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A15 compounds, strong coupling superconductivity and $YBa_2Cu_3O_{7-x}$

Abstract

The electron-phonon coupling constant λ has been calculated for A15 compounds assuming the width of the Γ_{12} band as 80 meV. λ has been found to be inversely proportional to the molecular weight. Using the values of λ the Coulomb pseudopotential μ* has been found to be negative for $YBa_2Cu_3O_{7-x}$

Key Words

A15 compounds; Strong coupling superconductivity; Electron-phonon interaction; Coulomb pseudopotential; $YBa_2Cu_3O_{7-x}$.

The A15 compounds have evoked considerable theoretical attention in recent years. Theoretical models aiming to provide an explanation of the low temperature behavior of the A15 compounds[1] have been attempted by several workers. However they suffer from certain shortcomings. These models explain some experimental results but fail to explaining others.

The objective of the present investigations has been to provide a qualitative/semi-qualitative explanation of a variety of properties of the A15 compounds using one view point; namely the BJT effect and the superconducting transition pertaining to the doubly degenerate Γ_{12} band lying near ε_F. This is based on the present knowledge of the band structure of the A15 compounds[2]. Using this model we have explained the nature of the structural transitions and the behavior of the related anomalies in the A15 compounds[3-7]. The interplay of the C-T transition and the SC has been explained by our model[5]. It also explains the enhancement of T_C with disorder[8] in V_3Si. Finally, we have investigated the effect of non-hydrostatic stress on the structural transition and the SC in A15 compounds which has accounted for many experimental observations[7].

When the electron-phonon coupling is strong the numerically derived equation for T_C is given by[9]:

$$T_C = (\Theta/1.45)\exp[-\{1.04(1+\lambda)\}/\{\lambda-\mu^*(1+0.62\lambda)\}] \quad (1)$$

where λ is the electron-phonon coupling constant, μ* is the Coulomb pseudopotential and Θ is the Debye temperature. The electron-phonon coupling constant λ is inversely proportional to the molecular weight M and is given by:

$$\lambda = N(0)\langle I^2\rangle/M\langle\omega^2\rangle \quad (2)$$

The Coulomb pseudopotential is given by:

$$\mu^* = \mu/[1+\mu\ln(E_B/\omega_0)] \quad (3)$$

where ω_0 is the maximum phonon frequency and E_B is an energy cut-off for screened Coulomb interaction in the theory of strong coupling superconductivity. This equation for T_C was obtained considering $F(\omega)$ of Nb and should be valid for other materials when structure in $F(\omega)$ is important. μ* is then calculated for A15 compounds using the band width of Γ_{12} band as 80 meV.[5] λ was then calculated using experimentally determined values[10] of T_C and Θ. The results are given in TABLE 1 for a number of A15 compounds. It is seen in Figure 1 that the dependence of lnλ on lnM falls under two classes;

Nb or V based A15 compounds. The data was least squares fitted to straight lines. The R^2 of least squares fitting was 0.76 and 0.98 for Nb based and V based A15 compounds respectively. For Nb-based A15 compounds the fitted equation is $\ln(\lambda) = -0.86 \ln M + 6.12$. For V based A15 compounds the fitted equation is $\ln(\lambda) = -1.09 \ln M + 6.84$. Therefore, λ is nearly inversely proportional to M.

In order to understand the superconductivity in

TABLE 1 : Measured and calculated quantities for superconductivity in A15 compounds

A15	V_3Si	V_3Ga	V_3Pt	V_3Au	Nb_3Al	Nb_3Sn	Nb_3Pt	Nb_3Au
M	179.8	222.5	347.9	349.8	305.7	397.4	473.8	475.7
Θ (K)	431	354	346	338	310	280	267	259
T_C (K)	17.03	15.00	2.73	2.83	18.07	17.97	10.03	10.59
μ^*	0.56	0.51	0.50	0.50	0.48	0.45	0.45	0.44
λ	3.19	2.84	1.60	1.62	3.20	3.15	2.22	2.24

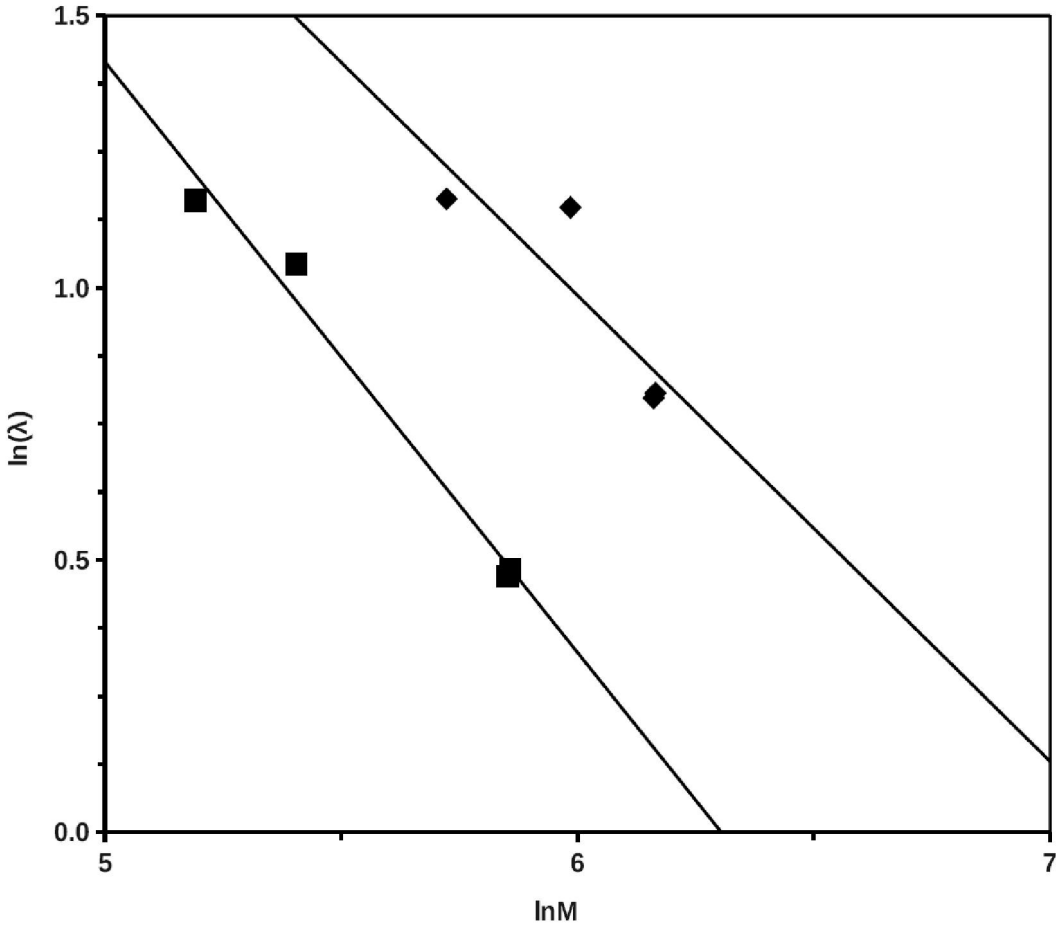

Figure 1 : lnM vesus ln(λ) for A15 compounds. It is seen that the dependence of lnλ on lnM falls under two classes; Nb based (■) or V (♦) based A15 compounds. The solid line through the data is the least-squares fitted straight line.

HTSC[11,12] the $YBa_2Cu_3O_{7-x}$ is chosen which is well studied. It has a transition temperature[13,14] of 92 K. TABLE 2 shows the calculated λ for $YBa_2Cu_3O_{7-x}$ using the least squares fitting results for A15 compounds. The μ^* is then obtained from Eq.1 using the experimentally determined values[15-17] of Θ and T_C. The results are given in TABLE 2. It is seen that μ^* is negative for $YBa_2Cu_3O_{7-x}$. In order to understand the nature the screened Coulomb interaction μ^* is plotted as a function of E_B/ω_0 in Figure 2. It is seen that μ^* has negative and positive regions separated by a diverging region which can be unphysical. The positive μ^* is known to occur for both weak and strong electron-phonon coupling in materials. However, negative μ^* probably occurs only for strong electron-phonon coupling superconductors such as HTSC. The unusual features that can suggest negative μ^* includes short ξ, van Hove singularity[18-20] or plasmons. The effect of disorder on Coulomb repulsion in superconductors has been considered before[21]. Disorder broadens the electronic band and can also enhance the Coulomb repulsion[5,22]. In the case of HTSC disorder reduces T_C which can be understood in terms of reduction of density of states at ε_F or due

TABLE 2 : Measured and calculated quantities for superconductivity in $YBa_2Cu_3O_{7-x}$

$YBa_2Cu_3O_7$	M	T_C (K)	Θ (K)	λ	μ^*
Nb based λ	294	92	500	3.43	-0.02
V based λ				1.91	-0.17

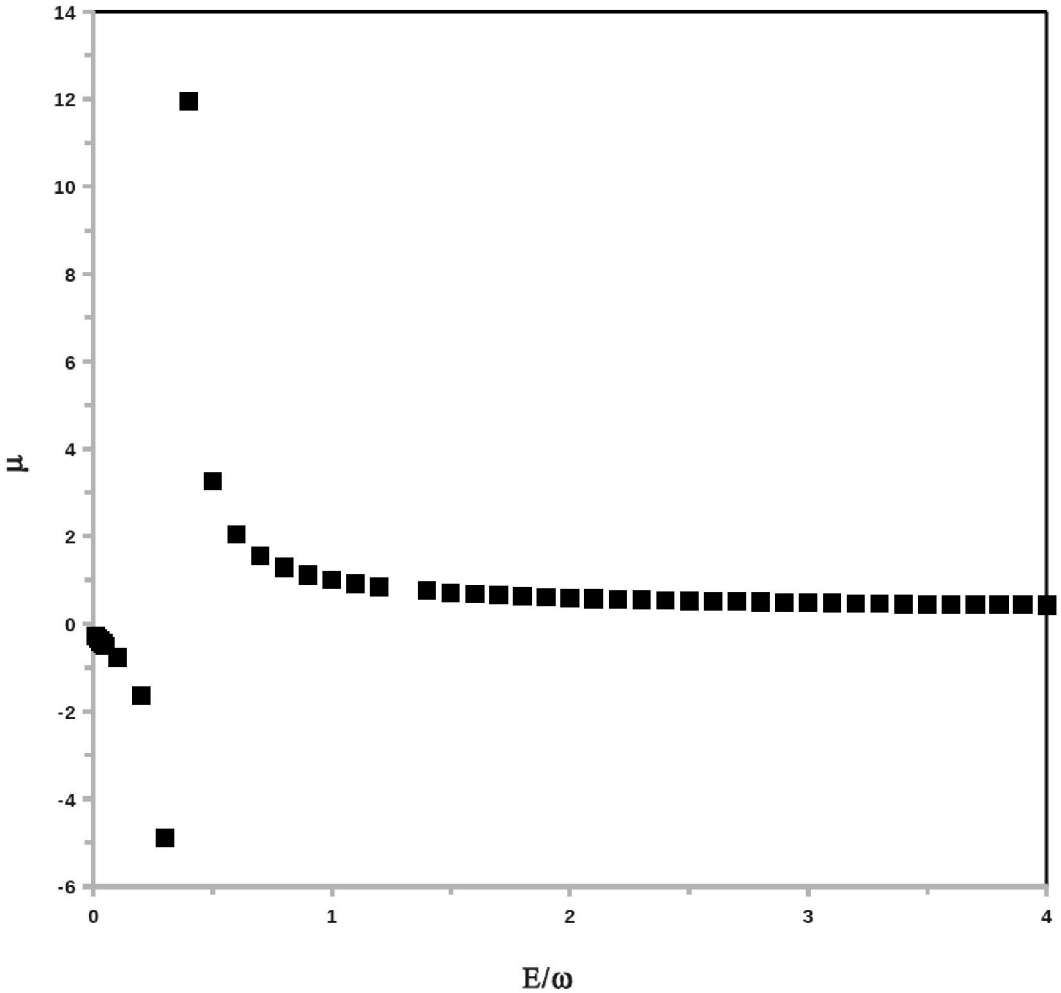

Figure 2 : The screened Coulomb interactionn μ* is plotted as a function of E_B/ω_0. It is seen that μ* has negative and positive regions separated by a unphysical diverging region.

to enhancement of Coulomb repulsion.

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