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Theoretical study of photoinduced superconductivity in $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) with two band model

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ABSTRACT

Dependences of the superconducting transition temperature (T_c) on hole concentration in $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) cuprate have been calculated in a frame work of canonical two-band BCS model containing Fermi surfaces of p and d holes. The shift of the chemical potential (μ) leads to the curve $T_c(n_h)$ with a maximum. The dependences of $T_c(n_h)$ for our system compared with available experimental data. Self –consistent equations for superconducting order parameter (Δ) are derived using Green's functions and equation of motion method. The enhancement of T_c is found due to doping.

Keywords: Green's function; p and d holes; critical temperature; hole concentration.
P A C S : 74.20.-z, 74.20.Fg, 74.20.Mn, 74.25. Bt

INTRODUCTION

It is of fundamental importance to explain the doping dependences of superconducting properties of photoinduced high-T_c cuprates. Doping dependences of the electronic chemical potential (μ) have been measured in $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) [1].

In our model, the pairing interaction between the participating bands is repulsive. Two two-band models for high-T_c superconductors has been known for a long time and for high-T_c superconductors these ideas have been developed further [2-7].

There are number of data indicating participation of several bands in the high-T_c superconducting mechanism. Two bands are found to intersect the Fermi level in Bi-2212. In $Bi_2Sr_2CaCu_2O_{8+\delta}$, the BiO-plane bands seem to be coupled to the Cu-O plane band [8]. In [2,3,4,9-10], a model of two over lapping hole bands has been used to reproduce the T_c dependences on the hole doping $La_{2-x}Sr_xCuO_4, YBa_2Cu_3O_{7-x}$ *and* $Bi_2Sr_2CaCu_2O_{8+\delta}$.

The optical reflectivity and the absorption spectra for the $Bi_2Sr_2Ca_{n-1}Cu_nO_x$ systems (n = 1,2,3) were measured at room temperature using c-axis oriented films [11]. In the reflectivity spectra, an increase of n enhanced a Drude-like reflection and shifted its plasma edge to the shorter wavelength region. In the absorption spectra, near-infrared absorption was enhanced with increasing n. These features reflected in the electronic structure and hence the superconductivity. In Bi-2212 system, the optical absorption spectra consisted of four discrete bands peaking at about 4.3, 3.7, 2.0-2.5 and 1.5-1.7 eV. The energies of characteristic peaks in Bi-compounds remain practically constant when Bi atoms are partially replaced by Pb and Ca by Y or Er atoms [12].

Recent experimental investigations on high-T_c cuprates systems, having compositions in the semiconductor regime, have shown light-induced changes, which are indicative of photoinduced superconductivity [13-25]. Although many aspects of the phenomena of high-T_c layered cuprates remain unexplained, the transition from the insulating and antiferromagnetic phase to the metallic and superconducting phase is known to be correlated with the density of charge carriers in the CuO_2 plane [22].

In some cases there is an increase of the critical temperature T_c with radiation doses [16-18]. The interesting result is the growth of the absolute value of diamagnetic moment almost clearly with radiation doses which saturates beyond a certain state [16]. The onset of transient photo induced super-conductivity, at high excitation levels, is a real phenomenon [15, 19].

The transient photo-induced super-conductivity is persistent at low temperatures and relax within days at room temperature [16, 20].

In this paper, we consider the photoinduced effect in cuprates superconductors taking into account the canonical two band model with p and d holes. The photoinduced effect induces the changes of hole concentration and leads to the change in superconducting properties. First we shall calculate the superconducting order parameters both for p and d holes and then calculate the dependences of superconducting transition temperature (T_c) on hole concentration (n_h) in $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) . This model can easily be generalized to two band system.

2. The Model Hamiltonian

The pairing mechanism in photoinduced superconductor is presently a subject of a vivid debate. There is great suspicion that some, if not all, photoinduced compounds are unconventional.

Many photoinduced superconductors have a complex band structure with several bands crossing the Fermi surface. These bands may be close in energy. The band separation can be

comparable to the gap value for photoinduced cuprates which requires consideration of the band structure, chemical potential and superconducting on an equal footing. This problem needs careful experimental and theoretical investigation.

The Mechanism of photoinduced superconductivity has been extensively studied but photoinduced superconductivity in cuprates is still to be being understood theoretically. One of the approaches for the photoinduced superconductivity in cuprates, at present lies in the two component scenario [4, 26, 27-30].

Our two-band model, in the context of photoinduced superconductivity, has common features with other models [4, 26].

In this paper, we present the self consistent calculations of the dependences of the chemical potential (μ) and the superconducting transition temperature (T_c) on the hole concentration (n_h) in the $Bi_2Sr_2CaCu_2O_{8+\delta}$ system.

We consider the following Hamiltonian for photoinduced two band structure [5] -

$$H = H_0{}^p + H_0{}^d + H_{pd} \qquad (1)$$

Where

$$H_0{}^p = \sum_p \in_p \left(C^+_{p\sigma}\ C_{p\sigma} + C^+_{-p\sigma'}\ C_{-p\sigma'}\right) + \Delta^+_{pp}\sum_p C_{p\sigma}\ C_{-p\sigma'} + \Delta_{pp}\sum_p C^+{}_{p\sigma}\ C^+{}_{-p\sigma'} \qquad (2)$$

$$H_0{}^d = \sum_d \in_d \left(C^+_{d\sigma}\ C_{d\sigma} + C^+_{-d\sigma'}\ C_{-d\sigma'}\right) + \Delta^+_{dd}\sum_d C_{-d\sigma'}\ C_{d\sigma} + \Delta_{dd}\sum_d C^+{}_{d\sigma}\ C^+{}_{-d\sigma'} \qquad (3)$$

and

$$\begin{aligned} H_{pd} = {} & V_{pd}\left\langle C^+_{p\sigma}\ C^+{}_{-p\sigma'}\right\rangle \sum_d C_{-d\sigma'}\ C_{d\sigma} + V_{pd}\left\langle C_{d\sigma}\ C\ {}_{-d\sigma'}\right\rangle \sum_p C^+{}_{p\sigma}\ C^+{}_{-p\sigma'} \\ & + V_{pd}\left\langle C^+_{d\sigma}\ C^+{}_{-d\sigma'}\right\rangle \sum_p C_{-p\sigma'}\ C_{p\sigma} + V_{pd}\left\langle C_{-p\sigma'}\ C_{p\sigma}\right\rangle \sum_d C^+_{d\sigma}\ C^+{}_{-d\sigma'} \end{aligned} \qquad (4)$$

Where p and d are momentum labels in the p and d bands respectively with energies $\in_p$ and $\in_d$, μ is the common chemical potential. Each band has its proper pairing interaction V_{pp} and V_{dd}, while the pair interchange between the two bands is assured by V_{pd} term.

We have assumed $V_{pd} = V_{dp}$, and we define the following quantities:

$$\in_p = \in_p{}^0 - \mu \qquad \in_d = \in_d{}^0 - \mu$$

$$\Delta_{pp}{}^+ = V_{pp}\left\langle C^+_{p\sigma}\ C^+{}_{-p\sigma'}\right\rangle$$

$$\Delta_{dd}{}^+ = V_{dd}\left\langle C^+_{d\sigma}\ C^+{}_{-d\sigma'}\right\rangle$$

Further we define –

$$\Delta_1{}^+ = V_{pd}\left\langle C^+_{p\sigma}\ C^+{}_{-p\sigma'}\right\rangle$$

$$\Delta_2{}^+ = V_{pd}\left\langle C^+_{d\sigma}\ C^+{}_{-d\sigma'}\right\rangle \qquad (5)$$

Now H_{pd} in equation (1) reads as

$$H_{pd} = \Delta_1^{+} \sum_d C_{-d\sigma'} \; C_{d\sigma} + \Delta_2 \sum_p C^{+}_{-p\sigma'} \; C^{+}_{p\sigma} + \Delta_2^{+} \sum_p C_{-p\sigma'} \; C_{p\sigma} + \Delta_1 \sum_d C^{+}_{d\sigma} \; C^{+}_{-d\sigma'}$$

So final Hamiltonian can be written as

$$\begin{aligned} H = & \sum_p \in_p \left(C^{+}_{p\sigma} \; C_{p\sigma} + C^{+}_{-p\sigma'} \; C_{-p\sigma'} \right) + \Delta^{+}_{pp} \sum_p C_{p\sigma} \; C_{-p\sigma'} + \Delta_{pp} \sum_p C^{+}_{p\sigma} \; C^{+}_{-p\sigma'} \\ & + \sum_d \in_d \left(C^{+}_{d\sigma} \; C_{d\sigma} + C^{+}_{-d\sigma'} \; C_{-d\sigma'} \right) + \Delta^{+}_{dd} \sum_d C_{-d\sigma'} \; C_{d\sigma} + \Delta_{dd} \sum_d C^{+}_{d\sigma} \; C^{+}_{-d\sigma'} \qquad (6) \\ & + \Delta_1^{+} \sum_d C_{-d\sigma'} \; C_{d\sigma} + \Delta_2 \sum_p C^{+}_{-p\sigma'} \; C^{+}_{p\sigma} + \Delta_2^{+} \sum_p C_{-p\sigma'} \; C_{p\sigma} + \Delta_1 \sum_d C^{+}_{d\sigma} \; C^{+}_{-d\sigma'} \end{aligned}$$

We study the Hamiltonian (6) with the Green's function technique and following the equation of motion method .

2.1 GREEN'S FUNCTIONS

In order to study the physical properties, we define the following normal and anomalous Green's functions [31-40] :

$$\begin{aligned} &(a) \quad G_p(p, \tau - \tau') = -\left\langle T_\tau \, C_{p\sigma}(\tau) \, C^{+}_{p\sigma}(\tau') \right\rangle \\ &(b) \quad G_d(d, \tau - \tau') = -\left\langle T_\tau \, C_{d\sigma}(\tau) \, C^{+}_{d\sigma}(\tau') \right\rangle \\ &(c) \quad f_p(p, \tau - \tau') = \left\langle T_\tau \, C_{-p\sigma'}(\tau) \, C_{p\sigma}(\tau') \right\rangle \\ &(d) \quad f_d(d, \tau - \tau') = \left\langle T_\tau \, C_{-d\sigma'}(\tau) \, C_{d\sigma}(\tau') \right\rangle \\ &(e) \quad f_p^{+}(p, \tau - \tau') = \left\langle T_\tau \, C^{+}_{p\sigma}(\tau) \, C^{+}_{-p\sigma'}(\tau') \right\rangle \\ &(f) \quad f_d^{+}(d, \tau - \tau') = \left\langle T_\tau \, C^{+}_{d\sigma}(\tau) \, C^{+}_{-d\sigma'}(\tau') \right\rangle \qquad (7) \end{aligned}$$

These Green's functions satisfy the following equations:

$$(\omega - \in_p) \; \langle\langle C_{p\sigma}, C^{+}_{p\sigma} \rangle\rangle = \delta_{pp'} - (\Delta_{pp} + \Delta_2) \; \langle\langle C^{+}_{p\sigma}, C^{+}_{-p\sigma'} \rangle\rangle \qquad (8)$$

$$(\omega - \in_d) \; \langle\langle C_{d\sigma}, C^{+}_{d\sigma} \rangle\rangle = \delta_{dd'} - (\Delta_{dd} + \Delta_1) \; \langle\langle C^{+}_{d\sigma}, C^{+}_{-d\sigma'} \rangle\rangle \qquad (9)$$

$$(\omega - \in_p) \; \langle\langle C_{-p\sigma'}, C_{p\sigma} \rangle\rangle = -(\Delta_{pp} + \Delta_2) \; \langle\langle C^{+}_{p\sigma}, C_{p\sigma} \rangle\rangle \qquad (10)$$

$$(\omega - \in_d) \; \langle\langle C_{-d\sigma'}, C_{d\sigma} \rangle\rangle = -(\Delta_{dd} + \Delta_1) \; \langle\langle C^{+}_{d\sigma}, C_{d\sigma} \rangle\rangle \qquad (11)$$

$$(\omega + \in_p) \; \langle\langle C^{+}_{p\sigma}, C^{+}_{-p\sigma'} \rangle\rangle = -(\Delta^{+}_{pp} + \Delta_2^{+}) \; \langle\langle C_{p\sigma}, C^{+}_{p\sigma} \rangle\rangle \qquad (12)$$

$$(\omega + \in_d) \; \langle\langle C^{+}_{d\sigma}, C^{+}_{-d\sigma'} \rangle\rangle = -(\Delta^{+}_{dd} + \Delta_1^{+}) \; \langle\langle C_{d\sigma}, C^{+}_{d\sigma} \rangle\rangle \qquad (13)$$

Further, we also obtain

$$(\omega + \in_p) \; \langle\langle C^{+}_{p\sigma}, C_{p\sigma} \rangle\rangle = \delta_{pp'} - (\Delta^{+}_{pp} + \Delta_2^{+}) \; \langle\langle C_{-p\sigma'}, C_{p\sigma} \rangle\rangle \qquad (14)$$

$$(\omega + \in_d) \; \langle\langle C^{+}_{d\sigma}, C_{d\sigma} \rangle\rangle = \delta_{dd'} - (\Delta^{+}_{dd} + \Delta_1^{+}) \; \langle\langle C_{-d\sigma'}, C_{d\sigma} \rangle\rangle \qquad (15)$$

To solve the above equations we have assumed:

$(\Delta_{pp} + \Delta_2) = \Delta_p$ and $\Delta^+{}_p \cong \Delta_p$

$(\Delta_{dd} + \Delta_1) = \Delta_d$ and $\Delta^+{}_d \cong \Delta_d$

Then

$(\Delta^+{}_{pp} + \Delta^+{}_2) = \Delta^+{}_p \cong \Delta_p$

$(\Delta^+{}_{dd} + \Delta^+{}_1) = \Delta^+{}_d \cong \Delta_d$ (16)

One can rewrite the equations (8) to (15) using (16) as ,

$(\omega - \in_p) \langle\langle C_{p\sigma}, C^+{}_{p\sigma} \rangle\rangle = \delta_{pp'} - \Delta_p \langle\langle C^+{}_{p\sigma}, C^+{}_{-p\sigma'} \rangle\rangle$ (17)

$(\omega - \in_d) \langle\langle C_{d\sigma}, C^+{}_{d\sigma} \rangle\rangle = \delta_{dd'} - \Delta_d \langle\langle C^+{}_{d\sigma}, C^+{}_{-d\sigma'} \rangle\rangle$ (18)

$(\omega - \in_p) \langle\langle C_{-p\sigma'}, C_{p\sigma} \rangle\rangle = -\Delta_p \langle\langle C^+{}_{p\sigma}, C_{p\sigma} \rangle\rangle$ (19)

$(\omega - \in_d) \langle\langle C_{-d\sigma'}, C_{d\sigma} \rangle\rangle = -\Delta_d \langle\langle C^+{}_{d\sigma}, C_{d\sigma} \rangle\rangle$ (20)

$(\omega + \in_p) \langle\langle C^+{}_{p\sigma}, C^+{}_{-p\sigma'} \rangle\rangle = -\Delta_p \langle\langle C_{p\sigma}, C^+{}_{p\sigma} \rangle\rangle$ (21)

$(\omega + \in_d) \langle\langle C^+{}_{d\sigma}, C^+{}_{-d\sigma'} \rangle\rangle = -\Delta_d \langle\langle C_{d\sigma}, C^+{}_{d\sigma} \rangle\rangle$ (22)

$(\omega + \in_p) \langle\langle C^+{}_{p\sigma}, C_{p\sigma} \rangle\rangle = \delta_{pp'} - \Delta_p \langle\langle C_{-p\sigma'}, C_{p\sigma} \rangle\rangle$ (23)

$(\omega + \in_d) \langle\langle C^+{}_{d\sigma}, C_{d\sigma} \rangle\rangle = \delta_{dd'} - \Delta_d \langle\langle C_{-d\sigma'}, C_{d\sigma} \rangle\rangle$ (24)

Finally, one obtains the Green's functions by solving coupled equations (17) to (24) as :

(a) Green's function **for p-holes** :

$$<< C^+{}_{p\sigma} \ , \ C^+_{-p\sigma'} >> = \frac{-\Delta_p}{\left(\omega^2 - E_p{}^2\right)} \qquad (25)$$

$$<< C^+{}_{p\sigma} \ , \ C_{p\sigma} >> = \frac{\left(\omega - \in_p\right)}{\left(\omega^2 - E_p{}^2\right)} \qquad (26)$$

$$<< C_{p\sigma} \ , \ C^+_{p\sigma} >> = \frac{\left(\omega + \in_p\right)}{\left(\omega^2 - E^2{}_p\right)} \qquad (27)$$

(b) Green's function **for d-holes** :

$$<< C^+{}_{d\sigma} \ , \ C^+_{-d\sigma'} >> = \frac{-\Delta_d}{\left(\omega^2 - E_d{}^2\right)} \qquad (28)$$

$$<< C^+{}_{d\sigma} \ , \ C_{d\sigma} >> = \frac{\left(\omega - \in_d\right)}{\left(\omega^2 - E_d{}^2\right)} \qquad (29)$$

$$<< C_{d\sigma} \ , \ C^+_{d\sigma} >> = \frac{\left(\omega + \in_d\right)}{\left(\omega^2 - E_d{}^2\right)} \qquad (30)$$

2.2 THE CORRELATION FUNCTIONS

Using the following relation [35-39] ,

$$\langle B(t')\ A(t)\rangle = \underset{\in\to 0}{Limit}\ \frac{i}{2\pi}\int_{-\infty}^{+\infty}\frac{\langle\langle A(t')\,;B(t')\rangle\rangle_{\omega-i\in}-\langle\langle A(t')\,;B(t')\rangle\rangle_{\omega+i\in}}{e^{\beta\omega}+1}\times\exp(-i\omega(t-t'))d\omega \qquad (31)$$

and employing the following identity ,

$$\underset{\in\to 0}{Limit}\left(\frac{1}{\omega+i\in-E_K}-\frac{1}{\omega-i\in-E_K}\right)=2\pi i\,\delta(\omega-E_K)$$

we obtain the correlation functions for the Green's function given by equations (25) as -

$$< C^{+}{}_{p\sigma}\, C^{+}_{-p\sigma'} >= \frac{-\Delta_p}{(\alpha_1-\alpha_2)}\left[f(\alpha_1)-f(\alpha_2)\right] \qquad (32)$$

where

$$\alpha_1 = +\sqrt{\in^2{}_p+\Delta^2{}_{pp}+\Delta^2{}_2+\Delta^{+}{}_{pp}\Delta_2+\Delta_2{}^{+}\Delta_{pp}} = +\sqrt{\in^2{}_p+\Delta^2{}_p}\ ,$$

$$\alpha_2 = -\sqrt{\in^2{}_p+\Delta^2{}_{pp}+\Delta^2{}_2+\Delta^{+}{}_{pp}\Delta_2+\Delta_2{}^{+}\Delta_{pp}} = -\sqrt{\in^2{}_p+\Delta^2{}_p} \qquad (33)$$

and $f(\alpha_1)$ & $f(\alpha_2)$ are Fermi functions.

Similarly, correlation function for the Green's function given by equation (26) is

$$< C^{+}{}_{p\sigma}\ \ C_{p\sigma} >= f(\alpha_2)+\left[\frac{\alpha_1-\in_P}{(\alpha_1-\alpha_2)}\right]\left[f(\alpha_1)-f(\alpha_2)\right] \qquad (34)$$

Similarly correlation functions for Green's functions (28) and (29) for d holes are obtained. One can define the two superconducting order parameters related to the correlation functions corresponding to Green's functions $<< C^{+}{}_{p\sigma}\ ,\ C^{+}_{-p\sigma'} >>$ and $<< C^{+}{}_{d\sigma}\ ,\ C^{+}_{-d\sigma'} >>$ for p and d holes respectively.

2.3 SUPERCONDUCTING ORDER PARAMETERS

Gap parameter Δ is the superconducting order parameter, which can be determined self consistently from the gap equation.

(1) For p holes :

The order parameter for the superconducting state is given by [41] –

$$\Delta_p = \frac{\left|V_{pp}\right|}{N}\sum_p < C^{+}{}_{p\sigma}\ ,\ C^{+}_{-p\sigma'} > \qquad (35)$$

where $\left|V_{pp}\right|$ is the pairing interaction constant for p holes and N is the total number of unit cells per unit volume.

Substituting the correlation function from equation (32) & using the relation,

$$\sum_{p} = 2\,N(0) \int_{0}^{\hbar\omega_p} d\in_p \qquad (36)$$

One can write the equation (35) as,

$$\Delta_p = \frac{|V_{pp}|}{N} \int_{0}^{\hbar\omega_p} d\in_p \frac{\Delta_p}{(\alpha_1 - \alpha_2)} [f(\alpha_2) - f(\alpha_1)] \qquad (37)$$

On further simplification, one obtains:

$$\frac{1}{|V_{pp}|N(0)} = \int_{0}^{\hbar\omega_p} d\in_p \frac{1}{(\alpha_1 - \alpha_2)} \left[\tanh\left(\frac{\beta\alpha_1}{2}\right) - \tanh\left(\frac{\beta\alpha_2}{2}\right)\right] \qquad (38)$$

(2) For d holes : In a similar manner we can obtain the expression for superconducting order parameter for d holes.

$$\frac{1}{|V_{dd}|N(0)} = \int_{0}^{\hbar\omega_d} d\in_d \frac{1}{(\alpha_1 - \alpha_2)} \left[\tanh\left(\frac{\beta\alpha_1}{2}\right) - \tanh\left(\frac{\beta\alpha_2}{2}\right)\right] \qquad (39)$$

We observe that expressions (38) and (39) reduce to standard BCS expressions [42].

Where

$$\alpha_1 = +\sqrt{\in^2_d + \Delta^2_{dd} + \Delta^2_1 + \Delta^+_{dd}\Delta_1 + \Delta^+_1\Delta_{dd}} = +\sqrt{\in^2_d + \Delta^2_d}$$

and

$$\alpha_2 = -\sqrt{\in^2_d + \Delta^2_{dd} + \Delta^2_1 + \Delta^+_{dd}\Delta_1 + \Delta^+_1\Delta_{dd}} = -\sqrt{\in^2_d + \Delta^2_d} \qquad (40)$$

Using equations (38) and (39), one can study the behavior of superconducting order parameter with temperature for both p and d holes.

2.4 DEPENDENCES OF CHEMICAL POTENTIAL (μ) ON CRITICAL TEMPERATURE (T_c) AND CRITICAL TEMPERATURE (T_c) ON HOLE CONCENTRATION (n_h)

Photoinduced phenomenon, generally, affects the chemical potential and carrier concentration in high T_c superconductors. One can study the dependence of T_c on the hole concentration n_h and chemical potential (μ) for the system $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) from the model Hamiltonian. The effective chemical potential (μ) corresponds to the average carrier concentration (n_h). The maximum of $T_c(n_h)$ corresponds to chemical potential (μ) lying in the common region of both bands roughly in the middle between $\in_0$ and $\in_c$, where $\in_c = Cut-off\ energy\ of\ lower\ band$ and $\in_0 = top\ energy\ of\ lower\ band$.

From two band model, one can study the dependence of the superconducting transition temperature on the hole concentration determined by chemical potential (μ) by studying:

(a) Dependence of chemical potential (μ) on critical temperature (T_c).

(b) Dependence of critical temperature (T_c) on hole concentration (n_h) .

(A). DEPENDENCE OF CHEMICAL POTENTIAL (μ) ON CRITICAL TEMPERATURE (T_c)

We calculate the superconducting transition temperature T_c , with chemical potential (μ) , In Matrix form superconducting order parameter can be written as [5] -

$$\bar{\Delta}_i = \sum_j V_{ij}\, G\,(\bar{\Delta}_j)\,\bar{\Delta}_j \qquad (41)$$

There are two superconducting gaps for p and d holes in our interband model. The expressions for the dependence of superconducting gaps as $T \to T_c$ on the hole concentration can be derived.

One can write the equations for superconducting gaps for p and d holes as follows -

$$\Delta_p = V_{pp}\, G_p(\Delta_p)\Delta_p + V_{pd}\, G_d(\Delta_d)\Delta_d \qquad (42)$$

$$\Delta_d = V_{dp}\, G_p(\Delta_p)\Delta_p + V_{dd}\, G_d(\Delta_d)\Delta_d \qquad (43)$$

where V_{pp} and V_{dd} is pairing interaction of p and d bands respectively, while the pair interchange between the two bands is assured by the V_{pd} term . The quantity V_{pd} has been supposed to be operative and constant in the energy interval for higher band and lower band, keeping in mind the integration ranges, the gap order parameter satisfy the system.

Since -

$$V_{pp} \cong V_{dd} < V_{pd}$$

so V_{pp} *and* V_{dd} can be neglected.

Now equations (42) and (43) read as –

$$\Delta_p = V_{pd}\, G_d(\Delta_d)\Delta_d \qquad (44)$$

$$\Delta_d = V_{dp}\, G_p(\Delta_p)\Delta_p \qquad (45)$$

The function G is defined as -

$$G(\bar{\Delta}_p) = N_p(0)\int \frac{d\in_p}{E_p}\tanh\frac{E_p}{2k_BT} \qquad (46)$$

$$G(\bar{\Delta}_d) = N_d(0)\int \frac{d\in_d}{E_d}\tanh\frac{E_d}{2k_BT} \qquad (47)$$

Where $N_p(0)$ and $N_d(0)$ are density of p and d states at the Fermi level.

Substituting equations (46) & (47) in equations (44) & (45) at critical temperature $T = T_c$, one obtains

$$\Delta_p = V_{pd}\ N_d(0)\ \Delta_d \int \frac{d\in_d}{\sqrt{\in^2{}_d + \Delta^2{}_d}} \tanh \frac{\sqrt{\in^2{}_d + \Delta^2{}_d}}{2k_BT_c} \qquad (48)$$

$$\Delta_d = V_{dp}\ N_p(0)\ \Delta_p \int \frac{d\in_p}{\sqrt{\in^2{}_p + \Delta^2{}_p}} \tanh \frac{\sqrt{\in^2{}_p + \Delta^2{}_p}}{2k_BT_c} \qquad (49)$$

We obtain $\frac{\Delta_p}{\Delta_d}$ from equation (48) and $\frac{\Delta_d}{\Delta_p}$ from equation (49) as follows :

$$\frac{\Delta_p}{\Delta_d} = V_{pd}\ N_d(0) \int \frac{d\in_d}{\sqrt{\in^2{}_d + \Delta^2{}_d}} \tanh \frac{\sqrt{\in^2{}_d + \Delta^2{}_d}}{2k_BT_c} \qquad (50)$$

$$\frac{\Delta_d}{\Delta_p} = V_{dp}\ N_p(0) \int \frac{d\in_p}{\sqrt{\in^2{}_p + \Delta^2{}_p}} \tanh \frac{\sqrt{\in^2{}_p + \Delta^2{}_p}}{2k_BT_c} \qquad (51)$$

On Multiplication of equations (50) and (51) , one obtains

$$V_{pd}V_{dp}\ N_p(0)N_d(0) \int \frac{d\in_d}{\sqrt{\in^2{}_d + \Delta^2{}_d}} \tanh \frac{\sqrt{\in^2{}_d + \Delta^2{}_d}}{2k_BT_c} \times \int \frac{d\in_p}{\sqrt{\in^2{}_p + \Delta^2{}_p}} \tanh \frac{\sqrt{\in^2{}_p + \Delta^2{}_p}}{2k_BT_c} = 1 \qquad (52)$$

At $T = T_c$ $\Delta_{p,d}(T_c) = 0$, so equation (52) takes the form

$$V_{pd}V_{dp}\ N_p(0)N_d(0) \int \frac{d\in_d}{\in_d} \tanh \frac{\in_d}{2k_BT_c} \times \int \frac{d\in_p}{\in_p} \tanh \frac{\in_p}{2k_BT_c} = 1$$

Since $V_{pd} = V_{dp}$, we obtain

$$V^2{}_{pd}\ N_p(0)N_d(0) \int \frac{d\in_d}{\in_d} \tanh \frac{\in_d}{2k_BT_c} \times \int \frac{d\in_p}{\in_p} \tanh \frac{\in_p}{2k_BT_c} = 1 \qquad (53)$$

We shall solve this equation numerically in next section for the dependence of critical temperature on chemical potential.

(B) DEPENDENCE OF CRITICAL TEMPERATURE (T_c) ON HOLE CONCENTRATION (n_h)

Konsin and coworkers [2, 3, 4, 10, 43] studied the dependence of carrier concentration on T_c. For studying of the doping dependence on the chemical potential, we have [10, 26] –

$$N_p(0)\int_0^{\in_1} f(\in)dE \;+\; N_d(0)\int_{\in_0}^{\in_c} f(\in)\;d\in \;= p \qquad (54)$$

Here $f(\in)=\{\exp[(\in-\mu)/k_BT]+1\}^{-1}$, p is the number of holes per cell and $\in_1$ is the width of the broad band. Equation (54) represents the condition of electroneutrality.

Using the condition of electroneutrality equation (54), we obtain the equation for the chemical potential as [10] -

$$N_p(0)\,k_BT\left[\frac{\in-\mu}{k_BT}-\log\left(1+\exp\left(\frac{\in-\mu}{k_BT}\right)\right)\right]_0^{\in_1}+N_d(0)\;k_BT\left[\frac{\in-\mu}{k_BT}-\log\left(1+\exp\left(\frac{\in-\mu}{k_BT}\right)\right)\right]_{\in_0}^{\in_c}=p$$

$$N_p(0)\left[\in_1-k_BT\log\left(\frac{1+\exp\left(\frac{\in_1-\mu}{k_BT}\right)}{1+\exp\left(\frac{-\mu}{k_BT}\right)}\right)\right]+N_d(0)\left[\in_c-\in_0+k_BT\log\left(\frac{1+\exp\left(\frac{\in_0-\mu}{k_BT}\right)}{1+\exp\left(\frac{\in_c-\mu}{k_BT}\right)}\right)\right]=p$$

(55)

where p is the total number of holes per cell.

The relation connecting n_h and p reads as $n_h = p - p_0$,

where $p_0 = N_p(0)\left(\in_1/2\right)$.

$\in_c$ = Cut-off energy of lower band,

$\in_1$ = Top energy of higher band,

$\in_0$ = Top energy of lower band.

$N_p(0)$ is density of p states at the Fermi level.

$N_d(0)$ is density of d states at the Fermi level.

NUMERICAL CALCULATIONS

Values of various parameters appearing in equations obtained in the previous section are given in Table 1. Using these values, we have made study of various parameters for the system $Bi_2Sr_2CaCu_2O_{8+\delta}$.

TABLE 1: VALUES OF VARIOUS PARAMETERS FOR $Bi_2Sr_2CaCu_2O_{8+\delta}$ SYSTEM

S.No.	Parameter	Value	Reference
1	Superconducting transition temperature (T_c)	95 K	[10,46]
2	Phonon energy $(\hbar\omega_p)$ for p holes	$1.6 \times 10^{-21}\ J$	[44]
3	Phonon energy $(\hbar\omega_d)$ for d holes	$1.5 \times 10^{-21}\ J$	[44]
4	Density of states at the Fermi surface N (0)	$\cong 4.95 \times 10^{19}\ J/atom$	[45]
5	Pairing interaction for p holes	$0.328\times10^{-19}\ J/atom$	[5]
6	Pairing interaction for d holes	$0.368\times10^{-19}\ J/atom$	[5]

7	Number of atoms per unit volume	~ 5×10^{22}	[45]
8	Boltzmann constant (k_B)	$1.38 \times 10^{-23}\ J/K$	
9	Electron Mass (m_e)	$9.1 \times 10^{-31}\ Kg.$	

3.1 SUPERCONDUCTING ORDER PARAMETER (Δ)

For the study of superconducting order parameter for $Bi_2Sr_2CaCu_2O_{8+\delta}$ system with two band model one finds three different situations: (i) The superconducting order parameter in the presence of p-holes only , (ii) The superconducting order parameter in the presence of d-holes only and (iii) The superconducting order parameter for both the holes.

(a) The SC order parameter for p-holes (BCS Type, in the absence of doping)

One obtains the expression for Δ_p as

$$\frac{1}{\left|V_{pp}\right| N(0)} = \int_0^{\hbar\omega_p} \frac{d\in_p}{(\alpha_1-\alpha_2)} \tanh\frac{E_p}{2k_BT} \qquad (56)$$

One can rewrite equation (56) as ,

$$\frac{1}{\left|V_{pp}\right| N(0)} = \frac{1}{2}\int_0^{\hbar\omega_p} \frac{d\in_p}{\sqrt{\in^2{}_p+\Delta^2{}_p}} \tanh\frac{\sqrt{\in^2{}_p+\Delta^2{}_p}}{2k_BT} \qquad (57)$$

Using the following changes in variables, and taking $\mu = 0$ in the absence of doping

$$\Delta_p = x\times10^{-21}\ J\ ,\in_p = \hbar\omega_p y\ ,\ d\in_p = \hbar\omega_p dy \qquad (58)$$

Equation (57) reduced to ,

$$\frac{1}{\left|V_{pp}\right| N(0)} = \int_0^1 dy \left[\frac{\tanh\frac{\hbar\omega_p}{2k_B}\frac{\sqrt{y^2+\left(\frac{x\times10^{-21}}{\hbar\omega_p}\right)^2}}{T}}{\sqrt{y^2+\left(\frac{x\times10^{-21}}{\hbar\omega_p}\right)^2}}\right] \qquad (59)$$

and taking the respective values from Table 1, one obtains

$$\frac{\hbar\omega_p}{2k_B} = 57.97\ K \cong 58 \qquad (60)$$

Using the above values and simplifying equation (60) , one obtains

$$\frac{1}{\left|V_{pp}\right| N(0)} = \int_0^1 \frac{dy}{\sqrt{y^2 + 0.3906 x^2}} \left[\tanh 58 \frac{\sqrt{y^2 + 0.3906\, x^2}}{T} \right] \qquad (61)$$

$$\text{Or} \quad 0.6173 = \int_0^1 \frac{dy}{\sqrt{y^2 + 0.3906 x^2}} \left[\frac{1}{e^{\frac{-116}{T}\sqrt{y^2+0.3906x^2}} + 1} - \frac{1}{e^{\frac{116}{T}\sqrt{y^2+0.3906x^2}} + 1} \right] \qquad (62)$$

Solving equations (62) numerically, one can study the variation of SC order parameter with temperature in the absence of d-holes. The values obtained from equations (62) are depicted in Table 2 and the behavior is shown in Figure 1 for p holes .

(b) The SC order parameter for p-holes (Effect of doping)

Using equation (57) ,

$$\frac{1}{\left|V_{pp}\right| N(0)} = \frac{1}{2} \int_0^{\hbar\omega_p} \frac{d \in_p}{\sqrt{\in^2_p + \Delta^2_p}} \tanh \frac{\sqrt{\in^2_p + \Delta^2_p}}{2k_B T} \qquad (63)$$

Using the following changes in variables

$$\Delta_p = x \times 10^{-21}\ J\ , \qquad \in_p = \in_p^{\,0} - \mu\ , \qquad d \in_p = d \in_p^{\,0} \qquad (64)$$

Equation (63) becomes ,

$$\frac{1}{\left|V_{pp}\right| N(0)} = \frac{1}{2} \int_{\mu}^{\mu+\hbar\omega_p} \frac{d \in_p^{\,0}}{\sqrt{\left(\in_p^{\,0} - \mu\right)^2 + \left(x \times 10^{-21}\right)^2}} \tanh \frac{\sqrt{\left(\in_p^{\,0} - \mu\right)^2 + \left(x \times 10^{-21}\right)^2}}{2k_B T} \qquad (65)$$

Further changes in variables as

$$\in_p^{\,0} = \hbar\omega_p y\ , \qquad d \in_p^{\,0} = \hbar\omega_p dy \qquad (66)$$

Equation (65) takes the following form

$$\frac{1}{\left|V_{pp}\right| N(0)} = \frac{1}{2} \int_{\frac{\mu}{\hbar\omega_p}}^{1+\frac{\mu}{\hbar\omega_p}} \frac{\hbar\omega_p dy}{\sqrt{\left(\hbar\omega_p y - \mu\right)^2 + \left(x \times 10^{-21}\right)^2}} \tanh \frac{\sqrt{\left(\hbar\omega_p y - \mu\right)^2 + \left(x \times 10^{-21}\right)^2}}{2k_B T}$$

(67)

Taking the following values,

$$\hbar\omega_p \cong 1.6 \times 10^{-21}\ J$$

$$k_B = 1.38 \times 10^{-23}\ J/K$$

Solving equations (62) and (67) numerically one can study the variation of superconductivity order parameter (Δ) with temperature in the absence of d-holes. The values obtained from equations (62) and (67) are depicted in Table 2 and the comparison of superconductivity order parameter for BCS type , in the absence of doping and effect of doping is shown in Fig. 1 for p holes.

TABLE 2: SUPERCONDUCTING ORDER PARAMETER (Δ_p) (p-HOLES) FOR $Bi_2Sr_2CaCu_2O_{8+\delta}$ SYSTEM

S.No.	Temperature (K)	$\Delta_p = x \times 10^{-21}\ J$ (BCS Type , in absence of doping)	$\Delta_p = x \times 10^{-21}\ J$ (Effect of doping)
1	10	2.43	2.38
2	20	2.42	2.37
3	30	2.41	2.35
4	40	2.37	2.30
5	50	2.27	2.21
6	60	2.10	2.00
7	70	1.81	1.73
8	80	1.35	1.25
9	90	0.50	0.38
10	95	0.00	0.08
11	96	0.00	0.00

(c) The SC order parameter for d-holes (BCS Type, in the absence of doping)

One obtains the following expression

$$\frac{1}{\left|V_{dd}\right| N(0)} = \frac{1}{2}\int_0^{\hbar\omega_d} \frac{d\in_d}{\sqrt{\in^2{}_d + \Delta^2{}_d}} \tanh\frac{\sqrt{\in^2{}_d + \Delta^2{}_d}}{2k_BT} \qquad (68)$$

With following changes of variables –

$$\Delta_d = x\times 10^{-21}\ J\,, \quad \in_d = \hbar\omega_d y\,, \quad d\in_d = \hbar\omega_d dy \qquad (69)$$

and taking the respective values from Table 1, one obtains

$$\frac{\hbar\omega_d}{2k_B} = 54.30K \cong 54\ K \qquad (70)$$

Using the above values and simplifying, equation (68) yields,

$$\frac{1}{\left|V_{dd}\right| N(0)} = \int_0^1 \frac{dy}{\sqrt{y^2 + 0.4444\,x^2}} \left[\tanh(54)\ \frac{\sqrt{y^2 + 0.4444\,x^2}}{T}\right] \qquad (71)$$

Or $$0.5495 = \int_0^1 \frac{dy}{\sqrt{y^2 + 0.4444\,x^2}} \left[\frac{1}{e^{\frac{-108}{T}\sqrt{y^2+0.4444\,x^2}}+1} - \frac{1}{e^{\frac{108}{T}\sqrt{y^2+0.4444\,x^2}}+1}\right]$$

(72)

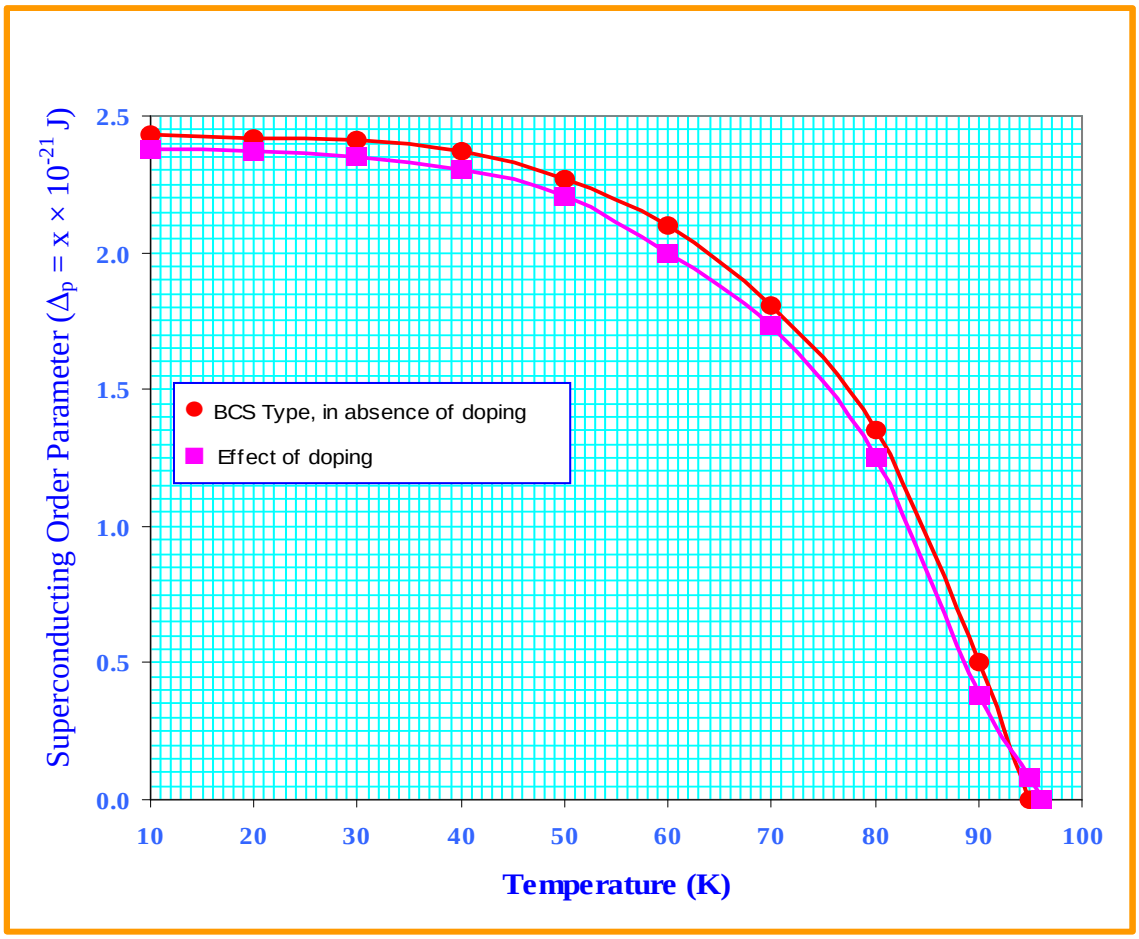

Fig :1 Behavior of superconducting order parameter (Δ_p) with temperature for p-holes.

(d) The SC order parameter for d-holes (Effect of doping)

Using equation (68) ,

$$\frac{1}{|V_{dd}|N(0)} = \frac{1}{2}\int_0^{\hbar\omega_d} \frac{d\in_d}{\sqrt{\in^2{}_d + \Delta^2{}_d}} \tanh\frac{\sqrt{\in^2{}_d + \Delta^2{}_d}}{2k_BT} \qquad (73)$$

Using the following changes in variables

$$\Delta_d = x\times10^{-21}\ J\ , \qquad \in_d = \in_d{}^0 - \mu\,, \qquad d\in_d = d\in_d{}^0 \qquad (74)$$

Equation (73) becomes ,

$$\frac{1}{|V_{dd}|N(0)} = \frac{1}{2}\int_{\mu}^{\mu+\hbar\omega_d} \frac{d\in_d{}^0}{\sqrt{\left(\in_d{}^0 - \mu\right)^2 + \left(x\times10^{-21}\right)^2}} \tanh\frac{\sqrt{\left(\in_d{}^0 - \mu\right)^2 + \left(x\times10^{-21}\right)^2}}{2k_BT}$$

(75)

Further changes in variables as

$$\in_d{}^0 = \hbar\omega_d y, \qquad d\in_d{}^0 = \hbar\omega_d dy \tag{76}$$

Equation (75) takes the following form

$$\frac{1}{\left|V_{dd}\right|N(0)} = \frac{1}{2}\int_{\frac{\mu}{\hbar\omega_d}}^{1+\frac{\mu}{\hbar\omega_d}} \frac{\hbar\omega_d dy}{\sqrt{\left(\hbar\omega_d y-\mu\right)^2+\left(x\times10^{-21}\right)^2}} \tanh\frac{\sqrt{\left(\hbar\omega_d y-\mu\right)^2+\left(x\times10^{-21}\right)^2}}{2k_BT} \tag{77}$$

Taking the following values,

$\hbar\omega_d \cong 1.5\times10^{-21}\ J$

$k_B = 1.38\times10^{-23}\ J/K$

Solving equations (72) and (77) numerically one can study the variation of superconducting order parameter with temperature in the absence of p-holes. The values obtained from equations (72) and (77) are depicted in Table 3 and the comparison of superconductivity order parameter for BCS type, in the absence of doping and effect of doping for d holes is shown in Fig. 2.

TABLE 3: SUPERCONDUCTING ORDER PARAMETER (Δ_d) (d-HOLES) FOR $Bi_2Sr_2CaCu_2O_{8+\delta}$ SYSTEM

S.No.	Temperature (K)	$\Delta_d = x\times10^{-21}\ J$ (BCS Type , in absence of doping)	$\Delta_d = x\times10^{-21}\ J$ (Effect of doping)
1	10	2.60	2.55
2	20	2.59	2.52
3	30	2.57	2.51
4	40	2.55	2.48
5	50	2.47	2.38
6	60	2.31	2.23
7	70	2.06	1.98
8	80	1.68	1.50
9	90	1.00	0.82
10	95	0.00	0.25
11	95.5	0.00	0.00

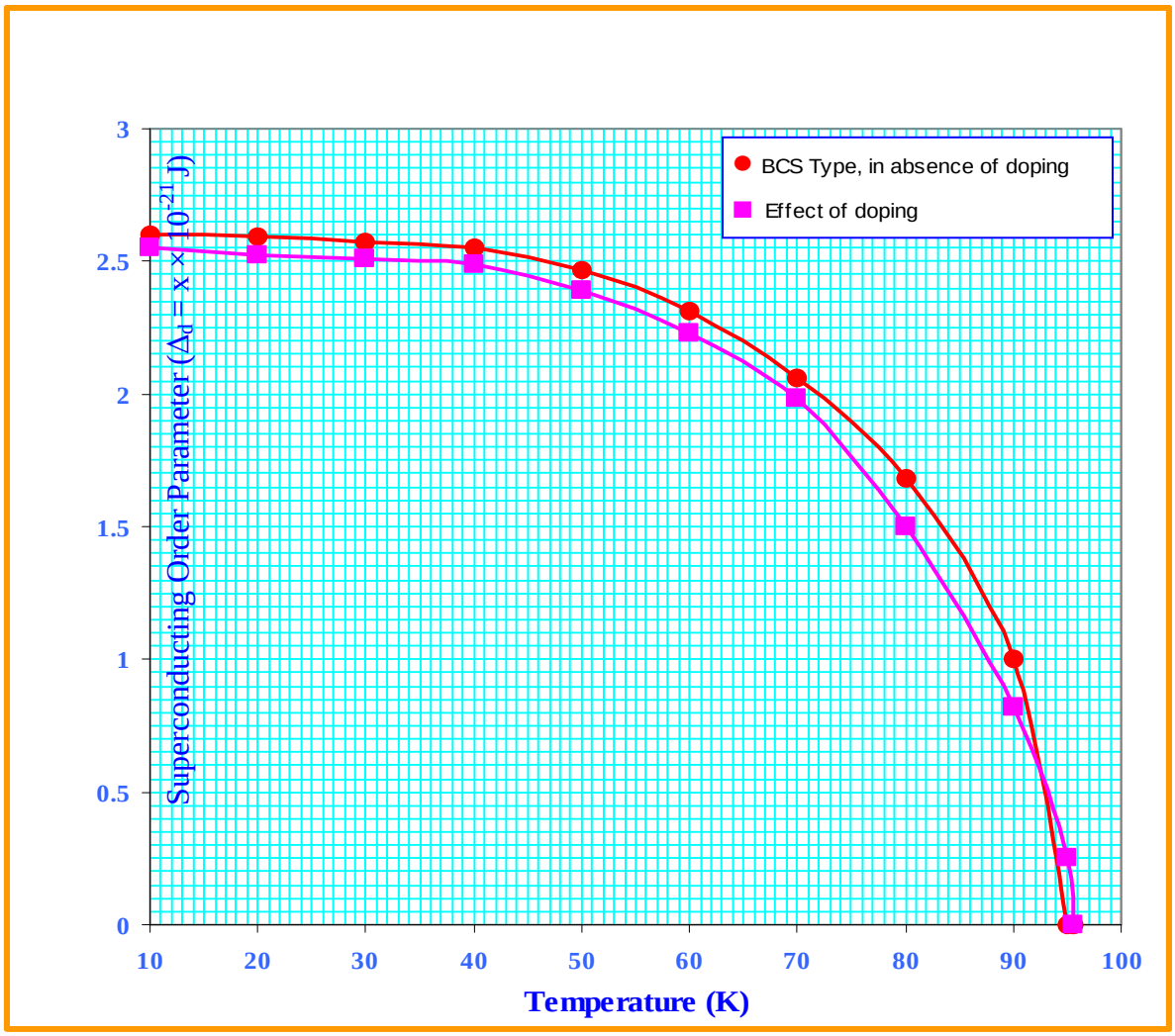

Fig :2 Behavior of superconducting order parameter (Δ_d) with temperature for d-holes.

TABLE 4: SUPERCONDUCTING ORDER PARAMETER $\left(\Delta = \Delta_p + \Delta_d\right)$

(p & d HOLES)

FOR $Bi_2Sr_2CaCu_2O_{8+\delta}$ **SYSTEM**

S.No.	**Temperature (K)**	$(\Delta = \Delta_p + \Delta_d) = x \times 10^{-21}$ *Joule* **(BCS Type , in absence of doping)**	$(\Delta = \Delta_p + \Delta_d) = x \times 10^{-21}$ *Joule* **(Effect of doping)**
1	10	5.03	4.93
2	20	5.01	4.89
3	30	4.98	4.86
4	40	4.92	4.78
5	50	4.74	4.59
6	60	4.41	4.23
7	70	3.87	3.71
8	80	3.03	2.75
9	90	1.50	1.20
10	95	0.00	0.33
11	95.5	0.00	0.07
12	96	0.00	0.00

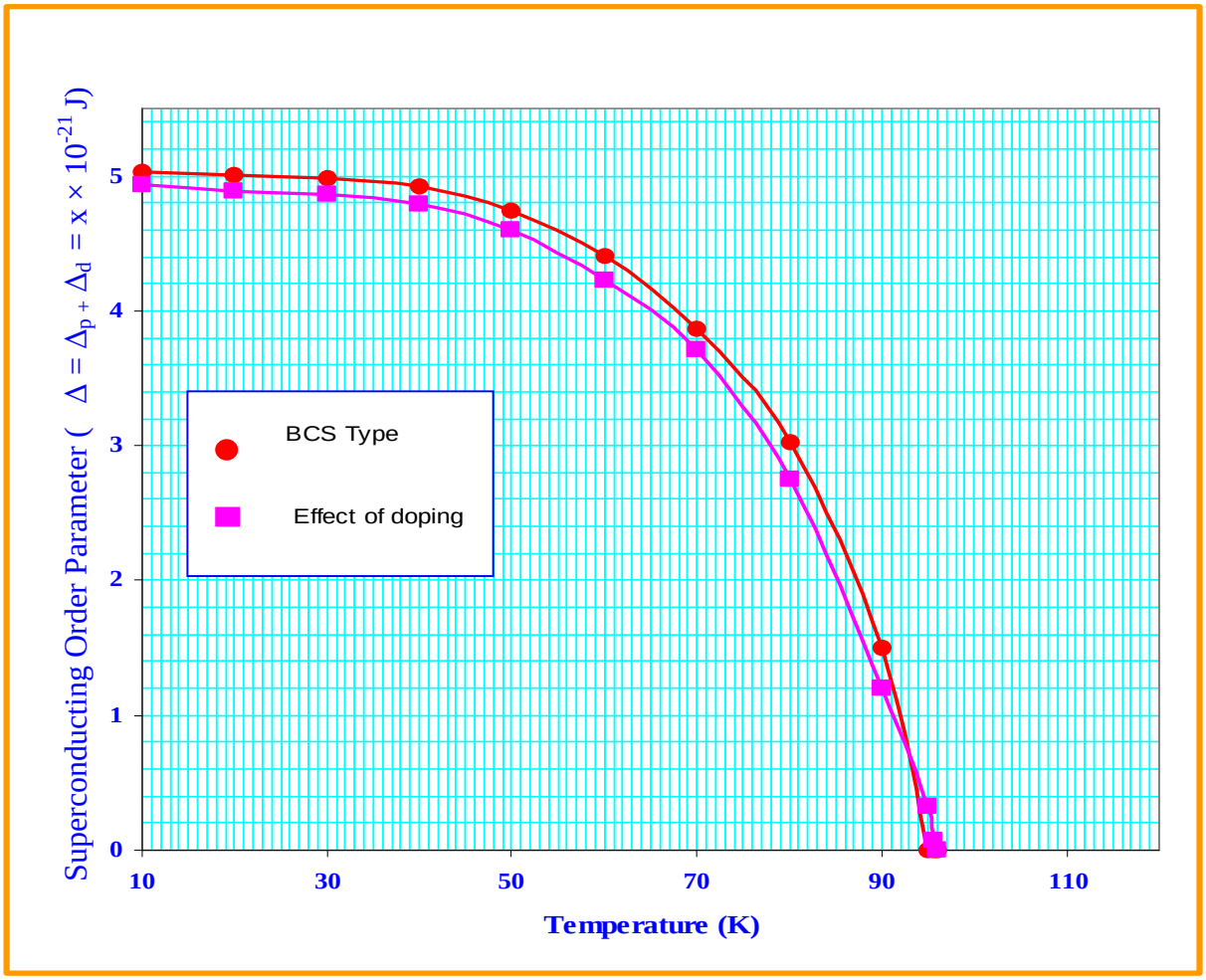

Fig :3 Behavior of superconducting order parameter ($\Delta = \Delta_p + \Delta_d$) with temperature For p and d-holes.

(e) SC order parameter in the presence of both p and d holes

The superconducting order parameter in the presence of both holes can be studied by taking a simple sum of both the parameters. Taking the sum of order parameter as $(\Delta = \Delta_p + \Delta_d)$ one can obtain the values by solving numerically as depicted in Table 4 and the comparison of superconductivity order parameter for BCS type, in the absence of doping and effect of doping for both p and d holes is shown in Fig. 3.

3.2 DEPENDENCE OF CHEMICAL POTENTIAL (μ) ON CRITICAL TEMPERATURE (T_c)

For $Bi_2Sr_2CaCu_2O_{8+\delta}$ superconductors, we used the best fitting parameters values for numerical estimation as follows :

$N_p(0) = density\ of\ states\ for\ p\ holes = 0.210\ eV^{-1}$,

$N_d(0) = density\ of\ states\ for\ d\ holes = 0.045\ eV^{-1}$,

$V_{pd} = The\ pair\ interchange\ between\ two\ bands = 1.65\ eV$,

$\in_c = Cut-off\ energy\ of\ lower\ band = 2.33\ eV$,

$\in_1 = top\ energy\ of\ higher\ band\ of\ the\ width = 2.5 eV$,

$\in_0 = top\ energy\ of\ lower\ band = 2.18 eV$,

$\hbar\omega_p = 1.6\times10^{-21}\ Joule = 0.010\ eV$,

$\hbar\omega_d = 1.5\times10^{-21}\ Joule = 0.009375\ eV$.

The small difference between $\in_c$ and $\in_0$ is taken keeping in mind the uncertainty in defining the effective bottom of the band $\in_c$.

The parameters are model dependent for the calculation of $T_c(n_h)$. These quantitative characteristic seem to be reasonable at least they are of the order proposed by Konsin and coworkers [10,26] for high T_c cuprates.

Applying the limits of integration on equation (53), for dependence of transition temperature (T_c) on chemical potential (μ) dependence, one obtains

$$V^2{}_{pd}\ N_p(0)N_d(0)\int \frac{d\in_d}{\in_d}\tanh\frac{\in_d}{2k_BT_c}\times\int \frac{d\in_p}{\in_p}\tanh\frac{\in_p}{2k_BT_c} = 1$$

Or,

$$0.02572\int_{-\mu}^{2.33-\mu}\frac{d\in_d}{\in_d}\tanh\frac{\in_d}{2k_BT_c}\times\int_{2.18-\mu}^{2.33-\mu}\frac{d\in_p}{\in_p}\tanh\frac{\in_p}{2k_BT_c} = 1 \qquad (78)$$

Solving numerically equation (78) , we obtain values given in Table 5 for T_c with respect to different doping parameters (μ).

3.3 DEPENDENCE OF CRITICAL TEMPERATURE (T_c) ON HOLE CONCENTRATION (n_h)

By substituting numerical values of chemical potential μ and Critical temperature T_c obtained from equation (78) in equation (55) with relevant parameters , we obtain dependence of critical temperature T_c **,** on hole concentration n_h **.**

Using equation (55), we obtain dependence of Critical temperature T_c on hole concentration (n_h) for system $Bi_2Sr_2CaCu_2O_{8+\delta}$ as shown in Table 5 and depicted in Fig. 4.

$$N_p(0)\left[\in_1 -k_BT\log\left(\frac{1+\exp\left(\frac{\in_1-\mu}{k_BT}\right)}{1+\exp\left(\frac{-\mu}{k_BT}\right)}\right)\right]+N_d(0)\left[\in_c-\in_0+k_BT\log\left(\frac{1+\exp\left(\frac{\in_0-\mu}{k_BT}\right)}{1+\exp\left(\frac{\in_c-\mu}{k_BT}\right)}\right)\right] = p$$

TABLE 5: DEPENDENCE OF CRITICAL TEMPERATURE (T_c) ON HOLE CONCENTRATION (n_h)

S.No.	Temperature T (K)	Chemical Potential (μ)	p	p_o	$n_h = p - p_0$
1	10	2.172	0.4561	0.2625	0.1936
2	20	2.174	0.4565	0.2625	0.194
3	30	2.177	0.4572	0.2625	0.1947
4	40	2.179	0.4577	0.2625	0.1952
5	50	2.182	0.4584	0.2625	0.1959
6	60	2.186	0.4594	0.2625	0.1969
7	70	2.193	0.4611	0.2625	0.1986
8	80	2.203	0.4637	0.2625	0.2012
9	90	2.222	0.4685	0.2625	0.2060
10	95	2.247	0.4749	0.2625	0.2124
11	95.5	2.262	0.4787	0.2625	0.2162
12	96	2.270	0.4795	0.2625	0.2170

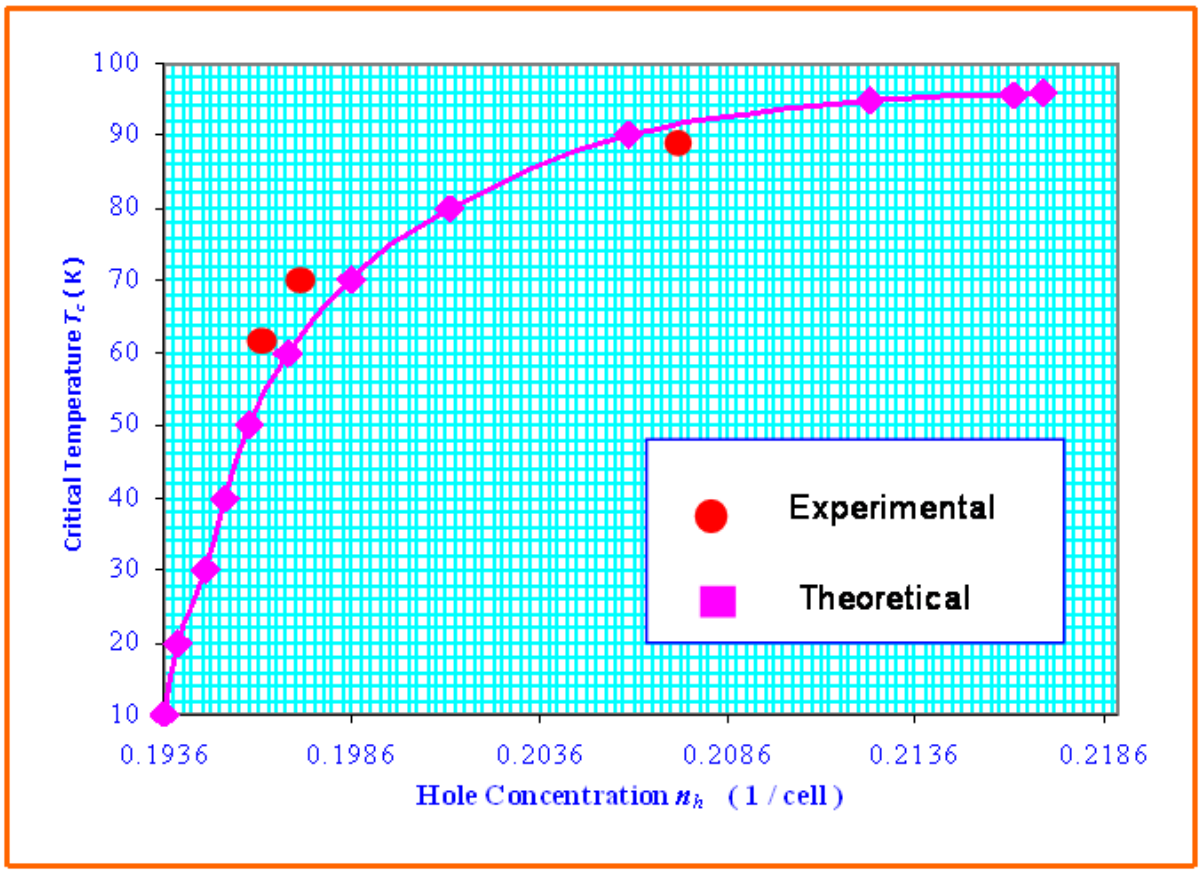

Fig : 4 Variation of Critical Temperature (T_c) with Hole Concentration (n_h) [10].

DISCUSSION AND CONCLUSION

In the foregoing sections, we have presented the study of photo-induced high T_c cuprate superconductivity by canonical two-band BCS Hamiltonian containing Fermi surfaces of p and d holes.

In the two-component model the superconductivity is caused by the interband repulsive electron- lattice and Coulomb interactions. The photo excitation produces a change of the hole doping (p) and as a result there is a shift in transition temperature ΔT_c for the high temperature cuprate superconductors.

Following the Green's function technique and equation of motion method, we have obtained the expressions for superconducting order parameter (Δ) for both p and d holes. We have discussed the effect of doping on superconducting order parameter. We have also presented theoretical study of dependence of superconducting transition temperature (T_c) on the hole concentration (n_h). Making use of values of various parameters given in Table 1 for the system $Bi_2Sr_2CaCu_2O_{8+\delta}$, we have made study of superconducting order parameter with and without doping and also dependence of critical temperature on chemical potential and hole concentration and wherever possible, compared our results with the available experimental data. We observe that:

(i) The transition temperature for our system $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) is found 95 K [10] and gets enhanced due to doping as is evident from the variation of superconducting order parameter with temperature.

(ii) The dependence of superconducting gaps for the system $Bi_2Sr_2CaCu_2O_{8+\delta}$ on temperature and the hole concentration have been found. In general, the doping causes deviation of gaps from the BCS. Due to doping there is marked decrease in superconducting order parameters. However, the display of two- superconducting gaps structure is attributed to a short coherence length of photoinduced superconductors. This is expected due to highly anisotropic nature of these systems. Obviously, the presence of the two-gap structure is perfectly in agreement with our model.

(iii) We have found that as hole concentration (n_h) increases, T_c increases and there is clear enhancement of T_c for our system. Our results agree with Konsin and Sorkin [10,46] .

One can also extend the present model with suitable modifications to study the electric field effects in cuprates. Under this study one can obtain $\Delta T_c(\vec{E})$ dependence on carrier concentration.

Further research work in the field of photoinduced superconductors is desirable to obtain such substances which may exhibit high enough transition temperature and such substances may find many exotic applications

Our model shows reasonable agreement with other studies in this regard and available experimental data. This mechanism emerges as a strong contender for an acceptable model for photoinduced cuprate oxides superconductors. The efforts to understand the pairing mechanism in these substances need to continue, for such efforts go hand –in –hand with enhancing future prospects for new HTSC materials and novel applications [47].

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