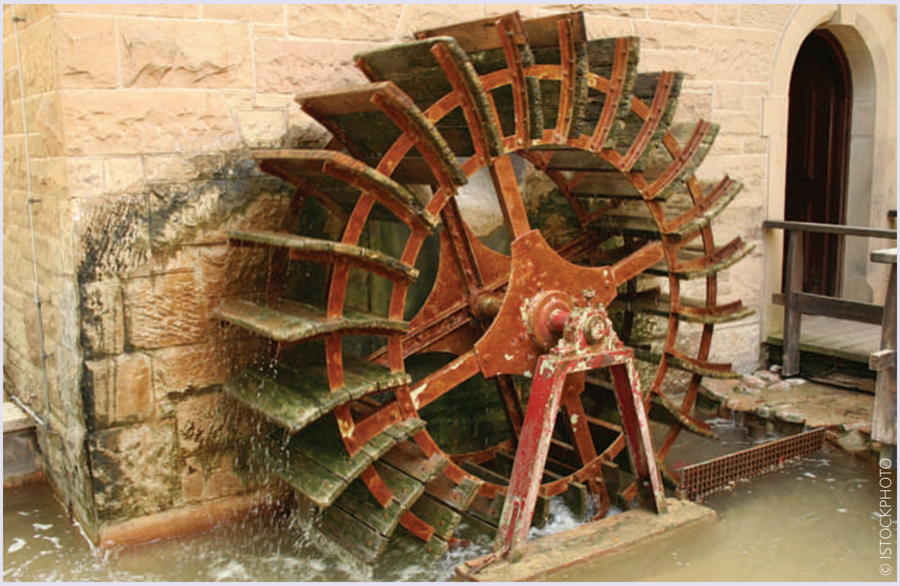
Atomic waterwheels set in motion

Waterwheels have been used for centuries to harness the energy of flowing water. Simulations reported in *Nature Nanotechnology* show that the same idea could be transferred to the atomic scale — a 'waterwheel' made of just a few atoms that is driven by a stream of electrons.

Advances in computational techniques have made it possible to investigate the ways in which a current affects individual atoms in a conductor. This power has provided a better understanding of the damage that can be done to electrical interconnects by the current-induced forces that act on atoms, a consideration that becomes increasingly important as circuitry gets smaller and smaller.

Daniel Dundas and his colleagues wondered, however, whether these forces could be put to a more productive use (*Nature Nanotech*. **4,** 99–102; 2009). To phrase it more technically, is the energy conserved by the current-induced forces or is there some spare that can be put to work? It is a question that has been considered before but no clear answer had been found — until now.

The system that Dundas *et al*. investigated is a simple one, comprising a line of atoms — an atomic wire — with an electrode attached at each end to enable a voltage to be applied. The wire is given a sharp bend in the middle, at an atom that



is of a different type from the others. In the simulations, this atom is allowed to move and its trajectory is calculated when a bias is applied.

When the wire is bent by 70° and 1 volt is applied, the central atom eventually settles into an orbital trajectory, the radius of which slowly increases. This demonstrates that net work is being done during each revolution: that is, the current-induced forces are non-conservative.

This current-driven atomic motor is, of course, overly simple. However, it represents a formal solution to an important question. And if nanotechnology continues to advance at the rate at which it has over the past decade or so, it may not be that long before devices based on this initial concept are realized in practice.

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