SCIENCEWATCH®
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Underdoped Superconductors Fill the Gap

by Simon Milton

The Physics Top Ten this period is heavily freighted by experimental papers #1, 3, 6, 7 and 9 on the unusual behavior of underdoped high-T_c (critical temperature) superconductors. They have frozen out string theory (#4, 8, 10), while astrophysics and cosmology have, for the moment, dropped beyond view.

The experimental thrust in superconductor physics, reflected in our highly cited papers, is to determine the fundamental physics of cuprate superconductivity rather than to search for immediate applications. The superconductor center stage in #1, 3, 7, and 9, is $Bi_2Sr_2CaCu_2O_8+\delta$, compacted to Bi2212 in the literature. The copper oxide superconductors crystallize in layers with CuO_2 slices alternating with the charge reservoir layers. Research attention is directed at mechanisms and structures.

For *Science Watch*, Zhi-xun Shen of Stanford University, who is a coauthor of #3 and 7, offered the following introduction to the physics of cuprate superconductors. "As you cool down a conventional superconductor it acts as a metal until it reaches the critical temperature T_c, below which it rapidly goes superconducting. However, the underdoped cuprates investigated in these papers seem to be preparing for the transition well before they reach T_c." Doping refers to the dramatic changes that occur in these substances when a small fraction of electrons is chemically removed, so that the holes can move freely and the insulator converts into a metal. In short these superconductors have complex heterostructures in which itinerant charge carriers and polarons coexist.

In a classical superconductor an energy

WHAT'S HOT IN PHYSICS...

Rank	*Paper*	*Citations This Period Nov-Dec 97*	*Rank Last Period Sep-Oct 97*
1	H. Ding, *et al.*, *"Spectroscopic evidence for a pseudogap in the normal state of underdoped high-T_c superconductors,"* *Nature*, 382(6586):51-4, 4 July 1996. [7 institutions worldwide] *UV473	39	7
2	K.B. Davis, *et al.*, *"Bose-Einstein condensation in a gas of sodiumatoms,"* *Phys. Rev. Lett.*, 75(22):3969-73, 27 November 1995. [MIT, Cambridge, MA] *TF684	29	2

gap opens up at T_c, reflecting the energy needed to break the Cooper pairs of electrons with opposite spins participating in superconductivity. The "gap" means that no conducting particles have the particular energy associated with the gap. Classically the energy gap opens up only at T_c, but what researchers see for copper oxide superconductors is the energy gap opening up way above the superconducting transition, at 200K for samples with a T_c of 80K. This is serious new physics, which is under intense investigation because any kind of crossover has much to say. The natural interpretation is that Cooper pairs form far above T_c in the cuprates. If this is correct it means that the superconducting transition in copper oxide superconductors is due to something other than the presence of Cooper pairs, such as a phase coherence transitin. This would signal that the mechanism is different from the BCS theory that applies to classical superconductors.

High-T_c superconductors are not like normal metals, where the Fermi-liquid model holds. Bi2212 deviates far from a Fermi liquid. Of papers #3 and 7 which report that the energy gap occurs well above T_c, Zhi-xun Shen says, "While the full implication of this observation is still under intense observation, a natural interpretation is that the Cooper pairs are formed well above T_c. If this holds then the critical step for the superconducting transition in the cuprates is the formation of the Cooper pair, rather than something else such as a phase coherence transition. This idea is further supported by our finding that the size of the superconducting gap in the underdoped regime does not scale with T_c"

The Stanford group has recently confirmed that the gap collapses very rapidly in higher doping regimes. Furthermore they have seen the same behavior in another cuprate system, Bi2201. The latest unpublished results report that the gap is seen in La-Sr-Cu-O, the system investigated in newcomer #6 which looks at the lattice distortions at optimum doping. Antonio Bianconi, Rome University, Italy, and colleagues report on structural measurements at the mesoscopic scale. According to Bianconi, "It is getting clear that the high T_c superconductors belong to a family showing a dynamic phase segregation of charge carriers." This idea of

3	A.G. Loeser, *et al., "Excitation gap in the normal state of underdoped $Bi_2Sr_2CaCu_2O_{8+\delta}$," Science*, 273(5273):325-9, 19 July 1996.[Stanford U., CA] *UY202	28	
4	J. Polchinski, *"Dirichlet branes and Ramond-Ramond charges," Phys. Rev. Lett.*, 75(26):4724-7, 25 December 1995. (U. Calif., Santa Barbara] *TL677	23	3
5	S. Nakamura, *et al., "InGaN-based multi-quantum-well-structure laser diodes," Japan. J. Appl. Phys.*, 35(1B):L74-6, 15 January 1996. [Nichia Industries, Ltd., Tokushima, Japan] *TU369	21	9
6	A. Bianconi, *et al., "Determination of the local lattice distortions in the CuO_2 plane of $La_{1.85}Sr_{0.15}CuO_4$," Phys. Rev. Lett.*, 76(18):3412-5, 29 April 1996. [U. Rome, Italy; Electrotechnical Lab., Umezono, Tsukuba, Japan] *UG829	21	
7	D.S. Marshall, *et al., "Unconventional electronic structure evolution with hole doping in $Bi_2Sr_2CaCu_2O_{8+\delta}$ angle-resolved photoemission results," Phys. Rev. Lett.*, 76(25):4841-4, 17 June 1996. [Stanford U., CA; Varian Assoc., Palo Alto, CA; U. Colorado, Boulder] *UR095	20	
8	E. Witten, *"Bound states of strings and p-branes," Nucl. Phys. B*, 460(2):335-50, 5 February 1996. [Inst. Advanced Study, Princeton, NJ] *TX008	19	

9	Y. Matsuda, *et al.*, *"Collective Josephson plasma resonance in the vortex state of $Bi_2Sr_2CaCu_2O_8 + \delta$," Phys. Rev. Lett.*, 75(24):4512-5, 11 December 1995. [Hokkaido U., Sapporo, Japan; Natl. Res. Inst. Metals, Tsukuba, Japan] *TJ630	18	
10	A. Strominger, C. Vafa, *"Microscopic origin of the Bekenstein-Hawking entropy," Phys. Lett. B*, 379(1-4):99-104, 27 June 1996. [U. Calif., Santa Barbara; Harvard U., Cambridge, MA] *UW433	16	5

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phase segregation connects the cuprate perovskites showing superconductivity with their cousins the manganese perovskites which exhibit giant magnetoresistance (see *Science Watch*, 8[5]:7, September/October 1997. Evidence is now mounting for a connection in the cuprates between antiferromagnetism and superconductivity, a convergence that will be explored in conferences slated for June 1998 to be held in Rome and Erice, Italy.

In another newcomer, #9, a group led by K. Kumagai of Hokkaido University, Japan, investigate exotic properties of the conducting plasma in layered superconductors. First author Yuji Matsuda informed *Science Watch*, "We have succeeded in observing the Josephson plasmon (a Cooper pair oscillation perpendicular to the superconducting planes) for the first time. We have actually demonstrated that this plasma mode is quite sharp and stable. This paper may be highly cited because Josephson coupling between superconducting layers plays an important role in determining the nature of the vortex state of high T_c superconductors." According to #9, the plasma resonance it describes is a powerful new means of investigating the properties of the vortex state of superconductivity. ■

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