arguments concerning the mechanism of charge transfer in the DNA stack.

The fundamental mechanism of molecular electron transfer requires an electronic mixing pathway between the initial and final states. In most intramolecular and intermolecular electron-transfer reactions, the charge is localized only at the first and last sites: the charge is thought to move between these two points in a single, coherent jump — much like a kicked football[2]. But when the states between the initial and final ones are sufficiently low in energy the charge can stop along the way, so that its overall trajectory looks more like the path of a wandering drunk. The coherent transfer process cannot get very far at room temperature, because the orbitals in which the electron density is found do not extend effectively over long distances and thermal disorder further localizes the charge. The latter, diffusive motion is responsible for the ordinary conductivity of real metals[3–5] (as described by Ohm's law).

So, depending on the energy, one expects different mechanistic behaviour: if the 'bridging states' (in DNA, these are the intervening base pairs) are very high in energy compared with the initial and final states, we should see coherent transport. This is generally called superexchange, and is characterized by a rapid exponential decay of the transfer rate or yield as a function of distance[2]. But if the intermediate bridging states are comparable in energy, or lower in energy, than the initial state, then one expects to see incoherent, hopping behaviour that decays only slowly with distance.

Meggers *et al.*[1] have used a clever photochemical method for inducing an electron hole on a guanine (G) base in the DNA structure. This hole (a positive charge centre prepared by removing an electron from the DNA stack) then wanders along the DNA chain. The energy of the hole when residing on adenine, cytosine or thymine bases is substantially higher than when on G, so the electron never stops except on other G bases. By measuring DNA fragments produced by chemical cleavage at the different G sites, Meggers *et al.* can actually measure the probabilities, and therefore the relative rates, of hole transfer along the strand.

The results are striking. They suggest that the electron does indeed hop incoherently among the G bases in a kind of random walk. This gives a weak, algebraic decay of the transfer rate with length. When moving from one G base to the next, however, the electron cannot stop in mid-journey, so that the transfer between two different G bases is like coherent superexchange, and decays exponentially with distance. Figure 1 shows three different hole transfer situations, and their measured rates.

The suggestion of two different mechanisms for transfer, one corresponding to coherent superexchange and the other to a random walk, reflects recent discussions[3–6] and observations for the photosynthetic reaction centre[7] (where the intermediate site is the bridging bacteriochlorophyll) and in synthetic donor/bridge/acceptor intramolecular electron-transfer systems[8]. It implies that, although superexchange could be appropriate for short-range electron transfer in DNA[9–12], for effective long-range transfer only the hopping process can occur. This is similar to what happens in both metals and molecular conductors; it differs from the (high-field) coherent transport described in carbon nanotubes[13].

The robust, malleable, one-dimensional structure of DNA is unique. It can be used to design functional nanostructures, and its charge transport capability in the appropriate energy regime can be quite good. The report by Meggers *et al.* and other recent measurements and models for charge motion in DNA may help settle a controversial question about the conductivity of this biologically important molecule[12]. They suggest that DNA's unique structure and π-electron bases do indeed provide appropriate pathways for long-range charge transport, but that the mechanisms for long-range transport and short-range transfer differ entirely. Once charges (especially holes) are created on the DNA chain, then hopping-type conduction can apparently occur among the G sites; this is observed by Meggers *et al.*, and was also suggested by earlier workers[14,15]. This simplistic hopping mechanism would indeed make DNA a fairly good hole conductor. The actual conductivity, however, will vary with the location and density of G-sites, with the injection energy and probability for the holes, and with the level of disordering in the helical stack. These sensitivities help to explain the wide variety of conductivities suggested by previous experiments and models. □

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Daedalus

Cell squeezing

We get many useful substances from plants. Sugar, digitalis, nicotine, turpentine, caffeine, essential oils, alginates, steroids — the list is endless. Usually, the plant must be grown, harvested and processed to extract the product. In theory, the plant tissues could be grown as a cell culture; even then, extraction would be a nuisance. Only a few single-cell products, such as penicillin and alcohol, are freely released by the growing cells. Daedalus now has a new twist.

Supercritical fluids, he points out, are wonderful solvents, with very high molecular diffusivity. Some of them (such as carbon dioxide, nitrous oxide and xenon) have critical points near ambient. Single cells are incompressible and can withstand great hydrostatic pressures. So Daedalus is developing supercritical cell culture.

Carbon dioxide, the essential carbon source for all green plants, seems the ideal supercritical medium. Yet such a high concentration could be damaging; xenon with a dash of carbon dioxide might be safer. But whatever mixture turns out best, cell culturing will be transformed. Its biochemistry will be speeded up enormously: feedstock and product molecules will diffuse in and out through the cell walls at a great rate. Even a small culture will churn out pharmaceuticals, alkaloids or perfumes in copious quantity. Existing culturing methods, such as those for antibiotics, and proteins from modified *E. coli*, will also go supercritical.

An older trade, herbal medicine, should also benefit. Traditional prescriptions can be highly complex for a very vague claimed action — typically 'clearing toxins' (unspecified) or 'boosting the immune system'. Their active ingredients, if any, and how they achieve their alleged effects, are seldom known. But supercritical culturing could generate plant metabolites in such quantities that their benefits could be swiftly clarified.

Even genetic engineering might be speeded up. In supercritical conditions, plasmids and proteins should drift in and out of cells, and be exchanged between them, with unprecedented ease. Indeed, a supercritical mixed-cell culture might even act as a sort of hybrid super-organism. All its different cell types, whether from a single organism or even from disparate species, might pool their biochemical and genetic resources into a mighty synergistic living combine, a cellular Frankenstein's monster.

David Jones