

smaller than 100 nm or so in size, a new force is expected to emerge<sup>2-4</sup>. When the electrons that constitute the current pass through a magnetic conductor, their spins will become preferentially aligned to the magnetic direction — that is, they are ‘spin-polarized’. These spins may be repolarized into a new direction when they encounter another magnet (Fig. 1a). In repolarizing the current, the nanomagnet experiences a torque (or turning force) associated with the change in angular momentum that occurs from the rotation of the electron spins. This spin-transfer torque can pump enough energy into the nanomagnet for its magnetic moment to precess — that is, it moves at microwave frequencies around the symmetry axis with ever-increasing amplitude until it reverses its orientation, accomplishing a magnetic switch (Fig. 1b).

The spin-transfer mechanism is both unique and efficient. It is unique because it relies on the amplification of magnetic precession. Under spin-transfer excitation, such precession can even become persistent under balanced conditions with a steady current and a static magnetic field. The mechanism is efficient because, theoretically, it would need a current of only a few hundred microamperes to reverse the moment of a nanomagnet whose reversal would otherwise

require the action of a very strong magnetic field (of the order of a tesla)<sup>5</sup>. This makes the spin-transfer mechanism very interesting as a means of writing magnetic memory.

The current-driven reversal of a nanomagnet has been seen in experiments<sup>5-8</sup>, with observations that are consistent with a spin-transfer mechanism. The presence of spin-transfer dynamics at microwave frequencies has also been implied by earlier work<sup>9</sup> in which a spin-transfer junction was irradiated with microwaves. To definitively prove the presence of a spin-transfer mechanism, however, the reverse microwave effect should be sought — that is, the persistent emission of microwaves (generated as the nanomagnet moment precesses) from a device through which current is flowing. This would be a unique signature for spin transfer and impossible for a current-induced magnetic field to produce.

This is exactly what Kiselev *et al.*<sup>1</sup> have done. They attached a broadband microwave receiver to a painstakingly fabricated, magnetic ‘nano-pillar’ — two interleaved layers of magnetic and non-magnetic materials, 70 nm by 130 nm in lateral size. The electron spin direction is set as the current passes through the thicker (fixed) magnetic layer, about 40 nm thick (Fig. 1a). As the current then moves into the much thinner magnetic

layer (3 nm thick), it creates a spin-transfer torque on the magnetic moment of this layer, which emits microwaves as its moment precesses continuously under spin-transfer excitation. By detecting this microwave radiation, Kiselev *et al.* were able to map out the oscillation strength at different frequencies as a function of the electric current and magnetic field, and then to compare this map quantitatively with a model calculation.

It is a very convincing experiment. The only input is a steady electric current. The output undeniably contains microwave emission, in the expected frequency range. Through the spin-transfer mechanism, a current is seen to excite high-frequency magnetic precession, much like the flow of air through a flute excites an audible air vibration.

A magnetic flute sounds like music to the ear for spintronics. What future will it hold for computer memory? In the short term, this will depend critically on two factors. First, the threshold current density needs to be lowered: integration with existing electronic technology would require switching currents of less than 10<sup>5</sup> to 10<sup>6</sup> amperes per square centimetre, but for present spin-transfer switches these are more than 10<sup>7</sup> amperes per square centimetre. Second, read-out signals need to be larger, which means that the resistance of a spin-transfer

Zoology

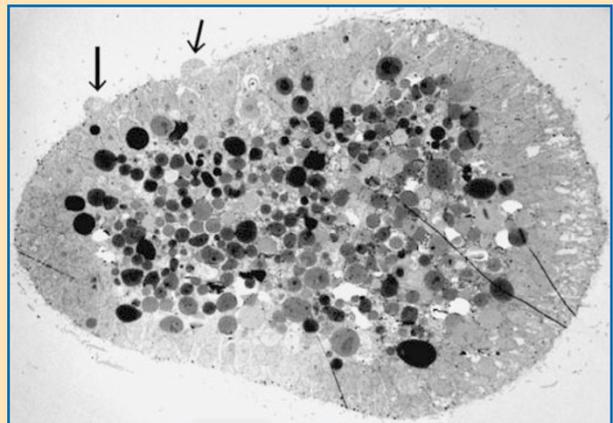
Light touch on the rudder

The larva of the box jellyfish *Tripedalia cystophora* is an uncomplicated creature: it consists of only five cell types. But studies of the animal and of one cell type in particular, the light-sensitive ‘ocellus’, have produced an intriguing set of observations. Most strikingly, the larvae seem not to have a nervous system of any kind to which the photoreceptors could be connected. In the words of Karin Nordström and colleagues, whose work it is, the photoreceptors are “self-contained sensory-motor entities” (*Proc. R. Soc. Lond. B* doi: 10.1098/rspb.2003.2504).

The life cycle of box jellyfish has three phases: a swimming larval stage; a stationary polyp; and the medusa, the familiar jellyfish form, again free-swimming, which in this case is square in cross-section (hence the name of the group). The larva is pear-shaped, but only about 200 μm in length. Tooled up with a transmission electron microscope, Nordström *et al.* set about looking at it in detail.

An individual larva has 10–15 ocelli, two of which are arrowed in this micrograph of the whole organism. Each consists of a single cell, and together they form an array around the rear-end of the animal relative to the direction of movement. The cell contains a ‘cup’ of screening pigment, which is filled with structures that Nordström *et al.* argue are the light-sensing devices. The cups point out at an angle towards the front of the animal. In swimming, the animal also rotates continually (at about two turns per second), so the photoreceptors constitute a scanning system of the light conditions ahead of it.

Another feature of each ocellus is a protruding hair-like cilium. Certain cilia can themselves act as photoreceptors. The authors think that that’s not the case here: such a function requires heavy modification, not evident in the ocellar cilia of the *Tripedalia* larva. So could the cilium be functioning as an active motor? Again no, it seems. Another larval cell type bears cilia for propulsion;



and the ocelli don’t have the extra power packs, in the form of mitochondria, that would be expected in a system that has the dual functions of light-sensing and propulsion.

The explanation that Nordström *et al.* plump for is that the function of the ocellar cilia is that of rudders. They control a larva’s swimming direction by flexing and stretching, steering it towards (or away

from) desirable (or undesirable) conditions signalled by the light regime.

There remains the question of why an array for sensing light conditions ahead of an organism should be set at the back of the body, rather than at the front. Nordström *et al.* have an explanation for that too. It’s because the sensor is also a rudder, and rudders work best at the stern. **Tim Lincoln**