INVESTIGATION OF THE BCS GAP EQUATION FOR d +i d CUPRATE SUPERCONDUCTORS

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ABSTRACT We consider a ($d_{x2-y2} + i\, d_{xy}$) cuprate superconductor and model the functional dependence of the corresponding pairing interaction $V(\mathbf{k},\mathbf{k}') = (V_{x2-y2}(\mathbf{k},\mathbf{k}')+V_{xy}(\mathbf{k},\mathbf{k}'))$ of purely electronic (or a combination of electron-electron(e-e) and electron-phonon(e-ph)) origin by a function of the form $V_{trial} = [(V_{x2-y2}(k_F, k_F) + V_{xy}(k_F,k_F))\, F(\varphi,\varphi')]$, where $V_{x2-y2}(\mathbf{k},\mathbf{k}') = V_1 (\cos k_xa - \cos k_ya)(\cos k'_xa - \cos k'_ya)$, $V_{xy}(\mathbf{k}, \mathbf{k}') = 4V_2 \sin(k_xa) \sin(k_ya) \sin(k'_xa) \sin(k'_ya)$, V_1 and V_2 are the coupling strengths, k_F is the Fermi momentum, $\varphi = \mathrm{arc}(\tan(k_y/k_x))$, and (k_x,k_y) belong to the first Brillouin zone (BZ). Within the BCS framework,the interactions lead to superconducting gap $\Delta_{d+id}(\mathbf{k})$ with nodes and anti-nodes in the singlet pairing channel. The gap may be thought of as the development of a small d_{xy} superconducting order parameter(OP) phased by $\pi/2$ with respect to the principal d_{x2-y2} one leading to the violation of both parity and time-reversal symmetry. We show that the zero-temperature superconducting gap, in the anti-nodal/nodal regions, is non-zero/zero provided the dimensionless coupling strength $g(k_F) \sim (D/2)(V_{x2-y2}(k_F,k_F)+ V_{xy}(k_F,k_F)) > 0$, where the quantity D is the density of energy states. This inequality is found to be satisfied if the Fermi momentum components do not get perched anywhere in the regions around $[(0,\pm\pi),(\pm\pi,0)]$ in the first BZ for $V_1 < 0$ and $V_2 < 0$, or $V_1 < 0$ and $V_2 > 0$. For $V_1 > 0$ and $V_2 > 0$ or $V_1 > 0$ and $V_2 < 0$, the requirement is just the opposite. The restrictions could be realized by manouvreing the doping level in a hole-doped system. We find that the OP amplitude $(\Delta_0/\hbar\omega_c)$ is an increasing function of $g(k_F)$.