MATERIAL WITNESS

SPINNING TOP-OLOGY

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The French philosopher-physicist Pierre Duhem, reviewing Oliver Lodge's 1889 book on electricity, complained that it was filled less with electromagnetic theory than with cumbersome mechanical models of it: "strings which move around pulleys, which roll around drums, which go through pearl beads, which carry weights". "We find ourselves", Duhem grumbled, "in a factory".

This probably seemed to him a tiresome British tendency. Hadn't Maxwell himself offered a mechanical model of the ether that looked like a network of bedsprings and piano wire, vibrating with light? But mechanical models have stood their ground; if anything, they have had a new lease of life. To Maxwell and Lodge they were analogies, mere aids to thinking. But with an increasing ability to engineer at microscopic and atomic scales, it is feasible to effect a literal translation from handmade components to invisibly small ones. Graphene origami and kirigami, DNA boxes and motors, molecular switches and ball-bearings: these can be made and monitored, and often are surprisingly well described using macroscopic mechanical concepts.

Maxwell's intuition of analogies between electromagnetic and mechanical degrees of freedom is now vindicated too — for example, in the wave physics that unites optical and acoustic/phonon scattering processes, as witnessed by work on photonic crystals and optical metamaterials and their acoustic counterparts. Recently, these correspondences have also been illustrated for topological insulators[1]: acoustic analogues of these electronic materials have been reported, possessing the same 'topologically protected' edge states that allow unidirectional travel of acoustic vibrations around the material's perimeter[2,3]. The key to these states is a breaking of the time-reversal symmetry of mechanical vibrations via rotation of fluid vortices around the 'meta-atom' components of such metamaterials. In principle, such structures could be used to channel acoustic vibrations in specific directions, say for noise management or sonar invisibility.

It's neat, but messy. The same principle has now been rendered in what one might call the solid state, and it is a suitably Maxwellian, Rube Goldberg contrivance: a hexagonal array of 54 spinning, vertically suspended gyroscopes, driven by motors and magnetically coupled so as to maintain a spring-like repulsion between neighbours[4]. The edge states arise within a bandgap of lattice acoustic modes: they correspond to excitations that can travel unidirectionally around the edge of the lattice, and which are, for topological reasons, robust against disruption caused by the presence of defects within the lattice. Deformations of the lattice that alter the couplings between neighbouring gyroscopes (while preserving their separation distance) can, however, reverse the directionality of the vibrational edge modes.

A mechanical analogue of a topological insulator might offer a useful model for exploring the electronic materials themselves — much as the first optical metamaterials[5] were initially devised to supply macroscopic analogues of plasmonic states in metals. But it's reasonable to envisage shrinking these arrays to make real materials, either using nanofabrication of electromechanical systems or using driven molecular gyroscopes[6] (if directionality can be imposed on them). ❐

References

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ARCHITECTURED MATERIALS

Straining to expand entanglements

Porous solids comprising a self-entangled coiled polymer fibre or metal wire reversibly increase their volume when either stretched or compressed in an axial direction, possibly providing a new type of mechanical behaviour for tuning functional properties.

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Ordinary materials decrease in density when elastically stretched and increase in density when compressed, in any direction. A few rare types of crystal and some porous solids, called stretch-densified materials, have directions in which this behaviour is reversed — stretch increases density while compression decreases it[1,2]. Now, writing in *Nature Materials*, David Rodney *et al.* have demonstrated materials that increase their volume when either stretched or compressed, becoming less dense[3]. In so doing, they remove the asymmetry found for both ordinary materials and rare stretch-densified materials, wherein