BIOMATERIALS

Silk spin-off

Evolution has produced some remarkable biological materials, and materials scientists try to cherry-pick the best properties to produce 'biomimetic' composites that transcend the originals. To this end, David Kaplan and colleagues have created a fusion protein that combines spider silk protein and a peptide (R5) that helps to deposit the silicate skeletons of microorganisms called diatoms (*Proc. Natl Acad. Sci. USA* doi:10.1073/pnas.0601096103). In diatom biosilicates, the organic

protein component improves the toughness of the inorganic silicon, and allows fine control of the microstructure — giving complex skeletons that are produced under mild aqueous conditions. Spider silk, on the other hand, is renowned for its tensile strength and, of particular importance for this study, can assemble itself from its constituent units. Silk assembly can be manipulated experimentally to produce many structures, from the threads seen in nature, to films, gels

and porous matrices. Silk studded with cell-binding domains or other biologically active molecules can even be made, to encourage the formation of tissues such as bone or cartilage.

Kaplan and colleagues cast their silk-R5 fusion protein into films or spun it into fibres, depositing silica

by adding a silicon solution during or after the process. They obtained spherical silica structures 0.5–2 μm in diameter (the picture shows silica deposited on a silk-R5 film; scale bar 2 μm). The strength and resilience of the silk-silica structures have not been tested, but the work shows in principle that they can be produced in different forms, for instance as silk fibres coated entirely in silica. The authors hope that their fusion strategy could produce a variety of composite materials. By adjusting the proteins involved, it might be possible to direct the deposition of titanium dioxide rather than silica, say.

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particles of half-integer spin, such as neutrons, getting too close to one another. Similar quantum-mechanical effects can be reproduced, at very low temperatures only billionths of a degree from absolute zero, on the entirely different scale of atomic physics in the matter phase known as a Bose–Einstein condensate^{2,3}.

What is surprising is that, in the quantum world, attraction isn't even necessary to form a stable bound system: repulsion can be enough. This prediction, like so much of quantum mechanics, is counterintuitive, as one would expect two repelling particles simply to fall apart to minimize their interaction energy. But in the presence of a periodic spatial perturbation this should no longer be true. Here, the energy of a particle cannot vary continuously, but is restricted to particular ranges of values. A pair of two repelling particles can therefore be stable simply because, if it fell apart, conservation of energy would require the two isolated atoms to have energies that would fall in a forbidden range.

Although periodic structures are the natural forms in which the atoms arrange themselves into crystals — and as such are very common in physics — interactions with the environment in the solid state dissipate energy, preventing the observation of the bound, repulsive pairs predicted by the theoretical model. Winkler and colleagues¹ circumvent this obstacle by using a periodic structure made of light. In such an 'optical lattice', ultracold atoms are ordered in a regular array of microscopic traps caused by the interference of two or more laser beams. The resulting ordered system of atoms resembles a solid-state configuration, and neutral atoms in an optical lattice do indeed share many properties with electrons in a metal. In contrast to a solid-state crystal, however, light crystals are free from defects and dissipative vibrations, and have thus proved ideal systems for the investigation of otherwise elusive quantum-physical phenomena⁴.

In Winkler and colleagues' experiments, the capabilities of the optical lattice are combined with a powerful tool that atomic physicists can

now use to change the nature of the interactions between two atoms, transforming attractions into repulsions, and vice versa. This trick is achieved by placing cold atoms in a uniform magnetic field, and tuning the intensity of the field across a resonance — known as a Feshbach resonance⁵ — that occurs when the energy of a bound molecular state is exactly equal to the energy of two colliding atoms. Following on from the observation of Bose–Einstein condensation^{6,7} (which involves 'bosonic' atoms of integer spin; atoms of half-integer spin are termed 'fermionic'), Feshbach resonances have made possible the observation of striking phenomena — including the formation of cold molecules⁸ and culminating in the observation of superfluidity among ultracold fermionic atoms⁹.

Winkler *et al.* take a cold gas of bosonic rubidium (⁸⁷Rb) atoms, which naturally have repulsive interactions, and first fill a three-dimensional, cubic optical lattice such that each lattice site confines either no atoms, or two identical atoms (Fig. 1). The authors then use a Feshbach resonance to control the interaction between the atoms forming the pairs. When interactions are cancelled, the pairs are not stable and the atoms quickly fall apart, diffusing within a few milliseconds across the lattice and hopping from one site to the next.

Figure 1 | Repulsive pairs. Repulsion between pairs of identical rubidium atoms in an artificial optical lattice causes them to be stable against separation, as Winkler and colleagues¹ demonstrate.

When repulsive interactions are restored, however, the separation process is halted. The pairs of atoms then live much longer together — several hundred milliseconds — clearly demonstrating that their stability is induced by the mutual repulsion of the constituents. The authors obtain additional information about the nature of the pairs by measuring the velocity distribution of the atoms and the energy of the bond.

This new type of bound object remains stable because, in the structured environment of the lattice, the large repulsive interaction between the atoms cannot be converted into kinetic energy. This result is general, as magnetic fields could be used to tune the strength of the interaction between other atomic species. An even broader impact could be achieved by extending the concept to mixtures of different atoms, and also by playing with quantum gases of different nature, both bosonic and fermionic⁴. Once more, it seems, optical lattices are demonstrating how useful they are for investigating many-body phenomena unobservable in other systems in which the interaction with the environment is too strong. As cold atoms are themselves a type of experimental simulator of quantum-physical effects, the result is a toolbox¹⁰ that kits us out to explore fascinating new avenues in quantum information and quantum states of matter. ■

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