synthetic antimicrobial peptide, Cecropin A, whereas *G707* was much less so. And expression of just one antimicrobial peptide (Diptericin or Cecropin A) in the gut of wild-type flies, by way of a transgene, caused a similar shift in the bacterial population.

Additionally, enhanced growth of *G707*, caused by production of antimicrobial peptides in the gut, was detrimental to the host. In the *Caudal-RNAi* flies, apoptosis of intestinal cells in the gut increased and fly survival decreased. These changes required the presence of *G707* bacteria, because apoptosis and survival returned to near-normal levels in germ-free animals (it is unclear how this change in bacterial population induces apoptosis). Whereas feeding germ-free animals *G707* bacteria induced cell death and mortality, feeding them "normal" microbiota (that are resident in wild-type animals, such as *A911*) did not induce cell death or changes in host survival. Moreover, *G707* fed to conventionally reared animals (with normal gut microbiota) did not induce any apoptosis. Indeed, germ-free animals first colonized with *A911* did not support the growth of *G707* and did not exhibit cell death after inoculation with *G707*.

The experiments by Ryu *et al.* elegantly demonstrate that the normal flora in the fly gut is sufficient to suppress the growth of pathogenic bacteria, a phenomenon referred to as colonization resistance. In humans, alterations in gut microbiota communities (such as that following antibiotic treatment) are theorized to lead to loss of colonization resistance and the expansion of minor gut microbial residents and other pathogens (*12*). This failure of colonization resistance has been linked to pathology induced by *Clostridium difficile* as well as infections in neutropenic patients. The data presented by Ryu *et al*. clearly establish the important role that microbiota play in their own proper maintenance, the ability of this microbial consortium to support and sustain health, and the critical role that properly regulated host immune responses play in supporting this microbial consortium.

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PHYSICS

From Complexity to Simplicity

A combination of positively and negatively charged current carriers may provide a key to understanding cuprate superconductors.

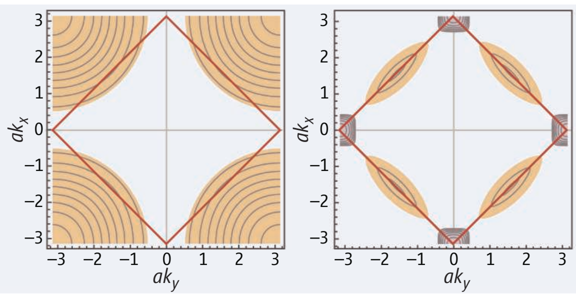
Sudip Chakravarty

HAMLET: Do you see yonder cloud that's almost in shape of a camel?
POLONIUS: By th' mass, and 'tis like a camel indeed.
HAMLET: Methinks it is like a weasel.
POLONIUS: It is backed like a weasel.
HAMLET: Or like a whale.
POLONIUS: Very like a whale.
—*William Shakespeare*

More than 20 years ago, Bednorz and Müller discovered superconductivity in copper oxides at remarkably high temperatures (*1*). Since then, physicists have struggled to understand the mechanisms at work. Recently, a set of experiments on cuprates in high magnetic fields (*2*–*6*) has completely changed the landscape of research in high-temperature superconductors (HTSs). In particular, the data suggest that the current carriers are both electrons and holes, when in fact the materials are "hole doped"—i.e., the current carriers should be positively charged. Moreover, the data cannot be reconciled with an important theorem about how electrons are organized in materials (*7*) unless one assumes that the signals arise from a combination of both holes and electrons. Until now, physicists have not been able to decide whether the cuprates, in Shakespeare's terms, are camels or whales; in fact, these experiments foreshadow a remarkable degree of simplicity in these complex materials.

The cuprates start out as insulators and become superconductors when doped with additional charge carriers. These so-called Mott insulators insulate by virtue of strong repulsive Coulomb interaction and need not break any symmetries in the lowest energy state, the ground state. A symmetry of a system is a transformation, such as a translation or a rotation, that keeps it unchanged. Such a symmetry is said to be broken, or spontaneously broken, if the system does not obey the symmetry of the underlying fundamental physical nature of the material; for example, a ferromagnet breaks the spin-rotational symmetry with its magnetization pointing in a definite direction. The notion of symmetry and broken symmetry finds many deep applications in physics.

Soon after the discovery of the cuprate superconductors, Anderson proposed (*8*) that their parent compounds begin as a featureless spin liquid that does not break any symmetries, called the resonating valence bond (RVB) state: "The preexisting magnetic singlet pairs of the insulating state become charged superconducting pairs when the insu-



In the pocket. Electron states in cuprates, with constant energy curves (black) plotted in momentum coordinates (ak_x, ak_y) in units of $\hbar/a$, where $\hbar$ is Planck's constant divided by 2π, and a is the lattice spacing. (**Left**) The Fermi surface separates the occupied states (light blue) from the unoccupied states (orange); the latter can act as positively charged carriers called holes. (**Right**) When the material is "underdoped," the Fermi surface may reconstruct, which forms two hole "pockets" (adding the four halves) (orange) and one electron "pocket" (adding the four quarters) (purple), as revealed by recent experiments.

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lator is doped sufficiently strongly" (*8*). Unfortunately, experiments show that the insulating phase is a simple antiferromagnet in which the spins are arranged in antiparallel manner, that is, with a broken symmetry. The materials remain antiferromagnets for a range of doping, and then, after a sequence of not well understood states as a function of doping, they become superconductors.

How this plays out experimentally can be understood by looking at the Fermi surface, a fundamental concept in condensed matter physics. The Fermi surface differentiates the occupied electronic states from the unoccupied states (in coordinates of momentum rather than "real" space). Electrons fill the Fermi surface up to some highest occupied energy called the Fermi energy (see the figure). The excitations from the Fermi surface (e.g., when a current flows) are called Landau quasiparticles (quasi, because they are combinations or superpositions of real particles).

The new experimental work (*2*–*6*) yielded measurements of the oscillations that arise from energy levels created by imposing a magnetic field on the material (the Landau levels). As the magnetic field is increased, the highest fully occupied levels sweep past the Fermi energy, and the system periodically returns to itself, hence the oscillation in physical properties. The oscillations of the Hall resistance (*2*, *4*), capable of detecting the sign of the charge carriers, seem to show the presence of electron and hole pockets in the Fermi surface, suggesting that it undergoes some kind of reconstruction. This requires a global deformation of the Fermi surface, most likely a broken symmetry, and is probably a general feature of underdoped HTS materials.

One might complain that these high field measurements are still considerably below the upper critical field where superconductivity disappears (about 100 T or more) and are affected by the complex motion of vortices generated by the magnetic field. This may be true, but quantum oscillations in many superconductors are observed at fields as small as half the critical field, with the oscillation frequencies unchanged from the nonsuperconducting state (with an increased damping, however). It is also known that the quasiparticles of HTSs do not form Landau levels (*9*). Thus, it is very likely that the quantum oscillation experiments are accessing the normal state beyond the realm of superconductivity. But what kind of state? As the oscillations definitively point to both electron and hole pockets, it cannot be a conventional Fermi surface, rather one that has undergone a reconstruction due to a broken symmetry at variance with the RVB picture (*10*).

We may be finally beginning to understand these superconductors after two decades. The fly in the ointment is the lack of observation of electron and hole pockets in other measurements in hole-doped superconductors (in angle-resolved photoemission spectroscopy, for instance) that are also capable of measuring Fermi surfaces [see, however, the work on electron-doped materials (*11*)]. Missing so far in experiments are also the higher frequency oscillations that must arise from the hole pockets, not just the electron pockets (*4*). With further experimental work, we should be able to tell just what kind of animal we are dealing with.

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CHEMISTRY

Taking a Selective Bite Out of Methane

A clever experiment enables the selective cleavage of a specific bond in a surface reaction.

C. Buddie Mullins and Greg O. Sitz

For more than a decade, scientists have attempted to use lasers to drive the selectivity of chemical reactions, with mixed success. On page 790 of this issue, Killelea and co-workers report a successful realization of this approach for a surface reaction (*1*).

For laser-driven selective chemistry to work, the laser must excite a particular vibrational mode in a molecule, and the energy must reside in that particular vibrational mode long enough for the molecule to dissociate and/or collide with another reactant molecule or surface. However, the energy in multi-atom molecules may be redistributed as a result of coupling between the vibrational modes in the molecule, and the excitation energy provided by the laser frequently may thus reside only transiently in the desired vibrational mode. As a result, demonstrating bond-selective chemistry of polyatomic molecules has proved harder to achieve than originally imagined (*2*).

Nevertheless, some success has been achieved for gas-phase reactants. Nearly two decades ago, Crim and co-workers described the first example of a bond-selective bimolecular reaction (*3*). When the authors selectively excited the OH or OD stretch in monodeuterated water (HOD) and then scattered the energetic molecules from H atoms, they observed two chemical reactions:

$$H + HOD \rightarrow OD + H_2 \text{ (path A)}$$
$$H + HOD \rightarrow OH + HD \text{ (path B)}$$

When the OH stretch was excited, path A occurred more than 100 times as frequently as path B; in contrast, excitation of the OD stretch produced reaction products almost exclusively via path B. The coupling between the OD and OH stretches is small, so that the excitation can be localized in a chosen vibration.

Bond-selective chemistry on solid surfaces is expected to be more difficult to achieve than that between gas-phase reactants, because energy can easily dissipate via the solid, and the coupling between the molecule and the surface is therefore often strong. Killelea and co-workers now greatly advance the field by reporting the C-H bond–selective dissociation in triply deuterated methane (CHD_3) on a Ni(111) surface. The dissociative adsorption of methane (CH_4), and hence the breaking of a C-H bond, on nickel is an elementary and rate-limiting surface chemical reaction used to produce molecular hydrogen from natural gas. Because of the importance of this reaction, there have been many studies

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