of the Bi-2212 wires enables coil winding and cabling, which is especially relevant for applications in very high-field magnets for nuclear magnetic resonance. This gives the potential for generating steady magnetic fields well over 30 T, with only minimal power expenditure for the cryogenic system required to keep the magnet cold.

To realize the full practical potential of this material, however, a number of other issues related to coil fabrication and the operation of superconducting magnets at very high fields must be overcome. These include the practical feasibility of carrying out the overpressure treatment over an entire coil-winding process, and the engineering challenges of mechanically reinforcing the winding for very high Lorentz-force-induced stresses. It should also be underlined that this material reaches very high critical currents under high magnetic field, yet only in a temperature range that requires operation near 4.2 K. Bi-2212 is therefore perhaps better described as a very high-field superconductor, rather than a high-temperature superconductor. Nevertheless, the achievement of increasing the critical current and engineering current density in round wires of Bi-2212 is a key milestone in bringing high-temperature superconductivity to an important area of scientific research and commercial magnet technology. ❐

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MATERIAL WITNESS

SOFT-HEARTED ROBOTS

PHILIP BALL

Most smart materials are not all that smart. They will typically change shape, or alter some other function such as transparency or conductivity, in response to an external stimulus. But this responsiveness tends to be a one-trick affair: the material will do its thing, then reverse it. A material that can reconfigure itself into an arbitrary shape has another order of smartness: you might compare it to the difference between a Babbage-style adding machine and a programmable computer. That, indeed, is why such a protean substance is often described as programmable matter.

One strategy for achieving that shape-shifting capability is immensely ambitious and arises from the vision sketched by Toffoli and Margolus when they first coined the phrase 'programmable matter'[1]. It imagines a set of fundamental building blocks — atoms, after a fashion — that are imbued with the ability to move, adhere, communicate and locate themselves. Given a target shape (or perhaps texture or appearance), they use algorithmic processes derived from distributed computing to figure out where each must go. There are already efforts to build such 'smart grains'[2,3], although at present they are macroscopic objects with only a limited subset of the required functionalities. Ultimately this approach merges with the field of reconfigurable robotics.

A simpler approach is to create continuous soft materials embedded with actuators that can deform them[4,5]. The range of shape changes will surely be more limited and already built into the architecture, but these 'soft machines' are much easier to make and could already find useful applications. Their compliance means that they can hold and manipulate delicate objects, and the use of elastomeric polymers enables a biocompatibility that recommends them for medical use.

One particularly convenient method for actuating soft robots is pneumatic: compressed air is used to inflate bubble-like chambers to cause deformation. Whitesides and colleagues have used bellows-type structures to induce bending in this way[4] and have even shown a self-healing capability towards puncture when the fabric is an especially soft silicone[6]. But the shape changes are still rather simple and restricted.

That is why the soft machine reported by Roche *et al.* moves matters along[7]. They use an actuation scheme that is already 50 years old: pneumatic extension and contraction of a tube surrounded by a tough fibrous mesh. This is fast and reliable, but in itself offers only one mode of actuation. However, Roche *et al.* recognize that nature works with a similarly limited actuator — contractile muscle fibres — to produce complex shape changes in tissues thanks to the coordinated action of many oriented fibres. The researchers have drawn on the morphology of the heart, where muscle fibres spiral gently around the cavities, to make a bowl-shaped elastomeric ventricle powered by these curving tubular actuators. Like the cardiac ventricle, the structure undergoes a twist as its base is drawn upwards towards the rim. The resulting device might not only serve as a prototype for medical prostheses, but, because each pneumatic tube is individually addressable, can also offer a simple model for understanding how pathological movements of the real ventricle are related to dysfunction of its muscular drivers. ❐

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