Origin of the Optimal Doping in high-Tc Cuprates

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Doping an insulator to make it a BCS-type superconductor, is equivalent to creating states in the Debye shell on both sides of the Fermi level. This doping is, therefore, equal to twice the product of the density of state, at the Fermi level, and the Debye temperature. This formula works well for optimally doped cuprates, suggesting a major role for phonons behind the superconductivity of these materials.

The optimal doping, $x_{opt} \approx 0.16$, of some cuprates remains a mystery to this day. It can be solved if we consider that these materials behave like BCS superconductors. Their Debye shell must be doped to provide carriers to form Cooper pairs when cooled below the critical temperature Tc. The doping is, then, given by $x \approx 2.\rho_0.\theta_D$, where ρ_0 is the density of state at the Fermi level and θ_D is the Debye temperature. Application of this formula to experimental data is shown below, where γ_n is the Sommerfeld constant.

Material	réf.	Tc (K)	θ_D (K)	γ_n (mJ.mol^{-1}.K^{-2})	ρ_0 (states/eV)	x
$La_{1.85}Sr_{0.15}CuO_4$	[1]	37	360	4.5	1.9	0.12
$YBa_2Cu_3O_7$	[1]	92	410	4-10	2.0	0.14
$YBa_2Cu_4O_{8.5}$	[1]	80	350	4.9	2.1	0.13
$Bi_2Sr_2CaCu_2O_8$	[1]	95	250	8	3.4	0.14
$Pr_{2-x}Ce_xCuO_{4-\delta}$	[2]	22	390	5.3	2.2	0.15
$Tl_2Ba_2CuO_{6+\delta}$	[3]	80*	218	6.6	2.8	0.11
$Sr_{0.9}La_{0.1}CuO_2$	[4]	43	404**	7.5	3.2	0.22

*Not optimal. **A more recent report gives 246 K [5], therefore **x = 0.13**.

ρ_0 is calculated, per copper atom, from $\gamma_n = \frac{1}{3}\pi^2 k_B^2 \rho_0$ [6,7].

To sum it up, the optimal doping was closely approached using a simple BCS argument. The latter was, also, used some years ago to successfully reproduce the small values of the isotope coefficient [8]. From these two facts, we can consider that the superconductivity at the optimal doping is governed by the electron-phonon interaction.

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