Symmetry of the Gap in Bi2212 from Photoemission Spectroscopy

In a recent Letter, Shen *et al.* [1] detected a large anisotropy of the superconducting gap in $Bi_2Sr_2CaCu_2O_8$ (Bi2212), consistent with d-wave symmetry from photoemission spectroscopy. Moreover, they claim that the change in their spectra as a function of aging is also consistent with such an interpretation. In this Comment, I show that the latter statement is not entirely correct, in that the data as a function of aging are inconsistent with a d-wave gap but are consistent with an anisotropic s-wave gap (assuming impurity scattering can be treated as in Ref. [2]).

In Ref. [1], the data show that the gap is close to zero along the (1,1) direction and maximum along the (1,0) direction, just as expected for a gap with $d_{x^2-y^2}$ symmetry. As the sample ages, the gap becomes nonzero along (1,1). This is attributed by them to poorer k resolution due to impurity scattering. This brings up the interesting question of what one theoretically expects for the excitation gap as a function of impurities. I do this for two cases where a spherical Fermi cylinder is assumed for simplicity's sake. For the d-wave case, the gap is assumed to be $\Delta\cos(2\phi)$ and for the anisotropic s-wave case, $\Delta|\cos(2\phi)|$. Thus, the modulus of the gap is the same, the only difference being the symmetry of the gap under rotations.

The self-energy equations at $T = 0$ in the Born approximation are [2,3]

$$\tilde{\omega} = \omega + \frac{\Gamma}{2\pi}\int_0^{2\pi} d\phi' \frac{\tilde{\omega}}{[\tilde{\Delta}(\phi')^2 - \tilde{\omega}^2]^{1/2}}, \quad (1)$$

$$\tilde{\Delta}(\phi) = \Delta(\phi) + \frac{\Gamma}{2\pi}\int_0^{2\pi} d\phi' \frac{\tilde{\Delta}(\phi')}{[\tilde{\Delta}(\phi')^2 - \tilde{\omega}^2]^{1/2}}, \quad (2)$$

where Γ is the strength of the impurity scattering. These solutions are then used to determine the angle-resolved density of states:

$$N(\phi,\omega) = N_0\,\mathrm{Im}\left(\frac{\tilde{\omega}}{[\tilde{\Delta}(\phi)^2 - \tilde{\omega}^2]^{1/2}}\right), \quad (3)$$

where N_0 is the density of states in the normal state. The excitation gap is where N first becomes nonzero. For the d-wave case, this is zero for all ϕ as soon as Γ is nonzero. Instead, the excitation gap employed here is the same as that defined in Ref. [1], that is, where the value of N/N_0 first becomes equal to $\frac{1}{2}$. These results are summarized in Fig. 1. As can be seen, the d-wave case is qualitatively inconsistent with the data, since it becomes rapidly gapless as Γ increases. In contrast, the anisotropic s-wave case gives a behavior consistent with the data, with the gap becoming isotropic (equal to $\Delta/2$) in the large Γ limit.

A final remark is that the gap equations have not been resolved (Δ was treated as fixed). One can easily calculate the reduction of T_c with Γ

$$\ln\left(\frac{T_{c0}}{T_c}\right) = c\left[\psi\left(\frac{1}{2} + \frac{\Gamma}{2\pi T_c}\right) - \psi\left(\frac{1}{2}\right)\right], \quad (4)$$

where T_{c0} is T_c for the pure system and c is 1 for the d-wave case and $1 - 8/\pi^2 \sim 0.19$ for the s-wave case. Similarly, Δ decreases as Γ increases with the effect being much larger in the d-wave case. This makes the d-wave case even more inconsistent with the data.

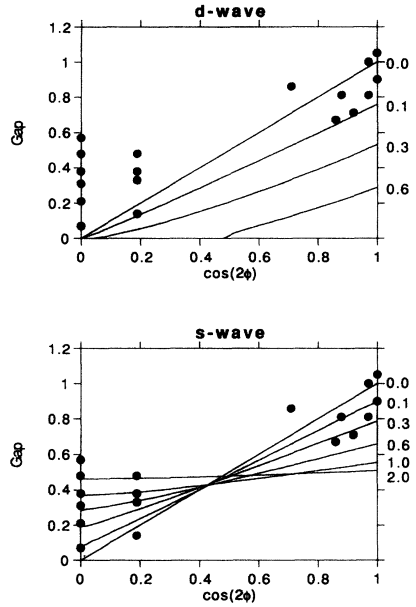

FIG. 1. Excitation gap as a function of position on the Fermi surface for various impurity concentrations for d-wave case and anisotropic s-wave case. The lines are labeled by values of Γ/Δ. The solid points are data from Ref. [1].

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