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Universal scaling relation in high-temperature superconductors[1]

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Superconductivity at elevated temperatures in the copper-oxide materials has proven to be one of the great challenges in condensed matter physics. Despite 18 years of intensive study, the nature of the superconductivity in these systems is still not agreed upon. Scaling laws express a systematic and universal simplicity among complex systems in nature. We have recently observed a scaling relation in the high-temperature superconductors[2] between the strength of the superconducting condensate ρ_s (a measure of the number of carriers in the superconducting state n_s), the critical temperature T_c, and the dc conductivity σ_{dc} just above the critical temperature: $\rho_s \simeq 35\,\sigma_{dc}\,T_c$. This scaling relation does not depend on the crystal structure, type of dopant, nature of the disorder, or direction. Interestingly, values for the elemental superconductors Nb and Pb also fall close to this line. However, it may be shown from spectral weight arguments that these points correspond to systems in the BCS dirty limit (the scattering rate $1/\tau$ is larger than the isotropic energy gap 2Δ); in the extreme dirty limit, the scaling relation $\rho_s \simeq 65\,\sigma_{dc}\,T_c$ is recovered. The implications of the clean and dirty-limit approaches within the copper-oxygen planes are discussed. The superconductivity perpendicular to the planes is often described within a BCS framework by the Josephson effect, which interestingly also yields $\rho_s \simeq 65\,\sigma_{dc}\,T_c$, where the superfluid density and the dc conductivity are now taken along the c axis. Despite the fact that the BCS model considers an isotropic energy gap, and the cuprates are considered to be d-wave in nature with nodes, the scaling behavior of the dirty-limit and the Josephson effect is in agreement with experimental observations. This suggests that electronic inhomogeneities may play a crucial role in the nature of superconductivity in these materials.

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[2]C.C. Homes *et al.*, Nature **430**, 539 (2004)