Comment on "Anomalously Large Gap Anisotropy in the *a*-*b* Plane of $Bi_2Sr_2CaCu_2O_{8+\delta}$"

Angle resolved photoemission on three samples of $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) was analyzed by Shen *et al.* [1] to obtain the dependence of the energy gap in the superconductor as a function of angular points around the Fermi surface. In contrast to previous reports on other superconductors [2], they found the gap to be very anisotropic. They assert that their data are only compatible with the *d*-wave order parameter in the superconductor, and "Our data are qualitatively incompatible with the extended *s*-wave scenario." Here we wish to challenge the last statement. A simple analysis shows that an *s*-wave order parameter fits the gap anisotropy better than the *d* wave which they advocate.

For a *d*-wave superconductor on a square lattice in two dimensions, the order parameter is usually expressed as

$$\Delta_d(\phi) = \Delta_{d0}[\cos(k_x a) - \cos(k_y a)] , \tag{1}$$

where the angular dependence results from $k_x = k\cos(\phi)$ and $k_y = k\sin(\phi)$. The photoemission measurements give $|\Delta(\phi)|$. Earlier we showed [3,4] that the *s*-wave order parameter has the general form on a square lattice of

$$\Delta_s(\phi) = \sum_l \Delta_{4l}\cos(4l\phi) . \tag{2}$$

The wide scatter in the data points prevents detailed fitting, so we simplify this to $\Delta_s = \Delta_0 + \Delta_4\cos(4\phi)$ which includes the first anisotropic term.

Experimental data was reported in Ref. [1] for three samples. They showed the data plotted vs the angular dependence in (1). Our Fig. 1 shows their data from sample 2 plotted vs $\cos(4\phi)$. The fit is better than their plot for *d*-wave superconductivity. The quality of fit can be given by a least squared fit according to the formula

$$R_{s,d} = \frac{1}{N}\sum_i^N [\Delta_{\exp}(i) - \Delta_{s,d}(\phi_i)]^2 , \tag{3}$$

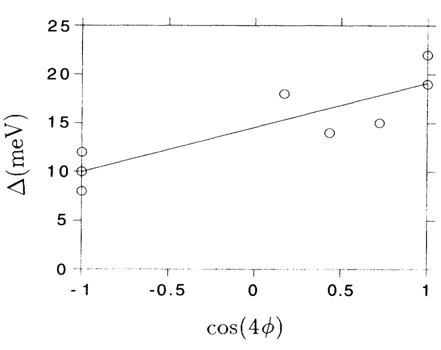

FIG. 1. Energy gap vs $\cos(4\phi)$ for the data of sample 2 in Ref. [1].

TABLE I. Least squared fits to the experimental points for *s*- and *d*-wave superconductivity.

Sample	1	2	3
N	4	8	10
s wave			
Δ_0 (meV)	5.2	14.5	11.8
Δ_4 (meV)	4.8	4.5	6.6
R_s	2.9	4.8	5.8
d wave			
Δ_{d0} (meV)	11.6	19.6	20.4
R_d	2.3	43.1	14.0

where N is the number of data points and $\Delta_{\exp}$ are the experimental points of gap vs angle. Table I shows R values for the two models. For sample 1 the fits are comparable, but for the other two samples the fit for the *s* wave is far better. The large values of R_d for sample 2 are difficult to reconcile with the *d*-wave model. Overall, the *s*-wave gap anisotropy fits the data better than the *d*-wave model.

Our fits give a consistent value of $\Delta_4 = 5 \pm 1$ meV for the anisotropic *s*-wave gap in Bi2212. The isotropic part Δ_0 varies among the three samples, because of the wide scatter in the experimental data.

The experimentalists remark that their data is time dependent, and the *d*-wave model fits better on fresh samples. However, since the aged samples are still superconducting, and must have an order parameter, the *s*-wave model fits both the fresh and aged samples. We conclude that the experimental data fits well the model of anisotropic *s*-wave superconductivity, which is contrary to the assertion in Ref. [1].

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