SrO and BaO high-temperature superconductivity

John D. Dow [a,1], Dale R. Harshman [b]

[a] *Department of Physics, Arizona State University, Tempe, AZ 85287 U.S.A.*
[b] *Physikon Research Corporation, P. O. Box 1014, Lynden, WA 98264 U.S.A.*

Abstract

$Sr_2YRu_{1-u}Cu_uO_6$ (for $0.05 \leq u \leq 0.15$) has only two types of layers: magnetic $YRuO_4$ layers doped on Ru sites with Cu, and non-magnetic $(SrO)_2$ layers. It superconducts (without cuprate-planes) in its SrO layers with an onset temperature of ≈49 K, and with an absolute critical temperature of 23 K, which coincides with the Néel temperature T_N at which the Ru moments stop fluctuating. $GdSr_2Cu_2RuO_8$ and $Gd_{2-z}Ce_zSr_2Cu_2RuO_{10}$ also start to superconduct near 49 K, because the SrO layers, not the cuprate-planes, superconduct. Four superconductors have been successfully predicted based on this idea. Pr_{Ba} defects destroy $PrBa_2Cu_3O_7$'s superconductivity (in the BaO layers). Our muon data show that $YBa_2Cu_3O_7$ exhibits *s*-wave or extended *s*-wave pairing, not *d*-wave pairing.

Key words:
High-T_c compounds; Y-based cuprates

1. Introduction

Today, we are sixteen years after the announcement of high-temperature superconductivity[1], with perhaps the most vigorous effort in history having been expended to understand the phenomenon. Yet now we have nothing resembling a consensus theory of high-temperature superconductivity; instead we have numerous concepts that are widely held but unproven. In this paper we shall address the following two such concepts: (1) that the superconductivity is located in the cuprate-planes; and (2) that the analogue of Cooper-pairing in these materials involves *d*-wave carriers. We shall present evidence that both of these widely believed concepts are invalid.

2. Evidence that the cuprate-planes do not superconduct

2.1. *Sr_2YRuO_6 doped with Cu: no cuprate-planes*

Sr_2YRuO_6 doped with Cu (on Ru sites) is an extremely interesting high-temperature superconductor because: it has no cuprate-planes; it superconducts with 5% to 15% Cu dopants; and it has an onset of superconductivity at a high temperature of ≈49 K (but does not become fully superconducting until the temperature is reduced to the Ru ordering temperature of 23 K, or below)[2–4]. Two other temperatures are relevant for Cu-doped Sr_2YRuO_6, namely 29.3 K, the temperature at which spin-glass fluctuations are observed[5], and 86 K, the temperature at which the moments of its Cu dopants order. The material has two layers per unit cell: (i) non-magnetic $(SrO)_2$ layers and (ii) $Y(Ru_{1-u}Cu_u)O_4$ layers which are ferromagnetic in the $a-b$ planes, but are stacked antiferromagnetically along the c-axis so that there is no magnetic field in the SrO layers at low temperatures.

Cu-doped Sr_2YRuO_6 superconducts and belongs

[1] Corresponding author. Present address: 6031 East Cholla Lane, Scottsdale, AZ 85253 U.S.A. Email: cats@dancris.com

to the same class of crystals as non-superconducting $Ba_2Gd(Ru_{1-x}Cu_x)O_6$. It also has two classes of cuprate sister compounds, $GdSr_2Cu_2RuO_8$ and $Gd_{2-z}Ce_zSr_2Cu_2RuO_{10}$, whose onset temperatures for superconductivity are *at virtually the same temperature as Cu-doped Sr_2YRuO_6's onset*, ≈49 K.

Given these facts we must make one of two choices: (i) the onsets of *p*-type superconductivity in the three superconductors $Sr_2YRu_{1-u}Cu_uO_6$, $GdSr_2Cu_2RuO_8$, and $Gd_{2-z}Ce_zSr_2Cu_2RuO_{10}$, all occur at essentially the same temperature because the superconducting entity is the same in all three compounds, or (ii) the similar values of $T_{c,onset}$ are an accident and there are two mechanisms of high-temperature superconductivity, one cuprate-plane mechanism for the two cuprates and a different one for the Cu-doped Sr_2YRuO_6 without cuprate-planes. The three main problems with the second choice are that (a) it violates Ockham's razor[6], (b) we are forced to treat the nearly coincidental values of $T_{c,onset}$ as accidental, and (c) there do not presently exist *any* successful theories of high-temperature superconductivity, much less the *two* required by such a choice. Thus we assume that there is only *one* theory.

Having adopted a one-theory model, the superconducting holes must be located in the SrO layers of $Sr_2Y(Ru_{1-u}Cu_u)O_6$ because only those layers are *p*-type and are also found in many superconductors. Consequently the holes of $GdSr_2Cu_2RuO_8$ and $Gd_{2-z}Ce_zSr_2Cu_2RuO_{10}$ must also occupy the SrO layers, not the cuprate-planes.

2.2. *Four new superconductors*

By assuming that the superconducting holes reside in the SrO (or BaO) layers, not in the cuprate-planes, we were able to successfully predict that $PrBa_2Cu_3O_7$, $Pr_{1.5}Ce_{0.5}Sr_2Cu_2NbO_{10}$, $Gd_{1.6}Ce_{0.4}Sr_2Cu_2TiO_{10}$, and $Eu_{1.5}Ce_{0.5}Sr_2Cu_2TiO_{10}$ all would superconduct. The predictions were fulfilled, and $PrBa_2Cu_3O_7$ is now a bulk superconductor, and the other three materials have exhibited granular superconductivity[2,7,8].

2.3. *$PrBa_2Cu_3O_7$*

Complementary evidence for the superconductivity occupying the SrO layers, or the equivalent BaO layers, in $PrBa_2Cu_3O_7$ is available from $PrBa_2Cu_3O_7$, which superconducts when clean, but stops superconducting once a few percent magnetic, pair-breaking Pr ions occupy Ba sites (such occupancy manifests itself in a number of other ways, most notably by a shortened *c*-axis). The asymmetry, namely that Pr on a Pr-site does not destroy the superconductivity, but Pr on a Ba-site does, although the two sites are virtually the same distance from the cuprate-plane in between, coupled with demonstrations that the destruction is due to the magnetism of Pr_{Ba} defects, implies that the cuprate-planes do not superconduct[2].

3. $YBa_2Cu_3O_7$: *s*-wave hole-pairing

In a recent muon experiment on $YBa_2Cu_3O_7$[9] we have demonstrated that the pairing of holes is nodeless, namely *s*-wave (or extended *s*-wave), and is inconsistent with *d*-wave pairing. This result for $YBa_2Cu_3O_7$ complements the earliest work, as well as the recent work of Klemm *et al.* on $Bi_2Sr_2CaCu_2O_8$[10], and, in effect, calls into question all claims to have observed *d*-wave superconductivity in clean material.

Acknowledgements

We thank the U.S. Office of Naval Research for their financial support of J.D.D. and D.R.H. (Contract No. N00014-94-1-0147), and D.R.H. acknowledges Physikon Project No. PL-206 for his support.

References

[1] J. G. Bednorz and K. A. Müller, Z. Phys. **B 64** (1986) 189.

[2] J. D. Dow and D. R. Harshman, "New picture of high-temperature superconductivity," J. Phys. Chem. Solids, in press.

[3] D. R. Harshman, W. J. Kossler, A. J. Greer, C. E. Stronach, E. Koster, B. Hitti, M. K. Wu, D. Y. Chen, F. Z. Chien. H. A. Blackstead, and J. D. Dow, Intl. J. Mod. Phys. **B 13** (1999) 3670.

[4] D. R. Harshman, W. J. Kossler, A. J. Greer, C. E. Stronach, E. Koster, B. Hitti, M. K. Wu, D. Y. Chen, F. Z. Chien, H. A. Blackstead, and J. D. Dow, Physica **B 289-290** (2000) 360.

[5] D. R. Harshman, W. J. Kossler, A. J. Greer, C. E. Stronach, D. R. Noakes, E. Koster, M. K. Wu, F. Z. Chien, J. P. Franck, and J. D. Dow, "Spin-glass behavior, spin-fluctuations, and superconductivity in $Sr_2Y(Ru_{1-u}Cu_u)O_6$," Submitted.

[6] Sir William of Ockham, 1348: *"Non sunt multiplicanda entia praetor necessitatem."*

[7] J. D. Dow, H. A. Blackstead, and D. R. Harshman, Intl. J. Mod. Phys. **B 14** (2000) 3444.

[8] J. D. Dow, H. A. Blackstead, and D. R. Harshman, Physica **C 364-365** (2001) 74.

[9] D. R. Harshman, W. J. Kossler, X. Wan, A. J. Greer, D. R. Noakes, C. E. Stronach, E. Koster, A. Erb, and J. D. Dow, "Nodeless pairing-state gap-function in single-crystal $YBa_2Cu_3O_7$," Submitted.

[10] Qiang Li Y. N. Tsay, M. Suenaga, R. A. Klemm, G. D. Gu, and N. Koshizuka, Phys. Rev. Lett. **83** (1999) 4160.