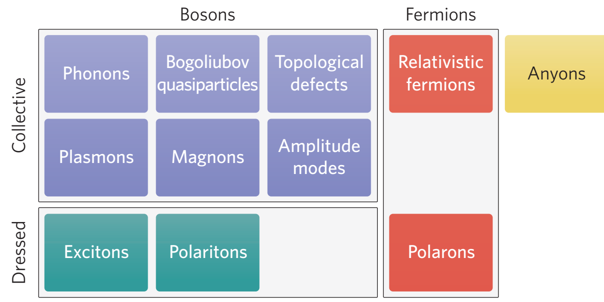
Fantastic beasts

Elementary particles are the building blocks of matter, but there is also a zoo of quasiparticles that are crucial for understanding how this matter behaves.



Schematic depiction of a selection of quasiparticles.

The idea that the world can be broken down into elementary particles has a long history, dating back to ancient India and Greece. And while physicists may have discovered most of these building blocks in the seemingly infallible standard model of particle physics, the language of particles does not stop once they merge together to create matter. On page 1085 of this issue, we discuss the history and role of a selection of quasiparticles — by no means an exhaustive list — to highlight how this concept is not only crucial for understanding and predicting a range of phenomena inside materials, but could also provide a platform for probing physics beyond the standard model.

John Dalton and Robert Brown laid the scientific framework for elementary particles in the early nineteenth century, but decades passed before an elementary particle was actually found experimentally. That situation changed very quickly in the early to mid-twentieth century, with particles discovered at such a rate that Enrico Fermi quipped, "If I could remember the names of these particles, I would have been a botanist"[1]. The particle zoo has been successfully popularized to general audiences — the excitement around the Higgs announcement shows how well particle physics captures the imagination of the public. But a second, lesser-known particle zoo emerged almost in parallel. And despite the lack of fame, it also played an important role in the development of physics in the last century.

One reason why these particles generate less interest may be because they are not viewed as real particles — which they are and they aren't. Starting from the 1930s, physicists realized that new entities could emerge from the interaction and dynamics of a collection of particles. These could also be described as particles, even without having a real particle at their core. A popular example of such emergent behaviour is a 'Mexican wave' at sporting events, which arises from the collective behaviour of a large number of interacting spectators. From phonons and plasmons to excitons and skyrmions, a whole host of quasiparticles emerge from the complex interactions inside materials[2].

But not all quasiparticles are collective excitations and some do have real particles at their core. Take electrons, for example. When electrons move inside a material they interact with the surrounding atoms and electrons. Because of all these interactions, the electrons often behave as though they are heavier than they should be. But these are elementary particles whose mass is not really negotiable. The electrons inside materials are not described as elementary electrons anymore, but should be thought of as electron quasiparticles.

A distinction is sometimes made between quasiparticles that arise from collective excitations and those that have real particles at their core, usually referred to as dressed particles — a real particle that has been dressed by some form of excitation. Polarons, for example, are electrons that are dressed with lattice deformation (a cloud of virtual phonons). But whether or not it's important to make this distinction is somewhat debatable. A schematic depiction highlighting the different groups (pictured) may have its use but what's important is that these quasiparticles provide a powerful framework for explaining complex many-body phenomena.

The analogy with elementary particles can go quite far. And just as accelerators can be built to probe the dynamics and structure of particles, colliders can be built to probe the dynamics of quasiparticles[3]. Such colliders could not only provide insights into the formation and characteristics of quasiparticles, but also help to identify the boundaries of the quasiparticle concept itself.

Quasiparticles already open the door to realms out of reach of conventional particle physics. In the standard model, particles come in two classes: bosons and fermions. In two-dimensional systems, quasiparticles can belong to a third, distinct class, known as anyons. Rather interestingly, anyons themselves come in two different classes: Abelian or non-Abelian. Abelian anyons play a major role in the fractional quantum Hall effect. And although non-Abelian anyon quasiparticles are yet to be seen experimentally, they appear to be within tantalizing reach, and could be used as a basis for topological quantum computation.

Anyons are not the only type of exotic quasiparticle that does not behave like any of the elementary particles. A flurry of quasiparticles akin to Weyl fermions were reported last year, which led to excitement about the discovery of all three of the fundamental fermions: Dirac, Weyl and Majorana[4]. But due to the different symmetry rules between high-energy physics and solid-state systems — high-energy has constraints imposed by Poincaré symmetry — it is now thought that there are several different types of fermionic quasiparticle with no high-energy analogue. The list of fermions just got longer[5].

The elementary particles that form the particle zoo have understandably stolen the spotlight — they're even available as soft toys (http://particlezoo.net/). But the quasiparticles that are key to understanding and describing the behaviour of materials sadly receive much less attention. As they extend into ever-more exotic realms, beyond the standard model, we hope that the public will become more aware of these fantastic beasts.

References

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