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TO STUDY SUPERCONDUCTING ORDER PARAMETER IN $YBa_2Cu_3O_{7-\delta}$ SYSTEM:

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ABSTRACT

Charge transfer, exactions. plasmons, charged bosons, biexicions, etc. arising from charge fluctuations in the system and (ii) The other type of models is guided by the belief that superconductivity in cuprates is of magnetic origin. This is motivated by the fact that pure "214" and “123" (i.e. x = 0) compounds are ant ferromagnetic insulators. There are many variants of magnetic mechanism. Magnetic mechanisms lean heavily on the Hubbard model. It envisages ant ferromagnetic correlations among the pairing quasi particles induced by spin fluctuation exchange. Recent nuclear spin relaxation measurement of oxygen isotope ^{17}O clearly indicate that the pairing in cuprate superconductors is of s-wave symmetry (and hence singlet). The models based on spin fluctuations mechanism will break the pair instead of strengthening them. Obviously, spin fluctuation mechanisms may be discarded in favour of charge fluctuation mechanisms for high - T_C systems. Using the experimental results for various parameters appearing in the above equations for the system $Y Ba_2Cu_3O_{7-\delta}$, we have obtained qualitative results. The results obtained from the theory are in the satisfactory agreement with available experimental results for the system $Y Ba_2Cu_3O_{7-\delta}$

Keywords:superconducting order parameter

INTRODUCTION

Tokura et al. discovered a new family of 2222 compounds $Bi_2Sr_2(Ln_{1-x}ce_x)_2$ Cu_2O_{10+y} and $T1_2Ba_2$ $(Ln_{1-x}ce_x)_2Cu_2O_{10+y}$ (Ln = Sm, Eu or Gd), having double BiO or TlO layered units, but with a different arrangement of CuO_2 sheets. The significant feature is that the new compounds ("2222" phase) show anomalously lower onset transition temperature (~ 25 K) as compared with "2212" (T_C = 80 - 108 K) and "2223" compounds (T_C = 110-125 K), even when the carrier (hole) concentrations are comparable. These new compounds demonstrate that T_C appears to depend critically on the stacking pattern of adjacent Cu-O sheets, rather than on simply the number of CuO sheets between the BiO or TlO bilayers. All these high - $T_C$cuprates have 2-dimensional CuO_2 planes (C - layeres). These sheets are the seat of conduction and are responsible for anistropic electrical and magnetic properties the CuO_2 layers, in turn, are placed in an environment of $Mn^P O_m$ (p-layers) with M = Cu. Bi, Tl. These sandwiches comparisingCuO_2-Mn^PO_mlayers are in turn separated by insulating (1) layers of rare earth of calcium etc. In the $La_{2-x}M_x$ CuO_4 (214 system), the p-layer is absent the copper oxygen bonds in the sheets are covalent with distance of the order of 1.9 A and coordination four. All the cuprate superconductors have two dimensional characteristics, the two-dimensional Cu-O sheets being common to them. The '123' rare earth compounds, with perovskite structure have, in addition, one dimensional chains. The superconductivity of cuprate oxide superconductors has been examined by a variety of experimental techniques. These systems show an apparently contradictory aspect. On one hand, various experiments suggest that there must be something essentially new in these high- T_c systems. This seems to be especially clear in the exceedingly high values of T_c the existence of superconductivity under strong correlation, remarkably small isotope effect, small coherence length a (few lattice spacings) and unconventional temperature dependences of normal state response function. In many cases pressure is found to have an unusually large effect in increasing T_C, unlike conventional superconductors where pressure usually decreases T_C.

OBJECTIVES

To study superconducting order parameter

RESEARCH METHODOLOGY

The following expression for superconducting order parameter Δ is obtain from the relation

$$\Delta = \sum_{K} \left\langle C^{+}_{K,\sigma} C^{+}_{-K,-\sigma} \right\rangle$$

by substituting the correlation function $\left\langle C^{+}_{K,\sigma} C^{+}_{-K,-\sigma} \right\rangle$ given by equation 1

$$\Delta = \sum_{K'} \frac{1}{2\sqrt{\left\{\in^{2}_{K''} + \in_{K''}\left(A - 2V(0)n\right) + A\cdot 4nV(0) + \Delta^{2}\right\}}} \times$$

$$\left[\frac{\left\{ \dfrac{g^{2}V(0)\Delta \cdot \dfrac{(2m)^{3/2}(\hbar\omega_{D})^{2}}{3\hbar^{3}}\sqrt{\in_{K''}}}{(2\pi)^{2}\sqrt{\left\{\in^{2}_{K''} + \in_{K''}\left(A - 2V(0)n\right) + A\cdot 4nV(0) + \Delta^{2}\right\}}} \right\} + \Delta}{\left\{ e^{-\beta\sqrt{\left\{\in^{2}_{K''} + \in_{K''}\left(A - 2V(0)n\right) + A\cdot 4nV(0) + \Delta^{2}\right\}}} + 1 \right\}} \right.$$

$$\left. - \frac{\left\{ \dfrac{g^{2}V(0)\Delta \cdot \dfrac{(2m)^{3/2}(\hbar\omega_{D})^{2}}{3\hbar^{3}}\sqrt{\in_{K''}}}{(2\pi)^{2}\sqrt{\left\{\in^{2}_{K''} + \in_{K''}\left(A - 2V(0)n\right) + A\cdot 4nV(0) + \Delta^{2}\right\}}} \right\} + \Delta}{\left\{ e^{+\beta\sqrt{\left\{\in^{2}_{K''} + \in_{K''}\left(A - 2V(0)n\right) + A\cdot 4nV(0) + \Delta^{2}\right\}}} + 1 \right\}} \right]$$

On simplification, one obtains

$$\Delta = \sum_{K''} \frac{\Delta}{2\sqrt{\left\{\in_{K''}^2 + \in_{K''}\left(A - 2V(0)n\right) + A\cdot 4nV(0) + \Delta^2\right\}}} \times$$

$$\left[\frac{1}{\left\{ e^{-\beta\sqrt{\left\{\in_{K''}^2 + \in_{K''}(A-2V(0)n) + A\cdot 4nV(0) + \Delta^2\right\}}} + 1 \right\}} - \right.$$

$$\left. - \frac{1}{\left\{ e^{+\beta\sqrt{\left\{\in_{K''}^2 + \in_{K''}(A-2V(0)n) + A\cdot 4nV(0) + \Delta^2\right\}}} + 1 \right\}} \right] \quad \ldots (1)$$

Dividing on both sides by Δ and changing summation over $\vec{K}$ into integration, using

$$\sum_{K''} = N(0) \int d \in_{K''}$$

We rewrite equation (1) as:

$$\frac{1}{N(0)} = \int_{-\hbar\omega_D}^{+\hbar\omega_D} d\in_{K''} \left[\frac{1}{2\sqrt{\left\{\in_{K''}^2 + \in_{K''}\left(A - 2V(0)n\right) + A\cdot 4nV(0) + \Delta^2\right\}}} \times \right.$$

$$\left. \left(\frac{1}{\left\{ e^{-\beta\left\{\in_{K''}^2 + \in_{K''}(A-2V(0)n) + A\cdot 4nV(0) + \Delta^2\right\}} + 1 \right\}} - \frac{1}{\left\{ e^{+\beta\left\{\in_{K''}^2 + \in_{K''}(A-2V(0)n) + A\cdot 4nV(0) + \Delta^2\right\}} + 1 \right\}} \right) \right]$$

... (2)

This equation (2) is the general expression for the superconducting order parameter. Equation (2) cannot be solved exactly and therefore we evaluate it numerically.

From above equation, we obtain on simplification

$$\eta_{K''} = \frac{1}{2}\left[\left(1 - \frac{Y_{K''}}{B_{K''}} \tanh \frac{B_{K''}}{2K_B T} + 2A_K\left(\frac{df}{dB_{K''}}\right)\right)\right] \ldots (3)$$

Here, $Y_{K''}, B_{K''}, A_{K''}$ have there usual meaning and value form equations (3).

$$A_{K''} = \frac{\alpha}{2} = 2V(q)m$$

$$n_{K''} = \frac{1}{2}\left[1 - \frac{\in_{K''} - V(0)n + \frac{g^2}{(2\pi)^2}\left(\frac{m^2 v_0(\hbar\omega_D)}{2\hbar^3 \in_{K''}}(\in_{K''} + 4nV(0)) - \frac{m^2 v_0(\hbar\omega_D)^2}{2\hbar^3 \in_{K''}}\right)}{\sqrt{\left\{\in_{K''}^2 + \in_{K''}(A - 2V(0)n) + A \cdot 4nV(0) + \Delta^2\right\}}}\right.$$

$$\left.\tanh \frac{\sqrt{\left\{\in_{K''}^2 + \in_{K''}(A - 2V(0)n) + A \cdot 4nV(0) + \Delta^2\right\}}}{2K_B T}\right]$$

$$\left(\text{Here, } A = \frac{g^2 m^2 v_0(\hbar\omega_D)}{(2\pi)^2 \hbar^3}\right)$$

On simplification, we obtain

$$n_{K''} = \left\langle C_{K\sigma}^{+} C_{K\sigma} \right\rangle = \frac{1}{2}\left[1 - \frac{\in_{K''} - V(0)n + A(2)}{\sqrt{\left\{\in_{K''}^2 + \in_{K''}(A - 2V(0)n) + A \cdot 4nV(0) + \Delta^2\right\}}}\right.$$

$$\left.\tanh - \frac{\sqrt{\left\{\in_{K''}^2 + \in_{K''}(A - 2V(0)n) + A \cdot 4nV(0) + \Delta^2\right\}}}{2K_B T}\right] \quad \ldots (4)$$

DATA ANALYSIS

SUPERCONDUCTING ORDER PARAMETER (Δ):

In order to study the variation of superconducting order parameter (Δ) with temperature. We rewrite the equation (4) by changing the variables of integration using :

$\in_{K''}\ y\hbar\omega_D$ and $\Delta = x \times\ 10^{-14}$ erg

$d \in_{K''} = dy\, \hbar\omega_D$

Table 1

Values of various Paramers for the System

[$YBa_2Cu_3O_{7-\delta}$]

1.	Density of states N (0)	4.1×10^{12} per erg-copper atom
2.	Phonon energy $(\hbar\omega_D)$	1.6×10^{-14} erg
3.	Number of atoms per unit volume (N)	5×10^{22} per cm^3
4.	Critical Temperature (T_C)	90 k
5.	Velocity of phonon (ν_0)	4×10^4 cm/sec
6.	Polaron binding energy (g^2)	2×10^{-5} erg
7.	Boltzman constant (k_B)	1.38×10^{-16}arg/k
8.	BCS attractive interactive strength	0.4512×10^{-12} erg
9.	Structure type and Cell parameter (123 phase)	Orthorhombic with an extended C-axis 11.686 A and a-and b-axis almost equal a = 3.8228 A b = 3.8895 A
10.	Phonon frequency $(\hbar\omega_0)$	80×10^{-6} erg
11.	Mass of electron (m_e)	9.1×10^{-28}gm
12.	Planck constant $(\hbar)$	6.62×10^{-27} erg sec
13.	Coulomb potential V(0)	0.2×10^{-14} erg

$$\frac{1}{N(0)} = \int_0^t \hbar\omega_D \, dy \left[\frac{1}{2\sqrt{\left\{(y\hbar\omega_D)^2 + y(\hbar\omega_D)(A - 2V(0)n) + A \cdot 4n(0) + (x \times 10^{-14})^2\right\}}} \times \right.$$

$$\left(\frac{1}{\left\{ e^{-\beta\sqrt{\left\{(y\hbar\omega_D)^2 + y\hbar\omega_D(A - 2V(0)n) + A \cdot 4nV(0) + (x \times 10^{-14})^2\right\}}} + 1 \right\}} \right.$$

$$\left. \left. - \frac{1}{e^{+\beta\sqrt{\left\{(y\hbar\omega_D)^2 + y\hbar\omega_D(A - 2V(0)n) + A \cdot 4nV(0) + (x \times 10^{-14})^2\right\}}} + 1} \right) \right] \quad \dots (5)$$

Using the quantitative values of various parameters given in Table 1. We rewrite equation (5) as follows:

$$\frac{1}{N(0)} = \int_0^1 (1.6 \times 10^{-14})^2 \, dy$$

$$\left[\frac{1}{2\sqrt{\left\{(1.6 \times 10^{-14} y)^2 + 1.6 \times 10^{-14} y (1.45 \times 10^{-14}) + 1.48 \times 10^{-14} + (x \times 10^{-14})^2\right\}}} \times \right.$$

$$\left(\frac{1}{\left\{ e^{-\beta\sqrt{\left\{(1.6\times10^{-14} y)^2 + 1.6\times10^{-14} y(1.45\times10^{-14}) + 1.48\times10^{-14} + (x\times10^{-14})^2\right\}}} + 1 \right\}} \right.$$

$$- \frac{1}{e^{+\beta\sqrt{\left\{\left(1.6\times10^{-14}\,y\right)^2+1.6\times10^{-14}\,y\cdot\left(1.45\times10^{-14}\right)+1.48\times10^{-14}+\left(x\times10^{-14}\right)^2+1\right\}}} \Bigg)\Bigg] \quad \ldots (6)$$

Equation (6) reduces finally as follows:

$$\frac{1}{N(0)} = \int_0^1 \frac{dy}{\sqrt{\left(y^2 + 0.906\,y + 0.578 + 0.390\,x^2\right)}} \times$$

$$\left[\frac{1}{\left\{ e^{-\frac{114}{T}\sqrt{\left(y^2+0.906y+0.578+0.390x^2\right)}} + 1 \right\}} - \frac{1}{\left\{ e^{\frac{114}{T}\sqrt{\left(y^2+0.906y+0.578+0.390x^2\right)}} + 1 \right\}} \right]$$

... (7)

When x = 0 and T = T_C = 90 K

Then equation (7) reduces as follows:

$$\frac{1}{N(0)} = \int_0^1 \frac{dy}{\sqrt{\left(y^2 + 0.906\,y + 0.578\right)}} \times$$

$$\left[\frac{1}{\left\{ e^{-1.26\sqrt{\left(y^2+0.906y+0.578\right)}} + 1 \right\}} - \frac{1}{\left\{ e^{1.26\sqrt{\left(y^2+0.906y+0.578\right)}} + 1 \right\}} \right] \quad \ldots (8)$$

Solving the integral appearing in equation (4) numerically, we obtain the values of x at various temperature, tabulated in Table 2.

Table 2

Superconducting Order Parameter (Δ)

S. No.	Temperature T(K)	$\Delta = (X \times 10^{-14})$ erg
1.	5	2.331
2.	10	2.331
3.	15	2.332
4.	20	2.334
5.	25	2.330
6.	30	2.325
7.	35	2.310
8.	40	2.290
9.	45	2.250
10.	50	2.200
11.	55	2.130
12.	60	2.040
13.	65	1.920
14.	70	1.770
15.	75	1.570
16.	80	1.320
17.	85	0.080
18.	90	0.000

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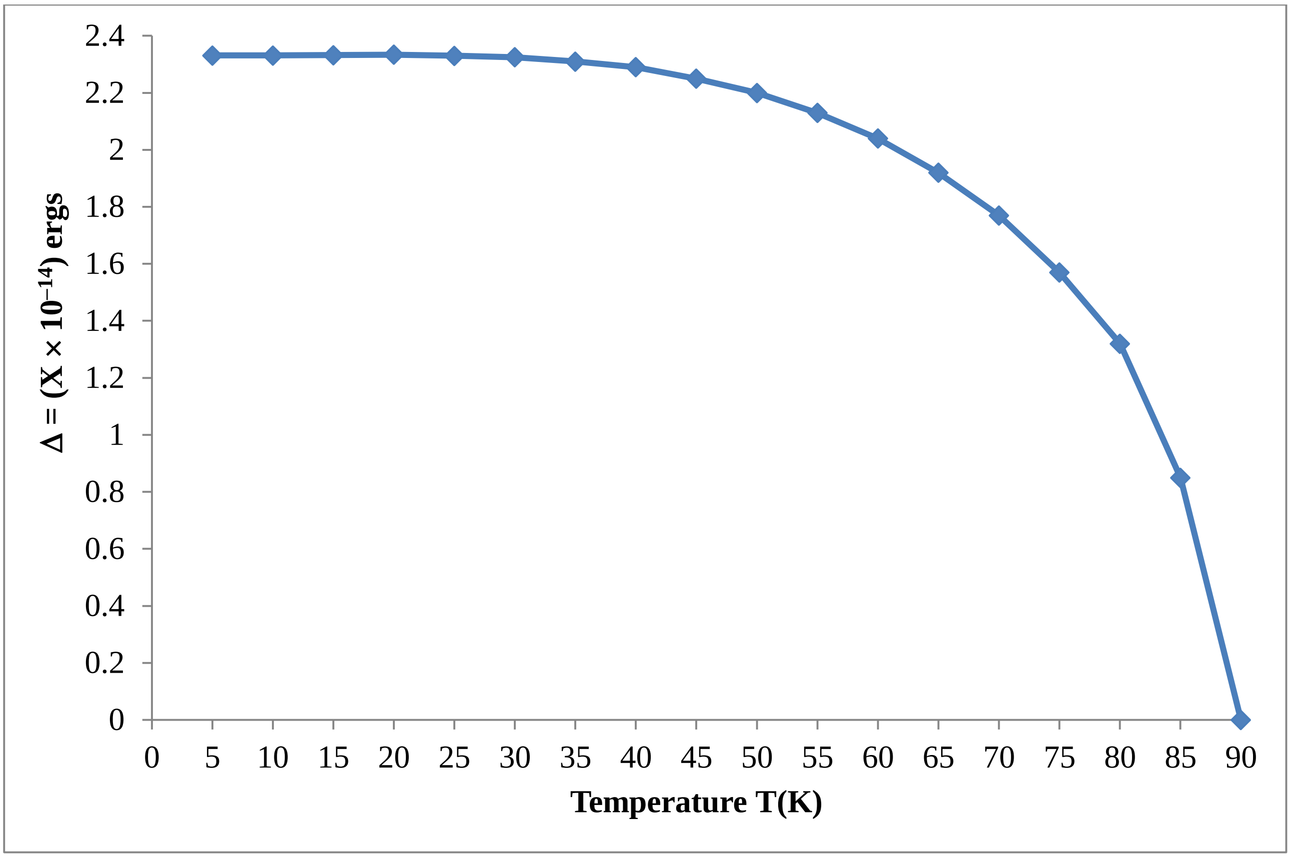
Fig. 1

Superconducting Order Parameter (Δ)



The variation of Δ with temperature T is shown in fig. 1 From BCS theory the limiting behaviour can be obtained by the following equations for weak coupling superconductors

$$\Delta(T) \approx \Delta_0 - \sqrt{2\pi\Delta_0 k_B T} \quad \exp\left[-\frac{\Delta_0}{k_B T}\right] T << T_C \qquad \text{... (9)}$$

Here, $\Delta_0 \equiv \Delta$ (T = 0)

and $$\Delta(T) \approx 3.06 \quad k_B T_C \left(1 - \frac{T}{T_C}\right)^{1/2} \quad (T_0 - T) << T_C \qquad \text{... (10)}$$

CONCLUSION

The specific heat behaviour obtained from our model, i.e. C_e^5 versus T behaviour is in satisfactory agreement with experimental data. The specific properties resemble well with the low T_C conventional metallic superconductors and shows the presence of an excitation energy gap.The density of states behaviour is just similar to that obtained from BCS theory for type I low - T_C conventional metallic superconductors. We note, that density of states is quite high for high- T_C systems. This result seems to be consistent with the gap of $YBa_2Cu_3O_{7-\delta}$ measured by far-infrared absorption.The general behaviour of superconducting gap as a function of temperature is similar to that BCS result. It is easy to see that from our model is greater than for low T_C metallic superconductors. This is quite consistent with experimental observations

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