CHAPTER VI

DISCUSSION AND CONCLUSION

In this thesis, the BCS formulation is applied to the superconductivity problem. We have presented a double square-well model as the microscopic interaction for the high-T_c superconductivity, with a logarithmic density of states at the Fermi level. We have obtained the isotope effect exponent expression α, as follows from Eq. (5.43)

$$\alpha = \frac{1}{2}\left[1+\left\{\frac{\tanh\left(\frac{E_c}{2k_BT_c}\right)\ln\left(\frac{E_F}{E_c}\right)}{\tanh\left(\frac{\hbar\omega_D}{2k_BT_c}\right)\ln\left(\frac{E_F}{\hbar\omega_D}\right)}\right\}\left\{\frac{\left[1-\lambda F\left(\frac{\hbar\omega_D}{k_BT_c}\right)\right]^2}{1-\left[1-\lambda F\left(\frac{\hbar\omega_D}{k_BT_c}\right)\right]^2}\right\}\right]^{-1}$$

This expression for α depends on the transition temperature T_c and the electron-phonon coupling interaction λ. In order to show α as a function of T_c, we can use three values of λ ; 0.01, 0.1 and 0.5 . All curves show that α goes to zero at the higher transition temperature as shown in Fig. 21. These results are in agreement with the experiments.

We have also found an expression for the electron-phonon coupling interaction as a function of T_c and λ (Eq. 5.44).

$$\lambda = \frac{1}{F\left(\frac{\hbar\omega_D}{k_BT_c}\right)}\left[1-\left[1+\left\{\frac{1}{\left(\frac{1}{2\alpha}-1\right)}\frac{\tanh\left(\frac{\hbar\omega_D}{2k_BT_c}\right)\ln\left(\frac{E_F}{\hbar\omega_D}\right)}{\tanh\left(\frac{E_c}{2k_BT_c}\right)\ln\left(\frac{E_F}{E_c}\right)}\right\}\right]^{-\frac{1}{2}}\right]$$

For a known isotope effect exponent and transition temperature we can find the empirical values of the coupling parameter (Table 11). (In our evaluation of α we choose the Debye temperature to be 440 K, the ratio of $E_c/2k_BT_c$ to be 20 and the temperature of the Fermi level to be 5800 K. Varying these values dose not change the results significantly)

The interesting result is primarily in the isotope effect exponent values for the high-T_c superconductors. From the experimental values in ref. [57-71], we can see that it is possible to separate these copper oxide superconductors into two groups. Firstly, $Ba_{1-x}K_xBiO_3$ and $La_{1-x}Sr_xCuO_4$, then materials have transition temperature of about 30 K and the α is the order of 0.16 to 0.41. Secondly, the above 75 K group, including the $YBa_2Cu_3O_{7-\delta}$, Bi-based and the Tl-based superconductors then superconductor have α of the order of 0.016 to 0.05. The value of the electron-phonon coupling interaction λ which we obtained from Eq. (5.44) gives the 30 K superconductor group a value in range 0.02 to 0.06 , and it appears that this coupling is about 0.005 in the 90 K group. The different of the electron-phonon coupling interaction between the two groups is about a factor of 10. Our model suggests that a transition temperature of about 30 K may be marginally within range of the phonon coupling mechanism, but almost completely dominated by the other electronic mechanisms in the 90 K superconductors. Our model cannot be applied to the anomalous isotope effect in the $La_{2-x}Sr_xCuO_4$, $YBa_{2-x}La_xCu_3O_z$ ($z \cong 7$) and $(Y_{1-x}Pr_x)Ba_2Cu_3O_{7-\delta}$ systems.

In conclusion, the presence or absence of the isotope effect on in the relation $T_c \alpha M^{-\alpha}$ with $\alpha = 0.5$ has been considered to be a rather clean-cut indication of the presence or absence of the conventional electron-phonon interaction. It was found that, with few exceptions, most of the conventional low-T_c superconductors are close to the BCS value ($\alpha = 1 / 2$) but in some cases α is zero, as in Ru and Zr. For the low-T_c materials, without abandoning the electron-phonon interaction, these results have been explained in the terms of a retarding effect, a large Coulomb repulsion or the strong-coupling theory. In the high-T_c superconductors, some of the models propose the conventional electron-phonon interaction cannot play a dominant role in the even occurrence of superconductivity, at least in the 90 K and the higher critical transition temperature superconductors.

It is not clear at the present time if the oxygen isotope effect in the 30 K superconductors and the almost complete absence of the isotope effect in the 90 K and Bi-based materials can be understood in a similar way to that for the low -T_c compounds. It appears that a full -fledged electron-phonon interaction is not sufficient to account for superconductivity above 40 K. The introduction of a large Coulomb repulsive term to explain the less-than-normal isotope effect will suppress T_c to an even lower value. Judging from the perovskite-like crystal structure of the copper oxide superconductor compounds associated with oxygen-copper bonds not along Cu-O chains or CuO_2 planes which is known to harbor complex phonons still play an important role in affecting excitation of an electronic nature which are responsible for superconductivity at 90 K and higher transition temperature. Only more experimental and theorectical works can find a more satisfactory for role the phonon in the new class of materials.