Is Cs_3C_{60} a cubic high temperature superconductor?

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A major issue of perspective in the field of superconductivity is whether or not there is a single, broadly construed "mechanism of high temperature superconductivity" which applies, albeit with different material specific details, to a broad class of unconventional superconductors. The prototypical, and so far most intensely studied family of high temperature superconductors (HTS) is the cuprates. In the cuprates, the superconducting phase occurs in close proximity to a commensurate, antiferromagnetically ordered phase with a substantial ordered moment ($m \sim 0.6\ \mu_B$). As a function of a control parameter (which in this case is the doping concentration), the antiferromagnetic Neel temperature, T_N, drops monotonically to zero. Meanwhile, the superconducting T_c first rises from T_c=0 to a maximal value and then drops back to zero with increasing distance from the antiferromagnetic phase. Also notable are the facts that the cuprates are quasi 2D (layered) materials , that they exhibit non-Fermi–liquid "bad metal" normal states, and that the superconducting state has non-trivial internal ("d-wave") structure involving sign-changes of the gap function.

The discovery of superconductivity in the Fe-pnictides has led to a year of excitement and discovery. Here, too, the superconducting phase occurs in the neighborhood of a commensurate antiferromagnetic phase with a large ordered moment ($m \sim 1/4\ \mu_B – 1\ \mu_B$) and, as a function of increasing doping concentration, T_N, drops to zero while T_c first rises to a maximum near the boundary of the magnetically ordered phase, and then drops to zero with increasing doping. These materials are also layered, although they are certainly less two dimensional (electronically) than the cuprates. The normal state resistivity also exhibits anomalously high values and a more or less linear T dependence at elevated temperatures, i.e. they are bad metals. The symmetry of the order parameter is still not established in the Fe-pnictides, and may even vary among materials in this family, but it is generally believed to involve a sign changing gap function (d-wave or sign changing s-wave). Despite this possible difference, and despite the fact that there are multiple bands at the Fermi energy in the pnictides (in contrast to the single band in the cuprates), there appears to be growing consensus that the parallels between the cuprates and the pnictides are profound, and indicative of common physics, and probably, at the core, a common mechanism.

Other layered, unconventional superconductors, including various organics and the 115 heavy fermion materials, also exhibit striking parallels with the cuprates. However, until recently, there was a general (although not universal) feeling that the superconductivity of alkali doped fullerides (A_3C_{60}), in common with MgB_2, should be viewed as belonging to the high temperature tail of the distribution of BCS superconductors, with the same basic electron-phonon mechanism, rather than as an unconventional HTS. However, a breakthrough in the field has occurred with the synthesis of a new member of the family, Cs_3C_{60}, reported by Takabayashi *et al*. Since T_c was already known to rise with increasing ionic radius of the Alkali atom (from T_c=19.5K for K_3C_{60}, to T_c=29.5 for Rb_3C_{60}, to T_c=33K for $RbCs_2C_{60}$), it was natural to speculate (consistent with what BCS reasoning would imply) that T_c would be still higher in Cs_3C_{60}, but its synthesis had, until the success of the present authors, not cleanly been achieved. An unexpected fringe benefit is that Cs_3C_{60} has a simple BCC (actually, A15) crystal structure, in contrast to the FCC structure of previously studied fullerides; in this structure, the C_{60} molecules are orientationally ordered, so the complicating presence of strong orientational ("merohedral") disorder, which has plagued the interpretation of previous experiments in A_3C_{60}, is not a factor in the present materials.

Several striking observations have been reported on this new material, all of which invite comparison with the cuprates, and with it the possible implication that the mechanism of superconductivity is unconventional. In the first place, Cs_3C_{60} at atmospheric pressure is an antiferromagnetic insulator with T_N=46K and a substantial ordered moment, $m \sim 1\mu_B$. Under pressure, T_N decreases, and eventually drops (probably discontinuously) to zero. The nature of the possible coexistence between superconductivity and antiferromagnetism is not, currently, clear. However, once antiferromagnetism has been destroyed, the superconducting T_c first rises to a maximum T_c = 38K, and then drops with increasing pressure. This non-monotonic behavior contrasts with the monotonically decreasing behavior that has previously been seen in all other members of the A_3C_{60} family. It is very reminiscent of the doping dependence of T_c in the cuprates. The normal state resistivities of all previously studied members of the A_3C_{60} family are certainly high enough to warrant their classification as "bad metals," although it is unclear how much of this high resistivity can be attributed to effects of randomness, for instance to the merohedral disorder.

There are several obvious differences between the cuprates and the fullerides. In A_3C_{60}, there are three bands (per C_{60}) at the Fermi energy, so these are multiband systems. However, the example of the Fe-pnictides convinces us that the single band character of the cuprates is probably not an essential feature of HTS. More interestingly, A_3C_{60} is cubic; if it indeed reflects common physics with the cuprates, this suggests that low dimensional physics is not an essential feature of the mechanism of HTS. This would be good news, indeed, from a practical viewpoint. Finally, there is no evidence of gapless nodal quasiparticles in A_3C_{60}, in contrast to those associated with the d-wave nodes in the cuprates. Again, the lessons of the Fe-pnictides make us less fast to use this observation as a basis for dismissing the analogy between the different families of materials. However, it does make it a problem of urgent interest to study the internal structure of the gap function in A_3C_{60}. It would also be very illuminating to better characterize the normal state, particularly the resistivity , in Cs_3C_{60} where we can neglect the effects of merohedral disorder, which complicate the interpretation of previous results.