amplitude for coupling along the legs has the opposite sign from that for coupling along the rungs.[8] Such behavior is reminiscent of the d-wave nature of the wavefunction describing the Cooper pairs in the high-T_c materials. (A d-wave function has four lobes; the two lobes along the x-axis are opposite in sign from the two lobes along the y-axis. See PHYSICS TODAY, January 1996, page 19.) The same behavior is seen in numerical calculations performed by Scalapino, Reinhard M. Noack of the University of Würzburg and Steven R. White of the University of California, Irvine.[9]

To test the predictions of superconductivity the experimenters first had to figure out how to dope the ladder compounds. That was not a trivial problem; the holes seem to resist going onto the ladders. Nevertheless researchers have managed to get the holes to leak from the chains onto the ladders in some compounds. Paradoxically, Takano notes, the very materials that would be easiest to understand theoretically—$SrCu_2O_3$ and its family—have not yet been successfully doped.

Last year, Z. Hiroi and Takano succeeded[10] in doping a copper oxide ladder compound: $La_{1-x}Sr_xCuO_{2.5}$. As the doping x increased, the material turned from an insulator to a metal. To the initial disappointment of the theorists, the compound never went superconducting. But subsequent studies have caused researchers to question whether one should even expect to see superconductivity in this particular compound.

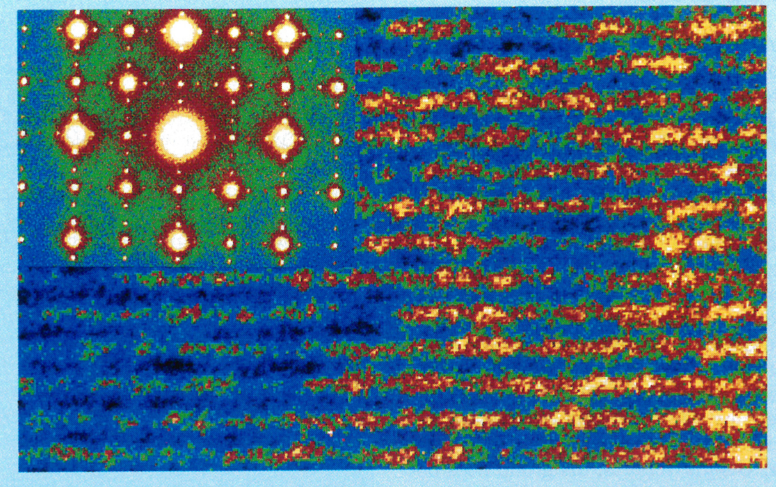
This summer, Jun Akimitsu and his colleagues at Aoyama Gakuin University, together with researchers from the University of Tokyo and from the Nippon Telegraph and Telephone Corp's Basic Research Laboratories in Kanagawa, reported[2] superconductivity in $Sr_{0.4}Ca_{13.6}Cu_{24}O_{41.84}$ at pressures above 3 gigapascals. This compound consists of layers of two-leg ladders in parallel with layers of copper oxide chains interspersed with planes containing the strontium and calcium cations.

The evidence for superconductivity is quite clear. The sample manifests the signature drop in resistivity at 12 K for a pressure of 3 GPa and at 9 K for 4.5 GPa. But two concerns have been raised: First, is the superconductivity coming from the ladders rather than the chains? Second, has the high pressure distorted the ladder structure of the compounds, perhaps even converting the structure into a more conventional three-dimensional superconductor?

Fueling the concern over the source of the superconductivity are studies made by Batlogg and his Bell Labs colleagues.[11] By measuring the spin susceptibility as a function of Sr doping y in the compound $La_{6-y}Sr_yCa_8Cu_{24}O_{41}$, the Bell Labs team established that the holes all go onto the chains. Like the sample studied by Akimitsu and company, this compound is a member of the general family $(La,Sr,Ca)_{14}Cu_{24}O_{41}$, but unlike the Japanese study, the Bell Labs experiment was done at ambient pressure.

Akimitsu asserts that, if one starts with $Sr_{14}Cu_{24}O_{41}$ and dopes it with Ca, some carriers are released to the ladder sites. Cava concedes that as many as one out of every six holes could be on the ladders; their resolution is not fine

Stars and Stripes in Manganese Oxide



Charge ordering in a $La_{0.33}Ca_{0.67}MnO_3$ lattice can be seen as regularly spaced stripes in this low-temperature high-resolution (0.5-nm) electron micrograph made by Cheng Hsuan Chen and Sang-Wook Cheong of Bell Laboratories, Lucent Technologies. In the strategically placed inset at the upper left, charge ordering is evidenced by the smallest stars in the electron diffraction pattern.

If one dopes antiferromagnetic insulators (especially transition metal oxides with a perovskite structure) with charge carriers, phenomena such as high-temperature superconductivity, phase separation and charge ordering can be produced. Over the last two years, a so-called colossal magnetoresistance has been found in $La_{1-x}Ca_xMnO_3$ when x ranges between 0.2 and 0.5. When a magnetic field of a couple of tesla is applied, the resistivity drops colossally—by several orders of magnitude. At low temperatures the material is a ferromagnetic metal in the doping range where the colossal magnetoresistance occurs; for $x > 0.5$, the ground state is an antiferromagnetic insulator. By doing transport, magnetic and diffraction studies over the last year, groups at the University of Tokyo[1] and at Bell Labs[2] have found indications of charge localization in manganese oxide.

In the charge-ordered state, the doped charge carriers localize along the diagonal direction of the manganese oxide square lattice and are visible as stripes. The image suggests a diagonal row of trivalent Mn ions separated by two diagonal rows of tetravalent Mn ions; the pattern repeats with a period of 1.65 nm.

What affects the ease with which electrons move through the crystal lattice from Mn site to Mn site? Correlation of the Mn 3d electrons, relative alignment of neighboring Mn spins, and interaction between the electrons and the lattice all play a role. The electron–lattice effect is especially strong when compared to nickel or copper oxides and can even impede the motion of electrons completely. In such an extreme case, the system can self-organize into a regular array such as the stripes seen here. The false colors in both the stripes and stars represent the electron beam intensity, with yellow being the highest, followed by red, green and blue.

The large magnetoresistance effect might be useful in magnetic field sensors, such as read heads for magnetic recording and position sensors.

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