

Urban climate

The water cooler

Ever thought about escaping the heat of the city by getting down to the lakeside?

According to Arón Jazcilevich and colleagues (*Climatic Change* **44**, 515–536; 2000), having a lake on your doorstep may not only provide a waterside retreat but help keep the city's climate appreciably cooler.

Mexico City, it seems, was such an example. Earlier this century, the relatively small city (86 km²) was bordered by Lake Texcoco (120 km²), and the 'urban heat island' effect — where city temperatures exceed those in surrounding rural areas — was only 1.5 °C. Urban expansion has dramatically altered the balance, so that the sprawling city (pictured), at 1,200 km², now dominates the Basin of Mexico. The lake has been reduced to a mere 10 km² or so in area, and the heat of the city can exceed that in neighbouring countryside by



8–10 °C. This commonly observed effect is usually explained by the surface geometry and thermal properties of all that extra concrete and asphalt.

But what part might the lake play? Jazcilevich *et al.* developed a model to reproduce urban climate under present-day conditions and those of 1921, using the respective city and lake areas. Then, taking the situation in 1921, and reducing lake area to today's extent, they found that the expected temperature

field was almost identical to that of today. From this the authors infer that the increase in city temperatures is largely due to the reduction in lake area and the evaporative cooling it provided, as well as the massive urbanization.

Perhaps the finding has come too late for Mexico City. As urban areas continue to swallow up land around the world, however, town planners would be wise to keep a little bit of Venice in their designs for the comfort and health of inhabitants.

Jim Gillon

Evolution

Bacterial cheaters

Joan E. Strassmann

Cooperative groups of higher organisms are vulnerable to cheaters that reap the benefits of cooperation without paying the costs. For example, an unrelated male lion may take a gazelle away from the females that killed it. On page 598 of this issue¹, Velicer and colleagues show that similarly selfish behaviour is also seen in bacteria — specifically, in groups of *Myxococcus xanthus*.

As they move through the soil, preying upon other microorganisms, *M. xanthus* individuals behave in group-coordinated ways that are more usually associated with complex social animals than with bacteria^{2,3}. Individuals move and feed as a cooperative, tight group reminiscent of teams of hunting army ants or wolves, but in this case secreting enzymes that kill and degrade (lyse) the prey before them^{2–4}.

But *M. xanthus* display their most dramatic social act when they are starving. Individuals aggregate even more densely than

when feeding and form a raised 'fruiting body' (Fig. 1, overleaf), in which a minority of cells convert from vegetative rods to hardy, spherical spores^{2,3}. During this process, many cells commit suicide and lyse, releasing their contents⁴. The contents of lysed cells might enable spore formation by other cells — the contents may be eaten, or might otherwise influence the sporulating cells⁴. The development of a fruiting body involves cell-to-cell signalling, the formation of a multicellular structure, and morphological changes in individual cells. Myxobacteriologists therefore consider the fruiting body to be a simple model system in developmental biology³, with processes at least partly analogous to those that form structures as complex and integrated as a fruitfly's body.

Standing in marked contrast to this cooperative, and often altruistic, behaviour, however, are the social cheaters described by Velicer *et al.*¹. The authors isolated *M. xanthus* mutants showing developmental

defects from six populations that had evolved in a liquid medium in which fruiting-body formation could not occur. The populations had evolved for 1,000 generations — a short time in evolutionary terms, but still a much longer period than would be feasible in experiments on most organisms. After this period, clones from all six mutant lines showed a decreased ability to form spores when starved on a solid substrate, a loss of function that is not surprising given that the bacteria had adapted to an environment in which the function is not needed.

Velicer *et al.* then mixed the mutants with ancestral (wild-type) populations, at a ratio of 1% evolved clone to 99% ancestral clone. Under these competitive conditions, five of the six defective clones produced more spores, relative to the number of input cells, than they had when in isolation. Three of the clones did even better in such mixtures than the wild-type clones, and thus qualified as 'cheaters'.

Velicer and colleagues also studied three other, previously known, developmental mutants that were defective in either of two signalling systems and, consequently, in spore production when in pure culture. In mixtures of 1% mutant to 99% wild-type clones, two of these mutant clones generated spores at a higher frequency than did the wild-type clones. So, some developmental mutants not only revert to spore production when in a mixture with wild-type cells, but can even be over-represented in the spores in comparison with their original frequency.

But exactly how these mutants cheat is not obvious. There is no clear functional class of altruists, analogous to honeybee workers or to stalk cells in cellular slime moulds, that the cheating *M. xanthus* avoid joining. The *M. xanthus* individuals that are the best candidates for altruists are the cells that lyse during development, although it is not even certain that these lysed cells are actually eaten by the sporulating cells. Moreover, we do not know whether the cheating clones cheat specifically by avoiding lysis. The mutants might simply be able to continue growing while some of the wild-type cells lyse, because the mutants do not pay all the metabolic costs of producing the signalling chemicals that contribute to the formation of the fruiting body⁵. If the mutants' advantage is indeed that they can simply keep on growing, they would need to be able to continue dividing after being plated on starvation medium. This might be possible, as they could eat lysed cells.

Cheating *M. xanthus* clearly evolve easily, but their fate in nature is uncertain. Rare cheaters exploit the wild-type bacteria to increase in frequency within groups. But when they become common, they disrupt sporulation, and the whole group suffers¹. So, an understanding of population struc-

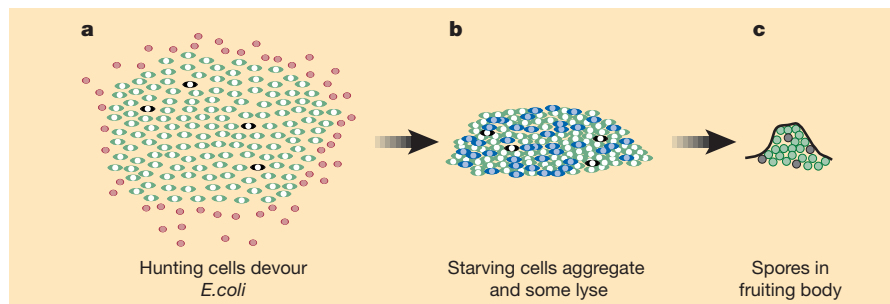


Figure 1 Cheating bacteria. a, Hunting *Myxococcus xanthus* individuals (wild-type are shown in green and cheaters in black) eat *Escherichia coli* (red) by secreting enzymes that degrade their prey. b, In the absence of prey, starving individuals aggregate even more closely into groups of 10^5 cells; many lyse (blue), whereas others form spores. c, Hardy spores in a fruiting body (end-on view) await more favourable conditions. Velicer *et al.*¹ show that cheaters, or developmental mutants, have increased in frequency at this stage because they sporulate more efficiently than the wild-type bacteria.

ture is crucial in comprehending the evolutionary importance of cheaters. If each group of *M. xanthus* is a clonal descendant of a single cell — like the cells in a fruitfly — then cheater groups will lose out to wild-type groups. If, in contrast, *M. xanthus* groups are mixtures of genetically distinct clones — like a pride of lions — then individual cheater mutants should be common in populations. In this case, the myxobacteria fall short as a developmental model for higher organisms, because between-cell signalling will have competitive elements not present in the development of organisms that have passed through a single-cell bottleneck⁶. Groups of myxobacteria would therefore be more analogous to social groups, with all of their inherent potential for conflict.

Velicer *et al.* argue that genotypic diversity within *M. xanthus* fruiting bodies is likely

to be common in the wild. But this will need to be confirmed before we can decide whether groups of these bacteria are more like the body of a fruitfly or a pride of lions — a model for development or for social evolution. ■

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Magnetoresistance

A new spin on magnets

Thomas F. Rosenbaum

Just like photons propagating through space, electrons flowing through a crystalline metal travel in simple plane waves. Add sufficient disorder and those electrons are no longer free to fly. Rather they will diffuse from scatterer to scatterer, performing a random walk through the 'dirty' metal. At very low temperatures, near absolute zero, the phase of the electron becomes important and quantum interference effects manifest themselves. At the quantum level both the amplitude and phase of the electronic wavefunction are needed to describe the electron completely. On page 581 of this issue, Manyala *et al.*¹ describe how these quantum interference effects not only dominate the behaviour of a metallic ferromagnet (a material similar to iron) at the relatively scorching temperature of liquid nitrogen, but might account for an entirely

new mechanism behind the magnetic response of solids.

In most models of charge transport in metals, it is safe to ignore the interactions between electrons. The Pauli exclusion principle (which forbids two electrons from being in the same state), and the interaction between negatively charged electrons and the positively charged ions in the lattice, dominate the thermal, optical and electrical properties. Electronic diffusion through a disordered medium such as a metallic alloy or a doped semiconductor — materials essential to the electronics industry — permits the charge carriers to interact more strongly (Fig. 1). The effects of electron–electron interactions in the presence of disorder are most pronounced at very low temperatures, generally within a degree of absolute zero, where the relative phases of the

diffusing electrons are not scrambled by thermal fluctuations².

Electrons carry spin as well as charge. Apply a magnetic field and spin-up electrons acquire a different energy from spin-down electrons. The energy difference created by the spins, combined with quantum interference effects, leads to an electrical resistance that changes with the square root of the applied magnetic field. This effect, known as magnetoresistance, has attracted much interest because of its technological potential, for example in magnetic data storage. Many different materials have shown magnetoresistance that involves scattering of conduction electrons by magnetic electrons. For example, when a magnetic field is applied the scattering may be reduced, leading to negative magnetoresistance.

In the ferromagnet studied by Manyala *et al.*¹, the unusual square-root dependence of the electrical resistance on magnetic field, and the positive nature of the magnetoresistance, point to a different underlying mechanism. In fact, the magnetoresistance of a classic semiconductor such as phosphorus-doped silicon, in which the effect was first observed³, switches from negative to positive when quantum interference effects emerge as the temperature drops below 1 K. This means that the resistance switches from shrinking with magnetic field to growing with magnetic field as the temperature is lowered.

Remarkably, Manyala *et al.*¹ show that the disordered, metallic ferromagnet $\text{Fe}_{1-y}\text{Co}_y\text{Si}$ behaves just like a doped semiconductor, but at a temperature two orders of magnitude higher. It is the large (megagauss) internal fields of the ferromagnet that allow this behaviour to occur at higher temperatures. The same electrons, with intertwined electronic spin and charge, are responsible for both the magnetic and electrical properties of $\text{Fe}_{1-y}\text{Co}_y\text{Si}$. This is in contrast to what happens in most magnetoresistive materials, where the electrons involved in electrical conduction are different from those responsible for the magnetism. In $\text{Fe}_{1-y}\text{Co}_y\text{Si}$, the effects of quantum coherence have been amplified by the magnetic nature of the doped FeSi host, in the same way that shrinking electronic devices to the nanometre scale reveals the subtleties of quantum processes at room temperature in quantum dots⁴ and magnetic heterostructures⁵.

The consequences of magnetoresistance in $\text{Fe}_{1-y}\text{Co}_y\text{Si}$ extend beyond the new insights that it provides into the fundamental quantum nature of charge transport in magnets. An electrical resistance that changes with magnetic field is the primary means of information storage in the hard disk on a computer. Magnetoresistive sensors are also found at the business end of a car's speedometer. New materials continue to emerge as potential candidates for mag-