populated, they overlap and start to form locally coherent patches (Fig. 1). For even stronger interactions, these patches inflate so as to minimize the interaction energy and finally condense into a single patch with long-range coherence.

This experiment constitutes an important step forward in the understanding of disordered systems with ultracold atoms, showing that weakly interacting bosons do cooperate to counteract localization in disordered systems, thus turning an insulator-like material into a metal-like material. The next step would be to study strongly interacting Bose gases, for which theory predicts that interactions should conversely cooperate with disorder to enhance localization. In strongly correlated Bose lattices the formation of an intriguing Bose glass phase has been predicted[9], the nature of which is still debated. Recent experiments with ultracold atoms in this regime suggest that the gap is suppressed[10] and the condensed fraction destroyed[11]. Further efforts are needed, however, to measure key features such as compressibility and suppression of the superfluid fraction (a related but more elusive quantity than the condensed fraction).

So far, disordered quantum gases have focused on bosons, which are relevant to ^{4}He in porous media. With a view to studying systems of direct relevance to metal–insulator transitions in electronic systems, a future challenge will be to study the fermion counterparts of this physics. ❐

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MAGNETIC NANOSTRUCTURES

Supercurrents in ferromagnets

Ferromagnetism and superconductivity are eternal enemies, so a current of superconducting pairs of electrons travelling within a ferromagnet raises several questions.

Teun Klapwijk

The deeply antagonistic electronic properties of superconductors and ferromagnets give rise to a tough question: what happens to the electron spins of superconducting Cooper pairs at the interface between a superconductor and a ferromagnet? The question poses two experimental challenges. First, in principle there is the need to know the local electronic properties at the interface to a level comparable to that reached in semiconductor heterostructures. Second, there is also a need to identify experimental Cooper-pair-related observables that depend on these interfacial properties. One outstanding property is the observation of a supercurrent through a ferromagnet over a given length, which is incompatible with the standard spin-singlet Cooper pairs. It is called the long-range proximity (LRP) effect. After a few previous indications, the evidence for such an LRP effect is now becoming rapidly stronger with the publication in *Nature Physics* of a paper by Jian Wang *et al.*[1], one of the first reports to describe this effect.

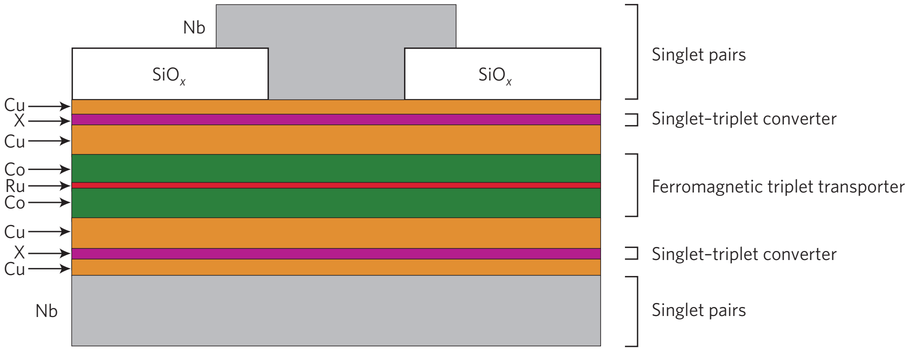

Figure 1 | Singlet to triplet conversion. The standard superconductor–normal-metal–superconductor junction has a clever X layer that converts the singlet pairs from Nb into triplet pairs, which then can travel within a ferromagnetic layer — the ferromagnetic triplet transporter. Afterwards the pairs are converted back to singlet pairs[7].

In a conventional superconductor the pairs are spin-singlet pairs in which one spin points up and the other down. If in contact with another material, the singlet Cooper-pair correlations decay inside a normal metal (N) over a length $\xi_N = \sqrt{\hbar D/k_B T}$ and in a ferromagnetic metal over a length $\xi_N = \sqrt{\hbar D/E_{exc}}$ (both materials assumed to be dirty with a diffusion constant D; $\hbar$ is Planck's constant divided by 2π, k_B is the Boltzmann constant and T represents temperature). In the normal metal the characteristic energy for dephasing is the thermal energy $k_B T$ and for the ferromagnet it is the exchange energy E_{exc}. As the Curie temperature is usually much higher than the critical temperature of a superconductor, one expects $\xi_S << \xi_N$ (where S represents the singlet state). Indeed, in a superconductor–ferromagnet–superconductor system, a supercurrent can, within this framework, be observed for thicknesses of the ferromagnet only on the order of ξ_S. Take note for example, the experiments on superconductor–insulator–ferromagnet–superconductor junctions[2], which are in excellent agreement with the theoretical expectations.

Nevertheless, some results did not fit into the mainstream. A resistance change of a ferromagnetic wire crossing a superconducting nanowire was observed and interpreted as signalling an LRP effect[3,4]. A report[5] in 2006 demonstrated a full supercurrent through the 100% spin-polarized half-metal CrO_2 over a length of 400 nm. Theorists had pointed out in parallel that an LRP effect in a ferromagnet would be the natural outcome if Cooper-pair correlations would be triplet rather than singlet correlations. The main problem was to invent or identify a mechanism to create triplet Cooper pairs in the ferromagnet. For conventional superconductors this would require a mechanism to convert singlet pairs into triplet pairs. Such a mechanism — a short-scale inhomogeneous orientation of the magnetization in the ferromagnet — was proposed[6], although it is not easily implemented experimentally. However, it underlined the central importance of the possibility of an LRP provided the materials system would enable a mechanism to convert singlet correlations into triplet correlations.

In the article by Wang *et al.*[1], the earlier result[5] that a supercurrent can flow in a ferromagnet over several hundreds of nanometres is confirmed using single-crystalline Co nanowire. They also report a rather peculiar pattern of the resistance in their nanoscale devices. Unfortunately the observation of a supercurrent as such does not provide conclusive evidence that it is indeed as a result of a triplet proximity effect. Keizer *et al.*[5] have argued that the full 100% spin polarization of the ferromagnet CrO_2 makes such a conclusion inescapable.

Within this context, an independent experiment reported very recently[7] is particularly interesting. Those authors created, very skilfully, a package of materials, which allowed them to intentionally separate the process of spin-triplet generation from the process of triplet diffusion leading to a supercurrent. As shown in Fig. 1, their starting point is a conventional superconductor–normal-metal–superconductor junction in which no peculiar spin-dependent properties are expected at the normal-metal/superconductor interface. They insert in the centre of the Nb layer a ferromagnetic Co film. This layer is meant to carry the Cooper-pair correlations, despite being magnetized. To avoid a net magnetization, which might create a net magnetic flux, they turned the Co into a synthetic antiferromagnet by placing a Ru layer in the middle of it. The two Co layers are antiferromagnetically coupled. The final step needed is to somehow create triplet pairs out of the singlet pairs. This is achieved by placing in the normal metal (Cu) between the superconductor and the ferromagnet a very thin weak ferromagnet (CuNi or PdNi alloys, represented by X in Fig. 1). This layer is assumed to provide the desired singlet–triplet conversion. A supercurrent travelled without any noticeable decay over a length from 12 to 28 nm, in contrast to samples without the singlet–triplet converter. Similar reports with the Cu_2MnAl Heusler alloy[8] and a new experiment on CrO_2 (ref. 9) demonstrating a supercurrent have appeared recently on the internet as well. The ban on a triplet proximity effect appears to be broken.

This recent set of experiments has created a very stimulating challenge for nanoscale physics with metallic structures. The focus should be on inventing methods to convert the singlet correlations of a conventional Bardeen–Cooper–Schrieffer superconductor into triplets, a realistic example of which involves ferromagnetic trilayers[10]. Given the long decay length of the triplet correlations, lateral structures can be implemented and tunnel junctions will be able to probe locally the nature of the states.

Theoretically interesting challenges arise as well. As the most powerful method to measure nanostructures is electrical transport, a microscopic theory for non-equilibrium superconductors including the possibility of triplet pairs is needed and will help to explain the results of Wang and coauthors. There is more to come. ❐

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