MATERIAL WITNESS

Out of step with time

In science, it is good to have an idea that is correct, but arguably it is even better to have one that is productive. Frank Wilczek's proposal in 2012[1] that there might exist 'time crystals' — systems that break translational symmetry and exhibit periodicity not in space but in time — was soon shown to be untenable in equilibrium systems[2,3]. But it became evident that such time crystals could exist in non-equilibrium systems driven by some periodic driving force — where, that is, time translational symmetry is broken externally in a discrete manner[4,5]. That such driving can produce time-periodic behaviour in the driven system seems unremarkable, but the key point about these 'discrete time crystals' (DTCs) is that their period is not simply that of the driving force but some integer multiple of it.

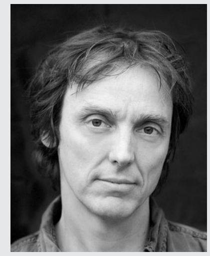
The real fecundity of Wilczek's idea, however, stems from how DTCs connect several hitherto unrelated topics in condensed-matter physics. The possibility of DTCs themselves emerged from initially unrelated work on periodically driven quantum systems, known as Floquet systems[6]. And it now seems that such DTCs sustain their oscillations without actually absorbing energy from the driving force, and so without heating up. That's a phenomenon that depends on their becoming trapped in a non-equilibrium state that cannot relax because of the presence of some degree of disorder, which in turn is connected to so-called Anderson localization, an effect first disclosed in the 1950s. In Floquet-type DTCs this is a many-body effect, and goes under the name of many-body localization[7].

So there's a rich mix of physics here, which can become manifest in a variety of physical systems ranging from ordinary crystals[8–10] to arrays of trapped ions[11]. And now research on time crystals has forged a link to yet another field of materials physics: quasicrystals.

Traditionally these materials show diffraction patterns consisting of sharp Bragg-like peaks, but arranged with symmetries seemingly forbidden on simple geometric grounds, such as 5-, 10- and 12-fold. It has been long and rigorously known that objects cannot be organized into crystalline lattices with those symmetries. But quasicrystals do not display perfect long-range order; they have local groupings of their elements with the appearance of such symmetries, but these do not recur with true periodicity. The Nobel-prize-winning work in which they were first observed by Dan Shechtman and co-workers in 1984 involved aluminium-manganese alloys[12], but quasicrystals have since been seen in many other alloys, as well as in polymers.

Now Autti et al. have described time quasicrystals, with quasiperiodicity in the breaking of time translation symmetry, in superfluid helium-3 (ref. [13]). Here the constituent elements of the 'crystal' are quasiparticles called magnons, which are collective magnetic excitations of the spin-1/2 ^{3}He nuclei. In the superfluid phases (denoted A and B) of ^{3}He, the spins may form a so-called spin superfluid, in which the magnons have become a Bose–Einstein condensate (BEC) and are all in the same quantum state. Autti et al. drove magnon BECs in the ^{3}He B phase with a periodic external magnetic field,using radiofrequency pulses delivered to the ^{3}He container via wire coils of the sort typically used for nuclear magnetic resonance measurements. The driving causes the magnon spins to precess (rotate in orientation) at a combination of frequencies: the drive frequency plus a lower frequency, the latter being the characteristic signature of a discrete time crystal.

But unlike other DTCs, this lower frequency is not an integer divisor of the drive — the two frequencies are incommensurate. That's what makes this a time quasicrystal. There's an analogy with the way ordinary spatial quasicrystals can be considered to be projections of higher-dimensional periodic crystals onto a plane slicing through at an incommensurate, irrational angle.



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When the magnetic driving is switched off, the magnon BEC evolves into a regular time crystal. This behaviour remains possible even without the forcing because the system is not truly in equilibrium — it relaxes quickly to a quasi-steady state that slowly decays, as the magnons themselves have a finite lifetime. Because this behaviour is exhibited only in the spin superfluid subsystem of the liquid helium sample, Autti et al. argue that both this regular time crystal and the time quasicrystal qualify as 'time supersolids'.

These experiments therefore add even more ingredients to the rich stew that Wilczek's fertile intuition set bubbling. ❐

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