



Figure 1 Polymers that can superconduct. Some organic polymers can be turned into conductors and semiconductors by chemical doping with impurities. Others can be made to superconduct by injecting them with charge carriers. In a thin film of the undoped polymer poly(3-hexylthiophene) (P3HT), conductivity occurs if charge carriers are injected. For the highest conductivity, the optimal arrangement of molecular planes of the polymer chains is perpendicular to the thin film's surface⁹. By injecting charge into a similar highly ordered film of P3HT, Schön *et al.*¹ have now observed superconductivity below 2.35 K. To inject enough charge they use a field-effect transistor geometry: source and drain electrodes are placed on top of the insulating surface (red), whereas the gate electrode is placed below. Applying a voltage to the gate electrode triggers a flow of charge along the surface of the thin film between the two other electrodes. (Redrawn from ref. 9.)

P3HT molecules can self-assemble into two-dimensional conjugated sheets, which can be oriented either parallel or perpendicular to the surface of the FET (Fig. 1)⁹. At room temperature, much higher charge mobilities are seen when these sheets are perpendicular to the FET's surface. So it appears that conduction in these polymers is not confined to the backbone of the molecule, leading to two-dimensional charge transport in the film⁹.

Studies of the P3HT film used by Schön *et al.* show that it has a nanocrystalline structure (in which ordered nanocrystals are embedded in a disordered matrix), but this does not appear to affect the two-dimensional charge transport in the film and so is not harmful for superconductivity. The density of injected charge can be monitored by the gate voltage, and the thin-film resistance exhibits a metal–insulator transition with a metallic-like temperature dependence. Increasing the charge density leads to a zero resistance state below 2.35 K, which the authors attribute to superconductivity, owing to its response to an external magnetic field. The suppression of the zero resistance

state by a high magnetic field is a defining feature of superconductivity.

Why has no one observed superconductivity in polymer films before? To achieve this experimental *tour de force*, Schön *et al.* overcame two major technical problems: the growth from solution of thin P3HT films with large nanocrystalline regions, and the tolerance of a high gate-voltage by the thin film at low temperatures. The FET gate-voltage had to be high enough to inject one charge carrier for every five polymer chains. This report will surely be the first of many investigations with the FET geometry and deposited nanocrystalline films.

Schön *et al.* also chose their polymer wisely. The arrangement of the molecular chains of P3HT is similar to the packing of donor molecules in the conducting salts of tetramethyltetraselenafulvalene (TMTSF), which were the first organic conductors to show bulk superconductivity¹⁰. But the one-dimensional character of TMTSF salts is still an important feature and possibly governs the nature of the superconducting pairing.

There is no evidence for one-dimensional transport in the polymer films studied by Schön *et al.*, and the nature of the pairing mechanism remains to be found. Strong hints in favour of a conventional explanation in terms of phonon-mediated superconductivity come from a similar study of the organic molecules pentacene, tetracene and anthracene¹¹. But it would not be altogether surprising if electron–electron interactions became important in the two-dimensional electron gas created in the FET studies.

Even if Little's model for superconductivity does not apply to these new results, we are probably witnessing a healthy revival of organic solid-state physics, which moved out of the mainstream of condensed-matter physics in the 1960s. The work of Schön *et al.* emphasizes that interdisciplinary work, involving both synthetic chemistry and condensed-matter physics, will advance the frontiers of both fields. ■

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Daedalus

Spinning rubbish

A gas turbine, says Daedalus, is a collection of combustion chambers directing its flame onto a set of turbine blades. The shaft horsepower drives a compressor to feed the combustion process, and the exit gas forms a jet exhaust (in the jet engine). The turbine blades, directly in the path of the flame, have a severe duty, and can be internally cooled. A hollow blade with a divider along the middle can receive water through a hollow central shaft. In the centrifugal field the water will cling to the outside of the shaft bore, and even a small difference in density (caused, for example, by boiling) will circulate the water vigorously through the blade. Daedalus calculates that a fast-spinning turbine could drive the water in its blades supercritical at the blade tips.

Oxygenated, supercritical water is a powerful and spontaneous oxidizing agent. A turbine fed not with cooling water, but with an oxygenated fuel slurry, would therefore generate heat in its turbine blades by burning the fuel circulating in them. So DREADCO engineers are now building turbines whose combustion is distributed between the combustion chambers and the first few rows of blades. Indeed, Daedalus reasons that an internally heated blade could generate torque on its own account, making possible an entirely new sort of turbine.

The major application of turbines with water-loaded blades will be chemical, however. Many processes generate a weak slurry of some nasty organic chemical, and it is appealing to burn this in a turbine to a solution of CO₂ in water, and get useful power in exchange. The pharmaceutical industry, with innumerable waste streams on the way to a few useful products, would be an obvious customer. And the sewage business is dedicated to turning its customers' waste into a weak water slurry, and getting rid of this somehow. Burning it in turbines could generate vast amounts of electricity. Even the waste heat, now represented by the hot fizzy water rejected by the turbines, should be easy to discharge. Expensive cooling towers might not be needed.

Even better, many reactions of 'green chemistry' seek to replace messy industrial processes by neat supercritical ones from which the product can be elegantly recovered by simple processing. What a pity that supercritical dry cleaning, a splendid way of tidying up tatty or dirty assemblies, cannot be reduced to turbine processing.

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