International Journal of Education and Science Research Review
E-ISSN 2348-6457
Volume-10, Issue-2 March-April-2023
P-ISSN 2349-1817
www.ijesrr.org
Email- editor@ijesrr.org

Theory of small polaron pairing on High Tc Superconductors

Vijay Kumar Pancholi

Department of physics , M.L.V Government college

Bhilwara, Rajasthan, India

ABSTRACT

One of the most pressing challenges in the field of physics is the formulation of a theory to explain the high-temperature superconductivity of copper oxides. Theoretical physicists have been struggling to overcome this obstacle for more than twenty years. These systems have a number of phases that are almost degenerate and compete with one another, which makes it difficult to get a handle on this issue because of the complex interaction that exists between a small number of processes. In this article, we will go through some very important experiments that put some critical restrictions on the pairing process of high-temperature superconductivity. Strong electron-phonon interactions as well as the presence of polarons and/or bipolarons have been conclusively shown by the unusual oxygenisotope effects that have been found in cuprates. Direct evidence for significant coupling to several phonon modes has been presented by angle-resolved photoemission and tunneling spectra. On the other hand, the spectra in question do not exhibit the strong coupling characteristics that are often associated with magnetic resonance modes.

Keywords: *High-Tc, Polaron Pairing Mechanism, Superconductivity*

INTRODUCTION

The detection of an isotope influence on Tc provided essential insights into the understanding of the microscopic theory of superconductivity, which was a significant step on the long road toward a microscopic comprehension of superconductivity. Because of this, the occurrence of an isotope effect suggests that the phenomenon of superconductivity does not have a genesis that is solely electronic. In the same year, it was pointed out that the contact between electrons and electron phonons gave rise to an indirect attractive attraction between electrons. This interaction may be responsible for superconductivity. The notion put out was essential in determining the mechanism that should be used. After some time, it was found that electrons that have an attractive relationship form bound pairs (also known as Cooper pairs), which result in superconductivity. However, the mere presence of electron pairs does not in and of itself suggest that the pairing is phonon-mediated. In point of fact, Bose condensation, which was taken into account in, is another potential process for superconductivity; nevertheless, the model was not able to adequately explain the presence of an isotope effect. In the end, Bardeen, Cooper, and Schrieffer came up with the BCS theory, which was the first microscopic theory of superconductivity that was shown to be correct.

Isotope Effect On Tc In High-Tc Cuprate Superconductors

Since Bednorz and Muller's discovery of superconductivity, significant efforts have been made to elucidate the microscopic pairing process for high-temperature superconductivity. These efforts have been ongoing ever

since. In certain of the cuprates, the critical temperatures are located much outside of a theoretical maximum maximum anticipated on the basis of the typical phonon-mediated process. The theoretical estimate, on the other hand, has not been well substantiated. Cuprates, on the other hand, have a more intricate crystal structure than low Tc elemental superconductors. They also consist of at least three different elements, which results in more complicated phononic and electronic densities of states. It is possible to characterize the structure of cuprates using the term "apical oxygen," which refers to the metal-oxygen charge reservoir. CuO2 planes are present in all high-Tc superconductors; however, the number of these planes differs throughout the various families of cuprates. The structure of cuprates may contain anywhere from a single layer to an infinite number of layers. The examination of the isotope effect in cuprates is without a doubt a great deal more challenging than it is in elemental superconductors.

$$\alpha_i = -\frac{\Delta T_c^i}{T_c}\frac{M_i}{\Delta M_i},$$

where the index is located i is used to signify an ingredient that has the mass Mi, such as oxygen. The magnitude of i may provide some information into the nature of the phonons that play a significant role in the occurrence of superconductivity. As was said earlier, the presence of a negligible or even nonexistent partial isotope exponent does not always indicate that the element in question does not play a substantial role in the phenomenon of superconductivity. To get at a judgment that is definitive about the part that lattice vibrations play in superconductivity, it is necessary to investigate not only the influence of the isotope on Tc, but also the effect of the isotope on a number of other parameters, such as the effective supercarrier mass and the supercarrier density ns. The latter effects may provide more knowledge regarding the function of phonons, which will be essential to comprehending the physical properties of high-temperature superconductors in the future. Studies on the movement of the Tc isotope have been carried out in practically all of the cuprates that are now known. An exhaustive analysis is presented here. The majority of the investigations that have been published up to this point have focused on the change in the oxygen isotope caused by replacement, in part because the experimental techniques involved are straightforward and trustworthy.

On the other hand, the doping dependency of the OIE has been subjected to a great deal of research in a variety of cuprate systems. The OIE grows for a certain family of doped cuprates as the critical temperature (Tc) decreases, and it may be much bigger than the BCS prediction. It is possible that the existence of high-temperature superconductivity in copper oxides is due, at least in part, to the participation of phonons, given that such an unusually large OIE was measured. Any valid theories for explaining the physics of high-Tc superconductors must consistently explain both the modest OIE in the optimally-doped samples and the anomalously large OIE in the underdoped samples. This is a requirement for any theories to be considered correct.

The fact that the OIEs do not disappear suggests that oxygen-dominated phonon modes play a role in the development of superconductivity in cuprates. Tunneling and angle-resolved photoemission spectra both exhibit significant coupling characteristics to various phonon modes, as we shall demonstrate in the next section of this article. This suggests that there ought to be isotope shifts associated with other atoms. Indeed, substantial copperisotope changes, with Cu being near to O, have been seen in underdoped and oxygen-depleted materials. These findings support the hypothesis that oxygen deficiency plays a role. Because of this, it may be deduced that Cu-dominated phonon modes play a key part in the pairing.

OBJEACTIVES

1. The study compounds consistently show that the polaron binding energy.
2. The study consistently demonstrates that the intrinsic gap (pairing) symmetry.

Determination Of the Electron-Phonon Coupling Strength in Undoped Parent Cuprates

Doped holes are tightly linked with phonons to create polarons and/or bipolarons, which is consistent with the fact that a large oxygen-isotope effect was shown to have an impact on the effective supercarrier mass. Because undoped parent compounds like La2CuO4 do not have any doped charge carriers to screen the electron-phonon interactions, it is only reasonable that these compounds should exhibit greater electron-phonon interactions. Extremely powerful electronphonon interactions have the potential to lower the electron hopping integral t via the polaronic, which might ultimately result in the renormalization of the magnetic exchange energy.

If both types of systems exhibit extremely high electron-phonon coupling, it is reasonable to anticipate that the antiferromagnetic (AF) exchange energy in antiferromagnetic cuprates and the ferromagnetic exchange energy in ferromagnetic manganites should depend on the mass of the constituent isotope. Following the conclusion of this straightforward line of reasoning, Zhao and his colleagues began research on the influence of oxygen isotopes on the AF ordering temperature TN in different parent cuprates as well as the effect of oxygen isotopes on the Curie temperature in ferromagnetic materials. On a consistent basis, a minor oxygen-isotope shift of TN was detected in doped, whilst on the other hand, a massive oxygen-isotope shift of the Curie temperature was recorded in doped. Given that the two types of material should have comparable electron-phonon coupling strengths, the significant discrepancy in the impact that the isotopes have on the magnetic ordering temperatures seems to be inconsistent. Because of the fact that the electron-phonon interaction renormalizes the antiferromagnetic exchange energy J via the fourth order process, we are going to show that the tiny isotope shift of TN is also compatible with a high polaron binding energy. This will be shown in the following paragraphs.

Two of the authors have put up the idea that the low and intermediate doping regimes of high-temperature superconductors may be described using the phrase "electronic phase separation," which is also known as "electronic inhomogeneities." It has also been suggested in that other and, to some degree, complementary explanations of the electrical inhomogeneities may be found in The essential components may be summed up as follows. The insertion of holes into the antiferromagnetically ordered CuO2 planes is the outcome of doping the parent component of a high-temperature superconductor. It has been shown that the addition of one more hole causes a local deformation of the system's spin and lattice structure as well as a disruption in the system's symmetry.

In other words, the development of a magnetic and lattice cluster, also known as a polaron, takes place simultaneously when a hole is introduced into the CuO2 plane. It has been estimated that there are around five to ten neighboring Cu atoms in the CuO2 plane that make up the magnetic cluster. In addition, taking into account both the strength of the electron-phonon coupling and the structure of the lattice, it has been calculated that the size of the lattice polaron is of the same order as the electron-phonon coupling. As a result, the quasiparticles may be understood as polarons of a size in between the two extremes. The movement of the magnetic cluster may be thought of in terms of two different time scales. Due to the fact that it is connected

with a high spin-flip energy, the local distortion of the antiferromagnetic background is not very mobile. On the other hand, the (undressed) hole that is contained inside the cluster is very mobile. Because the dressed hole is also an intermediate-sized lattice polaron, the mobility of the cluster, which was already rather low, is reduced even more by this property.

When additional doping is applied to the CuO2 planes, the occurrence of these two different time scales has a significant impact on the electrical structure of the material. The process of adding holes to the system does, in fact, cause some of the clusters to intersect with one another. In the midst of a backdrop that is dominated by strong antiferromagnetic interactions, these linked clusters come together to create a conducting subsystem. The magnetic interaction between the clusters exerts a somewhat attractive force on each other. The clusters, however, do not form a homogenous sea in an antiferromagnetic background because of the conflict between potential energy (including the magnetic energy) and kinetic energy. Instead, the clusters, also known as magnetic-lattice polarons, establish a percolative network in which the holes are able to move about with relative ease.

The dimension D of this network is less than two if it is assumed that the holes are mostly restricted in the CuO2-planes. We want to call attention to the fact that the hole subsystem, also known as the percolation network, is not a static structure but rather one that is dynamic and has a distinctive time scale. In addition to these key characteristics, the idea of the magnetic-lattice polaron and the percolation network also include a few more. To begin, the network is arranged in accordance with its intermediate distances. The groups of holes are aligned in the appropriate directions. One of the factors that contributed to the formation of this ordering is the fact that the contact between clusters is favorable along these lines, but unfavorable along these directions. As a consequence of this, holes may readily travel in the directions, but their mobility along the axes is drastically hindered. This results in the energy spectrum of holes having a significantly anisotropic structure, with a large dispersion in the M-direction and a minor dispersion in both the X and Y-directions. In this sense, the percolative model readily explains the substantially anisotropic Fermi surface that has been experimentally seen in high-Tc superconductors with extended saddle points (Van Hove singularities) in both the X and Y directions. Doping alters the characteristic size of the ordered network, but it has very little influence on the band structure of the material itself. This is an essential point to keep in mind.

Electronic inhomogeneities and the electron-lattice interaction

The mere presence of electronic inhomogeneities has significant repercussions for the interaction between electrons and lattices, and these repercussions are independent of the precise structure of the electronic inhomogeneities. In point of fact, the separation of the electronic phases means a decreased screening of the attractive interaction between electrons and ions. In particular, the interaction of charge carriers with ions in the antiferromagnetic areas that are insulating is only marginally screened, which results in an amplification of the long-range component of the electron-lattice interaction. As a result, the interaction between the electrons and the lattice may be broken up into two portions.

$$H_{eL} = \sum_{\mathbf{k},\sigma} \sum_{\mathbf{q},\nu} \left[g_S(\mathbf{k}, \mathbf{q}\nu) + g_L(\mathbf{k}, \mathbf{q}\nu) \right] c^{\dagger}_{\mathbf{k},\sigma} c_{\mathbf{k}+\mathbf{q},\sigma} b^{\dagger}_{\mathbf{q},\nu} + h.c.\,,$$

The pairing interactions

According to our concept, the primary contributor to the pairing potential is the long-range in-plane interaction of charge carriers (holes) with completely symmetric (A1g) and non-totally symmetric optical phonons. This interaction takes place inside the crystal lattice. Because of the interaction, hole states are mixed in with near states. As a result, the pairing potential that is provided by this interaction is directly dependent on the density of states that can be found on the Fermi surface. In cuprate superconductors, the value of the parameter F is substantially anisotropic, with significantly bigger values in directions a and b than in between. Therefore, the portion of the pairing potential that is concerned with long-range interactions is also substantially anisotropic. An explanation for this anisotropy may be found in, which states that it is a direct result of the existence of electronic inhomogeneities. They are asymptotically independent, which is another significant feature of the paired interaction that was discussed. Cooper pairs have only a modest connection with distinct variables. Because of this, the real phase difference in the a and b directions relies mostly on other interactions, which in this context refers to short-range interactions.

These interactions have a little impact on max and the critical temperature Tc. Below, we show that even a very tiny Coulomb repulsion, which is entirely symmetric, has a dramatic influence on the free energy of the s-wave type of superconducting state (it enhances it), but it has no effect on the free energy of the d-wave state Fd. This is something that we will demonstrate in further detail in the next section. As a result of this, very small changes in the short-range component of the Coulomb repulsion or the short-range interaction with phonons or other sign-alternative interactions may turn an s-wave type of superconductivity into a d-wave type without a significant change in max (and Tc). Although a consideration of strong coupling is required to accurately characterize high-Tc superconductors, the effects of various pairing interactions may be explored within the framework of the basic BCS theory. An in-depth analysis of the solutions that were attained as a result of both long-range and short-range interactions is provided in In this section, we will provide the most important findings from the computational analysis of the BCS gap equation at zero degrees Celsius, taking into consideration the various pairing potentials discussed before.

CONCLUSION

We have constructed the polaronic pairing mechanism of HTSC in cuprates and employed it to examine the physical characteristics of throughout the preceding sections. The concept of polaron is predicated on the premise that an electron would autolocalize inside an ion crystal as a result of its interaction with longitudinal optical vibrations under the influence of the local polarization that is brought about by the electron itself. We have found formulas for the superconducting order parameter by using the Green's function approach and the equation of motion method. The electron is restricted to the local-polarization-induced potential well, and it conserves it using its own Green's function technique. We determined that the contribution from phonons is sufficiently minimal. acquired for the system, which is in satisfactory accord with We have conducted in-depth research on the density of states at a variety of temperatures, as well as the specific heat, free energy, and critical field, by making use of the numerous factors mentioned in.The temperature dependence of the specific heat capacity is fairly in excellent accord with experimental.

REFERENCES

1. H. Kammerling-Onnes, Comm. Physical Lab. Univ. Leiden, No. 120b and 122b (1911).
2. E. Maxwell, Phys. Rev. 78, 477 (1950).

3. C. A. Reynolds, B. Serin, W. H. Wright, and L. B. Nesbitt, Phys . Rev. 78, 487 (1950).

4. H. Fr¨ohlich, Phys. Rev. 79, 845 (1950).

5. L. N. Cooper, Phys. Rev. 104, 1189 (1950).

6. M. R. Schafroth, Phys. Rev. 100, 463 (1955).

7. J. Bardeen, L. N. Cooper, and J. R. Schrieffer, Phys. Rev. 108, 1175 (1957).

8. G. M. Eliashberg, Sov-Phys.-JETP 11, 696 (1960).

9. W. L. McMillan, Phys. Rev. 167, 331 (1968).

10. J. G. Bednorz and K. A. M¨uller, Z. Phys. B 64, 189 (1986).

11. J. P. Franck, in: Physical Properties of High Temperature Superconductors IV (World Scientific, Singapore 1994), ed. by D. M. Ginsberg, p.189.

12. P.W. Anderson, The Theory of Superconductivity in the High-Tc Cuprate Superconductors, Princeton University Press, 1998.

13. M. K. Crawford, M. N. Kunchur, W. E. Farneth, E. M. McCaron III, and S. J. Poon, Phys. Rev. B 41, 282(1990).

14. H. J. Bornemann, D. E. Morris, H. B. Liu, and P. K. Narwankar, Physica C 191, 211 (1992).

15. J. P. Franck, S. Harker, and J. H. Brewer, Phys. Rev. Lett. 71, 283 (1993).

16. G. M. Zhao, K. K. Singh, A. P. B. Sinha, and D. E. Morris,, Phys. Rev. B 52, 6840 (1995).