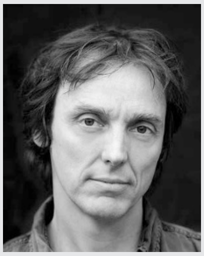
MATERIAL WITNESS

MAKING ANYON SOUP



PHILIP BALL

While particle physicists wait with some anxiety to see whether the Large Hadron Collider will produce any new physics beyond the standard model, it's rather delightful to see some of the field's vibrant inventiveness blossoming in a new playground: materials science. That conjunction, seemingly unlikely at face value, comes about from the way in which exotic new particles are being realized in the form of quasiparticle excitations of electrons in so-called quantum materials.

For example, Dirac's relativistic formulation of quantum theory in the late 1920s predicted not only positrons, the antimatter counterparts of electrons, but also several other unusual new types of fermion: neutral particles that are their own antiparticle, called Majorana fermions; and massless chiral particles called Weyl fermions. The latter have been seen as quasiparticles in quantum materials such as TaAs (ref. 1), while quasiparticles in graphene correspond to massless Dirac fermions[2]. Majorana fermions are more elusive, but they might be realized in, for example, structures involving topological insulators[3].

Another exotic class of particle first predicted in a particle physics context and now sought in quantum materials is the skyrmion, an unusual kind of baryon realized in the form of topological, vortex-like quasiparticle excitations in magnetic materials[4]. A particularly intriguing particle, hypothesized originally by Wilczek[5], is the anyon. This may exhibit quantum statistics intermediate between bosons, which have integer spin and may occupy the same quantum state as one another, and fermions, which have half-integer spin and are excluded from the same quantum state.

Once again the argument for the existence of such particles is topological. Anyonic statistics become possible for particles confined in two dimensions, for which the exchanging of two indistinguishable particles (the operation that sets fermions and bosons apart) involves complex 'braidings' of spacetime world-lines — in effect allowing the wavefunctions of the exchanged particles to acquire an arbitrary increment of phase. This constraint immediately suggests that two-dimensional quantum materials might be the place to look for such objects.

That, indeed, has been recognized for some time. It has been suggested that the vortex-like, fractionally charged quasiparticles observed in the fractional quantum Hall effect, seen in thin films of metallic material in the presence of a strong magnetic field, have anyon-like features. This anyon-like signature was reported in a fractional quantum Hall fluid in 2005[6].

But detecting anyons this way involves observing rather subtle quantum interference behaviour. It might in principle be easier to see them in materials called quantum spin liquids, in which the spins remain disordered and dynamic even at absolute zero because of quantum fluctuations. A team of researchers, including Wilczek himself, has now proposed what should be a relatively straightforward way to spot anyons in such systems, using neutron spectroscopy[7]. The method would identify a telltale signature of anyon excitation by scattered neutrons: namely, that the scattering cross-section at the energy threshold follows a power law with an exponent that depends on how 'boson-like' or 'fermion-like' the quasiparticles are.

The quest for anyons isn't just academic: a certain type of anyon has been proposed as the potential elements of error-proof quantum computers[8]. All the more reason, then, to welcome ways of finding them. ❐

References

1. Xu, S.-Y. *et al. Science* **349,** 613–617 (2015).
2. Novoselov, K. S. *et al. Nature* **438,** 197–200 (2005).
3. Linder, J., Tanaka, Y., Yokoyama, T., Sudbø, A. & Nagaosa, N. *Phys. Rev. Lett.* **104,** 067001 (2010).
4. Mühlbauer, S. *et al. Science* **323,** 915–919 (2009).
5. Wilczek, F. *Phys. Rev. Lett.* **49,** 957–959 (1982).
6. Camino, F. E., Zhou, W. & Goldman, V. J. *Phys. Rev. B* **72,** 075342 (2005).
7. Morampudi, S. C., Turner, A. M., Pollmann, F. & Wilczek, F. *Phys. Rev. Lett.* **118,** 227201 (2017).
8. Venema, L. *Nature* **452,** 803–805 (2008).

CHALCOGENIDE-BASED 2D MATERIALS

Intrinsic nanoscale patterning

A method to realize regular patterns with nanometre precision during the synthesis of $PtSe_2$ and CuSe monolayers has been developed.

Joseph W. Lyding

Two dimensional (2D) materials show great promise for applications in electronics, chemical sensing and catalysis[1]. While graphene, a single sheet of carbon atoms, has been the most studied 2D material, the transition metal dichalcogenides (TMDs) and the transition metal monochalcogenides (TMMs) are now receiving major focus worldwide. TMDs are layered structures with the formula MX_2, in which a layer consists of a sheet of metal atoms (M) bonded to two adjacent