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TO STUDY ELECTRONIC SPECIFIC HEAT OF POLARON EFFECTS IN HIGH-Tc COPPER OXIDE SUPERCONDUCTORS

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ABSTRACT

A large number of electronic structure calculations show that the important electronic states in high - $T_C$cuprates are dominating by the copper d and oxygen p orbitals, with strong hybridization between them. Photon, electron and positron spectroscopies provide important information about the electronic states, and comparison with electronic structure calculations indicate that while many features can be interpreted in terms of existing calculations, self energy corrections or "correlations" are important for a more detailed understanding. The examination of the superconductivity of cuprates by a variety of experimental technique show apparently contradictory aspect. On the one hand, various experiments suggest that there must be something essentially new in these superconductors. On the other hand, many of the superconducting properties appear surprisingly similar to the conventional superconductors.

***Keywords:*electronic specific heat**

INTRODUCTION

One of the most exciting developments in science in the past few years is the discovery of high - temperature superconductivity in some Copper oxide based compounds. This great discovery has posed the two new problems of making high temperature superconducting materials available to technology at liquid nitrogen or even high temperatures on one hand and of exploring the possible mechanism of high temperature superconductivity on the other.

The discovery of superconductivity in the Ba–La–Cu–O system at temperatures as high as 30 K by Bednorz and Muller started the present explosion of interest in superconductivity. The first system of high- T_C oxide superconductors discovered was $La_{2-x}M_xCuO_4$ (M = Ba, Sr, Ca) with T_C value in the range of 25 - 40 K and usually referred as 214 system. The discovery of superconductivity with T_C around 90 K in 123 system having general formula $LnBa_2Cu_3O_{6+x}$ (x=0.95, Ln=Y, Nd, Sm, Eu, Gd. Dy, Ho, Er, Im, Yb) with orthorhombic structure followed immediately. It was soon established that the first kind of 214 high- T_C oxide superconductors possessed K_2NiF_4 structure with an orthorhombic distortion and compositions corresponding to maximum T_C (~40 K) in the Sr and Ba systems being x = 0.4 and 0.15 respectively. '123' oxide superconductors did not possess the K_2NiF_4 structure but instead had the defect Perovskite structure. These intermediate high- T_C superconductors are Ceramic oxides, not metals, and have mechanical properties of ceramics. These systems are brittle, not ductile like metals.

Lanthanum Copper oxide, La_2CuO_4 is the proto type compound for '214' class of layered materials and when doped with Ba, Sr and Ca, exhibits superconductivity at temperature as high as 40 K. La_2CuO_4 is also a superconductor under special condition of preparation.

The basic materials for 214 and 123 class of ceramic superconductors are insulators, exhibiting long-range antiferromagnetic order. Obviously, these systems exhibit a rich variety of cooperative phenomena, including metal - insulator transitions, antiferromagnetism and superconductivity under varying degree of doping.

In early 1988 several non rare - earth based copper oxide systems involving the elements bismuth and thallium exhibiting superconductivity between 60 and 125 K were discovered [22–243] The first series, which is common to both bismuth and thallium-containing oxides is $A_2''B_2''Ca_{n-1}Cu_nO_{2n+4}$ where double Tl0 (Bi-0) layers of separate perovskite like $B_2Ca_{n-1}Cu_nO_{2n+2}$ slabs (B = Ba when A = Tl and B = Sr when A = Bi).

The second series $TlBa_2Ca_{n-1}Cu_nO_{2n+3}$consists of monolayers of T1-0 separating $Ba_2Ca_{n-1}Cu_n0_{2n+2}$ slabs. In both the series, the general trend appears to be that T_C increases with increasing number of consecutively stacked CuO_2 layers (n), the highest T_C being exhibited by $T1_2Ba_2Ca_2Cu_3O_{10}$. Bi (Ca, Sr)$_{n+1}$ - Cu_n 0_{2n+4} (n = 1, 2, 3) have orthorhombic structure where as $T1_2Ca_{p-1}Ba_2Cu_n$ 0_{2n+4} (n = 1, 2, 3, 4) have primitive tetragonal structure. Bi – Sr – Ca - Cu - O and T1 - Ba - Ca Cu - O classes are more complex than the 214 and 123 classes of high - T_C superconductors. In both Bi and Tl containing systems it has been found that there are at least two crystal phases which give rise to a superconducting state, i. e., a high - T_C phase with 4-layered perovskite structure and low T_C, phase with 3 layered perovskite structure. It has been reported that T_C depends on the number of Cu 0 layers in the series $T1_2Ba_2Ca_{n-1}Cu_n0_{2n+4}$, T1 $Ba_2Ca_{n-1}Cu_nO_{2n+3}$ and $Bi_2Sr_2Ca_{n-1}Cu_2O_{2n+4}$. This has added new dimensional to the search for high - T_C superconductors and to the development of a theory for these systems. However, it seems unrealistic to increase T_C to very high values by increasing n. Inter growths seem to give rise to high- T_C.S but it has not yet been possible to obtain recurrent intergrowths.

OBJECTIVES

To study electronic specific heat

RESEARCH METHODOLOGY

The electronic specific heat per atom of a superconductor is determined from the following relation:

$$C_s^e = \frac{\partial}{\partial T} \cdot \frac{1}{N} \sum_K 2 \in_K \left\langle C_{K\sigma}^{+} C_{K\sigma} \right\rangle \qquad \text{... (1)}$$

Changing the summation over $\vec{K}$ into integration, and substituting the correlation function and on simplification, we obtain equation (1) as:

$$C_s^e = \frac{\partial}{\partial T} \cdot \frac{2N(0)}{N} \int_0^{\hbar\omega_D} \in_{K''} d \in_{K''} \left[1 - \frac{\left(\in_{K''} - V(0)n + Al2 \right)}{\sqrt{\left\{ \in_{K''}^2 + \in_{K''} \left(A - 2V(0)n \right) + A \cdot 4nV(0) + \Delta^2 \right\}}} \times \right.$$

$$\tanh - \frac{\sqrt{\left\{\in_{K''}^2 + \in_{K''}\left(A - 2V(0)n\right) + A\cdot 4nV(0) + \Delta^2\right\}}}{2K_BT}\Bigg] \qquad \text{... (2)}$$

$$C_s^e = \frac{2N(0)}{N}\int_0^{\hbar\omega_D} \in_{K''} d\in_{K''} \frac{\left(\in_{K''} - V(0)n + Al2\right)}{2K_BT^2}$$

$$\times \operatorname{sech}^2\left\{\frac{\sqrt{\left\{\in_{K''}^2 + \in_{K''}\left(A - 2V(0)n\right) + A\cdot 4nV(0) + \Delta^2\right\}}}{2K_BT}\right\} \qquad \text{... (3)}$$

DATA ANALYSIS

Using given the quantitative values of various parameters given earlier, we rewrite equation (3) for the electronic specific heat of a superconductor, as

$$C_S^e = 2\times 4.1\times 10^{12}\int_0^1 y\left[\frac{(\hbar\omega_D)^2 dy\left(y\hbar\omega_D - 0.2\times 10^{-14} + 0.925\times 10^{-14}\right)}{2\times 1.38\times 10^{-16}\times T^2}\times\right.$$

$$\left.\operatorname{sech}^2 \frac{\sqrt{(y\hbar\omega_D)^2 + y\hbar\omega_D\left(1.45\times 10^{-14}\right) + 1.48\times 10^{-28} + \left(x\times 10^{-14}\right)^2}}{2\times 1.38\times 10^{-16}\times T}\right] \qquad \text{... (4)}$$

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

and $\Delta = x\times 10^{-14}$ erg

$$C_S^e = 8.2\times 10^{12}\int_0^1 ydy\left[\frac{2.56\times 10^{-28}\times\left(1.6\times 10^{-14}y + 0.725\times 10^{-14}\right)}{2.76\times 10^{-16}\times T^2}\right.$$

$$\left.\operatorname{sech}^2 \frac{\sqrt{y^2\left(2.56\times 10^{-28}\right) + y\times 1.6\times 10^{-14}\times 1.45\times 10^{-14} + 1.48\times 10^{-28} + x^2\times 10^{-28}}}{2.76\times 10^{-16}\times T}\right]$$

$$\text{... (5)}$$

$$C_S^e = \frac{12.16\times 10^{-14}}{T^2}\int_0^1 dy\left[\left(y^2 - 0.453y\right)\operatorname{sech}^2\frac{57.97}{T}\times\sqrt{\left(y^2 + 0.906\,y + 0.578 + 0.390\,x^2\right)}\right]$$

$$\text{... (6)}$$

Using the values of xat various temperature given in Table 1, we obtain the values of C_s^e at various temperatures, are given in Table 2. The variation C_s^e with T is shown in fig1. The variation of C_s^e/T with T is shown in fig 2 and the variation of C_s^e/T with T^2 is shown in fig.3(a)and fig. 3(b).

Table 1

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

Table 2

Electronic Specific Heat $\left(C_S^e\right)$

S. No.	Temperature (T) (K)	C_S^e (10^{-18} erg/atom-K)	C_S^e/T (10^{-20} erg/atom-K^2)	T^2 ($^oK^2$)
1.	20	0.001	0.005	400
2.	25	0.01	0.04	625
3.	30	0.06	0.20	900
4.	35	0.15	0.428	1225
5.	40	0.29	0.725	1600
6.	45	0.48	1.06	2025
7.	50	0.69	1.38	2500
8.	55	0.94	1.70	3025
9.	60	1.19	1.98	3600
10.	65	1.45	2.23	4225
11.	70	1.74	2.48	4900
12.	75	2.01	2.68	5625
13.	80	2.28	2.85	6400
14.	85	2.54	2.98	7225
15.	90	2.80	3.11	8100

Fig. 1

Electronic Specific Heat (C_S^e)

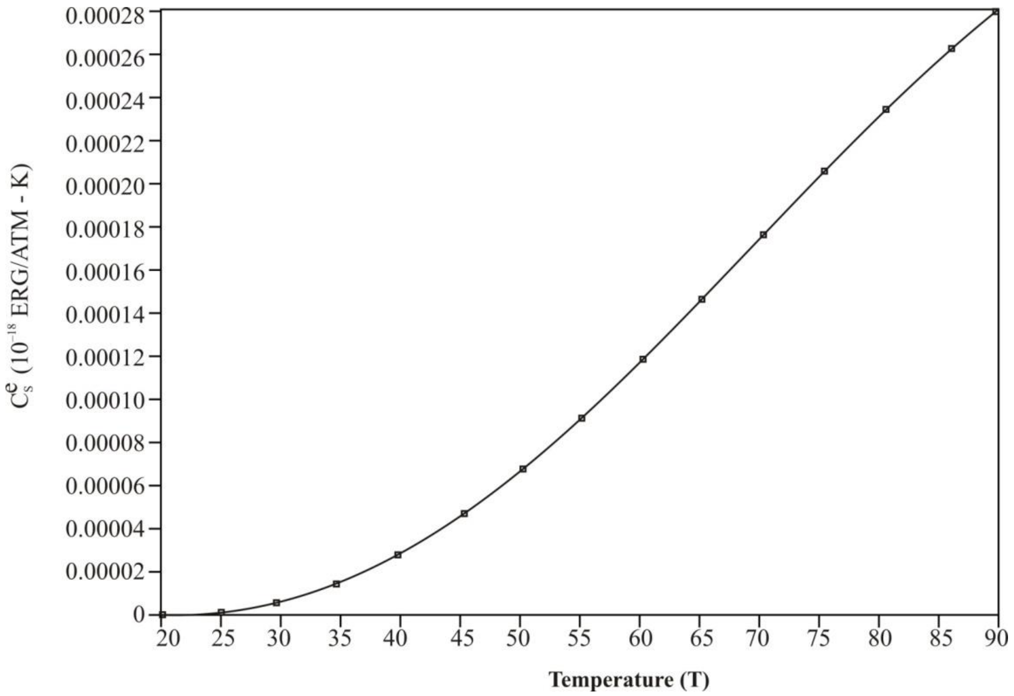


Fig. 2

Electronic Specific Heat (C_S^e)

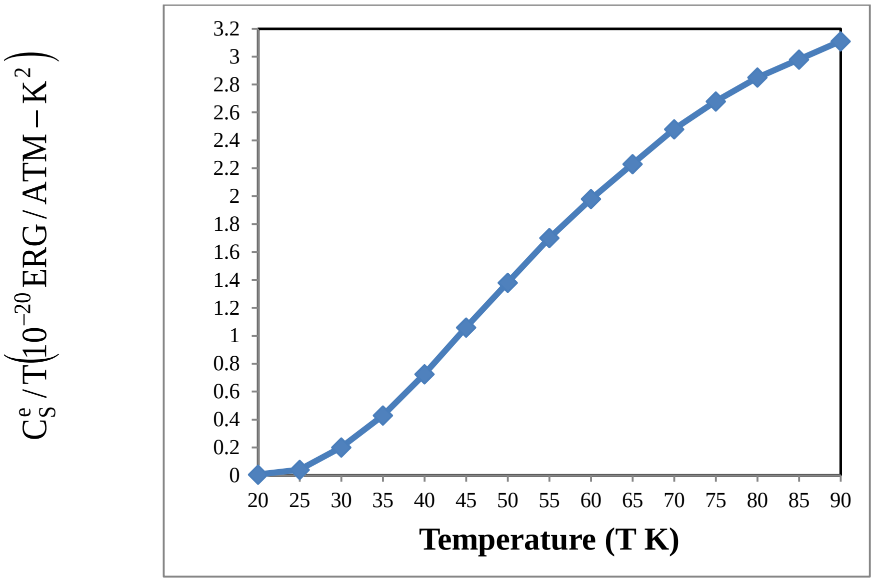
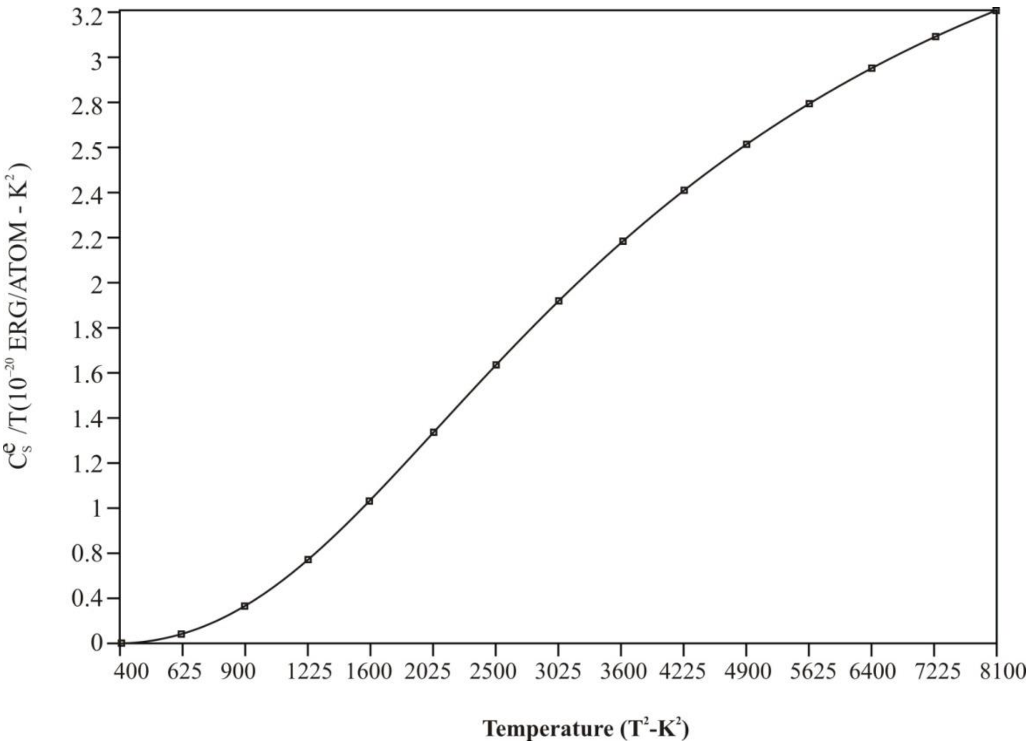


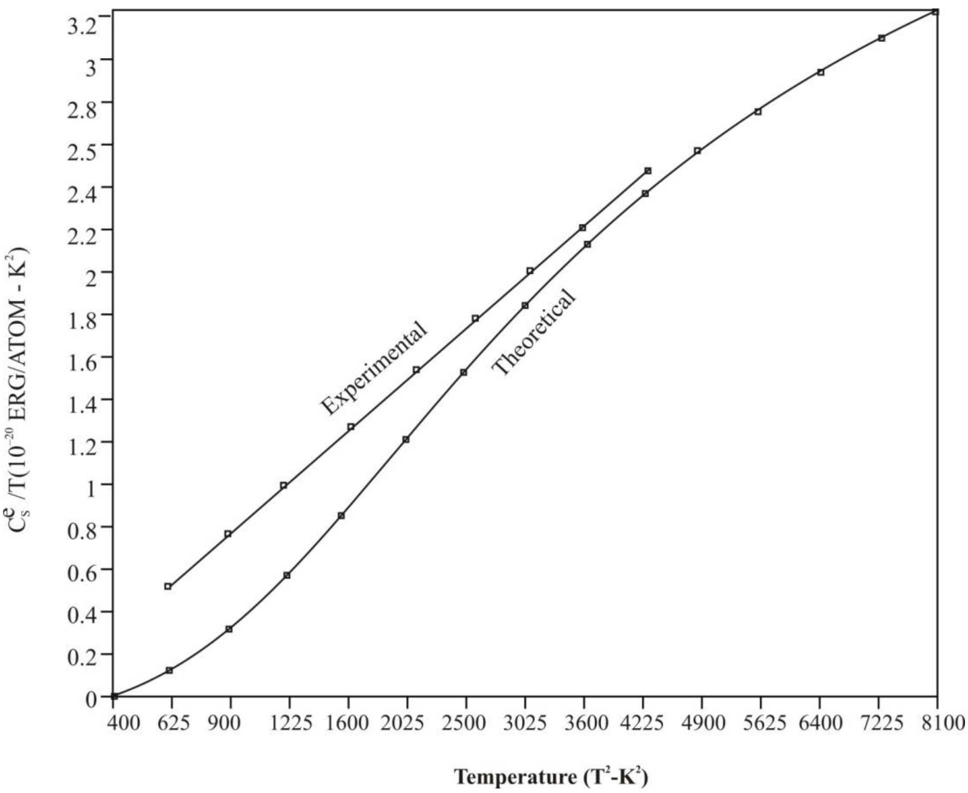
Fig. 3 (a)

Electronic Specific Heat (C_S^e)



3.2
3
2.8
2.5
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.4
0
400 625 900 1225 1600 2025 2500 3025 3600 4225 4900 5625 6400 7225 8100
Temperature (T²-K²)
Cₛᵉ /T(10⁻²⁰ ERG/ATOM - K²)

Fig.3(b)



3.2
3
2.8
2.5
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
400 625 900 1225 1600 2025 2500 3025 3600 4225 4900 5625 6400 7225 8100
Temperature (T²-K²)
Cₛᵉ /T(10⁻²⁰ ERG/ATOM - K²)
Experimental
Theoretical

CONCLUSION

The discovery of high temperature superconductivity in cuprates have raised two important and almost certainly related issues (i) What is the possible mechanism of pairing responsible for superconducting in these systems ? and (ii) What is the nature of normal state ?. The experimental results clearly show that the coherence length of these superconductors is very small~ 10 A° and there is considerable anisotropy. Within a short time a large number of mechanisms have been suggested so far; some are half baked ideas, some are repetitions of the old models, and a few of doubtful parentage. Experimental results clearly suggest that although the pairing may be of BCS type, there are additional pairing mechanisms. The occurrence of a very small isotope effects clearly indicates that there is a limited involvement of phonon - induced pairing. mechanism. Obviously, the phononic contribution is always there to a small measure, where as the electronic mechanism leads to considerable enhacement of T_C. The high value of the gap ratio $2\Delta(0)$, T_C ~ 7to 10 clearly indicates that the strong electron -correlations, which without any doubt are present in these systems.

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